DEVELOPMENTS IN THE NORTH SEA AND THEIR CONSEQUENCES FOR THE MARINE ENVIRONMENT

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by

D. Eisma

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INTRODUCTION

The North Sea, a shallow sea covering part of the North-west-European continental shelf, has in recent years experienced an enormous increase in human activities. Shipping, fisheries, extraction of oil, gas, sand and gravel, military activities and dumping of waste materials have been developed on a large scale. Particularly the Southern North Sea, where most of the shipping, gravel extraction and waste dumping is concentrated together with an important part of the natural gas extraction and fisheries, has become a rather crowded sea-area (Fig. 1). Some of these activities have had a clearly negative effect on the marine environment, for other activities this is less clear, but beneficial effects on marine life have hardly been observed. On future consequences there is still considerable uncertainty but past experience with the effects of large scale human activities focussed on a relatively small area indicates that if nothing more is done to prevent a deterioration of the North Sea environment, more negative effects are to be expected. Negative effects are here broadly defined as effects that result in a reduction of the natural abundance and diversity of marine life in the North Sea. In this paper the North Sea environment and the effects of human activity up to the present will be discussed and an indication is given of what is necessary now or will be so in the near future in order to prevent further deterioration. The emphasis is on the effects for the marine environment but also some mutually negative interaction has developed between some of the activities themselves such as between fisheries and oil and gas extraction.

II. THE NORTH SEA ENVIRONMENT

On the basis of waterdepth and bottom morphology the North Sea is generally divided into four parts (Fig. 2) : the Southern North Sea south and east of Dogger Bank with a maximum depth of 51 metres and an average depth of 30-40 m (70-90 m in some isolated submarine valleys), the Central North Sea north of Dogger Bank down to the 100 m depth line (waterdepth in some isolated valleys down to more than 250 m), the Northern North Sea north of the 100 m depth line up to Orkney and Shetland (waterdepth 100-150 m, in some isolated valleys more than 200 m), and the Norwegian Channel or Norwegian Trench with a waterdepth of 700 m in the Skagerrak, c. 225 m off Stavanger and c. 500 m at the continental margin.

The North Sea basin is slowly subsiding and had been doing so for approximately 225 million years. During subsidence it was simultaneously filled with sediment so that the sea remained shallow and during short periods even fell dry. The total thickness of the sediments in the central part is now c. 7 kilometers. Before the formation of the North Sea basin the southern part belonged to a large eastwest basin that was gradually filled with peat which after some time became coal. During the formation of the coal natural gas was formed (CH_4 - methane - as well as H_2S, CO_2 and hydrocarbons of a higher order). The gas migrated upwards through cracks and pores of the sediments that had been deposited on top of the coal but became confined below layers of rock salt formed during Permian. In this way the gas fields in the southern North Sea area originated. Later oil with associated gas was formed in the sediments deposited on top of the rock salt. This oil also migrated and was trapped below impermeable layers (clay, rock salt). When at the end of the Tertiary, approximately 1 million year ago, the climate cooled down, large masses of ice were formed around the poles during four, probably six cold periods and sealevel sank periodically to c. 100 metres below present level. During these periods the North Sea floor became dry land and during at least two cold periods ice sheets flowed southward from Scandinavia and Scotland and covered almost the entire North Sea area. Approximately 11 000 years ago the climate became warmer again, sealevel rose and c. 5 000 years ago the present situation was established.

1. Bottom deposits

The sediments on the present North Sea floor have for a large part been formed during or at the end of the last cold period and were deposited by ice, by rivers or by the wind. These are mainly sandy sediments or gravel and were reworked to some extend during the rise of sealevel. Present rivers do not carry sand or gravel into the North Sea, only mud (in suspension). The mud is deposited in several isolated areas where current velocities are favourable for mud deposition. Because of their mixed origin the bottom deposits show a very patchy distribution (Fig. 3). The seafloor is not flat but especially the sands and gravels have been accumulated as large sand and gravel banks. Also broad valleys have been eroded into the seafloor during the cold periods when the North Sea was land (the Norwegian Channel and smaller valleys in the Outer Silver Pit area and in the Central and Northern North Sea). Many of these valleys were subsequently filled up with sediment. In the very shallow Southern North Sea linear sand banks have been formed (up to 65 km long, 2 km wide and 40 m high) as well as large sand dunes (up to 15 m high and some hundreds of meters long). The linear banks follow the general direction of the tidal currents at a small angle; the sand dunes are aligned perpendicular to the main currents, like large sand ripples. In the finegrained deposits covering the deeper parts of the North Sea floor (Fladen Grounds, Norwegian Channel) there are so-called pockmarks : circular or oval depressions op to 200 m wide and 10 m deep. They are formed by gas escaping from the mud.

2. Water flow

Water flow in the North Sea (Fig. 4) is related to:

- inflow of ocean water between Scotland and Shetland (9 000 km^3/yr) and around Shetland into the Norwegian Channel (42 000 km^3/yr),
- inflow of Channel water through the Straits of Dover (4900 $\pm$ 725 km^3/yr),
- inflow of river water (290 km^3/yr) and of low salinity water from the Baltic (500 km^3/yr),
- tidal currents (Fig. 5) : the tidal wave enters through the Straits of Dover, between Scotland and Shetland, and between Shetland and Norway, and moves anticlockwise through the North Sea,
- "residual currents" (Fig. 3, 4) being related to the wind field over the North Sea and to a small residual movement in the tidal wave, resulting in a generally anticlockwise circulation in the North Sea,
- windstress, affecting the water surface and resulting in surface waves, wave movement decreasing with increasing waterdepth; in shallow parts of the North Sea, such as the Southern Bight, the whole water column may be moving during strong winds, in deeper parts this happens only during very severe storms,
- density differences, especially in the coastal areas where the surface water will be somewhat warmer and less saline than the deeper water.

The net result of all these movements in the general anti-clockwise flow shown in Fig. 3 and Fig. 4 but the variability is large because of the variable wind conditions. This circulation keeps material supplied from land (chiefly by rivers) close to the coast and only very small part escapes in an off-shore direction perpendicular to the coast. The entire water-mass of the North Sea is renewed, on the average, in somewhat less than a year, but in some parts the water may stay much longer than in other parts.

The mixing of ocean water with various types of the river water, and changes in the chemical composition of the water (because of plankton growth and decomposition of organic material), produce a number of distinct watermasses (Fig. 6). There is a continuous flow through the boundaries but it is a more or less steady state. During the winter the boundaries are in a slightly different position than during the summer.

An important feature of the North Sea is the thermocline that develops every year in the deeper parts of the North Sea. During spring and summer the surface water down to ca. 40 m depth is warmed up to a temperature of 14-16° C whereas the deeper water remains at 6-7° C. Cooling during autumn and increasing storm activity result in mixing of surface water and deeper water.

3. Chemical composition

The chemical composition of the ocean water entering the North Sea between Scotland and Norway, and the Channel water entering through the Straits of Dover, is in the North Sea strongly influenced by

- the admixture of fresh water from the land
- the growth and decay of organisms
- pollution
- the supply of material from the atmosphere
- processes that regulate the adsorption (or desorption of

elements and compounds onto (or from) suspended particles and bottom sediments.

Because of the supply of river water there are strong gradients between the coastal waters and the more oceanic water further offshore.

For plankton growth and hence for all other life in the sea nitrogen (present as nitrate, nitrite and ammonia), phosporous (present as phosphate) and to some extent silicon (present as silicate) are necessary besides water, carbondioxide and sulphate. The latter three are present in abundance but N, P and Si (the so-called nutrients) occur in low concentrations (in the order of mg/1). They are supplied by rivers, nitrate also from the atmosphere with rain. Silicate is necessary for the growth of diatoms which in temperate seas like the North Sea form a large part of the phytoplankton. Also a number of trace metals like zinc and copper are important for plankton growth, as well as a number of organic compounds such as vitamins. Phytoplankton forms the food basis for all other organisms in the sea.

Pollutants enter the North Sea from rivers, from direct discharges and from the atmosphere. Supply from the atmosphere is relatively small but can be important for some trace metals and chlorinated hydrocarbons.

On the processes of adsorption and desorption, that mainly take place in estuaries, not much is known but many substances in the sea, including pollutants, are adsorbed on particles in suspension (mostly $<70\mu m$) : concentrations in suspended matter and in finegrained bottom deposits of all kinds of elements and compounds are usually one or more orders of magnitude higher than in solution or in sandy bottom deposits.

Dispersal of many substances is therefore strongly related to the dispersal of suspended matter which acts as a carrier. In the North Sea suspended matter comes from rivers, from coastal erosion and seafloor erosion, from the Atlantic Ocean the Channel and the Baltic, from the atmosphere and primary production. In total c. 40 million ton (dryweight) of non-living suspended material is moved through the North Sea, to which must be added the amounts of phytoplankton and other plankton that are temporarily present between March and October but are almost entirely decomposed again at the end of the year. C. 14.5 million ton of non-living suspended material is transported out of the North Sea into the North Atlantic Ocean (Norwegian Sea). Of the remaining c. 25 million ton 20-30 % is deposited nearshore (in estuaries, on tidal flats, or dumped on land), 40-60 % is deposited in the Skagerrak/Kattegat and the Norwegian Channel, and c. 8 million ton is deposited in several small areas in the Southern North Sea (Outer Silver Pit, German Bight)

4. Phytoplankton (primary production)

The growth of phytoplankton in the North Sea is strongly related to the season : high in early spring, less in summer and autumn and almost absent during winter. The limiting factors are largely the amount of sunlight that is available (minimum in winter) and the concentrations of nutrients in the water (high at the beginning of spring, low in summer, increasing in autumn, high again during winter). Plankton growth is optimal where the sunlight can penetrate far into nutrients-rich waters, which occurs during spring outside the more turbid coastal areas. Sometimes also later in the year, when the turbidity drops in the coastal waters during a period of very calm weather and when nutrients are supplied from rivers, plankton growth may be locally and temporarily very high. Diatoms are abundant in the North Sea in early spring, followed by dinoflagellates when the silica has almost been used op. Phytoplankton growth can be measured by adding radioactive carbon to a sample in the form of bicarbonate. In the Channel yearly 80-200 gr carbon (C) may be bound as organic matter per m^2, in the Falden Grounds this is 50-125 gr C/m^2 (in winter less than 0.5 gr/m^2). Phytoplankton is consumed by zoöplankton and these in their turn are consumed by larger organisms (food-chain). Most of the organic matter that is consumed by animals is used for swimming and other body-functions and only less than 10 % goes into flesh and skin. High up in the food chain only a very small fraction of the original amount of phytoplankton is present in the form of animals. About all the orginic matter formed in the North Sea is consumed or decomposed. Only a very small fraction (in order of less than 1 %) is retained in bottom deposits.

5. Bottom fauna and flora

Depending on type of bottom (rock, gravel, coarse sand, fine sand, mud) the water depth and the conditions of temperature, salinity, turbidity etc. different faunal and floral associations are present on the sea floor. Flora is restricted to those parts of the sea floor which receive sufficient light for photo-synthesis. Large algae prefer a firm base and therefore live mainly on rocky and gravelly shores, sometimes in dense fields, and form a basis of attachment for other organisms.

The food supply is important for the distribution and density of bottom fauna : sand bottoms are usually poor in food while there is often considerable movement of the bottom by currents and waves, so that populations on sandy bottoms are usually rather poor in number. Muddy bottoms however, which have a high food supply, usually support populations of high density, except when oxygen is lacking which in the North Sea area is very rare (mainly in some fjords). The patchy distribution of the bottom deposits in the North Sea has resulted in a very patchy distribution of bottom fauna. Relatively rich areas are e.g. a narrow strip along the Dutch coast with fine sand and mud, the muddy areas of the Oyster Grounds, the German Bight and the Skagerrak, and some coastal inlets as well as large parts of the Waddensea. The surf zone is almost barren because of the combination of strong wave action and low temperatures in the winter. The bottom fauna provides the food (molluscs, worms) for many fish species (e.g. bottom dwelling flatfish like sole and plaice, and cod).

6. Fish

Marine animals live in great number in the North Sea, swimming, floating and on or in the bottom. Fish especially has been important : eleven species, but chiefly herring and mackerel, are heavily fished and account for 93 % of the yearly catches. Each species occurs in several subpopulations with different spawning areas, usually migrating between loosely defined sea-areas. Some fish species migrate from the sea into fresh water and the reverse, the most famous example in the North Sea being the eel. The entire North Sea is populated by fish - and fishing extends over the North Sea - but especially important are the shallower areas around the North Sea (the Oosterschelde, the Waddensea, and shallow nearshore areas). Here young fish grows up and only begins to live in the open North Sea when large enough. Also shrimp and other smaller organisms grow up in shallow parts like the Waddensea and the swales on the beaches. These shallow areas are warm in summer but cold in winter so that many species show a seasonal migration. Also there is migration to and from areas that are especially suitable for spawning (e.g. gravel and coarse sand for herring). Most fish species have pelagic (planktonic) eggs and larvae that gradually develop into mature fish, some species gathering together in large schools (herring, mackerel), some moving near to the seafloor (cod), some going to live on or half in the seafloor (sole, plaice).

7. Birds and marine mammals

Birds in the North Sea area live mainly nearshore and obtain their food on the beaches and rocks, on tidal flats and salt marches, in lagoons and on the mainland. Among the coastal areas especially the Waddensea is important for many species. A small number of bird species (such as the fulmar) live most of the year out in the sea and only for a short time come to the shore to lay eggs and rear their young. Migrating birds, including many small singing birds and birds of prey like owls, cross the North Sea in large numbers. They cross the North Sea everywhere, mainly during spring and autumn, but in periods of bad weather they follow the coasts and cross only for a small distance (like at Strait Dover-Calais and in the Skagerrak).

Many birds nestle in the saltmarshes along the tidal flats, some in coastal dunes and on steep isolated cliffs (Helgoland, some Norwegian and Scottish cliffs).

Marine mammals (dolphins, seals) are relatively rare now in the North Sea but have been more common in the past.

III. DEVELOPMENTS IN THE NORTH SEA

Human activity in the North Sea - fisheries, shipping and marine warfare - goes back in time at least as far as the Roman period or earlier and some countries bordering the North Sea have a long seafaring tradition. The way these activities are carried out have changed very much during history and the technological developments since the beginning of the 19th century but especially in the last twenty years profoundly changed their character and increased their scale. The number of ships and their size and speed now are larger than ever and there have been important shifts towards different types of ships and cargo, as well as to different techniques of fishing and treatment of catches. To fishing for human consumption has been added fishing of large quantities of small fish for fish meal (mainly concentrated in Denmark). The total catch of fish in the North Sea increased from 1.5 million tons in 1947 to 3.3 million tons in 1975. The total number of (chiefly small) fishing vessels involved is approximately 18 000, according to an estimate of 1975. In total approximately 200 000 ships of all types yearly cross the North Sea, mainly in the southern part, with Rotterdam-Europoort, Antwerp, Hamburg and London as the main ports. A large number of ships carry oil of which c. 200 million tons is yearly supplied through the Straits of Dover. Here on the average 300 ships pass every day. Besides oil, transported in very large tankers, there is bulk transport of ores, coal, cereals, oil products, chemical half-products and end-products. The increase in shipping and the increasing dangers involved made it necessary to regulate the traffic with beacons, pilots, onshore radar and traffic lanes and to increase the safety requirements for ships. The increase in ships size, especially of tankers, resulted in a shift of the harbours towards the coast. This is clearly demonstrated in the development of Rotterdam-Europoort. In order to improve the access to the harbour a deep channel was dredged through the North Sea floor and further dredging is envisaged so that the largest ships can reach Europoort.

Oil and gas exploration and extraction started in the North Sea after the finding of the large gas-field in Groningen in northern Holland in 1959. At first gas and some oil was found in the Southern North Sea mainly in the British sector, in the Danish sector and later also in the Dutch sector. After 1967 many oil fields and some large gas fields were found in the Central and Northern North Sea, chiefly along the central axis (Fig. 7). The effort was very succesfull and at the moment the North Sea is regarded as one of the major oil and gas producing areas. The development of oil and gas exploitation involved the construction in the sea of platforms, pipelines and storage tanks and a large support system of supply-ships, helicopters, floating cranes, radiocommunications and submersibles with harbour facilities, wharves, stores, offices etc. on land.

Extraction of sand and gravel from the seafloor has strongly increased after 1960, mainly in the Southern North Sea, because of an increasing shortage of suitable possibilities for extraction on land. In the order of 10 to 20 million ton is extracted annually; the exact amount is not known because of illegal dredging of gravel. Disposal of industrial waste and sewage has also increased. Over 11 million ton of city sewage are discharged daily into the coastal waters of the North Sea and annually more than 5 million ton of sewage sludge, ca. 1.5 million ton of chemical waste from industries (chiefly through Rotterdam and the Humber estuary), 6 million tons of coal washings and 4 million tons of coal waste (dumped on the shoreline near Teesmouth), 1 million ton of power station ash and 2 million ton of colliery waste. In addition there is the pollution coming down the rivers (Rhine, Elbe, Thames, Humber, Weser, Tees). The chemical waste includes acids (sulphuric acid, cyanide), gypsum, compounds of iron chromium, arsenic, cadmium, titanium and other metals, and many organic compounds including chlorinated hydrocarbons.

Military use of the North Sea in the past was limited to naval warfare with surface ships and later submarines, and to the laying of mines, dumping of waste ammunition and the use of training areas. Mines from both World Wars are supposedly still present north of the Dutch Wadden Islands and in the German Bight. More recently, acoustic devises for the identification of ships and for subsurface navigation have been placed on the North Sea floor. Telephone cables, old and new, cross the North Sea between the bordering countries.

IV. CONSEQUENCES FOR THE MARINE ENVIRONMENT

The increasing activities in the North Sea have had and still have consequences for their environment, affecting large groups of people on and along the North Sea : fishermen, the industries and commerce based on fisheries, those who come to the North Sea for recreation, the tourist industry and the widespread tourist supporting business, communities along the coast that feel the onshore consequences of marine activities (most recently in Yarmouth, Aberdeen and smaller Scottish harbours, Orkney, Shetland and Stavanger).

The dredging of gravel has endangered the spawning grounds of herring which are situated on gravel beds and in areas with a coarse sandy bottom. Gravel extraction also left an irregular bottom topography full of holes which made trawling dangerous. Gravel dredging near to the coast of Hallsands, Devon, led to increased coastal erosion and the disappearance of the village within 20 years. Dredging of sand however, when done by scrapping off the surface and keeping well away from the coast to avoid erosion, gives far less problems, although the fauna that forms the food of fish living on or near to the bottom (e.g. sole, plaice, cod), lives in the uppermost five centimeters of the bottom. In general disturbances and loss of bottom fauna because of sand dredging is very local and temporary; the fauna is restored after a few years at most and even large-scale sand extraction for the construction of an artificial island will not lead to a lasting disturbance of the bottom fauna.

Fisheries have increased at such a rate that around 1975 there was serious overfishing and since that time fishing has been severely restricted. Overfishing of demersal fish most probably has not only endangered the commercial species but also the non-commercial fauna that is fished up by bottom trawls and usually dies, but nothing definite is known about this.

The offshore oil and gas industry has experienced a number of spectacular accidents whereby much oil flowed into the sea and sometimes also reached the seafloor. The harmfull effects of such accidents - which do not happen often but have large consequences and are very expensive - depend very much on the conditions at the time the accident happens, the type of oil involved, how long and how much oil flows out etc. The main danger is for plankton, birds, benthic organisms along the coast and the coastal recreation. Through plankton, oil compounds may enter the food chain. Plankton also contains eggs and larvae of higher organisms (also of the commercial fish species) and during the Bravo accident on Ekofisk there was the danger of decimating the mackerel stock in the North Sea by killing their eggs. The effects of a large oil drilling accident are comparable to the effects of a large tanker accident. After such an accident the fauna and flora need to restore themselves. Oil that remains exposed to the air partly evaporates and partly is decomposed by bacteria, but oil that is buried in sediment (the seafloor, tidalflats, saltmarshes) can remain there for a much longer time. If oil pollution occurs repeatedly, flora and fauna are not able to recuperate, resulting in a large and lasting destruction of coastal marine life. This has not happened yet but the frequency of tanker accidents with large oil spills near Bretagne goes in that direction. Potentially much more harmfull, however, are the small quantities of oil that are continuously spilled. This largely done by ships (tanker cleaning at sea, discharge of waste oil) and since c. 1930 oil patches and sometimes birds dying or dead from oil have been and still are a familiar phenomenon on North Sea beaches.

The oil and gas extraction has led to disturbance of the seafloor in several ways. From platforms and supply ships waste equipment is dumped into the sea so that in former drilling areas fishermen get their nets torn. Also drilling mud and material brought up from below the seafloor are locally dumped and can suffocate bottom fauna. Pipelines have to be buried into the sediment but especially in the sandy parts of the Southern North Sea, where current velocities are high, this is very difficult or impossible to achieve so that pipelines are only thinly covered or lie on top of the bottom sediment. Gas pipelines are coated with concrete for protection and to increase the weight. When a pipeline lies at the surface the concrete (as well as the pipeline itself) can be damaged by fishing gear and may get loose from the pipe. This can also happen when the concrete is of inferior quality. The pipe then becomes buoyant and rises, may break or may be hit by a ship. For these reasons pipelines have been protected by cages that allow fishing gear to pass over them, or covered with sandbags. The disturbance of the seafloor by the oil and gas industry is limited to small lanes crossing the North Seafloor and to small areas around drilling and production platforms, but at present the number of such areas has increased to more than one thousand.

One of the most serious problems of the North Sea is water pollution, chiefly with heavy metals and organic compounds. They enter the North Sea from rivers, from direct discharges and from the atmosphere. Radioactivity enters the North Sea in very small quantities through the Straits of Dover and around Scotland as well as from the air. Much pollution enters the North Sea from nearshore and onshore sources and in bottom deposits as well as in suspended matter and in solution the concentrations are higher nearshore than offshore (e.g. mercury, copper, chlorinated hydrocarbons). The rather rapid dispersal of water and suspended matter in the coastal waters and in most of the Southern North Sea because of the tides, reduces the concentrations of discharged pollutants rapidly to low values but the result is a gradual increase of pollutant concentrations over a large area. This is clearly reflected in bottom sediments. Recent mud deposits in the North Sea show an increase in trace element content towards the top of the deposit (Fig. 8). In sediments accumulated since 1800 in the German Bight southeast of Helgoland the concentration of mercury has increased 8 times in the period 1800-1975, the concentration of cadmium 7 times, the concentration of lead c. 10 times, the concentration of zinc and manganese c. 4 times, the concentrations of copper and cobalt c. 2 times and the concentrations of nickel, chromium and iron less than 2 times. The increase in concentration on a year-to-year basis, and even on a ten-year basis, is very small and may even show a reverse trend towards a decrease (Fig. 9), but in the long run there is an overall increase for all trace metal concentrations, indicating a slow but steady pollution of the North Sea, but predominantly in the coastal waters where the suspended matter concentrations are highest. Bottom sediments, of which the age can be determined with considerable precision (with Pb-210) for the last 150 years, are at present the only possibility for establishing a zero-level of concentrations before pollution started and for obtaining an indication of long-term trends.

Supply of pollutants from the atmosphere is probably important for lead (from automobile exhaust) and chlorinated hydrocarbons like DDT and PCB's. They are both present in offshore bottom deposits in relatively high concentrations. That the Southern North Sea, surrounded by highly industrialized and densely populated areas receives the comparatively highest amount of pollutants through the atmosphere is reflected in the concentrations of HCB, dieldrin and PCB's in livers of cod caught in the Southern North Sea, which are 4, 5 and 7 times, respectively, higher than in livers of cod caught in the Northern North Sea.

An important study for the assessment of the dispersal of pollutants through the North Sea and the effects of a major nuclear accident in Windscale (England) and La Hague (France) is the study of the dispersal of Cs-137 from these plants. From the Irish Sea around Scotland and from the Channel through the Straits of Dover the Cs-137 is transported in solution into the North Sea, follows there the anticlockwise circulation, comes into the Skagerrak, is for a small part transported into the Baltic but for the greater part goes northward along the Norwegian coast into the Norwegian Sea (Fig. 10, 11). There it is transported further northward along the Norwegian coast into the Barentz Sea with the result that the Cs-137 activity in the water in that area is raised to three times the activity normally found in the Norwegian Atlantic Ocean.

The assessment of the effects of North Sea activities and pollution on the marine fauna and flora is - for non-commercial species - hampered by lack of knowledge on zero-levels and on the influence of natural variability. For some marine mammals, however, records are available. Whales were regularly present in the North Sea during the Middle Ages but have vanished from there because of intensive whaling. Two species of dolphins are common in the North Sea, one living more in the coastal areas, the other offshore in more oceanic water. A third species occasionally visits the North Sea from the South. Because of the construction of enclosures, of water pollution (PCB's) and of disturbance the number of specimens has declined very much in the Southern North Sea and especially along the coasts of Holland, Germany and Denmark. Along the Dutch coast, where they were still abundant ca. 40 years ago, no dolphins are left. Seals have been abundant along the North Sea coasts but have now almost disappeared from the Dutch Wadden Sea and the southern Dutch inlets because of water pollution and disturbance.

V. CONCLUSIONS

Summarizing, the marine environment of the North Sea is threatened in several ways : by waterpollution, by overfishing and by bottom disturbance. Fishing is now extremely regulated, but research on and control of stocks is only extended to commercial species. Strict regulations have been made for drilling safety and pipelines are protected but the possibility that large accidents occur is not excluded. International rules have been made to restrict water pollution but there are many possibilities for exemption and evasion so that oil continues to pollute beaches, rivers like the Rhine still carry large concentrations of pollutants to the North Sea and so-called black listed substances are still being discharged in the coastal waters. At present the effects of human activity are especially noticeable in the coastal waters of the Southern North Sea and in the Southern Bight. There is however, not sufficient knowledge on the North Sea fauna as a whole and much more research is needed. It follows that there is a clear need for stronger restrictions on polluting activities and for the employment of techniques that do not endanger the environment. Up to now more effort has gone into developing North Sea activities than in the assessment of their consequences and preventing negative effects. Present assessments are hampered by a lack or detailed knowledge on dispersal by currents and waves in the North Sea, on the effects of North Sea activities on non-commercial species, or on many of the physical and chemical processes involved, and on base-levels (zero-levels). Moreover it is at present very difficult to separate long-term natural fluctuations from the effects of human activities. Lack of sufficient knowledge makes if possible at this moment that species disappear or are strongly reduced without hardly anybody noticing it, let alone know the cause of it. The decline and disappearance of mammals, however, as well as the decline of the Auk in the Channel, and the increase in trace metal concentrations since 1800, are indications for the gradual long-term pollution and degradation of the coastal waters in the Southern North Sea, which is still continuing at present.

For many activities in the North Sea (shipping, fishing, extraction of sand, oil and gas, military activities) it can be stated that with certain restrictions and by conducting them in such a way that the least possible harm is done to the marine environment, their harmfull effects will generally be small. This being so, these activities may yet result in a strong deterioration of the North Sea environment :

- the control on the observance of rules and the use of technical methods that in themselves are good, is much more difficult at sea than on land. Even in a densely populated area like Holland chemical waste could be dumped illegally on a large scale in spite of local knowledge and the warnings of many environmental organizations. Control on the dumping of waste equipment and other waste from supplyships is not feasible.

- there is the possibility of serious accidents with oil drilling or with tankers, which can endanger the North Sea environment, fisheries and coastal recreation for a long time,
- there is a general disturbance of the North Sea because of frequent drilling, burrowing, dredging, dumping, trawling and navigating.

Next to the continuing waterpollution, the increasing general disturbance of the North Sea may well become one of the most important threats to marine life. It is known that many marine and coastal bird species and mammals are very sensitive to disturbance, especially when they are with eggs or young. For other marine fauna of the North Sea no data are available on this, but many fish species are sensitive to sound and smell and many motile species may simply leave areas where much human activity is going on. It is therefore possible that in the future the total number of activities in certain sea areas will have to be limited in order to present the marine environment from deteriorating, or that very stringent restrictions will have to be introduced.

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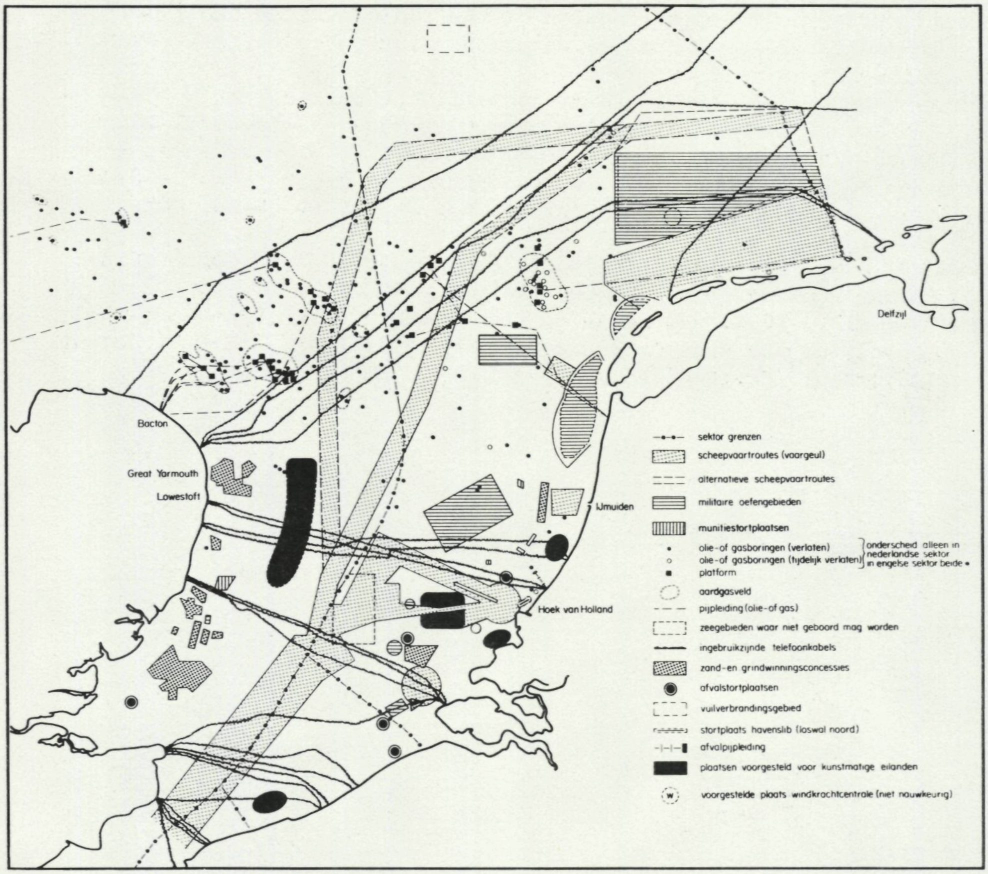

Fig. 1. Distribution of actual and planned activities in the Southern Bight of the North Sea (modified after EISMA, 1979).

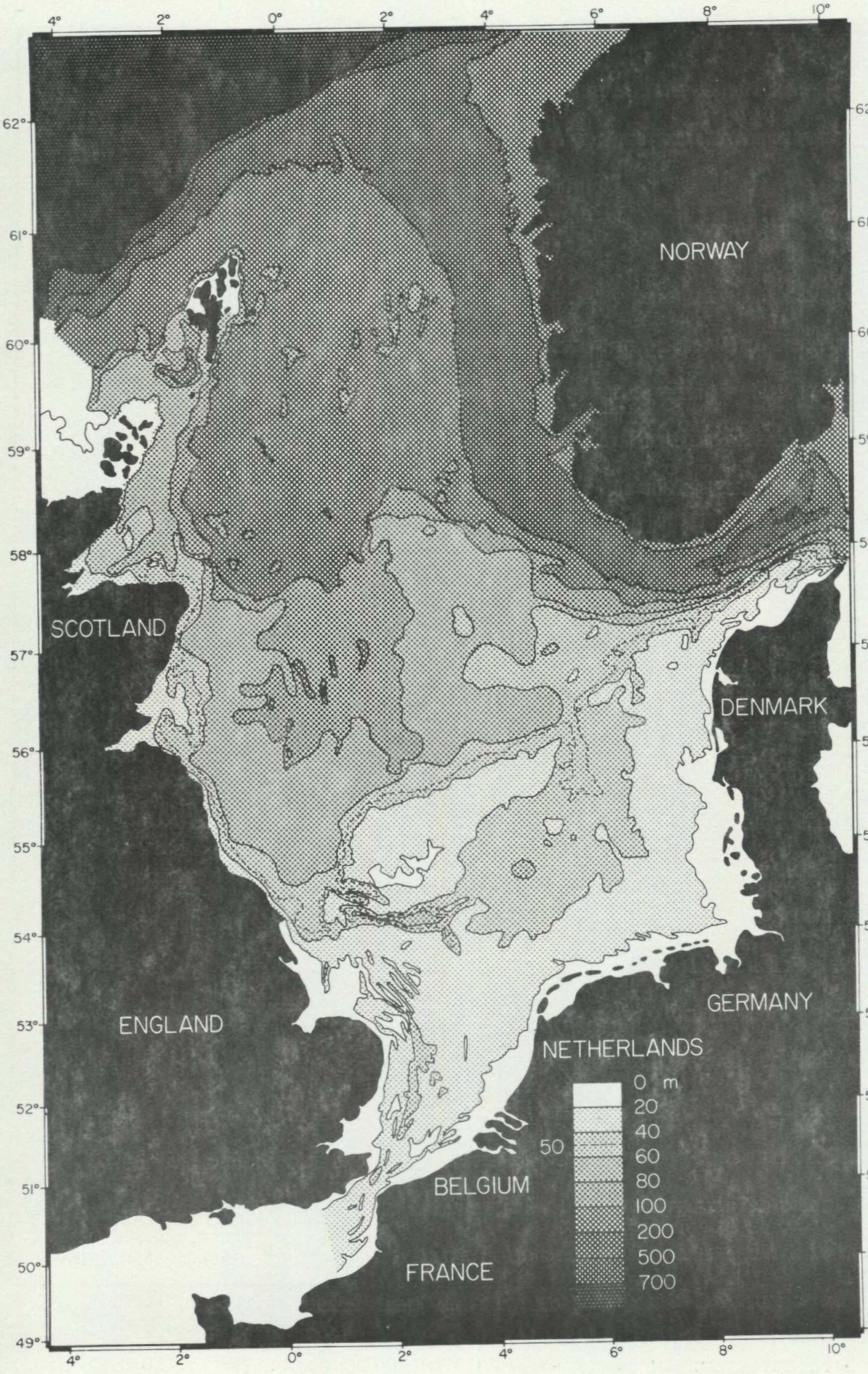

Fig. 2. Depth chart of the North Sea.

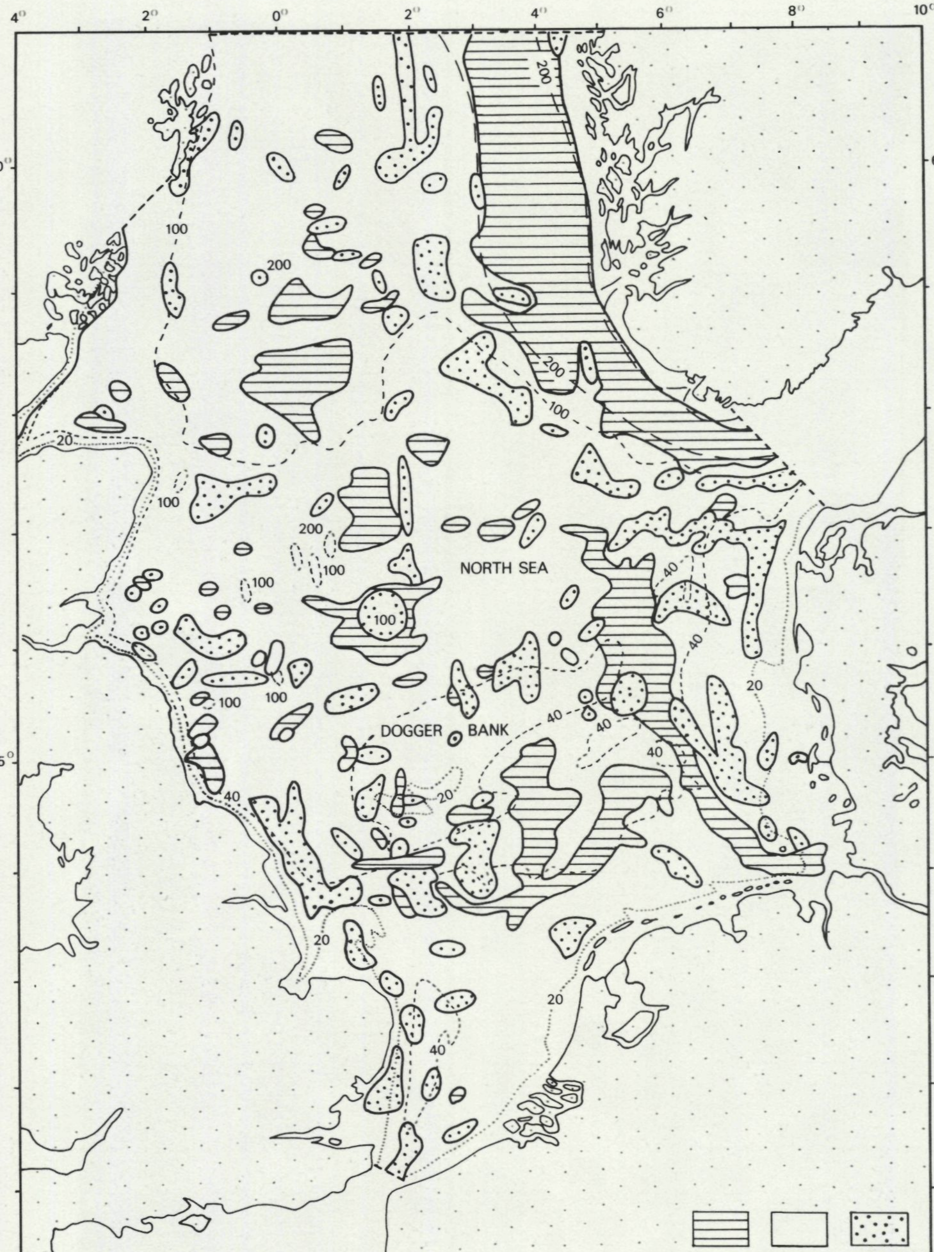

Fig. 3. Distribution of mud, sand and gravel on the North Sea floor (after VEENSTRA, 1971).

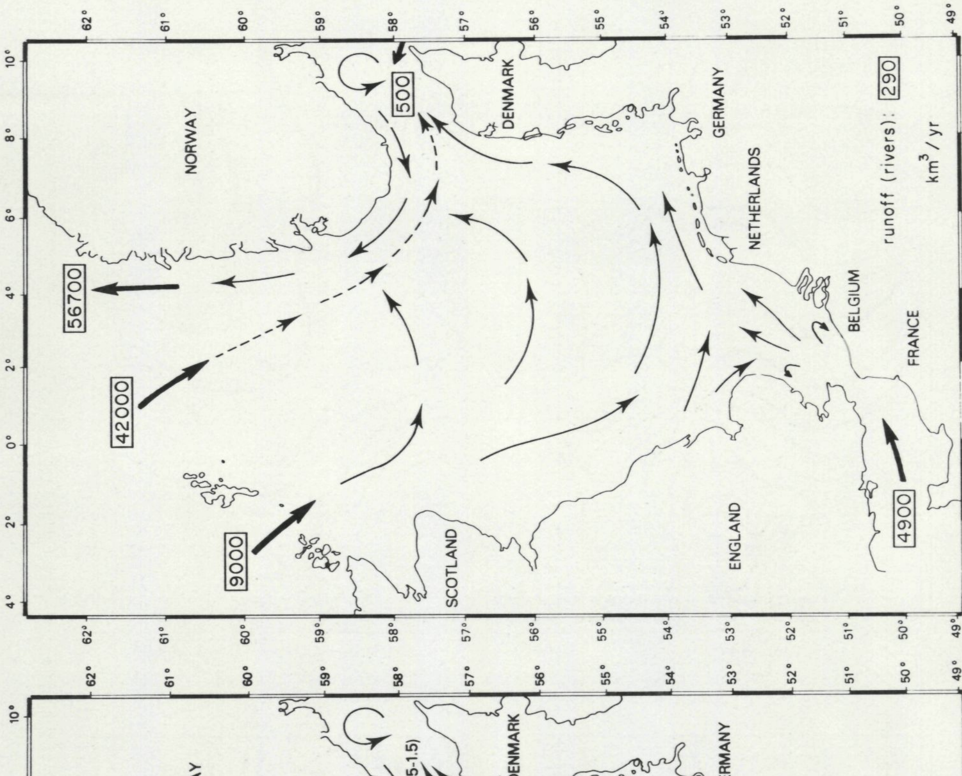

Fig. 4. Inflow of water into the North Sea (a), the numbers indicating inflow in km^3/year, and the general distribution of suspended matter in the North Sea (b), the heavy lines and numbers indicating the concentration of suspended matter in mg/1. The general water circulation in the North Sea is indicated by arrows, the broken arrows indicating subsurface flow.

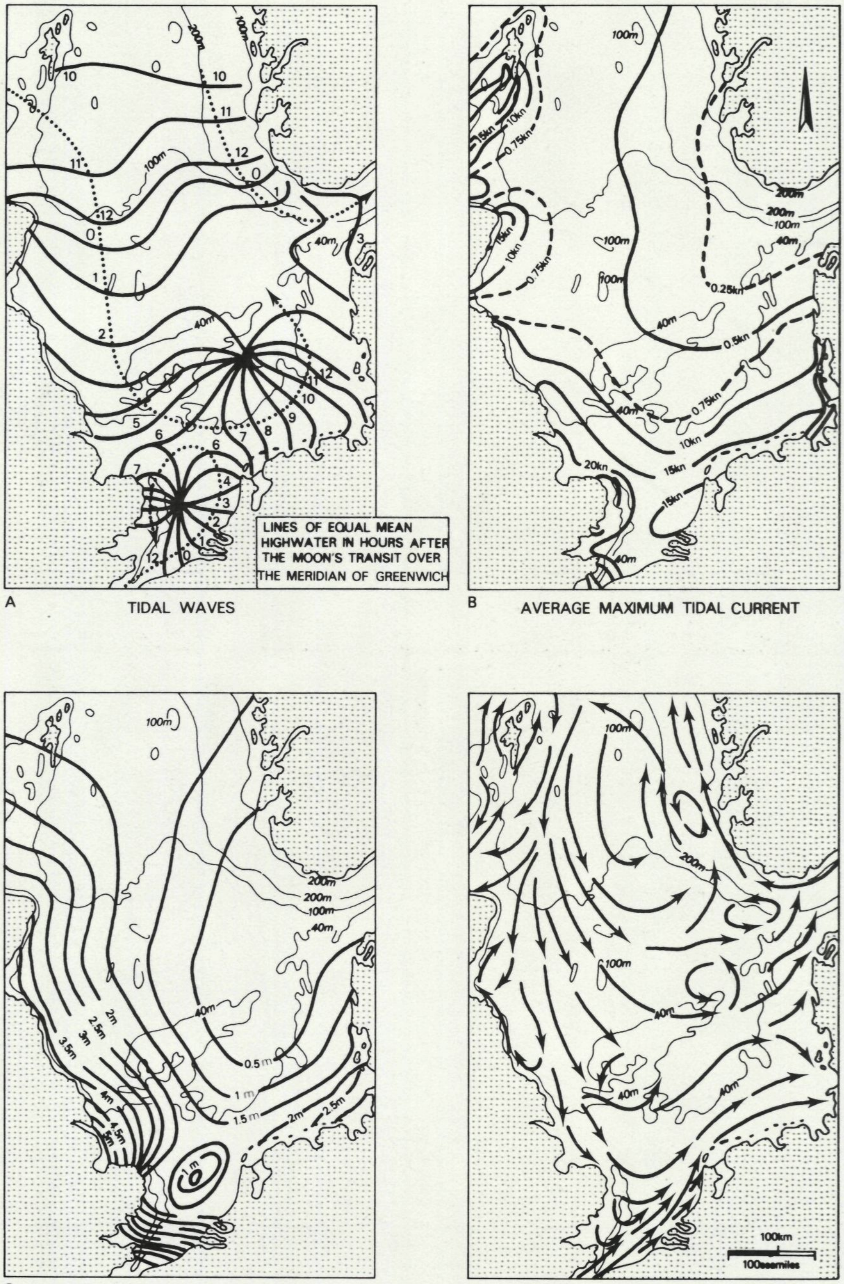

Fig. 5. Tidal flow and average surface currents in the North Sea (from HOUBOLT, 1968).

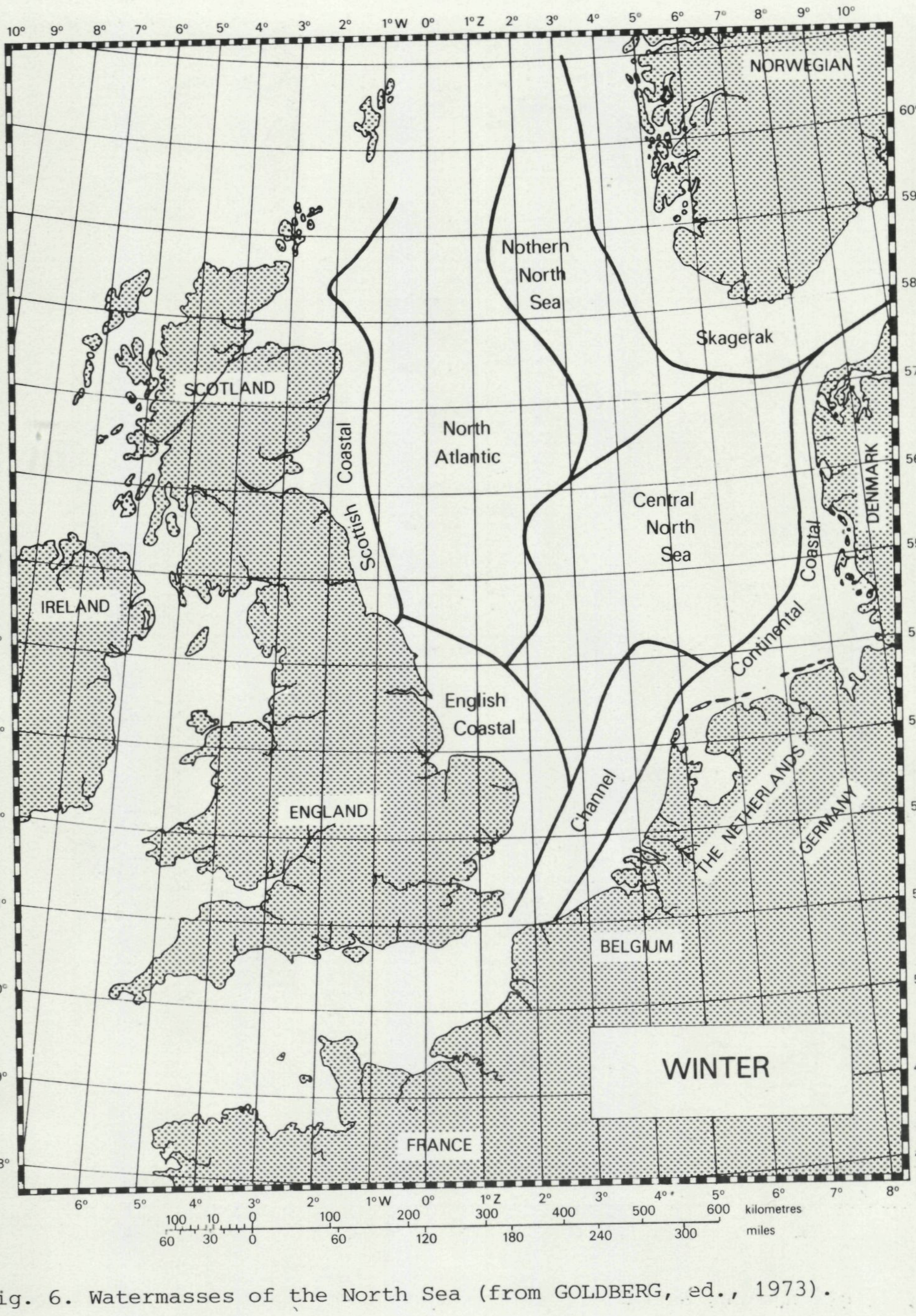

Fig. 6. Watermasses of the North Sea (from GOLDBERG, ed., 1973).

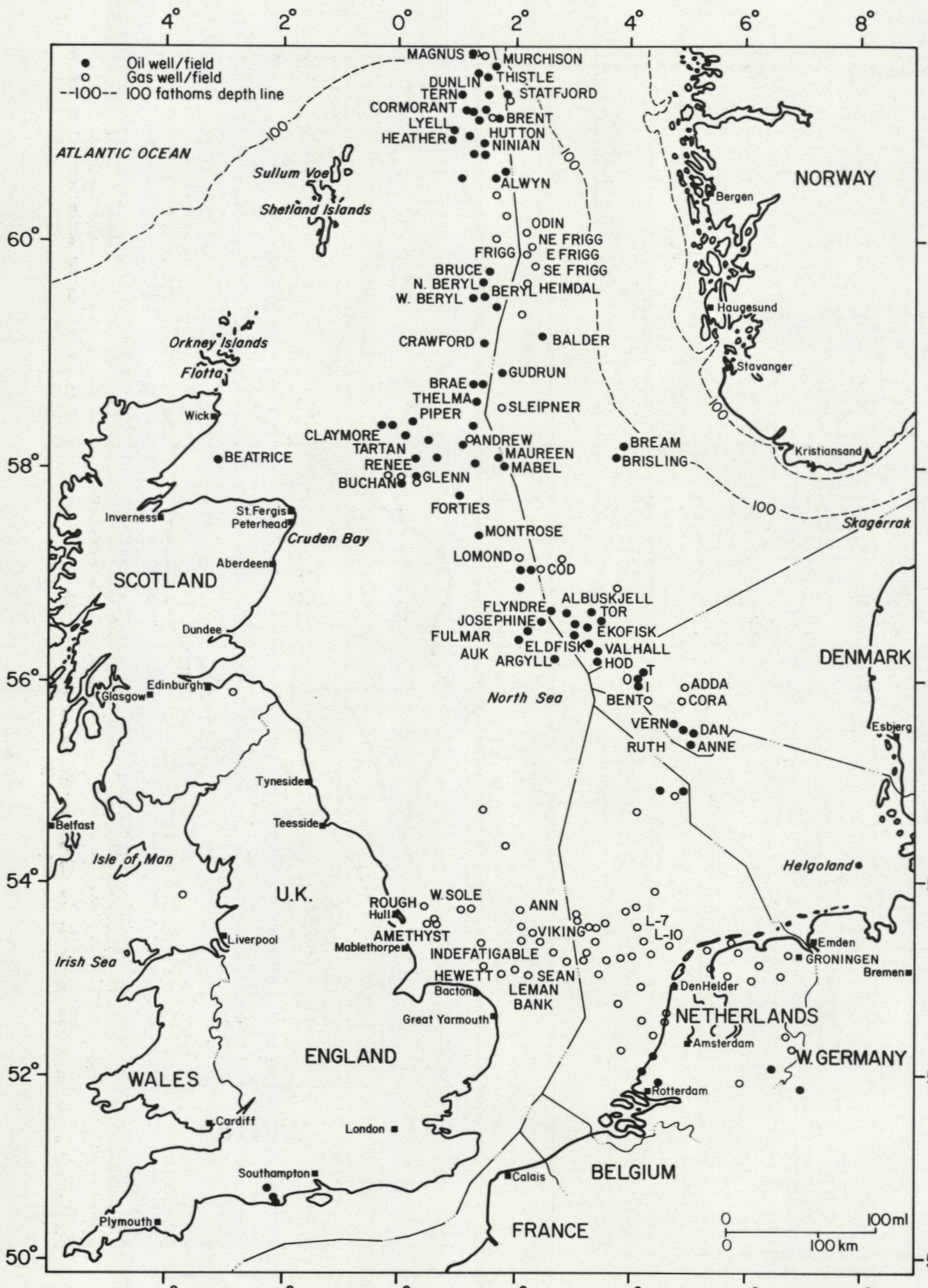

Fig. 7. Oil and gas extraction in the North Sea (source : World Oil, vol. 187 (3), 1978).

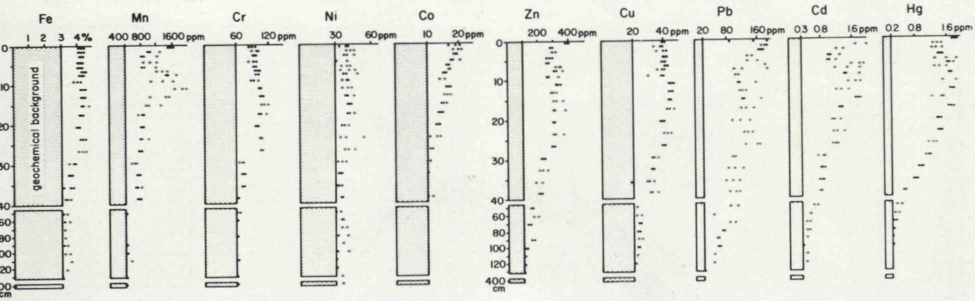

Fig. 8. Trace metal concentrations in a sediment core from the German Bight. Shaded column : natural concentration before pollution started (= zero-level = geochemical background) (after FÖRSTNER and REINECK, 1974).

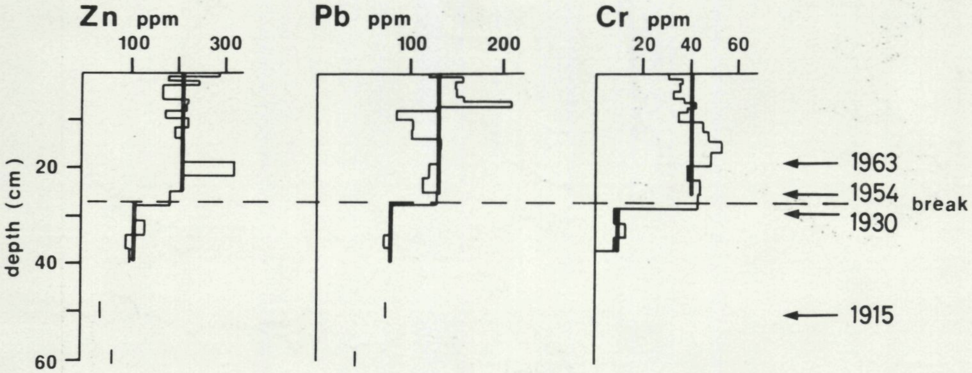

Fig. 9. Trace metal concentrations in the top of a sediment core from the German Bight, comprising the major part of this century. Dates are based on dating with Pb-210, a natural isotope with a half-life of 22 years, and on Cs-137 from fall-out (after DOMINIK et al., 1978). The break is due to temporary non-deposition and/or erosion.

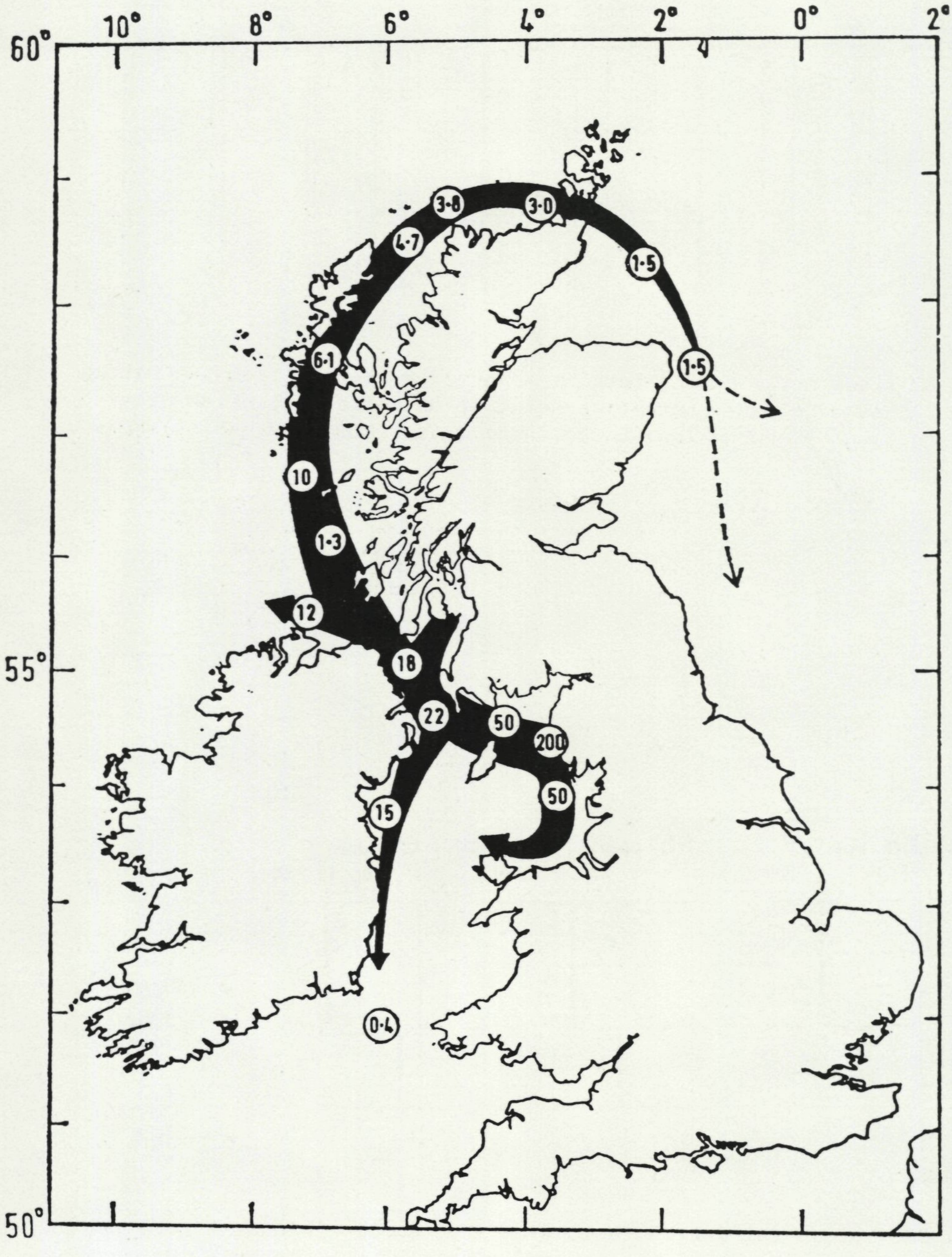

Fig. 10. Dispersal of caesium 137 from Windscale and La Hague through the Irish Sea (after JEFFERIES et al., 1973).

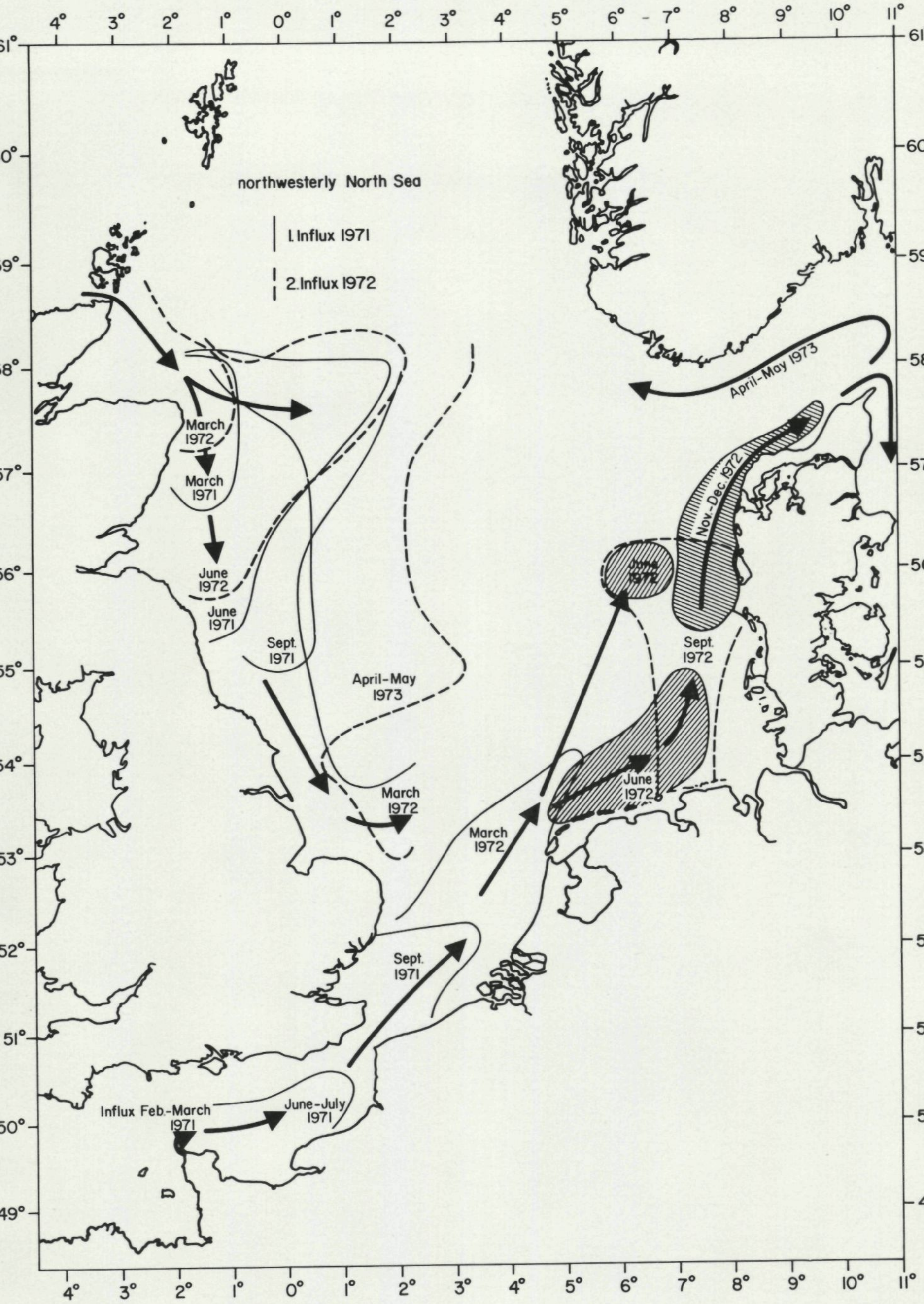

Fig. 11. Dispersal of caesium 137 from Windscale and La Hague through the North Sea (after KAUTSKY, 1973).