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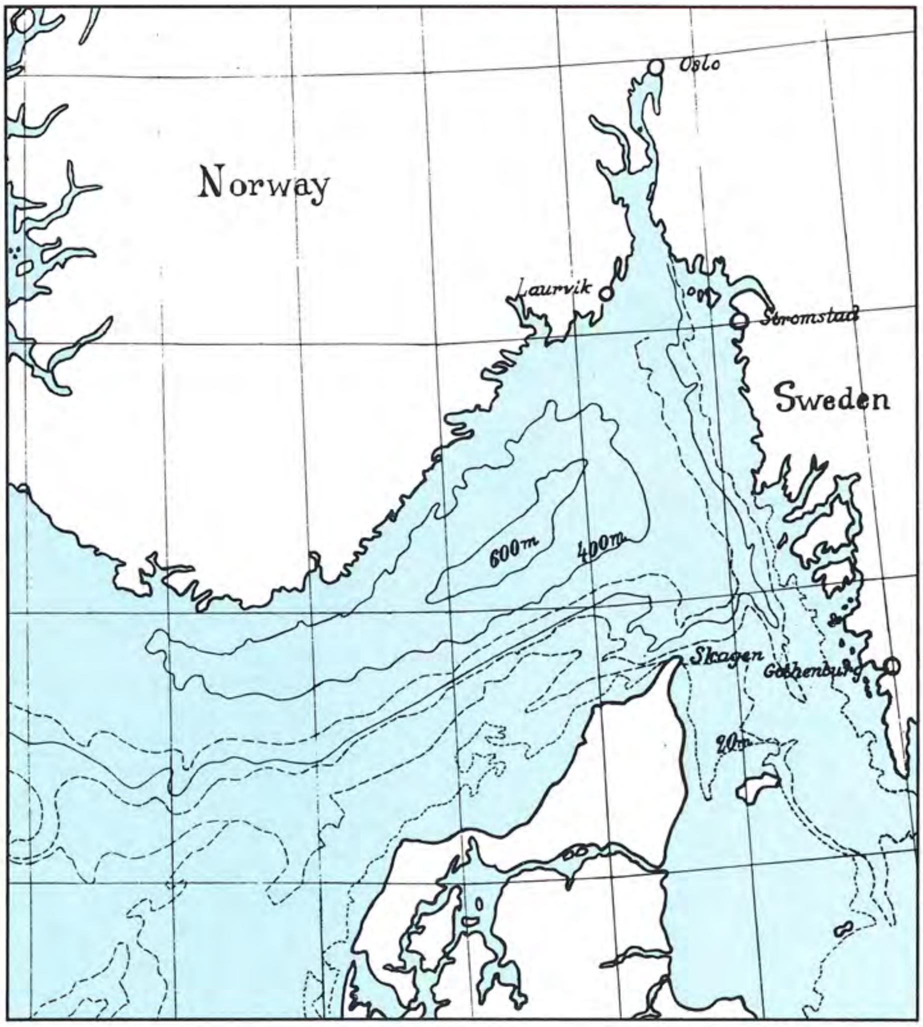

SKAGERRAK
- the gateway to the North Sea

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SKAGERRAK
- the gateway to the North Sea

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SMHIs tryckeri Norrköping 1990

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Skagerrak - the gateway to the North Sea

Preface

The blooming of poisonous algaes, the epidemic of deaths among the seals and the influence of the North Sea have all given rise to grave concern about the increasing risks for the Skagerrak.

The Skagerrak is the least investigated area of all our sea regions. The coastal regions and particularly the fiords have been given much attention but the hydrographic conditions in the open Skagerrak have been regarded as oceanic and the Skagerrak has not been considered to be exposed to pollution or eutrophication.

A summary of the hydrography of the Skagerrak is hereby presented as an introduction to the increasing investigation and monitoring of the environmental conditions of the Skagerrak

Boundaries and topography

The Skagerrak connects the North Sea to the Baltic Sea and is regarded as being part of the North Sea, whereas the Kattegat is understood to be part of the Baltic and is included in the concept when the name Baltic Sea is used. Figure 1 shows a map of the Skagerrak.

The boundary between the North Sea and the Skagerrak runs from Hanstholm on Jutland to Lindesnes on the south coast of Norway. The surface area of the Skagerrak is 32 300 km^2, the volume 6780 km^3 and the average depth 210 meters.

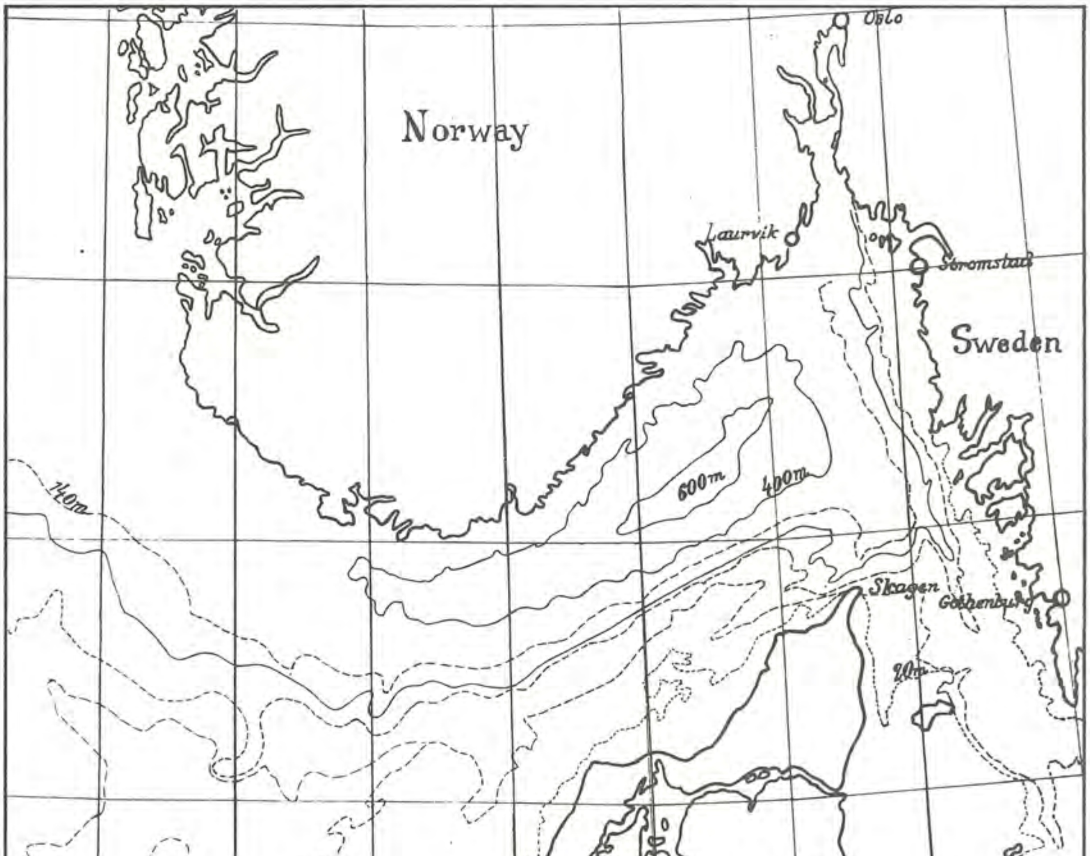


Fig 1. Map showing the depths of the eastern North Sea and the Skagerrak.

The relatively large average depth depends on the Norwegian Trench, which follows the Norwegian coast and deepens as it nears the Skagerrak. The Norwegian Trench reaches it's greatest depth, roughly 700 m, about 35 nautical miles due east of Grimstad. The sill (the deepest connection) between the Norwegian Trench and it's continuation nortwards to the Norwegian Sea (Atlantic Ocean) is 270 m deep and lies outside Utsira.

Eastwards the Norwegian Trench stretches almost to the Swedish coast before continuing southwards along this coast until it leads into the Kattegat by the Deep Furrow.

With the exception of the sill in the Norwegian Trench, one cannot discern a hydrographic border between the Skagerrak and the North Sea. The boundary between the Skagerrak and the Kattegat is usually drawn from the Skaw reef to the Paternoster Lighthouse. However within the Helsinki Commission, this boundary is drawn from the Skaw along the latitude 57°44'8 N. As the first named boundary has been used for calculating the surface and volume of the Skagerrak, this is the one we will use here.

Along the Swedish and Norwegian coasts there are many deep fiords that stretch a long way inland. The biggest of these is the Oslo Fiord.

A typical fiord is relatively deep, but has a shallower sill at the mouth. Usually a river or large stream runs into the heads of the fiords. Oslo-, Ide- and Gullmarsfiords are typical sill fiords. The Oslo Fiord has it's sill in the part of the inner fiord that is near Dröbak. This sill is 20 m deep. The maximum depth inside the sill is 164 m. In the Ide Fiord the sill depth is 9 m and the maximum depth inside the sill is 42 m. The Gullmars Fiord's sill depth is 38 m and it's maximum inside depth is 119 m.

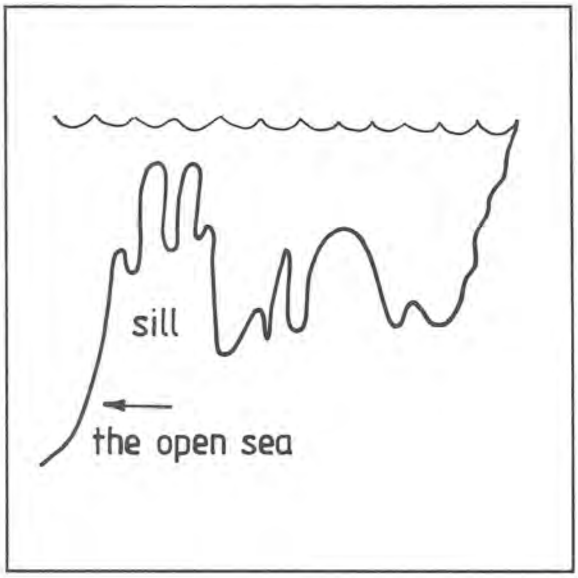


Fig 2. A typical fiord

The Ide Fiord is the border between Norway and Sweden. The most important Swedish fiord is the Gullmars Fiord. South of this fiord is a whole system of fiords between the mainland and the islands of Orust and Tjörn. This fiord system is called the Uddevalla fiords. In reality they are not true fiords but rather a system of semi-enclosed bights connected to each other by means of narrow sounds. They are however commonly called fiords.

Skagerrak is the least investigated of all our sea regions. The coastal regions and particularly the fiords have been given much attention but the hydrographic conditions in the open Skagerrak have been regarded as oceanic and the Skagerrak has not been thought to be a target for pollution or eutrophication.

Water balance

It is difficult to find information on the evaporation from the Skagerrak's surface in the available literature. In the following section I have therefore tried to estimate the evaporation by using the information obtained from the Norwegian, Danish and Swedish hydrological coastal stations.

The yearly precipitation is reported to be 700 mm (Grimås and Svansson 1985). This represents about 23 km^3. The influx of river water has been calculated by Svansson (1975).

Table 1 shows the average water discharge of the various rivers.

TABLE 1 Rivers running out into the Skagerrak

Name	Catchment area km^2	Water discharge m^3/s
Örekilsälven	1327	21.0
Diverse Swedish rivers	1543	24.0
Tista	1550	23.7
Glomma	41284	708.0
Mosseelv	690	10.7
Dramselv	16020	313.0
Numedalslågen	5513	115.7
Skienselv	9975	298.0
Toke	1168	33.0
Vegårdselv	491	15.6
Nidelv	3907	124.5
Tordalselv	1700	63.1
Otra	3539	149.0
Mandalselv	1746	87.0
Diverse Norwegian rivers	11717	249.0
Total	102870	2245.3

Supply of river water to the Skagerrak 1911-1950 : 2245.3 m^3/s = 71 km^3/year

Table 2 shows the water balance of the Skagerrak

TABLE 2

Supply	km^3/year	Removal	km^3/year
Fresh water			
From Kattegat	515		
		Evaporation	13
Precipitation	23		
River water	71		
Total	609		13

The contribution of fresh water to the North Sea is thus: 609 - 13 = 596 km^3/year

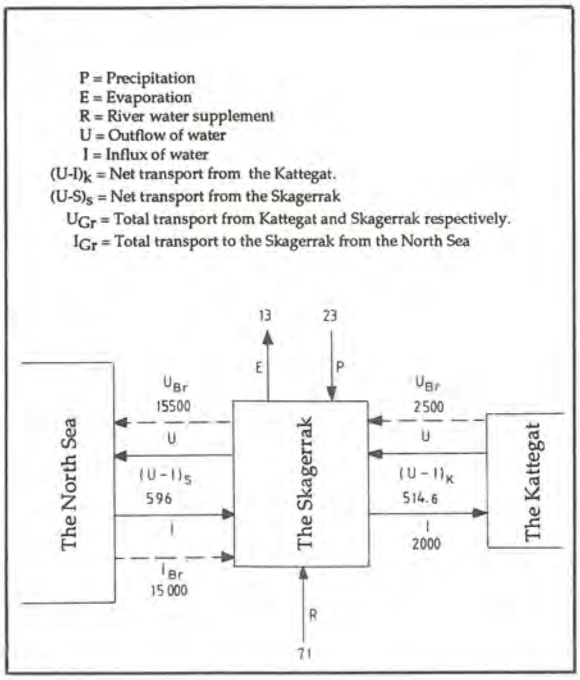


Fig 3. Box diagram showing the water balance in the Skagerrak

Fig 3 shows the water balance of the Skagerrak in the form of a box diagram. The net gain of fresh water from the Kattegat is 514.6 km^3/year. Naturally this is blended with salt water and orginates partly from the Baltic and partly from rivers and precipitation in the Kattegat.

A deep current of Skagerrak water to the Kattegat is blended with brackish water, which in the surface layer flows out from the Baltic. A surface current of about 2500 km^3/year of Baltic (brackish) water from the Kattegat is thus formed. This current, called the Baltic current, continues northwards along the Swedish coast until it joins the Norwegian Coastal current off Norway. The latter current is reinforced with fresh water, mostly from Glomma and Dramselv, before continuing out to the Atlantic as a rather narrow coastal stream.

It is usual to call the whole system for the " Baltic current" and this is the term I will be using throughout.

The Baltic current lies above a very large water transport of at least 15 000 km^3/ year that mainly comes from three directions: a) From the English Channel, as a surface current sweeping up the West coast of Denmark. This is called the "Jutland current". b)From the Orkney/Shetlands area, streaming more or less eastwards, and c) From the outer part of the Norwegian Trench in the form of a deep current. As a rough guide one can say that the greater part of the water that flows into the North Sea temporarily occupies the Skagerrak.
Fig 4 shows the surface currents of the Skagerrak according to Svansson (1972).

Fig 4. Map showing the surface currents in the Skagerrak (Svansson 1975).

The total transported amount is thus 15 000 km³/year influx from the North Sea plus 2500 km³/year influx from the Kattegat, of which about 2000 km³/year return, making the total outflow of 15 500 km³/year.

The turnover time for the Skagerrak's water has been calculated as being a few weeks in areas of strong currents and somewhat longer in coastal areas or in the water at a lower depth than 270 m in the Norwegian Trench (Grimås and Svansson 1985). Rodhe (1987) gives about 100 days as being the extent of the Skagerrak water's turnover time.

Fig 5 shows a cross section of the Skagerrak from Norway to Denmark which demonstrates the condition of the currents (Rodhe 1987). We can see the Baltic current flowing out along the Norwegian coast as a surface current. An outflow is also to be found under the 270 m level. The influx of the Jutland current along the Danish coast, with a maximum velocity on the surface and under the 270 m level indicates an anti-clockwise circulation, both on the surface and in the depths.

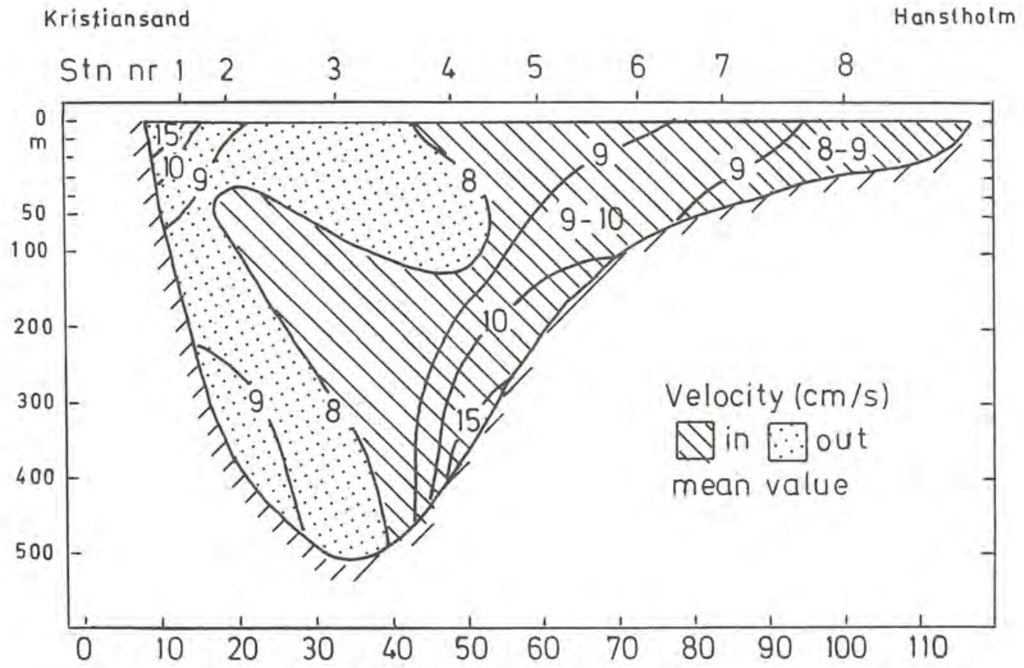


Fig 5. Cross section of the Skagerrak showing in- and outflow (Rodhe 1987)

The water's circulation

As in most sea areas the surface currents of the Skagerrak are heavily dependent on the wind, though there is a permanent circulation where the centre is formed by the Baltic and Jutland currents. Because of these the Skagerrak water circulates in an anti-clockwise direction.
Fig 6 shows the Skagerraks surface circulation measured by means of so called "drifting cards". A drifting card is composed of a small sealed plastic envelope containing a numbered postcard holding a request that the finder send the postcard to the institute that has distributed the drifting card. The finder is recompensed with a small reward.

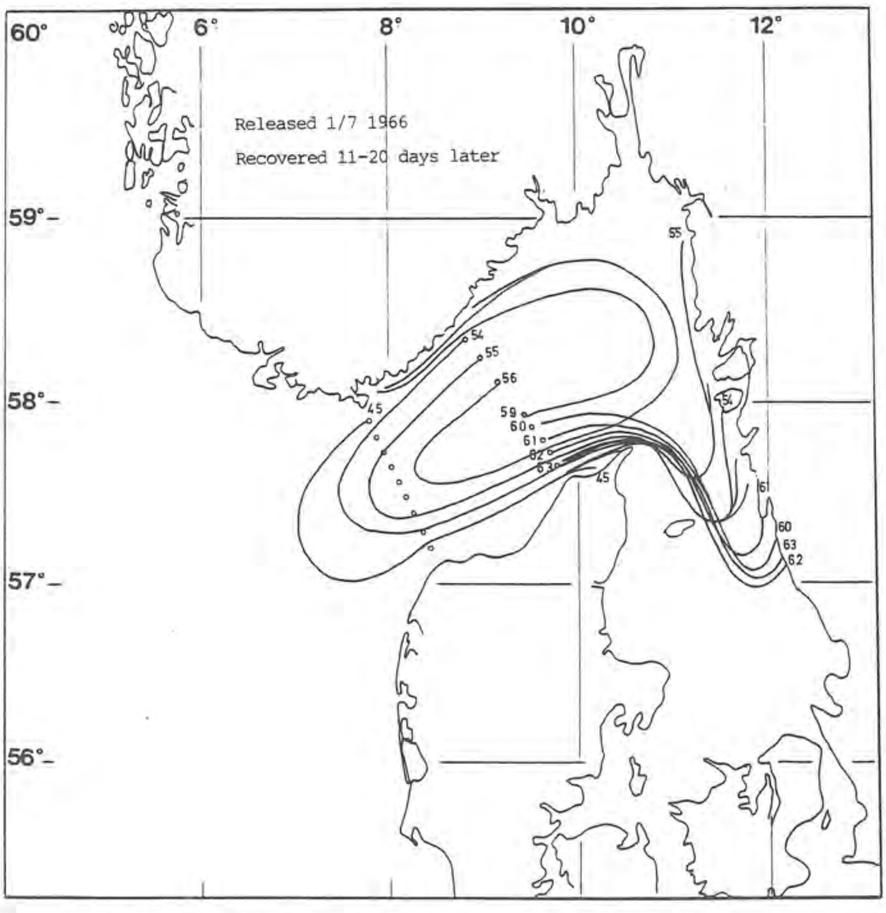


Fig 6. The circulation of the surface water in the Skagerrak using the" drifting cards" measuring method. (Engström 1967).

The plastic envelope is fastened by a brass wire to a little aluminium current cross that hangs about 20 cm under the envelope. The envelope contains enough air so that it can float in a vertical position.

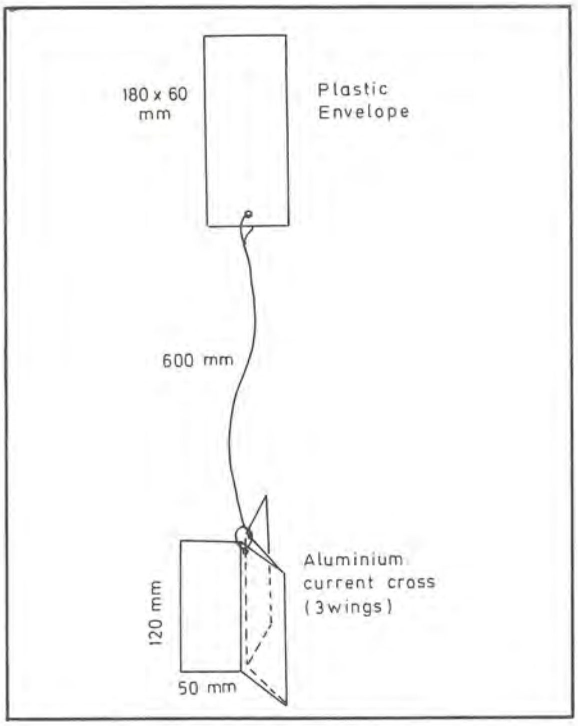


Fig 7. Drifting card.

The drifting cards are laid out in a line straight across the Skagerrak. The resultant spreading of the envelopes gives an ideas of the current conditions. In the figure can clearly be seen both the Jutland current forcing it's way into the Kattegat off the Skaw, and the Baltic current along the Swedish and Norwegian coasts (Engström 1966). The anti-clockwise circulation causes a welling up of water from the depths in the central area of the Skagerrak. This upwelling has been estimated to be in the region of 8000 km^3/year (Grimås et Svansson 1985).

Normally the Baltic current follows the Swedish coast both in the Kattegat and the Skagerrak depending partly on the Coriolis force that deflects all movement in the Northern hemisphere to the right, and partly on the prevailing south-west winds.

The Baltic current can also vary in strength and can occasionally spread itself out over nearly all the surface of the Skagerrak. The current is strongest some nautical miles from land and off the coast of Norway it can have a westward speed of more than three knots. It can also run against a fresh westerly wind and thus give rise to a choppy sea.

The Baltic current's volume of water is largest during Summer and lowest during Winter. It is reinforced by supplementary river water, mostly from Göta, Glomma and Drams rivers.

The Jutland current gets it's lower salinity (31-34 PSU) by the supplement of river water from the large continental rivers that run out into the North Sea. The current can have a very high speed and it is not unusual to measure speeds of between 2 to 3 knots.

The Jutland current can change course depending on the strength and direction of the wind from the Skaw. It can force it's way deep into the Kattegat, steer straight for the Swedish coast or veer to the north east towards the Väderöarna.
The circulation in the depths also has an anti-clockwise motion (Rodhe 1987).

Waves

Tides

The tidal system is underdeveloped in the Skagerrak. This is because the tidal waves in the North Sea move in an anti-clockwise direction depending on the Coriolis force, and are strongest on the east coast of England. Owing to the bottom friction in the shallow North Sea, the waves are weakened continually. The amplitude of the tide is therefore very small by the time the waves reach the boundary area between the North Sea and the Skagerrak.

Fig 8 shows the tide's phases in hours and amplitude in cm for the most important tide component M2 in the western seas (Svansson 1972). At spring tides the amplitude of the tide on the Swedish coast is about 30 cm. Tidal currents are weak, about 1-2 cm/s, except in narrow sounds.

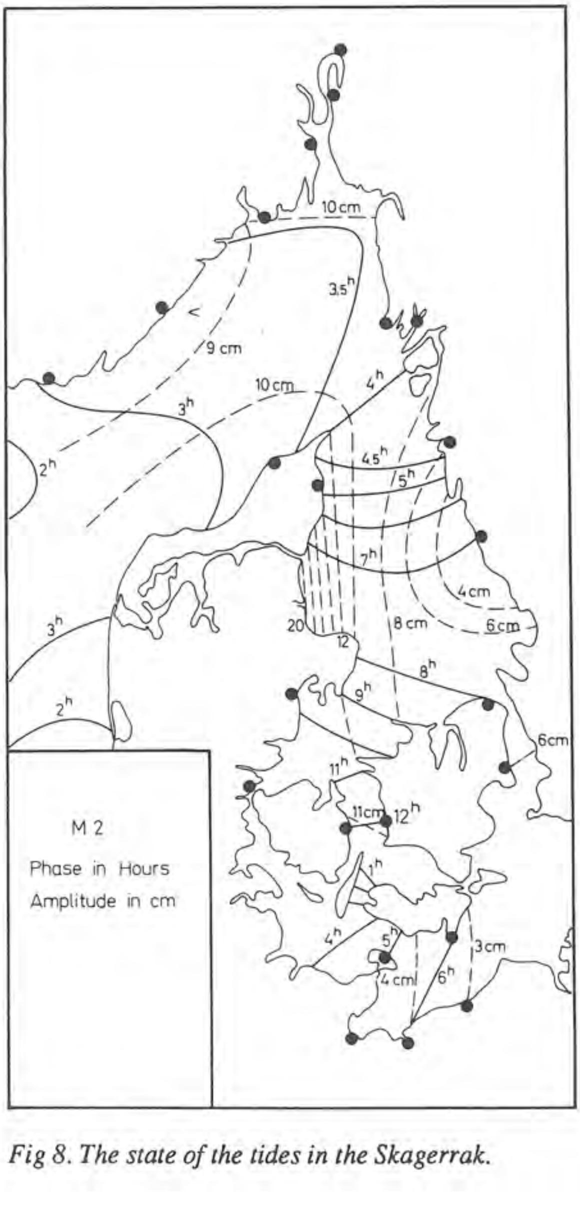


Fig 8. The state of the tides in the Skagerrak.

Internal waves

Internal waves occur in the border area between surface water and deep water. They are formed in the pycnocline, or density stratification. In the Skagerrak they can reach heights of some tens of metres, yet are practically unnoticable at the surface. They were first observed by Otto Pettersson in the Gullmars Fiord when the halocline at Bornö station alternately rose and sunk with an amplitude of up to 20 m.

The water´s stratification

The stratification of the water is dependent on the differences in density in a vertical direction. Water with a higher density lies under the "lighter" water. The boundary zone between two such layers is called the pycnocline or density stratification. In this zone the water density changes sharply within some tens of metres. There are two kinds of pycnoclines in the sea: a) The halocline or salinity stratification and b) the thermocline or temperature stratification.

In the Skagerrak the halocline is formed under the Baltic current's brackish water, which has a lower density than the deeper water in the Skagerrak. The water from the Baltic therefore lies above the saltier North Sea water.

The Jutland current also builds a halocline. There are no other pronounced halocline in the rest of the Skagerrak however. The thermocline are formed on the surface during Spring, when the water is warmed up by the sun. The warmer water gets a lower density and cannot sink downwards. The thermocline increase during Summer and in the beginning of Autumn. It cannot penetrate through the halocline in the Baltic current, but in other parts of the Skagerrak it can grow to a thickness of up to 30 m, depending on the length of the Summer and the intensity of the sun (see fig 9).

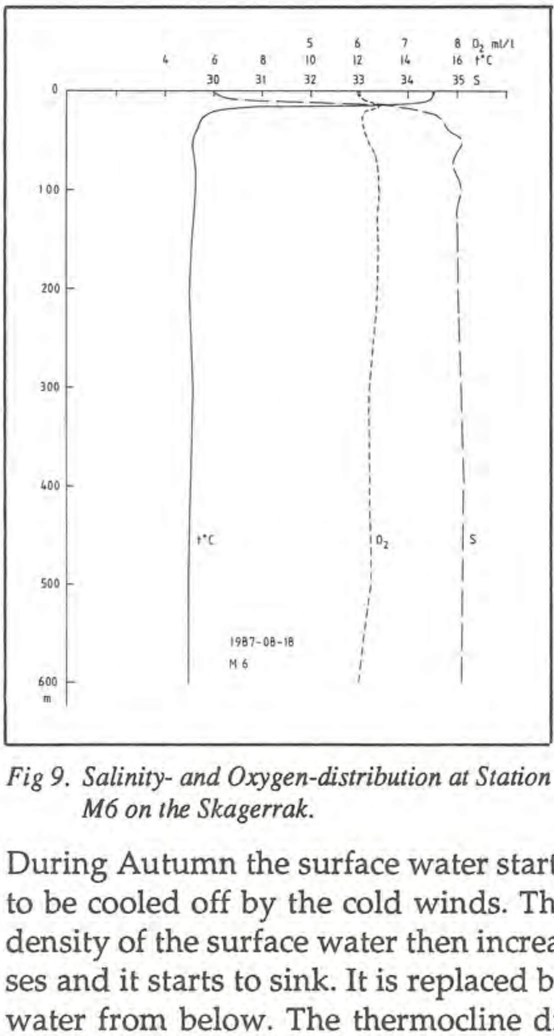


Fig 9. Salinity- and Oxygen-distribution at Station M6 on the Skagerrak.

During Autumn the surface water starts to be cooled off by the cold winds. The density of the surface water then increases and it starts to sink. It is replaced by water from below. The thermocline disappear entirely during Winter. The water then gets the same temperature down to the sea bed or, in the case of the deeper parts where the halocline is to be found, down to this layer. This is called vertical convection. During Spring the thermocline once more starts it's development cycle.

Salinity and temperature distribution

Fig 9 shows the vertical stratification in the Skagerrak at station M6 in the Skagerrak Trench in August 1987. We can see a surface layer of about 20 m with a lower salinity (30 PSU units), high temperature (15°) and nearly constant oxygen content (6 ml/l). This layer consists of Baltic water with a lower density. Under the surface the water is homogeneous with very nearly a constant salinity and temperature down to the bottom.

Fig 10a shows the salinity distribution in a cross section of the Skagerrak from Oksöy in Norway to Hanstholm on Jutland. Off the Norwegian coast one can see the Baltic current with it's low salinity in the surface water and on the Danish side the Jutland current appears in the same way. Similarly, fig 10b shows the temperature distribution. Here too one can distinguish both the Baltic and the Jutland currents by the different temperatures.

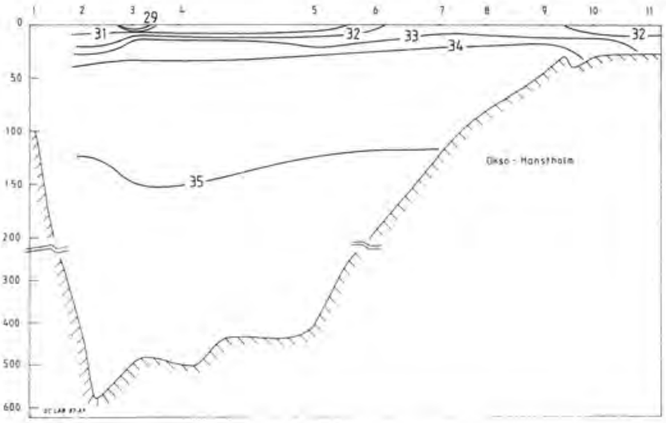


Fig 10 a. Cross section Oksöy-Hanstholm showing the Skagerrak's salinity, April 1987.

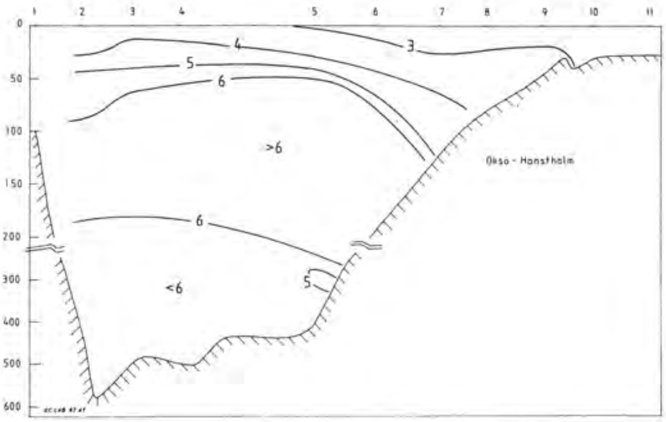


Fig 10 b. Cross section Oksöy-Hanstholm showing the Skagerrak's temperature, April 1987

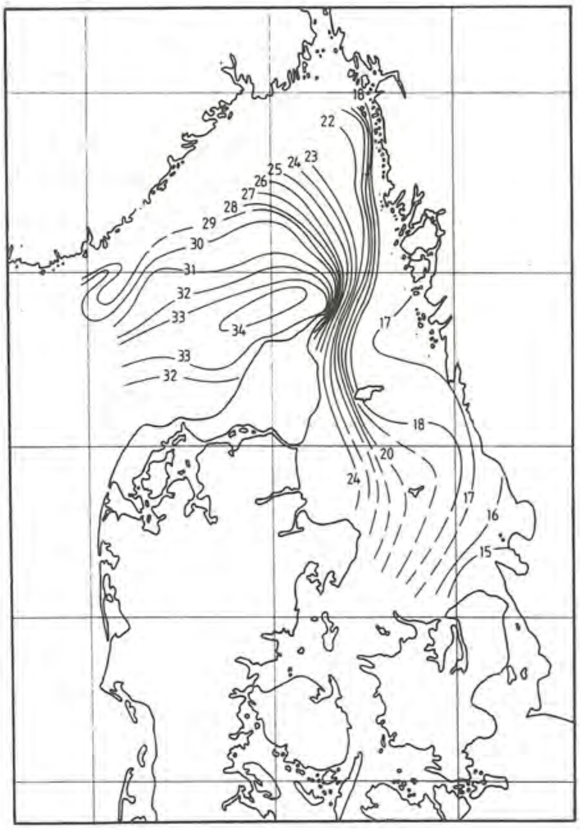


Fig 11 a. Salinity distribution on the surface of the Skagerrak, April 1987.

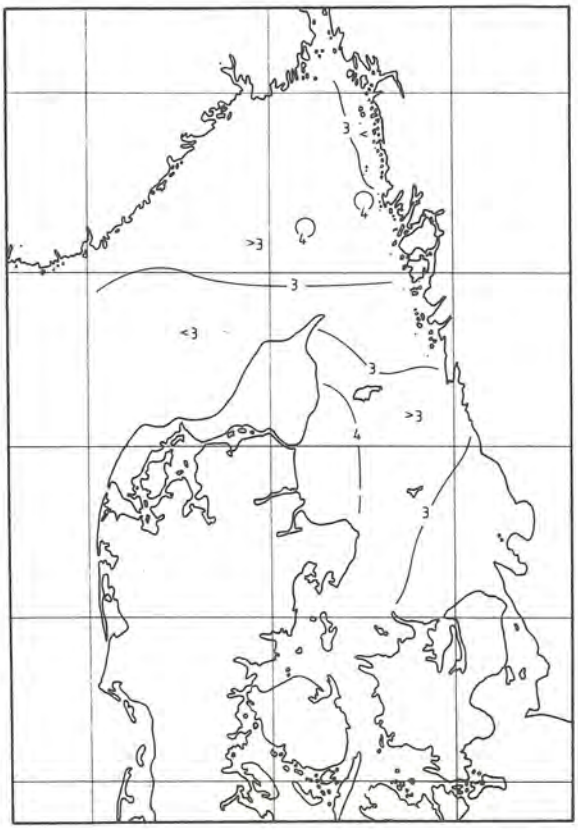


Fig 11 b. Temperature distribution on the surface of the Skagerrak, April 1987.

Fig 11a and 11b show the surface distribution of the salinity and temperature in the Skagerrak on the same occasion (April 1987).

The figures demonstrate the so called Skagerrak Front, where the salinity is drastically changed in the border area between the Kattegat and the Skagerrak (Fonselius 1989).

The Baltic current's water can sometimes spread out over the entire surface of the Skagerrak. In the depth of the Skagerrak the salinity conditions are practically oceanic, with a salinity of about 35 PSU, and do not differentiate from the conditions in the North Sea. In the depths of the Norwegian Trench one can notice periods of rising temperatures. These periods can last for several years before the temperatures suddenly fall (fig 12). This is because bodies of water with a high density are formed in the central North Sea during cold winters. This water runs over the lip down into the Skagerraks deepest part during the latter part of Winter and in early Spring (Ljöen and Svansson 1972).

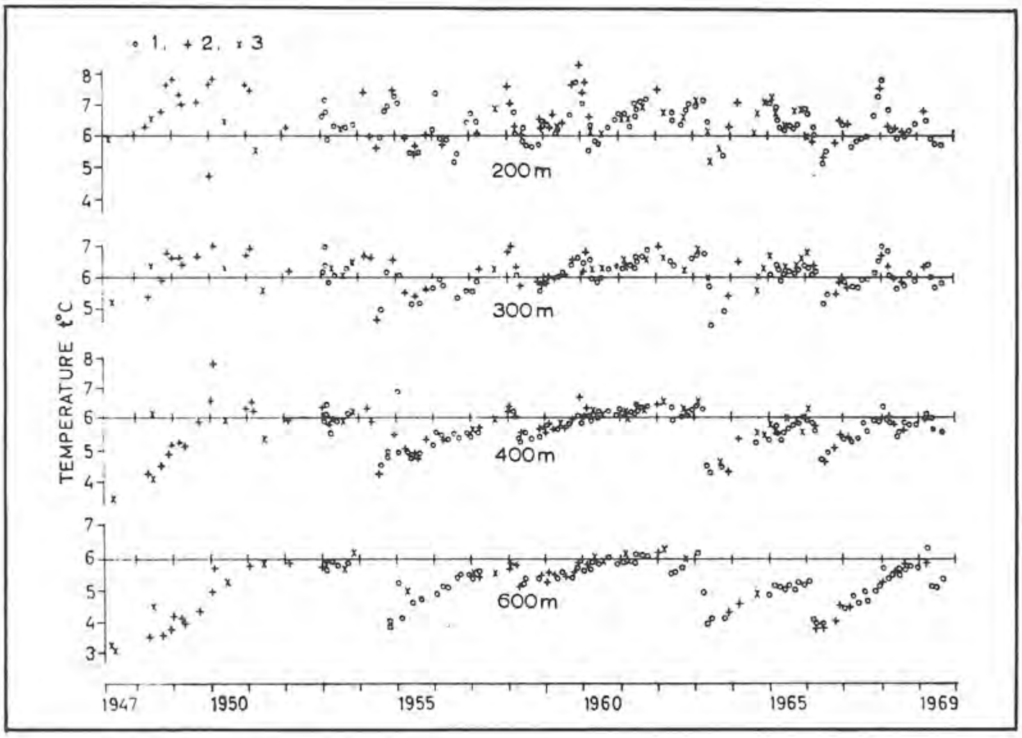


Fig 12. Long term temperature variations at some deep stations in the Skagerrak. (Ljöen et Svansson 1972)

Oxygen conditions

In the open Skagerrak the oxygen conditions are good (see fig 9). The oxygen saturation there is always above 85 %. In the threshold fiords and in the coastal areas of high industrial discharge it can be worse and many Norwegian fiords suffer from a complete lack of oxygen together with a resultant formation of hydrogen sulphide. This is the case with the Oslo, Ide and Udevalla fiords because of the communal and industrial discharge of organic material that consumes oxygen.

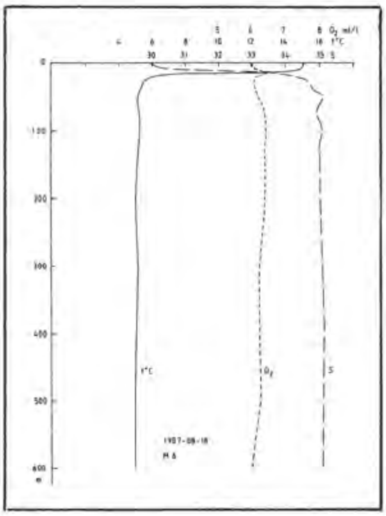


Fig 9 (shown before). Oxygen distribution at M6.

Nutrient salt conditions

Fig 13 a and b show the typical vertical distribution of nutrients at a deep water station on the Kattegat. In the surface layer, which consists of Baltic water with a low salinity, one can see that the nutrients are for the most part used up during the Summer. In the depths, the distribution of nutrients is homogeneous.

A certain amount of variations in the deep water contents of nitrates, silicates and total nitrogen occur in fig 13 b, but this depends on a lack of finesse in the methods of analysis, which can show strong deviations when dealing with large amounts of these elements.

The welling up of deep water in the middle of the Skagerrak gives an estimated supply of 175 000 tons P/year to the surface water (Grimås et Svansson 1985). Nutrients are brought to the Skagerrak by the Baltic current from the Kattegat and the Baltic. The Jutland current has a very high content of nitrates that come mainly from Germany and Denmark.

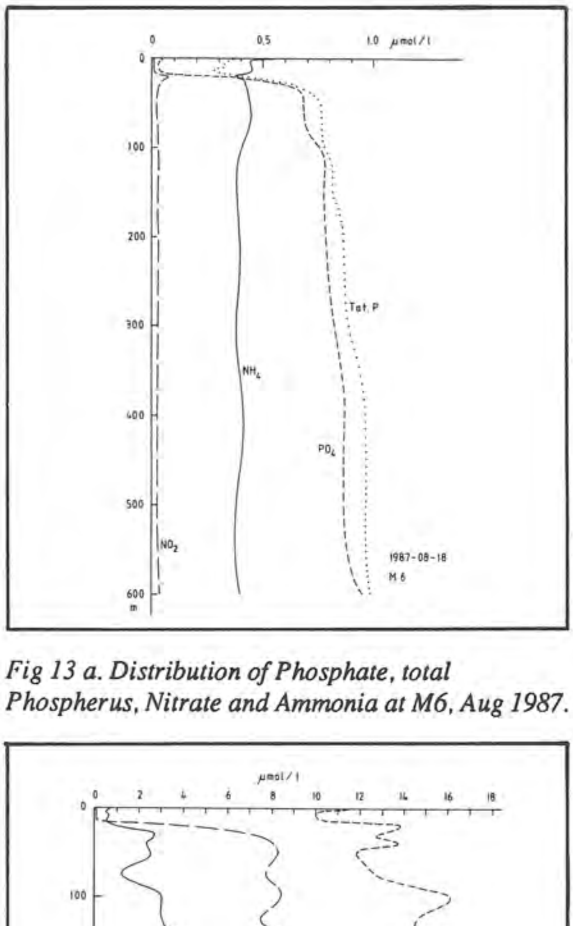


Fig 13 a. Distribution of Phosphate, total Phospherus, Nitrate and Ammonia at M6, Aug 1987.

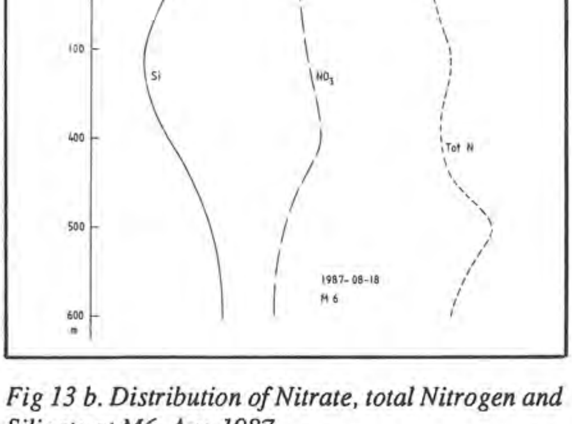
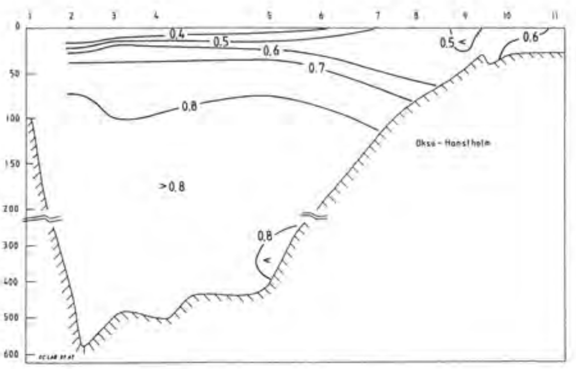


Fig 13 b. Distribution of Nitrate, total Nitrogen and Silicate at M6, Aug 1987.



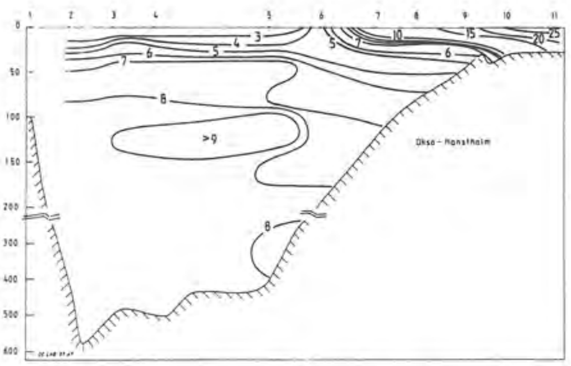
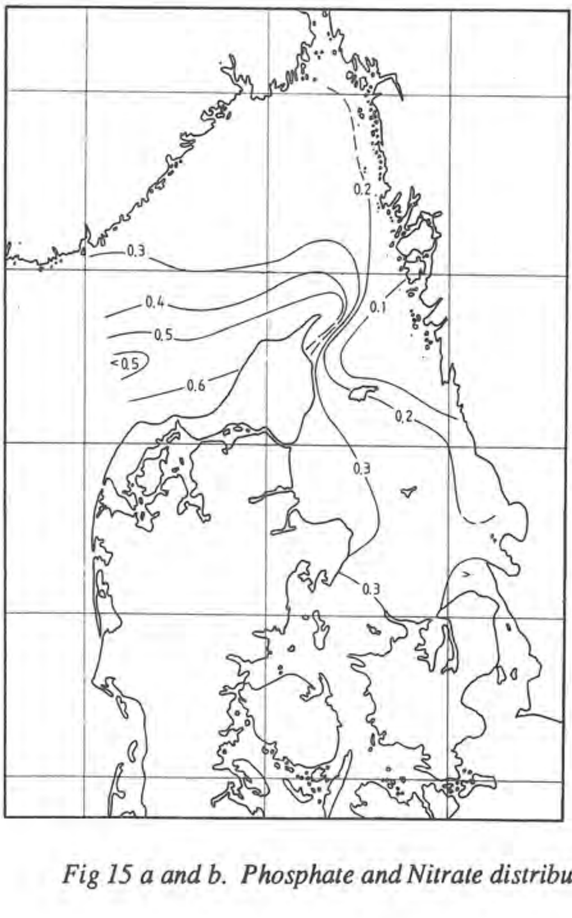


Fig 14 a and b. Cross section Oksöy -Hanstholm showing the distribution of Phosphate and Nitrate. April 1987

In fig 14 a and b one can see the distribution of nitrates and phosphates in the cross-section Oksöy - Hanstholm. One can clearly distinguish both the Baltic and the Jutland currents in the surface layer by their high concentration of nutrients.

Fig 15 a and b show the phosphate and nitrate distribution in the Skagerrak surface water in April 1987 (Fonselius 1989). One can clearly see the Jutland current owing to it's high content of nitrates. During Summer, this nitrogen disappears entirely due to the primary production and the surface water holds neither nitrates nor phosphates.



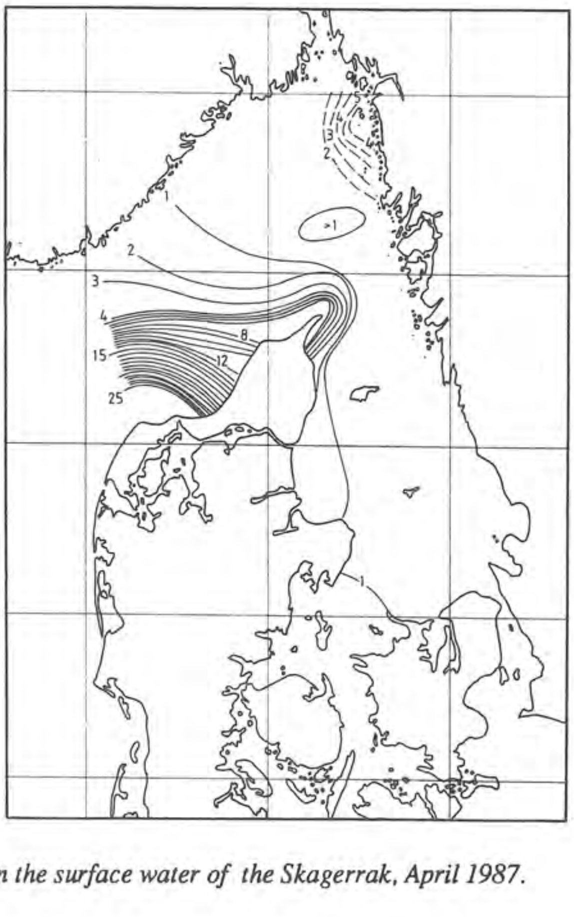


Fig 15 a and b. Phosphate and Nitrate distribution in the surface water of the Skagerrak, April 1987.

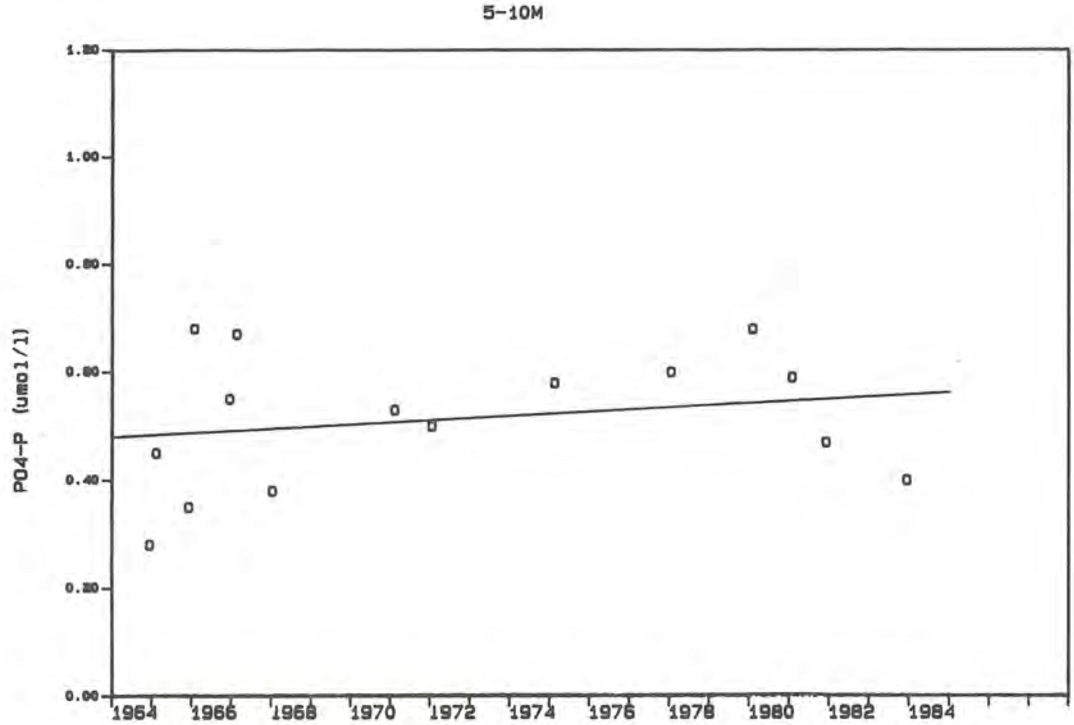
The rivers that flow out directly into the Skagerrak and northernmost Kattegat also contain high concentrations of nutrients. Table 3 shows the total supply of phosphorus and nitrogen directly to the Skagerrak from river water and communal sewage works on the Swedish coast. We also include the supply from the River Göta which admittedly flows out into the northern Kattegat but is almost immediately transfered to the Skagerrak.
One can see that the River Göta is the largest Swedish source of phosphorus and nitrogen to the Skagerrak.

TABLE 3

Supply	Total Phosphorus tons/year	Total Nitrogen tons/year
Municipal sewage works 1985	10	500
Industries	9	60
Fish farming	3	15
Coastal areas directly	60	900
To the Skagerrak from Swedish rivers	39	1300
Total from Sweden to the Skagerrak	121	2775
River Göta	390	19600
Gothenburg area´s sewage works	180	2000
Total load from Sweden	691	24915

The combined load from Denmark and Norway is 3380 tons P/year and 51 200 tons N/year. Of this total Denmarks contribution is negligable. When both the River Göta and Gothenburg region are included, the total yearly load to the Skagerrak lies around 4 100 tons P and 76 100 tons N (Report 3472, National Swedish Environmental Protection Board).

In the open sea one cannot find any significant trends for nutrients. Owing to the primary production of plankton in the surface water during the summer months the concentrations of nutrients are decreased to practically nothing and it is therefore difficult to use these summer figures in analysing a trend. One must therefore use the winter estimates and these are unfortunately relatively few.



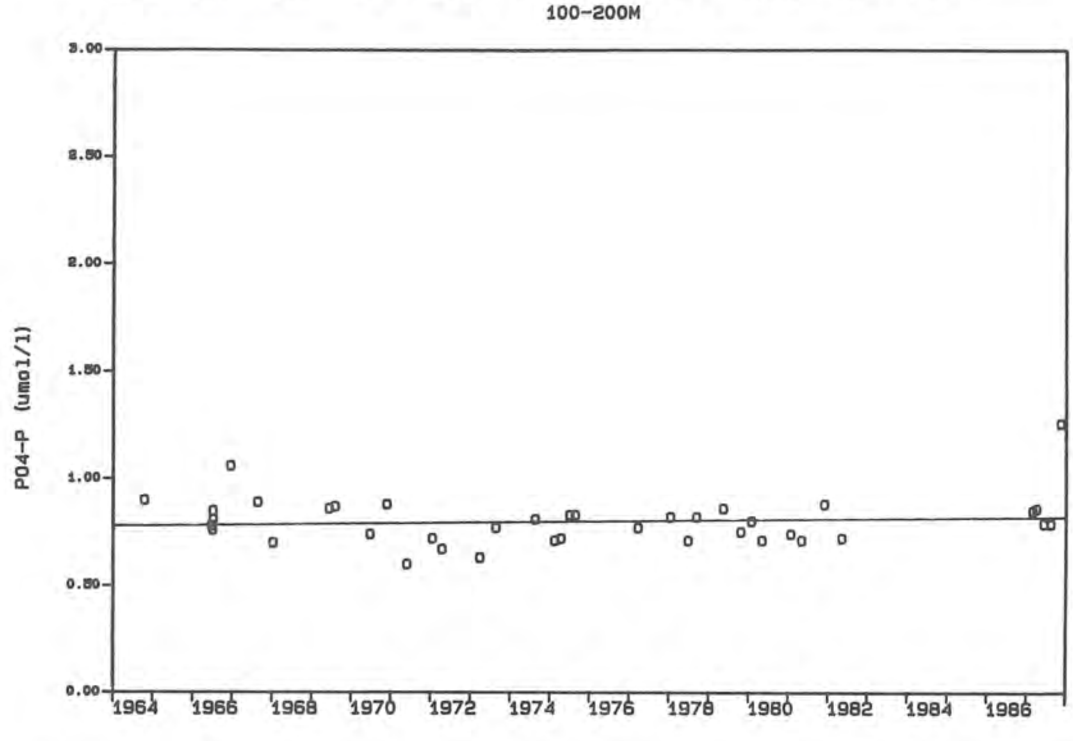


Fig 16 a and b. Long term variations in Phosphate content of the Skagerrak surface water. Daily mean values 1964 - 1987.

Only a few determinations of nitrates have been carried out during the period 1964-1987 and plankton blooming starts as soon as March and does not stop until the end of November. One is therefore limited to the results of the phosphate analysis and these in turn are limited to the three winter months of December, January and February. Fig 16 a shows the daily average of phosphates during the winter months at station Å18 between 5 to 10 m depth from 1964 to 1987. The weak increase can not be classed as significant.

Fig 16 b shows the variations in phosphates as daily averages in the depths of the Skagerrak during an entire year between 100 to 200 m during the same period of time. One cannot discover any signs of a trend.

The hydrographic conditions in some of the important fiords.

Oslo Fiord

Oslo Fiord is the largest of the Norwegian fiords in the Skagerrak. It is about 125 km in length when measured from the outer sill to Bunne Fiord's innermost part. Fig 17 shows a map over Oslo Fiord. Fig 18 a shows a longitudinal section of the bottom configuration and salinity distribution.

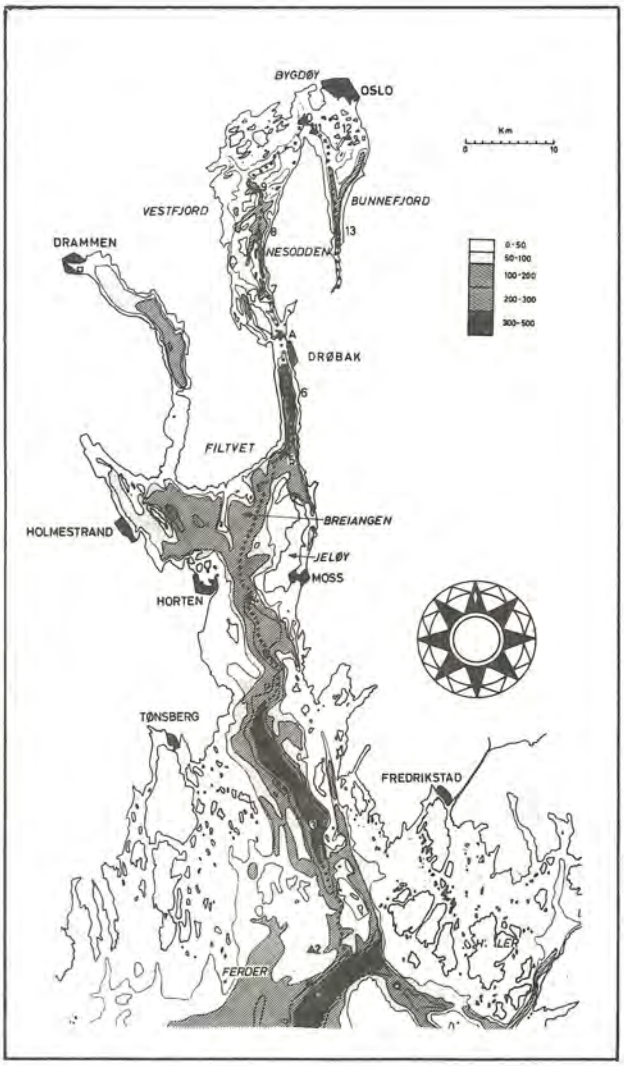


Fig 17. Bathymetric map of the Oslo Fiord.

It is usual to divide Oslo Fiord into three main parts. The area from Ferder to the narrowing between Horten and Moss is called The Outer Fiord. The River Glomma flows out into this at Fredrikstad. The area between this narrowing and the shallower and even smaller narrowing off Dröbak is called the Middle Fiord. This includes the wide area Breiangen, from which the Drams Fiord branches off, and also the smaller area north of Dröbak. The area within Dröbak is called the Inner Fiord.

One can distinguish four importantsills. The outermost, the Hvaler Ridge, stretches from the mouth of the fiord from Hvaler Islands on the east side to the Bolaerne Islands on the west side. This has a sill depth of about 100 m and separates Oslo Fiord from the deeper Skagerrak. The second under-water ridge of importance, the Jelöy Ridge, lies in the Middle Fiord and stretches from Jelöy towards the northwest. The sill depth is a little over 100 m.

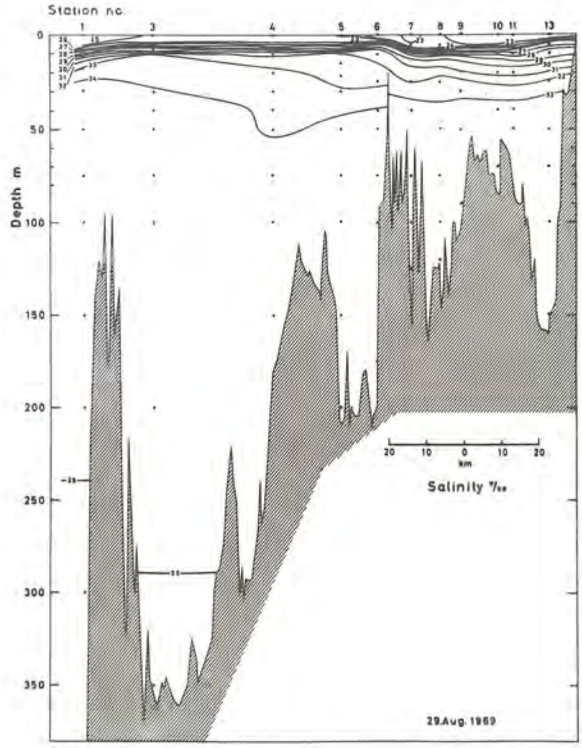
The most importantsill off Dröbak separates the Middle Fiord from the Inner Fiord. The silldepth is only 19.5 m while the maximum depth inside the sill is 164 m.

Finally, in the Inner Fiord, the Bygdöy Ridge separates the West Fiord from the Bunne Fiord, which stretches in a southerly direction. The sill depth is 55 m. On both sides of this sill, depths of about 160 m can be found.

A lowered salinity is characteristic for the whole area outside the mouth of the fiord, mainly owing to the influence of the Baltic current. To this is added the local discharge of the River Glomma in the Outer Fiord and the River Dram in the Middle Fiord. A number of smaller rivers run out into the Inner Fiord.

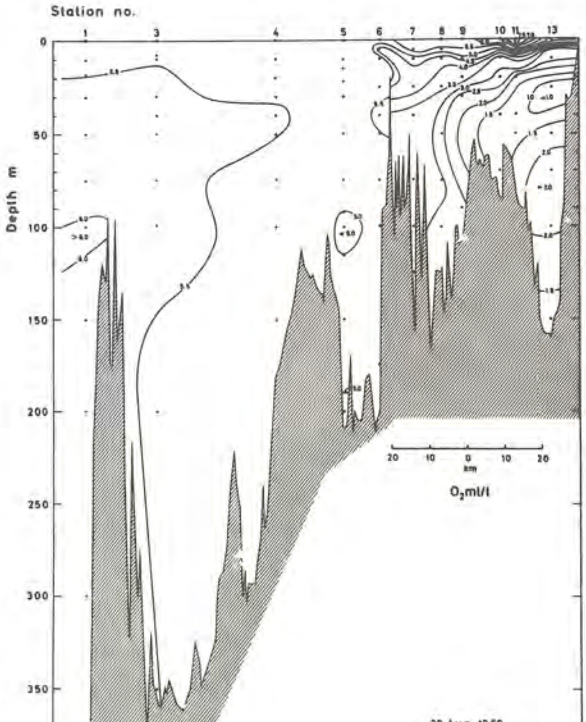
The halocline lies at a depth of about 10 m (see figure 18 a).

Owing to many sills the water turnover in the deeper parts is hindered, causing a periodical oxygen shortage and a resultant hydrogen sulphide formation, particularly in Bunne Fiord. The communal drainage water from Oslo collects mostly in Bunne Fiord (ICES 1970). Fig 18b shows the distribution of oxygen in Oslo Fiord.



Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations.

Fig 18 a. Distribution of the salinity content in the Oslo Fiord (Beyer 1970).



Longitudinal section from the mouth (left) to the head (right) of the Oslofjord. Dots mark depths of water bottle observations.

Fig 18 b. Distribution of the Oxygen content in the Oslo Fiord (Beyer 1970).

The Ide Fiord

The Ide Fiord is part of the border between Norway and Sweden. It is about 25 km long and curves off in a right angle at Halden (fig 19). Two main sills are to be found in it's mouth with sill depths of 8.5 - 9.5 m. Inside these lie two large basins with a maximum depth of about 40 m (see fig 18 a). The most important supply of fresh water is provided by the River Tista, which runs through Halden, and the River Berby at the furthermost point of the fiord. The former is strongly polluted by communal and industrial drainage water, while the latter contains clean water.

Fig 19. Surface map of the Ide Fiord showing the hydrographic stations.

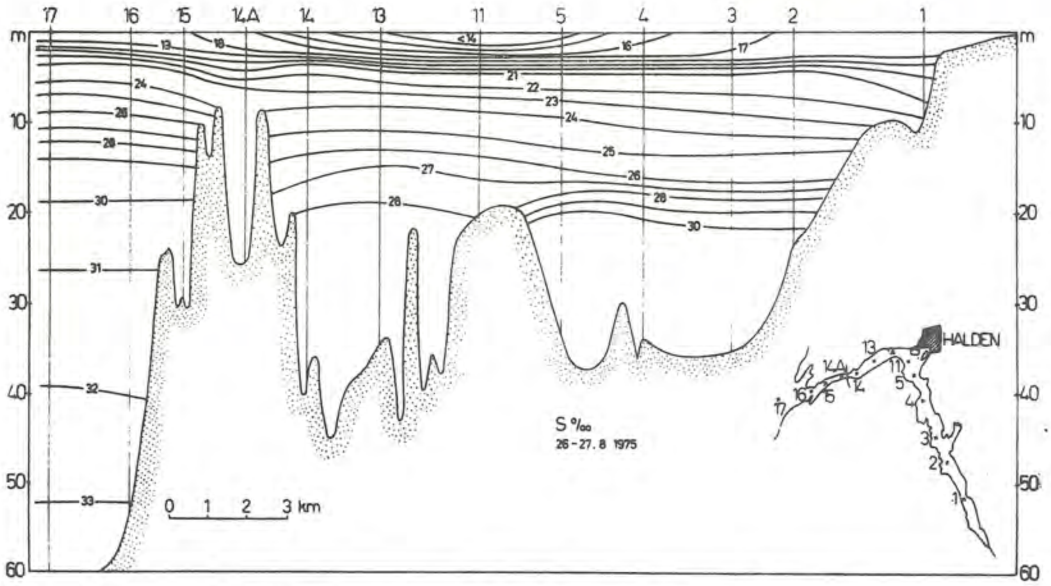


Fig 20 a. Distribution of the salinity in the Ide Fiord

Ide Fiord runs out into Single Fiord, which is more like a bight than a fiord (see fig 19). Ide Fiords lengthy and narrow form together with the high sills at the mouth tend to limit the turnover of water in the depths. The influx of fresh water builds a thin layer of brackish surface water that isolates the deeper water from contact with the atmosphere.

Fig 20 a shows the distribution of salt in August 1975. One can clearly see the supplement of fresh water from the River Tista in the surface water (station 11 in the figure)(Engström 1975).

Fig 20 b shows the distribution of oxygen and hydrogen sulphide in the Ide Fiord in August 1988 (Fyrberg 1988). Periodically the heavy Autumn storms cause the water in the Ide Fiord to be completely changed and the hydrogen sulphide disappears temporarily from the fiord.

The Ide Fiord is heavily polluted by industrial discharge from the pulp and paper mills in Halden. Fig 20 c shows the spread of lignosulphonic acid from the factory in Halden. This water has a high oxygen consumption and, as a result of the low turnover of water in the depths of the fiord, hydrogen sulphide is formed as the oxygen is used up (Engström 1975).

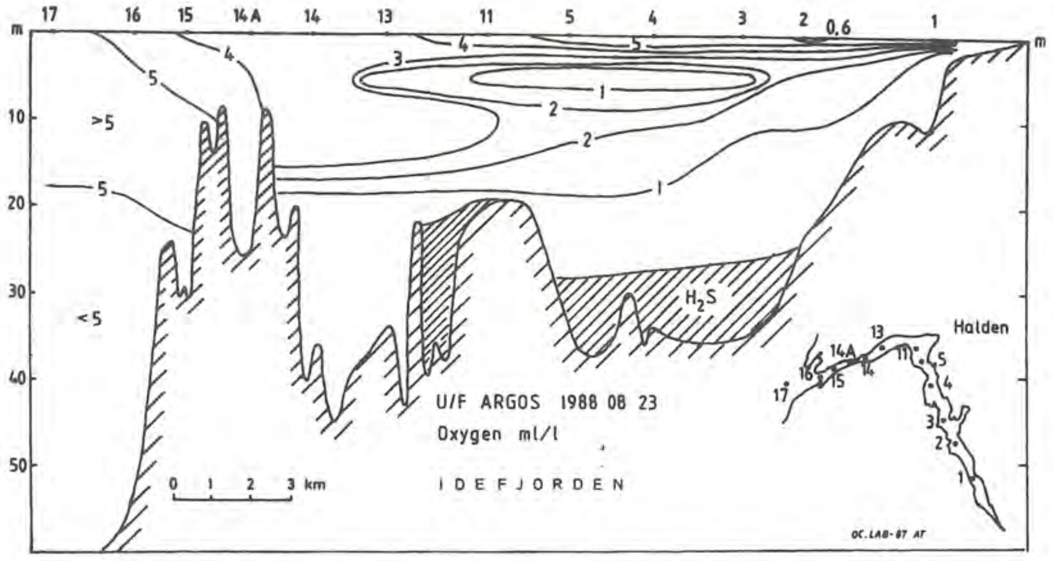


Fig 20 b. Distribution of the Oxygen and the Hydrogen Sulphide in the Ide Fiord.

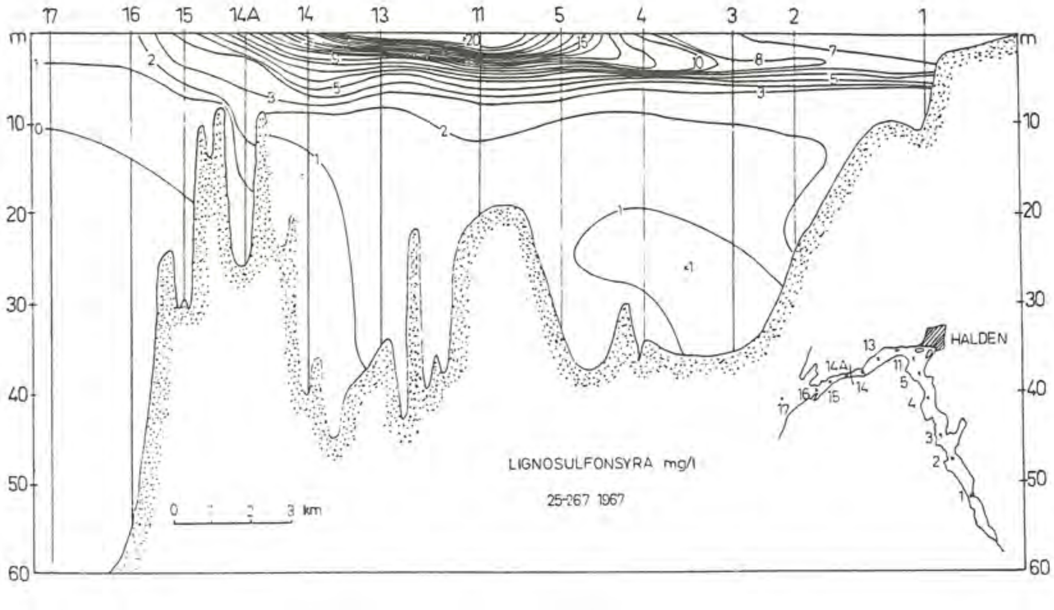


Fig 20 c. Distribution of the Ligno-sulphonic Acid in the Ide Fiord.

Fig 21. Map of the Gullmars Fiord.

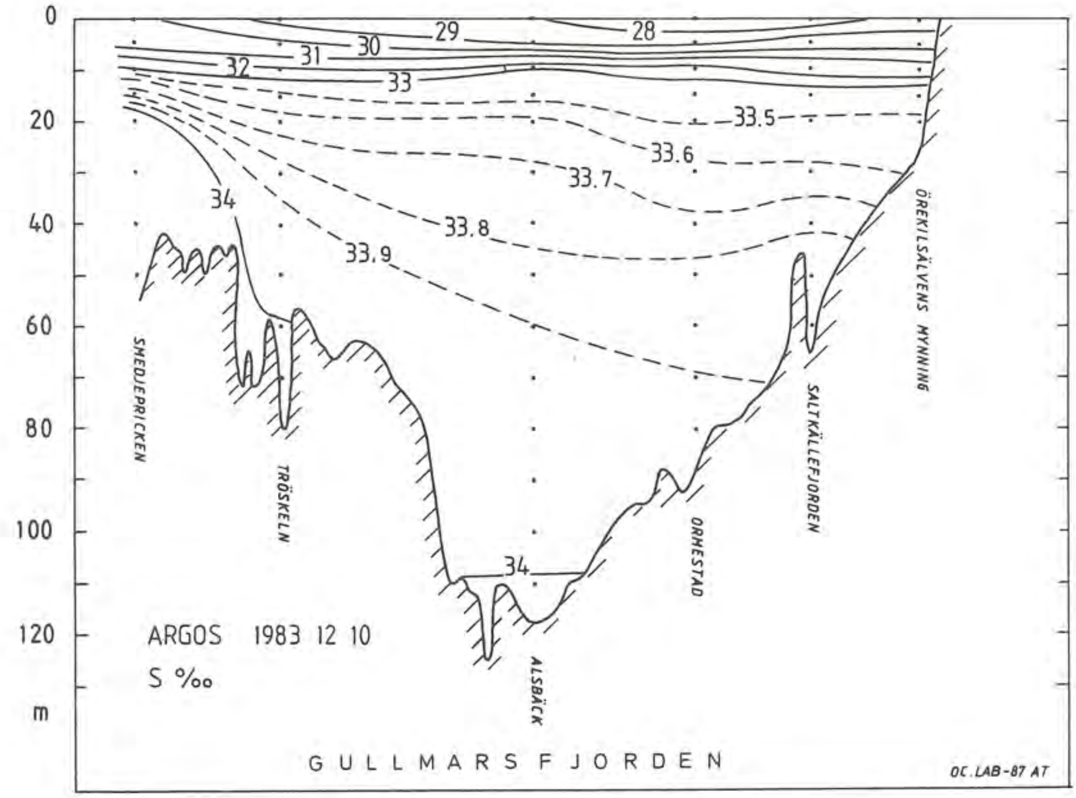
Gullmars Fiord

Gullmars Fiord or Gullmaren as it is also called (fig 21) is a typical sill fiord. It is 29 km long and the width varies between 1 to 4 km. The surface is about 50 km^2 and it reaches it's biggest depth of 125 m off Alsbäck. In the mouth there is a sill at 42 m depth. There is also a narrow and shallow trench inside Skaftön, which connects Gullmaren with Koljö Fiord.

Gullmaren has two bi-fiords furthest up the fiord, Saltkälle Fiord and Färlev Fiord. (see fig 21). The former has a sill at 45 m at it's mouth and a maximum depth inside the sill of 66 m. In the innermost part of Saltkälle Fiord the River Örekil joins the fiord with an average supply of 21 m^3/s, the only large source of fresh water in Gullmars Fiord.

Fig 22 a shows a vertical longitudinal section of the fiord in December 1983, from the mouth to the Saltkälle Fiord, showing the salinity distribution.

Fig 22 b shows a corresponding distribution of the oxygen. We can see how the oxygen content in the water at the bottom lies under 1 ml/l. This is because this deep water has not been changed during the summer.



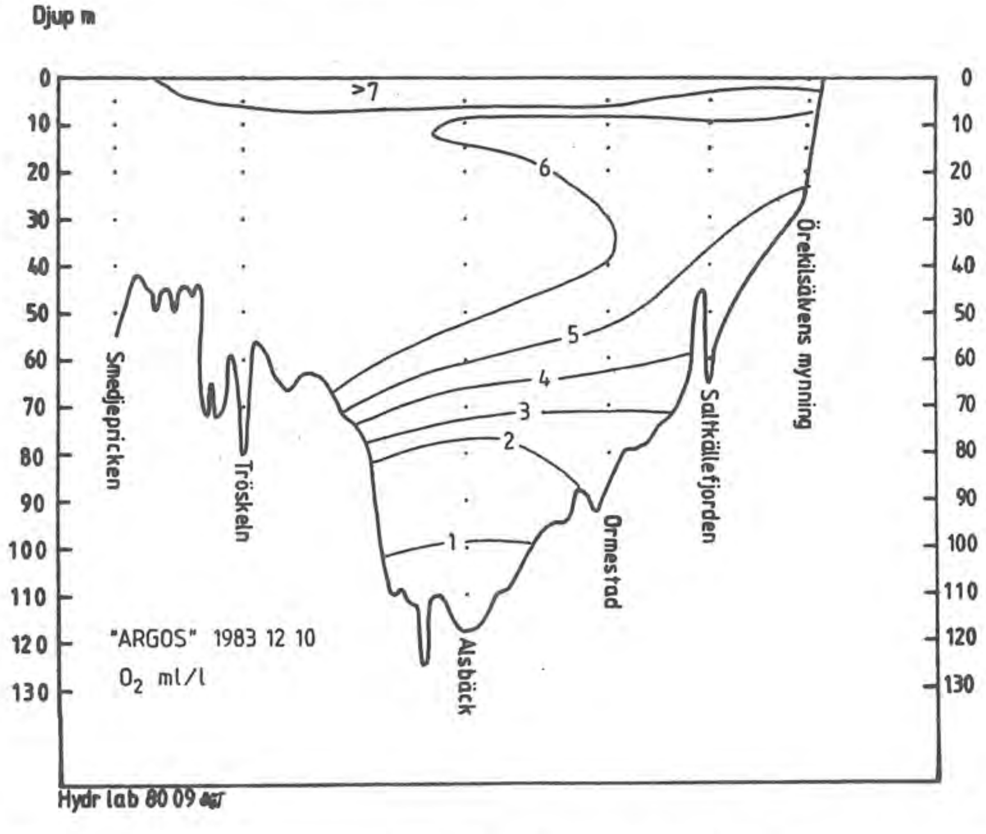
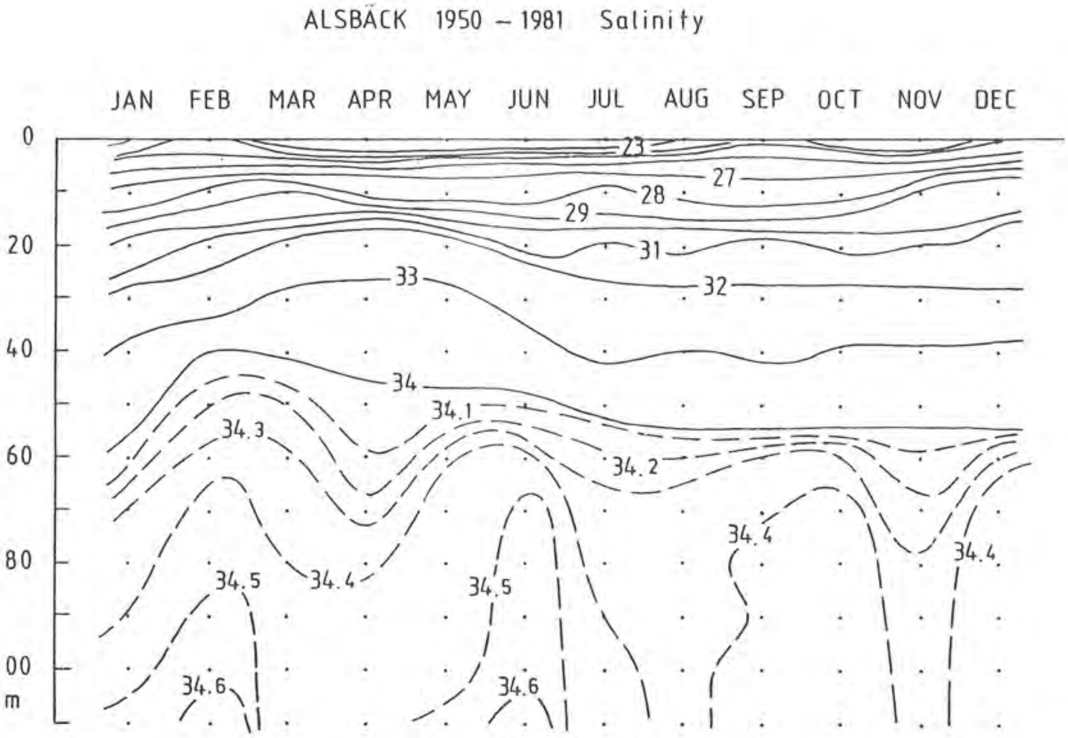


Fig 22 a and b. Longitudinal section of the Gullmars Fiord showing the salinity and oxygen content in December 1983.



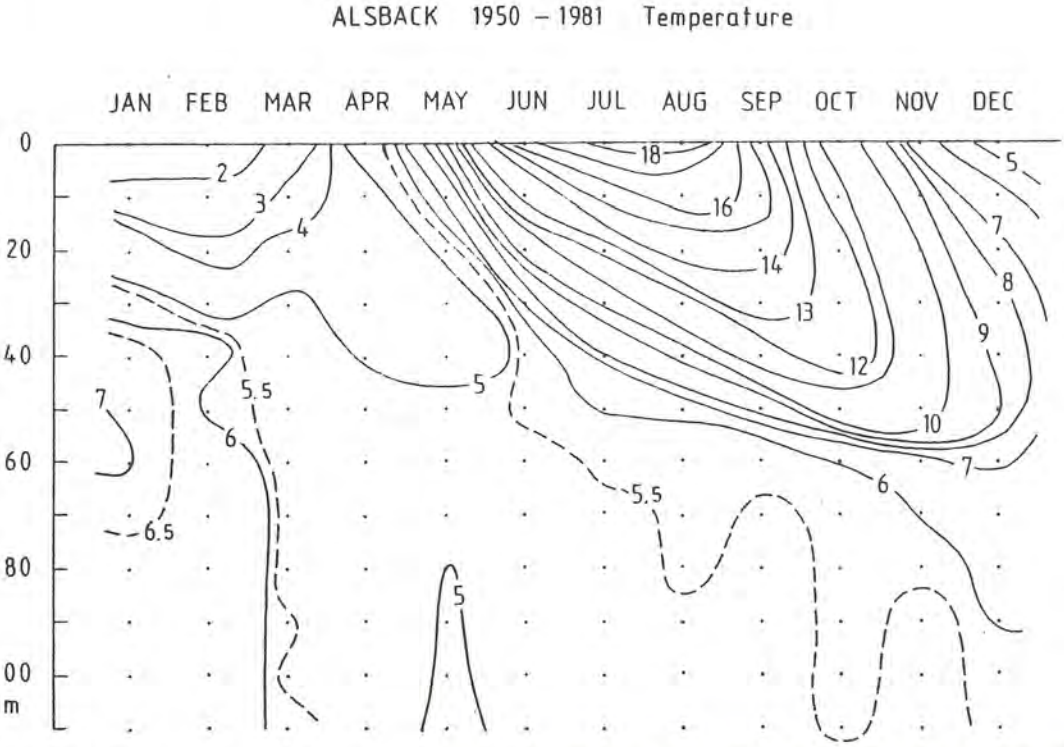


Fig 23 a and b. The average salinity and temperature distribution off Alsbäck, during the period 1950 - 1981.

Fig 23 a shows the average yearly salinity off Alsbäck. We can see how the deep water is perodically changed by the influx of saltier water over the threshold. The water is stratified with a roughly 20 m deep surface layer which has a lower salinity.

Fig 23 b shows the yearly temperature averages at the same place. One can see how the water is warmed up, down to a depth of about 50 m (Svansson 1984).

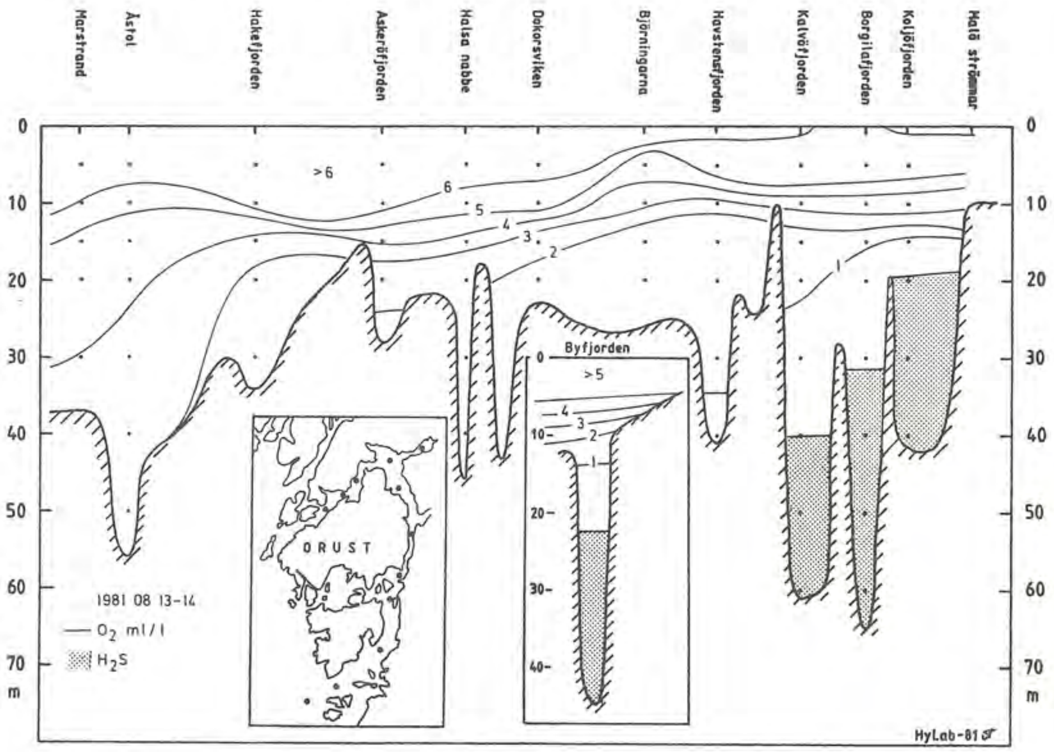


Fig 24. Map and longitudinal section of the Uddevalla Fiords showing the distribution of Oxygen and Hydrogen Sulphide in August 1981.

Uddevalla Fiords

The water landwards of Orust and Tjörn is called the Uddevalla Fiords. They are however not true fiords but rather a system of semi-enclosed bays and bights separated from each other by shallow sills.

The By Fiord, which stretches in to Uddevalla from Havstens Fiord, is the only true fiord. Fig 24 shows the distribution of oxygen in the fiord system in June 1986. We can see how the oxygen values in certain fiords are very low and that hydrogen sulphide is present at the bottom of By Fiord, Kalvö Fiord, Borgila Fiord and Koljö Fiord. The presence of hydrogen sulphide in Koljö Fiord is through natural causes, but in all the others the most probable cause is the communal and industrial discharge in the area.

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