Ödsmål, Kville sn, Bohuslän

Hällristning Fiskare från bronsåldern	Rock carving Bronze age fishermen

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BROFJORDEN IX

PHYSICAL - CHEMICAL CONDITIONS, NUTRITIONAL ABILITY AND RELATED ECOLOGICAL ASPECTS OF BROFJORDEN

by

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1. INTRODUCTION

The investigation of Brofjorden was caused by the OK/Texaco oil refinery plant now under construction. The investigation, engaging people from different disciplines, was conducted by the Swedish National Environment Protection Board, and started in December 1972. The basic investigation, preceding the refinery production start, is now finished. A control investigation, after the production start, is to be set about.

The water of Brofjorden is part of the water of the Bohuslän coast, which in many respects is similar to the water of Kattegatt. The Bohuslän coastal waters are sometimes said to be the extension of Kattegatt. This is due to the fact that the current (on an average) transports Kattegatt surface water northwards along the Swedish coast, and is forced by the Jutland current to follow close to the Bohuslän coast up towards Norway before it gets mixed and looses its identity. See illustration below

Though belonging to Kattegatt as regards water quality, Brofjorden is connected to the Skagerrak geographically and in some biological respects. The area has been investigated at times during this century and the past. The oldest data to find were salt and temperature recordings by F.L. Ekman in 1878. The first values from stn. 5 Malmö drag are shown in Fig. 28, rewritten by modern computer technique.

However, in the present investigation starting in the end of 1972, the chemistry of the marine environment and the chemical connections to the marine life are emphasized.

The following presentation of the result is given in three parts. First the marine chemistry aspects of the investigation are discussed for the entire fjord, second Brofjorden as a recipient for refinery wastes is discussed and third some of the results are shown in diagram form in a diagram annex.

2. MARINE CHEMISTRY OF BROFJORDEN

2.1. Measurements

The physical - chemical part of the investigation was carried out by the Hydrographic Department of the Fishery Board of Sweden in Gothenburg and the primary phytoplankton production was measured by the Marine Botanical Institute at the University of Gothenburg. Zooplankton hauls and analysis of samples were carried out at the Laboratory of Marine Research in Lysekil and at the Hydrographical Department in Gothenburg. The position of the stations are indicated on the map (Fig. 1).

Data from measurements in the Brofjorden area can be found in the following publications: Ekman (1880), Engström (1970), Kwiecinski (1973), SMHI (1970 a, b, c) (1971 a, b), Öström (1973 a, b), Öström and Lith (1973), Johansson and Svansson (1974).

2.1.1. Old data

Phosphate has been measured in Brofjorden since 1962 by the research vessel Thetis on regular cruises along the West Coast and in the Bohuslän fjords approximately four times a year. Figure 15 is an example of a mean seasonal cycle obtained by putting data from different years, but from the same station and depth, on the same time axis.

Data for calculations are taken from the Fishery Board, Medd. Nos. 77, 93, 104, 112, 116 and 132 and Series Hydrography, Reports Nos. 16, 17, 18, 19, 21, 22, 14 and 25. Comparing it with figures 4 and 11 it can be seen that the development of the phosphate content in the surface water in 1973 follows the average pattern for the ten year period 1962-1972. This in turn points to the fact that also other processes, connected to the phosphate changes, will behave normal in relation to the preceding ten year period. In other words it is implicated that 1973 can be considered a normal year seen to the seasonal features, although time displacement of events or deviations in parametric details can be observed compared to long time means.

As a part of this investigation a study of old data from earlier work in this area has been done by Jan Johansson and Artur Svansson at the Hydrographic Department in Gothenburg. Most data originate from the Gullmar Fjord, particularly the Bornö Station, but also measurements from other stations, regularly visited, are included and presented as mean values 1962-1971

It is an important task to predict the fate of a pollution discharged into the sea area. As a first rough step daily series of salinity are used to compute these concentrations by means of a simple diffusion model. The result is presented in Johansson and Svansson (1974).

2.2. Nutrients

2.2.1. Nitrate

The nitrate values at the surface (Fig. 3, 10) show a dramatic decrease during the spring. From the high winter values they go down to almost zero in the run of about a month. The low values are then maintained during the summer, the measured values at times approaching zero. This condition has a direct connection with the plant growth in the water as described in section 2.4.

In October nitrate values start to rise again, and towards the end of the year they will reach the original high winter values. The nitrate is supplied mainly from the deeper nitrogen rich water outside the fjord. This is done by vertical water exchange which is obstructed by a strong pycnocline during the summer, but favoured through the weak stratification during the winter. (Fig. 9, 14).

2.2.2. Nitrite

Nitrite shows up a similar pattern with high winter values, a decrease in the spring, low summer values and an increase again in late autumn. Part of the explanation is that nitrite, together with nitrate is utilized by plant growing in the water. However, in an oxidating environment the nitrite (NO_2^-) is oxidized further to nitrate (NO_3^-) . This oxidation is commenced by nitrifying bacteria and it has been observed that the process is faster during the high water temperature in the summer.

2.2.3. Ammonia

The ammonia is also coupled to the plant production with low values in summer due to uptake by plants and higher winter values. However, there is a supply of ammonia within the water, emanating from the decomposition of dead organic material. The decomposition of proteins in an oxidative environment can for simplicity be illustrated by $RCH(NH_2)COOH + O_2 \longrightarrow RCOOH + NH_3 + CO_2$ (R is some radical) which means that amino compounds are decomposed to carbondioxide and ammonia. This temporary increase is best observed at some depth (Fig. 20, 29). The so formed ammonia is oxidized to nitrite according to the formula

$$2\,NH_3 + 3\,O_2 \longrightarrow 2\,HNO_2 + 2\,H_2O$$

The so formed nitrite is oxidized further to nitrate

$HNO_2 + \frac{1}{2}\,O_2 \longrightarrow HNO_3$ as described before. The rate of decomposition as well as the rate of the oxidation of ammonia, is dependent of temperature. In the summer with higher temperatures and therefore higher rates, we can see peaks of higher ammonia values after supply of organic material (Fig. 29). Another behaviour of the nitrogen-curves illustrates this transformation $NH_4 \rightarrow NO_2 \rightarrow NO_3$. As can be seen from figures of e.g. Stn. 1, 2 and 4, nitrogen curves, there is a general tendency of the ammonia first to go up in September, October and then go down in November, December. The nitrite has the same tendency but weaker. The nitrate on the other hand remains fairly low during September, October and rises to reach maximum values in

November, December. The two curves cross each other, the ammonia going down, the nitrate going up. This situation can be interpreted as the sequence of events when organic matter is decomposed. In September, October the primary phytoplankton production goes down, due to shortening~~s~~ days with subsiding light energy. The plant nitrogen uptake decreases and the nitrate is available in sufficient amount to meet with the demand from the plants. Ammonia is consumed directly by plants in the main during deficiency of nitrate, and is therefore now free to accumulate in the water. At the same time there is a rich supply of dead organic material from the heavy summer - autumn plant production, especially in the lower part of the euphotic zone. Decomposition of amines from the plant protein gives ammonia and the ammonia values rise. However, in an oxidizing environment, such as in the free water with a content of dissolved oxygen, the ammonia is oxidized to nitrite, and the nitrite curve also rises. The nitrite is then oxidized further to nitrate whereby the nitrate curve also rises. As time passes the organic material will become decomposed or leave the water layer by sinking, while the oxidation of ammonia to nitrite and nitrate continues. Therefore the ammonia and nitrite values will turn and go down to finally approach zero in the winter, while at the same time the nitrate values continously rise.

Analyzing the ammonia curves, a certain connection with the plant production is observable. After high production values follows a raise of ammonia values. This is more distinct in the lower part of, or below, the euphotic zone . It is explained by the formation of ammonia in the water, due to decomposition of dead plant material. After some time the supply of decomposable matter decreases, and the ammonia values also decrease to the original level because the ammonia is consumed by plants and oxidized to nitrite.

2.2.4. Total nitrogen

Total nitrogen has been measured in Brofjorden. The principle of the method is an oxidation by persulfate of all nitrogen, both dissolved and particulate organic as well as reduced inorganic to nitrate. The nitrate is then reduced to nitrite through mercury-cadmium catalyzation and recorded photometrically. However, the method is rough and recorded values vary in a wide range. Also intercalibration give discouraging results. The main conclusion to be drawn from the total nitrogen data is that the organic part usually dominates, the inorganic nitrogen content constituting on an average some 10% of the total nitrogen.

2.2.5. Phospate

The phosphate (PO_4^{---}) behaves very much in the same manner in sea water as does the nitrate. The high winter values decrease rapidly in February and March as they are taken up by plants. (In strong winters with ice cover, the seasonal nutrient depletion in the surface layer might occur later, but the discussion here concerns 1973). However, the phosphate has attracted a great interest in later years when artifical phosphate supply to waters has caused an abnormally high growth (eutrofication). Whereas too high nitrate content is usually a problem in run-off water from farming areas, phosphate followed by eutrofication is mostly a problem in urban or industrial areas.

From figures 4 and 11 can be seen that after the period in spring when phosphate values approach zero, there is a slight recovery before the values again approach zero in late summer.

In the autumn when plant growth ceases due to fading light, and the vertical water movements are faciliated due to outlevelled density by cooling at the surface, phosphate from below is transported to the surface water which gradually reaches the high winter values.

As can be seen from figure 17 the phosphatevalues show up a horizontal gradient with increasing values towards land. This reflects a seaward phosphate transport from land, and is verified by analyses of the fresh water, supplied through Broälven, discharging in the innermost part of Brofjorden.

2.2.6. Total phosphorus

The total phosphorus content of the water shows up a similar seasonal pattern as the phosphate (Fig. 30). This is somewhat astonishing, as the total value should not necessarily change when phosphate is taken by up plankton, that is, when changing from inorganic to organic form. The fact that it does, indicates that the phosphorus when converted into organic form in some way leaves the system. The explanation is probably that the organic bound phosphorus in plankton, being particulate, sinks down when the organisms die. Those deposited on the bottom or accumulated in pycnoclines are not caught by the water sampler and the high values are thus not recorded, why the average values, although higher to their amount, follow the same pattern as the phosphate.

2.3. Oxygen

The oxygen saturation values (Fig. 6, 13) are most interesting from ecological viewpoint. Looking at the upper part of the water, the connection with the primary production is striking. The uptake of carbondioxide under release of oxygen using energy from sunlight is a process known as assimilation by photosynthesis. This process can be traced easier in the marine environment where the carbonic acid balance displacement alters the pH value and the oxygen release affects the saturation value. The photosynthetic assimilation can be illustrated by the following formula where reserve energy in the form of glucose is formed by carbondioxide, water and energy from the sun under liberation of oxygen.

$$6\ CO_2 + 6\ H_2O \xrightarrow{674\ 000\ cal} C_6H_{12}O_6 + 6\ O_2$$

The oxygen saturation is chosen instead of absolute values to eliminate effects of the altered solubility due to temperature and salinity. In the beginning of the year the water is approximately saturated due to low biological activity within the water and good exchange with the atmosphere is favoured by low stability and subsequent increased vertical exchange. In the upper strata, near the surface, the oxygen values starts to rise, at the same time as the primary production peak indicates a higher content of phytoplankton in the water. After the spring bloom the oxygen values go down again, approximately to saturation. This situation is maintained during the depression in the plant production.

When primary production sprout up again in the summer the oxygen values rise and the maximum occurs at the same time as the primary production maximum. It is notable that the highest value does not appear at the surface where the ultraviolet sunrays kill part of the algal flora, but below the layer of detrimental light penetration. In the autumn when production ceases due to fading light the oxygen saturation again goes down to normal saturation.

Looking now at the lower water layer, two main peaks of low oxygen saturation is seen. The first is narrow and follows in time short after the steep peak of the spring bloom of phytoplankton. The other is a slower raise of undersaturation with approximately the same delay relative to the summer production. The produced mass of plankton dies gradually and sinks slowly through the water. Microbial decomposition starts and oxygen consumption sets in. The oxidation of dead plankton organisms can be illustrated as follows, after Richards (1965) . Assuming the C : N : P ratio to be 106 : 16 : 1 by atoms as given before, and arranging the proteins into simple groups consisting of carbohydrates, amines and phosphate the complete oxidation to carbon dioxide, nitrate and phosphate yields an oxygen consumption of 276 atoms for stoichiometric reasons, according to the following formulae

$$(CH_2O)_{106} \quad (NH)_{16} \quad H_3PO + 106\ O_2 \Longrightarrow$$

$$106\ CO_2 + 106\ H_2O + 16\ NH_3 + H_3PO_4$$

A comparison now with the ammonia curve is interesting since, as pointed out before, the complete oxidation of ammonia to nitrate will proceed gradually and reduce the ammonia value From (Fig. 29) can be seen that rather high ammonia values occur after the spring production peak and after the summer production, but that the values soon go down to the normal again. This is caused by the oxidation to nitrite and then nitrate utilizing more oxygen as follows

$$16\ NH_3 + 32\ O_2 \Longrightarrow 16\ HNO_3 + 16\ H_2O$$

Summing these two equations thus give the following formula for the complete oxidation

$$(CH_2)_{106} \quad (NH_3)_{16}\ H_3PO_4 + 138\ O_2 \Longrightarrow$$

$$106\ CO_2 + 16\ HNO_3 + H_3PO_4 + 122\ H_2O$$

This theoretically achieved value, 276 : 1 by atoms, as a measure of the utilization of oxygen for oxidation of organic matter associated with one atoms of phosphorus can be compared with Fig. 18. This is a plot of the apparent oxygen utilization versus PO_4-P values at Stretudden. The relation found is 217 : 1 . At the bottom of this station the deep hole outside Stretudden, signs of a beginning stagnation are seen at times. Under a heavy load of organic material, oxygen values below 50 % saturation were recorded in September. Also accumulation of nutrients started, shown by high analysis values.

Considering the heavy undersaturation of oxygen in lower layers, the second peak, following the summer production, with a maximum in the autumn, is a wellknown phenomenon in Kattegat waters. The first peak following the spring bloom in phytoplankton has not been observed before. A review of Kattegat data (routine sampling by the Swedish Cost Guard for the Fishery Board of Sweden) from the same period of time does not show any similar low values. This first undersaturation peak is therefore obviously a local phenomenon, caused by the heavier primary production near land and by a poorer water exchange in the fjord.

Analyzing the characteristics of the oxygen saturation curve, the question is raised whether the undersaturation in lower layers, is caused not only by decaying plants but also by respiration by animals. Such a guess is legitime since it is known that large numbers of small copepodes (crustaceans) and other animals, the zooplankton, are grazing on the stock of phytoplankton, and that these zooplankton being animals necessarily respire. Samples of zooplankton have been collected with a zooplankton net with a meshsize of 165μ and a diameter of 1 m. An analysis of the samples for station 2 Brofjorden was made for the entire 1973 and the biomass was calculated by the author according to volume tables according to Ackefors (1972). Details of the calculations are given in figure 7. A zooplankton peak following the spring peak of primary production was not found But Fig7 yet shows a main peak in time well corresponding to the case of grazing phytoplankton from the summer production. The absence of a spring peak is explained by the fact that the zooplankton requires other favourable conditions than food to become abundant, a.o. a higher water temperature. The conclusion is that the huge undersaturation of the oxygen in lower layers in the autumn could be a combined effect of decaying phytoplankton and respiration of zooplankton.

2.4. Yellow substance

Yellow substance in the sea water is considered to be mainly of terrestrial origin. It consists of large molecules, similar to lignin, being rest products from the decomposition of organic material of plant origin, so called humic substances. The yellow substance is therefore used as a measure of the degree of coastal influence on a water mass. Yellow substance data normally decrease from land and outwards. That normally means a decrease in yellow substance with an increase in salinity. This is not only an effect of dilution,

it is known that also sedimentation of yellow substance takes place. When fresh river water with high content of yellow substance is introduced into the saline sea water flocculation of yellow substance is observed, the flocks then precipitating to the bottom. However, yellow substance is produced also within the water itself, marine humus, why interpretation of yellow substance data is more complex than just to trace fresh water influence. In Brofjorden the yellow substance - salinity relation (Figures 33, 34) are in the highly saline regime within which the relation is approximately linear. Breakdown of yellow substance is slow and for analysis on a month scale it is sometimes used as a conservative parameter.

2.5. Oil

This section is an extract from a report by Stig Carlberg and Staffan Lööf on the analysis of Brofjorden oil samples.

Analysis of oil (nonpolar hydrocarbons) in seawater is done on routine basis by the Hydrographic Department of the Fishery Board of Sweden in Gothenburg.

The Brofjorden material 1973 comprises 148 analyses. The result is shown in figure 36, and in the following table.

Figures give number of samples

Concentration range in mg/l	0.05	0.10	0.15	0.20	0.25	0.50	>0.50
	115	17	3	5	3	2[x]	3[x]

[x] These samples are probably contaminated by the research vessel, as viewed from the look of the spectrum.

Generally, concentrations above 0.5 ml/l seem to occur more frequently in the surface water than in deeper layers. However, this tendency is weak. It is very common that all analyses from one sampling occasion in Brofjorden show concentrations below 0.05 mg/l.

However, at a few occasions all samples contained remarkably high concentrations without an obvious reason to suspect contamination from boat or laboratory. An explanation can not be given today. It ispossible that there is a natural seasonal fluctuation of the hydrocarbon content of Brofjorden. Further information on this subject can only be achieved by continued measurements.

3. THE DEEP HOLE OUTSIDE STRETUDDEN

The following general observations from 1973 concern the situation at the bottom of station 3 Stretudden. The bottom depth is 48 m.

The stability below 30 m is low compared to the almost permanently present pycnocline to the top layer of Baltic Water. The density at the bottom expressed as σ_t values varies only between 25 and 27 throughout 1973.

Temperature varies from 4.4 in December to 14.2 at the end of August at the bottom of station 3.

Salinity varies from max. 34.8 in October to a min. 32.0 in December.

Oxygen saturation varies from 49 % mid. October to a slight oversaturation of 101 % in December.

Reviewing these conditions, and the fact that nutrients at some occasions took on very high values, caused the deep hole outside Stretudden (stn. 3) to be given some attention. The data for σ_t, temperature, oxygen, phosphate and salinity at the bottom during 1973 are given in diagram form (Fig. 22-26). The result is difficult to interpret , however, some comments will be given.

During the spring the phosphate values decrease, and a connection with the phosphate uptake by algae during the spring bloom is implicated. The phosphate is then transported up to the euphotic zone by vertical exchange, which is facilitated by the weak stability in the winter and spring. Through the summer the values rise again indicating a slight stagnation. As can be seen from Fig. 23, 25 the water in the deep hole is replaced by saltier water in September rising the σ_t - value. This event is connected with a drop in the phosphate values. Soon thereafter stagnation starts again and phosphate values rise until convection starts in the late autumn.

In general the stability below 30 m is low throughout the year. This means that we can expect similar conditions in the water column below 30 m, and that the water entrapped in the actual deep hole is fairly homogenous. The oxygen values (Fig. 22) show a considerable fall off with a minimum of 43 % saturation in October. This is certainly connected with a heavy precipitation of dead planktonic organisms emanating from the main summer and autumn production. This organic material is decomposed and oxidized by the action of microorganisms. The activity of these microorganisms and thereby the rate of oxygen consumption is dependent of temperature, and the bottom water temperature during the oxygen minimum is still relatively high (Fig. 24), above 9°C . The effect of respiration by animals is difficult to estimate quantitatively, but as can be seen from Fig. 7 the zooplankton are abundant, and it is possible that both bottomliving and planktonic animals contribute to the oxygen consumption by their respiration.

4. BROFJORDEN AS A RECIPIENT

4.1. The waste water treatment

By due permission from the Scanraff Company a schedule over the principle for waste water treatment is shown in Fig. 19.

The contaminated process water is first treated mechanically. Oil is removed from the surface and deposits are scraped off from the bottom. In the next stage chemicals are added to the water under continous stirring. Flocculation occurs and by the aid of air bubbles flotation is brought about to remove the deposited matter. In the third stage a bed of certain species of aerobe bacteria is used to reduce the content of dissolved organic compounds such as hydrocarbons and phenols. The refinery domestic sewage is let into the same basin. Then the water is let out into the oxidation pool, where further decomposition of organic material takes place. Finally the water from the oxidation pond is pumped out into the fjord, strongly diluted with cold, saline water to increase the density, whereby sinking and mixing into the fjord water is favoured.

The solid wastes (sludge) is burnt in an incinerator. Then the ashes are washed and the washing water is let down into the oxidation pool. The fate of the ash is notknown.

Fig. 19 shows the principle of the waste water treatment. This is done in 3 steps. Refering to the figure these are:

1. Mechanical treatment unit.
2. Chemical treatment unit.
3. Microbiological decomposition unit.

It must be pointed out that Fig. 19 is only a principle scetch, many details are omitted and the real installation has many functions left out here for clarity.

4.2. Expected effects of the pollution.

Quantities involved are for the industrial sewage water 2400 m^3/day as a mean value and 3100 m^3/day at a maximum. For the ballast water 3600 m^3/day mean value and 4800 m^3/day at a maximum.

With the present refinery capacity of 7 milj. metric tons crude oil per year, the intention is to let out 1.2 - 1.5 kg oil/hour and less than 0.1 kg phenol per hour into the fjord. This means 13 metric tons of oil per year and a little less than 1 ton of phenol per year.

It is difficult to predict the effects of the polluted water let out into the fjord. We know that it contains poisonous substances such as sulphides and phenol. The general fear for the organic substances let out continously over a long time, are their effects on marine animals. Many activities of these animals, sexual behavoir, feeding efforts, defence reactions etc. are directed by chemical signals. If we disturb the natural occurence of these organic signal substances by introducing interferring artificial substances, we may disturb these activities. A fjord previously being a nursery for young fish, might be deserted if organic compounds let out in the water cause avoidance reactions. Eg. local fish population might starve if the compounds block the olfactory organs, or die out if they inhibit the sexual activity. It is obvious that in these respects a weak but continous pollution is worse than a heavy accidental. But of all these things our present knowledge is rudimentary. Only continued investigations and comparison with present conditions will help to give an answer.

We also know that the refinery waste water contains heavy metals. The sources are two, one is the original content of the crude oil, mainly Vanadinum, Nickel and Crome, the other catalysts within the refinery precess. Of the metals we know that they accumulate in plant and animal tissue, and that they thus may reach toxic concentrations. But to what extent, and with which consequences this will occur in Brofjorden, only continued investigations will give an answer to. A control program for Brofjorden is to be set about.

Strong currents set up by ship propellers may cause erosion of bottoms and damage of bottom communities. Heavy shipping traffic generally causes oil spill, detrimental to the adjacent shores.

The water exchange of Brofjorden is regarded to be considerable at times. Exchange of 70 % of the water of the fjord in two days is an extreme value given by Svensson (1973). However there are indications that over long periods the exchange is poor. Low oxygen values have been reported before and are found also in the autumn of 1973. High concentrations of nutrient salts are found in the deep hole at Stretudden. The bottom sediment maps, ref. Cato (1973), also indicate a poor water exchange. Wändahl (1970) gives the value 13 - 25 % exchange per day. This dissonance of conclusions is not analyzed further.

Oil and phenol wastes are known to develop unpleasant flavour in fish and shellfish. They are not necessarily making a health hazard, but the unpleasant flavour makes the fish meat useless for food. Landing of occasional contaminated catches of inferior quality in this respect will have a catastrophic effect on the fish sales market, which is much greater than the share of inferior fish. Sales on the fish market in Paris dropped to half the normal value after the "Torrey Canyon" catastroph. This had no direct connection with the quality of the fish actually offered for sale.

Mironov (1968) reports extreme sensitivity to oil pollution by the early development stages of plaice. Injury in spawn was noted at concentrations of 10^{-4} - 10^{-5} ml/l. In these concentrations 40-100 % of the hatched pre-larvae showed signs of degeneration and perished.

5. CLOSING REMARKS

To draw the right conclusions out of the numerous data collected is an intricate task requiring careful and thoughtful attention. In this report are given the general features of Brofjorden with ecological, pure chemical and recipiental aspects. More delicate scientific treatment of detailed problems will be given in separate papers in international journals.

A common impression of all the investigated details is that Brofjorden today is a clean, unpolluted, sound water with an undisturbed ecological balance.

Data and special studies from the part of the Brofjorden investigation which was performed by the Fishery Board of Sweden is presented in previous report No:s 144, 149, 154, 156, 161, 165, 169, 175. This is the closing issue concerning the basic investigation, securing for the future the possibility of comparisons, and with its possession of experience, stimulating the coming control investigation.

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Fig. 1. The location of stations in Brofjorden

2. The location of Brofjorden

3. Distribution of inorganic nitrogen compounds, station 2 Brofjorden in 1973

4. Distribution of phosphate, station 2 Brofjorden in 1973

5. Primary production, station 2 Brofjorden in 1973

6. Dissolved oxygen saturation percentage, station 2 Brofjorden in 1973

7. Zooplankton biomass, station 2 Brofjorden in 1973

8. Dissolved oxygen saturation percentage, station 2 Brofjorden and station 5 Malmö Drag, first half of 1974

9. Maximum stability at station 2 Brofjorden in 1973

10. Distribution of inorganic nitrogen compounds, station 5 Malmö Drag in 1973

11. Phosphate distribution at station 5 Malnö Drag in 1973

12. Primary production at station 5 Malmö Drag in 1973

13. Dissolved oxygen saturation percentage at station 5 Malmö Drag in 1973

14. Maximum stability at station 5 Malmö Drag in 1973

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24. Temperature at the bottom and surface of station 3 Stretudden in 1973

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27. Nitrate distribution of Brofjorden in June 1973

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29. Inorganic nitrogen compounds at station 1 Inre Brofjorden in 1973

30. Phosphate phosphorus and total phosphorus at station 2 Brofjorden in 1973

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34. Relation between salinity and yellow substance at station 2 Brofjorden

35. Salinity distribution in February 1973

36. Histogram of hydrocarbon content in Brofjorden samples in 1973

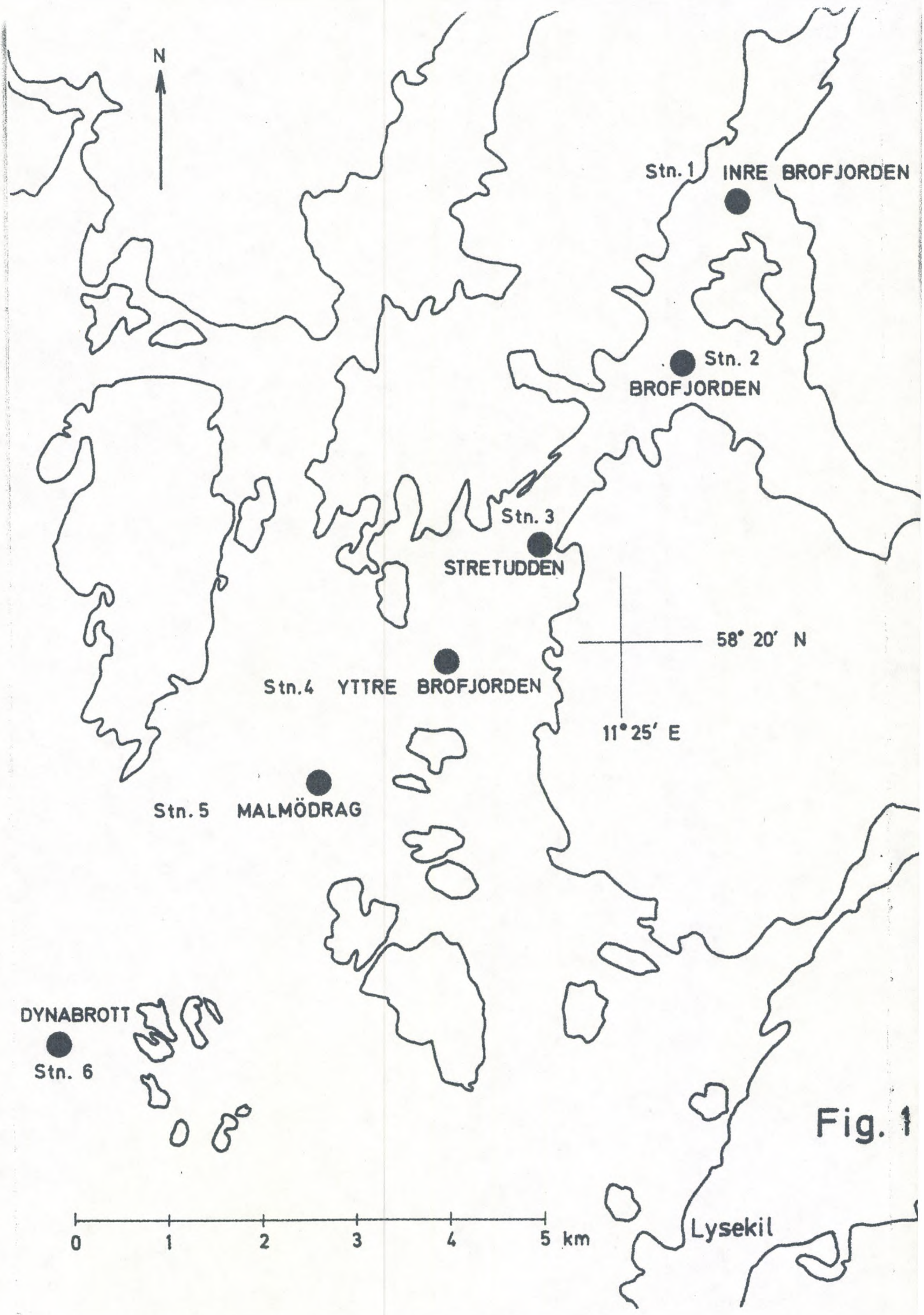

N
Stn. 1 INRE BROFJORDEN
Stn. 2
BROFJORDEN
Stn. 3
STRETUDDEN
58° 20′ N
11° 25′ E
Stn.4 YTTRE BROFJORDEN
Stn. 5 MALMÖDRAG
DYNABROTT
Stn. 6
0
1
2
3
4
5 km
Lysekil

Fig. 1

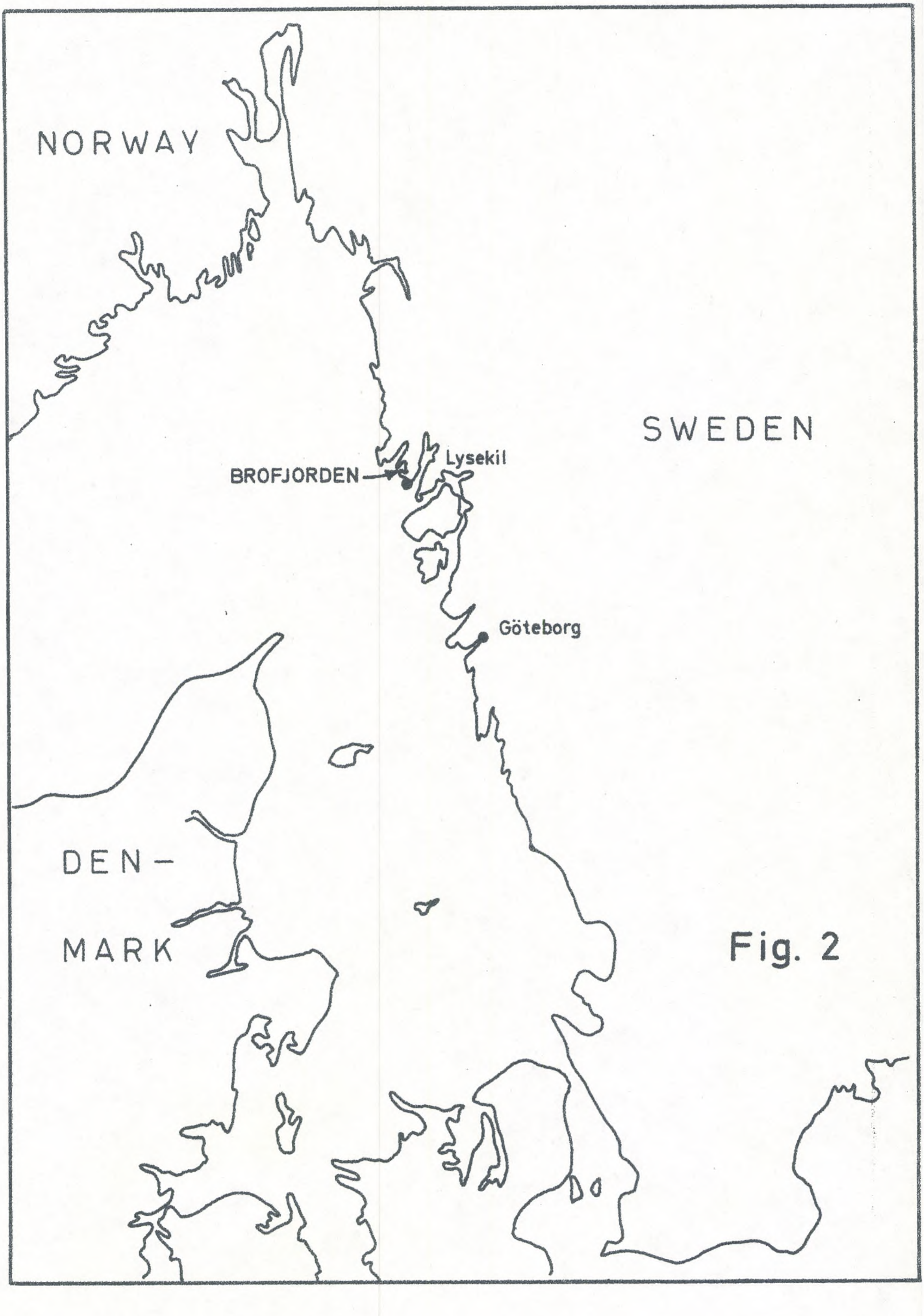
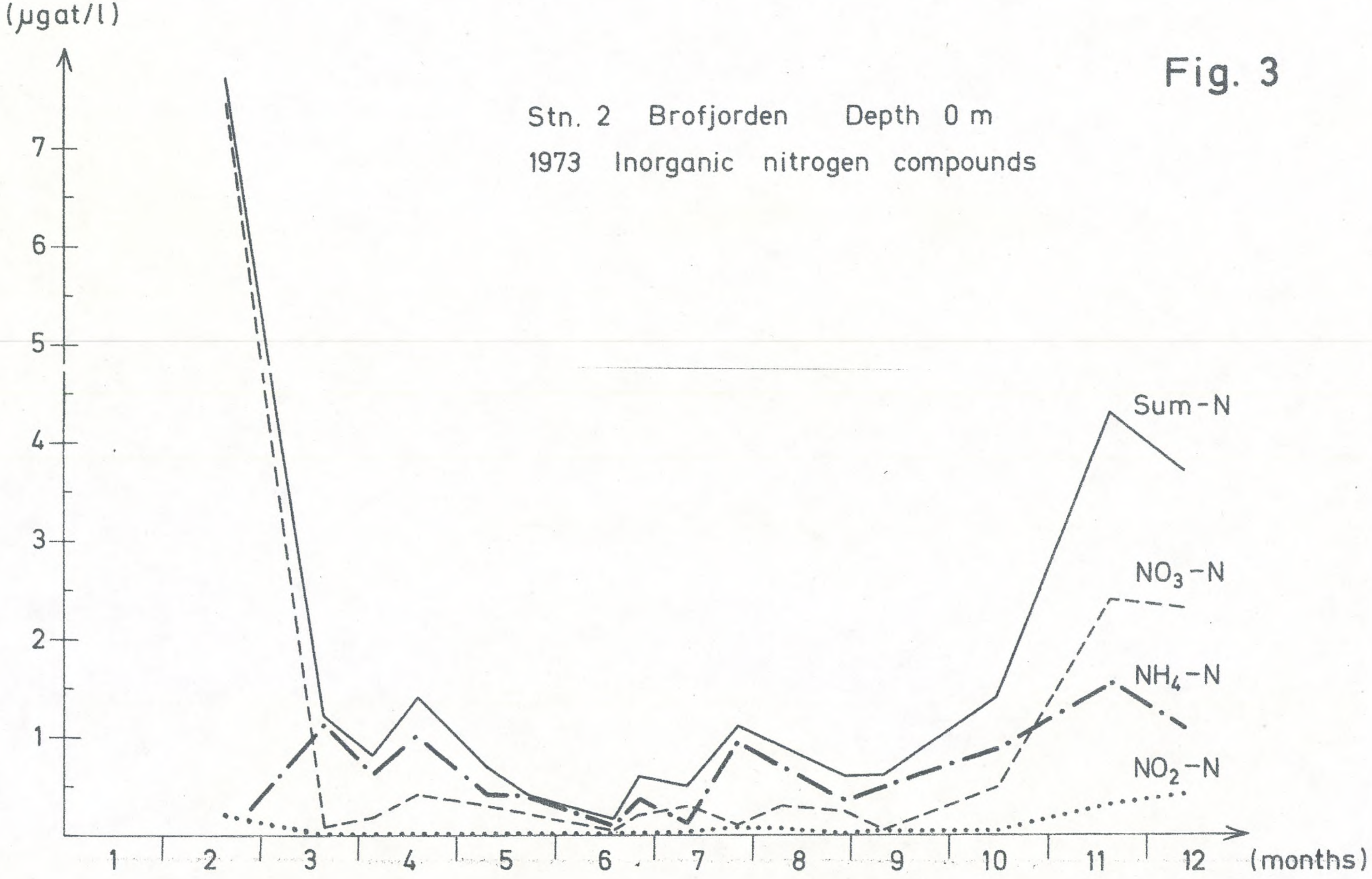


Fig. 2

Fig. 3



Stn. 2 Brofjorden Depth 0 m

1973 Inorganic nitrogen compounds

Fig. 4

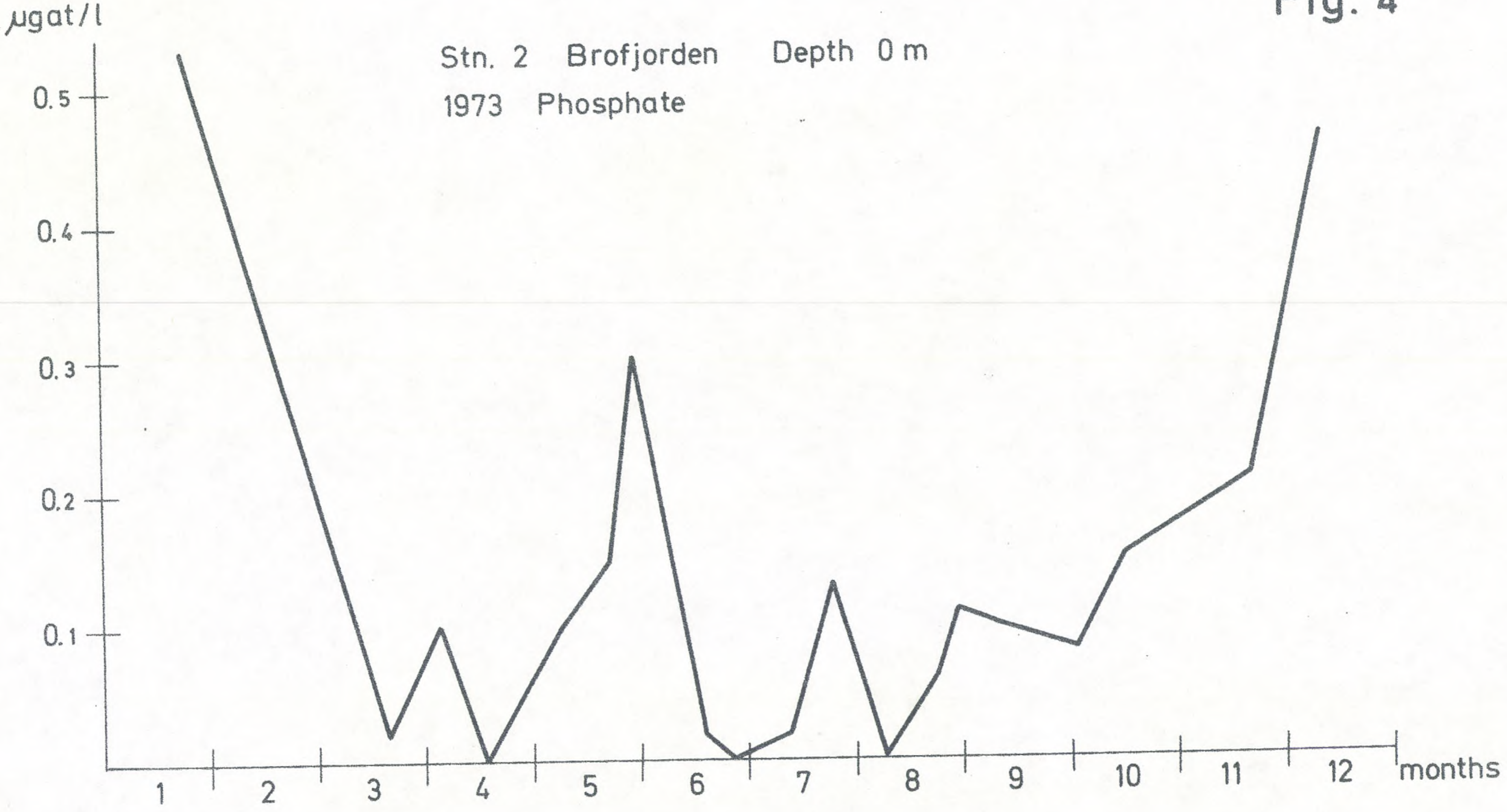

Stn. 2 Brofjorden Depth 0 m
1973 Phosphate
µgat/l
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
8
9
10
11
12
months

Fig. 5

Stn. 2 Brofjorden

1973 Primary production

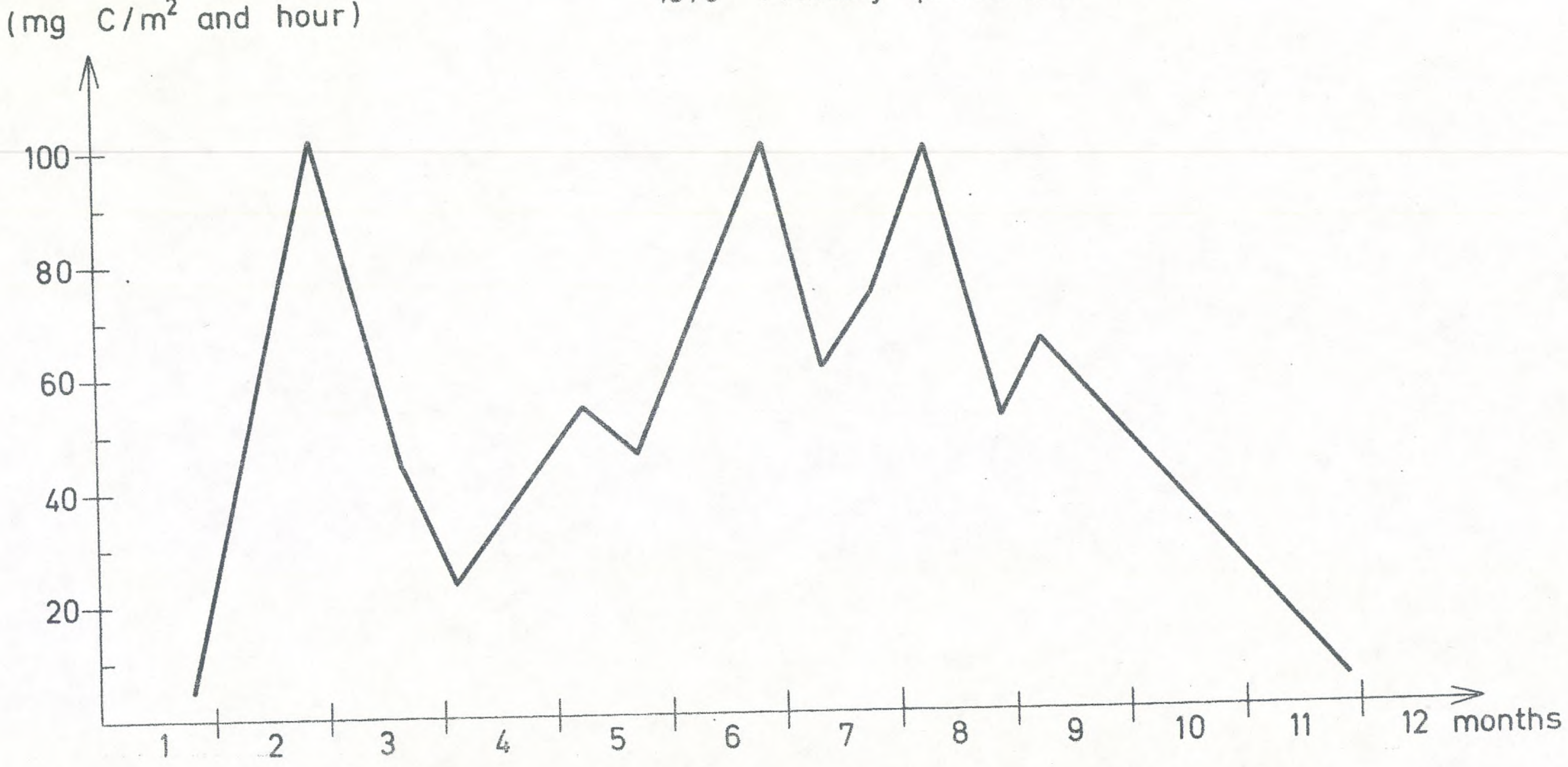


Fig. 6

Stn. 2 Brofjorden

O_2 Saturation percentage (Weiss)

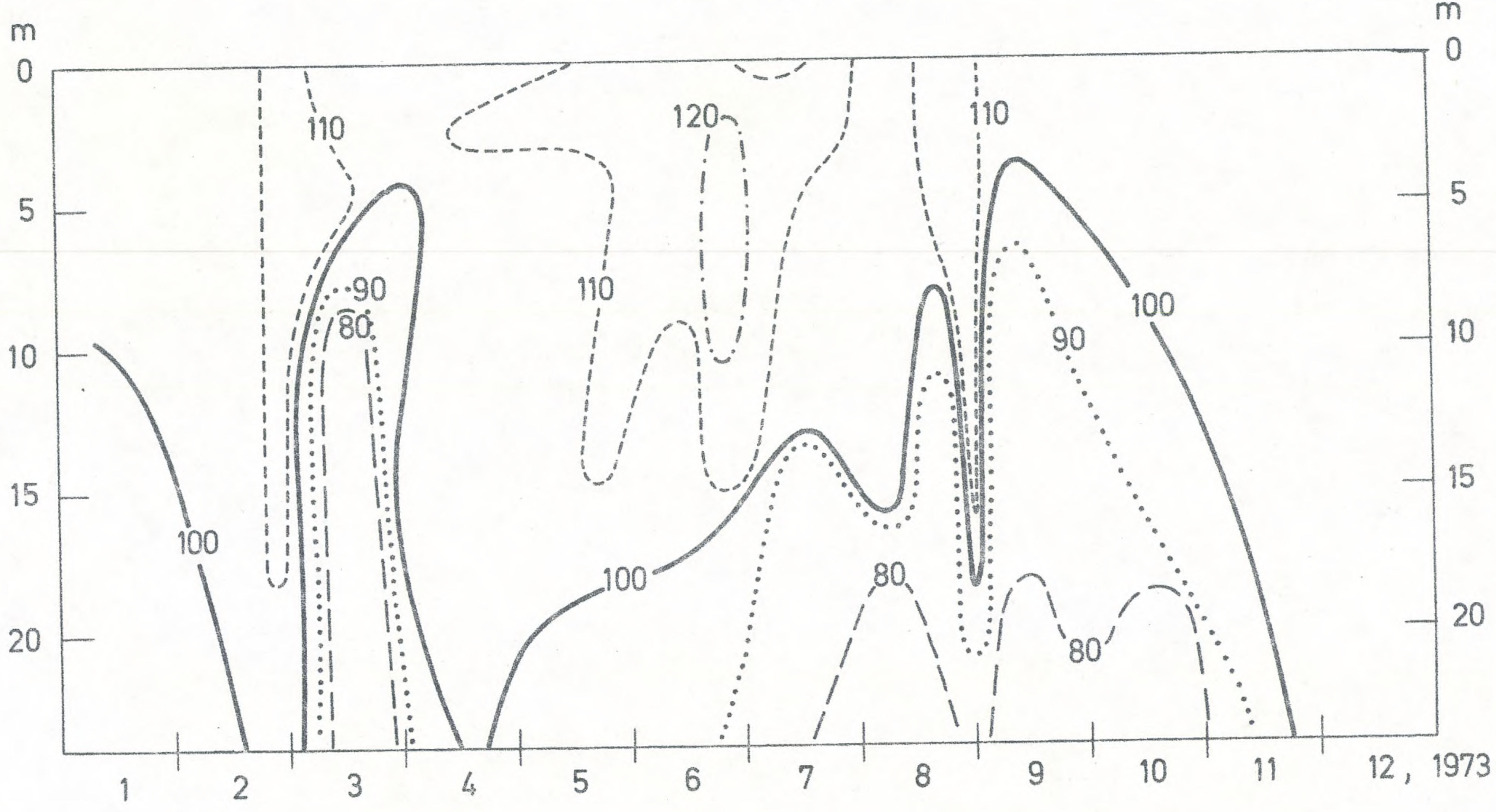
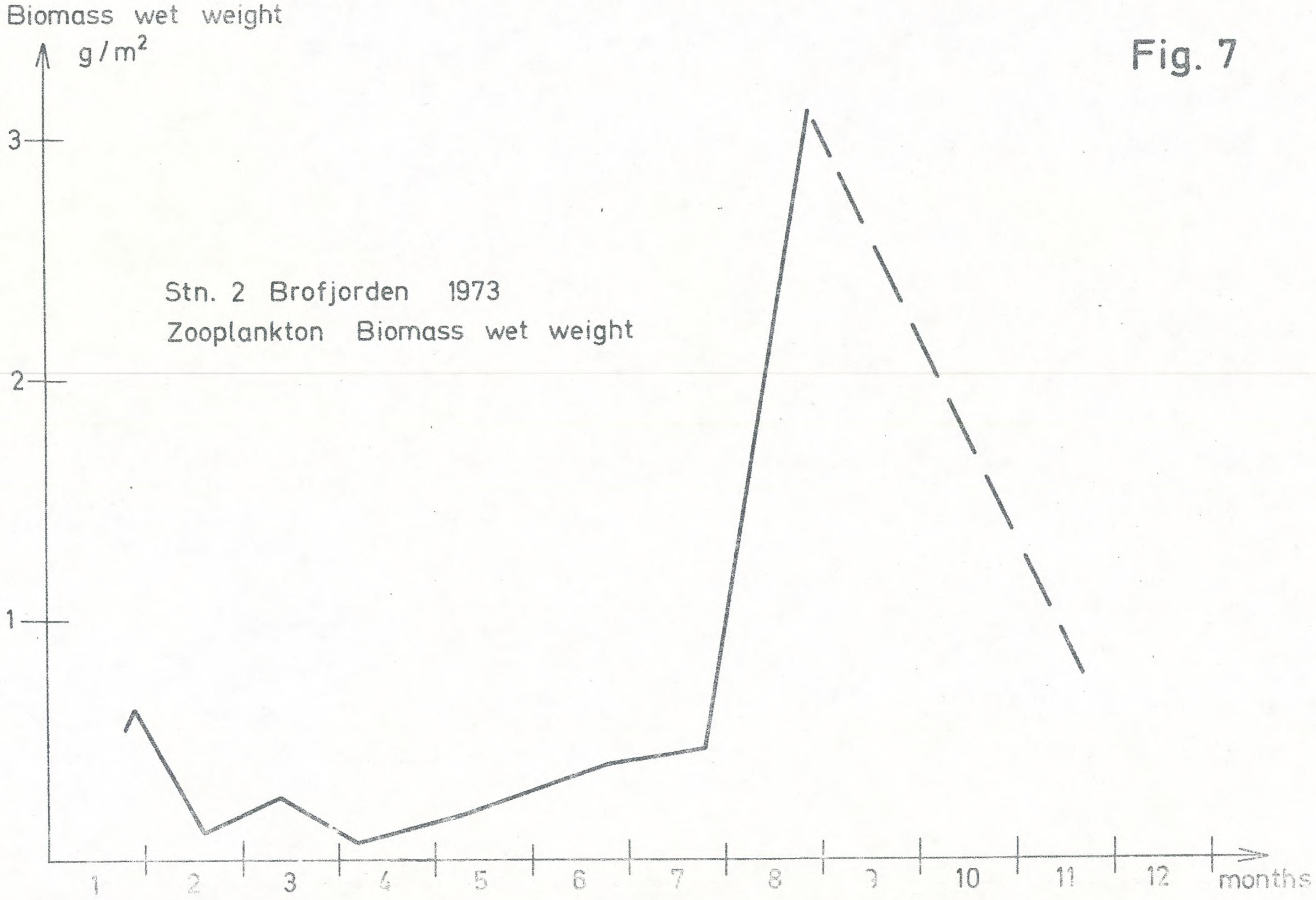


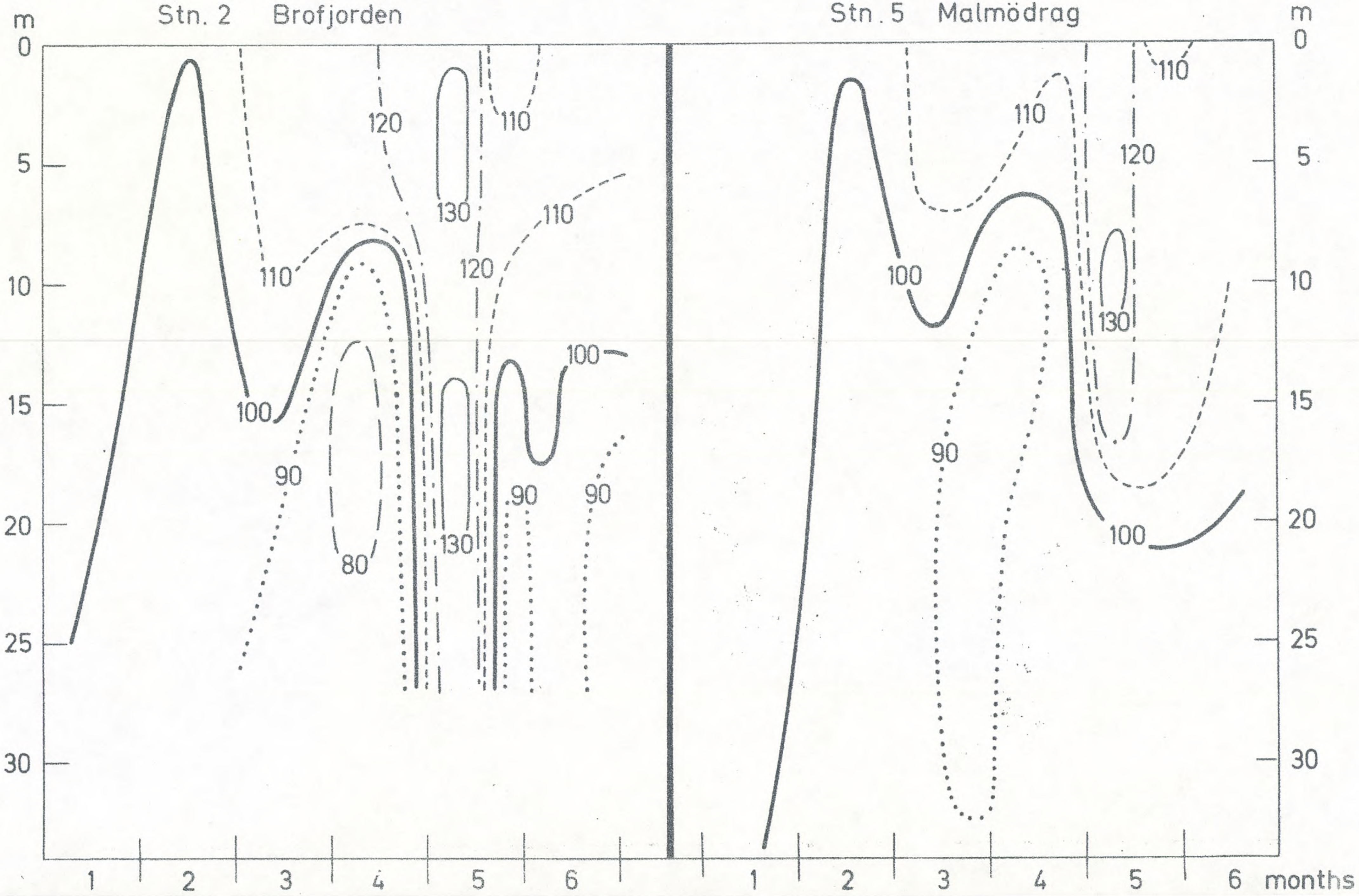
Fig. 7



Stn. 2 Brofjorden 1973
Zooplankton Biomass wet weight

Fig. 8

1974 O_2 Saturation percentage



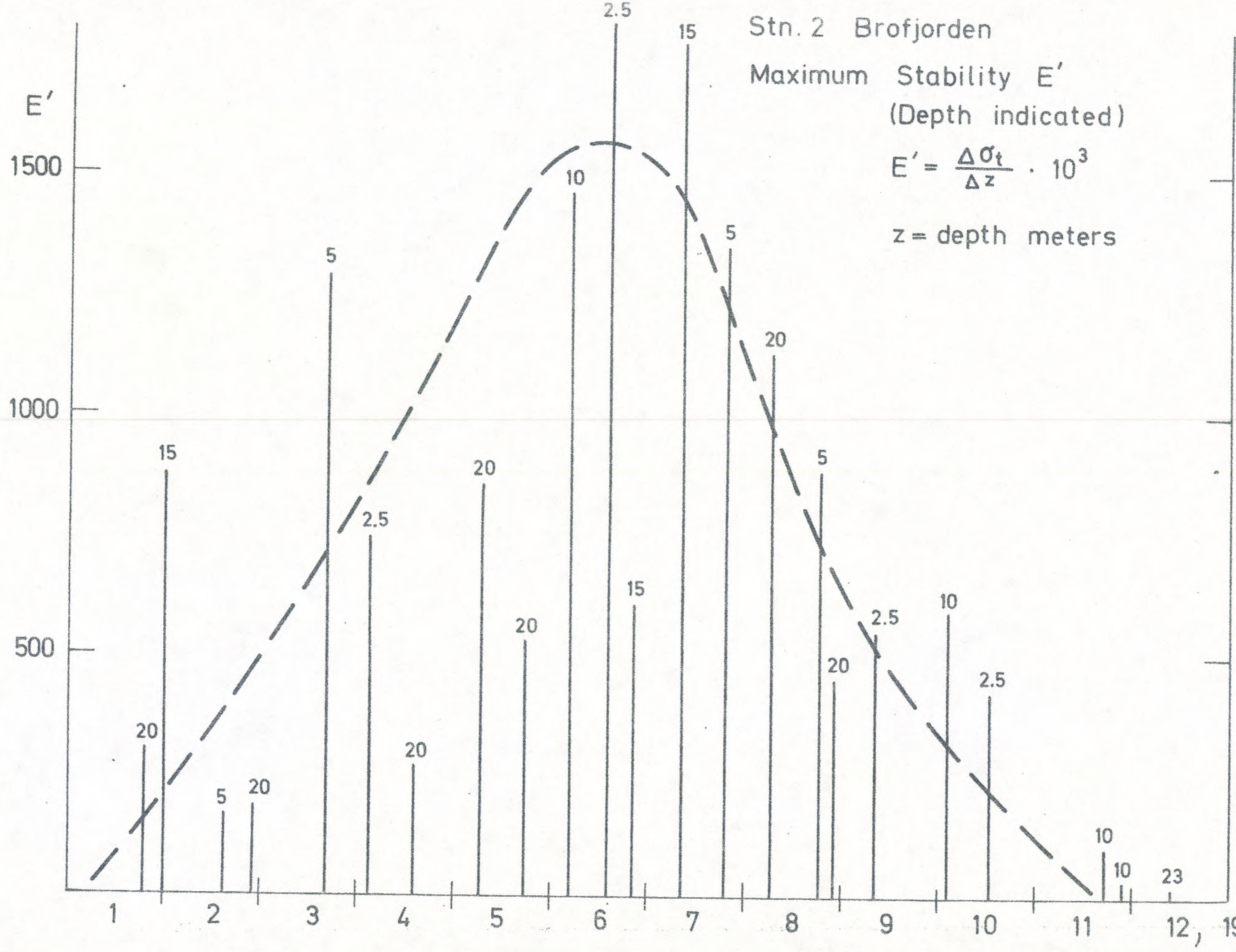


Fig. 9

Stn. 2 Brofjorden

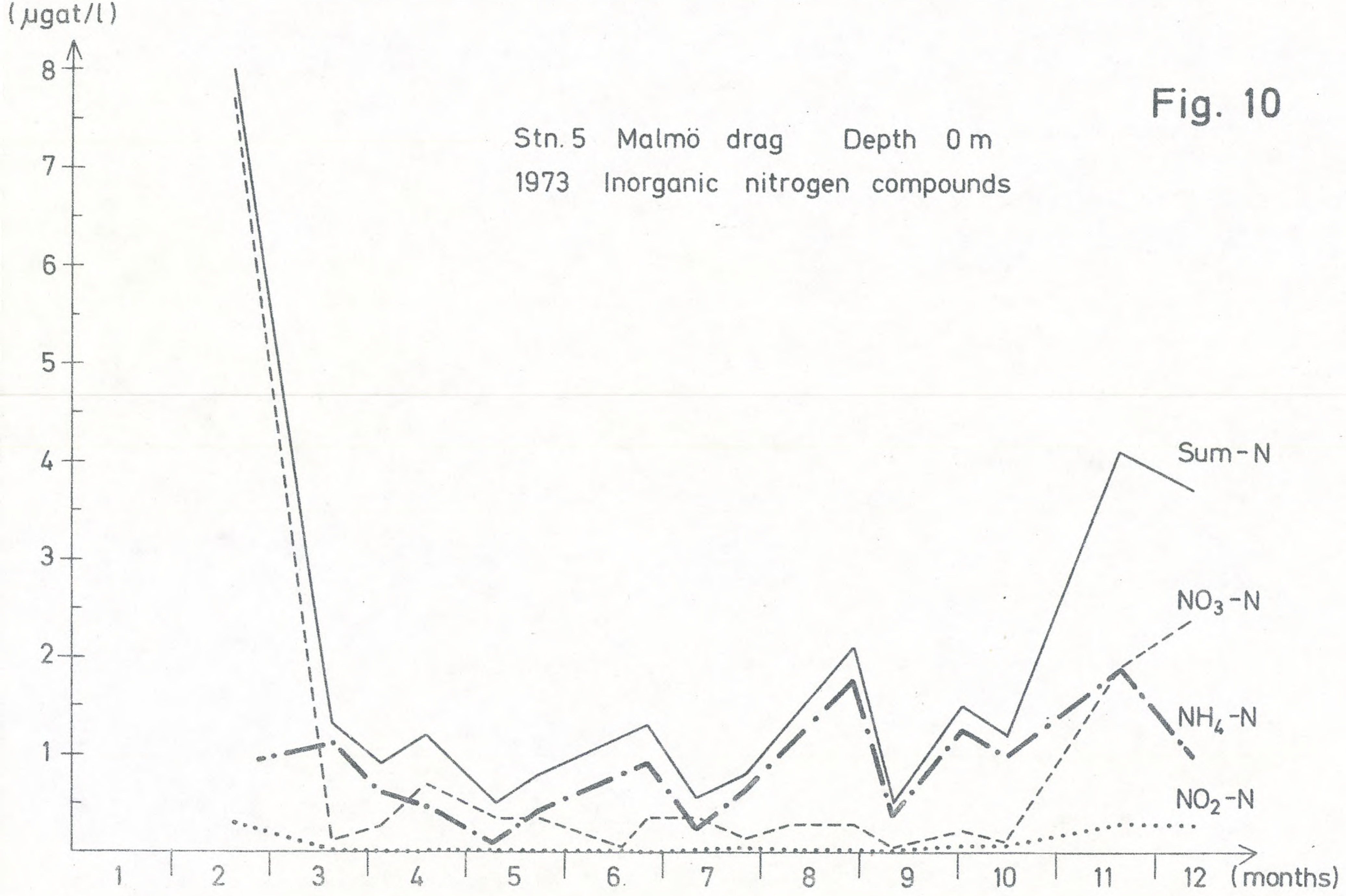
Maximum Stability E′

(Depth indicated)

$$E' = \frac{\Delta \sigma_t}{\Delta z} \cdot 10^3$$

z = depth meters

Fig. 10



Stn. 5 Malmö drag Depth 0 m
1973 Inorganic nitrogen compounds

Fig. 11

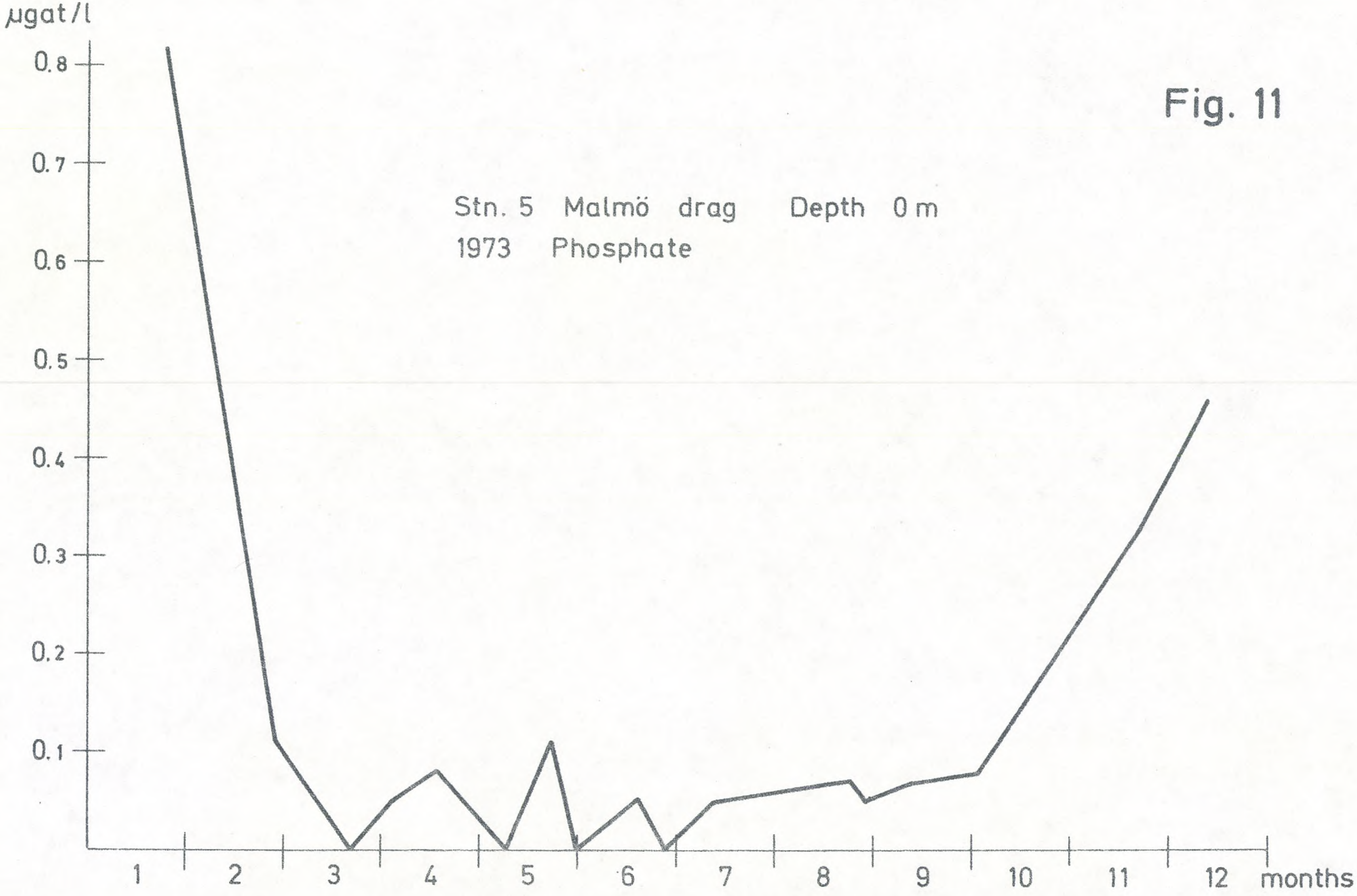

Stn. 5 Malmö drag Depth 0 m
1973 Phosphate
µgat/l
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1
2
3
4
5
6
7
8
9
10
11
12
months

Fig. 12

Stn. 5 Malmö drag
1973 Primary production

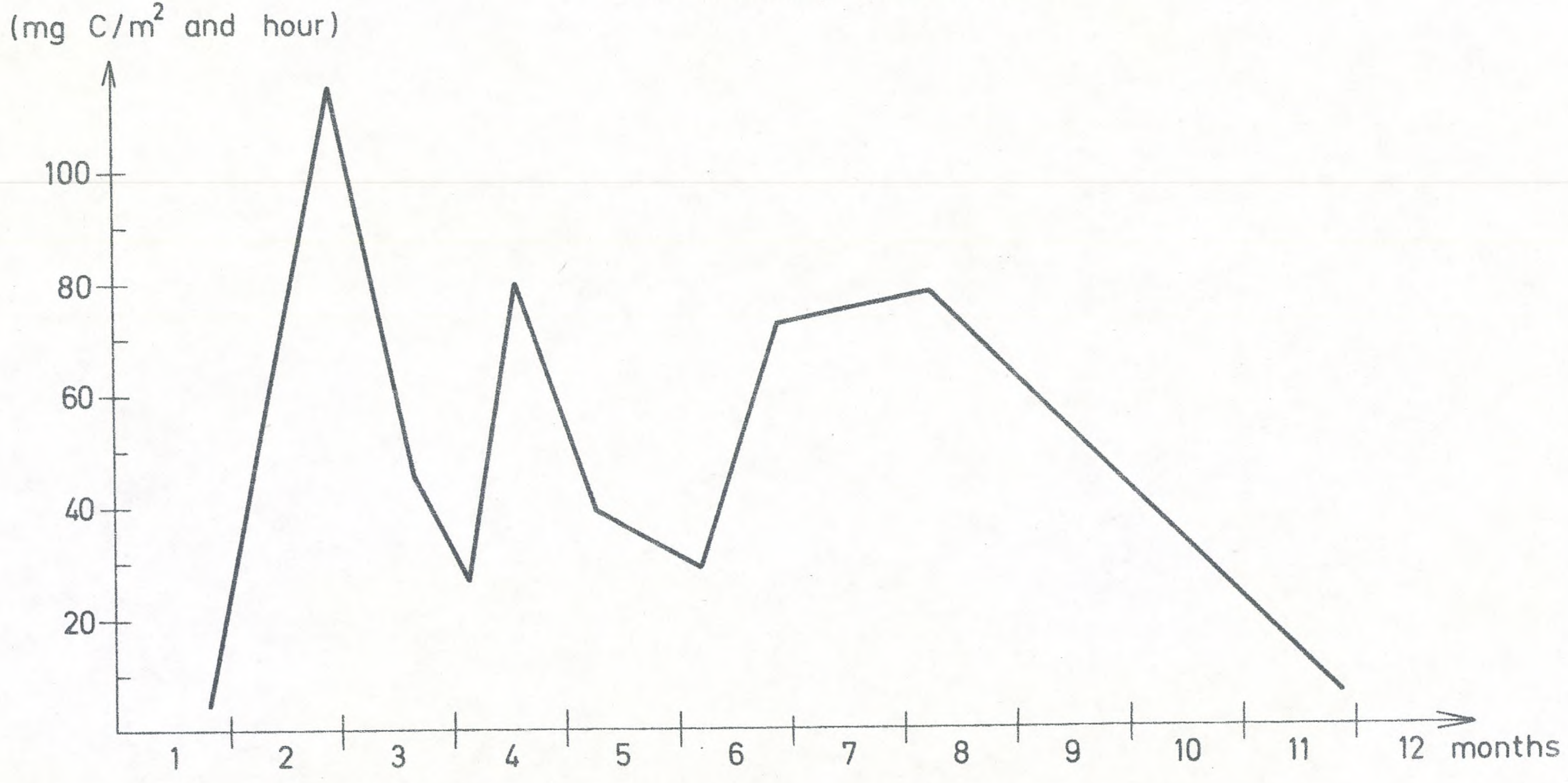


Fig. 13

Stn. 5 Malmö drag

O_2 Saturation percentage (Weiss)

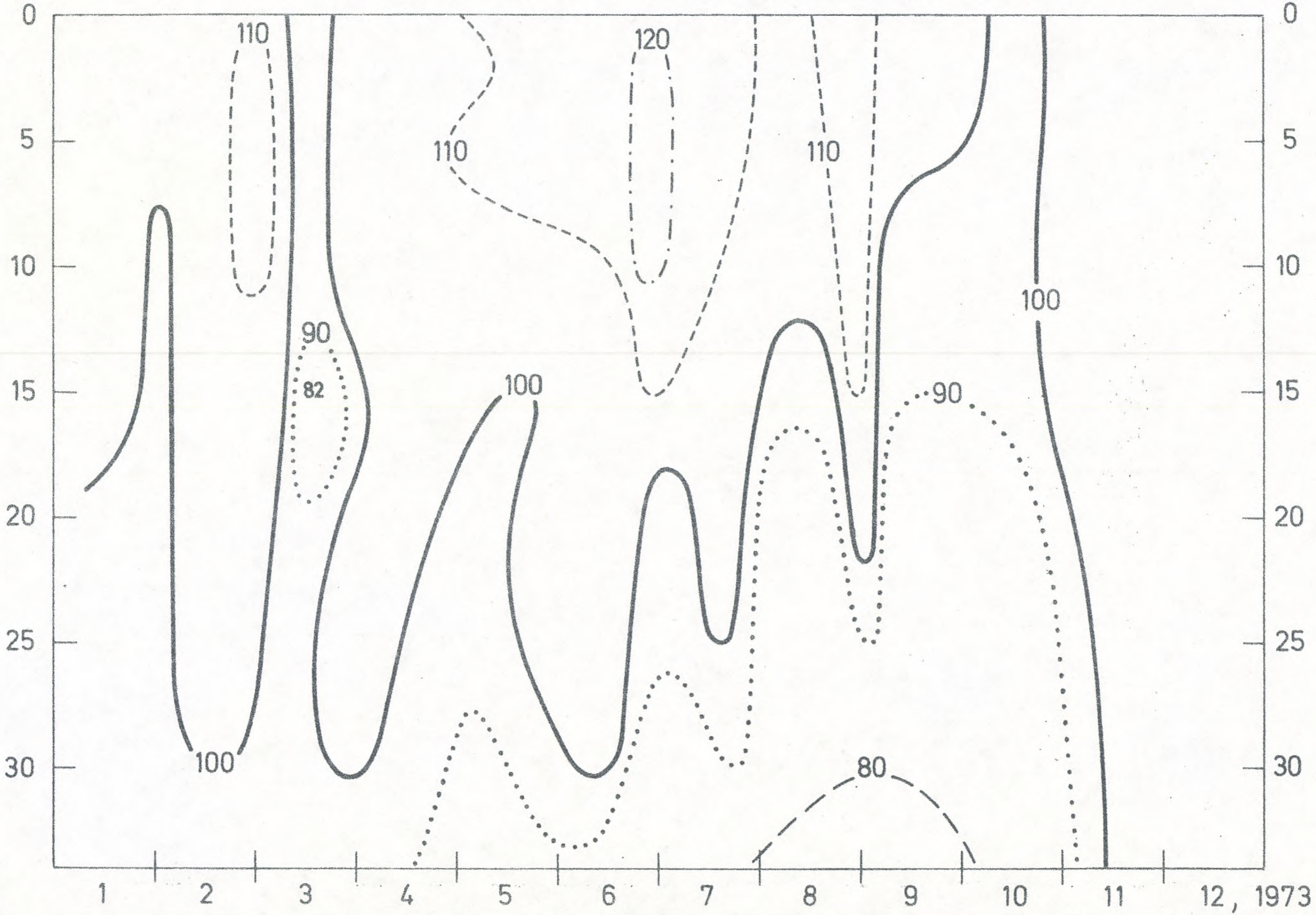
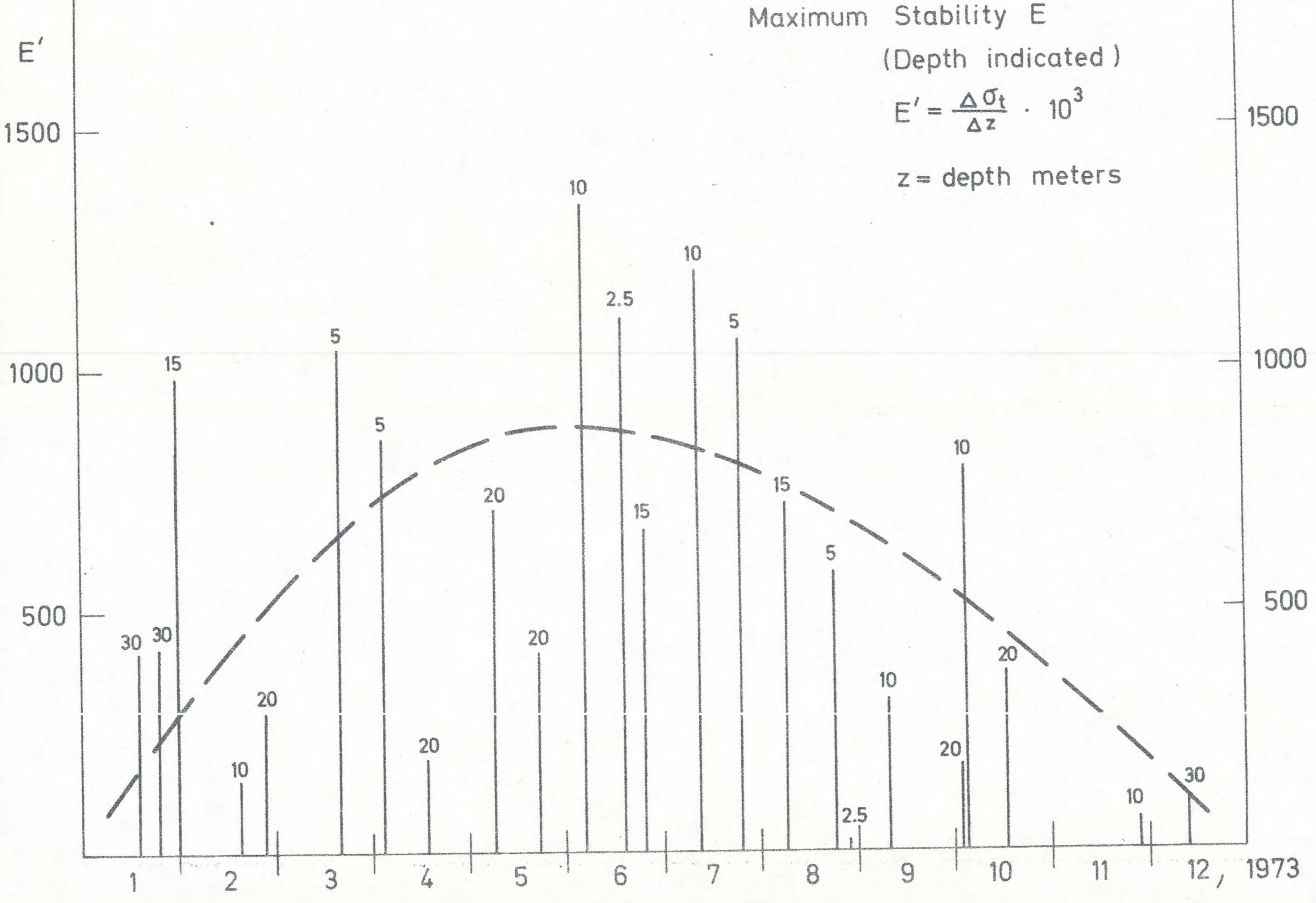


Fig. 14



Stn. 5 Malmö drag
Maximum Stability E
(Depth indicated)

$E' = \frac{\Delta \sigma_t}{\Delta z} \cdot 10^3$

z = depth meters

Fig. 15

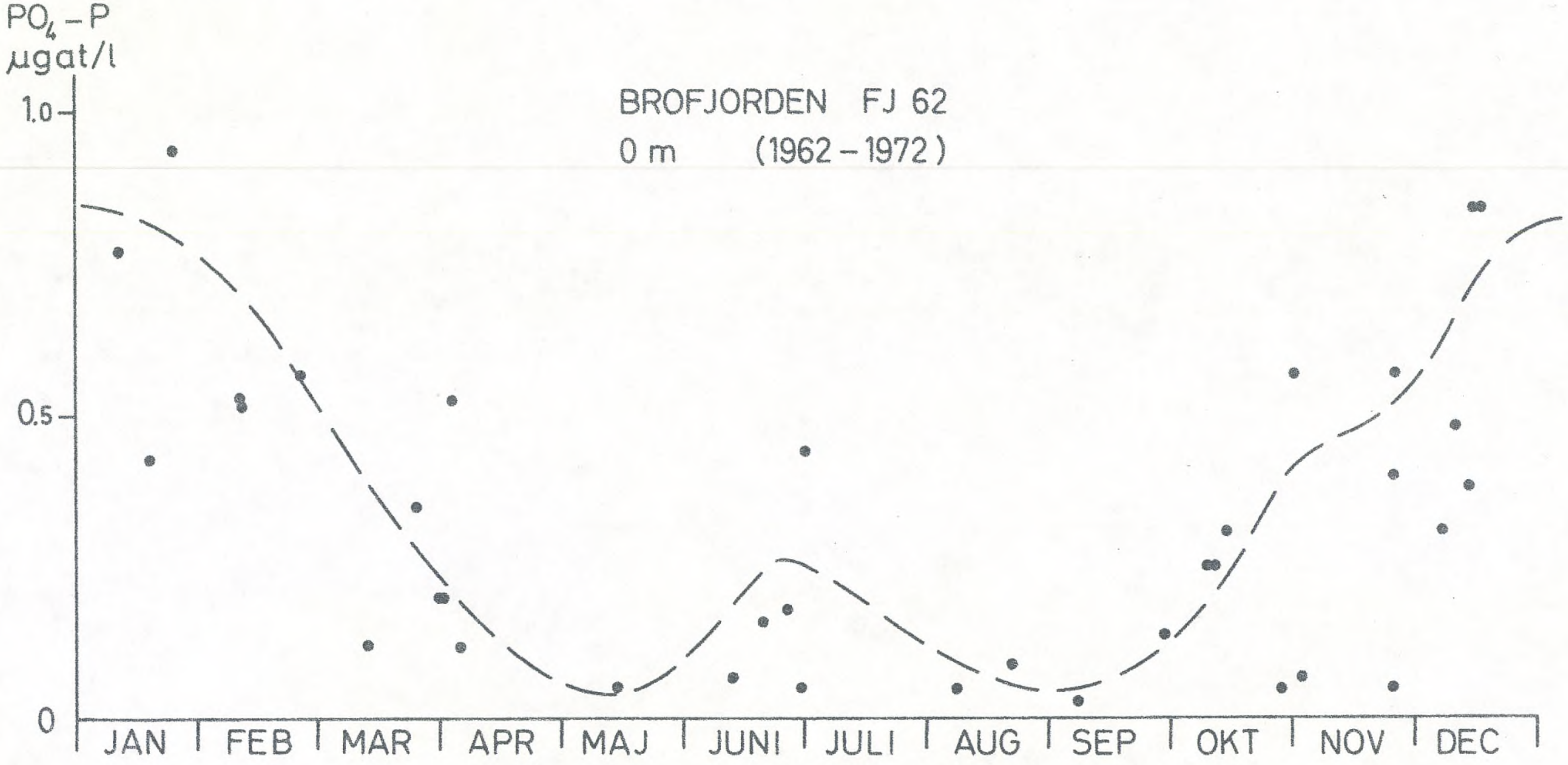

BROFJORDEN FJ 62
0 m (1962 – 1972)
PO₄ – P
µgat/l
1.0
0.5
0
JAN
FEB
MAR
APR
MAJ
JUNI
JULI
AUG
SEP
OKT
NOV
DEC

Fig. 16

Total values for the water column 0 – 30 m

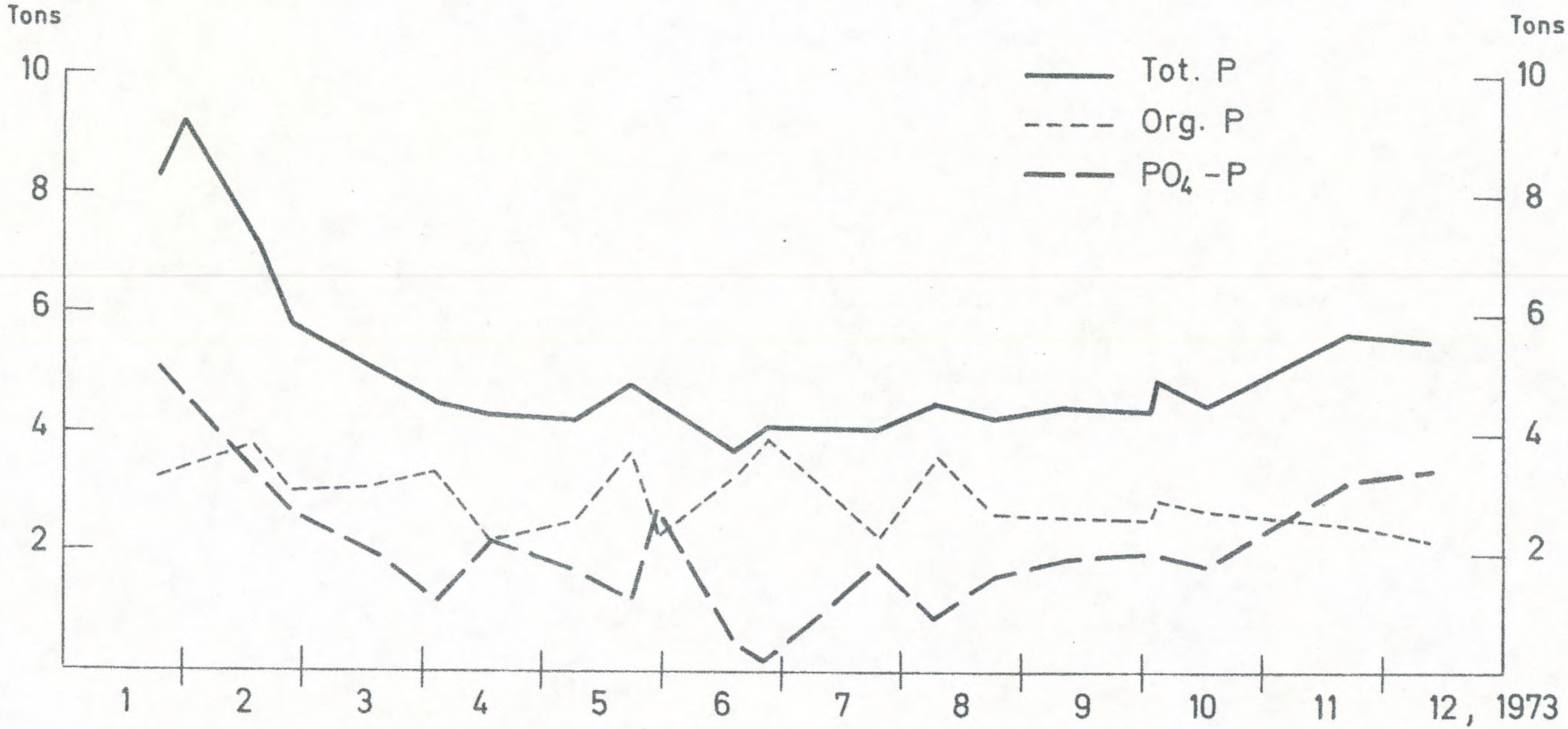
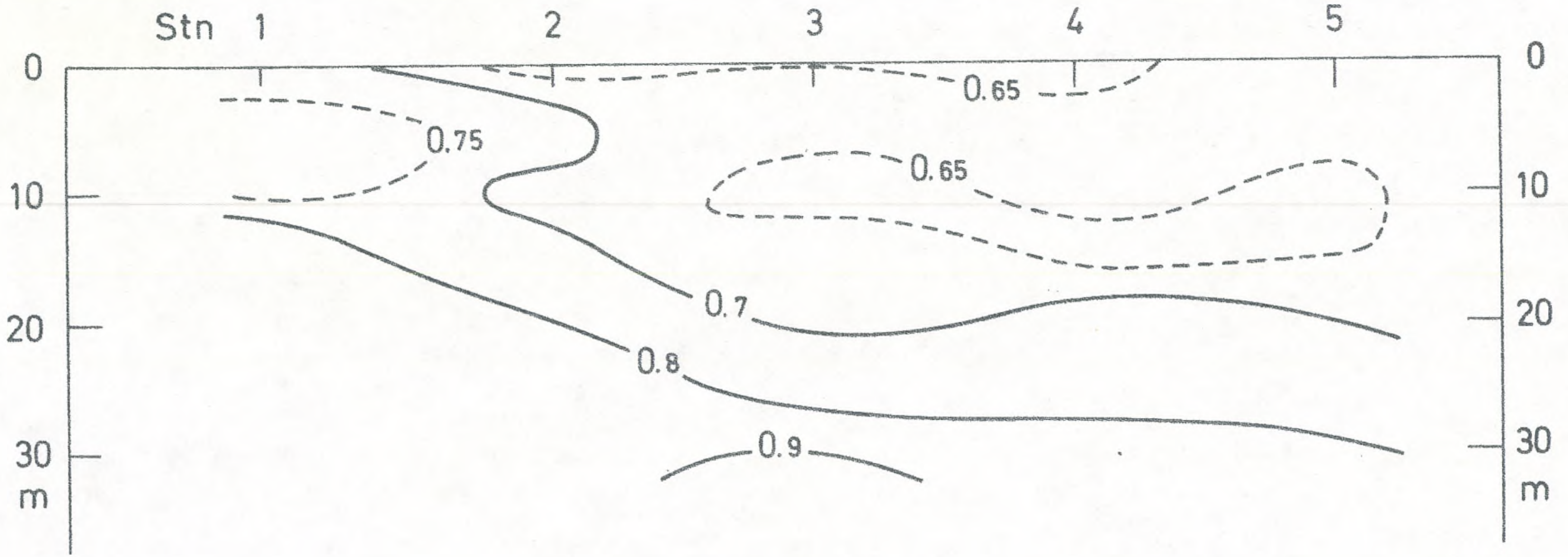


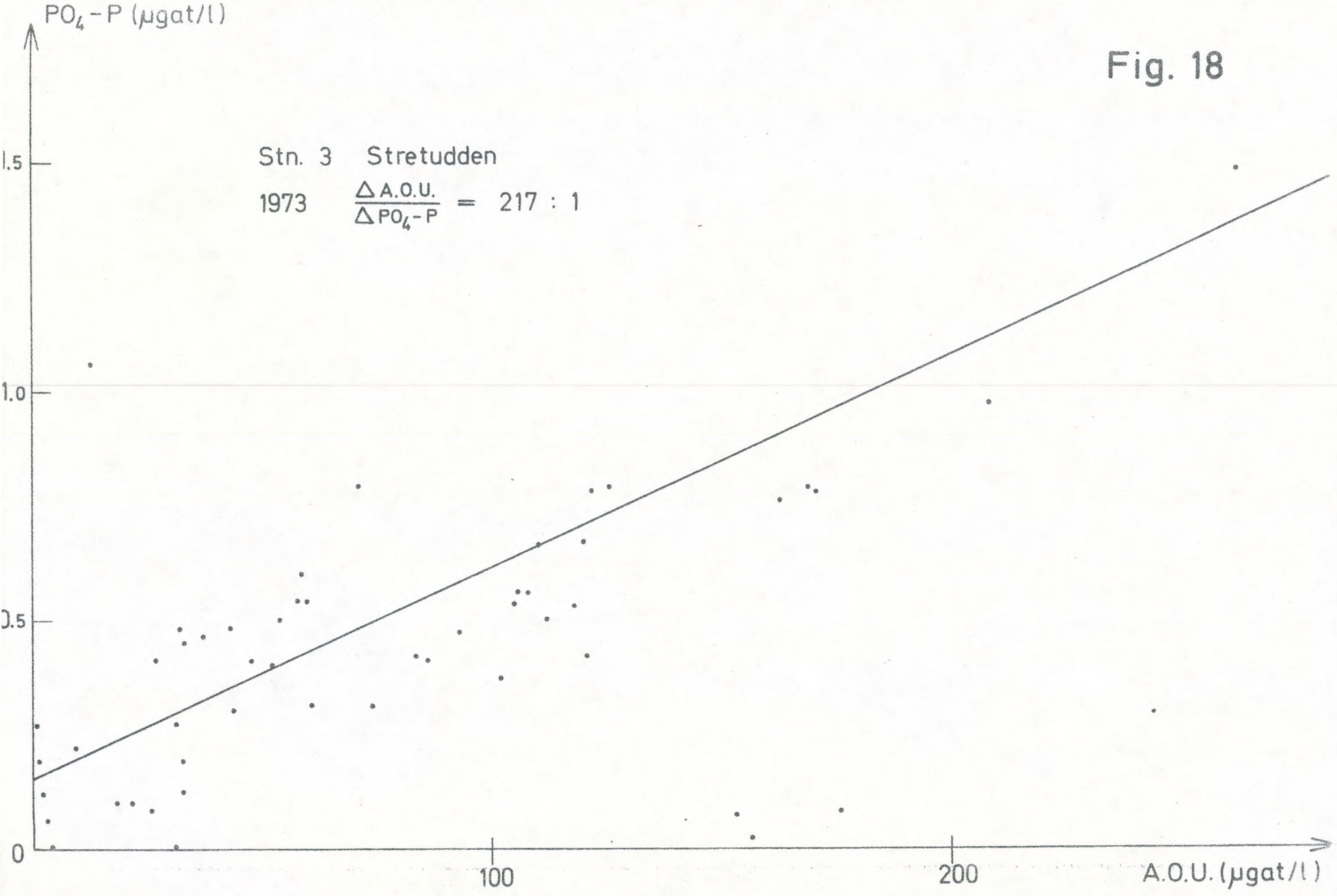
Fig. 17



Tot. P µgat/l

Annual means

Fig. 18


PO$_4$-P (µgat/l)
Stn. 3 Stretudden
1973 $\frac{\Delta \text{A.O.U.}}{\Delta \text{PO}_4\text{-P}}$ = 217 : 1
1.5
1.0
0.5
0
100
200
A.O.U. (µgat/l)

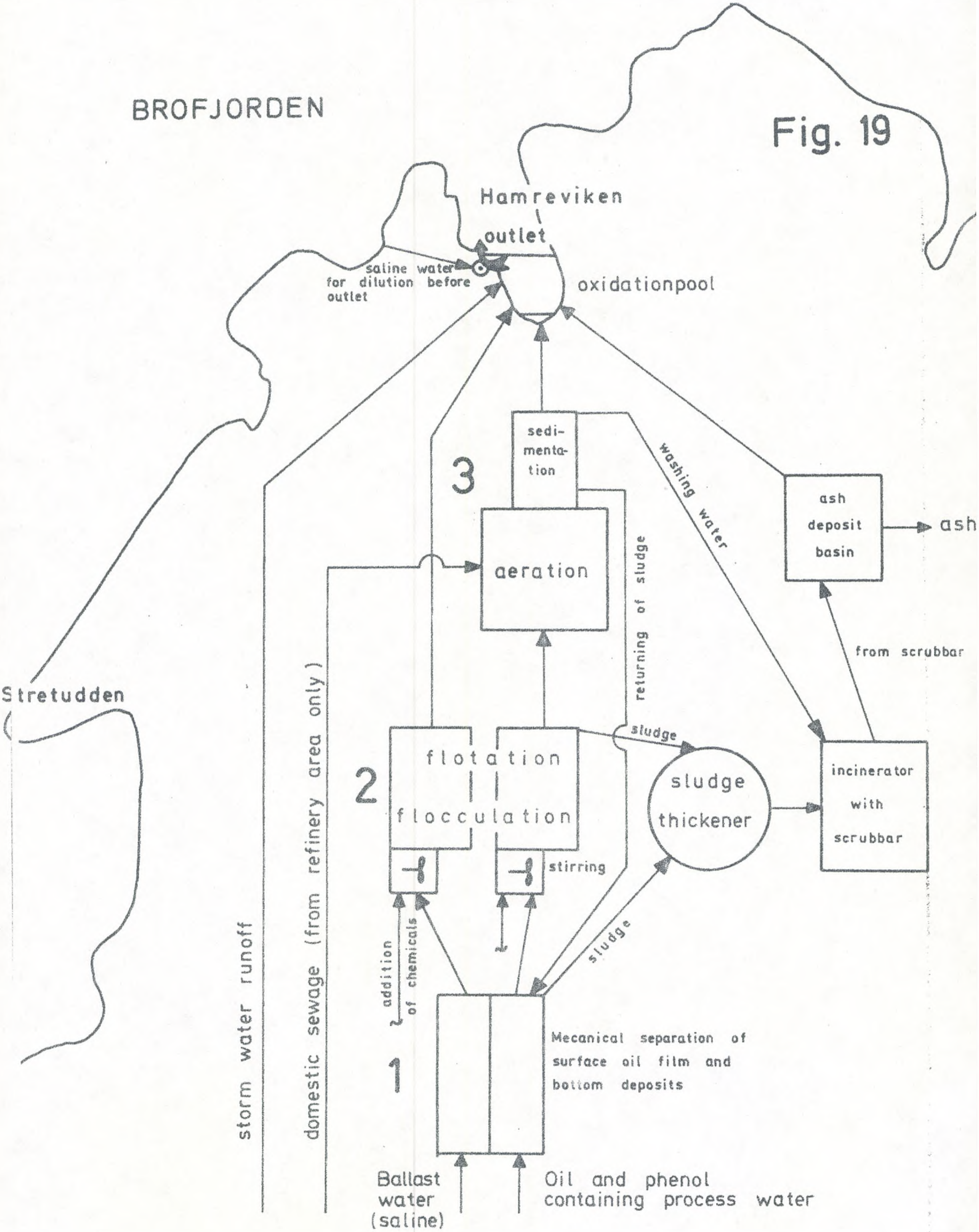


Fig. 19

Outline of the basic arrangement for treatment of the waste water from the OK / Texaco oil refinery plant at Brofjorden

Fig. 20

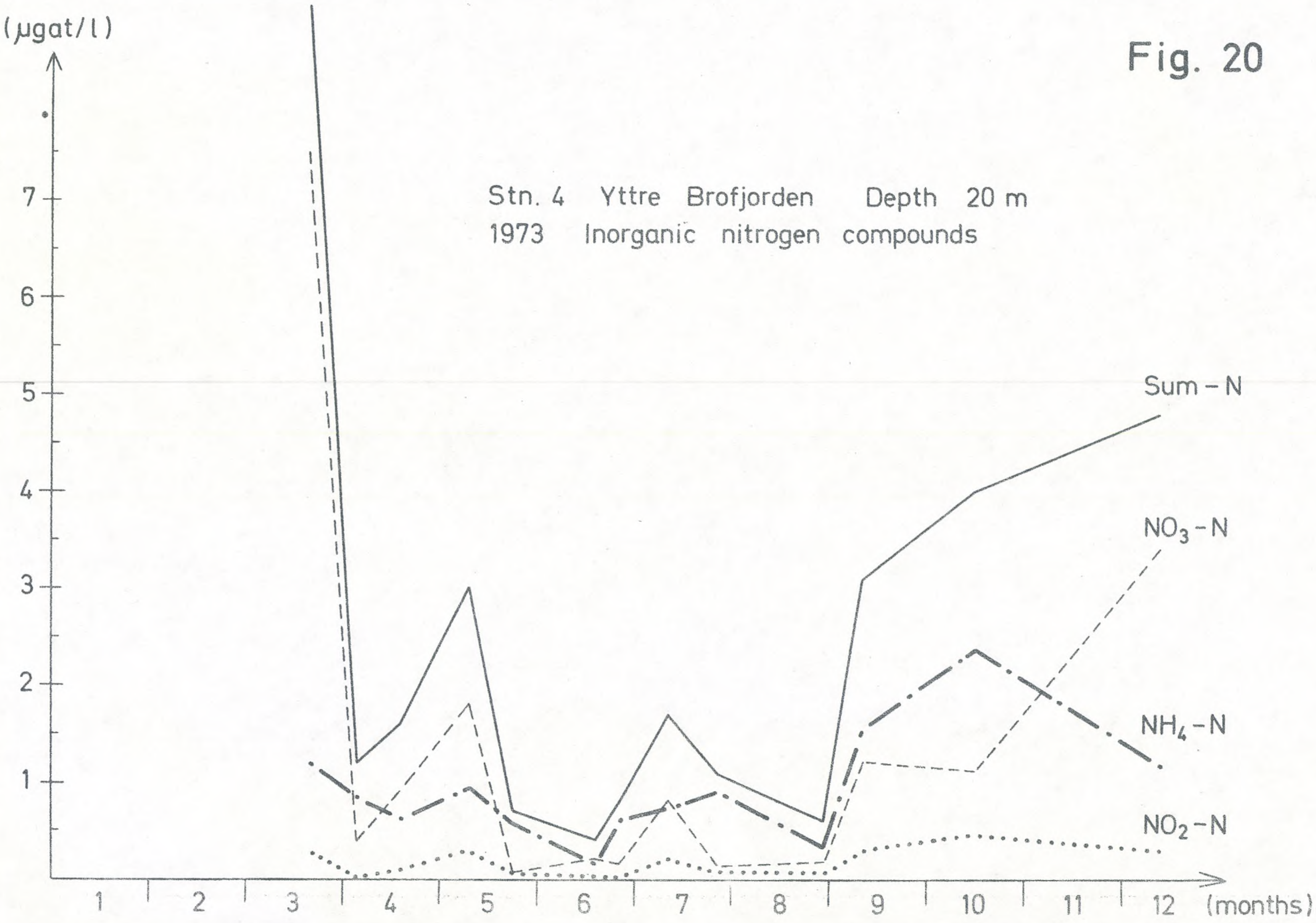
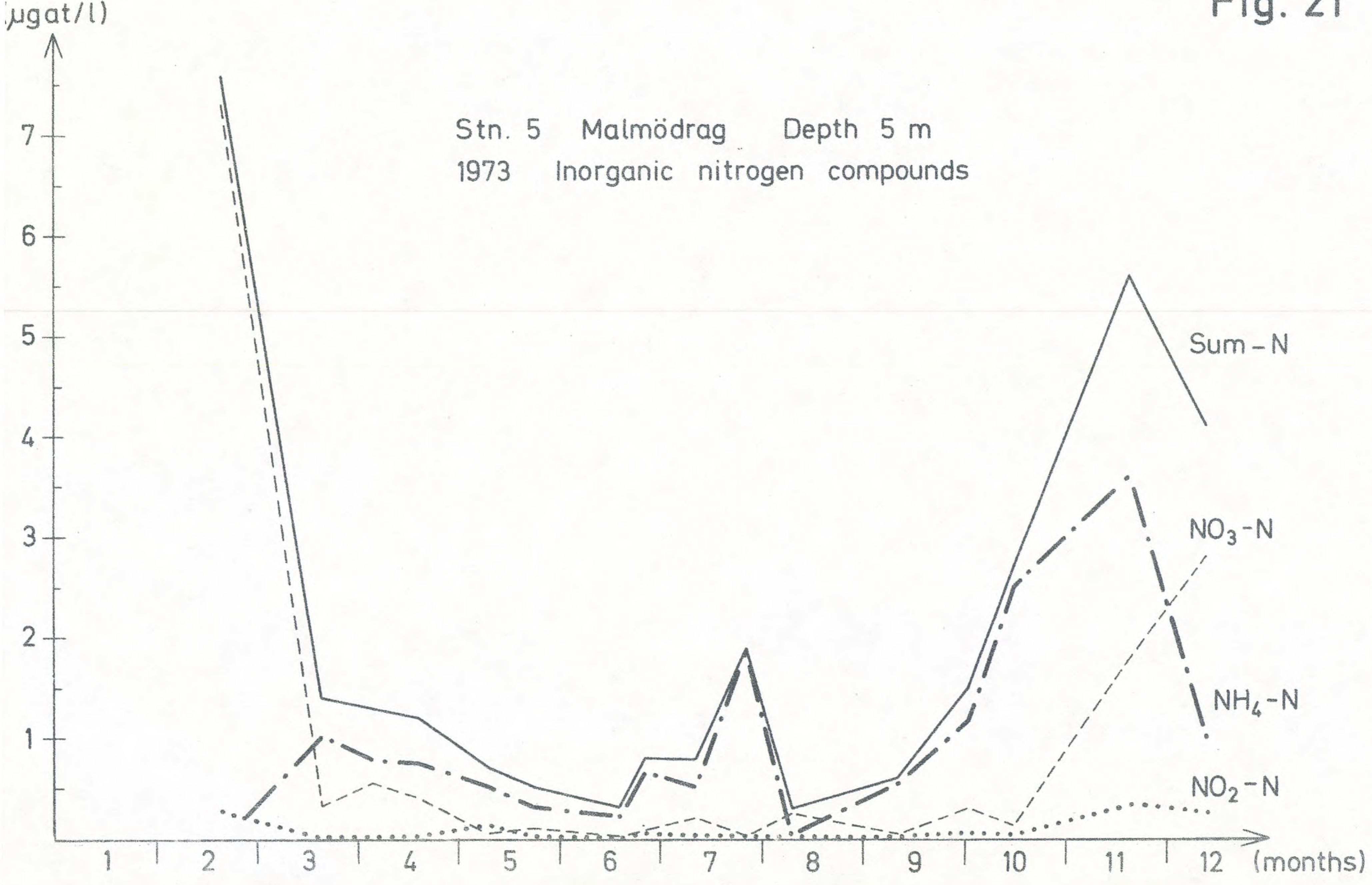

Stn. 4 Yttre Brofjorden Depth 20 m
1973 Inorganic nitrogen compounds
(μgat/l)
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
(months)
Sum – N
NO_3 – N
NH_4 – N
NO_2 – N

Fig. 21



Stn. 5 Malmödrag Depth 5 m
1973 Inorganic nitrogen compounds

Fig. 22

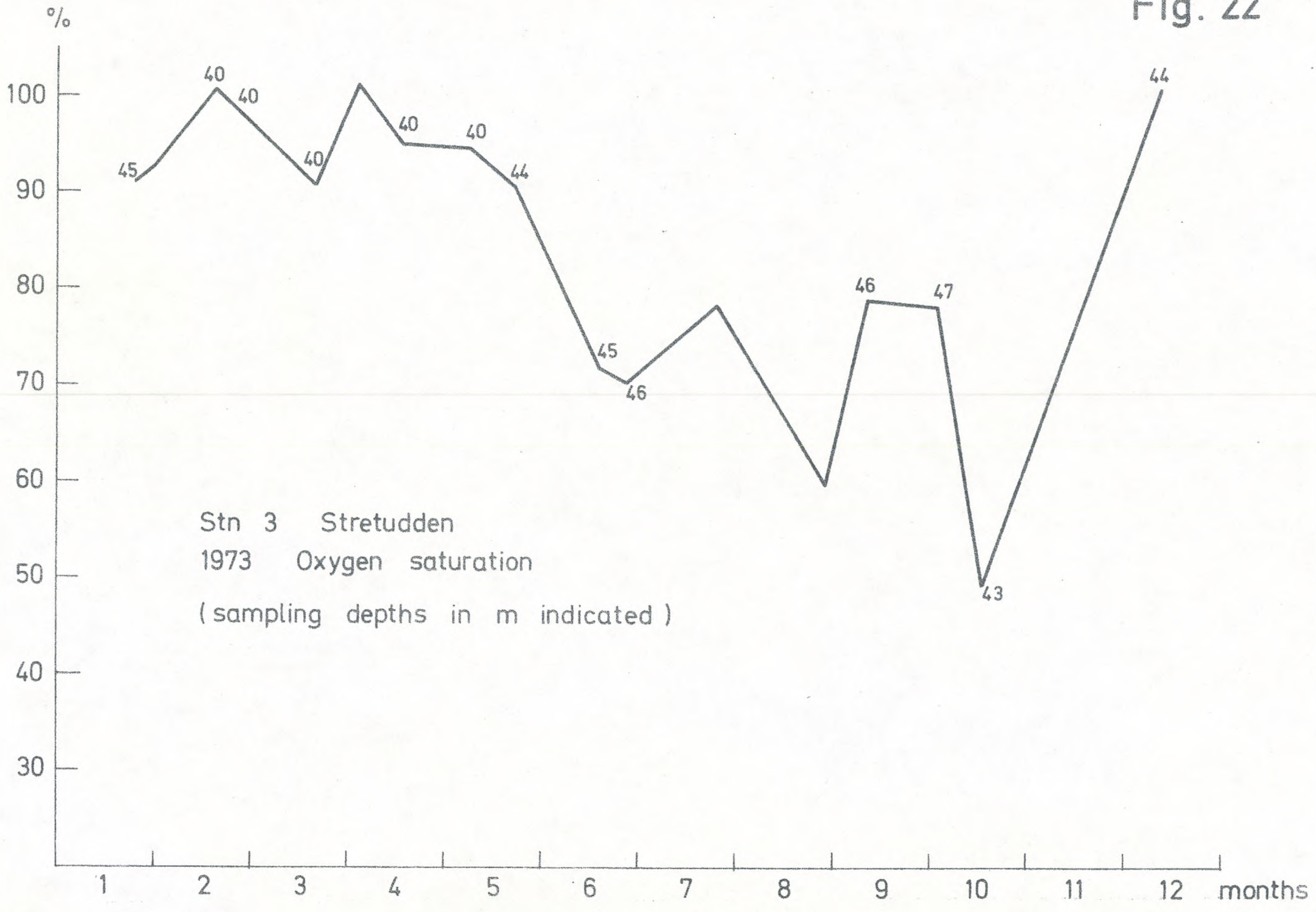
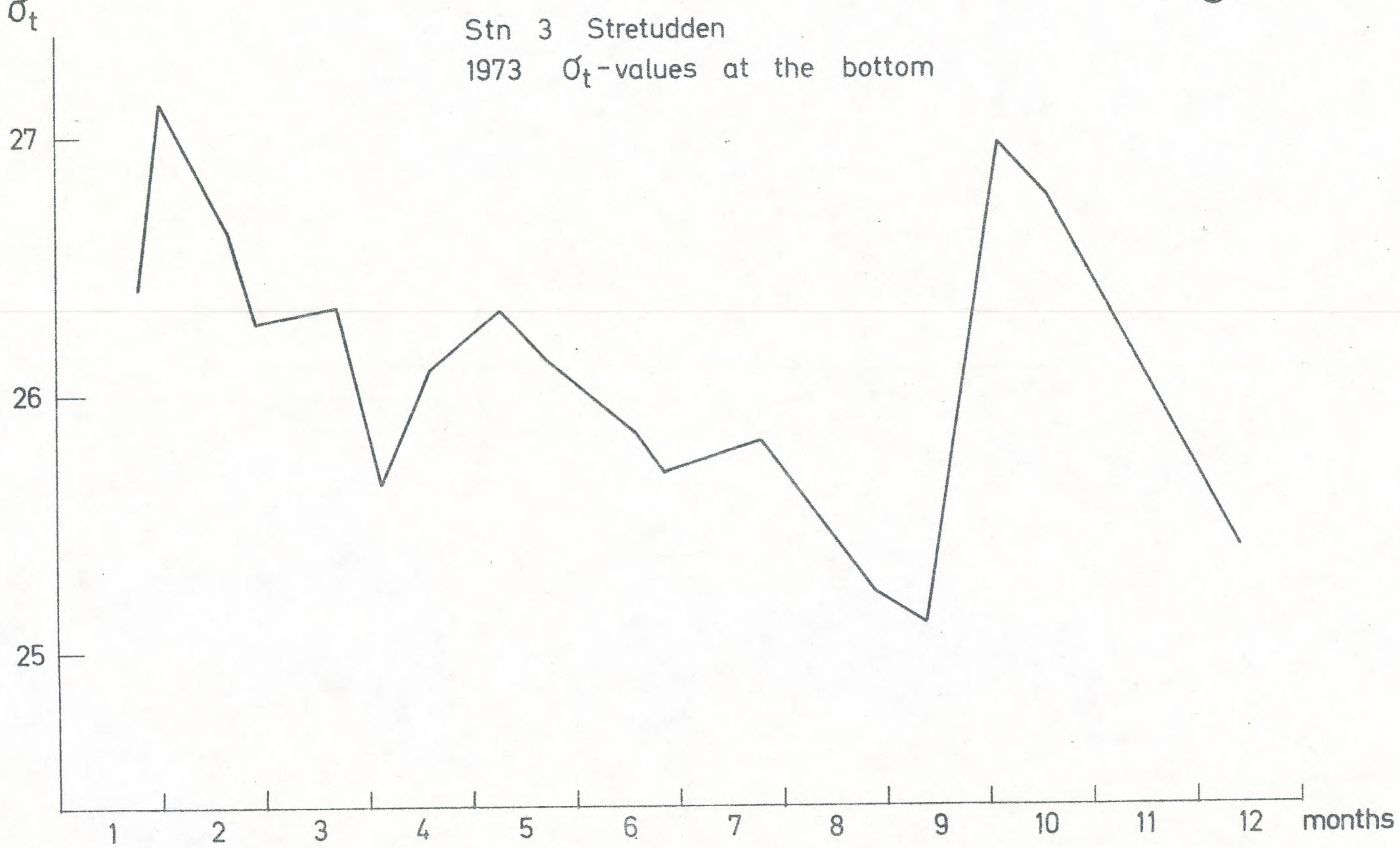

%
100
90
80
70
60
50
40
30
1
2
3
4
5
6
7
8
9
10
11
12
months
45
40
40
40
40
40
44
45
46
46
47
43
44
Stn 3 Stretudden
1973 Oxygen saturation
(sampling depths in m indicated)

Fig. 23



Stn 3 Stretudden
1973 σ_t-values at the bottom

Fig. 24

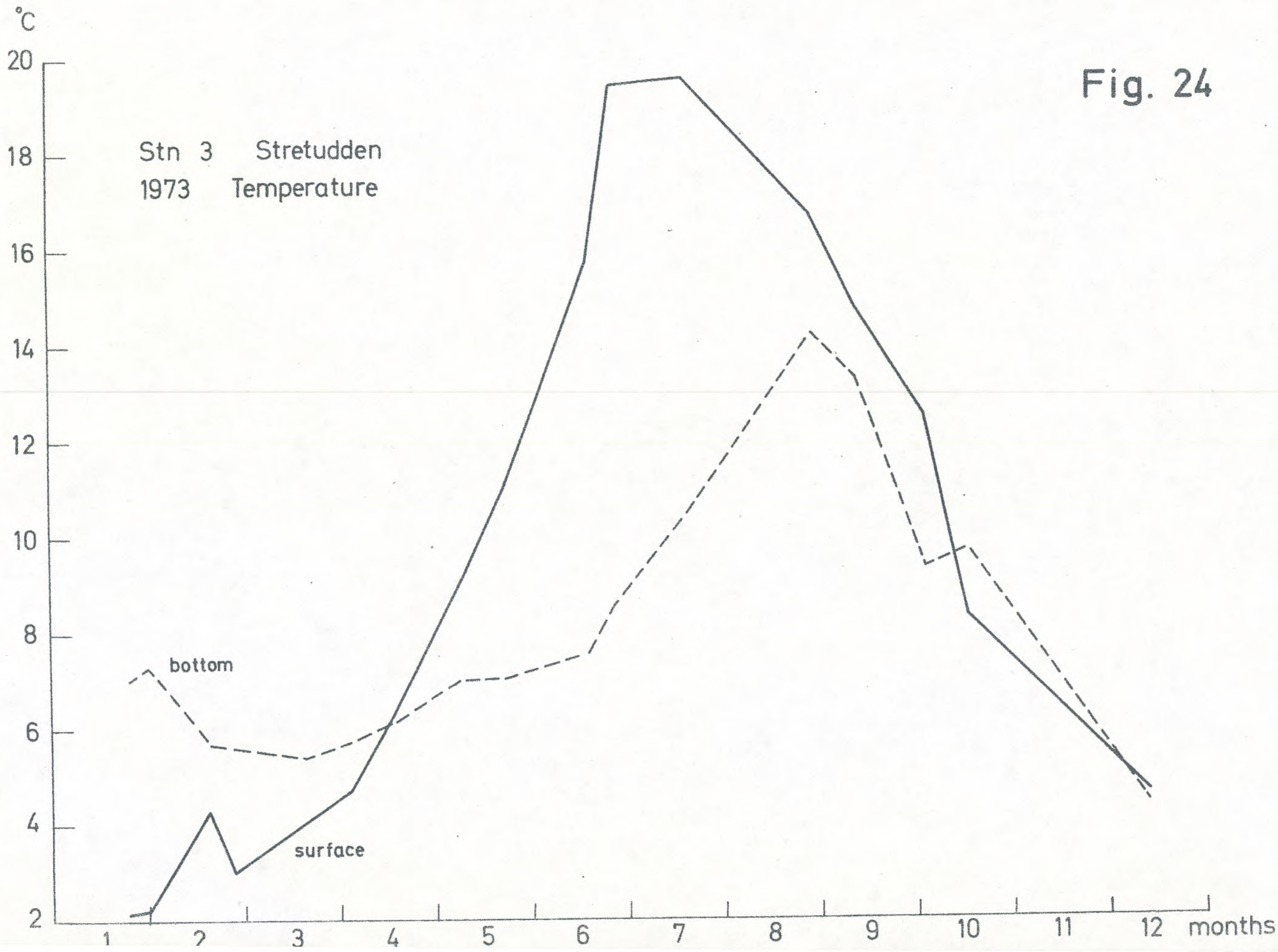

Stn 3 Stretudden
1973 Temperature
°C
20
18
16
14
12
10
8
6
4
2
bottom
surface
1
2
3
4
5
6
7
8
9
10
11
12
months

Fig. 25

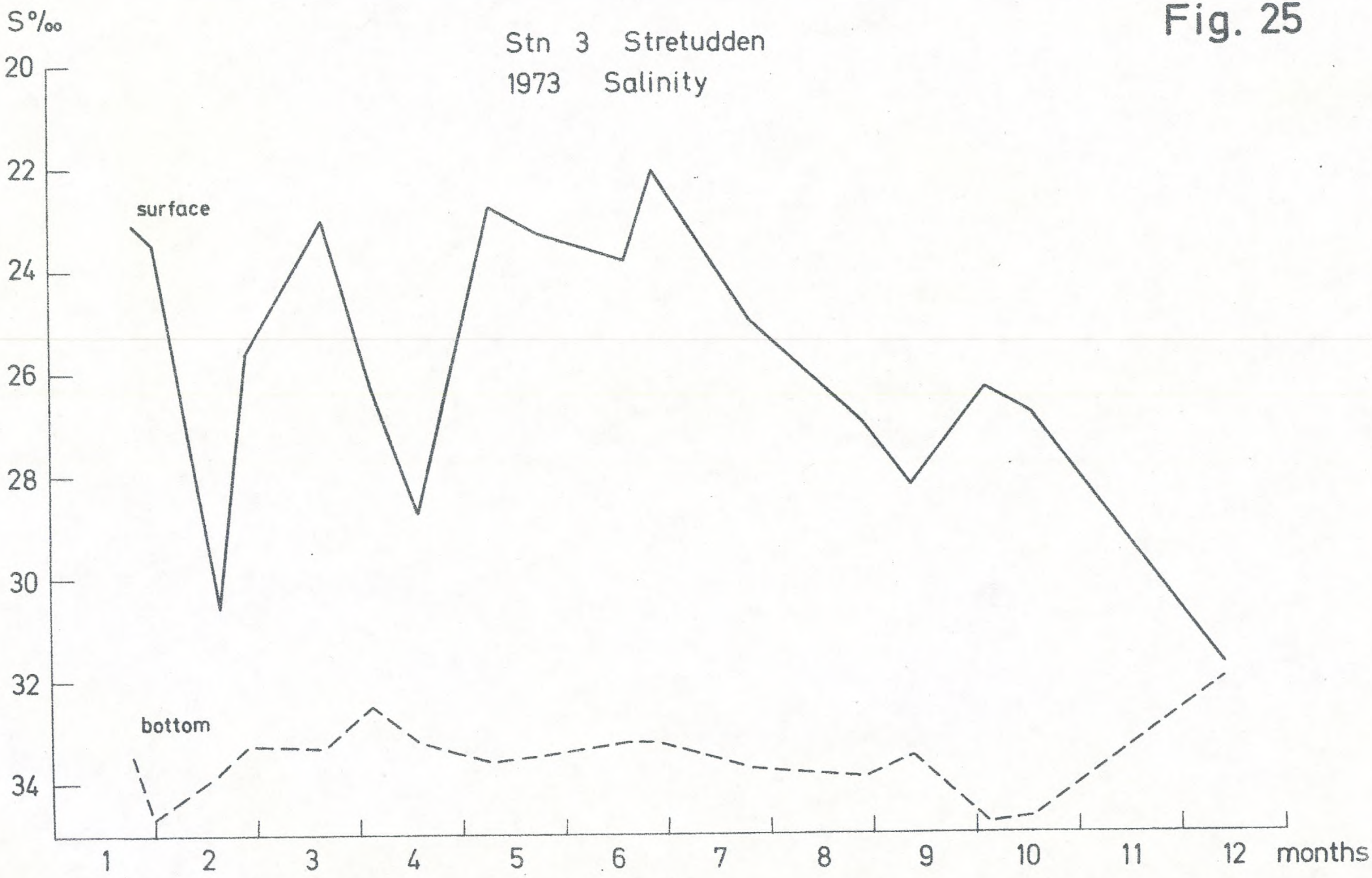
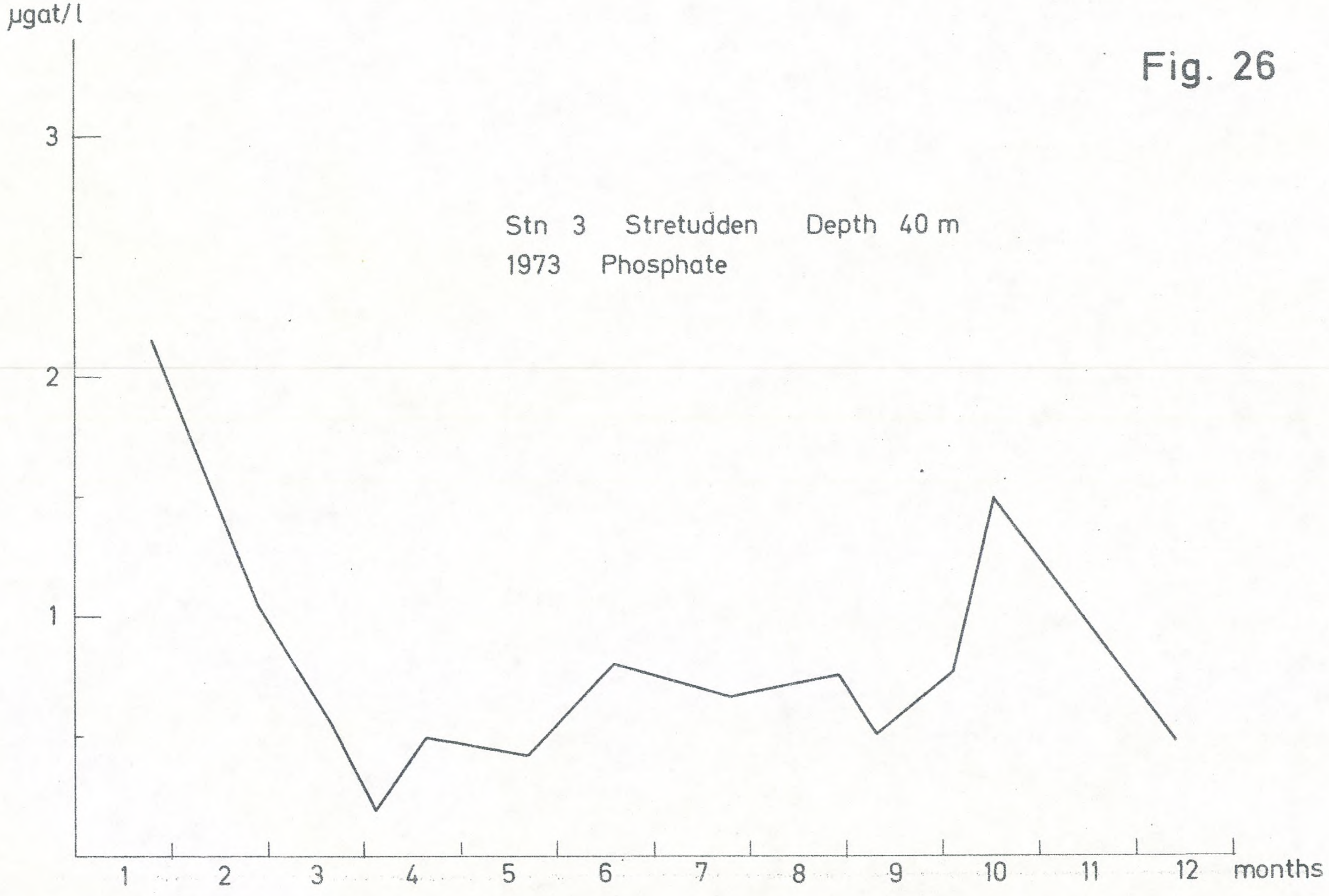

Stn 3 Stretudden
1973 Salinity

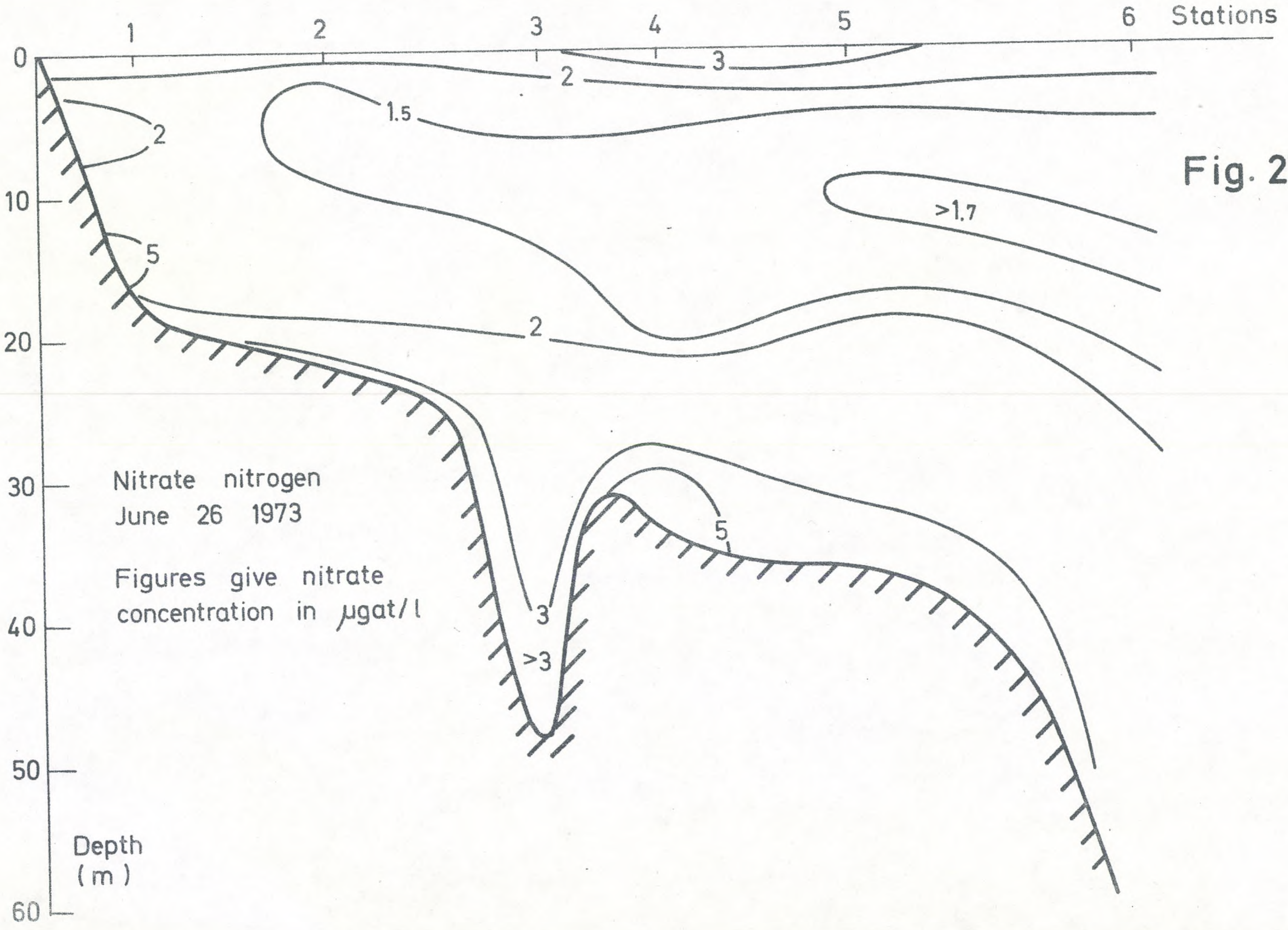
Fig. 26



Stn 3 Stretudden Depth 40 m

1973 Phosphate

Fig. 27



Nitrate nitrogen
June 26 1973

Figures give nitrate concentration in µgat/l

```
 MALMÖ DRAG               LAT: N 50 18 30  LONG: E 11 20 30

LOCAL DATE AND TIME   GREENWICH MEAN TIME  WIND WIND   CLOUD   WAVE      AIR       SECCHI PROD:START DURAT
YEA MON DAY HOU MIN                        DIR. VEL.   COVER   HEIGTH    TEMP      DEPTH        HR MT HR MT
 78  12  09  02  45   78  12  09  01  45   E    8 M/S NO OBS   NO OBS    1,0 C

DEPTH TEMP. OXYG % SAT  A.O.U SALT  PO4P TOTP ORGP NO3N NO2N BOTH NH4N SUMN TOTN ORGN SIGMA SOUNDV STABIL.
  M   CELS. ML/L        MA/L  0/00  MA/L MA/L MA/L MA/L MA/L MA/L MA/L MA/L MA/L MA/L        M/S

  0    5.6                   30.700                                                   24,23  1468,5
  3,5  5.8                   31,000                                                   24,44  1469,7    61,0
  8,9  6.0                   31.000                                                   24,42* 1470,6    -4,3
 17,8  6.0                   31,400                                                   24,74  1471,3    35,4
 26,7  8,4                   33,300                                                   25,90  1483,2   131,0
 41    8.7                   34.400                                                   26.72  1486.0    57.0

DEPTH    OIL  FEN ORGC YEL. PH  CPROD NETPR CORPR NETCO CARB  SUMN ORGN TOTN CARB/ ORGC/ TOTC/ MEAN MEAN
  M      MG/L MIG MG/L          MGC/QMH                 MG/L  /PO4 /OP  /TP  PO4P  ORGP  TOTP  N/P  C/P

  0
  3,5
  8,9
 17,8
 26,7
 41

* = UNSTABLE DENSITY STRATIFICATION
NOTE:  DATA OBTAINED FRCM THE GUNSHIP  *ALFHILD*IN 1878
 SALINITY VALUES ARE REVISED
```

Fig. 28

Fig. 29

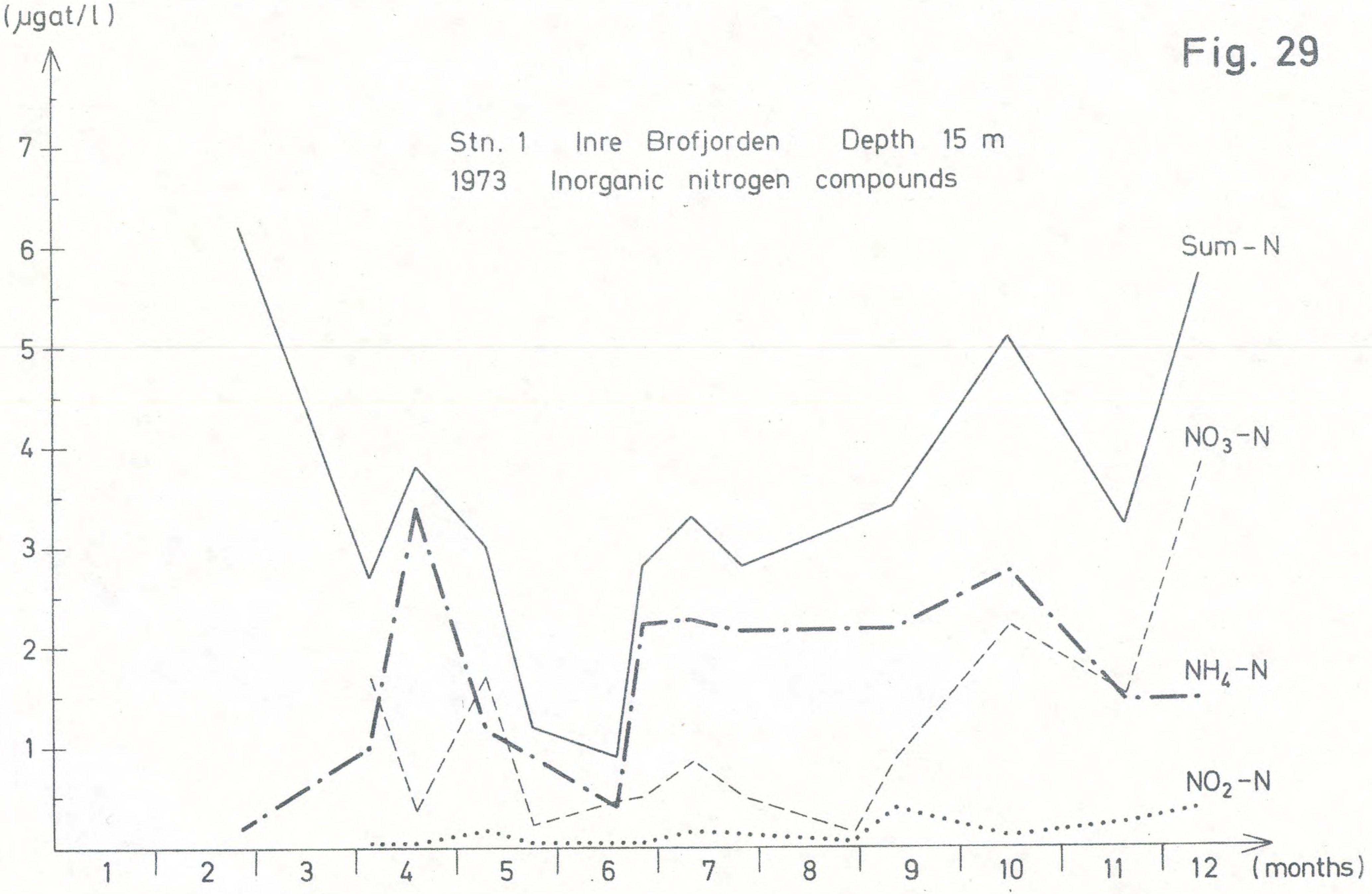
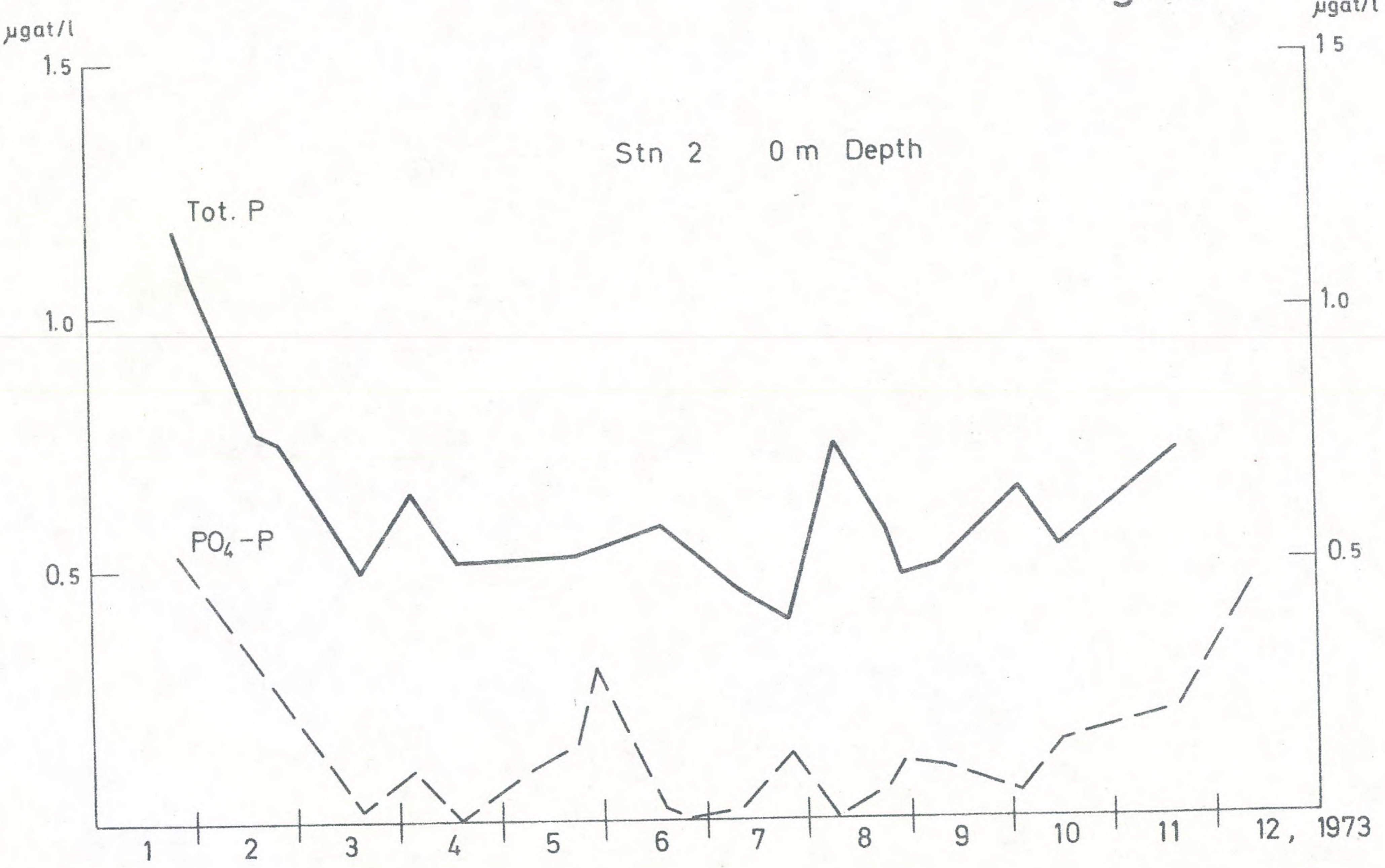

(µgat/l)
Stn. 1 Inre Brofjorden Depth 15 m
1973 Inorganic nitrogen compounds
Sum-N
NO_3-N
NH_4-N
NO_2-N
7
6
5
4
3
2
1
1
2
3
4
5
6
7
8
9
10
11
12
(months)

Fig. 30


Stn 2 0 m Depth
Tot. P
PO_4-P
μgat/l
1.5
1.0
0.5
μgat/l
1 5
1.0
0.5
1
2
3
4
5
6
7
8
9
10
11
12 , 1973

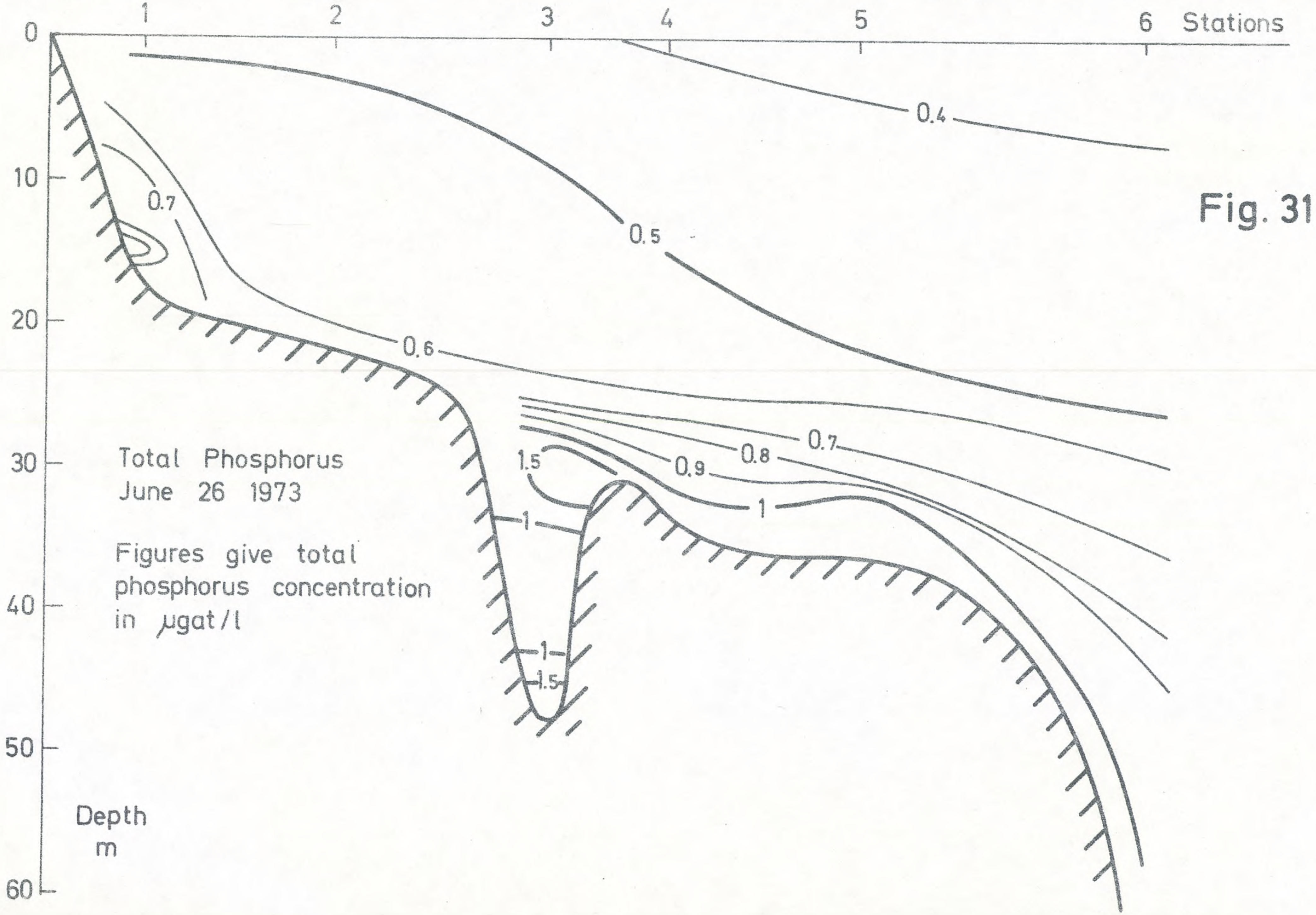


Fig. 31

Total Phosphorus
June 26 1973

Figures give total
phosphorus concentration
in µgat/l

Fig. 32

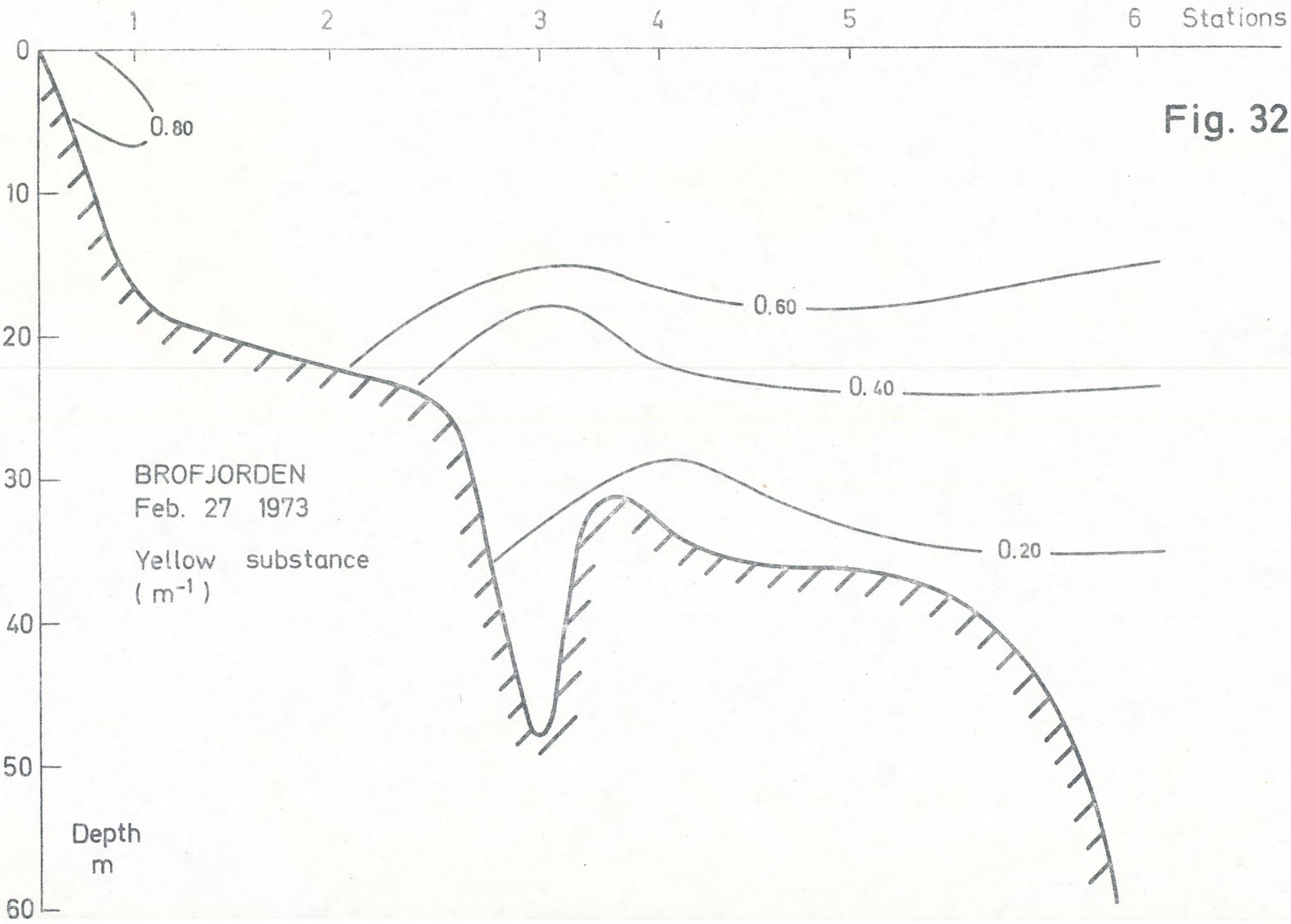

Stations
1
2
3
4
5
6
0
10
20
30
40
50
60
Depth
m
0.80
0.60
0.40
0.20
BROFJORDEN
Feb. 27 1973
Yellow substance
(m⁻¹)

Fig. 33

Stn 5 Malmö drag
1973 Relation between salinity
and yellow substance

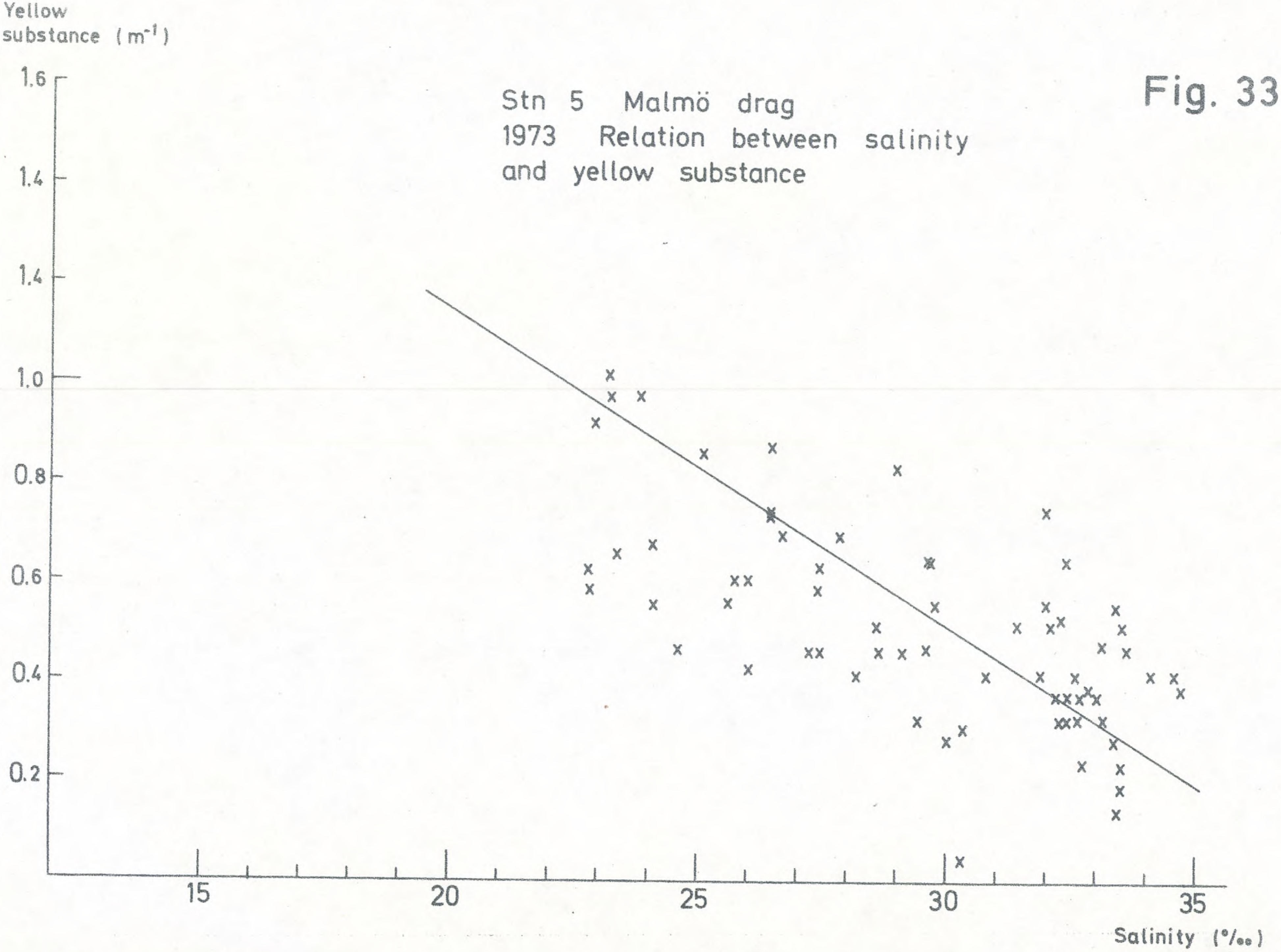
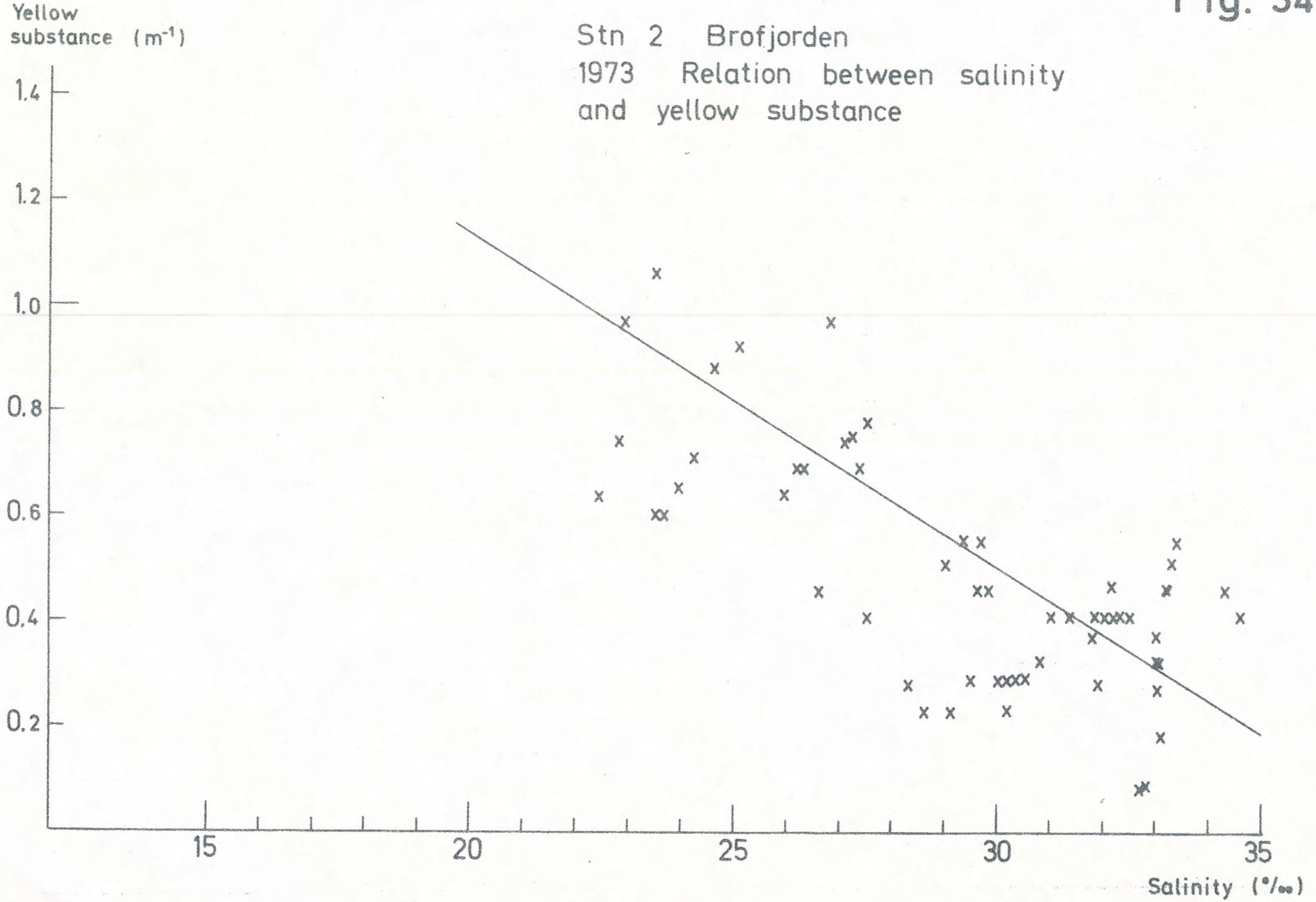
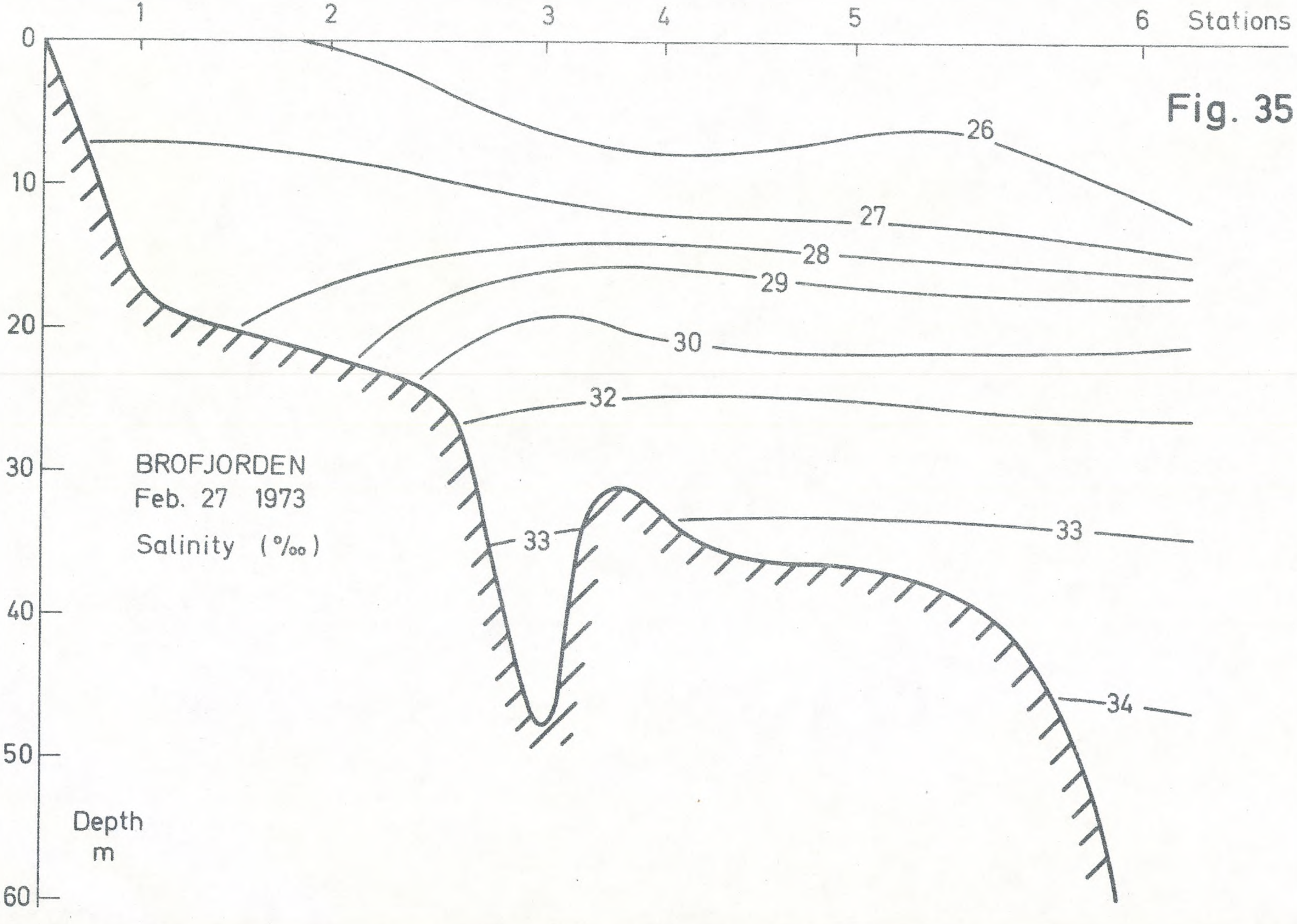


Fig. 34



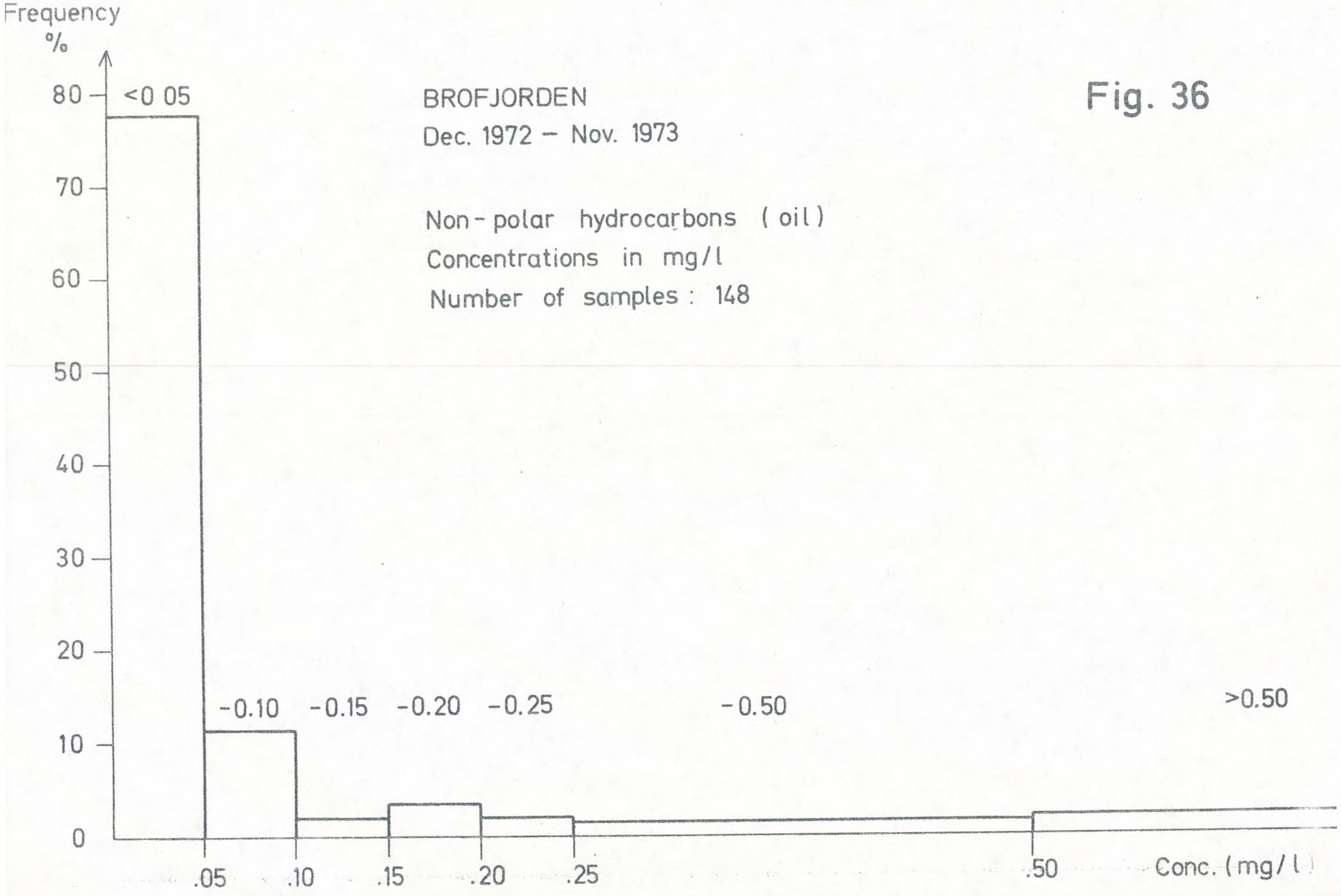
Stn 2 Brofjorden
1973 Relation between salinity
and yellow substance

Fig. 35



BROFJORDEN
Feb. 27 1973
Salinity (‰)
Stations
1
2
3
4
5
6
Depth
m
0
10
20
30
40
50
60
26
27
28
29
30
32
33
33
34

Fig. 36


BROFJORDEN
Dec. 1972 – Nov. 1973
Non-polar hydrocarbons (oil)
Concentrations in mg/l
Number of samples : 148
Frequency %
80
70
60
50
40
30
20
10
0
<0 05
-0.10
-0.15
-0.20
-0.25
-0.50
>0.50
.05
.10
.15
.20
.25
.50
Conc. (mg/l)