Ödsmål, Kville sn, Bohuslän

Hällristning
Fiskare från
bronsåldern

Rock carving
Bronze age
fishermen

MEDDELANDE från
HAVSFISKELABORATORIET · LYSEKIL nr 234
Hydrografiska avdelningen, Göteborg

AERIAL PHOTOGRAPHY OF COASTAL WATERS
Some results from a test at Brofjorden on the Swedish west coast.

by

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AERIAL PHOTOGRAPHY OF COASTAL WATERS - an approach towards spectrally differentiated photography for increased information of water and bottom properties. SOME RESULTS FROM A TEST AT BROFJORDEN ON THE SWEDISH WEST COAST.

C O N T E N T S

INTRODUCTION

For all time algae have been used by man. In Sweden they have been utilized as soil-improvement but only to a minor extent. Elsewhere, the interest for algae and algal products such as alginates, agar and pharmaceutics has increased drastically. Today "Sweden is the only industrialized country with rocky shores which has no seaweed industry whatever" (Michanek 1975).

The resources of algae in Sweden are less known, a regrettable fact bearing in mind that these soon must be utilized.

The algal vegetation clearly reflects the state of the environment and if this changes, the vegetation will also change with respect to the composition of species, their abundance and extension. A well known circumstance is, for example, the powerful growth of green algae in eutrophic waters.

The eel-grass, Zostera marina, is common in calm bays at a depth of 0.5-8 m, where it often forms big fields with long "grass", and these so called Zostera meadows are enormously high in production and form a "children's nursery" of vital importance for many of our most essential fish for food. These ecologically important meadows have not been mapped in a satisfactory way with earlier methods.

These were some of the reasons for trying aerial photography in order to document the vegetation of coastal waters. Another phenomenon that hopefully could be studied by aerial photography is the spatial arrangement of phytoplankton, the so called patchiness.

A suitable test site was available at Brofjorden on the Swedish west coast, since this area had recently been thoroughly investigated before the establishment of an oil refinery, and the conditions there are fairly well known.

It was also thought that the continuous outlet of oil from the refinery (approved by the water court) could be studied.

Under these premises an application was submitted to the Swedish Board for Space Activities, and a grant was returned to provide the necessary means for a pilot project in accordance with the ideas outlined above.

METHODS

Two flight registrations were made simultaneously with ground truth investigations. The first occasion was on September 3, 1976 and the second one on May 27, 1977. The photographic equipment was a set of four parallel and vertically-mounted Hasselblad cameras with a device for simultaneous exposures. The altitude was 750 meters, giving a true length of approximately 400 meters of the side of the picture. To allow stereo-effect studies there was a 60% overlapping of subsequent pictures. The exposure time was 1/125 or 1/250 of a second and the lens opening was 4 for all exposures.

In order to obtain better information, the cameras were supplied with filters. See Table 1.

Table 1. Film types and filters.

Camera No	Filmtype	Filter	Approximate transmitted wavelength interval (nm)
1	Black and white panchromatic, Kodak Plus -X 5062	Wratten 58	500-600
2	Color film Kodak Aerocolor neg. 2445	(No filter)	400-700
3	Color Infrared sensitive film Kodak Aerochrome IR 2443	Wratten 12	500-900
4	Color Infrared sensitive film Kodak Aerochrome IR 2443	1:st reg.: Wratten 58	500-600 and 700-900
		2:nd reg.: Wratten 25	580-900

Motives for the choice of films and filters were the following:

1. Chlorophyll patchiness should be recorded as differences in gray tone level on black and white film, allowing a numerical interpretation by reading the optical density of the film on a densitometer. The film is sensitive to green light, and the filter was applied to take away disturbing light intensity, especially in the blue region where there normally is a considerable amount of light from the sky reflected back by the sea surface.

2. An unfiltered true color picture was considered essential for the interpretation of the information contained in the material. The film was overexposed one to two steps to increase the visual penetration into the water.

3. and 4. The infrared color film was intended to record the benthic algae and also the oil slicks, if any, on the sea surface. The penetration into the water is less in the infrared region, but the oil is usually initially present at the surface. Positive infrared color film is known to give a good contrast of plant chlorophyll, which appears bright red. The film itself is sensitive to infrared light up to approximately 900 nm.

Ground truth investigations of the water were made simultaneously with the flight observations.

For the interpretation of the photos in respect of the benthic vegetation, profiles of the plant distribution in an earlier investigation were used. These ground truth informations were completed with mappings of two new areas chosen after studying the photos.

GROUND TRUTH ("Sea truth")

Ground truth parameters were: salinity, temperature, dissolved oxygen, secchi depth, chlorophyll a, carotenoids, extractable organic substances, mineral oil and yellow substance. Samples for quantitative and qualitative analysis of phytoplankton were also taken. These ground truth data were used to calibrate the information provided by the pictures. There were 25 ground truth stations and their positions can be seen on the map on page 15.

At the first registration samples were taken from the surface and from 2.5 m depth, and at the second from 2.5 m depth. At both registrations samples were also taken at the surface, 2.5, 5, 10, 15 and 20 m depth at Vert 2 and Vert 5.

Methods for the analysis of salinity, temperature, dissolved oxygen, extractable organic substances, mineral oil and yellow substance are those routinely applied by the Fishery Board of Sweden, listed in Carlberg (1972). Secchi depth was measured with a white disc of 25 cm diameter. A plain glass viewer was used. Chlorophyll and carotenoids are analysed after Strickland & Parsons (1972). Phytoplankton species are mainly named according to Heimdal et al. (1973).

The investigation of the benthic vegetation was made in two areas around the old benthic stations Bro 1 and Bro 5. See map on page 15.

PHOTOGRAPHIC ALTERATIONS

The large number of pictures, delivered by The National Land Survey of Sweden in Gävle who were responsible for carrying out the aerial photography, were in the form of negative film material. For some purposes positive film was required, especially for the IR-registrations where chlorophyll stands out clearly as bright red with a good contrast to the paler surroundings. In some instances a lower optical density of the entire positive picture was achieved by manually changing the exposure time in order to get a better separation of dark tones in the water and thereby increasing the depth penetration. Such a weakening of the pictures meant a corresponding loss of information for the land, which of course is of no importance in this analysis.

SUB-SURFACE STEREO EFFECT

An attempt was made to better define groups of benthic algae on the bottom by using a stereographic viewer. It turned out, however, that the stereo effect to a large extent was lost in the water, probably due to the different light refraction. Whereas hillsides on land stood out beautifully in all details, the continuous slope which forms the sea bottom was fuzzy and undetermined below the water surface. Some use of the stereo effect could be made, such that a boat or other drifting objects (hopefully also drifting algae) could be seen as hanging freely at the surface and at a distance from the bottom. Loose rolls on the bottom and bunches of algae reaching some meters above the bottom could not be seen clearly, however, and any advantage in this case of stereo over single pictures was not obvious.

DENSITOMETRY

On a series of pictures over the free water surface (flight strip B) a densitometric determination was made on a MacBeth TD 504 at centre of pictures. This equipment is useful to digitalize the photographic information and the resolution is far better than that which can be achieved by the eye. The densitometer values were used for a comparison mainly with the chlorophyll content of the free water, but also with carotenoids and secchi depth.

DENSITY SLICING

Some of the photographic material was used for a density slicing on the equipment at the Geographic Institution, University of Lund. Through this equipment it was also possible to get a continuous density graph of a line across the picture. The density graph was partly corrupted by the difference in light intensity between centre and outer parts of the picture. The attempt to apply density slicing to the material was therefore not very successful. Some improvement for observing patchiness could be noted, however, and the method was to a certain extent helpful when mapping the Zostera meadows.

RESULTS

The results of the project are somewhat difficult to present, being in the form of a large number of photographs which are expensive to reproduce.

The following is a description of the photographic results together with a presentation of ground truth information.

Ground truth

The ground truth investigation has a value of its own, e.g. for future comparisons, and all data concerning the pelagic conditions are presented on pages 40-44.

Benthic vegetation

The extension of algal belts in shallow water have been best recorded on the true-color film (camera no 2) and on the infrared-sensitive (IR) film, Wratten 12 filtered (camera no 3). To separate different species and communities was very difficult, mainly because the bigger algae were often mixed together and usually covered with filamentous species, mainly red algae. Moreover, the strongly pigmented algae also contrasted poorly with the dark granite bottom.

However, rocky bottoms were easy to identify because they often ended in a light sand bottom without vegetation. As the Zostera meadows appeared some meters from the rocky bottom, it was easy to map this bottom as well as the Zostera meadows themselves. (Fig. on page 24.)

At the first registration the transparency was greater than usual and it was possible to follow the hard bottom with vegetation down to the soft bottom within the whole area. Only the deepest hard bottoms could not be seen. However, the production from these depths is not very high. (The large brown algae were, for example, not found below 4 m.)

At the second registration the surface was 0.2-0.3 m beneath mean water level (see Table 2), and the brown algae Fucus vesiculosus and Ascophyllum nodosum reached the surface. They were rich in epiphytes and on the positive IR photos they could be seen as red and distinct parts. At the first registration these communities were to a large extent covered with water, and therefore all parts were not recorded as red areas and thus difficult to assess.

Table 2. Water level.

Date	Time	Water level (cm)* Smögen (10 km V Brofjorden)	Water level (cm)* Tjärnö (60 km N Brofjorden)
1976-09-03	11	+ 20	+ 26
	12**	+ 24	+ 33
	13	+ 24	+ 36
1977-05-27	16	- 19	- 17
	17**	- 24	- 22
	18	- 27	- 23

*0 = mean water level

** = time for registration

Thus it should be noted that algae at the water surface can be recorded as red on the positive IR-film, regardless of their apparent color to the eye. That means in turn that the actual water level has a great influence on the result.

Hence algal vegetation was difficult to map while it was rather easy to map hard bottom surfaces covered with algae. However, earlier investigations in this area have shown that the vegetation almost exclusively depends on depth and exposure to waves and was in rough outline in Brofjorden as follows:

0 - 0.5 m:	Fucus vesiculosus. On sheltered parts: Ascophyllum nodosum. On parts strongly exposed to waves: Polysiphonia brodiaei and/or Ceramium spp.
0.5 - 2 m:	Fucus serratus. (Lower part (1-2 m) mixed with Laminaria saccharina and L. digitata.)
2 - 3.5 m:	Laminaria. (Laminaria saccharina - dom. and L. digitata.)
>3.5 m:	Mixture of mainly red algae: Furcellaria fastigiata, Chondrus crispus, Corallina officinalis, Phyllophora spp., Cermium spp., Brongniartella byssoides and Bonnemaisonia hamifera.

See also fig. on page 24.

The Zostera meadows have been best recorded on the black-and-white film and on the true color film.

At the first registration when the transparency was greater than usual the Zostera meadows were very well developed and appeared as dark areas over a light bottom. Only in parts where the Zostera went down to 7-8 m, it was difficult to see its whole extension.

At the second registration the transparency was several meters less than usual and the Zostera, which just had started its vegetation period, was undeveloped. It could be seen excellently at 3-4 m depth but how far down it went could not be established.

Density slicing was tested when mapping the Zostera meadows and proved to be a good technique, but gave not so much additional information.

(The extension of the Zostera meadows in shallow water showed an amazing similarity at the two registrations.)

The Zostera does not extend deeper than to the normal secchi depth of the place where it grows. This means that, with this kind of remote sensing technique, it is possible to map Zostera meadows everywhere on the Swedish west coast under the following prerequisites: the secchi depth at the registration is preferrably greater than usual for the place, the Zostera is well developed (=autumn) and the bottom makes a sufficient contrast. At the first registrations these conditions were fulfilled and it became possible to map the Zostera meadows for one of the areas on the Swedish west coast which is most abounding in fish.

With maps over hard bottoms drawn after aerial photographs, good maps of the depths and a perspicuous knowledge of the vegetation, it is possible to construct maps for the most important vegetation communities in coastal waters. Maps drawn in this way are shown in figures on pages 32 and 33.

When comparing the results with other investigations it should be noted that water vegetation then often means reeds and other fanerogams, which grow on the bottom but have their main parts above the water surface. What is recorded here is truly submersed marine vegetation.

Chlorophyll, carotenoids and phytoplankton

Ground truth data from the first registration showed an uneven distribution of most parameters whereas data from the second occasion showed an unusually uniform distribution. At both registrations the chlorophyll concentration was highest at a depth of 10 m. (Perhaps the halocline there had caught the plankton from an earlier algal bloom at the surface.) The aerial registrations, however, mainly showed the conditions near the surface. After studying the figures on pages 28 and 29 it would seem possible to take the values from the surface and 2.5 m depth and correlate with the photographs.

In order to record phytoplankton chlorophyll distribution in the upper part of the free water column the Panchromatic black-and-white film was used. The Wratten 58 filter was used to take away all wavelengths below 500 nm, that is, to avoid blue color influence. The optical density, at the center of all pictures was measured by a densitometer. The result is presented in the graph on page 30. A comparison with the ground truth distribution of chlorophyll at the surface, presented on the map, page 31, shows a very good resemblance with the picture interpretation.

Whereas benthic algae normally change seasonally and only slightly, the pelagic chlorophyll shows a more momentary picture with diurnal variations and changes taking place with a time scale of days when parcels of water containing the plankton algae are exchanged. Pelagic chlorophyll has to be recorded more frequently in order to provide information about the concentration over longer periods of time. The good agreement between ground truth and densitometer values is promising for the use of aerial remote sensing for quantitative chlorophyll determinations. Since chlorophyll concentration approximately can also be related to biomass and primary production of the water the method has a potential use for surveys of these parameters over large areas.

Carotenoids behaved almost in the same way as chlorophyll.

The results of the phytoplankton samplings from the first registration are shown on pages 34-39. It should be noted that the composition of plankton algae was almost the same for the whole area. The samples from Vert 2 and Vert 5 at the second registration showed an almost pure bloom of the dinoflagellate Dinophysis lachmanni. Thus, the differences that have been registered in the photos depend on differences in the number of cells and not on the composition of species.

Oil

Oil on the water surface has not been recorded with this technique, partly because it is not very sensitive to oil and above all because oil on the water was not present to any noticeable extent at the time of the registrations. For the amounts let out from the refinery, a photographic technique should not be recommended. A much more sensitive method for oil would be fluorescence recordnings after exitation with pulsed laser.

CONCLUSIONS

Aerial filtered photography can be used for the study of benthic algal communities but must be complemented by ground truth investigations. Under certain conditions the method is most suitable for the mapping of Zostera meadows. For studying pelagic chlorophyll and carotenoids the method is good, but for the detection of oil spills it will not add any further information to what can be seen from ordinary aerial photography.

LEGENDS TO FIGURES AND DATA SHEETS

Page

15 Map over Brofjorden with the flight strips A, B and C, and with the ground truth sampling stations indicated as small filled circles. The scale to the left of the strips indicates the geographic position of the (approx. centre of) pictures along the flight strips. (These picture numbers are also used for the catalog of pictures where the respective numbers are applied directly to each picture to avoid confusion.)

16 Secchi depth in meters on 1976-09-03. A plain glass viewer was used.

17 Oxygen oversaturation percentage on 1976-09-03.

18 Chlorophyll a concentration on 1976-09-03, surface values.

19 Ditto at 2.5 m depth.

20 Concentration of carotenoid pigments, 1976-09-03, surface values.

21 Ditto at 2.5 m depth.

22 Concentration of mineral oil at surface on 1976-09-03.

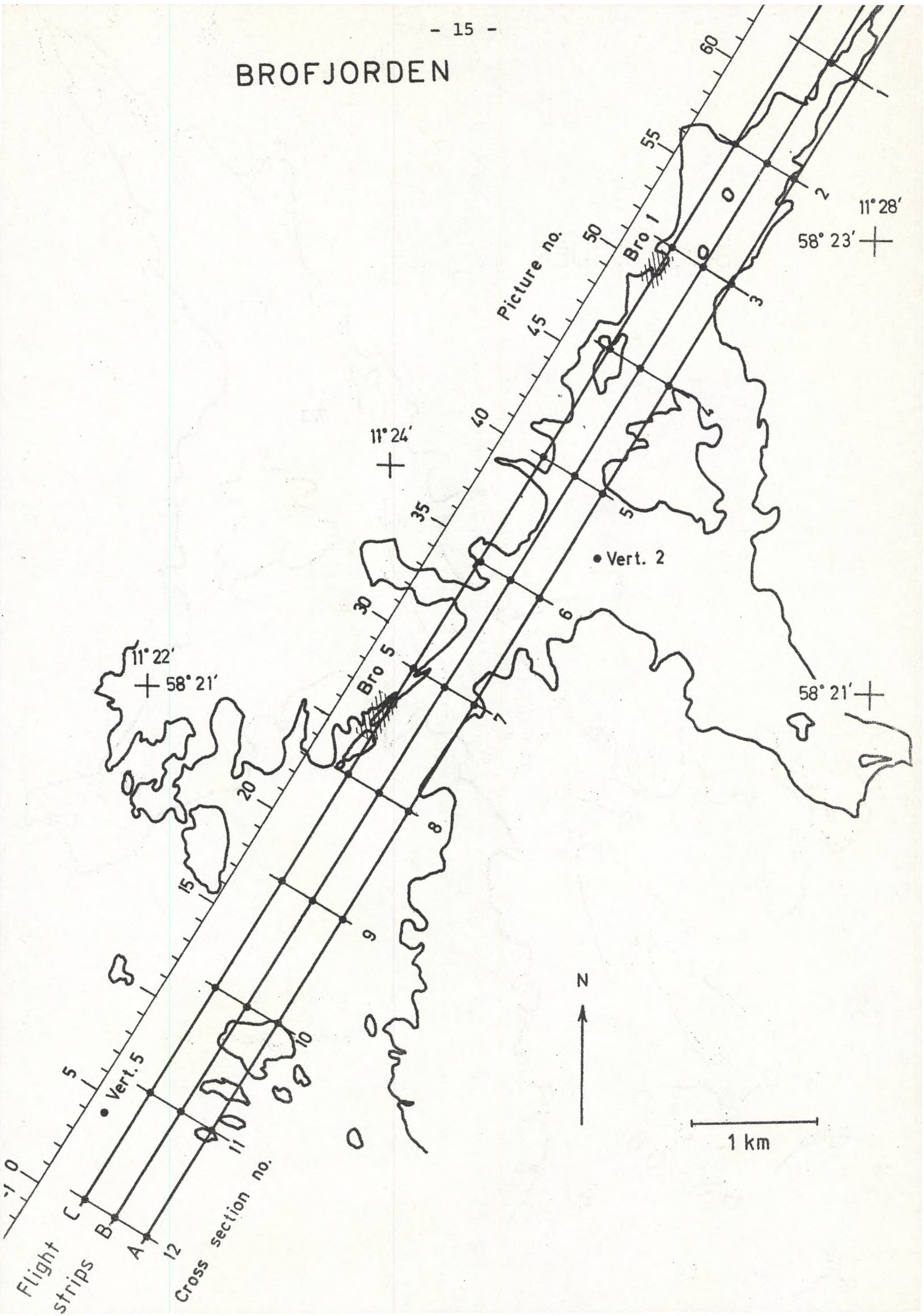
23 Yellow substance on 1976-09-03, 2.5 m depth.

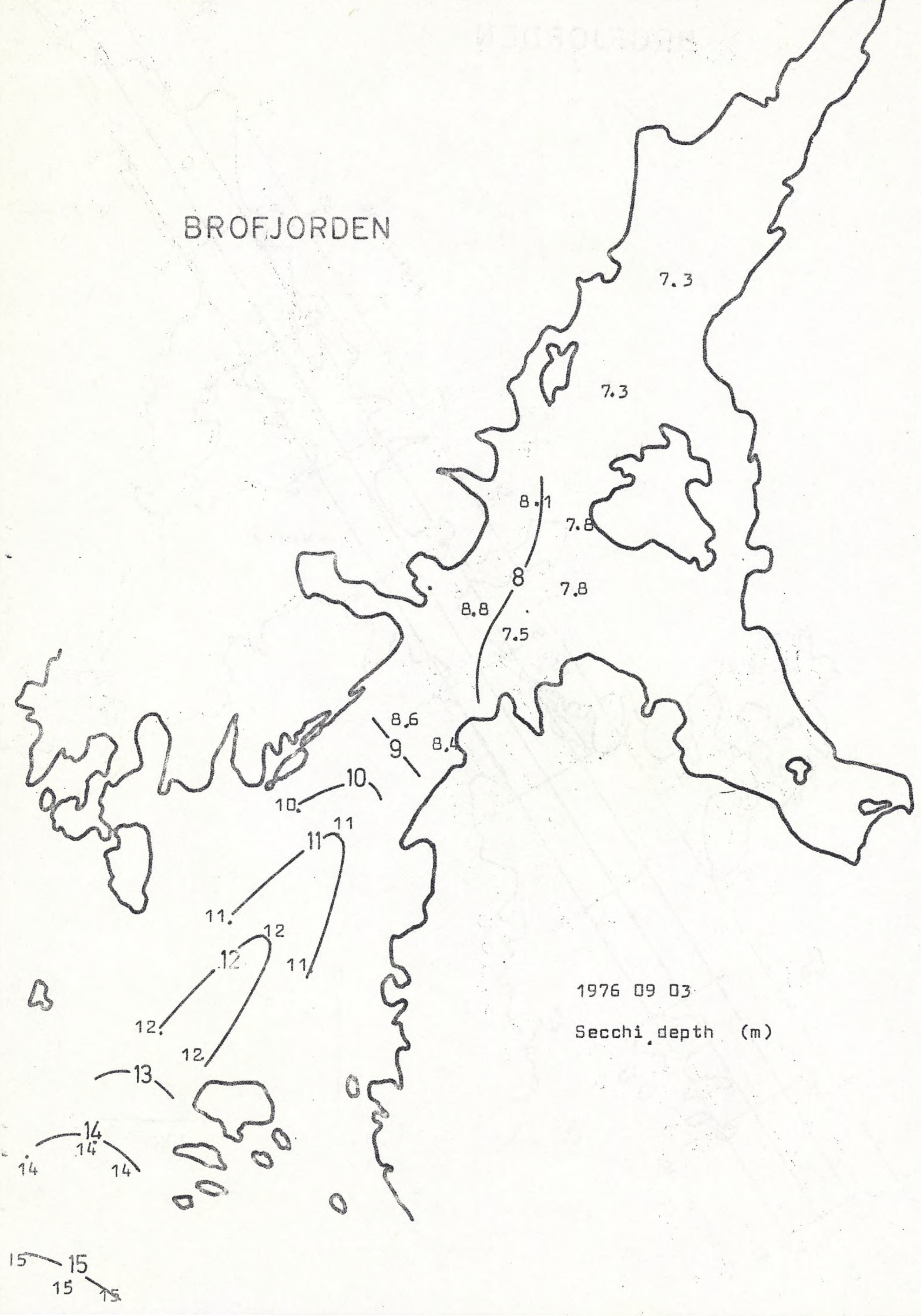
24 Schematic picture of the vegetation on a semi-exposed shore in Brofjorden.

25 Secchi depth in meters on 1977-05-27. A plain glass viewer was used.

26 Chlorophyll a concentration on 1977-05-27, 2.5 m depth.

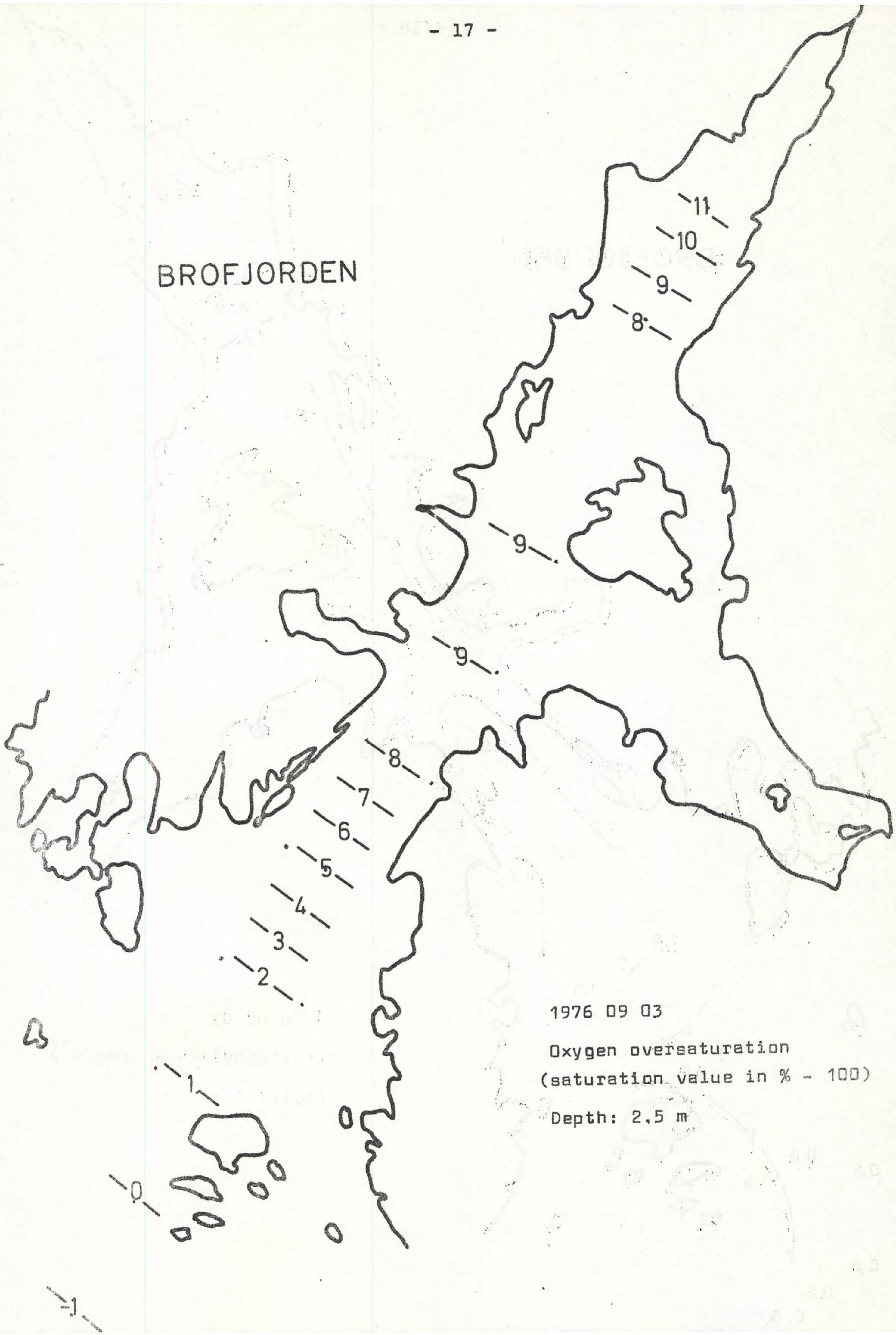
BROFJORDEN

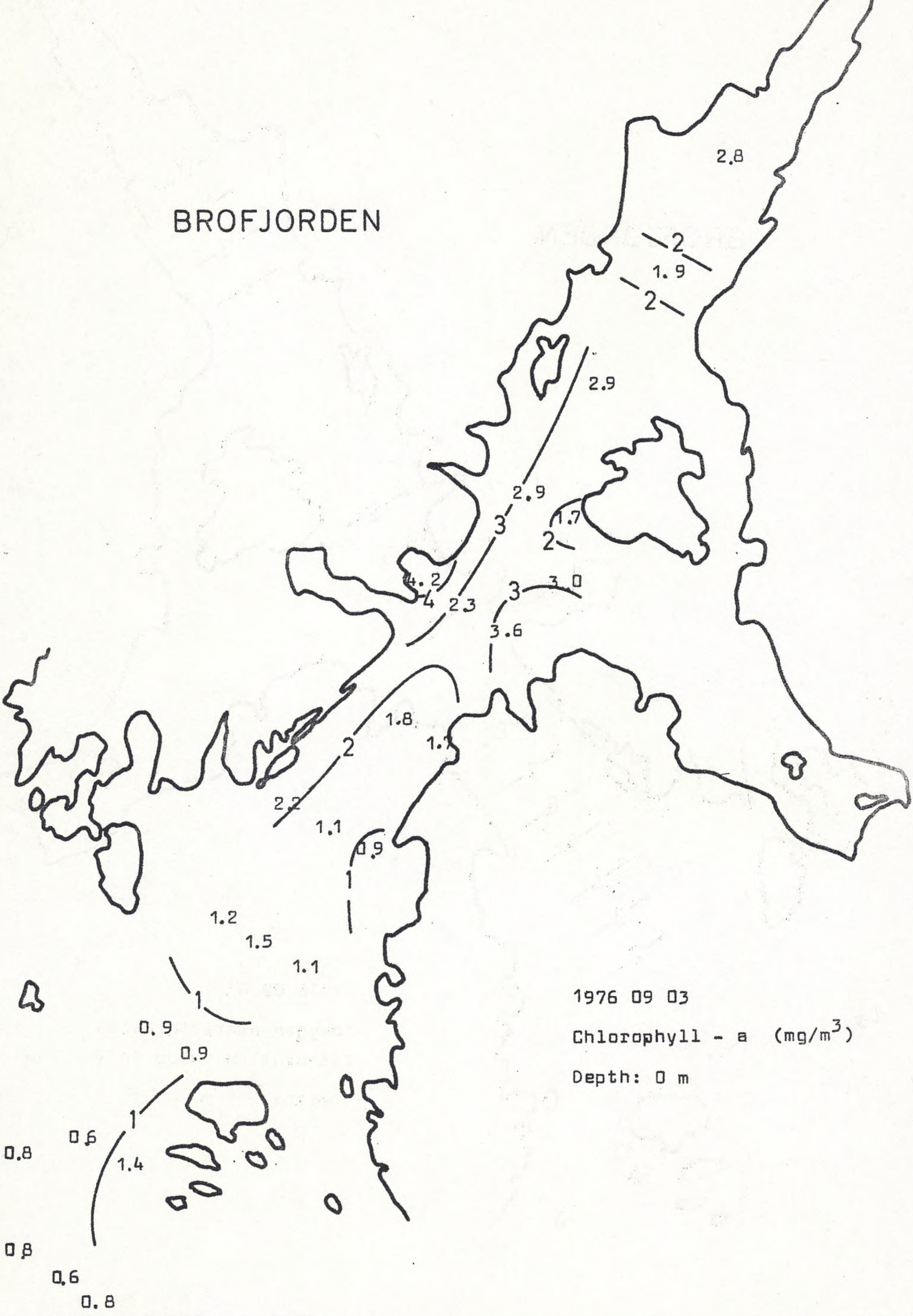

Picture no.
-1
0
5
15
20
30
35
40
45
50
55
60
Bro 1
Bro 5
Vert. 2
Vert. 5
11°28'
58° 23'
11°24'
11°22'
58° 21'
58° 21'
2
3
4
5
6
7
8
9
10
11
12
Flight strips
C
B
A
Cross section no.
N
1 km



1976 09 03

Secchi depth (m)

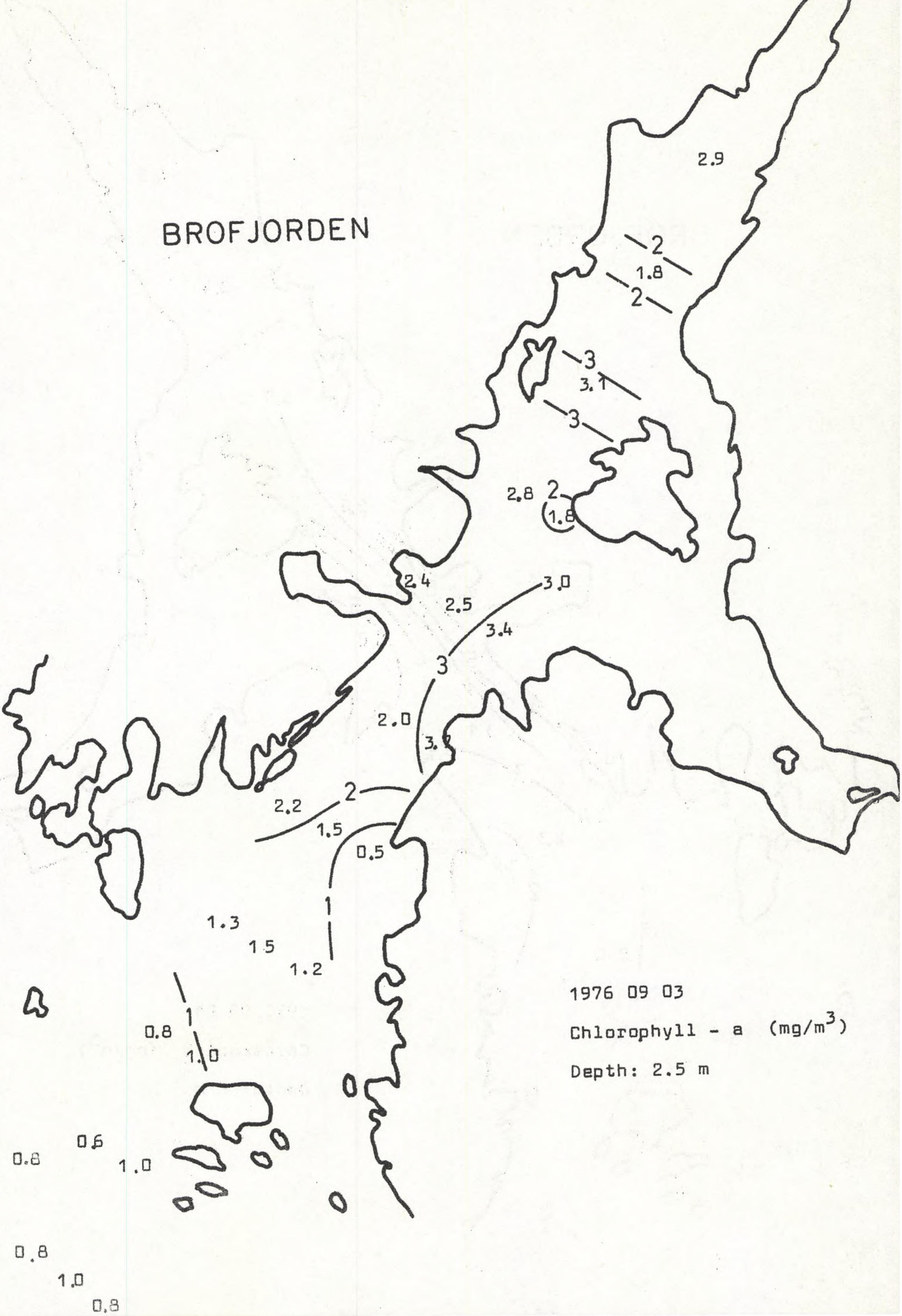

BROFJORDEN
11
10
9
8
9
9
8
7
6
5
4
3
2
1
0
-1
1976 09 03
Oxygen oversaturation
(saturation value in % - 100)
Depth: 2,5 m



1976 09 03

Chlorophyll - a (mg/m^3)

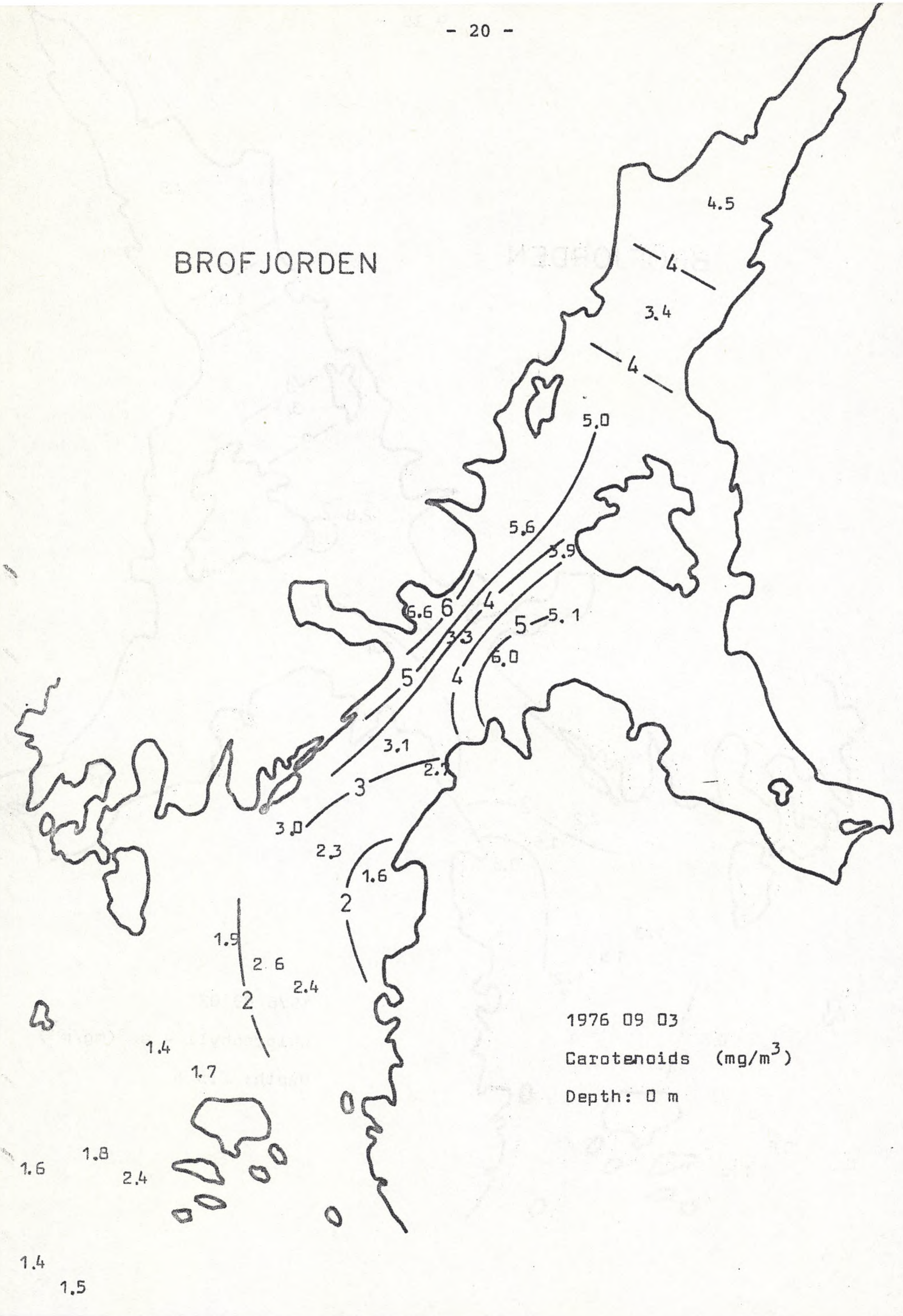
Depth: 0 m

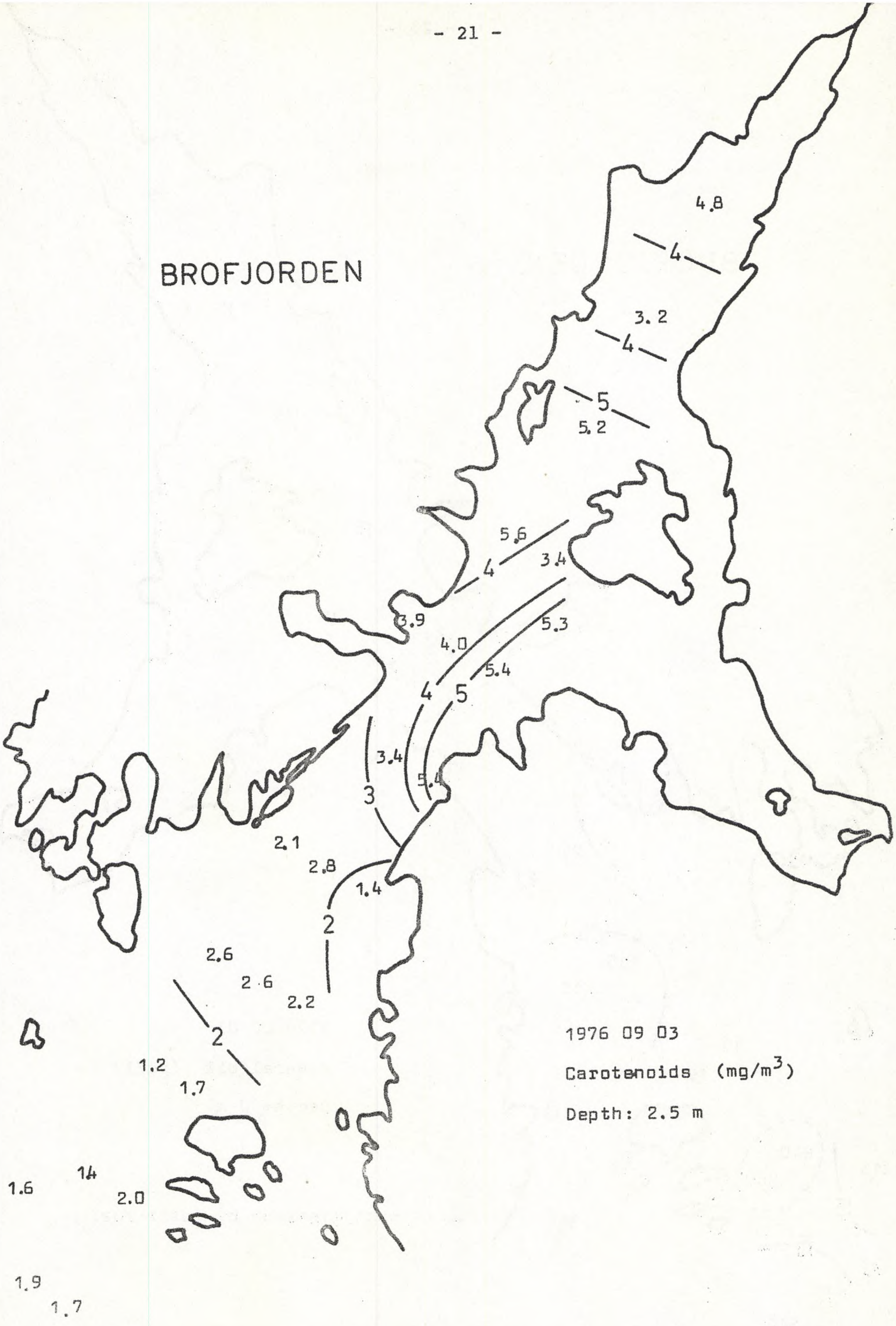


1976 09 03

Chlorophyll - a (mg/m^3)

Depth: 2.5 m


BROFJORDEN
4.5
4
3.4
4
5.0
5.6
3.9
6.6
6
4
5
5.1
3.3
6.0
5
4
3.1
2.7
3
3.0
2.3
1.6
2
1.9
2.6
2.4
2
1.4
1.7
1.8
1.6
2.4
1.4
1.5
1976 09 03
Carotenoids (mg/m3)
Depth: 0 m

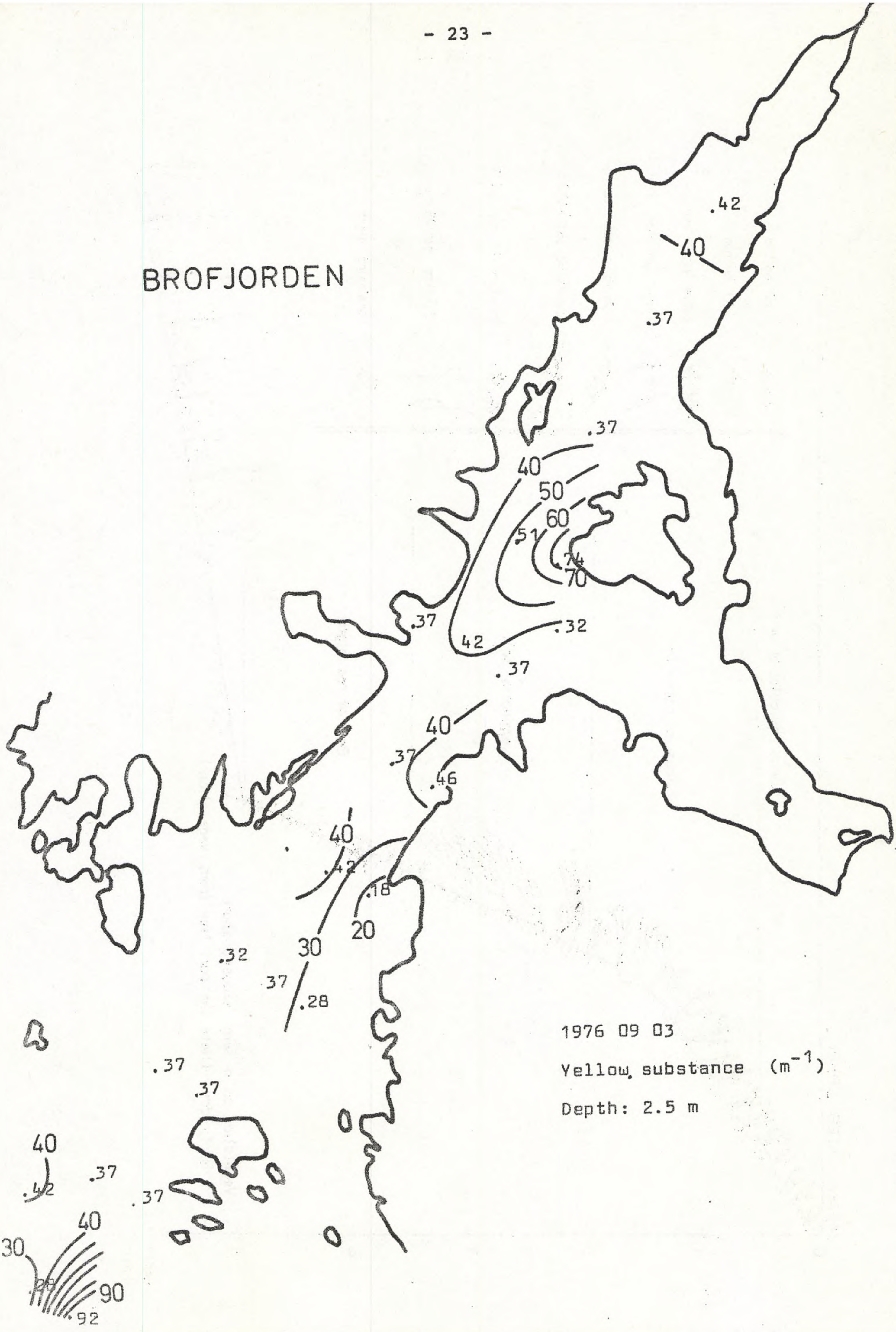


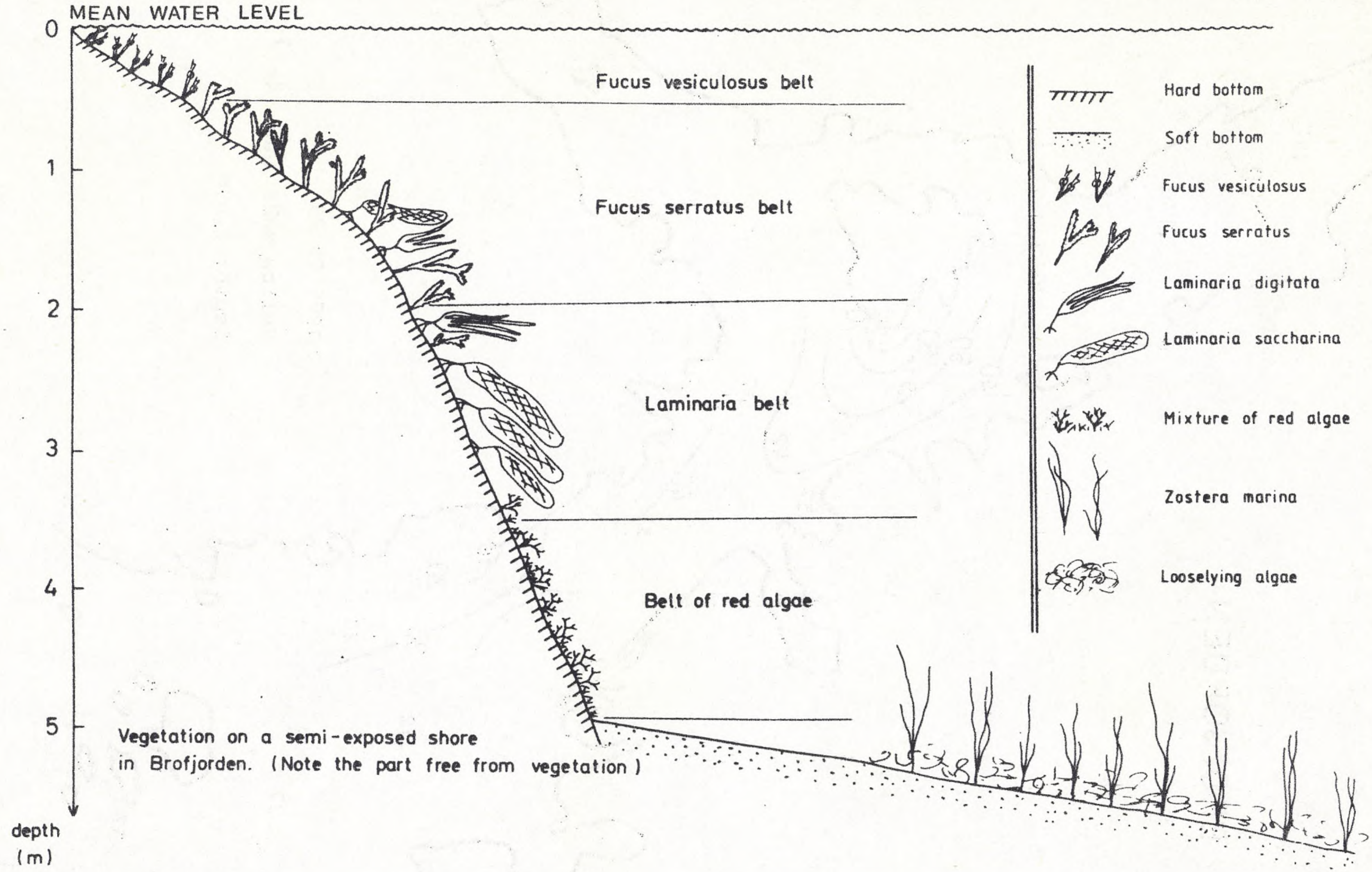
1976 09 03

Carotenoids (mg/m^3)

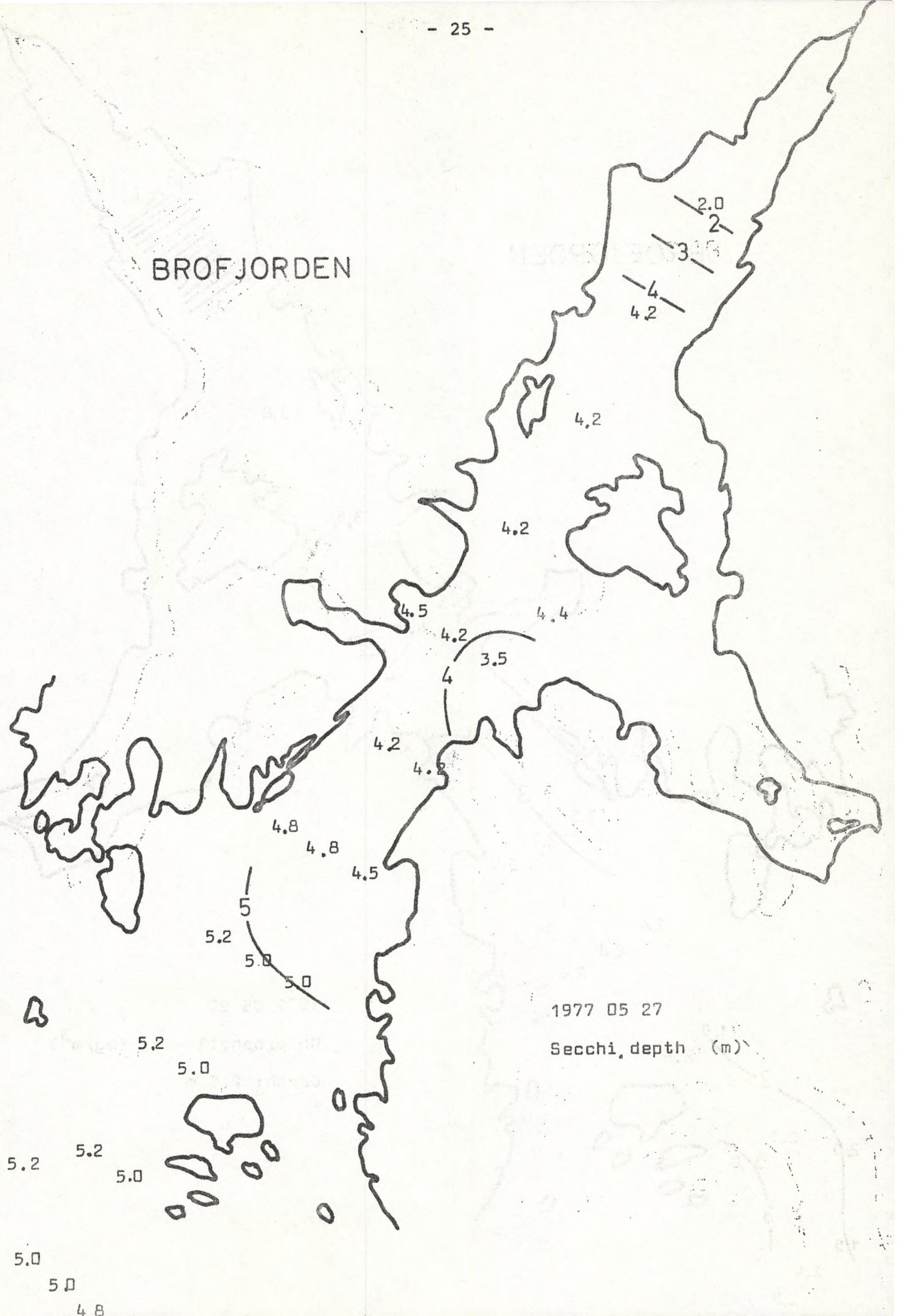
Depth: 2.5 m

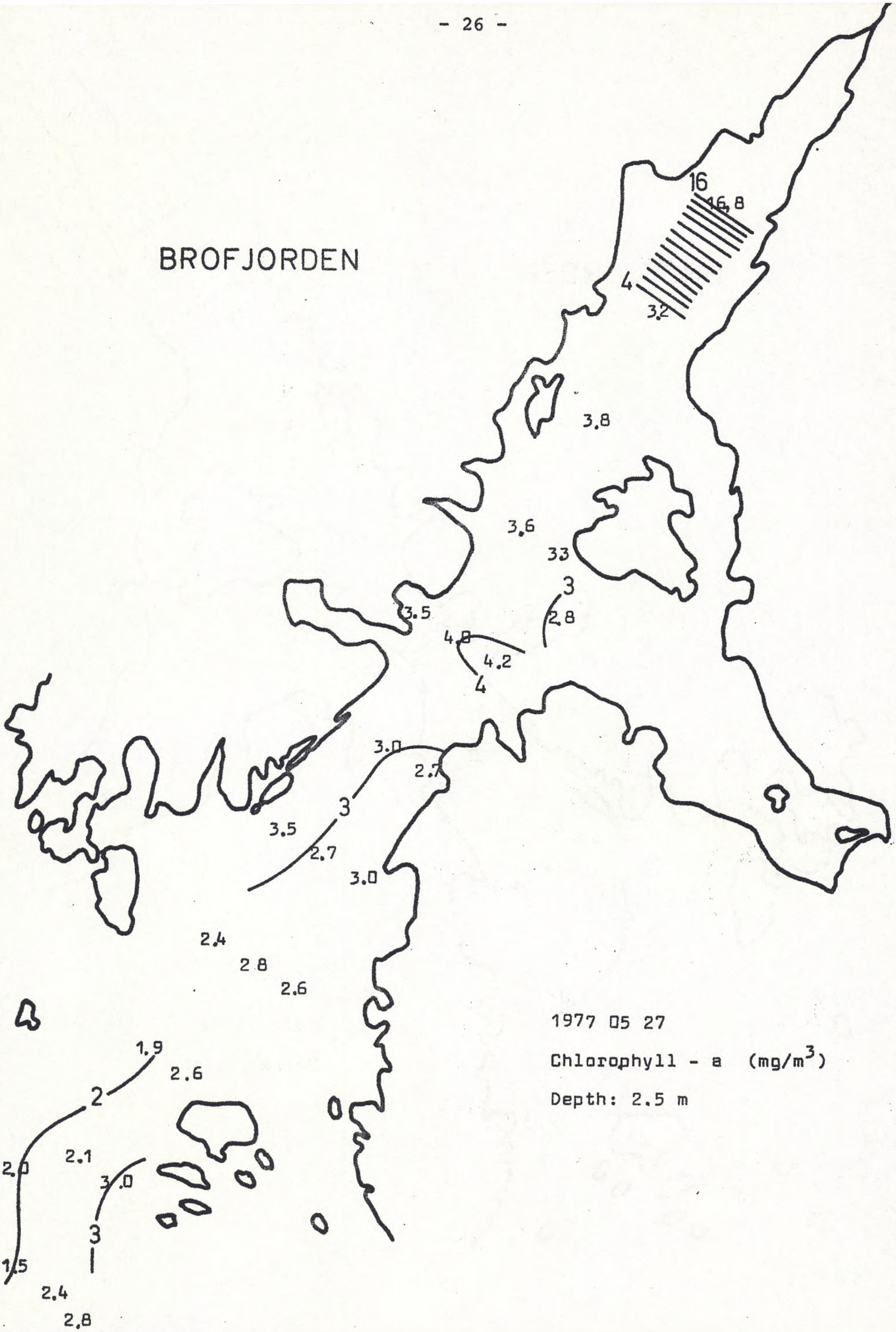

BROFJORDEN
<15
<15
<15
<15
<15
<15
<15
15
25
17
24
15
21
22
15
<15
<15
19
19
840
260
<15
15
15
33
<15
<15
1976 09 03
Mineral oil (µg/l)
Depth: 0 m
---- contamination by motor fuel


BROFJORDEN
.42
40
.37
.37
40
50
60
.51
.74
70
.37
42
.32
.37
40
.37
.46
40
.42
.18
20
30
.32
37
.28
.37
.37
40
.42
.37
.37
40
30
.28
90
.92
1976 09 03
Yellow substance (m^{-1})
Depth: 2.5 m



Vegetation on a semi-exposed shore in Brofjorden. (Note the part free from vegetation)

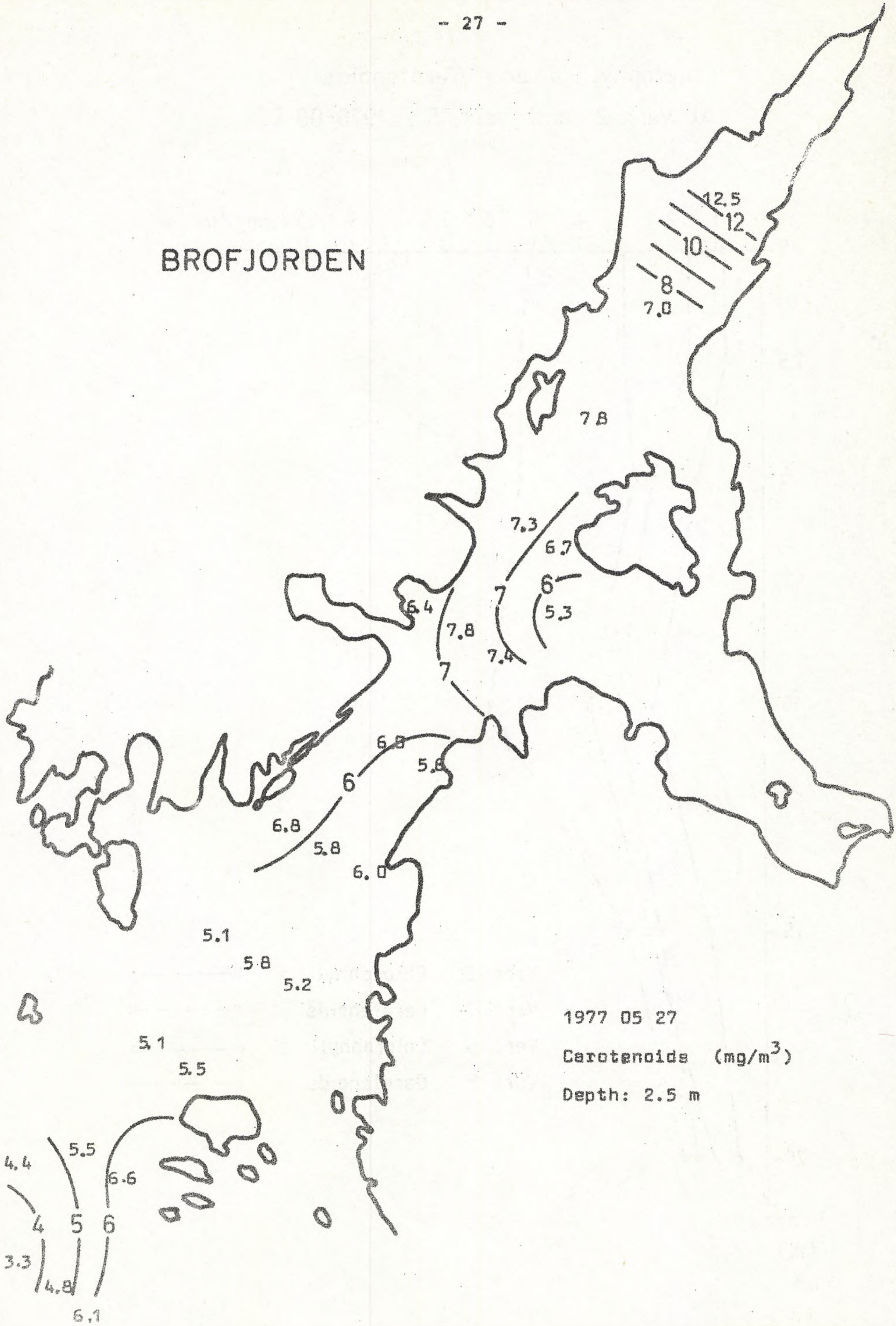

BROFJORDEN
2.0
2
3
4
4.2
4.2
4.2
4.5
4.4
4.2
3.5
4
4.2
4.2
4.8
4.8
4.5
5
5.2
5.0
5.0
5.2
5.0
5.2
5.2
5.0
5.0
5.0
4.8
1977 05 27
Secchi depth (m)



1977 05 27

Chlorophyll - a (mg/m^3)

Depth: 2.5 m

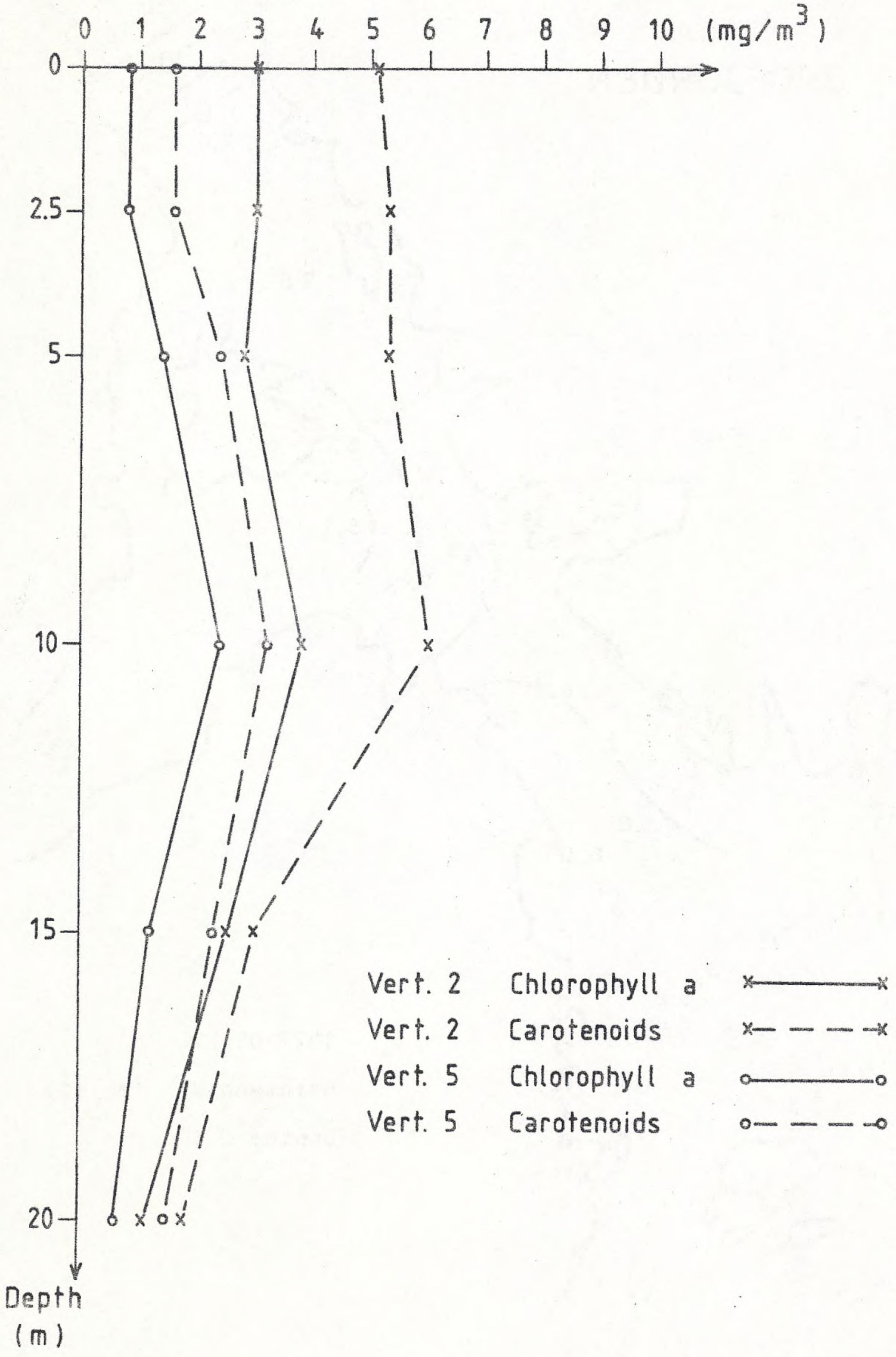


1977 05 27

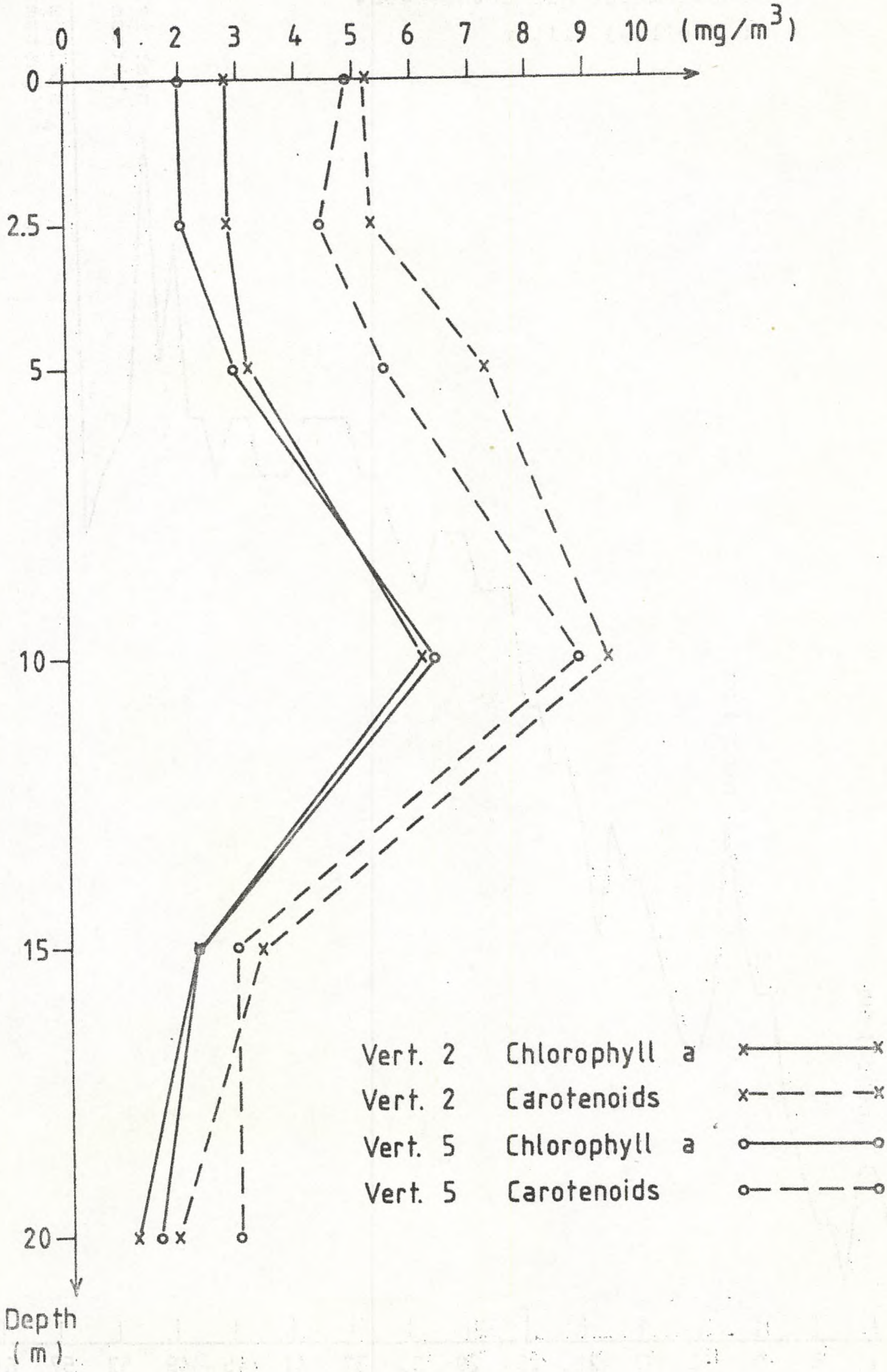
Carotenoids (mg/m^3)

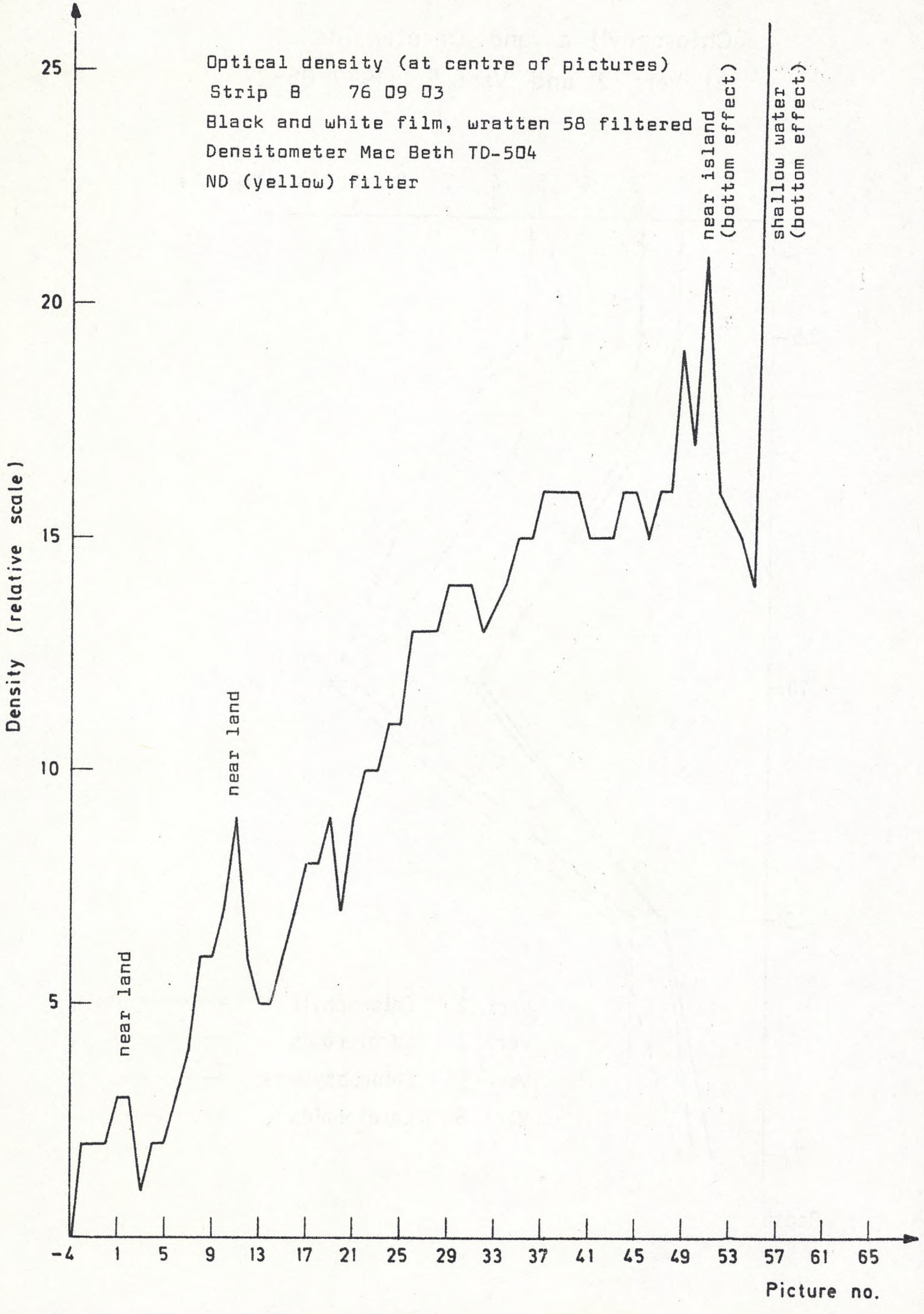
Depth: 2.5 m

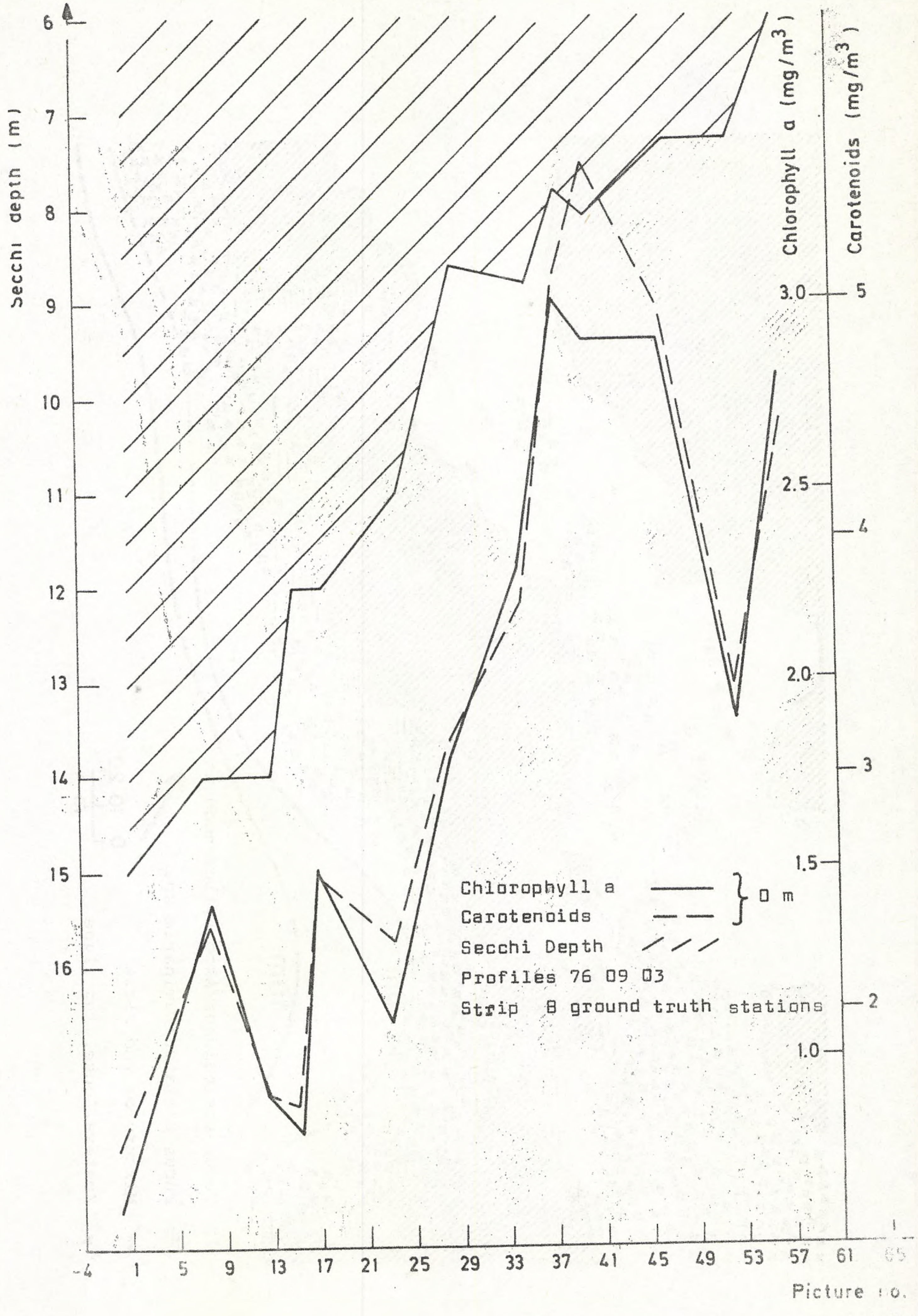
Chlorophyll a and Carotenoids
at Vert. 2 and Vert. 5 1976-09-03

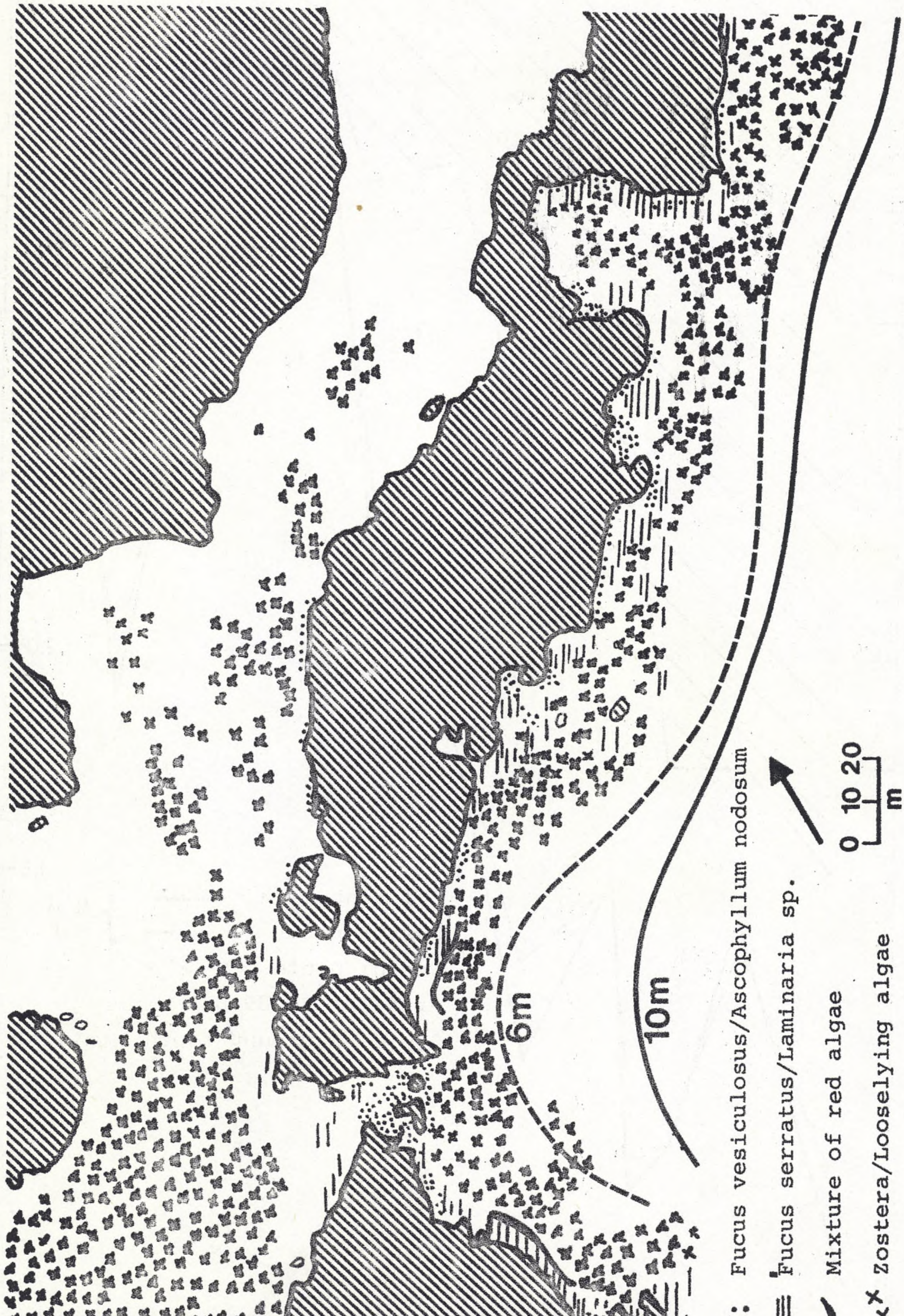


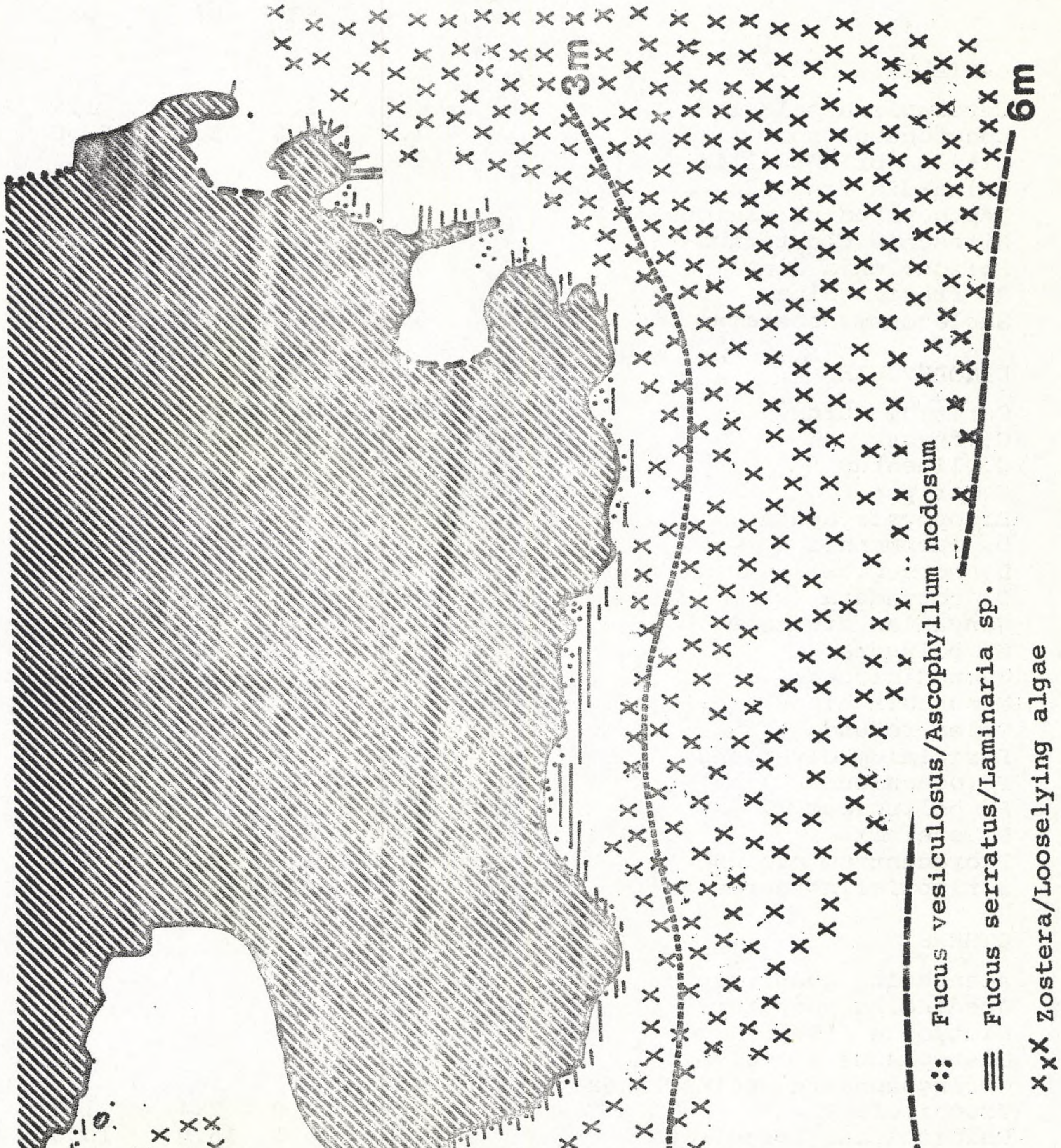
Chlorophyll a and Carotenoids
at Vert. 2 and Vert. 5 1977-05-27




Optical density (at centre of pictures)
Strip 8 76 09 03
Black and white film, wratten 58 filtered
Densitometer Mac Beth TD-504
ND (yellow) filter
near island (bottom effect)
shallow water (bottom effect)
near land
near land
Density (relative scale)
25
20
15
10
5
-4
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
Picture no.


Secchi depth (m)
6
7
8
9
10
11
12
13
14
15
16
Chlorophyll a (mg/m3)
Carotenoids (mg/m3)
3.0
2.5
2.0
1.5
1.0
5
4
3
2
Chlorophyll a
Carotenoids
0 m
Secchi Depth
Profiles 76 09 03
Strip 8 ground truth stations
-4
1
5
9
13
17
21
25
29
33
37
41
45
49
53
57
61
65
Picture no.


6m
10m
0 10 20
m
Fucus vesiculosus/Ascophyllum nodosum
Fucus serratus/Laminaria sp.
Mixture of red algae
Zostera/Looselying algae


3m
6m
Fucus vesiculosus/Ascophyllum nodosum
Fucus serratus/Laminaria sp.
Zostera/Looselying algae
0 10 20
m

BROFJORDEN 1976-09-03

	Number of cells (thousands/liter) Depth 0 m Station: B2	B3	B4	B5	B6
BACILLARIOPHYCEAE					
Cerataulina pelagica	0.8	1.2	3.2	1.4	2.0
Chaetoceros spp.	7.2	3.8	35.0	62.0	65.0
Ditylum brightwellii					
Guinardia flaccida				0.2	
Leptocylindrus danicus			3.0	0.7	0.2
Nitzschia closterium	0.2	45.0	40.0	8.0	35.0
Rhizosolenia alata	0.2		0.2		
R. fragilissima			0.4		
Skeletonema costatum	105.0	80.0	40.0	11.0	40.0
DINOPHYCEAE					
Ceratium furca	4.6	4.0	1.8	4.8	5.0
C. fusus		0.4	0.4	0.2	0.2
C. lineatum					
C. tripos	0.6	0.4	0.4	0.1	0.2
Dinophysis acuta				0.1	
D. lachmannii					
D. morvegica					
D. rotundata			0.2		
Gonyaulax digitale	0.8	0.8	1.2	3.2	0.8
G. polyedra	18.4	15.0	36.4	44.0	31.4
Gymnodiniaceae	10.0	60.0	5.0	23.0	20.0
Minuscula bipes			0.2		
Oblea rotunda					
Peridinium divergens	0.2	1.2	1.0	0.6	0.2
P. oceanicum					
P. pellucidum	0.4				
P. steinii	1.4	0.8	1.0	0.6	0.6
Prorocentrum micans	2.8	1.0	2.0	3.0	2.6
Scrippsiella faeroense	0.4	0.8	1.4	1.3	0.8
OTHERS					
Acanthoica quattrospina					
Apedinella spinifera				3.0	
Dictyocha fibula	0.2				0.2
Distephanus speculum					
Meringosphaera mediterranea					
Trochiscia ?	0.6	3.0	2.4	1.7	1.2
Unidentified flagellates	20.0	15.0	45.0	10.0	60.0

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Number of cells (thousands/liter)
Depth 0 m
Station:

	B7	B8	B9	B10	B11	B12
BACILLARIOPHYCEAE						
Cerataulina pelagica	1.0	0.4		2.4		
Chaetoceros spp.	7.4	20.4	15.8	6.0	7.0	10.6
Ditylum brightwellii	0.2	0.2				
Guinardia flaccida						
Leptocylindrus danicus		0.8		2.6		1.2
Nitzschia closterium	10.0	5.0	10.0	15.0	18.0	11.0
Rhizosolenia alata						
R. fragilissima		0.2				
Skeletonema costatum	20.0					7.6
DINOPHYCEAE						
Ceratium furca	4.8	1.8	2.4	0.6	3.2	0.8
C. fusus						
C. lineatum		0.4				
C. tripos		0.4	0.2			0.2
Dinophysis acuta						
D. lachmannii						
D. norvegica		0.2				
D. rotundata						
Gonyaulac digitale	0.2					
G. polyedra	16.8	4.8	5.8	2.4	5.4	
Gymnodiniaceae	45.0	35.0	40.0	15.0	45.0	15.0
Minuscula bipes			0.2		0.2	
Oblea rotunda						
Peridinium divergens	1.6	0.6	0.6	0.2	0.4	0.2
P. oceanicum						
P. pellucidum						
P. steinii	0.2	0.4	0.4	0.2	0.4	
Prorocentrum micans	2.6	0.4	1.4	0.4	1.2	0.4
Scrippsiella faeroense	0.2	0.4		0.6	1.4	
OTHERS						
Acanthoica quattrospina					0.2	
Apedinella spinifera						
Dictyocha fibula	0.4	0.2		0.4		0.4
Distephanus speculum						
Meringosphaera mediterranea						
Trochiscia ?	1.8	1.0	0.8	0.2		
Unidentified flagellates	25.0	10.0	35.0	20.0	44.0	30.0

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Number of cells (thousands/liter)
Depth 2.5 m
Station:

	B2	B3	B4	B5	B6
BACILLARIOPHYCEAE					
Cerataulina pelagica	0.4		1.8	2.0	0.4
Chaetoceros spp.	90.6	7.0	4.8	19.2	4.8
Ditylum brightwellii					
Guinardia flaccida					
Leptocylindrus danicus			20.0		
Nitzschia closterium	40.0	15.0	50.0	5.0	5.0
Rhizosolenia alata	0.2				
R. fragilissima	0.4				
Skeletonema costatum	256.0	20.0	10.0	120.0	
DINOPHYCEAE					
ceratium furca	4.8	3.0	2.6	6.0	3.0
C. fusus	0.2	0.4	0.6	5.0	0.2
C. lineatum	0.6				
C. tripos	0.6		0.2	0.4	0.2
Dinophysis acuta					
D. lachmannii		0.2	0.2		
D. norvegica					
D. rotundata					
Gonyaulax digitale	1.8		0.4	0.8	0.4
G. polyedra	17.0	13.8	34.0	64.8	32.2
Gymnodiniaceae	195.0	130.0	65.0	65.0	32.0
Minuscula bipes			0.2		
Oblea rotunda					
Peridinium divergens	1.4	0.4	1.4	2.8	1.4
P. oceanicum		0.2	0.2		
P. pellucidum					
P. steinii	1.2	0.6	2.4	0.4	0.6
Prorocentrum micans	3.2	1.2	2.6	6.0	2.6
Scrippsiella faeroense	2.2	0.6	0.6	1.2	1.2
OTHERS					
Acanthoica quattrospina	0.2				
Apedinella spinifera					
Dictyocha fibula		0.4		0.4	0.2
Distephanus speculum					
Meringosphaera mediterranea	15.0				
Trochiscia ?	0.4	2.6	1.0	4.0	0.2
Unidentified flagellates	200.0	40.0	40.0	60.0	30.4

BROFJORDEN 1976-09-03	Number of cells (thousands/liter) Depth 2.5 m Station:					
	B7	B8	B9	B10	B11	B12
BACILLARIOPHYCEAE						
Cerataulina pelagica						0.4
Chaetoceros spp.	3.0	6.6	0.6	7.0	8.2	7.2
Ditylum brightwellii			0.4	0.2		
Guinardia flaccida						
Leptocylindrus danicus						
Nitzschia closterium	2.0	4.0	2.0	7.0	16.0	9.0
Rhizosolenia alata		0.2				0.2
R. fragilissima						
Skeletonema costatum	2.0	2.4		2.0	0.6	1.2
DINOPHYCEAE						
Ceratium furca	3.6	2.0	3.8	0.8	2.0	2.0
C. fusus		0.2		0.2		
C. lineatum				0.2		
C. tripos	0.4		0.2		0.2	
Dinophysis acuta						
D. lachmannii						
D. norvegica	0.2					0.2
D. rotundata						0.2
Gonyaulax digitale	0.2					
G. polyedra	16.6	9.6	5.4	2.0	5.4	
Gymnodiniaceae	40.0	20.0	12.0	26.0	40.0	16.0
Minuscula bipes						
Oblea rotunda	0.2					
Peridinium divergens	0.8	1.2	0.2		0.8	0.4
P. oceanicum						
P. pellucidum	0.2	0.2		0.2		
P. steinii	0.2	0.2				
Prorocentrum micans	2.4	1.2	0.8	0.8	1.2	0.6
Scrippsiella faeroense	0.8	0.2	0.4		0.2	
OTHERS						
Acanthoica quattrospina						2.0
Apedinella spinifera						
Dictyocha fibula	0.2				0.4	0.4
Distephanus speculum		0.2				
Meringosphaera mediterranea						
Trochiscia ?	0.6	0.4	0.2		0.2	
Unidentified flagellates	18.0	10.0	6.0	25.0	32.0	26.0

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Number of cells (thousands/liter)
Station: Vert 2

	Depth: 0 m	2.5 m	5 m	10 m	15 m	20 m
BACILLARIOPHYCEAE						
Cerataulina pelagica		2.2			0.6	
Chaetoceros spp.	22.9	12.8	7.0	4.0	5.0	1.2
Ditylum brightwellii	0.1			0.2	0.2	
Guinardia flaccida	0.2		0.2			0.2
Leptocylindrus danicus	9.0	1.0			2.2	
Nitzschia closterium	3.0	10.0	30.0	15.0	8.0	11.0
Rhizosolenia alata						
R. fragilissima	0.3					
Skeletonema costatum	14.0	25.0	95.0	52.2	38.0	29.0
DINOPHYCEAE						
Ceratium furca	5.2	3.0	3.2	1.2	5.4	4.0
C. fusus	0.2	0.2	0.3			
C. lineatum				0.6		
C. tripos	0.2	0.6	0.2	0.2		
Dinophysis acuta			0.2			
D. lachmannii						
D. norvegica	0.2					
D. rotundata	0.3	0.2				
Gonyaulax digitale	0.7	2.0	0.6	1.4		
G. polyedra	35.5	39.6	46.2	39.2	3.6	
Gymnodiniaceae	22.0	80.0	90.0	311.0	51.0	
Minuscula bipes	1.0					
Oblea rotunda				0.4		
Peridinium divergens	1.4	1.2	0.6	1.0		
P. oceanicum						
P. pellucidum	0.8					
P. steinii	0.5	0.2	0.8	1.0	0.2	0.2
Prorocentrum micans	2.6	4.2	3.0	2.6	2.4	0.2
Scrippsiella faeroense	0.6	1.2	0.8	0.6		
OTHERS						
Acanthoica quattrospina	2.0			1.0	0.2	
Apedinella spinifera	3.0			1.0		
Dictyocha fibula	0.1		0.2			
Distephanus speculum	0.1			0.4		
Meringosphaera mediterranea		15.0	5.0	13.0	5.0	1.0
Trochiscia ?	2.3	0.8	0.2			
Unidentified flagellates	2.0	70.0	75.0	29.0	27.0	

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Number of cells (thousands/liter)
Station: Vert 5

	Depth: 0 m	2.5 m	5 m	10 m	15 m	20 m
BACILLARIOPHYCEAE						
Cerataulina pelagica		2.2				
Chaetoceros spp.	12.2	9.6	23.4	7.6	1.6	1.6
Ditylum brightwellii						
Guinardia flaccida	0.2					
Leptocylindrus danicus			1.4	2.0		
Nitzschia closterium	10.0	9.0	1.2	16.0	6.0	7.0
Rhizosolenia alata					0.2	
R. fragilissima						
Skeletonema costatum	6.4	4.0	26.2	21.6	30.0	4.6
DINOPHYCEAE						
Ceratium furca	0.4	0.6	2.4	0.6	1.0	1.2
C. fusus			0.2			
C. lineatum				0.4		
C. tripos	0.2	0.2		0.6		
Dinophysis acuta						
D. lachmannii						
D. norvegica						
D. rotundata						
Gonyaulax digitale	0.2			0.2	0.2	
G. polyedra	0.6	1.2	4.8	10.4	0.4	
Gymnodiniaceae	15.0	12.0	6.0	108.0	27.0	7.0
Minuscula bipes				0.2		
Oblea rotunda						
Peridinium divergens	0.2	0.4	0.6	0.4	0.2	
P. oceanicum						
P. pellucidum					0.2	
P. steinii			0.2	0.2		
Prorocentrum micans	0.6	1.0	0.8	0.4	0.4	
Scrippsiella faeroense	0.2	0.2	0.8	0.4		
OTHERS						
Acanthoica quattrospina				6.0	0.2	
Apedinella spinifera						
Dictyocha fibula			0.2			0.2
Distephanus speculum				0.2		
Meringosphaera mediterranea						
Trochiscia ?			0.2			
Unidentified flagellates	40.0	10.0	6.7	18.0	23.0	6.0

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Station	Depth (m)	Temp. (^{o}C)	Salinity ($^{o}/oo$)	Sigma T	Oxygen (ml/l)	O_2-sat. (%)	Secchi depth (m)	Chl-a (mg/m^3)	Carot. (mg/m^3)	Tot. extr. subst. (mg/l)	Mineral oil (mg/l)	Yellow subst. (m^{-1})
B2	0	17.35					6.0*	2.8	4.5	0.039	0.015	
B2	2.5	17.42	26.907	19.26	6.32	111		2.9	4.8			0.42
B3	0	17.35					7.3	1.9	3.4	0.026	0.015	
B3	2.5	17.50	26.917	19.25	6.13	108		1.8	3.2			0.37
B4	0	17.42					7.3	2.9	5.0	0.024	0.015	
B4	2.5	17.40	27.010	19.35	6.16	108		3.1	5.2			0.37
A5	0	17.59					7.8	1.7	3.9	0.053	0.015	
A5	2.5	17.49	26.915					1.8	3.4			0.74
B5	0	17.45					8.1	2.9	5.6			
B5	2.5	17.55	26.985	19.29	6.17	109		2.8	5.4			0.51
A6	0	17.50					7.5	3.6	6.0	0.031	0.015	
A6	2.5	17.55	26.864					3.4	5.4			0.37
B6	0	17.55					8.8	2.3	3.7	0.067	0.015	
B6	2.5	17.60	26.855	19.18	6.17	109		2.3	4.0			0.42
C6	0	17.60					2.5*	4.2	6.6			
C6	2.5	17.55	26.861					2.4	3.9			0.37
A7	0	17.50					8.4	1.7	2.7	0.079	0.017	
A7	2.5	17.60	26.839					3.7	5.4			0.46
B7	0	17.55					8.6	1.8	3.1	0.066	0.025	
B7	2.5	17.60	26.861	19.19	6.12	108		2.0	3.4			0.37
A8	0	17.45					9.0*	0.9	1.6	0.100	0.021	
A8	2.5	17.50	26.700					0.5	1.4			0.18

* bottom

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Station	Depth (m)	Temp. (^{o}C)	Salinity ($^{o}/oo$)	Sigma T	Oxygen (ml/l)	O_2-sat. (%)	Secchi depth (m)	Chl-a (mg/m^3)	Carot. (mg/m^3)	Tot. extr. subst. (mg/l)	Mineral oil (mg/l)	Yellow subst. (m^{-1})
B8	0	17.55					11	1.1	2.3	0.032	0.024	
B8	2.5	17.50	26.798	19.16	5.96	105		1.5	2.8			0.42
C8	0	17.44					10	2.2	3.0	0.082	0.015	
C8	2.5	17.42						2.2	2.1			
A9	0	17.50					11	1.1	2.4	0.025	0.015	
A9	2.5	17.42	26.843					1.2	2.2			0.28
B9	0	17.45					12	1.5	2.6	0.038	0.015	
B9	2.5	17.40	26.881	19.25	5.83	102		1.5	2.6			0.37
C9	0	17.45					11	1.2	1.9	0.030	0.022	
C9	2.5	17.41	26.801					1.3	2.6			0.32
B10	0	17.40					12	0.9	1.7	0.026	0.019	
B10	2.5	17.45	26.714					1.0	1.7			0.37
C10	0	17.32					12	0.9	1.4	0.026	0.019	
C10	2.5	17.32	26.716					0.8	1.2			0.37
B11	0	17.45					14	1.4	2.4	0.280	0.260	
B11	2.5	17.45	26.801					1.0	2.0			0.37
C11	0	17.40					14	0.6	1.8	0.960	0.840	
C11	2.5	17.45	26.715					0.6	1.4			0.32
A12	0	17.10					15	0.8	1.5	0.046	0.015	
A12	215	17.28	26.596					0.8	1.7			0.92
B12	0	17.22					15	0.6	1.4	0.036	0.015	
B12	2.5	17.20	26.628	19.10	5.69	99		1.0	1.9			0.28
C12	0	17.20					15	0.8	1.4	0.058	0.033	
C12	2.5	17.20	26.484					0.8	0.8			0.28

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Station	Depth (m)	Temp. (^{o}C)	Salinity ($^{o}/oo$)	Sigma T	Oxygen (ml/l)	O_2-sat. (%)	Secchi depth (m)	Chl-a (mg/m^3)	Carot. (mg/m^3)	Tot. extr. subst. (mg/l)	Mineral oil (mg/l)	Yellow subst. (m^{-1})
Vert 2	0	17.55	26.885	19.22	6.11	108	7.8	3.0	5.1	0.097	0.015	0.46
Vert 2	2.5	17.60	26.869	19.19	6.16	109		3.0	5.3			0.32
Vert 2	5	17.41	27.058	19.38	6.22	109		2.8	5.3			0.46
Vert 2	10	15,82	31.106	22.82	4.71	82		3.8	6.0			0.28
Vert 2	15	14.55	32.436	24.12	4.75	81		2.5	3.0			0.51
Vert 2	20	13.15	33.055	24.88	4.46	75		1.1	1.8			0.51
Vert 5	0	17.42	26.447	18.91	5.70	100	14	0.8	1.6	0.044	0.015	0.46
Vert 5	2.5	17.30	26.579	19.04	5.80	101		0.8	1.6			0.42
Vert 5	5	17.42	26.822	19.20	5.89	103		1.4	2.4			0.32
Vert 5	10	16.38	31.211	22.78	5.24	93		2.4	3.2			0.28
Vert 5	15	14.29	32.752	24.41	5.47	93		1.2	2.3			0.60
Vert 5	20	12.90	33.447	25.23	5.33	89		0.6	1.5			0.09

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Station	Depth (m)	Temp. (^oC)	Salinity ($^o/oo$)	Sigma T	Oxygen (ml/l)	O_2-sat. (%)	Secchi depth (m)	Chl-a (mg/m^3)	Carot. (mg/m^3)	Tot. extr. subst. (mg/l)	Mineral oil (mg/l)	Yellow subst. (m^{-1})
B2	2.5	17.8	20.6				2.0	16.8	12.5			
B3	2.5	16.0	20.9				4.2	3.2	7.0			
B4	2.5	16.1	21.0				4.2	3.8	7.8			
A5	2.5	15.4	20.6					3.3	6.7			
B5	2.5	15.8	20.9				4.2	3.6	7.3			
A6	2.5	16.1	20.4				3.5	4.2	7.4			
B6	2.5	15.8	20.9				4.2	4.0	7.8			
C6	2.5	16.2	21.0				4.5	3.5	6.4			
A7	2.5	15.5	21.0				4.2	2.7	5.6			
B7	2.5	15.4	20.6				4.2	3.0	6.0			
A8	2.5	15.2	20.5				4.5	3.0	6.0			
B8	2.5	15.3	20.6				4.8	2.7	5.8			
C8	2.5	15.2	20.6				4.8	3.5	6.8			
A9	2.5	15.4	20.9				5.0	2.6	5.2			
B9	2.5	15.3	20.6				5.0	2.8	5.8			
C9	2.5	15.1	20.6				5.2	2.4	5.1			
B10	2.5	15.4	20.7				5.0	2.6	5.5			
C10	2.5	15.0	20.7				5.2	1.9	5.1			
B11	2.5	15.0	20.6				5.0	3.2	6.6			
C11	2.5	14.8	20.6				5.2	2.1	5.5			
A12	2.5	14.8	20.7				4.8	2.8	6.1			
B12	2.5	14.6	20.7				5.0	2.4	4.8			
C12	2.5	14.7	20.6				5.0	1.5	3.3			

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Station	Depth (m)	Temp. (^oC)	Salinity ($^o/_{oo}$)	Sigma T	Oxygen (ml/l)	0_2-sat. (%)	Secchi depth (m)	Chl-a (mg/m^3)	Carot. (mg/m^3)	Tot. extr. subst. (mg/l)	Mineral oil (mg/l)	Yellow subst. (m^{-1})
Vert 2	0	15.5	20.6				4.4	2.8	5.2			
Vert 2	2.5	15.7	20.6					2.8	5.3			
Vert 2	5	15.4	20.9					3.1	7.2			
Vert 2	10	11.9	23.1					6.1	9.3			
Vert 2	15	9.0	27.0					2.2	3.3			
Vert 2	20	7.1	30.0					1.1	1.8			
Vert 5	0	14.7	20.6				5.2	2.0	4.9			
Vert 5	2.5	14.8	20.9					2.0	4.4			
Vert 5	5	14.7	21.1					2.9	5.5			
Vert 5	10	10.8	24.8					6.3	8.8			
Vert 5	15	8.8	28.4					2.2	2.9			
Vert 5	20	6.8	31.2					1.5	2.9			

LITERATURE

During the work within the project the following literature has been found very useful.

Apel, R.J., 1976. Ocean Science from Space EOS transactions, American Geophysical Union, Vol. 57, No. 9.

Arvesen, C.J., Millard, J.P. and Weaver, E.C., 1973. Remote Sensing of Chlorophyll and Temperature in Marine and Fresh Waters. Astronautica Acta, Vol. 18.

Bressette, W.E., 1973. The use of near infrared photography for aerial observation of phytoplankton blooms. NASA, Langley, L-8769.

Carlberg, S.R. (Ed.), 1972. New baltic manual. Cooperative Research Report. Series A, No. 29. International Council for the Exploration of the Sea. Charlottenlund, Denmark.

Clarke, G.I., Ewing, G.C. and Lorenzen, C., 1970. Spectra of Backscattered Light from the Sea Obtained from Aircraft as a Measure of Chlorophyll Concentration. Science, Vol. 167.

Engelmann, T.W., 1883. Farbe und Assimilation. Botanische Zeitung, Jahrgang 41, No. 1.

Fitzgerald, E., 1974. Multispectral Scanning Systems and their potential application to earth - resources surveys. Part 2: Spectral properties of materials. Plessey Radar Ltd. United Kingdom.

Goldman, C.R., Richards, R.C. and Pearl, H.W., 1974. Limnological studies and Remote Sensing of the Upper Truckee River Sediment Plume in Lake Tahoe, California - Nevada. Remote Sensing of Environment, Vol. 3.

Gower, J.F.R., 1975. Uses of aerial photography in studying coastal areas. ICES C.M. 1975/C:2.

Heimdal, B.R. et al., 1973. An Annotated Check-List of Plankton Algae from the Oslofjord, Norway (1951-1972). Norw. J. Bot. 20: 13-19.

Horne, A.J. and Wrigley, R.C., 1975. The use of remote sensing to detect how wind influences planktonic blue-green algal distribution. Verh. Internat. Verein. Limnol. No. 19.

Jain, S.C., 1976. On interpretation of the spectral reflectance of natural water. Ph. O. Thesis, York University, Toronto.

Jamison, D.W., 1972. Aerial Remote Sensing as a tool in Seaweed Surveys. Proc. Intl Seaweed Symp. 7: 351-357.

Jerlov, N.G. and Steeman Nielsen, E. (Eds), 1974. Optical Aspects of Oceanography. Academic Press, London.

Michanek, G., 1975. Seaweed Resources of the Ocean. FAO Fisheries Technical Paper, No. 138.

Nyqvist, B.G. and Person, T., 1975. Fjärranalys av bentiska alger. Meddelande nr 10 från Svenska Havsforskningsföreningen. p. 122-127.

Öström, B., 1976. Fertilization of the Baltic by nitrogen fixation in the blue-green alga Nodularia spumigena. Remote Sensing of Environment, Vol. 4.

Steele, J.H. and Yentsch, C.S., 1960. The vertical distribution of chlorophyll. J. Mar. Biol. Ass. U. K. 39.

Strickland, J.D.H., 1960. Measuring the production of Marine Phytoplankton. Fish. Res. Bd. Canada, Bull. 122.

Strickland, J.D.H. and Parsons, T.R., 1972. A Practical Handbook of Seawater Analysis. Ibid., Bull. 167. 2nd. ed.

Strong, A.E., 1974. Remote Sensing of Algal Blooms by Aircraft and Satellite in Lake Erie and Utah Lake. Remote Sensing of Environment, Vol. 3.

Svensk Lantmäteritidskrift 1977:3.

Wastensson, L. et al., 1972. Photo Interpretation of Tree Species, Aquatic Macrophytes and Bedrock Outcrops. Meddelande från Naturgeografiska Institutionen vid Stockholms universitet Nr A 40.

Wezernak, C.T., Turner, R.E. and Luzenga, D.R., 1976. Spectral Reflectance and Radiance Characteristics of Water Pollutants. NASA contractor report CR - 2665.

Wolff, G. and Lindner, A., 1974. Zur Luftbildinterpretation bei der Kartierung des Verlandungsgürtels und der submersen Pflanzengesellschaften in Gewässern mit geringer Sichttiefe. J. R. 3/1974.

Wrigley, R.C. and Horne, A.J., 1974. Remote Sensing and Lake eutrophication, Nature, Vol. 250, No. 5463.

Wrigley, R.C. and Horne, A.J., 1975. Surface algal circulation patterns in Clear lake by remote sensing. NASA TM X - 62, 451.

Wrigley, R.C., Klooster, S.A., LeRoy, M.J., Horne, A.J. and Anderson, H.M., 1975. Field measurement of algal biomass by infrared reflectance. NASA TM X - 73, 107.

For our choice of ground truth parameters and sampling stations a basic knowledge of the area presented in the following works (some of them in Swedish), has been of valuable aid.

Brandt, M., 1974. Rapport angående oceanografiska basundersökningar under 1973 i Brofjordenområdet. SMHI.

Cato, I., 1974. Sedimentologisk och geokemisk basundersökning i Brofjorden. Meddelande från Maringeologiska Laboratoriet. Göteborg. 6.

Hallbäck, H., Hagström, O. and Winström, K., 1974. Fiskeribiologiska undersökningar i Brofjorden 1972-1974. Meddelande från Havsfiskelaboratoriet. Lysekil. 175.

Kwiecinski, B. and Öström, B., 1973. Primary production at Bornö 1963. Ibid. 154.

Öström, B., 1973. A formula system for primary production. Ibid. 149.

Öström, B., 1973. Brofjorden I. Hydrographical measurement program and some basic data. Ibid. 144.

Öström, B. and Lith, M., 1974. Data processing and oceanographical data. Ibid. 156.

Öström, B., 1974. Physical-chemical conditions, nutritional ability and related ecological aspects of Brofjorden. Ibid. 176.

Öström, B. (Editor). Oceanographical data. Brofjorden Investig. Ibid. 165 and 169.

Rex, B. and Rex, M., 1975. Brofjordsundersökningen 1973-1974. Marin Botanik, Marinbotaniska institutionen, Göteborg.

Smith, S., 1975. Kvantitativa undersökningar av mjukbottenfaunan i Brofjorden 1970-1973. Kristinebergs Marinbiologiska Station.

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The photographic material is stored (under lock) by the Fishery Board of Sweden, Hydrographic Department in Göteborg. The photographs are classified as secret material according to law, which naturally will limit their use. However, for scientific purposes authorization to use the pictures may be obtained and in principle the material is available to anyone for future use after a given permission.

We regret that the cost of reproduction of color prints is such that it is not possible for us to provide them in the number necessary for an inclusion in this report. This means that we are unable to display examples of the many splendid pictures in the photographic material; we can merely present the results of their interesting applications to marine problems.