Ödsmål, Kville sn, Bohuslän

Hällristning
Fiskare från
bronsåldern

Rock carving
Bronze age
fishermen

MEDDELANDE från
HAVSFISKELABORATORIET · LYSEKIL

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Long Term Variations of Oceanographic Parameters in the Baltic and Adjacent Waters

by

Hans Nilsson and Artur Svansson

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Introduction.

Fonselius (1969) showed that oxygen gas concentrations had decreased in the Gotland Deep since the beginning of the century. But he also showed that salinity had increased during the same period. The oxygen decrease may therefore be due to a strengthened stability of the water mass diminishing a downward transport of oxygen. Human pollution followed by an increased input of e.g. phosphorus is another important change which has occurred during the time period concerned. So far we do not know which of the two events that is the most important; research is continued to find out the portion between them and to find other possible causes of the oxygen change. Therefore it is important to study the variations of all long time series which exist. In this paper most stress is put on salinity and temperature time series but reference is also made to series of oxygen, fish catches, sediments etc.

The longest time series, e.g. Anholt, has been processed by harmonic analysis. The same procedure has been applied also on the time series of the run off of the river Vuoksi.

1. Existing Time Series

1.1 Sea Water

1.1.1. Salinity and Temperature

The longest time series are those originating from the regular measurements on board light vessels. Most series started already in 1880. Only few of them are still being continued.

During the two World Wars all the Swedish lightships were withdrawn for longer or shorter periods, whereas some of the Danish ships were measuring all the time. The longest and most complete series are those made on board L/V Anholt Nord, i.e. 93 years without unnormal interruptions, see further Table 1. (With normal interruption we mean withdrawal caused by ice conditions). See map for positions.

Information on the publications of most of the lightship data can be found in Svansson (1971a). The reason not to process all available timeseries in this paper was either their being only medium-long or that they originated from places positioned near the position of the measurements of a processed series.

There is some uncertainty concerning the Swedish data. Unfortunately it was necessary to correct hydrometer determinations 1880 - 1922 by adding 0.5 ‰ to all values. See further Svansson (1974).

Long time series of temperature and salinities measured in some deep parts of the Baltic, the Gotland Deep and the Landsort Deep, are available from 1890.

1.1.1.1. Salinity

Most of the existing time series from the lightvessels are presented in Fig:s 1 - 10. The annual mean values (NB in the northern Baltic usually comprising only part of the year due to ice conditions) were smoothed by 5-year running means procedure.

Studying Fig:s 1 - 10 we observe that the variations are smallest in the northern Baltic (Fig:s 1 - 4) and largest in the Belt Sea and the Kattegat (Fig:s 9 and 10). All the series from the Swedish lightships show highest values in their beginning i.e. in the 80 ies. Minima occur everywhere between 1920 - 1940. After World War II there are again higher values everywhere.

Comparison between salinities from Swedish and Danish lightships in the Belt Sea and in the Kattegat show that the addition of 0.5 ‰ to original Swedish data may have been too large (0.5‰ was chosen as a general mean value of a higher correction for Northern Baltic data and a very low correction for Öresund data). In Fig:s 5 - 8 a dashed line indicates uncorrected values 1880 - 1922.

Fig:s 11 and 12 show salinities measured at two Finish Coastal Stations. Ulkokalla is situated in the Bothnian Bay and the salinity curve is rather alike the salinity curve of Sydostbrotten (Fig. 1). The curve from Utö is interesting since it shows the unbroken increase of salinity during the World War II.

Fig. 13 compares the salinity in four different regions. Christiansö represents Western Baltic proper and Anholt the Kattegat. There is a minimum at Anholt in the late 20 ies, at Christiansö a few years later, at Gråhara probably at the same time as Christiansö but in the Bothnian Sea not until in the late 30 ies.

The variation of deep salinities have been described by e.g. Hela (1966), Fonselius and Rattanasen (1970), Matthäus (1972) and Lindquist (1959). In the Gotland Deep and the Landsort Deep generally there is a maximum in the beginning of the 20 ies, a minimum in the middle of the thirties and again a maximum in the beginning of the 50 ies, i.e. similar conditions as in the surface waters.

1.1.1.2. Temperature

Fig. 14 - 21 show long term variations of the temperature measured on board some of the Swedish and Danish lightvessels. The Swedish data do not include winter temperatures, but from Gedser Rev both these types of data as well as complete annual data are presented (Fig:s 20 a and b).

There is a general rise in temperature from the 30 ies which has been recorded all over the North Atlantic (see e.g. Smed 1952). There does not seem to be any obvious correlation between temperature and salinity. Matthäus (1972), however, who also studied long term trends of deep temperatures, believes that in both temperature as well as in salinity there has been long term increase since the beginning of this century: "the mean rise in salinity in the Gotland Deep has been about 1.25‰ (at 100 and 200 m depth); the mean rise of temperature 1.42 °C at 200 m depth".

1.1.2. Oxygen

Deep oxygen of the Baltic was studied by Fonselius (1969). There is probably some (positive) correlation with salinity, but also an influence of human activity (sewage). A similar investigation showed that such a decrease has taken place also in the Kattegat (Corin et.al. 1969) mostly during July - November. Hermann and Vagn Olsen (1970), however, also found values from the 20 ies and 30 ies which are as low as they are today. A further study of these low values from the 20 ies and 30 ies shows that there were values as low as 60 % saturation also in the Skagerrak North of Jutland.

1.2. Sediments

Time series which are longer than described above, can be found in sediment cores.

Hallberg (1974) describes a 46 cm long core from a station in the Gotland Deep. The core goes back to the end of the 16th century. The parameters studied were Zn, Cu and Mo contents in the sediment and the redox changes. The ratio $R = \frac{Cu + Mo}{Zn}$ is shown to be a useful indicator of the redox state of the sediment and during 1920 - 1950 it shows a clear minimum. He also compares the redox changes with temperatures computed by means of oxygen isotop (O^{18}) determinations in an ice core from Camp Century east of Thule in Greenland (Dansgaard 1970).

Also Niemistö and Voipio (1974) studied the bottom sediment in the Gotland Deep. There the time series starts in the beginning of the 16th century. In a figure they compare Mn, C and the redox potential, and in another Fe, Mn and Fe/P. In the first figure they even show the datings of the maximum glacier extension on the Kebnekaise Mountains (Karlén 1973).

1.3. River Runoff

Interesting connections with oceanographic parameters are the river runoffs. Measurements have been made for long time: Göta Älv since 1807, Motala Ström 1858 and Vuoksi since 1847.

Fonselius (1969) has shown that Vuoksi can be considered representative of the runoff to the Gulf of Finland, in spite of the fact that it is discharging into lake Ladoga.

The runoff of the river Vuoksi will be studied more closely below.

1.4. Fish Catches

To study long time variations of fish catches is difficult due to large variations in fishing intensity. In spite of this there are a number of observations which cannot be explained by varying fishing intensity only.

Lindroth (1965) has described the salmon stock (Salmo salar) in the Baltic and in the rivers which flow into the Baltic. He also compared with ice and salinity. The "salmon graph" (1870 - 1950) shows that much salmon was caught before 1895 and in the 40 ies. In the time lapse between, the catching was about 1/3. This minimum agrees with the time of low salinity at the Swedish lightvessels (Fig:s 1 - 4).

Another fish, the catches of which vary with salinity, is vendace (Coregonus albula, Johansson 1964). The stock has a strong maximum every 25 - 30 years. Johansson states also that one vendace-period seems to be 6 - 7 years, the last one of which culminated in 1958. In accordance with Prof. Järvi (Johansson op-cit.) the vendace do not survive a salinity higher than 2‰ in the surface and 3‰ in the deep. This means that a vendace maximum should occur at the same time as a salinity minimum. A small salinity minimum can be seen at Sydostbrotten in the Gulf of Bothnia some years before the vendace maximum 1958 in the Bay of Bothnia (Fig. 1). Johansson (1974) shows a graph of the vendace with maxima 1916 - 1917, 1928 and 1955 - 1958. After a minimum in 1964 the catches increase strongly due to trawl fishing was introduced in the 60 ies.

Anheden, Berntsson and Svansson (1974) described the variations of catches of eel in the Baltic and in the Hanö Bight during a period from 1931 to 1971. From the graph of total catches in the Baltic it can be seen that the catches had a strong maximum in the late 30 ies, a minimum in the beginning of the 40 ies and again a flat maximum at the end of the 50 ies.

Molander (1952) has shown that the temperature of the water is a regulating factor on the occurence of sprat (Sprattus sprattus). He also describes the catches of the West Coast of Sweden 1936 - 1951. Lindquist (1964) shows that the difference in air temperature between northern and southern Bohuslän shows a minimum around 1900 and maxima around 1880 and 1925, the latter one being smaller, however. Lindquist (op.cit.) is of the opinion that sprat fishery has varied accordingly between northern and southern

Bohuslän.

Many attempts have been made to find a relation between fishery of North Sea herring (Clupea harengus) in winter at the West Coast of Sweden and some hydrographical parameters (Andersson 1960, Svansson 1965). One thing seems to be rather clear. If the amount of Baltic water is considerably larger than normal in the Eastern Skagerrak the herring will leave these areas. There was a large "herring period" with culmination in 1880 ies and dying out about 1920. During 1942 - 1954 there was again North Sea herring off Bohuslän, although in small quantities. A close study of the correlation between herring catches and winter salinities would be very interesting.

2. Closer Study of Some of the Time Series

A few of the long series, which are practically unbroken, e.g. those from Anholt (temperature and salinity 93 years), Utö (salinity 90 m, 51 years) and Vuoksi (river runoff, 122 years) were processed in the following way.

2.1. Running Means

Fig. 22 shows running means of the temperatures measured at Anholt L/V of 3, 5, 7, 9, 11, 13, 15 and 17 years. Fig. 23 shows a similar picture for the salinities. Fig. 24 shows running means (3, 5, 7, 9, 11 and 13 years) of the deep salinities at Utö. Fig. 25 presents running means (3, 5, 7, 9, 11, 13, 15 and 17 years) of runoff data of the river Vuoksi (at Imatra).

A correlation coefficient was computed for Anholt, salinity, and Vuoksi, river runoff. Using annual means a low correlation was found (the coefficient was not explicity computed). Using 17-year running means, however, a correlation coefficient of - 0.89 was found.

2.2. Harmonic Analysis

By means of harmonic analysis (see e.g. Liljequist 1970) periodograms (amplitude - period) were constructed. For Anholt (temperature and salinity) periods of 5, 6, ---- 20 years were tested, for Vuoksi (river runoff) 5, 6, ---- 40 years. Around 4 periods indicated by Maximov (1970) viz. 14 months, 7 years, 11 years and 19 years also monthly means were used. To compare annual means with monthly means, a periodogram analysis of all monthly means for 10 months to 20 years was constructed for salinity at Anholt. Results:

2.2.1. Anholt. Temperature

Fig. 26 shows a processing of annual means. There are maxima around 5 - 6 years, 12 - 13 years and 17 - 19 years. Fig. 27 shows the same processing using monthly means around the four Maximov periods. The annual variation of temperature is clear (8.2 °C). The remaining parts of the computation are difficult to interput.

2.2.2. Anholt. Salinity

In Fig. 28 the dashed line shows the processing of annual means. There are maxima around 5, 7, 9 - 10, 13, 16 and 20 years. The continuous line shows the periodogram of monthly means. There are particularly large maxima around 9 and 11 years.

Fig. 29 shows a processing of monthly means around the 4 periods in the same scale as in Fig. 27 and Fig. 31. The 12-month-maximum is 2.2‰ S.

2.2.3. Vuoksi, River Runoff

Fig. 30 shows a processing of annual means. There are smaller peaks at 5, 8, 11 - 12 years. There is a "large" peak at 28 - 32 years. Fig. 31 shows a processing of monthly means around the four Maximov periods. The 12 month maximum is only 33 m^3/s. There is a rather "large" peak around 6.5 years and around 10.5 years. An investigation concerning 27 - 33 years did not change the result already achieved with the annual means processing.

3. Discussion

There is apparently a high negative correlation between river runoff to the Gulf of Finland and the surface salinity of the Kattegat. Also deep salinities and deep oxygen follow suite. Fig. 23, surface salinity at Anholt Nord, as well as deep salinities in the Gotland Deep (Fonselius, Rattanasen 1970) shows 3 maxima, centered around 1890, 1915 and 1950 which apparently correspond to minima in river runoff. Dickson (1972) is of the opinion that salinity variations in the Kattegat are more correlated with the variations of the influx of water from the North Atlantic. The reason for the various interpretation ways is the fact that both influx of ocean water and precipitation are both dependent on large scale atmospheric circulation.

In the sediments (Hallberg 1974) there is a clear minimum of the Ratio R (See Ch. 1.2.) in the period 1920 - 1950 but no more correlation with salinity is possible to find. The "salmon curve" (Ch. 1.4.) also shows 3 maxima centered around 1885, 1920 and 1945, the second one being very weak, however. The "vendace curve" (Ch. 1.4.) seems to be less correlated with large scale salinity variations in the Bothnian Sea. Steemann Nielsen (in Anon. 1971) shows that there is a positive correlation between primary production measured at Anholt L/V during 1954 - 1969 and salinity.

Temperature is not very much correlated with salinity even if Matthäus stresses a general secular rise in both parameters during half a century. Lindquist (1964) shows that the difference in air temperature between northern and southern Bohuslän shows a minimum around 1900 and maxima around 1880 and 1925, the latter one being smaller, however. Lindquist (op.cit.) is of the opinion that sprat fishery has varied accordingly.

There is small similarity between the various results of harmonic analysis, and with this technique it does not seem to be possible to find all the periods indicated by Maximov (1970). In the analysis of temperature at Anholt Nord, there are maxima around 6, 13 and 19 years. In the analysis of river runoff we find 5, 8, 11 and 17 years (and a very large maximum at 28 years), whereas the result of processing Anholt Nord salinity, the annual periodogram (Fig. 28) gives maxima at 7, 10 and maybe 13 and 16 years. In the monthly periodograms (Fig. 28) instead of a maximum at 10 years, there are 2 maxima, one at 9 years the other at 11 years. The amplitude of these maxima are higher than of the 10 years maximum. In other places of the graphs the amplitude of the annual means are higher than of the monthly means. A closer mathematical investigation of these differences ought to be done.

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Data of temperatures and salinities measured at Finnish lightvessels and coastal stations were published before 1914 in Finl. Hydrogr. - Biol. Untersuchungen and thereafter in Havsforskningsinstitutet, Skrifter.

Data of temperatures and salinities measured at Swedish lightvessels were published 1880 - 1913, monthly means of temperatures : Svenska hydrografisk - biologiska kommissionen, Fyrskeppsundersökningen 1923, 1880 - 1918, monthly means of salinities as well as 1914 - 1918 monthly means of temperatures : Meddelande från Havsfiskelaboratoriet no. 102. 1919 - 1922, temperatures and salinities will be published in Meddelanden från Havsfiskelaboratoriet, 1923 - 1947 : Svenska hydrografisk-biologiska kommissionen, Fyrskeppsundersökningen, 1948 - 1969 : Fishery Board of Sweden , Report, Series Hydrography and 1970 - 1972 : Meddelande från Havsfiskelaboratoriet no. 148.

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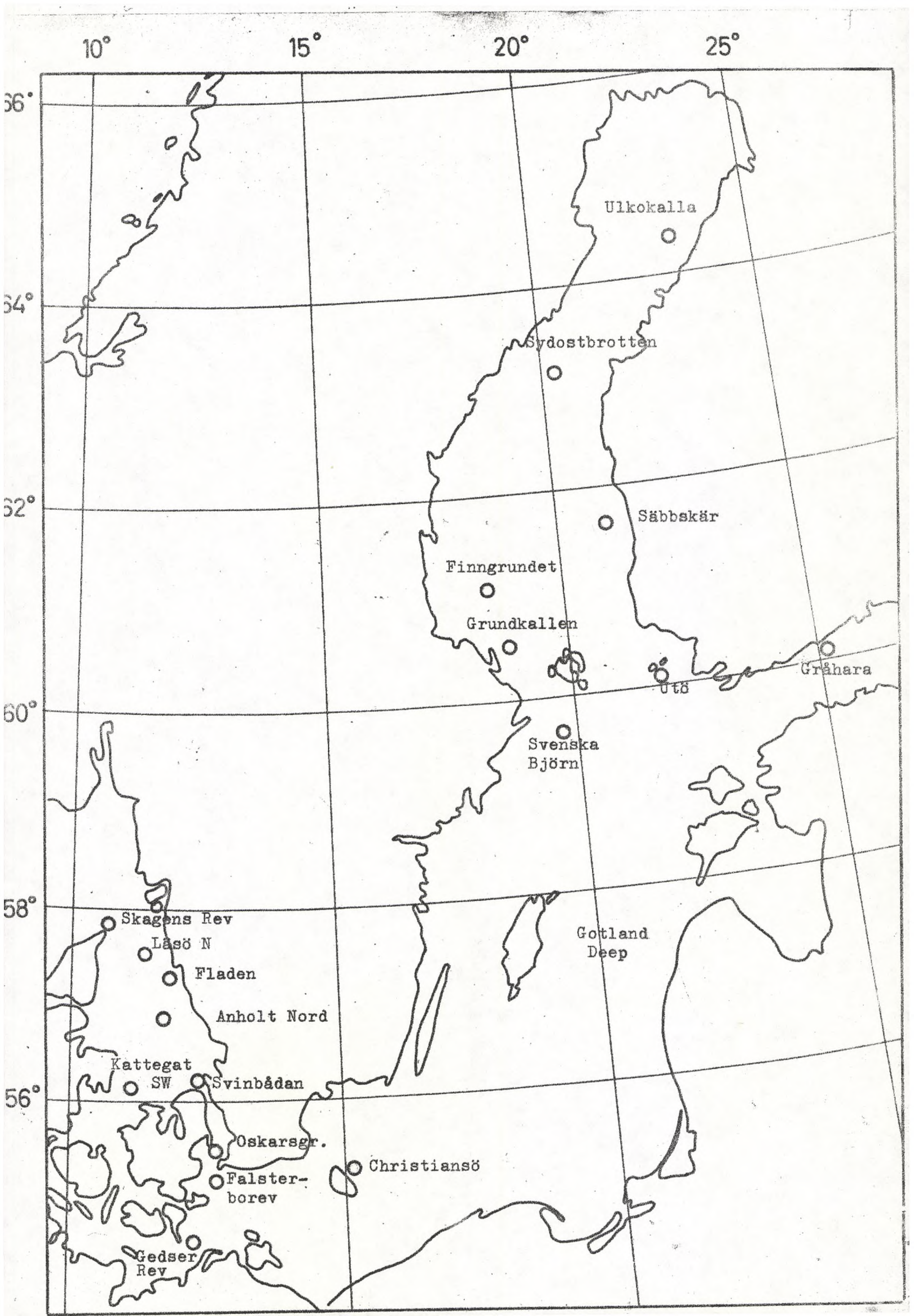
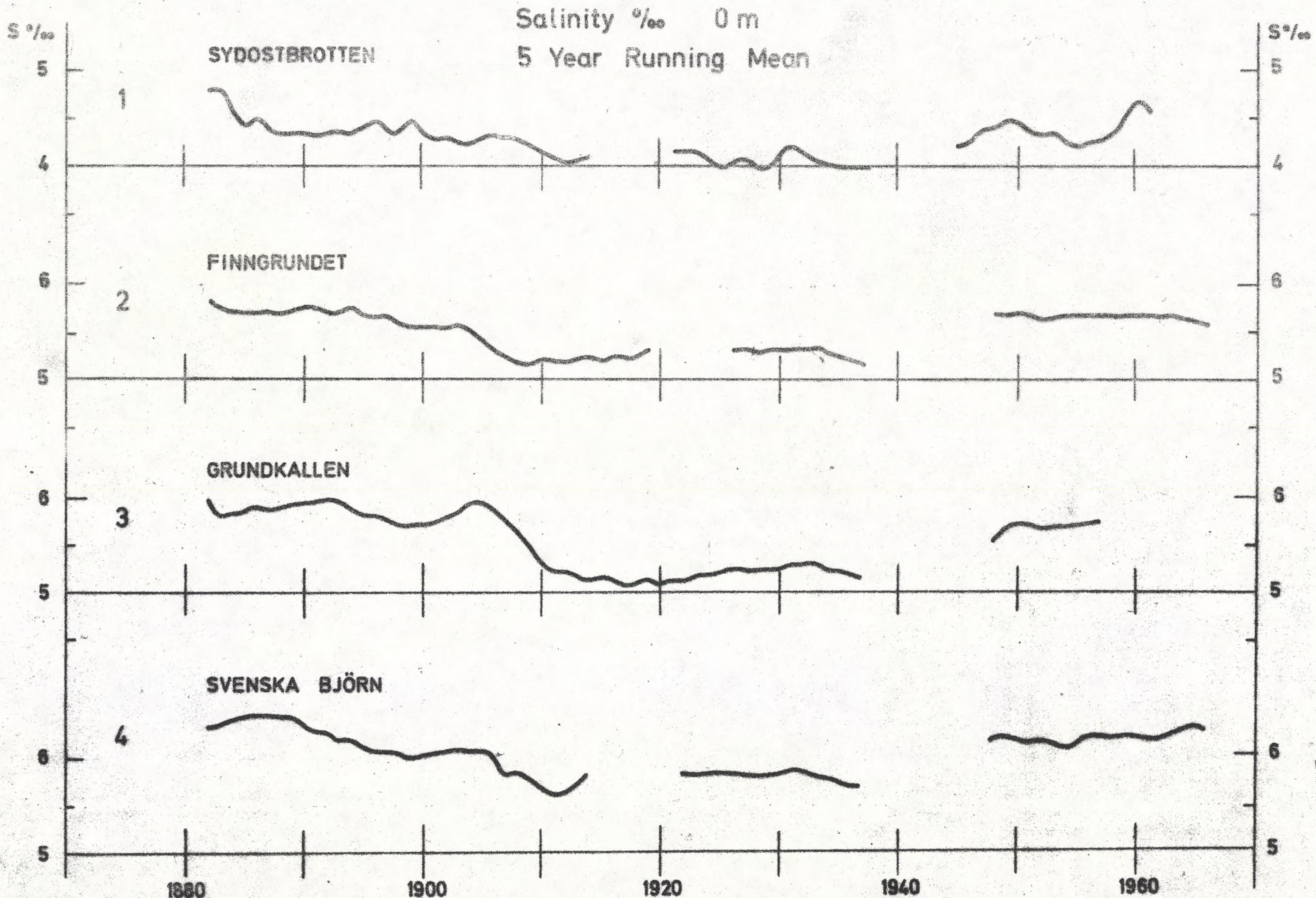
Table 1.

Length of Time Series

				years
Sydostbrotten	1880-1916,	1919-1940,	1943-1963	80
Finngrundet	1880-1921,	1923-1940,	1946-1969	83
Grundkallen	1880- ,	-1939,	1946-1959	74
Svenska Björn	1880-1916,	1920-1939,	1946-1968	80
Falsterborev	1880-1914,	1920-1939,	1950-1970	76
Svinbådan	1880-1914,	1919-1939,	1946-1960	68
Oskarsgrundet	1881-1914,	1923-1939,	1950-1961	63
Fladen	1893-1914,	1919-1939,	1948-1969	65
Skagens Rev	1880- ,	-1939,	1947-	87
Läsö Trindel (L. Nord)	1880- ,	-1939,	1943-	90
Anholt Knob (A. Nord)	1880-			93
Schultz's Grund (Kattegat SW)	1880-		-1970	91
Gedser Rev	1880-1915,	1920-1939,	1946-	83
Christiansö	1880-1885,	1889-1892,	1898-	85



10°
15°
20°
25°
66°
64°
62°
60°
58°
56°
Ulkokalla
Sydostbrotten
Säbbskär
Finngrundet
Grundkallen
Gråhara
Utö
Svenska
Björn
Gotland
Deep
Skagens Rev
Läsö N
Fladen
Anholt Nord
Kattegat
SW
Svinbådan
Oskarsgr.
Christiansö
Falster-
borev
Gedser
Rev

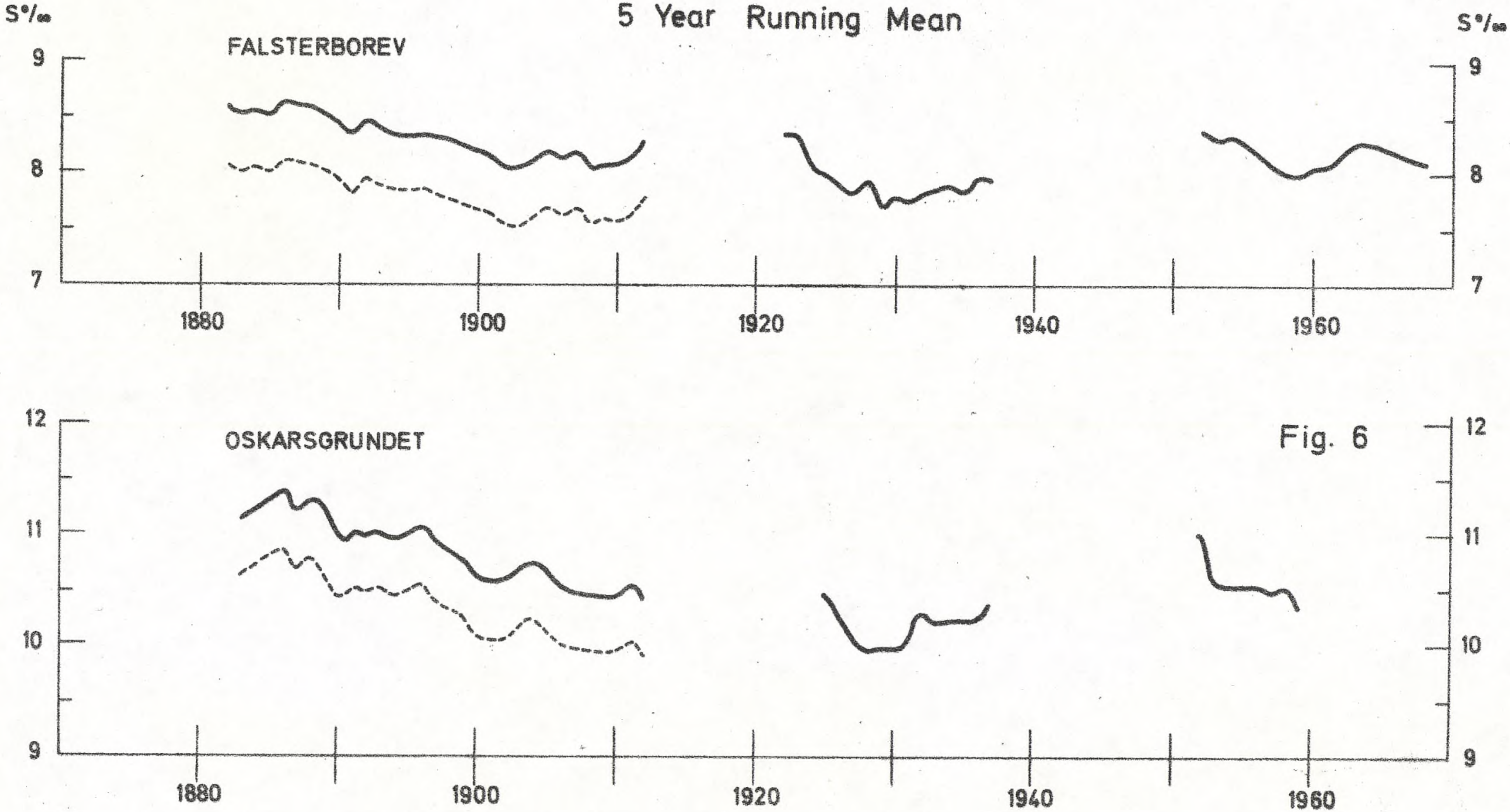


Salinity ‰ 0 m
5 Year Running Mean
S ‰
S ‰
SYDOSTBROTTEN
FINNGRUNDET
GRUNDKALLEN
SVENSKA BJÖRN
1
2
3
4
5
4
6
5
6
5
6
5
1880
1900
1920
1940
1960

Fig. 1 – 4

Fig. 5

Salinity ‰ 0 m
5 Year Running Mean



----- uncorrected values

Fig. 5-6

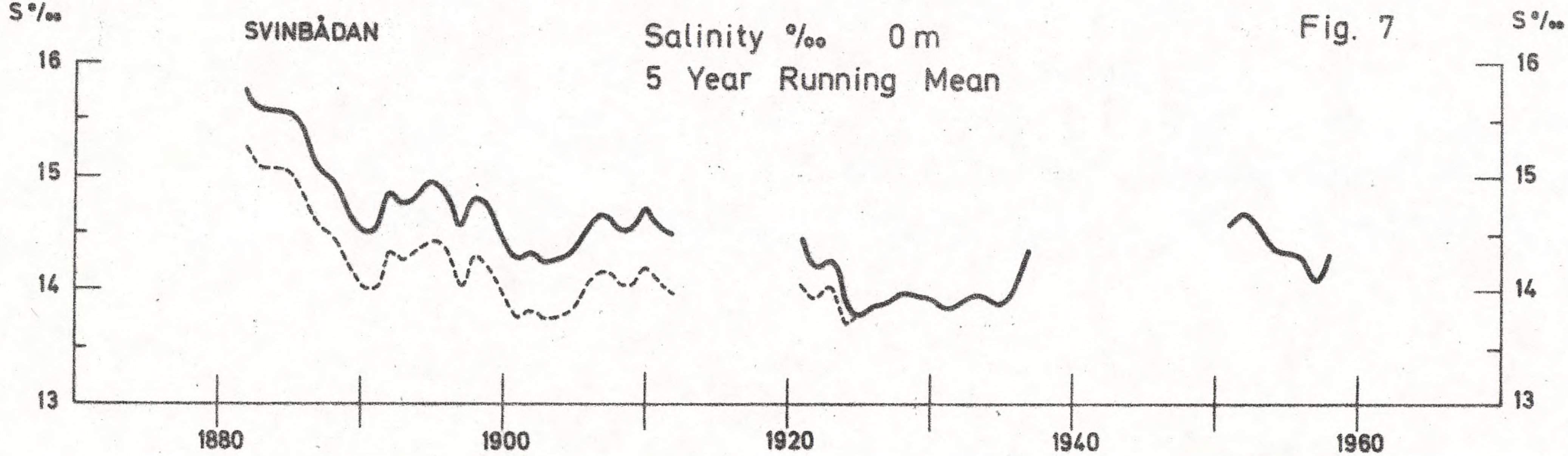


Fig. 7

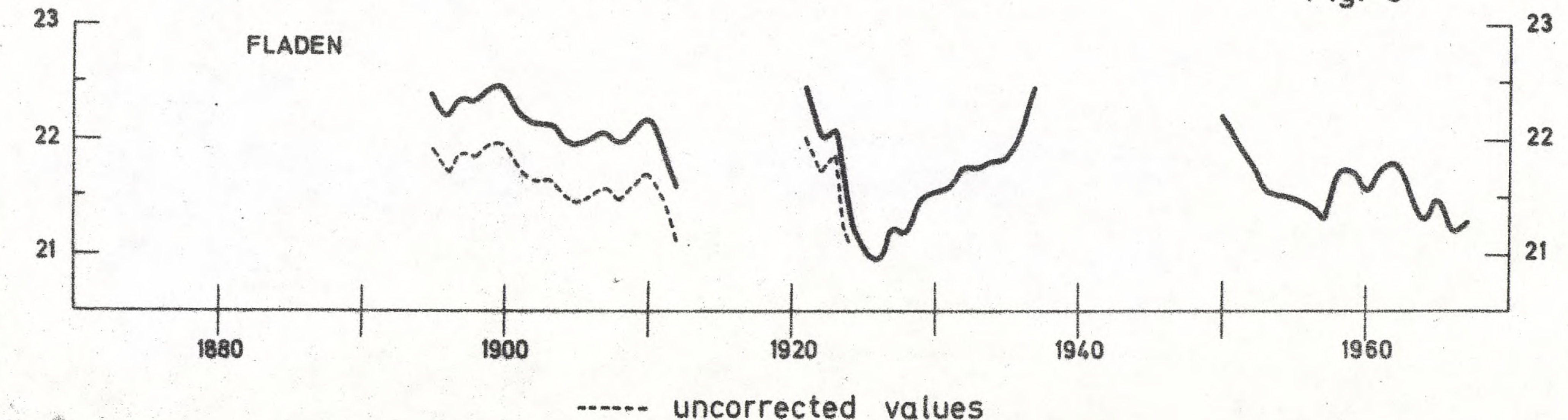


Fig. 8

Fig. 7-8

Salinity ‰ 0 m
5 Year Running Mean

Fig. 9

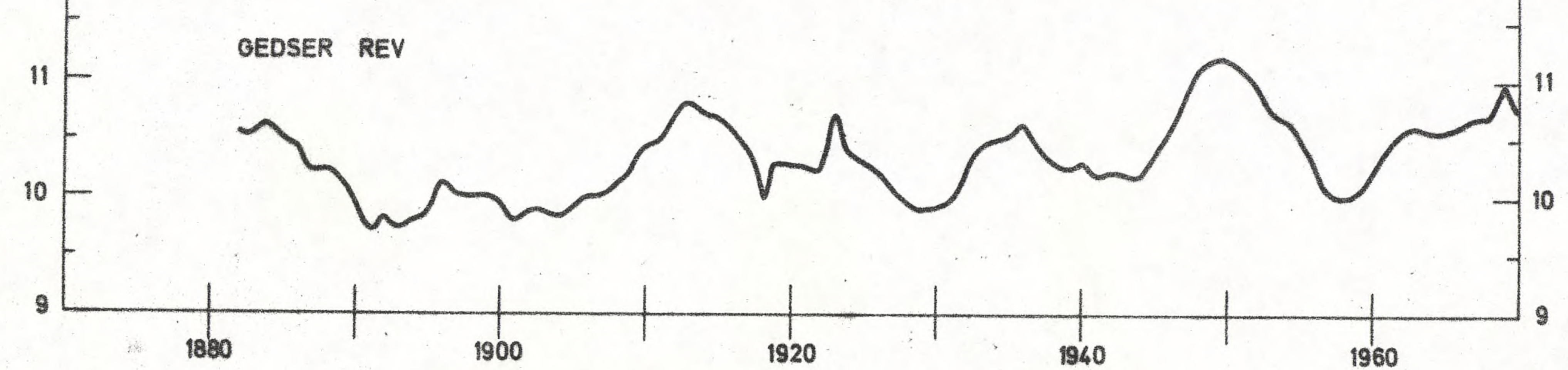


Fig. 10

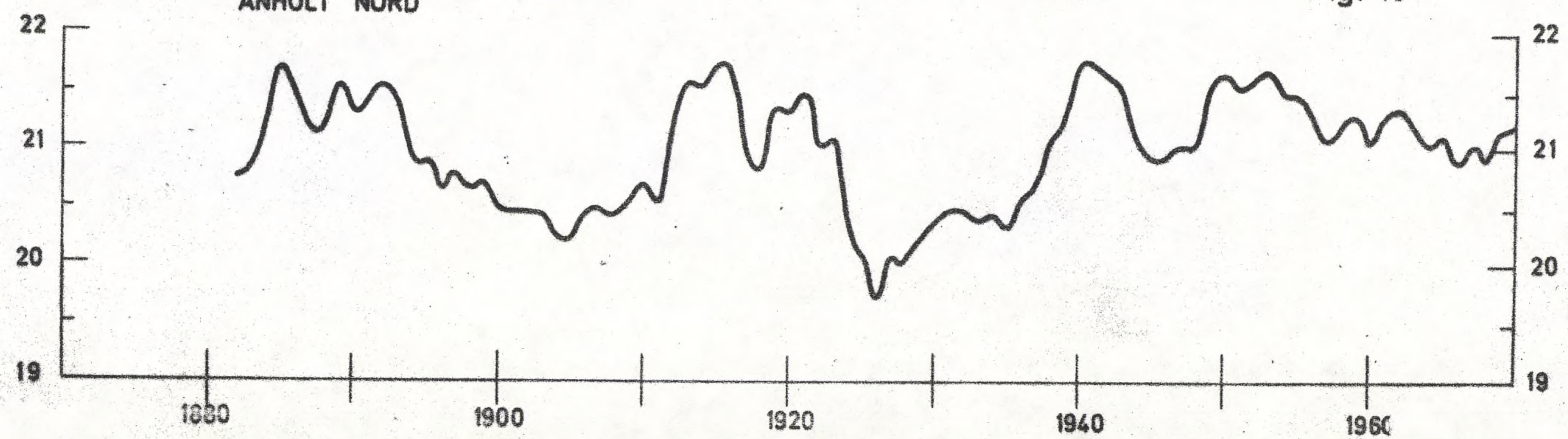


Fig. 9 - 10

Fig. 11 – 12

Salinity ‰ 0 m
5 Year Running Mean

Fig. 11

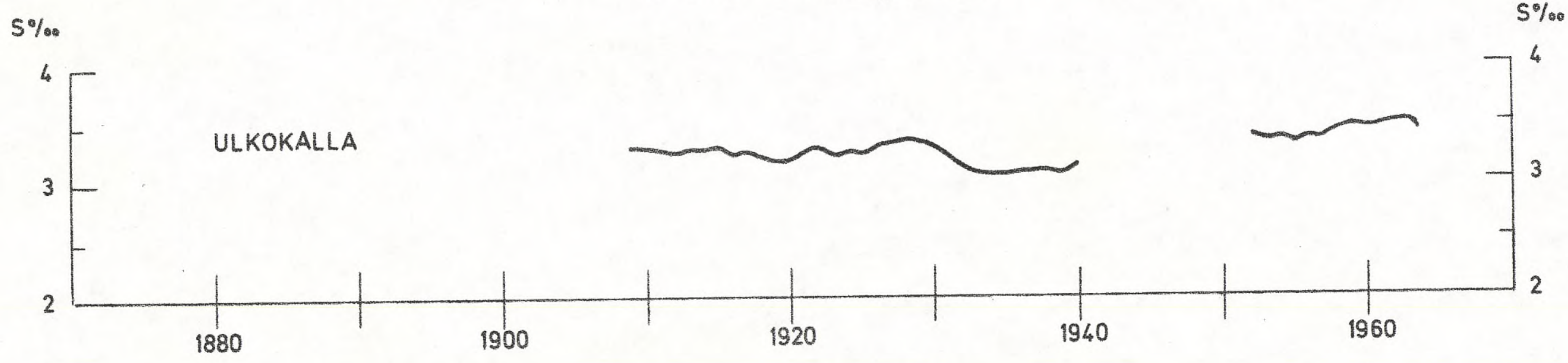
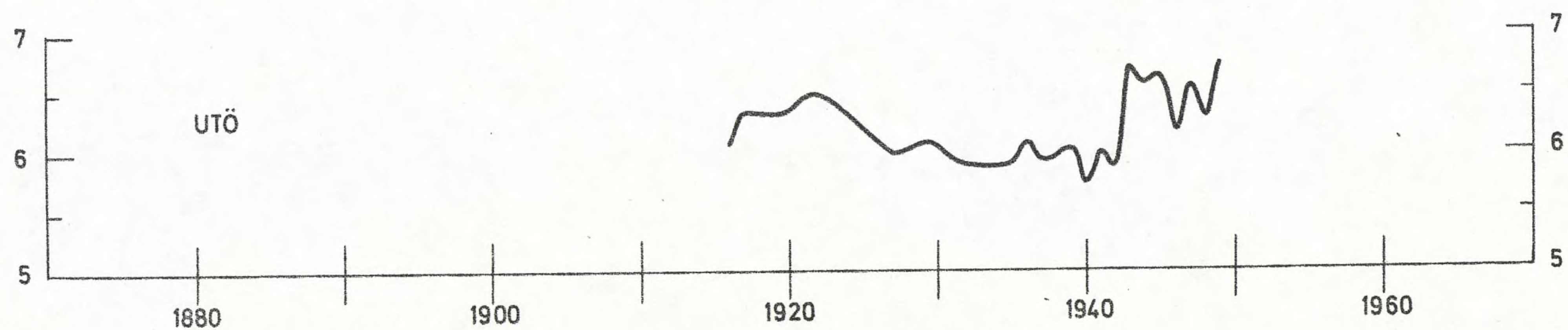


Fig. 12



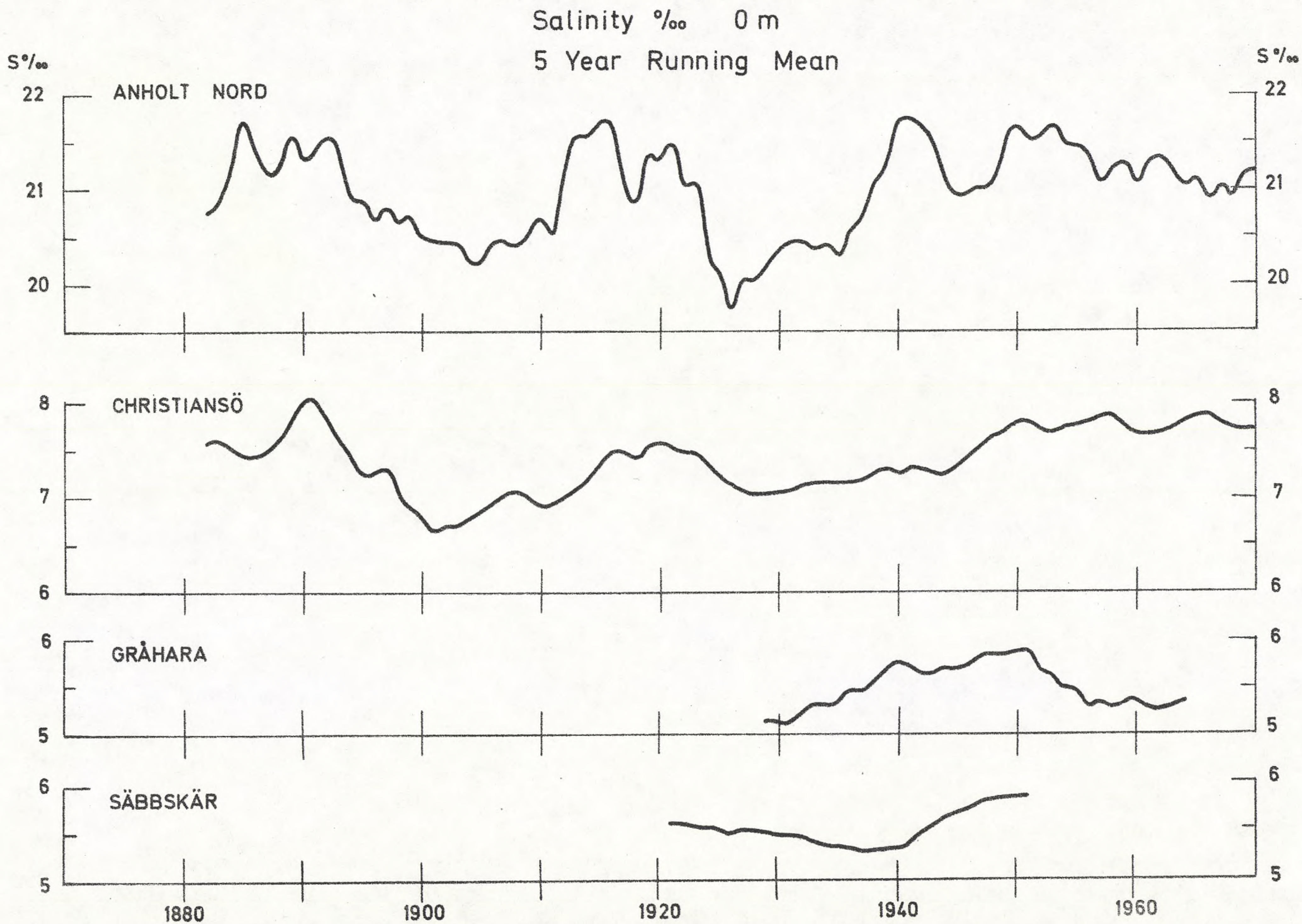
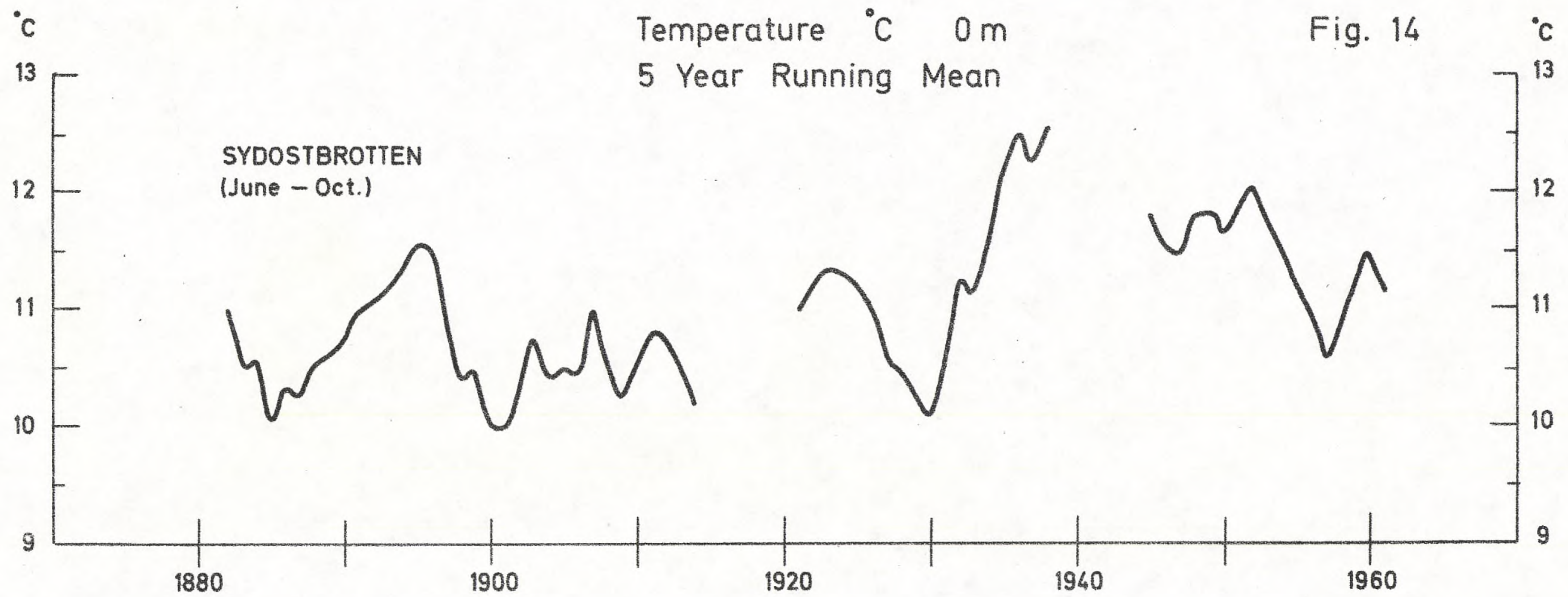

Salinity ‰ 0 m
5 Year Running Mean
S ‰
S ‰
ANHOLT NORD
22
21
20
CHRISTIANSÖ
8
7
6
GRÅHARA
6
5
SÄBBSKÄR
6
5
1880
1900
1920
1940
1960

Fig. 13

Fig. 14 – 15



Temperature °C 0 m
5 Year Running Mean
Fig. 14
°C
SYDOSTBROTTEN
(June – Oct.)
13
12
11
10
9
1880
1900
1920
1940
1960

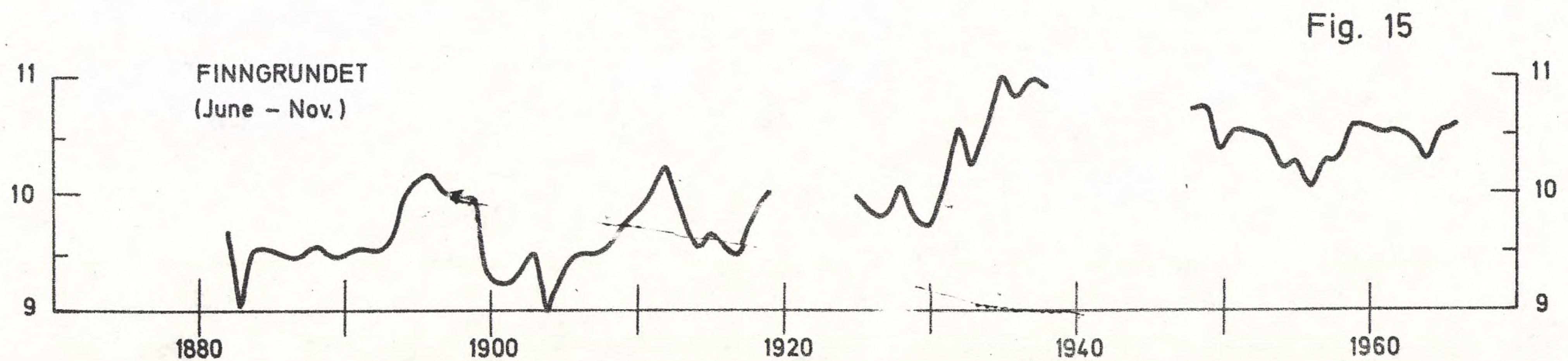


Fig. 15
FINNGRUNDET
(June – Nov.)
11
10
9
1880
1900
1920
1940
1960

Temperature °C 0 m
5 Year Running Mean

Fig. 16

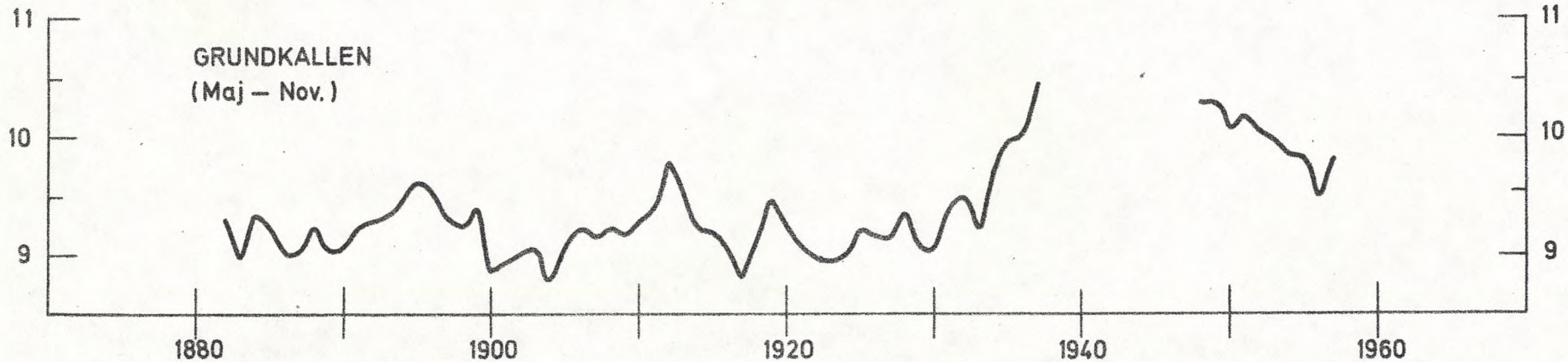


Fig. 17

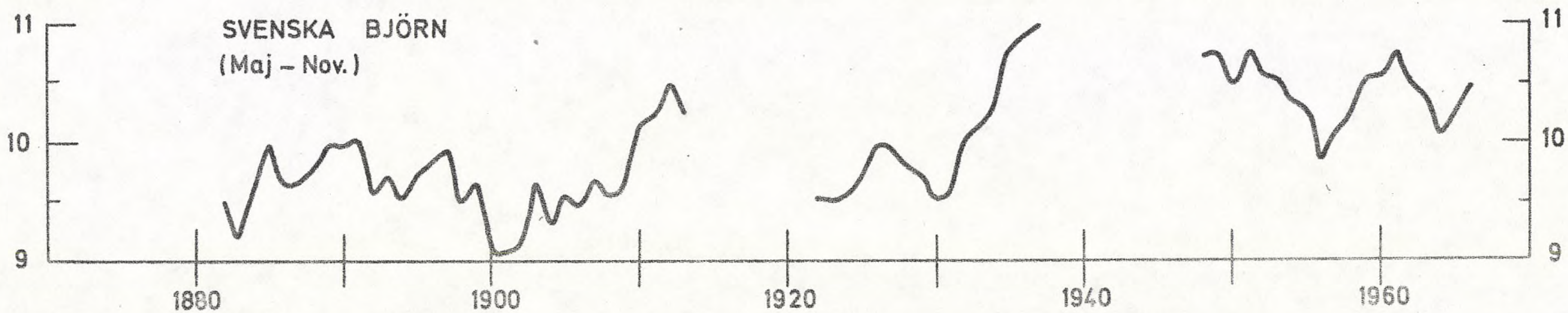


Fig. 16 – 17

Temperature °C 0 m
5 Year Running Mean

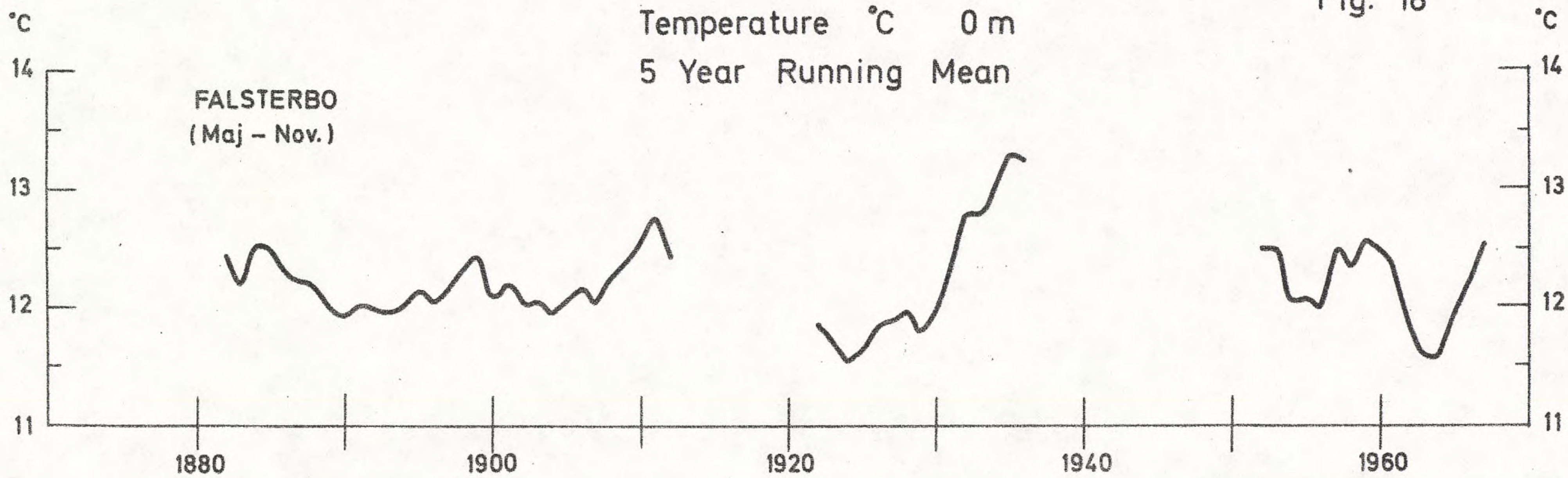


Fig. 18

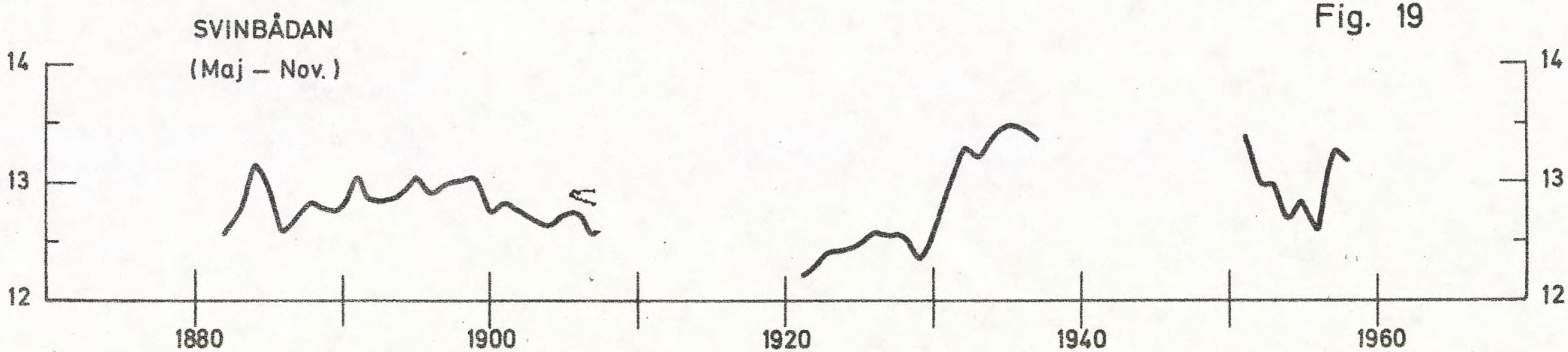


Fig. 19

Fig. 18 – 19

Fig. 20

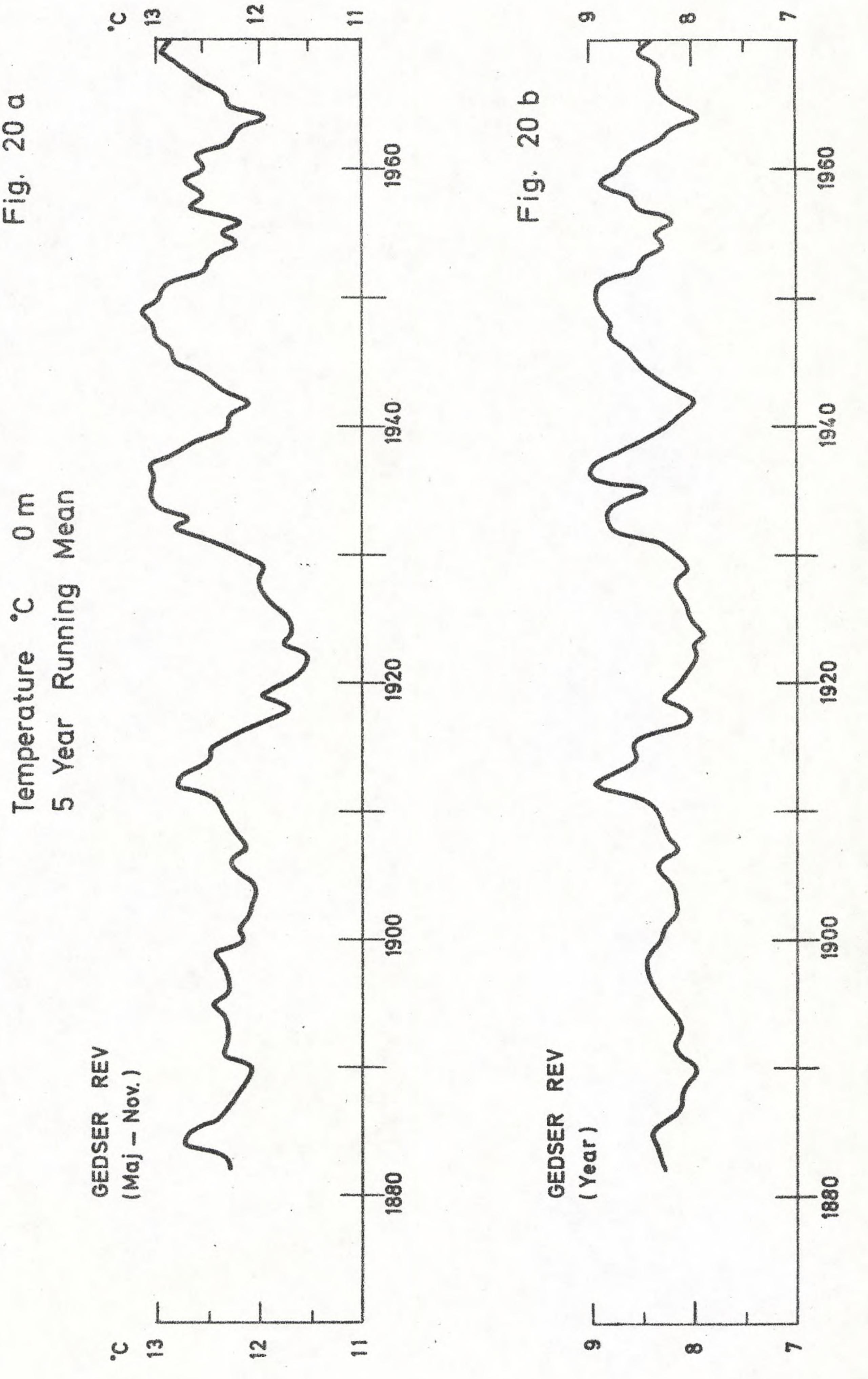


Fig. 20 a
Temperature °C 0 m
5 Year Running Mean
GEDSER REV
(Maj – Nov.)
°C
13
12
11
1880
1900
1920
1940
1960
Fig. 20 b
GEDSER REV
(Year)
9
8
7

Fig. 21

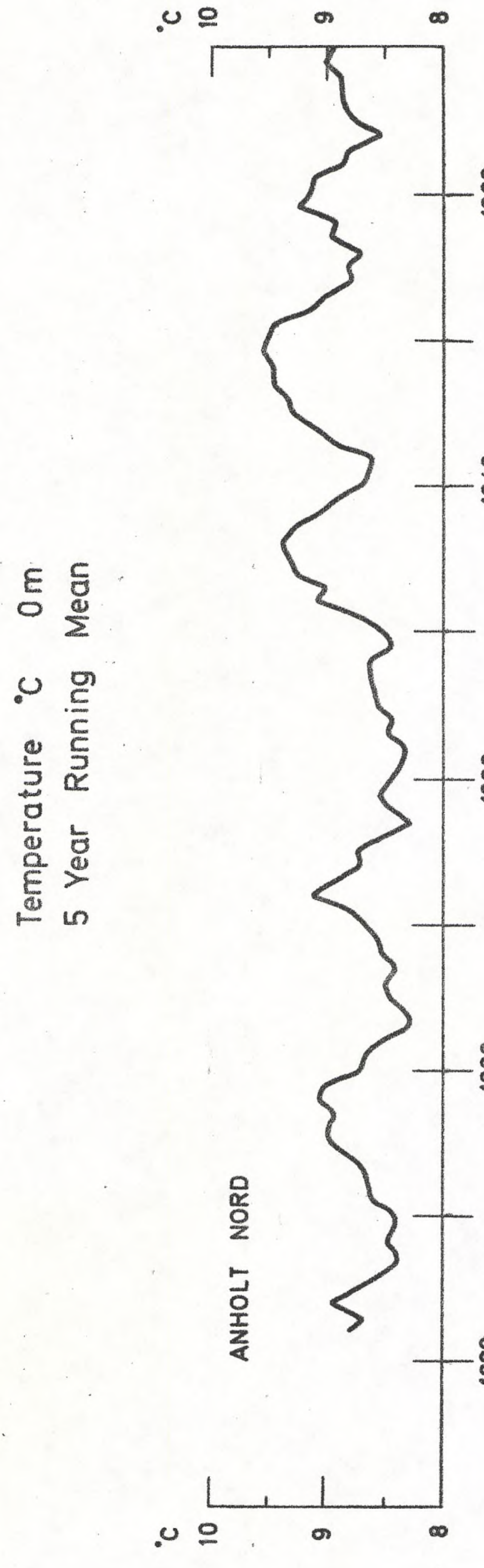

Temperature °C 0 m
5 Year Running Mean
ANHOLT NORD
°C
10
9
8
1880
1900
1920
1940
1960

Fig. 21

Fig. 22

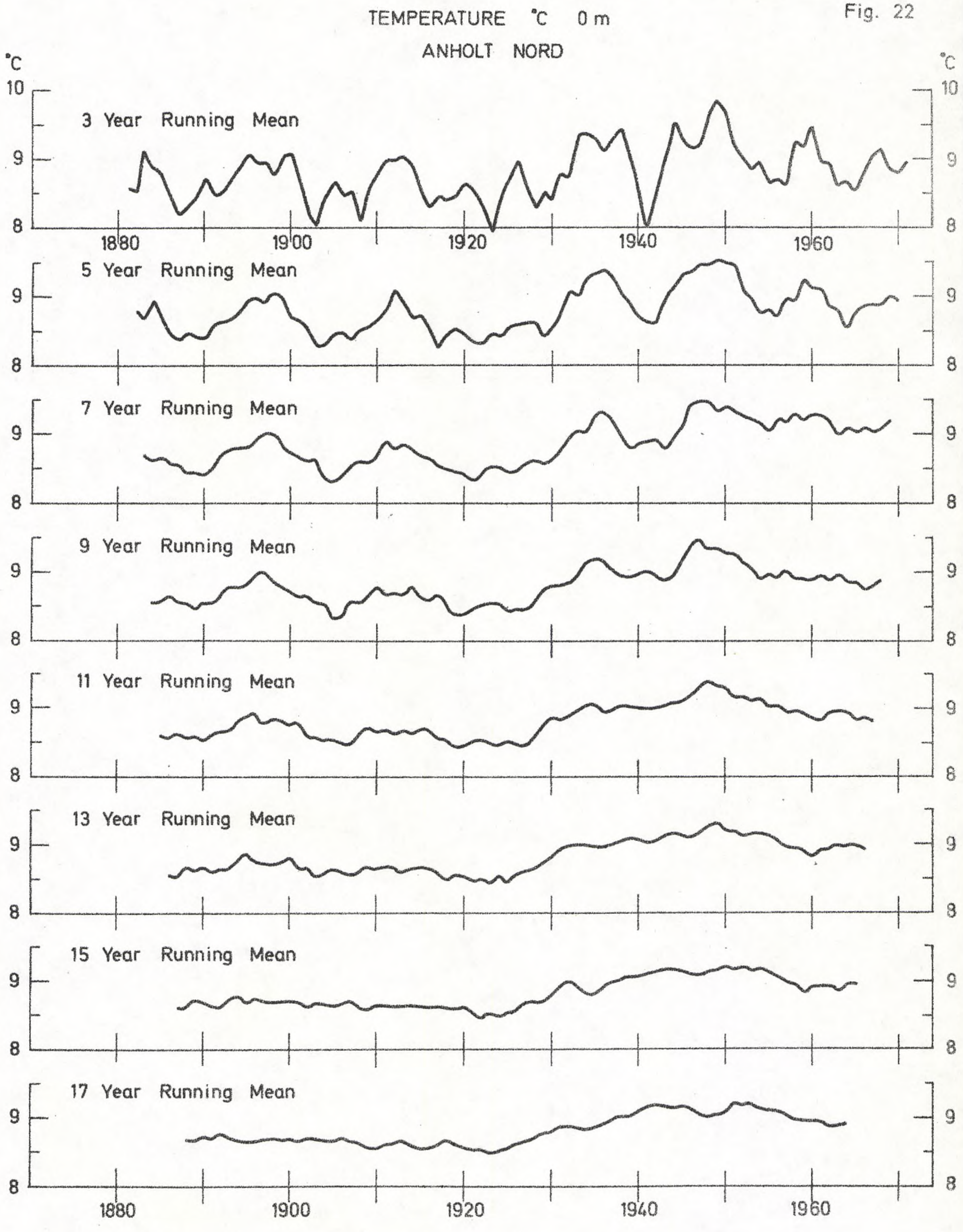
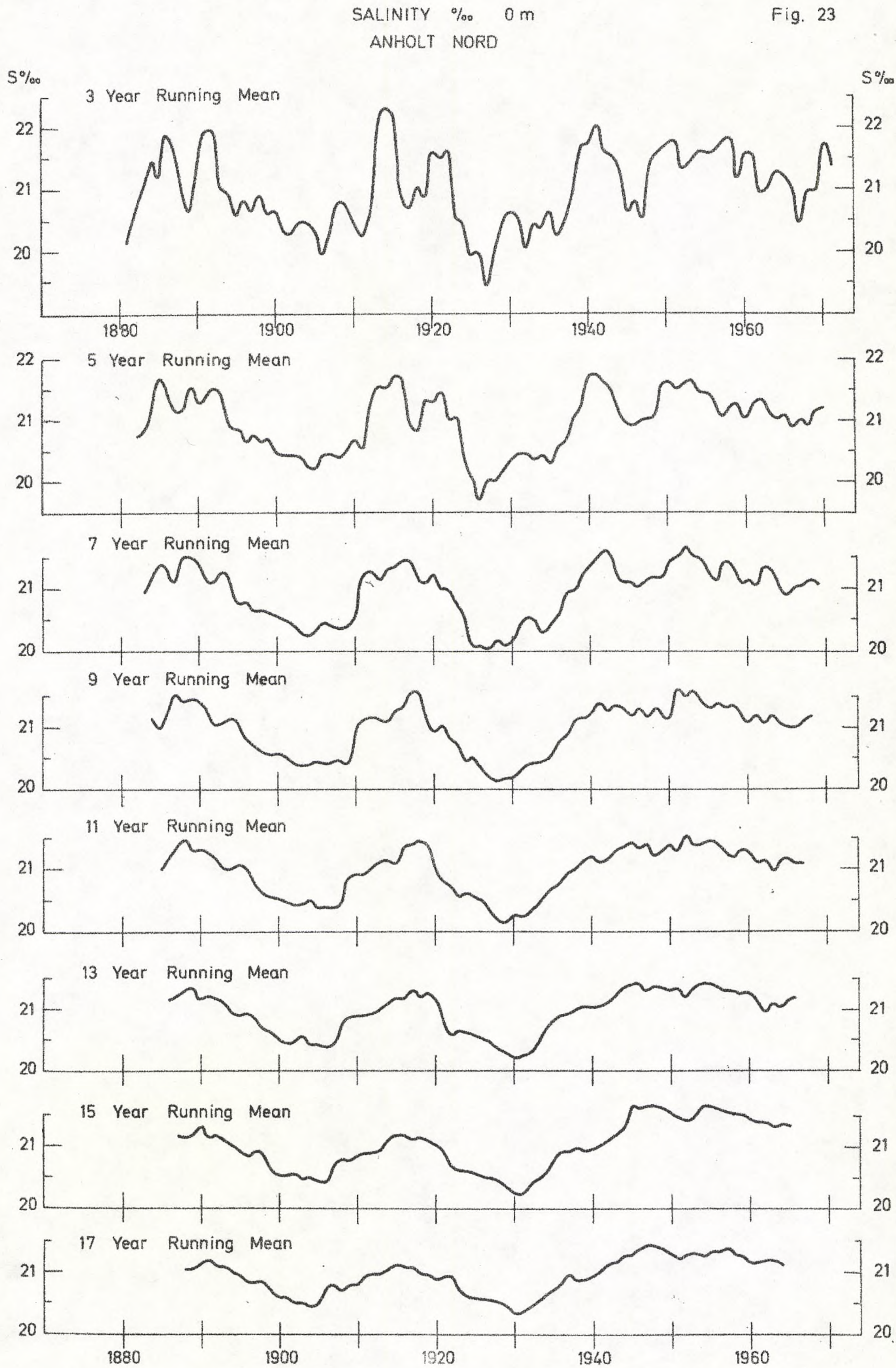

TEMPERATURE °C 0 m
ANHOLT NORD
°C
10
9
8
3 Year Running Mean
5 Year Running Mean
7 Year Running Mean
9 Year Running Mean
11 Year Running Mean
13 Year Running Mean
15 Year Running Mean
17 Year Running Mean
1880
1900
1920
1940
1960

Fig. 23


SALINITY ‰ 0 m
ANHOLT NORD
S‰
S‰
3 Year Running Mean
5 Year Running Mean
7 Year Running Mean
9 Year Running Mean
11 Year Running Mean
13 Year Running Mean
15 Year Running Mean
17 Year Running Mean
22
21
20
1880
1900
1920
1940
1960

Salinity ‰ 90 m UTÖ

Fig. 24

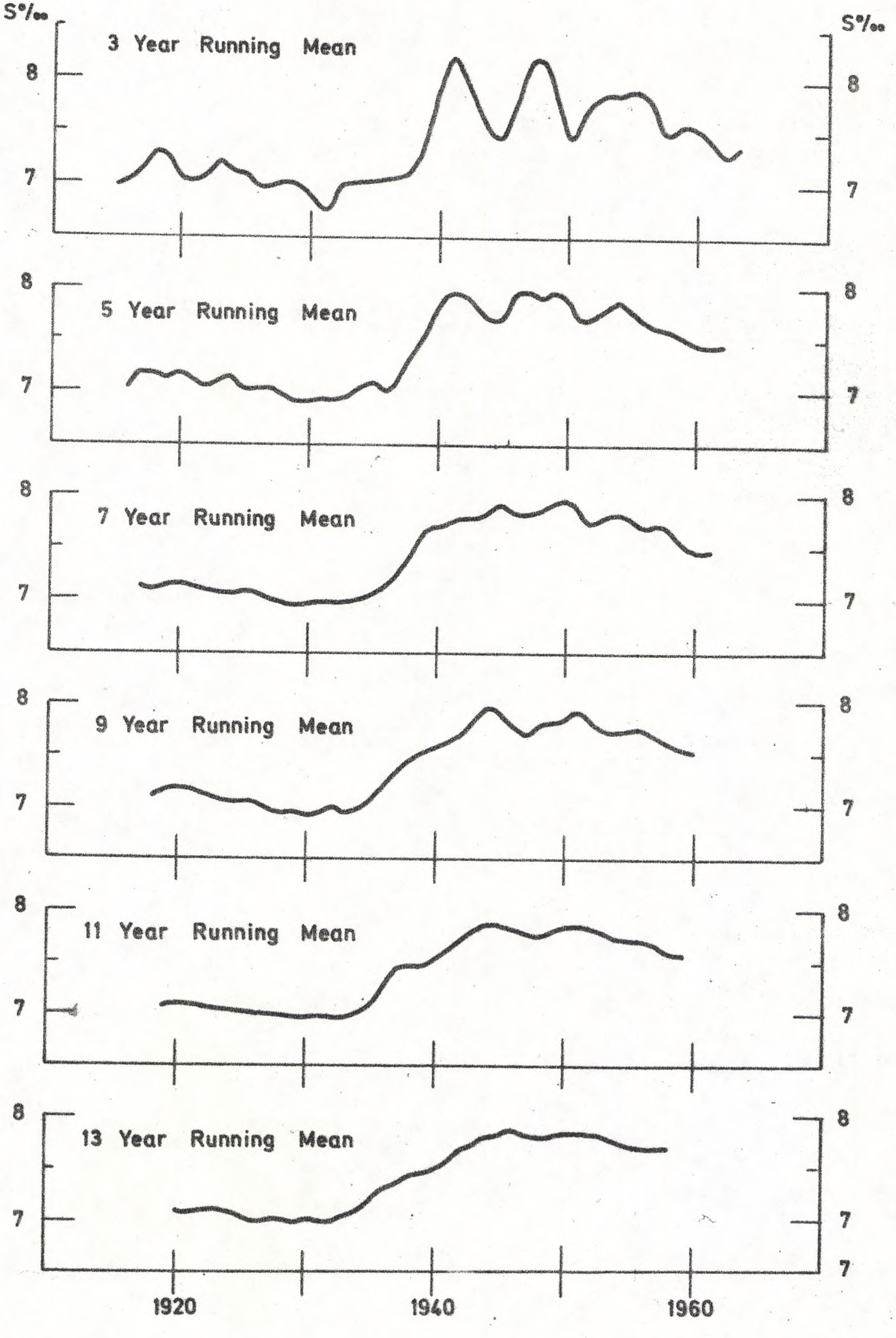


Fig. 25

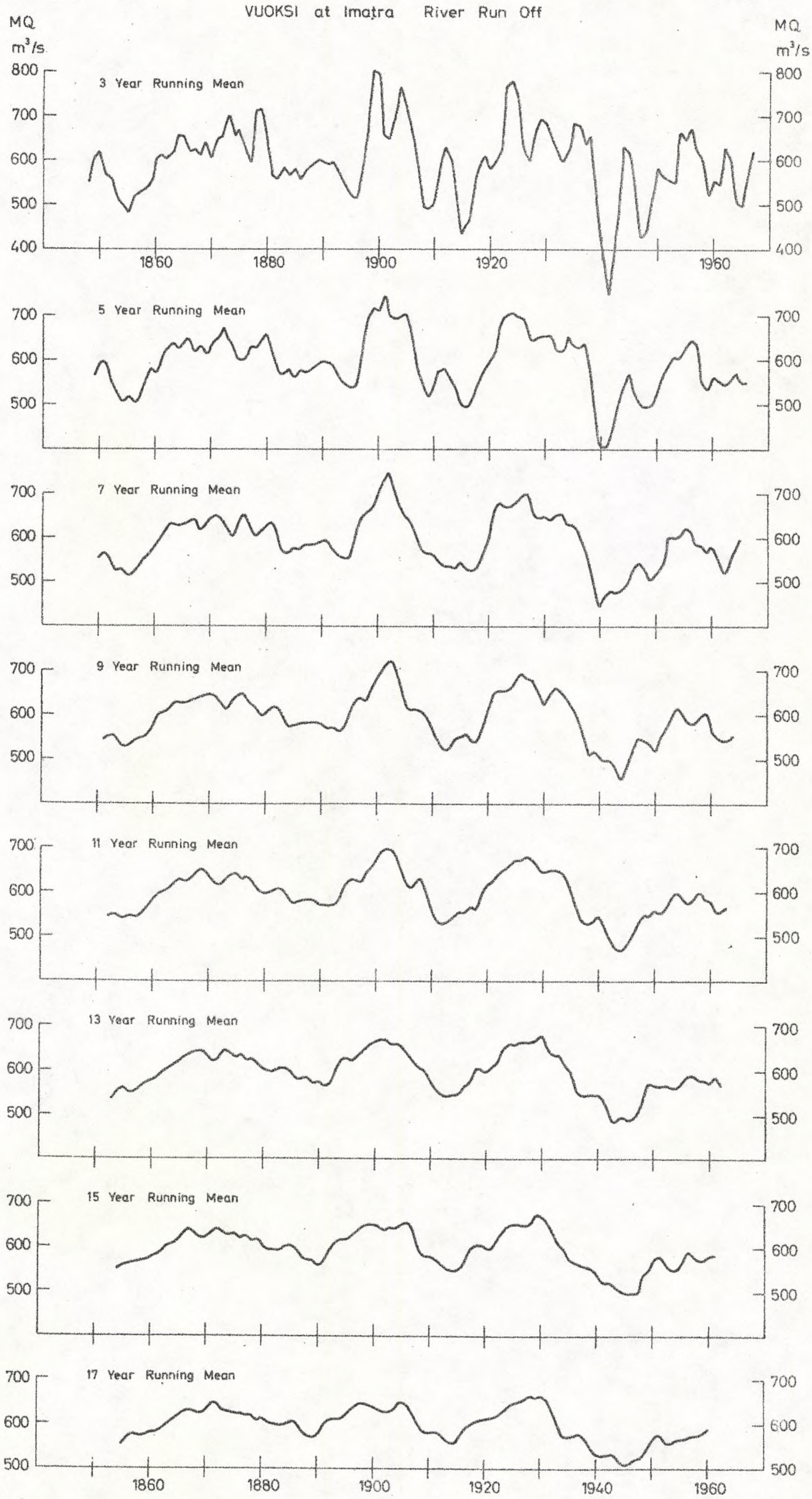

VUOKSI at Imatra River Run Off
MQ
m³/s
3 Year Running Mean
5 Year Running Mean
7 Year Running Mean
9 Year Running Mean
11 Year Running Mean
13 Year Running Mean
15 Year Running Mean
17 Year Running Mean
800
700
600
500
400
1860
1880
1900
1920
1940
1960

Fig. 26

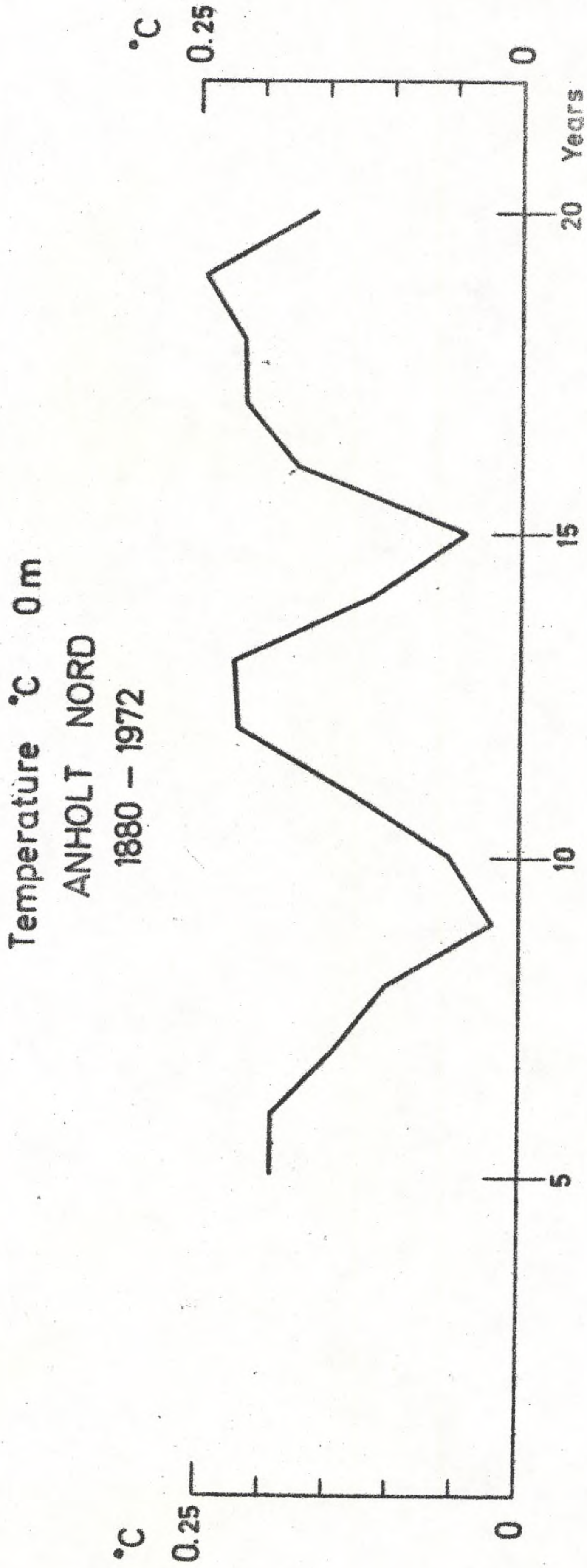
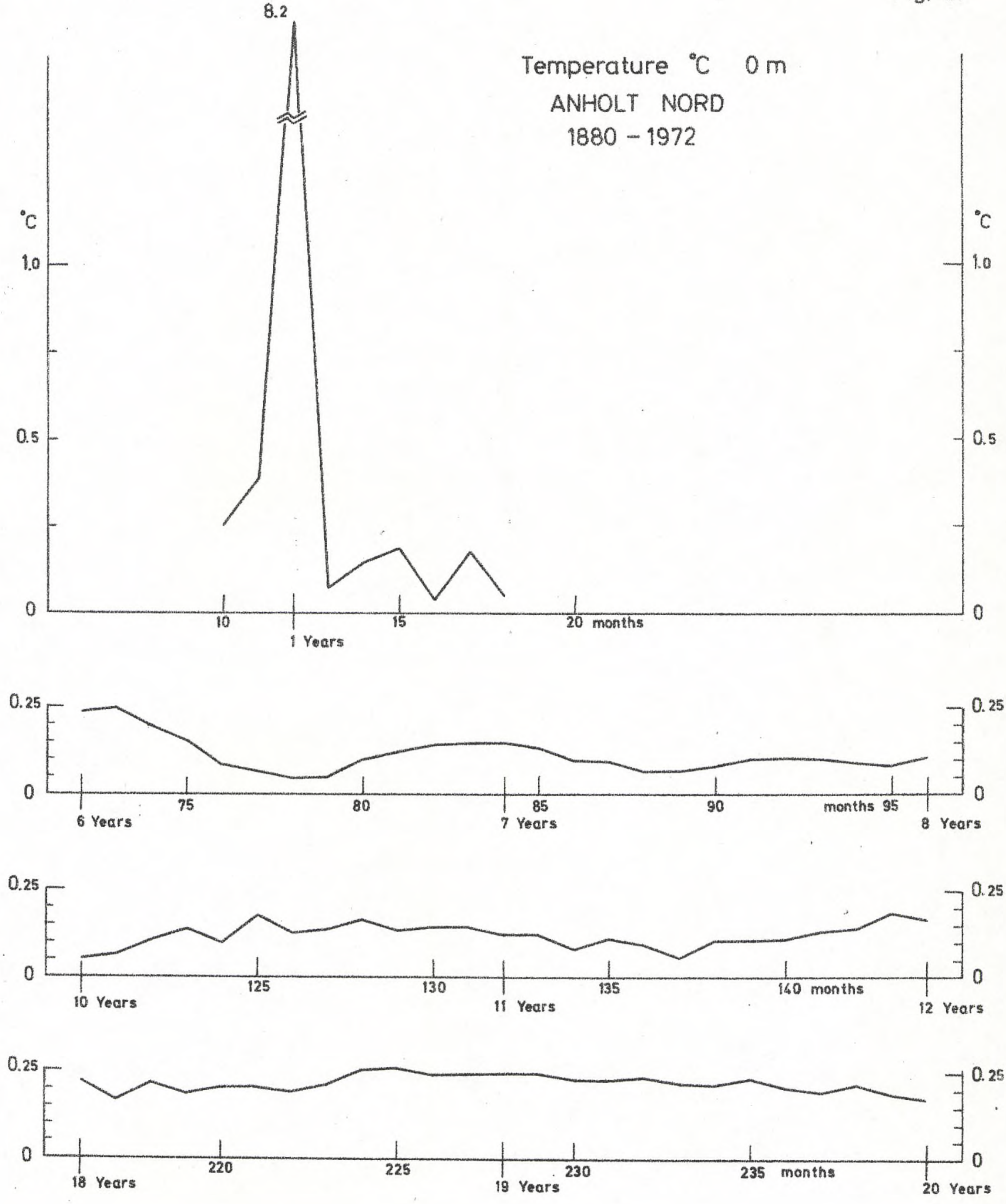
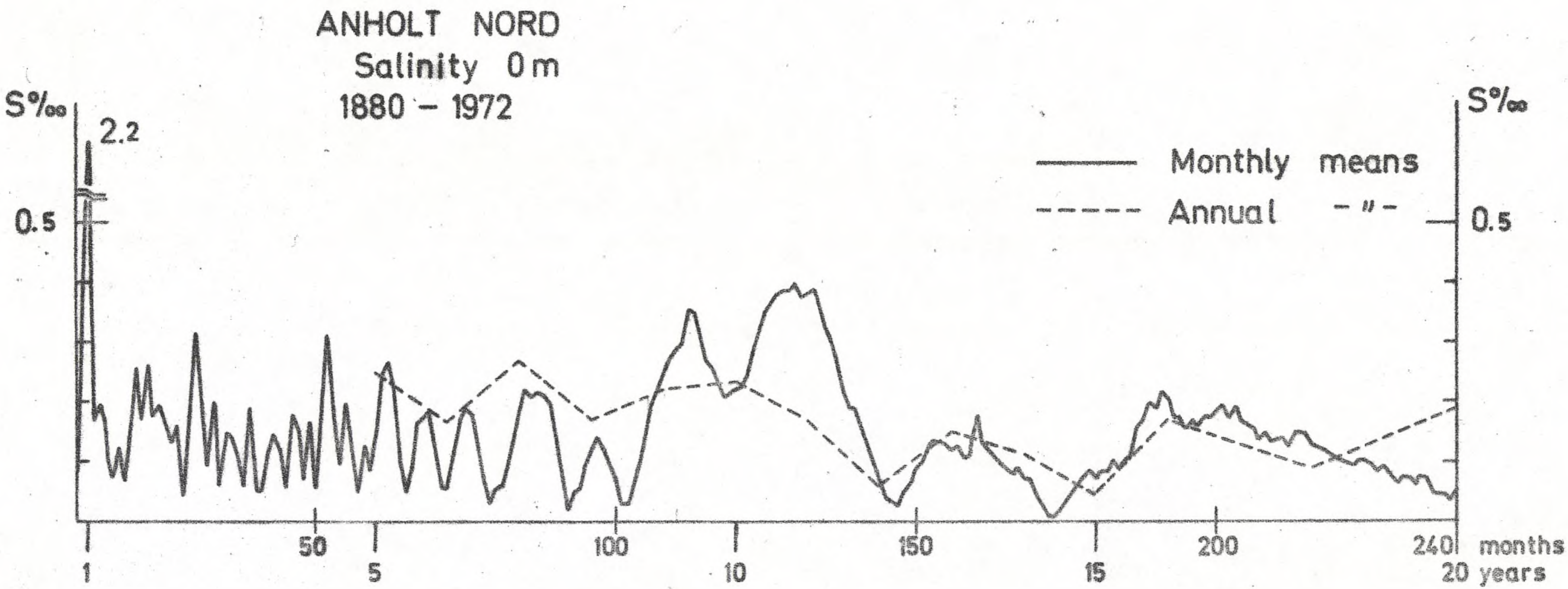


Fig. 27



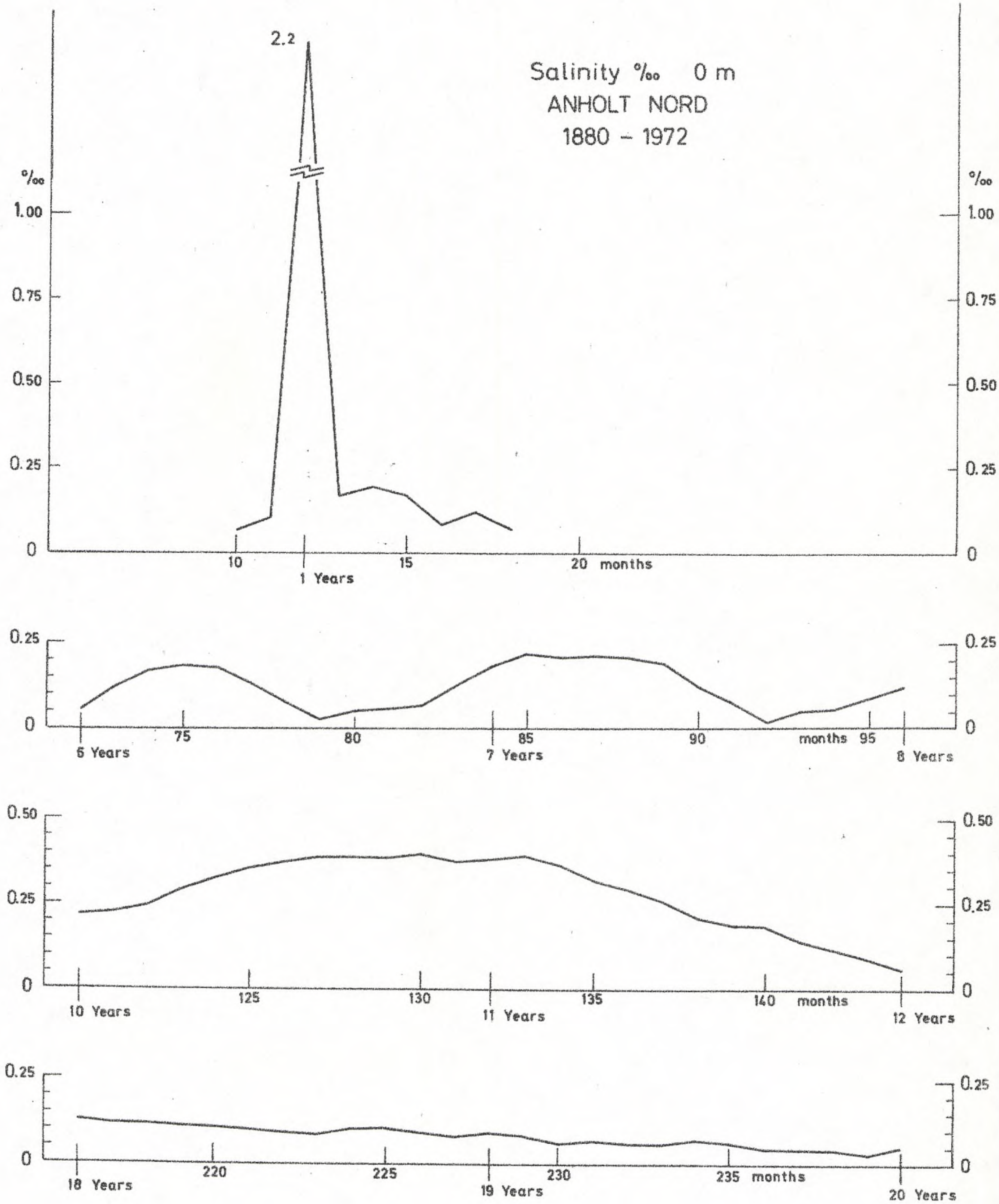
8.2
Temperature °C 0 m
ANHOLT NORD
1880 - 1972
°C
1.0
0.5
0
10
15
20 months
1 Years
0.25
0
75
80
85
90
months 95
6 Years
7 Years
8 Years
0.25
0
125
130
135
140 months
10 Years
11 Years
12 Years
0.25
0
220
225
230
235 months
18 Years
19 Years
20 Years

Fig. 28



ANHOLT NORD
Salinity 0 m
1880 – 1972
S‰
2.2
0.5
S‰
0.5
Monthly means
Annual -"-
1
50
5
100
10
150
15
200
240 months
20 years

Fig. 29



Salinity ‰ 0 m
ANHOLT NORD
1880 – 1972
2.2
‰
1.00
0.75
0.50
0.25
0
10
15
20 months
1 Years
0.25
0
75
80
85
90
months 95
6 Years
7 Years
8 Years
0.50
0.25
0
125
130
135
140 months
10 Years
11 Years
12 Years
0.25
0
220
225
230
235 months
18 Years
19 Years
20 Years

Fig. 30

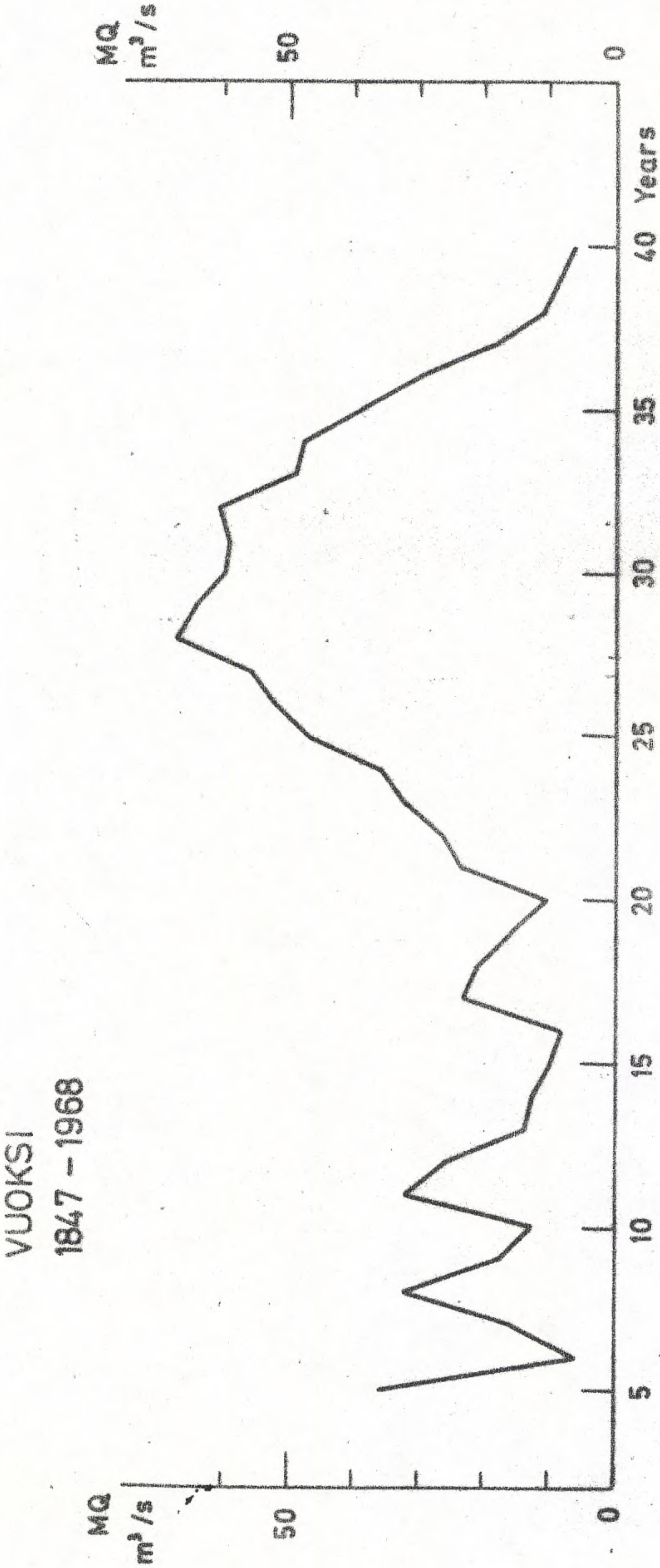
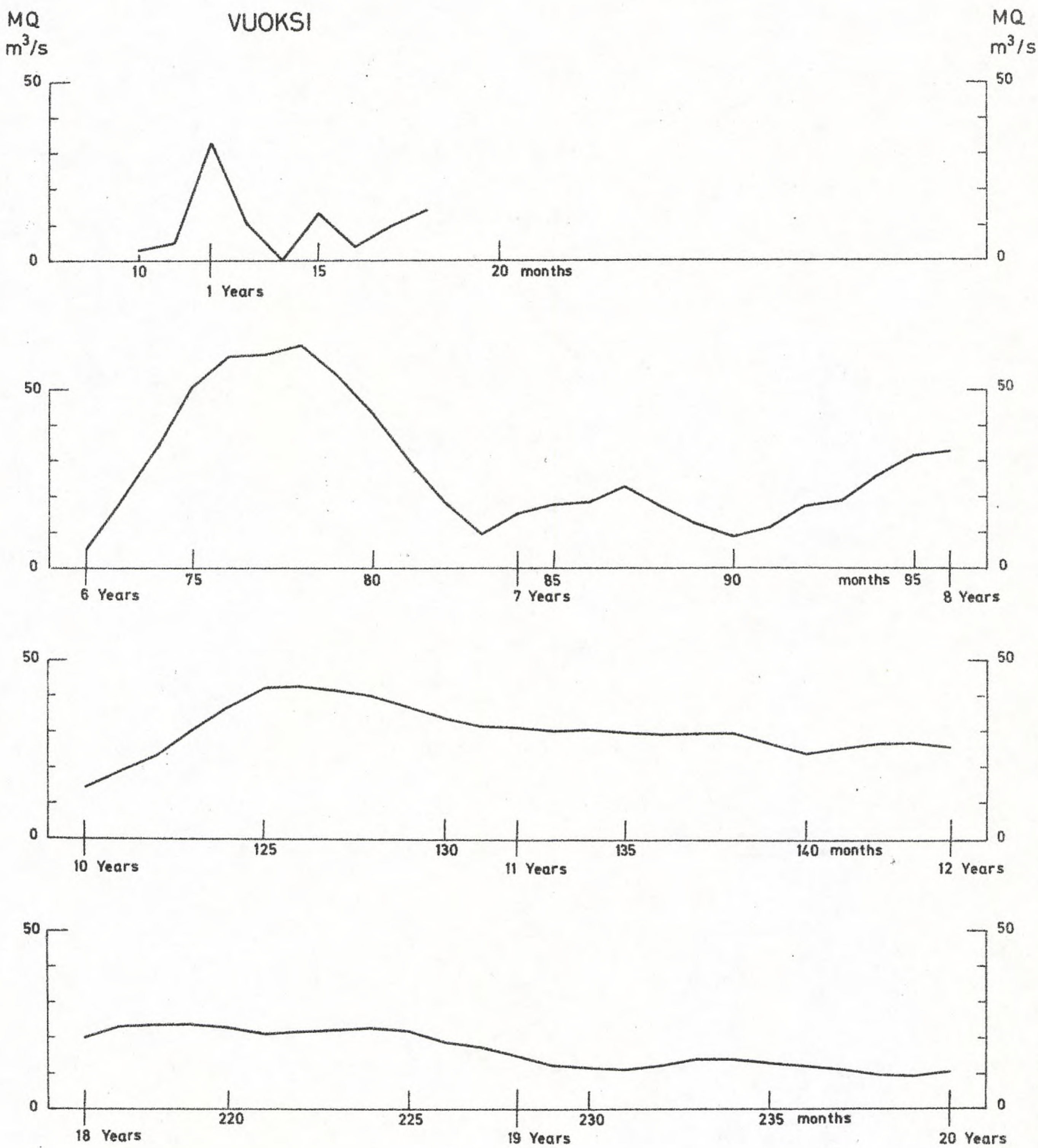


Fig. 31


MQ
m³/s
VUOKSI
MQ
m³/s
50
0
10
15
20 months
1 Years
50
0
6 Years
75
80
85
7 Years
90
months 95
8 Years
50
0
10 Years
125
130
11 Years
135
140 months
12 Years
50
0
18 Years
220
225
19 Years
230
235 months
20 Years