Composition of the Non-metallic Inorganic Components of the Marine Alga Nereocystis luetkeana over the Growing Season

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FISHERIES AND MARINE SERVICE
SERVICE DES PÊCHES ET DES SCIENCES DE LA MER

TECHNICAL REPORT No.
RAPPORT TECHNIQUE N° 568

1975

Environment Canada
Fisheries and Marine Service

Environnement Canada
Service des pêches et des sciences de la mer

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Department of the Environment
Fisheries and Marine Service
Research and Development Directorate

Ministère de l'Environnement
Services des Pêches et des Sciences de la mer Direction de la Recherche et Développement

TECHNICAL REPORT NO. 568

RAPPORT TECHNIQUE N°. 568

(Numbers 1-456 in this series were issued as Technical Reports of the Fisheries Research Board of Canada. The series name was changed with report number 457)

(Les numéros 1-456 dans cette série furent utilisés comme Rapports Techniques de l'office des recherches sur les pêcheries du Canada. Le nom de la série fut changé avec la rapport numéro 457)

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This is the twenty-fifth Technical Report from the Research and Development Directorate Vancouver Laboratory, Vancouver, B.C.

Ceci est le vingt cinqiéme Rapport de la Direction de la Recherche et Développement, Laboratoire de Vancouver Vancouver, (C.-B.)

1975

TABLE OF CONTENTS

		Page No.
ABSTRACT		iv
THE RESOURCE POTENTIAL IN BRITISH COLUMBIA		1
THE NON-METALLIC INORGANIC COMPONENTS OF *NEREOCYSTIS*		4
(i)	Introduction	4
(ii)	Collection and Preparation of Samples	5
(iii)	Methods of Analysis	6
	(a) Nitrate	6
	(b) Silica	8
	(c) Sulphur (Sulphate)	9
	(d) Carbonate	10
	(e) Phosphorus (Phosphate), Boron (Borate)	12
(iv)	Results and Discussion	12
REFERENCES		20
TABLE 1	Nitrate content of the fronds and stipes of *Nereocystis* over the growing season	22
TABLE 2	Silica content of the fronds and stipes of *Nereocystis* over the growing season	23
TABLE 3	Sulphur and corresponding sulphate content of the fronds and stipes of *Nereocystis* over the growing season	24
TABLE 4	Carbonate content of the fronds and stipes of *Nereocystis* over the growing season	25
TABLE 5	Phosphorus and corresponding phosphate content of the fronds and stipes of *Nereocystis* over the growing season	26
TABLE 6	Boron and corresponding pyroborate content of the fronds and stipes of *Nereocystis* over the growing season	27
TABLE 7	Mean, minimum and maximum concentrations of non-metallic inorganic components in *Nereocystis* over the growing season	28

		Page No.
FIGURE 1	Apparatus for determining evolved carbon dioxide	11
FIGURE 2	Seasonal variation in the nitrate content	29
FIGURE 3	Seasonal variation in the silica content	30
FIGURE 4	Seasonal variation in the sulphate content	31
FIGURE 5	Seasonal variation in the carbonate content	32
FIGURE 6	Seasonal variation in the phosphate content	33
FIGURE 7	Seasonal variation in the borate content	34

ABSTRACT

The biomass of the marine alga Nereocystis luetkeana on the coast of British Columbia, as assessed by past and more recent surveys, is presented as an overture to the analytical results obtained for the non-metallic inorganic components elaborated by the alga over the growing season.

The seasonal variations in the nitrate, silica, sulphur (sulphate), carbonate, phosphorus (phosphate) and boron (borate) contents including the concentration differences between the fronds and stipes of Nereocystis luetkeana throughout the season are presented and discussed in connection with the overall mineral content of the alga and its commercial significance.

RÉSUMÉ

Les auteurs font le rapport entre la biomasse d'une algue marine de la côte de la Colombie-Britannique, Nereocystis luetkeana, déterminée par des relevés effectués à des époques plus ou moins lointaines, et l'utilisation possible des résultats d'analyses effectuées sur les composés non métalliques élaborés par cette algue pendant la saison de croissance.

On y présente les variations saisonnières des contenus en nitrate, silice, soufre (sulfate), carbonate, phosphore (phosphate) et bore (borate), ainsi que les différences de concentrations entre les frondes et les stipes au cours de la saison. Ces données sont discutées en fonction du contenu minéral de la plante et de son importance commerciale.

THE RESOURCE POTENTIAL IN BRITISH COLUMBIA

As early as 1914 (Cameron, 1914) the beds of Nereocystis luetkeana on the coast of British Columbia were surveyed and charted. In that survey A.T. Cameron on behalf of the Biological Board of Canada (later the Fisheries Research Board of Canada) estimated that the southern district of B.C., comprising the southeast coast of Vancouver Island from North West Bay to the north of Saanich Peninsula and the islands to the east of the peninsula from the Bellenas Group to the Washington State boundary, contained 123,000 tons of Nereocystis with some 34,000 tons of that amount located south of Saltspring Island.

The Howe Sound and Burrard Inlet district when surveyed were shown to support negligible kelp populations. However, the north coast of Vancouver Island from Hope Island to Baronet Passage was estimated to contain 225,000 tons of floating kelp considered to be principally Nereocystis luetkeana.

An extensive survey of the coastline except for the Queen Charlotte Islands and the west coast of Vancouver Island was undertaken from August to September 1946 by R.F. Scagel from the Fisheries Research Board of Canada and B.K. Farrar of the B.C. Research Council. A report of this survey recorded the exact location of significant kelp beds together with appropriate estimates of the available and commercially accessible quantities of seaweed (Scagel, 1946). The northern zone from Wales Island, at the Alaskan boundary, south to Cape Caution was estimated to contain 126,036 tons and 82,765 tons of available and commercially accessible tonnage of Nereocystis respectively. The central zone bounded

by Cape Scott, Cape Caution, Seymour Narrows and Yuculta Rapids was considered to support 79,133 tons and 60,447 tons of available and accessible Nereocystis respectively. The survey of the southern zone from Seymour Narrows and Yuculta Rapids south to the Washington State boundary was not completed and only Cape Lazo with 21,000 tons, Dodd Narrows with 50 tons and Sansum Narrows with 75 tons were recorded. Details from the above survey together with information acquired from additional surveys undertaken by the B.C. Research Council from 1944-47, mainly in the southern zone, were combined to afford an estimate of 169,074 tons of available Nereocystis in the southern zone (British Columbia Research Council, 1948). Combining these figures cited above a total biomass of 374,243 tons could therefore be considered as an estimate of available Nereocystis in the coastal zone specified. However, the early surveys excluded the Queen Charlotte Islands and the west coast of Vancouver Island. The latter coastal area was subsequently surveyed in 1965-67 for the Pacific Kelp Co. Ltd., and a final estimate of 457, 081 tons of Nereocystis was considered to be contained by the coastal region from Ucluelet to Cape Cook on the west coast of Vancouver Island (Huff and Company, 1967). About the same time (1967) a survey for North Pacific Marine Products Ltd., of the marine plants on the north coast of Graham Island, Queen Charlotte Islands, concluded that 92,386 tons of Nereocystis were available from Cape Naden to just east of Klikidamen Creek (North Pacific Marine Products Ltd., 1967). A more recent inventory, however, of that area of Graham Island by the Fisheries Operations in August and September 1973 determined the available biomass of Nereocystis at only 54,089 tons (Blakley et al,, 1973). This obvious discrepancy in available tonnage may be due to yearly fluctuations in the

growth potential of the kelp beds caused by varying environmental parameters and/or may be a function of the intrinsic differences in the methodology of biomass assessment.

This latter facet of biomass measurement is the subject of a recent report (Foreman, 1975) in which a method is described for the inventory of floating kelp. The method proposed is the culmination of an intensive study of the biomass data acquired from aerial photography and kelp bed surveys in the neighbourhood of Malcolm Island, Queen Charlotte Strait. With this method the biomass of Nereocystis supported by the Malcolm Island area was illustrated to be only 37% of the figure concluded from the 1946 survey. Again this discrepancy between surveys may be a function of fluctuations in yearly growth but is more likely to stem from the differences inherent in the assessment procedures of the two surveys with the most recent employing a more decisive methodology. Using this most recent technique the yearly fluctuations in the standing crop of giant floating kelp together with more accurate assessments of the biomass in potentially commercial areas should be realized more conveniently. Nevertheless, with the figures cited from the past surveys an estimate of the biomass of Nereocystis luetkeana on the coast of British Columbia could be considered, with the present knowledge, to range from 885,413 to 923,710 wet tons annually.

NON-METALLIC INORGANIC COMPONENTS OF NEREOCYSTIS LUETKEANA

(i) Introduction

Nitrogen, silicon, sulphur, carbon, phosphorus, boron, oxygen, iodine, bromine, chlorine and fluorine are the non-metallic components in the periodic table of elements. These electronegative elements are so called since they tend to acquire electrons to form negative ions called anions. The common oxides formed by these elements such as nitrate, silicate, sulphate, carbonate, phosphate and borate are acidic anions which normally exist in nature as salts with cations. As a chemical environment the sea is a fairly uniform medium except for the seasonal fluctuations of nitrogen, phosphorus, silicon and a few trace elements. The principal anions in ocean seawater, other than halogens, are sulphate at 2649 ppm, borate at 26 ppm and bicarbonate at 140 ppm (Sverdrup et al., 1942). The latter anion in the sea is in equilibrium with the dissolved carbon dioxide which is essential to the photosynthetic production of sugar in plants in accordance with the following simplified scheme:

$$H_2O + CO_2 \text{ (dissolved)} \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- + H^+ \rightleftharpoons CO_3^{=} + H^+$$

$$\downarrow \quad h\nu + \text{chlorophyll}, \quad \Delta G = +114 \text{ KCal}$$

$$O_2 + (CH_2O) \longrightarrow \text{hexose phosphates} \longrightarrow \text{polysaccharides}$$

The principal anions do not suffer the same variability in content in ocean seawater as do the phosphate and nitrate components which exhibit considerable seasonal fluctuation. The major parameters affecting these fluctuations are the proximity of rivers which transport these elements to the sea and the ready assimilation of these anions by the benthos algae as growth prerequisites.

Similar seasonal fluctuations are reported for silicon which ranges from 0.02 to 4.0 ppm in ocean seawater (Sverdrup et al., 1942). These fluctuations stem from the silicon cycle in the sea which involves the assimilation of this element by marine organisms followed by the subsequent partial dissolution of the skeletal remains on the death of the organisms. Silicon in seaweeds may occur from adhering diatoms or sand entrapped in the plant tissue, but it may be also play a minor role in the cell-wall structure of the algae.

Apart from the halide content alluded to in an earlier report (Whyte et al., 1975) the content of the other non-metallic inorganic elements in Nereocystis luetkeana are presented in this report in some cases as the constituent elements but also as the corresponding oxides most commonly found in nature.

(ii) Collection and Preparation of Specimens

The samples analyzed for anionic components were those examined for the cation component of the alga (Whyte et al., 1974(a)).

Specimens of the alga were collected from selected kelp beds off the north side of Stanley Park in Vancouver in the middle of the months April through October. Only attached plants were collected, placed in

plastic bags, and transported to the laboratory in insulated coolers containing ice. After separating the constituent segments of the algae the adhering epiphytes, epifauna and surface water were removed and the fronds and stipes (including pneumatocysts) were packed separately in plastic bags and stored at -31^{o}C. Subsequent freeze drying of the specimens afforded dry alga which was ground to 20 mesh size with a porcelain mortar and pestle and stored in the freeze dryer to ensure anhydrous conditions existed for the samples during the period of analyses. Each lot analyzed contained portions from at least ten separate plants collected at the same time.

(iii) Methods of Analysis

(a) Nitrate

An Orion Research Ionalyzer model 801 digital pH/mv meter was interfaced with a printer and coupled to an Orion 92-07 nitrate ion electrode, an Orion 94-53A iodide ion electrode and an Orion 92-02-00 double junction reference electrode which had the outer junction filled with 1M sodium sulphate.

Preliminary experiments had shown that the chloride and iodide ions had to be removed from the test solution, by titration with silver sulphate solution, prior to assessing the nitrate ion content by the selected "known addition" method. As the polymers leached from the alga on cold or hot aqueous extraction were demonstrated to affect the response of the nitrate electrode, by probable blockage of the membrane, the soluble inorganic components of the alga were extracted initially as the aqueous-methanol layer in the extraction procedure using the solvent system

chloroform-methanol-water (Whyte et al., 1970)

A sample of completely dry aqueous-methanol layer (100 mg) was diluted to 250 ml with deionized water, 100 ml of the resulting solution was placed in a 250 ml beaker, the electrodes inserted into the solution and the chloride equivalence point titrated exactly by the addition of saturated silver sulphate solution to a predetermined potentiometric reading provided by the iodide electrode. Using an Orion 605 electrode switch, the potentiometric reading of the nitrate electrode after stabilization was then recorded using the printer operating at 1 readout per 6 seconds. Exactly 1 ml of 2×10^{-2} M sodium nitrate was added and on stabilization the change in potential resulting from the addition of nitrate was furnished from the printer readout. The following equations were used to calculate the nitrate content in the aqueous-methanol fraction which as a percentage of the dry alga afforded the content of the alga:

$$\frac{Co'}{C\Delta} = \frac{Co'Vo'}{MaVa} = \frac{1}{(\text{antilog } \frac{\Delta E}{S} - 1)}$$

Since $Co'Vo' = CoVo$

$$\text{Then } Co = \frac{MaVa}{Vo} = \frac{1}{(\text{antilog } \frac{\Delta E}{S} - 1)}$$

$$\text{Percentage nitrate in aqueous-methanol sample} = \frac{\text{Co} \times 6200}{4 \times \text{weight sample (g)}}$$

Co' = nitrate ion concentration after addition of X ml silver sulphate

Co = nitrate ion concentration in original solution

CΔ = change in nitrate ion concentration of additive

Vo' = volume of original solution + X ml silver sulphate solution

Vo = original volume of solution (100 ml)

Va = volume of additive

Ma = molarity of additive (2×10^{-2} M)

ΔE = change in potential on addition of additive

S = electrode slope = 59.2 mv (determined experimentally)

(b) Silica

The dry alga (5 g) was added to a well-glazed porcelain crucible and ignited at 500°C for 20 hrs. in an electric muffle furnace. The white residue was treated with concentrated hydrochloric acid (5 ml), boiled for five minutes, evaported to dryness on a steam bath and further heated for 3 hrs. Concentrated hydrochloric acid (5 ml) was added to the residue, followed by 25 ml water and the mixture heated prior to being filtered through a tared ignited SELAS crucible. The silica residue was washed with hot water till chloride free and the crucible with silica reignited at 500°C prior to weighing. The silica was reported as a direct percentage of the dry alga.

(c) Sulphur (Sulphate)

The seaweed (0.2 g) was added to a 100 ml nickel crucible followed by finely ground sodium carbonate (0.5 g) which was thoroughly mixed with the seaweed prior to the addition of 0.5 ml water. Sodium peroxide (calorific grade, 0.5 g) was added in 0.1 g lots slowly with thorough mixing until the mixture was dry and granular. The crucible was carefully heated on a hot plate and the contents stirred carefully till fused. After cooling, the fused material was covered to a depth of about 0.2 cm with more sodium peroxide and the contents reheated until fusion reoccurred and the particles adhering to the sides of the crucible were covered with the melt by rotating the crucible carefully. Heating was continued for a further ten minutes. The crucible when cool was placed into 100 ml of water contained in a 600 ml beaker and a watch glass immediately placed over the beaker. When the decomposition reaction had ceased the crucible was removed by a glass rod and washed thoroughly into the beaker. The resultant solution was made slightly acidic with concentrated hydrochloric acid then transferred to a 250 ml volumetric flask, cooled, diluted to volume and filtered through a Whatman No. 541 filter paper into a 250 ml erlenmeyer flask. To a 200 ml sample of this solution concentrated hydrochloric acid (ca 0.5 ml) was added and the resultant solution boiled for 5 minutes, then 10 ml of 10% aqueous barium chloride was added slowly with constant stirring. After boiling for a further 5 minutes the mixture was allowed to digest at 60^{o}C for a further 5 hrs. The barium sulphate formed was collected on a tared ignited (800^{o}C) SELAS crucible, washed with boiling water till chloride free, washed with

ether, ignited at 800°C and weighed when cold.

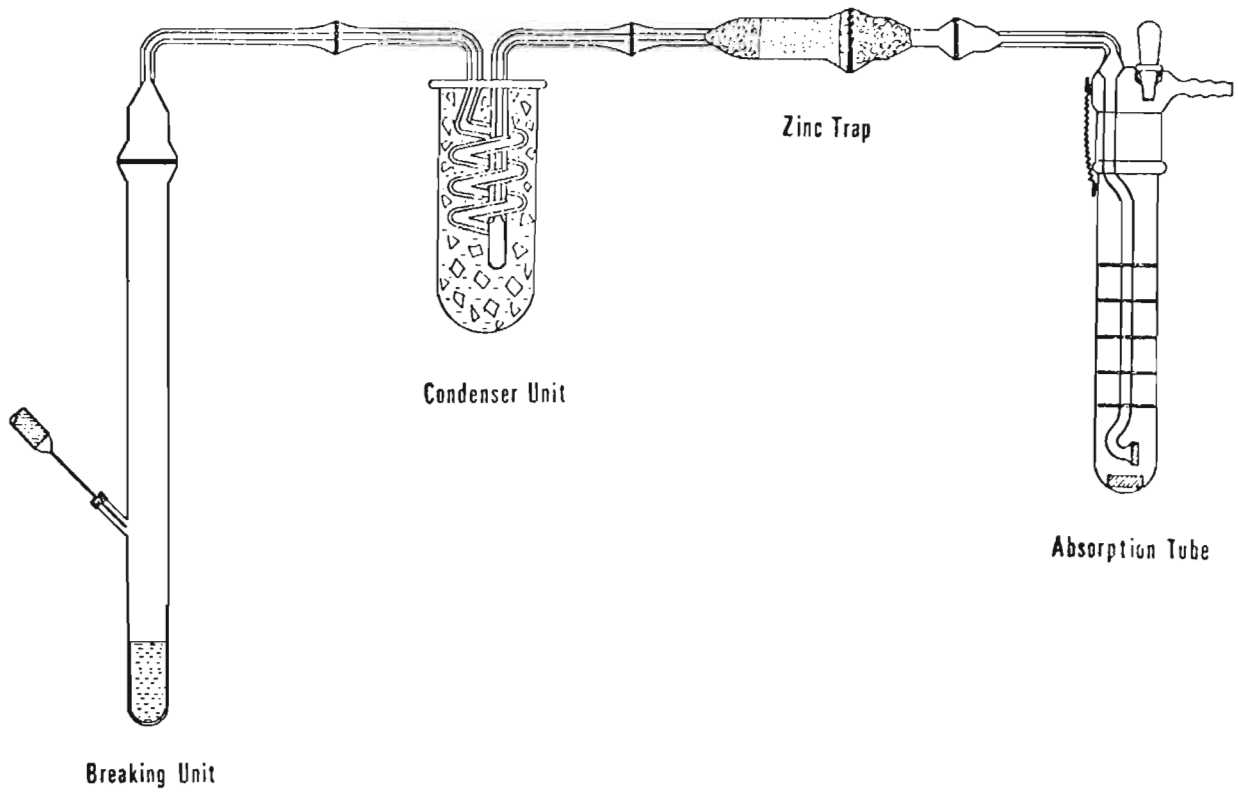
$$\text{Percentage sulphur in alga} = \frac{\text{weight precipitate} \times 0.13735 \times 125}{\text{weight sample (g)}}$$

$$\text{Percentage sulphate in alga} = \frac{\text{weight precipitate} \times 0.41158 \times 125}{\text{weight sample (g)}}$$

(d) Carbonate

The dry alga (approx. 0.5 g) was weighed accurately into a 13 x 100 mm test tube which was then placed in the breaking unit of the gas absorption apparatus, Fig. 1. The carrier gas, nitrogen, was freed from carbon dioxide impurity by scrubbing through a saturated aqueous barium hydroxide solution and dried by passage through silica gel prior to its introduction into the apparatus. The gas was introduced through the rubber septum of the gas inlet arm by means of a syringe needle and the system was purged with nitrogen for 15 mins. Standardized aqueous barium hydroxide (15 ml, 0.05 N), aqueous ethanol (35 ml, 50%) and phenolphthalein indicator were added to the absorption tube through the cap opening and the magnetic "spinfin" Teflon stirring bar positioned at the base of the tube was started. Using a syringe 1N aqueous hydrochloric acid (5 ml) was injected into the test tube and heat applied to the base of the tube by placing under the breaking unit a heating mantle (50 ml, containing sand) operating at about 60°C. The carrier-gas needle was inserted below the opening of the test tube and nitrogen was allowed to flow at 15 ml/min. for a further 1 hour before back titration. Standard hydrochloric acid (0.05 N, 10 ml) was added from a 5 ml class A burette,

Fig. 1



the tip of which was inserted 4-5 cm into the absorption tube, and the titration was then continued slowly using 0.025N hydrochloric acid. As splashing occurred inside the trap, regular washing of the upper portions with aqueous ethanol was continued throughout the titration which was terminated at a colourless endpoint. No blank determinations were necessary under these standard conditions and all volumes were corrected to 0.05 normality.

$$\text{Percentage carbonate} = \frac{(15 - X) \times 0.15002}{\text{weight sample (g)}}$$

X = back titre of 0.05 N hydrochloric acid

(e) Phosphorus (Phosphate); Boron (Pyroborate)

Samples of the fronds and stipes of the alga were ashed at 500^{o}C and the residual inorganic components dissolved in lithium carbonate-nitric acid buffer prior to being analyzed with a Jarrell-Ash direct reading emission spectrometer. The ppm of phosphorus and boron in the dry alga were obtained and converted to corresponding oxides using the conversion factors for phosphorus to phosphate (PO_4^{3-}) and boron to pyroborate ($B_4O_7^{2-}$) which were 3.0662 and 3.590 respectively.

(iv) Results and Discussion

In this series of reports on the chemical composition of the giantkelp Nereocystis luetkeana we have described the variation in the content of cationic elements (Whyte et al., 1974(a)) and halogen components

(Whyte et al., 1975) of the alga over the growing season. This present report concludes the assessment of the inorganic content of the alga by recording the variation in the content of non-metallic elements which are presented in most cases as their corresponding oxides, namely nitrate, silica, sulphate, carbonate, phosphate and borate.

Although the organic nitrogen content of many species of algae has been reported in the literature (Vinogradov, 1953) few, if any, details on the seasonal variation in the nitrate content of benthos algae have been reported. To estimate this inherent component of the alga use was made of a nitrate ion selective electrode. The initial problems associated with electrode techniques were the high halide content (principally chloride) of the aqueous extracts which caused considerable instability in the electrode response and secondly the problems associated with the water soluble polymeric components which adversely affected the electrode response, presumably by blocking the membrane pores.

The latter problem was eradicated by using the aqueous methanol extract of the alga (Whyte et al., 1970) as a starting material in the determination. The halide problem was overcome by the removal of the halogens from the test solution with aqueous silver sulphate employing a solid state iodide ion selective electrode to detect the equivalence point of the chloride titration. The nitrate content of the remaining solution was then determined by the"known addition"method using the nitrate sensing electrode.

The nitrate contents of both segments of the alga throughout the growing period are presented in Table 1. The fronds exhibited an average nitrate content of 0.81% with a total range for the season of

0.52 to 1.35% which was reflected in the rapid assimilation of this anion in the one month period from April to May. A steady decline in content of nitrate from the highest level in May towards the end of the season, Fig. 2, may be explained by the increased utilization of nitrate into the metabolic system as the sporangia on the fronds tend towards complete maturation. The marked decline in the nitrate content of the fronds was not exhibited to the same extent by the stipes, which lack fruiting bodies, and a gradual decline from 0.35% in May to 0.12% in October provided the total range for the nitrate content in that segment of the alga which averaged 0.24% throughout the season, Fig. 2.

The silica contents which were determined by acid leaching of ashed samples of the fronds and stipes of the alga are presented in Table 2. The seasonal average value for the stipes at 0.460% was considerably greater than the value for the silica content of the fronds at 0.145%. A general decline in the silica content of the stipes was observed as the season progressed in contrast to the greater fluctuation exhibited in the content of silica in the fronds which registered peak levels at 0.240% and 0.183% in June and September respectively, Fig. 3.

It is not known whether silicon in brown algae is present as an integral cellular entity or whether it arises from entrapped siliceous material. In the course of analyzing the fronds, however, minute particles of granular silica were observed in some of the siliceous residues. Thus, the lower values for the silica in the fronds at approximately 0.1% were considered to be more representative of the actual silica level in that portion of the plant. On the other hand, the lack of significant fluctuation in the silica content of the stipes implied that

the assessed content of 0.45 ± 0.05% was a legitimate background level for the silica in that segment of the alga.

The total sulphur content in Nereocystis was assessed by determining the precipitable barium sulphate formed following an alkaline oxidative fusion of the algal samples. This procedure afforded the total sulphur content of the alga from which the corresponding sulphate content was calculated. The sulphur content in algae ranks among the highest for the inclusion of this element in any organism in nature. The element exists principally in the oxidized state as inorganic sulphate or as equivalent half ester sulphate groups attached to constituent polysaccharides such as the fucoidan in the brown algae or the carrageenans and agaroids in the red algae.

The results obtained for the total sulphur and corresponding sulphate content of the fronds and stipes of Nereocystis over the growing season are presented in Table 3. The sulphate content of the fronds ranged from 2.58 to 3.45% over the season and provided an average value of 2.96% inclusion. At the beginning of the season a general upward trend was noted for the sulphate content of the fronds which, however, was reversed in the months of August and September to reach the lowest level of 2.7%. Nevertheless, this low value was succeeded by the highest level for the season at 3.45% the following month of October, Fig. 4.

Considerably less sulphate was evident in the stipes of the alga which exhibited marked fluctuations of sulphate content throughout the season, Fig. 4; a seasonal average of 1.55% stemmed from a range in concentration of 1.09 to 1.99%.

The total sulphur contents of the fronds and stipes of Nereocystis luetkeana, ranging throughout the season from 0.86 to 1.15% and 0.36 to 0.66% respectively, were considerably less than the value quoted for Norwegian seaweed meal (Ascophyllum nodosum) at 2.5 to 3.5% and suggested the probability of lesser inclusion of constituent fucoidan in the B.C. alga.

The carbonate contents of the fronds and stipes of Nereocystis were determined by the acid liberation of carbon dioxide from the dry samples and the subsequent determination of the evolved gas in an apparatus developed for the estimation of alginic acid by acid decarboxylation (Whyte et al., 1974(b)). The results obtained from these determinations are presented in Table 4. The fronds were observed to contain from 0.050 to 0.072% carbonate over the growing season yielding an average concentration of 0.060%, whereas the stipes contained 0.025 to 0.041% carbonate over the same period to afford an average figure of 0.035% for the season.

A general increase in the carbonate content of both segments of the alga was observed as the season progressed with slightly more fluctuation being exhibited by the fronds, Fig. 5. This general increasing trend as the season progressed may be due to an increase in attached calcareous organisms or a decline in the photosynthetic process affecting the carbonate equilibrium in the alga. Although carbonate is intensively concentrated in the Corallinaceae and certain Chlorophyceae in warm and tropical seas this anion is seldom associated with temperate or cold water algae (Vinogradov, 1953). The minor accumulation of carbonate noted in Nereocystis would certainly corroborate this conclusion.

The phosphate and borate contents of the fronds and stipes of Nereocystis were calculated from the values obtained for the parent elements

which were assessed by emission spectrometry and the results obtained are presented in Tables 5 and 6 respectively. The fronds exhibited a phosphate content ranging from 0.67 to 1.59% over the season to provide an average content of 1.01%. The initial decline in the phosphate content of the fronds at the beginning of the season was reversed in June and thereafter a steady accumulation of this anion was observed as the season progressed to yield the highest content in October at 1.59%, Fig. 6. This cumulative effect was not reflected in the phosphate content of the stipes which fluctuated markedly throughout the season within the range of 0.28 to 0.86%, Fig. 6, and afforded an average concentration for the fronds of 0.61%. The lowest concentration in the stipes was observed in July at 0.28% with the highest inclusion of 0.86% occurring in the month of September, Fig. 6.

The seasonal variation in the boron content, expressed as the corresponding pyroborate for both segments of the alga, is recorded in Table 6 and illustrated in Fig. 7. The fronds averaged 287 ppm of pyroborate throughout the season and provided a range of borate content of 190 to 438 ppm. The stipes contained a higher concentration of this anion averaging 318 ppm over the season with a range of 158 to 485 ppm. Both portions of the alga exhibited considerable fluctuations in their constituent borate contents throughout the season with maxima registered for the fronds in June and August and for the stipes in June and September with a minimum level being registered by both segments of the alga in July, Fig. 7. A comparison of these results with the value for the boron content of ocean seawater, 65 ppm as pyroborate, demonstrates the ability of Nereocystis to concentrate this element from the environmental medium.

The anionic components alluded to in this report are presented in Table 7 as the mean, minimum and maximum levels of these components which were encountered in Nereocystis luetkeana over the growing season. The halogen content of the alga, which formed the basis of an earlier report (Whyte et al., 1975), is also included in Table 7 for completeness.

The major anionic content of the fronds, Table 7, totalling 19.88% was composed of 15.1% chloride, 2.96% sulphate, 1.01% phosphate and 0.81% nitrate, whereas the principal cationic content of the fronds, totalling 18.88%, was composed of 10.71% potassium, 6.57% sodium, 0.84% magnesium and 0.76% calcium (Whyte et al., 1974(a)). Thus the total inorganic content of Nereocystis fronds, neglecting the minor and trace elements, was assessed at 38.76%. This figure is lower than the ash content of 40.2% previously determined, however, when the cations are expressed as their corresponding oxides, which must be partially formed under ashing conditions, then an inorganic content of 41.21% is provided which when averaged with the previous value affords a figure of 39.99% in good agreement with the ash content.

Similarly, the principal anionic content of the stipes totalling 21.7%, Table 7, composed of 19.3% chloride, 1.55% sulphate, 0.61% phosphate and 0.24% nitrate which when summated with the major cations, totalling 24.71% consisting of 19.10% potassium, 4.45% sodium, 0.56% magnesium and 0.60% calcium (Whyte et al., 1974(a)) provide a total inorganic content, neglecting the minor and trace elements, of 46.41%. When the cations are expressed as corresponding oxides a value of 52.49% inorganic content is obtained and with the previous value affords an average of 49.45% which agrees favourably with the ash content of 51.3% determined experimentally.

These data indicate the exceptionally high content of inorganic chemicals concentrated by Nereocystis luetkeana relative to the commercially utilized Atlantic species of the Laminariaceae (Black, 1950) and Fucacea (Jensen et al., 1968), particularly Ascophyllum nodosum, which affords an ash content of approximately 20% and provides an inorganic content composed principally of 3% potassium, 4% sodium, 3% calcium, 0.9% magnesium, 4.5% chloride and 3.5% sulphur (Jensen, 1971).

Nereocystis has the remarkable ability to concentrate potassium ions and as such the corresponding chloride salt contitutes the major difference in inorganic content between this Pacific alga and those cited from the Atlantic ocean. The high proportion of inorganic chemicals in Nereocystis will probably limit its use as a high level mineral supplement in feedstuffs for livestock but may assure its utilization as a mineral source for the fertilizer or inorganic chemicals industry.

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TABLE 1

Nitrate Content of the Fronds and Stipes of

Nereocystis over the Growing Season

Month	Nitrate (% Dry Weight)	
	Fronds	Stipes
April	0.52	0.31
May	1.35	0.35
June	1.11	0.31
July	0.94	0.26
August	0.56	0.16
September	0.52	0.20
October	0.64	0.12

TABLE 2

Silica Content of the Fronds and Stipes of *Nereocystis* over the Growing Season

Month	Silica (% Dry Weight)	
	Fronds	Stipes
April	0.151	0.531
May	0.092	0.507
June	0.240	0.442
July	0.083	0.461
August	0.108	0.415
September	0.183	0.420
October	0.158	0.446

TABLE 3

Sulphur and Corresponding Sulphate Content of the Fronds and Stipes of *Nereocystis* over the Growing Season

Month	Sulphur (% Dry Weight)		Sulphate (% Dry Weight)	
	Fronds	Stipes	Fronds	Stipes
April	0.86	0.39	2.58	1.18
May	0.95	0.64	2.85	1.93
June	0.93	0.45	2.79	1.36
July	1.09	0.66	3.27	1.99
August	1.02	0.36	3.07	1.09
September	0.90	0.51	2.70	1.53
October	1.15	0.59	3.45	1.77

TABLE 4

Carbonate Content of the Fronds and Stipes of

Nereocystis over the Growing Season

Month	Carbonate (% Dry Weight)	
	Fronds	Stipes
April	0.053	0.025
May	0.052	0.029
June	0.050	0.031
July	0.063	0.038
August	0.061	0.040
September	0.069	0.039
October	0.072	0.041

TABLE 5

Phosphorus and Corresponding Phosphate Content of the Fronds and Stipes of Nereocystis over the Growing Season

Month	Phosphorus (% Dry Weight)		Phosphate (% Dry Weight)	
	Fronds	Stipes	Fronds	Stipes
April	0.30	0.21	0.92	0.64
May	0.22	0.18	0.67	0.55
June	0.22	0.22	0.67	0.67
July	0.29	0.09	0.89	0.28
August	0.36	0.23	1.10	0.71
September	0.39	0.28	1.20	0.86
October	0.52	0.19	1.59	0.58

TABLE 6

Boron and Corresponding Pyroborate Content of the Fronds and Stipes of Nereocystis over the Growing Season

Month	Boron (ppm Dry Weight)		Pyroborate (ppm Dry Weight)	
	Fronds	Stipes	Fronds	Stipes
April	60	44	215	158
May	53	68	190	244
June	76	116	273	416
July	61	60	219	215
August	122	118	438	424
September	94	135	337	485
October	94	79	337	284

TABLE 7

Mean, Minimum and Maximum Concentrations of

Non-Metallic Inorganic Components in Nereocystis

Over the Growing Season*

Component	Fronds		Stipes	
	Mean	Range	Mean	Range
Chloride, %	15.1	12.7-17.0	19.3	15.1-26.9
Sulphate, %	2.96	2.58-3.45	1.55	1.09-1.99
Phosphate, %	1.01	0.67-1.59	0.61	0.28-0.86
Nitrate, %	0.81	0.52-1.35	0.24	0.12-0.35
Silica, %	0.145	0.083-0.240	0.460	0.415-0.531
Carbonate, %	0.060	0.050-0.072	0.035	0.025-0.041
Iodide, ppm	914	529-1423	1163	826-1548
Pyroborate, ppm	287	190-438	318	158-485
Bromide, ppm	<79	0-<79	<79	0-<79

*Dry Weight basis

Fig. 2

Nitrate Content

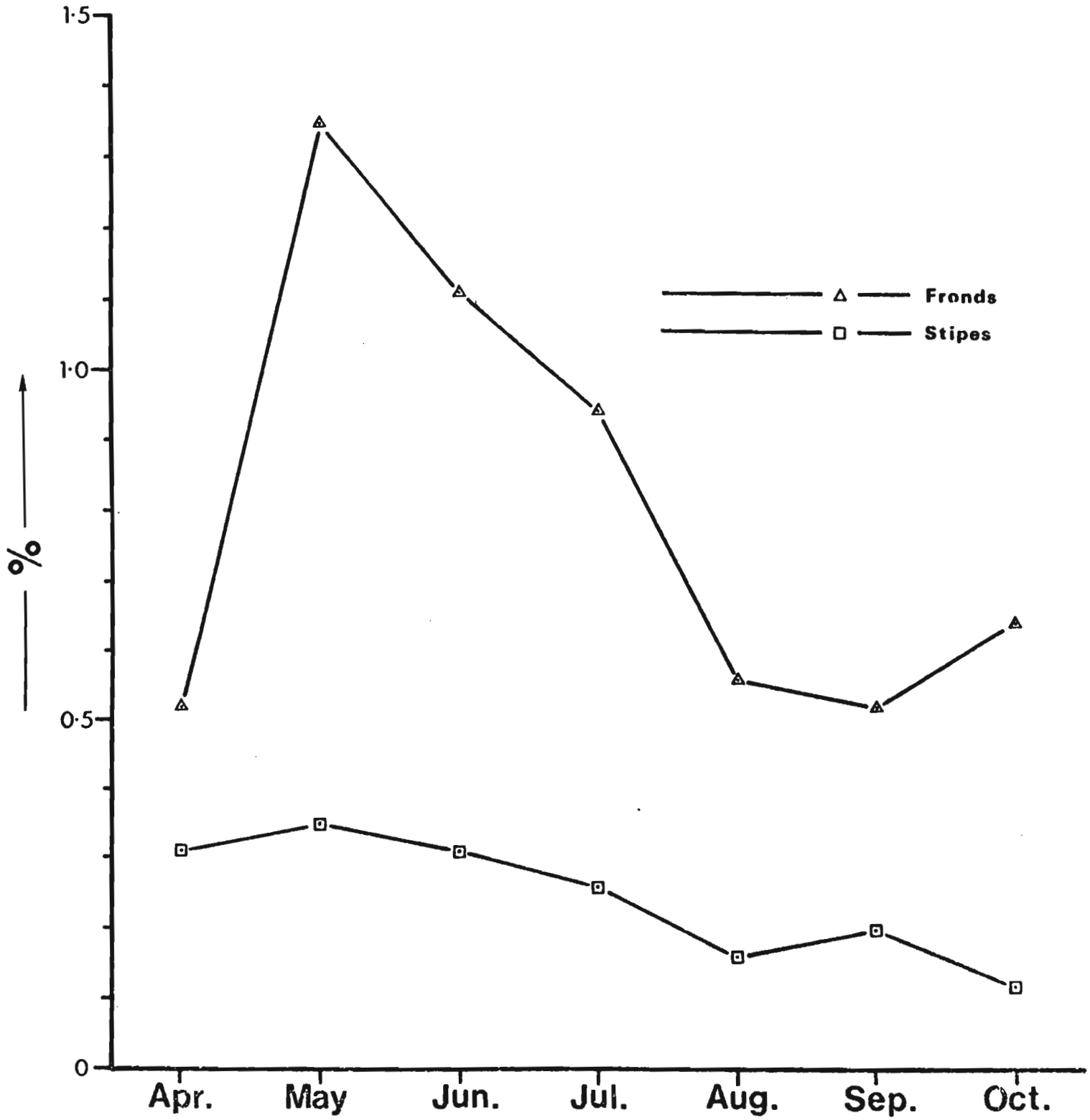


Fig. 3

Silica Content

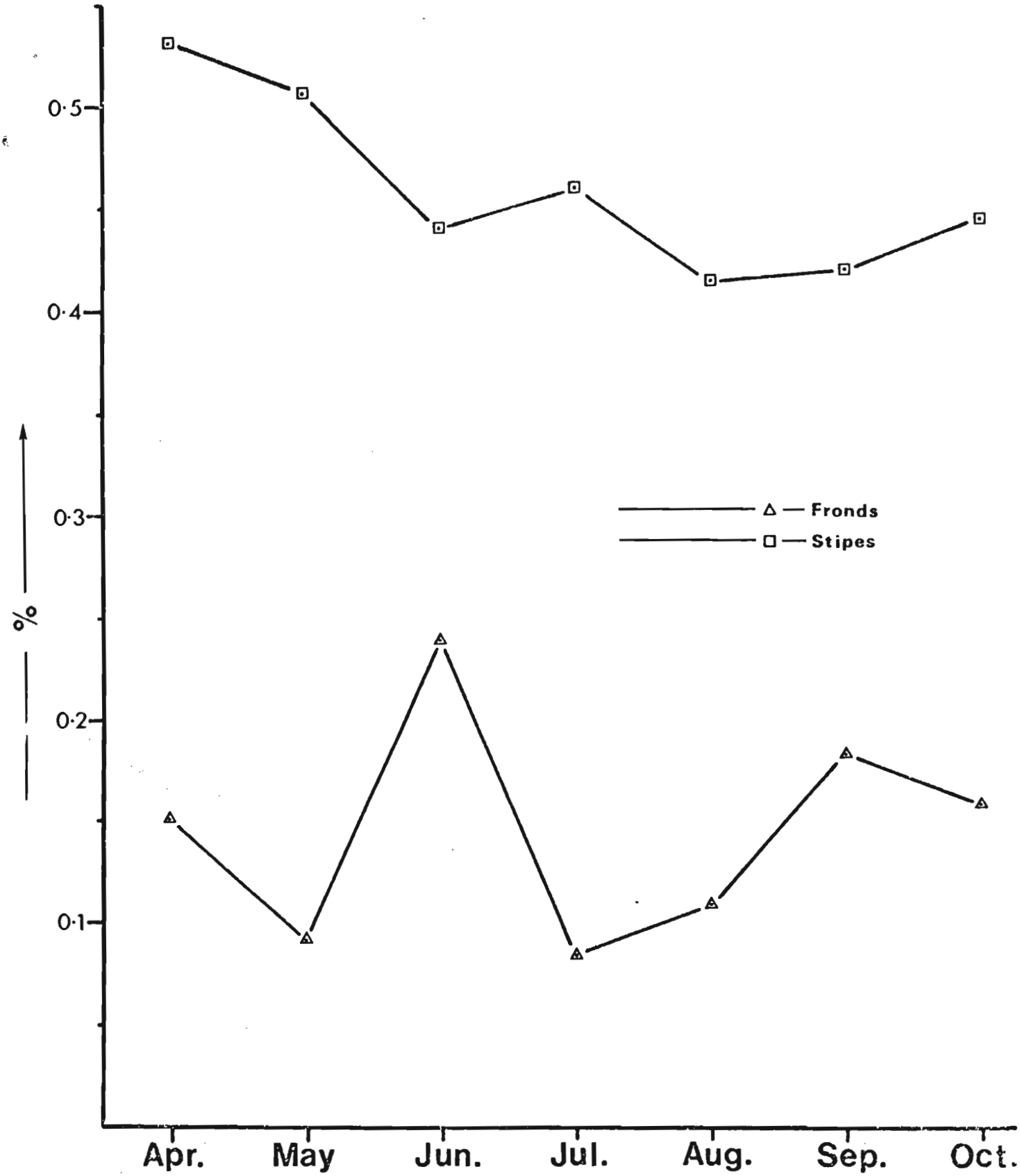


Fig.4

Sulphate Content

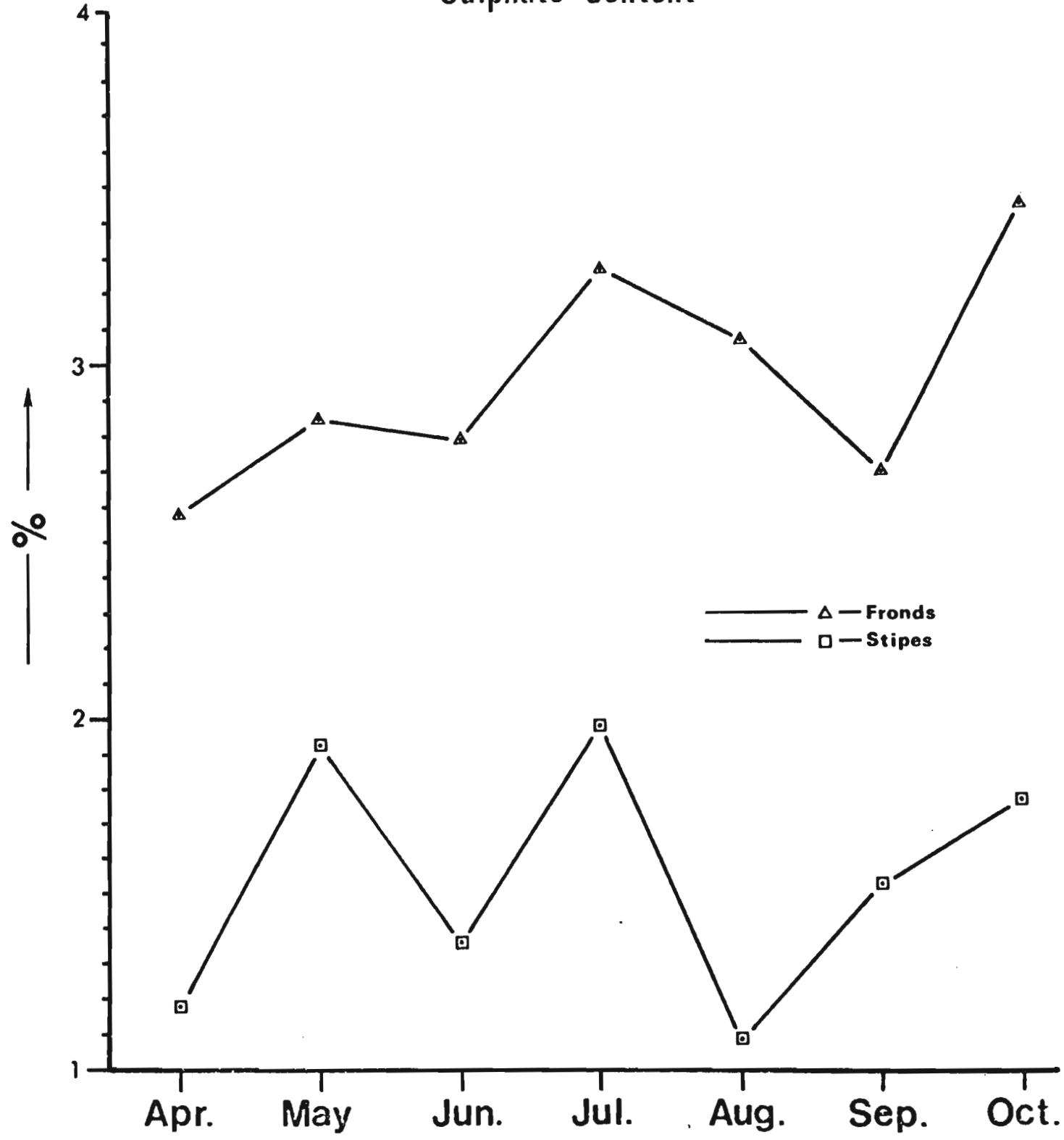


Fig.5

Carbonate Content

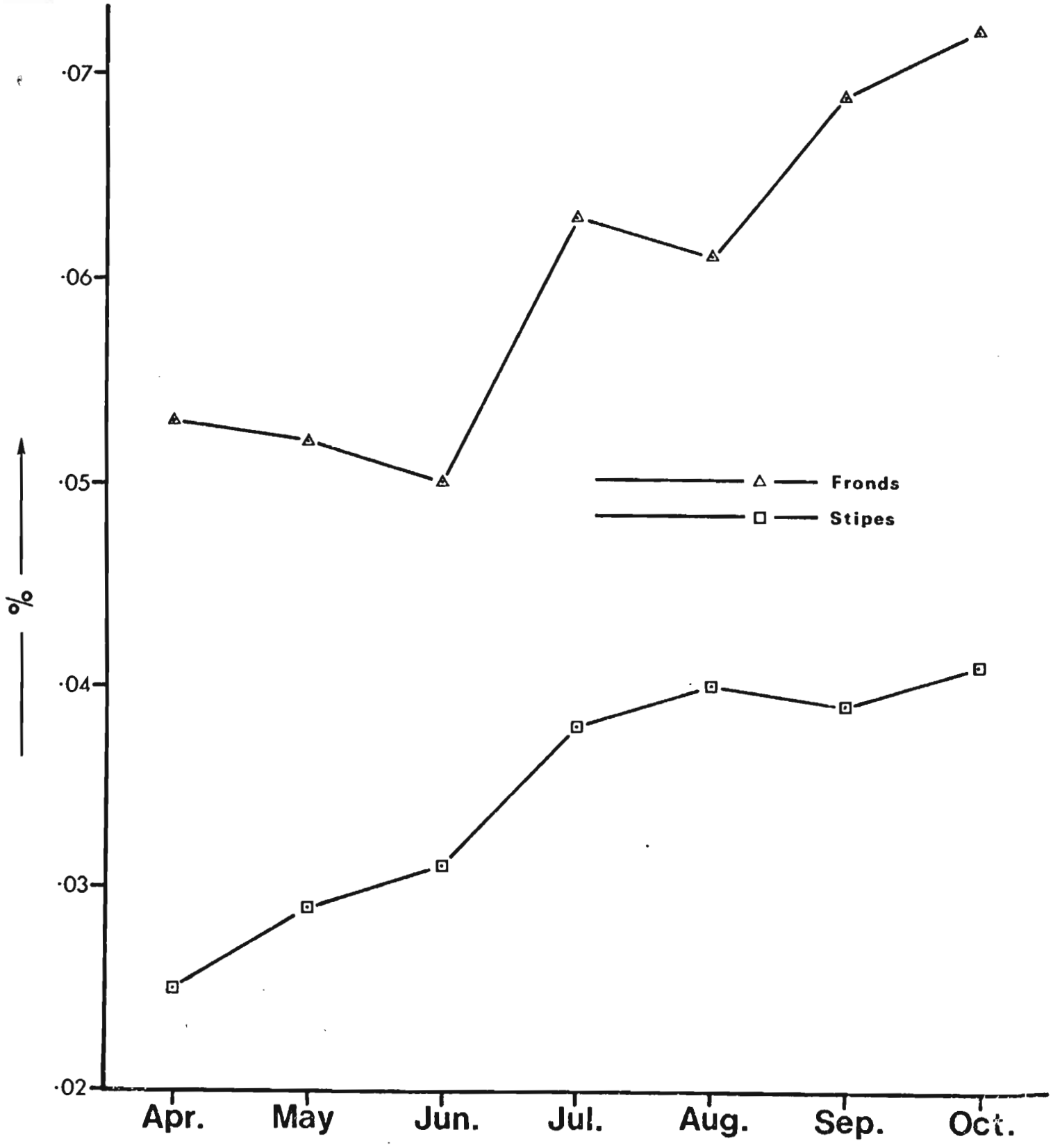


Fig.6

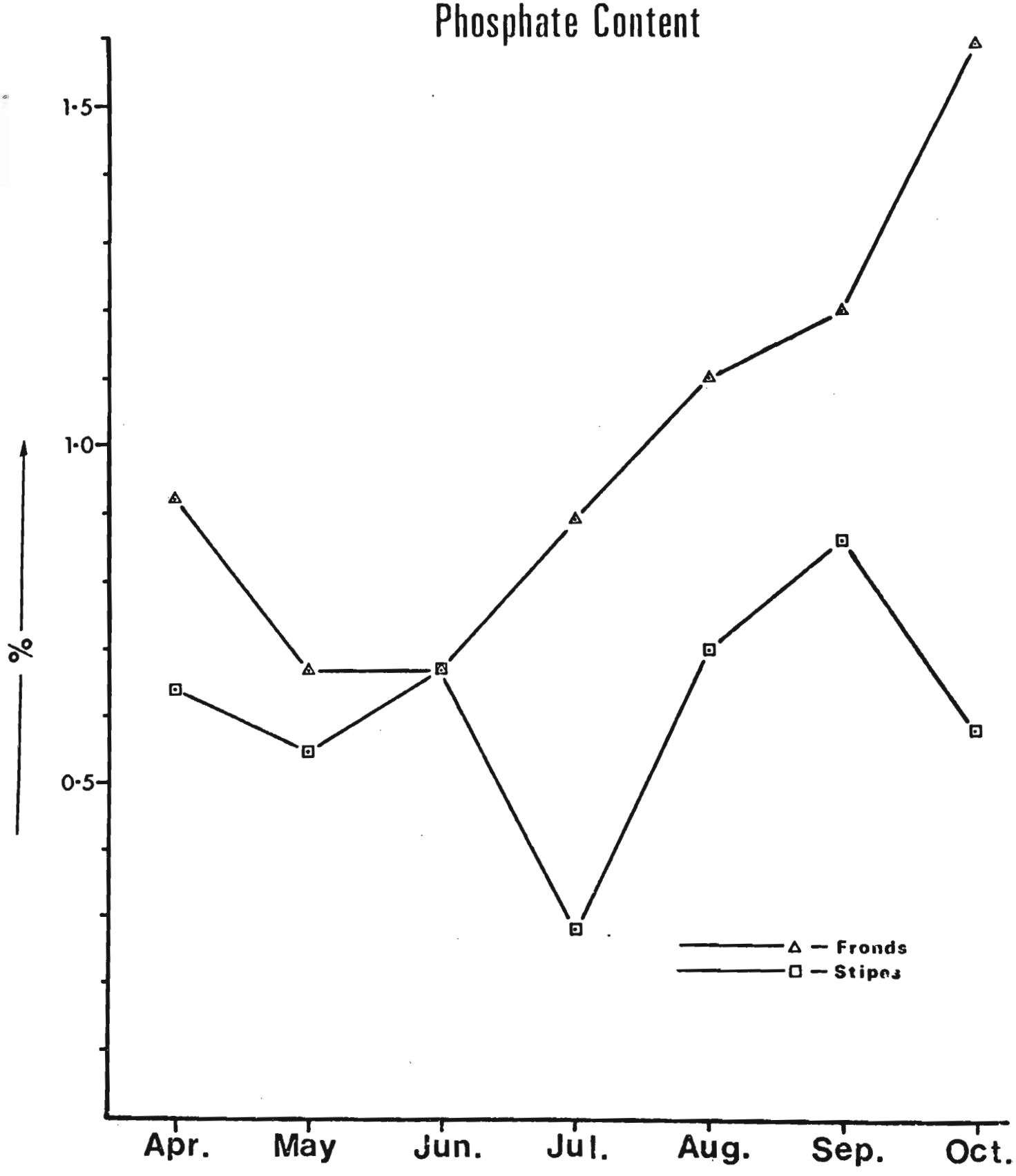
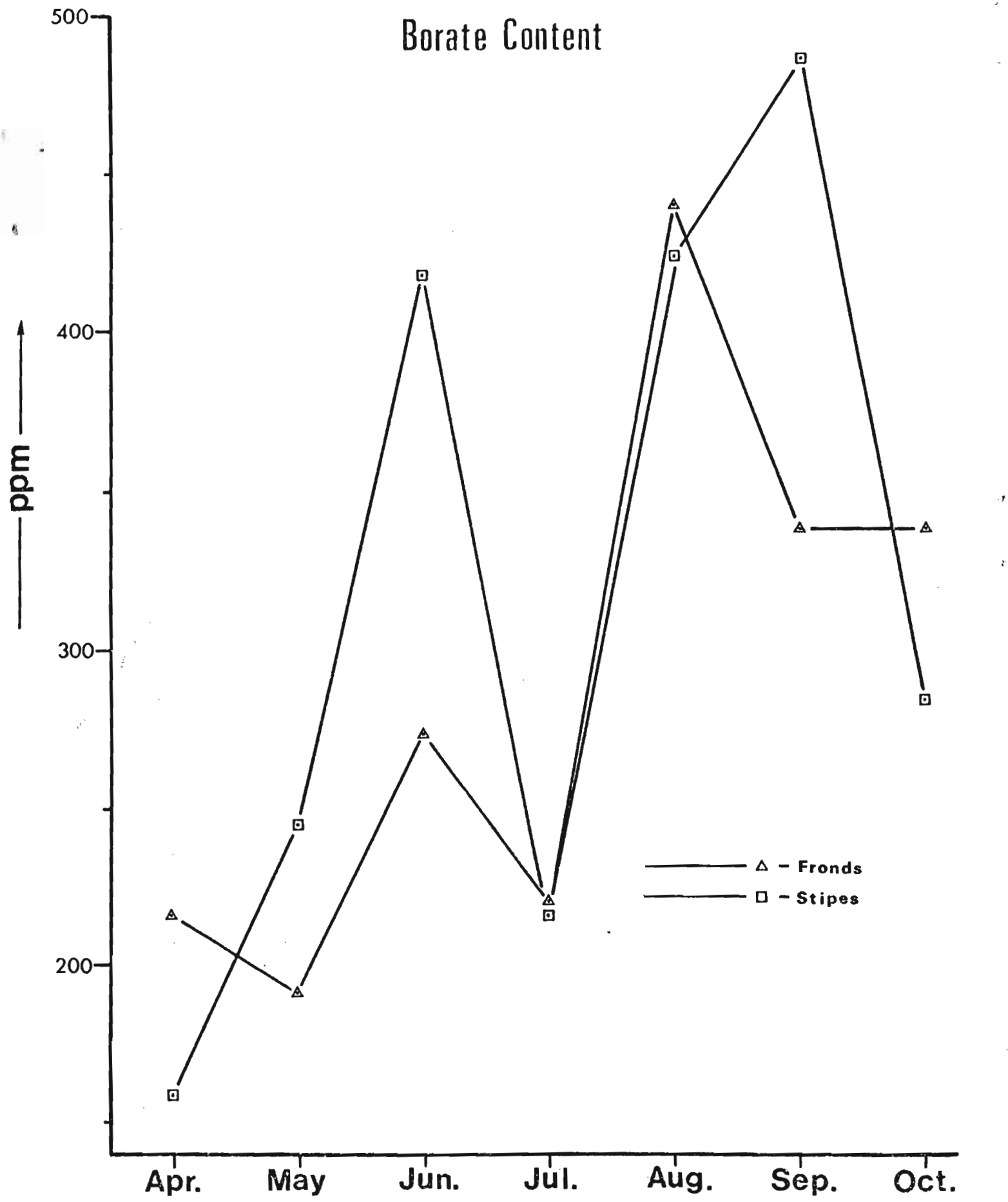

Phosphate Content
1·5
1·0
0·5
%
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
Δ — Fronds
□ — Stipes

Fig.7


Borate Content
500
400
300
200
ppm
Apr.
May
Jun.
Jul.
Aug.
Sep.
Oct.
△ - Fronds
□ - Stipes