CHAPTER 2

SEASONAL VARIATIONS IN THE MINERAL CONSTITUENTS
The marine algae absorb the essential inorganic nutrients from the surrounding sea water and utilize them for their normal growth. Due to saline environment, the problem of mineral uptake and distribution in marine algae, markedly differs from that of terrestrial plants or even fresh water algae. In contrast to fresh water algae, marine algae have a remarkable ability in regulating the mechanism of mineral uptake and subsequently maintaining ionic balance in the cells. Hence it is obvious that the cellular mechanisms are responsible for fitting these plants for the submerged condition of life in sea water.

The analytical data of sea water as well as the marine plants reveal that their main inorganic constituents are cations like Na, K, Ca, Mg and anions like Cl, SO₄, NO₃ and PO₄. Marine algae often reveal a remarkable tolerance for inorganic elements. Perhaps this feature is an indicative of their ecological demand for maintenance of life processes. It is known that the sea water has very high concentration of Na and Cl ions. However, it is interesting to note that inspite of the high concentrations of these ions, marine algae keep enough uptake of K, Mg, Ca from the surrounding sea water.

The problem of mineral absorption in marine algae will have three aspects: (i) Chemical composition of sea water, (ii) relationship between the constituents of sea
water and the constituents of marine plants and (iii) change in the composition of sea water due to various factors and its effects on the constituents of marine algae. Hence it is of importance to consider the mineral composition of sea water while studying the inorganic constituents of marine algae. The composition of sea water changes from place to place and from month to month under the influences of various factors such as light, temperature and rainfall. Moreover, biological activity is one of the major factors that may constantly modify the relative concentrations of the minerals in sea water. Any such variation in chemical composition of sea water, will exert an influence upon the physiological behaviour of marine algae and as a result the constituents of the plant will also change. It is therefore, desirable to correlate seasonal variations of the mineral constituents of surrounding sea water with those of the alga.

II. REVIEW OF THE PREVIOUS LITERATURE

(1) Analysis of Sea water:

Many investigators have attempted to study the composition of sea water. Black and Dewar (1949) have studied the seasonal variations in temperature, pH, salinity, dissolved oxygen, phosphate and nitrate in the inshore waters at three positions on the Argyllshire coast. These investigators found a prominent effect of seasonal
environmental conditions on the composition of sea water which changes from season to season. The chemical composition of sea water, in the vicinity of the Atlantic Provinces of Canada has been studied by Young et al. (1959). They observed that the salt water in the Bras d'or Lakes of Cape Breton Island, N.S. was different from that of the contiguous Atlantic Ocean and showed evidence of much dilution. In India, Rao (1965) has studied the seasonal variations in chemical constituents of sea water from Bhavnagar coast and recorded the lowest values of dissolved salts during the monsoon. According to him this low level of dissolved salts is due to the influx of fresh water run down by the rivers and rainfall. Patil and Joshi (1967) have studied seasonal variations in the inorganic constituents of the sea water collected from the sea shores of Bombay. They have observed that the major inorganic constituents of the sea water like Na, K, Mg, Ca and Cl change in their concentrations from season to season.

Work of these investigators clearly indicate that there are prominent variations in the composition of sea water from place to place and from season to season. This view has been kept in mind in the present investigation.

(ii) Mineral Constituents of Marine algae:

Although several workers have tried to determine the chemical properties of sea water, quite a few have attempted
to correlate with the chemical constituents of marine algae. Black and Dewar (1949) have correlated the variations in the composition of the sea water with the chemical constituents of two species of Laminaria. They have found that there is a correlation between the chemical constituents of the algae and their environment. They observed that a period of rapid photosynthesis occurs from March to June/July, but restricted in July/August when nitrate is undetectable in the water and phosphate is as low as 0.16 - 0.20 mg atom/m$^3$. The replenishment of photosynthetic layer with nutrients is retarded in July/August, apparently due to warming of inshore waters which may set up a thermocline restricting vertical mixing. The autumn cooling of the uppermost water facilitates vertical mixing, regenerating the nutrients in the photosynthetic region and a second burst of photosynthesis at a reduced rate from spring 'out burst' occurs in October/November.

Macpherson and Young (1952) have studied the seasonal variations in the chemical composition of Fucaceae in the Maritime Provinces, Canada. They have analysed, over a period of two years, the monthly samples of Fucus vesiculosus, F. evanescens and Ascophyllum nodosum for their contents of moisture, mineral salts, inorganic nitrogen, mannitol, laminarin and alginate. They observed that the ash content was at a minimum in the winter months while alginate was at a maximum level. The converse was true in spring and
Organic nitrogen and laminarin remained relatively constant throughout the year. Mannitol was highest in the summer and autumn, fluctuating with the temperature of the winter. The water content was at a minimum during the winter and at a maximum in the spring in conformity with land plants.

Wort (1955) has recorded the seasonal variations in chemical composition of fronds and stipes of *Macrocystis integrifolia* and *Nereocystis luetkeana* for dry weight, ash, total nitrogen, total phosphorus, sulphur, copper, zinc, iron, ether solubles, algin, mannitol, fucoidin and laminarin. He observed that there was higher content of all substances in fronds than that of the stipes. The contents of these two species of algae showed a parallel variation but differed in values.

Young and Langile (1958) have studied the inorganic elements of numerous marine species of green, red and brown algae from the Atlantic coast of Canada. They found that there are variations in ash and K contents of *Chondrus crispus* from season to season but no variations in trace elements were noticed. They also observed that level of Na is relatively constant at 2.5 to 3.5% for all the species and the K concentration is higher in about half the species, highest being recorded in *Rhodymenia* in which K amounts to 7.11%.
Recently, in our laboratory Patil and Joshi (1967) have studied seasonal variations in moisture and ash percentages, titratable acidity, total nitrogen, carbohydrate, sodium, potassium, magnesium, calcium and chloride contents of Ulva lactuca and the data obtained are correlated with the variations in the chemical composition of sea water. They have also suggested from their study that the changes in the metabolic environment as well as in atmospheric temperature are responsible for the observed variations in the alga. In general, Patil and Joshi (loc.cit.) have recorded maximum values for inorganic constituents of U. lactuca in February and low values during monsoon. The results obtained by these investigators are similar to those of Mita (1961) who has worked on U. pertusa. However, when compared to other groups of algae the result differs. The main object of this investigation is to compare the results of U. lactuca with that of S. ilicifolium. This will supplement the data collected in our laboratory earlier.

In conclusion it can be stated that in marine algae there exist definite seasonal variations in chemical constituents and this may be largely due to the variation in the chemical composition of sea water.

III. WORK DONE IN INDIA ON MINERAL CONSTITUENTS OF SEA WATER AND MARINE ALGAE

(1) Sea Water:

In India, a good deal of work is being carried out
at Central Salt and Marine Chemicals Research Institute, Bhavnagar, on several aspects of physical and chemical properties of sea water and their effects on marine algae. Sheshadri (1965) has reviewed the physical and chemical properties of sea water while Sharma and Dave (1965) have studied the salinity, density, osmotic pressure, freezing and boiling points, vapour pressure as well as the macro and micro mineral constituents of the sea water. Chauhan (1965) has recorded the temperature, salinity, dissolved oxygen, turbidity and phosphate and nitrate contents of sea water at Okha. Rao (1965) has studied the seasonal variations in chemical constituents of sea water and observed the lowest values of dissolved minerals during the monsoon. He has stated that this low level of dissolved salts is due to the dilution of sea water by the addition of fresh water from the rivers and rainfall during monsoon. Patil and Joshi (1967) have analysed sea water at Bombay and have correlated its composition with the constituents of U. lactuca.

(ii) Marine Algae:

Several workers have analysed the algae belonging to various taxa for their chemical constituents. Pillai (1956) has analysed the algae of the Mandapam coast and found that the amounts of Fe, B and Zn were higher in brown algae than in green algae. Rao and Tipnis (1965) have investigated Na, K, Ca, Mg, CO₃, Cl and SO₄ contents from the water soluble...
and insoluble fractions of many algae belonging to Chlorophyceae and Phaeophyceae. Langalia et al. (1965) have studied Na, K and Rb contents of Halimeda, Gracilaria, Ulva, Sargassum johnstonii and two other species of Sargassum.

These investigations from India have contributed to the understanding of the problem of inorganic nutrition of the marine algae. It seems, however, not much attempt has been made to undertake a detailed study of one alga with reference to all aspects of investigation. This is the main object of the present investigation in which Sargassum ilicifolium has been selected as the main type.

IV. ROLE OF MINERAL ELEMENTS IN PLANT METABOLISM

Like higher plants, marine algae too, require the same essential elements for their growth and metabolism. The importance of these mineral nutrients in marine algae can be better understood if the role of each element in plant metabolism is reviewed. Therefore, an attempt is made to give a brief account of this subject with special reference to the major constituents of the plant in the following pages.

(i) Sodium:

As Na is the most dominant cation of the sea water,
it plays an important role in the physiology of marine plants. Na is present in all plants, but exact role of this element in plant metabolism is not clearly understood. However, there are several instances where Na appears to be beneficial to plants when present in minute quantities. It is believed that Na is responsible for maintenance of adequate osmotic pressure and it can also replace K but not completely. In normal plants and in majority of the marine algae K accumulation is more than that of Na, while this ratio falls down in halophytes.

Growth responses to sodium salts at macro levels have long been studied in representatives of Chenopodiaceae (Keller, 1925; Eijk, 1934 and 1939; Black, 1956; Ulrich and Ohki, 1956; Ashby and Beadle, 1957). Brownnel and Wood (1957) have observed that Atriplex vesicaria, a saline plant, accumulates large amounts of Na and Cl in their leaves. This plant did not survive in Na-free cultures indicating that it is a Na dependent plant. Beadle et al. (1957) have reported that the leaves of A. vesicaria contains as high as 5.2% of Na and thus it forms a dominant cation. Black (1960) has also recorded more Na than K, in the leaves of A. vesicaria and he further stated that the specialized mechanism of Na uptake in the plant should be looked upon as osmoregulatory and not in nutritional point of view. Williams (1960) has reported that Halogeton glomeratus requires sodium and accumulates it in its leaves. This
particular halophytic weed is known to accumulate oxalic acid. The acid content was directly related to the Na supply which also prevented incipient wilting.

Sodium appears to be an essential element for the growth of blue-green algae. However, this requirement of Na for the growth of other algae is not yet confirmed. Gerloff et al. (1952) reported a beneficial effect of Na on *Microcystis aeruginosa*. Allen (1952) found that 25 cultures of various Cyanophyceae grow well in a medium which contains Na but lacks K. This indicates that Na can be replaced by K. Allen and Arnon (1955) have shown that Na is essential for the blue green alga *Anabaena cylindrica*.

Kratz and Myers (1955) showed that both Na and K are required for the maintenance of maximal growth rate of *Anabaena variabilis*, *Anacystis nidulans* and a strain of *Nostoc muscorum*. Grosse (1963) has shown that *Rhodopseudomonas spheroides* requires sodium when grown aerobically in the dark. However, a metabolic basis for the Na requirement in blue-green algae is not clearly demonstrated. Brownnel and Nicholas (1967) have observed that the nitrite accumulates in Na-deficient cultures of *Anabaena cylindrica* and nitrate reductase markedly increases in cells grown without Na. On this basis, it has been proposed that Na is required for the transformation of N₂ gas into ammonia. Evans and Sorger (1966) in their review on the role of mineral elements, described that most of the enzyme systems that can be
activated by Na are preferentially activated by K. Possibly in blue-green algae, similar enzyme systems are preferentially or only activated by Na.

Guillard (1962) has mentioned that Na and other ions may have a dual role namely: (1) the maintenance of sufficiently high internal osmotic pressure to prevent desiccation of cells bathed by a solution of high osmotic pressure and (2) specific nutritional requirements. Droop (1958) has shown that certain marine algae have a high non-osmotic Na requirement. McLachlan (1960) showed that the flagellate, Dunaliella tertiolecta, has a clearly distinguishable osmotic Na requirement.

Although Na can be substituted by K which has a similar charge, in Na dependent plant, K cannot replace Na entirely. Eppley (1959) has shown that Li can penetrate in exchange of Porphyra, but in this case cells survive only for a few hours. Singh (1967) has noted that a mud-flat halophyte, Sesuvium portulacastrum, could not grow when cultured in Na-free nutrient solution. It can be stated that in the course of time, plants have come to depend on Na ions which cannot be completely replaced by K. Possibly the marine plants require Na as a cofactor for their metabolic processes.

The recent work of Larsen (1967) indicates that the halophytic bacteria require Na as an essential metabolite.
These extreme halophytes like the *Halobacterium* group are highly specialized organisms. These bacteria not only can manage to live and grow in a concentrated brine containing 25 to 30% salt in the form of NaCl, but they absolutely require a very strong salt brine for their best growth and maintenance (Larsen, 1962). These extreme halophytes also have a specific requirement for NaCl for growth in the culture media and when NaCl was replaced by other salts or compounds in the culture medium, no growth was obtained. Sodium ions can partially be substituted by K ions only (Brown and Gibbons, 1955; Christian, 1956).

Baxter and Gibbons (1954, 1956 and 1957) found that the enzymes of the extreme halophytes are functional at the very high salt concentrations found within the cells. Thus indicating that the extreme halophytes have enzymes which are halotolerant or even halophilic. It was shown that Na is effective in activating the halophilic enzymes (cf. Larsen, 1967). A strong stimulatory effect of both NaCl and KCl upon the enzymes of the extreme halophytes, reveal that, these three intracellular constituents play a vital role in the cells of the extreme halophytes by keeping the enzymes in an activated state. NaCl and KCl not merely activate the enzymes but also act as stabilizers of the enzymes.

Stevenson (1966), while studying the uptake of glutamate by *Halobacterium*, found that only NaCl stimulates the mechanism of uptake of glutamate and replacement of Na
by K or Cl gave a negligible uptake. This observation clearly indicates a specific function of Na in the extreme halophytes and its possible connection with the process of oxidative phosphorylation.

Marine algae, generally maintain a low level of Na even though its concentration in sea water is found more than any other cations. Previous data on Na content of various marine algae reveal that the concentration of Na does not exceed 5% of the dry plant tissues (Young and Langile, 1958; Mita, 1961; Langlie et al., 1965; Rao and Tipnis, 1965; Patil and Joshi, 1967). However, the importance of Na for marine algae is not clearly understood.

It seems Na, like K, has a specific role in plant metabolism but in varied proportion. Although evidences are lacking for the essentiality of Na to algae other than Cyanophyceae, it may have an important function in plants as it influences the growth of many. For halophytes it is must element for full growth.

(ii) Potassium:

K, which is one of the most essential element for the plant growth has very little concentration in sea water. Harvey (1957) has recorded 0.39 g of K per litre of sea water while Na value for the same amount of sea water is 11.1 g.
K has a wide distribution in all plants and is an absolute requirement for plant growth. It is present in all tissues of great vitality as well as in the storage organs. It is more abundant in young and actively growing regions. K is essential for hydration, cell organization and permeability. It also increases incorporation of amino acids in proteins. K is more intimately linked with Na since the elements can replace each other. However, K cannot be completely replaced by chemically similar elements like Na and Li (Eppley, 1959).

K is widely distributed in marine plants as well as in glycophytes. Buckovac and Wittwer (1957) have shown with the use of isotopic K that it is most rapidly absorbed and also highly mobilized in the plant cells. Since K is present in high concentration in the metabolically active regions of plants, such as young leaves, buds and root tips, it indicates its role in growth metabolism. The average values for K in terrestrial plants range from 0.3% to 6%. In the leaves of *Atriplex vesicaria* which is considered to be a halophyte, Beadle et al. (1957) have recorded 2.2% K. Another marine plant *Sesuvium portulacastrum* shows 2.97% of K (Singh, 1967). Mishra (1967) has observed that K is present in smaller amounts in saline soil than the garden soil. His work on *Clerodendron inerme*, which grows in both the habitats, shows that the uptake of K, under saline conditions is nearly double the amount of the uptake under garden conditions.
It seems that even though marine plants grow in a Na-rich environment, K is absorbed in appreciable amounts and hence these plants are not entirely dependent on Na for their growth. The deficiency of K results in leaf damage, low water or high water content of the leaf, less development of chlorophyll, decreased photosynthetic activity, increased respiration, disturbed carbohydrate metabolism and altered ionic balance.

Kachmar and Boyer (1953) have mentioned that the enzyme for transphosphorylation from PEP to ADP is activated by K and Mg. Boyer and Stout (1958) have stated that K is linked with carbohydrate metabolism. Evans (1963) has shown that when KCl was added to the enzyme, pyruvic acid kinase, it results in an increased activity. K also activates certain enzymes which synthesize peptide bonds (Webster, 1956). Von Korff (1953) has indicated that K stimulates acetyl CoA formation suggesting that K may be essential for citrate formation from free acetate. Rasmussen and Smith (1961) have shown that K affects citric acid concentration and in turn malic acid. K also activates enzymes like fructokinase and transacetylase. It is an indispensable ion for the pyruvate phosphokinase system.

The work of Neeb (1952) has shown that in the green alga, Hydrodictyon, potassium deficiency brings about an impoverishment of cellular substances as a result of the
inhibition of photosynthesis. It was observed by Clendenning et al. (1956) that the photosynthetic rate decreases, if Nostoc is deprived of K. Daniel (1956) has reported that respiration in the presence of glucose was depressed in Chlorella deficient in K. Eppley (1960) found that absence of K and Na from artificial sea water markedly reduces respiration and subsequent addition of high concentrations of NaCl and KCl restores the initial rate in the red alga Porphyra perforata. Bergquist (1959) observed a stimulation of respiration by K in the brown alga, Homosira banksii. Pirson and Badour (1961) have found that K deficient green algae, enter into a stage of high carbohydrate level; nevertheless protein level and turnover are not affected until the late stage of deficiency.

The substitution of Rb for K in physiological processes has been studied for many years. Pirson (1939) has shown complete physical replacement of K by Rb in Chlorella but it is found less effective than K in supporting assimilation, chlorophyll formation and cell division. Kellner in 1950 (cf. Epstein, 1965) in Ankistrodesmus braunii. Scott and DeVor (1957) in Ulva lactuca and Eppley (1962) in Porphyra have shown that Rb can replace K. However, Baum and O'Kelly (1966) studied Rb substitution for K in 21 species of fresh water algae and they observed that only 6 species could show better response to Rb.
Thus, with the above experimental evidences, it can be concluded that K is metabolically one of the important cations for enzymatic activity, protein metabolism, photosynthesis and respiration. Above all, it is being an indispensable mobile element found intimately associated with the growth metabolism of all the plants.

(iii) Magnesium:

Magnesium is next to Na in order of cations concentration in sea water. Harvey (1957) has recorded 1.33 g of Mg per litre of sea water. Even though Mg is available in large quantities in sea water, it appears that its uptake is comparatively low. The investigations of Pradhan (1957), Warrick (1960) on the mangroves and halophytes of Bombay and of Beadle et al. (1957) on three species of Atriplex from Australia have shown that these plants have developed a tendency towards Mg deficiency. Canal (1928) has reported that Salicornia and Suaeda show low Mg contents.

Magnesium, since it is a constituent of chlorophyll, is obviously an absolute requirement for all autotrophic plants. It is found in organic combinations in chlorophyll. Hase et al. (1957) have shown that cells of Chlorella ellipsoides are etiolated when grown in N or Mg-free medium but are normal in colour if P or K is omitted.
Mg is generally present in the combined form in the protoplasm and also in the form of a free or inorganic salt in the cell sap (Gilbert, 1957). Beer et al. (1951) have shown that young cells, rapidly growing tissues and active mitotic cells are rich in Mg. Webb (1949 and 1951) has observed that Mg is required for cell division in many bacteria. Similar observation has also been recorded by Tamiya (1964). Zilling et al. (1959) have shown a direct role of Mg in protein synthesis in *Escherichia coli* at the stage of binding RNA with large polypeptide structures.

Several workers (Yirson and Bardour, 1961; Bardour, 1961; Calling, 1963) have shown that in green algae Mg has a vital role to play in nitrogen and carbohydrate metabolism. It is shown that it is an important cation in the synthesis of nucleic acid such as RNA and the protein.

Of all the inorganic elements, Mg is of foremost importance since it affects many physiological processes in plants. Hill and Wittingham (1957) observed a decrease in the rate of photosynthesis in *Chlorella* deprived of K, Mg or Mn. Arnon (1959) has stated that Mg plays an important role in photosynthetic phosphorylation. Shibke and Pinchot (1961) have found that in cell free particles from the bacterium, *Alcaligenes faecalis*, Mg is necessary for phosphorylation. Mg plays a predominant role in promoting the formation of the enzyme substrate complex and the resulting intermediate of the reaction. Nason and McClory
(1963) have shown that Mg forms the cofactor for phosphofructokinase, ATP phosphoglyceric transphosphorylase, enolase, pyruvate carboxylase and gluconokinase.

Mg acts as a cofactor in numerous enzymes associated with carbohydrate metabolism and glycolysis. Mazelis and Stumpf (1955) have found that Mg is associated with adenine nucleotide and Krebs cycle intermediates, in the esterification of P into ATP. Chorin-Kirsh and Mayer (1964) observed the activation of ATPase in Chlamydomonas snowiae. It is indicated that Mg makes the cofactor of hexokinase, pyruvic phosphokinase and pyruvic acid dehydrogenase. Besides that it is also a cofactor of carboxylating enzymes in plants. Weissbach et al. (1956) have found that RUDP carboxylase which catalyses the reaction of CO₂ fixation requires Mg as a cofactor. Mg is essential for maximum activity of RUDP carboxylase.

Williams (1957) observed that Mg affects organic acid metabolism and Mg deficiency decreased malic acid and citric acid contents in tomatoes. Moore et al. (1961) found that when barley roots were placed in a solution of Mg sulphate at pH 5 for 3 hours, it resulted in an increased accumulation of organic acid content. From this they concluded that excess of Mg absorption and organic acid metabolism were closely related.

As a conclusion it can be stated that Mg is one of the essential elements for plant growth. It plays an important
role in photosynthesis and organic acid metabolism. It also takes an active part in protein synthesis. It is the principal ingredient of a chlorophyll molecule. Mg deficiency interrupts cell division in plants. Mg is available in large amounts in sea water, but its uptake appears to be comparatively less in marine plants. The information regarding its mobility and distribution in plant is scanty.

(iv) Calcium:

Calcium is the third dominant cation of sea water and is present in smaller quantities than either Na or Mg. Harvey (1957) has recorded 0.42 g of Ca per litre of sea water. Ca distribution in the sea water has been exhaustively studied, for it is a major constituent of many skeletal remains found in marine sediments. Many marine algae deposit CaCO₃ as part of the structure of their cell walls. Ca concentration in sea water is important in understanding the carbonate concentrations in sea (Sheshadri, 1965).

Among the divalent cations entering into the plant cells, Ca is an essential element. The calcium requirement of many marine plants is considerably less than that found in natural habitats. Ca ions undoubtedly play a part in the maintenance of cytoplasmic membranes and in wall structures. Ca enters in the plant cells as calcium pectate, a constituent of the middle lamella. Ca is a factor in the migration of glucosides and the neutralization of acids. This indicates that a good amount of Ca must be required for better growth.
of plants. Hewitt (1951) is of the opinion that Ca maintains cell organization, hydration and permeability. It thus indirectly influences many enzyme systems. Ca activates enzymes like arginine kinase, adenosine triphosphatase, adenyl kinase and potato apyrase (McElroy and Nason, 1954), proteinase (Gorini, 1950). Eyster (1964) has reported that it is the essential element for nitrogen fixation in algae.

Organic acid metabolism is intimately correlated with Ca metabolism. Ilgin (1938) observed that there is a positive correlation between Ca content and organic acids of plants. Biarucha and Dabholkar (1958) have found that increase in Ca contents is correlated with variations in total organic acids. Rasmussen and Smith (1961) have shown that in leaves of Valencia oranges, increase in Ca content shows a corresponding increase in malic and oxalic acids. Splittstoesser and Beavers (1964) have found that Ca concentration was responsible for increased accumulation of succinic and malic acids in potato discs. It indicates that Ca may stimulate malic dehydrogenase to synthesize more malate from oxalacetate. It also appears that Ca can influence organic acid metabolism in plants. Recently Karmarkar (1968) has observed in Bryophyllum pinnatum that large amounts of Ca ions are absorbed and transported within cells to the active sites of organic acid metabolism and Ca ions may account for the large pools of malic acid present in the Crassulacean succulent.
Epstein (1961) has shown that Ca is essential for maintaining the integrity of the selective ion transport mechanism. Eppley and Cyrus (1960) observed that Porphyra cells rapidly lose their weight when grown in Ca-free 30% sea water. The loss of K and gain of Na was recorded in the absence of Ca. Lack of Ca gradually brings about leakage through the cell membranes resulting in increasing movements of salts across their concentration gradients. Ca may maintain K:Na selective sites on the membrane or participate in labile membrane structure.

Jacobson et al. (1960) and Waisel (1962) have found that Ca influences absorption of Na and K in excised cereal roots. Osmond (1966) has also made a similar observation in Atriplex. It was further found by him that excess of Na in the medium interferes with Ca uptake. Moore et al. (1961) showed that Mg is absorbed slowly in the presence of Ca and they proposed that Ca, which influenced absorption of other ions, was localized on the cell surface. Whitenberg and Joham (1964) while studying the carbohydrate distribution in cotton plants observed that Ca can be substituted partially by Na in maintaining carbohydrate translocation. How a dissimilar element can do this function is not clearly understood. They observed that Na was able to help in maintaining Ca in plants in a condition conducive to the synthesis of cellular constituents.
Ca contents in marine plants are generally low as compared to other glycophytic plants. Walker (1957) found that plasmolemma of Nitella cells act as barriers to the diffusion of Ca. Bower and Wedleigh (1954) and Osmond (loc.cit.) observed that high sodium in the environment interferes with Ca uptake. It is possible that Ca absorption is hindered by the presence of Na in the saline environment. However, there is no real deficiency of Ca in marine plants.

Hoagland and Leib (1915) found that fucoidin from Laminariaceae contains Ca and sulphate. Kylin (1943) observed that the polysaccharide from Calethrix scopulorum exists in nature as Ca or Mg salt of a polysaccharide sulphuric ester. Wassermann (1949) has reported that alginic acid may occur in brown algae associated with Ca, Mg and Na. Eppley (1957) has also observed in killed Porphyra perforata tissues, binding of large amount of Na, Ca and SO$_4$ with polysaccharide. These observations indicate that Ca, which is absorbed, is utilized for binding with other complex compounds in the cell.

Considering all these investigations it can be stated that Ca plays an important role in plant metabolism as it is associated with a number of metabolic processes. Ca is essential for cell integrity and is relatively immobile. In marine plants Ca uptake seems to be hampered by excess of Na in the external medium and hence affects mineral metabolism of the saline plants.
Chlorides

Chlorine, present as a chloride ion, is the most abundant ion in sea water and constitutes about 55% by weight of the dissolved material. Harvey (1957) has recorded 19.8 g of Cl per litre of sea water. Cl is used as a measure of the salinity of sea water.

The exact role of Cl in plant metabolism is not clearly understood. Chloride maintains the osmotic pressure of the cells. It is believed that chloride ions in large quantities may not be useful to plants but in low quantities, they are essential for suitable plant growth. However, it remains to be demonstrated that it is an essential element for all plants.

Lipman (1938) has shown that Cl is certainly a highly beneficial ion for plants. Warburg (1949) and Arnon and Whatley (1949) have shown that Cl ions are essential for photosynthesis in green plants. According to them Cl ions exert a protective action upon chloroplast in vitro and they are required for FMN pathway. The light sensitive vitamin K₁ is also protected by Cl ions. Schwartz (1956) has reported a stimulation due to Cl in the photochemical reduction of ferricyanide, by lyophilised cell of Chlorella pyrenoidosa. Eyster (1958) and Eyster et al. (1958) have reported that Cl promotes a four fold increase in the growth of Chlorella pyrenoidosa. Easton (1942) and Raleigh (1948)
have shown that there is a significant increase in growth when plants are supplied with additional Cl. Chlorine has been shown to be an essential element for higher plants (Broyer et al., 1959).

The investigations of Hiatt and Evans (1960) have shown that NaCl concentration affects malic dehydrogenase activity and thereby controls its synthesis. Joshi et al. (1962) have observed that under saline conditions, there is a greater synthesis of amino acids rather than organic acids, by stimulating transaminases and inhibiting malic dehydrogenase. Webb and Burley (1965) have also observed that in salt marsh halophytes during the dark fixation of $^{14}$CO$_2$, Cl ions stimulate amino acid synthesis. While working on Bryophyllum pinnatum, Karmaker (1968) has found that when NaCl was added to the nutrient solution, the synthesis of amino acid was more than the organic acids, while the reverse was observed in the control (NaCl free) plants. Mishra (1966) has indicated that Cl ions in the environment inhibit malic and succinic dehydrogenases while they activate glutamate-oxaloacetate and glutamate-pyruvate transaminases.

Cl deficiency causes a wilting of leaves, stunting of roots and a suppression of lateral branching. Under these conditions roots become shorter and thicker. Cl deficiency symptoms first appear in mature leaves, later in old and young leaves (Wooley and Broyer, 1957). Wooley et al. (1958)
have found that Cl was translocated from older to younger leaves and from high concentration to low concentration. MacRobbie and Dainty (1956) found in Nitellopsis obtusa that Na and Cl undergo active transport and Na is actively transported outwards and chloride inwards. They have suggested that inwardly directed "chloride pump" is associated with the tonoplast in Nitellopsis.

Some marine algae can tolerate a wide range of sea water concentrations while others are adapted to much narrower ranges. Montford (1931) found that certain sublittoral species are immediately and irreversibly damaged by dilute sea water or fresh water. Biebl (1939) observed that intertidal red algae have several possible means of avoiding plasmolytic damage in hypertonic concentrations of sea water.

Walter (1955) who studied the problem of halophytes in detail found that halophytes possess high osmotic values in their cell sap. Walter (loc.cit.) has suggested that in halophytes Cl produce an increase in the succulence whereas sulphates do not produce this effect. This is due to the fact that the hydration of proteins is increased by chlorides, and that on the contrary it is largely decreased by sulphates. According to Walter (loc.cit.) the succulent chloride halophytes must be distinguished from non-succulent sulphate halophytes.
Steiner (cf. Walter, 1955) observed an increase in osmotic values of *Salicornia europaea* from the East coast of the United State from 31.9 to 43.4 atm. The partial pressure of the chlorides rose from 27.8 to 38.3 atm. while the other osmotically active substances remained partially unchanged. A similar observation was made for *Juncus gerardi*, where osmotic value rose from 27.8 to 38.3 atm. while that of chlorides changed from 10.5 to 20.2 atm. (Walter, 1955).

Adriani (1956) stated that Cl ions are present as free ions in the plants. They are not connected to plasma as the absorbing ability of the plasma for anions is very poor. He further reported that Cl causes swelling of the plasma when present in large quantities the absorption of other cations is prevented. Under such special conditions the Cl ions occupy a special position amongst the marine plants.

To summarize, it can be stated that Cl ions are essential for the growth of the plants. Chlorides maintain the hydration and also the osmotic balance between the plant and the environment. The intake of chlorides by the plants is easier than that of sulphates. Chlorides are generally found as free ions in the vacuoles, often in a very high concentration. They develop succulence and retard the growth of a plant. The problem of marine plants, is to develop a capacity to tolerate more Cl in their tissues.
Chloride ions stimulate amino acid synthesis and inhibit
the synthesis of organic acids. Chloride accumulation in
the tissues modifies metabolic processes.

(vi) Sulphur:

Sulphates form the most important source of sulphur
for plants. They occur abundantly in natural waters. Next
to Cl, $\text{SO}_4$ is found in highest concentration in sea water.
Lyman and Fleming in 1940 (cf. Furon, 1963) have recorded
2.7 g/kg of $\text{SO}_4$ in sea water. Majority of algae, like
higher plants use $\text{SO}_4$ in the reduced form of sulphur. Plants
accumulate $\text{SO}_4$ in the vacuoles, while S is found to be
incorporated into numerous organic compounds. S is essential
for the synthesis of amino acids like methionine, cystine,
cysteine which are the normal constituents of the proteins
of algae. S is an important metabolite for the synthesis of
sulpholipids. It has been observed that there is a binding
effect between sulpholipids of green or brown algae and
chlorophyll and a functional relationship has been suggested
between sulpholipids and photosynthesis (Kennedy and Collier,
1963). Although sulpholipids are not directly involved in
photosynthetic $\text{O}_2$ evolution; they may form a reservoir of
S, and carbon (Miyachi and Miyachi, 1966).

$\text{SO}_4$ absorption and subsequent fixation is largely
dependent upon light. Bidwell and Ghosh (1963) have shown
that the uptake and fixation of $\text{S}^{35}$-labelled sulphate by
Fucus vesiculosus are increased by light. They further stated that an active exchange of the sulphate portion of the sulphated polysaccharide, fucoidin was 20 to 600 times greater than that of $^{14}$C, depending on the duration of the experiment.

S deficiency sometimes results in a decrease in chlorophyll contents. S containing nucleotides occur in synchronous Chlorella and Euglena which may have a role in cell division. O'Kelley and Deason (1962) have shown that S is required for zoospore formation in Protosiphon.

The exceptionally high acidity of the cells of various species of Desmarestia is mainly due to the presence of sulphuric acids (Schiff, 1962). Marine sea weeds are characterised by the presence of sulphated polysaccharides. The best known are probably carragenin of red algae and fucoidin of brown algae. The presence of adenosine-3'-phosphate-5'-phosphosulphate in some marine algae indicates that $SO_4$ is essential for the synthesis of such compounds. Polysaccharides esterified with sulphuric acid also occur in green algae.

In general, S is an important element which is involved in the synthesis of amino acids, sulpholipids and many complex polysaccharides. S is a mobile ion but its uptake as $SO_4$ by the marine plants is much less when compared to that of Cl ions.
(vii) **Nitrogen**: 

Nitrate and ammonia are the principal sources of nitrogen which is considered to be one of the highly essential nutrients for the normal growth of plants. In sea water nitrate is present in micro quantities. Nitrates taken up by the plants have to be reduced to ammonia before N is incorporated into the nitrogenous compounds.

Nitrate as a source of N is available in inorganic and organic forms. N is a constituent of protein molecule. It is also found in important molecules such as purines, pyrimidines, porphyrines and coenzymes which are extremely important in the process of plant metabolism. As it is known that the purines and pyrimidines are present in the nucleic acids, RNA and DNA which are essential for protein synthesis.

N deficiency brings down chlorophyll content. Its deficiency also causes anthocyanin formation in higher plants. When the level of nitrogen increases in plant tissues, the cell size increases. Low N level causes a decrease in protein synthesis as a result there is a decrease in cell size and cell division. N constitutes the structure of many vitamins. N assimilation is indirectly connected with photosynthesis since the energy source, hydrogen donors and carbon skeletons are ultimately derived from the latter processes.
The values for N in marine algae vary between 0.99 and 5.44% of dry matter. Average values are, for Enteromorpha 1.57, Macrocystis pyrifera 1.28, Laminaria saccharina 1.80, Fucus vesiculosus 1.64, Rhodymenia palmata 2.91, and Chondrus crispus 2.00 (Vinogradov, 1953). N accumulates in varying amounts in different forms, in different algae. Sometimes nitrates accumulate in the vacuoles of marine algae, in Valonia to the extent of 2,000 times and in Halicystis 500 times the nitrate value of sea water. (Jacques and Osterhout, 1938). When N source is low in sea water there is a considerable reduction in the abundance of marine algae.

Thus nitrogen plays an integral part in life processes of plants since the synthesis of cellular proteins, amino acids, purines, pyrimidines, nucleic acids and enzymes is dependent on this essential element.

(viii) Phosphorus:

Plants absorb P ion in the form of orthophosphate which exists in water either in the inorganic or in organic form. The concentration of soluble phosphate phosphorus in natural sea water is present in small quantities. Like N, the low concentration of P may limit the growth of marine plants.
Simonis and Urbach (1963) have observed that Na, as compared to K, stimulates phosphate uptake in *A. skistosomus* in light or in darkness when phosphates were supplied in low concentration and particularly with Na, there was an increase in the TCA soluble organophosphate. Kylin (1964) has found that in *Scenedesmus*, phosphate is necessary for the uptake of Na, but on the other hand it affects the uptake of sulphate. He further stated that phosphate deficient cells show high levels of inorganic S, soluble reduced S, and lipid S, but protein S is low. Recently Kylin (1967) has shown that Cl absorption is inhibited by adding phosphate to deficient *Scenedesmus* cells, but it stimulates the uptake of Ca, Sr, Rb and Cs ions. The basic mechanisms by which phosphate influences both anion and cation absorption is however, not yet understood clearly. Phosphate deficiency in algae results in the accumulation of large amounts of fat. Stoch (1965) has noticed that stimulation of cyst formation in *Ceratium cornutum* is due to a specific effect of phosphate deficiency.

P plays a key role as energy transferer in photosynthesis and respiration. P is involved in glycolysis and fatty acid synthesis. It is present in nucleoproteins, pyridine-nucleotides and coenzymes such as pyridoxal phosphates, thiamine phosphates, NAD and NADP. P is intimately connected with nitrogen metabolism.
In higher plants phytin which is storage form of phosphates in seeds, contains Ca and Mg salts. The phosphate of phytin is utilized in germination, in the process of phosphorylation.

P as a constituent of ATP is involved in almost every metabolic process. A deficiency in P thus inhibits ATP formation under such conditions there is a high absorption of nitrogen and consequently there is an increase in amino acids. A decrease in P also brings about a corresponding increase in sugars.

P is a mobile ion and as phosphate it is found in actively growing regions of plants. It has a manifold function in the plant life processes. It is one of the major nutrient elements required for normal growth of algae and is intimately associated with plant metabolism.

V. MATERIAL AND METHODS

_Sargassum ilicifolium_, a common brown alga, is mostly restricted to the Indian coasts. It grows in abundance on the sea shores of Ratnagiri. The thallus of _S. ilicifolium_ reaches to the size of 10-12 feet in height at its maximum development. The alga attains a high morphological complexity very much resembling the higher plants. It has a narrow, elongated much branched axis on which, branchlets are borne. The branchlets give
rise laterally to small, leaf like blades with conspicuous midrib and serrate margins. Along the dilated petiole are separate, modified stalks on which air bladders are borne. The axis as well as the blades show the same internal anatomical structure.

*E. ilicifolium* was collected at low tides from the intertidal zones of the rocky shores of Ratnagiri. The alga was collected between 9 and 10 a.m. during the last week of every month from June 1967 to May 1969. Haxo and Clendenning (1953) have reported that the rates of photosynthesis and respiration vary with the vegetative thalli and reproductive thalli. Only blades of vigorously growing vegetative thalli were selected for the present investigation.

The plant samples were collected every month from the same locality over a period of two years and were immediately brought to the laboratory, in the sea water. The procedure for washing the plant material was that of Eppley (1959). The plants were washed scrupulously first to free them from extraneous matter in filtered sea water and then in synthetic sea water to remove the remaining traces of contaminating epiphytes. The composition of synthetic sea water as prepared by Eppley (*loc.cit.*) is given below. The plants were then rinsed quickly in fresh water to remove the surface salt and blotted dry immediately. The sea water in which the alga was found, was also collected at the same time and brought to the laboratory.
in polythene bottles, filtered and used for further analysis. The temperature of the day as well as of sea water was recorded.

Moisture percentage was determined by drying the accurately weighed 10 g algal material to a constant weight in an oven at 95°C. The ash content was found out by igniting 5 g oven-dried powder of the material at 600°C in an electric muffle furnace in a silica crucible to the constant weight. The ash thus obtained was used in the estimation of Na, K, Ca and Mg, while chlorides, sulphate, nitrate and phosphate were estimated from the oven-dried material. The estimation of the inorganic ions was carried out by the following conventional titrimetric, gravimetric and colorimetric methods, described by various workers. Sodium (Reitmeier, 1943), potassium (Robertson, 1939), magnesium (Richards, 1954), calcium (Flaschka, 1959), chlorides (Volhard, 1956), sulphate (Allison et al., 1954) and phosphate (A.O.A.C., 1960). The samples of sea water were analysed for Na, K, Ca and Mg by the same methods as in the case of plant material while other constituents were analysed by following methods:

chlorides (Richards, 1954), sulphate (Gupta and Ananthanarayana, 1963), nitrate (Barne, 1959) and phosphate (Strickland and Parson, 1965).
(1) **Composition of Synthetic Sea Water**:

Synthetic sea water was prepared by the formula used by Eppley (1959) and its composition is given below.

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>NaCl</td>
<td>0.5 M</td>
</tr>
<tr>
<td>MgSO₄</td>
<td>0.027 M</td>
</tr>
<tr>
<td>KCl</td>
<td>0.025 M</td>
</tr>
<tr>
<td>CaCl₂</td>
<td>0.01 M</td>
</tr>
<tr>
<td>Tris-Hydroxymethylaminomethane buffer, pH 7.8, 0.05 M.</td>
<td></td>
</tr>
</tbody>
</table>

At the suggestion of Eppley (cf. Joshi et al., 1962) the formula of artificial sea water was further improved by adding trace elements in the following concentrations:

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na-EDTA</td>
<td>45 µM</td>
</tr>
<tr>
<td>FeSO₄</td>
<td>14.9 µM</td>
</tr>
<tr>
<td>H₃BO₃</td>
<td>9.75 µM</td>
</tr>
<tr>
<td>MnCl₂</td>
<td>2.02 µM</td>
</tr>
<tr>
<td>ZnSO₄·7H₂O</td>
<td>1.73 µM</td>
</tr>
<tr>
<td>CuSO₄·5H₂O</td>
<td>0.2 µM</td>
</tr>
<tr>
<td>(NH₄)₂MoO₄</td>
<td>0.25 µM</td>
</tr>
</tbody>
</table>

Glass distilled water and A.R. grade reagents were used in preparing the synthetic sea water.

**VI. RESULTS AND DISCUSSION**

Ratnagiri belongs to the southern part of the Indian West coast and is situated in between the Long. 73° 18' E
and Lat. 17° N. It falls into subtropical zone having three distinct seasons namely monsoon, winter and summer. Monsoon sets in, more or less in the middle of June and it starts raining heavily in July and lasts upto the middle August. From mid-August onwards sunshine is interrupted by showers. This latter condition prevails upto the middle of September and this period is considered as post-monsoon period. Next starts winter season when the temperature is fairly low and cold prevails till February. Then begins the summer from March onwards till May. The average rainfall in monsoon is about 160 cm. The minimum and maximum temperatures range between 24° C and 29° C during monsoon, 15° C and 26° C during winter and 28° C and 36° C during summer. Although there are three distinct seasons, winter is mild as the temperature is fairly high.

The seasonal variations in inorganic constituents of *S. illicifolium* and the sea water in which it was found are presented in Tables I and II. The data presented are the analysis carried out for two years from June 1967 to May 1969. The results were confirmed during the period of June 1968 to May 1969 and they were statistically analysed. The noteworthy feature in these findings are the significant seasonal variations in inorganic constituents of sea water as well as those of *S. illicifolium*.

Similar work on *U. lactuca* has also been done in our laboratory and this showed marked seasonal variations in
### TABLE I

**SEASONAL VARIATIONS IN INORGANIC CONSTITUENTS OF SARGASSUM ILICIFOLIUM AND SEA WATER**

(In *S. ilicifolium* values are expressed as g per 100 g)  
(dry material while for sea water g per litre)

<table>
<thead>
<tr>
<th></th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
<th>Summer</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>June</td>
<td>July</td>
<td>Aug</td>
<td>Sept</td>
<td>Oct</td>
</tr>
<tr>
<td><strong>Moisture %</strong></td>
<td>80.79</td>
<td>80.98</td>
<td>81.23</td>
<td>81.61</td>
<td>82.24</td>
</tr>
<tr>
<td><strong>Ash %</strong></td>
<td>29.55</td>
<td>30.54</td>
<td>29.86</td>
<td>30.41</td>
<td>32.75</td>
</tr>
<tr>
<td><strong>SODIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sargassum</em></td>
<td>3.05</td>
<td>2.81</td>
<td>2.68</td>
<td>2.93</td>
<td>3.45</td>
</tr>
<tr>
<td><strong>POTASSIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sargassum</em></td>
<td>5.73</td>
<td>6.43</td>
<td>6.22</td>
<td>6.54</td>
<td>7.05</td>
</tr>
<tr>
<td><em>Sea water</em></td>
<td>0.371</td>
<td>0.284</td>
<td>0.249</td>
<td>0.362</td>
<td>0.456</td>
</tr>
<tr>
<td><strong>Na/K Ratio in</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sargassum</em></td>
<td>0.534</td>
<td>0.437</td>
<td>0.431</td>
<td>0.446</td>
<td>0.489</td>
</tr>
<tr>
<td><em>Sea water</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>MAGNESIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sargassum</em></td>
<td>1.87</td>
<td>1.97</td>
<td>1.94</td>
<td>2.15</td>
<td>2.36</td>
</tr>
<tr>
<td><em>Sea water</em></td>
<td>1.36</td>
<td>1.19</td>
<td>0.954</td>
<td>1.21</td>
<td>1.38</td>
</tr>
</tbody>
</table>

..... contd.
<table>
<thead>
<tr>
<th></th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
<th>Summer</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>June</td>
<td>July</td>
<td>Aug</td>
<td>Sept</td>
<td>Oct</td>
</tr>
<tr>
<td><strong>CALCIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>1.49</td>
<td>1.42</td>
<td>1.35</td>
<td>1.48</td>
<td>1.57</td>
</tr>
<tr>
<td>Sea water</td>
<td>0.404</td>
<td>0.282</td>
<td>0.248</td>
<td>0.345</td>
<td>0.423</td>
</tr>
<tr>
<td><strong>CHLORIDES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sea water</td>
<td>21.86</td>
<td>16.84</td>
<td>14.76</td>
<td>18.56</td>
<td>21.82</td>
</tr>
<tr>
<td><strong>SULPHATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>1.74</td>
<td>1.67</td>
<td>1.51</td>
<td>1.63</td>
<td>1.72</td>
</tr>
<tr>
<td>Sea water</td>
<td>2.33</td>
<td>1.89</td>
<td>1.86</td>
<td>2.17</td>
<td>2.24</td>
</tr>
<tr>
<td><strong>NITRATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>3.45</td>
<td>0.537</td>
<td>0.825</td>
<td>2.61</td>
<td>5.64</td>
</tr>
<tr>
<td>Sea water*</td>
<td>0.481</td>
<td>0.328</td>
<td>0.562</td>
<td>0.665</td>
<td>0.738</td>
</tr>
<tr>
<td><strong>PHOSPHATE</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>0.481</td>
<td>0.328</td>
<td>0.562</td>
<td>0.665</td>
<td>0.738</td>
</tr>
<tr>
<td>Sea water*</td>
<td>0.831</td>
<td>0.232</td>
<td>0.524</td>
<td>0.732</td>
<td>0.935</td>
</tr>
</tbody>
</table>

* Values are expressed as µg per litre.
### TABLE II

**SEASONAL VARIATIONS IN INORGANIC CONSTITUENTS OF SARGASSUM ILCIFOLIUM AND SEA WATER**

(Values are expressed as meq per 100 g dry material, while for sea water they represent meq per litre)

<table>
<thead>
<tr>
<th></th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
<th>Summer</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SODIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>132.6</td>
<td>122.3</td>
<td>116.6</td>
<td>127.5</td>
<td>150.1</td>
</tr>
<tr>
<td>Sea water</td>
<td>537.6</td>
<td>403.1</td>
<td>376.2</td>
<td>453.7</td>
<td>545.5</td>
</tr>
<tr>
<td><strong>POTASSIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>146.6</td>
<td>164.4</td>
<td>159.1</td>
<td>167.3</td>
<td>180.3</td>
</tr>
<tr>
<td>Sea water</td>
<td>9.1</td>
<td>7.28</td>
<td>6.38</td>
<td>9.3</td>
<td>11.69</td>
</tr>
<tr>
<td><strong>MAGNESIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>153.8</td>
<td>162.0</td>
<td>159.5</td>
<td>176.8</td>
<td>194.1</td>
</tr>
<tr>
<td>Sea water</td>
<td>113.3</td>
<td>99.1</td>
<td>79.5</td>
<td>100.8</td>
<td>115.0</td>
</tr>
<tr>
<td><strong>CALCIUM</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>74.37</td>
<td>70.87</td>
<td>67.38</td>
<td>73.87</td>
<td>78.36</td>
</tr>
<tr>
<td>Sea water</td>
<td>20.2</td>
<td>14.1</td>
<td>12.4</td>
<td>17.25</td>
<td>21.55</td>
</tr>
</tbody>
</table>

... contd.

---

**TABLE XI**

**SEASONAL VARIATIONS IN INORGANIC CONSTITUENTS OF SARGASSUM ILCIFOLIUM AND SEA WATER**

(Values are expressed as meq per 100 g dry material, while for sea water they represent meq per litre)
<table>
<thead>
<tr>
<th></th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
<th>Summer</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>June</td>
<td>July</td>
<td>Aug</td>
<td>Sept</td>
<td>Oct</td>
</tr>
<tr>
<td>CHLORIDES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>231.1</td>
<td>214.9</td>
<td>192.4</td>
<td>207.04</td>
<td>246.7</td>
</tr>
<tr>
<td>Sea water</td>
<td>615.8</td>
<td>478.4</td>
<td>415.7</td>
<td>522.8</td>
<td>611.8</td>
</tr>
<tr>
<td>SULPHATE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>36.25</td>
<td>34.79</td>
<td>32.5</td>
<td>33.96</td>
<td>35.83</td>
</tr>
<tr>
<td>Sea water</td>
<td>48.85</td>
<td>39.6</td>
<td>38.7</td>
<td>45.2</td>
<td>46.7</td>
</tr>
<tr>
<td>NITRATE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Sea water</td>
<td>0.023</td>
<td>0.018</td>
<td>0.028</td>
<td>0.087</td>
<td>0.188</td>
</tr>
<tr>
<td>PHOSPHATE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sargassum</td>
<td>16.0</td>
<td>10.9</td>
<td>18.66</td>
<td>22.66</td>
<td>24.6</td>
</tr>
<tr>
<td>Sea water</td>
<td>0.028</td>
<td>0.008</td>
<td>0.017</td>
<td>0.024</td>
<td>0.038</td>
</tr>
</tbody>
</table>

TABLE II (contd.)
### TABLE III

**DISTRIBUTION OF Na, K, Ca, Mg AND Cl IONS IN PLANTS OF DIVERSE HABITAT**

(Values are expressed as g per 100 g dry material)

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Name of the plant</th>
<th>Plant organ</th>
<th>Na</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Cl</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Marine</td>
<td>Sargassum</td>
<td>Thallus</td>
<td>3.18</td>
<td>6.54</td>
<td>1.54</td>
<td>2.21</td>
<td>8.63</td>
<td>Present work.</td>
</tr>
<tr>
<td>5. Mangrove</td>
<td>Ceriops</td>
<td>Mature leaves</td>
<td>1.57</td>
<td>1.22</td>
<td>1.06</td>
<td>0.794</td>
<td>2.566</td>
<td>Chirputkar (1969).</td>
</tr>
<tr>
<td>6. Mangrove</td>
<td>Avicennia</td>
<td>Mature leaves</td>
<td>4.1</td>
<td>1.00</td>
<td>-</td>
<td>-</td>
<td>7.5</td>
<td>Rains and Epstein (1967).</td>
</tr>
<tr>
<td>7. Salarine</td>
<td>Clerodendron</td>
<td>Mature leaves</td>
<td>5.49</td>
<td>3.02</td>
<td>2.48</td>
<td>0.69</td>
<td>6.24</td>
<td>Mishra (1967).</td>
</tr>
</tbody>
</table>

..... contd.  

---

**TABLE III contd.**

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Name of the plant</th>
<th>Plant organ</th>
<th>Na</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Cl</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. Riverine</td>
<td>Populus</td>
<td>Mature leaves</td>
<td>4.3</td>
<td>1.02</td>
<td>1.06</td>
<td>0.794</td>
<td>2.566</td>
<td>Chirputkar (1969).</td>
</tr>
<tr>
<td>11. Upland</td>
<td>Quercus</td>
<td>Mature leaves</td>
<td>5.7</td>
<td>3.05</td>
<td>2.48</td>
<td>0.69</td>
<td>6.24</td>
<td>Mishra (1967).</td>
</tr>
<tr>
<td>12. Mountain</td>
<td>Pinus</td>
<td>Mature leaves</td>
<td>1.2</td>
<td>3.73</td>
<td>2.83</td>
<td>1.81</td>
<td>2.13</td>
<td>Mishra (1967).</td>
</tr>
</tbody>
</table>

---

**TABLE III contd.**

<table>
<thead>
<tr>
<th>Habitat</th>
<th>Name of the plant</th>
<th>Plant organ</th>
<th>Na</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Cl</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>14. Freshwater</td>
<td>Salix alba</td>
<td>Mature leaves</td>
<td>4.3</td>
<td>1.02</td>
<td>1.06</td>
<td>0.794</td>
<td>2.566</td>
<td>Chirputkar (1969).</td>
</tr>
<tr>
<td>15. Riverine</td>
<td>Populus</td>
<td>Mature leaves</td>
<td>5.7</td>
<td>3.05</td>
<td>2.48</td>
<td>0.69</td>
<td>6.24</td>
<td>Mishra (1967).</td>
</tr>
<tr>
<td>16. Upland</td>
<td>Quercus</td>
<td>Mature leaves</td>
<td>1.2</td>
<td>3.73</td>
<td>2.83</td>
<td>1.81</td>
<td>2.13</td>
<td>Mishra (1967).</td>
</tr>
<tr>
<td>Habitat</td>
<td>Name of the plant</td>
<td>Plant organ</td>
<td>Na</td>
<td>K</td>
<td>Ca</td>
<td>Mg</td>
<td>Cl</td>
<td>Reference</td>
</tr>
<tr>
<td>-------------------------</td>
<td>------------------------------------</td>
<td>----------------------</td>
<td>-----</td>
<td>------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>----------------------------</td>
</tr>
<tr>
<td>9. Halophyte</td>
<td>Semevium portulacastrum</td>
<td>Mature leaves</td>
<td>9.9</td>
<td>3.97</td>
<td>0.37</td>
<td>0.54</td>
<td>8.64</td>
<td>Singh (1967).</td>
</tr>
<tr>
<td>10. Pasture plant with capacity for salt tolerance</td>
<td>Atriplex vesicaria</td>
<td>Mature leaves</td>
<td>5.2</td>
<td>2.2</td>
<td>0.76</td>
<td>-</td>
<td>9.6</td>
<td>Beadle et al. (1957).</td>
</tr>
<tr>
<td>11. Halophyte (sandy) sulphate</td>
<td>Spinifex squarrosus</td>
<td>Mature leaves</td>
<td>1.93</td>
<td>0.39</td>
<td>0.32</td>
<td>1.54</td>
<td>2.52</td>
<td>Vakharis (work from our laboratory).</td>
</tr>
<tr>
<td>12. Halophyte</td>
<td>Cressa cretica</td>
<td>Mature leaves</td>
<td>2.25</td>
<td>0.51</td>
<td>1.02</td>
<td>0.38</td>
<td>2.32</td>
<td>Mirchandani (work from our laboratory).</td>
</tr>
<tr>
<td>13. Halophyte</td>
<td>Aeluropus</td>
<td>Mature leaves</td>
<td>1.23</td>
<td>0.59</td>
<td>0.33</td>
<td>0.28</td>
<td>1.84</td>
<td>Warich (1960).</td>
</tr>
<tr>
<td>14. Halophyte</td>
<td>Sueda</td>
<td>Mature leaves</td>
<td>8.55</td>
<td>1.94</td>
<td>0.56</td>
<td>0.5</td>
<td>-</td>
<td>Warich (1960).</td>
</tr>
<tr>
<td>16. Terrestrial glycophyte</td>
<td>Zea mays</td>
<td>Entire plant</td>
<td>-</td>
<td>0.92</td>
<td>0.23</td>
<td>0.18</td>
<td>0.14</td>
<td>Miller (1938).</td>
</tr>
<tr>
<td>17. Terrestrial glycophyte</td>
<td>Jatropha curcas</td>
<td>Mature leaves</td>
<td>0.64</td>
<td>2.36</td>
<td>5.03</td>
<td>4.5</td>
<td>1.83</td>
<td>Torne and Joshi (1964).</td>
</tr>
</tbody>
</table>
inorganic constituents (Patil and Joshi, 1967). Our results are compared with those findings in *U. lactuca* and similar other investigations. Table III lists the major elements whose concentrations in various plants of diverse habitat have been estimated in recent years in our laboratory and elsewhere. These results are also considered in the discussion.

(1) **Moisture and Ash Contents:**

The values for moisture and ash contents in the tissues of *S. ilicifolium* are presented in Table I. The water content of the plant, under prevailing conditions at Ratnagiri, ranges from 78.83 to 84.72 %, with an average value of 81.1 during the year. The minimum value of 78.83 is recorded in January and the maximum value of 84.72 is obtained in April. There is a gradual increase in moisture content from June to October and then decrease to the minimum value in January. The values again rise from February to April with a drop in May.

Mackpherson and Young (1952) have observed the moisture content in three different members of Fucaceae in Canada. It was found by them that water contents are minimum during winter and maximum in spring. They have further stated that this observation in these algae is similar with the land plants. Their values for moisture content in three species of Fucaceae from Canadian East
coast are ranging from 69.4 to 80.5 in *Ascophyllum nodosum*, 73.8 to 83.5 in *Fucus vesiculosus* and 76.1 to 88.4 in *F. evanescens*. A similar variation is observed by Wort (1955) in dry matter content of *Nereocystis luetkeana* from British Columbia coastal waters. Patil and Joshi (1967) while studying the seasonal variations in moisture content in *U. lactuca* have obtained in contrast to *S. ilicifolium*, a maximum value of 80.93 in December and February. Our results for water content in *S. ilicifolium* are almost in conformity with those of Macpherson and Young (loc.cit.) and Wort (loc.cit.).

The values for ash contents are also shown in Table I. They show a different pattern of variation from that of moisture content in *S. ilicifolium*. The ash contents of the plant range from 27.93 to 35.48 with the average value of 31.14. The minimum value of 27.93 is recorded in May while the maximum value of 35.48 is recorded in November. The values show a gradual increase from August to November with a slight fall in winter. The ash percentages are at minimum during summer months.

There are numerous investigators who have done detailed ash analysis of marine algae. The results of these investigators are recorded in Table IV and the results of the present investigation are also recorded in the same for comparison. It is obvious from the works of investigators mentioned in the table as well as that
### TABLE IV

**ASH CONTENTS IN VARIOUS ALGAE**

<table>
<thead>
<tr>
<th>Name of the plant</th>
<th>Place</th>
<th>Range in percentage</th>
<th>Highest values in month/season</th>
<th>Lowest values in month/season</th>
<th>Author</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <em>Laminaria</em> sp.</td>
<td>West Coast, Scotland</td>
<td>13 - 46</td>
<td>November to January</td>
<td>March to June/July</td>
<td>Black and Dewar</td>
<td>(1949)</td>
</tr>
<tr>
<td>2. <em>Fucus</em> sp.</td>
<td>Scotland</td>
<td>13.8 - 30.5</td>
<td>January/March and October and November</td>
<td>-</td>
<td>Black</td>
<td>(1949)</td>
</tr>
<tr>
<td>4. <em>Fucus vesiculosus</em></td>
<td>Scotland</td>
<td>17.8 - 37.3</td>
<td>June and August</td>
<td>December</td>
<td>Moss</td>
<td>(1950)</td>
</tr>
<tr>
<td>5. <em>Fucus</em> sp.</td>
<td>Canada</td>
<td>19 - 27</td>
<td>Winter months</td>
<td>-</td>
<td>Macpherson and Young</td>
<td>(1952)</td>
</tr>
<tr>
<td>6. <em>Ascophyllum nodosum</em></td>
<td>Canada</td>
<td>14 - 31</td>
<td>Winter months</td>
<td>-</td>
<td>Macpherson and Young</td>
<td>(1952)</td>
</tr>
<tr>
<td>7. <em>Macrocytis interfolia</em></td>
<td>British Columbia</td>
<td>19 - 52</td>
<td>Late fall and Winter</td>
<td>-</td>
<td>Wort</td>
<td>(1955)</td>
</tr>
<tr>
<td>8. <em>Nereocystis lustkeana</em></td>
<td>British Columbia</td>
<td>32 - 63</td>
<td>Late fall and Winter</td>
<td>-</td>
<td>Wort</td>
<td>(1955)</td>
</tr>
</tbody>
</table>

..... contd.
<table>
<thead>
<tr>
<th>Name of the plant</th>
<th>Place</th>
<th>Range in percentage</th>
<th>Highest values in month/season</th>
<th>Lowest values in month/season</th>
<th>Author</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>10. <em>Fucus spiralis</em></td>
<td>Spain</td>
<td>20 - 32</td>
<td>March and September</td>
<td>July and November</td>
<td>Primo</td>
<td>(1956)</td>
</tr>
<tr>
<td>11. <em>Chondrus crispus</em></td>
<td>Atlantic coast</td>
<td>21 - 25</td>
<td>January</td>
<td>August</td>
<td>Young and Langille</td>
<td>(1958)</td>
</tr>
<tr>
<td>14. <em>Sargassum sp.</em></td>
<td>Bhevnagar (India)</td>
<td>25 - 34</td>
<td>-</td>
<td>-</td>
<td>Rao and Tipnis</td>
<td>(1965)</td>
</tr>
<tr>
<td>15. <em>Ulva lactuca</em></td>
<td>Bombay (India)</td>
<td>25 - 34</td>
<td>February</td>
<td>November</td>
<td>Patil and Joshi</td>
<td>(1967)</td>
</tr>
<tr>
<td>16. <em>Sargassum ilicifolium</em></td>
<td>Ratnagiri (India)</td>
<td>27.93 - 35.48</td>
<td>November</td>
<td>May</td>
<td>Present investigation.</td>
<td></td>
</tr>
</tbody>
</table>

* During receptacle development;  ** Stipes and fronds
of ours that there are distinct seasonal variations in ash contents. In general high ash percentages are recorded during winter months while low values are for the summer.

From these observations it is obvious that the values for ash in *S. ilicifolium* are within definite range and show seasonal variations. However, the variation is much less than those of many species mentioned above. Possibly it may be due to the lesser fluctuation of minerals in the habitat where the alga grows. It is evident from the results of various investigators that the range of ash contents in the plant differ from place to place and also from time to time. It is also noted that different parts of the same plant vary in ash percentages. The ash content of *S. ilicifolium* is found to be maximum during late monsoon and early winter when the alga attains the maximum growth of its life cycle. As the plant has to develop a pool of minerals before it enters into reproductive stage, possibly large amount of cations are stored during the period.

(ii) Sodium:

Na concentrations of the sea water and *S. ilicifolium* are presented in Table I and Figure 4. These values represent the contents of Na in twelve different months. It is evident from the table that Na is the dominant cation of the intertidal waters of Ratnagiri in which
SEASONAL VARIATIONS IN SODIUM CONTENTS OF
SARGASSUM ILICIFOLIUM AND SEA WATER

MONTHS

Fig. 4

SODIUM
S. ILICIFOLIUM ▲—▲
SEA WATER ○--○
S. ilicifolium is found. Na contents of the sea water range from 8.65 to 13.85 g per litre with an average value of 11.61 g for the period of one year. Several investigators have analysed sea water for the mineral contents. In order to compare our results, the values obtained by other workers are given below.

Lyman and Fleming in 1940 (cf. Furey, 1963) have recorded 10.56 g/kg of Na in sea water. Harvey (1957) has recorded 11.1 g per litre of Na in the sea water that he has analysed; while Young et al. (1959) have reported a value of 9.55 g/kg for the sea water in the vicinity of Atlantic Provinces of Canada. In India, Seshadri (1965) has recorded 10.56 g/kg of Na at Bhavnagar. Sharma and Dave (1965) have recorded 10.6 g/kg of Na in the Gujarat coastal waters (1965). Recently Patil and Joshi (1967), while studying the seasonal variations in chemical composition of sea waters from Bombay coast for a period of 10 months, have found that Na contents range from 6.35 to 15.08 per litre. Our values fall within the range of those recorded by other investigators and show a distinct seasonal variations.

The salinity of the intertidal sea water goes down during monsoon as there are heavy rains at Ratnagiri and hence low values for Na are recorded in July and August. In October the temperature is fairly high and this may cause in the evaporation of water as a result Na content
also rises. There is a gradual decrease in Na content from November to January and then increase up to May. The values for Na content vary with temperature indicating that the concentration of Na in the sea water is largely controlled by the temperature factor (Fig. 7).

It is obvious from the Figure 4 that the variations in Na content of *S. ilicifolium* show a similar pattern of Na concentration in sea water. The low value of 2.68 % is recorded in August and the highest value of 3.57 % in April. The values gradually rise from August to November with a fall in December and January. The values are fairly at high level during summer months and show the highest value in April. The value of 3.52 in November is very near to the highest value recorded in April. Young and Langille (1958) have analysed *Chondrus crispus* for a period of 8 months. Their values for Na range from 3.43 to 3.7 % without showing a well-defined variation in *C. crispus*. However, within the small range they have observed maximum value in April and minimum in August. Patil and Joshi (1967) have analysed *U. lactuca* from the sea shores of Bombay for seasonal variation in Na content and their values range from 3.52 % to 5.05 %. They have observed that there is less Na accumulation in monsoon and more in winter as compared to summer. The maximum value is recorded in December while low value is in August. The values in other saline and non-saline plants are recorded in Table III.
From the table, it is clear that saline plants investigated in our laboratory reveal that the Na contents are less during monsoon and maximum values may be either in winter or in summer months.

Na contents of *S. illicifolium* range from 2.68 to 3.57 g per 100 g dry material with an average value of 3.18% in the year. Young and Langille (1958) have analysed numerous species of green, red and brown algae from the Atlantic coast of Canada and observed a relatively constant sodium level at 2.5 to 3.5% for all the species irrespective of their groups. However, they have not attempted seasonal variations. Nita (1961), who has also not undertaken seasonal variations, records 0.93% of Na in *U. pertusa*. Langalia et al. (1965) who have analysed *Sargassum johnstonii*, *U. fasciata*, *Halimeda tuna* and *Gracilaria* at Bhavnagar, have found that these plants contain 3.2%, 3.1%, 3.4% and 3.8% of Na respectively. Rao and Tipnis (1965) have analysed a number of marine algae belonging to different groups at Gujarat coast. They have found 1.67% of Na in *S. cinctum* and 1.47 in *S. johnstonii*. The values given above indicate species of the same genus differ in their Na content and quite likely same species at different places to show variations in Na accumulation. Hence it can be said that Na concentration is not only dependent on the concentration in the surrounding sea water but also dependent on the efficiency of individual plants to accumulate Na ion in
their tissues and this may be a genetic phenomenon. It is obvious from Table II that although Na dominates in seawater, it is not the dominant cation but only a major constituent of the inorganic fraction of *S. ilicifolium.* The dominant cations are Mg and K, and Na stands only for a third place in the plant. Figure 6 shows the uptake ratios of Na in *S. ilicifolium* and *U. lactuca.* It appears that *U. lactuca* accumulates more Na than *S. ilicifolium.* However, reverse is true for K.

Table III reveals that the range of Na in glycophytes is from 0.6 to 1.4 g per 100 g of dry tissue, while in saline plants these values range from 1.2 to 9.9%. It seems that in majority of the saline plants Na accumulation is fairly high. As indicated by Larsen (1967) halophytes while adapting themselves to the condition of saline environment have developed the ability not only to tolerate Na ion but also to depend upon it for normal growth. The same may be true in case of marine algae.

Usually Na is found associated with Cl ions. Besides, it can also be present in a bound form with a complex organic molecule. Mita (1961) has found that the main inorganic compounds of mucilage of *U. pertusa* and *E. compressa* are Na, Mg and S. He has suggested that mucilages of green sea weeds consist of Na and Mg salts of sulphate esters of polysaccharides. It is possible that Na which accumulates in *S. ilicifolium* is bound to organic constituents such as...
algic acid so that its harmful or toxic effects can be overcome. Wassermann (1949) has stated that algic acid, the major constituent of cell wall of brown algae occurs naturally associated predominantly with cations such as Ca, Mg and Na. *S. illicifolium* which contains a good amount of algic acid may be associated with sodium.

In conclusion it can be stated that Na is the third large cation constituent of *S. illicifolium* even though it predominates in the outer environment. Its concentration in the plant tissue falls only next to Mg and K. Na content shows a definite seasonal variation with a well defined maximum and minimum during the year. The concentration of Na is less than that of K throughout the year. This condition shows that Na has less metabolic importance than that of K. Since the high level of Na is injurious to the plant itself, its uptake is reduced by preferring K in its place. In *S. illicifolium* perhaps Na is necessary only to maintain osmotic balance. It is likely that there may exist some sort of mechanism which continuously throws Na outside the plant. In *S. illicifolium* Na may constitute a part of complex polysaccharides present in the cellular component of the alga.

**(iii) Potassium:**

K contents of the sea water and *S. illicifolium* are given in Table I and II. K concentrations of the sea
water of Ratnagiri range from 0.249 to 0.463 g per litre with an average value of 0.39. Harvey (1957) has recorded 0.39 g of K per litre of sea water, while Young et al. (1959) have found 0.341 g/kg of K in the sea water of Atlantic coast. In India, Seshadri (1965) has recorded 0.38 g/kg of K in the sea water from Bhavnagar and Sharma and Dave (1965) obtained 0.388 g/kg of K from Gujarat coastal waters. Rao (1965) has observed that K contents of the sea water at Bhavnagar range from about 0.1 to 0.39 g per litre during the year. Patil and Joshi (1967) while studying the seasonal variations, have recorded that K contents in the sea water at Bombay range from 0.26 to 0.51 g per litre. These observations show that our values at Ratnagiri fall within the range of those values recorded by other investigators.

It is obvious from Figure 5 that the pattern of K variations in sea water is almost similar to that of Na. The maximum value of 0.463 g per litre of sea water is obtained in February and the minimum value of 0.249 is recorded in August. The values obtained in October, April and May are also fairly high and are very near to the maximum value of February. The low values for K in sea water are recorded during monsoon months with an increase in October and then the concentrations of K show gradual decrease up to January. K contents increase with the advancement of summer. This indicates that variation in
SEASONAL VARIATIONS IN POTASSIUM CONTENTS OF S. ILICIFOLIUM AND SEA WATER

Fig. 5

S. ILICIFOLIUM 9 PER 100 g DRY MATERIAL

SEA WATER 9 PER LITRE

POTASSIUM

S. ILICIFOLIUM ▲▲
SEA WATER O---O

MONTHS

JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY

Fig. 5
K contents are similar to that of Na contents of the sea water from Ratnagiri and show a definite seasonal variations during the year.

*Salicornia ilicifolium* has an appreciable amounts of K in the cells. The maximum value of 7.63% is recorded in February and very near to this value of 7.56 is observed in November. The minimum value of 5.46 is obtained in May. In general K values are fairly high throughout the year. In *Salicornia ilicifolium* the minimum value for Na is observed in August and maximum in summer months, whereas K is found at higher level during monsoon and winter months and the minimum in the summer months. This indicates that the pattern of K concentrations in *Salicornia ilicifolium* differs from that of Na during the year.

The analysis of other marine plants in our laboratory indicate that maximum values for K are observed either in monsoon or winter but not in summer. Mishra (1967) has recorded in *Clerodendrum inerme* the maximum value of 1.61% in winter and minimum value of 1.01% is found in monsoon. While studying the seasonal variations in mineral constituents of *Senecio portulacastrum*, Singh (1967) has observed the maximum value of 2.7% of K in monsoon, and the minimum value of 1.21% is recorded in summer. Patil and Joshi (loc.cit.) who studied the seasonal variations in inorganic constituents of *U. lactuca*, have found the
maximum value of 3.83% in February with a slightly lower value of 3.6 in December and the minimum value of 1.7% in May. All these investigations indicate that K accumulation in the plant tissues is found maximum during monsoon and winter months.

It is of interest to record K values are high in *S. ilicifolium*. The values are much higher than that of *U. lactuca* (Fig. 6). The plant shows average value of 6.54% which is considerably high. The normal values for K in glycophytes vary from 0.3 to 6.0% (Ferry and Ward, 1959). The Table reveals that saline plants as well as non-saline plants accumulate K in high amounts. Marine plants uptake and accumulate more quantities of K even though the element is many times less than that of Na in the external environment. It is well known that K is an indispensable element and due to this saline plants absorb K in a much greater proportion as compared to its presence in the environment. Many marine algae show more K than Na. For example, Young and Langille (1958) have studied eleven algal specimens of various species belonging to Chlorophyceae, Phaeophyceae and Rhodophyceae from Atlantic coast of Canada. They found that in 6 species, K is more than Na and notably high value of 7.11% K is recorded only in Rhodymenia. Their values for K in the dry matter of *Laminaria longicruris* and *L. digitata* are 4.67% and 4.95% respectively. Langille *et al.* (1965) have recorded 8.0% of K in *S. johnstonii* and
RATIO INDICATING UPTAKE OF Na AND K FROM SEAWATER IN S. ILICIFOLIUM & U. LACTUKA

MONTHS

JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY

JUN JUL AUG SEP OCT NOV DEC JAN FEB MAR APR MAY

MONTHS

Fig. 6

SODIUM

POTASSIUM
4.0% in U. fasciata while Na contents are 3.2 and 3.1 respectively. Rao and Tipnis (1965) have found 7.35% of K in S. cimerum which is more than that of Na. All these works show that marine algae have maximum affinity for K eventhough its concentration is found very less in the external environment. The selective accumulation of K ions has been already observed by Scott and Hayward (1954) and Eppley (1959). It can be stated that K values for S. ilicifolium is remarkably high and the efficiency in absorbing K are much more than Na when compared with its concentration in the external environment. Sometimes the concentration of K in the plant tissue exceeds more than 20 times from that of Na in sea water (Table I and II and Fig. 10).

It is possible that in marine plants both Na and K elements are essential. The preferential absorption of K is the most important aspect of physiological activities of saline plants. This can be explained in the view of Epstein (1966), who reviewed the dual pattern of ion absorption by plants, has stated that when K concentrations are low in the external medium a powerful mechanism of K uptake must exist for substantial absorption of K. This has to take place when chemically related Na is also present in high proportion in the external medium. In such cases a plant develops a mechanism whereby a high affinity for K is developed. In such circumstances
mechanism is highly selective for K, eventhough chemically similar Na is present. By such mechanism, the plant regulates its K uptake. Epstein (loc.cit.) further extends his statement that in another mechanism Na is taken in just to balance osmotic gradients.

The Na/K ratio in *S. illicifolium* is less than one throughout 12 months. The maximum Na/K ratios are found from March to June. The values gradually increases from July to October and then decrease in winter months. This indicates that the Na/K ratios vary with that of temperature which appears to be the controlling factor (Fig. 7).

In Figure 8 the Na and K contents of *S. illicifolium* are shown graphically. While the concentration of K is higher than that of Na throughout the year, the pattern of variation in the plant is almost similar. However, with the advancement of summer as the Na concentration increases in the plant as well as in the surrounding sea water, the amount of K decreases showing a narrow range of variations in concentration between these two ions.

Perry (1968) in his radioactive experiment using Na\(^{14}\)HCO\(_3\), has shown that the cells of *Micrococcus sodonensis* require a higher K level for the intracellular accumulation of CO\(_2\) but not for the fixation reactions. In *S. illicifolium* it is observed that there is an increase in K concentration during the time of active photosynthetic period. This high
SEASONAL VARIATIONS IN MEAN TEMPERATURE AND 
\[ \frac{\text{Nd}}{\text{K}} \] RATIO IN S. ILICIFOLIUM

MONTHS

Fig. 7
Figure 8 shows the accumulation of sodium and potassium in S. ilicifolium over the months of the year. The graph indicates that sodium and potassium levels vary significantly throughout the year, with peaks and troughs corresponding to different months. The highest levels of sodium are observed in January and May, while the highest levels of potassium are seen in July and August. The figure highlights the importance of monitoring these elements in plants for ecological and agricultural purposes.
level of K content in the plant tissues may play an important role in the uptake and accumulation of CO₂ as in the case of lower organisms like N. spongiosa (Perry, loc. cit.). In short, K may have some significant functions in the metabolic activities of S. ilicifolium.

As a conclusion it can be said that K is an indispensable cation for all the plants in general and S. ilicifolium in particular. It is accumulated in the plant remarkably in large amounts throughout the year and shows distinct monthly variations. Na/K ratio is found to be less than one during the entire year. The high content of K in S. ilicifolium may play a major role in osmoregulation besides many other significant functions.

(iv) Magnesium:

Magnesium concentrations of the sea water and of S. ilicifolium are shown in Table I and II. The values for Mg contents of the sea water range from 0.95 to 1.52 g per litre with an average value of 1.32. Lyman and Fleming in 1940 (cf. Puron, 1963) have obtained 1.27 g/kg of Mg in the sea water, Harvey (1957) has recorded 1.33 g of Mg per litre of sea water, while the values of Young et al. (1959) are 1.47 g/kg of Mg for the sea water from Atlantic coast. In India, Seshadri (1965) and Sharma and Dave (1965) have reported 1.28 g/kg and 1.3 g/kg of Mg in sea waters from Bhavnagar and Gujarat coast. Patil and Joshi (1967), who studied.
seasonal variations, have observed that Mg contents of the sea water at Bombay range from 0.79 to 1.57 g per litre. Our values are similar to those of other investigators and show seasonal variations.

It is obvious from Figure 9, the pattern of variations in Mg contents of the sea water from Ratnagiri is similar to that of Na and K. The maximum of 1.52 g per litre of the sea water is recorded in March and the minimum value of 0.95 is found in August. Mg concentrations are at minimum in monsoon months and gradually rise in October and November with a decline in December and January. From February to May the contents of Mg in sea water remain at a high level. This indicates that there are seasonal variations in Mg contents of sea water and these are reflected to some extent in S. ilicifolium. The maximum value of 2.78 % in November and minimum value of 1.77 % in May are recorded in the plant. The average value is 2.21 % which is indicative of fairly high concentration of this ion.

The results from our laboratory on seasonal variations in Clerodendron inerme (Mishra, 1967) show that the maximum Mg contents which amount about 0.71 % are in summer while the minimum of 0.29 % in monsoon. The work on Seavium portulacastrum has also shown a similar pattern of variations (Singh, 1967). Patil and Jeshi (1967) have observed a distinct seasonal variations in Mg contents in U. lactuca. They have
SEASONAL VARIATIONS IN MAGNESIUM CONTENTS
OF S. ILICIFOLIUM AND SEA WATER

MAGNESIUM
S. ILICIFOLIUM $\Delta$ $\Delta$
SEA WATER $\circ$ $\cdots \cdots$

Fig. 9
CONCENTRATION OF Na, K, Mg, Ca AND Cl IONS IN S. ILICIFOLIUM

Fig. 10
recorded maximum value of 4.42 in February and minimum in May. Our results also show common features with the findings of these workers and exhibit a distinct seasonal variation. The maximum values are observed from November to February, a period of winter, with slight fluctuations in the Mg content.

Mg is an important element of non-saline and fresh water plants. However, there is little information available regarding Mg in marine plants. The average values for terrestrial plants are 0.05 to 0.7 % of dry matter (Ferry and Ward, 1959). Table III records Mg contents in the saline and non-saline plants and shows that saline plants have low Mg values. But the same may not be true in marine algae. Mita (1961) has recorded a high value of 4.2 % of Mg in U. pertusa and 3.28 % of Mg in F. compressa. Rao and Tipnis (1965) have recorded water soluble Mg values of 0.9 % in S. cinctum, while 1.07 % in S. johnstonii. They have also analysed a number of other marine algae which belong to the groups of Chlorophyceae and Phaeophyceae and noticed that calcium content was greater than Mg in Phaeophyceae. In S. ilicifolium Mg is the dominant cation and is found more than calcium (Table II). Patil and Joshi (1967) have observed that Mg is the main and dominant cation of V. lactuca which shows average value of 281.04 meq per 100 g dry material (3.21 % dry material). In S. ilicifolium, the average value is 2.21 % which is equal to 181.8 meq per
100 g of dry material, indicates that the plant is Mg rich. This shows that the plant accumulates Mg less than that of green marine algae as represented by *U. pertusa* (Mita, loc.cit.) and *U. lactuca* (Patil and Joshi, 1967). However, the Mg content in *S. ilicifolium* is found to be more than all other cations in meq basis (Fig. 10). Mg content in sea water is 110.8 meq per litre while in *S. ilicifolium* is is 184.1 meq showing thereby the high capacity of the plant to accumulate this ion. From the Figure 11 and Table V, it is clear that the magnesium uptake ratio in *S. ilicifolium* is fairly high but it is less than that of *U. lactuca*.

It is well known that Mg is a cofactor for photosynthesis and also a constituent of the chlorophyll molecule. It can influence many physiological processes. The maximum utilization of Mg is only 10-15% of total Mg present in the plant. In plant Mg balances the anions like Cl, $\text{SO}_4$ and cation like Na, possibly in *S. ilicifolium*. Mg may play the same role and besides it may also be one of the constituents of the polysaccharides present in the alga.

Recently Hang and Smidsrod (1967) have explained that the content of the divalent metals calcium, magnesium and strontium in brown algae, to a large extent is determined by the exchange of ions taking place between the sea water and the alginate present in the algae. Since
**TABLE V**

**UPTAKE RATIOS IN SARGASSUM ILICIFOLIUM AND ULVA LACTUCA AND SEA WATER**

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>Aug</th>
<th>Sept</th>
<th>Oct</th>
<th>Nov</th>
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<th>Jan</th>
<th>Feb</th>
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<th>Apr</th>
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<tr>
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<td>-</td>
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<td>0.554</td>
<td>0.369</td>
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<td>0.397</td>
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<tr>
<td>S. ilicifolium</td>
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<td>0.272</td>
<td>0.297</td>
<td>0.301</td>
<td>0.319</td>
<td>0.28</td>
<td>0.287</td>
<td>0.221</td>
</tr>
</tbody>
</table>
RATIO INDICATING UPTAKE OF Mg AND Ca FROM SEAWATER IN S. ILICIFOLIUM & U. LACTUCA

Fig. 11
S. ilicifolium contains fairly good amount of alginic acid. Mg is accumulated in greater quantities.

It appears very little work is done on Mg distribution in marine algae and according to Eppley (1962) there are no data on Mg transport in algae. The uptake of Mg against its low concentration in sea water is an indicative of its possible physiological importance in many life processes of the plant.

(v) Calcium:

Calcium concentrations in the sea water and S. ilicifolium are presented in Table I and II and Figure 12. Our values for Ca contents in the sea water at Ratnagiri range from 0.248 to 0.447 with an average value of 0.38 g per litre for 12 months. Lyman and Fleming in 1940 (cf. Furon, 1963) have recorded 0.4 g/kg of Ca content in sea water. Harvey (1957) has reported 0.42 g of Ca per litre of sea water while the sea water of Atlantic coast analysed by Young et al. (1959) shows 0.374 g/kg of Ca. In India, Seshadri (1965) has obtained 0.41 g/kg of Ca at Bhavnagar while the values of Ca for Gujarat coastal waters are 0.4 g/kg (Sharma and Dave, 1965). Rao (1965) observed that Ca contents of the sea water at Bhavnagar range from about 0.12 to 0.38 g per litre during the year. While studying on seasonal variations in Ca contents of the sea waters at Bombay, Patil and Joshi (1967) have obtained the values
ranging from 0.212 to 0.413 for 10 different months. These results of various workers indicate that our values for Ca at Ratnagiri are in a range of others observations at different places.

From Figure 12 it is evident that the pattern of Ca variations in sea water is very much similar to that of other cations. The maximum values are recorded in February with little fluctuations and minimum values during monsoon months. The lowest values of 0.248 is recorded in August; This shows that there are definite seasonal variations in Ca contents of the sea water. The values for Ca in S. ilicifolium also show such variations during the year.

It is obvious from the figure that Ca contents in S. ilicifolium are at low from June to September and then there is a rise in October and November. The values for Ca remain fairly at high level during winter months and there is a fall in March and again rise in April with a slight drop in May. The maximum value of 1.69 is recorded in February and minimum value of 1.35 in August. The values obtained in November and December are near to the maximum values. S. ilicifolium shows an average value of 1.54 g per 100 g dry material while Rao and Tipnis (1965) have recorded 1.91 % in S. cinereum and 3.24 % in S. johnstonii as a water soluble fraction. Young and Langille (1968) have recorded Ca contents of 1.10 % in Ascophyllum nodosum, 0.98 % in Fucus vesiculosus, 1.04 in Laminaria longicruris
SEASONAL VARIATIONS IN CALCIUM CONTENTS
OF S. ILICIFOLIUM AND SEA WATER

Fig. 12
and 1.29 in \textit{L. digitata}. They have also studied seasonal variation in Ca content of \textit{C. crispus}. The maximum value of 1.57 \% is obtained in November and minimum of 0.96 \% in July. Mitra (1961) has observed 0.34 \% of Ca in \textit{U. pertusa}. Patil and Joshi (loc.cit.) have recorded Ca values in \textit{U. lactuca} and their values range from 0.21 to 0.4 \% g per 100 g dry material.

Rao and Tipnis (loc.cit.) who have analysed member of marine algae belonging to Chlorophyceae and Phaeophyceae have recorded maximum value of 3.24 in \textit{S. johnstonii} and 0.59 in \textit{U. rigida} and observed that calcium, in general is present in larger quantities in Phaeophyceae compared to that present in Chlorophyceae. Our Figure 11 indicates that Ca is more in \textit{S. illicifolium} while it is low in \textit{U. lactuca}. The observation is in conformity with the general statement made by Rao and Tipnis (1965). These workers have also noticed that the calcium content is greater than magnesium in Phaeophyceae. However our values depicted in Figure 10 clearly show that in \textit{S. illicifolium} Mg is more than Ca. The observation is in contrast to the general statement made by Rao and Tipnis (1965). \textit{S. illicifolium}, a Phaeophycean member of our research interest, contains less calcium than Mg. However, Ca content is more than those of green algae mentioned above.
However, the content of Ca in *S. ilicifolium* is fairly high when compared to that of green algae as represented by species of *Ulva*. It may be mentioned that the work of Hang and Smidsrod (1967) who have demonstrated that alginates in the brown algae are rich in guluronic acid residues which have a greater affinity for calcium in the calcium magnesium ion exchange reaction. In spite of the low concentration of Ca from that of Mg in the sea water, *S. ilicifolium* absorbs Ca in larger proportions. This may be due to the greater affinity of alginic acid towards Ca that operates in *S. ilicifolium*.

The values for Ca in land plants vary between 0.1 to 3.5 g per 100 g of dry tissue (Ferry and Ward, 1959). Ca contents of various saling plants and non-saline plants are presented in Table III. The work on saline plants carried out in our laboratory indicates that Ca content in marine plants are comparatively less in amounts. Whereas in glycophytes like *Jatropha curcas* (Torne and Joshi, 1964) and in *Bryophyllum pinnatum* the Ca content is much higher than in saline plants being 5.03 % and 4.63 % respectively. The relatively low Ca content of the marine plants may be due to the presence of high levels of Na which depresses potential Ca uptake. Bower and Wadleigh (1954) and recently Osmond (1966) observed that high concentration of Na in the external medium interfered with Ca uptake. Quite likely the high concentration of Na in sea water may hamper Ca
absorption in *S. ilicifolium*. The low contents of Ca in marine plants may be due to some barrier or inhibition for inward diffusion of Ca. Walker (1957) has found that the plasmalemma of *Nitzella* cells act as a barrier to the diffusion of Ca even though this is not a marine alga. A similar kind of barrier may exist for absorption of Ca in many saline plants.

Whitenberg and Johan (1964) while working on cotton plants on the carbohydrate distribution observed that Ca can be substituted partially by Na in maintaining carbohydrate translocation. They observed that Na was able to help in maintaining Ca in plants in a condition conducive to synthesis of cellular constituents. How a structurally different element like Na can substitute Ca is not clearly understood. If the view of Whitenberg and Johan (loc.cit.) is accepted then low amounts of Ca in marine plants can be explained.

(vi) Chlorides:

Cl concentrations in the sea water and *S. ilicifolium* are presented in Figure 13. The Cl contents in sea water at Ratnagiri range from 14.76 to 22.95 g per litre. Harvey (1957) has recorded 19.8 g of Cl in sea water while Young et al. (1959) have observed 17.17 g/kg of Cl in the sea water from Atlantic coast. In India, Seshadri (1965) has
recorded 18.97 g/kg of Cl at Bhavnagar. Sharma and Dave (1965) have found 19.0 g/kg of Cl from the Gujarat coastal waters. They have also analysed about 47 samples of sea water from Gujarat coast and the values for Cl range from 16.31 to 25.24 g/kg. Rao (1965) has found that sea waters of the coast of Bhavnagar show a chlorinity of about 6 to 19 g/kg from July to June. Patil and Joshi (1967) while working on seasonal variations in Cl contents of sea water at Bombay have recorded the values ranging from 10.82 to 22.37 g per litre. Our values are similar to those of other investigators and show monthly variations.

It is obvious from Figure 13 that Cl from the sea water shows a common features of variations observed in other cations. The minimum value of 14.76 g per litre of sea water is obtained in August while maximum value of 22.95 g per litre in April when the temperature is at its peak. Rao (1965) attributes the low value of Cl in August to the influx of fresh water from rivers and heavy rainfall during the month. A similar observation is made in the waters of Bombay (Patil and Joshi, loc.cit.). The low value of Cl in August at Ratnagiri, where it rains heavily during the month, can be attributed to the dilution of sea water due to the addition of large amount of fresh water brought by the rivers and rain water. Our results further show a wide range of monthly variations in Cl content of sea water during the year.
SEASONAL VARIATIONS IN CHLORIDE CONTENTS
OF S. ILICIFOLIUM AND SEA WATER

Fig. 13
It is evident from Figure 13 that in *S. ilicifolium* the minimum value of 6.81 in August and that onwards there is a steady increase up to November with a fall in December and January. The maximum value of 9.89 is obtained in February with a drop in March and April there is a gradual decline in Cl contents up to August. Kanwisher (1957) found that thalli of *F. vesiculosus*, *G. crispus*, and *U. lactuca* retained internal Cl concentrations proportional to those in the ambient solutions of concentrated sea water. It is clear from the results that in *S. ilicifolium* Cl concentrations are proportional to those of the sea water. The wide range of variations in Cl contents of *S. ilicifolium* is an indication of its ability for high osmoregulatory mechanism.

The study of chlorides is an important subject in understanding the problem of marine plants. Since chlorides are the dominant anions in the external environment, they naturally accumulate in large quantities in the plant tissues. The entry of chlorides is faster than that of sulphates. According to Walter (1961) these ions are stored in vacuoles. To store such high amounts of ions in vacuoles the cell must exert enough pressure to hold them against the gradient. Due to Na and Cl rich environment these ions enter in large amounts. On the contrary, the behaviour of glycophytes is quite different as they are very sensitive and tolerate salts only in very small amounts.
The values for Cl in glycophytes and various saline plants are given in Table III. It is clear from the table that halophytes accumulate a large amount of chlorides in their tissues as compared to glycophytes. Normal values of Cl in land plants vary from 1 to 3% of dry material (Ferry and Ward, 1959). Rao and Tipnis (1965) have recorded as high as 15.63% of Cl in water soluble constituents of Codium dwarakense. They have also recorded 7.26% of Cl in S. cinereum. Patil and Joshi (1967) while working on U. lactuca have observed 7.15% of Cl per 100 g dry thallus. Our value which is considerably high (Fig. 14) is of interest to compare with the results of other workers. All these observations indicate that Cl accumulation in plants depends on its concentration in the surrounding environment and also on the ability of individual plants to maintain these ions in the tissues.

Biebl (1939) observed that intertidal red algae develop several possible means like small cells with dense contents, high intercellular osmotic values and great tolerance to plasmolysis. This adaptations present plasmolytic damage in hypertonic concentrations of sea water. Biebl (1962) has reported that most intertidal algae are more resistant and can survive over a wide concentration range of 0.1 to 3.0 times that of sea water. However, the algae from tidal pools or near low water mark can tolerate only concentrations of 0.5 to 1.5 times that of sea water. These observations
RATIO INDICATING UPTAKE OF Cl FROM SEA WATER IN S.ILICIFOLIUM AND U. LACTUCA

Fig. 14
indicate that *S. ilarifolium* an intertidal alga, has a high capacity of resisting Cl concentrations.

In conclusion it can be said that there are distinct monthly variations in Cl contents of *S. ilarifolium*. Cl accumulation in algae depends on the concentration in the external environment and also on the ability of individual plant to uptake and retain these ions in the cells. From Figure 10 it is clear that Cl are the dominant ions of the plant. When we compare uptake of Cl in *U. lactuca* and *S. ilarifolium*, it is very clear that the brown alga has much more uptake capacity for Cl than that of the green one (Fig. 14). The high content of Cl ions indicate that *S. ilarifolium* has a very good osmoregulatory mechanism and it can survive over a wide range of salinity.

(vii) Sulphate:

Sulphate content of the sea water and *S. ilarifolium* are given in Table I and Figure 15. The average value for $\text{SO}_4$ during the year is 2.35, with a range from 1.86 to 2.29. The maximum value of 2.35 is obtained in November while the minimum value of 1.86 is found in August. The values are at minimum during monsoon months and remain at high level in rest of the year. Lyman and Fleming in 1940 (cf. Furon, 1963) have recorded 2.65 g/kg of $\text{SO}_4$ in the sea water. Young et al. (1959) have recorded 2.36 g/kg of $\text{SO}_4$ in the sea water of
Atlantic coast. In India, Seshadri (1965) has reported 2.65 g/kg of $\text{SO}_4$ in sea water at Bhavnagar. Sharma and Dave (1965) have analysed about 47 samples of sea water from Gujarat coast and their values for $\text{SO}_4$ range from 2.31 to 4.08 g/kg. Rao (1965) has obtained 2.73 g per litre from the Gujarat coast sea waters. Our results for $\text{SO}_4$ at Ratnagiri vary within the range of the values recorded by other investigators and show a seasonal variations similar to that of Cl and other cations.

$\text{SO}_4$ contents of _S. allicifolium_ are shown graphically in Figure 15. It is obvious that the variation is within a narrow range. $\text{SO}_4$ content of the plant ranges from 1.51 to 1.84 g per 100 g dry material with an average of 2.2 for the year. Unlike Cl the variation in $\text{SO}_4$ content is found to be limited in the plant. However, within this small range the minimum value of 1.51 is obtained in August and maximum of 1.84 in November. During monsoon months the $\text{SO}_4$ content of the plant is low and in rest of the months the values are almost constant without much variation.

Wort (1955) has studied sulphur percentages in _Macrocystis integrifolia_ and _Nereocystis lueticana_ and found that the variations between maxima and minima were not apparent. He has recorded the average sulphur content of _Macrocystis_ frond 1.52 % and 1.11 % for the stipes. _Nereocystis_ fronds contained an average of 1.23 % and the
SEASONAL VARIATIONS IN SULPHATE CONTENTS
OF S. ILICIFOLIUM AND SEA WATER

Fig. 15
stipes contained 1.01% of sulphur. He observed that all these values were within the limit of variations. Mita (1961) has recorded 2.05% of sulphur in F. compressa and 2.96% in U. pertusa. Rao and Tipnis (1965) have recorded sulphate contents in a number of algae belonging to Chlorophyceae and Phaeophyceae and their values range from 2.5 to 12.2 g per 100 g dry material. In S. cincereum they have found 3.79 g per 100 g dry material while 3.03 in S. johnstonii. Our values are similar to those of other workers.

The minimum value of the sea water in August is also reflected in the plant. The low value during monsoon may be due to the dilution of sea water at Ratnagiri. SO₄ content in S. ilicifolium is comparatively less and there is no prominent seasonal variations during the year. The high concentration of Cl ions in the external environment may interfere with the uptake of SO₄ by the plant. SO₄ is the constituent of many polysaccharides found in algae and possibly in S. ilicifolium it may be found as a part of such unusual compounds like fucoidin which is present in this alga.

(viii) Nitrate:

The nitrate contents of the sea water are shown in Table I. The monthly values for nitrate vary between 0.537
to 8.89 μg per litre. The minimum value of 0.537 is observed in July and maximum of 8.98 in February. Near to the higher value 8.45 is obtained in June. There is a precipitous fall in nitrate content of sea water from June to July and the values remain at low till September. Then there is a rise in October and November with a fall in December and January. The maximum value is obtained in February and then there is a gradual fall up to May.

Black and Dewar (1949) while studying the nitrate content of the sea water samples from localities namely Loch Melfort, Shuna Island and Cullipool, they observed that after March nitrate begins to decrease and again this decrease is most marked in the Loch. Between March and April 1948 nitrate in Loch Melfort dropped from 6.4 mg atoms/m³ to almost zero and remained at this level until September. Complete exhaustion of nitrate was not observed at Shuna Island and Cullipool until July. Nitrate is almost certainly absent in all localities during July and August. Nitrate is regenerated during September and increases gradually during the autumn and winter reaching a maximum of about 6.8 mg atoms/m³ in January. In India, Chauhan (1965) has studied the seasonal variations in nitrate content of sea water at Port Okha. He observed that nitrate content is almost absent in August and September and the highest concentration of 11.6 μg/litre is recorded in the month of February. He has attributed the rise in February 1965
that many algae in this month were cast ashore and some of
them were floating in the water. These algae were dead and
decaying. The decay of these algae may be one of the
contributing factor to the high nitrate concentration in
the water. The same may be true in the case of our maximum
nitrate observation in February and June in the sea water
at Ratnagiri. Our values further show common features of
variation observed by other workers and exhibit a marked
monthly variation.

Nitrate is one of the important nutrients that
limit the growth of many algae. *S. ilicifolium* shows a
rapid growth when the nitrate is found to be abundant in
sea water. As the nitrate content of sea water is low
during summer the plant shows very poor growth and also
several changes in metabolic products.

(ix) Phosphate:

Phosphate concentration of sea water and *S. ilicifolium*
are given in Table I and Figure 16. The values for sea
water range from 0.232 to 1.15 μg per litre during the
year. The maximum value of 1.15 is obtained in February
and the minimum 0.232 is observed in July. The variation
in phosphate content is similar to that of nitrate. The
phosphate content is found to have three peaks, one in
June, another in October and the third in February. Of the
throe. February is the highest. The low values are observed in July, April and May during the year. Black and Dewar (1949) who studied the phosphate contents of sea water collected from three different localities namely Loch Melfort, Shuna Island and Cullipool, have observed that phosphate content begins to decrease after March, the decrease being most marked in the Loch water, although the open sea at Cullipool has a phosphate content in April not much greater than the Loch. Minimum values of 0.16 to 0.20 mg atom phosphate-p/m$^3$ are obtained in all localities by June and remain at this low level until September, when there is an increase again to the winter maximum in December, January and February. Abnormally high values were obtained in December for Loch Melfort (0.75 mg atom P/m$^3$) and Shuna Island (0.63 mg atom P/m$^3$), which can only be attributed to contamination by land drainage, as the value for Cullipool was normal. Chauhan (1965) while studying the seasonal variations in phosphate contents of the sea water at Port Okha, has reported maximum value of 1.05 µg per litre in September and minimum value of 0.1 in June. Our values for phosphate content at Ratnagiri show a similar variation reported by other workers.

Phosphate contents of *S. ilicifolium* are shown in Figure 16. The monthly values vary between 0.328 g in July and 0.985 g per 100 g dry material in November. The phosphate contents are at maximum during winter months and remain at
Fig. 16

SEASONAL VARIATIONS IN PHOSPHATE CONTENTS OF *S. ILICIFOLIUM* AND SEA WATER

PHOSPHATES

* S. ILICIFOLIUM

SEA WATER

JUL  AUG  SEP  OCT  NOV  DEC  JAN  FEB  MAR  APR  MAY

MONTHS

SEA WATER MG PER LITRE

0.0  0.2  0.4  0.6  0.8  1.0  1.2

* S. ILICIFOLIUM 9 PER 100g DRY MATERIAL
low in summer and monsoon months. Black and Dewar (1949) observed that the increase in photosynthesis, mannitol, laminarin and algic acid in Laminaria are followed by the increase in phosphate content of the sea water. *S. ilicifolium* also shows rapid growth and high metabolic products corresponding with the increase in phosphate content of the sea water. Our values for phosphate in *S. ilicifolium* show a marked monthly variations during the year.

Hoffmann and Reinhardt in 1952 and Hoffmann in 1953 and 1956 (cf. Biebl, 1962) have found that from dead thalli of *Fucus vesiculosus, Ulva lactuca* and *Laminaria saccharina* as much as 30% of the organic phosphorus was remineralized within 12 months. The highest value of phosphate in our seasonal studies of mineral constituents of sea water from Ratnagiri is obtained in February. This may be due to the death and decay of many algae especially *Sargassum spp.* which are usually cast ashore during the month of February at Ratnagiri coast. This possible explanation can also be given for nitrate contents of the sea water during the same time as attributed by Chauhan (1965) for the nitrate content of the sea water from Port Okha in Gujarat.