Ödsmål, Kville sn, Bohuslän

Hällristning
Fiskare från
bronsåldern

Rock carving
Bronze age
fishermen

MEDDELANDE från
HAVSFISKELABORATORIET · LYSEKIL
nr 144

BROFJORDEN I

HYDROGRAPHICAL MEASUREMENT PROGRAM AND SOME BASIC DATA

by

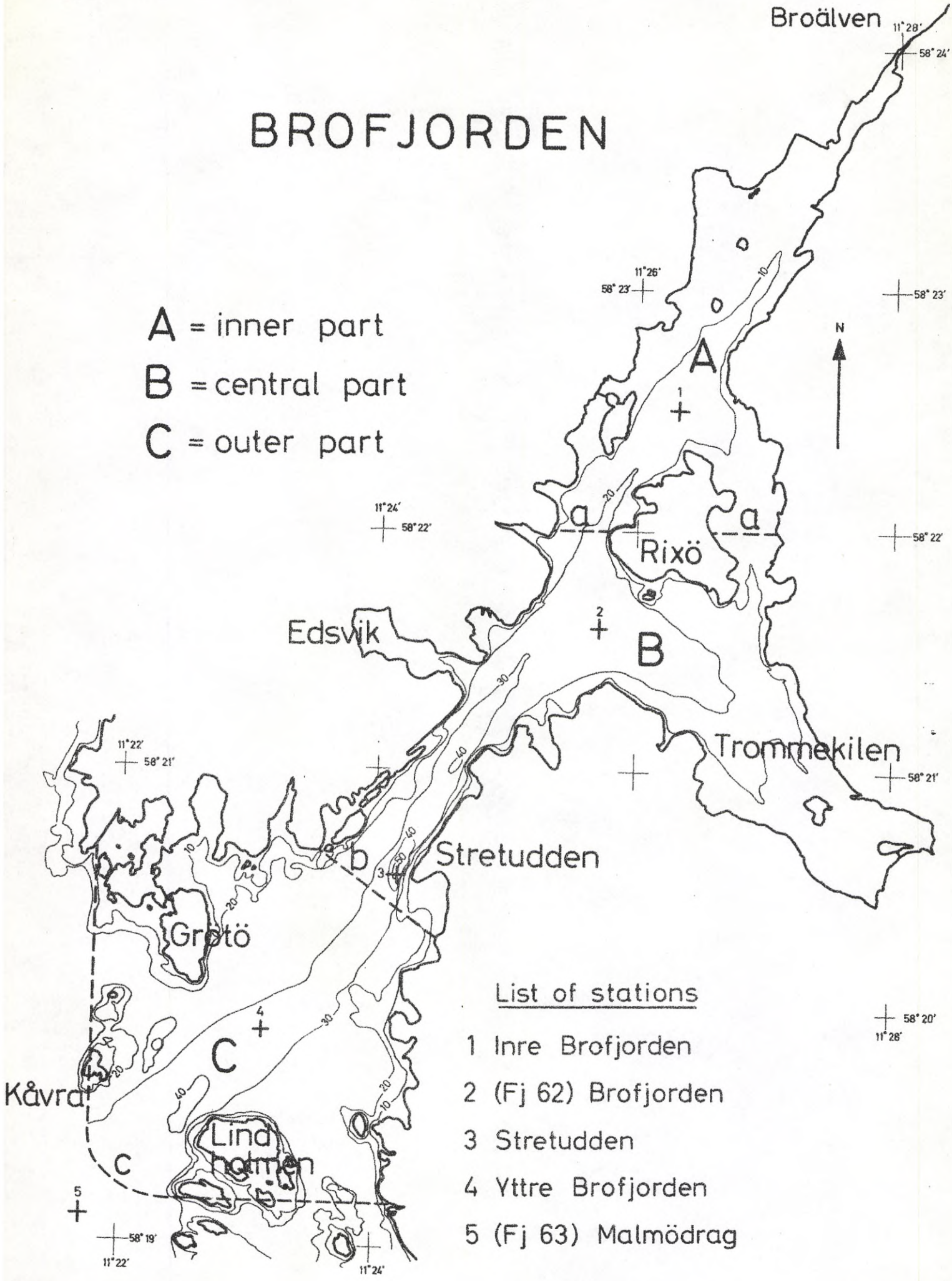
Bertil Öström

April 1973

Brofjorden, north of Lysekil, has been studied since the 1920's. The investigations performed--marine biological, fishery biological and hydrographical--have been parts of other projects and, with few exceptions, not concerned primarily with conditions in Brofjorden. Fish taggings, for example, have given information on the migrations of placie, whiting and other fish species, hydrographical observations on the movements of in-shore waters, and bottom samples information about the animal communities of the Swedish west coast. During the years, an interesting material has been collected, which can also be used in other contexts.

The fiord became a special subject of study when an industrial plant (an oil refinery, OK) was planned to be established there. Since 1972 the fiord is being studied co-operatively, as a consequence of the ruling of the Västerbygd Water Rights Court of 13 July 1971 (a so-called basic investigation).

When sufficient material has been collected, the Institute of Marine Research will publish measurement results, and compilations of own and others' work. The series may suitably be called "Brofjorden", and the first contribution follows here. The intention is also to include other contributions in the Meddelanden published by the Laboratory.



List of stations

1 Inre Brofjorden

2 (Fj 62) Brofjorden

3 Stretudden

4 Yttre Brofjorden

5 (Fj 63) Malmödrag

Some basic data about Brofjorden.

Brofjorden is located in the central part of Bohuslän. It has a SW - NE orientation and extends 7 km into the country, as measured from the mouth at Stretudden. There is a sill of a depth of 34 m at Kåvra (at C, the curved line on the map). There is a narrow deep basin at a depth of 52 m outside Stretudden. Another small trough at 41 m depth is situated just inside the sill.

Low oxygen values of 1.81 ml/l June 29, and 4.51 ml/l Sept. 7, 1972 taken at a depth of 25 m at station 2 Brofjorden (see map) indicate that the fiord may not be as well ventilated as was previously assumed.

The fiord has been subdivided by the lines a, b and c into three parts, A, B and C, called the inner, central and outer part. (See map).

A computation of the surface area and the water volume gives the following values.

Table 1.

	Brofjorden inside Stretudden (A +B)	Brofjorden inside sill (A + B + C)
Surface area $(km)^2 = m^2 \cdot 10^6$	8.3	14.3
Water volume $(km)^3 = m^3 \cdot 10^9$	0.11	0.24

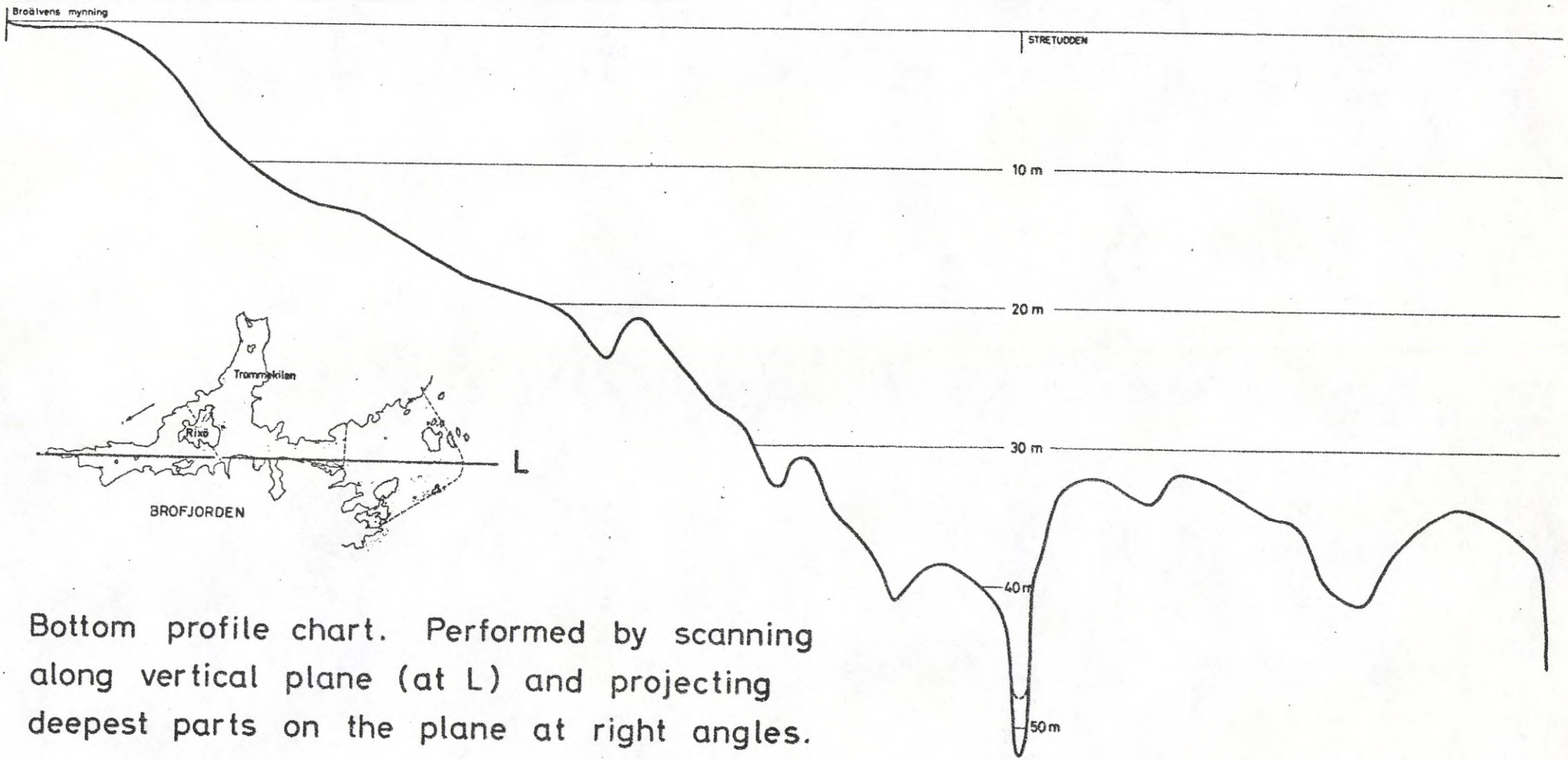
By dividing the volume by the surface area of the fiord inside Stretudden, one obtains an "average" depth of 13 m.

The period for the free oscillation is $T = \frac{4\,l}{\sqrt{g\,h}}$ for

the lowest frequency, where
l = the length of the fiord
g = gravity acceleration
h = the average depth.

This gives T = 40 min.

BROFJORDEN



Bottom profile chart. Performed by scanning along vertical plane (at L) and projecting deepest parts on the plane at right angles.

An estimate of the fresh water supply to Brofjorden can be made with the aid of precipitation data if the drainage area is known.

A roughly calculated value of this area is 90 km^2. The precipitation values are given as monthly means over the period between 1931 - 1960, for the precipitation stations Hållö, Dingle and Kristineberg, below in Table 2 (the values were kindly submitted by the Swedish Meteorological and Hydrological Institute by personal communication).

Monthly means of precipitation through the years 1931 - 1960

	Hållö	Dingle	Kristineberg
Jan	52 mm	66	63
Feb	35	41	41
Mar	27	31	32
Apr	39	47	46
May	34	41	38
June	50	64	61
July	67	89	81
Aug	72	87	86
Sept	75	93	90
Oct	70	88	83
Nov	68	86	81
Dec	59	79	71
Year	648	812	773

The values from Kristineberg are fairly good averages of those from the stations at Hållö and Dingle, as can be seen from Table 1, and will therefore be considered representative for the entire area.

Taking the evaporation into consideration, which for this area can be estimated as 300 mm per year, and adding to the precipitation figures 5 % of their original values, in order to compensate for a systematic recording error, the net annual precipitation value for the area becomes appr. 510 mm. Using these figures, the fresh water supply to Brofjorden is 46 · 10^6 m^3/year, or 1.5 m^3/s as an average, reaching a minimum of 0.3 m^3/s in May and a maximum of 3.3 m^3/s in September. Thus Brofjorden has a very moderate outflow of fresh water and should,

therefore, be almost lacking in estuarine circulation with a fresh water outflow on top of a saline in flow.

The highest water level ever recorded at Smögen is + 148 cm in 1920. The lowest is - 82.4 cm in 1956. Water levels have probably been lower but have not been recorded since the inlet to the recorder is placed at too shallow a depth. An estimate, therefore of a lowest extreme value would be - 100 cm, giving a maximum difference of 258 cm. An average value of the semi diurnal tidal sea level variation is 25 cm, varying from 15 cm at neap to 35 cm at spring tide. The water volume within these differences at the surface of Brofjorden is shown in Table 3 below.

Table 3.

	Brofjorden inside Stretudden (A+B)	% of total volume (A+B)	Brofjorden inside sill (A+B+C)	% of total volume (A+B+C)
Surface area multiplied by 2.58 m	$21.4 \cdot 10^6$	19.5	$36.9 \cdot 10^6$	15.4
Surface area multiplied by 0.25 m	$2.0 \cdot 10^6$	1.8	$3.6 \cdot 10^6$	1.5

If the variation of 25 cm is to take place uniformly over an 6 hour period, the volume change would be 166 m^3/s. If the width of the "neck" at Stretudden is 350 m and the depth is 20 m, the cross-section area is $7 \cdot 10^3 m^2$. This gives a flow velocity of 2 cm/s, caused by the tidal sea level variation.

It is obvious that the water exchange caused by the tides and the fresh water supply is of small magnitude. As rather high water velocities have been recorded, it is probable that most of the circulation is caused by wind and air pressure forcing.

Some of the data material available from the regular cruises of the Fishery Board research vessels, published in Meddelande Nr 77, have been used to calculate average salinities in Brofjorden, for the depths 0-10 m and for depths below 20 m. Assuming a 2-layer flow with the interface somewhere between these depths, and applying Knudsens

relations for a fjord we get:

$$Q_1 = \frac{S_2}{S_2 - S_1} \cdot F$$

$$Q_2 = \frac{S_1}{S_2 - S_1} \cdot F$$

where Q_1 = outflow in upper layer

Q_2 = inflow in lower layer

S_1 = salinity in upper layer

S_2 = salinity in lower layer

F = fresh water supply

The values $Q_1 = 8.4\ m^3/s$ and

$Q_2 = 6.9\ m^3/s$ which are obtained also satisfy the equation $Q_2 + F = Q_1$

Assuming the upper layer in the relation to be 15 m deep and the velocity profile to be a straight line from zero at 15 m to its maximum at the sea surface, and considering the corresponding cross section area to be rectangular with a width of 350 m, the maximum velocity caused by the fresh water driven circulation is 0.3 cm/sec., which means it is negligible.

Measurement program

During a meeting at the Hydrographic Department on November 21, 1972, with representatives from the Swedish Environment Protection Board, the present working program was made up. The data obtained from this program during 1972 are given on page 10-14. A cooperation has been established between several institutions in the project Brofjorden:

1. The Fishery Board of Sweden, Institute of Marine Research, its Biological department in Lysekil, performing the fishery biology investigation and its Hydrographic Department in Gothenburg investigating the hydrography in the fjord.
2. The Swedish Meteorological and Hydrological Institute (SMHI), investigating the hydrography in the surrounding area.
3. The Kristineberg Zoological Station, Fiskebäckskil, examining the bottom fauna.
4. The Marine Geological Laboratory, University of Gothenburg, responsible for the geological bottom investigation.
5. The Marine Botanical Institute, University of Gothenburg, measuring the primary production.

The Kristineberg Zoological Station has collected samples since plans for placing an oil refinery at Brofjorden were first discussed. Furthermore, Molander in the 20th studied the bottom fauna in the fjord (Molander 1962). The Institute of Marine Research in Lysekil has been trawling in the area for about 40 years and the Hydrographic Department in Gothenburg has performed hydrographic measurements in Brofjorden during regular cruises of the research vessels since 1922.

Oljekonsumenterna AB (OK) has kindly submitted data from their previous measurements in the area (1969 - 1971).

The close cooperation of the above mentioned institutions promises a rather good case study of Brofjorden. The program for the Fishery Board's participation in the investigation during 1973 is shown in the time schedule below.

Measurements take place during one day of the week cited.

1973 Week No	Fishery Board hydrography in Brofjorden	Marine Botanical Inst. primary prod. in Brofjorden	SMHI hydrography in surrounding area
2	x		
4	x	x	x
6	x		
8	(x)		
9	x	x	x
11	x	x	
14	x	x	x
16	x	x	
19	x	x	x
21	x	x	
26	x	x	x
28	x	x	
30	x	x	x
32	x	x	
35	x	x	x
37	x	x	
40	x	x	x
42	x		
45	x	x	x
47	x		
50	x	x	x

The hydrography program is intended to support the plankton sampling and primary production measurement program. The plankton and primary production measurements at the Marine Botanical Institution and the hydrography program of the Fishery Board are coordinated to obtain simultaneous measurements.

Program for the Fishery Board hydrography in Brofjorden.

Station No	Name	Position Lat.	Long.	Measurement depths (bo = bottom)	Bottom depth
1	Inre Brofjorden	58 22.50	11 26.30	0, 2.5, 5, 10, 15, bo	18
2	(Fj 62) Brofjorden	58 21.60	11 25.70	0, 2.5, 5, 10, 15, 20, bo	22
3	Stretudden	58 20.55	11 24.15	0, 5, 10, 15, 20, 30, 40, bo	52
4	Yttre Brofjorden	58 19.90	11 23.10	0, 5, 10, 15, 20, 30, bo	34
5	(Fj 63) Malmö drag	58 19.10	11 21.70	0, 5, 10, 15, 20, 30, bo	36
6	Dynabrott	58 17.60	11 18.60	0, 10, 20, 40, 50, 60, 80, bo	96

Number of measurements are shown in the time schedule. It will be difficult to cover station 6 with rough seas with the present boat equipment. It is therefore resonable to count on a lower frequency for this station.

Parameters

Temperature	all stations	all depths
Salinity	"	"
Yellow substance	"	"
Dissolved oxygen	"	"
Total phosphorus	"	"
Phosphate phosphorus	"	"
Nitrate	"	"
Ammonium	"	"
Oil	Surface all stations, 5 and 20 m at station 2 and 5	
Phenol	"	"
Org. carbon	"	"
Nitrite	All stations 0,5 and 20 m	
Total Nitrogen	" " "	

pH follows the primary production measurements

Measurement data

The long record of data from Brofjorden is being continued as new data are obtained by the Fishery Board research vessels on regular cruises. The data from 1893 - 1966 are published by Engström (1970).

The Swedish Meteorological and Hydrological Institute has recorded current and temperature, both reported in their communications of 1970 and 1971.

The OK Refinery has made its own investigations from Nov. 1969 through Sept. 1971. In this case, the phenol content is most interesting as background data, and the results are given below.

The station studied is situated halfway between Stations 2 and 3 on map Pos. N 58°21.0′ E 11°24.5′.

The figures in table give phenol content in ug per litre. < means less than.

Date	1 m depth	20 m depth
69 11 13	<0.1	<0.1
70 03 19	<0.1	<0.1
70 05 21	<0.1	<0.1
70 07 09	<0.1	<0.1
70 08 26	<0.1	<0.1
70 10 27	trace	trace
70 12 10	<0.1	<0.1
71 02 11	<0.1	2.5
71 04 29	<0.1	<0.1
71 08 03	<0.1	<0.1
71 10 05	<0.4	<0.1

Also interesting is an oil content determination from 1971 taken at Station 2, Brofjorden and Station 5. Malmödrag. Data are tabled below. The figures give the content of nonpolar hydrocarbons in mg/l.

Date	Depth (m)	Stn. 2 Brofjorden (Fj 62)	Stn. 5 Malmödrag (Fj 63)
71 02 16	0	<0.05	<0.05
	5	0.05	<0.05
	30	<0.05	<0.05

Another Oil determination was made in 1972 at the same stations and the results are listed below:

72 09 13	0	<0.05	0.05
	5	<0.05	<0.05
	30	<0.05	<0.05

Brofjorden hydrographical data 1972

Date	Station	Oil content as nonpolar hydrocarbons (mg/l)
72 11 23	2. Brofjorden (Fj 62)	< 0.05
	3. Stretudden	< 0.05
	4. Yttre Brofjorden	< 0.05

All 3 samples are surface samples.

1. Inre Brofjorden 72 12 07

Bottom depth = 18 m, Wind = SSW 18 m/s, Airtemp. = 7.0 °C

Cloud: 3/8 Sea: 2

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	pH
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	
0	6.09	27.623	7.25	0.51	0.90	17.5	8.29
5	6.11	27.641	7.16	0.48	0.94	17.0	8.29
10	6.13	29.122	7.11	0.37	0.65	10.5	8.30
15	6.23	29.863	7.04	0.37	0.67	7.0	8.31
18	6.27	29.950	6.98	0.37	0.73	7.0	8.27

2. (Fj 62) Brofjorden 72 12 07

Bottom depth = 25 m, Wind = SSW 21, Airtemp. = 6.5 °C

Cloud: 4/8 Sea: 3

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	pH
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	
0	6.37	29.682	7.06	0.31	0.61	6.5	8.31
5	6.38	29.739	6.91	0.29	0.57	7.0	8.32
10	6.48	29.868	7.12	0.31	0.56	5.5	8.32
15	6.45	29.889	7.04	0.33	0.55	5.5	8.32
20	6.41	29.916	7.01	0.32	0.59	6.0	8.32
25	6.28	29.949	7.00	0.34	0.66	7.0	8.31

3. Stretudden 72 12 07

Bottom depth = 44 m, Wind = SSW 22 m/s, Airtemp.= 6.5 °C

Cloud: 5/8 Sea: 4

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	pH
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	
0	6.56	29.799	7.24	0.28	0.60	5.0	8.33
5	6.62	29.782	7.20	0.30	0.58	5.0	8.33
10	6.59	29.840	7.19	0.29	0.53	5.5	8.33
15	6.57	29.842	8.33	0.29	0.57	5.0	8.33
20	6.59	29.558	7.15	0.28	0.54	5.5	8.33
25	6.52	29.880	7.13	0.30	0.57	5.5	8.33
30	6.54	30.339	6.98	0.35	0.70	6.0	8.32
44	7.30	32.354	6.73	0.32	1.07	7.0	8.31

4. Yttre Brofjorden 72 12 07

Bottom depth = 33 m, Wind = SSW 22 m/s, Airtemp. = 6.5 °C

Cloud: 1/8 Sea: 4

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	pH
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	
0	6.66	29.840	7.20	0.29	0.53	4.5	8.32
5	6.64	29.836	7.18	0.32	0.54	4.5	8.33
10	6.67	29.846	7.20	0.32	0.60	4.5	8.33
15	6.64	29.862	7.22	0.31	0.53	4.5	8.33
20	6.59	29.857	7.19	0.32	0.54	4.5	8.33
25	6.62	29.887	7.20	0.33	0.56	4.5	8.33
33	6.62	30.269	7.11	0.43	0.88	5.5	8.32

5. (Fj 63) Malmö drag

Bottom depth = 34 m, Wind = SSW 23 m/s, Airtemp. = 6.5 °C

Cloud: 2/8 Sea: 4

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	pH
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	
0	6.69	29.779	7.19	0.32	0.55	5.0	8.32
5	6.68	29.786	8.33	0.32	0.61	4.5	8.33
10	6.67	29.780	7.19	0.32	0.62	5.0	8.33
15	6.69	29.791	7.16	0.32	0.56	4.5	8.33
20	6.64	29.801	7.21	0.33	0.59	5.0	8.33
30	6.65	29.857	7.10	0.32	0.58	5.0	8.33
34	6.85	30.876	6.87	0.55	1.16	6.0	8.31

1. Inre Brofjorden 72 12 14

Bottom depth = 18 m, Wind = SSW 7 m/s, Airtemp. = 8 °C

Cloud: 5/8 Sea:2

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	Phenol	Org.C	pH	Oil
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	µgat/l	mg/l		mg/l
0	5.32	23.765	7.43	0.46	0.98	27.0	5.6	2.9	8.21	<0.05
5	5.49	25.024	7.30	0.45	0.81	20.0			8.22	
10	5.73	26.070	7.29	0.40	0.68	14.5			8.25	
15	6.20	27.812	6.97	0.40	0.67	10.0			8.26	
18	6.36	28.040	6.78	0.50	0.87	10.5			8.25	

2. (Fj 62) Brofjorden 72 12 14

Bottom depth = 25 m, Wind = SSW 7 m/s, Airtemp. = 8 °C

Cloud: 5/8 Sea: 2

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	Phenol	Org.C	pH	Oil
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	µgat/l	mg/l		mg/l
0	5.56	25.271	7.41	0.38	0.77	19.0	<2.5	2.4	8.24	<0.05
5	5.55	25.253	7.38	0.46	0.76	19.0	<2.5	2.22	8.25	<0.05
10	5.83	26.275	7.40	0.44	0.63	14.0			8.28	
15	6.19	27.929	7.11	0.40	0.61	9.0			8.27	
20	6.74	30.045	6.83	0.43	0.72	8.0	<2.5	1.2	8.28	<0.05
25	7.04	31.473	6.44	0.53	0.94	9.0			8.27	

3. Stretudden 72 12 14

Bottom depth = 48 m, Wind = SSW 7 m/s, Airtemp. = 8 °C

Cloud: 6/8 Sea: 2

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	Phenol	Org.C	pH	Oil
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	µgat/l	mg/l		mg/l
0	5.64	25.925	7.44	0.36	0.68	15.5	<2.5	2.0	8.27	<0.05
5	5.72	25.993	7.50	0.39	0.67	15.0			8.28	
10	6.07	27.647	7.27	0.38	0.60	9.0			8.28	
15	6.31	28.451	7.08	0.40	0.61	8.0			8.28	
20	6.69	29.884	7.06	0.42	0.73	8.0			8.29	
30	7.17	31.816	6.58	0.49	0.93	9.0			8.28	
40	7.30	32.150	6.56	0.56	1.08	9.0			8.29	
48	7.41	32.482	6.66	0.69	1.24	9.0			8.30	

4. Yttre Brofjorden 72 12 14

Bottom depth = 32 m, Wind = SSW 10 m/s, Airtemp. = 8 °C

Cloud: 7/8 Sea: 3

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	Phenol	Org.C	pH	Oil
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	µgat/l	mg/l		mg/l
0	5.87	26.737	7.31	0.38	0.63	11.5	2.5	1.9	8.29	0.05
5	5.87	26.761	7.41	0.38	0.64	11.5			8.29	
10	6.03	27.468	7.36	0.35	0.61	9.0			8.29	
15	6.50	29.199	7.36	0.42	0.71	7.5			8.29	
20	6.82	30.363	6.94	0.46	0.77	8.0			8.29	
32	7.28	32.236	6.63	0.56	1.02	8.5			8.29	

5. (Fj 63) Malmö drag 72 12 14

Bottom depth = 34 m, Wind = 10 m/s, Airtemp. = 8 °C

Cloud: 8/8 Sea: 3

Depth	Temp.	Salinity	Oxygen	PO_4-P	Tot.P	Si	Phenol	Org.C	pH	Oil
m	°C	‰	ml/l	µgat/l	µgat/l	µgat/l	µgat/l	mg/l		mg/l
0	5.99	27.381	7.41	0.37	0.66	9.0	<2.5	1.6	8.28	<0.05
5	6.01	27.451	7.54	0.37	0.67	8.5	<2.5	1.6	8.28	<0.05
10	6.13	27.859	7.38	0.38	0.63	8.0			8.28	
15	6.48	29.065	7.31	0.40	0.77	7.5			8.29	
20	6.73	30.146	7.07	0.44	0.76	7.5	4.0	1.5	8.30	<0.05
30	7.12	31.713	6.83	0.52	0.90	8.0			8.29	
34	7.30	32.312	6.57	0.67		9.0			8.29	

References:

DIETRICH, GÜNTER & KALLE, KURT, 1957: Allgemeine Meereskunde.-p. 325-341.

ENGSTRÖM, SVEN, G., 1970: Hydrographical Observations from the Fjords of Bohuslän during the years 1893-1966. Meddelande från Havsfiskelaboratoriet, Lysekil Nr 77.

Swedish Meteorological and Hydrographical Institute, Investigation presented
to Statens Skeppsprovningsanstalt, dated 5.3.1970
" " 27.10.1970
to Statens Naturvårdsverk " 15.7.1970
to Statens Vattenfallsverk " 29.3.1971
to Västerbygdens Vattendomstol " 30.1.1971