FISHERY BOARD OF SWEDEN
Institute of Marine Research, Report No. 1

PHYSICAL AND CHEMICAL OCEANOGRAPHY OF THE SKAGERRAK AND THE KATTEGAT

I. Open Sea Conditions

by

ARTUR SVANSSON

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The vignette on the title-page represents Bronze Age fishermen; from a rock-carving at Ödsmål, parish of Kville, Bohuslän.

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Contents

This compilation of the Hydrographical (Physical and Chemical) Conditions in the Skagerrak and the Kattegat covers mainly the open sea. A second volume on Coastal Conditions is planned but will probably be delayed for a time, as the preparatory work so far is rather scarce.

Author's address:
Institute of Marine Research
Hydrographic Department
Box 4031
S-400 40 GÖTEBORG 4, SWEDEN

1. Introduction

The first hydrographic investigation of the Skagerrak started by F. L. EKMAN in 1868 and continued in 1869, was restricted to the coast of Bohuslän (EKMAN, 1870). Even then at that time F. L. EKMAN showed that the salinity of the Koster fjord was that of nearly unmixed ocean water.

During the summer of 1872 an expedition was carried out in the North Sea by the German ship POMMERANIA (MEYER, 1875). In their big survey of the hydrography of the Skagerrak and the Kattegat, "Grunddragen av Skageracks och Kattegatts hydrografi", OTTO PETTERSSON and GUSTAF EKMAN (1891) regarded these results as very important together with those of the German ship DRACHE during the summers of 1882 and 1884 (Anon. 1886), because "in the hydrography of the North Sea we must find the explanation of the conditions that were found in the Skagerrak and the Kattegat" (Translation from Swedish, PETTERSSON and EKMAN, 1891, referred to in the following as "Grunddragen").

During the summer of 1877 F. L. EKMAN surveyed the Baltic, the Kattegat and the Skagerrak extensively. The results were edited by O. PETTERSSON after F. L. EKMAN's death (EKMAN and PETTERSSON, 1893). In the winter of 1878—79 G. EKMAN took measurements in those parts of the skerries of Bohuslän, where there was extensive herring fishery (G. EKMAN, 1880). This started in the winter of 1877—78, when, for the first time since 1808, the winter herring invaded the coast and skerries of Bohuslän. During the period 13—19 February 1890, five ships were sent out on expeditions into the Kattegat and the Skagerrak ("Grunddragen").

In 1897 O. PETTERSSON and G. EKMAN published a further paper, emphasizing especially the connection between the hydrographic factors and the decline of the herring fishery off the coast of Bohuslän in the winter of 1896—97. This problem became more and more acute in the Swedish oceanographic investigations, which after the establishment of the International Council for the Exploration of the Sea in 1902 became part of the international cooperative work.

The authors of "Grunddragen" are of the opinion that "on the bottom of the deep parts of the Skagerrak there is a mighty layer of water, which because of its salinity of a little more than 35 ‰ must originate from the Atlantic Ocean. It does not have the same salinity 35.5 ‰ as the surface water of the Atlantic Ocean around the Faroes and Shetlands during the summer, but is, in respect of salinity, more like the water which enters from the North Atlantic over the north plateau and the western edge of the Norwegian channel" (Translation from Swedish of p. 132 in "Grunddragen"). The last conclusion was made by the authors after their study of the sections measured by the R/V DRACHE 1884 (Fig. 1, stations Dr). The high salinity of

35.8 ‰ may be too high, but the relative picture is very informative (see also EGGVIN, 1940). Current measurements carried out in June 1961 (LJØEN, 1962) confirm the old theory that water flows southwards in the outer part of the Norwegian channel (vicinity of D6, at 50, 100 and 145 m, while at 10 m it is variable). "Grunddragen" gives an account of a winter expedition (February 1890), when the isohaline of 35 ‰ was located deeper than it was in the summer of 1877. "Between winter and summer there must be an inflow of water that is more salty so that its mass increases" (Translation from Swedish of p. 133 in "Grunddragen"). This remark also refers to water of a salinity of between 34 and 35 ‰ (here called 34—35 Water). We continue the quotation "Above the 34—35 Water we find the Bank Water, 32—34 ‰ S. This water is found especially outside the west coast of Norway and on the Norwegian banks." This type of water plays a very important role in the discussion of the herring fishery.

In 1880 a large number of Danish and some Swedish lightvessels started daily observations of temperature and salinity but also of surface currents many times a day. Except for L/V Grisbådarna, which made observations during 1923—1928, and L/V Skagens Rev, the lightvessels were and are still not situated in the Skagerrak (see further Ch. 4).

2. Boundaries. Topography

2.1. Boundaries

In this review of the physical and chemical conditions in the Skagerrak and the Kattegat also the adjacent seas, the North Sea, the Belt Sea and the Baltic will be mentioned when deemed necessary.

Oceanographic limits as they are defined by WATTENBERG (1949) and others have been preferred. These differ sometimes from those approved by the 1952 International Hydrographic Conference (ANON. 1953).

The border between the North Sea and the Norwegian Sea is drawn along the latitude of 61° N from Norway to the Shetland Isles continuing to the British Mainland (ANON. 1953). The southern border of the North Sea is preferably South Foreland—Cap Griz Nez in the Strait of Dover (LEE 1970). The border between the Skagerrak and the North Sea (ANON. 1953) is a line drawn between Hanstholm (Denmark) and Lindesnes (vicinity of Mandal, Norway). In Fig. 2 this line approximately coincides with section 0: 0.

The border between the Skagerrak and the Kattegat (WATTENBERG 1949) is a line drawn between Skagen and Marstrand (Fig. 2 approximately section 0: 11).

The border between the Kattegat and the Belt Sea (WATTENBERG 1949) consists of two lines: Hassensør (SSE of Ebeltoft)—Sjaellands odde (section 1: 2, 3) to that part of the Belt Sea which is called Samsø Baelt and Gilleleje—Kullen (section 2: 0) to that part of the Belt Sea, which is named Öresund.

The border between the Baltic and the Belt Sea (WATTENBERG 1949) also consists of two lines: a) Gedser Rev—Darsser Ort (passing the Darsser Sill (section 4: 7, 8)) to that part of the Belt Sea which is named the Bay of Mecklenburg and b) Dragør—Saltholm—Limhamn to the Öresund (approximately section 2: 6). Note, however, that ANON. (1953) puts the southern boundary line of Öresund along Stevns Klint—Falsterbo, section 2: 8. This line is always used in conventions of fishing and pollution.

Sometimes we speak only of the North Sea and the Baltic. The Skagerrak is then included in the North Sea and the Kattegat in the Baltic. The border is a line drawn between Skagen and Marstrand. The Convention on the protection of the marine environment of the Baltic Sea Area defines this boundary to be the parallel of the Skaw at 57° 44′ 8″ N.

2.2. Topography

The North Sea is usually described as a shallow sea with a mean depth of 94 m. Along the coast of Norway there is, however, a deep trench, the Norwegian Trench (the German name RINNE is often used by British fishermen: the Norwegian Rinne) with a maximum depth of 700 m in the Skagerrak. The sill depth of this "Skagerrak Deep" is 270 m and is situated off Utsira in Norway (approximately N 59°20′). From the Norwegian Trench in the Skagerrak a narrow trench (named the Deep Trench) penetrates down into the Kattegat along the Swedish coast. The depth decreases from approximately 100 m in the North to about 75 m SW Vinga but increases again to approximately 100 m in isolated deeps down to Anholt. Generally speaking, however, the Kattegat is very shallow with a mean depth of 23 m.

The sill depth between the Baltic and the North Sea is situated at Darsser Sill (D. SCHWELLE, see above) and is 18 m. The sill depth does not increase above approximately 23 m in the Belt Sea and the southern Kattegat until we come to the Anholt area but also in the Belt Sea there are isolated deeps of up to 80 m in depths.

At the border line between Öresund and the Baltic the sill depth is only 8 m. The maximum depth (50 m) of the Öresund is off Landskrona. Table 1 presents volumes, areas and mean depths of the areas concerned. The values for the Baltic have been slightly revised by DAHLIN (1973) and EHLIN, MATTISSON and ZACHRISSON (1974). A very thorough study of the late quaternary history was made by MÖRNER (1969). This work contains among other things, a very detailed geological map of the (present) seabed of the Kattegat. See also FLODÉN (1973).

3. Fresh Water Supply

While relatively much is known about the fresh water supply to the Baltic (Brogmus 1952, Mikulski 1970, 1972), we do not have these figures for the Kattegat and the Skagerrak published in summary form. Here an attempt will be made to present some rough figures. Whereas Swedish and Norwegian data of river discharge are published, this is not the case with Danish discharges. Instead such figures are roughly computed from net precipitation figures published by Anon. (1971). The discharge of Danish rivers to the Kattegat may be subdivided into 3 parts:

a) from the island of Sjaelland with a catchment area of 2460 km^2. With a net precipitation figure of 180 mm/year we arrive at 14 m^3/s.
b) from Jylland, except Limfjord, a catchment area of 5815 km^2. With a net precipitation figure of 300 mm/year we get 55 m^3/s.
c) from the Limfjord. There is a discharge from Jylland to the Limfjord corresponding to a catchment area of 7200 km^2. With a net precipitation figure of 350 mm/year we arrive at a discharge of 80 m^3/s. Assuming that most of this fresh water is drained to the North Sea, we take 30 m^3/s as a very rough discharge figure from this area to the Kattegat.

In this way we have a total discharge of 99 m^3/s from the Danish rivers discharging to the Kattegat. Adding the Swedish river contribution (Table 2) we arrive at 885 m^3/s to the Kattegat. The total catchment area is 81,115 km^2.

The volume water discharged by Swedish rivers to the Skagerrak is small, 45 m^3/s (Table 2). The figure is taken from Melin (1955) and represents the period 1909—50.

The water discharged by Danish rivers to the Skagerrak is still smaller. We assume the catchment area to be 1000 km^2 and the net precipitation to be 300 mm/year. We then get 10 m^3/s.

The Norwegian figures were taken from Anon. (1958). They represent the period 1911—1950. Tollan (pers. comm.) is of the opinion that the figures also represent the period 1931—1960. Tollan gives a total discharge of 2190 m^3/s to the Skagerrak from Norwegian rivers 1931—1960, and it seems permissible to fill up the difference by a post "others" of 249 m^3/s in Table 2.

Adding all contributions from the three countries we get a total discharge of 2245 m^3/s to the Skagerrak.

4. Positions of Some Permanent Points of Observation

The Kattegat and Belt Sea area is characterized by a very great density of observing lightvessels from which measurements have been carried out daily, with regard to currents even several times a day. Fig. 2 gives the positions of the points of observations. SVANSSON (1971) contains information as to where and how the data is stored. This type of observation platform, however, hardly exists in the Skagerrak. Hence the research vessels are of special importance in this area.

As part of the international investigation directed by the International Council for the Exploration of the Sea, Sweden undertook measurements in the Eastern part of the Skagerrak (Fig. 1, stations S) and Germany in the Western part (stations D) during the years 1902—1914 in February, May, August and November. Mean values were computed and presented as sections by KOBE (1934).

Whereas there are very few measurements in the open Skagerrak in the period 1915—1946, both Norwegian and Swedish research vessels started work in this area in 1947, the Norwegian on a section Arendal—Hirtshals, which is still under survey, the Swedish on section M between Arendal and Skagen (1947—1960), section Å perpendicular to the Swedish coast of Smögen (from 1962) and section P between Marstrand and Skagen (from 1947). Ten year means of temperature, salinity and chemical parameters at the Å section are presented in Ch. 9.

Swedish measurements of chemical parameters in the Kattegat started 1965 at 4 positions: Fladen and Kullen (see Table 15), Lilla Middelgrund (N 56° 57.5′ E 11° 45.5′) and Stora Middelgrund (N 56° 34′, E 12° 13′). They are usually made from research vessels 4 times a year but at Fladen and some coastal positions since 1971 measurements are being made on a monthly basis by the Swedish Coast Guard.

Recently (1974) a Danish 5 year project started to investigate the transports of water and material through the Belt Sea and the Kattegat. At the same time the Fishery Board of Sweden commenced to survey 10 stations at a section Frederikshavn—Göteborg twice a month. Measurements with automatically recording instruments is an integral part of the projects.

5. Currents. Waves

In the following account the least important currents, those generated by the tides, will be dealt with first, then follow wind currents and, lastly, the permanent currents. This division has been made because stratification has little effect on the tidal currents, somewhat more on the wind currents, but determines the permanent currents.

5.1. Current Measurements

The lightvessel observations mentioned above comprise mostly surface currents determined up to 8 times a day with a current cross. On Swedish lightvessels measurements were also made at a depth near the bottom, but the method was probably not quite reliable. On Danish lightvessels measurements at many depths have been carried out on some occasions with J. P. JACOBSEN's level-current-meter, see Table 4.

Measurements with automatically recording current-meters have been carried out on different occasions since 1911, see Table 3. Scattered observations with EKMAN's current meter or with drifting parachutes will be referred to below.

5.2. Standing Waves. Characteristic Periods

Like, for example, organ pipes sea basins have their characteristic periods. In a closed channel of length l and depth h this period is $T = 2l/\sqrt{gh}$ (frictionless conditions), where g is the acceleration of gravity and $\sqrt{gh}$ the velocity of long barotropic waves. (Barotropic means conditions, when stratification is neglected.) If the channel is closed only at one end, the period is double that magnitude. These are the lowest modes of oscillation with one nodal line but there may also be higher modes with two, three or more nodal lines (overtones). TOMCZAK (1968) gives a period of 5 hours for the semienclosed Skagerrak. KOLTERMANN (1968) worked with a barotropic x-y model North Sea — Skagerrak — Kattegat with open boundaries (with sea level variations) toward the Norwegian Sea, the Channel and the Baltic. He found three important characteristic periods: 21.8, 10.7 and 4.3 hours (friction included). SVANSSON (1972) found a period of 11 days in a multichannelled system (friction excluded) Baltic — Skagerrak. Further modes for this system were 1.65 days (nodal line in the southern Gulf of Bothnia), 1.25 days (nodal lines in the Gulf of Bothnia and the northern Baltic proper) and 0.99 days (nodal lines in southern Öresund, Darsser Sill region, northern Baltic proper and middle Gulf of Bothnia). As friction may be decisive, these figures can only be used as guidelines. The peak of 5 days found by MAGAARD and KRAUSS (1966) in frequency analyses of the Baltic sea level data, may be a nonlinear characteristic period.

In stratified seas there are also internal (baroclinic) waves. These travel nearly 2 orders of magnitude slower than barotropic waves (1:50 is an often used ratio). Whereas barotropic waves in enclosed seas are fast enough to hit the boundary coast, be reflected and together with the original wave form standing waves (barotropic seiches, see above), the internal waves need much more time before they can build up corresponding features. But in the open sea there may also exist so-called Poincaré waves; they consist of a cellular pattern of standing waves with near-inertial period. This period depends upon the Coriolis parameter, which means that it is latitude dependent (latitude 30° : inertial period = 24 hours, 55° : 14.7 h., 60° : 13.9 h., 65° : 13.3 h., 90° : 12 h.). MORTIMER (1967) considered the internal wave pattern in the Great Lakes to consist of nearshore Kelvin waves (Cf. Ch. 5.3.) but in open sea of standing Poincaré waves.

KULLENBERG (1935) in his investigation of internal waves in the Kattegat, also found periods which he supposed to have the inertial period (see also 5.3 Tides). Also in the Skagerrak inertial periods were found (TOMCZAK 1968).

5.3. Tides

In the areas concerned, the local tide generated by the gravity of the sun and the moon can be neglected. Only the tidal waves originating from the ocean have to be considered. The tidal variations are usually looked upon as composed of several (harmonic) tidal components, each with its period. These components have in any given place the very same (but local) sinusoidal tidal variation, determined by a certain amplitude (= half of the range between ebb and flow) and a certain phase (can be expressed as the delay in hours of the high water after the meridional passage of the corresponding period "moon"). In the North Sea, Skagerrak, Kattegat and the Belt Sea the most important components are semidiurnal: M2, 12.42 hours, S2, 12.00 hours, N2, 12.66 hours and μ2, 12.87 hours, whereas diurnal components, e.g. O1 and K1 are smaller. During full moon and new moon (the syzygies) the contributions of M2 and S2 are added at the most, we have spring tides.

Fig. 154 A (Fig. 3) in DEFANT (1961) shows lines connecting places with the same interval in hours after the upper culmination of the moon in Greenwich and the high water for the North Sea and the western Skagerrak. In Fig. 154 B (Fig. 4) in the same work one can see that, while sea level differences (not amplitudes) of more than 4 meters are common along the east coast of Great Britain, the corresponding figures at the mouth of Skagerrak are less than 25 cm. The reason for this asymmetry, as assumed by DEFANT, is that the tidal wave entering the North Sea from the north, which, on account of the rotation of the earth, has a larger amplitude "to the right" along the coast of Great Britain (Kelvin wave), looses a great deal of energy in the shallow southern part of the North Sea. The reflection of the wave, which should make the picture symmetrical in case of no friction, would thereby be weak. Furthermore it is assumed that a small portion of the incoming wave goes directly through the Skagerrak to the Baltic and is lost there. For the tide in the area dealt with in this paper, Fig. 5 has been composed with the help of DEFANT (1934 and 1961). A few smaller changes have been made from SVANSSON (1962); a more reliable figure has been obtained for Smögen after the Tidal Institute in Liverpool (present Institute of Oceanographic Sciences) processed data from one year (1959). Also some corrections have been made for Bornö and Göteborg. In spite of the fact that in later years a fair number of current measurements have been carried out in the Skagerrak no analyses of the tides have been made of the material, the reason of course being that no sizeable figures are to be expected. The few cm/s which appeared in the material from 1913 (Table 3) indicates the small order. In the spectral-analyses which have been performed (TOMCZAK 1968) the semidiurnal tide seems weak and sometimes difficult to distinguish from the inertial periods.

The M2-tide in the Kattegat has been summarized best by DEFANT (1934). One gets the impression of a wave entering from the north and loosing all its energy in the Danish Straits, so that it neither enters the Baltic nor is reflected. It is largely the deflecting force of the rotation of the earth (the Coriolis force) that makes the amplitude larger on the Danish side than on the Swedish (Kelvin waves). See Fig. 6 for an explanation where the Coriolis effect has been computed for a current of 10 cm/s. As appears in SVANSSON (1962) this is the correct order of magnitude according to the results of processing of measurements from L/V Anholt Knob and other sources (JACOBSEN 1913). In later years also measurements from L/V Läsö Rende (Table 4) have been processed (ROSSITER 1968). Tidal currents are reasonably uniform at all the horizons, 2.5 m, 5, 10, 15 and 20 m. M2-amplitudes were 20, 23, 26, 26 and 23 cm/s respectively. It is to observe that L/V Läsö Rende was situated in a narrow passage, and that bottom depth was 22 m.

The to and fro movements in two opposite directions is a simplification. In reality the current rotates, usually clockwise. The current vector end points describe an ellipse with its major axis in the longitudinal direction and its minor axis, in the Kattegat 3—4 times shorter, in the transversal direction.

Internal waves with, among other things tidal periods appear in the halocline. KULLENBERG (1935) found in his investigations with a submerged float in the Fladen area that the halocline could attain an amplitude of 1.3 m at springtide. Internal tidal waves may disturb the vertical distribution of tidal currents (SCHOTT 1971).

5.4. Wind Currents and other Currents Generated by the Effects of Atmospheric Pressure

5.4.1. Wind Currents

When a wind blows over a sea surface it exerts on it a drag, the wind stress, which causes the water to move. According to theory the surface current is deviated to the right of the wind. The angle of deflection increases regularly with depth, so that at a depth D, the so-called Ekman Depth, the current is directed opposite to the surface current. The velocity decreases regularly with increasing depth and is at depth D only one twenty-third of the value at the surface. The depth D depends upon the value of the vertical eddy viscosity coefficient K_{vz}.

In relatively homogeneous water K_{vz} is of the order 0.1 m^2/s with a corresponding Ekman Depth of 125 m. But in the Kattegat K_{vz} is probably much smaller. JACOBSEN (1913) computed K_{vz} by means of tidal observations at various depths on board Danish lightvessels and obtained figures between 0.00003 and 0.0011 m^2/s. DEFANT (1934), however, showed that similar measurements made during a few weeks 1931, were in accordance with a theoretical approach with $K_{vz} = 0.01$ m^2/s.

The vertical eddy viscosity coefficient is probably not a constant. Near bottom smaller values are expected (RODHE 1973), near sea surface the coefficient is probably a function of the wind stress. G. KULLENBERG (1971) has shown that the vertical eddy diffusion coefficient K_{dz} usually is very low in upper layers of the Kattegat and that it is a function of stratification, wind stress and the absolute value of the velocity gradient. There seems further to be a relation between K_{dz} and K_{vz}.

The surface current is often supposed to have a velocity of 1 % of the velocity of the wind. This factor has usually been obtained when measuring the surface current with a current cross, 0.5 m high. For more shallow objects the factor is greater. OLSSON (1968) used 3 % for drift bottles. Theoretically the velocity of the surface current is inversely proportional to the magnitude D of the Ekman Depth. As D may be smaller in the Kattegat the surface current may accordingly be larger than usually assumed. In GUSTAFSON och OTTERSTEDT (1931) there is an interesting theoretical attempt to account for the way, in which the spreading downward of a drift-current is modified, when K_{vz} is no longer constant but suffers a diminuation in the vicinity of a discontinuity surface.

5.4.2. The Direct Effect of Atmospheric Pressure

In the open ocean the adjustment to atmospheric pressure is usually very rapid, the long wave velocity being much higher than the velocity of low and high pressures. In this case sea levels adjust to normal atmospheric pressures implying that statically a change of the atmospheric pressure of one millibar is giving a change of the sea level of 1 cm. In the vicinity of coasts and in bays with large characteristic periods this is no longer true.

If the sea levels at Smögen are compared with the atmospheric pressures a remarkably good correlation is obtained (Fig. 7). Furthermore it is clear that in this area a change of the atmospheric pressure of 1 mb brings about a change of the sea level of 2 cm rather than the 1 cm expected. A low atmospheric pressure is usually related to westerly winds, which raise the sea level in the North Sea and the Skagerrak. In Mandal the static response is more correct according to theory (SVANSSON and SZARON 1975). That the correlation between atmospheric pressures and levels of the Baltic is very low is quite evident due to the long characteristic period.

Finally we note that the variations of atmospheric pressure hardly ever exist without winds. WITTING (1918) introduced the concept of an anemo—baric effect expressing the two-fold influence of atmospheric pressure.

5.4.3. Indirect Wind Effects

The presence of coasts creates indirect wind currents, sea level currents. For the sake of simplicity, let us first consider the effects of a wind blowing longitudinally over a narrow lake with a pycnocline (discontinuity of density). The surface layer is brought to the downwind end of the lake, where the water level rises sufficiently to create an excess pressure which will force the water back, mainly below the pycnocline. After initial oscillations (seiches) steady state conditions prevail and practically the same amount of water is transported back (Fig. 8, Stage 1). Gradually (but slowly) also the pycnocline starts to incline and at (a second) steady state condition the inclination is just large enough for the current to cease below the pycnocline and then also the transport back must take place above the pycnocline (Fig. 8, Stage 2).

For our waters these latter effects can be assumed to be unusual, since the winds hardly ever display the constancy required, close to a coast, however, changes in the stratification can occur fairly rapidly.

The Kattegat and the Belt Sea are far more influenced by winds and changes in the atmospheric pressure over the North Sea and the Baltic than by the direct effects of the corresponding local forces. This has been shown by DIETRICH (1951) and others, whose maps of the currents in the Kattegat under different wind conditions are reproduced here as Figs 9—12.

It is evident that tidal waves entering the Belt Sea are practically extinguished in the straits, but longer waves, which are probably damped less (LAMB 1953), may enter the Baltic more easily. Large long-term oscillations (order of magnitude 14 days) cause the Kattegat water to be drawn alternately into the Baltic or out into the Skagerrak, which creates large salinity variations in the Kattegat and the Belt Sea and also along the coast of Bohuslän (Fig. 16) due to the large horizontal transports (see also below under sections "Salinity").

Fig. 13 shows daily means of currents measured 1967 partly SW Hållö at a depth of 50 m (see Table 3) partly at L/V Halsskov Rev. Oscillations of 5-day type are apparently dominant. There is also a clear negative correlation between the two series. Fig. 14 shows the daily means of the N- and E-components of the German current meter records during the cooperation 1966 at two stations, one at the entrance into the Skagerrak of the Jutland Current (Stn. 41) and the other on the border between the Skagerrak and the Kattegat (44). The figure also shows measurements of currents from two Danish lightvessels. The similarity between the E-components of Stn. 44, at 40 m, and of L/V Skagens Rev, at the surface, is quite evident. There seems, however, to be hardly any similarity between the record of Stn. 41 and the remaining records. The data period is short but the comparison gives some support to the idea, that the strong variations on the border between the Skagerrak and the

Kattegat are caused mainly by the Baltic oscillations and not by Jutland Current variations.

Remembering Fig. 13 we now see that the phase seems to be the same for the current (N-comp.) at 50 m depth off Smögen and for L/V Skagens Rev (E-comp.). An explanation may be this: when the sea level of the Baltic sinks and the water transport is outwards, the Jutland Current is forced to take another direction. The E-component at L/V Skagens Rev and the N-component at Hållö are both weakened. When on the other hand the transport is flowing inwards to increase the level of the Baltic, the conditions may be "normal" with the Jutland Current flowing eastward at L/V Skagens Rev and northward at Hållö.

Another interesting relation is seen in Fig. 15. In connection with the water transports created by changes of wind and atmospheric pressure, the sea level of the entire Baltic oscillates. In this process Kattegat water is drawn alternately into the Baltic or out into the Skagerrak, which creates large salinity variations in the Kattegat and the Belt Sea and also along the coast of Bohuslän (Fig. 16) due to large horizontal transports (discussed further in Ch. 6).

Kelvin waves have been mentioned earlier. By this we mean a long wave influenced by the deflecting Coriolis force but nevertheless without transversal velocities. The width of the barotropic (no influence from stratification) Kelvin wave is of the order of some hundreds of kilometers. The tidal wave in the Kattegat seems to be a good example of this category. It travels in a longitudinal direction with the velocity of a barotropic long wave (see Fig. 6).

Due to their much lower speed internal Kelvin waves should be restricted to a much narrower strip along the coast. Actually the strip is of the order 5 km or again 1/50 (5.2) of the width a barotropic Kelvin wave (Walin 1972). At those coasts, however, which in relation to the wind have a favourable direction for (Ekman) upwelling this may be so strong that there are no longer two layers of water but only upwelled deep water.

A few words about upwelling. When the wind blows in some relation to a coast, the winddriven transport will cause sea level differences perpendicular to the coast. These differences will give rise to a gradient current along the coast. In a bottom friction layer there is a compensation for the winddriven transport perpendicular to the coast. If the depth is large in relation to the Ekman depth (see 5.4.1.) the most effective wind is an alongshore one. For the Swedish West coast a northerly wind would give most upwelling. As the Ekman depth is probably rather small this would also hold true in nature. Unfortunately it is difficult to distinguish separate local upwelling effects from large scale effects of the Baltic.

5.5. Permanent (Residual) Currents

Actually nothing is more permanent than the tide, which with great punctuality surges back and forth. Tidal currents are not usually, however, referred to as permanent currents. The Gulf Stream is a typical permanent current even though it varies (at least) with the season. If, on the other hand, the period of the variations is less than a few weeks the current should not be considered permanent.

The tide enters the Skagerrak and the Kattegat like in a narrow channel without large variations across the channel. Also the tide has the same direction from surface to bottom. This is, however, not always the case with the permanent currents, which consist mainly of the Baltic Current (influenced by the water exchange of the Baltic) in all of this region and the offshoot of the permanent current system of the North Sea into the Skagerrak.

5.5.1. The Water Exchange of the Baltic

In many respects the Kattegat and the Belt Sea can be regarded as a big river mouth, where usually there is a tongue of saline bottom water, which is pressed towards the sea by an increase of the runoff.

The problem of the water exchange is rather complicated and it is not astonishing that there is more than one approach to the problem. First are presented the classical ideas of MARTIN KNUDSEN (1899 and 1900).

It is assumed that in the strait between the ocean and an enclosed sea filled with brackish water there are two layers, a top one consisting of outflowing brackish water (Q_1 m^3/s) and a bottom one (Q_2 m^3/s) of much higher salinity flowing inwards (Fig. 17). It is furthermore assumed that at a certain section we can distinguish between the two regimes and also determine their respective salinities. Finally assuming the salt transport to be zero we obtain the KNUDSEN relations

$$Q_1 = \frac{S_2}{S_2 - S_1} \cdot Q_0$$

$$Q_2 = \frac{S_1}{S_2 - S_1} \cdot Q_0$$

where Q_0 is the fresh water supply.

KNUDSEN applied the formulae at many sections. Most interesting is the Darsser Sill section at the smallest depth (the sill depth) between the Baltic and the ocean. For the period 1877—1897 KNUDSEN found in the literature 19 measurements of the salinity at 19 m depth. Of these he kept 13 values disregarding all salinities below 15.5 ‰ because "these salinities cannot renew the deep water of the Baltic". So for S_2 he got 17.4 ‰ and without going much into detail S_1 was taken as 8.7 ‰. Thereby the compensating inflowing current would be of the same magnitude as the fresh water supply Q_0.

The two salinities 8.7 ‰ and 17.4 ‰ are thereafter found in the literature over and over again, e.g. in SCHULTZ (1930) and BROGMUS (1952), as well as in a paper by KULLENBERG (1967). KULLENBERG computes a factor by which the annual supply into the Baltic of a (conservative) pollutant is to be multiplied. KULLENBERG found this factor to be 35.1 and it means that if e.g. 10,000 tons a year are supplied, in a steady state there will be an accumulation of 351,000 tons. We derive this factor by dividing the volume of the Baltic (V_B) by that part of the outflow which does not re-enter. The Kattegat water (salinity S_K) consists of y parts of Baltic water (salinity S_B) and (1-y) parts of ocean (Skagerrak) water (salinity S). When Q_2 km³ of the Kattegat water flows back into the Baltic, y parts of it are therefore of Baltic origin and it is only $Q_1 - y\, Q_2$ that really leaves the Baltic ultimately. Our factor f is derived from

$$f = \frac{V_B}{Q_1 - y\, Q_2}$$

$$Q_1 = \frac{S_K}{S_K - S_B} \cdot Q_0$$

$$Q_2 = \frac{S_B}{S_K - S_B} \cdot Q_0$$

$$S_K = (1\text{-}y)\, S + y\, S_B$$

With these assumptions the factor f turns out to be independant of the conditions in the Kattegat:

$$f = \frac{V_B}{Q_0} \cdot \left(1 - \frac{S_B}{S}\right)$$

If we use the value of Q_0, from Table 2 a, 439 km³/year, $V_B = 20{,}920$ km³ and $S = 34.8$ ‰ we derive at

$$f = 47.7 - 1.37\, S_B$$

KNUDSEN's relation was applied to the northern part of the Kattegat by SCHULZ (1930). He found $Q_1 = 5.3\, Q_0$ and $f = 0.2$ for the Kattegat.

It is quite clear that there are difficulties to find the right salinities to enter into the Knudsen equations. Furthermore there seem to be a few cases when there are currents in the opposite directions on top of the other.

Table 4 shows mean values of Danish current measurements determined at non-surface horizons. (The mean values for the surface measurements are presented in Table 5). While the data of L/V:s Läsö Rende and Lappegrund clearly reveal outgoing (in the surface layer) and ingoing (in the deep) currents, the outgoing currents are remarkably weak at L/V Anholt Knob and L/V Schultz's Grund. L/V Anholt Knob is often assumed to be situated in some kind of "countercurrent" in Kattegat (DIETRICH 1951, SVANSSON 1968); the data from L/V Schultz's Grund is more difficult to interpret.

STOMMEL and FARMER (1953) and, in a slightly different manner, KULLENBERG (1955) derived a relation between the transports Q_1 and Q_2 as functions of the fresh water supply Q_0 for an estuary assumed to contain well mixed water. The solution of the problem is such that Q_2 as function of Q_0 increases from zero ($Q_0 = 0$) up to a maximum, thereafter decreases steadily to zero for $Q_0 = Q_{0\,max.}$, when the fresh water fills the sill area completely. SVANSSON (1972) presented arguments that the Baltic may be assumed to be well-mixed in this respect with a maximum Q_2 at $Q_0 \approx 30$ km^3/month and $Q_{max.} \approx 100$ km^3/month. These figures are, however, very uncertain and must be checked.

By means of his investigations JACOBSEN (1925) established a formula, by which the water transport (total from surface to bottom) can be computed if only the magnitude of the surface current at L/V Drogden is known. WYRTKI (1954) kept JACOBSEN's formula for the Öresund

$$M_S = 1.5 \times V_D$$

where M_S is the net transport in km^3/month and V_D is the magnitude (with its sign) in cm/s at L/V Drogden, but used for the Belts

$$M_B = 4.1 \times V_H$$

where V_H is the value of the surface current at L/V Halsskov Rev and M_B is the net transport through the Belts in km^3/month. By means of such formulae HERMANN (1967) derived a northgoing transport through the Öresund of 460 km^3/year and a southgoing one of 350 km^3/year.

Note that we are no longer talking of a 2-layer system; the transport is in every case either outgoing or incoming.

SOSKIN (1963) improved the formulae of JACOBSEN and WYRTKI mostly by using one formula for incoming transports and another for outgoing transports. To construct his formulae SOSKIN also used data for the period 1921—1931, possibly even 1898—1912 for which periods figures for the fresh water supply are available. Then he computed the transports for every year 1898—1944. The difference between outgoing and incoming transports is called water exchange. The fluctuations are really large; one asks if it is possible that some years there is no net outflow at all. It seems to be quite clear that two various types of atmospheric circulation, zonal (with westerly winds) with large amounts of precipitation and meridional with smaller amounts of precipitation are most responsible for the variations. As mentioned above we have data of the total fresh water supply only for short periods but we can study the outflow from some large river like SOSKIN and others have done, see Fig. 18, where the runoff data of the river Vuoksi in Finland are included. Even if the variations are large the river transport hardly goes down to zero. Table 6 shows the various components of the water exchange. LISITZIN (1967) used the day-to-day variations in sea level to claim that the average water quantity involved every year in the renewal of the Baltic is $Q_1 = 1754$ km^3, Q_2 would then be 1315 km^3.

The present author has tried a method of computing the steady state concentrations of an outlet by using the following rough model. The area is subdivided into many boxes, each one extending from surface to bottom. The mean salinities in each box were computed from mean values of ANON. (1933) for the Danish light-vessels and GRANQUIST (1938) for the Northern Baltic, while the remaining salinities were interpolated. Assuming the salt transports to be zero "compensation transports" were calculated for each section. Then these "transports" were used to compute the steady state concentrations of 10,000 tons of a substance released every year 1) in the middle of the area (Fig. 19) and 2) in the Danish sounds (Fig. 20). The substance is, of course, assumed to behave like salinity without going into any biological cycle or sediment. Note that one of the ideas is to proceed out to clean water.

5.5.2. The Skagerrak and the North Sea Proper

It seems quite probable that all the inflows of water to the North Sea unite in the Skagerrak and leave the area along the Norwegian coast.

Fig. 21 shows the probable surface currents: on the Danish side the incoming Jutland Current, from the Kattegat the Baltic Current and along the coasts of Sweden and Norway the two currents united. At non-surface horizons we know much less but some measurements were made, see Table 3. Furthermore, measurements have been carried out from anchored research vessels. The data show that the currents are usually running in the same direction from surface to bottom (HELLAND-HANSEN 1907, SVANSSON 1961, ANON. 1969). Therefore it is less advisable to use the method of "layer of no motion" to compute geostrophic currents out of data of temperature and salinity as KOBE (1934) and TOMCZAK (1968) did. SVANSSON and LYBECK (1962) tried to compute the geostrophic transport by referring to measured surface currents in calm weather. They got a transport of approximately 500,000 m^3/s (equiv. to 16,000 km^3/year) for both ingoing and outgoing currents. Table 7 shows the mean values during 16 days of German current measurements during the cooperation in 1966 at the section Hanstholm—Mandal (See Fig. 2). Fig. 22 shows the daily mean of July 9 on the same occasion. It is evident from this figure, as well as from the salinity maps in the Atlas of the cooperation 1966 (ANON. 1970), that a great part of the water circulating in the Skagerrak comes from the Norwegian Sea along the 150—200 m isobaths, but in the surface layers there is probably also a transport from, for example, the Southern North Sea. Table 8 shows some kinds of N-component for the L/V Horns Rev (N 55° 34.1′ E 07° 10.5′) as presented by JACOBSEN (1913). These figures are important to consider when we discuss the possible influence of the heavy pollution in the SE corner of the North Sea on the water discussed here (Cf. Ch. 10.3). KAUTSKY (1973) presents distributions of Cs 137 (See Ch. 8.3.) which are in accordance with a transport from the Strait of Dover to the Skagerrak.

There is possibly a closed horizontal circulation in the Skagerrak (e.g. LINDQUIST 1970). In ENGSTRÖM (1967) there are indications of such closed paths of surface drifters. We do not know, however, whether ordinary horizontal eddy diffusion may be an agency strong enough to transport objects from one strong current to the other.

The criticism presented above of KOBE's (1934) geostrophic computations may be less relevant along the coast of Norway where, contrary to conditions in the Jutland current, bottom friction probably plays a much smaller role and a geostrophic layer of no motion at some great depth may be plausible. A recent calculation of geostrophic transports between stations M 7 and M 8 (Position in Fig. 1) for 13 cases 1948—1959, confirmed the seasonal variations disclosed by KOBE: maximum in November (500 000 m^3/s) and minimum in February (200 000 m^3/s). The M 7—M 8 transports were higher respectively lower than these one's.

In order to further study seasonal variations Tables 8 and 9 are investigated. Table 8 shows mean surface currents measured at L/V Horns Rev, SW of Denmark in the North Sea. One may think that annual variations at this position reflect the same variations that are met with along Norway, i.e. of the North Atlantic current. Whereas a winter maximum is found, the minimum occurs in Summer. — Table 9 shows the monthly mean values of the N-component for 5 months in 1967 of data from the current meter SW of Smögen. There is a summer minimum and a highest value in October. — Finally reference is made to JACOBSEN (1925) and SVANSSON (1965) concerning deep currents (20 m) measured at L/V Schultz's Grund 1910—1916. Again is found a winter maximum and a summer minimum.

If the variations at L/V Horns Rev are disregarded we may make the following interpretation. The current along Norway is nearly independant of the Baltic outflow, whereas the Kattegat deep current, and the currents in the SE corner of the Skagerrak (Ch. 5.4.3.) are influenced both by the Baltic outflow and the Atlantic inflow. The surface currents in the Kattegat are usually at their maximum in Spring and at minimum in late Summer (Table 5), facts which would complicate a comparison between the Kattegat and the Skagerrak.

An alternative interpretation would be to assume a winter maximum and a summer minimum to be a more general phenomenon. In this case the geostrophic late winter minimum must be discarded and the Baltic outflow considered to have a small influence on the deep current of the Kattegat. Further work is necessary before this question can be solved.

A transport figure of 500,000 m^3/s from the North Sea, presented above, would be compared with other figures given in the literature, see Table 10. Apparently they differ considerably.

5.6. Surface Waves

WAHL (1973) presented results of wave measurements made by means of an accelerometer anchored in the vicinity of L/V Fladen (Position, see Fig. 2). The significant wave heights $H_{1/3}$ m (average of the heights (double amplitudes) of the one-third highest waves) was computed and compared with the wind velocity V m/s. A formula $H_{1/3} = 0.12\ V$ was found for more open sea conditions and $H_{1/3} = 0.075\ V + 0.15$ for land winds (NE-E).

6. Salinity

6.1. General

Fig. 23 is a map from ANON. (1927) of the mean distribution of the surface salinity in the Baltic and the North Sea (August). The large river mouth features of the Kattegat—Skagerrak area appear quite clear. Looking also on the North Sea proper the map shows low salinity regions along the coast of Norway of Baltic water, in the German Bight and (less pronounced) along the British coast. Water of higher salinity comes from north and south. On the maps of salinity at different horizons (GOEDECKE ET AL. 1967) the wedge of high salinity from north seems to pass the Fladen Ground area on all horizons down to 40 m. (Already BÖHNECKE (1922) interpreted currents in the North Sea from salinity distribution maps.) On the maps of the deeper horizons there are indications of two wedges, one along the British coast, and one along the outer edge of the Norwegian Trench. Fig. 24 shows the salinity distribution in the Eastern North Sea and the Skagerrak at 50 m during the summer of 1966 (International Skagerrak Expedition, ANON. 1969). It is here evident how the more saline water enters the Skagerrak along the outer edge of the Norwegian Trench.

Fig. 25 shows a salinity section in the Kattegat and the Belt Sea constructed from the mean values of observations made by the Danish lightvessels from L/V Skagens Rev to L/V Gedser Rev during the period 1903—1926 (positions in Fig. 2). It presents the equilibrium established between the excess of fresh water, the mixing conditions and possibly also the currents in the Skagerrak.

The surface salinities vary with, among other things, fresh water supply and sea level variations of the Baltic. The short term variations seem to depend highly on the sea level variations: When the sea level in the Baltic rises the Baltic water is drawn back (to the Baltic) from the surface of the Kattegat. The further north we go in the Kattegat the more often the bottom water is exposed, whereby the vertical water exchange is greatly intensified. During what was probably the largest inflow of saline water into the Baltic—in December 1951 (WYRTKI 1954 b)—the Kattegat was for a long period of time almost void of Baltic water, see Fig. 26.

It also seems probable that the "movement of a cold water front" described by EGGVIN (1940) is to be explained in the same way: a strong fall of the sea level (110 cm) in the Baltic during January 1937. (Finally, see Ch. 11.1 discussing a connection with herring fishery.)

But when we look at monthly means of salinity and sea levels the influence of the variation of fresh water supply is increasing. The connection between surface salinity (Fig. 27) and sea level is no longer so clearcut.

Figs. 28, 29 and 30 show the month to month variations at L/V Schultz's Grund, L/V Läsö Trindel and Bornö Station respectively. The lowest surface salinities occur in May and June concurrently with Sum 1 in Table 6 being at a maximum. It therefore looks as if the sea level variations are not of great importance with respect to this phenomenon. The bottom salinities being at their highest at the same time (not for Bornö, however) suggest that the compensation current may have increased simultaneously with the outgoing current. This does not fit in, however, with the deep current at L/V Schultz's Grund being close to its minimum in the early summer. See also Ch. 5.5.2.

Figs. 31 and 32 show two quite different pictures of the salinity conditions at the section Å in the Skagerrak, one in the spring and one in the late autumn. From what has been said above, we do not know if the difference is due mostly to variations in fresh water supply or sea level variations.

Table 11 shows the frequency distribution of salinities measured once a day at L/V Fladen during the decade 1951—1960.

6.2. Long-Term Variations

Fig. 18 shows a long series of surface salinities measured at L/V "Schultz's Grund". The data were taken from JENSEN (1937), NEUMANN (1940) and Publications of Danish lightvessel data (See References). The top curve shows the variation in fresh water supply of one of the larger rivers to the Baltic. It seems quite feasible that a small amount of precipitation gives high salinity, in the Kattegat nearly immediately, in the Baltic 5—10 years later. Also SCHOTT (1966), who carried out Fourier analysis of series of monthly means of surface salinity in the North Sea, concludes that long-term fluctuations of surface salinity can be correlated with fluctuations in the discharge of river water and in precipitation, and that these in their turn depend upon the west wind component over central Europe. A different interpretation has been given by DICKSON (1971 and 1972). He thinks that one important effect is the increased influx of water from the North Atlantic under the stress of the increased southerly wind.

Table 12 contains all monthly means of surface salinities at L/V Anholt Nord (up to 1945 Anholt Knob). Annual means are in parentheses when a month's value is missing or was based on few original measurements. In the latter case also the monthly mean value is in parentheses. These salinities were recently used in a study by NILSSON and SVANSSON (1974).

7. Temperature

7.1. General

Figure 1 (b) in DIETRICH (1950) shows the temperature distribution during the year for a station in the English Channel. Due to the strong tidal motions the water is well mixed from surface to bottom and there is never a thermocline. Figure 1 (a) in the same publication is a similar picture from the southern part of the Northern Sea. The annual salinity variations are small (34.9—35.1 ‰) but there is a well developed thermocline in the summer. Fig. 1 (c), similar to our Fig. 35, is constructed from data from the Kattegat. Due to the yearround haline stratification the temperature variations differ somewhat from the conditions mirrored in DIETRICH's Fig. 1 (a).

7.2. The Upper Layers of the Skagerrak

Fig. 33 shows a temperature section between Skagen and Risör in the early summer of 1966. On account of the considerable counterclockwise circulation along the edges, ascending motions are created in the horizontally stationary central part. These motions cause the isolines to appear like a dome. In the summer relatively cold water rises towards the surface; the warming up proceeds from the surface downwards and the result is a very marked thermocline, which is evident in the figures on p. 73 in ANON. (1970). Here the observations have been made with a continuously recording instrument (Delphin).

Table 13, taken from TOMCZAK and GOEDECKE (1962) shows minima and maxima, partly in the incoming Jutland Current, partly in the dome in the centre and, finally, in the outgoing current along the coast of Norway. The outgoing water differs from the incoming in so far as, in the winter, its temperature is lowered and, in the summer, raised due to the influence of the Baltic water from the Kattegat.

7.3. The Deep Water of the Skagerrak

The seasonal variations decrease with increasing depth. Instead, rather large flucuations are created in the bottom water owing to cold winters forming such heavy water in the North Sea that this water sinks to the bottom, see Fig. 34. The phenomenon has been described by LJØEN (1965), SVANSSON (1966) and by LJØEN and SVANSSON (1972).

7.4. The Kattegat and the Belt Sea

If the temperature development at a lightvessel in Kattegat (Fig. 35, L/V Fladen) is compared with that at a Baltic lightvessel (Fig. 36, L/V Ölandsrev) rather great differences appear. Partly are corresponding temperatures generally higher at L/V Fladen except for the surface during winter, partly are the seasonal variations at corresponding depths larger at L/V Fladen. The first mentioned fact probably depends upon the Skagerrak's temperatures being higher than those of the Baltic. The larger seasonal variations are easy to explain for the surface layer. The great stability created by the salinity stratification gives higher summer temperatures and lower winter temperatures (which leads to earlier freezing in the Kattegat than at the same latitude in the Baltic). It is easy to understand that the stability prevents a swift cooling of the deeper strata in the autumn, but the question is how the heat reaches down at all. A permanent inflow of warmer water from the Skagerrak is probable. Already in the beginning of this century there was the opinion (ANON. 1903) that this warmer water originated from the southern banks of the North Sea and was therefore called Southern Bank Water. The ideas were supported by temperature studies during the whole year in the Kattegat. Our Figs. 37 and 38 of the temperature conditions at 20 m and 30 m respectively (ANON. 1933) confirm these ideas: maximum in the northern Kattegat in August but occurring continuously later southwards, October in Öresund being the extreme.

The theory in ANON. (1903) that the maximum would occur still later in the Baltic is not confirmed by this material, nor by LENZ (1971). The intrusion theory is also supported by the fact that the water is continuously being cooled. — In winter the conditions seem to be opposite in the sense that intruding water with minimum temperature in February in the northern Kattegat is slightly heated towards Öresund, where the minimum occurs in March.

7.5. Long-Term Variations

LEE (1970) may here be quoted: "SMED (1963) gives the 5-year running means of sea surface temperature for each month of the year for the northern and central North Sea. In the former area these show a minimum in the early 1920s for all months except July—September, for which it took place in the late 1910s with a secondary minimum in the late 20s. A break in the records due to the Second World War prevents the exact timing of the maximum from being established, but in general it occurred between 1935 and 1945. In the 1950s all months, except November and December, show a downward trend and all this applies especially to May. PRAHM (1958) has examined the bottom temperature record for summer in the central and northern North Sea in the regions of the Great Fisher Bank and the Fladen Ground."

NILSSON and SVANSSON (1974) investigated annual means of surface temperatures measured at L/V Anholt Nord 1880—1970. 15 year running means show a weak minimum (8.5°C) around 1920 before the rise started toward a maximum around 1950 (9.2°C). The curve of 5 year running means has maxima in 1898, 1912, 1935, 1950 and 1960.

8. Chemical Parameters. Primary Production. Optical Conditions

Below, in Ch. 9, will be presented 10-year mean values of Swedish measurements of temperature, salinity, oxygen, phosphate-phosphorus and total phosphorus in the Skagerrak. Corresponding results from the Kattegat also include silicate and nitrate (Table 15). There are chemical observations carried out also by other countries, e.g. Denmark, but so far unpublished. Observations made by GDR, mainly in the North Sea proper but also some in the Kattegat were recently published (FRANK ET AL. 1972). They include NO_3-N, NH_4-N, SiO_2-Si, chlorophyll and sometimes seston.

8.1. Oxygen

Table 14 shows the variations in oxygen saturation 1966—1973 near the old position of L/V Fladen. In the late summer a minimum occurs in the deep-water probably due to sinking organic matter requiring more oxygen than is supplied. Danish observations in the Kattegat in September 1968 show that the saturation percentage increases from S to N, but also from W to E in the Northern Kattegat.

The results of the international investigation 1966 gave a few low oxygen figures (SVANSSON 1968). While saturation values in most of the Skagerrak were generally higher than 90 % except for a couple of values close to Denmark and Sweden (80—90 %) they were lower in the SE corner of the Skagerrak and the N part of the Kattegat; between Frederikshavn and Göteborg values as low as 40 % were observed.

FONSELIUS (1969) has shown that the oxygen figures for the deeper parts of the Baltic and the Gulf of Bothnia have dropped since the end of the 19th century. A similar investigation shows that such a decrease has also taken place in the Kattegat (CORIN ET AL. 1969) mostly during July—November. HERMANN and VAGN OLSEN (1970) have examined all data from a more statistical point of view. They also find a decrease since the observations early this century, the values were, however, as low during the 30's as they are now. In HERMANN and VAGN OLSEN (1970 b) is shown the marked decrease (appr. 1 ml/l) of the oxygen content of the bottom-water in the Öresund during the period 1966—1969 as compared with 1956—1964.

8.2. Phosphorus

HERMANN ET AL. (Loc. cit.) also show that the PO_4-P figures have increased in Öresund during the same time. At a station S of Ven a doubling at the surface and a 40 % increase in the deepwater have taken place.

Danmarks Fiskeri- og Havundersøgelser carried out observations of total phosphorus (and currents) every day for about 8 months 1969—1970 at 4 depths from L/V Halsskov Rev. The mean values at 0 m and 15 m for the entire period are 0.81 and 0.96 μgat/l respectively, but the fluctuations are large.

8.3. Pollution (Biochemical Oxygen Demand, Nitrogen, Phosphorus, Cæsium 137 and Strontium 90)

A working group in ICES recently published a comprehensive report of the present knowledge of the pollution of the North Sea (ANON. 1974). This report includes not only the Skagerrak but also the Kattegat to a certain degree. Table 16 which is extracted from this report, presents values of BOD, N and P in sewage discharged to the Skagerrak from all the surrounding countries but to the Kattegat only from Sweden. There is always a great problem in estimating the correct figures as pointed out in the Report (loc. cit.): "The input data were of varying completeness in respect of the discharges to rivers and estuaries. Some countries (e.g. Sweden and England) assumed that the majority of a discharge made directly to an estuary or fjord would ultimately reach the sea, but others provided only data on the discharges entering the sea or the outer reaches of estuaries." For this reason information on population is included. Further comments to Table 16:

a) Dry Weather Flow from Norway is estimated releases to rivers, estuaries and fjords. Dry Weather Flow from Sweden is estimated on the assumption that water use per person is the same as for Norway (0.391 m^3/day).
b) BOD: Norwegian figures are estimated at 60 g/person and day for raw sewage. Swedish BOD is 7 day (70 g/person and day) for raw sewage. The figures are reduced in relation to the degree of treatment.
c) Nitrogen and Phosphorus: Norwegian figures are estimated at 12 g N and 2.5 g P per person and day. Swedish figures are estimated from direct measurements of total N and total P concentrations in river mouths and by assuming that discharge is 13 g N and 4 g P per person and day in areas lying between rivers. Figures for Denmark were calculated using 56 mg N and 8.9 mg P per litre for raw, 30 mg N and 5.8 mg P per litre for settled and 20 mg N and 4.5 mg P per litre for biologically treated sewage.

The ICES Report also contains input of pollution in industrial wastes. To the Skagerrak there comes from Norway a total flow of 1,030,000 m^3/day, mostly originating from pulp paper industry with a BOD of 215 tonnes/day. Sweden presents a figure of 265,000 m^3/day (BOD = 60 tonnes/day) for Skagerrak and Kattegat taken together.

Sewage sludge is dumped outside the Oslofjord at 50° 10′ N, 10° 40′ E. There are no other authorized dumpings in the Skagerrak or the Kattegat.

AARKROG (1974) presented some information on Strontium -90 (Sr 90) and Caesium 137 (Cs 137) in "Danish waters" (about Denmark, the Faroe isles and Greenland). Around the Danish islands there was a Sr 90 maximum in surface water in 1965 of 1.1 picocurie (pCi) pr liter whereas the present values are around 0.7 pCi/l (0.1 pCi/l around the Faroes). There seems further to be an inverse relation with salinity. The author (loc. cit) makes the following rough calculation of a Baltic Sr 90 annual budget (mean of 1969—71): from rivers 200 curie, from precipitation 400 and from the North Sea 150 curie, i.e. 750 curie to the North Sea. But the figures change, e.g. of precipitation 1973 only 30 curie and from the North Sea a somewhat higher figure due to a probable somewhat enlarged radioactive pollution of the North Sea.

Concerning Cs 137 there is such a heavy uptake by fresh water plants that the ratio Cs 137/Sr 90 is smaller in the brackish Baltic than in the more saline Kattegat water. In the ocean this ratio is approx. 1.5.

Comparison of Cs 137 contents in fish tissue shows that there is about 100 pCi/kg in cod from the Danish islands compared to 15 pCi/kg for Faroe Isle cod. The value 100 pCi/kg is low compared to 1965 values for meat, milk etc. but is relatively high compared to recent concentrations in land food.

KAUTSKY (1973) shows the distribution of Cs 137 from nuclear fuel reprocessing plants in France and Scotland.

8.4. Optical Conditions

A very large amount of basic optical investigations were made in the Gullmar fjord, particularly by JERLOV (see e.g. JERLOV 1968). These will be reviewed in more detail in Part II.

MALMBERG (1964) measured transparency by means of a beam transmittance meter in two wave lengths (380 mμ and 655 mμ). Computations of dissolved Yellow Substance (absorption coefficient $= a_y$) and (roughly) particle content could be made. MALMBERG (loc. cit.) distinguishes between the following water masses:

a) Baltic Water, $S < 32$ ‰, $a_y > 0.30$.
b) Continental Coastal Water, $S < 34$ ‰, $a_y = 0.10$—0.30.
c) Skagerrak Water, $S < 34$ ‰, $a_y = 0.05$—0.10 and
d) Atlantic Water, $S > 35$ ‰, $a_y < 0.05$.

HØJERSLEV (1971) made Tyndall (particles) and fluoresence measurements on a cruise from Copenhagen to Bergen in September 1970. Fluorescence like Yellow Substance was found to be inversely proportional to salinity. There were indications of considerable amounts of Yellow Substance furnished by rivers into the Kattegat in addition to the high concentrations of the water from the Baltic (see also BLADH, 1972). — The particle distribution in the Skagerrak showed among other things (relative) maxima between 25—50 m probably coinciding with minima in vertical eddy viscosity coefficient distributions (EHRICKE 1969). In the Kattegatt high values were found near the bottom: "Under the influence of horizontal flow and a bottom consisting of loose sediments, this is to be expected." — Returing to water mass aspects the Baltic water is particle-rich and the Atlantic water particle-poor.

Very little is found in literature on irradiance measurements in the Kattegat and the Skagerrak but there is some information in JOHNSSON and KULLENBERG (1946), particularly from the Gullmar fjord.

8.5. Primary Production

Recently STEEMANN NIELSEN (1971) published values of the primary production at some lightvessels in the Kattegat as measured by the C 14 method. Table 17 shows the variations from month to month at L/V Anholt Nord, the mean total annual primary production was 71 g C/m^2. Table 18 presents the variations of the annual value during many years. From the latter table it is clear that the natural variations from year to year are so large that it is impossible to discern any possible long term trend of increase. There seems to be a correlation between primary production and salinity.

9. Decade Mean Values of Water Parameters

From 1962 hydrographical data have been punched on ICES punch cards (Anon. 1973), "Hydro Master", "Hydro Depth" and "Hydro Chemistry". Since the "Hydro Chemistry" card contains all information from a station where chemical parameters were measured, data on these cards have been used in a processing of data 1962—1971 from 52 stations in the Kattegat and the Skagerrak (See also Johansson and Svansson 1974). The result is presented both as quarterly and annual means, whereas the data were too scarce for a presentation of monthly means.

Figs. 39—44 show conditions (N.B. the logarithmic depth scale) as they appear in the section Å (See Fig. 2 for position). In Fig. 39, the salinity section, we see that the less saline Baltic water is at its maximum in Quarter II. Fig. 40 is a presentation of the temperature conditions. In Quarter I the water is coldest in the surface along the Swedish coast. In Quarter II the surface water is now warmest, and there is a minimum of $< 5°C$ at 20 m above the deepest part. In Quarter III the conditions are similar to those of Quarter II. In Quarter IV the Baltic water is again relatively cold. The bubble of water warmer than 10°C is particular.

Oxygen, Fig. 41: In the surface layers there is the highest supersaturation in Quarter II (primary production?), whereas conditions in Quarter IV show nearly 100 % saturation. At deeper horizons the conditions are "most favourable" in Quarter II, whereas in Quarter IV there are values lower than 85 %.

Phosphate-Phosphorus, Fig. 42: Surface values are highest in Quarter I and IV, approximately 0.4 μgat/l and lowest in Quarter II and III, approximately 0.1 μgat/l. There are some rather high values at deep horizons of station 18 B.

Fig. 43 presents annual means of salinity, density and oxygen saturation percentage, and Fig. 44 shows PO_4-P and total phosphorus (Tot.-P). Whereas Tot.-P is somewhat higher than PO_4-P in the surface layer, there is no difference in the deep.

Table 15 is an extract of the decade mean values computed for two Kattegat stations. The values of phosphorus at the Fladen station do not differ considerably from those in the Skagerrak, but the Kullen values show influence from the Öresund. Also oxygen is lower at Kullen. Apart from the influence from pollution, the Kullen values may also be explained in terms of vertical stability which is greater at Kullen.

10. Sediments

In an article by EISMA (1973) there is a map of the distribution of muddy sediments in the North Sea except the eastern Skagerrak. MÖRNER (1969) has a rather detailed map of the sea-bed of the Kattegat. The shallow western parts are covered with sand and coarse silt but also till, gravel, stones etc. The deeper eastern parts are covered with clay and fine silt. Also in ANON. (1965) there is detailed information in this respect.

OLAUSSON ET AL. (1972) present determinations of carbon, nitrogen, phosphorus and some heavy metals in Kattegat and Eastern Skagerrak sediments (usually 0—2 cm of the sediment surface):

Carbon: Open sea sediments have generally 0.5—1 % carbon of dry substance. Only in the vicinity of the Öresund are there larger values up to 2.5 %. Higher amounts of carbon at sediment surface as compared with depths of 2—4 cm, are only met with in the northern Öresund.

Phosphate-Phosphorus: The higher values in the sediment surface as compared with non-surface amounts can be interpreted as an increase from the 1960's, particularly in the SE Kattegat and off Göteborg where values up to 1000 ppm were found.

Lead: The Pb/C ratio is usually 5 units in the Skagerrak. Higher values probably indicate input of lead from, e.g., gasoline. Kattegat values are usually slightly larger than 5.

Mercury values are higher in the sediment surface than deeper down, particularly off Göteborg and in the northern Öresund, where the amounts are approximately 0.4 mg/kg dry weight.

The sedimentation process in northern Kattegat may influence bottom conditions according to RODHE (1973). Suspended matter is carried with the Jutland Current and settles in the Deep Trench.

11. Fisheries Hydrography

11.1. Herring *(Clupea harengus)*

Many attempts have been made to find a relation between fishery of North Sea Herring in winter at the West Coast of Sweden and some hydrographic parameters (ANDERSSON 1960, SVANSSON 1965). This herring spawns in the autumn in the North Sea and does not migrate for food in winter.

One thing seems to be rather clear: if the amount of Baltic water is considerably larger than normal in the Eastern Skagerrak and the fjords of Bohuslän, the herring will leave these areas (ANDERSSON op. cit.). O. PETTERSSON and G. EKMAN (1897) could draw this conclusion from salinity measurements in a famous example when after a long period of herring winters, the herring disappeared in December 1896 (temporarily, however; the Herring Period did not cease until about 1920). Looking now at sea levels at Landsort for the period concerned, it is quite evident that it was low during December 1896 and January 1897 (See Ch. 6.1.). While, however, a high sea level in the Baltic is a necessary condition for a good herring fishery, it is not at all sufficient.

For the first time since 1920, North Sea herring were again caught, although in small quantities, during the period 1942—54, on the coast of Bohuslän (ANDERSSON 1960). SVANSSON (1965) showed that during most years 1942—54 t-S plots seem to belong to one water mass, while those for 1935—41 and 1955—57 fall more along a straight line.

The autumn spawning herring of the Kattegat and the spring spawning herring of the Skagerrak may meet critical environmental conditions for eggs and larvae (See e.g. ACKEFORS 1970). The eggs of herring are not pelagic but adhere to the bottom. As hatching takes at least one week but usually more the eggs may be exposed to water of very different temperatures. The larvae are pelagic and highly dependent upon surface currents and surface waves. Daily vertical migration of herring larvae is dependent on density stratification of the water (HÖGLUND 1970).

DIETRICH ET AL. (1959) write about concentration of herring and the distribution of temperature in the northern North Sea:

a. In summer and autumn the herring is concentrated in the core of the cold bottom water.

b. The lower the temperature of this cold water, the longer is the duration of the concentration.

c. The geographical position of this concentration fluctuates with the dislocation of the centre of the cold water.

d. The daily vertical movements of the herring schools are influenced by the structure of the thermocline.

11.2. Sprat *(Sprattus sprattus)*

According to Swedish investigations 1959—63 (LINDQUIST 1970) the spawning of sprat in the Skagerrak is sharply defined to an area at the border between the Kattegat and the Skagerrak, where Baltic water meets Jutland current water. The spawning takes place in May—June in water warmer than 6°C. Calm wind conditions seem to favour a good year class.

Sprat fishing takes place mainly during the period October—March. Water temperature seems to be the main factor regulating the occurence of sprat in Swedish waters (LINDQUIST 1964). When the surface water layers are cooled, the warmest water will be met with near the bottom in the more shallow areas of the archipelago.

In LINDQUIST (1964) attention is drawn to the changes in the localization of sprat fishing since 1859. These changes are supposed to be due to hydrographical changes (water temperature). Since there are no hydrographical series of such length, observations of air temperature along the coast of Sweden and Norway were used. It is probable that the larger catches in the northern part of Bohuslän up to 1920 (MOLANDER 1952) can be explained by higher air temperatures and thereby higher sea water temperatures, compared with the southern part where during the period before 1920 the catches were small and the temperatures were lower. The differences of temperature between neighbouring cooled areas are of greater importance for distribution than absolute temperature values.

The growth of O-group sprat is dependent on food supply. Increased lengths are supposed to be due to higher precipitation and land-influence (LINDQUIST 1973).

11.3. Deepwater Prawn *(Pandalus borealis)*

During the period 1963—66 the fishery for deepwater prawn (at 50—500 m depth) in the Skagerrak area showed a marked decline (RASMUSSEN 1967). This author thinks that probably the abnormal cooling of the bottom water (See Ch. 7.3. and Fig. 34) in the winter 1962—63 was the main factor causing the decline. HÖGLUND and DYBERN (1966) claim overfishing to be a more important factor. Mass occurrence of a medusa, *Tima bairdi*, toward the end of the period was probably related to the cold water masses and may have had an additional effect.

11.4. Cod *(Gadus morhua)*

Studying ANDERSSON (1964) we are thrown into an interesting discussion of spawning migrations. Whereas it is quite evident that eggs and larvae which are "let" free in the water move with the currents, it is more difficult to follow the author when he presupposes along the coast of Norway a southward current by which the cod are passively transported from the Barents Sea to spawning grounds in the coastal waters of Mid-Norway. Active spawning migrations rather independent of hydrographical factors seem to be a much more probable alternative not only for cod but for most fish species.

Returning to egg and larvae, the author (ANDERSSON op. cit.) argues that favourable conditions for a good yearclass of e.g. cod, which spawns in winter, is a calm and cold winter. This would be the case because the vertical convection then penetrates deeper and brings more nutrients to the surface.

11.5. Mackerel *(Scomber scombrus)*

The studies referred to above (Ch. 11.2.) in May and June during 1959—1963 (LINDQUIST 1970) also included eggs and larvae of mackerel. The spawning was most intense along the Norwegian coast of the Skagerrak. (The mackerel seems to prefer to migrate into the Skagerrak swimming against the water current.) It is supposed that temperature must reach a magnitude of 12°C before spawning can take place in the surface waters.

In the coldest months of winter the mackerel seems to stay in deeper parts of the Norwegian Trench, e.g. the western parts. In the middle of the summer it spreads over the whole North Sea (LINDQUIST and HANNERZ 1974).

11.6. Haddock *(Melanogrammus aeglefinus)*

With the Jutland Current many larvae are transported to the Skagerrak and Kattegat and this seems to be the main source for the haddock stock in this area (HÖGLUND 1930, 1933). In DIETRICH ET AL. (1959) there are interesting relations between catches of haddock and water temperature: "conclude that a correlation between the concentration of haddock and the temperature exists in the region of the Dogger Bank as soon as the total number of fish in this area and the differences in temperature reach a sufficient level.

11.7. Other Fishes

So far, not much has been written about the hydrographic conditions in relation to such important fishes as whiting, coalfish, Norway pout, plaice, sole, sandeel, etc.

12. Heavy Metals, Organochlorine Pesticide Residues and PCBs in Fish

In the ICES Report already referred to in Ch. 8.3. (ANON. 1974) there is a comprehensive part dealing with a Fish and Shellfish Base-Line Study. This study was carried out largely in 1972 and was concerned with organochlorine pesticide residues, PCBs and certain metals. Cod, plaice, herring, shrimp, and mussels of specified age or size were sampled over the whole North Sea and analysed. The result of the shrimp investigation will be excluded here due to the low sampling rate. Mussels, indicators of coastal conditions, which are not taken up here will also be excluded. From the Skagerrak there is therefore information on cod, plaice and herring only. From the Kattegat, otherwise included in the report, there were no samples except from the northernmost part. The acronym IR will be used below when reference is made to the ICES Report.

WESTÖÖ and RYDÄLV (1971) presented information on mercury in fish, and so did also SOMER (1972), who particularly pointed out the importance of relating concentrations to fish weight (age).

In Ch. 8.3. there is some information on Caesium 137 contents in fish tissue.

12.1. Mercury

As mentioned already, SOMER (loc. cit.) relates concentrations y mg/kg, wet weight, to the weight x kg. The following rough relations were derived from SOMER's drawings:

Herring: $y = 0.22\,x + 0.023$

Flounder, (Kattegat): $y = 0.073\,x + 0.06$. In the Öresund the values may be five times higher.

Plaice: $y = 0.063\,x + 0.050$ for the North Sea, but 0.025 mg/kg lower for the Kattegat. As usual the concentrations were higher in the Öresund.

Porbeagle, Lamna nasus (The North Sea Proper and the Atlantic Ocean): $y = 0.05\,x$

Cod: $y = 0.025\,x + 0.17$. In the Öresund the values may be five times higher.

Looking a little more carefully into the concentrations reported for the North Sea Proper, a higher concentration, 0.08 mg/kg in a fish weighing one kg, is found in the SE corner (the German Bight) than in the open northern part, where the value is 0.04 mg/kg in a fish weighing one kg.

Such a geographical difference is still more emphasized in paper IR. The southern part of the North Sea, particularly the German Bight, has the highest values both for cod, plaice and herring, whereas the Skagerrak values are quite similar to those of the Northern North Sea. (It must be remembered that this synopsis does not include coastal areas, e.g. the Göteborg archipelago, where high mercury concentrations are encountered).

12.2. Cadmium and Lead

Contrary to the case of mercury, the ICES Base-Line Study shows that the concentrations of cadmium, ranging between 0.02 and 0.5 mg/kg, and lead, ranging between 0.1 and 3.0 mg/kg, were highest in the Skagerrak. Judging from the intercalibration sample there is no reason to suppose that the values, determined by Sweden, are inaccurate. It has been noted, however, that high values were reported when small samples with consequently higher detection limits had been used.

12.3. Zinc and Copper

Paper IR: There were slightly higher values of zinc in the Southern North Sea. The mean concentrations of zinc and copper in herring were reported to lie between 3 and 17 mg/kg and 0.6 and 3.6 mg/kg respectively. In both cases this is somewhat higher than for cod and plaice.

12.4. Organochlorine Pesticide Residues and PCBs

Jensen et al. (1972) determined DDT and PCB in the Baltic but also on some samples from the sea area here concerned. Whereas the amounts of DDT in the Baltic in herring may come up to 40—50 mg/kg on fat bases, in the northern Kattegat they were only 2—3 mg/kg.

Paper IR: The highest total DDT concentrations in cod muscle were reported for the Swedish and Danish west coasts and off Germany. Almost without exception the concentration of PCB was reported to be greater than that of DDT. In no case did the mean concentrations reach 0.1 mg/kg (wet weight basis). Cod liver with its usually much higher concentrations was not analysed. (Cod liver from the Göteborg archipelago has been declared unfit for human consumption on account of high PCB content.) In herring the concentrations are higher as expected in the light of the much higher lipid content of herring muscle. — Dieldrin was not analysed on Skagerrak samples. It may be noted in this connection that fish, except salmon and flatfish, from a small area off the mouth of the River Viskan have been declared unfit for human consumption due to their high dieldrin content.

12.5. Comments on Geographical Differences

The concentration of a substance in sea water is very much a function of the discharge at the boundaries of (sedimentation may be regarded a negative discharge at the bottom) and the exchange with other sea areas by diffusion and advection (dispersion processes, see also Ch. 5.5.1.). The concentrations in fish tissue are still more complicated due to enrichment processes, migration and other causes.

Higher concentrations in fish sampled in the German Bight and in the Öresund (and off Göteborg depending upon the definition of the coastal area) may be caused by large inputs and/or less effective dispersion. It will be important to study this problem more carefully with, e.g., mathematical models.

The Skagerrak seems to be less affected by pollution, if lead and cadmium are excluded, concentrations of which must be checked (Cf. Pb/C ratios in sediments, Ch. 10.2.). In the open Kattegat the conditions seem to be acceptable concerning mercury, other parameters must be investigated more before a statement can be made.

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References

AARKROG, A., 1974: Radioaktiv forurening af havet. Fisk og Hav 74. Danmarks Fiskeri- og Havundersøgelser.

ACKEFORS, HANS, 1970: Sillen förr och nu i Västerhavet och Nordostatlanten. Göteborgs Naturhistoriska Museum, pp. 23—86.

ANDERSSON, K. A., 1960: On the Causes of the Great Fluctuations in the Herring Fishery on the West Coast of Sweden. — Inst. Mar. Res. Lysekil, Series Biol., Rep. No. 12. 53 pp.

ANDERSSON, K. A. m.fl., 1964: Fiskar och Fiske i Norden. Stockholm, Bd. 1—2.

ANONYMOUS, 1866: Ergebnisse der Untersuchungsfahrten "Drache" in der Nordsee in den Sommern 1881, 1882 und 1884. Veröff. Hydrogr. Amt. der Admiralität, Berlin 1886.

— 1903: Redogörelse för Svenska Hydrografisk-Biologiska Kommissionens verksamhet under tiden 1 Maj 1901—30 April 1902 med återblick på vad som uträttats af den Svenska Hydrografiska Kommissionen under föregående tid. Svenska Hydrografisk-Biol. Komm. Skrifter I, pp. 1—10.

— 1927: Atlas für Temperatur, Salzgehalt und Dichte der Nordsee und Ostsee. Herausgeg. von der Deutschen Seewarte Hamburg.

— 1933: Mean values of observations from Danish light-vessels. København, 1933, 12 s. Tbl. Special print of the Nautical-Meteorological Annual 1932.

— 1953: Limits of oceans and seas. International Hydrographic Bureau, Special Publication no. 23, 3rd ed. Monte-Carlo.

— 1958: Hydrologiske undersøkelser i Norge. Utdrag av det hydrologiske materiale for 50-årsperioden 1900—1950. Oslo, Norges Vassdrags- og Elektrisitetsvesen. 236 + 54 pp.

— 1962: Mean monthly temperature and salinity of the surface layer of the North Sea and adjacent waters from 1905 to 1954. ICES, Copenhagen.

— 1965: Oceanographic Atlas of the North Atlantic Ocean. Section V. Marine Geology. U.S. Naval Oceanographic Office, Washington, D.C.

— 1967: Øresunds-vand-komiteens undersøgelser 1959—64. Report on the investigations of the Swedo-Danish Committee on Pollution of the Sound (Engl. summary). København.

— 1969: Joint Skagerrak Expedition, Current measurements and turbidity records. ICES Oceanographic data lists. Vol. 4.

— 1970: Joint Skagerrak Expedition 1966, Atlas. ICES Oceanographic data lists. Vol. 5.

— 1971: Vandressource, 1971. København, Forureningsrådet — sekretariatet. Publik. nr. 14. 261 pp.

— 1973: Manual on ICES Oceanographic Punch Cards. 3rd edit.

— 1974: Report of working group for the international study of the pollution of the North Sea and its effects on living resources and their exploitation. Cooperative Research Report, No. 39, 191 pp.

BLADH, J.-O., 1972: Measurements of Yellow Substance in the Baltic and Neighbouring Seas During 1970—1972. Medd. fr. Havsfiskelab. Lysekil, nr 138.

BROGMUS, W., 1952: Eine Revision des Wasserhaushaltes der Ostsee. Kieler Meeresforschungen Bd. IX/1: 15—42.

BULLETIN HYDR., 1913. ICES.

BÖHNECKE, G., 1922: Salzgehalt und Strömungen der Nordsee. Inst. für Meereskunde (N.F.) A. Heft 10, 34 pp.

CARRUTHERS, J. N., 1935: The flow of water through the Straits of Dover as gauged by continuous current-meter observations at the Varne Lightvessel. II. Fishery Invest. (London), 14: 1—67.

CARTWRIGHT, D. E., 1961: A study of currents in the Straits of Dover. J. Inst. Navigation, 14: 130—151.

CORIN, CH., FONSELIUS, S. H. and SVANSSON, A., 1969: On the oxygen and phosphate conditions in the Kattegat and Öresund 1900—1968. Medd. fr. Havsfiskelab., Lysekil nr. 62.

DAHLIN, HANS, 1973: A new Computation of the Volume of the Baltic and its Different Parts. Medd. fr. Havsfiskelab., Lysekil, nr. 157. 12 + 72 pp.

DEFANT, ALBERT, 1934: Ergebnisse der Strom- und Wasserstandmessungen im südlichen Kattegat. In: DEFANT, A. u. O. v. SCHUBERT: Strommessungen und ozeanographische Serienbeobachtungen der 4-Länder . . . Veröffentl. d. Inst. f. Meeresk, Berlin, N.F.R.A. H. 25. pp. 9—60.

— 1961: Physical oceanography. Vol. 2. Pergamon Press. 598 pp.

— und O. v. SCHUBERT, 1934: Strommessungen und ozeanographische Serienbeobachtungen der 4-Länderunternehmung im Kattegat 10—17 Aug. 1931. Veröffentl. d. Inst. f. Meereskunde, Univ. Berlin. N.F.: A Geogr.-naturwissensch. Reihe. H. 25. 144 pp.

DICKSON, ROBERT R., 1971: A recurrent and persistent pressure-anomaly pattern as the principal cause of intermediate-scale hydrographic variation in the European shelf seas. Deut. Hydr. Z. Bd. 24, H. 3, pp. 97—119.

— 1972: The beginnings of a new Baltic inflow? ICES, Hydrogr. comm. C.M. C: 10. 7 pp.

DIETRICH, G., 1950: Die natürlichen Regionen von Nord- und Ostsee auf hydrographischer Grundlage. Kiel. Meeresforsch. 7 (2): 35—69.

— 1951: Oberflächenströmungen im Kattegat, im Sund, und in der Beltsee. Deut. Hydrogr. Z. 4, 129—150.

— SAHRHAGE, D., SCHUBERT, K., 1959: Locating fish concentrations by thermometric methods. Modern Fishing Gear of the World, pp. 453—461.

DOOLEY, H. D., 1974: Hypotheses concerning the circulation of the North Sea. J. Cons. Int. Explor. Mer, 36 (1): 54—61.

EGGVIN, JENS, 1940: The movement of a cold water front. Fiskeridirekt. Skr. Ser. Havundersøgelser (Rept. Norwegian Fish and Mar. Invest.) 6 (5), 1—151 pp.

EHLIN, U. ET AL., 1974: Computer based calculations of volumes of the Baltic area. 9th Conf. of the Baltic Oceanographers, Kiel Apr. 1974, Paper No. 7.

EHRICKE, KLAUS, 1969: Beitrag zur Bestimmung der turbulenten Vertikaldiffusion im geschichteten Meer am Beispiel des Skagerraks. Kieler Meeresforsch. Bd. 25 (2): 233—244.

EISMA, D., 1973: Pollution. In GOLDBERG, EDW., edit.,: North Sea Science. NATO North Sea Science Confr., Aviemore, Scotland. 15—20 Nov. 1971, pp. 131—150.

EKMAN, F. L., 1870: Om salthalten i havsvatten utmed Bohuslänska Kusten. K. Vetenskapsakad. Handlingar, 9 (4), 44 pp.

— 1875: Om de strömningar som uppstå i närheten av flodmynningar. Oevers. K. Vetenskapsakad. Handlingar, 32 (7), 43—134.

— and PETTERSSON, OTTO, 1893: Den svenska hydrografiska expeditionen 1877. Kungl. Vetenskaps.-Akad. Handlingar 25 (1), 163 pp.

EKMAN, G., 1880: Hydrografiska undersökningar vid Bohuskusten. Bih. t. G:s o Bohusläns Hushålln., Sällsk. Quartalsskrift 1880, 42, 68 pp.

ENGSTRÖM, SVEN, G., 1967: Laying out Surface Drifters in the Eastern North Sea and Skagerrak in the Summer of 1966. Medd. fr. Havsfiskelab., Lysekil, nr. 33. 8 pp.

FISCHER, G., 1959: Ein numerisches Verfahren zur Errechnung von Windstau und Gezeiten in Randmeeren. Tellus (1959) Vol. 11, 60—76.

FLODÉN, T., 1973: Notes on the bedrock of the eastern Skagerrak with remarks on the Pleistocene deposits. Acta Universitatis Stockholmiensis, Stockholm contributions in geology. Vol. XXIV: 5.

FONSELIUS, S. H., 1969: Hydrography of the Baltic Deep basins III. Fish. Board of Sweden, Series Hydrography No. 23, 96 pp.

— 1970: Om Öresunds föroreningsproblem. Fauna och flora. Årg. 65, nr. 1: 5—10.

FRANCK, H. ET AL., 1972: Ozeanologische Untersuchungen der DDR in der nordöstlichen Nordsee in den Jahren 1965—1969 (nebst Einzeluntersuchungen im Kattegat). Geodätische u. Geophys. Veröff. R. IV H. 8. 31 + 81 pp.

GOEDECKE, E., SMED, J. and TOMCZAK, G., 1967: Monatskarten des Salzgehaltes der Nordsee dargestellt für verschiedene Tiefenhorizonte. Erg.-heft zur DHZ, Reihe B, Nr. 9.

GRANQUIST, G., 1938: Zur Kenntnis der Temperatur und des Salzgehaltes des Baltischen Meeres an den Küsten Finnlands. Havsforskn. inst. skr. No. 122: 1—166, Helsingfors.

GUSTAFSSON, T. och OTTERSTEDT, B., 1931: Strömmätningar i Kattegatt 1930. Svenska Hydrografisk-Biologiska Kommissionens Skrift Hydr. X.

HASSELROT, T., 1971: Kvicksilverundersökningar 1966—1970. Statens Naturvårdsverk, Undersökningslaboratoriet.

HELLAND-HANSEN, B., 1907: Current measurements in Norwegian Fjords, the Norwegian Sea and the North Sea in 1906. Bergens Mus. Aarbok 15: 1—61.

HERMANN, FREDE, 1967: Hydrografiske undersøgelser foretaget af D.F.H. og "Skagerrak". Øresunds-vand-komiteens undersøgelser 1959—64, København, Danskt-svenskt komitee. IV. Hydrografi. Kemi. pp. 55—77, (4.0.). (Vandudvekslingen i Øresund. (4.1.0.)

— 1975: Measurements of currents and total phosphorus at L/V Halsskov Rev during the Baltic Year. To be published.

— and VAGN OLSEN, O., 1970: Long term fluctuations in oxygen and phosphate concentrations in the Kattegat, the Belt Sea and the western Baltic. ICES, Hydrogr. Comm. C.M. C: 27.

— og VAGN OLSEN, O., 1970 b: Iltforholdene i danske farvande. Skrifter fra Danmarks Fiskeri- og Havundersøgelser nr. 30.

HILDING, S., 1948: Om tidvattnet å västkusten. Svensk Geogr. Årsbok s. 75—85.

HÖGLUND, HANS, 1932: Har 1931 varit ett gynnsamt yngelår för kolja? Ny svensk fiskeritidskrift, nr. 1: 8—10.

— 1933: Om utsikterna för koljefisket. Ny svensk fiskeritidskrift, nr. 15: 169—172.

— 1968 (1938): Further investigations of the diurnal changes in the vertical distribution of Herring-fry in the Kattegat. Medd. Havsfiskelab., Lysekil, nr. 55.

— and BERNDT DYBERN, 1966: Decreasing catches in the Swedish fishery for Pandalus borealis. Medd. fr. Havsfiskelab., Lysekil, nr. 13. 9 pp.

HØJERSLEV, N. K., 1971: Tyndall and fluorescence measurements in Danish and Norwegian waters related to dynamical features. København Univers., Inst. f. fysisk oceanogr. rep. 16, 12 pp.

JACOBSEN J. P., 1908: Der Sauerstoffgehalt des Meereswassers in den dänischen Gewässern innerhalb Skagen. — Medd. fr. Komm. f. Havundersøgelser. Ser. Hydr. Bd. I Nr. 12.

— 1913: Beitrag zur Hydr. der dänischen Gewässer. Ibid. Bd. II, Nr. 2.

— 1913 b: Strommessungen in der Tiefe in dänischen Gewässern in den Jahren 1909, 1910 und 1911. Ibid. Bd. II, Nr. 3.

— 1925: Die Wasserumsetzung durch den Öresund, den grossen und kleinen Belt. Ibid. Bd. II, Nr. 9.

JENSEN, AA., 1937: Fluctuations in the hydrography of the transition area during 50 years. Rapp. et P.V. Cons. Perm. Expl. Mer. Vol. CII. p. 3—49, Copenhague.

— 1940: The influence of the currents in the Danish waters on the surface temperature in winter, and on the winter temperature of the air. Medd. fr. Komm. f. Danmarks Fiskeri- og Havundersøg. Ser. Hydr. B. III, 1—52.

JENSEN, S., JOHNELS, A. G., OLSSON, M. and OTTERLIND, G., 1972: DDT and PCB in herring and cod from the Baltic, the Kattegat and the Skagerrak. Ambio Special Report No. 1: 71—85.

JERLOV, N. G., 1953: Influence of suspended and dissolved matter on the transparency of sea

water. Tellus V (1): 59—65.
— 1968: Optical Oceanography. Amsterdam, Elsevier. 13 + 194 pp.
JOHANSSON, JAN and SVANSSON, A., 1974: Processing Historical Data from the Gullmar Fjord and the Brofjorden Area. Medd. fr. Havsfiskelaboratoriet, Lysekil, nr. 161, 17 pp.
JOHNSSON, HARALD O., 1949: Termisk-hydrologiska studier i sjön Klämningen. Medd. fr. Geogr. inst. vid Stockholms högskola, Nr. 70. 154 pp.
JOHNSON N. G. and KULLENBERG, B., 1946: On radiant energy measurements in the sea. Sv. hydrogr.-biol. komm. skrifter. 3. ser., Bd. I/1. 27 pp.
KALLE, K., 1949: Die natürlichen Eigenschaften der Gewässer. Handb. der Seefischerei Nordeuropas, v. I, part 2. Stuttgart. 1951.
KAUTSKY, H., 1973: The distribution of the Radio Nuclide Caesium 137 as an Indicator for North Sea Water Mass Transport. Deutsche Hydr. Z. Bd. 26: 241—246.
KNUDSEN, M., 1899: De hydrografiske forhold i de danske Farvande inden for Skagen i 1894—1898. Beretning fra Kommissionen for videnskabelig undersøgelse af de danske Farvande. Bd. 2: 2, 19—79, København.
— 1900: Ein hydrographischer Lehrsatz. Ann. d. Hydrogr. u. Marit. Meteor. Bd. 28, pp. 500—504.
KOBE, G., 1934: Der Hydrographische Aufbau und die dadurch bedingten Strömungen im Skagerak. Veröff. Inst. f. Meereskunde Berlin N.F. Heft 26. 1—62.
KOCZY, F. F., 1954: Monthly average values of hydrographical observations on Swedish lightships 1923—1952. Fishery Board of Sweden, Series Hydrography, Rep. No. 5.
KOLTERMANN, K. P., 1968: Zum Schwingungssystem des Kattegats in Periodenbereich von 2 bis 25 Stunden. Diplomarbeit, Univers. Hamburg. 48 pp.
KULLENBERG, B., 1935: Interne Wellen im Kattegat. Sv. Hydr. Biol. Komm. Skr. ser. Hydrografi XII. 17 pp. Göteborg.
— 1955: Restriction of the underflow in a transition. Tellus 7 (2): 215—217.
— 1967: Oceanografi för Nordiska Hälsovårdshögskolan. Mimeo.
KULLENBERG, G., 1971: Vertical Diffusion in Shallow Waters. Tellus, v. 23 (2), pp. 129—135.
KÄNDLER, R., 1951: Einfluss der Wetterlage auf die Salzgehaltschichtung im Übergangsgebiet zwischen Nord- und Ostsee. Deutsche Hydrogr. Zeitschrift, Band 4, pp. 150—160.
LAEVASTU, T., 1962: Water types in the North Sea and their characteristics. Hawaii Inst. of Geophysics, No. 24.
LAMB, HORACE, 1953: Hydrodynamics. 2nd ed. Cambridge, Univers. Press. 15 + 738 pp.
LAZARENKO, N. N., 1974: Water level and volume variations of the Baltic Sea. IXth Conference of Baltic Oceanographers (Kiel, FRG), 6 pp.
LEE, ARTHUR, 1970: Currents and Water Masses of the North Sea. Oceanogr. Mar. Biol. Ann. Rev. V. 8: 33—71.
LENZ, WALTER, 1971: Monatskarten der Temperatur der Ostsee dargestellt für verschiedene Tiefenhorizonte. Ergänz. Hft. D. Hydrogr. Z. Reihe B, Nr. 11, 148 pp.
LINDQUIST, ARMIN, 1964: Zur Fischereihydrographie der Sprotte (Clupea sprattus) an der Schwedischen Westküste. Inst. of Marine Research, Lysekil, Ser. Biology No. 15, 87 pp.
— 1970: Zur Verbreitung der Fischeier und Fischlarven im Skagerak in den Monaten Mai und Juni. Inst. of Marine Research, Lysekil, Ser. Biology No. 19, 82 pp.
— 1973: Growth and Environment of Sprat. Medd. fr. Havsfiskelaboratoriet, Lysekil nr. 146, 11 pp.
— and LENNART HANNERZ, 1974: Migrations of the mackerel in the northern North Sea and in the Skagerrak. J. Cons. int. Explor. Mer, 35 (3): 276—280.
LISITZIN, EUGENIE, 1943: Die Gezeiten des Bottnischen Meerbusens. Fennia 67. 47 pp.
— 1967: Day-to-day variation in sea level along the Finnish coast. Geophysica, vol. 9 (4): 259—275.
— 1970: The seasonal water balance of the ocean. Comm. Phys. — Mathem. Vol. 40.
LJØEN, R., 1962: Om hydrografiske forhold i Skagerak og den nordøstlige del av Nordsjøen og

deres betydning for fordelingen av brislingegg og yngel. Fiskets Gang:s. 179—187.
— 1965: On the exchange of deep waters in the Skagerack. ICES, Hydr. Comm. 157.
— and SVANSSON, ARTUR, 1972: Long-term variations of subsurface temperatures in the Skagerrak. Deep-sea Research, v. 19, pp. 277—288.
MAGAARD, L. and KRAUSS, W., 1966: Spektren der Wasserstandsschwankungen der Ostsee im Jahre 1958. Kieler Meeresf. XXII (2): 155—162.
MALMBERG, S., 1964: Transparency measurements in the Skagerrak. Medd. Oc. Inst. Göteborg, No. 31.
MELIN, RAGNAR, 1955: Vattenföringen i Sveriges floder. SMHI, Medd. ser. D, nr. 6. Stockholm.
MEYER, H. A., 1875: Zur Physik des Meeres. Jahresbericht der Commission zur wissenschaftlichen Untersuchung der deutschen Meere in Kiel für die Jahre 1872, 1873. Jg. 2 u. 3: Die Expedition zur Physikalischchemischen und biologischen Untersuchung der Nordsee im Sommer 1872, pp 3—41.
MIKULSKI, ZDZISLAV, 1970: Inflow of river water to the Baltic sea in the period 1951—1960. Nordic Hydrologi 4: 216—227.
— 1972: The inflow of the river waters to the Baltic Sea in the years 1961—70. VIII-th Conference of the Baltic Oceanographers — Copenhagen, Denmark: 2—4 October 1972. 5 pp.
MOLANDER, ARVID, R., 1952: The sprat fishery and the sprat of the West Coast of Sweden. Inst. Marine Res., Lysekil, ser. Biology, Rep. No. 2. 67 pp.
MORTIMER, CLIFFORD, H. I., ed., 1967: Lake Currents. (Lake Michigan basin). Chicago, Federal Water Pollution Control . . . 11 + 363 pp.
MÖRNER, NILS-AXEL, 1969: The late quaternary history of the Kattegat Sea, and the Swedish West Coast, deglaciation, shorelevel displacement, chronology, isostasy and eustasy. Stockholm. Sveriges geologiska undersökning, årsb. 63 nr. 3, ser. C nr. 640. 487 pp.
NEUMANN, G., 1940: Mittelwerte längerer und kürzerer Beobachtungsreihen des Salzgehaltes bei den Feuerschiffen im Kattegatt und in der Beltsee. Ann. d. Hydr. u. marit. Meteor. 68 (11): 373—386.
NILSSON, HANS and SVANSSON, A, 1974: Long term variations of oceanographic parameters in the Baltic and adjacent waters. Medd. fr. Havsfiskelab. Lysekil, No. 174, 11 pp.
NYBERG, LEIF, 1966: Preliminary results of current measurements in the Eastern Skagerrak in 1965. Medd. fr. Havsfiskelab., Lysekil, nr. 16.
OLAUSSON, ERIC ET AL., 1972: Sedimentundersökningar på Västkusten: förändringar och konstans. Medd. fr. Maringeologiska lab., Göteborg, nr. 2. 24 + 32 pp.
OLSSON, B., 1968: Report on investigations of some drift bottles in the Baltic. Medd. fr. Havsfiskelab., Lysekil, nr. 57.
OTTERLIND, G., JANSEN, S. and OLSSON, M., 1971: DDT and PCB in Baltic fish. ICES, E: 31.
PETTERSSON, H., 1923: Göta älvmynningens hydrografi. Göteborgstraktens natur.
PETTERSSON, O., and EKMAN, G., 1891: Grunddragen av Skageracks och Kattegats hydrografi. Kungl Vet. Ak. Handl. N.F. Bd. 24.
— 1897: De hydrografiska förändringarna inom Nordsjöns och Östersjöns område under tiden 1893—1897. K.V.A:s Handl. N.F. Bd. No. 5, 125 pp.
PRAHM, G., 1958: Summer Bottom Temperature in two Selected Areas of the Central North Sea in the Years 1900—1956. Annales biol. Copenhagen, Vol. 13, pp 78—79.
RASMUSSEN, BERGER, 1967: Temperaturforhold og rekefiske i Skagerak 1962—66. Fiskets Gang 47, pp. 842—7.
RODHE, J., 1973: Sediment transport and accumulation of the Skagerrak—Kattegat border. Institute of Oceanography, University of Gothenburg. Report No. 8.
ROSSITER, J. R., 1968: The Analysis of Tidal Streams—Laesö Rende. Tidal Institute internal report No. 12: 1—3.
SCHOTT, F., 1966: Der Oberflächensalzgehalt in der Nordsee. Ergänz. Hft. D. Hydrogr. Z., Reihe A, Nr. 9, pp. 55.
SCHOTT, F., 1971: On horizontal coherence and internal wave propagation in the North Sea.

Deep-sea Res., Vol. 18: 291—307.

SCHULZ B., 1930: Der Wasseraustausch zwischen der Nord- und Ostsee. Petermanns Geogr. Mitt., H. Wagner Gedächtnisschrift, Erg. Heft Nr. 209.

SMED, JENS, 1963: Near Northern Seas. Annales biol., Copenhagen, Vol. 18, pp. 34—42.

SOMER, ERIK, 1972: Kviksølv i fisk 1968—1972. København, ATV (Akad. f. de tekn. vidensk.), Isotopcentralen, 73 + 23 pp.

SOSKIN, I. M., 1963: Long term changes in the hydrological characteristics of the Baltic. Hydrometeorological Press, Leningrad, (in Russian), 159 pp.

STEEMANN NIELSEN, E., 1958: A survey of recent Danish measurements of organic productivity in the sea. ICES rapp. Proc.-Verb. des réunion. Vol. 144.

— 1971: In Anonymous 1971.

STOMMEL, H. and FARMER, H. G., 1953: Control of salinity in an estuary by a transition. J. Mar. Research, Vol. 12: 13—23.

SVANSSON, ARTUR, 1959: Some computations of water heights and currents in the Baltic. Tellus, 11, 231—239.

— 1961: Currents in the Skagerack, ICES, C.M. Hydrogr. Comm. No. 127, 6 pp.

— 1962: Strömförhållandena i Skagerack och Kattegatt. The Swedish Shipbuilding Research Foundation. Rep. No. 29.

— 1965: Some hydrographical problems of the Skagerack. Progress in Oceonogr. 3, pp. 355—372.

— 1966: Long-Term Variations of Subsurface Temperatures in the Skagerack. ICES C.M. 1966/N: 19 Hydrogr. Comm. 12 pp.

— 1968: The International Skagerrak Expedition 1966. Conditions in the Northern Part of the Kattegat and along the Swedish Coast of the Skagerrak. Medd. fr. Havsfiskelab., Lysekil, Nr. 56, 15 pp. (C.M. 1968/C: 37, hydrogr. Comm.)

— 1969 a: Measurements with a Richardsson Current Meter in the Eastern Skagerrak, May—October 1967. Medd. fr. Havsfiskelab., Lysekil, Nr. 67, 41 pp.

— 1969 b: A semi-permanent automatic current meter station in the Eastern Skagerrak. Medd. fr. Havsfiskelab., Lysekil. Nr. 69.

— 1970: First results of a new numerical model for Baltic water levels. Medd. fr. Havsfiskelab., Lysekil, Nr. 95, 22 pp.

— 1971: Storage of oceanographic observations at lightvessels and coastal stations in the Baltic and the Transition area. Medd. fr. Havsfiskelab., Lysekil, Nr. 99, 18 pp.

— 1972: Canal models of sea level and salinity variations in the Baltic and adjacent waters. Fishery Board of Sweden, s. Hydrography, rep. 26, 72 pp.

— 1972 b: The water exchange of the Baltic. Ambio Special Report, No. 1: 15—19.

— 1974: Decade Mean Values of Salinities Measured on Swedish Lightships 1880—1970. Medd. fr. Havsfiskelab., Lysekil. Nr. 162, 47 pp.

— 1975: Interaction between the coastal zone and open sea. Third Baltic Symposium on Marine Biology, Havsforskningsinst:s skrift, Helsingfors, No. 239.

— and LYBECK, L., 1962: Currents in the Skagerack II. ICES Hydrogr. Comm. C.M. 130, 14 pp.

— and SZARON, JAN, 1975: Sea level computations of the Baltic with a 20-canal model. Tellus, vol. 27, No. 6.

SVERDRUP, H. U., JOHNSON, MARTIN W. and FLEMING, RICHARD H., 1946: The Oceans. New York, Prentice-Hall. 1059 pp.

THORADE, H., 1936: Strombeobachtungen am Nordausgange des Kattegats. Ann. der Hydrogr. Jg. 64. Pp. 243—253.

TOMCZAK, G., 1968: Die Wassermassenverteilung und Strömungsverhältnisse am Westausgang des Skagerraks während der internationalen Skagerrak-Expedition im Sommer 1966. Deutsche Hydrogr. Z. Bd. 21 (3): 97—105.

— 1969: Die thermischen Verhältnisse der oberen Wasserschichten des Skagerraks im Sommer 1966 auf Grund von "Delphin"-Messungen. Deut. Hydrogr. Z. Bd. 22: 5.

— und E. GOEDECKE, 1962: Monatskarten der Temperatur der Nordsee, dargestellt für verschiedene Tiefenhorizonte. Deutsche Hydrogr. Z. Erg.-Heft R. B, Nr. 7.

WAHL, G., 1973: Vågstatistik från svenska kustfarvatten, Fyrskeppet Fladen. Visuella observationer och vågregistreringar. Allmän rapport från Statens Skeppsprovningsanstalt Nr. 35. English summary.

WALIN, G., 1968: Vinddrivna vattenomsättningar vid Östersjökusten — kommentar till några observationer. N. Forskningsrådet-Aktuellt.

— 1972: Some observations of temperature fluctuations in the coastal region of the Baltic. Tellus, 24 (3), pp. 187—198.

VAUX, David, 1955: Current Measuring in shallow waters by towed electrodes. J. of Mar. Res. V. 14: 194.

WATTENBERG, HERMAN, 1949: Entwurf einer natürlichen Einteilung der Ostsee. Kieler Meeresforschungen VI, 10—17.

WESSEL, L., 1971: Havsströmmar. Marinstabens hydrografiska detalj.

WESTÖÖ, GUNNEL and RYDÄLV, MARIANNE, 1971: Metylkvicksilverhalten i fisk fångad i mars 1968—april 1971. (Metyl mercury levels in fish.) Vår Föda, årg. 23 (7—8): 179—321.

WYRTKI, KLAUS, 1954: Schwankungen im Wasserhaushalt der Ostsee. Deutsche Hydr. Z. Bd. 7: 91—129.

— 1954 b: Der grosse Salzeinbruch in die Ostsee im November und Dezember 1951. Kieler Meeresforsch. X/1: 19.

WITTING, ROLF, 1918: Hafsytan, geoidytan och landhöjningen utmed Baltiska hafvet och vid Nordsjön. Fennia 39/5: 1—346.

ZWIEBLER, G., 1964: Beobachtungen auf den deutschen Feuerschiffen der Nord- und Ostsee im Jahre 1963 (sowie Monatswerte von Temperatur und Salzgehalt). D. Hydrogr. Inst. Hamburg, Nr. 2142.

Data of currents, temperatures and salinities measured at Danish lightvessels were published by Det Danske Meteorologiske Institut, Charlottenlund: 1880—1896 Meteorologisk Aarbog, part 3; 1897—1961 Nautical—Meteorological Annual; 1962— Oceanographical observations from Danish light-vessels and coastal stations.

Data of parameters measured at Swedish lightvessels (and Bornö station) were published:

monthly means of temperatures, 1880—1913, in Svenska hydrografisk-biologiska kommissionens skrifter, fyrskeppsundersökningen 1923,

monthly means of temperatures, 1914—1918, and monthly means of salinities, 1880—1918, in Meddelande från Havsfiskelab. nr 102,

daily measurements of temperature, salinity and current, 1923—1947, in Svenska hydrografisk-biologiska kommissionens skrifter, fyrskeppsundersökningen,

daily measurements of temperature, salinity and current, 1948—1969, in Fishery Board of Sweden, Report, Series Hydrography,

daily measurements of temperature, salinity and current, 1970—1972, in Meddelande från Havsfiskelab. nr 148.

Data of sea levels measured on Swedish stations (Vattenstånden vid Sveriges kuster) were published 1887—1944 by Statens meteorologisk-hydrografiska anstalt, thereafter by Sveriges meteorologiska och hydrologiska institut.

Data of sea level measured on Finnish stations were published in Havsforskningsinstitutets skrifter (after 1913).

Table 1.
Volumes, Areas and Mean Depths

Sea areas	Mean depth m	Surface m^2	Volume m^3
The North Sea (incl. the Skagerrak, SVERDRUP ET AL. 1946)	94	$575{,}000 \cdot 10^6$	$54{,}000 \cdot 10^9$
The Skagerrak	210	$32{,}300 \cdot 10^6$	$6{,}780 \cdot 10^9$
The Kattegat (EHLIN ET AL. 1974)	23	$22{,}040 \cdot 10^6$	$506 \cdot 10^9$
The Belt Sea (EHLIN ET AL. 1974)	14	$20{,}350 \cdot 10^6$	$291 \cdot 10^9$
The Baltic (excl. the Belt Sea and the Kattegat, EHLIN ET AL. 1974)	56	$372{,}700 \cdot 10^6$	$20{,}920 \cdot 10^9$

Table 2.
Swedish rivers discharging to the Kattegat
1931—1960 (U. EHLIN pers. comm.)

	Catchment area, km^2	Discharge, m^3/s
Viskan	2,201	32
Ätran	3,343	46
Nissan	2,682	40
Lagan	6,444	70
Göta älv	50,181	530
Others	5,289	68
	70,140	786

Norwegian rivers discharging to the Skagerrak
1911—1950 (See p. 9)

	Catchment area, km^2	Discharge, m^3/s
Tista	1,550	23.7
Glomma	41,284	708.0
Mosseelv	690	10.7
Dramselv	16,020	313.0
Numedalslågen	5,513	115.7
Skienselv	9,975	298.0
Toke	1,168	33.0
Vegårdselv	491	15.6
Nidelv	3,907	124.5
Tordalselv	1,700	63.1
Otra	3,539	149.0
Mandalselv	1,746	87.0
Others	11,717	249.0
	99,300	2190.0

Swedish rivers discharging to the Skagerrak

	Catchment area, km²	Discharge, m³/s
Örekilsälven	1,327	21
Others	1,543	24
	2,870	45

Table 2 a.
Summary of discharges

	m³/s	km³/year
Baltic (MIKULSKI 1970, 1972), 1951—1970	13,900	439
Belt Sea (BROGMUS 1952)	225	7
Kattegat 1931—1960	885	28
Skagerrak 1911—1950	2,245	71
	17,255	545

Table 3.
Measurements with automatically recording current-meters
(Positions, see Figures 1 and 2)

Station no	Latitude ° ′	Longitude ° ′	Depth bottom m	Obs. depth m	Period of observation		Publication or availability
S				10	June 1911		Bull. Hydr. ICES
S				40	,, ,,		,, ,,
S 6	57 56	09 40	100	80	Aug 1913		,, ,,
	57 15.7	11 46.5	44	15.5	21.7—2.8	1930	GUSTAFSSON och
	57 15.7	11 46.5	44	7.5	2.8—14.8	1930	OTTERSTEDT 1931
	57 15.7	11 46.5	44	15.5	2.8—14.8	1930	,,
	57 15.7	11 46.5		11.5	2.8—9.8	1930	,,
	57 17	11 38	60	11.5	25.10—6.11	1930	,,
	57 17	11 38	60	31.5	25.10—6.11	1930	,,
	S. Kattegat				10.8—17.8	1931	DEFANT und SCHUBERT 1934
4030	57 56.9	11 19.7	58	12	21.9—3.10	1960	ZWIEBLER 1963
4031	57 49.4	10 50.9	76	65	21.9—25.9	1960	,,
4032	57 23.3	09 17	39	13	22.9—30.9	1960	,,
4034	57 43.4	07 56.8	446	8	22.9—1.10	1960	,,
4035	57 42.9	07.56	438	75	22.9—30.9	1960	,,
SW of Smögen	58 14	11 03	100	50	21.4—10.6	1965	NYBERG 1966
,, ,,	58 14	11 03	100	50	1.7—28.7	1965	,,
,, ,,	58 14	11 03	100	50	2.11.-65—21.1.-66		,,
32	57 26.8	06 59.3	123	17	21.6—9.7	1966	ANON. 1969
33	57 47.7	07 04	405	400	21.6—9.7	1966	,,
34	57 51.7	07 51	516	511	22.6—10.7	1966	,,
35	57 52	07 47	518	37	22.6—24.6	1966	,,
36	57 50.3	07 48.2	513	18	22.6—22.6	1966	,,
37	57 56.2	07 48.2	323	38	22.6—24.6	1966	,,
38	57 39.6	08 01.8	304	28	23.6—12.7	1966	,,
39	57 39.9	08 03.8	290	285	23.6—25.6	1966	,,
40	57 29.2	08 11	125	120	23.6—10.7	1966	,,
41	57 28.8	08 11.8	110	19	23.6—10.7	1966	,,
42	57 11.5	08 23.6	33	10	23.6—10.7	1966	,,
43	57 51	10 51	92	16	24.6—11.7	1966	,,
44	57 50.1	10 51.9	81	40	24.6—11.7	1966	,,
45	57 50.6	11 17.3	99	12	24.6—11.7	1966	,,
46	57 51.1	11 17	97	40	25.6—11.7	1966	,,
SW of Smögen	58 14	11 03	100	50	16.5—22.11	1967	SVANSSON 1969 b
W of Göteborg	57 41.15	11 34.65	25	5	4½ months	1970	AB Hydroconsult Uppsala
				10	1966—1971, 34 months		,,
				16	1966—1972, 46 months		,,
				22	1966—1973, 51 months		,,

Table 4.
Currents, cm/s

Depth m	0 1910—30*	2.5	5	10	15	20	25	
Läsö Rende 5/9 1912—14/11 1913	22.0	26.0	24.7	9.7	—0.2	—2.2		Rossiter (1968)
Anholt Knob 17/6—17/9 1910	—5.0	1.7	—2.3	—4.3	—5.1	—4.3	—3.9	Jacobsen (1913)
Schultz's Grund 1910—1916	10.0	2.4	0.4	—9.4	—18.2	—19.0	—15.0	Jacobsen (1925)
Lappegrund 1/9—22/11 1909 22/6—17/8 1912	35.0	27.0	17.5	—10.3	—13.2	—11.3	—9.0	Jacobsen (1925)
Halsskov Rev** July 1969—Jan 1970 April 1970—May 1970	13.0	15.0	13.0	12.0	9.0			Hermann (1975)

* Dietrich 1951

** Preliminary

Table 5. Monthly and annual long year (vectorial) means of surface currents (knots) at Danish Light-vessels (from DIETRICH 1951). Positive values indicate outflow, negative ones inflow.

Lightship	Obs. Period	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year	Outflow
Skagens Rev	1901/30	—0.11	—0.07	0.26	0.16	0.00	—0.03	—0.08	—0.06	0.04	0.21	0.08	0.07	0.04	W-N-ENE
Läsö Rende	1901/30	0.36	0.46	0.59	0.52	0.54	0.28	0.29	0.28	0.37	0.56	0.48	0.48	0.44	NW-N-ENE
Östre Flak	1909/30	0.07	0.21	0.27	0.31	0.38	0.33	0.29	0.24	0.23	0.20	0.14	0.11	0.23	W-N-ENE
Läsö Trindel	1901/30	0.28	0.35	0.46	0.42	0.43	0.27	0.25	0.25	0.34	0.43	0.32	0.33	0.34	W-N-ENE
Anholt Knob	1901/30	0.06	0.07	0.01	—0.02	—0.08	—0.33	—0.38	—0.34	—0.11	0.02	0.01	0.05	—0.09	W-N-ENE
Lappegrund	1901/30	0.59	0.87	0.92	0.77	0.80	0.46	0.56	0.51	0.72	0.75	0.56	0.81	0.69	NNW
Drogden	1901/30	0.08	0.20	0.21	0.18	0.22	0.06	0.11	0.07	0.18	0.13	0.00	0.14	0.13	NE-ENE
Schultz's Grund	1901/30	0.06	0.20	0.34	0.35	0.40	0.19	0.22	0.11	0.24	0.06	0.22	0.19	0.20	WNW-N-E
Halsskov Rev	1922/30	0.31	0.30	0.25	0.14	0.28	0.05	0.23	0.19	0.20	0.07	0.23	0.14	0.18	N
Gedser Rev	1901/30	0.13	0.27	0.19	0.10	0.16	0.12	0.17	0.20	0.19	0.08	0.07	0.12	0.15	S-W-NW

Table 6.
Components of the Water Budget of the Baltic, km^3/month

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year
River Runoff Z* (MIKULSKI 1970, 1972)	26.1	27.9	31.7	47.0	63.3	49.4	36.7	34.3	33.6	31.5	29.9	28.0	438.7
Precipitation N (BROGMUS 1952)	13.5	10.8	10.4	10.9	11.8	12.9	16.0	19.7	17.1	17.8	16.2	14.8	171.9
Evaporation V (BROGMUS 1952)	15.8	10.8	6.1	4.2	3.5	6.2	13.2	18.8	20.3	25.0	25.7	22.9	172.5
Sum 1 (S = Z+N—V)	23.8	27.9	36.0	53.7	71.6	56.1	39.5	35.2	30.4	24.3	20.4	19.9	438.1
Volume change Δ H* (LAZARENKO 1974)	—28.9	—30.8	—13.7	3.1	12.7	37.7	22.7	2.1	4.8	—5.6	—2.3	—6.5	
Sum 2 (S — Δ H)	52.7	58.7	49.7	50.6	58.9	18.4	16.8	33.1	25.6	29.9	22.7	26.4	

* 1951—1970

Table 7.
German Current Data from 1966. Positions in Fig. 2.

Date	Current Components, cm/s. Stn no 34 Obs depht 511 m N	E	Stn no 38 28 m N	E	Stn no 40 120 m N	E	Stn no 41 19 m N	E
66 06 24	—2.3	—2.7	—2.7	1.5	13.4	11.7	20.0	27.9
25	—2.1	—0.1	—2.1	—1.2	9.2	10.7	15.0	29.9
26	—0.1	—1.2	—2.4	—0.7	8.4	10.1	16.6	35.3
27	—0.6	—1.2	—0.1	0	10.8	13.3	18.6	34.3
28	—1.3	0	0	0	12.3	13.0	24.1	32.3
29	0.4	—1.3	—0.2	0.6	13.0	14.1	14.5	44.3
30	0.2	0.5	—0.4	1.7	11.4	13.6	12.4	28.1
66 07 01	0.4	—1.4	0	0.5	14.1	14.0	15.8	29.6
02	—1.5	—2.8	0	0.2	15.3	16.9	12.6	27.4
03	—0.4	—1.0	0	0	12.5	16.2	14.6	34.5
04	0.1	0.2	—0.2	0	12.7	16.2	9.4	27.2
05	2.2	4.6	0	0	14.5	15.9	10.1	23.0
06	2.3	5.4	—0.1	0	15.7	19.7	6.3	22.6
07	2.1	4.0	0.8	2.2	13.3	17.4	7.0	16.2
08	0.1	0.6	1.4	4.6	17.1	19.3	12.5	23.8
09	—1.6	—4.4	1.8	5.1	23.6	27.6	15.9	36.3

Table 8. ~ N-Component cm/s 1897—1908 at L/V Horns Rev (JACOBSEN 1913).

January	22.0	July	11.8
February	21.6	August	19.1
March	22.0	September	14.7
April	17.1	October	20.6
May	15.1	November	19.8
June	11.8	December	21.6

Table 9.
Monthly Means of Currents Measured SW of Smögen. N-Components at 50 m Depth

April 1971	17 cm/s	September 1967	14
June 1967	19	October 1967	29
July 1967	8	October 1971	37
August 1967	9		

Table 10.
North Sea Inflows and Outflows according to various authors

km³/year	Dooley 1974	Kalle 1949	Carruthers 1935	Cartwright 1961	Svansson and Lybeck, 1962
Inflow a) Orkney — Shetland	9,500	23,000			
b) Western Norwegian Trench	34,800				
c) Strait of Dover	18,500		2,000	7,400	
d) Baltic	500				
Outflow	63,300				16,000

Table 11.
Frequency (%) of salinities S ‰ measured once a day at L/V Fladen 1951—1960

S ‰	12.50—14.99	15.00—17.49	17.50—19.99	20.00—22.49	22.50—24.99	25.00—27.49	27.50—29.99	30.00—32.49	32.50—34.99	>35
0 m	0.8	8.0	21.6	28.8	24.6	11.1	3.3	1.7	0.1	
5 m		5.1	15.6	27.1	26.3	15.4	7.2	3.2	0.3	
10 m		0.2	4.4	13.3	23.3	20.2	17.8	16.2	4.5	
15 m			0.1	1.5	8.2	13.1	17.7	37.5	21.9	
20 m				0.04	1.3	3.8	10.6	38.6	45.6	
30 m						0.1	0.7	16.5	82.6	0.1
40 m							0.1	4.4	95.2	0.3

Table 12 a.

S ‰ Anholt Lightvessel

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
1880	23.3	21.3	22.8	17.2	18.7	18.1	17.6	17.6	17.8	23.4	26.3	27.8	21.0
1					18.7	18.3	18.0	20.7	17.9	18.1	20.9	22.5	(19.4)
2	25.3	24.2	24.0	16.9	18.5	17.9	15.8	17.3	16.5	15.4	25.3	23.5	20.1
3	24.8	25.9	25.8	23.2	20.8	21.2	19.2	20.0	19.9	20.5	23.3	25.0	22.5
4	24.5	22.9	16.7	16.8	19.3	20.7	17.7	16.9	17.5	23.7	26.0	25.7	20.7
5	20.8	20.2	24.5	20.3	19.5	21.8	20.2	20.1	21.9	21.9	18.9	23.9	21.2
6	25.0			20.0	19.7	19.3	24.2	22.2	19.8	20.2	19.4	27.6	(21.7)
7	22.6	22.6	22.7	22.1	21.3	21.8	23.0	23.2	21.0	23.6	21.8	24.0	22.5
8	22.7				19.8	18.9	18.4	20.7	19.9	22.5	21.9	24.4	(21.0)
9	21.2	23.9		18.5	13.5	15.6	18.9	21.7	20.5	19.6	19.5	22.0	(19.5)
1890	23.6	21.9	22.2	20.1	17.2	23.0	22.7	21.0	20.3	23.8	21.4	19.0	21.4
1		24.1	23.9	17.0	18.4	18.5	18.8	19.4	21.7	22.2	22.8	25.7	(21.1)
2	25.2	24.0	18.4	21.8	20.7	20.1	20.3	18.8	19.9	19.3	19.8	24.3	21.1
3				24.7	18.1	19.0	17.9	18.6	24.2	23.9	23.2	23.3	(21.4)
4	20.9	25.6	22.0	13.8	16.0	18.3	17.9	20.1	21.5	20.5	24.2	25.2	20.5
5	22.2			23.2	14.2	16.4	21.4	20.9	22.7	24.0	21.8	21.1	(20.8)
6	21.9	24.9	21.5	18.6	18.4	17.5	19.0	18.6	18.6	21.5	23.1	21.4	20.4
7	23.8	26.5	22.8	21.1	18.9	16.6	19.3	17.8	20.9	21.6	20.7	24.3	21.2
8	24.2	25.8	19.5	18.5	17.9	18.2	21.6	20.4	20.2	19.3	22.1	26.7	20.4
9	25.3	22.3	22.2	21.0	16.9	17.1	16.4	19.9	20.6	24.1	25.6	21.4	21.1
1900	16.9	21.0	23.7	19.8	21.4	16.5	18.5	18.5	20.5	24.2	20.5	22.0	20.3
1	20.5	21.6	18.6	19.6	17.3	19.1	18.5	19.5	20.1	21.2	25.0	25.3	20.5
2	25.9	20.2	16.6	17.5	17.7	18.0	23.4	23.4	20.6	18.0	20.2	20.5	20.2
3	24.5	27.4	22.4	19.6	14.5	14.3	18.7	21.8	20.3	18.9	20.2	18.9	20.1
4	17.2	20.7	18.7	21.3	22.7	21.4	22.8	22.5	18.5	18.5	23.5	24.6	21.0
5	25.5	26.3	16.1	17.2	18.1	15.9	20.8	20.9	20.6	19.5	17.8	23.3	20.2
6	22.8	22.6	22.4	17.2	14.3	15.1	17.6	18.8	19.0	19.1	21.2	26.6	19.7
7	24.5	22.3	23.6	18.8	17.6	17.2	19.2	21.9	21.9	15.1	15.6	21.0	19.9
8	26.4	29.5	18.5	15.4	19.5	18.7	18.4	20.6	22.5	19.1	20.5	25.6	21.2
9	23.9	24.0	(18.3)	19.4	20.6	21.8	22.0	23.9	19.2	16.7	21.4	23.9	(21.3)
1910	25.5	23.2	18.9	17.4	16.9	15.6	17.1	17.4	19.3	21.7	22.9	22.1	19.8

Table 12 b.
S ‰ Anholt Lightvessel

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
1911	25.8	25.5	23.0	18.4	15.6	14.1	18.7	16.0	22.7	20.6	25.0	19.9	20.4
2	21.2	21.6	21.3	21.4	19.2	19.3	14.8	17.2	20.7	20.5	22.8	25.9	20.5
3	22.9	22.0	24.2	20.7	15.6	19.0	19.4	19.2	14.9	17.7	23.6	28.8	20.6
4	23.2	23.0	20.5	18.0	19.6	17.3	16.5	19.0	20.8	22.9	21.8	25.2	24.9
5	24.2	22.7	23.3	24.2	21.6	20.4	20.0	20.2	20.7	16.9	20.3	23.9	21.5
6	25.9	24.1	16.1	17.6	17.4	18.0	18.8	20.1	19.9	22.3	21.2	21.2	20.2
7	20.5	(19.9)	(20.3)	22.7	19.6	16.2	18.0	17.0	22.4	25.7	25.3	25.3	(21.1)
8	22.9	19.3	17.1	16.0	15.4	25.5	23.1	21.6	24.0	22.1	19.3	21.1	20.6
9	22.8	19.3	20.4	21.9	17.9	20.7	19.9	23.3	23.2	23.8	19.1	23.3	21.3
1920	26.5	25.0	24.2	17.5	18.8	17.7	17.3	19.8	20.2	17.9	22.5	21.1	20.7
1	26.3	24.9	23.4	21.4	17.7	21.9	22.7	23.1	22.9	24.5	23.2	21.9	22.8
2	24.4		21.7	18.2	19.2	20.5	19.8	20.4	17.8	18.7	23.9	26.0	(21.0)
3	23.4	(22.2)	14.9	17.3	22.2	23.7	20.8	21.9	22.3	22.6	24.1	19.7	(21.3)
4	(17.3)		(20.5)	20.4	17.0	(18.0)	19.5	17.3	19.7	20.5	20.9	21.7	(19.4)
5	25.0	24.3	19.3	17.8	15.9	19.9	18.0	18.3	23.4	23.4	21.6	22.9	20.8
6	21.2	18.9	20.3	17.0	15.9	15.3	16.5	21.3	23.8	21.9	21.2	21.9	19.6
7	23.3	19.6	17.8	22.4	22.0	19.4	14.9	14.8	17.9	22.7	21.4	18.2	19.5
8	21.3	23.3	16.8	18.5	17.9	23.3	24.2	22.8	19.8	19.8	20.7	22.0	19.2
9	20.4	(19.0)	(22.0)	21.4	17.8	20.1	21.2	20.9	21.2	23.3	23.0	22.4	(21.1)
1930	23.1	19.9	19.2	17.9	17.4	18.5	21.2	21.8	19.7	24.0	28.1	20.1	20.9
1	21.6	19.5	22.2	21.2	16.2	17.7	19.6	18.5	19.9	22.4	20.6	21.8	20.1
2	26.2	23.8	19.2	18.3	16.8	17.2	18.5	18.9	20.1	22.0	20.0	25.1	20.5
3	20.8	23.1	17.3	20.7	15.6	14.5	19.9	23.2	19.6	20.2	21.1	20.8	19.7
4	23.6	27.2	23.3	15.3	18.0	18.6	20.7	20.9	19.5	23.3	22.6	19.2	21.0
5	21.4	27.4	20.4	19.0	16.3	16.9	20.7	20.1	19.6	23.9	20.4	19.1	20.4
6	21.4	21.1	19.1	20.6	16.4	16.8	18.0	19.9	19.7	21.9	24.8	25.4	20.5
7	23.6	20.1	20.9	18.0	16.3	19.3	19.7	17.8	21.3	19.5	20.8	21.3	19.9
8	23.3	22.8	25.5	24.1	18.6	18.3	18.2	15.3	18.7	21.1	23.6	23.1	21.1
9	22.4	25.7	20.9	19.7	17.8	21.3	20.2	19.0	17.0	20.5	24.9	28.2	21.5
1940	28.3			20.5	19.7	17.8	19.5	21.1	26.8	21.0	22.2	23.8	(22.4)
1	21.3		25.0	20.5	19.7	17.8	19.5	21.1	23.3	20.5	20.7	23.1	(21.1)

Table 12 c.
S ‰ Anholt Lightvessel

Year	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
1942	(25.2)			(21.5)	21.4	21.4	22.9	20.1	20.0	24.2	23.2	25.0	(22.5)
3	21.0	24.8	23.2	22.5	20.8	18.1	19.2	21.0	18.6	21.0	19.7	23.5	21.1
4	28.5	25.0	19.4	18.2	19.2	18.3	16.6	17.6	20.8	21.9	23.5	23.6	21.1
5	23.9	23.2	24.8	21.9					17.2	20.3	20.3	23.3	(21.9)
6	23.2	22.4	17.2	19.3	12.8	16.3	17.8	19.6	19.3	19.0	20.3	22.2	19.1
7	22.0			25.8	16.7	18.0	22.0	18.8	20.6	24.9	22.1	22.4	21.3
8	22.4	18.8	20.7	19.5	17.3	18.2	18.2	19.2	23.4	26.6	24.8	24.1	21.1
9	26.2	26.0	22.4	19.9	19.1	18.6	18.1	22.1	16.7	21.7	23.9	26.5	21.8
1950	24.3	21.5	23.3	21.7	16.8	20.3	20.5	19.0	22.6	25.9	23.2	22.2	21.8
1	20.9	20.2	21.7	23.9	19.2	18.7	21.5	20.2	20.0	18.2	22.9	31.1	21.5
2	28.7	24.7	22.0	19.5	18.8	23.7	21.6	19.4	22.5	21.6	19.3	20.7	21.9
3	20.6	25.2	23.0	20.3	16.5	16.8	17.3	21.2	22.3	19.8	20.8	21.9	20.5
4	25.0	(22.0)	18.9	22.8	19.8	18.0	22.0	21.8	22.4	23.9	24.0	22.7	(21.9)
5	23.3	21.8	(19.1)	19.7	20.8	17.7	17.9	17.8	19.9	23.2	23.8	25.8	(22.4)
6	25.3	(20.6)	(16.0)	18.7	18.2	17.1	19.2	22.0	21.4	21.5	22.2	24.8	(20.6)
7	22.3	22.6	18.9	20.9	20.3	19.5	19.8	20.6	21.6	23.6	21.9	22.1	21.2
8	23.0	22.4	(20.7)	16.1	19.3	15.9	18.1	19.8	16.9	21.3	21.5	23.1	(19.8)
9	23.8	21.9	19.3	17.7	16.6	20.0	20.0	20.0	23.9	22.5	22.1	22.6	20.9
1960	26.6	25.8	23.6	22.9	23.0	23.8	22.7	20.3	20.2	17.7	21.8	24.5	22.7
1	21.5	21.8	24.4	20.7	18.3	20.0	21.6	21.1	18.9	18.2	22.2	24.1	21.1
2	24.6	26.2	18.7	17.8	17.9	19.1	19.9	20.7	23.2	18.7	20.3	23.5	20.9
3	(20.5)			18.5	18.2	18.1	20.9	20.1	19.8	25.2	23.4	22.1	(20.7)
4	22.9	24.0	16.1	17.2	19.0	18.6	22.3	22.5	23.2	22.3	23.6	24.9	21.4
5	24.2	24.0	20.5	19.5	18.0	19.2	24.6	22.2	20.7	21.0	24.2	23.0	21.8
6	21.4	(19.5)	23.2	20.5	16.4	18.0	20.6	20.1	23.8	19.9	18.6	24.2	(20.5)
7	24.9	22.6	24.5	22.0	16.9	16.5	18.5	18.0	18.7	21.6	24.3	23.8	21.0
8	22.0	21.8	21.0	21.1	16.3	15.4	19.0	17.7	16.8	22.0	21.8	21.6	19.7
9	20.8	21.0	21.9	23.0	19.1	19.0	23.0	17.1	23.8	25.3	28.9	22.7	22.1
1970	19.9		22.1	21.8	19.2	19.8	20.4	19.4	20.5	22.1	24.9	21.8	21.1
1	20.1	20.5	21.6	18.7	18.6	19.8	24.7	20.8	20.9	24.2	26.8	26.3	21.9
2	19.3	18.7	20.4	21.8	18.3	19.2	19.7	20.0	20.8	22.3	26.1	27.2	21.2

Table 13.
Maxima and Minima of Temperatures

	in the Jutland Current				in the Middle				in the Outgoing Current			
	Min.		Max.		Min.		Max.		Min.		Max.	
Depth m	t°	Month	t°	Month	t°	Month	t°	Month	t°	Month	t°	Month
7.5	3.5	II	16	VIII	4	II	15	VIII	2	II	16	VIII
20	4	III	15	VIII	5	III	11	X	2.5	III	15.5	IX
30	5	III	13	VIII	5	III	10.5	X	4	II	14	IX
40					5.5	III—IV	9	X—XI	4.5	III	13	IX—X
60					5.5	IV	8.5	XI	5	III	10	X
80					6	IV	8	XII	5	III	9.5	X
100					6	IV—V	7.5	XI	5.5	III—IV	8.5	X

Table 14.
Fladen 50 m Percentage of Oxygen Saturation

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1966					91			63	68	77		
1967		93			93							89
1968		95				87			67		65	
1969	91			81					73		98	
1970	90			98	92	89	90	69	71	85	96	
1971	93		93	95			73	82		90	92	
1972		93	89	82	95	92	78	78	68	65		91
1973	96	98	94	90	88	84		76	67	83	92	
Mean value	93	95	92	89	92	88	80	74	69	80	87	90

Table 15. Decade Mean Values 1965—1971 (μgat/l everywhere except O_2 %).

Kullen (N 56°14′ E 12°22.2′)

	PO_4 I	PO_4 II	PO_4 III	PO_4 IV	PO_4 I—IV	Tot. P I	Tot. P II	Tot. P III	Tot. P IV	Tot. P I—IV	O_2 % I	O_2 % II	O_2 % III	O_2 % IV	O_2 % I—IV	NO_3 I—IV	SiO_2 I—IV
0 m	0.64	0.12	0.18	0.43	0.32	0.95	0.52	0.49	0.78	0.66	100	107	103	98	102	0.80	6.1
5	0.64	0.14	0.19	0.44	0.33	0.90	0.48	0,51	0.90	0.68	98	107	104	100	103	0.73	7.0
10	0.69	0.16	0.17	0.53	0.36	0.93	0.64	0.48	0.64	0.61	89	100	99	85	94	1.04	5.8
15	0.78	0.68	0.33	0.54	0.57	1.01	0.95	0.48	0.71	0.74	85	81	81	80	82	2.92	9.6
20	0.80	0.75	0.71	0.67	0.73	1.07	1.09	0.99	0.93	1.01	86	76	64	71	73	4.57	14.9

Fladen (N 57°11.5′ E 11°40′)

	PO_4 I	PO_4 II	PO_4 III	PO_4 IV	PO_4 I—IV	Tot. P I	Tot. P II	Tot. P III	Tot. P IV	Tot. P I—IV	O_2 % I	O_2 % II	O_2 % III	O_2 % IV	O_2 % I—IV	NO_3 I—IV	SiO_2 I—IV
0 m	0.55	0.09	0.07	0.29	0.23	0.77	0.35	0.40	0.50	0.50	101	106	102	99	102	1.00	4.1
5	0.54	0.09	0.07	0.29	0.24	0.73	0.35	0.31	0.61	0.49	101	107	105	100	103	0.68	4.4
10	0.55	0.10	0.06	0.34	0.25	0.75	0.48	0.30	0.52	0.51	100	106	102	95	100	1.25	3.7
15	0.61	0.31	0.10	0.39	0.34	0.77	0.61	0.31	0.49	0.53	98	99	99	95	97	2.31	4.7
20	0.60	0.40	0.17	0.42	0.38	0.77	0.56	0.32	0.52	0.54	98	99	91	95	95	2.77	4.9
30	0.62	0.51	0.30	0.47	0.46	0.80	0.72	0.52	0.57	0.65	94	96	85	91	91	3.75	7.7
40	0.68	0.59	0.54	0.52	0.57	0.79	0.82	0.70	0.64	0.73	94	93	75	93	88	4.33	8.9
50	0.69	0.71	0.64	0.55	0.64	0.86	0.93	0.77	0.63	0.79	93	90	71	88	85	4.36	10.2
75	0.73	0.79	0.83	0.58	0.73	0.90	0.97	0.89	0.70	0.85	92	90	65	87	83	4.73	10.6

Table 16.

	Dry Weather Flow m^3/day	Population	BOD tonnes/year	N tonnes/year	P tonnes/year
Skagerrak	756,000	1,687,000	40,060	8,150	1,710
Kattegat (Sweden only)	427,000	1,094,000	82,420	15,165	1,545

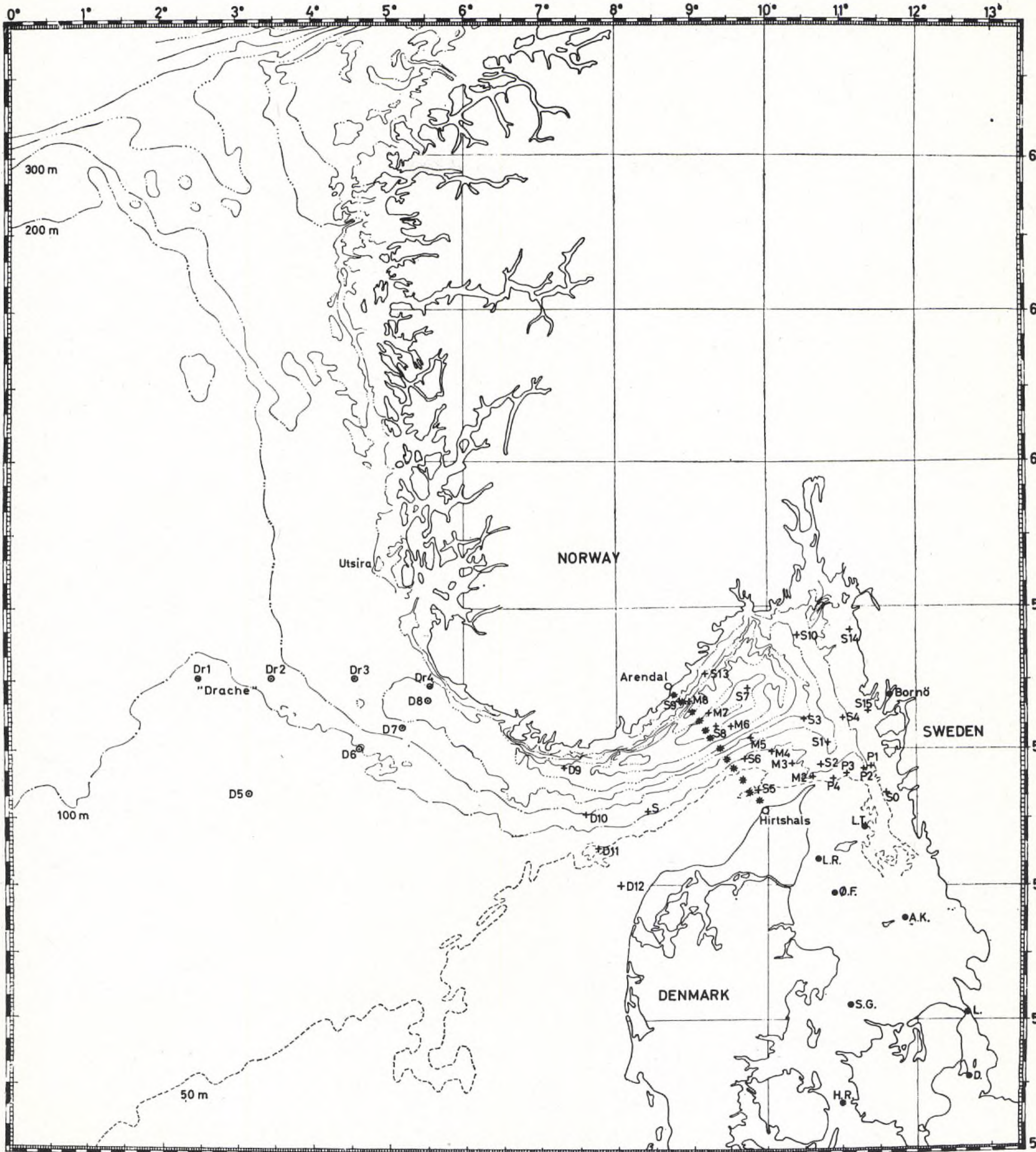
Table 17.
Primary Production at L/V Anholt Nord 1964—1967, 1969

g C/m² and month

I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Σ g C/m² and year
1	4	9	4	6	8	7	9	7	9	4	2	71

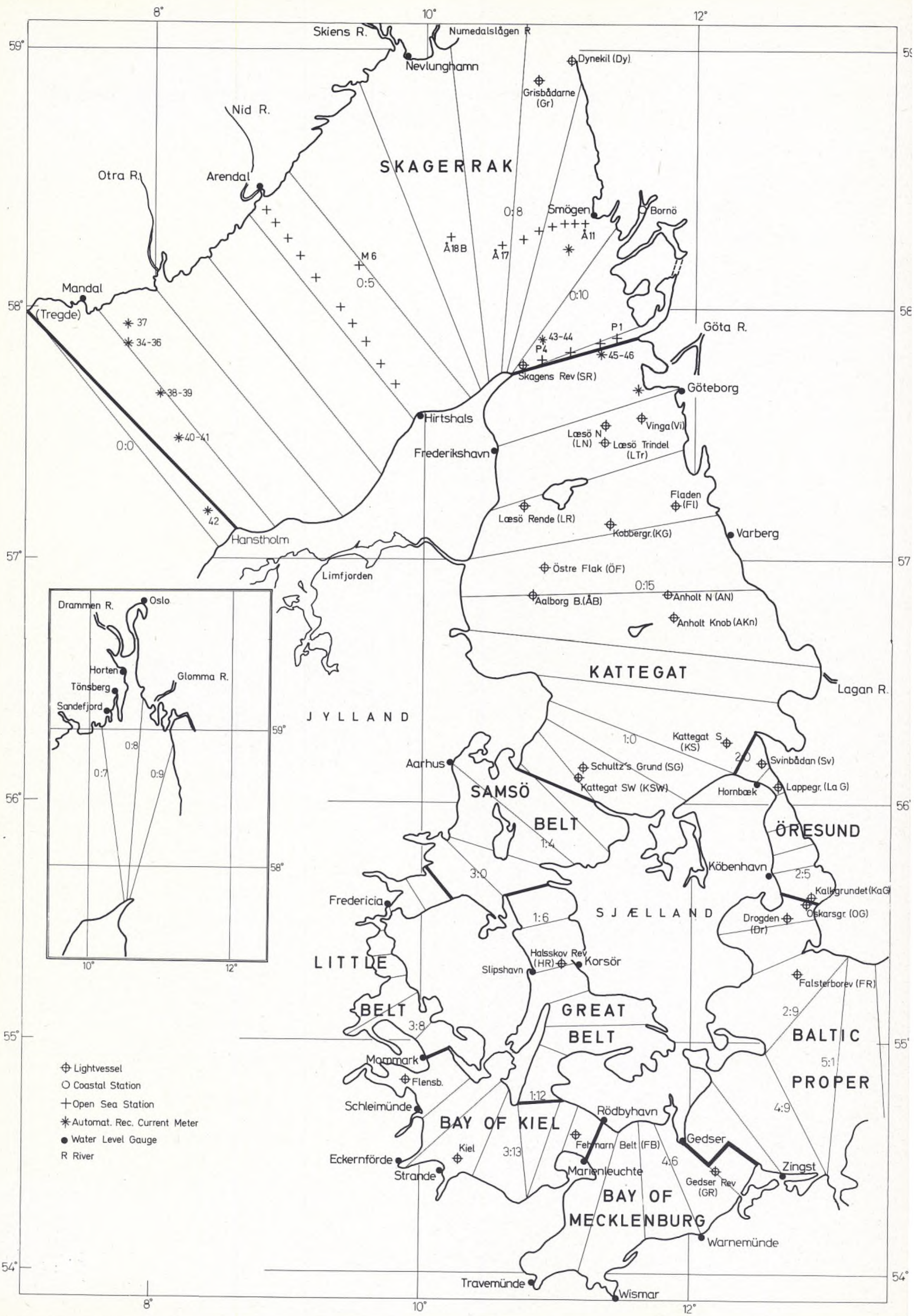
Table 18.
Primary Production (g C/m² and year) determined by the C 14-Method
(STEEMANN NIELSEN 1971)

Year	Halsskov Rev	Fladen	Anholt Nord	Aalborg Bugt	Läsö Rende
1953	80				
1954	82		110		
1955	88		80		
1956	80		70		
1957			105		
1958			90		
1959			100		
1960			120		
1961					
1962					
1963					
1964			65		121
1965			57		
1966			51		
1967	94	77	85	70	
1968	134				
1969	101		95	86	
1970					



From Svansson (1965)

Fig. 1. Chart for the Norwegian Channel and surroundings showing hydrographic stations.



8°
10°
12°
59°
58°
57°
56°
55°
54°
Skiens R.
Numedalslågen R
Nevlunghamn
Dynekil (Dy)
Grisbådarne (Gr)
Nid R.
Otra R.
Arendal
SKAGERRAK
0:8
Smögen
Bornö
Å11
Å18 B
Å17
M 6
0:5
0:10
Mandal
(Tregde)
37
34-36
43-44
P1
P4
45-46
Göta R.
Skagens Rev (SR)
Göteborg
38-39
Hirtshals
Vinga (Vi)
Læsö N (LN)
Læsö Trindel (LTr)
40-41
0:0
Frederikshavn
Fladen (Fl)
Læsö Rende (LR)
42
Kobbergr. (KG)
Varberg
Hanstholm
Limfjorden
Östre Flak (ÖF)
0:15
Aalborg B. (ÅB)
Anholt N (AN)
Anholt Knob (AKn)
Drammen R.
Oslo
Horten
Glomma R.
Tönsberg
Sandefjord
0:8
0:7
0:9
KATTEGAT
Lagan R.
JYLLAND
1:0
Kattegat S (KS)
2:0
Svinbådan (Sv)
Aarhus
Schultz's Grund (SG)
Kattegat SW (KSW)
Hornbæk
Lappegr. (La G)
SAMSÖ
BELT
ÖRESUND
1:4
København
2:5
3:0
Kalkgrundet (KaG)
Oskarsgr. (OG)
Fredericia
SJÆLLAND
Drogden (Dr)
1:6
LITTLE
Halsskov Rev (HR)
Korsör
Slipshavn
Falsterborev (FR)
BELT
3:8
GREAT
BELT
2:9
BALTIC
PROPER
5:1
Mommark
Flensb.
1:12
4:9
Schleimünde
Rödbyhavn
BAY OF KIEL
Gedser
Kiel
3:13
Fehmarn Belt (FB)
4:6
Eckernförde
Marienleuchte
Zingst
Strande
Gedser Rev (GR)
BAY OF
MECKLENBURG
Warnemünde
Travemünde
Wismar
Lightvessel
Coastal Station
Open Sea Station
Automat. Rec. Current Meter
Water Level Gauge
R River

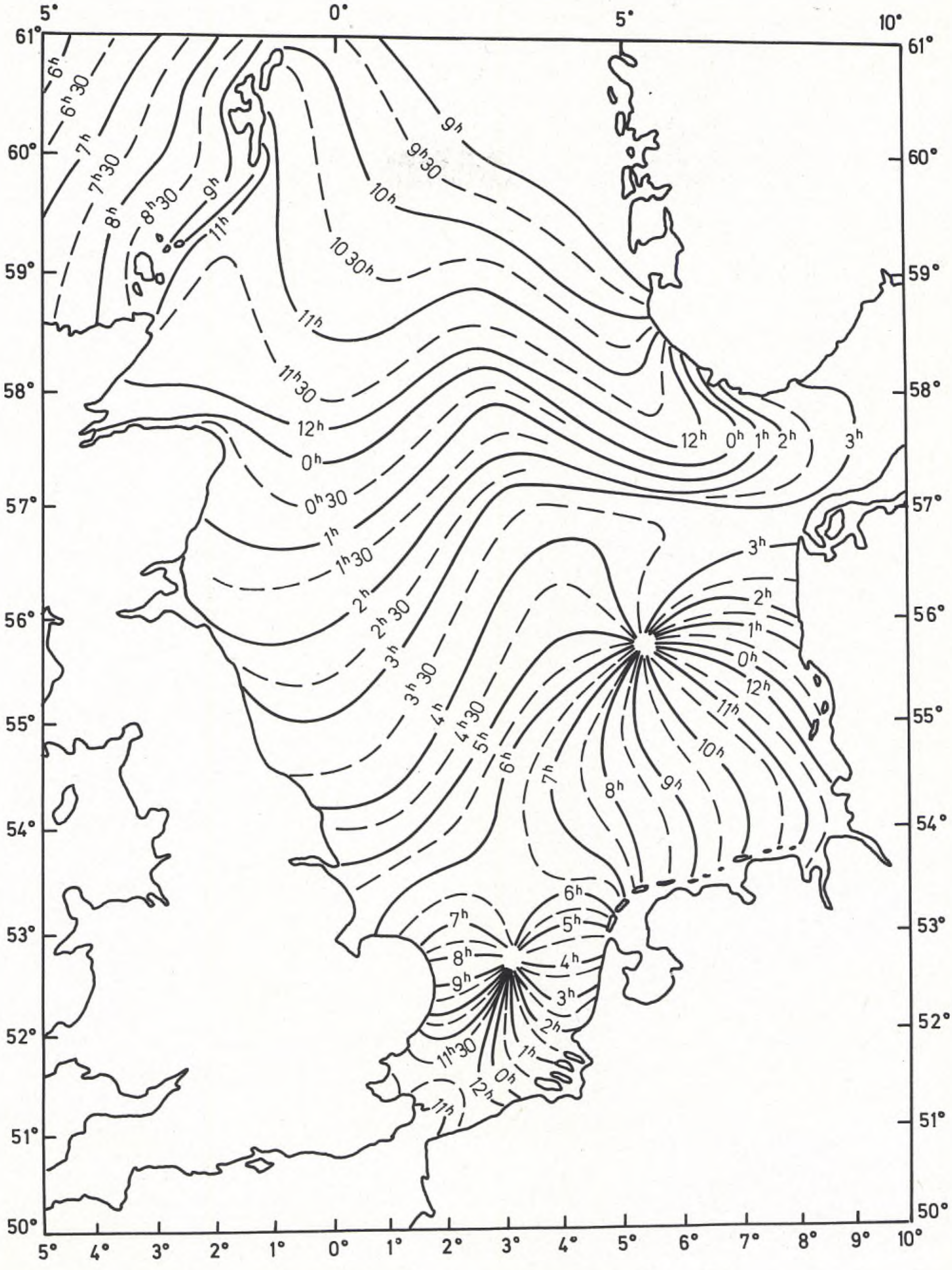


Fig. 3. Lines of the same time interval between upper culmination of the moon in Greenwich (solar hours) and high water. (Reproduced from DEFANT [1961].)

Fig. 2. Map of the Skagerrak, the Kattegat and the Belt Sea. The original purpose of the sectioning was for model work. N.B. The Danish lightvessels Laesö Trindel, Anholt Knob and Schultz's Grund were 1945 replaced by Laesö Nord, Anholt Nord and Kattegat SW respectively. The Danish lightvessel Östre Flak was 1943 replaced by Aalborg Bugt.

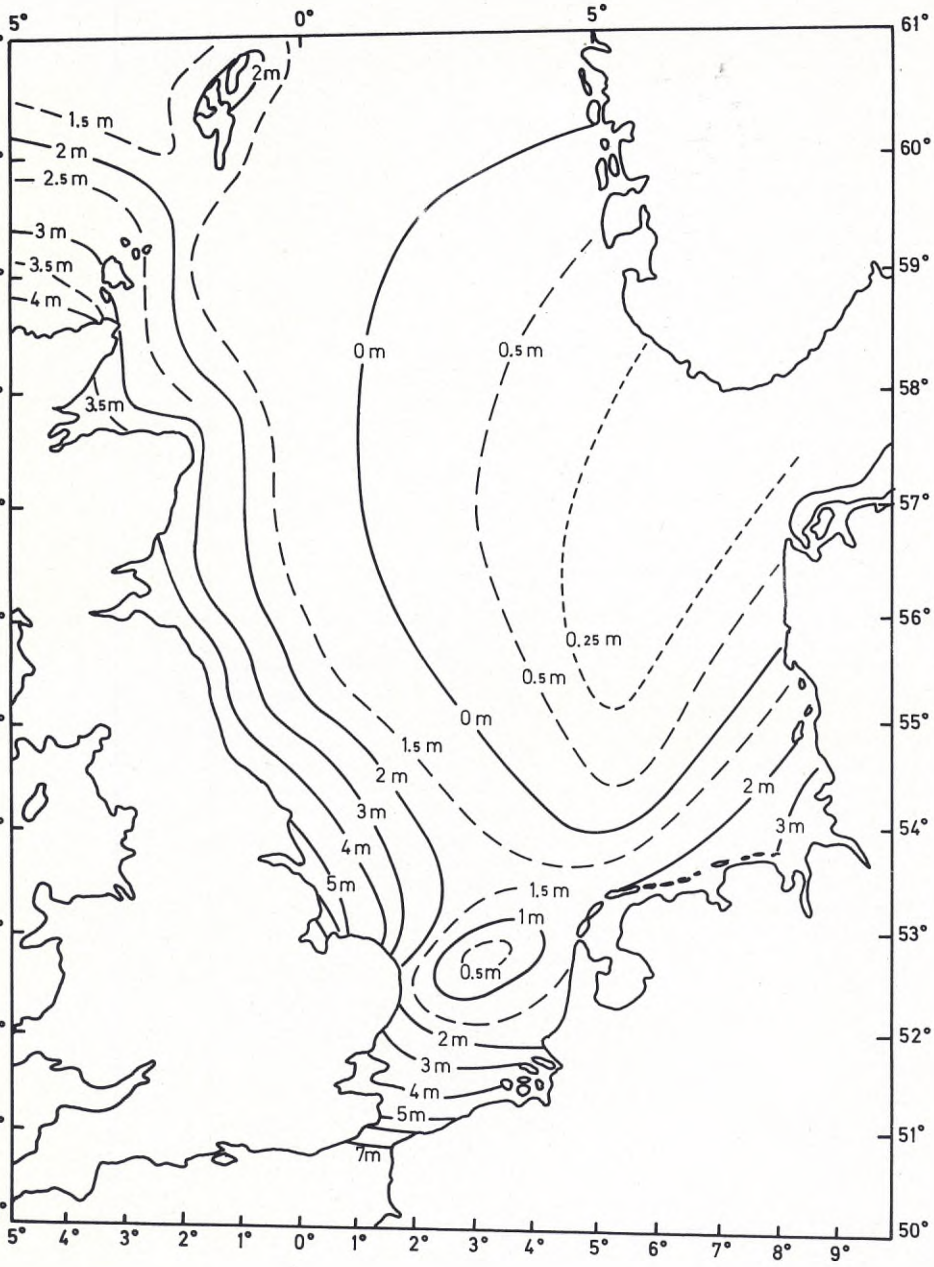


Fig. 4. Lines connecting the same average spring tide range in the North Sea. (Reproduced from DEFANT [1961].)

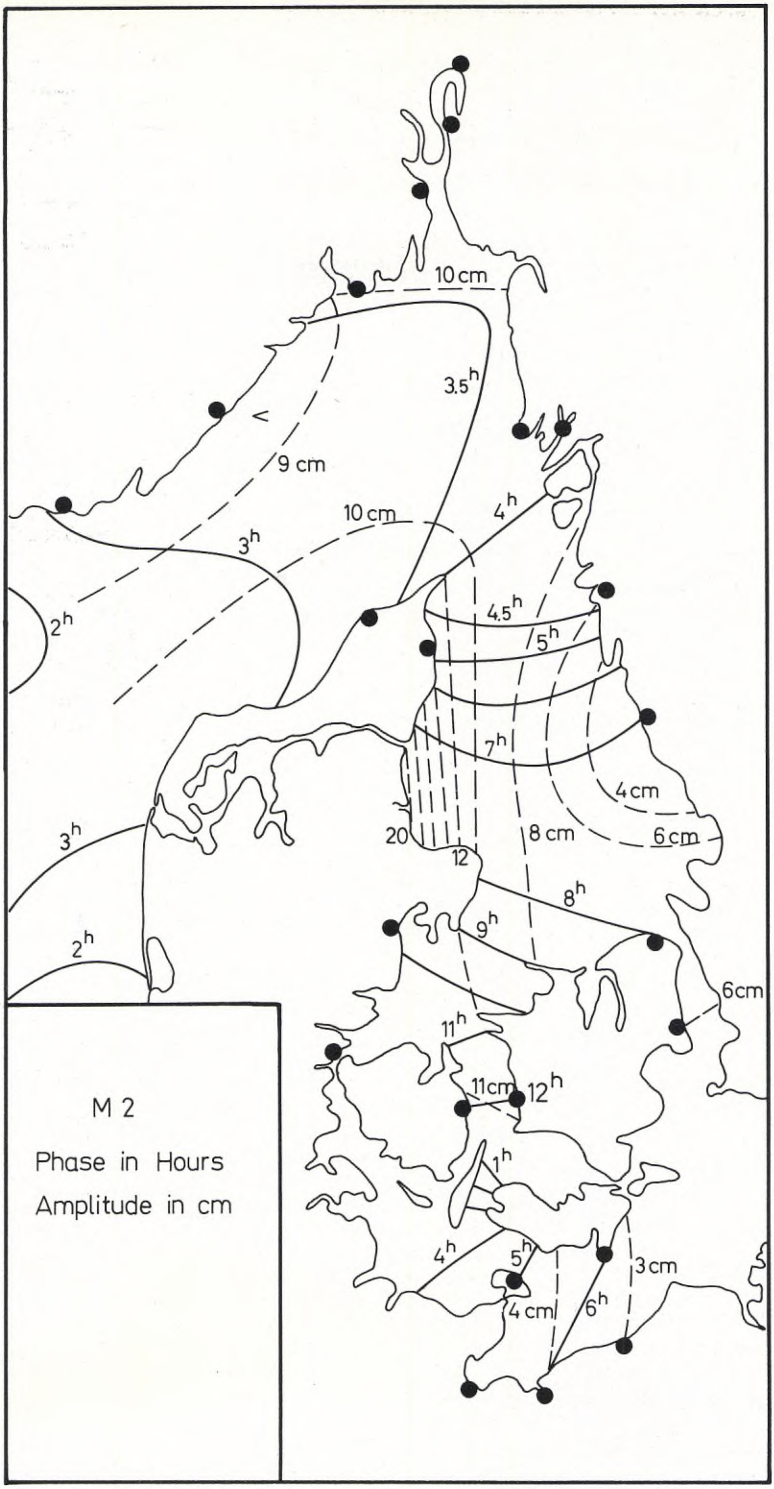


Fig. 5. Phases and amplitudes of the tidal component M2 (12.42 hours). No isolines have been constructed in W. Baltic due to lack of observations. Sea level gauges are indicated by filled circles.

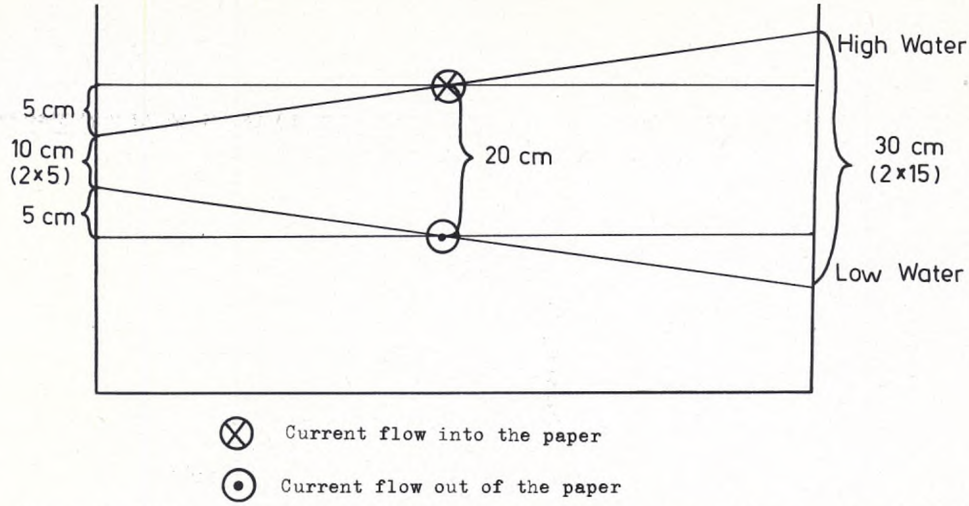


Fig. 6. The different effect on opposite sides of a canal of a progressive tidal (Kelvin) wave.

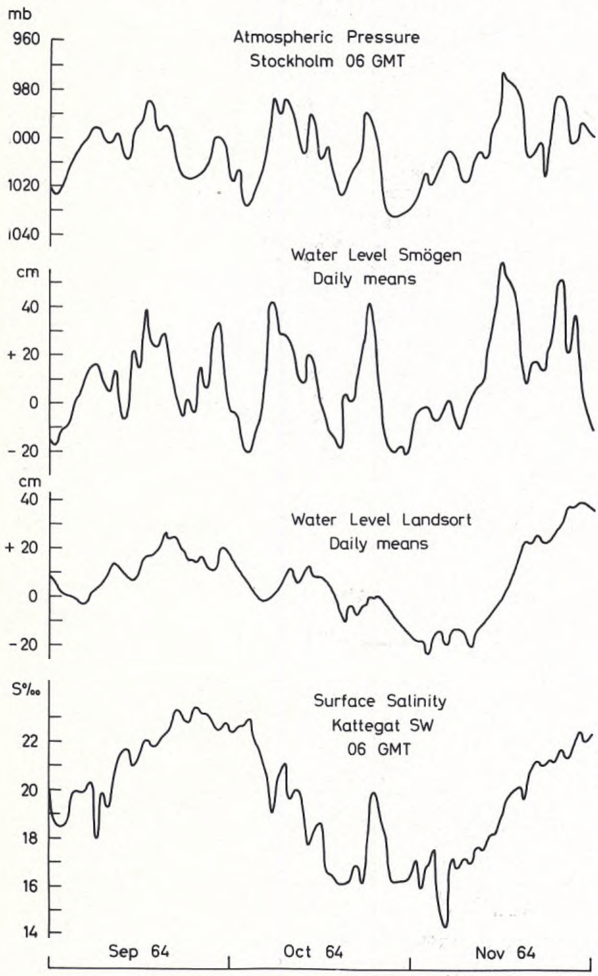


Fig. 7.

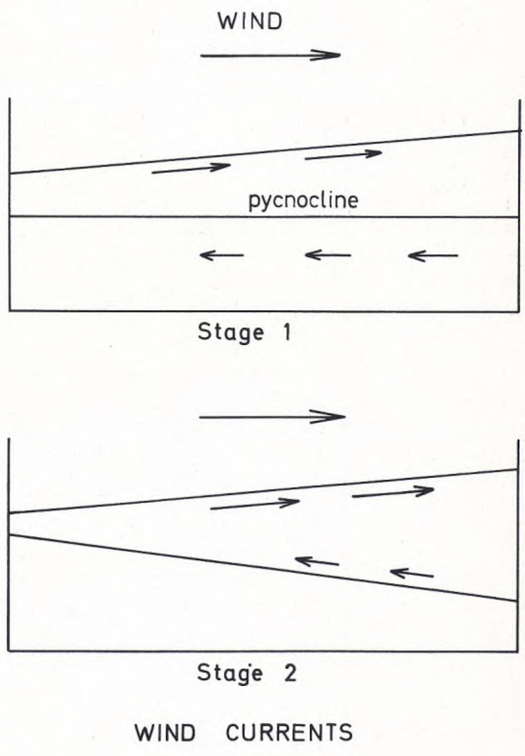


Fig. 8. The development of windinduced circulation in a two layered closed channel.

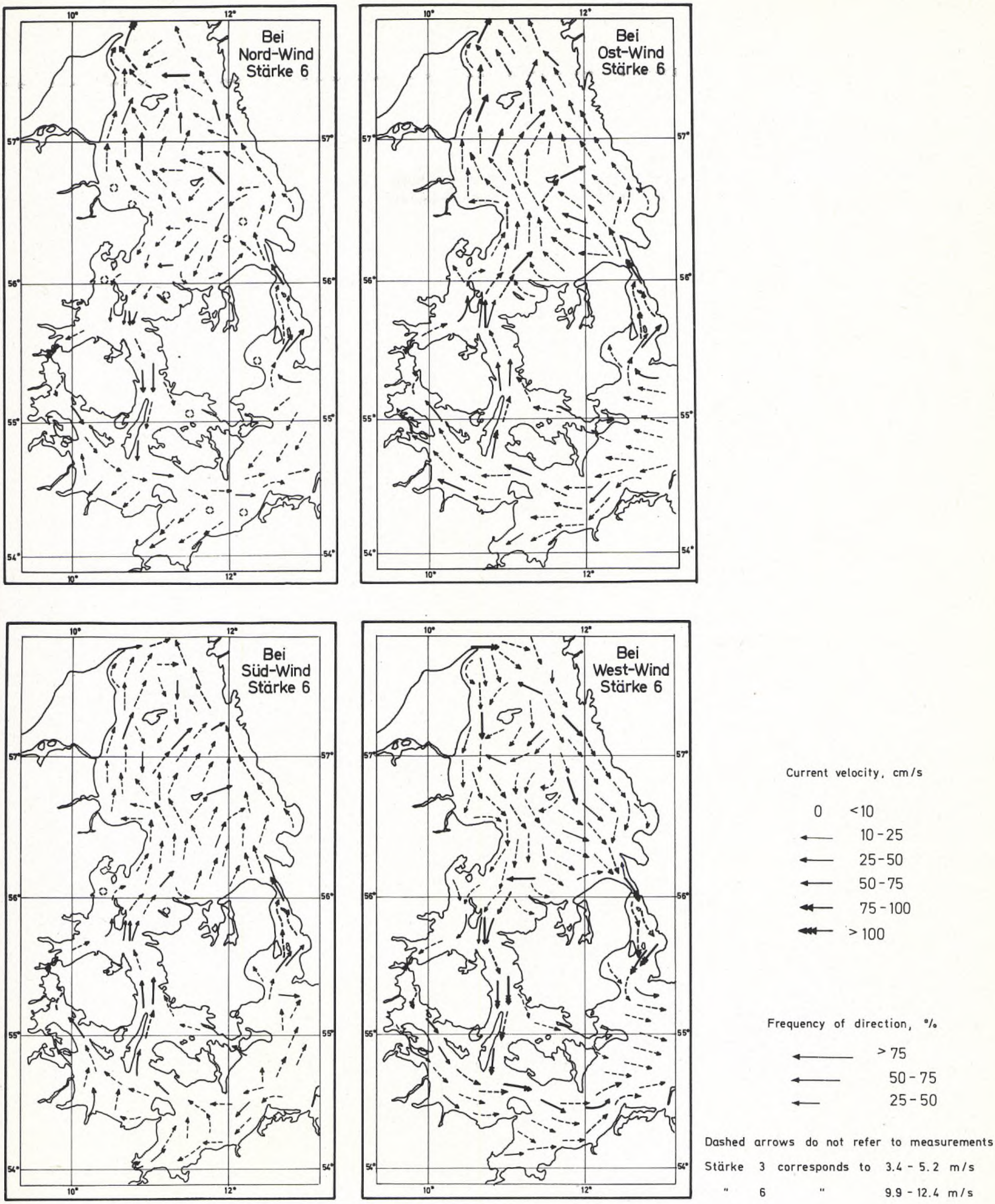
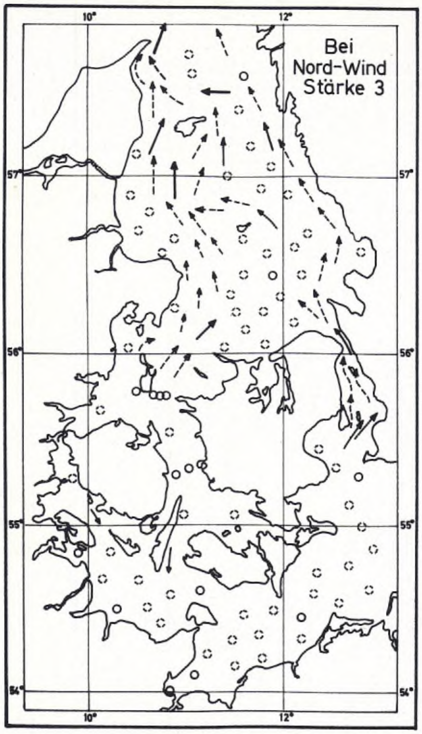
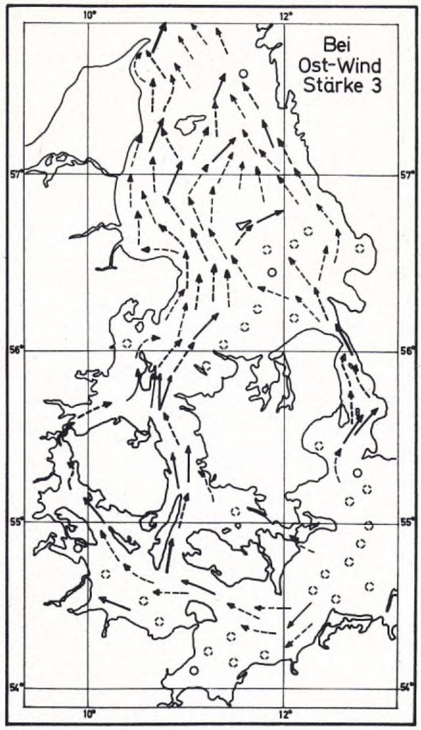
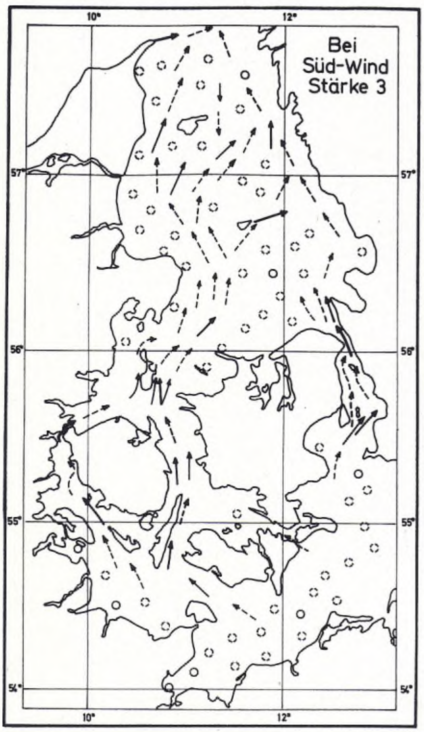
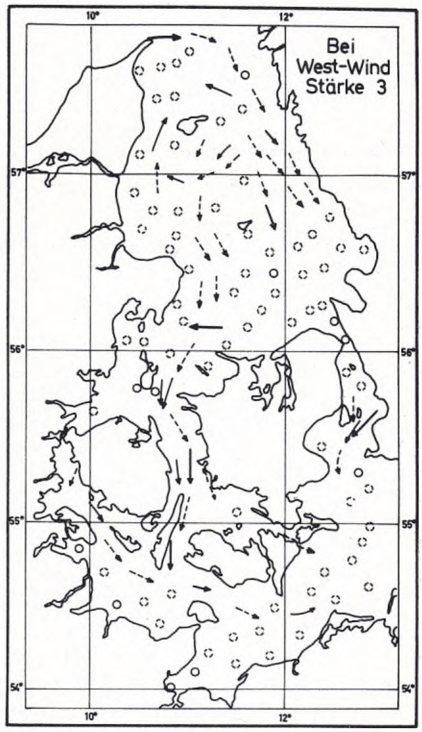


Fig. 9—12. Charts of surface currents at various wind conditions. Current observations made aboard 18 lightvessels in 1937 and at further 22 stations in other years provide the basic material. (Reproduced from DIETRICH [1951].)


Bei
Nord-Wind
Stärke 3
10°
12°
57°
56°
55°
54°


Bei
Ost-Wind
Stärke 3
10°
12°
57°
56°
55°
54°


Bei
Süd-Wind
Stärke 3
10°
12°
57°
56°
55°
54°


Bei
West-Wind
Stärke 3
10°
12°
57°
56°
55°
54°

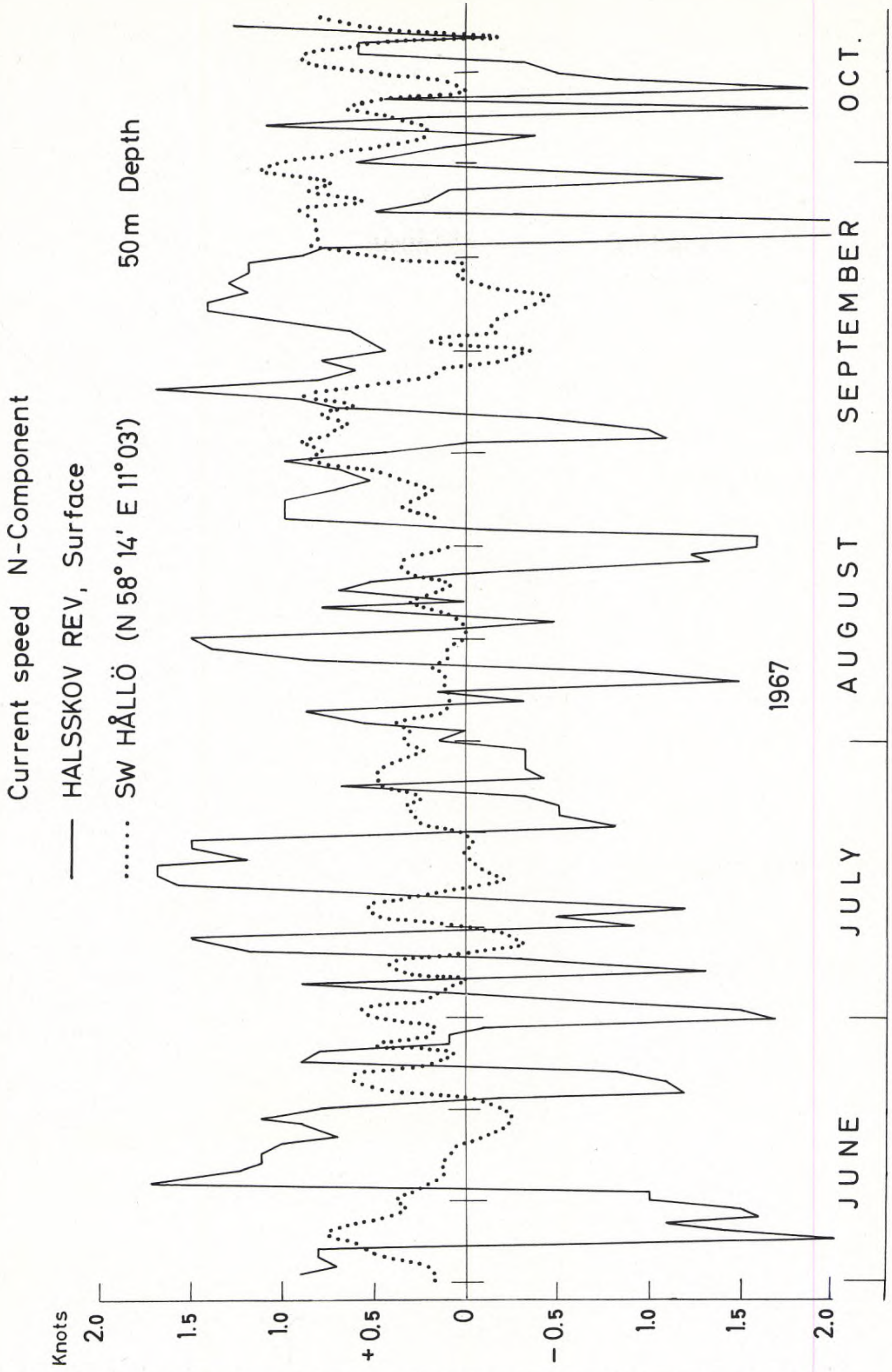


Fig. 13. Daily means of currents measured SW Smögen every 20th minute and at lightvessel Halsskov Rev 8 times a day.

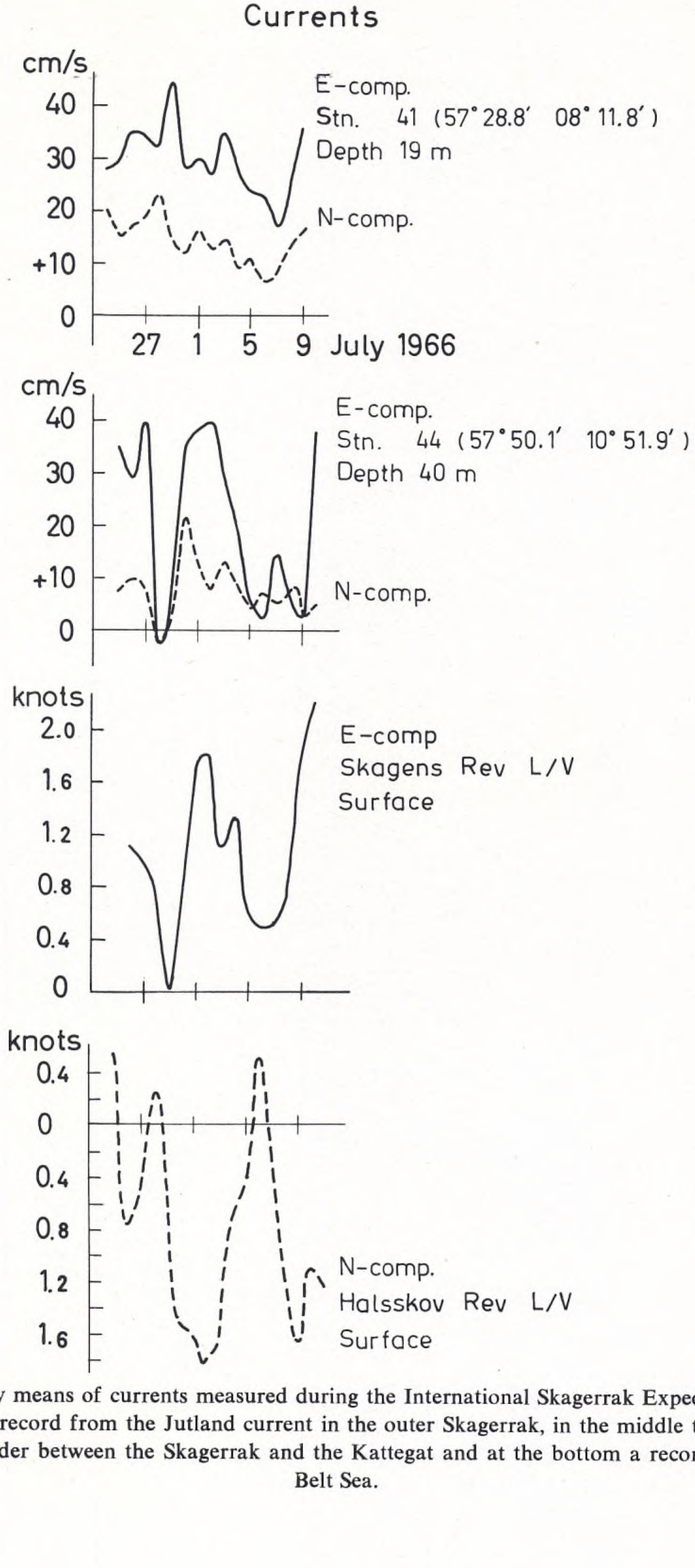


Fig. 14. Daily means of currents measured during the International Skagerrak Expedition 1966. At the top a record from the Jutland current in the outer Skagerrak, in the middle two records from the border between the Skagerrak and the Kattegat and at the bottom a record from the Belt Sea.

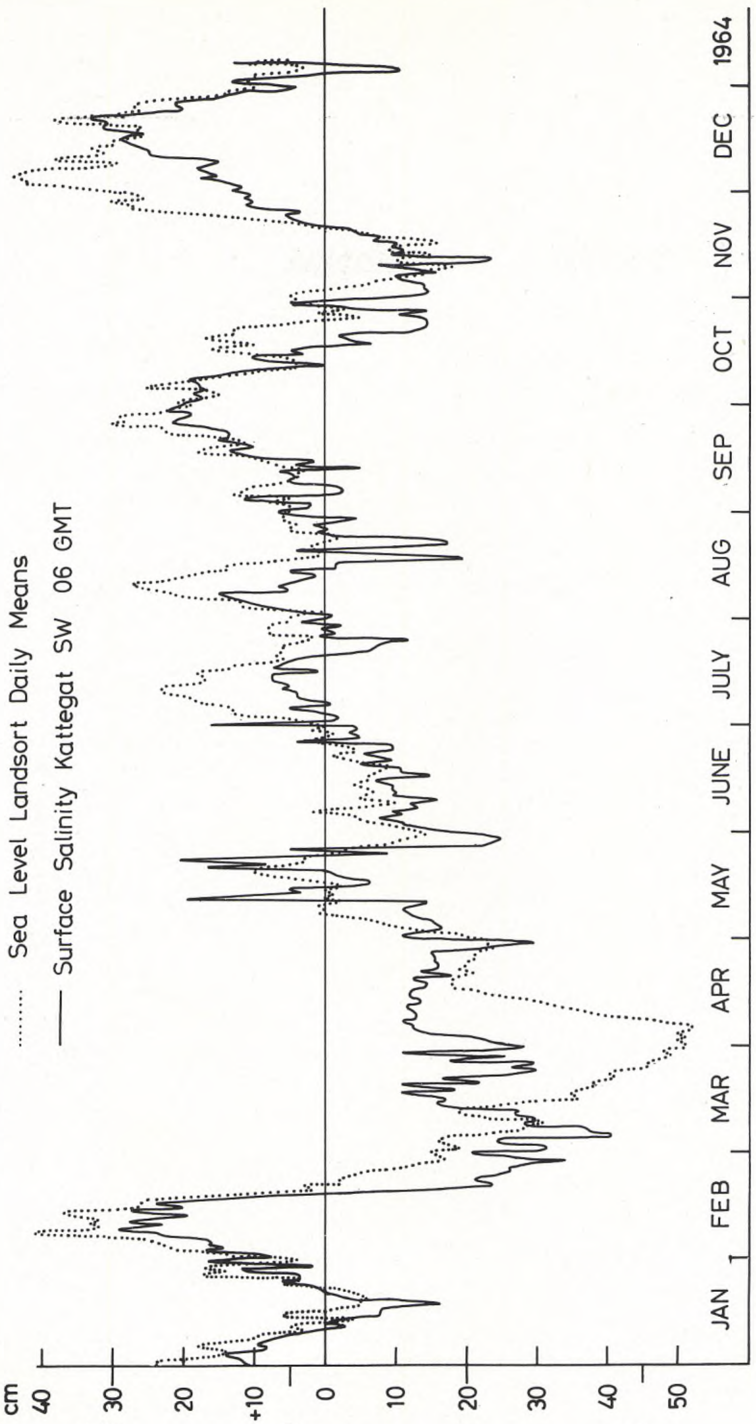


Fig. 15. A comparison between the variations during one year (1964) of the daily means of hourly readings of the sea levels at Landsort and of the surface salinities measured once a day at the L/V Kattegat SW.

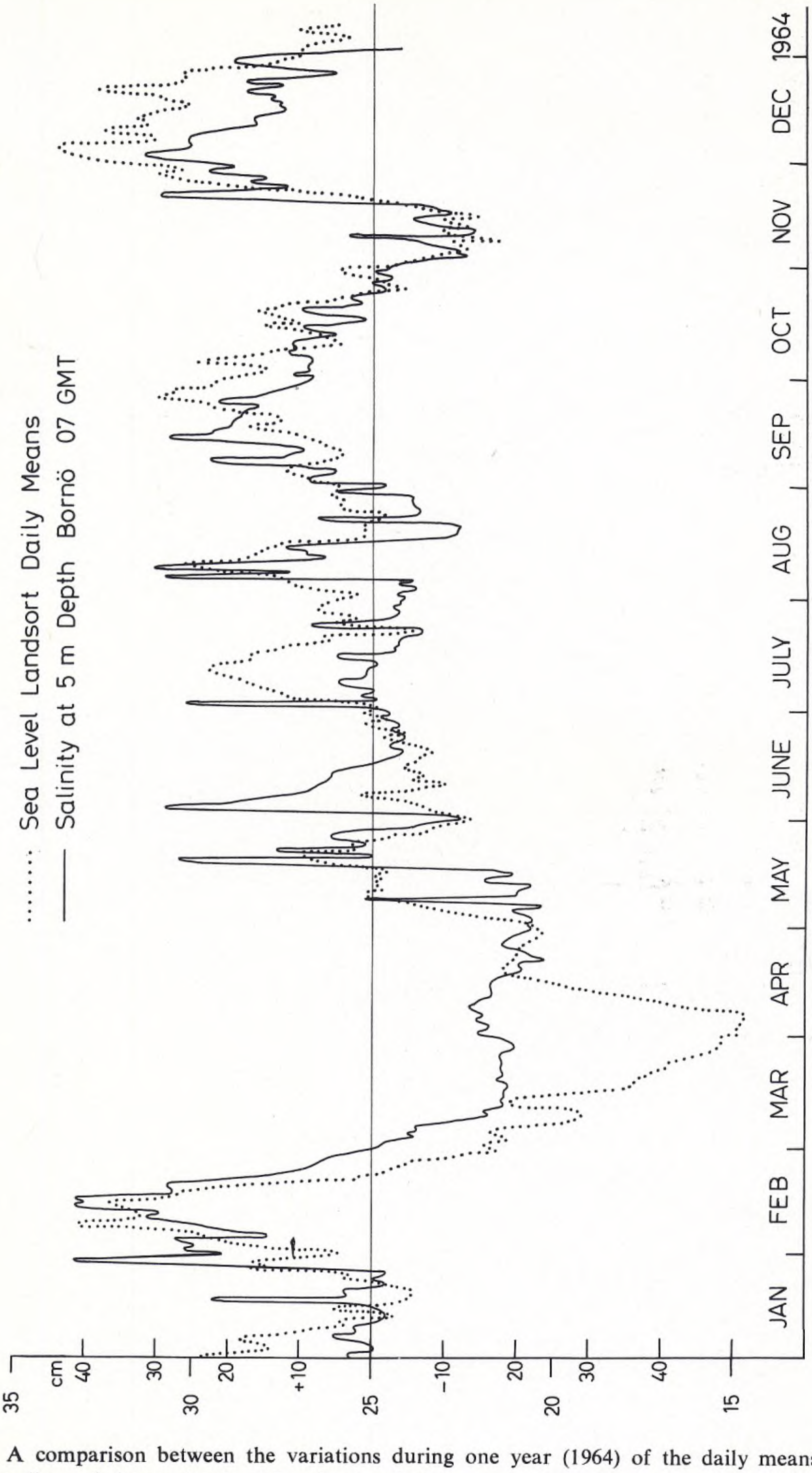


Fig. 16. A comparison between the variations during one year (1964) of the daily means of hourly readings of the sea levels at Landsort and of the surface salinities measured once a day at Bornö Hydrographical Station.

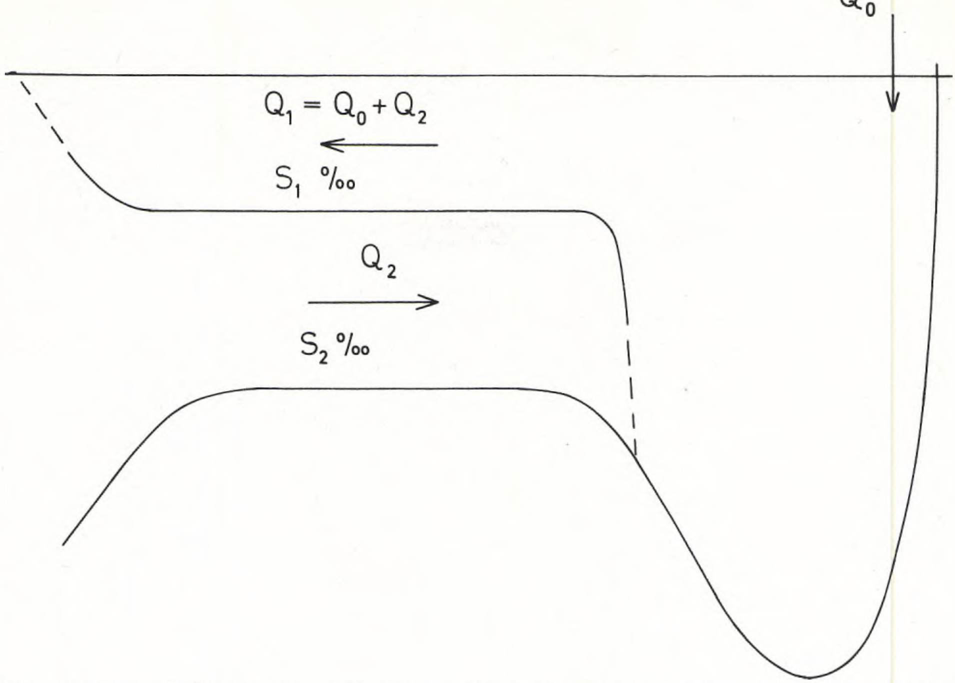


Fig. 17. Schematic figure of an enclosed sea with the fresh water discharge Q_0 and the salinity S_1 ‰ connected through a strait with an ocean of the salinity S_2. The compensation transport is designated Q_2.

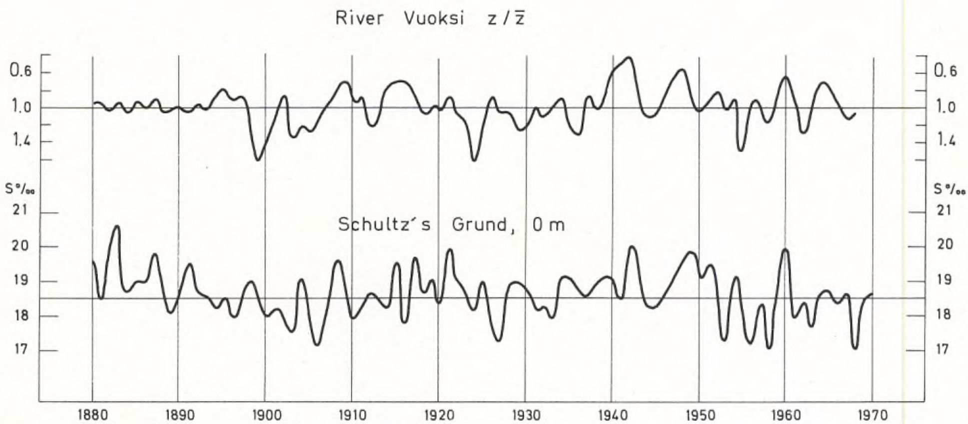


Fig. 18. Comparison of the ratio between the annual mean value and a long-term mean value of the discharge of the river Vuoksi, which flows into the Gulf of Finland through Lake Ladoga (top), and the annual mean of surface salinities at the L/V Schultz's Grund (From 1945, L/V Kattegat SW).

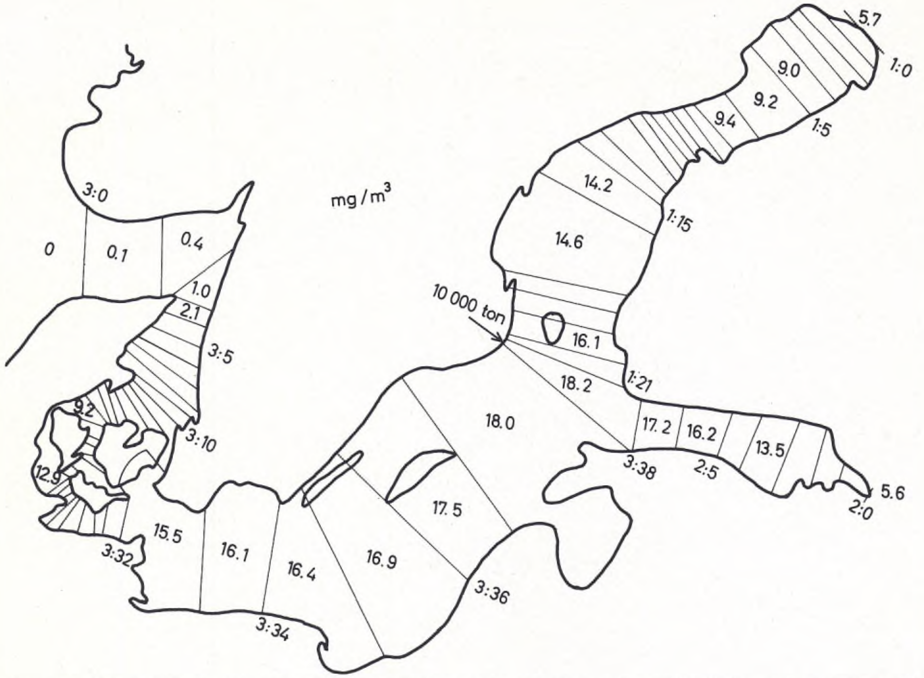


Fig. 19. Theoretically computed steady state concentrations (in mg/m^3) in various parts of the Baltic and adjacent seas, concentrations caused by the hypothetical discharge of 10,000 tons pr year of a conservative substance in the middle of the Baltic.

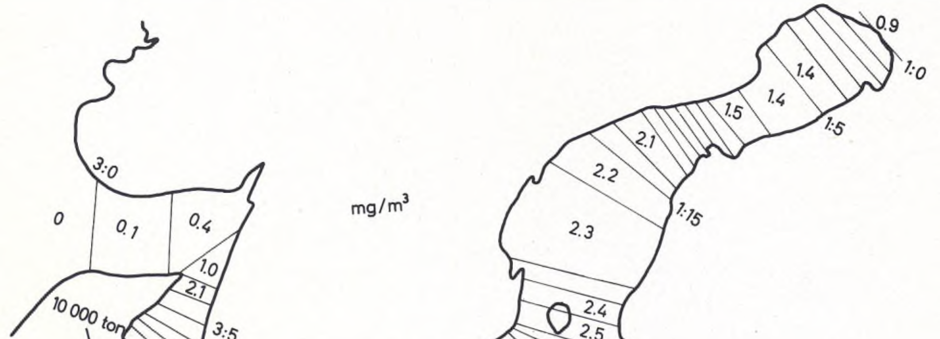


Fig. 20. A computation similar to that one displayed in Fig. 19, but with discharge into the Belt Sea.

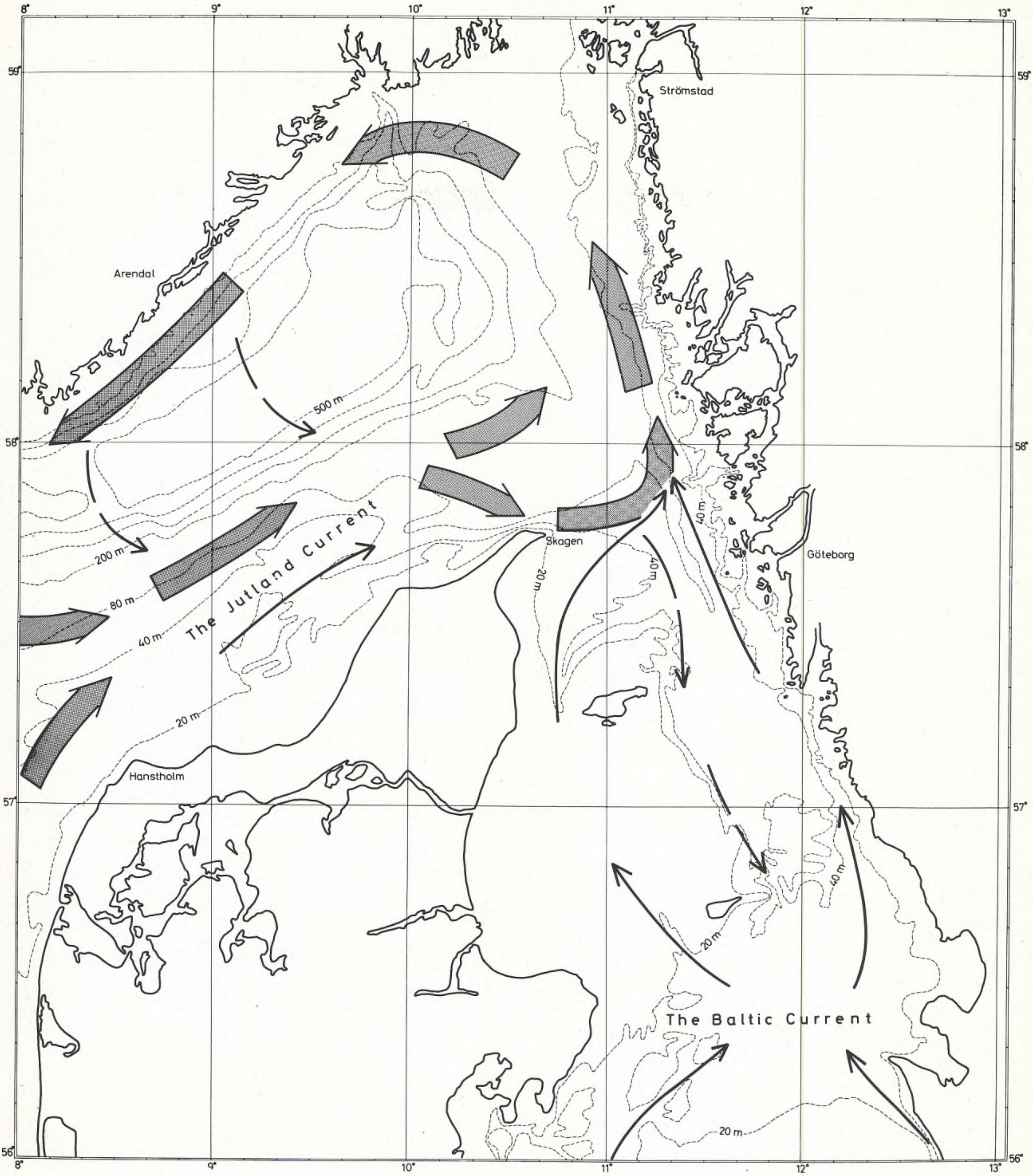


Fig. 21. A simplified map of the surface currents of the Kattegat and the Skagerrak. In the Kattegat the "countercurrent" is indicated, which originates from the large mixing between the Jutland Current and the Baltic Current. The main bulk of this fusion is, however, leaving the Skagerrak along the coasts of Sweden and Norway.

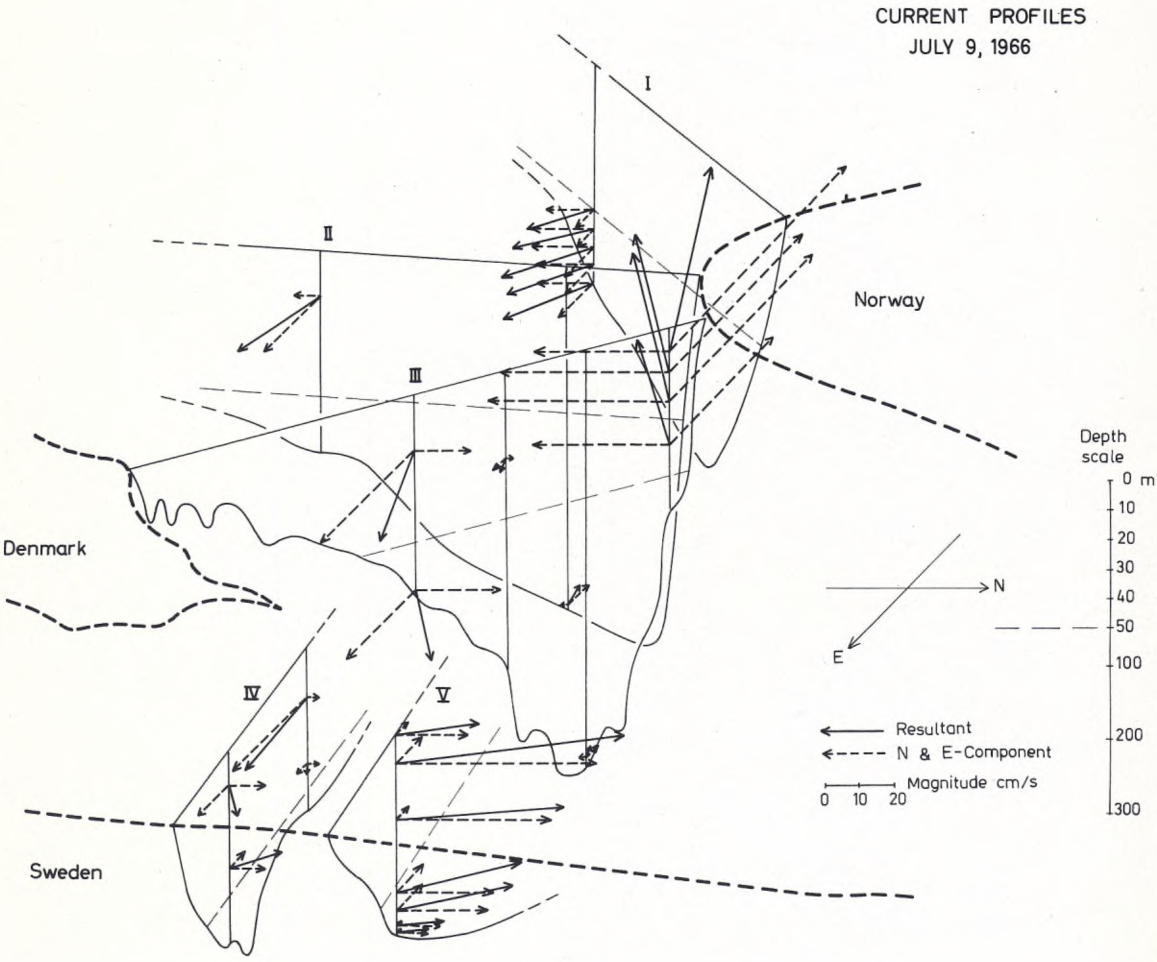


Fig. 22. Daily means of currents measured on July 9, 1966, during the International Skagerrak Expedition.

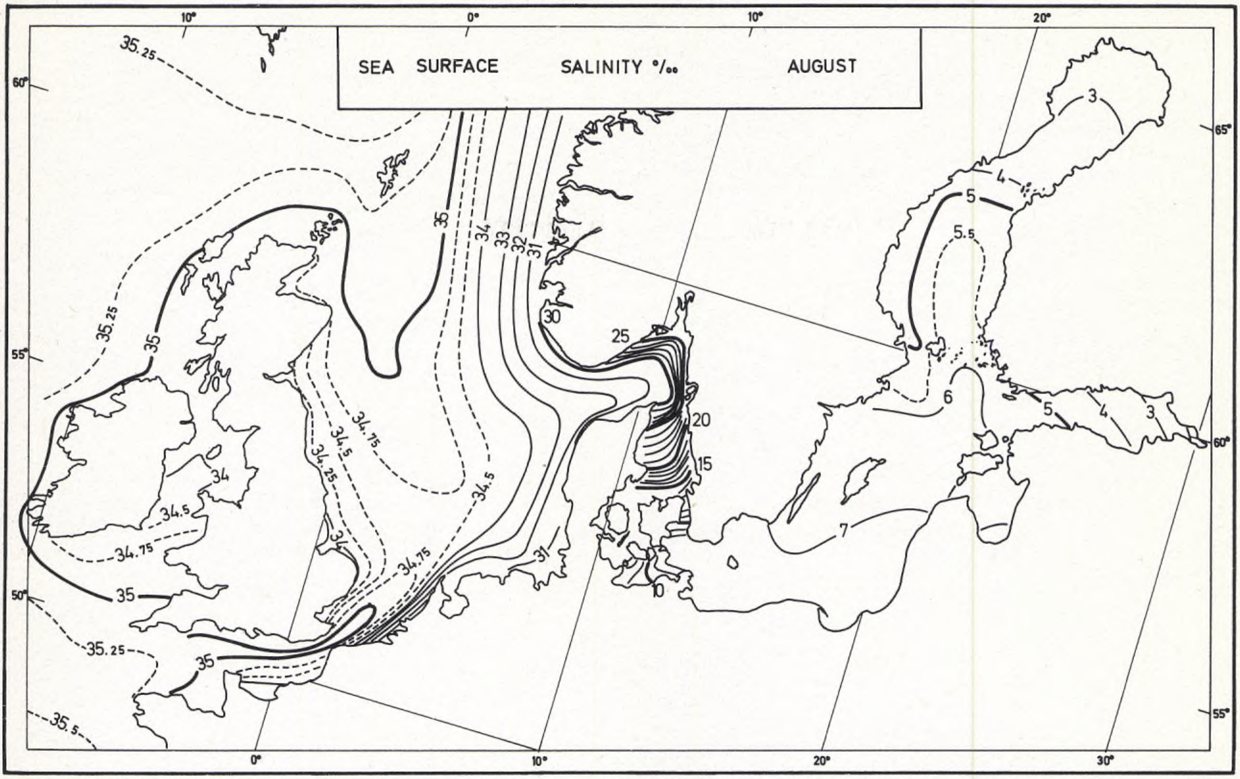


Fig. 23. Chart displaying long-term means of surface salinity. (Reproduced from ANON. 1927.)

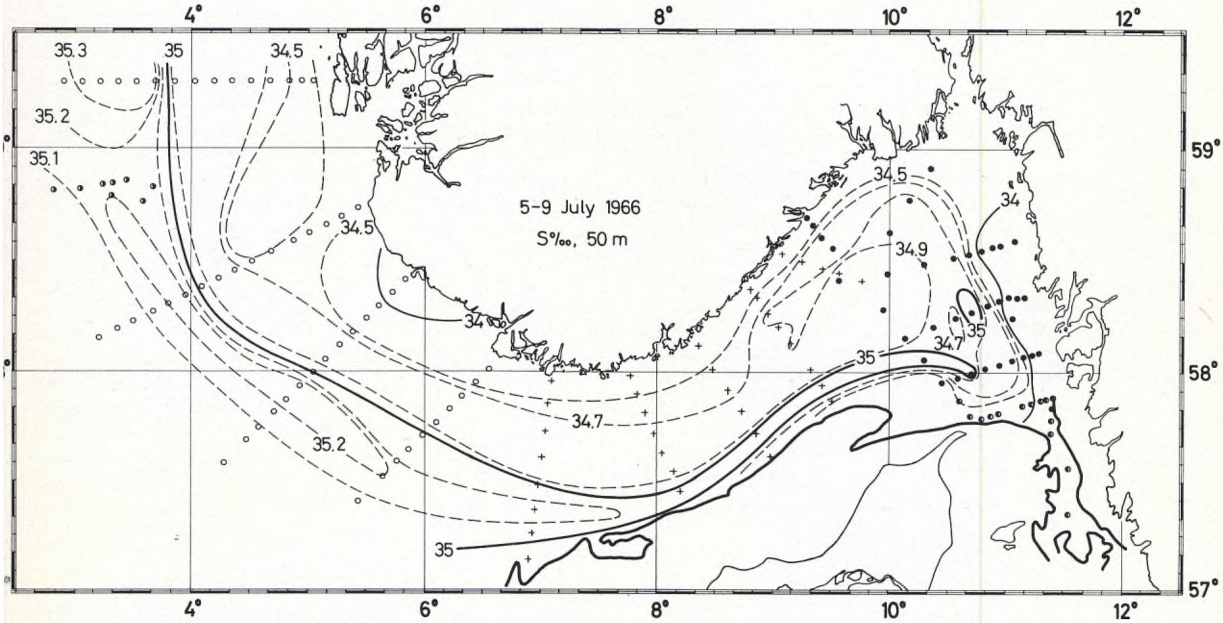


Fig. 24. Salinities at 50 m depth measured during the International Skagerrak Expedition 1966. (Reproduced from ANON. 1970.)

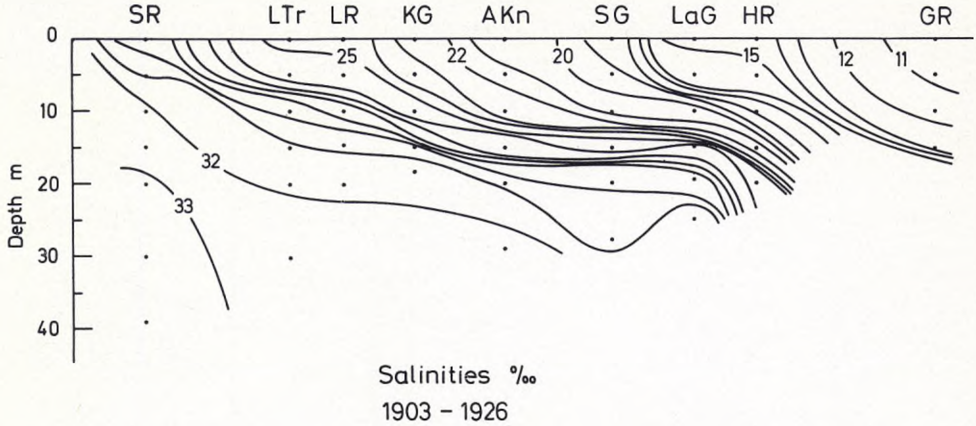


Fig. 25. Longituditional section of long-term means of salinity constructed by means of lightvessel data, published in ANON. 1933. Positions of lightvessels in Fig. 2.

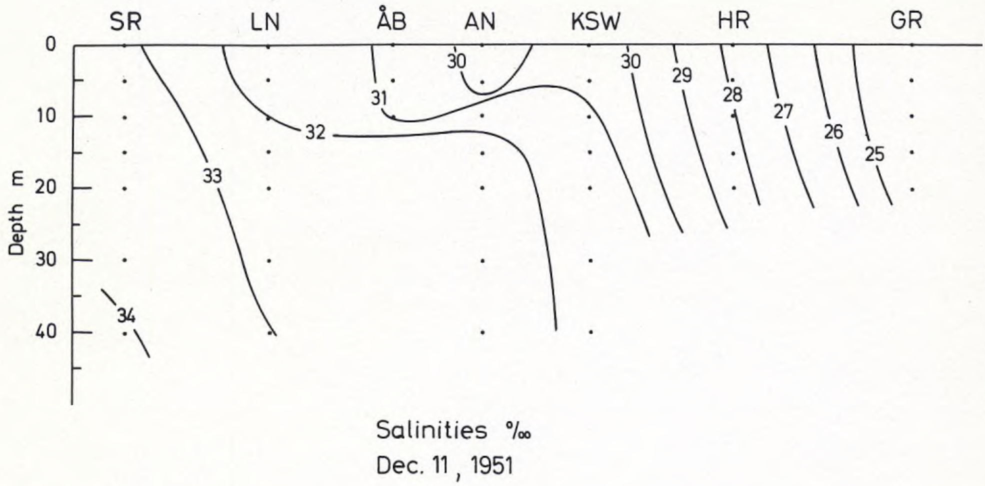


Fig. 26. Longitudinal section of salinities measured on one day in December 1951 during the large inflow to the Baltic of water of high salinity. Positions in Fig. 2.

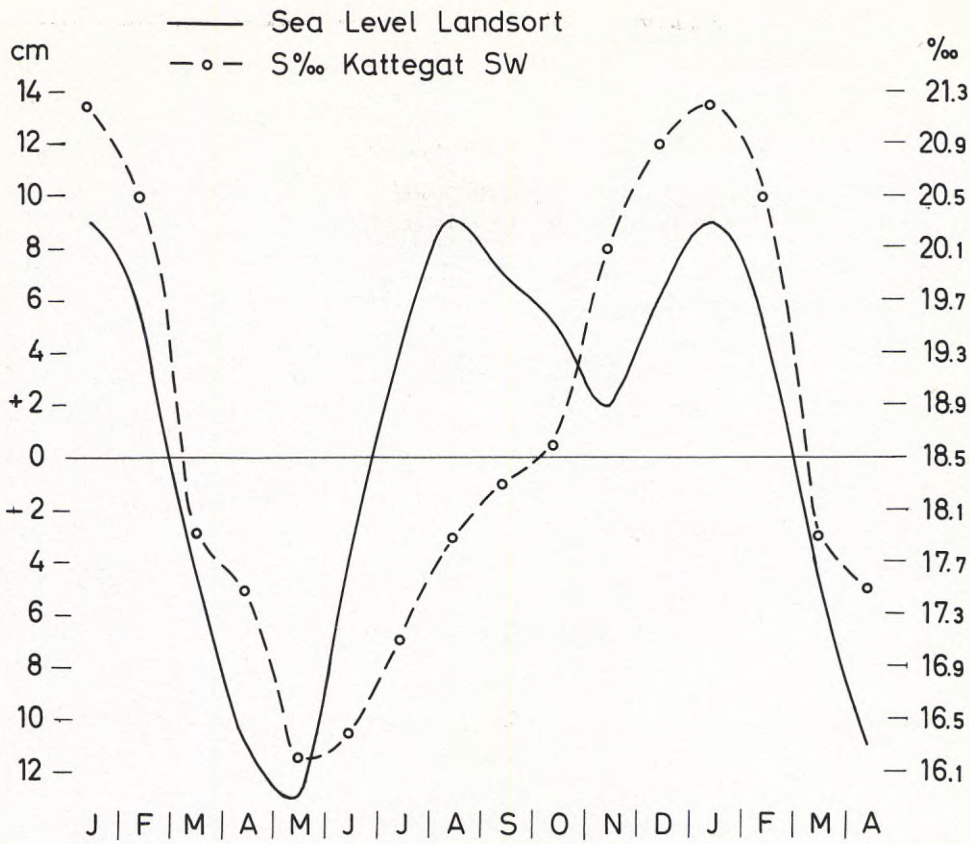


Fig. 27. Long-term monthly means of sea levels of the Baltic and surface salinities of the Kattegat.

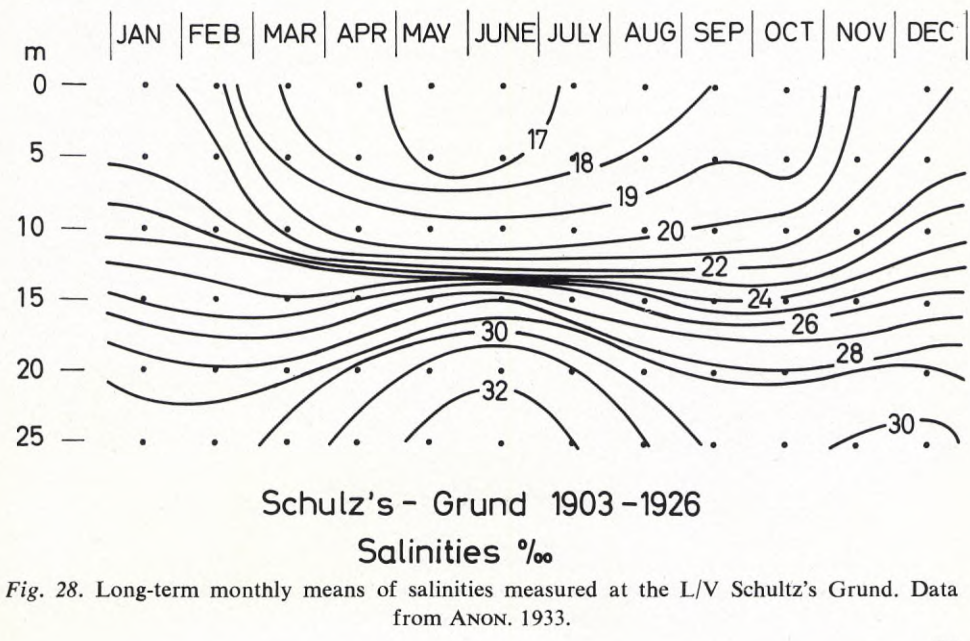


Fig. 28. Long-term monthly means of salinities measured at the L/V Schultz's Grund. Data from Anon. 1933.

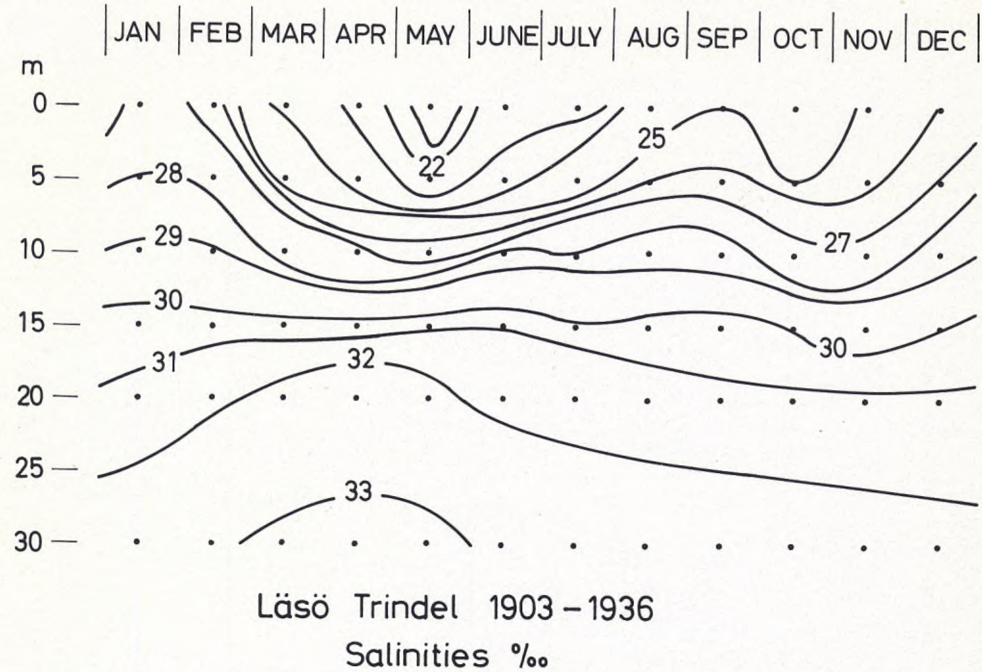


Fig. 29. Long-term monthly means of salinities measured at the L/V Läsö Trindel. Data from ANON. 1933.

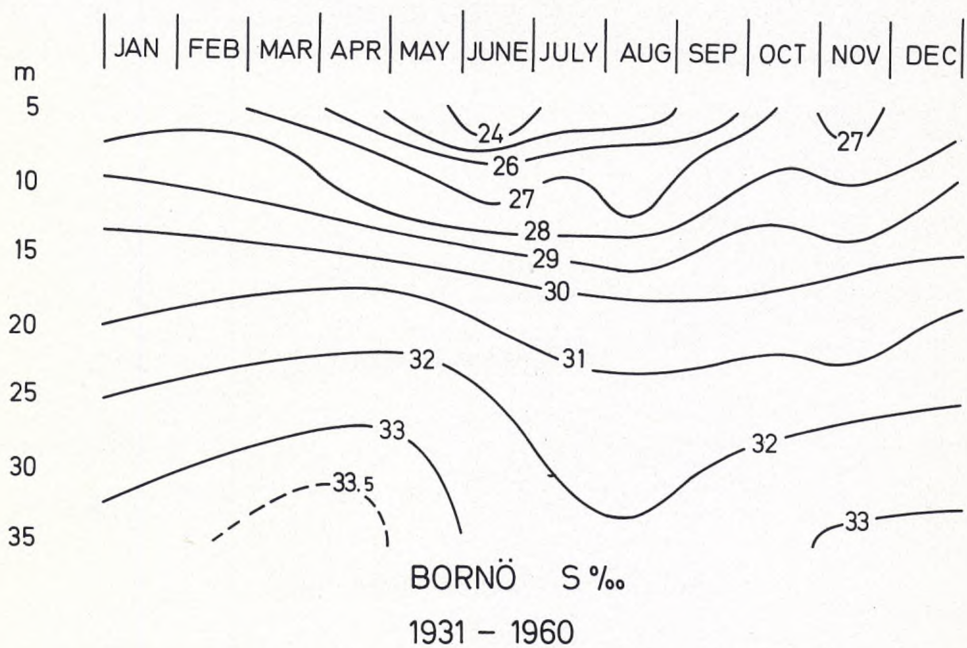


Fig. 30. Long-term monthly means of salinities measured at Bornö Hydrographical Stations. Data from SVANSSON 1974.

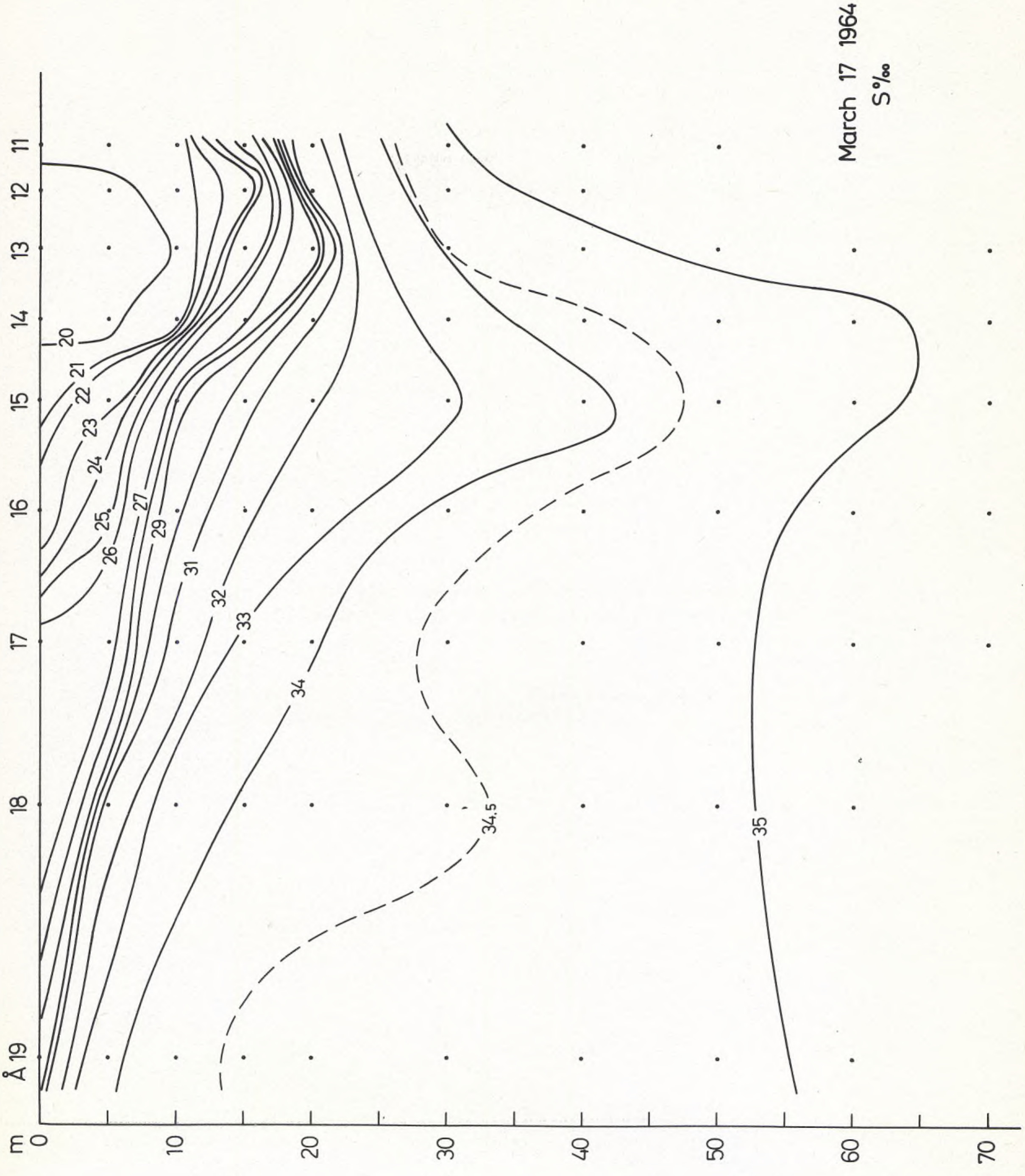


Fig. 31. Salinity section in the Skagerrak (See Fig. 2.) constructed by means of data obtained during a cruise in the spring of 1964.

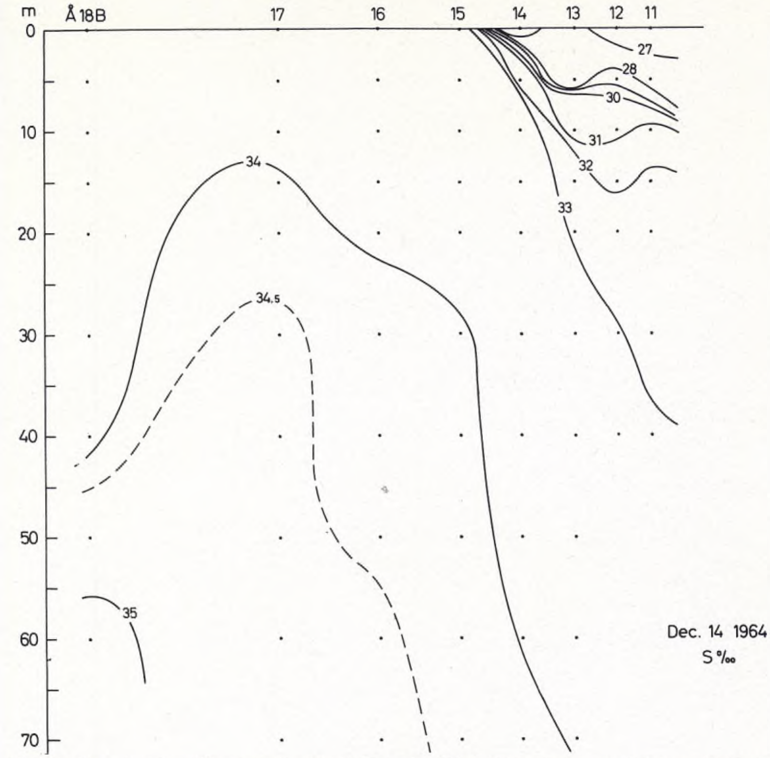


Fig. 32. Salinity section in the Skagerrak (Positions in Fig. 2.) constructed by means of data obtained during a cruise in December 1964. (Reproduced from ANON. 1970.)

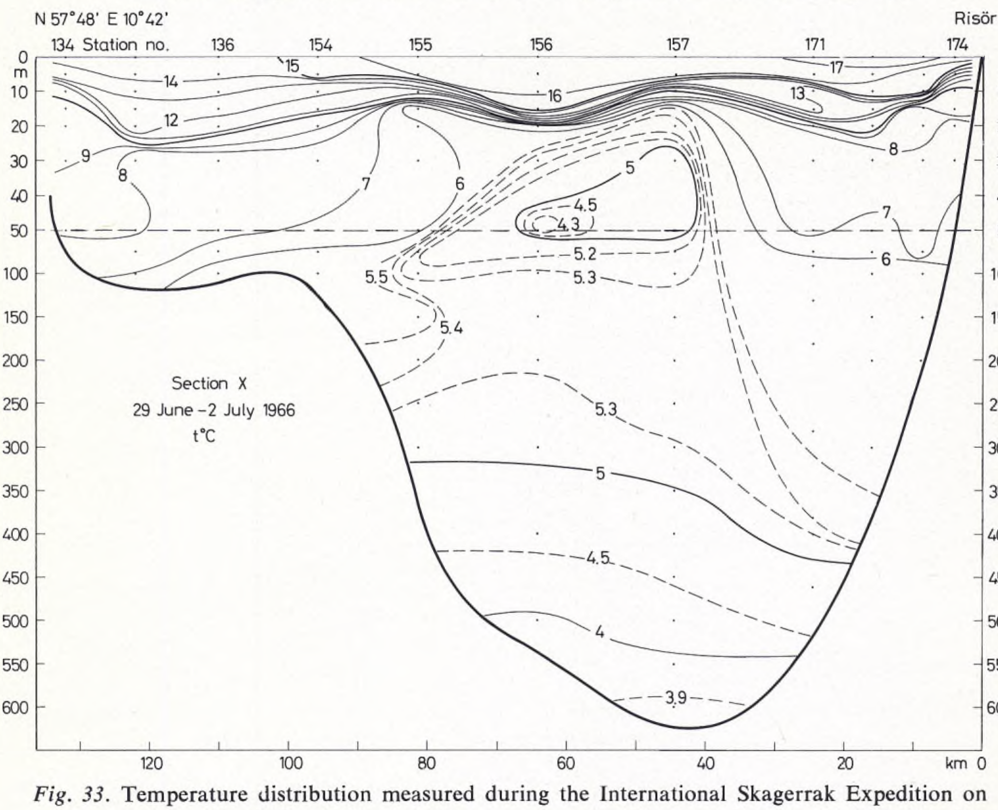


Fig. 33. Temperature distribution measured during the International Skagerrak Expedition on a section running from Skagens Rev to Norway approximately through station Å 18 B (Fig. 2.).

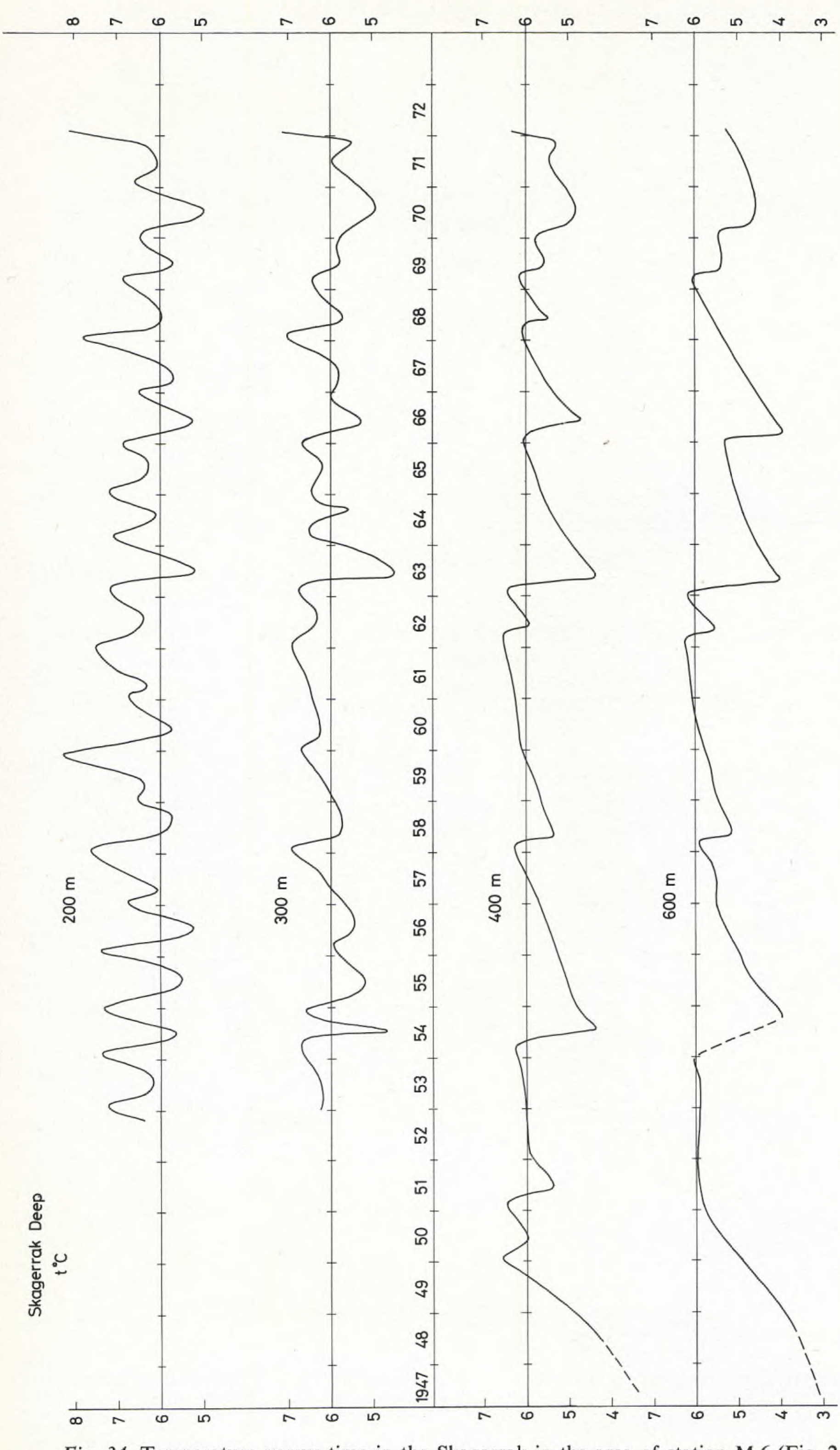


Fig. 34. Temperature versus time in the Skagerrak in the area of station M 6 (Fig. 2.).

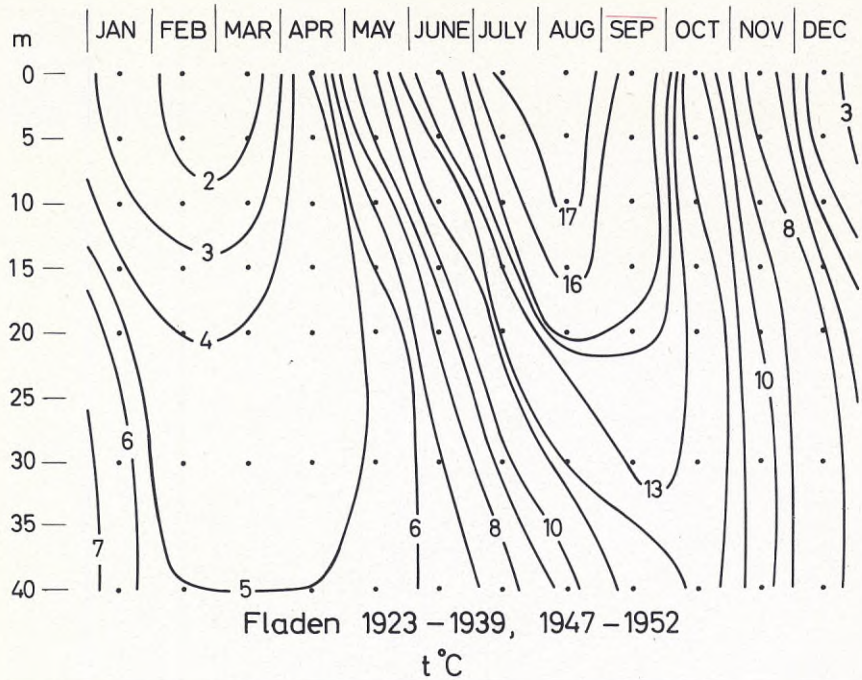


Fig. 35. Long-term monthly means of temperatures measured at the L/V Fladen. Data from Koczy (1954).

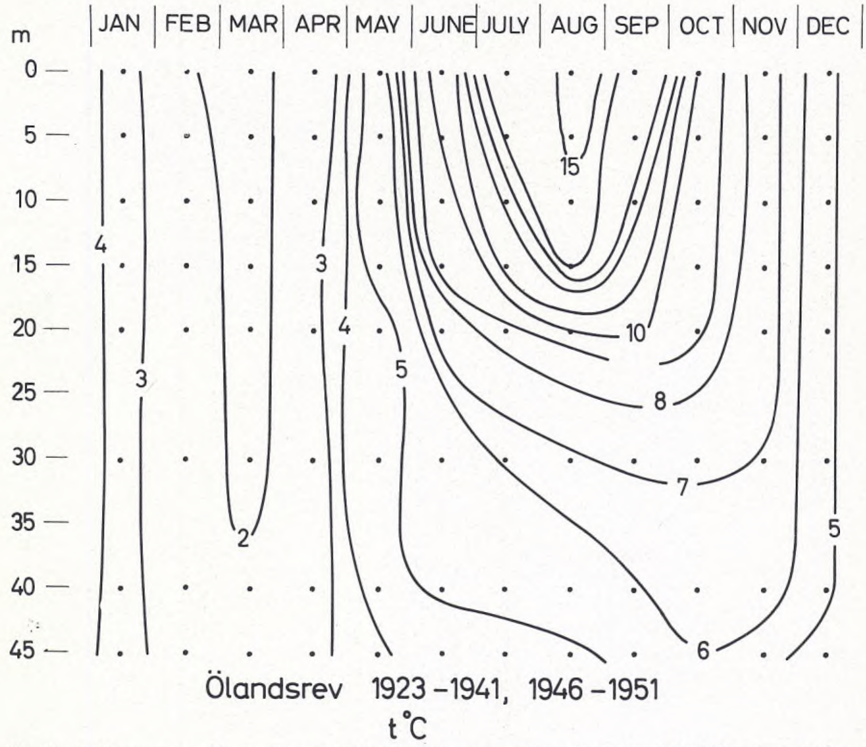


Fig. 36. Long-term monthly means of temperatures measured at the L/V Ölandsrev (Southern Baltic at N 56°07′ and E 16°34′). Data from Koczy (1954).

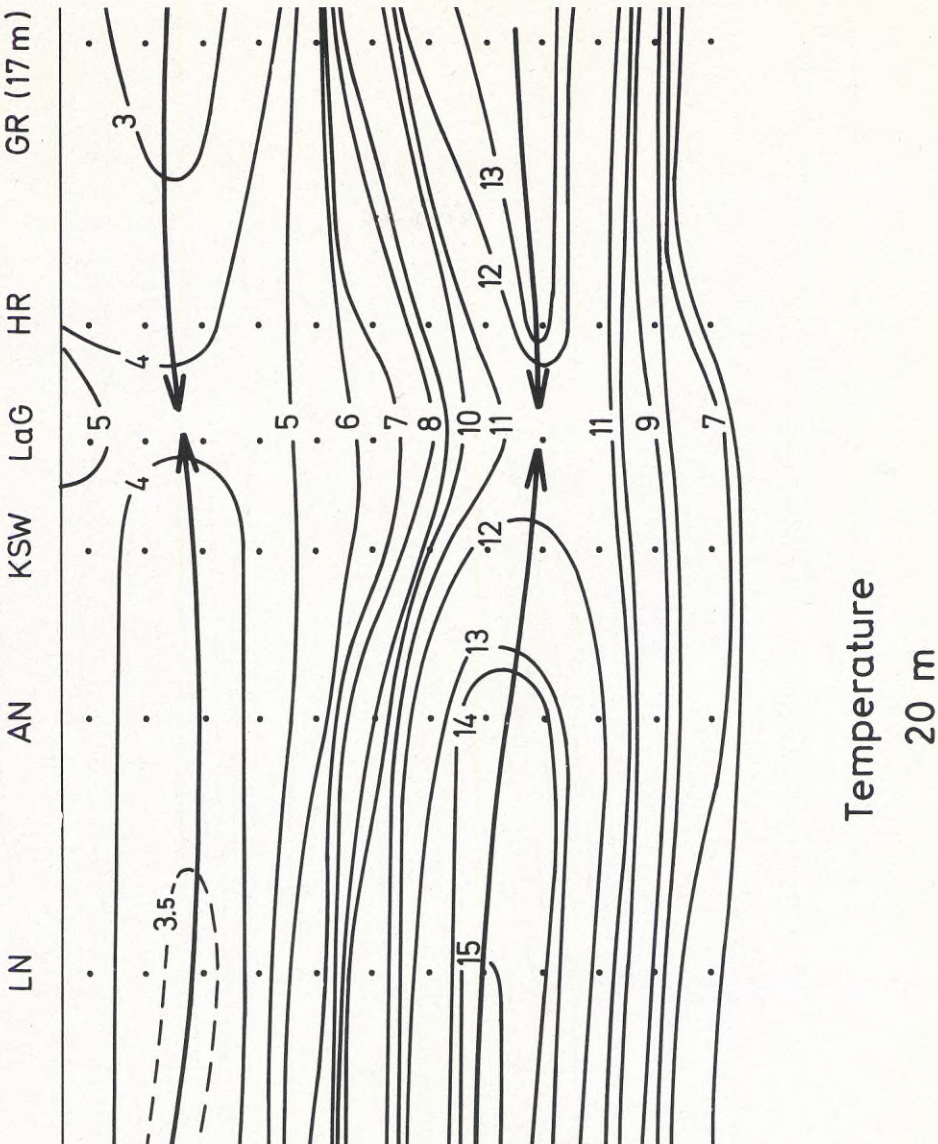


Fig. 37. Long-term means of temperatures measured at lightvessels (Positions in Fig. 2.) at 20 m depth. Arrows indicate minima and maxima. Data from ANON. (1933).

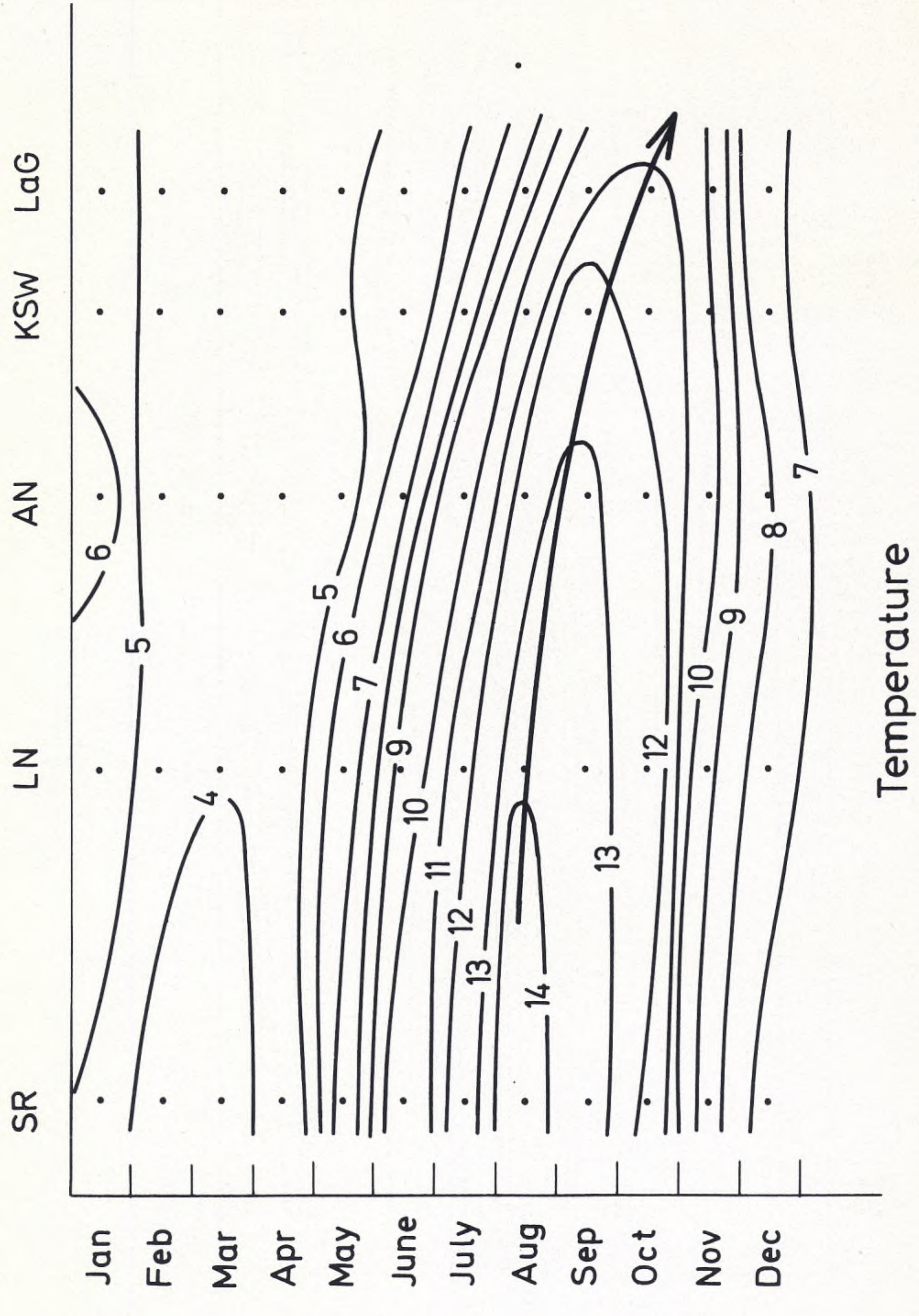


Fig. 38. Long-term means of temperatures measured at lightvessels (Positions in Fig. 2.) at 30 m depth. Arrow indicates maximum values. Data from ANON. (1933).

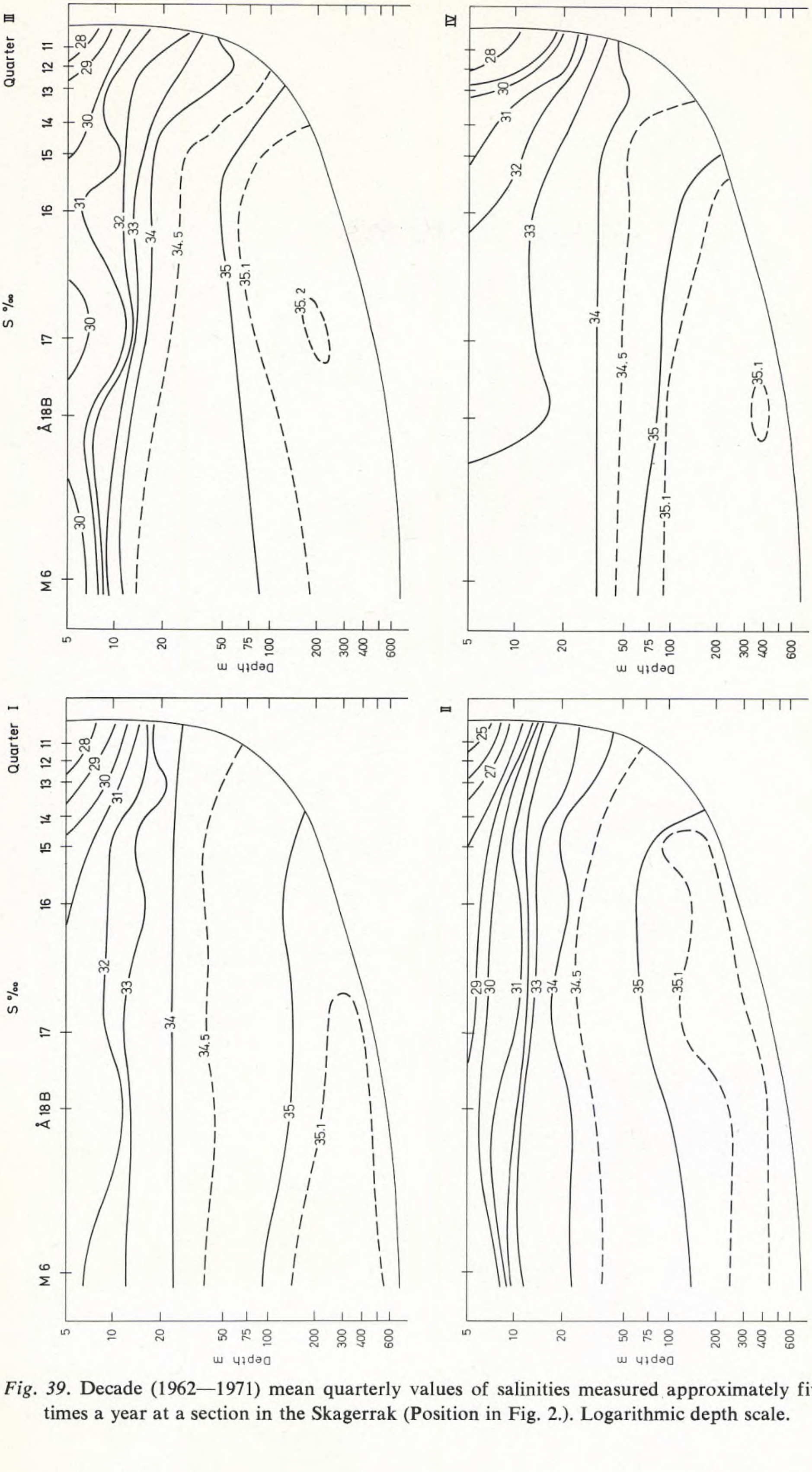


Fig. 39. Decade (1962—1971) mean quarterly values of salinities measured approximately five times a year at a section in the Skagerrak (Position in Fig. 2.). Logarithmic depth scale.

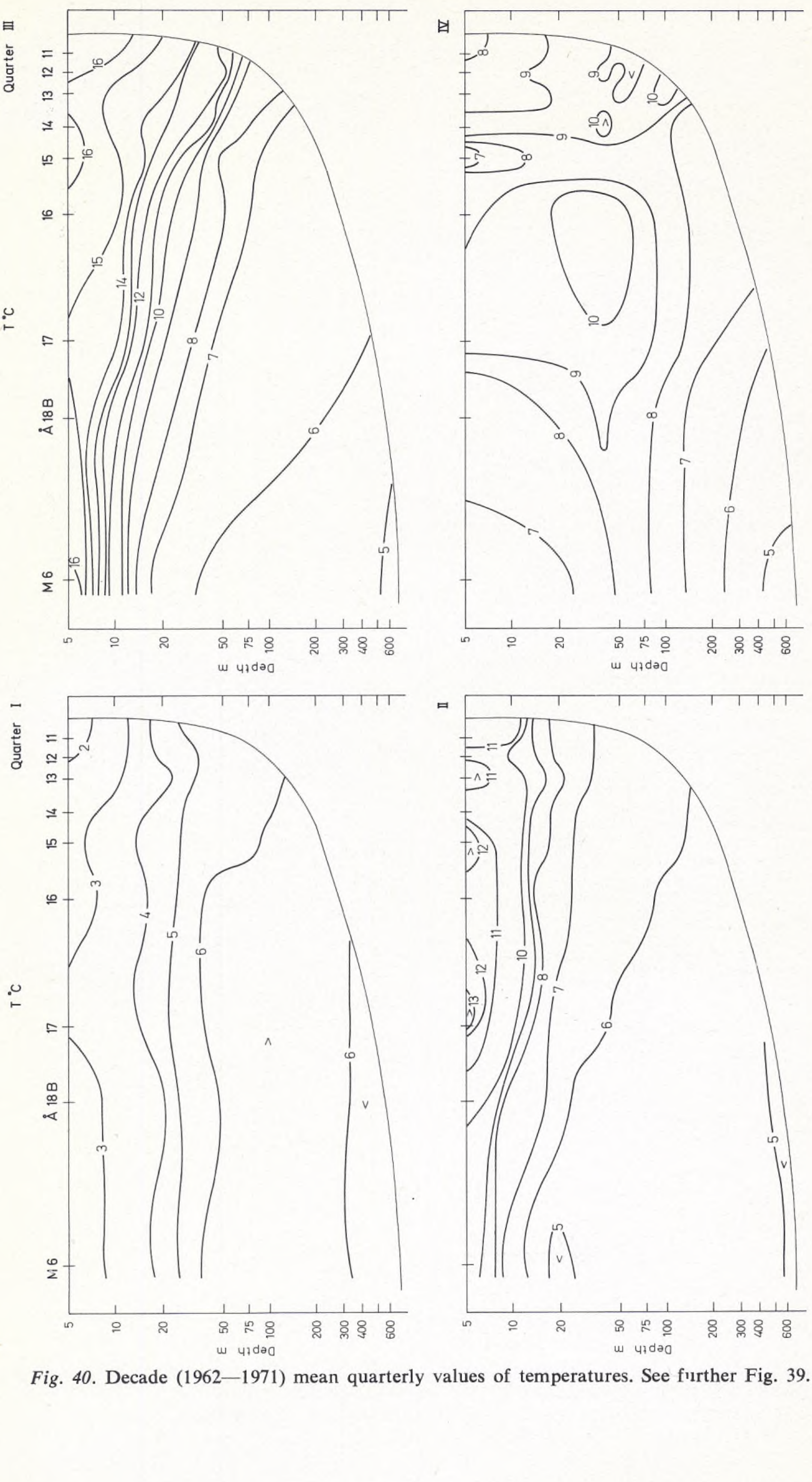


Fig. 40. Decade (1962—1971) mean quarterly values of temperatures. See further Fig. 39.

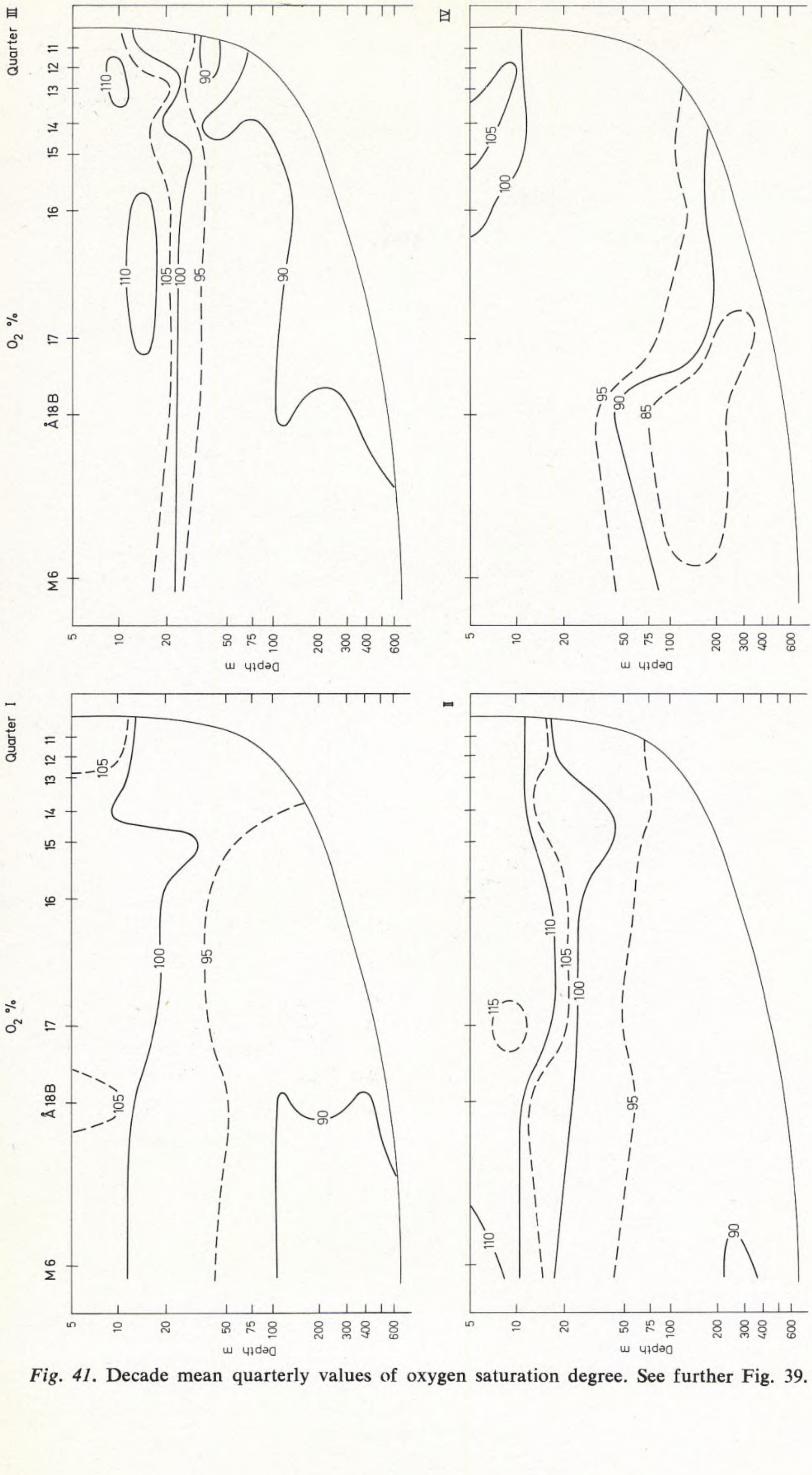


Fig. 41. Decade mean quarterly values of oxygen saturation degree. See further Fig. 39.

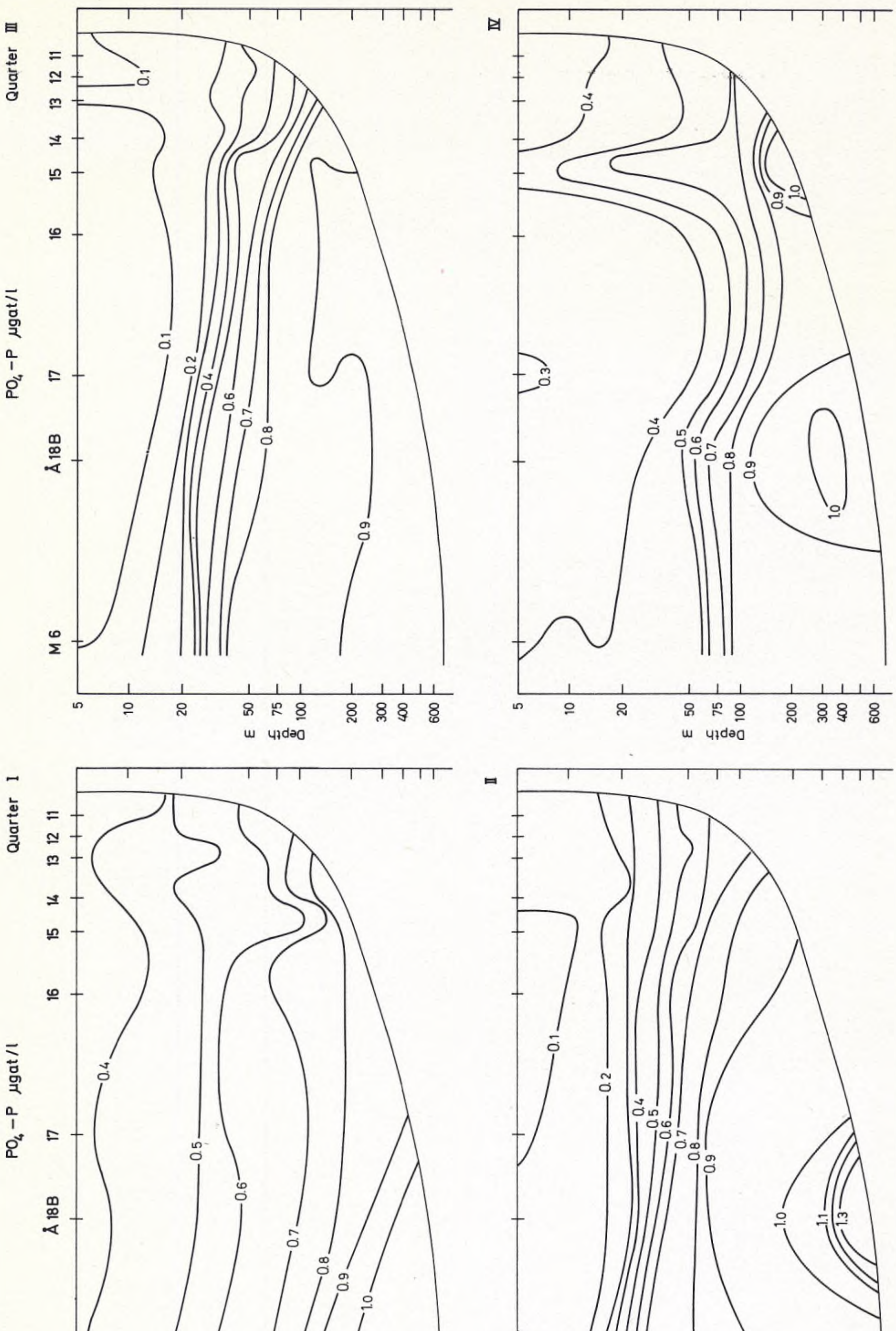


Fig. 42. Decade mean quarterly values of phosphate-phosphorus. See further Fig. 39.

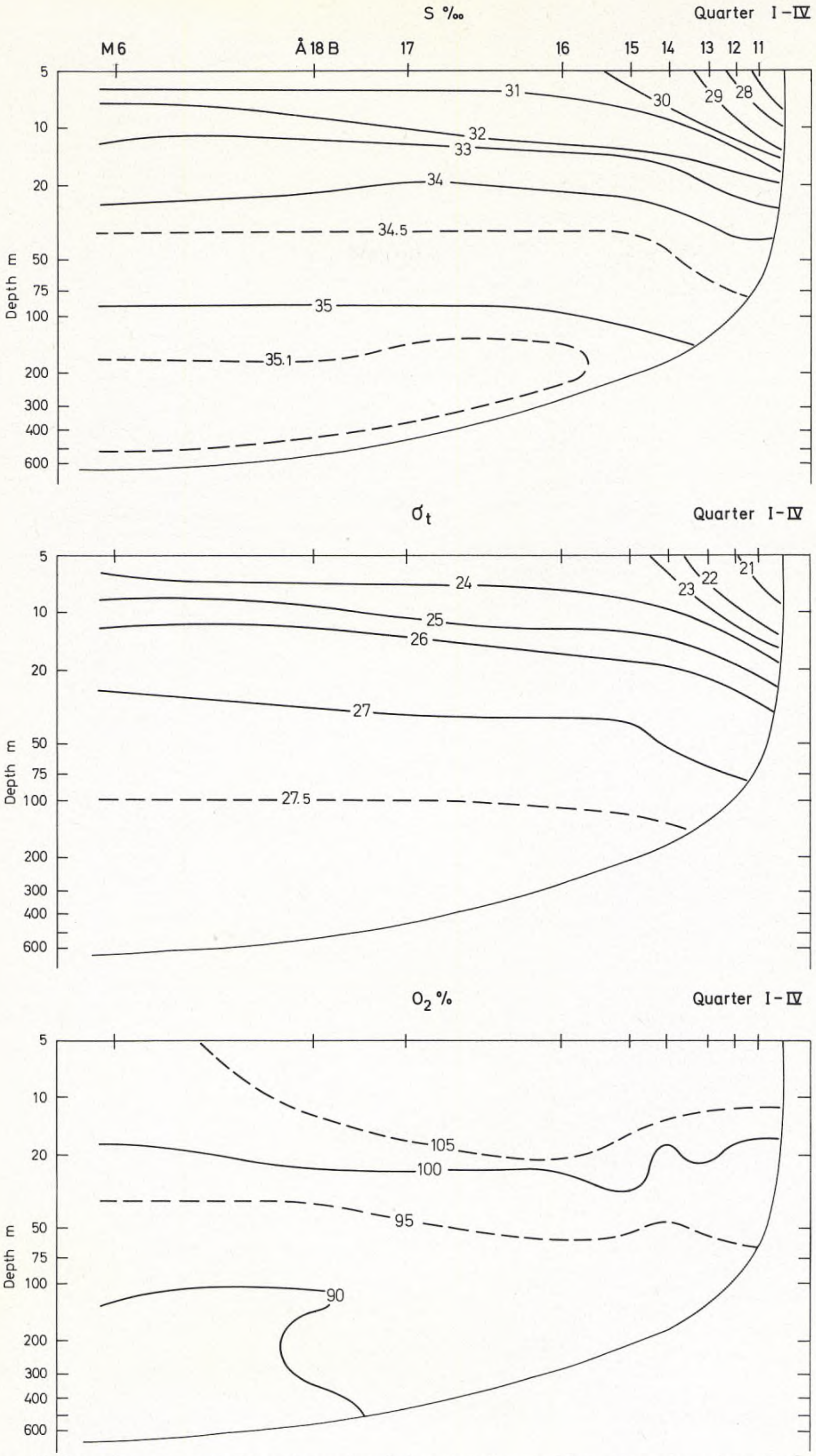
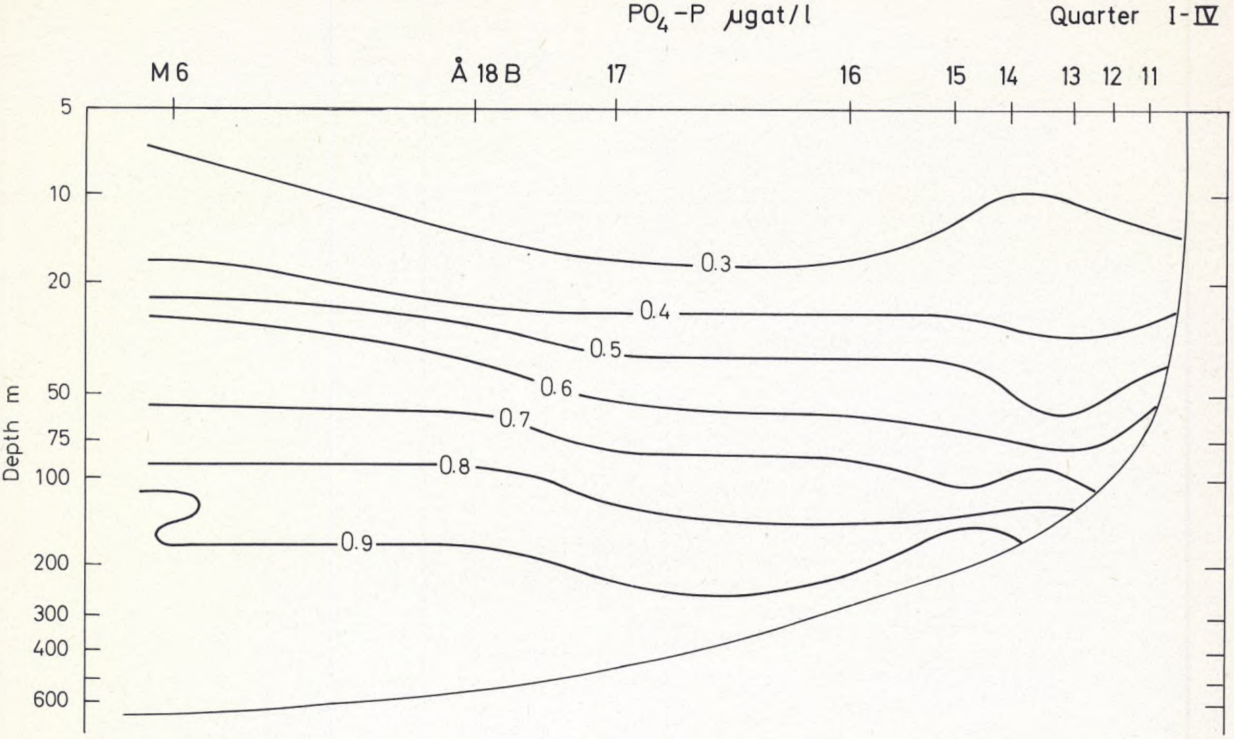


Fig. 43. Decade mean annual values of salinity, density-σ_t and oxygen saturation degree. See further Fig. 39.



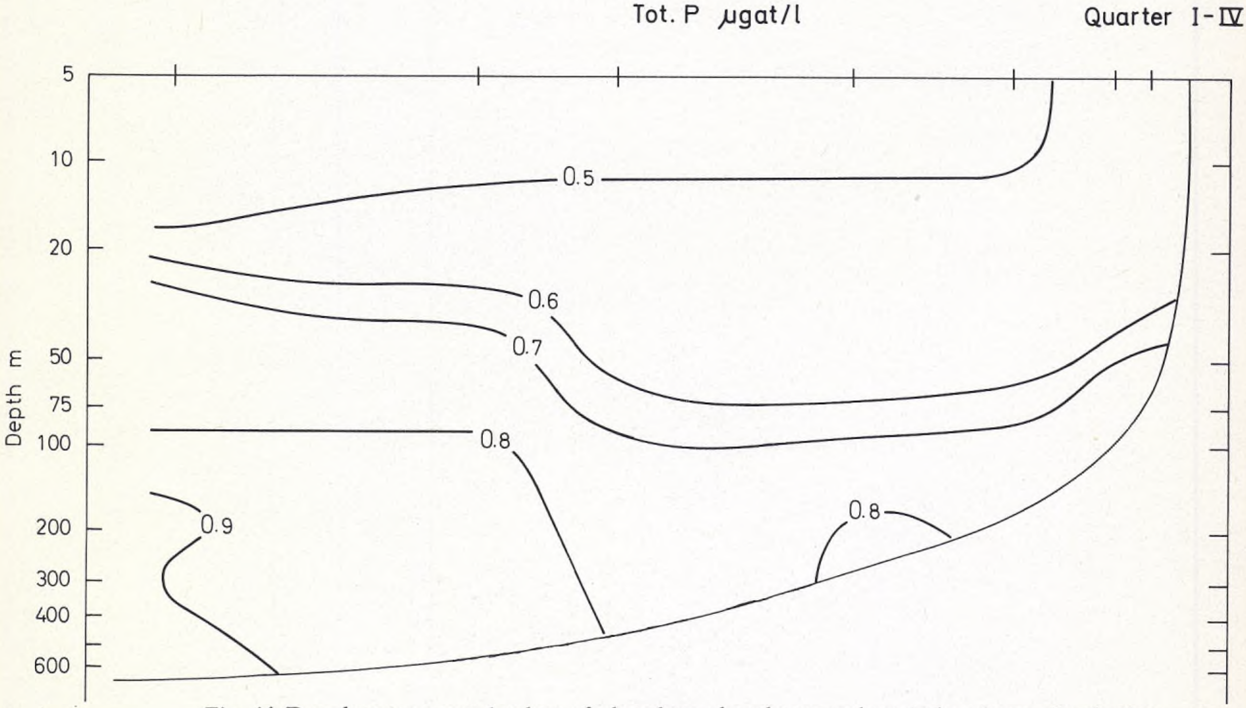


Fig. 44. Decade mean annual values of phosphate-phosphorus and total phosphorus. See further Fig. 39.

Note to the librarian:

The following series of publications have ceased to appear:
Institute of Marine Research, Lysekil,
Series Biology, Reports (1—19, 1950—1970)

Fishery Board of Sweden,
Series Hydrography, Reports (1—26, 1951—1972)

The new series of publications, of which this is the first number, will contain contributions on all fields of marine research relevant to fishery science.

Quotation: *Report, Fish. Bd. Sweden, Inst. Mar. Res.*

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