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PRODUCTIVITY IN RELATION TO ENVIRONMENTAL VARIABLES IN THE FAXAFLOI REGION 1966-1967

by

Thórunn Thórdardóttir and Unnsteinn Stefánsson[1)]
Marine Research Institute, Reykjavík

Introduction

Faxaflói and the adjacent shelf area is economically an important region, and biologically it is of great interest. It is highly productive and provides suitable spawning areas as well as nursery grounds for various species of fish. This has stimulated hydro-biological research in the region, *inter alia* intensive seasonal studies in the period February 1966 to March 1967. The objective of these investigations was to attempt to relate biological conditions to various oceanographic factors. The present paper describes the preliminary results of one aspect of these studies, viz. the relationship between primary production and physical and chemical variables. A more complete and detailed account is in preparation. The results here presented may also be considered as a contribution to a more general programme, in operation for several years, of assessing the productivity conditions in various regions inside the Icelandic territorial limits.

Material and Methods

In the 13 months period, February 1966 to March 1967 15 hydro-biological surveys were made in the study area, including primary production measurements during 13 of these surveys. On each cruise observations were carried out at 23 stations (Fig. 1).

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1) The University of Iceland and the Marine Research Institute, Reykjavík

Temperature, salinity and nutrient concentrations were determined on samples from standard depths.

The nutrient samples were quick-frozen in polyethylene bottles and stored in a deep-freezer until thawed and analyzed ashore after collection. Experiments made by Stefánsson and Ólafsson (1970) indicated that this was a satisfactory preservation procedure for samples from the Faxaflói region. Colorimetric analyses were made with a Unicam SP 500 spectrophotometer according to the methods of Mullin and Riley (1955 a, b) for nitrate and silicate and of Murphy and Riley (1962) for phosphate. Salinity was determined from conductivity measurements using an Auto-Lab inductive salinometer.

Primary production measurements employing the C^{14}-technique (Steemann-Nielsen 1952) were made on samples from the standard depths 0, 10, 20 and 30 m. These samples were all illuminated in a temperature-regulated incubator at a light intensity of about 10,000 lux which is similar to that used for other productivity measurements in Icelandic waters in the past 20 years. Samples for quantitative analysis of phytoplankton were collected at the same depths were productivity was measured. A part of this material has been analyzed and the results are kept on file at the Marine Research Institute. These will be referred to where appropriate in the text.

From observations of cloud cover over Keflavík during the year 1960 (information received from the Meteorological Institute, Reykjavík) weakly means of the incoming light energy at 64°N were estimated and from these data critical depth was derived (Sverdrup 1953).

Topography

Faxaflói (Faxa Bay) is a relatively short and broad bay, less than 50 km long and 90 km wide, located on the southwest coast of Iceland between the large peninsulas Reykjanes and Snæfellsnes. The inner part of the bay is quite shallow, especially the nearshore area in the northern part, where depths less than 20 m extend 10-15 km offshore. The area inside the 50 m isobath which has a large extension in the southern part is nearly 60% of the total area inside the bay, while depths between 50 and 100 m occupy a little over 30%. Near its mouth there is a small region with depths greater than 100 m. This is the innermost part of the Jökuldjúp (Fig. 1) which cuts into the continental shelf from the southwest, and reaches depths of more than 300 m in the westernmost part of the study area.

Otherwise, in most part of the shelf area outside the bay, depths are between 100 and 200 meters. Thus, there is a considerable depth range in this region: from about 30 m at the shallowest stations to 250-320 m at the deepest stations outside the bay.

Circulation

In the bay proper as well as on the continental shelf outside the current system is largely governed by the normally clockwise circulation around Iceland. Thus direct and indirect current measurements (Hermann and Thomsen 1946, Malmberg 1968, 1969, Stefánsson and Gudmundsson 1969) have indicated a mean residual surface current of about 3-5 miles a day towards north or northwest along the mouth of the bay. Just north of Gardskagi there is normally a current component directed eastwards bringing water from the shallow coastal area south of Reykjanes into the southern part of Faxaflói while in the northern part of the bay there is on the average a net outflow to the west and northwest. From experiments with sea bed drifters (Malmberg 1969) the bottom currents appear to flow in the sama general direction as the surface drift but with an average velocity of only about 1/2 mile per day. It should be emphasized, however, that these are average figures which may differ drastically from actual current velocity and direction at any particular time. In this respect variable wind conditions play a major role, contribute to mixing of water masses and lead to fluctuations in the distribution of coastal water in the bay (Stefánsson and Gudmundsson 1977).

Hydrography

The water inside Faxaflói is essentially Atlantic water, relatively warm and saline, but appreciably diluted by freshwater from land, mainly rivers draining into the eastern and northeastern part of the bay. Of these the most important one is the glacial river Hvítá in Borgarfjördur. In the nearshore area west and southwest of Gardskagi another source of freshwater is often indicated. Here a tongue of low-salinity water may extend towards the north. This was e.g. observed in March, April, May and June 1966 and in January 1967 (Stefánsson and Gudmundsson 1977).

These general features are revealed by the horizontal distribution of salinity in the surface layer (Fig. 2). During most part of the year the salinity ranges from about 34.60‰ at nearshore stations inside the bay to 35.20‰ or more at the deepest stations on the shelf. However, at times of large fresh water afflux and following periods of prevailing southerly winds (cf. Stefánsson and Gudmundsson 1977), in particular in summer, considerably lower salinities will be found inside the bay (Fig. 2c). Details of the seasonal fluctuations in salinity at three selected stations (Fig. 4) reveal that the annual salinity range may exceed 1.2‰ at nearshore stations, amounts to about 0.6‰ at the mouth of the bay, while at the deepest station the salinity remains remarkably uniform throughout the year. At station 23 which was located in the vicinity of the main runoff areas, the seasonal salinity variations resemble corresponding variations in runoff (Fig. 4), if a time lag of about 1/2 month is allowed for. Similarly, at the mouth of the bay, the main variations in salinity seem to correspond to those found nearshore (station 23) about 1 1/2 months earlier. However, the correlation between runoff and fresh water content inside the bay is weak and applies mainly to the inner part. On the other hand, it has been shown (Stefánsson and Gudmundsson 1977) that there exists a close correlation between the total freshwater volume in Faxaflói and the southerly wind component for the same period.

In winter the near-surface temperature distribution (Fig. 3a) is characterized by low nearshore temperatures ($< 2°C$), increasing to 7° or more at the deepest stations outside the bay. This marked horizontal temperature gradient is reduced in spring (Fig. 3b), in summer (Fig. 3c) the highest temperatures ($> 11°C$) occur inside the bay. In autumn (Fig. 3d) the horizontal temperature gradient is again reversed. The annual temperature range (Fig. 4) exceeds 10°C at the shallow nearshore stations, amounts to about 6°C near the mouth of the bay, but only about 4°C at the deepest stations outside.

At all stations there was a marked increase in stratification in spring and/or early summer due to development of thermocline. As would be expected this developed at an earlier date at the shallower stations where stratification may also be stable in winter because of freshwater admixture to the surface layers (Figs. 4,8,9). At the deep stations, however, the water was stable only during the months June to August or September, and the stratification was due to vertical temperature gradient alone. As the water becomes shallower, the seasonal temperature range increases progressively, and so does the temperature - induced stratification. Added to this is the effect of vertical salinity gradients which become more and more important as the shallower part of the bay is approached. Consequently, at inshore stations such as

St. 23 (Fig. 4) the vertical density gradient was about twice that found near the mouth of the bay (st. 16) and three times that of St. 8 in the deepest part of the study area.

Nutrient relationships

In previous studies (Stefánsson 1968) it was found that in the northern Irminger Sea the nitrate-phosphate relationship indicated identical ratio of change in Atlantic water and Polar water, $\Delta N:\Delta P = 14 \cdot 3:1$. In Atlantic water the nutrients were found to be utilized or regenerated in approximately the same ratio as it is in the water, whereas in Polar water the concentration ratio was smaller than the ratio of change, leading to nitrate depletion when the phosphate concentration was still 0.2-0.3 µg-at/L. The present studies also suggest almost the same ratio of change (Fig. 5), but the regression line expressing nitrate as a function of phosphate has an intercept which is intermediate between that for Atlantic water of the northern Irminger Sea and Polar water. Thus in the Faxaflói region, nitrate will normally approach zero when the phosphate concentration is still about 0.1 µg-at/l, implying that nitrate is more likely to be limiting for plant growth than phosphate. Therefore, in comparing primary production and nutrient consumption we have (Figs. 8,9) selected nitrate rather than phosphate. However, the presence of small amounts of ammonia as a nutrient source can not be excluded, but ammonia analyses were not performed.

The silicate-phosphate relationship (Fig. 6) suggests that the ratio of change may not be linear. Normally, the $\Delta Si:\Delta P$ ratio was found to be higher during the initial stages of the nutrient uptake than later on when both silicate and phosphate had been reduced to small concentrations. The relationship shows a considerable scatter which is mostly due to variable fresh water influence, but also to the fact that phosphate winter concentrations were found to be significantly higher in 1967 than in 1966, while the winter silicate concentrations were about the same in both winters. The rivers draining into Faxaflói contain reactive silicate in concentrations exceeding 200 µg-at/L (Stefánsson, unpublished data). Consequently, the low salinity coastal water has appreciably higher silicate concentrations than the surface water of the deeper stations. Diatom growth should therefore be favoured in the inshore area and might - other factors being equal - be expected to last longer.

Nutrient cycles

Seasonal variations of nutrient concentrations in the near-surface layer, typical for different parts of the study area are illustrated in Fig. 7. The main features may be summarized as follows:

a) All three nutrients, nitrates, phosphates and silicates revealed very similar variations.

b) Winter concentrations of nitrates ranged between 10 and 12 µg-at/L, of phosphates between 0.8 and 0.95 µg-at/L, of silicates between 6.5 and 7.5 µg-at/L at deep stations, but exceeded 10 µg-at/L at shallow stations.

c) There was generally a rapid decrease in nutrients in spring associated with the onset of the spring bloom, while the net regeneration, beginning towards the end of summer took place much more slowly.

d) At the shallow stations appreciable nutrient uptake began already during the second half of March, at the mouth of the bay during first half of May, but at the deepest stations not until the second half of May.

e) Minimum values of the nutrient concentrations were at most stations found in the period June-July. At this stage nitrates were in general in the range 0.2 - 0.4 µg-at/L, but significantly higher at some of the deep stations, phosphates were generally 0.1 - 0.2 µg-at/L, and silicates 0.1 - 0.4 µg-at/L.

If we look at the variations for all stations (Figs. 8,9) certain anomalous features will be apparent. Thus at stations 1, 2, 19, 21, 22 and 23 a sudden concentration increase occurred in late April followed by a second decline. At stations 4, 8 and 13 such secondary maxima were found in late June. At the other stations such irregularities in the seasonal cycle were absent. We will return to these features later.

Primary Productivity

When productivity measurements started at the end of March 1966 the growth appeared to be well on its way in the shallowest part of the study area (Fig. 10a) At these innermost stations stratification was stable due to fresh water admixture in the near-surface layer. It will also be seen (Figs. 8,9) that the uptake of nutrients had gone farther at the more southerly stations (st. 22-24) than at those farther north (st. 19-21), which suggests a somewhat earlier start in the southern part of the shallow area. Farther offshore there was little sign of the onset of plant growth, although a slight reduction of nutrients was observed near the mouth of the bay, with a trifle higher productivity values than in the outer area where they were extremely low.

Two weeks later, about the middle of April (Figs. 8,9) the outermost part of the area was still as impoverished with respect to growth as before, there was a slight increase in growth at the shallow stations off Reykjanes and in the mouth of the bay, but appreciable production was limited to the innermost part of the area. The available data indicate changing hydrographic conditions in the period between observations and a rather irregular growth development at some of the localities. Thus at St. 20 and 22 high-salinity water with relatively high nutrient content had replaced the low-salinity water found there during the preceding survey. At St. 22 the average productivity values for 0-30 m were similar to those measured at the end of March, while at St. 20 they had decreased. At the more southerly stations (2, 23 and 24) the productivity remained considerable to high and there was a further decrease in nutrient concentrations although these were somewhat higher than anticipated from the production rate. This could be due to renewal of nutrients in the surface layers in the intervening period by advection or by vertical turbulence which might have suppressed the growth intermittently. This supposition receives some support from the t,S relationships of these stations which indicate shifting hydrographic conditions during the spring months.

A remarkable situation was observed in late April (Fig. 10b) in the southern inner part of the bay. Productivity had dropped to low values in spite of increase in nutrient content and no less favourable stability conditions than previously. Possible explanation for this low productivity might be lack of plants. Analysis of phytoplankton at some of the stations concerned showed very poor vegetation, especially the diatoms. This was in marked contrast to the relatively rich growth found in this part of the area during the other spring surveys (Thórdardóttir, unpublished data). At the mouth of the bay the primary production had increased significantly, but was still at a moderate level. In the outer part of the area there was little evidence of production increase except at St. 14, where the spring development in general seemed to be more like that of the stations in the mouth of the bay.

In contrast to the impoverished growth in late April the area was rather productive in early May (Fig. 10c). This applied in particular to the bay proper and the southern and shallower part of the outer area where productivity was considerable to high. Both at the mouth of the bay and over the shallow area off Reykjanes the growth seemed to be well on its way, especially at St. 14. The relatively high production levels observed throughout spring and summer at this station were presumably due to frequent intrusions of water from the area south of Reykjanes giving rise to favourable conditions for growth both with regard to nutrients and stratification. At the outer stations farther north the production had increased only slightly, although significantly, except at St. 8 and 10, where it was still very low. At the near-shore stations in the southern part of the bay the production was relatively high, and the nutrient increase observed in late April had disappeared leading to a new growth maximum. A somewhat different development pattern seemed to apply to the northerly near-shore stations inside the bay.

In the outermost part of the area the main phytoplankton outburst seems to have taken place in the three weeks period preceding the survey at the beginning of June, as evidenced by the abrupt fall in nutrient concentrations. Presumably, this was brought about by the increased stability and improved light conditions during the latter half of May. However, it appears that the bloom was brought to an end within the three weeks period, as indicated by the almost complete exhaustion of nutrients from the surface layers and low productivity levels when observed in the beginning of June. With reference to the findings in other years (Thordardóttir 1976) it seems reasonable to assume that a vigorous growth took place in these outer waters during the latter half of May. At the mouth of the bay production was still appreciable at the beginning of June, but nutrients were reduced to very low levels in the near-surface layers all over the study area with the exception of a few stations (3, 6, 14).

In general it can be said that summer situation prevailed when the area was surveyed in the beginning of June (Fig.10d). It can be assumed that at this stage the spring bloom was over everywhere in the area and the winter stock of nutrients exhausted from the stratified surface layers. This situation was essentially maintained in June and July. In July the primary production of the area was at a minimum coinciding with maximum stability (Figs. 8,9) and thus minimal renewal of nutrients by vertical diffusion. Yet, it appears that in the southernmost part of the bay and in the region west and southwest of Reykjanes, continued renewal of nutrients to the photic zone must have taken place (cf. St. 2, 3, 4, 6, 8 and 14), leading to prolonged productivity. This applies to the summer season as a whole (Fig. 10d).

When surveyed in August the conditions in the study area had changed considerably. Coinciding with a significant, although small, increase in nutrients, the primary production had increased appreciably, especially in the southern part of the area (Figs.8,9). Clearly, the stratification had been disturbed from what it was in July, but the stability was still adequate to allow considerable production in large part of the area (e.g. St. 2, 14 and 15, see Figs.8,9). It can not be definitely established whether this change was a temporary one or whether it represented an early start of the normal autumn mixing. Looking at the area as a whole the mean summer production was considerable (Fig.10d), including the northern part, where the mean values exceeded 2 mg C/m^3h except at two stations.

The next survey was made around September 20 when a pronounced autumn mixing had certainly commenced. At this time the production had declined considerably in the region outside the bay, although it was still appreciable inside, especially in the southern part (Fig. 10d). However, due to the autumn mixing the surface layers were enriched with nutrients, and even more so in the outer part of the area. Consequently, the reduced productivity there could not be attributed to low levels of nutrients. A possible explanation might be sought in the difference between the thickness of the mixed layer inside and outside the bay. In the outer part this layer exceeded 50 metres, but was appreciably thinner inside the bay, due to admixture of fresh water. It must be presumed that the plant stocks will be more dispersed vertically where the mixing reaches farther down, and besides, the time spent by the plants in the photic zone will be reduced.

At the end of October the vertical mixing was found to be still more pronounced than in September and now significant production was only found at shallow stations in the southern part of the bay.(Fig. 10 f).

During the surveys following the one in October, practically no primary production was observed anywhere in the study area.

Discussion

In our attempt to analyze the immense data collected in the Faxaflói area during 1966-1967 and to present the results in a short communication we have had to limit ourselves to what we consider the most essential features. In making this effort we have drawn upon the experience gained by environmental research conducted for many years in Icelandic waters. Thus our assessment of production levels in Faxaflói during the one year period 1966-1967 is not only based on the values measured during that particular year but also on those obtained in other years as well as in other areas around Iceland. We can cite as an example that the highest primary production values measured in Faxaflói in 1966-1967, 25 mgC/m^3.h at St. 2. proved to be only one half of those found in more than one occasion in late May in the coastal area off Reykjanés (Thórdardóttir 1976), and only 1/4 of those found on the Selvogsbanki, south of Iceland in May 1977 (unpublished data).

The general features of the primary production in different parts of the area (Figs. 8, 9.) are clearly related to nutrient cycles, stability and station depth. At the inshore stations where depth is shallow and stratification developes at an earlier date than farther offshore, appreciable production starts relatively early, even at the end of winter, with concurrent uptake of nutrients. With increasing depth and distance from the shore the onset of growth is progressively delayed. At the deepest stations significant stratification of the surface layers is not attained until by the end of May.

Intense production normally coincides with a rapid drop in the nutrient levels. For any particular area the time period at which appreciable nutrient reduction takes place (Fig. 11) should therefore reflect the onset of appreciable phytoplankton growth. From Fig. 11 it will be seen that the change in time of the spring reduction in nutrient concentrations, and hence the onset of spring bloom, is most pronounced over the outer part of the bay, in the transition zone between coastal and more oceanic water where change in depth is also conspicuous.

Another general feature which applies to the majority of the stations is a late-summer production maximum which normally follows a marked decrease in stability and subsequent increase in nutrients in the surface layers. These general features can thus all be accounted for in accordance with expectation.

There are, however, certain irregularities not only in the production levels and their relation to physical and chemical variables but also in the production distribution in space and time, which are not easily explained. A few of these will now be considered.

The changable hydrographic conditions, especially in spring in the shallowest part of the area seem to give rise to short-time variations in the conditions for growth. Our observations are too few to get a clear picture of these irregularities both in production and nutrient concentrations. An example of the variability which may occur at short time intervals is provided at St. 1 and 24 (Figs. 8,9) a station occupied in the beginning and at the end of each survey. A comparison of the curves for this station, however, reveals the same main trends, characteristic for the near-shore region, especially in the southern part.

Except for the minermost part of the bay, stratification was poorly developed in April 1966 and even as late as May 7-9 (Figs. 8,9). According to the calculated critical depth (Fig. 12), some increase in production should have been possible before the end of April everywhere inside the 100 m depth contour, even in the absence of stratification. In agreement with this the measured production values were higher than those found during the winter minimum. But they were still very low, and appreciable growth did not take place near the mouth of the bay until the surface layers became moderately stable. Intrusions of low-salinity coastal water to the outerpart of the bay may, at least temporarily aid in the development of stratification, but owing to variations in the distribution of these intrusions, undoubtedly associated with the wind regime, the stratification at a given locality may break down again and consequently disturb the production development.
Thus at some of the stations (e.g. St. 16 and 17) the stability in May 7-9 was even less than in late April, and a lasting stratification was not established until the incoming radiation had increased appreciably after the middle of May.
This may explain, at least partly, the irregular growth development observed at many of the stations in early spring. On the whole, however, the growth development takes place at an earlier date near the mouth of the bay than in the outer area

due to shallower depths and occasional intrusions of coastal water referred to above.

Productivity values at the shallow stations in the southeastern part of the bay (St. 1, 2, 23, 22) were appreciably higher than those at stations of similar depths in the northwestern part (St. 19, 20, 21). Similarly, in the shelf area just outside the bay, the values were considerably higher in the southeastern part than in the northwestern part of the area. This will be apparent, if we compare the productivity at St. 4, 5, 14 and 15 with those at St. 17, 18, 11 and 12. In neither case can this difference between regions be adequately accounted for by difference in stratification or conclusively by difference in nutrient cycles. Thus stations 15 and 18 had the same depth, similar stratification and almost identical variations in nitrate concentrations from March through July. Yet, they differed markedly in production values. It is possible, in some cases at least, that the low production levels were more apparent than real, as the production peak may have occurred between our observations and we thus missed it. As stated earlier, this was undoubtedly the case at the deep stations, such as 8, 9, 10, 11 and 12. Therefore, in order to obtain a reliable assessment of the annual production at a given station, even more frequent observations than here made are probably needed. However, the repeatedly high values found at some stations and consistently low at others, make it likely that the apparent regional differences were real.

We can offer no well-established explanation of these regional differences in primary production. However, we propose as a possible hypothesis that water entering the study area from the region south of Reykjanes may be relatively nutrient rich, possibly due to turbulent mixing as it flows across the Reykjanes Ridge. Continued influx of this water might then lead to relatively high production and rapid nutrient uptake in the southern and southeastern part of the area, whereas with increasing distance from the source region the water becomes nutrient deficient and less productive, leading to the relatively low production levels observed in the northern part of the area. It follows that southerly winds which accelerate influx to the study area from the region east of the Reykjanes Ridge should promote production in the southern part of Faxaflói, while northerly winds would tend to reduce such an influx from the south. Since it has also been demonstrated (Stefánsson and Gudmundsson 1977) that northerly winds increase the transport of fresh water out of the bay, they might give rise to an earlier stratification and hence an earlier start of plant growth in the outer part of the bay on its north side.

It should be emphasized that the hypothesis here formulated to explain regional variations in primary production is only a tentative one, the validity of which needs to be examined by further observations.

The secondary nutrient maxima observed in spring at certain stations especially in the southern part of the bay and referred to earlier, were in most cases (but not always) associated with a decline in primary production. It can not be seen that these irregularities in the seasonal nutrient cycle relate to corresponding changes in hydrographic conditions occurring specifically at these stations. Nor can they be attributed to unusual meteorological conditions in the bay or adjacent regions. Thus during the period April 15-26, preceding the most conspicuous nutrient reversals, moderate easterly and southeasterly winds were most common, but these wind directions predominated through most of the year. However, investigations on the freshwater budget in Faxaflói (Stefánsson and Gudmundsson 1977) indicated that during the period in question significant inflow of coastal water into the bay and the area west of Gardskagi took place from the region south of Reykjanes. We propose that the sudden increase in nutrients may have resulted from the influx of this water. In this connection it must be borne in mind that the variations which we have been describing represent local changes rather than individual, i.e. we are following changes taking place at fixed localities, but not necessarily those taking place in a given water mass.

It remains to explain the general lack of plants which was experienced on April 25-27, coinciding with otherwise favourable growth conditions. We suggest that in the southern part of the bay a phytoplankton bloom may have occurred shortly after the survey on April 13-15, leading to depletion of nutrients and subsequent reduction in the plant stocks. We envisage that following this course of events the influx of nutrient-rich water from the south took place. But in the coastal region south and west of Reykjanes from which this water was presumably derived, only very limited plant growth had taken place up to that time, and hence a certain time was needed for the plants to develop. This, we believe, may explain our findings of low primary production and small stock of plants in spite of seemingly favourable growth conditions at the end of April 1966.

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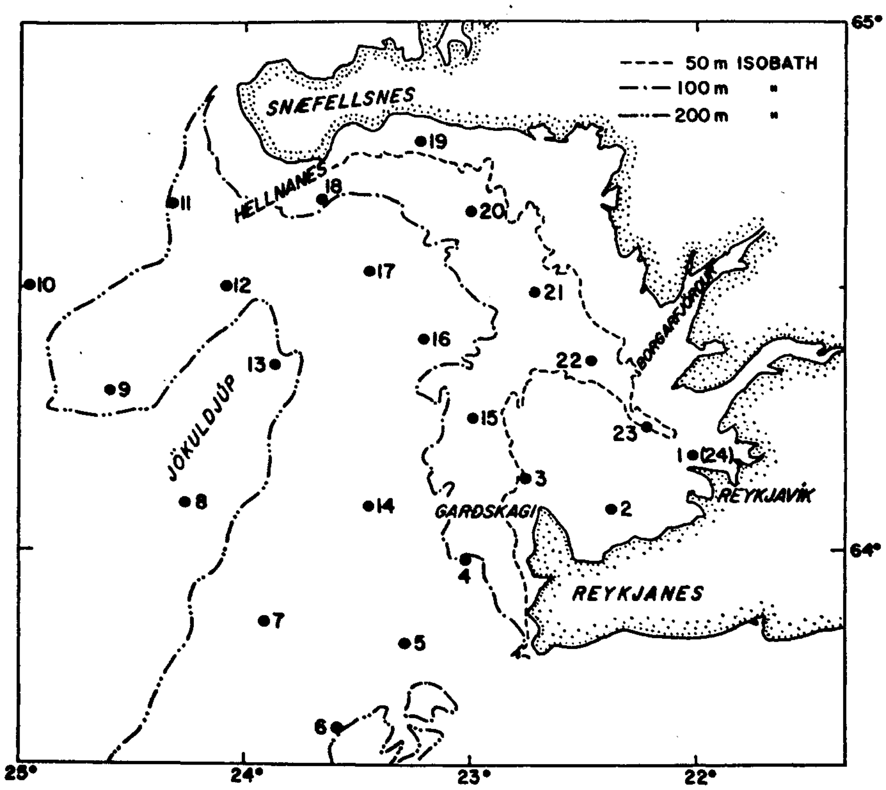

Fig. 1. A map of the study area with stations occupied.

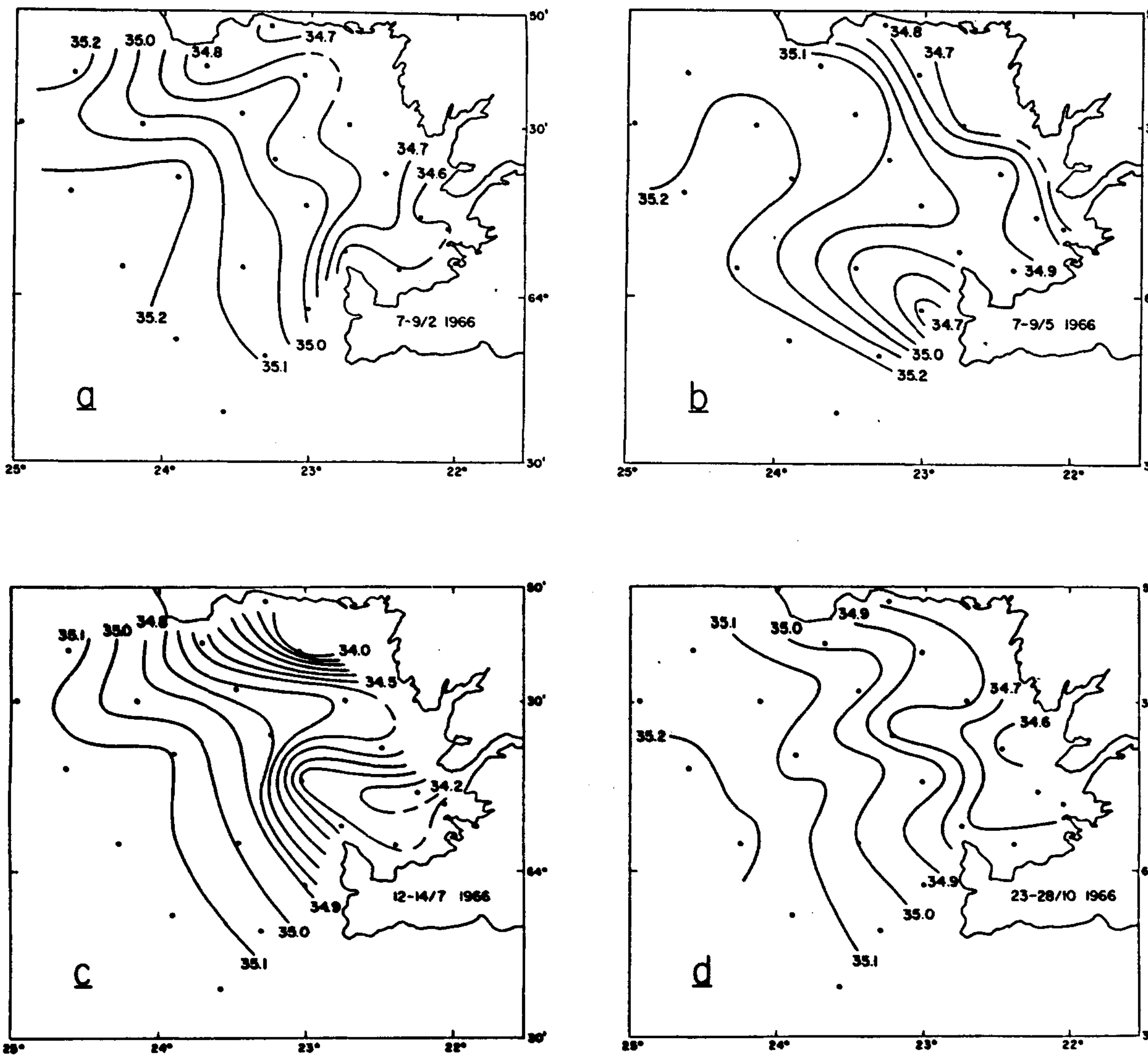

Fig. 2. Mean salinity distribution in the surface layer (0-20 m); a) 7-9/2 1966, b) 7-9/5 1966, c) 12-14/7 1966 and d) 23-28/10 1966.

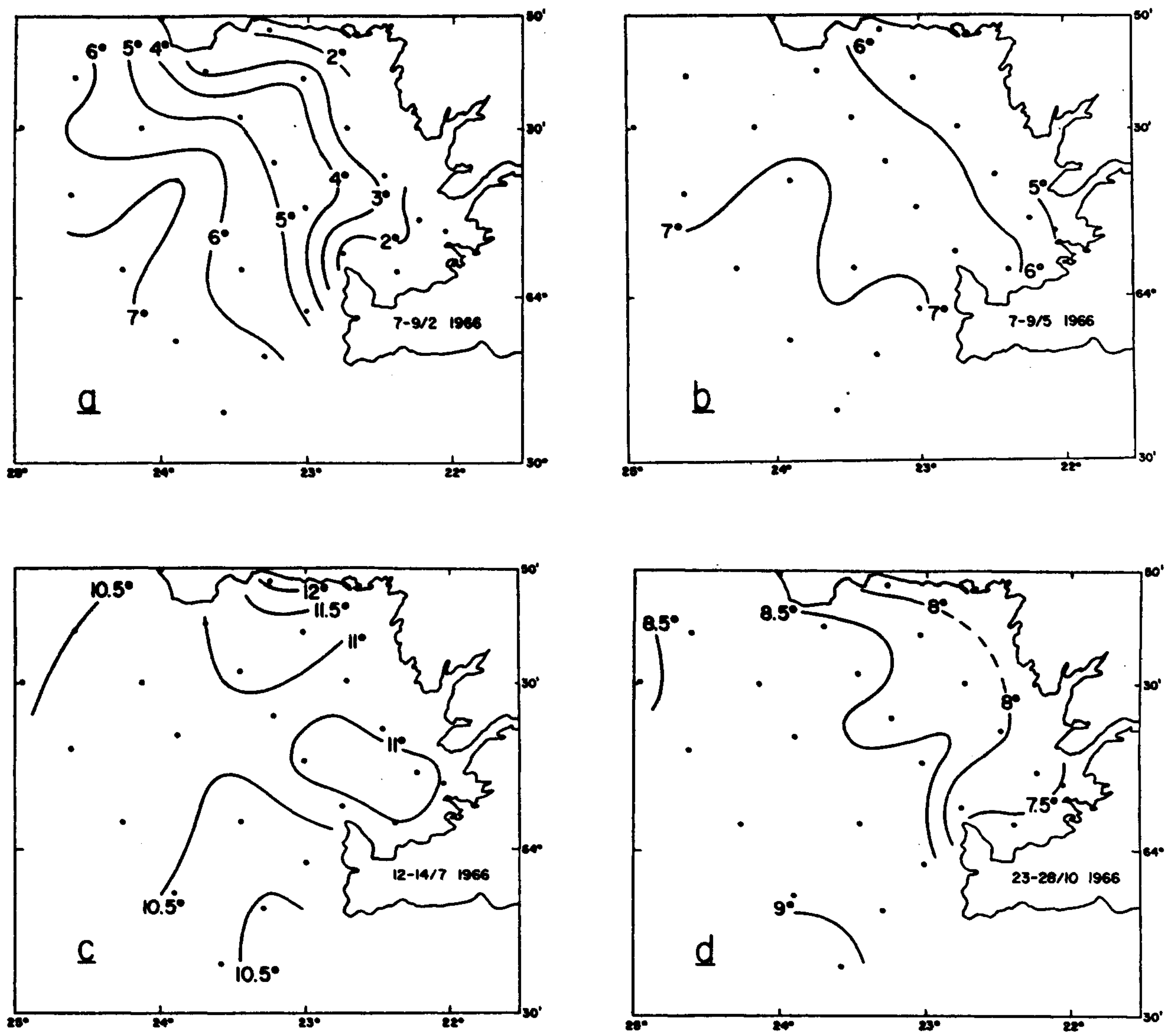

Fig. 3. Mean temperature distribution in the surface layer (0-20 m):
a) 7-9/2 1966, b) 7-9/5 1966, c) 12-14/7 1966 and d) 23-28/10 1966.

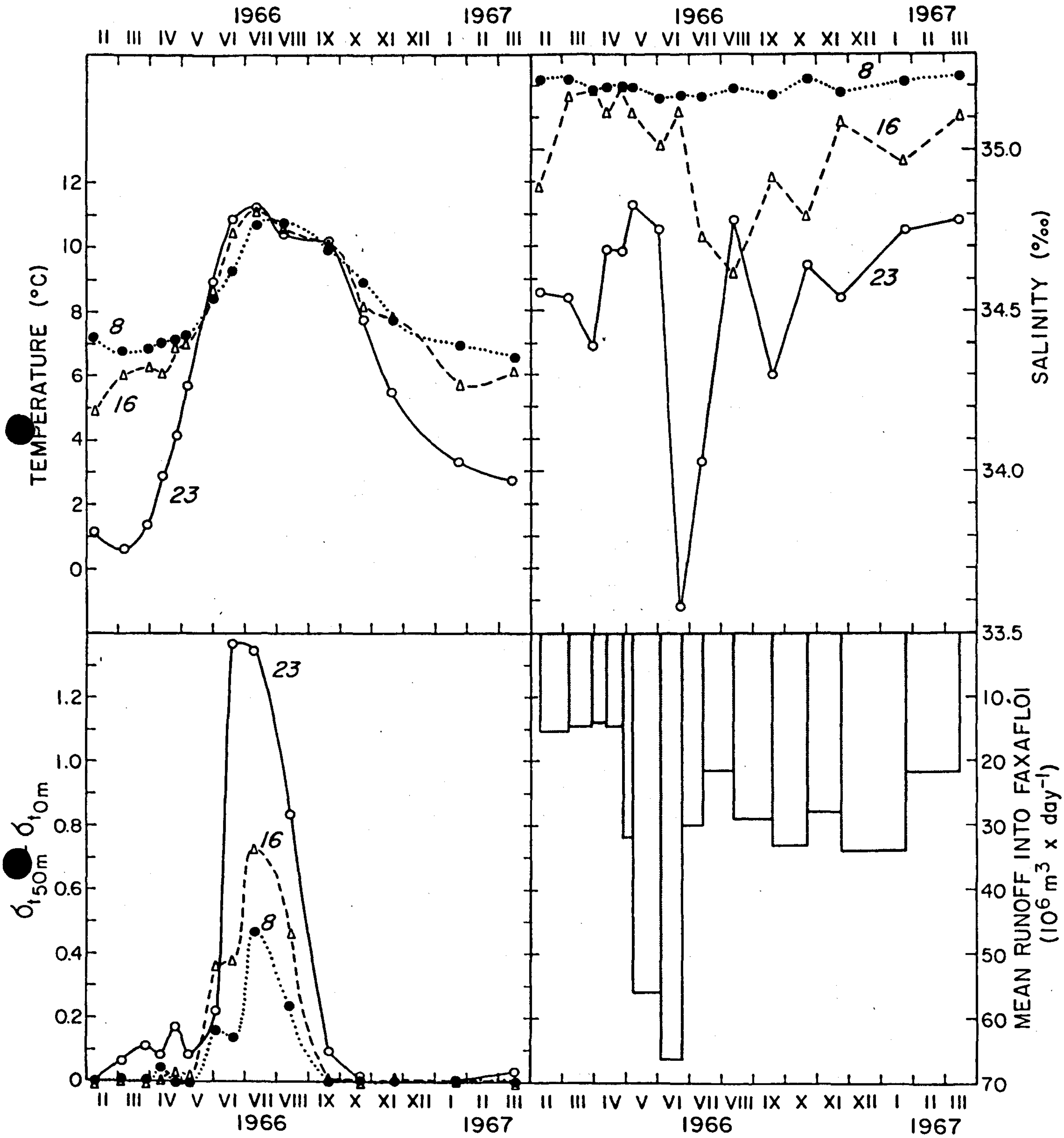

Fig. 4. Seasonal variation at three selected stations (8, 16 and 23, for location, see Fig. 1) of temperature and salinity at 10 m and stability (δ_t 50 m - δ_t 0 m). The mean runoff into Faxaflói between surveys is also shown.

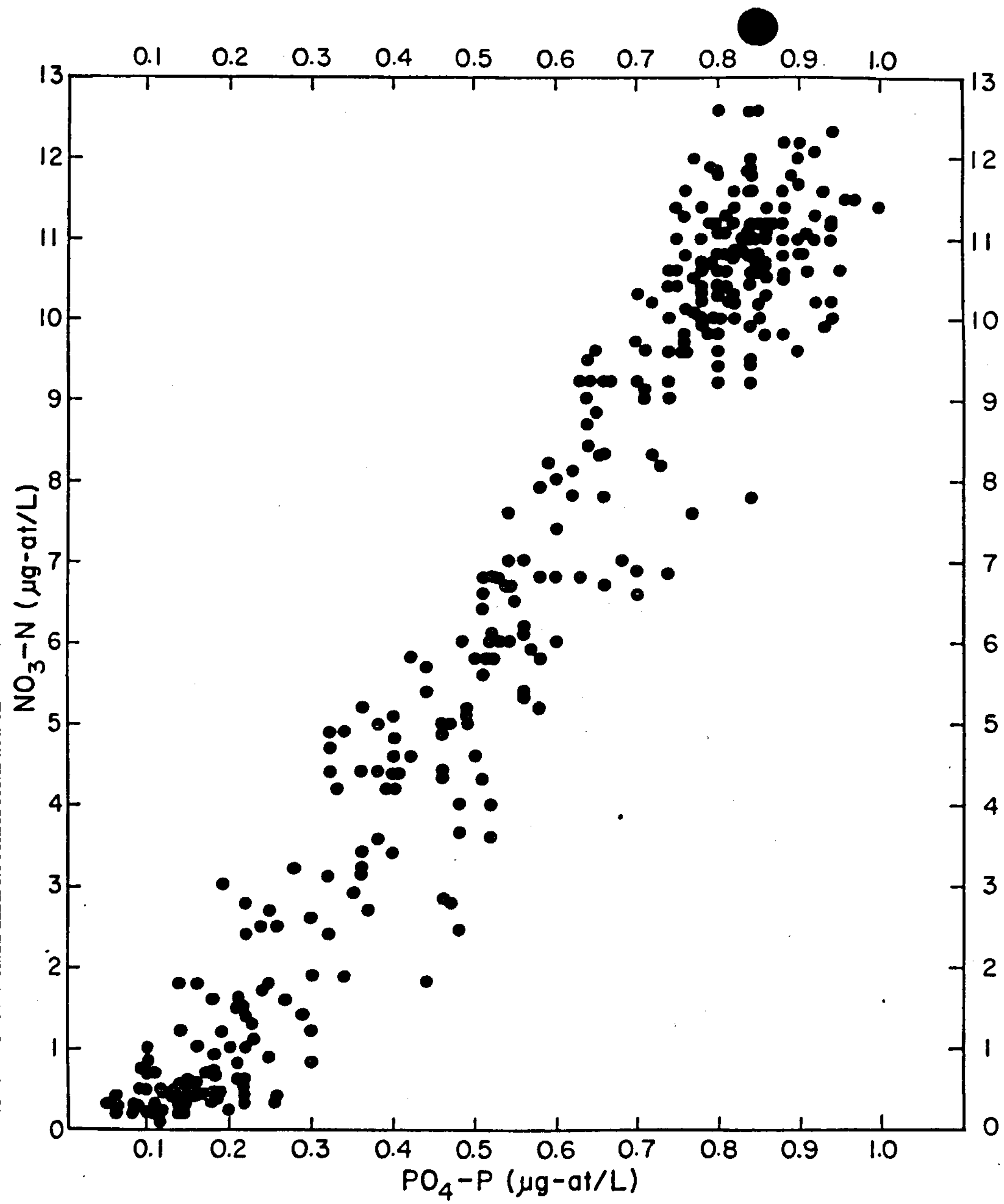

Fig. 5.

Relationship between phosphate and nitrate for 0-10 m.

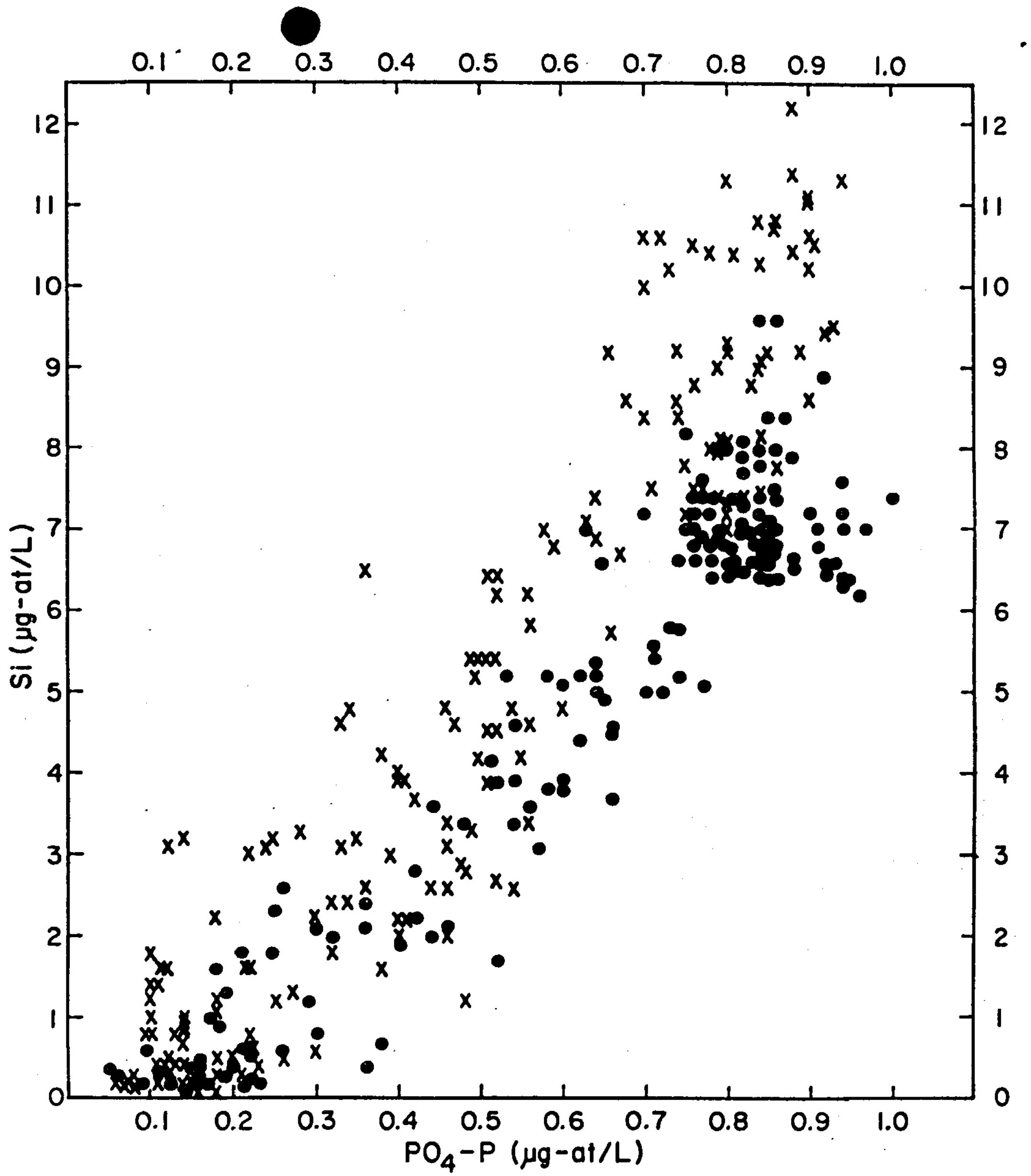

Fig. 6.

Relationship between phosphate and silicate for 0-10 m.
The black dots indicate observations where $S \geq 35^{0}/00$, crosses indicate observations where $S < 35^{0}/00$.

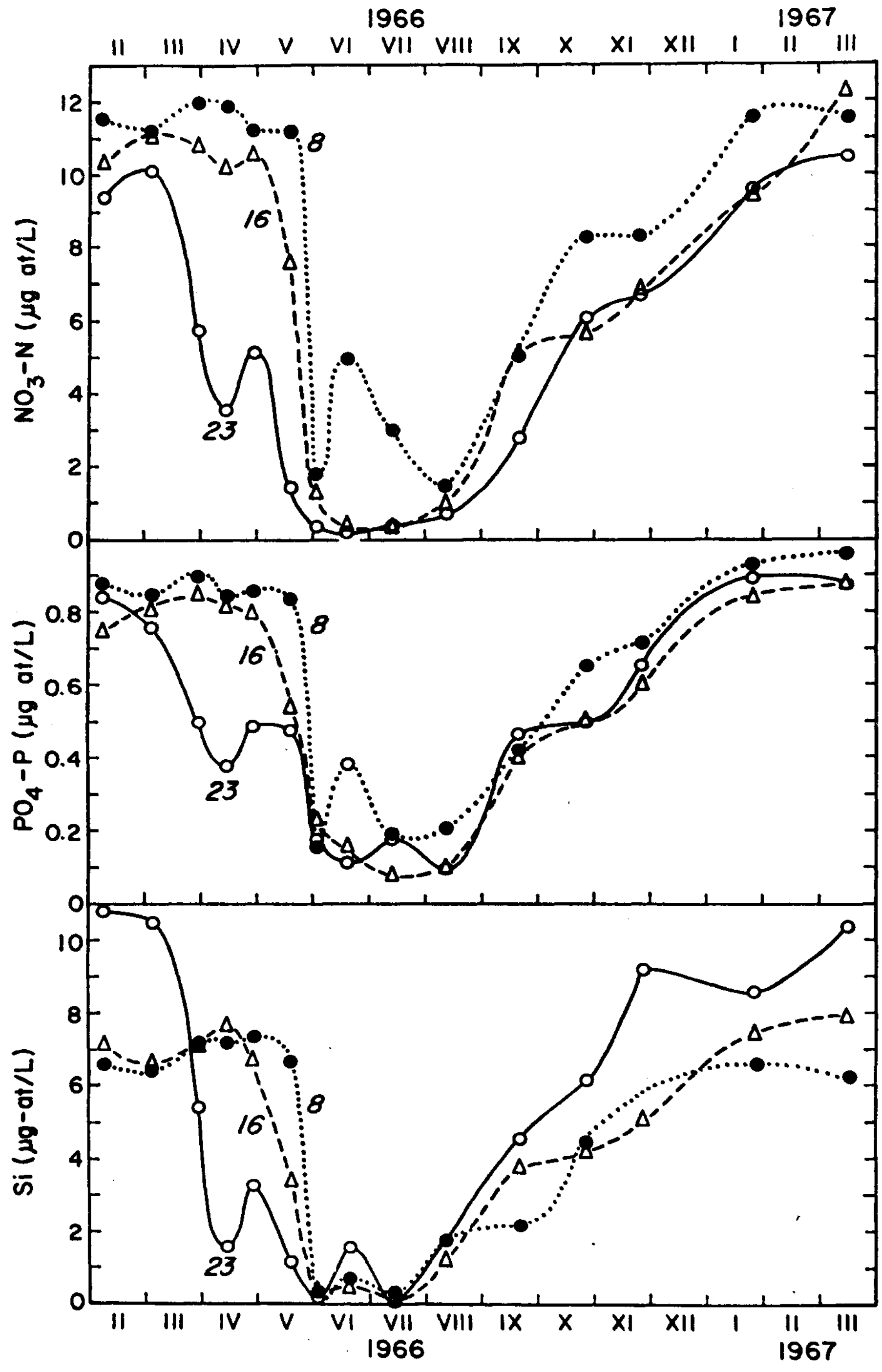

Fig. 7. Seasonal variations at three selected stations (8, 16 and 23, for location see Fig. 1) of nitrate phosphate and silicate (mean for 0-10 m).

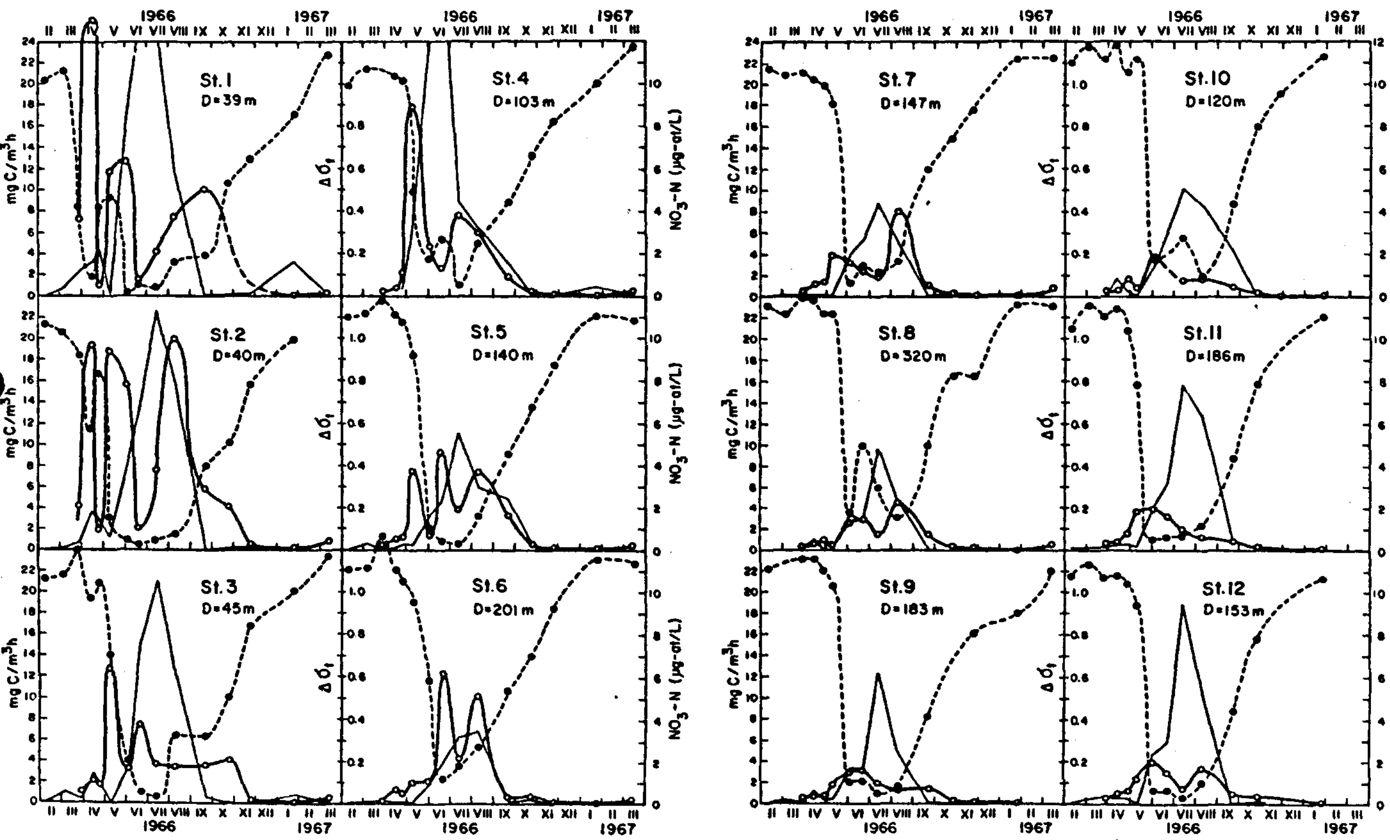

Fig. 8. Seasonal variation for stations 1-12 in primary production (thick solid line) at 10 m, nitrate (dotted line) at 0-10 m (mean) and stability (thin line) expressed as difference in density between the 50 m level (or bottom if depth is less than 50 m) and the sea surface.

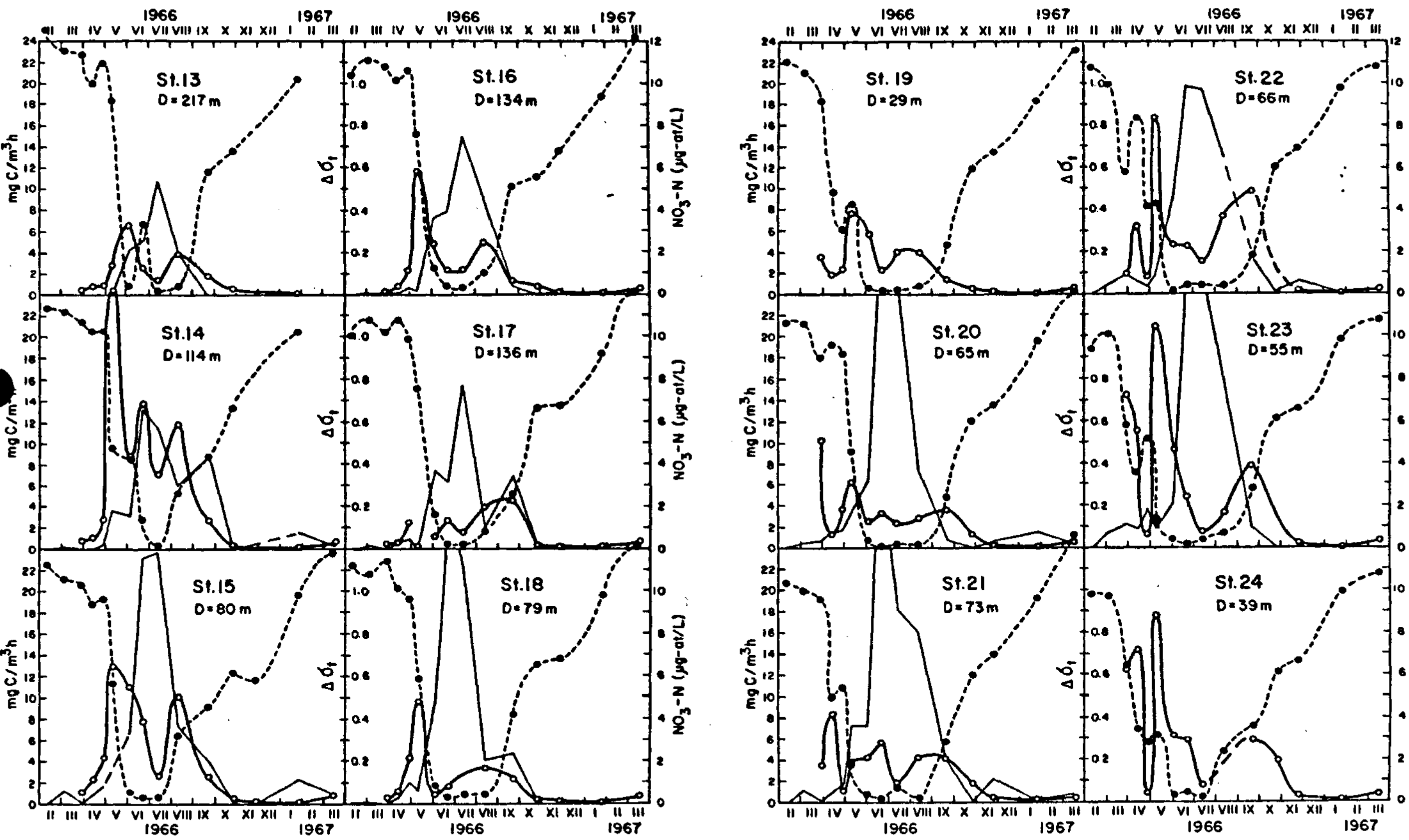

Fig. 9. Seasonal variation for stations 13-24 in primary production (thick solid line) at 10 m, nitrate (dotted line) at 0-10 m (mean) and stability (thin line) expressed as difference in density between the 50 m level (or bottom if depth is less than 50 m) and sea surface.

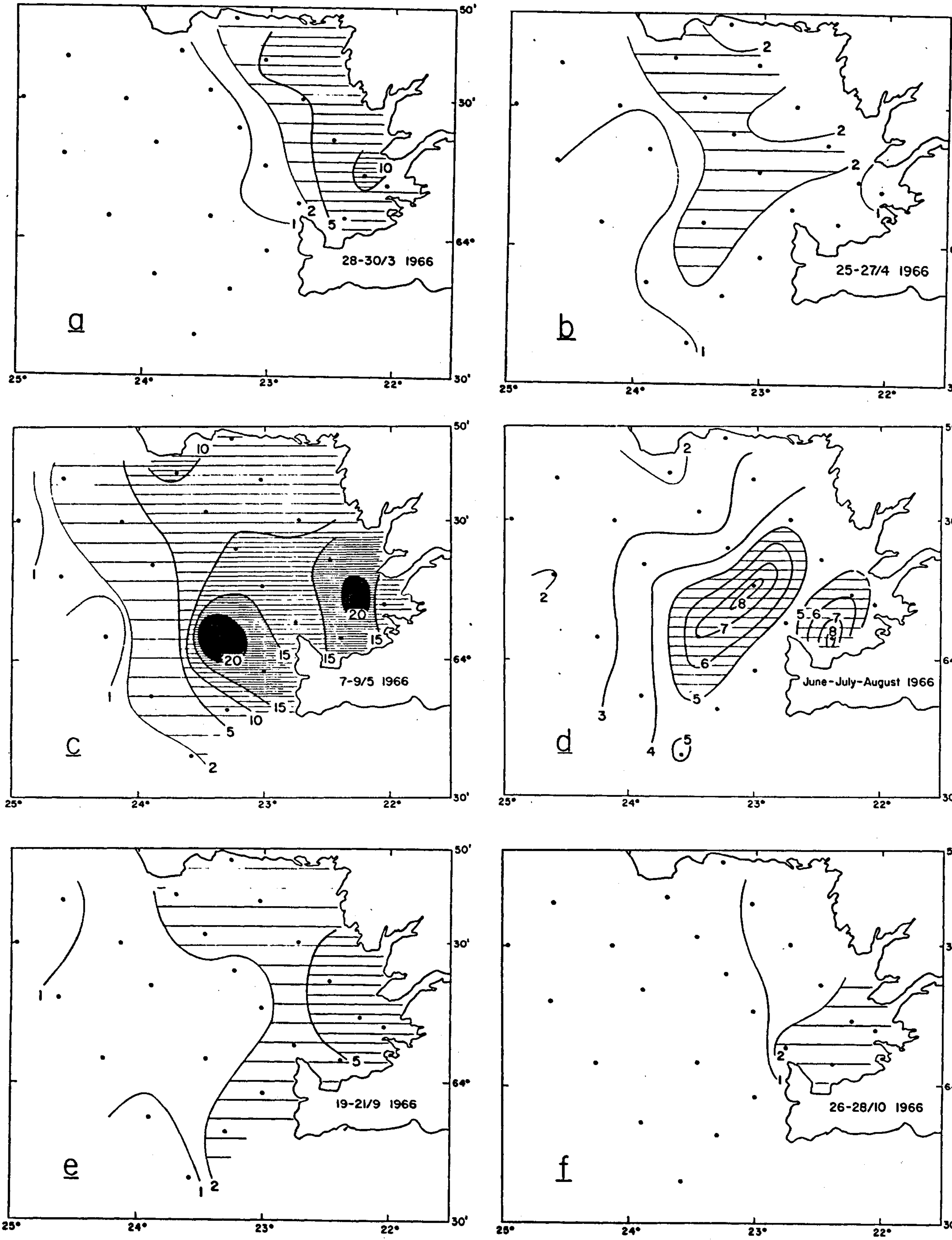

Fig. 10. Mean primary production (mgC/m^3 h) for 0-30 m, a) 28-30/3 1966, b) 25-27/4 1966, c) 7-9/5 1966, d) the period June-August based on the average from four surveys, e) 19-21/9 1966 and f) 26-28/10 1966.

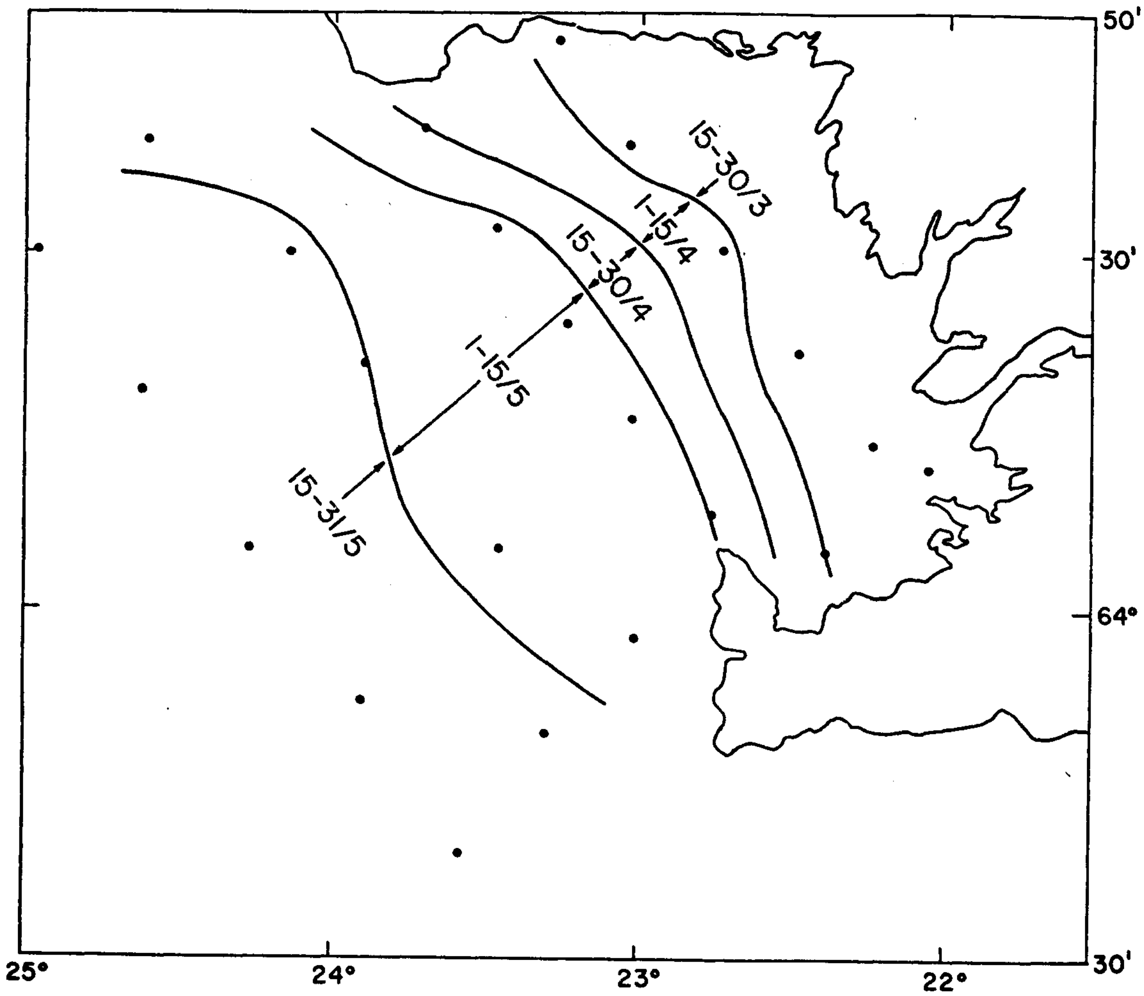

Fig. 11. Times of main nutrient uptake in spring in different parts of the study area.

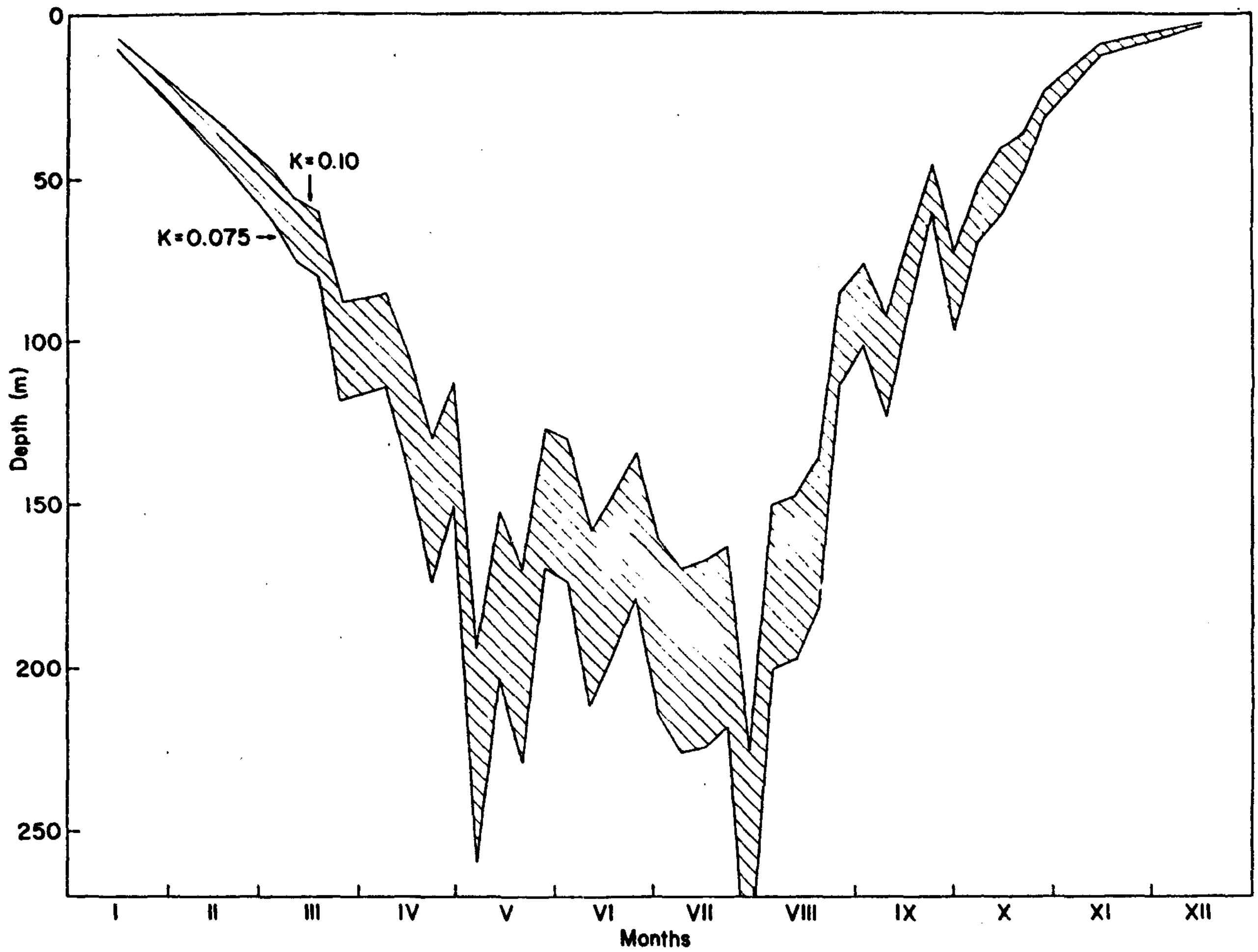

Fig. 12. Critical depth, D_{cr} , calculated for two values of extinction coefficient (K= 0.10 and K= 0.075). Data used collected at the meteorological observation station in Keflavík (64°00´N).