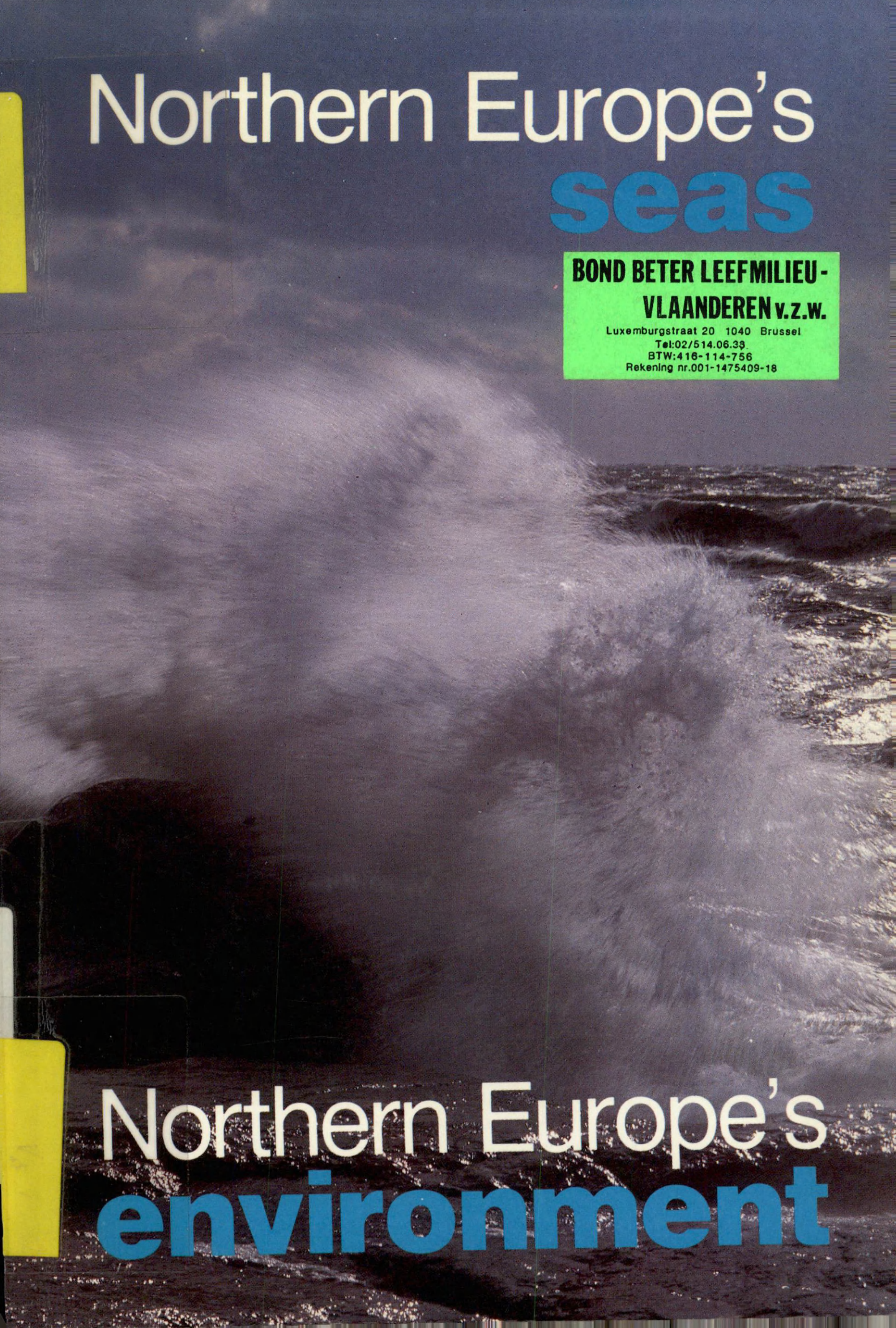
Northern Europe's
seas



Northern Europe's
environment

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Report to the Nordic Council's International
Conference on the Pollution of the Seas,
16 – 18 October 1989

Northern Europe's **seas**

Northern Europe's **environment**

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Cover photographs: Björn-Eyvind Swahn, Naturfotograferna (front);
Sven Halling, Naturbild (back).
Photograph, pages 2 – 3: Bengt Hedberg, Naturbild.
Photograph, page 8: Stefan Örtenblad, Naturbild.

Design: Rolf Hernegran.
Norstedts Tryckeri AB, Stockholm, 1989.

This book is printed on paper produced by a process using
considerably less chlorine than conventional paper manufacturing.
It is therefore less harmful to the marine environment.

Cover: Macoprint Matt Miljö, 240 g.
Main body of the book: Magnomatt Miljö, 100 g.

ISBN 91-38-12246-4.

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Preface

In 1986 an International Conference on Transboundary Air Pollution was held under the auspices of the Nordic Council. The Conference reached agreement on joint action to tackle the threat to the environment and human health posed by pollution of the atmosphere.

Our seas, too, are being polluted in a manner representing a threat to all forms of life. The increasingly serious trend of marine pollution must be stopped now if the damage is not to escalate beyond repair.

Pollution of the seas and oceans, and a realization of their importance to the future of our environment and our terms of existence, form the background to the Nordic Council's initiative once again to bring together Members of Parliament from many different countries, with the aim of creating a common platform for further action against degradation of the environment. This time, the focus of attention will be marine pollution.

This report was written by environmental journalist Britt Aniansson, Sweden, for the Presidium of the Nordic Council. It has been scrutinized by experts at the Nordic countries' environment protection agencies and by researchers in the marine sciences. Joint funding was provided by the Nordic Council and the Nordic Council of Ministers.

The purpose of the report is to provide those attending the Nordic Council International Conference on the Pollution of the Seas with facts about and a background to the problems of pollution of the sea. In addition, it is my hope that it will help to create fuller and broader public awareness and understanding of these issues throughout Europe.

Stockholm, 19 April 1989

Karin Söder
President of the Nordic Council

1 The sea — its basic properties and role

For most people, the sea evokes strong emotions. Like space, we perceive the major seas of the world as something boundless, infinite, vast, free and unspoilt. In reality, theirs is an extremely limited infinity. The world ocean is in fact a very large lake, surrounded by land just like an inland lake. The sea may seem boundless, but sooner or later, whatever course you steer across it, you reach land again. The sea has no outlet for the polluted precipitation that falls on its surface, for the massive amounts of different substances pouring into it daily from the land in rivers, or for all the direct discharges occurring from land and at sea. The volume of water in the ocean is admittedly enormous, but this water is one component part of a continuous cycle and is involved in a constant exchange of different substances between land, air and sea.

If we tried to represent the quantity of water in the world ocean to scale on an ordinary globe, we would not be able to apply a coat of paint thin enough. Someone has worked out that, if all the various water reservoirs of our planet were evenly distributed over its surface, the water of the world ocean would form a layer that was an average of 2.6 km deep.

Understanding the sea's limitations, regarding the world ocean as a gigantic lake, is the first step towards a knowledge and understanding of the marine environment. The next step is to take a realistic view of the limitations of coastal sea areas in terms of depth and water exchange. *Figure 1* in this book shows what the world would look like without seawater. The coastal seas of northern Europe cover the shallow continental shelf, the continuation of the landmass into the sea. Modern skyscrapers placed on the floors of our coastal seas would generally rise well above the surface of the water. If one of Europe's big cathedrals, that of Cologne, were to be put somewhere in the North Sea with a depth of about 90 m (the average for that sea), the top 70 m of its towers and spires would still be visible. Undeniably, this gives us some sort of perspective on ideas about 'infinite amounts of water' and 'bottomless seas'. Our coastal waters should, rather, be regarded as shallow, gently splashing basins.

Photograph: Göran Hansson, Naturfotograferna.

Figure 1. The water in the sea conceals a fascinating sight — the seabed, a varying landscape of mountain ranges, plateaux, vast plains and valleys. Round the continents, as a continuation of the landmass, is the continental shelf, the floor of our coastal seas. The world ocean — everything on earth that we call sea — has an average

depth of almost 4 000 m, but the seas of northern Europe are much shallower basins. The Baltic and North Seas are typical shallow-water shelf seas, with average depths of 55 and 90 m, respectively.

Illustration from Hachette/Les Guides Bleues©, Paris. Drawn by Tanguy De Remur.

What is the sea?

Seas cover over 70 % of the earth's surface, i.e. an area of around 360 million km^2. In terms of volume, that is roughly 1 billion km^3 (1 m^3 of water is the same as 1 000 litres and 1 km^3 is equal to 1 billion m^3). *Fact panel 1* shows the volume of the seas in relation to the earth's other stores of water. In round figures, the seas contain 97 % of all the water on earth. Over 2 % is locked up in ice, while less than 1 % is fresh water or water vapour in the atmosphere.

The world ocean – the entire area of what we call sea – is divided into individual **oceans** and **adjacent seas**.

Adjacent seas are defined in various ways and may be either **mediterranean** or **marginal** seas.

Definitions of the world's seas and oceans vary, but according to one common classification there are three oceans:

- The Pacific Ocean
- The Atlantic Ocean
- The Indian Ocean.

Another definition – as the names suggest – includes the Arctic and the Southern or Antarctic Ocean among the oceans. The Arctic Ocean is the northernmost part of the Atlantic, a mediterranean sea. The Southern Ocean is the collective name for the parts of the Pacific, Atlantic and Indian Oceans surrounding Antarctica.

From the oceans there are long arms reaching in between the main continental landmasses. Here we find the large and small mediterraneans, which are surrounded almost entirely by land.

The large – or intercontinental – mediterraneans include

- The Arctic Ocean and Norwegian Sea (Arctic Mediterranean)
- The Mediterranean and the Black Sea (European Mediterranean)
- The Caribbean Sea and Gulf of Mexico (American Mediterranean).

Fact panel 1

Where the earth's water is to be found

All the water on earth, whether salt, brackish or fresh, together forms the **hydrosphere**. This includes the seas and oceans, glaciers, and the groundwater, lakes and rivers of the continents. The amounts below are in round figures, in cubic kilometres (km^3) of water.

	km^3 of water
Oceans and seas	1 300 000 000
Salt lakes	100 000
Total salt water:	***1 300 100 000***
Polar ice and glaciers	28 500 000
Water vapour in the atmosphere	12 700
Biological water in plants	1 000
Total unavailable fresh water:	***28 513 700***
Lakes (freshwater)	120 000
Rivers	1 230
Soil moisture	65 000
Groundwater to 800 m depth	4 000 000
Deeper groundwater	4 400 000
Total available fresh water:	***8 586 230***

Small — or intracontinental — mediterranean seas include

- The Baltic Sea, including the Gulf of Bothnia, the Gulf of Finland and the straits between the Scandinavian peninsula and the continent of Europe
- The Red Sea
- The Persian Gulf
- Hudson Bay.

Marginal seas are a special type of adjacent sea, located along the margins and mainland coasts of the continents and separated from the oceans by islands, archipelagos or peninsulas. They include

- The North Sea (including the Skagerrak)
- The Irish Sea
- The Barents Sea
- The Bering Sea
- The Sea of Japan
- The Sea of Okhotsk
- The East China Sea.

The 'Seven Seas', which seamen have sailed on and sung about down the centuries, are, strictly speaking, the North and South Pacific, the North and South Atlantic, the Indian Ocean, the Arctic Ocean and the Southern Ocean.

Several other terms are used to refer to seas. However, these have more to do with the special characteristics of particular sea areas. A sea may for example be described as a shelf sea, a shallow or deep sea, or a coastal sea.

From shallows to the depths

The seas conceal a fascinating sight – the seabed. *Figure 1* shows its varying landscape of mountain ranges, plateaux, vast plains and valleys. The shallow areas off many coasts are called the **continental shelves**, some of which hold reserves of oil and natural gas. The entire Baltic and North Seas, together with coastal areas of the Norwegian and Barents Seas, the sea around the Faeroes and Iceland and part of the sea around Greenland, lie on these wide shelves and are consequently referred to as **shelf seas**. A shelf sea can also be termed a shallow sea, since its water is rarely more than 200 m deep. The shelf seas are biologically very productive. Though accounting for barely 10 % of the total area of the world ocean, they yield around 90 % of all marine fish catches.

Initially, the seabed is a fairly evenly sloping continuation of the land and here, on the continental shelf, greater depths than around 200 m are therefore rare *(figure 2)*. The average depth is about 180 m, and individual deep basins may drop to just over 400 m. One exception in the North Sea/Norwegian Sea is the deep Norwegian

Trench, which reaches depths of over 700 m. The width of the continental shelf can, however, vary considerably off different landmasses. Off the north coast of Siberia, the shelf extends 1 200 km from land, while in other parts of the world, e.g. along the west coast of Latin America, it is only a kilometre or so wide. There the seabed plunges more or less straight down into the depths.

Beyond the continental shelf there is a long and relatively steep descent – the **continental slope**. It is often cut by deep submarine valleys or canyons, which are extensions of river mouths. The steepness of the slope can vary, with gradients from 4 to 20° occurring.

Where the continental slope ends, at a depth of 3 800 – 4 000 m, the **deep sea** begins. This part of the sea floor, which consists mainly of vast plains (deep-sea or abyssal plains), in fact accounts for a large proportion of the earth's surface. Considerable areas are flat and uniform, but there are also colossal deeps (trenches) and dramatic chains of mountains and isolated peaks. Long submarine mountain chains are known as oceanic or mid-ocean ridges and are the result of magma forcing its way up from inside the earth and solidifying when the continents, or crustal plates, drifted apart. These ridges make up an almost continuous system throughout the world ocean.

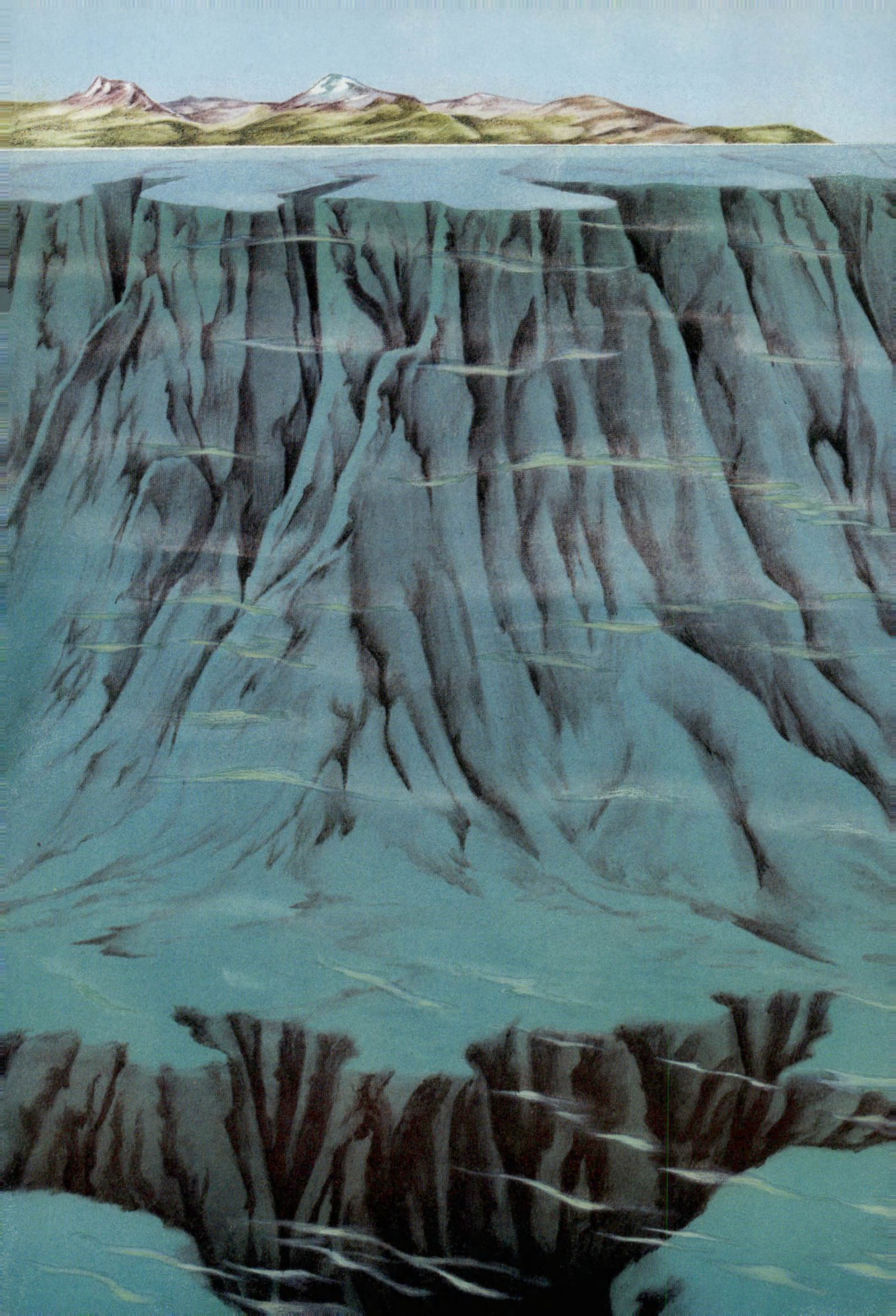
Oceanic ridges can be several thousand metres high. The greatest depths known are the 11 524 m deep Mindanao (Philippine) Trench and the Marianas Trench (11 034 m), both in the Pacific east of the Philippines.

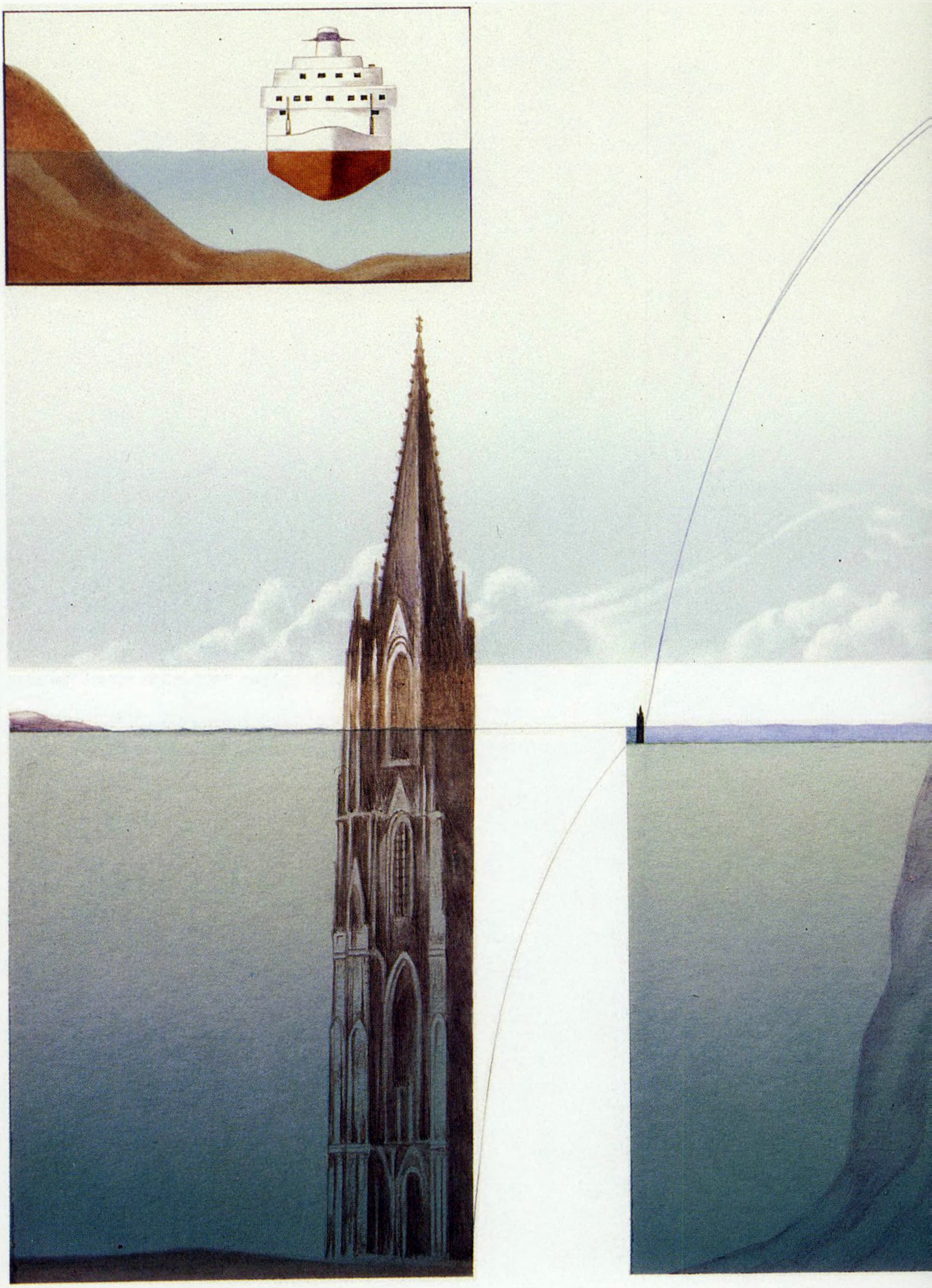
Figure 2. The continental shelf is a continuation of the landmass. Of varying width, the shelf initially slopes fairly gently and evenly into the sea, and is rarely deeper than about 200 m. Its average depth is 180 m, though in a few places it may be over 400 m deep. The continental shelf may extend over a thousand kilometres from land, e.g. off the north coast of Siberia, while in other areas, such as along the west coast of Latin America, it is only a kilometre or so wide, the seabed plunging more or less straight down into the depths. Seas on continental shelves — shelf seas — are biologically productive. Accounting for barely 10 % of the total area of the world ocean, they nevertheless yield around 90 % of all marine catches of fish and shellfish.

Beyond the continental shelf there is a long and steeper descent — the continental slope. It is often cut by deep submarine valleys or canyons, which are extensions of river mouths. The steepness of the slope can vary. Sometimes it is comparatively gentle, sometimes a more dramatic transition from shelf to deep sea. The slope extends from depths of a few hundred metres down to where the deep sea begins, almost 4 000 m below the surface.

The deep sea floor consists mainly of vast, monotonous plains. The unlit area of the seabed covers a total of some 60 % of the earth's surface. On the deep ocean bed are the dramatic heights — known as ocean ridges — formed by magma from inside the earth when the continental plates moved apart. Here there are also the precipitous trenches that fall away to depths of over 11 000 m.

Illustration: Bosse Falk.





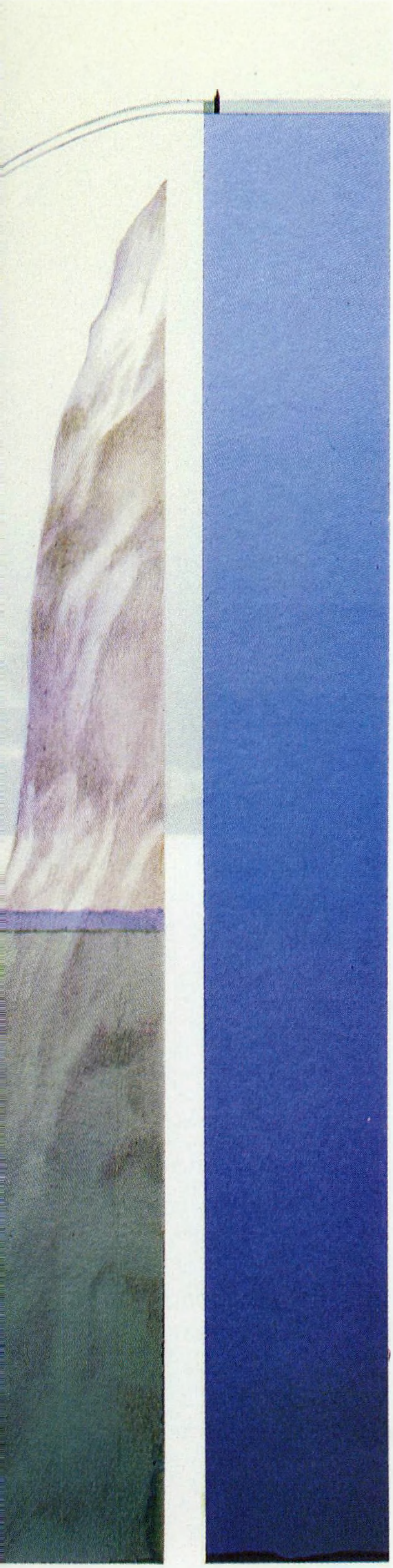


Figure 3. The continental shelf, with its average depth of 180 m, is very much a shallow ledge, compared with the real depths of the oceans.

Everest, the world's highest mountain (8848 m), would not reach above the surface of the sea from a deep sea trench over 11000 m deep. From the average depth of the world ocean, 3800—4000 m, however, it would rise to an imposing height above the sea.

Modern skyscrapers are well over 400 m high (the Empire State Building in the United States, once the world's highest edifice, is 'only' 381 m tall). Placed on the bottom of an average shelf sea, such a skyscraper would only be half hidden by water. Most sea areas really close to the coastline are only a few tens of metres deep. Here the shallow water is sometimes even a problem for larger ships.

If majestic Cologne Cathedral were placed somewhere of average depth in the North Sea, its top 70 m would still be visible above the water. In large areas of the North Sea, over 100 m of the cathedral would rise out of the water. In the Baltic, it would rise about 105 m above the surface from a place of average depth for this sea.

Thus, 'the sea' is one thing, coastal sea areas quite a different thing as far as depth, water volume and water exchange are concerned.

Illustration: Bosse Falk.

Figure 3 compares depths in the sea and heights on land. It makes it clear that the continental shelf is a very shallow plateau. A sea located entirely on the shelf can almost be compared to a large lake, or a basin.

The seabed as an environmental history book

The seabed tells us what has happened and is happening beneath the earth's crust, to the seawater itself, and to the various inputs to the seas. A great deal of information can be obtained about events and conditions in the sea by studying volcanic activity, the genesis of various formations on the deep sea floors and, regardless of depth and location, the **sediments** on the seabed. These sediments consist of particles of varying origin that have been distributed, deposited on and incorporated in the bottom of the sea by a range of interacting factors. In greatly simplified terms, sediment on the seabed can be of two main types:

- Gravel, sand, clay, dredging spoil, sludge, organic material from industrial plants and urban centres, and other similar material, washed down or actively introduced into the sea from the surrounding land by rivers, land run-off, sewage, dumping or other processes. Pollutants can enter the sea attached to the particles of such material.
- The remains of marine plankton – drifting microscopic plants and animals – and other organic material produced and living in the sea or in rivers entering it.

Examined in more detail, the sediments and their formation – sedimentation – are far more complex, being affected by many different physical, chemical and biological factors.

The seabed can be either **hard** or **soft** (see below). Soft bottoms or substrates – which consist entirely of sediments – account for around 98 % of the floor of the world ocean. Large numbers of animals live on and in them. The sediment cover of the seabed varies from place to place, but generally it is of great significance to the cycling of different substances in the sea, both substances that should be found in the normal marine ecosystem and those that are foreign to it, i.e. anthropogenic contaminants. The sediments are in a sense the final destination of every substance entering the sea, and what happens there – in terms of composition, turnover, movement and environmental effects – is dependent on a number of interacting factors, including

- distance from the land and what is transported from the landmass concerned
- prevailing winds and currents in the area
- the temperature of surface waters
- the depth of the water
- nutrient levels in the water and the resultant production of plankton and other organisms
- the activity of macroscopic bottom-dwelling (benthic) animals and of micro-organisms, primarily bacteria, on and in the seabed/sediments.

Along the edges of the continents are structures known as sedimentary or sedimentation basins. Here large quantities of sediment from rivers have been deposited in the course of millions of years. The North Sea is an example of this. Beneath its fairly even floor there is a sedimentation basin over 6000 m deep. At times in its history, areas of the North Sea have been dry land. Traces of submerged forests, for example, can be found in its sediments.

The sea – a complex, changing system

The sea, as a system, is complex and changeable. It is impossible to give a brief but full account of all the factors affecting its physical and chemical characteristics, or of all the mechanisms determining the nature of life in the sea and why various processes operate as they do. To provide an exhaustive description of the sea in general and various sea areas and their environments in particular, detailed explanations would be needed of the forces controlling the winds, currents, tides, water circulation and exchange, and of the laws governing a host of chemical, biochemical and biological processes. Here, therefore, only an introductory overview of a number of important phenomena will be given.

The sea in the water cycle

A constant interchange of water occurs between the sea, the atmosphere, rivers, lakes, soil, ice and vegetation *(figure 4)*. The basis of this water cycle is the constant evaporation of large quantities of water from the sea. It is important to remember that what enters the sea via rivers, lakes and precipitation is not just

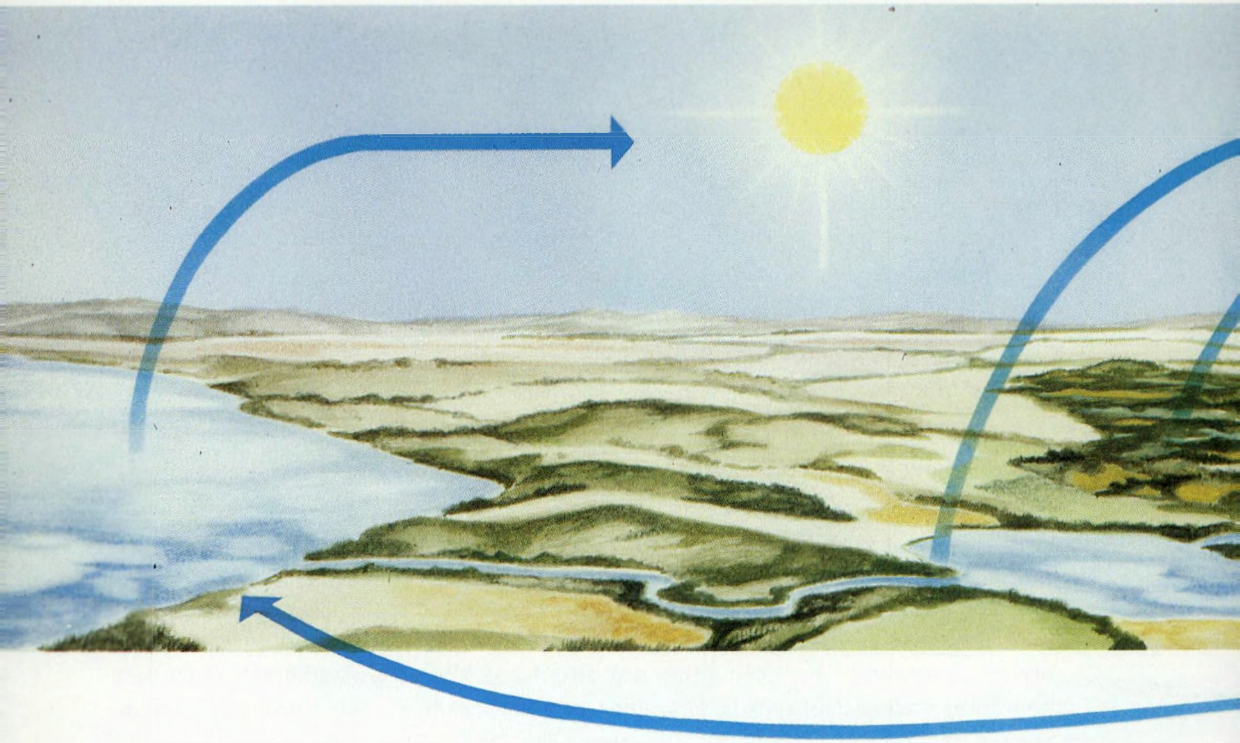


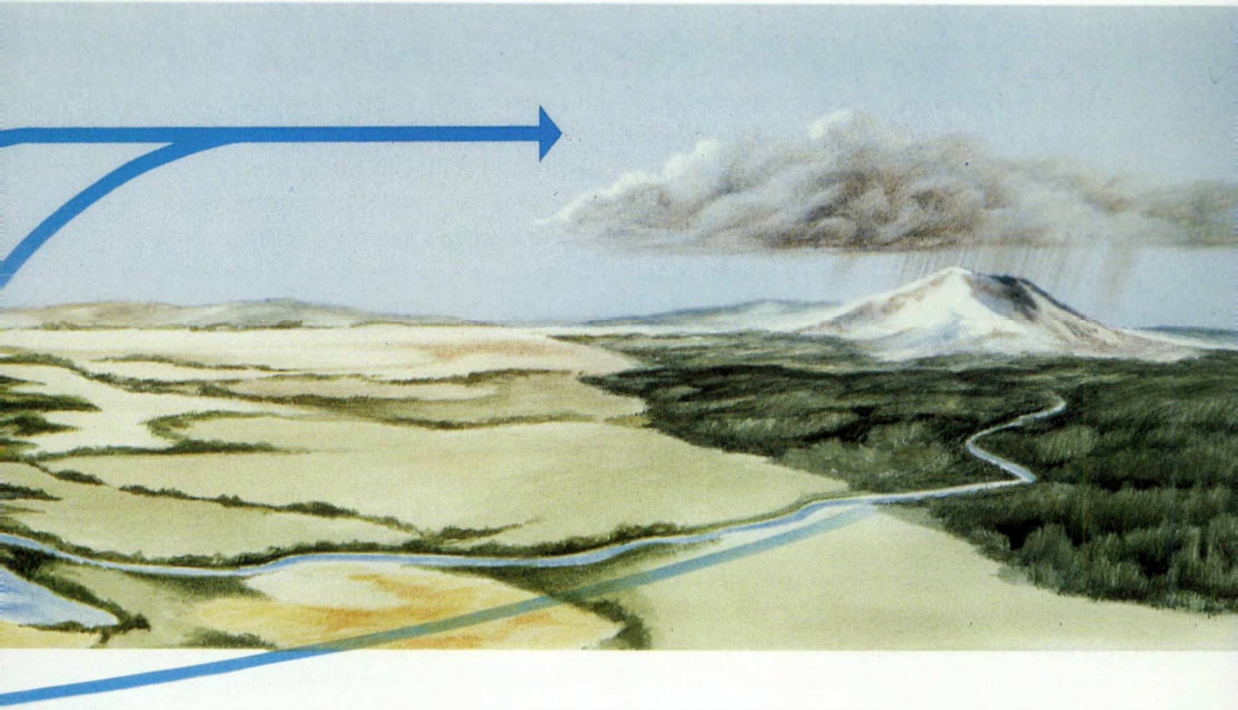
Figure 4. A constant exchange of water occurs between the sea, the atmosphere, rivers, lakes, ice sheets and glaciers, soil and vegetation. This water cycle, ultimately powered by the sun, is entirely dependent on evaporation from the sea.

Water enters the sea from ice, rivers, land run-off, groundwater and precipitation. Water that evaporates from the sea is carried in over the land and falls as rain or snow. It has been calculated that evaporation supplies the atmosphere with over 300 billion m^3 of water every year in the form of water vapour. Roughly two-thirds of this water returns as rain over the sea, but the rest falls as precipitation on land. This water leaches salts from bedrock and unconsolidated deposits and these salts are carried down to the sea by rivers and groundwater flow. In this way the supply of salts in the sea is replenished.

On land, water evaporates from lakes and rivers, soil and vegetation. This water forms precipitation, together with that formed by water vapour from the sea, condensed on dust particles and salt crystals.

This cycle not only involves 'useful' salts, but also other substances dissolved in water flowing off the land. Northern European seas, for instance, are influenced more directly by polluted precipitation from the land than are open areas of the world ocean.

Illustration: Bosse Falk.



water. The water flowing and raining into the sea brings with it a wide range of substances. These include various salts (mineral substances) that have been leached out of bedrock and unconsolidated surface deposits on land (and which keep the salinity of seawater constant), and pollutants, which are transported both by water and through the atmosphere. In all, over 220 million tonnes of dissolved substances of every kind enter the world ocean in one year.

According to an old Chinese proverb, 'the sea must be deep, for it spurns nothing entering it'. In view of the enormous masses of water in the sea, it is easy to believe that the large quantities of substances, both nutrients and pollutants, added to it by man ought to be diluted so much that they become harmless and 'disappear'. However, the facts of marine life are not as convenient as that, at least not in coastal sea areas.

Salts and gases determine the properties of seawater

Seawater is saline. Its **salinity** is almost always constant in the open sea, ultimately due to the prevailing currents. Water masses are mixed together and a balance is achieved between the various salts of seawater. This natural process shows clearly that the seas and oceans are not separate, but make up one coherent system. Nearer to coasts, seawater is increasingly mixed with incoming fresh water from rivers, lakes and precipitation.

The oceans have an average salinity of 35 parts per thousand (‰), i.e. 3.5 %, varying between around 33 and 38 ‰ depending on inputs and evaporation. The

Baltic is an example of a sea with maximum freshwater dilution, while tropical seas are instances of almost maximum evaporation. In the Persian Gulf, salinity can be as high as 41 ‰, the highest figure recorded anywhere in the world ocean.

On average, then, 1 m^3 of seawater contains around 35 kg of salts, the most important of which is common salt, sodium chloride ($NaCl$). If all the seawater on earth were to evaporate, it would leave a 60 m thick layer of salt on the seabed.

As soon as normally saline seawater begins to be diluted with fresh water and its salinity falls substantially below 35 ‰, it is called **brackish** water. A broad definition classes all water from 0.5 to 30 ‰ salinity as brackish. Below 0.5 ‰ it is fresh water. When salinity is over approximately 30 ‰, oceanic conditions are said to exist.

The Baltic is the world's largest brackish water sea. The waters around Scandinavia, from the Gulf of Bothnia and out through the Skagerrak, offer a sampler of different types of water. Here most mixtures of salt and fresh water are to be found, both near the surface and at greater depth, from almost pure fresh water to virtually oceanic water. This provides considerable scope to compare the ecology of different sea areas, since no other factor affects the distribution of living organisms as decisively as salinity.

It is not surprising that seawater contains the majority of known elements – all the evidence suggests that life on earth began (and probably could only begin) in the sea. The main constituents of ocean water are shown in *figure 5.* All salts in seawater are in solution and thus occur in the form of ions (electrically charged atoms or groups of atoms).

Apart from these dominant constituents, the other elements present occur in extremely small, but biologically often decisive, quantities.

Many organisms have a specialized ability to take up large quantities of a particular element. In many cases the organism derives no biological benefit from accumulating the substance in question, and in fact it is not known why this phenomenon occurs. For example, the tunics of sea squirts have a vanadium concentration 180 000 times higher than that of the surrounding water. In the same way, oysters take up large amounts of zinc, lobsters sizeable quantities of copper, etc. This ability to take up a given element in such large amounts is known as specific bioaccumulation. In fact it is only by studying the tissues of marine organisms that scientists have been able to demonstrate the presence of certain elements in seawater – elements which occur in such low concentrations in the water itself as to be undetectable, even with modern analytical techniques. It goes without saying that the same process of bioaccumulation can involve other substances as well, e.g. other metals, radioactive substances or halogenated hydrocarbons, high levels of which can thus build up in the tissues of marine animals. (Bioaccumulation and biomagnification will be described later.)

Seawater contains several elements considered particularly valuable by man, such as gold and uranium. However, they are enormously diluted. There is believed to be a total of around 10 million tonnes of gold in seawater in the world as a whole, but the proportions are one part gold to a million parts of water. And 1 kg of seawater contains approximately 0.0000031 mg of uranium.

Salts of nitrogen, phosphorus and silicon are the most important plant nutrients

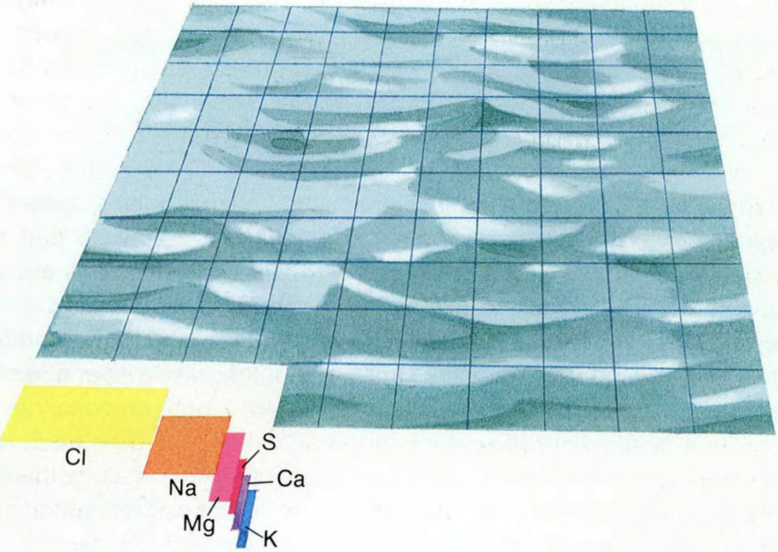


Figure 5. Seawater consists on average of 96.5 % water and 3.5 % salts. In round figures, therefore, 1 m^3 of seawater contains 35 kg of salts.

Oceanic water thus usually has a salinity of 35 ‰, but the figure can vary between about 33 and 38 ‰, depending on inputs and evaporation. The highest salinity found in seawater anywhere, 41 ‰, has been recorded in the Persian Gulf. The Baltic is an example of seawater with maximum dilution with fresh water — at its lowest, salinity is 3-4 ‰.

As soon as normal seawater begins to be diluted with fresh and its salinity falls substantially below 35 ‰, it is described as brackish water. A broad definition classes all water from 0.5 to 30 ‰ salinity as brackish. Below 0.5 ‰ it is fresh water, and over 30 ‰ it is oceanic.

About 99 % of the salts in the sea are made up of six elements: chlorine (Cl), sodium (Na), sulphur (S), magnesium (Mg), calcium (Ca) and potassium (K). Easily the biggest share is accounted for by chlorine and sodium, which form common salt, sodium chloride (NaCl). The exact proportions of the twelve most important salts vary, but the 35 kg of salts in 1 m^3 seawater consist of approximately 19 kg of chlorine, 10 kg of sodium (together about 29 kg of NaCl), 1.2 kg of magnesium, 1 kg of sulphur, 0.4 kg of calcium, and 0.4 kg of potassium, and altogether about 1 kg of bromine, carbon and boric acid.

Illustration: Bosse Falk.

in seawater. Planktonic algae most readily assimilate inorganic nitrogen, in the nitrate or ammonium form, and phosphorus in the form of phosphate. Natural concentrations vary widely from one area to another. As a rule, nutrient salts are plentiful in estuaries, coastal waters and regions of 'upwelling'. Sunlight, water temperature and the supply of nutrients govern the growth of organic material in the sea — from plankton upwards through the food chains.

As well as salts, seawater contains dissolved gases, the most important of which ecologically are oxygen and carbon dioxide. It also contains gaseous nitrogen. If oxygen depletion (deoxygenation or anoxia) arises on the seabed, poisonous hydrogen sulphide gas may form.

The concentration of dissolved oxygen in the water column says a great deal about the state of a sea area. Normally, surface water should be saturated with oxygen, i.e. the concentration should be in the region of 6–10 ml per litre of water. Oxygen should be present throughout the water column, right down to the bottom. The warmer and more saline seawater is, the less oxygen will dissolve in it.

Surface water is supplied with oxygen by photosynthesis – the most fundamental of all life processes, both in the sea and on land – and by atmospheric oxygen dissolving in it. The 'choppier' a sea is, the more easily waves can dissolve oxygen in the water. It is estimated that marine phytoplankton releases up to 70 % of all the oxygen making up our atmosphere. Biological production in the sea is thus of decisive importance to all life on earth.

Seawater with a good supply of dissolved oxygen can oxygenate water in an adjacent area by direct exchange of water. In this way the deeper parts of the oceans are supplied with a large input of oxygen-rich water by powerful cold currents from the Arctic and Antarctic. When the production/absorption of oxygen is slower than the rate at which it is consumed in an area, sooner or later a deficiency will arise. Anoxic areas of seabed can then develop. This oxygen depletion may be temporary, lasting only until new, oxygen-rich water arrives, but in many areas with slow water exchange it may prove permanent.

In discussions about the 'greenhouse effect' – the gradual warming of the atmosphere due to anthropogenic emissions of carbon dioxide (from the burning of fossil fuels), halogenated hydrocarbons (e.g. CFCs) and other 'greenhouse gases' – it has been suggested that the oceans will save the day. Some have argued that the sea will take care of the large surpluses of carbon dioxide produced by man, as a result of both combustion and large-scale deforestation in the tropics. As yet there are no clear-cut answers as to how much carbon dioxide the world ocean could turn over. Enormous amounts of carbon are known to be stored in the sea. Atmospheric carbon dioxide dissolves in seawater and becomes involved in photosynthesis. In all there is more than 60–70 times as much carbon in the sea as in the air, not including the carbon stored in the sediments. The sea can thus absorb some surplus carbon dioxide from the atmosphere, but the process is very slow, and no one knows what will happen if inputs continue at the present rate.

Figure 6 outlines the exchange processes that operate between the natural reservoirs of carbon dioxide – the atmosphere, the sea, and plant life. As in so many other cases before, man's intervention in the processes of nature is not in harmony with the pace of those processes. We are producing excessively large surpluses of carbon dioxide far too quickly. The oceans have a mixing time of around a thousand years and are a very inert component of the climatic system. The uppermost layers of water have a relatively rapid rate of exchange with the atmosphere, and here changes can be evened out in the space of a few months or years. Overall, though, the rate of exchange between surface and deep waters of the oceans is very slow. There is thus a tangible risk of seawater becoming 'saturated' with carbon dioxide when it is added as rapidly and in such quantities as is now occurring.

Another probable effect of global warming of the atmosphere is a rise in world sea level. Such a rise would be caused by a combination of two factors – the large ice caps would start to melt, and the warmer seawater would undergo thermal expansion, increasing its volume. If carbon dioxide continues to be emitted at the present rate, it is estimated that its atmospheric concentration will have doubled by around 2060. This could result in a global temperature increase of 1.5–4.5 °C, causing a rise in sea level of up to 1.5 m. Coastal states throughout the world would be directly affected, and certain countries would be in danger of being partially or completely submerged.

Gases and other substances are constantly being exchanged between the atmosphere and seawater. A theory that is still much discussed among researchers is that there is a 'microlayer', a 0.05 mm thick boundary layer between the atmosphere and the upper layer of the sea. All natural waters contain organic molecules which have a water-soluble and a fat-soluble component. These molecules accumulate in the boundary layer between air and water, with the water-soluble part in the water and the fat-soluble component in the air. A thin, greasy film thus forms on the water surface. Here comparatively high concentrations of fat-soluble substances can build up.

In general seawater has a high pH (on average, 8), making it resistant to the effects of acidifying substances. The high pH of seawater is due to the existence of a carbonate–carbon dioxide system with a significant buffering effect.

Halocline and thermocline form effective barriers

Water of high and low salinity, and cold and warm water, may form layers in the same sea, with no appreciable mixing. Stratification of the water column can also arise in fiords and other types of water body.

More saline water is denser and sinks to the bottom, with fresher, less dense

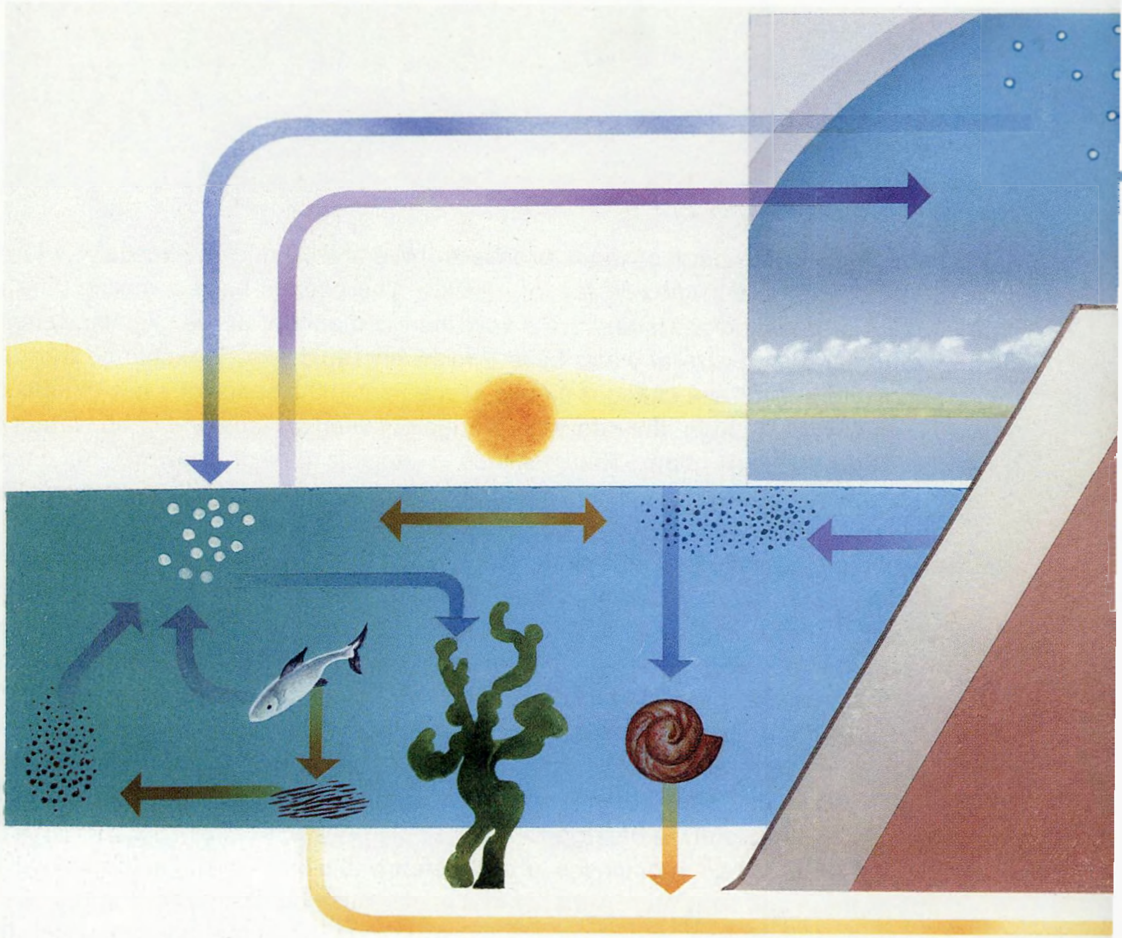
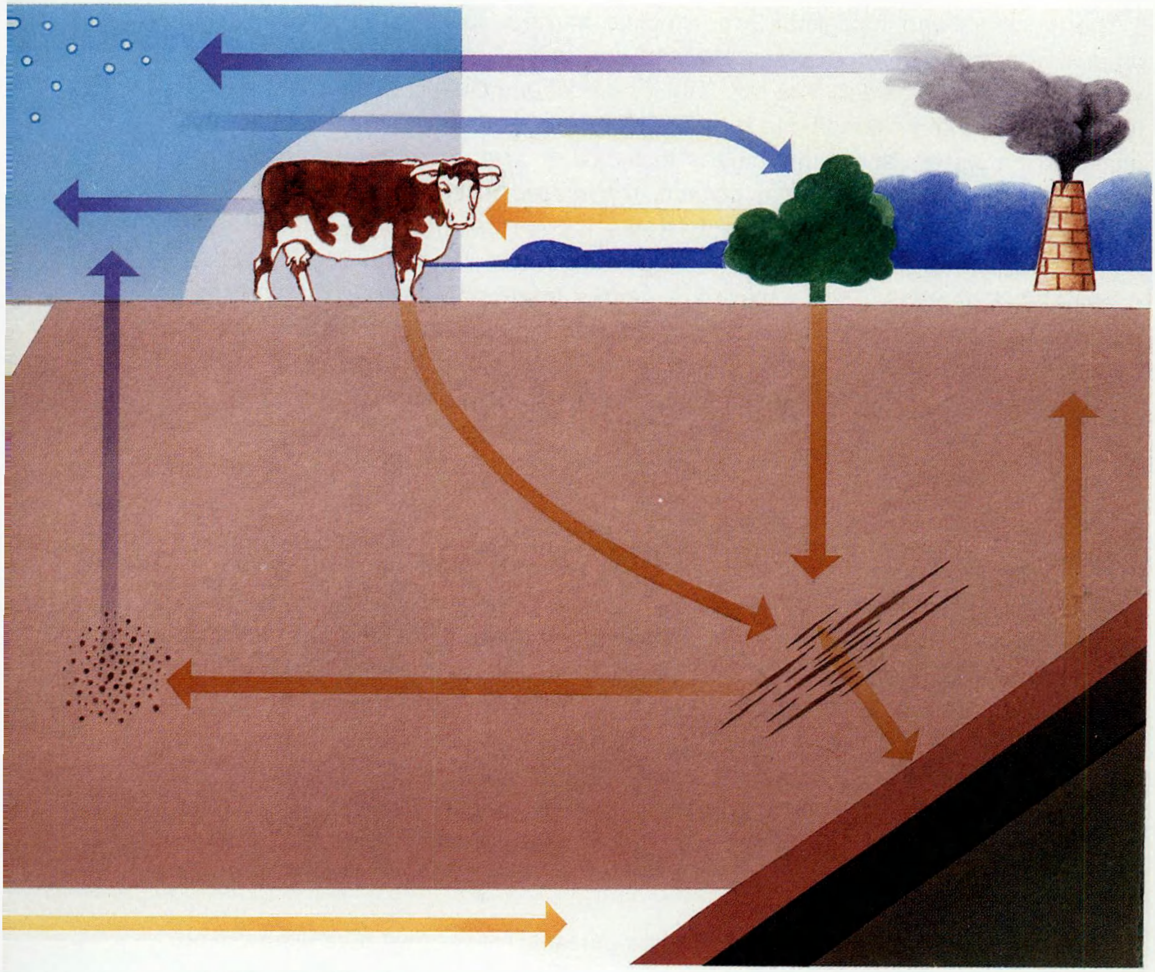


Figure 6. The carbon cycle is a complex chain of processes by which carbon compounds circulate between the atmosphere, water, living organisms and minerals. Gaeous carbon dioxide forms and is released when oil, coal and other fossil fuels are burnt. It is also constantly formed and given off when people and animals breathe, and when micro-organisms in soil and water break down organic matter (dead plants and animals). In both cases, conversion of energy is involved. In addition, carbon dioxide forms when vegetation is removed on a large scale, as in the tropical forests.

Carbon dioxide can also become 'locked up' again, but basically only in two ways. It is fixed by photosynthesis, the most essential of all life processes, and to some extent it is absorbed by seawater. It has been suggested that the seas will save us from the 'greenhouse effect', the gradual atmospheric warming due to a contantly rising level of carbon dioxide. There is considerable uncertainty, however, about how much carbon dioxide the sea will in fact be able to absorb. There is a great danger of surface layers becoming 'saturated' with carbon dioxide. Mixing of seawater is a sluggish process, so there is reason to believe that carbon dioxide absorption will not be able to keep pace with the rise in atmospheric concentrations caused by man's activities.

Illustration: Bosse Falk.



water floating on top of it. Higher salinity is thus found in water nearer the bottom than in surface water, and a clear boundary layer forms between the two masses of water, known as a **halocline**. Such boundary layers mainly form in sea areas where ocean and fresh water can mix with and influence each other, but they are also found in more markedly oceanic water. Haloclines can arise at different depths, usually from around 15 m to some 80 m.

The varying temperature of the water at different depths can also create a boundary, referred to as a **thermocline**. In sea areas which can also have a halocline, the thermocline is found above it. A thermocline arises between the uppermost, heated layers of water and the colder water at greater depth. In warm seas the thermocline may be as deep as 300 – 400 m, or even deeper. In temperate regions, it rarely forms at greater depth than 15 – 30 m. When the surface water cools again, the thermocline breaks down.

A **front** is a zone in which water masses with differing characteristics meet, but remain separate. In the North Sea, for example, fronts typically form in areas where water that is uniform from the surface to the bottom meets stratified water.

Thermoclines and haloclines are effective barriers to currents which would otherwise mix the different water masses vertically – more saline and fresher water, warmer and colder. The resultant stratification influences the chemistry of the water and affects conditions for the sea's living organisms. For example, the fact that the water cannot mix means that oxygen and nutrients are not evenly distributed throughout the water column. If the flow of nutrient salts from deep water is obstructed, large, unproductive areas, marine 'deserts', may form. In such nutrient-poor, barren areas in warm seas, the water is crystal-clear down to considerable depths – since there are neither large amounts of plankton, nor particles to cloud the water – and the sea is a deep blue. Not for nothing is this beautiful, warm colour called the 'desert colour' of the seas. In water stratified by salinity and/or temperature, the distribution of animals and plants is restricted.

Currents, winds, tides and water exchange

The detailed movements of large water masses in the sea at different times are a science in themselves. Just as there are prevailing wind systems, there are also generally prevailing sea currents. Yet, although certain currents predominate and produce a general pattern of water flow, they do not always determine how the water in fact circulates. Some currents are permanent, others are weather-dependent and more short-lived. Various climatic factors may affect circulation of the water, and so a definite, detailed system of currents can never be established for a given sea area. Water movement and exchange are also determined by such factors as air pressure, bottom topography, and fluctuations in river and other inputs.

A marine current may be either a **surface current** (also known as a wind-driven current or sometimes a residual current), a **deep current** or a **vertical current** *(figure 7)*.

In very general terms, surface currents are created and driven by winds at the surface, while deep currents are the result of differences in density between different layers of water, which cause the water to move. The density differences themselves are due to the diverging temperature and salinity of individual water masses. Colder and more saline water flows over the seabed beneath warmer and somewhat less saline water. Deep currents also result from the earth's rotation and the interacting gravitational forces of the earth, moon and sun. The rotation of the earth subjects moving air and water to a diverting force, which causes large-scale ocean currents to move clockwise in the northern hemisphere and counter-clockwise in the southern hemisphere – known as the Coriolis effect.

By and large, wind-driven surface currents correspond to the prevailing wind systems of a given area, though the Coriolis effect changes their direction somewhat. In other words, surface currents are dependent on the wind and may vary in direction. They usually move more slowly than the winds that give rise to them. Deep currents, which may be at depths of between 4 000 and 5 000 m, are even slower than surface currents and often move in the opposite direction to them.

Since the major ocean currents are moving water masses which often have a different temperature from their surroundings and a large capacity to store heat, they are of great importance to climate in that they make temperature fluctuations less extreme. One well-known example of this is the warm Gulf Stream or North Atlantic Drift, which regulates the climate of northern Europe and ultimately makes it possible for man to live in areas like northern Scandinavia. If the Gulf Stream were to disappear, the climate would change very drastically throughout this region. It is estimated that the warm water of the Gulf Stream raises the surface temperature of the North Sea by 6–9 °C, for example, which has a decisive impact on the regional climate. The Gulf Stream divides into two main branches around the 20th parallel in the eastern Atlantic. The northern branch flows past Ireland, through the Faeroe-Shetland Channel and into the Norwegian Sea; along the coast of Norway it is known as the Norwegian Current. This powerful flow is still noticeable as far north as the Barents Sea. The water forced into this area by the Gulf Stream turns, flows along the east coast of Greenland (the East Greenland Current) and continues south, some of it subsequently moving on up the west coast of Greenland (as the West Greenland Current) and some flowing round Iceland. This current, now cold, then passes below the warmer Atlantic water around Iceland and the water column becomes stratified. (The Jutland Current flowing into the Skagerrak is also an offshoot of the Gulf Stream.)

The seas adjacent to the oceans may be partially cut off from the major ocean current systems by sills at their entrances. Nevertheless such a sea may still be fairly deep and develop its own deep water systems, with properties typical of the area concerned. Such currents are chiefly influenced by climatic conditions. In addition, water either flows out from the adjacent sea to the ocean, or from the ocean over the sill into the sea. The Baltic is one example of a sea where sills prevent the free passage of water and currents from a larger oceanic system (the North Sea and ultimately the Atlantic).

Vertical mixing of the water in a sea area is necessary if nutrients and oxygen are to be distributed throughout the water column. Vertical currents occur to a varying extent and with varying strength in different areas.

A very pronounced form of vertical current is known as **upwelling**, which occurs when water moves away from a continent. To replace this water along the coastline, water rises from deeper, colder layers and 'fills the gap'. The surface water temperature drops and the upwelling deep water can thus have an equalizing influence on climate. Another tangible effect of upwelling is that large quantities of nutrients from the sea bottom are returned to the surface water and can be used in primary production. The earth's most productive fishing areas are in regions of upwelling. The term upwelling is also used to refer to the more generally occurring vertical mixing of seawater that results in nutrients being brought up from bottom water to surface water (see below concerning eutrophication).

This process can also operate in the other direction – **downwelling** – currents carry substances from layers nearer the surface to greater depths.

Sills between sea areas, and also shallow sills at the mouths of fiords, can effectively block currents and wave movements and hence water exchange.

Tides are another phenomenon with a major effect on the movement of water in

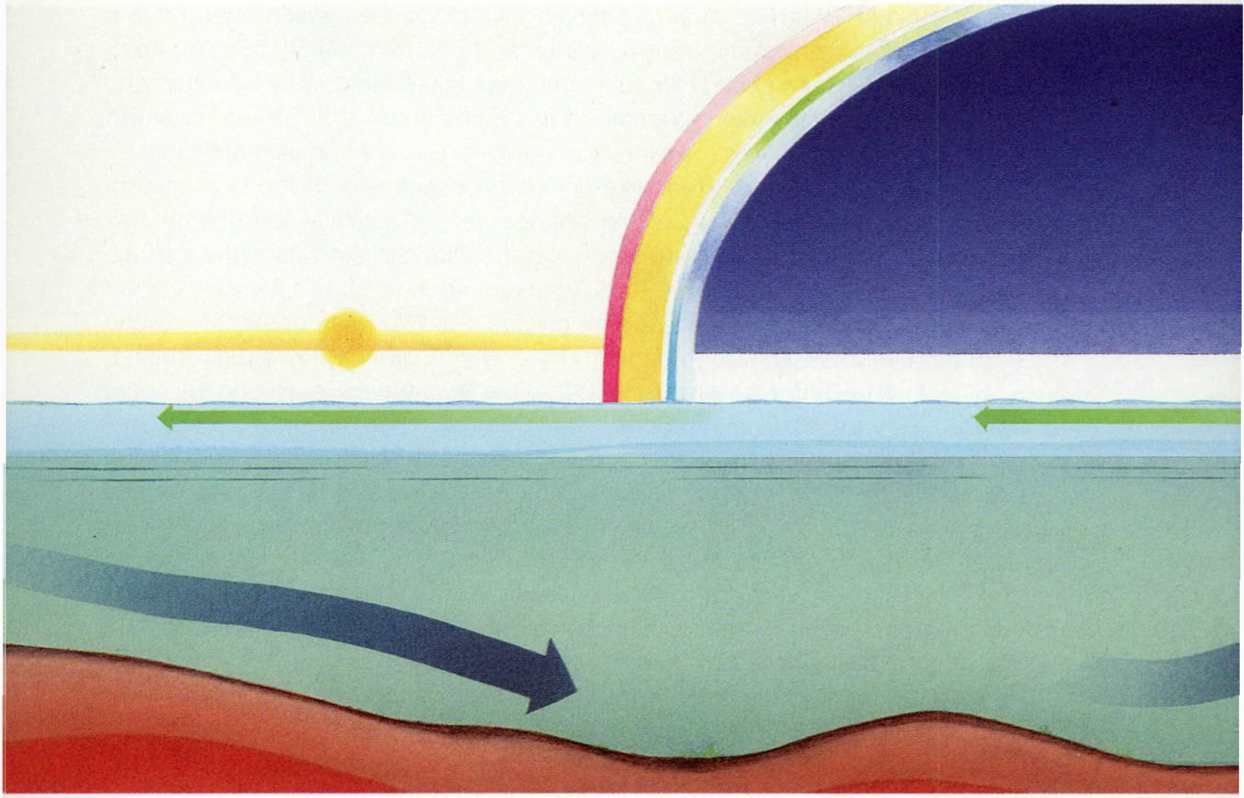


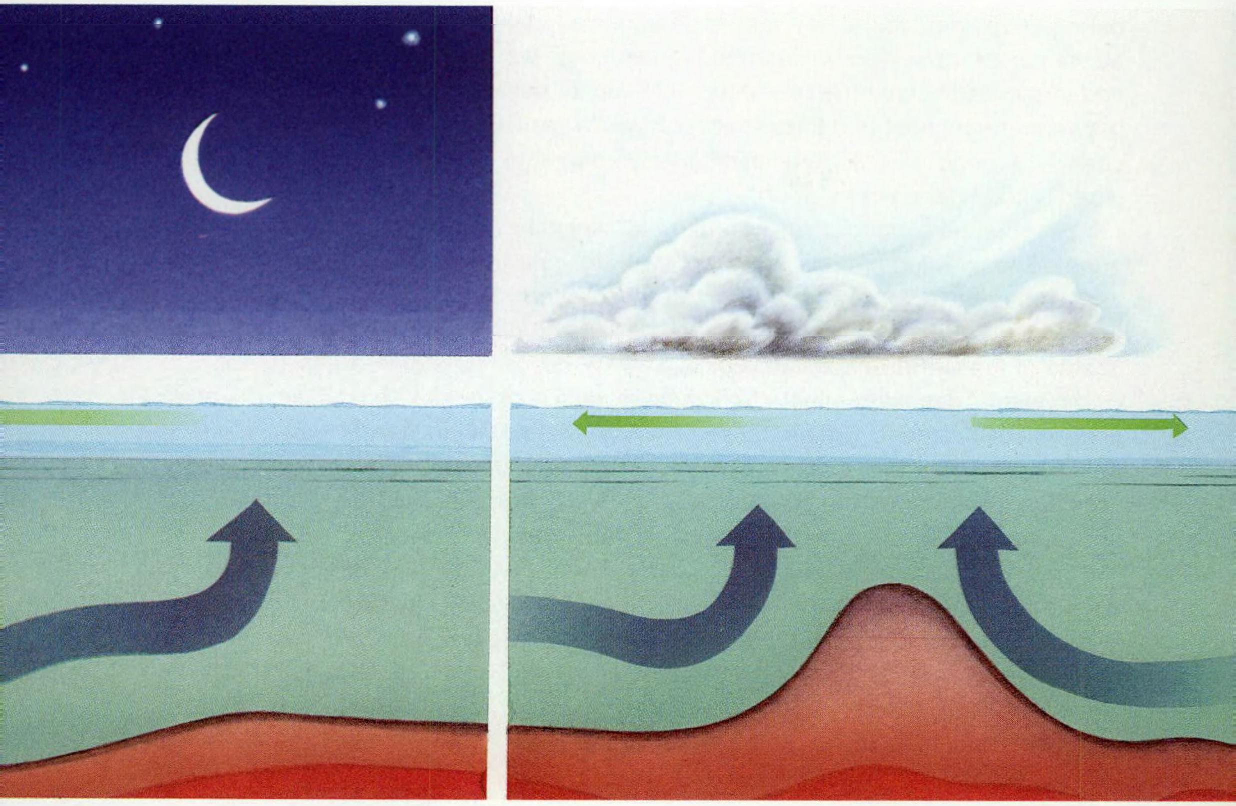
Figure 7. Currents in the sea may be either surface currents, deep currents, or vertical currents.

Surface currents are created and driven by winds at the surface. Deep currents result from differences in density between layers of water, which cause movement. The density differences themselves are due to the diverging temperature and salinity of different water masses. Colder and more saline water flows over the seabed beneath warmer and less saline water. Deep currents also result from the earth's rotation and the interacting gravitational forces of the earth, moon and sun.

By and large, wind-driven surface currents correspond to the prevailing wind systems of an area. They can vary in direction and are usually slower than the winds that give rise to them. Deep currents, which may be at depths of several thousand metres, are even slower than surface currents and often move in the opposite direction to them.

Vertical currents are generated in various ways. They differ from the horizontal surface and deep currents in that they most frequently flow from the seabed up towards the surface. They can arise when major current systems meet and 'collide', and also near other types of obstacle, such as coasts, submarine peaks and similar features that force water to rise. Upwelling and downwelling are important types of vertical current.

Illustration: Bosse Falk.



a sea area. The largest tidal range, i.e. difference between low and high water, has been recorded in the Bay of Fundy, west of Nova Scotia in Canada. There the difference between the highest high tide and the lowest low tide can be up to 21 m. Tides can also cause very powerful currents. In the Pentland Firth in Scotland, currents with a speed of 11 knots have been recorded. The Lofoten Islands maelstrom, the Moskenstrøm, is an instance of dangerous eddy currents resulting from the tidal effect.

Tides are a periodic alternation of low and high water level in the sea and are due to the gravitational pull of the sun and moon. When the water rises the tide is said to be flowing, and when it falls it is said to be ebbing. The weakest tidal waves are called neap tides and the strongest waves spring tides. In different parts of the world there are either semidiurnal tides (ebb and flow twice daily, e.g. in the Atlantic and North Sea) or diurnal tides (ebb and flow once daily, e.g. in the Gulf of Mexico). There are also mixed tides, with ebb and flow admittedly occurring twice a day, but with varying height, e.g. in the Pacific.

Tidal waves are hardly noticeable on the open sea, but have major effects in shallow water near coasts and in inlets and bays. When a tidal wave on its way out from the land meets the next wave on its way in, the latter is reinforced. Tidal waves of this kind occur in the English Channel and the North Sea. On Britain's coasts, the tidal range averages around 3 – 4 m during spring tides and 1.5 – 2.5 m during neap tides. In the Kattegat and Skagerrak, only a small difference of around 30 cm can be observed between the highest high water and the lowest low water, and in the Baltic itself the tidal effect is minimal, perhaps just a centimetre or two between the highest and lowest water level. In the Gulf of Saint-Malo on the west coast of France, the sea level can vary by up to 13.5 m. Here, at La Rance, is the world's first tidal power station.

Tides create a special environment for animals and plants. Only organisms adapted to the fluctuations in water level are able to live in the **intertidal zone**, where they have to be able to contend with alternating dry and wet conditions. Intertidal zones are found on various types of coastline. The salt marshes on the coasts of the North Sea are biologically a very special type of intertidal zone.

The levelling, mixing effect of currents gives the open sea, especially, a stable, uniform environment. The processes involved are slow in the larger water masses; near coasts they are more rapid. There the environment is also more varied. Currents transport all the substances originating from the land, as well as plants and animals of all sizes, both horizontally and vertically.

Currents, boundary layers in the water column (where they exist), winds and tides are important elements in the process that results in the gradual circulation and replacement of the water in a sea area. In one area the water may move at great speed, while somewhere else it may stand almost still. The Baltic is a typical example of a sea with very slow water exchange. It has been calculated that it takes several decades for all the water in the Baltic to be renewed. In the North Sea, it takes about three years for the water of the German Bight to be replaced, while the water of the northern North Sea is exchanged roughly every six months.

Zones of the sea and their plants and animals

The sea is one coherent ecosystem, in which everything is mutually dependent. All living things interact with their environment. For practical reasons, however, the sea and the life in it need to be divided into smaller ecosystems, or zones. Conditions vary between these zones, though ultimately the sea is one large entity.

Almost all primary production, in the form of growth of phytoplankton, in coastal sea areas occurs in the uppermost 10–15, perhaps 30 m of water. Larger plants, such as attached algae, account for some primary production near coasts. In the open sea, where almost all primary production is ascribable to microscopic plankton, the lower limit of primary production is at a depth of around 100–200 m. In both cases the limit is determined by how far sunlight can penetrate. The more turbid the water, the shallower the zone of production. This zone, in which new growth occurs and light energy is converted into chemical energy, is thus fairly narrow, while the consumption zone, which is entirely dependent on downward transport of energy, is very large. Areas of the seabed that are unlit by the sun account for almost 60 % of the earth's surface.

Photograph: Stefan Rosengren, Naturbild.

The sea can be divided into three main biological zones:

- the **littoral zone**, or **littoral** (the shore zone), which extends from the upper part of the splash or spray zone, through the intertidal zone (if there is one) down to the lowest limit of vegetation, i.e. where light cannot penetrate,
- the **pelagic zone**, or **pelagial**, which is the actual mass of water (as opposed to the seabed) and the life in it, and
- the **benthic zone**, or **benthal**, which consists of the lower parts of the littoral zone and the seabed below that zone, and the life there.

Fact panel 2

An abundance of life in the sea

Marine plants consist of algae (including symbiotic species, or symbionts) and flowering plants. The algae are described in *fact panel 3.*

Symbiotic algae are species living in association with certain animals (particularly cnidarians and giant clams), an arrangement of mutual benefit to the alga and the animal, e.g. in terms of obtaining nutrition.

Only around 50 flowering plants are found in the sea. They have early relatives on land, but have managed to adapt to the marine environment. Almost without exception, such plants grow in shallow coastal waters and estuaries. Eel grass is one example. Many marine flowering plants form 'meadows', which provide food and shelter for young organisms, such as larvae and fish fry.

Marine procaryotes are the most primitive of organisms living in the sea, comprising the blue-green algae and bacteria. Unlike every other form of marine life, procaryotes lack a cell nucleus. Although extremely simple, these organisms play a decisive role in the marine ecosystem.

Microscopic fungi in the sea, like bacteria, play a part in breaking down organic material, releasing nutrients that can be returned to the food chains.

Marine animals are numerous and varied, both in size and in the way they function. They include everything from microscopic zooplankton to the world's largest mammals, the whales. The following is a very small selection of the many groups of animals living in the sea:

These main zones are subdivided into different depth zones. Both the pelagic and the benthic world have a euphotic (or photic) zone, to which sunlight can penetrate, and an aphotic zone, which light never reaches.

The pelagic zone can also be divided horizontally into the oceanic province – the open sea – and the neritic province – the areas close to and affected by coasts. This subdivision is a useful one in biological and ecological terms, too, when we are discussing environmental effects. The shallow coastal part of the sea is characterized by a high level of production, everything from plankton to mammals, marked variations in temperature and nutrient supply during the year, and stress resulting from pollutant inputs and other human activities. The open sea only has plankton production, its environment is more stable, and with increasing depth seasonal variations in salinity and temperature decline.

Higher life forms are present throughout the world ocean, even at the greatest depths, down to around 11 000 m. But despite their enormous volume, the seas exhibit less biological variation than the land. Most variation is found in coastal waters. On the earth as a whole there are 1 200 000 known animal species. Fewer

- Protozoans, incl. amoeboids, e.g. foraminiferans, radiolarians, and ciliates
- Sponges, including glass or silica, calcareous and horny sponges
- Cnidarians, including various jellyfishes, medusae, corals and sea anemones
- Comb jellies
- Many different worm species
- Rotifers
- Bryozoans (moss animals or sea mats)
- Brachiopods (lamp shells)
- Chaetognaths (arrowworms)
- Larvae of marine animals
- Molluscs, including bivalves (mussels etc.), gastropods (e.g. limpets, whelks, sea slugs) and cephalopods (e.g. octopuses, cuttlefish)
- Segmented worms, including polychaetes, leeches and oligochaetes
- Arthropods, such as sea spiders, lobsters, crabs, shrimps, copepods, mysids, krill, amphipods, and the few insects to be found in seawater
- Echinoderms, including feather stars and sea lilies, starfish, brittle stars, sea urchins and sea cucumbers
- Tunicates, e.g. sea squirts
- Cephalochordates, e.g. lancelets
- Jawless vertebrates, including lampreys and hagfish
- Vertebrates with jaws, which include bony fish, cartilaginous fish, reptiles (such as turtles, sea snakes and marine iguanas), birds, and all marine mammals, e.g. whales, seals, dugongs and manatees, and predators such as the sea otter and polar bear.

than 15 % of these, or roughly 160 000 species, live in the sea *(fact panel 2)*. Similarly, the number of plant species is not in proportion to the living space available in the oceans. This dearth of species in the sea is due partly to the fact that there are as good as no insects there (insects make up a considerable proportion of the species found on land), and virtually no flowering plants (which have generally been unable to adapt to the marine environment).

The water body, the pelagial, is a fairly uniform environment. Here only around 3 000, or less than 2 %, of the 160 000 marine animal species spend the whole of their lives. Most other species spend a short time, as larvae or fry, drifting around in the sea, but then settle on or in the seabed and stay there. Organisms in the pelagial either float freely or swim. The word plankton comes from the Greek *planktós*, which means 'wandering'. Actively swimming animals, such as fish, cephalopods (e.g. octopuses), marine reptiles and mammals (seals, dolphins, whales etc.), are referred to collectively as nekton. The majority of organisms in the water column, however, allow the wind, currents and the density stratification of the water to determine their movements.

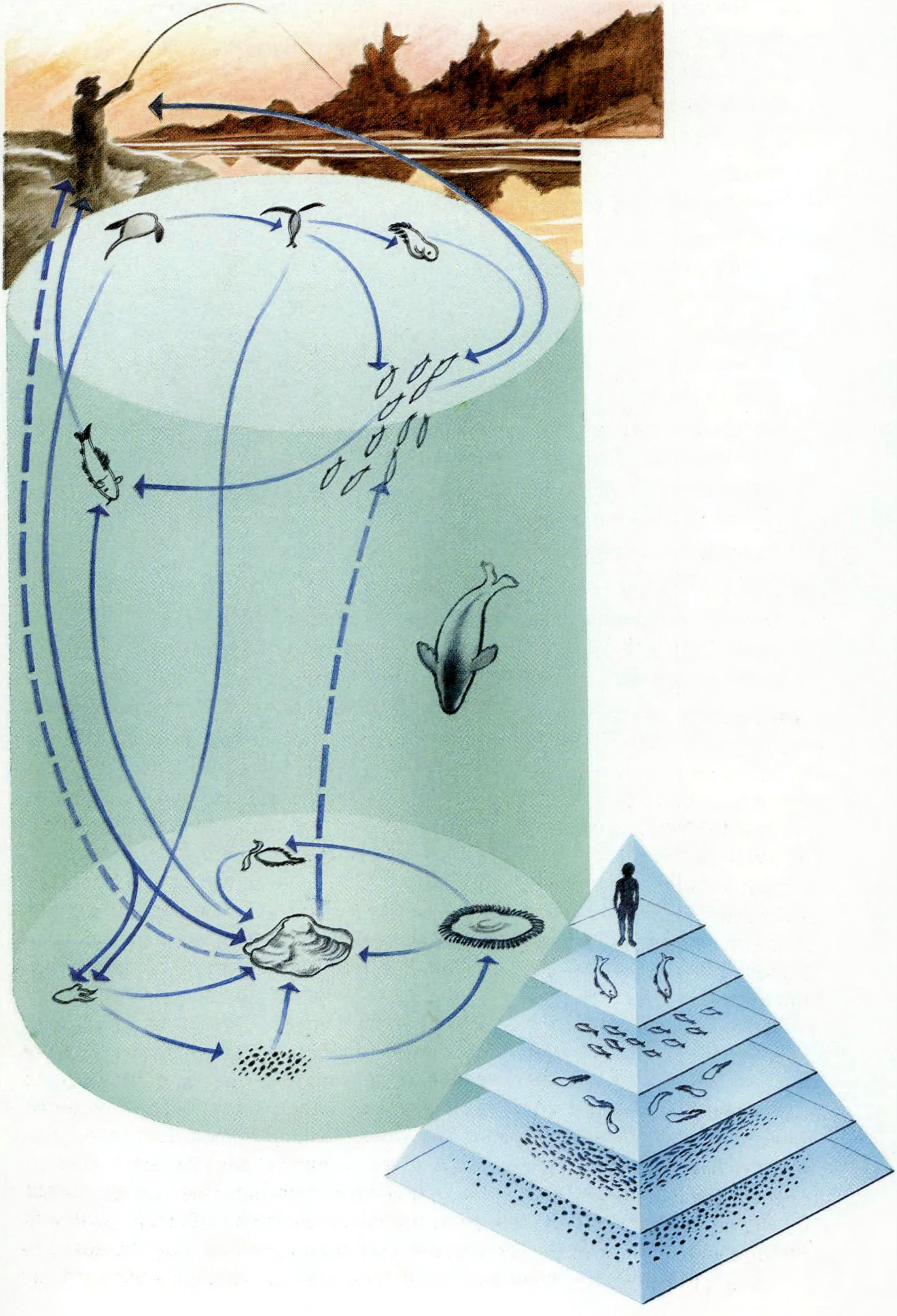


Figure 8. The most important food chains in the sea — in the water body itself (pelagic) and on the seabed (benthic).

The key link in the pelagic food chain is primary production of planktonic algae, followed by secondary production of zooplankton and other plant-eating organisms. Phytoplankton, in other words, is mainly eaten by zooplankton, which in turn is fed on by fish fry and some adult fish (herring). Fish fry, larvae and other 'marine infants' are eaten by larger fish, which in turn become prey for predatory fish species. These fish are then eaten by sea birds, marine mammals and man.

The benthic food chain varies depending on whether a hard or soft substrate is involved. On a hard substrate, the chain begins with primary production of macroalgae or epiphytic algae. The algae are grazed by various animals, e.g. gastropod molluscs, which account for secondary production. These animals may in turn be eaten by bottom-feeding fish, lobsters, crabs and other benthic predators, which in turn become the prey of sea birds, marine mammals and man. On hard substrates, filter feeders are also found, e.g. bivalves. On a soft substrate, the main primary producers are larger seed-bearing plants and benthic microalgae. They are grazed by a group of organisms that are referred to as detritus feeders. These animals, however, feed mainly on food raining down from the surface water — both living organisms and dead material. On the soft bottom there are also filter-feeding animals, e.g. bivalves, which eat what they can filter out of the water. A soft-bottom food chain ends with demersal fish, which eat bivalves, gastropods and other animals living on and in the seabed. These fish are then eaten by sea birds, marine mammals and man.

A biological pyramid shows how energy is transferred and converted between different trophic levels. To produce 10 kilocalories (kcal) in the form of flesh from a large predatory fish (e.g. cod), there has to be an input of 100 000 kcal of energy in algae, which yields 10 000 kcal in zooplankton after the first conversion step; a further conversion results in 1 000 kcal in the form of fish fry, which becomes 100 kcal of flesh in a small fish (e.g. herring).

Illustration: Bosse Falk.

The sea floor, as was noted earlier, may be either hard or soft. A **hard** bottom or substrate may consist of gravel, pebbles, boulders or rocks. Hard-bottom areas are mostly found near coasts. Although they only account for just over 1 % of the floor of the world ocean, they exhibit incomparably the greatest species diversity. Of some 157 000 benthic species, roughly 127 000 are found on hard substrates. The algae and animals found there are either permanently attached in one place (sessile) or have some device enabling them to suck or cling onto the bottom. The hard-bottom fauna consists mainly of filter-feeding species. Hard-bottom animals include mussels, barnacles, sea squirts, starfish, sea anemones, scallops and sea cucumbers. Algae, which only grow in the euphotic zone, are found in all sizes, from the microscopic planktonic species to the large macroalgae — green, brown and red algae *(fact panel 3)*.

A **soft** bottom or substrate is made up of loose, soft deposits of sediment. It can provide a home for a range of animals, which either burrow into it or live on its surface (either crawling or attached). Most of the 30 000 animal species concerned live in burrows of their own making. They live, directly or indirectly, on organic matter raining down from upper layers of the water column and are known as sediment feeders. Some actively filter their food from the water while it is still suspended, others feed on material in the actual sediments. Examples of soft-bottom animals are starfish, brittle stars, lugworms and other polychaetes, sea cucumbers, threadworms, flatworms, small crustaceans, bivalve molluscs, ciliates (protozoans) and rotifers. The smallest animals measure less than a tenth of a millimetre across. Plants found on soft bottoms consist of microalgae and certain seed-bearing plants with roots.

As can be seen from *figure 8*, which is a highly simplified diagram showing the most important **food chains** in the pelagic and benthic zones – and their interaction – marine animal life can be broadly divided into animals that feed on living organisms and animals that eat dead organic material. The latter are called detritus feeders (or detritivores), the word detritus encompassing everything from entire dead animals and plants or parts of them, through animal excrements, to bacteria and other micro-organisms. Probably their actual food is not the physical particles as such, but bacteria attached to the plant remains and other material raining down.

Benthic animals play an important role in the cycling of nutrients and oxygen in the marine environment. Most of the macroscopic species are to be found in the top approx. 5 cm of sediments. Animals living at greater depth in the seabed are either large and dig deep burrows, or else very small. When bottom-dwelling animals burrow, feed on sediment and move particles around, they also help to oxygenate the bottom. This mixing, or **bioturbation**, is important to the 'health' of the seabed. The organisms concerned do an impressive job of work. Off the coast of the Netherlands, for example, there have been found to be 17 lugworms per square metre, and from a depth of 20–40 cm in the sand that number of worms throw around 75 l of sand up to the surface in a year. This ingestion and shifting of sand means that the sandy bottom can be turned over and oxygenated to a depth of over 30 cm every year.

We can get some idea of the state of the seabed by studying the colour of the sediments. The top few centimetres, where reactions dependent on oxygen (oxidation reactions) occur, are light brown. Further down in the sediments there is no oxygen, and here 'reducing' conditions prevail. The sediment is turned black by various sulphides, including that of iron. The boundary layer between these strata of sediment is known as the **redoxcline**, another of the clear dividing lines in the sea that tell us about its environment. In the black, anoxic sediment there are bacteria which can manage without oxygen gas, since they are able to obtain the oxygen they need from inorganic compounds such as nitrates, sulphates, carbon dioxide and carbonates. The conversion processes performed by these bacteria result in the formation of other chemical compounds, chiefly hydrogen sulphide, ammonia and methane. As more organic matter reaches the bottom and has to be broken down there, consuming the oxygen available, the redoxcline becomes thinner and is found higher up in the sediments. This boundary can thus be used as an indicator of the load of organic matter or contamination with other materials which are not broken down in the normal manner.

The food chains of the sea together form food webs. Marine food chains always begin with the production of plants, mainly planktonic species or **phytoplankton**, but also other, larger algae. The efficient photosynthesis and production of organic material carried out by these organisms constitute the sea's **primary production** and are absolutely essential to the continuation of life in the sea. Some primary production, as was noted, is accounted for by large algae on rocks and sunlit areas of the seabed. Phytoplankton lives and reproduces in the pelagial, the mass of water of the sea.

Algae provide food for the next link in the chain – small planktonic animals, or **zooplankton**. These animals in the water column, together with benthic animals whose food rains down from the surface water, are responsible for **secondary production** in the sea.

Zooplankton includes copepod crustaceans, krill, and the larvae and fry of many different animals, later stages of which live on the seabed or swim freely in the water. When zooplankters spend the whole of their lives in the water column they are called pelagic zooplankton, or holoplankton. Species which eventually settle on the bottom as adults are termed benthic zooplankton (meroplankton).

Zooplankters may be herbivores, omnivores or carnivores. When they feed on free-floating planktonic algae, they are said to graze, and this is a highly efficient process in the sea. Both planktonic and larger animals graze – large algae, for instance, are grazed by many different species. On land only about 10 % of the green biomass is utilized directly by grazing animals. In the sea, on the other hand, anything between 50 and 100 % of the plant mass constituted by algae is grazed.

Microscopic decomposer organisms – i.e. bacteria, bacteria-eating organisms and fungi – play a very important part in the marine food web. Such organisms are found both in the water, where they convert material and thus release nutrients for further use, and on the seabed. Their job is to break down organic matter – plant and animal remains, excreta, and other micro-organisms – and they form part of the decomposer chain. The process by which organic matter is broken down and previously organically bound elements, including nitrogen and phosphorus, are released is called mineralization. This process also liberates carbon dioxide, which can be recycled in primary production. In anoxic conditions, nitrogen in nitrate form can be converted by special bacteria and given off to the atmosphere as nitrogen gas, a process known as denitrification. In waters with populations of blue-green algae, certain species of these algae can transform atmospheric nitrogen into forms of nitrogen that are available to plants. This process is termed nitrogen fixation.

The next link in the pelagic food chain is that small zooplankton species are fed on by larger zooplankters, which in turn are eaten by fish fry, shrimps and other small animals in the water. Some adult fish, e.g. herring and related species, also feed directly on zooplankton. However, planktonic animals can also provide food without themselves being eaten, since about 30 % of their daily production is passed on in the form of excrements, which settle to the seabed and become food for both micro- and macroscopic benthic fauna. The benthic food chain continues in roughly the same manner.

Fish search for their food either in the water itself (pelagic species) or on the bottom (bottom-feeding or demersal fish). In north European waters, herring, sprat and mackerel are typical pelagic fish species, while cod, haddock, whiting and flatfish are common demersal species.

Finally, fish are eaten by large predatory fish, sea birds and marine mammals, e.g. seals. The largest of the sea's mammals, the baleen whales, however, often have a short food chain: some species, for example, are dependent on a type of small crustacean known as krill. (Other whales, the toothed whales, eat fish, squid, cuttlefish and seals.) Man is at the top of the food chain and, to varying degrees, makes use of fish, shellfish and marine mammals.

The food webs of the sea are complex and often longer than their counterparts on land. On land, grass grows, cows eat grass, and we eat cows. Or else we eat vegetables direct, without an intermediate step. In the sea several intermediate stages often have to be passed before the energy that began with phytoplankton conversion of sunlight into chemical energy reaches its end organism. Every intermediate stage in which energy is transferred from one organism to another is called a trophic level (or energy or food level), and the term biological pyramid is used in this context *(figure 8)*. There may perhaps need to be five conversion stages from phytoplankton to cod flesh (and then another step from cod to man). These 'transfers' are not in fact energy-efficient. Generally, organisms at different levels have to do work to make the 'raw material' available to themselves or others as food, and this work consumes a great deal of energy. A rule of thumb in ecology is that 90 % of the energy is lost every time conversion takes place within a biological pyramid. On this basis, 100 000 kilocalories (kcal) of plankton are needed to produce 10 kcal of cod. However, the marine food chains are not as wasteful of energy as it might appear. As we have seen, grazing makes maximum use of the food available; virtually nothing is wasted. Moreover, many animals in the sea are cold-blooded and do not need energy to maintain a constant body temperature. The reason why energy is nevertheless lost at each intermediate step is that all organisms burn some of their food/energy intake when they respire. Respiration is photosynthesis 'in reverse', consuming oxygen and re-forming carbon dioxide.

Life in the sea is dependent on there being suitable environments and conditions for all the various organisms at the different stages of their lives. The shallow **coastal or shore zone** (the littoral zone) is essential in this regard. It provides a breeding ground, nursery, shelter, food store and many other things for fish and other marine animals. Disturbed or damaged coastal waters therefore seriously affect both plants and animals. If breeding grounds disappear, if shelter-providing plants are no longer available, if production declines so that the food store runs low or is exhausted, if necessary resting and feeding sites are lost – then not only the coastal zone, but also the marine environment generally will be affected. One example of a possible environmental impact is the disappearance of bladder wrack from eutrophicated waters. A bladder wrack plant is more than just a plant, it is a small community in its own right. A teeming variety of life is dependent on this seaweed for shelter and a place to feed.

A river **estuary** provides a very special kind of environment. As in salt marshes, plants and animals in estuaries have to tolerate fluctuating conditions. In a salt marsh, species must cope with the alternating ebb and flow of the tide. A characteristic feature of an estuary is that it is a sheltered area with an alternating input of salt and fresh water. Estuarine organisms consequently have to be able to withstand sharp fluctuations in the salinity and temperature of the water. Salt water comes in from the sea, fresh water from rivers and precipitation. These water masses mix, are sucked in and pushed back. Estuaries are rich in nutrients, due to inputs from the land, and are considered to be highly productive throughout the world. At the same time they are very vulnerable. The river water supplies not only nutrients, but also pollutants. Many animals spend shorter or longer periods of their lives in estuaries. They are important feeding and resting grounds for sea birds, for example.

Salt marshes are primarily found in intertidal zones (see above). Extensive areas of salt marsh are found on the North Sea coasts of the Netherlands, the Federal Republic of Germany and Denmark. They have formed as a result of silt being deposited up to the high water level. Marshes can form in the shelter of sandbanks on low-lying coasts. Many of the salt marshes on the Netherlands coast are now surrounded by dikes and are under cultivation. An area reclaimed from the sea in this way is called a polder. Marshes in saltwater areas are often biologically very productive. The Wadden Sea (Waddenzee), a zone of salt marshes and estuaries along the coast of the continent, bounded to the north-west by the Frisian Islands, is of very great importance to many animals and plants *(figure 9)*. It has a combination of the estuarine and marsh environments. Salt marshes have rich and often unique populations of marine plants and animals. They are also an important component in nutrient cycling in the coastal zone. Like estuaries, they are a vulnerable environment. Many species live in difficult conditions, with a constant alternation of salt and fresh, dry and submerged. Further strains imposed by man may therefore have greater detrimental effects here than in a quieter and less fluctuating coastal environment.

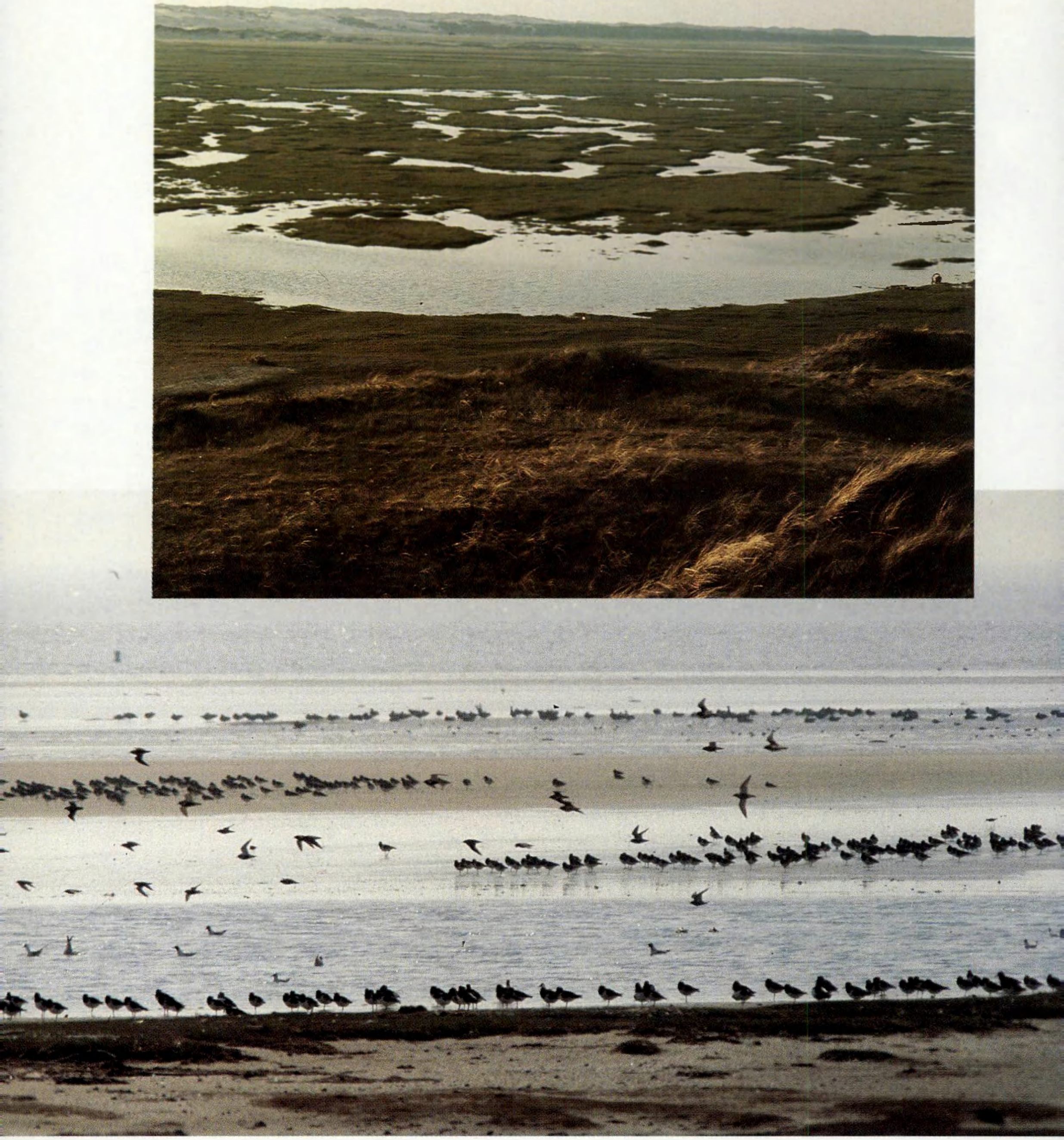


Figure 9. Salt marshes are a very special type of marine environment, generally in the intertidal zone. They are biologically very rich, with unique populations of marine plants and animals. Parts of the coasts of the Netherlands, the Federal Republic of Germany and Denmark, on the Wadden Sea, are typical salt marshes. This area is of great biological significance to the whole of the North Sea. The tremendous numbers of shorebirds (waders) are a characteristic feature of the Wadden Sea.

Photographs: P. Roland Johansson and Göran Hansson, Naturfotograferna.

Fact panel 3

Algae – from microscopic to quite large

Algae can be microscopically small or quite large. The smallest microalgae measure at most only a few micrometres across, while some attached macroalgae may grow to lengths of 60 m. Between those two extremes, various sizes and shapes are found.

Microalgae are generally speaking the same thing as phytoplankton. These single-cell microscopic organisms are the basis for all marine life. They may be free-floating or attached to macroalgae or the seabed. Phytoplankton species are usually pelagic, i.e. only occur in the actual water column, but microalgae (especially diatoms) can also be benthic, at least in the euphotic zone near coasts. Such algae account for a substantial level of primary production, on both soft and hard substrates.

Planktonic algae are not necessarily small, however. Sargasso, or gulfweed, is an example of a species that occurs as long, free-floating fronds. It is a type of brown algae which can either be attached to a substrate or, if it is torn loose, drift around in the sea buoyed up by air bladders.

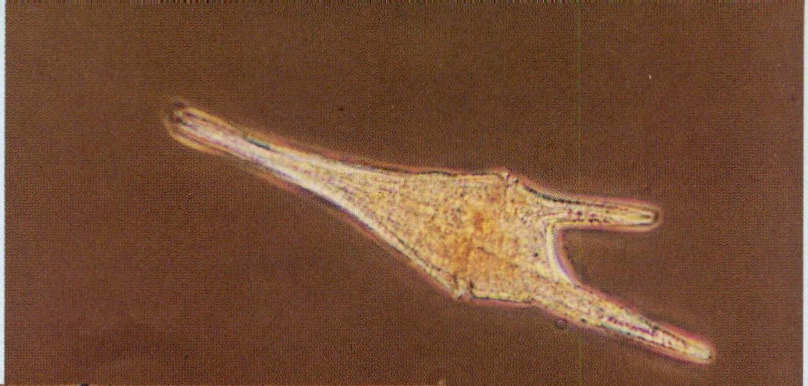
Microscopic planktonic algae exhibit an enormous diversity of species. They are also very beautifully shaped *(figure 10)*. Diatoms, for example, are sometimes called the jewels of the sea.

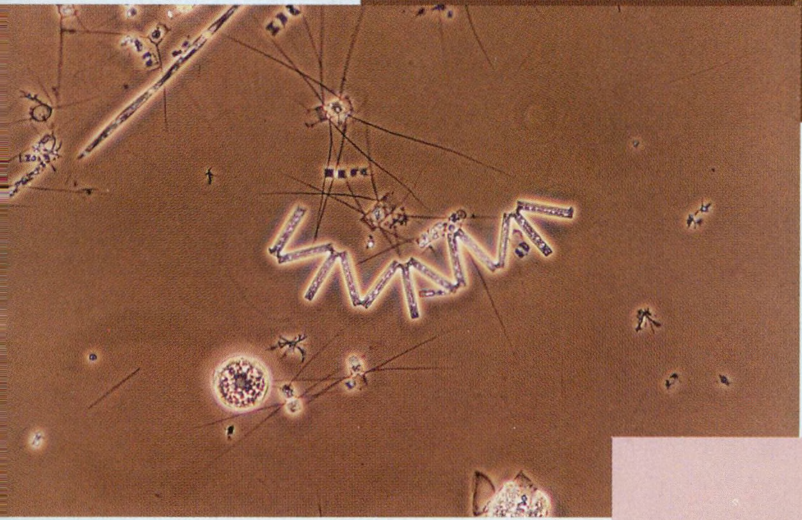
Planctonic algae are divided into a large number of groups. Among the more important groups of algae in seas are diatoms and dinoflagellates. In markedly brackish waters and fresh waters blue-green algae can be found.

Diatoms have a pillbox-shaped silica shell, with a bottom and a lid. These algae can join together to form long chains. Algal blooms in spring are mainly made up of diatoms. Like many other algae, they grow by cell division and can give rise to heavy blooms in a short time. In all there are some 20 000 diatom species, and they are found in large numbers both in surface water and on the seabed. Diatoms are an important source of food both for larger filter-feeding animals and for the small copepods.

Dinoflagellates are somewhat larger than diatoms and can also form long chains. These algae have two whip-like threads, called flagella, which serve as simple organs of movement. The dinoflagellates are not a uniform group, individual species differing in their appearance and way of life. A remarkable characteristic of some species is that they can cause the sea to 'phosphoresce'. Dinoflagellates, too, mainly reproduce by dividing. They prefer slightly warmer water, and autumn blooms often include a large proportion of dinoflagellates. In warmer waters they can cause heavy blooms known as red tides (in more northerly latitudes the water turns a coffee-brown colour). Dinoflagellates can produce toxins *(fact panel 4)*.

Blue-green algae are an intermediate form of organism – procaryotes – and are regarded as closely related to bacteria. An alternative name for them is in fact cyanobacteria. Blue-green algae form colonies and, given a plentiful nutrient supply, can reproduce extremely rapidly by dividing. A bloom of this kind can greatly discolour water in the space of a few hours. Blue-green algae





need not in fact be blue-green in colour; they may be red, black or brown. A highly specific property of some species of this group is that they fix nitrogen, i.e. convert atmospheric nitrogen gas into plant-available forms of nitrogen. Blue-green algae are mainly found in coastal waters and are often attached to hard substrates along shores. Some species are pelagic, however. Blue-green algae can also produce toxins.

Macroalgae are usually attached to hard substrates. They can be divided into three groups: green, brown and red algae *(figure 11).*

The nearer to the water surface and sunlight algae grow, the more they flourish. Algal zonation, i.e. the depths at which different types of algae occur, is governed by several factors. Penetration of sunlight determines the lower limit of algae, but other important factors include competition with other organisms for space, how heavily grazed algae are by various animals, how often the site dries out, etc. Green algae are usually found nearest the surface of the water, and with increasing depth we then find brown algae, followed by red algae, which can grow at the greatest depths. 'Seaweed' is a collective name for large, attached algae, whether green (e.g. sea lettuce), brown (e.g. bladder wrack, sea belt) or red (e.g. purple laver). It does not apply to plants such as eel grass, which is one of the few marine flowering plants. Kelp is another collective term, referring chiefly to certain large brown algae.

Growing on the large algae that are attached to the bottom, there is often another type of algae, known as epiphytes. These are generally filamentous, branched green, brown and red algae. Filamentous epiphytic algae are favoured by eutrophication and can grow in such large quantities on the supporting macroalgae that the latter do not receive enough sunlight. The growth and survival of the macroalgae may then be impeded to such an extent that they die. The eutrophication of coastal waters has in general resulted in a marked expansion of filamentous, finely branched algae at the expense of the larger

Figure 10. Diatoms and dinoflagellates are two types of planktonic algae (microalgae or phytoplankton) of importance in the sea areas of northern Europe. These algae are microscopic, only a few thousandths of a millimetre across, but when they bloom they occur in such numbers that they can totally change the colour and 'consistency' of the water. In very intense blooms, there may be up to 100 million algal cells in a litre of seawater.

Photographs: Lars Edler, Department of Marine Ecology, Marine Botany Laboratory, Lund University, Sweden.

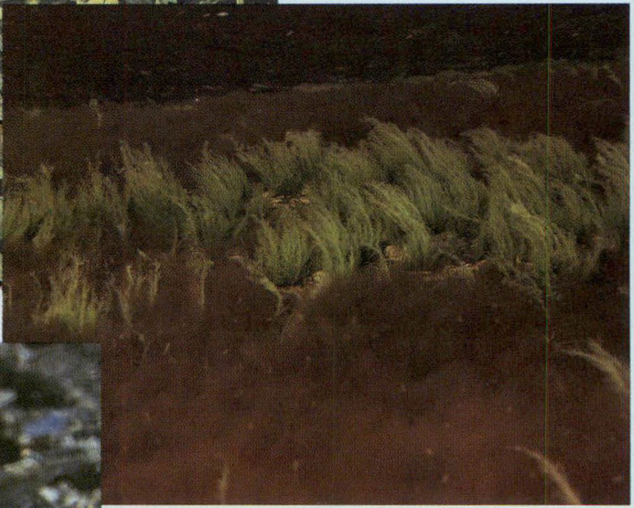
algae. Epiphytic algae are considered 'slimy' and slippery, while the large bottom-growing algae are generally regarded as 'clean' and distinct in form.

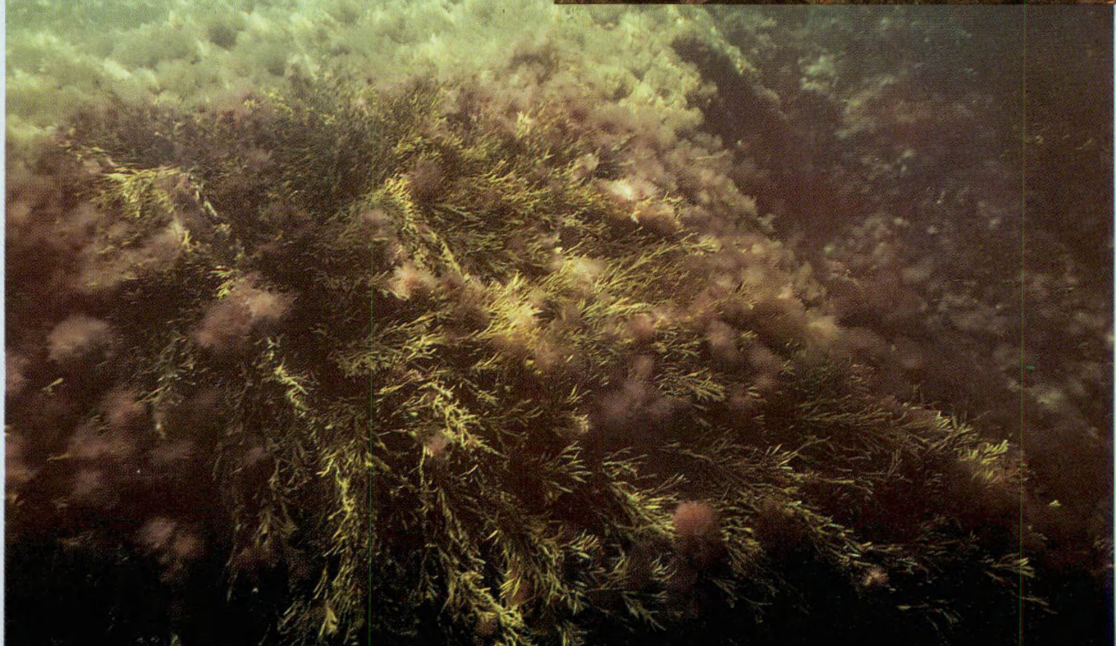
Macroalgae have no real roots, taking up all their nutrients straight from the water. They prefer salt water, and the number of species therefore increases with rising salinity. They are hardy, capable of withstanding great stresses from storms and waves and grazing animals. Tests have shown that their holdfasts, with which they attach themselves to hard substrates, are highly effective. Bladder wrack will stay put even if it is subjected to forces of up to 42 kg/cm^2.

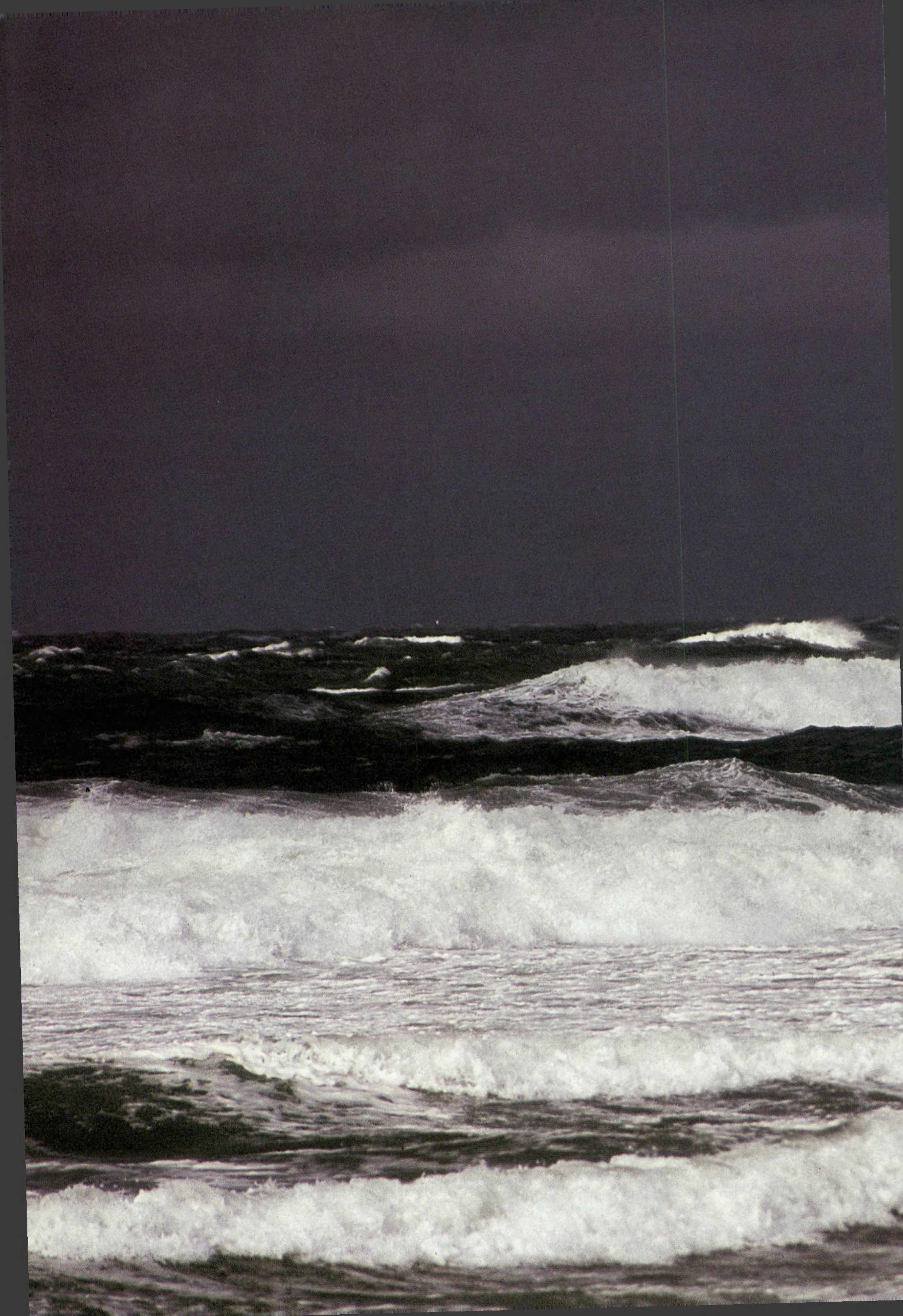
Brown and red algae are of commercial interest to the food and pharmaceuticals industries. Important substances are produced from algae, including alginates and agar. Some of these are used as stabilizers in the food industry and as a culture medium for bacteria. Since algae are rich in nitrogen and potassium, they are harvested for use as fertilizers in agriculture. Norway is a major algae-harvesting nation, and in Japan, for example, red algae are considered a delicacy and are cultivated for human consumption.

Figure 11. Larger algae (macroalgae) attached to hard substrates can be divided into three main groups: green, brown and red algae. Bladder wrack provides a nursery, shelter and feeding place for many different animals in the sea. A single bladder wrack plant may on closer inspection turn out to be teeming with life. If this seaweed disappears from a polluted or otherwise affected littoral zone, it will have detrimental repercussions throughout the coastal ecosystem. But bladder wrack is not the only important species. All macroalgae are of importance to marine animals and food chains. These photographs show different communities of green, brown and red algae.

Photographs: Stefan Rosengren, Naturbild (bladder wrack); Tony Holm, Naturfotograferna; Lars-Ove Loo, Nordkoster, Sweden.







2 How man affects and pollutes the sea

Large quantities of many different substances reach the oceans and seas every day, both near coasts and out at sea. The substances which affect the marine environment enter it either by direct discharge from sources on land or at sea (point sources and dumping), via rivers or land run-off (diffuse sources), or through the atmosphere, mainly from land-based sources (atmospheric deposition). These inputs have varying effects, depending on where and when they reach the sea, the quantities involved, and how the area 'responds' to the input.

The term pollutant or pollution is often used in a general sense, to refer to a substance introduced into the environment as a result of human activities. An international group of experts* has adopted the following definition of marine pollution:

> Pollution of the marine environment means 'the introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) which results in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water and reduction of amenities'.

Our chemical society — a mixed blessing

Modern industrial society produces in the region of 300 000 new chemical compounds in laboratories the world over every year. Most of them get no further than that, but an estimated 70 000 substances are in daily use in various sectors of our societies. These range from very simple chemicals to highly poisonous compounds. Pesticides, drugs, cleaning agents, fuels and oils, paints and timber preservatives, laboratory chemicals, industrial chemicals, solvents, combinations of different substances and products — all are examples of chemicals in everyday use. The word 'chemical' has an often undeservedly negative ring to it — a chemical is not the same thing as a poison. Life itself is advanced chemistry, and the vast and diverse family of chemicals includes numerous extremely simple compounds that cause no biological damage.

Photograph: Göran Hansson, Naturfotograferna.

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* This group — known as GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Pollution) — is a joint body of the IMO (International Maritime Organization), FAO (Food and Agriculture Organization of the United Nations), UNESCO (United Nations Educational, Scientific and Cultural Organization), WMO (World Meteorological Organization), WHO (World Health Organization), IAEA (International Atomic Energy Agency), the United Nations and UNEP (United Nations Environment Programme).

Our societies, then, deal with large quantities of chemicals – including stable organic compounds – in a wide range of products. These substances may 'escape' and end up in the natural environment at any of the many stages in their handling. It may be during storage and transport, when raw materials are extracted, as a result of emissions and wastes from industries in which chemicals are manufactured or refined, or from industries which use chemicals as additives in manufacturing processes, or as a result of discharges to sewers or atmospheric emissions from non-manufacturing sources, such as hospitals, laboratories and power stations. Stable compounds can also reach the natural environment when products are used, in refuse and municipal sewage following their use, through the use and handling of pesticides and other chemicals in agriculture, forestry, horticulture and private gardens, or from motorized transport (fuel handling and exhaust gases). The risk of an impact on the environment is present at every stage, from raw materials handling, via production and transport, to use of products and finally (where relevant) their destruction.

Harmless or harmful to the environment?

In the environmental context, an important measure of the potential danger of a substance is its stability or persistence. Substances that do not readily degrade can accumulate in increasingly high concentrations in organisms and ecosystems, whereas unstable, degradable compounds either disappear from the system or undergo chemical conversion within a foreseeable period of time, usually to more innocuous substances.

International agreement has been reached on basic guidelines for a broad classification of chemicals in terms of their potential hazardousness to the environment. It is considered important to assess the following properties of a substance:

- its solubility in alcohol (fat solvents) and in water
- its tendency to degrade in nature, especially in the aquatic environment
- its genetic effects on animals
- its effects on the reproductive capacity of animals.

The more readily a substance dissolves in alcohol, the greater is the risk that it may be fat-soluble and hence be taken up and accumulated by living organisms. Water-soluble substances are not taken up to the same extent.

Stability and the danger of a long-term genetic effect or influence on reproductive capacity are interrelated factors.

Pollution or contamination?

Sometimes a distinction is made between 'pollution' and 'contamination', according to which contamination is considered to arise when a substance can be shown to be present, even in small quantities, in an ecosystem or organism where it should not normally be found. It is not pollution, according to this definition, until the substance is present in such an amount or in such a context that it causes measurable damage to living organisms.

The borderline between contamination and pollution may be difficult to determine. Toxicologists point out that the mere presence of a chemical compound does not necessarily entail damage. It is only when an organism has come into contact with (been exposed to) a substance – or a combination of substances – and reacted unfavourably to it that we can talk about a harmful effect and possible toxicity. A substance that is not taken up by plants, animals or man has no toxic effect, however potentially poisonous it may be. Toxicity is determined to a large extent by the concentration of a substance, its stability and where in the body it is stored and affects the individual. More or less any substance can poison living organisms if administered in sufficiently large doses.

Expressions like 'environmental poisons' are often used – and sometimes misused – in public debate. Though such terms may be viewed as emotionally charged and vague, it is in fact quite legitimate to distinguish a group of substances, introduced into the environment by human activities, which are persistent, bioaccumulate, and have a scientifically proven and marked toxic effect on living organisms. Researchers working in the field of ecotoxicology (the study of poisons in the natural environment) in Scandinavia use the term 'environmental poison' (*miljögift* etc.) in this specific sense. Their colleagues in other countries often refer to this class of pollutants as 'environmental toxicants' or else use more descriptive terms, such as 'persistent toxic substances', 'persistent pollutants' or 'bioaccumulating toxic substances'.

Direct or indirect effects?

A broad distinction can be made between the direct and indirect effects of a substance. Here, too, there is some uncertainty about where to draw the line. Generally, an input of a substance or combination of substances is said to have a direct effect if an organism is immediately killed by it. If fish die straightaway as a result of a discharge into the water, a direct effect is obviously involved. A bird that becomes smeared with oil and dies of hypothermia may also serve as an example of the direct effect of an input to the environment on a living organism.

An indirect effect is involved if environmental factors change in such a way that animals or plants are unable to exist or conditions for them seriously deteriorate. Disturbed reproductive capacity is an indirect effect of certain toxic substances. The parent generation of seals, for example, may survive, but suffer deformities or become incapable of producing young. Benthic animals dying as a result of oxygen depletion and hydrogen sulphide formation on the seabed are another example of an indirect effect of an input. These animals are not killed by the nutrients added to the sea area concerned, but by the changes in conditions caused by eutrophication, oxygen depletion at the bottom and finally, sometimes, the formation of toxic hydrogen sulphide.

The direct and indirect effects of a substance can also be expressed in terms of acute and chronic toxicity. A substance or combination of substances possesses acute toxicity if organisms are killed as soon as they come into contact with it. Chronic toxicity manifests itself as a long-term influence, resulting in deformities or reproductive disorders.

Bioavailability, bioaccumulation and biomagnification

As was seen in chapter 1, currents, salinity, temperature and various other factors determine how substances are transported in seawater and possibly settle on the seabed. A number of different factors also govern a substance's **bioavailability**, i.e. the likelihood of living organisms in the marine environment taking it up and perhaps being detrimentally affected by it. As was noted above, a substance only becomes an environmental risk when it can in fact be taken up by and hence possibly affect the health and vital functions of living organisms.

Many factors influence the environment – there is not always an obvious link between a discharged substance and evidence of environmental damage. The nature of the substance (e.g. its molecular structure), the form in which it disperses (as a gas, in solution, or adsorbed onto particles), the type of emission source (point or diffuse), winds, precipitation, river flow, sea currents, the tendency of organisms to migrate over larger or smaller areas, and other factors determine whether damage will be caused and, if it is, how serious it will be. The life of a given substance is also dependent on how readily it reacts chemically with other substances.

In the aquatic environment, fat-soluble substances, including substances that are persistent and toxic, are found in living organisms, in benthic sediments, bound to particles in the actual water column, and in the surface film between air and water.

Animals and human beings can take in environmental toxicants through the digestive tract, respiratory system or skin, and in some cases by direct absorption into the bloodstream.

Lung-breathing animals are generally most vulnerable to toxicants via their food and drink, i.e. through the digestive tract. Uptake with the air they breathe is of less importance by comparison.

In animals that breathe through gills, efficient uptake of substances occurs straight from the water. Their gills serve as a transport mechanism for oxygen and hence for other substances dissolved in the water.

Toxic substances can enter the bloodstream of mammals directly from the mother's blood, passing via the placenta into the foetal bloodstream. In birds, they pass in a corresponding fashion straight from the egg yolk to the embryo. Until the young bird hatches out, the yolk is its only food, and it contains the same levels of poisons as the mother's other tissues.

In mammals, enriched levels of toxicants in the mother are also passed on in milk when the young feed. Milk is rich in fat, and the majority of toxic substances in the environment are fat-soluble.

When a marine organism takes up a substance straight from the water or in its food, and levels of the substance build up in its tissues, a process known as **bioaccumulation** is said to occur. The substance is added to the body more rapidly than it is eliminated, resulting in a gradually increasing concentration in tissues. The older the animal gets, the higher its tissue concentrations of persistent substances accumulated during its lifetime become *(figure 12)*.

Persistent pollutants which can be taken up and accumulated in animal tissues – primarily fatty tissues – are passed on both between generations of the same species and between species. Marine mammals, birds of prey and other predators accumulate the persistent substances present in their prey, acquiring increasingly high levels in their own tissues. The higher up in the food chain the predator is, the more animals with high concentrations it will have eaten. The phenomenon of substances being concentrated via food chains is termed **biomagnification** *(figure 12)*. High levels of DDT or PCBs in seals and birds, for example, are the result of this type of gradual, long-term enrichment along food chains.

Synergy or antagonism?

Toxicants rarely occur alone in the natural environment, and it is known that different substances can strengthen or weaken each other's biological effects. One substance may reinforce the impact of another so that the end result is greater than a simple addition of the two substances' effects. This is known as synergy. The biological damage is greater than either of the individual substances alone could have caused. Substances can probably also weaken each other's effect, a phenomenon termed antagonism. We still know comparatively little about synergy and antagonism between toxic substances released into the environment, but interactive effects are known to occur in living organisms.

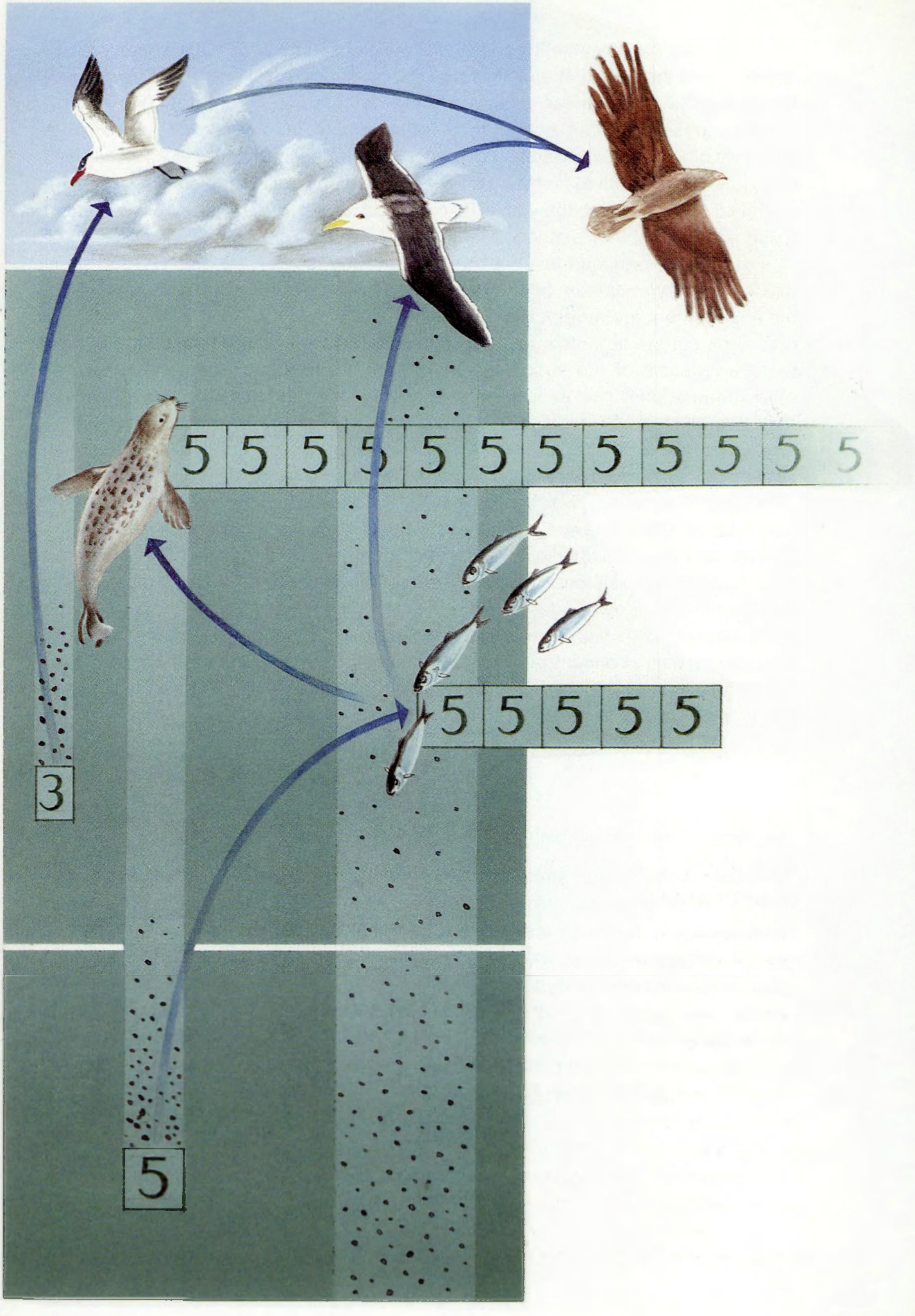
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Figure 12. Bioaccumulation occurs when an organism, e.g. a fish or a seal, takes up a substance straight from the water or in its food, and levels of the substance build up in its tissues. The substance enters the body more rapidly than it is eliminated, resulting in a gradually increasing concentration in tissues. The older the animal gets, the higher its tissue concentrations of persistent substances become. Bioaccumulation involves one individual at a time.

Biomagnification is the same process, but involving several steps, from species to species, or from one generation to the next. First an organism accumulates a toxicant. This organism, e.g. a zooplankter, is then eaten by a fish, which thus receives the total amount of pollutants contained in all its prey, i.e. all the zooplankton it eats. This fish is later eaten by another fish, a sea bird or a marine mammal (e.g. a seal). The fish, bird or seal ingests the sum of the toxic substances contained in all the fish it has eaten. This enrichment of substances through the food chains can continue, e.g. from predatory fish or marine mammal to man. Biomagnification also occurs when a marine mammal passes on enriched levels of toxicants to its young, either via the bloodstream and placenta during gestation, or in its milk when the young feed. Birds pass them on to their young via the egg yolk.

Illustration: Bosse Falk.

Activities and substances significant to the marine environment

In this book terms such as inputs of substances, pollution, pollutants, and persistent toxic substances/environmental toxicants are used in the light of the above discussion. Many of the substances and concentrations that are referred to have already been found to have harmful effects in the marine environment. In other cases, either it has not been scientifically proved that inputs cause environmental damage, or else no reliable data are available on either quantities of inputs or short- or long-term effects. Some anthropogenic substances can justifiably be called environmental toxicants, while in other cases there is room for discussion as to whereabouts on a scale of hazardousness a substance should be placed.

Whatever terminology we use, ultimately what matters is that we make a realistic assessment of what has happened, what is happening now and what may happen in the future in the complex ecosystems of the marine environment, near our coasts and in the open sea, as a result of large-scale human influence.

The most important groups of substances introduced into the marine environment by human activities, with observed or conceivable environmental effects, are:

- Substances that increase turbidity
- Degradable and oxygen-consuming organic compounds
- Persistent organic compounds (chiefly halogenated hydrocarbons)
- Metals, primarily heavy metals
- Nitrogen and phosphorus compounds (nutrients)
- Oil and oil products (petroleum hydrocarbons)
- Radioactive substances and cooling water from nuclear power plants.

The origins of these different inputs can be roughly grouped in terms of the four areas of human activity listed below. The relative importance of these sectors naturally varies from one country to another, depending on socioeconomic structure (energy production, industrial activity, farming and forestry, urbanization etc.), geographical location, environmental protection measures implemented etc. Substances are introduced into the marine environment from:

- **Industry: industrial processes, products and wastes**
- **Urban areas: energy production, transport and wastes**
- **Agriculture, forestry and mariculture**
- **Shipping (including dumping), offshore oil and gas production, and port operations.**

Industry

The most important sectors of industry and individual types of manufacturing and processing industry from the point of view of marine pollution are

- mining
- forest-based industries, i.e. pulp and paper manufacturing
- iron, steel and non-ferrous metals (smelters, coking plants, iron and steel works, foundries, ferroalloy plants etc.)
- chemicals industry (petrochemicals, including oil refineries, plastics, rubber, chlor-alkali industry, pesticides manufacturing, pharmaceuticals, fertilizers, production of industrial chemicals generally, etc.)
- engineering (metal products, mechanical engineering, electrical engineering, motor vehicle and railway equipment manufacturing, shipbuilding, instrument engineering) and surface treatment industries (rustproofing, staining, galvanizing, chromium-plating, painting of metal parts).

Discharges from mines mainly consist of

- heavy metals, such as copper, lead, zinc and cadmium, during extraction and from old waste tips at abandoned mines where sulphide ores were once processed.

The main discharges and emissions from the pulp and paper industry are

- chlorinated organic material from the bleaching of chemical pulp, i.e. the constituents of bleaching plant effluent
- chlorinated fungicides (slimicides)
- organic material that consumes oxygen and increases turbidity (fibres and other components)
- nutrients
- sulphur and nitrogen oxides from plants generating process energy
- other processing industry chemicals with varying fields of application.

Discharges and emissions from the iron, steel and non-ferrous metals industry mainly comprise

- heavy metals, such as arsenic, cadmium, copper, lead, mercury etc. from ore-based and other metal processing plants, metal-bearing particulates (i.e. iron oxide, lead, zinc, cadmium, chromium, nickel) from iron and steel works; these metals enter the environment in emissions to the atmosphere and to water, and as a result of dumping of wastes
- process gases containing dioxins, from iron and steel works and non-ferrous metal works
- sulphur from smelters using sulphide-based raw materials
- persistent organic substances such as PAH (polycyclic aromatic hydrocarbons) from coking plants (leakage from ovens and quenching), aluminium plants, graphite electrode manufacturing, etc.
- oil from various process operations
- nitrogen oxides from coking plants
- nutrients from pickling of stainless steel (in pickling baths) and from coking plant effluents
- sulphur and nitrogen oxides from plants generating process energy
- other processing industry chemicals with varying fields of application.

The main discharges and emissions from the inorganic and organic chemicals industry are

- complex waste waters that are not easily degraded, containing complex mixtures of organic chemicals
- persistent organic compounds from pesticides manufacturing
- atmospheric emissions of volatile hydrocarbons and nitrogen and sulphur oxides from the petrochemicals industry
- heavy metals, such as mercury, cadmium, chromium etc. to the atmosphere and to water; mercury discharges to water from the chlor-alkali industry are a major problem
- nutrients from the fertilizer industry and other heavy chemical manufacturing, such as the explosives industry, food processing, and the manufacture of phosphoric acid
- phosphorus-containing gypsum waste from the fertilizer industry and liquid waste from the titanium dioxide industry, which is often dumped
- oil from various process operations, including refineries
- sulphur and nitrogen oxides from plants generating process energy
- other processing industry chemicals with varying fields of application.

Discharges and emissions from the engineering and surface treatment industries mainly consist of

- cutting fluids from metal parts processing
- hydrocarbons from solvents, paints, lacquers etc.
- heavy metals from galvanizing and chromium- and nickel-plating
- solvents from degreasing tanks
- cyanide compounds from cyanide-containing baths used to electroplate iron and steel surfaces with zinc, cadmium, copper, silver etc.
- oil from various process operations
- sulphur and nitrogen oxides from plants generating process energy.

PCBs (polychlorinated biphenyls) are found in capacitors, transformers and similar installations in energy-consuming industries. The same types of power distribution installations are found in many other locations in the community as a whole.

Generation of process energy (especially by the combustion of coal) produces large quantities of fly ash containing heavy metals. If this fly ash is dumped or disposed of on tips in an unsuitable manner, heavy metals can leak from it. The same problem of course arises from coal burning in general (see below concerning urban areas and heavy metals).

Photograph: Torbjörn Lilja, Naturfotograferna.

Urban areas

The most important activities in urban areas with regard to marine pollution relate to human use and consumption of products, transport, waste management, and stationary energy plants for heating and electricity generation. Coal-, oil-, coke- and biomass-fired power and district heating plants, along with nuclear power stations, are not assigned to the 'industrial' sector in this context, since they are plants which keep entire communities going, not just their industrial operations.

Urban activities of significance include

- municipal sewage treatment plants, treating sewage from households and industrial plants, hospitals and other sources, and handling of the resultant sewage sludge
- handling and treatment of stormwater
- energy production (generation of power and useful heat at plants burning fossil fuels or biofuels, and at nuclear power stations)
- domestic waste management, involving incineration, landfills, or in some cases recycling (glass, paper, metals, batteries)
- management of hazardous wastes from factories, energy production plants, hospitals, laboratories, households etc.
- transport (cars, heavy goods vehicles, buses, aircraft)
- dredging of port entrances and dredging/dumping for land reclamation purposes.

The most frequently occurring inputs to the sea from urban activities are

- nutrients (phosphorus and nitrogen) from sewage treatment plants
- organic degradable material from sewage treatment plants and untreated sewage (substances that consume oxygen and increase turbidity)
- sulphur and nitrogen oxides and carbon dioxide from the combustion of fossil fuels and biofuels for energy production
- persistent organic compounds, such as dioxins, in flue gases from domestic waste incinerators, hospital furnaces, coal-fired power stations etc., and in exhaust gases from petrol- and diesel-engined vehicles
- persistent compounds (PAH) from small-scale combustion, especially wood-fired heating, and from vehicle exhausts and incineration of domestic wastes
- pesticides used in gardens, allotments, parks etc.
- persistent organic compounds from chemical products for use in private households, the public sector, small businesses etc.
- diffuse inputs of oil from various sectors
- heavy metals, especially lead from vehicle exhausts, and mercury and cadmium from refuse incineration and in flue gases from energy production plants (fossil fuels, biofuels)
- heavy metals from leaking waste tips (domestic and other waste), and from solid wastes (fly ash, ‘desulphurization gypsum’ and similar products) resulting from energy production
- heavy metals, such as mercury and cadmium, in dumped digested sludge
- persistent organic compounds, heavy metals etc. accumulated in sediments that are disturbed and dumped following dredging
- oil, soot, heavy metals, salts etc. transported by stormwater.

Agriculture, forestry and mariculture

The main substances added to the marine environment by modern agriculture (arable and livestock), forestry and marine aquaculture are

- nutrients (nitrogen and phosphorus compounds) from the application of fertilizers and leaching from farm and forest soils; large-scale 'land improvement', including extensive drainage of wetlands to create arable and forest land, also contributes to the leaching of nutrient salts and soil metals
- ammonia in gaseous form from animal manure (unsuitably stored or applied)
- heavy metals, mainly cadmium from artificial fertilizers (in agriculture and forestry) and mercury and cadmium in digested sludge applied to fields
- persistent organic compounds in chemical pesticides, such as dieldrin, lindane and toxaphene, which disperse in both water and the atmosphere
- nutrients from mariculture (phosphorus and nitrogen), as well as antibiotics and other substances used in mariculture.

Photograph: Rolf Nyström, Naturbild.

Shipping, oil and gas production, port operations

Pollutants from these activities may reach the sea in various ways, including

- shipping accidents at sea (releasing oil, chemicals or radioactive materials)
- accidents in connection with oil or gas production (blow-outs, explosions, fires)
- discharges of oil, waste water etc. from ships in operation (operational, legal discharges, as well as illegal discharges, e.g. from prohibited tank cleaning at sea)
- recurrent discharges from oil platforms
- spills during loading, unloading and other port operations
- marine dumping or incineration of wastes at sea
- treatment of boat hulls, port constructions etc. with organotin paints.

The most important substances that may be released and dispersed in these ways are

- hydrocarbons – oil products in various forms – either in large quantities in a short time due to accidents (acute discharges) or in small amounts over a long period (chronic or diffuse discharges, which together represent a larger total input per year than acute discharges); chronic discharges originate from both land-based sources and offshore production
- oil and chemicals included in drilling muds (which get into the sea around platforms), and in oil production water
- chemicals carried by ships, which may be released as a result of accidents or careless handling in port
- garbage – including plastics and other materials that are not readily degradable – from ships and coastal activities
- organotin compounds, used to prevent fouling of boat hulls, port constructions, fishing equipment etc. by plants and animals; these disperse directly into the water from boats, and indirectly when silt from port dredging operations is dumped and heavy metals deposited in the silt from these compounds are released
- halogenated hydrocarbons (hexachlorobenzene, octachlorostyrene etc.), hydrochloric acid and dioxins from incineration of wastes at sea
- radioactive substances, as a result of accidents involving nuclear fuel carriers, or dumping.

3 Four problems in the marine environment

A large number of different substances, with varying biological effects, enter the marine environment from an equally large number of sources on land and at sea. Coasts and seas are also affected in other ways by human activities. Beaches, coastlines and areas of the seabed are affected and reshaped by sand and gravel extraction, dredging, land reclamation, major construction projects, extensive urbanization, tourism and shipping. Commercial fisheries (for fish and shellfish) also have biological effects on the marine environment.

The expression marine environment problem can thus refer to virtually any activity with an appreciable effect on the sea, its shores or the seabed. Here we will look more closely at just four areas directly related to inputs of substances or groups of substances from human activities:

- Persistent organic compounds (halogenated hydrocarbons)
- Nutrients, eutrophication and oxygen depletion
- Heavy metals
- Oil and oil products.

A fifth marine pollution problem – inputs of radioactive substances and discharges of cooling water from nuclear power plants – is not dealt with specifically in this book. As the description of the seas around Iceland and Greenland makes clear, however, radioactive substances are dispersed over large areas by currents, and radioactivity can indeed be a marine problem, at the local, regional and global levels. More and more nuclear power plants are being built on coastal sites, with a growing danger of the spread of radionuclides, due to normal operations, negligence or actual accidents. Sea transport of nuclear fuels also involves a potential risk of inputs to the marine environment.

In normal operation, a nuclear power station discharges radionuclides – primarily caesium-134 and caesium-137 – along with the cooling water from its reactors. Large volumes of seawater are taken in as cooling water and discharged again after use. Normally emissions of radioactivity from this source are relatively small. However, considerable radioactive discharges do occur from nuclear fuel reprocessing plants.

Discharges of cooling water also have an environmental impact in the sense that the change in water temperature has local effects on plants and animals. Some species are favoured by warmer water, while others may be eliminated. One detrimental effect is that many parasites thrive at the higher temperature.

Persistent substances can prove toxic in the environment

A great many unpleasant ecological 'surprises' have turned up in the marine environment since the 1960s. Substances once believed to be harmless have proved to cause large-scale and unforeseeable damage to living organisms. These substances are of varying origin and composition, but are together classed as stable or persistent, and have three decisive properties in common. They are

- not readily degradable, or not at all degradable, in nature,
- toxic to living organisms and
- bioavailable (living organisms can take them up and accumulate them).

These persistent substances include a number of

- stable organic compounds (mainly halogenated hydrocarbons)
- heavy metals
- organometallic compounds.

1. Persistent organic compounds (halogenated hydrocarbons)

It has emerged that some highly stable organic compounds – chiefly halogenated hydrocarbons – can have serious environmental effects in the sea. The substances concerned include

- halogenated hydrocarbons such as DDT, toxaphene, PCBs etc.
- chlorinated organic material in bleaching plant effluent from the pulp and paper industry
- polycyclic aromatic compounds, including PAH, from combustion
- organometallic compounds, e.g. in paints.

A new focus of attention in recent years has been dioxins and dibenzofurans, which have been found to have accumulated in marine organisms and sediments.

Natural or man-made halogenated compounds

Life on earth is founded on a number of fundamental biochemical processes, such as photosynthesis and the ability of carbon atoms to bind together in long chains or complex ring structures to form specific molecules. Without carbon, life would never have come about, since all basic groups of compounds to be found in living organisms are built around carbon atoms.

A hydrocarbon is a chemical compound containing carbon and hydrogen atoms. The hydrocarbons are the simplest classes of compounds dealt with in organic chemistry – the chemistry of carbon compounds – and can be regarded as the basic building blocks of most organic compounds. Crude oils are an excellent example of naturally occurring hydrocarbon mixtures.

Carbon compounds are by nature readily degradable. The natural carbon cycle is on an enormous scale. All living material is broken down and, like other atoms, the carbon atoms are released and return to the cycle.

Stable carbon (organic) compounds are created when one or more of a hydrocarbon's hydrogen atoms are replaced by atoms of chlorine, fluorine or bromine. These elements are known as halogens, and the end product of the substitution process is called a halogenated hydrocarbon. If all the hydrogen atoms on the carbon chain are replaced by halogens, the new compound is said to be fully halogenated. A simple rule of thumb is that the more halogen atoms a hydrocarbon contains, the more stable the resultant compound will be. The term 'polychlorinated' means that the compound contains several chlorine atoms. It can thus be regarded as a basic rule that the more halogenated a hydrocarbon is, the greater the danger of it becoming a serious environmental toxicant. In chemical terms, things are admittedly not quite as straightforward as that. The stability or persistence of a compound is also dependent, for example, on the position of the halogen atoms in the molecules.

The majority of man-made halogenated hydrocarbons are halogenated with chlorine and are variously referred to as chlorinated organic compounds, organochlorine compounds, organic chlorine compounds etc. If the hydrocarbon's hydrogen atoms are replaced by atoms of fluorine, the corresponding terms are fluorinated organic, organofluorine or organic fluorine compound.

Some of the halogenated hydrocarbons – primarily chlorofluorocarbons (CFCs) – are responsible for depleting the vitally important ozone layer in the earth's atmosphere. These compounds, often known as freons (Freon in fact being a trade name for a number of these fluorinated hydrocarbons), remain stable for several decades in the atmosphere. It is precisely this stability that enables them to reach the ozone layer, 25–35 km above the surface of the earth, without themselves being broken down or modified before they get there. Only at these altitudes, where solar radiation is able to break down the halogenated hydrocarbon, are free halogen atoms released. A single chlorine atom has the capacity to destroy in the region of 10 000 molecules of ozone. One atom of bromine can break down 50 000 – 100 000 ozone molecules. A thinner ozone layer will enable much more ultraviolet radiation at wavelengths harmful to living organisms – UV-B radiation – to reach the earth's surface from the sun. Apart from the damage that will be caused to vegetation, animals and human beings on land, there will be effects on the marine environment. Algal photosynthesis is sensitive to ultraviolet radiation and has already been adversely affected by existing levels in certain areas. Stronger UV-B radiation will be able to penetrate to depths of several metres in the water and have genetic effects on marine organisms. It is feared that life in the upper layers of the sea may be eliminated over large areas, especially in sea areas near the poles. So far it is in the polar regions, Antarctica and the Arctic, that the most pronounced depletion of ozone has been recorded.

Man, then, manufactures carbon compounds with such properties that they remain stable when they enter the natural environment. But nature herself also produces substances of this kind. It has been known since the 1930s that certain lichens are able to produce organochlorines. Several hundred such compounds are now known to form naturally in the environment. Chlorinated hydrocarbons are thus not inherently foreign to nature, as is usually claimed in environmental debate. Analyses of centuries-old peat bogs and humic substances from groundwater have shown that chlorinated organic compounds were formed long before industrialization and the air pollutants of today. It has not been established, however, on what scale they are produced naturally, though considerable quantities are probably involved.

Nor is it known how bioavailable these natural organochlorines are. An informed guess, however, is that they differ somewhat in their biochemical properties from the chlorinated substances produced by man. If naturally occurring organochlorines were as toxic as DDT or PCBs, for example, serious biological effects ought to have been discovered on a large scale and in many different environments. More research needs to be done on the occurrence, dispersion and effects of natural chlorinated compounds, but scientists point out that the discovery of these substances in the environment does not justify brushing aside the dangers of industrially manufactured halogenated/chlorinated organic compounds.

With some qualification, therefore, it can be said that man-made halogenated compounds must be regarded as alien to nature. Clear links have been shown to exist between substances in this category and serious damage to a range of marine organisms.

There is a difference, however, between halogenated compounds and heavy metals, which should be borne in mind in a discussion of the environmental hazards of persistent substances. Cadmium, lead, mercury and all the other heavy metals occur naturally in the environment. They have become toxicants, ultimately, owing to concentrations and input pathways – environmental problems arise because large quantities of them end up in the wrong place, i.e. in living organisms that are unable to eliminate them. It is sometimes said that 'pollutants are resources in the wrong place in the system'. That definition is particularly applicable to the heavy metals. On the other hand, halogenated hydrocarbons resulting from human activities, together with man-made organometallic compounds, must generally be regarded as unnatural, even if similar substances do occur naturally. The effects of DDT, toxaphene, PCBs, lindane, dieldrin etc. on living organisms show that animals are unable to deal with, break down and eliminate these substances. Some degradation may occur, but many breakdown products can be as toxic as or even more persistent and toxic than the original substances.

Tip of the iceberg?

In recent years, a number of chlorinated and other halogenated organic compounds have been released into the environment, including marine ecosystems, and only proved to be extremely persistent after a long passage of time. Many of them have been taken up and accumulated in the fatty tissues of living organisms and had toxic effects. DDT and PCBs, for example – two types of organochlorine that are reasonably well known and can be analysed – have dispersed in the sea with currents and winds and can now be found in organisms throughout the world ocean. The discovery that penguins in Antarctica, a continent once believed to be 'clean' and unaffected by industrial society, had DDT and PCBs in their fatty tissues came as a rude awakening for many. And now dioxins are being found in mammals in the Arctic region.

At present no one in fact knows the extent to which persistent organic compounds occur and the scale of their impact on the marine environment. Many researchers fear that the decades ahead will reveal new threats to the environment and that the effects we have already seen will prove to be just the tip of the iceberg. For one thing, a large number of stable organic compounds have been handled, and hence released, dispersed and accumulated in the environment, over the years – compounds which, to be honest, we know very little about. And for another, there are indications of synergistic effects in the natural environment.

In the view of many scientists, the basic principle should be that stable organic substances should automatically be suspected to be potential environmental toxicants. Therefore, if their manufacture and use are to be permitted at all, such substances should as far as possible be kept in closed systems so that they do not escape into the natural environment. If the opposite principle is applied – that stable organic compounds should not be classed as toxicants until effects have been observed in ecosystems – there is a great danger of new problems arising in the future, similar to those posed by PCBs, DDT, chlorofluorocarbons, dioxins, toxaphene etc. There is good reason to be particularly careful with substances whose technical applications require them to be persistent – such as flame retardants, insulating oils, heat carriers and lubricant additives – or which are intended to be biologically active as pesticides. However, vigilance is necessary with all stable organic compounds – in theory, most compounds of this type could presumably have environmentally harmful properties.

Organochlorine compounds in the marine environment

To date, a wide range of stable chlorinated or otherwise halogenated organic compounds have been shown to be present in the marine environment, including the following:

- PCBs – polychlorinated biphenyls (some 200 compounds in all).
- PCAs – polychlorinated alkanes (or paraffins, CPs).
- PCCs – polychlorinated camphenes, collectively known as toxaphene.
- PBBs – polybrominated biphenyls.
- PCTs – polychlorinated terphenyls.
- PCNs – polychlorinated naphthalenes.
- DDT – dichloro-diphenyl-trichloroethane. DDT has several derivatives, with similar toxic effect, known as DDE, DDD, DDA etc. The various DDT substances are usually grouped together as ΣDDT (i.e. total DDT).
- Dioxins – a collective term for over 200 different chemical compounds. Strictly speaking they consist of two groups of substances with similar effects:
  - polychlorinated dibenzo-*p*-dioxins (PCDDs) (true dioxins)
  - polychlorinated dibenzofurans (PCDFs).

  A dozen of these compounds – the 'dirty dozen' – have been found to be extremely toxic. The most poisonous of them is known as TCDD (2,3,7,8-tetrachlorodibenzo-*p*-dioxin) and is one of the most toxic substances known to man.
- HCB – hexachlorobenzene.
- Aldrin, dieldrin, endrin, telodrin and chlordane (drins). Belong to the cyclodienes group.
- Lindane, a hexachlorocyclohexane (HCH). Lindane is the form γ-HCH. By-products or breakdown products are the α- and β-HCH forms.
- Polychlorinated phenols (chlorophenols).
- Chlorinated solvents.
- EDC tar (dichloroethane tar, from the manufacture of PVC plastics).

Pesticides and PCBs – old threats still relevant

Several of the substances listed above have been used and continue to be used as pesticides in many countries, including DDT (banned in most countries, however), toxaphene (which replaced DDT), HCB, aldrin, dieldrin, endrin, chlordane, phenoxy acids and lindane.

DDT was in large-scale use in the 1950s and 60s, large amounts of it being applied as an insecticide. Since the 1970s, it has been banned in many industrial nations, but it still occurs extensively in the developing world. DDT can be transported in the atmosphere, and can thus affect the environment even in countries that prohibit its use. DDT has low solubility in water, but dissolves readily in fats. Usually it is not the parent DDT compound, but its degradation products, primarily DDE, that cause biological harm. Different animal species, especially birds, have varying degrees of sensitivity to these substances. DDT and DDE are probably not toxic to man. As an insecticide, DDT has become increasingly ineffectual, since many insect species have developed resistance to it.

Toxaphene was introduced as a substitute in many countries when DDT was prohibited. However, it proved to have roughly the same toxicity and biological effects as the compound it replaced. Toxaphene, too, disperses widely in water and the atmosphere. It is now found in approximately the same concentrations as DDT and PCBs once were in fish, birds, seals and other marine organisms. It has also been shown to be present in animals in areas where this pesticide has never been used, demonstrating its large-scale dispersion. Fish in the Atlantic have by and large the same toxaphene levels as those in the Baltic, for example.

PCB compounds began to be produced in the 1920s and, in simple terms, they are oils with a variety of technical uses. Since they are chemically stable and can withstand high temperatures, they have been very useful as dielectrics (insulators) in capacitors and transformers, and as hydraulic and heat-transfer fluids. In addition, PCBs have been used in pressure-sensitive copying paper and as plasticizers in certain paints, adhesives and plastics. Unlike the various pesticides, PCBs have never been intentionally released into the natural environment, but have escaped during the combustion of oil residues and refuse and during decommissioning and dismantling of installations containing PCBs. PCTs, PCAs, PBBs and PCNs have largely the same applications as the PCBs – as insulating, flame retardant and other types of additives. PCBs disperse in both air and water, and dissolve readily in fats, with the result that they accumulate in the fatty tissues of living organisms. Large quantities of PCB compounds may be found in benthic sediments, from where they pass through the water to living organisms.

The manufacture of PCBs has now largely ceased, and substitute products are available on the market. However, the PCB problem will not be eliminated until these compounds have been recovered from all the products containing them. As long as PCB-containing capacitors and transformers are still in use, for example, 'stockpiles' of PCBs will remain, along with the risk of these substances escaping into the environment.

Recently concern has emerged about one chemical variant of the PCB group, namely coplanar PCB molecules, which are even more toxic than 'ordinary' PCBs. Coplanar PCBs and hexachloronaphthalenes are persistent organic compounds that are believed to be in the same class as dioxins as regards toxicity.

DDT, PCBs and other substances have gained our attention, their use has been restricted, concentrations in the environment have to some extent begun to fall – why, then, do we continue to study and discuss them? There are two compelling reasons. One is that these compounds are still present in ecosystems and having toxic effects. The other is that we are now beginning to know so much about their properties, dispersal pathways and effects that they can be used as models in the study of other halogenated hydrocarbons and similar persistent substances.

Apprehension about dioxins

Dioxins and dibenzofurans are not deliberately manufactured, but form during the production, use or burning of organic material in the presence of chlorine. They are produced in most combustion processes, even natural ones, such as forest fires. The less efficient the combustion is, the more dioxins are formed. Dioxins can be shown to occur in vehicle exhausts and in flue gases from waste incinerators, iron and steel works, pulp and paper mills (liquor recovery plants) and coal-fired power stations. Incineration of hazardous wastes can produce dioxins (see below regarding ocean incineration), as can incineration in hospital furnaces. Dioxins are subject to long-range transport in the environment, mainly through the atmosphere. There is a great deal to suggest that they represent a major regional and perhaps global problem. Dioxins may also be found in effluents from pulp mills producing bleached pulp, and in products made from such pulp (e.g. coffee filters, babies' nappies, hygiene products). Very small quantities of dioxins also occur as impurities in products such as PCBs, chlorophenols and phenoxy acids. Extremely small amounts are involved, perhaps only a few hundredths of a gram per year from an entire country's emissions, but the toxicity of many dioxins is so great that even minute quantities are an environmental risk.

The expression 'TCDD equivalents' is used to indicate the combined toxic effect of the various individual dioxins (PCDDs and PCDFs), with reference to the amount of 2,3,7,8-TCDD that would have the same effect. Swedish researchers have calculated that all the fish in the Baltic contain the equivalent of an estimated 10 g of TCDD. This may sound very little, but in theory 10 g in TCDD-equivalent terms probably corresponds to the tolerable daily dioxin intake of the whole of Sweden's population (some 8.5 million) over 50 years, based on a risk assessment made by a group of Nordic scientists. The group has estimated the 'maximum tolerable weekly intake' to be 35 picograms (35 millionths of a millionth of a gram) per kilogram of body weight.

Chlorinated organic material from the pulp and paper industry

Chemical pulp is produced by boiling wood chips under pressure. This dissolves lignin, a coloured substance which binds together the cellulose fibres in wood. To obtain perfectly white pulp, any remaining lignin and the coloured lignin compounds have to be eliminated. This process is known as bleaching, but should really be referred to as 'further lignin removal'. After bleaching, the lignin dissolved is washed out of the pulp. The chlorine compounds used in bleaching react chemically with the lignin molecules and break chemical bonds in them. Bleaching is a several-stage process, using various agents including chlorine gas and chlorine dioxide. (Bleaching chemicals, incidentally, are manufactured by the chlor-alkali industry.) Sometimes pulp is first bleached with oxygen gas, so as to reduce the amount of chlorine used at later stages. (Both pulp bleaching and chlor-alkali production are described in more detail in chapter 5.)

Throughout the bleaching process, a certain amount of the lignin released enters the washing water and other water that may be discharged with plant effluent. Chlorinated organic compounds are formed in several ways during the bleaching process, e.g. by chemical binding of chlorine to dissolved wood components. Hundreds of different substances are produced – so far some 300 have been identified, but this is still only a small fraction of the total chlorine content of discharges. It is known that resin and fatty acids and a number of chlorophenols and related compounds (chloroguaiacols, chlorocatechols and chlorothiophenes) can be released from wood components as they are gradually broken down. Effluents also contain traces of dioxins. The chlorine compounds in bleaching plant discharges are a highly diverse and imperfectly identified mixture of substances.

Unknown compounds spreading on a large scale?

Swedish researchers have investigated the effects of pulp industry effluents on animals and sediments in the Baltic, in a project extending over several years. One general conclusion which they drew concerned discharges of chlorinated substances to the marine environment, irrespective of source. It was found that chlorinated compounds spread over large areas. Perhaps the most worrying lesson learnt was that we still know so little about the structures and distribution patterns of these substances.

When scientists analyse the quantities of chlorinated compounds present in an organism, e.g. in the flesh of a fish, they try as far as possible to extract the substances using organic solvents, arriving at an EOCl value, i.e. the quantity of organic chlorine compounds extractable with the solvents used.

The research project referred to has shown that fish and benthic animals take up chlorinated substances in their fatty tissues. But it has only been possible to identify a small fraction of the compounds found in fish. The structure and biological effects of most of the substances present in fish living wild in affected areas are unknown. Even less is known about the substances occurring in sediments.

The researchers have illustrated this using a 1 000 m high column, representing

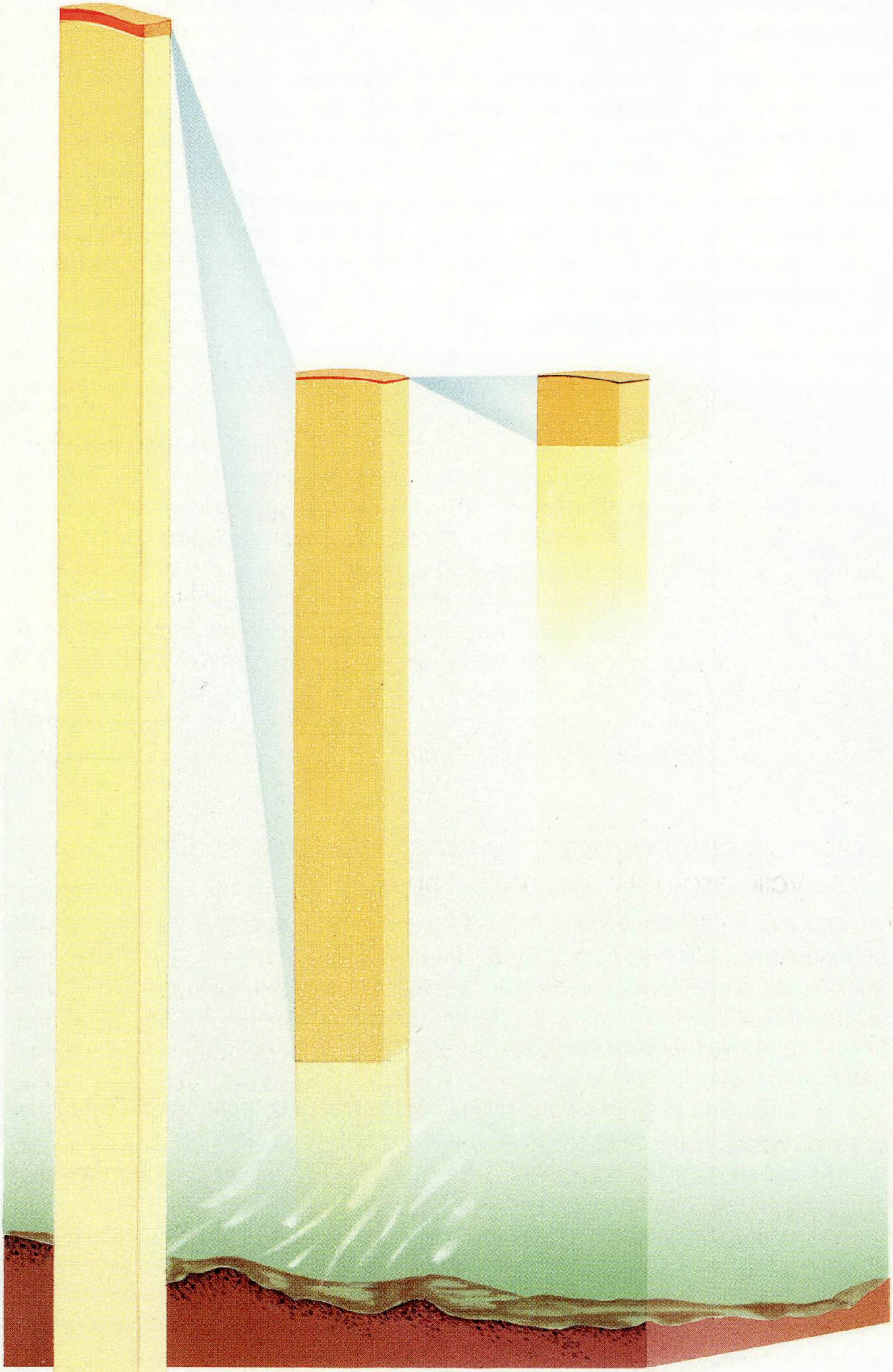


Figure 13. Swedish scientists have investigated the effects of pulp industry effluents on animals and sediments in the Baltic, as part of a several-year project. Only a very small proportion of the chlorinated compounds involved have been identified. The researchers have illustrated this using a 1 000 m high column, representing the total quantity of chlorinated compounds in sediments. Of these 1 000 m, a mere 10 m correspond to all known substances, and only 1 cm of the 10 m represents dioxins and furans. Thus, 990 m have yet to be identified.
Illustration: Bosse Falk.

the EOCl content of sediments in the Bothnian Sea *(figure 13).* Of these thousand metres, ten correspond to all known substances (PCBs, DDT, hexachlorobenzene, chlorophenols etc.), with a mere centimetre accounting for dioxins and furans. The remaining 990 m have yet to be identified. The same uncertainty exists wherever organochlorine compounds enter the marine environment, not just in the northern Baltic.

Organochlorine substances probably disperse on a large scale in the environment. High concentrations of organically bound chlorine have been found far away from conceivable, identifiable sources, suggesting that these compounds may spread over great distances.

There is thus uncertainty both about precisely which halogenated substances disperse in the marine and other environments, and about where they originate.

Polycyclic aromatic hydrocarbons

The polycyclic aromatic hydrocarbons – PAH – include around a hundred of the petroleum hydrocarbons and are natural constituents of oil. When this and other fossil fuels are burnt, especially on a small scale (when combustion is often incomplete), PAH compounds form and escape to the atmosphere or to water, and hence into the environment. Polycyclic aromatic hydrocarbons also form naturally, e.g. during forest fires. The biggest anthropogenic PAH emissions thus derive from small-scale combustion, such as the burning of wood in small boilers for domestic heating, and from petrol and diesel engine exhaust gases. Combustion in vehicle engines is never complete, either, and many harmful residues are thus produced and escape with exhaust gases.

Polycyclic aromatic hydrocarbons are also emitted from combustion processes at coking plants, aluminium plants, energy production installations and waste incinerators.

PAH compounds can occur both in gaseous form and bound to particles, e.g. soot. In water these hydrocarbons are often particle-bound and consequently they can also disperse with sewage.

Organometallic compounds

Organometallic compounds are compounds containing both carbon and metal atoms. In the marine pollution context, the organotin compounds are probably the best known. They are used in anti-fouling preparations for boat hulls, port constructions, fishing gear etc. to prevent the growth of algae and animals. The organotins include tributyl tin oxide, tributyl tin fluoride and triphenyl tin hydroxide. Some organotin compounds are used in agriculture as pesticides. The organotin group are acutely toxic to phytoplankton and benthic animals and have caused damage to oyster farms in several areas of the North Sea. They are now banned in many countries, including the United States, France, the United Kingdom and Sweden.

Organometallic compounds can also contain lead or mercury, such compounds being used as pesticides and stabilizers. Organic mercury compounds are still used in some countries as fungicides (seed dressings) and as paint additives.

Organic lead compounds include, in particular, the highly toxic petrol additives tetramethyl lead (TML) and tetraethyl lead (TEL). Organometals are usually fat-soluble and can thus be taken up by living organisms.

Serious environmental damage caused by persistent organic compounds

Over the years it has been observed that the four most important mammals in the Baltic Sea – the three seal species, grey, ringed and common (harbour) seal, and the otter – are all suffering a marked decline. It is generally recognized that persistent organic compounds are an important factor in making conditions less favourable for these animals.

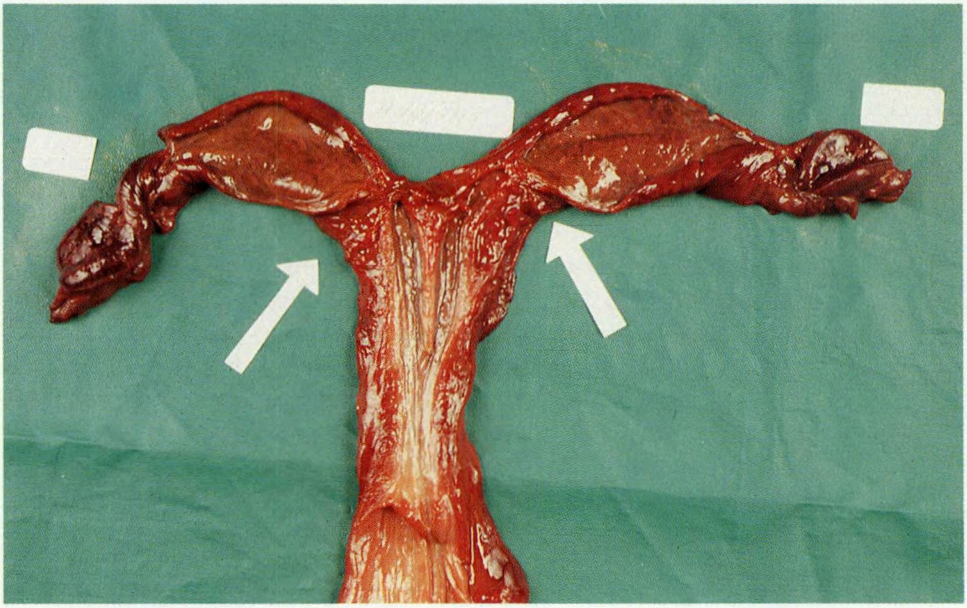
PCBs have substantially reduced seal populations, due to the fact that they cause uterine and hormone disorders in the females. Some 40 % of female seals have conditions of this type due to PCBs and other persistent organic substances. *Figure 14* shows a case of occlusion, i.e. obstruction, of the uterus. Other pathological uterine conditions observed include tumours and stenosis (narrowing) of the uterus. Only around 25 % of female seals are now giving birth to pups, compared with the normal figure of 80–90 %. The females that do have pups pass on PCBs in their milk.

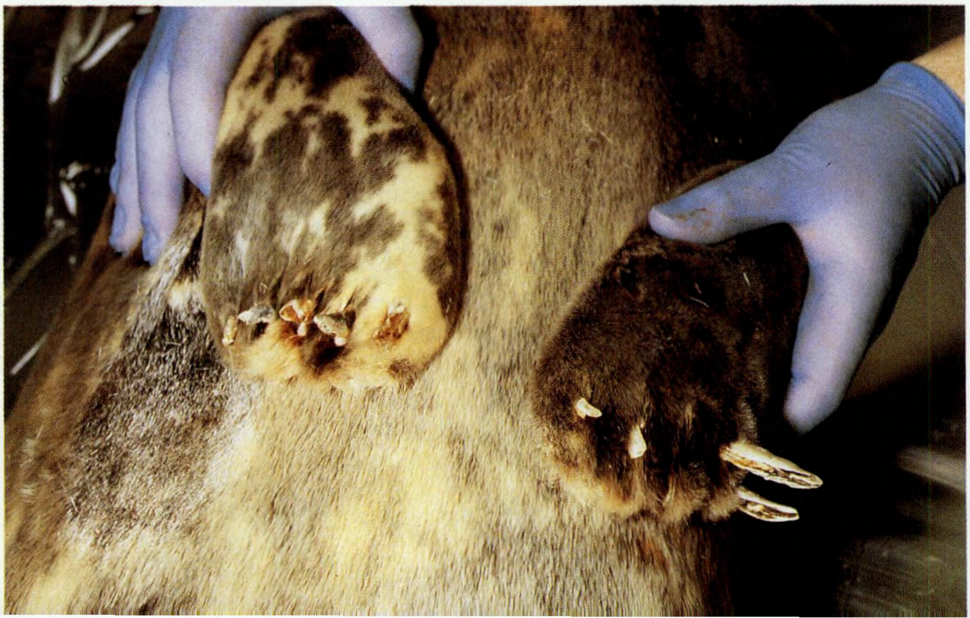
Disturbed hormone production can also result in metabolic disorders and impairment of the immune system, in both males and females. Swedish scientists have compiled data on the pathological conditions observed in all the seals examined between 1977 and 1983. They found

Figure 14. Between 1977 and 1983, researchers at the Museum of Natural History in Stockholm compiled data on the pathological conditions observed in seals examined along the entire length of the Swedish coastline (Baltic and Skagerrak). The uterus shown is from a ringed seal from the Gulf of Bothnia. In both horns (where implantation of the embryo occurs) an occlusion is present. The animal is sterile for the rest of its life. Most probably these occlusions are caused by organochlorine pollutants, especially PCBs. These lesions are common among Baltic seals.

Malformed claws are also common, probably because of high levels of PCBs in the seals' food. The horn material of the claws is brittle and breakage and loss of claws are common. Sometimes claws are bent upwards.

Photographs: Mats Ohlsson and Bengt Ekberg, Museum of Natural History, Stockholm, Sweden.





- uterine conditions (see above)
- skin disorders (changes in the skin and fur similar to the human condition known as chloracne)
- claw changes *(figure 14)*, leaving the claws deformed and brittle
- intestinal ulcers
- serious kidney damage (probably a sign of disturbed metabolism)
- adrenocortical hyperplasia (enlargement of the adrenal cortex)
- skeletal lesions.

In some European coastal areas, bans have been imposed on the consumption of cod livers with a PCB content of over 5 – 15 mg/kg (the limits vary from one country to another).

DDT/DDE and toxaphene have caused damage to fish, birds and mammals. These substances are toxic to fish in quite low concentrations. In some countries, cod livers from the Baltic are no longer permitted to be sold for human consumption owing to their high DDT levels. DDT/DDE may cause cancer in mammals. In predatory birds like the white-tailed (sea) eagle, osprey and guillemot, these persistent compounds have caused sterility. Where birds have been able to produce and lay eggs, they have often failed to hatch, due to shells being abnormally thin and breaking. In recent years, however, the abundance of some bird species has begun to increase again, which suggests that DDT/DDE levels at least are beginning to decline.

The main reason why birds have been particularly seriously affected by DDT/DDE and toxaphene is that they lack mechanisms to eliminate them and increasingly high concentrations therefore build up in their tissues. The effects of DDT/DDE were observed at roughly the same time as it was discovered that more land-dependent predatory birds had suffered mercury poisoning. Some of these effects are similar, since both DDT/DDE and mercury affect the nervous system (see the section on heavy metals).

Chlorinated organic material from the pulp industry's bleaching plant discharges has been found to cause damage to fish and benthic animals. Material of this kind also becomes bound in sediments. In the vicinity of pulp mills, damage observed includes fish with fin erosion (damaged or reduced fins), skeletal deformities such as curvature of the spine *(figure 15)* in four-horned sculpin and bleak, fewer larvae and fry in water kilometres from the discharge point, deformed gills, impairment of the immune system, disturbed osmoregulation (salt balance), jaw deformities, such as 'upnose' skull deformation in pike *(figure 15)*, and skin ulcers. Chlorinated

Figure 15. Several different types of damage to fish have been found in the vicinity of pulp mills using chlorine for bleaching. Two examples of skeletal anomalies are curvature of the spine and 'upnose' deformities. Illustrated, a four-horned sculpin (spinal anomaly) and a pike (jaw deformity).

Photographs: (sculpin) Steve Hamilton, for the National Environmental Protection Agency, Sweden; (pike) Erik Lindesjöö, Department of Zoology, Uppsala University, Sweden.

compounds have also affected the survival of common mussels and amphipod crustaceans and caused changes in algal communities.

Fish take up dioxins either in their food or direct from the water through their gills, and once taken up they are stored in fatty tissues. High concentrations of dioxins have so far been measured in fat species of fish in the Baltic and in hepatopancreas from crabs caught in the Skagerrak/Kattegat. It should be observed that very few studies of dioxin levels in fish and shellfish have as yet been carried out anywhere in the world. Analyses are complicated and expensive. It will thus only be possible to assess dioxin concentrations in marine organisms when a large number of comparable analyses have been performed in several different locations.

It is suspected that, in man, dioxins can cause cancer, impair the immune system and disturb reproduction. In very high concentrations, they can be an acute cause of chloracne, an eczema-like skin disease.

Persistent substances in the Arctic

Both organochlorines and other persistent substances, including heavy metals, are carried considerable distances by winds. In the last few years their transport through the atmosphere has been monitored, and they have been found to travel from the heavily industrialized areas of Western Europe and the Soviet Union, and from North America, up to the Arctic and back again.

Warm air masses from industrial regions in the northern hemisphere are carried northwards and rise when they meet the cold air of the Arctic. A haze of air pollutants from Europe and North America hangs over the whole of the Arctic in winter. In summer, the polar air masses spread out north of our coastlines. The contaminated air from the south again has to rise, and so the air 1 – 2 km and more from the earth's surface is clean. However, all the pollutants do not remain in the Arctic region. In winter relatively little deposition occurs in the Arctic – but enough to leave its mark on the region's environment and organisms. Most of the pollutants are carried by air streams southwards to temperate regions again. The Arctic thus serves as a 'staging post' in the dispersion and mixing of air pollutants.

Chlorinated hydrocarbons can also spread over large areas by means of the mechanisms that maintain chemical equilibrium between concentrations of different substances in seawater and air. Henry's law, governing the exchange between water and air, is of great importance to the global distribution of pollutants and explains why the same concentrations of organochlorines and other substances are found in air over the sea and in air over human settlements. In this way, the sea can become the final destination of many such substances.

In the Arctic areas of North America, levels of polychlorinated hydrocarbons in fish, seals, polar bears and caribou (reindeer) are now so high that the inhabitants of these areas have a daily intake far higher than the guidelines recommended by the World Health Organization. One substance found in these animals is toxaphene – a chemical previously sprayed on a large scale on the cotton fields of the southern United States. Other studies indicate that the polar bear will die out in the early 21st century in certain Arctic regions as a result of reproductive disturbances. Some marine fish in the far north of Canada have been found to have severe liver damage.

The discovery of dioxins in seals, polar bears and Brünnich's guillemots in the Arctic proves that these substances, too, can spread over great distances. They have been transported either through the atmosphere or by ocean currents.

2. Nutrients, eutrophication and oxygen depletion

Eutrophication – overfertilization – of sea areas, accompanied by intense mass growth of algae, has been recorded in the past few decades in many coastal waters around the world. Some of the algae involved, moreover, produce toxins. Heavy algal blooms as such are nothing new – they occurred in European waters in the 19th century. However, the problem has grown considerably and is now giving rise to serious concern.

Nutrients essential to life

Plants cannot grow without a supply of nutrients and light. If there is a shortage of either, growth is limited, or stops altogether. There also has to be a balance between the different nutrient elements required. An abundance of one or two elements is not enough if a third, biologically decisive nutrient is in short supply. Such a nutrient is said to be growth-limiting. In seawater, nitrogen is most commonly the growth-limiting element, but in some areas it may be phosphorus. For diatoms, silicon can also be the limiting factor. The structure and composition of planktonic algae determine how much nitrogen, phosphorus, silicon and other essential nutrients they need.

The plant nutrient elements nitrogen, phosphorus and silicon are not poisons; quite the contrary, they are a crucial foundation for all life, including our own. If plant nutrients – in the form of salts – were not constantly circulating in terrestrial and marine ecosystems, life would cease to exist. Environmental problems arise, however, when excessive amounts are added to an ecosystem in a short time.

The normal nutrient cycle in the sea

As a rule, less primary production occurs in the open sea than in the nutrient-rich coastal zone. By and large, the nutrients that are produced are consumed, and the vast majority of the resulting organic matter is broken down before it reaches the seabed. Essential nutrients are brought up to the surface layer either from degradation in the water column, or with upwelling deeper water. Sedimentation is on a proportionately smaller scale than in coastal areas. Decomposer organisms present in the water convert the bound nitrogen and phosphorus into compounds that can again be utilized by algae for primary production in surface water. The balance between production and consumption is dependent on a number of different factors, however:

- a large volume of water,
- good water circulation,
- a good supply of oxygen,
- a good supply of nutrient salts from deep water, and
- balance between, in particular, the amounts of nitrogen and phosphorus.

Very large algal blooms, and deoxygenation and dead areas of seabed, are therefore unusual phenomena in sea areas that can justifiably be referred to as open sea.

The closer an area of sea is to a coast, the more noticeable is the influence of the land, both the natural influence and that stemming from human activities. For natural reasons, the water near a coast is always richer in nutrients, since rivers replenish supplies from the large landmasses which they drain. In these waters, therefore, we find a higher normal level of primary production and hence a richer flora and fauna, but also heavier sedimentation.

In simplified terms, in the temperate regions of northern Europe a coastal sea area's annual cycle of exuberant life and lethargic inactivity should involve the phases described below.

Roughly between November and March/April, the sea is just 'ticking over'. Primary production is very low, since the water is cold and limited light is available. During these months virtually no nutrients are consumed, and supplies can build up. Nutrients are released from decaying organic matter as inorganic salts and return to the surface layer of the sea, and nutrients also enter the sea with river water. Gradually, concentrations of inorganic nitrogen and phosphorus and of silica rise – the table is laid for the sea's planktonic algae.

As soon as the light begins to return and the water becomes slightly warmer, the feast begins. This initial, explosive growth of planktonic algae is known as the spring bloom and is an entirely natural phenomenon. These blooms usually consist mainly of diatoms. The supply of nutrients in the surface water is quickly exhausted, and in a balanced ecosystem plankton growth gradually declines as nutrients are used up and/or zooplankton in the area grazes on the mass of newly formed phytoplankton. Zooplankton abundance does not reach its peak as early in the year as this, however, so many of the planktonic algae die and 'rain' down to the deep water and the bottom. There, too, the system has not yet begun to function optimally, since the water is still cold enough to inhibit to some extent the ability of bacteria to break down this organic matter efficiently. Large amounts of sinking phytoplankton are eaten by benthic fauna.

Algal production does not cease altogether, but during the summer it proceeds at a calmer pace and large-scale blooms normally do not occur. Productivity in summer is almost entirely determined by how rapidly the system can break down the first generations of algae and release the nutrients assimilated by them, and by how efficiently nutrients are recycled from the zooplankton grazing on the spring bloom. These nutrients are returned directly to the surface water and reused in the calmer algal production of the summer months. Supplies of silicon are generally not totally exhausted by the spring bloom, unless it is exceptionally heavy. If a very intense bloom does occur, however, the silicon will be used up and no further growth of diatoms will be possible.

In the summer, sunlight heats an increasing depth of water, and a thermocline forms. This acts as a barrier to upward transport of nutrients from deeper water. Below the thermocline, however, benthic animals and micro-organisms continue to degrade organic material that has sunk through the water column, and so the store of nutrients in these deep layers gradually builds up.

In the autumn another natural algal bloom – most commonly of dinoflagellates – can develop in the water, which is warmer by now. For this to occur, the water has to be mixed, as happens for example during autumn storms or when the surface water cools down again sufficiently for the thermocline to disappear. Some of the nutrients that were stored below the thermocline can then be brought up to the surface water again.

Mineralization, nitrogen fixation, nitrification, denitrification and *precipitation and sorption* are five important processes in nutrient cycling in the sea (and in soil on land). Both the nitrogen and the phosphorus cycle are complex processes, whose many component elements have to function properly.

Mineralization is the process whereby special bacteria and other micro-organisms in the water or on the seabed break down dead plants and animals (organic matter) that have rained down through the water column. The micro-organisms convert the nitrogen locked up in plant and animal tissues into ammonium ions and the bound phosphorus into phosphate ions. The next stage in the process involves other, equally specialized micro-organisms, which convert the ammonium ions into nitrite and nitrate ions with the help of oxygen. This is known as nitrification. Both mineralization and nitrification are chemical conversion processes – the nitrogen remains in the water, in a form available to plants. Sooner or later the nitrogen thus recycled is again used in primary production.

Denitrification, on the other hand, provides a 'safety valve' for the sea to eliminate nitrogen. Nitrate ions contain oxygen atoms, and this oxygen is readily utilized by bacteria living at the boundary between the oxygenated and anoxic layers of benthic sediments (the redoxcline). They use the oxygen to break down organic matter, releasing nitrogen gas. Marine organisms are unable to utilize gaseous nitrogen – it is in the wrong form – and this gas gradually rises through the water column and finally escapes to the atmosphere. Denitrification gives the sea a certain capacity to rid itself of excess nitrogen. However, this is assuming that inputs of nitrogen are not abnormally high.

Nitrogen fixation is performed by certain species of blue-green algae in fresh and brackish waters. Like some bacteria and leguminous plants on land, these algae can convert atmospheric nitrogen into plant-available nitrogen and store the latter. If a nitrogen shortage arises in the system, the fixed nitrogen can enter circulation again. Whereas denitrification is a way of eliminating excess nitrogen, nitrogen fixation is a method of storing nitrogen to meet future requirements.

Removal from solution, by precipitation or sorption, is in this context a process almost exclusively of relevance to phosphorus. When oxygen is plentiful in benthic sediments, quite a large amount of phosphorus is bound in them. This occurs at the same stage as mineralization. To a large extent the phosphate ions remain in the sediments, and the seabed can thus be 'charged' with phosphorus. This is not an unchanging state, however. As soon as a deficiency of oxygen arises – and in particular when hydrogen sulphide begins to form – phosphate ions are released again and carried up into the surface water. The sea 'saves up' the phosphorus and fertilizes the water at a later stage.

... and the abnormal cycle: eutrophication and algal blooms

Eutrophication has long been a familiar phenomenon in freshwater environments in many parts of Europe and North America. Lakes become 'choked' with algae, reeds and other freshwater plants as a result of nitrogen and phosphorus discharges from towns, factories and other man-made sources. It has not been uncommon, either, for eutrophication to occur in inlets, fiords and estuaries and in archipelagos – areas with limited and slow water exchange and heavily influenced by inputs from land. Only in recent years, however, have we begun to see indications of – and in several cases directly observe – more open coastal sea areas also being affected by eutrophication and its repercussions for vegetation and fauna.

The actual process of eutrophication is not a simple one to study or describe. *Figure 16* outlines the developments generally considered to be involved.

A normal marine nutrient cycle is a broadly balanced system, unless large quantities of nutrients are introduced from various sources. In a balanced cycle, production and consumption largely cancel each other out. Eutrophication arises when overproduction of organic material – phyto- and zooplankton – occurs and this material is not eaten or broken down at the same rate as it forms.

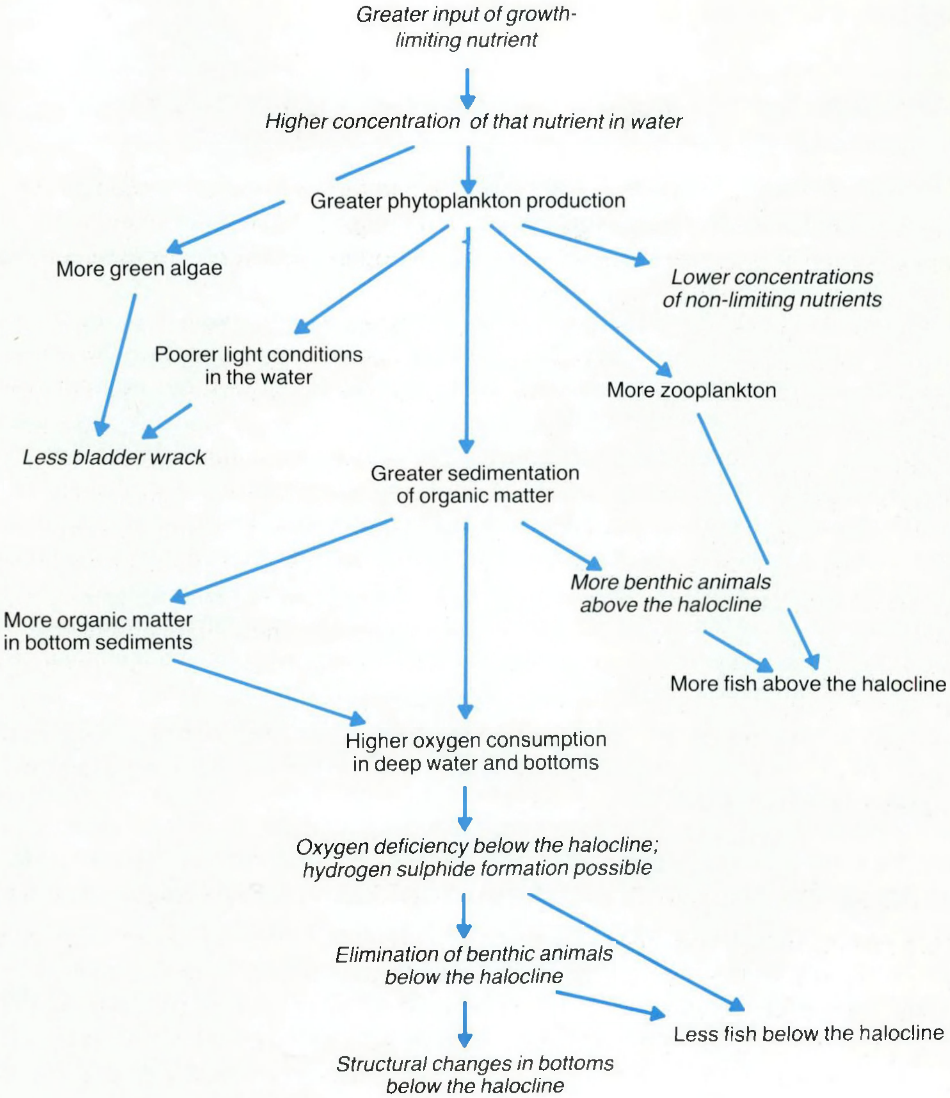


Figure 16. Eutrophication in a sea area is a process involving many component stages and physical, chemical and biological changes, both in surface waters and at greater depths.

This diagram is from *Sweden's marine environment — ecosystems under pressure* (Monitor 1988), National Environmental Protection Agency, Solna, Sweden.

The main inputs of nitrogen and phosphorus to coastal seas come from the land, the atmosphere, and with currents from other sea areas rich in nutrients. The most important sources are

- Discharges from urban areas with inadequate or no sewage treatment
- Deposition of airborne nitrogen and phosphorus compounds
- Direct industrial discharges of nutrients
- Leaching from farmland and forests.

These additional inputs of plant nutrients increase concentrations in surface waters along coasts, as well as disturbing the ratios of different elements in the water. Nitrogen and phosphorus levels rise, while concentrations of other nutrient elements, such as silicon, may fall. A reduced supply of silicon in seawater may also be a result of soil acidification. Normally, this element is supplied to the sea by natural land run-off. However, acidification locks up silicon in soils. Recent research shows that various substances, including the metal cobalt, can be leached from soil in acidified areas. Large amounts of this metal may create conditions favouring algal blooms. A marked shift in the proportions of different nutrients in the marine environment points to a disturbance of the ecosystem that has created new conditions. Eventually it may result in the displacement of once dominant algal species and the establishment of conditions benefiting other species.

When spring and increasing hours of daylight arrive, the table is now not just laid for the phytoplankton – it is positively groaning under the weight of food. Growth of algae does not merely occur at its normal explosive rate – it becomes extreme and uncontrolled *(figure 17)*. Algae go on blooming, beyond the end of spring and into the summer. In eutrophicated waters, algal blooms continue virtually throughout the growing season. Summer blooms and heavy autumn blooms become common. The rest of the system has neither time nor the capacity to deal with all the organic material this produces. The zooplankton is unable to graze down these huge new growths of algae, and the micro-organisms and benthic animals of the decomposition chain cannot keep up with all the food raining down from the constantly productive surface water. Large amounts of dead algae and other organic matter thus settle to the bottom, below the thermocline.

The more of this material there is to be broken down, the more oxygen is consumed. If the bottom water contains plenty of dissolved oxygen and is regularly replenished with oxygen-rich saline water, the oxygen might last until everything has been broken down. In shallow areas with poorer water exchange, however, the oxygen eventually runs out. If the concentration falls below about 2 ml/l of water, benthic fauna will not survive. Both the deep water and the seabed then become excessively or completely depleted of oxygen (hypoxic or anoxic), and the bottom becomes a sort of death trap for any animals there. If they do not escape in time they will die, compounding the tragedy: first, truly dead areas of the seabed develop, almost totally devoid of any life; and second, the dead benthic animals add to the backlog of organic matter that should be broken down, but is now left

Figure 17. Heavy bloom of microalgae in the Skagerrak.

Photograph: Bo Brännhage, Naturfotograferna.

undecomposed. Fish flee from the area. Demersal (bottom-feeding) fish species are adversely affected not only by the oxygen depletion and possible formation of hydrogen sulphide, but also by a shortage of food, since benthic animals have been eliminated.

One source of anxiety is the fact that algae often appear to produce toxins when

Fact panel 4

Algae can produce strong poisons

It has been known for a long time that dinoflagellates are able to produce poisons, or toxins. These toxins are of three main types, causing one of three conditions:

- PSP (paralytic shellfish poisoning)
- DSP (diarrhoetic shellfish poisoning)
- NSP (neurotoxic shellfish poisoning).

PSP and DSP occur in northern Europe. NSP is caused by species that prefer warm, tropical waters.

The toxins concerned accumulate in bivalve molluscs (oysters, mussels etc.) and cause illness in human beings and sea birds that eat bivalves. Fish may be poisoned directly by algae or by zooplankters that have fed on the toxic algae. Bivalves themselves do not seem to be affected, however.

PSP is linked to a number of species of dinoflagellates in the *Gonyaulax* and *Pyrodinium* genera. The symptoms of PSP are blockage of nervous impulses, which results in paralysis within one or a few hours of eating the shellfish. In serious cases, paralysis of the respiratory organs can occur, causing death. There is no antitoxin, and some PSP toxins are among the most potent known.

Quite a number of *Gonyaulax* species are found in the waters of northern Europe. Large-scale blooms with accompanying concentration of toxins in bivalves have occurred since the 1960s in both Europe and the United States. Fish kills, benthic mortalities and other damage have also been caused by these algae. Only a few people have died so far, but potentially toxin-producing algae

they bloom *(fact panel 4)*. Depending on the species and the type of toxin, these poisons may kill fish and other marine animals, render shellfish poisonous, and fatally poison terrestrial mammals. This has occurred in recent years in the Baltic (blue-green algae) and in the Kattegat, Skagerrak and North Sea (dinoflagellates). A recent instance was the toxin-producing alga *Chrysochromulina polylepis*, which in the early summer of 1988 brought death and destruction to a broad belt of sea stretching from the west coast of Sweden a good way along Norway's south coast *(fact panel 5)*.

... oxygen depletion and death in the benthic zone

In sea areas in which no mixing is brought about by currents or wave movements, new sediment is constantly deposited on top of old, halting the supply of oxygen to lower layers of sediment. Even if there is oxygen in the water, the older sediments are to be found in the normal algal flora around our coasts.

DSP is believed to be caused by dinoflagellates belonging to the genus *Dinophysis*. Numerous cases of DSP have been reported in the Netherlands, Sweden, Norway, France and Spain. It resembles ordinary food poisoning, with diarrhoea, nausea, shivering and headache. DSP passes and does not normally cause lasting damage.

Blue-green algae can produce strong toxins, which may kill animals that swallow large amounts of algae-contaminated water. *Nodularia* is the name of a genus of blue-green algae that bloomed in the Baltic in the early 1980s and killed various animals, including dogs. Larger birds, cattle etc have also died after drinking water with high concentrations of blue-green algae. Several species can develop poisons, and blue-green algal toxins are extremely poisonous substances, comparable with cobra toxin, curare and strychnine. They attack the nervous system, the liver or the skin, depending on the type.

Our present knowledge of toxin production in marine algae is limited. Outbreaks of large-scale blooms and toxin production by algae have become more common in recent decades, in coastal waters throughout the world. Scientists generally believe that this phenomenon will continue, at least if nothing is done to restore as far as possible the nutrient balance of coastal sea areas. Increasingly, the possibility is beginning to be discussed of a link between the mass occurrences of toxic algae in recent years and transportation of ballast water by tankers between different sea areas of the world. When seawater is carried from one area to another in this way, 'new' species may be introduced into the area where the ballast is pumped out. An alga which in its original environment perhaps is not known to produce a toxin may suddenly start to do so as a result of the different conditions in its new environment.

are cut off from oxygenation. The sediments exhibit marked, distinct stratification, rather than being well mixed (see the section on the Baltic).

The next process occurring in these anoxic sediments is that of decomposition by bacteria in the layers of sediment below the redoxcline – the boundary between the oxygen-containing (oxidizing) surface sediments and the deeper, anoxic (reducing) layers. These bacteria do not need oxygen gas, obtaining the oxygen they require from sulphates and other compounds. This produces hydrogen sulphide, a toxic, water-soluble gas that makes deoxygenated areas of the seabed almost totally unfit for animal life. In an anoxic benthic environment, special bacteria can also convert metals in sediments, releasing them into the water column. Inorganic mercury can be converted into methyl mercury, which is readily taken up by fish. As was mentioned above, phosphorus also begins to leak from the sediments.

Oxygen can also become depleted on the seabed when large quantities of degradable organic material, such as sewage sludge, sewage effluent and pulp mill

Fact panel 5

The 'killer' alga *Chrysochromulina polylepis*

During part of May–June 1988, a heavy bloom of algae of the species *Chrysochromulina polylepis* formed a broad belt stretching through the Danish Belts, the Sound, along the entire length of Sweden's west coast (the Kattegat and Skagerrak), and all the way along the Norwegian coast of the Skagerrak and North Sea from the outer Oslo Fjord to Bømlo in Hordaland. This alga completely dominated some of these waters for around a month. In all, an area of some 75 000 km^2 was affected. The algae killed or caused damage to vast numbers of living organisms exposed to them, down to depths of around 20 m – farmed salmon and trout, benthic fauna, macro- and microalgae. Some wild fish were also killed, but the majority of free-living fish species – cod, haddock, mackerel and herring – managed to escape from the area. On average, some 5 million algal cells per litre of seawater were recorded in the waters affected. At greater depth, concentrations were as high as 80 million cells/litre.

This small alga is common in Scandinavian waters, but did not use to be included in routine phytoplankton analyses. It was some time, therefore, before it was realized which species was involved. The poison it produced was a cytotoxin, i.e. a poison that attacks cell walls. The animals that were killed were unable to survive because of disruption of their fluid balance. Common mussels, which did not die, accumulated the toxin. The fish that survived and remained in the area do not appear to have done this, however.

Around 100 tonnes of farmed fish were killed along the west coast of Sweden, and about 500 tonnes along the Norwegian coast. Only fish farmers who managed to evacuate their cages to other waters were able to rescue at least some of their stocks. In Danish waters, for some reason, the algae were not toxic.

The extent of fish and benthic mortalities is not known. It is clear, however, that virtually all cod fry in the affected coastal waters of Norway died. Another effect of the algal invasion was a population explosion of common mussels. They could spread at liberty on rock walls formerly inhabited by organisms killed by the algae. Never before had mussels been seen living at such great depths as 30 m. Their rapid growth resulted in overcrowding, and large numbers dropped to the seabed and died. Over these layers of dead mussels, and already dead benthic animals, there then grew a white mat of sulphur bacteria. These alarming and dramatic developments continued for a long time *(figure 18)*. The areas hit have subsequently been recolonized, and one year after the onslaught of the algae the environment appears by and large to have recovered.

How, then, could *Chrysochromulina polylepis* undergo this mass development and kill on a scale which shocked both scientists and the public? We now know that a combination of eutrophication and weather conditions created a favourable environment for this particular algal species. The winter had been mild and damp, resulting in above-normal nutrient losses from the land. Concentrations of nitrogen were 80 % higher and those of phosphorus 50 % higher than the 10-year average in the water in March, before the usual spring bloom. In addition, the surface water was a few degrees warmer than was normal for the time of year. Concentrations of nutrients were not remarkably high in May – most of them had been used up in the spring bloom. Silicon and phosphate concentrations were in fact low. The halocline was quite deep, and nitrogen from deeper layers of water could therefore be carried up to the surface layer. Winds were easterly, the weather sunny, and the surface water temperature rose rapidly. The water column was stable. But the main factor favouring this alga, researchers now believe, was a change in the relative proportions of nutrients in the water.

Figure 18. The massive bloom of the toxin-producing alga *Chrysochromulina polylepis* that occurred in early summer 1988 in the Kattegat, Skagerrak and along the south coast of Norway caused mass deaths among fish and benthic organisms. Large sections of benthic communities were wiped out. One year later some recovery had been observed, but for some time the effects of the algae were devastating.

Photograph: Katrin Österlund, Department of Physiological Botany, Uppsala University, Sweden.

fibres, are discharged and form a layer on the bottom. This material also needs to be broken down, a process requiring oxygen. If major discharges occur from towns, industrial plants and other point sources, bottom areas near the discharge point may suffer oxygen depletion with the same ecological effects as when the benthic zone has to deal with excessive amounts of dead plankton.

Both oxygen depletion and hydrogen sulphide formation may be temporary, and the damage can be repaired if the environment improves. Animal life will gradually return – the seabed will be 'recolonized'. This occurs in different ways in different marine environments. Basically, the process is as follows. A few very hardy, 'opportunistic' species settle fairly quickly in such areas. Typical opportunists include certain polychaetes (bristle worms), which swim or drift into the area. Opportunistic species are characteristically small, fast-growing and numerous, have a short life cycle and high mortality, are very adaptable (i.e. do not require a highly specialized environment), are often detritus feeders (i.e. eat dead plankton), and have a longer breeding season than other organisms. These species are at an advantage as long as the environment is in a really poor state, but as it recovers and other species are able to colonize it, the opportunist organisms are eliminated, unable to cope with the competition.

Away from the most badly affected environment, in which opportunistic species settle, other benthic animals gradually establish a transitional community. This

Figure 19. Eutrophication also results in the mass development of certain macroalgae with a 'filamentous' structure. Large quantities of such algae can first grow on the seabed or in the littoral zone, e.g. on rocks, or as epiphytes. Later they may be torn away and either cause oxygen depletion on the bottom, or pile up in thick, slimy ridges on the shore.

Photographs: Staffan Widstrand, Naturbild (algae in water); Staffan Arvegård, Naturfotograferna (algae on rocks); Rutger Rosenberg, Kristineberg Marine Biology Station, Sweden (algae on beach).

consists of fewer and more specialized species, but contains a larger total number of animals than there will be in the final benthic fauna.

Recolonization is a variable process, in terms of time, space and environmental conditions. The first animals may appear within a couple of weeks, and then it may take anything from a matter of months to a few years before animal life returns to normal. What this normal state will be like will depend very much on the conditions prevailing in the area and on what species arrive first. There is no guaranteeing that a recolonized, once dead area of the seabed will have exactly the same animal communities as prior to the large-scale mortalities caused by oxygen depletion. A great many biological and ecological factors determine the final composition of the fauna.

Oxygen depletion and hydrogen sulphide formation, then, can 'heal', but in some areas, including the deep basins of the Baltic Sea, they have become permanent. A rule of thumb is that oxygen depletion first occurs in sea areas with marked stratification of the water column – such as distinct haloclines and thermoclines – together with large-scale plankton production and poor water exchange.

Shifts between plant and animal species

Eutrophication also has other effects on the marine environment. The thick algal 'soup' that arises in the water prevents light from penetrating to the depths at which brown and red algae grow. The bladder wrack belt may disappear altogether. Only fast-growing, filamentous green and brown algae (epiphytic algae) near the surface thrive, since they have an abundant supply of nutrients and light. *Figure 19* gives an impression of how filamentous green algae can flourish and how this affects shores.

Mortalities among animal species are not the only thing to follow in the wake of eutrophication. On shallower bottoms, above the halocline, where oxygen is still present in the water and there is plenty of food in the form of phyto- and zooplankton, benthic animals usually become more abundant. Similarly, fish production increases above the halocline. An area affected by eutrophication may therefore appear to be biologically highly productive, despite the fact that at greater depth it is in the process of suffocating. Conditions vary from one area to another, however. Natural competition and the distribution of species may be affected in such a way as to give certain species a competitive edge over others. Such a shift between the species of an area is itself one of the environmental effects of eutrophication. In serious cases, demersal fish may be affected by such changes.

3. Heavy metals

In the 1950s and 60s, large groups of people unknowingly and tragically served as indicators of the toxicity of a number of heavy metals. In the Minamata and Niigata areas of Japan, factories discharged methyl mercury, which was taken up and concentrated by fish and shellfish. The local people, who were major consumers of fish, were poisoned by the mercury, which caused serious damage to the central nervous system. In the 1970s, mercury-dressed seed led to a similar tragedy in Iraq, where people ate the seed raw or made bread from it. Several thousand people died of mercury poisoning, and many suffered irreversible brain and nerve damage. In the 1960s, people in Japan ate cadmium-contaminated rice, with serious repercussions in the form of skeletal deformities and kidney damage.

Natural, mobile and toxic

Heavy metals are elements that exist naturally in the environment in relatively low concentrations. Unlike most other naturally occurring elements, certain heavy metals – in particular lead, cadmium and mercury – do not appear to serve a biological function in any living organism. Indeed, even in small amounts these metals are harmful to both animals and plants. Some metals, such as zinc and copper, are constituents of enzymes, proteins, vitamins and other essential building blocks of life, but intake by organisms must not be too high. The threshold between useful, or at least harmless, and directly harmful intakes is very low.

Other heavy metals often discussed in the environmental context are arsenic, chromium, nickel, vanadium and tin. Another metal that causes damage to plants and animals, and probably also to man, is aluminium. Aluminium, however, is not classed as a heavy metal.

Heavy metals are indestructible and do not break down. They are thus examples of persistent substances, and become environmental toxicants when they appear in too large a quantity in the wrong place.

Metals occur in different chemical forms, with varying degrees of bioavailability. The heavy metals may occur in ionic form, when they are dissolved in water, or as inorganic or organic complexes. They can also bind to particles. Metals fairly readily form compounds with other elements.

The mobility of metals in the environment also varies according to their physical and chemical properties. Cadmium, arsenic, nickel and zinc are transported and disperse very easily, whereas lead, mercury, chromium and copper need special conditions to be mobilized and 'migrate'. Inorganic mercury can be converted by bacteria in anoxic sediments, for example, to an organic form, methyl mercury, which is considerably more mobile and also more toxic than the original form. This change – methylation – makes the now organic mercury soluble in fats, enabling it to cross critical barriers in the body. In methyl form, mercury can penetrate the blood–brain barrier and the placental barrier. It is therefore an insidious and potentially dangerous metal, even though initially after its release into the environment it is tightly bound to soil particles or benthic sediments. Methylation, in other words, is a process that can occur in the natural environment. There are indications that it could possibly also take place in the digestive tracts of certain mammals.

Wide dispersion of metals in air and water

Particulate lead, arsenic, cadmium, copper, chromium, mercury, vanadium and zinc usually originate in anthropogenic emissions, are transported through the atmosphere for varying distances, and then fall to the ground or onto water. Mercury vaporizes readily, and thus often occurs as a vapour and can be transported over considerable distances. Lead can be carried by winds and washed out of the air by precipitation.

It is estimated that some 50 % of heavy metal inputs to the North and Baltic Seas originate as air pollutants. Airborne heavy metals either fall directly onto the surface of the sea, or are emitted on land, fall to the ground and are finally carried out of the soil into rivers flowing down to the sea. When transported by rivers or in sewage, these metals are usually bound to organic or inorganic particles. In addition to these processes, acidification of soils has resulted in heavier leaching of heavy metals that were previously firmly bound to soil particles. Metals that become highly mobile in an acid environment include cadmium and zinc (and also aluminium).

Sediments an indicator of metal concentrations

Once heavy metals have reached the marine environment, they are mainly deposited in sediments in the vicinity of the discharge or inflow zone. The strength of sediment binding varies. Cadmium is released from the particles it was transported on and dissolves in the water. Mercury, as was noted earlier, may be tightly bound to the sediments, but following methylation it can again become mobile in the environment. Arsenic, zinc and nickel do not undergo sedimentation as readily, and disperse over a larger area.

The fact that the metals in a discharge initially settle to the sediments, then, does not necessarily mean that they remain there. Some exchange is always taking place between sediments and the water immediately above them. Burrowing benthic animals may help to mix the sediments and remobilize metals in them.

When heavy metals are discharged into deep fiords and sea areas with poor water exchange, the bottom can act as a 'trap' for them. Concentrations tail off, the nearer the mouth of the fiord or the further from the discharge area in the sea they are measured, if the metals are removed from solution due to their becoming trapped at great depth where the water is calm and stagnant. The metals may then be toxic to organisms in the area. The seabed in the immediate vicinity of point sources is often totally devoid of benthic fauna, owing to the poisonous environment.

As a general rule, heavy metals become increasingly toxic, the fresher the water is. Organisms in a brackish water area therefore run a greater risk of damage than those living in metal-contaminated but more saline water. Thus the Baltic is more sensitive to metal inputs than, say, the open North Sea or the oceans. Regardless of salinity, however, it is more dangerous from an environmental point of view to discharge heavy metals in shallow waters, such as littoral zones, than in deeper water.

Since metals undergo sedimentation, the sediments are an indicator of heavy metal concentrations in a sea area. Concentrations in sediments may be thousands of times higher than those found in the overlying water. To gain an accurate picture of heavy metal levels in sediments, however, it is not sufficient to take the occasional sample. Sampling must be long-term, stretching over several years.

Further concentration of metals can occur in phytoplankton, which may have levels several thousand times those found in the water. Metal concentrations can also be measured in animal species, e.g. mussels and other filter feeders.

Combustion, sewage and dredging release metals

There are a great many interacting sources of heavy metals in a modern industrial society:

- Industrial processes can result in direct discharges with waste water and emissions to the atmosphere (from combustion etc.).
- Stormwater and overflow of urban sewage contain heavy metals.
- Heavy metals are found in digested sludge and effluent from sewage treatment plants and may enter the environment by direct discharge to water, dumping of

sludge, and the use of sludge as a fertilizer and soil conditioner in agriculture.

- Burning of wastes in industry and in municipal garbage incinerators releases heavy metals into the atmosphere, through which they spread further.
- Combustion of coal, oil and other fossil fuels releases some of their heavy metal content into the atmosphere.
- Vehicle exhausts contain lead, if leaded petrol is used.
- Pesticides may contain heavy metals (large-scale inputs of mercury used to occur in this way, for example), and artificial fertilizers often contain cadmium. These metals spread from soil into water, and also through the atmosphere.
- Dumping of metal-contaminated sediments (dredging spoil) can transfer metals from one site to another.
- Contaminated fibre sediment from pulp and paper manufacturing can release heavy metals into the sea. Old waste tips at mines and municipal refuse tips can leak metals into soil water and groundwater, which eventually carry them down into the sea. Leakage of the latter kind is facilitated by soil acidification.

Nervous system and genetic damage

Cadmium and methyl mercury are readily accumulated by animals and human beings. Generally speaking, metals have low solubility in fats, but methyl mercury can be transported without difficulty in fatty tissues. These metals can react with proteins. Mercury is therefore found in protein-rich tissues in animals and man. Cadmium in ionic form is taken up directly from aqueous solution by organisms living in water. Predatory animals, e.g. birds of prey such as the white-tailed eagle and large predatory fish, ingest these metals with their prey. It seems, however, that only mercury can be accumulated by biomagnification.

Mercury is highly toxic, owing to its ability, in the methylated form, to cross biological barriers which inorganic mercury cannot penetrate. It has been demonstrated beyond doubt that methyl mercury causes damage to the central nervous system – damage to the brain and the rest of the nervous system – that can result in paralysis and impairment of sensory organs, motor ability etc. It has been found that methyl mercury can cause genetic damage to human tissue samples, and such damage could therefore be caused in both marine mammals and man.

Methyl mercury is readily taken up by fish and shellfish. Fish can themselves be affected by the toxicity of mercury. In acidified lakes in which methyl mercury levels are rising, behavioural disturbances and impaired reproduction are being observed in animal populations.

In the 1960s it was discovered that a number of bird species in Sweden had been poisoned by mercury. The birds were found dead or suffering from serious paralysis and muscle spasm. Many exhibited clearly disturbed behaviour patterns, symptoms that were later also to be seen in connection with DDT poisoning. For example, birds began to move clumsily, trampled on their own eggs, or had difficulty flying and landing. Impairment of the nervous system also caused a

Figure 20. In the 1960s it was discovered that a number of bird species in Sweden had been poisoned by mercury. Later it became clear that birds that found their food in the sea, e.g. white-tailed eagles and guillemots, had also suffered mercury poisoning via their prey — fish with high levels of mercury. This is one of many examples of how heavy metals can 'migrate' through ecosystems.

Photograph: Göran Frisk, Naturbild.

deterioration in their overall success – it was more difficult for them to find food, escape from their enemies, and cope with physical strains *(figure 20)*.

The affected birds had either eaten dressed seed themselves, or rodents and small birds that had previously ingested mercury in such seed from farmland. A link was established between the use of alkyl mercury as a fungicide on seeds and these cases of poisoning. Mercury seed dressings were banned, and bird populations gradually recovered.

Cadmium is taken up by plants, such as cereals, fodder crops and fungi, and is thus passed on to human beings. The population of an ordinary modern industrial society already has a high exposure to cadmium, and excessive loads and resultant harmful effects are only a short step away. Cadmium is highly mobile in the environment, and easily accumulates in living organisms. In man, it mainly affects the kidneys.

It has also been found that, in fish, cadmium can disturb reproduction, inhibit growth, reduce the formation of white blood cells and impair oxygen uptake. Osmoregulation and blood enzyme balance may also be disturbed in fish, these in turn leading to skeletal deformities. In the marine environment, cadmium is more toxic in brackish water than in more saline seawater.

Cadmium is dangerous to man because of the narrow margin between the amounts we already have in our bodies and the level at which damage may begin to occur. For this reason, the load must be reduced from all sources – on land and in water. Cadmium levels in the northern hemisphere, i.e. in the highly industrialized western world, have increased tenfold since the 19th century.

In high concentrations, lead can damage the blood-forming organs, nervous system and kidneys of human beings. It is known that lead that has entered the body can be stored in the skeleton and the brain and remain latent there, but later be remobilized and cause damage. There are indications of lead causing behavioural and mental disturbances, e.g. affecting concentration, learning ability and co-ordination. Children and the unborn foetus are particularly sensitive. Growing individuals are always affected more severely than adults. Children take up around 50 % of the lead entering their bodies via their digestive tracts, while adults only take up one-tenth as much by this route.

Photograph: Tommie Jacobsson, Naturfotograferna.

4. Oil and oil products

The oil products used daily as fuels in energy production, machinery and vehicles, and as raw materials in the petrochemicals industry, are mineral oils. There are other naturally occurring types of oils: lipids (containing fatty acids) and essential oils. Lipids may be of animal origin (e.g. whale, seal and fish liver oil) or vegetable origin (e.g. palm, rapeseed, linseed, sunflower, olive and coconut oil). Essential oils are usually natural (essence of roses, oil of lavender), but can also be manufactured synthetically for use in paints and perfumes.

What is oil?

According to the basic definition, an oil is an organic compound that is insoluble or not readily soluble in water. Mineral oils are produced from crude oil, which is a mixture of different hydrocarbons. Crude oil (also known as rock oil or petroleum) also contains small amounts of oxygen, nitrogen and sulphur and traces of some fifty other elements, chiefly metals, the concentrations varying between sources. When it is extracted from the ground, crude oil consists of many thousands of different chemical components. No two crude oils are alike: physical properties and chemical composition vary from one reserve to another and even between different depths in the same well.

Crude oils, then, are naturally occurring complex mixtures of organic compounds. Reserves of natural gas and oil have formed over millions of years as plants and animals have been broken down and undergone chemical change at high temperature and pressure.

Crude oil usually contains up to 95 % hydrocarbons, but hydrocarbon contents as low as around 50 % also occur. The amounts of oxygen, nitrogen and sulphur vary. In round figures, oil can have an oxygen content of between 0 and 7 %, a nitrogen component of 0–2 %, and between 0 and 7 % sulphur. Naturally low-sulphur oil is now in particularly high demand, since it does not need to be desulphurized prior to use as a heating and fuel oil. North Sea oil contains very little sulphur, while most crude oils from traditional Middle Eastern producers have a medium or high sulphur content.

The crude oil pumped from wells is a mixture of natural gas, water (formation or production water) and oil. The first stage in its processing is separation of the gas from the oil. The gas is further purified to remove carbon dioxide, hydrogen sulphide and water, and transported under pressure by pipeline. The resultant 'dry' gas consists mainly of methane – which, incidentally, is the simplest of all hydrocarbons – with a small admixture of ethane and propane.

During drilling, use is made of 'drilling muds'. These are mixtures of water, clay and various chemicals, which are pumped down through the drill pipe and back up between the pipe and the borehole in order to cool, lubricate and clean the bit, maintain pressure – to prevent blow-outs – and carry drilled rock fragments (cuttings) and other material up to the surface. In offshore oil production, some of this mud ends up in the water around platforms. The oil- and chemical-containing drilling muds now in use are less acutely toxic than those employed in the past. Nevertheless, their effect on benthic animal communities does not appear to have become less marked. Offshore use of diesel-based muds has been banned in the North Sea since 1987.

The crude oil is led to tanks, where water and solid particles are removed, after which the oil is distilled at refineries. The end result of refining is a number of 'fractions', with differing characteristics:

- Natural gas
- Raw gasoline (benzine and naphtha), the end product of which is called motor gasoline or petrol
- Intermediate distillates, the end products of which include light gas oil, diesel oil, aviation fuels, kerosene etc.
- Heavy distillates, whose end products are heavy gas oil (used as feedstock for cracking processes), waxes and lubricants
- Residue, the end products of which are heavy fuel oils and bitumen.

Crude oil as such, then, is rarely used, but it provides the raw material for the refining and production of a large number of products. Oil is a commodity touching on the everyday lives of us all. It is still our dominant energy source, in the form of fuel oils (for heating) and transportation fuels, and it forms the basis for the whole of the petrochemicals industry – and hence for many other industrial sectors. Around 90 % of all basic chemicals are made from natural gas and crude oil, and all plastics are based on oil products. Yet only 5–10 % of total world output of petroleum is used in the petrochemicals sector. Most of it we burn to obtain heat and power.

Acute and chronic inputs of oil

Oil gets into the sea in various ways. The most dramatic inputs result from accidents – an oil tanker springing a leak or a 'blow-out' on an oil platform in an offshore field. Such incidents result in large quantities of oil being lost in a short time, oil which can be carried far from the scene of the accident by currents and winds, causing widespread damage. The effects of this acute type of discharge, involving the loss of tens or hundreds of thousands of tonnes of oil, have been studied in detail. We know relatively well what happens, in the short and long term.

In 1967 the supertanker *Torrey Canyon* went aground off the south-west coast of Britain and some 120 000 tonnes of crude oil escaped into the sea. Just over ten years later, in 1978, the French coast was hit by an even bigger spill, when another tanker, the *Amoco Cadiz*, ran aground and 220 000 tonnes of crude oil was spread along a 360 km stretch of the Brittany coast. Apart from the major impact on beaches, fisheries and mussel and oyster farms were severely affected.

In 1977 a blow-out occurred at the Norwegian Bravo oil platform in the North Sea. 22 000 tonnes of crude oil poured out in the space of a few days, and the slick stretched over a total area of some 4 000 km^2. This accident happened in the early spring, limiting the damage done to marine animal life.

Another major blow-out occurred in 1979 in the Gulf of Mexico, discharging in the order of 500 000 tonnes of oil. In the warm, choppy water, roughly half the oil evaporated, a quarter sank to the seabed, and the rest was broken down by oil-degrading bacteria.

In 1988 a fire broke out on the British Piper Alpha platform in the North Sea, and the platform sank. The loss of oil was limited, but subsequently it has emerged that there were over 5 tonnes of PCBs in the platform's transformers (total annual inputs of PCBs to the North Sea from land-based sources are estimated at around 3 tonnes). The oil company maintains that these PCBs burnt up during the accident, a claim very much doubted by many observers. Thus another risk associated with offshore oil and gas production is now being discussed, along with all the others. Other North Sea platforms probably also have installations containing PCBs on board.

Major tanker accidents have also occurred in the Baltic Sea. The biggest was in 1981, when a ship ran aground off Lithuania and discharged at least 10 000 tonnes of oil. In 1977 the tanker *Tsesis* went aground south of Stockholm, spilling 1 000 tonnes of fuel oil. Two years later there was a similar accident on the Latvian coast, involving the *Antonio Gramsci*, and 6 000 tonnes of crude oil poured into the sea. For a variety of reasons, the Baltic is very sensitive to oil damage.

So far this year (1989), three tanker accidents have occurred in sensitive marine areas. In February two vessels, one Argentinian and the other Peruvian, ran aground off Antarctica. Both ships caused small oil spills in the area. In the discussions under way about the exploitation of Antarctic natural resources, conservationists have underlined the considerable dangers of oil discharges in this special and sensitive environment.

In March 1989 Prince William Sound, on the south coast of Alaska, was devastated by a major tanker accident, described as the worst in US history. An American vessel went aground and some 30 000 tonnes leaked out. The Sound is a rich biological environment.

The environmental effects of these three accidents will not be fully known for several years, however.

Serious accidents involving oil are naturally feared, but researchers are concerned that smaller, continuous discharges – chronic, diffuse inputs – place a heavier burden on the environment in the longer term. We still know very little about the ways benthos, fish and shore ecosystems are affected by constant exposure to oil, especially in areas with ice. Anxiety stems from the fact that the oil itself, or oil interacting with other substances in the marine environment, could have biological effects even in low concentrations in the thin surface film of the water, in the water column and in sediments.

Chronic inputs account for a total of 50–90 % of all oil or oil-derived organic compounds entering the sea. In a sea like the Baltic, chronic/diffuse discharges are responsible for practically all additions of oil. A significant amount of oil and gas enters the seas continuously from natural sources, too (see below).

Natural sources and man-made inputs

Chronic, diffuse inputs originate from

- land-based sources
- ships in the course of normal operations
- offshore production of oil and gas
- natural oil seeps into the sea.

Land-based sources include towns and cities, industrial plants, and river inputs. Urban handling of oil products results in leakage and spills into rivers and streams, discharges via sewage works and in dredging spoil, and atmospheric emissions, due to evaporation and incomplete combustion. Oil is discharged directly from coastal towns, factories and refineries. It is released from treatment plants for oily ballast, from oil terminals and from port operations.

In normal operation, ships discharge small amounts of oil with coolant water and in the form of minor leakage from engines, tanks and pipes. These 'operational' discharges are probably considerable, seen over a longer period. In some areas ships are not now allowed to clean their oil tanks at sea, but some do so all the same. Substantial amounts of oil enter the sea in this way, at varying distances from land. No exact figures are available on how much oil is legally discharged. One estimate for the North Sea is 1 000 – 1 500 tonnes a year. Illegal discharges are far higher. Again, there are no precise figures, but estimates range from just over 1 000 to 60 000 tonnes a year in the North Sea.

Offshore oil and gas production, like other industrial activities, involves operational discharges. Drilling muds containing oil and chemicals are used. These muds are expensive, and operators try as far as possible to recycle them. Drilling mud that is discharged ends up in the sea together with the fragments of drilled rock known as rock cuttings. Production water also contains oil and chemicals, which contaminate the seawater near platforms. Production water and contaminated cuttings have been identified as major sources of oil inputs. In the immediate vicinity of a platform, within a radius of 200 m, oil concentrations in sediment may be between 1 000 and 10 000 times higher than the background level when oil-based drilling mud has been used in development of the field. Concentrations then fall rapidly with increasing distance, but 5–7 km from the platform they may still be above normal.

Quite a large number of exploratory wells are being drilled in the North Sea, the Baltic and the Barents Sea. Spills of oil and chemicals may be expected to increase at the same pace as these operations – both exploratory drilling and continuous production. With every new borehole, moreover, there is a growing risk of major discharges, even if blow-outs are very uncommon.

In 1985 some 29 000 tonnes of petroleum hydrocarbons entered the North Sea as a result of offshore activities. A few per cent came from oil spills and 6–9 % consisted of oil in production water. 90 % – just under 26 000 tonnes – of this input came from drilling.

Previously, oil production in the North Sea has mainly taken place south of 62 °N. As will be seen in the section on the Barents Sea, the search is now on for new oil fields much further north.

Natural seepage is a further source of oil inputs. No one knows for certain on what scale this occurs, but estimates are between 1 and 10 million tonnes of petroleum a year in the world ocean as a whole.

In all, it is estimated that 3.3 million tonnes of oil and oil products enter the world ocean every year. Globally, some 45 % of this total stems from marine transport (from oil field to consumer) – this includes both normal transport discharges and tanker accidents resulting in major oil spills. Around 38 % of the oil input into the seas and oceans comes from land-based sources, including rivers, and atmospheric deposition, about 9 % from natural sources, some 6 % directly from refineries, and 1–2 % from offshore oil production. The figures are uncertain, but do give us some idea of the situation. The exact breakdown varies from one sea to another. Estimates for the Baltic and North Seas are given in the sections dealing with the state of these sea areas.

Degradation of oil in the sea

Oil and oil products are not completely insoluble in water. 17–25 % of crude oil, primarily its aromatic hydrocarbon component, is water-soluble. These compounds include PAH, benzene and toluene, which are acutely toxic in water. Certain aliphatic hydrocarbons in oil also have acute toxicity in water. Other fractions are volatile and evaporate relatively quickly. The rate of evaporation is dependent on various factors, including composition and where oil is discharged.

Oil that enters seawater is immediately exposed to mechanical, chemical and biological degradation processes. The oil spreads over the sea surface, light components evaporate, others dissolve in the water. The fraction remaining on the surface usually forms an emulsion with the water. Oil droplets disperse in the water column, some oil becomes attached to particles, 'tar balls' of heavy oil form, some oil is taken up by organisms and some is broken down by bacteria or by sunlight. Thick oil slicks can drift with the winds and currents and reach the shore.

The behaviour of oil is dependent on a range of physical and chemical factors in the areas in which inputs occur. If the water and the air are warm, large amounts of oil can evaporate immediately. Powerful, high-energy waves can break up and finely divide the oil, enabling it to mix more easily with the water and begin to be broken down. Evaporation is slower in regions with low temperatures than in areas where both water and the atmosphere are warm. However, even in the North Sea for example, some 40 % of oil discharged on the open sea is estimated to evaporate within about five days.

Among the bacteria in seawater, there are some which literally eat oil. They make use of the organic material in dissolved oil and oil droplets and break it down. Afterwards, the number of bacteria will have risen markedly, and carbon dioxide and water will be left as by-products. The more oil there is to degrade, the more bacterial populations grow. For the bacteria to thrive, however, oxygen gas and nutrients must be available.

Research in Norway indicates that oil is not necessarily broken down more slowly by bacteria in open, cold waters than in warm. Bacteria in cold seas are adapted to their environment and grow just as rapidly as oil-degrading bacteria in other waters. Other researchers maintain the opposite view – that the decomposition rate of oil is at least ten times slower in cold water than in warm. A point on which there is agreement, however, is that there is least risk of oil damage if a discharge occurs on open water, irrespective of the water temperature. The worst problems arise when oil gets into water that is mixed with ice, since it is not then in a free body of water. If oil is discharged near the edge of the ice, or in slushy ice in the water, only small amounts manage to evaporate or become finely dispersed. Oil may drift beneath the ice, considerably impeding its degradation. Plants and animals below the edge of the ice are immediately affected by the oil.

Photo-oxidation is a process occurring in the presence of sunlight, in which oil is broken down into more water-soluble components. If this process takes place in open water, it assists in rapidly breaking down the oil. Photo-oxidation in the vicinity of ice, however, may have the opposite effect – when oxidized, volatile components such as toluene form substances that are considerably more toxic than the actual oil.

Evaporation, dissolution and dispersion in the water column and degradation by bacteria and sunlight are the principal processes that eventually dispose of a discharge of oil. Man himself assists with active clean-up measures. Physical removal is preferable to the use of chemical dispersants. In some cases these agents may be toxic or combine with the oil to form toxic compounds. They are not always effective, and so their use is often pointless. Waves – as well as chemical dispersants – may help to finely divide the oil. Two types of emulsions may form, either oil-in-water or water-in-oil. The latter is usually called 'mousse' and is very resistant to weather and degradation processes.

Birds, benthos and shore life worst affected

Depending on the composition and amount of oil discharged, the duration of the discharge, the time of year at which it occurs, the water and air temperature, weather conditions, species composition in the area affected, and other factors, the amount of damage caused can vary.

As far as accidents involving major oil spills are concerned, it has been found that the biggest environmental threats in more temperate waters are to sea birds, benthic organisms and the animals living in and dependent on beaches and rocky shores.

The actual water column and its animal life recover relatively quickly, provided degradation is able to proceed at the normal pace. Oil remains in the water for just a few weeks, whereas it can be detected in benthic sediments for decades. It may also take quite a few years for benthic life to recover and for recolonization to be completed. Benthic animals cannot escape, and so either adapt to the hydrocarbons or are killed.

Considerable uncertainty exists concerning the accumulation of petroleum hydrocarbons in benthic sediments. No one knows at present whether or not this 'charging' of the sediments, together with the constant presence of low concentrations of such hydrocarbons in the water, can have long-term biological effects. The uncertainty is due largely to the fact that oil has been entering the seas since time immemorial without demonstrably causing damage.

Sea birds are affected in two ways by acute oil discharges. First, birds in the area become oiled *(figure 21)*, making their plumage useless as thermal insulation and causing hypothermia and death. And second, the oil severely impairs shore zones as sources of food. When a major oil spill occurs, sea bird populations are the ones to be hit earliest and hardest by the oil patches and slicks floating on the

Figure 21. When oil is released into the sea, the fate of the oil itself and of the marine environment can vary. The oil is immediately exposed to mechanical, chemical and biological degradation processes. A certain amount of it evaporates at once, some dissolves in the water, while some forms emulsions with the water. Eventually most of the oil in open water is broken down by bacteria and sunlight.

Environmental problems due to discharges of oil mainly arise on beaches, low-lying areas near the coast, and on the seabed. The water column of the sea and its animal life recover relatively quickly if the oil is broken down at the normal pace.

Sea birds are badly hit by oil washed towards the coast by winds and currents. They become smeared with oil, ruining their plumage and hence their thermal insulation, which results in rapid death due to hypothermia. Coastlines are also badly fouled by tar balls and oil slicks. It takes a long time to clean up an oil-contaminated area satisfactorily. Fish, crustaceans, bivalve and gastropod molluscs, and plants in the littoral zone and on shallow areas of the seabed are all directly affected by the oil.

Photograph: Arne Schmitz, Naturfotograferna.

surface of the water. Clean-up operations may in fact be designed primarily to take account of bird life. To save as many birds as possible, it is important to dissolve the oil quickly. However, this method is detrimental to fish and other animals. Emulsified and dissolved oil are a bigger threat to them than oil slicks.

Fish may be affected in two ways. Fish eggs and larvae are considerably more sensitive than adults to the effects of oil (especially to the effects of refined oil products, which are more toxic than crude oil). Cod eggs are particularly sensitive. Adult fish generally escape from an oil-contaminated area. Oil can accumulate in the tissues of fish and bivalves and cause tainting.

On shores and shallower areas of the seabed in temperate waters, harmful effects persist for longer than in the water itself – crustacean, bivalve and gastropod communities are usually eliminated by oil. They return, but it takes time. For fish and other organisms, the shore zone is seriously affected or destroyed as an area for reproduction. Beaches become fouled with oil and, quite apart from the damage to animal and plant life, their recreational value may be destroyed for a long time to come. Rocky shores, where waves eventually wash away some of the oil, are the least badly affected. Low-lying shore meadows suffer the worst effects – they cannot be mechanically flushed clean of oil like rocks.

At the edges of large ice masses, as was noted above, oil discharges can cause major damage. Oil may be retained beneath the margins of the ice and impair primary production in the spring, when the ice melts. This will affect the entire food chain of the area. Animal life suffers less damage if a discharge occurs in winter than if it takes place in the spring or summer. The more active the biota, the greater the damage. In polar regions, as elsewhere, reproduction, nesting, rearing of young etc. all have to be squeezed into the spring and summer months.

4 How healthy are our coastal seas?

The following contains a concise description of some features of our coastal seas and some known facts about the environmental status of four bodies of water in northern Europe:

- the North Sea and the Skagerrak
- the Norwegian Sea and the Barents Sea
- the North Atlantic in the region of the Faeroe Islands, Iceland and Greenland
- the Baltic Sea and the Kattegat.

The North Sea and the Skagerrak

The North Sea is the largest marginal sea of the Atlantic and a shallow marine region on the European continental shelf (*figure 22*).

Geographically, the North Sea area is defined as follows:

- the North Sea south of 62°N
- the Skagerrak, with a southern limit extending east from Cape Skagen, roughly at 57°N
- the English Channel and its approach east of 5°W.

The North Sea has a mean depth of some 90 metres. Its greatest depth is about 725 m, in the Norwegian Trench (a trough or 'graben') that follows Norway's south coast. In area, the North Sea measures 575 000 km^2. As a sea, it is a relatively enclosed and shallow basin.

The North Sea is one of the world's few major marine regions to have been formed by the flooding of a landmass. A sedimentation basin has formed over a period of at least 250 million years. After the last Ice Age, roughly 20 000 years ago, the North Sea began to take its present shape. The coast varies greatly, in both structure and degree of exposure. In northern Norway and Scotland, there are rugged cliffs directly facing the powerful waves and winds of the Atlantic, and deep fiords whose bottoms lie deeper than the seabed beyond them. To the south, the

Photograph: Stefan Rosengren, Naturbild.


NORWEGIAN SEA
Faeroe Islands (Denmark)
Tórshavn
62°
Faeroe-Shetland Channel
Shetland Islands
Sullom Voe
Lerwick
Orkney Islands
Kirkwall
Flotta
St. Fergus
Cruden Bay
Aberdeen
Forth
Firth of Forth
Glasgow
Edinburgh
GREAT
BRITAIN
Tyne
Newcastle
Teesside
Ouse
Humber
Leeds
Easington
Manchester
Sheffield
Grimsby
Theddlethorpe
Trent
The Wash
Bacton
Great Ouse
Thames
LONDON
IRELAND
Irish Sea
NORWAY
Mongstad
Bergen
Hardangerfjorden
Kårstø
Stavanger
The depths of the Norwegian fiords are not shown on this map.
Glomma
Klarälven
OSLO
Oslofjorden
Idefjorden
Halden
Ørekilsälven
Gullmarn
Lysekil
Göta älv
725
Skagerrak
Norwegian Trench
SWEDEN
Gothenburg
The Skaw
Frederikshavn
Limfjorden
Kattegat
Jutland
Esbjerg
COPENHAGEN
DENMARK
BALTIC SEA
NORTH SEA
13 Dogger Bank
German Bight
Emden
Uithuizen
Ems
Den Helder
IJmuiden
NETHERLANDS
AMSTERDAM
The Hague
Rotterdam
Maas
The Ruhr area
Cologne
BONN
RHINE
Antwerp
Schelde
BELGIUM
BRUSSELS
Strait of Dover
Pas de Calais
Calais
English Channel
Channel Islands (GB)
Cap de la Hague
Le Havre
Gulf of St-Malo
Brittany
Seine
Marne
PARIS
FRANCE
Meuse
LUXEMBOURG
LUXEMBOURG
Bay of Biscay
Bremerhaven
Hamburg
Bremen
ELBE
WESER
FEDERAL REPUBLIC OF GERMANY
Main
GERMAN DEMOCRATIC REPUBLIC
BERLIN
Leipzig
Dresden
Karl-Marx-Stadt
POLAND
CZECHOSLOVAKIA
PRAGUE
Basle
SWITZERLAND
AUSTRIA
ITALY
Depth in metres
0
20
50
100
200
500
1 000
2 000
4 000
Oil field/Oil well
Gas field/Gas well
Oil or gas pipeline
Exclusive economic zones
North Sea area and its drainage area
0
100
200 km

Figure 22. The North Sea: major population centres, rivers, industrial areas and other discharge and emission sources in its drainage basin. National sectors, with producer countries' oil and gas platforms, are shown in broad outline.

Illustration: Stig Söderlind.

land is less exposed and the coastlines of the Netherlands, the Federal Republic of Germany (FRG) and Denmark are characterized by large sandy areas, dunes, clay, salt marshes, deltas and sheltered bays.

Fish, oil, gas, sand and gravel

The North Sea is one of the world's most productive fishing areas. In 1984, the North Sea – which represents about 10% of the north-east Atlantic – provided a fish yield corresponding to one-third of the total north-east Atlantic catch. About half the North Sea catch is composed of demersal (bottom-living) species, such as cod and plaice. Twenty per cent of the fishing takes place in the open sea, where mackerel and herring are caught. However, there is a general consensus that virtually all the main fish stocks in the North Sea are overexploited.

Other natural resources too – oil, gas and minerals – abound. Figure 22 shows the sites of marine oil and gas (offshore) production in the various countries' sectors. The offshore industry began with the production of gas in the 1960s and was followed by oil drilling at the beginning of the 1970s. At present, some 85 billion m^3 of gas and 165 million tonnes of oil are produced annually. More than 4 000 wells have been opened, 150 production platforms have been built and 8 000 km of pipelines have been laid. Gas is produced mainly in the southern North Sea, in water masses shallower than 50 m. The gas belt extends from the English to the Dutch coast (between 53°N and 54°N). The oilfields stretch across the median lines of the British, Norwegian and Danish sectors, between 56°N and 62°N, and operations are concentrated in the East Shetland Basin, between about 60°N and 62°N. There, drilling takes place at depths as great as 300 m. Typically, the platforms are located 100–150 km from the coast. The countries conducting offshore oil and/or gas operations are the UK, Norway, the Netherlands, Denmark and the FRG.

The offshore industry also provides employment and earnings on the mainland in the form of supply industries of various kinds. The oil and gas industry is, for obvious reasons, one that cannot last for ever. Some fields are expected to run dry as early as in the 1990s.

The North Sea has major resources of mineral aggregates on the seabed, and dredging for these resources takes place on a relatively large scale. Operations are regulated by most coastal nations as a result of the hazards for coastal protection and the environment. In recent years, some 30 million m^3 of sand and gravel have been extracted annually, mostly from the areas off the coasts of the

UK, Belgium and the Netherlands. This dredging is feared to be potentially harmful to the benthos. Large-scale disturbances of the seabed can also damage the hard gravelly areas that constitute nursery and spawning grounds for herring.

Land reclamation is an activity characteristic of the North Sea and most pronounced on the Dutch coast, with the diked-in Ijsselmeer and other polders reclaimed from the sea that are now fertile farmland. Extensive dredging and building operations are under way in several areas around the North Sea to sustain maritime transport and other activities.

Two of the world's largest harbours – Antwerp and Rotterdam – are on the North Sea. Roughly 5 000 ships each with a capacity of more than 100 gross register tons can operate simultaneously in them. International shipping is strictly regulated by 'trafficseparation schemes' in the North Sea. There is also extensive traffic between the littoral nations of the North Sea and along their coasts. The major rivers are important transport routes to inland centres.

The North Sea is crucially important to these commercial activities in and between the surrounding countries, but it is also extremely significant as a habitat for plants and animals in profusion.

The North Sea Report (see below) describes these habitats as being 'rich in marine life. Large and diverse resident and migratory bird populations are found along most of the North Sea coastline. Marine mammals and especially seals are also widely distributed. The shallow and highly productive Wadden Seas have their own rich flora and fauna, and fragile and vulnerable ecosystems; they also provide the major habitat for the early stages of many commercial species of fish caught in the open North Sea. Many of the estuaries are flanked by salt marshes which support rich and sometimes unique populations of marine plants and animals and are important in the turnover of nutrients in the coastal zone.'

In addition, the North Sea is important as a recreation area for the large populations on the continent, in the UK and in the Nordic countries.

Water, currents and circulation

The volume of water in the entire North Sea, including the Skagerrak, is approximately 47 000 km. Its waters in the open sea are typically oceanic, with a salinity of around 35‰. Along the coasts and in the major estuaries, where fresh water is carried by the rivers, there is a mixture of saline and fresh water. Another source of fresh water is precipitation.

The North Sea is thus characterized by various water types in different areas.

The inflows may be observed in the central North Sea, where water from five different sources can be demonstrated:

- Water of Atlantic origin (the Gulf Stream), which enters the North Sea through the English Channel. Clear water of high salinity and low nutrient content.
- Water of Atlantic origin (the Gulf Stream), which enters via the Orkney-Shetland area. Clear water of high salinity and low nutrient content.
- Brackish water from the Baltic, which flows into the northernmost section of the North Sea via the Skagerrak. Fairly turbid water of low salinity and high nutrient content.
- Brackish water – from rivers and land run-off – from the coastal areas of the UK. Highly turbid water of low salinity and high nutrient content.
- Brackish water – from rivers and land run-off – from the continental coasts. Highly turbid water of low salinity and high nutrient content.

Water circulation varies greatly in various parts of the North Sea. In general, it takes about 36 months for the water in the German Bight to leave the North Sea. In the northern North Sea, the water remains for only about six months.

Figure 23 also shows the prevailing surface currents in the North Sea. A number of factors, such as air pressure, wind direction, precipitation levels and other meteorological conditions, can disrupt the prevailing pattern of currents and circulation.

In general, long-term circulation in the North Sea may be said to be anticlockwise. The main dispersion of water out of the North Sea takes place along the Norwegian and Swedish coasts in the Norwegian Current, which is a continuation of the Jutland Current from the Kattegat and the Danish Straits.

Studies of water circulation and currents in the North Sea have shown, in particular, that water discharged from British east-coast estuaries spreads throughout the North Sea. Water discharged from continental estuaries tends to be more confined to the eastern parts of the North Sea and flows along the coast up to the Skagerrak, where it joins the Norwegian Current and exits northwards along the Norwegian coast.

Figure 23. Depths and prevailing surface currents in the North Sea.
Illustration: Stig Söderlind.


NORWEGIAN SEA
Faeroe Islands (Denmark)
62°
Faeroe-Shetland Channel
Shetland Islands
Viking Bank
Orkney Islands
Variable and wind driven
NORWAY
The depths of the Norwegian fiords are not shown on this map.
Glomma
Klarälven
SWEDEN
Hardanger-fjorden
Oslo-fjorden
Idefjorden
Orekilsälven
Gullmarn
Göta älv
725
Skagerrak
Norwegian Trench
The Skaw
Kattegat
Limfjorden
Great Fisher Bank
Jutland
Forth
Firth of Forth
GREAT BRITAIN
Tyne
Variable weak and wind driven
White Bank
DENMARK
BALTIC SEA
NORTH SEA
Sylt
15 Dogger Bank
German Bight
Helgoland
IRELAND
Irish Sea
Ouse
Trent
Humber
The Wash
WESER
ELBE
Ems
GERMAN DEMOCRATIC REPUBLIC
POLAND
NETHERLANDS
FEDERAL REPUBLIC OF GERMANY
Oyster Grounds
Great Ouse
Thames
Lek
Waal
Maas
Strait of Dover
Pas de Calais
Scheldt
BELGIUM
LUXEMBOURG
RHINE
English Channel
Channel Islands (GB)
Gulf of St Malo
FRANCE
Seine
Marne
Meuse
Main
CZECHOSLOVAKIA
Brittany
AUSTRIA
SWITZERLAND
ITALY
Bay of Biscay
Depth in metres
0
20
50
100
200
500
1 000
2 000
4 000
Surface currents
North Sea area and its drainage area
0
100
200 km

Towns, rivers, landmasses

In round figures, the aggregate population in the eight North Sea nations – Norway, the UK, France, Belgium, the Netherlands, the FRG, Denmark and Sweden – is 210 million people. However, it is not the total number of inhabitants of the North Sea nations, but the combined load from human activities in the sea's drainage area (cf. the section on the Baltic) that is decisive for the North Sea environment. The drainage area comprises the landmasses, towns, rivers, etc. which 'drain' into the North Sea and can thereby affect its environment (*figure 22*).

Nevertheless, the North Sea countries are densely populated, and surrounding the North Sea are a number of large towns and other urban areas, intensively cultivated farmland, major industrial centres and other foci of human activity. Several large rivers, draining substantial areas, flow into the North Sea. Some of these rivers also contain water, and therefore pollutants, from countries other than the North Sea nations (such as the German Democratic Republic (GDR), Czechoslovakia and Switzerland).

Figure 22 is a schematic and imprecise illustration of the North Sea's drainage area, showing the largest rivers and population centres that can affect the North Sea. In addition, there are major industrial areas, agricultural regions and other activities that may be deemed to contribute to the anthropogenic input of nutrients and pollutants into the North Sea. Oil and gas production is also shown. The contribution of shipping is, as explained below, hard to quantify.

North Sea monitored in Quality Status Report

For the Second North Sea Conference, in 1987, a Quality Status Report (QSR) was drawn up by a scientific-technical working group comprising experts from all the North Sea countries. The report has been criticized as vague and deficient in data but is nonetheless the most ambitious attempt to date to summarize the North Sea nations' view of – and knowledge concerning – the inputs and concentrations of various substances and their ecological impacts, and to give a general assessment of the environmental status of the North Sea. Throughout the report, it is emphasized that the lack of comparable data creates difficulties and that major efforts must be made as soon as possible to ascertain the status of the North Sea. This insight was also conveyed to the 1987 North Sea Conference, and it may be hoped that it will lead to larger research inputs concerning both sources and dispersion routes of contaminants on the one hand, and impacts and possible countermeasures on the other.

The following brief summary is based on the QSR, which starts by pointing out that the magnitudes of pollutants entering the North Sea vary from one year to the next, owing to:

- natural variations (rivers and water exchange)
- economic factors (intensity of industrial operations etc.)
- major industrial restructing (e.g. that oil and gas extraction started in the mid 1970s)
- environmental legislation, which helps to reduce discharges.

The North Sea today – a polluted sea

- The most serious environmental effects are found in near-shore areas of the North Sea along the Dutch, German and Danish coasts. These areas are characterized by slow water circulation, heavy inputs from rivers and point sources, stratification of the water column and ecologically sensitive littoral zones of importance to flora and fauna throughout the North Sea.
- The heavy discharges from British rivers and other major British sources mainly affect areas close to the continental coast, rather than the UK coast, since tides and currents wash pollutants away from the western parts of the North Sea towards its eastern areas.
- Elevated nutrient concentrations off the continental coasts – from the Netherlands up to the Skagerrak and Kattegat – have made large-scale algal blooms, with concomitant oxygen depletion in the water, elimination of benthic fauna, fish mortality, etc., more frequent. Algal species composition is changing, and this is probably a sign of a long-term disturbance of the ecosystem.
- The benthos has been damaged near coastal sources of discharges, as well as around oil platforms and at dumpsites.
- Fish manifesting pathological changes have become more frequent in certain coastal areas.
- Sea birds are accumulating organochlorine substances and heavy metals.
- Elevated heavy-metal concentrations have been measured in water and sediment near the continental coasts and in certain parts of the central North Sea.
- Populations of common (or harbour) seal in the North Sea are declining in

several areas: the animals are affected by PCBs and other pollutants, and have incurred reproductive difficulties.

- The heavy seal mortality of summer 1988 is an enigma: no one knows with any certainty whether the seals' immune systems were debilitated by their poor habitat (the result of pollution), or whether the virus disease that affected the animals would have had such far-reaching effects in any case.
- Discharges of oil from oilfields have increased, with elevated hydrocarbon concentrations in sediment and water as a result. The illegal discharge of oil from ships is a threat to sea birds in sensitive coastal areas.
- The impact of human activity is discernible in the central North Sea – the open sea – as well. Further investigations and assessments of the status of the central North Sea are required.

Heaviest inputs via rivers and air

Data on the inputs of metals, certain chlorinated substances and nutrients have been provided by the North Sea nations in so far as such data are available at all. Since the figures are unreliable in many cases, and in other cases different countries' figures are difficult to compare, there is a large grey zone between the lowest and highest estimates. *Table 1* shows the range between the estimated maximum and minimum values for nitrogen, phosphorus, cadmium, mercury, copper, lead, zinc, chromium, nickel, arsenic, chlorinated pesticides (such as lindane, aldrin and dieldrin), DDT and PCBs originating from eight different types of discharge source. In addition, there is the input of oil (*table 5*) and garbage. Around 20 000 tonnes of garbage, enters the North Sea annually.

The figures in *table 1* refer to the years 1983–1986. More recent data have probably been compiled since, but at the time of writing (1989) they should be of roughly the same distribution and order of size, with a reservation for the variations mentioned by way of introduction.

Dumping of waste in the North Sea in 1985 accounted for the following inputs:

- 2.1 million tonnes of liquid industrial waste (primarily from the titanium dioxide industry)
- 1.6 million tonnes of solid industrial waste (colliery wastes and fly ash)
- 65 million tonnes of dredged material (from harbours and the seabed)
- some 5 million tonnes of sewage sludge (from the UK, the only country to dump such waste)
- more than 105 000 tonnes of environmentally hazardous wastes *for incineration* at sea, from Belgium, the Netherlands, Norway, Spain, the UK and the FRG. Here, it is important to point that this entire quantity of wastes was not released into the marine environment: the estimated quantity of substances entering the sea in 1985 *after incineration* is shown in *table 1.*

Table 1. Summary of contaminant inputs to the North Sea in tonnes per annum[1]

Source	Nitrogen		Phosphorus		Cadmium	
	Max	Min	Max	Min	Max	Min
River Inputs	1 000 000	–	76 000	–	52	46
Direct Discharges	95 000	–	25 000	–	20	20
Atmospheric	400 000[2]	–	N/A[3]	–	240	45
Dumpings:						
Dredgings	N/A	–	N/A	–	20	–
Sewage Sludge	11 700	10 000	2 800	2 200	3	–
Industrial Waste[4]	N/A	–	N/A	–	0.3	–
Incineration at Sea[5]	N/A	–	N/A	–	0.1	–
Total (Rounded)	1 500 000	–	100 000	–	335	135

Source	Mercury		Copper		Lead	
	Max	Min	Max	Min	Max	Min
River Inputs	21	20	1 330	1 290	980	920
Direct Discharges	5	5	315	–	170	–
Atmospheric	30	10	1 600	400	7 400	2 600
Dumpings:						
Dredgings	17	–	1 000	–	2 000	–
Sewage Sludge	0.6	–	100	–	100	–
Industrial Waste	0.2	–	160	–	200	–
Incineration at Sea	spärmängder		3	–	2	–
Total (Rounded)	75	50	4 500	3 000	11 000	6 000

Source	Zinc		Chromium		Nickel	
	Max	Min	Max	Min	Max	Min
River Inputs	7 370	7 360	630	590	270	240
Direct Discharges	1 170	–	490	–	115	–
Atmosheric	11 000	4 900	900	300	950	300
Dumpings:						
Dredgings	8 000	–	2 500	–	700	–
Sewage Sludge	220	–	40	–	15	–
Industrial Waste	450	–	350	–	70	–
Incineration at Sea	12	–	1.7	–	3	–
Total (Rounded)	28 000	22 000	5 000	4 200	2 100	1 450

Source	Arsenic		HCH (e.g. Lindane)		Drins	
	Max	Min	Max	Min	Max	Min
River Inputs	360	320	3	3	0,1	–
Direct Discharges	220	–	0	–	N/A	–
Atmospheric	120	40	N/A	–	N/A	–
Dumpings:						
Dredgings	200	–	N/A	–	N/A	–
Sewage Sludge	spårmängder	–	N/A	–	N/A	–
Industrial Waste	40	–	N/A	–	N/A	–
Incineration at Sea	0,1	–	N/A	–	N/A	–
Total (Rounded)	950	820	3	3	0,1	–

Source	DDT		PCB	
	Max	Min	Max	Min
River Inputs	0,1	–	3	3
Direct Discharges	0	–	0	–
Atmospheric	N/A	–	N/A	–
Dumpings:				
Dredgings	N/A	–	N/A	–
Sewage Sludge	N/A	–	N/A	–
Industrial Waste	N/A	–	N/A	–
Incineration at Sea	N/A	–	N/A	–
Total (Rounded)	0,1	0	3	3

[1] The table is taken from the *Quality Status Report of the North Sea. A Report by the Scientific and Technical Working Group*. The report was presented to the second North Sea Conference, held in London in October 1987. The report is a synthesis of the national reports presented to the conference. The report was published in September 1987.

It should be noted that all figures for inputs, with the possible exception of dumping, are subject to considerable uncertainty, the extent of which is variable and difficult to quantify.

The figures used in this table are the "rounded" totals taken from other tables in the report.

The totals do not include amounts entering the North Sea from the North Atlantic, the English Channel and the Baltic Sea.

[2] Estimates as reported by the Fourth Meeting of the Paris Commission Working Group on Atmospheric Inputs.

[3] N/A = no data available

[4] Include both solid and liquid waste

[5] Refers to material burnt and assumed to be discharged from the stack; this therefore represents the maximum amount which would enter the sea.

As *tables 2 and 3* show, large quantities of pollutants come via rivers and estuaries: the material includes 80% of the estimated total supply of river water. Water from continental rivers starts as a narrow strip near the Dutch coast and then broadens gradually as it circulates northwards along the coast of Schleswig-Holstein. Water from the River Elbe is diluted more rapidly than water from the Rhine, and at the junction of these water masses fronts, in which algal blooms can arise, are often formed.

Uncertainty about the role of atmospheric deposition in North Sea pollution (as in the pollution of all other marine areas) is still considerable. But there is a consensus that airborne contaminants have hitherto been underestimated as a source of marine pollution. Within the Paris Commission, work is now under way to gain a better and more detailed picture of the airborne inputs of pollutants to the North Sea.

Eutrophication, algal blooms, oxygen depletion and death in the benthic zone

Most of the nutrients in the North Sea come from the North Atlantic to the north and the English Channel to the south (*table 4*). Thus, natural inputs are quantitatively predominant, but environmental effects in the form of eutrophication and algal blooms are caused by local inputs of nutrients from rivers and land run-off in coastal areas. The most severe effects are noticeable along the coast of the continent, where nutrients from the major rivers and intensively cultivated farmland have raised concentrations to twice their natural levels – though levels have not risen much in the past seven years. Eighty per cent of all riverine nutrient inputs are to the southern North Sea (south of 54°N); 90% of these nutrients are localized on the continental coasts, especially along the coast from the Netherlands northwards to the Skagerrak and Kattegat. The impact of riverine inputs from the British coast is very striking, but these discharges are soon diluted by the much greater volume of water in the recipient sea. Rivers from the European mainland are much larger and their impact proportionally greater, as may be seen along these countries' coasts. It is estimated that riverine inputs raise nitrogen concentrations by a factor of four and phosphorus concentrations by a factor of seven compared with inputs from natural sources alone.

In the North Sea, marked increases in nitrogen and phosphorus concentrations have been noted, while silicon concentrations have remained fairly constant. The result is a change in the ratios of the various nutrients in coastal areas.

Table 2. River inputs to the North Sea, in tonnes per annum[1]

Country	Year of Estimates	River flow	Nitrogen		Phosphorus		Cadmium	
		Mm^3/D[2]	Max	Min	Max	Min	Max	Min
Sweden	1984	47.1	17 600	–	281	–	0.2	–
FR of Germany	1985	87.0	259 000	–	16 490	–	12.1	–
Belgium	1983	1.8	4 700	–	1 570	–	0.4	0.3
Netherlands	1984	259.0	599 000	–	52 000	–	25.4	–
Norway	1983/84	67.9	N/A[3]	–	N/A		N/A	–
Denmark	1983	10.9	22 000	–	2 400	–	0.1	–
UK	1985/86	89.7	110 740	–	3 439	–	14.1	7.7
Total (Rounded)		565	1 000 000		76 000		52	46

Country	Mercury		Copper		Lead	
	Max	Min	Max	Min	Max	Min
Sweden	0	–	25.0	–	N/A	–
FR of Germany	8.8	8.8	290.0	–	259.1	–
Belgium	0.1	0.1	4.9	4.3	2.9	–
Netherlands	6.3	–	661.0	–	395.0	–
Norway	N/A	–	65.0	–	16.0	–
Denmark	0	–	2.4	–	0.8	–
UK	5.3	4.3	282.9	239.5	303.4	245.5
Total (Rounded)	21	20	1 330	1 290	980	920

Country	Zinc		Chromium		Nickel		Arsenic	
	Max	Min	Max	Min	Max	Min	Max	Min
Sweden	125.0	–	N/A	–	N/A	–	N/A	–
FR of Germany	2 098.7	–	N/A	–	N/A	–	N/A	–
Belgium	28.0	–	1.4	–	6.0	–	N/A	–
Netherlands	3 408.0	–	475.0	–	N/A	–	292.0	–
Norway	248.0	–	15.0	–	N/A	–	N/A	–
Denmark	8.0	–	0.4	–	N/A	–	N/A	–
UK	1 450.6	1 440.4	141.4	97.6	265.3	233.2	64.9	28.1
Total (Rounded)	7 370	7 360	630	590	270	240	360	320

Country	HCH (e.g. Lindane)		Drins		DDT		PCB	
	Max	Min	Max	Min	Max	Min	Max	Min
Sweden	N/A	–	N/A	–	N/A	–	N/A	–
FR of Germany	0.5	0.5	N/A	–	N/A	–	2.9	2.9
Belgium	0	0	N/A	–	N/A	–	N/A	–
Netherlands	2.3	–	0.1	–	N/A	–	0.4	–
Denmark	N/A	-	N/A	–	N/A	–	N/A	–
Norway	N/A	–	N/A	–	N/A	–	N/A	–
UK	0.4	0.4	N/A	–	0.1	–	N/A	–
Total (Rounded)	3	3	0.1	–	0.1	–	3	3

[1] The table is coming from the Quality Status of the North Sea. A Report by the Scientific and technical Working Group. The report was presented to the second North Sea Conference, held in London in October 1987. The report was a synthesis of the national reports presented to the conference. The report contains a summary of the status of the North Sea environment. The report was published in September 1987. It should be noted that these figures are subject to considerable uncertainly owing to, among others, analytical difficulties and hydrological variations. No French figures are included in the totals, as no French rivers discharge directly into the North Sea.

[2] Mm^3/D = Million cubic meters per Day.

[3] No data available

Table 3. Inputs from major rivers into southern North Sea (tonnes/annum)[1]

	Nitrogen		Phosphorus		Cadmium	
	Max	Min	Max	Min	Max	Min
Germany						
Ems	22,000	–	690	–	0,7	–
Weser	87,000	–	3,800	–	2.9	–
Elbe	150,000	–	12,000	–	8.4	–
Netherlands:						
Area A: Western Scheldt	48,900	–	6,300	–	6.9	–
Area B: Eastern Scheldt	13,400	–	700	–	0.5	
Area C: Rhine, Meuse	420,000	–	37,000	–	13.8	–
Belgium:						
Yzer	1,600	–	170	–	0.1	0.1
Lys Bypass	3,100	–	1,400	–	0.2	–
UK:						
Humber	41,537	–	584	–	4.0	2.8
Thames	31,280	–	110	–	1.8	1.2
Total (Rounded)	818,817	–	62,754	–	39.3	37.5
Total as a % of all river inputs into North Sea	80	–	80	–	75	80

	Mercury		Copper		Lead		Zinc	
	Max	Min	Max	Min	Max	Min	Max	Min
Germany:								
Ems	0.4	–	21.2	–	12.4	–	43.8	–
Weser	1.1	–	84.0	–	25.6	–	219.0	–
Elbe	7.3	–	182.5	–	219.0	–	1,825.0	–
Netherlands:								
Area A: Western Scheldt	0.9	–	81.0	–	86.0	–	452.0	–
Area B: Eastern Scheldt	0.1	–	12.0	–	8.8	–	70.0	–
Area C: Rhine, Meuse	3.9	–	442.0	–	248.0	–	2,533.0	–
Belgium:								
Yzer	0.1	0	1.4	0.8	1.0	–	7.0	–
Lys Bypass	0.1	–	3.5	–	1.9	–	21.0	–
UK:								
Humber	0.8	0.6	116.9	111.5	123.9	121.3	357.5	353.7
Thames	1.1	1.0	25.3	18.1	40.9	40.1	58.5	57.5
Total (Rounded)	15.8	15.4	969.8	956.6	767.5	764.1	5,586.8	5,582.0
Total, as a % of all river inputs into North Sea	75	80	75	75	80	80	75	75

	Chromium		Nickel		Arsenic		HCH (Lindane)	
	Max	Min	Max	Min	Max	Min	Max	Min
Germany:								
Ems	N/A	–	N/A	–	N/A	–	0	–
Weser	N/A	–	N/A	–	N/A	–	0.1	–
Elbe	N/A	–	N/A	–	N/A	–	0.4	–
Netherlands:								
Area A: Western Scheldt	120.0	–	N/A	–	70.0	–	0.2	–
Area B: Eastern Scheldt	8.8	–	N/A	–	4.2	–	N/A	–
Area C: Rhine, Meuse	293.0	–	N/A	–	161.0	–	1.8	–
Belgium:								
Yzer	0.5	–	1.5	–	N/A	–	0	–
Lys Bypass	1.0	–	4.5	–	N/A	–	0	N/A
UK:								
Humber	62.0	59.5	125.0	122.8	23.1	17.2	0.3	0.3
Thames	16.5	9.4	35.7	29.2	2.5	0.7	0.1	–
Total (Rounded)	501.8	492.1	166.7	158.0	260.8	253.1	2.9	2.9
Total, as a % of all river inputs into North Sea	80	85	60	65	75	80	90	90

	Drins		DDT		PCB	
	Max	Min	Max	Min	Max	Min
Germany:						
Ems	N/A	–	N/A	–	0.6	–
Weser	N/A	–	N/A	–	1.8	–
Elbe	N/A	–	N/A	–	0.5	–
Netherlands:						
Area A: Western Scheldt	0.0	–	N/A	–	0.1	–
Area B: Eastern Scheldt	N/A	–	N/A	–	N/A	–
Area C: Rhine, Meuse	0.1	–	N/A	–	0.4	–
Belgium:						
Yzer	N/A	–	N/A	–	N/A	–
Lys Bypass	N/A	–	N/A	–	N/A	–
UK:						
Humber	N/A	–	0	–	N/A	–
Thames	N/A	–	0	–	N/A	–
Total (Rounded)	0.1	–	0.1	–	3.3	–
Total, as a % of all river inputs into North Sea	98	–	60	–	99	99

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[1] The table is from *Quality Status Report of the North Sea. A Report by the Scientific and Technical Working Group.* The report was presented to the second North Sea Conference, held in London in October 1987. The report is a synthesis of the national reports presented to the conference. The QSR was published in September 1987.

Table 4. Inputs of nutrients to the North Sea Area[1]

Source	Nitrogen		Phosphorous	
	tonnes/year	%	tonnes/year	%
Water from the Northeast Atlantic:				
Gulfstream	7 000 000	75	1 085 000	81
Via the English Channel	705 000	8	82 000	6
Atmospheric deposition	400 000	4	20 000	2
Rivers	1 073 000	12	111 000	8
Sewage	129 000	1	35 000	3
Total	9 307 000		1 333 000	

[1] The table has been compiled by the Ministry of Environment (Miljøverndepartementet), Oslo, Norge.

It is entirely clear that the concentration of planktonic algae in the North Sea has increased and that the composition of species has changed in recent years. Changes in species composition are, however, discernible throughout the northeast Atlantic; changes in the North Sea's algal communities cannot therefore be ascribed unequivocally to the impact of high nutrient concentrations. Marine botanists are nevertheless convinced that the marked shift from diatoms to dinoflagellates is a sign that the ecosystem is being disturbed, if at a slow rate.

The biomass of phytoplankton has increased throughout the southern North Sea. Studies along the coasts have shown that increased algal production is almost definitely a result of raised nutrient concentrations in these areas, i.e. an effect of eutrophication. Adverse meteorological conditions may play a part, promoting water stratification (and reducing mixing), but they would not have their present impact if nutrient concentrations were not already extremely high. The Netherlands, the FRG, Denmark and Sweden have all reported increased nutrient inputs off their coasts. Atmospheric deposition also plays an important role, but how important is not yet known.

In the German Bight off Helgoland, the plankton biomass has increased fourfold since the 1960s. Diatoms are becoming scarcer, while the dinoflagellate species are thriving. Off the Belgian coast, too, an increase in the frequency of flagellate blooms has been recorded.

Dutch studies show that primary productivity has almost doubled along the Netherlands' 30-kilometre-wide coastal strip since the 1930s. Overall, primary productivity in the area has increased by 17% in the same period. There has been a marked shift in the species composition, with a striking increase in the proportion of flagellates.

In the German Bight and Danish coastal waters, in particular, extensive and prolonged algal blooms have occurred in the last few years. In 1981, for example, the entire eastern North Sea was affected by a large bloom of *Ceratium furca*, with consequent widespread oxygen depletion. There were serious mortalities in the benthos from the German Bight to an area off the coast of Jutland. Other algal blooms have brought similar effects on benthic fauna, demersal fish and also commercially important shellfish. Oxygen depletion in the Kattegat is now reported on a virtually regular basis by Danish and Swedish researchers. In the Kattegat, the Norwegian lobster has almost entirely disappeared. Dinoflagellate blooms in this area have previously resulted in benthic and fish mortalities.

The oxygen content of North Sea water as a whole is usually near or above the saturation point, which suggests healthy conditions. In the summer a warmer surface layer is formed; the resulting stratification prevents water exchange between different layers. The input of fresh riverine water also causes stratification in estuaries, such as that of the Elbe. Along the British coast, oxygen depletion is prevented since the tides promote water exchange. However, the oxygen content has on several occasions fallen to serious levels in the German Bight and along the Danish North Sea and Kattegat coasts, as well as along the Swedish Kattegat coast.

Benthos, fish and algae damaged at point sources

Benthic animals, being stationary organisms, are good indicators of environmental conditions at sea. In the North Sea, it has been possible to show that the benthos has been damaged near direct discharges of pollutants (point sources) and in areas with poor water circulation. Benthic fauna and flora are also eliminated on the seabed surrounding oil rigs and dumpsites. Along the German, Danish and Swedish coasts, mortality in the benthos has probably been caused by eutrophication with concomitant algal blooms and oxygen depletion (see above).

A large number of demersal fish in parts of the German Bight, in Danish, Dutch and British coastal waters and in the vicinity of Dogger Bank have manifested pathological external changes: lesions, gill destruction and skin diseases. There is no clear evidence that the increased prevalence of fish diseases is caused by pollution, but there are ample signs of a correlation.

Algae in intertidal zones are also good indicators of changes in the marine environment. The flora of some semi-demarcated coastal areas, such as the Wadden Seas and the British North Sea coast, show changes that are assumed to be caused by inputs of pollutants or nutrients from urban areas, industrial installations and farmland.

Increasing concentrations of heavy metals in water and sediment

Large quantities of heavy metals enter the North Sea via rivers and by atmospheric deposition. In the North Sea, fronts easily form in the water. Less saline water remains near the coast, while more saline water stays in the deeper parts of the sea. Water exchange is therefore poor. Metal concentrations in water and sediment are considerably higher along the coasts than out in the open sea (which, however, has higher metal concentrations than ocean water). Of riverine metal inputs to the North Sea, 60–80% are in the southern sections. There, too, the most serious effects are observed. Narrow strips of turbid coastal water serve as 'metal traps'. This effect, combined with processes in the sediments in estuaries and front barriers, greatly impedes the further movement of metals into the open sea.

Sediments in the German Bight contain elevated concentrations of mercury, cadmium, zinc, copper and lead. Metal concentrations are also high in certain dumpsites and in the bottom sediment in Norwegian fiords, which also serve as metal traps.

In recent years scientists have begun to wonder whether sediments may possibly be transported from coastal areas out into the open sea. High concentrations of heavy metals characterize surface sediments at the Oyster Grounds and Great Fisher Bank, far from the coast. Analyses of these sediments suggest that, chronologically, contamination is correlated with increased industrial activity since the end of the 19th century.

Oil discharges, environmental toxicants and coastal habitation harm birds

Table 5 shows the estimated total annual input of oil to the North Sea. Discharges of oil from refineries and reception facilities have diminished, while overall oil discharges from oil and gas production in the North Sea have increased. As pointed out above, oil and chemicals spread during the actual drilling. In the immediate vicinity of a platform, oil concentrations can be 1 000 – 10 000 times higher than the background level in the sediment; the level usually declines rapidly with increasing distance from the oil rig.

Table 5. Total oil input to the North Sea[1]

Source	Tonnes/year
Natural Seeps	1 000
Atmosperic	7 000 – 15 000
Rivers, Land run-off	16 000 – 46 000
Coastal Sewage	3 000 – 15 000
Coastal Refineries	4 000
Oil Terminals and Reception Facilities	1 000
Other Coastal Industrial Effluent	5 000 – 15 000
Offshore Oil and Gas production	29 000
Sewage Sludge	1 000 – 10 000
Dumped Industrial Waste	1 000 – 2 000
Dredged Spoils	2 000 – 10 000
Operational Ship Discharges	1 000 – 2 000
Accidental or Illegal Discharge from Shipping	No agreed estimate
Total	71 000 – 150 000 tonnes

[1] The table is from *Quality Status Report of the North Sea. A Report by the Scientific and Technical Working Group*. The report was presented to the second North Sea Conference, held in London in October 1987. The report is a synthesis of the national reports presented to the conference. The QSR was published in September 1987.

Hydrocarbon concentrations increase in the sediments around point sources and oil rigs. The direct effects of oil on sea birds – oiling, hypothermia and death – are the most familiar. In areas with a rich fauna and important coastal and littoral zones, even a very small oil spill can cause considerable damage.

The North Sea coasts are important locations for large numbers of different sea birds. These are threatened by oil, land-reclamation projects, pollution from estuarine areas and the occurrence of pesticides and organochlorine compounds in water and food.

Most of the oil that kills sea birds along the coasts probably comes from illegal ship discharges. Drifting oil from the rigs usually evaporates, disperses, sinks or is decomposed before it reaches the coast. In the North Sea, legal, operational oil discharges from ships are estimated to be in the order of 1 000 tonnes per annum, while illegal discharges are estimated to be substantially larger. The absolute minimum figure is 1 000 tonnes p.a., and the true figure may be as high as 60 000 tonnes p.a. Aerial surveillance has had a deterrent effect, but cannot keep up with the illegal discharges of oil that takes place when tanks are washed at sea. A majority of the oiled birds found are smeared with oil from this source.

Concentrations of organochlorine compounds and metals are found in sea birds in various parts of the North Sea. Worst affected are the birds occupying the areas along the continental coast, where pollution levels are also highest. Certain pesticides recur throughout the North Sea, whereas other chlorinated and stable substances are found in the highest concentrations in the German Bight and other polluted coastal areas.

In general, the concentrations of metals in fish and shellfish are relatively low. A study carried out by ICES (the International Council for the Exploration of the Sea) and the Paris and Oslo Commissions shows that the areas identified as more polluted than others with respect to concentrations in fish and shellfish are:

- the *Firth of Forth:* cadmium
- the *Humber Estuary and the central North Sea:* copper
- the *Southern Bight, the German Bight and the north-east coast of Britain:* lead (of which the content in the open sea is thought to be due to atmospheric deposition)
- the *Firth of Forth and the north-east coast of Britain:* zinc
- *Certain Norwegian fiords and the north-east coast of Britain:* mercury
- *the coasts of Belgium and the Netherlands, the German Bight and the Firth of Forth:* arsenic.

The concentrations of organochlorine compounds (pesticides and PCBs) in fish are moderate or low in most cases. The highest levels (of PCBs) have been found in livers from flounder and other species caught in Helgoland and off the Dutch coast.

The above-mentioned study also covers several organic compounds. In the North Sea, the Belgian coast and the Oslo Fjord were identified as more contaminated by PCB compounds and the German Bight, the Oslo Fjord and the Humber Estuary as more contaminated by organochlorine pesticides.

Land reclamation to protect coasts, industrial installations and the building of docks and harbours are activities that affect plant life in intertidal zones and, in the long run, also the existence of wader birds there.

Impact on fish and fisheries

Intensive fishing is the heaviest stress to which fish in the North Sea are exposed. The QSR states that any subtle effect from pollution on the overall fish stocks is completely masked by such factors as fishing intensity, annual variation in breeding success and growth. Most fish stocks are overexploited, but as a whole they continue to maintain their yield.

ICES and other expert organizations are studying fish stocks, their yield and the repercussions of environmental factors in the North Sea. To date, there is no evidence that environmental impact, other than in the form of intensive fishing, really affects fish stocks. In the QSR, however, a number of local effects are defined, usually on fishing waters or the benthos rather than on actual fish stocks. The effects concerned are always in areas close to shores and in shallow waters. They include oxygen depletion in Helgoland and around the island of Sylt, in Norwegian fiords, on the west Jutland coast and in the Kattegat.

Mussel-fishing in the Western Scheldt has evidently been affected by pollution with bacteria and cadmium in waste water, and fish have been affected near oil platforms. Fishing has had to be limited in certain Norwegian fiords owing to excessive mercury and cadmium concentrations. Organotin compounds from anti-fouling paints applied to boat hulls have damaged oyster hatcheries in the Thames Estuary and elsewhere; moreover, organotin compounds probably have more generally harmful effects on marine life, not only on oysters.

Flounders have suffered liver damage in the German Wadden Sea and near petrochemical industries in Sweden. In the Dutch Wadden Sea, pathological changes believed to be caused by pollutants have been noted in fish.

The input of polluting substances is thus considered capable of causing damage to fish along coasts and in estuaries, but it is more difficult to prove the effects of coastal discharges on fish in the larval and fry stages, since natural mortality is high at these stages of the life cycle in any case.

German researchers have suggested that PCB concentrations in the gonads of fish in the southern North Sea may impair egg survival and reduce the larvae's chances of survival. This may be one reason why certain fish populations are declining in the southern North Sea.

In the German and Danish Wadden Seas, mussel farming is on the increase, but in the Dutch Wadden Sea the environment is now subject to such pressures that no more mussel hatcheries should be started there.

Traditional fishing areas are being closed, or being fundamentally changed by land-reclamation projects, harbour development, platform and pipeline construction, cable-laying, the dumping of sludge and mineral waste and the extraction of gravel and sand.

Fishing areas and spawning/nursery areas are not evenly distributed. Consequently, the impact of one particular building project or the like may be larger than the size of the area would suggest. And that very area may be especially important.

Common seals declining along the continental coast

Through hunting and influence on seals' habitat, their existence has long been threatened. In several areas, the seal populations are being eliminated, or have already disappeared. The grey seal has entirely disappeared from the Skagerrak; the common seal, on the other hand, has flourished there since hunting was banned in 1960.

The common seal has virtually disappeared from river estuaries in the south-west Netherlands. Seals inhabiting the Dutch Wadden Sea and the delta area, like the seals in the Western and Eastern Frisian Wadden Sea, have difficulty in breeding, which is probably because the females have accumulated PCBs. Seals in the Frisian Wadden Sea are particularly hard hit, since this area receives the pollution load from the Rhine and the Dutch coastal area. High PCB concentrations are also found in seals from the Danish and Schleswig-Holstein portions of the Wadden Sea. There, however, reproduction does not appear to be affected to the same extent.

The common seal has entirely disappeared from the Western Scheldt.

On average, grey seals around the British coast have relatively low DDT and PCB concentrations, but some of the highest concentrations of accumulated organic compounds have been found in animals from the North Sea coast off East Anglia. Some other high concentrations have also been recorded in common seals off British coasts.

Concentrations of pesticides and PCBs in marine mammals generally reflect the dispersion of these substances in the environment and in fish. Consequently, the highest concentrations in the North Sea are found along the continental coasts, in the Southern Bight and the German Bight; along the coast northwards, concentrations are progressively lower.

Large-scale seal mortality in summer 1988, when some 15 000 common seals died in the course of a few weeks throughout the North Sea and the Skagerrak, was caused by a distemper virus. Nevertheless, researchers are unsure of overall causes and effects. Certain researchers believe that the seals' physical condition has deteriorated as a result of a prolonged pollution exposure, which could have impaired their immune system and resistance to various diseases. Other researchers entirely reject this theory and claim that the pandemic was a natural phenomenon.

The Norwegian Sea and the Barents Sea

The Norwegian Sea is a large intercontinental mediterranean sea and constitutes the transition of the north-east Atlantic to the Arctic. The Arctic Ocean and the Norwegian Sea together form what is called the Arctic Mediterranean. The Norwegian Sea is the area between 62°N and 70°N, i.e. between Kråkenes and Tromsø, bounded by the Barents Sea to the north.

On the continental shelf itself, the Norwegian Sea is a shallow shelf sea with a depth of 200–500 m. Outside the continental shelf, the seabed descends to a depth of more than 3 000 m before rising to the Iceland shelf. The Norwegian Sea is thus a deep sea between Norway and Iceland.

The Barents Sea is a marginal sea of the Atlantic and part of the polar basin around the Arctic. It is a shelf sea with a mean depth of 230 m. The Barents Sea is bounded by a line at 70°N at the Norwegian coast and extends around Svalbard, Franz Josef Land and Novaya Zemlya. Owing to its northerly latitude, it is partially covered by polar ice for part of the year.

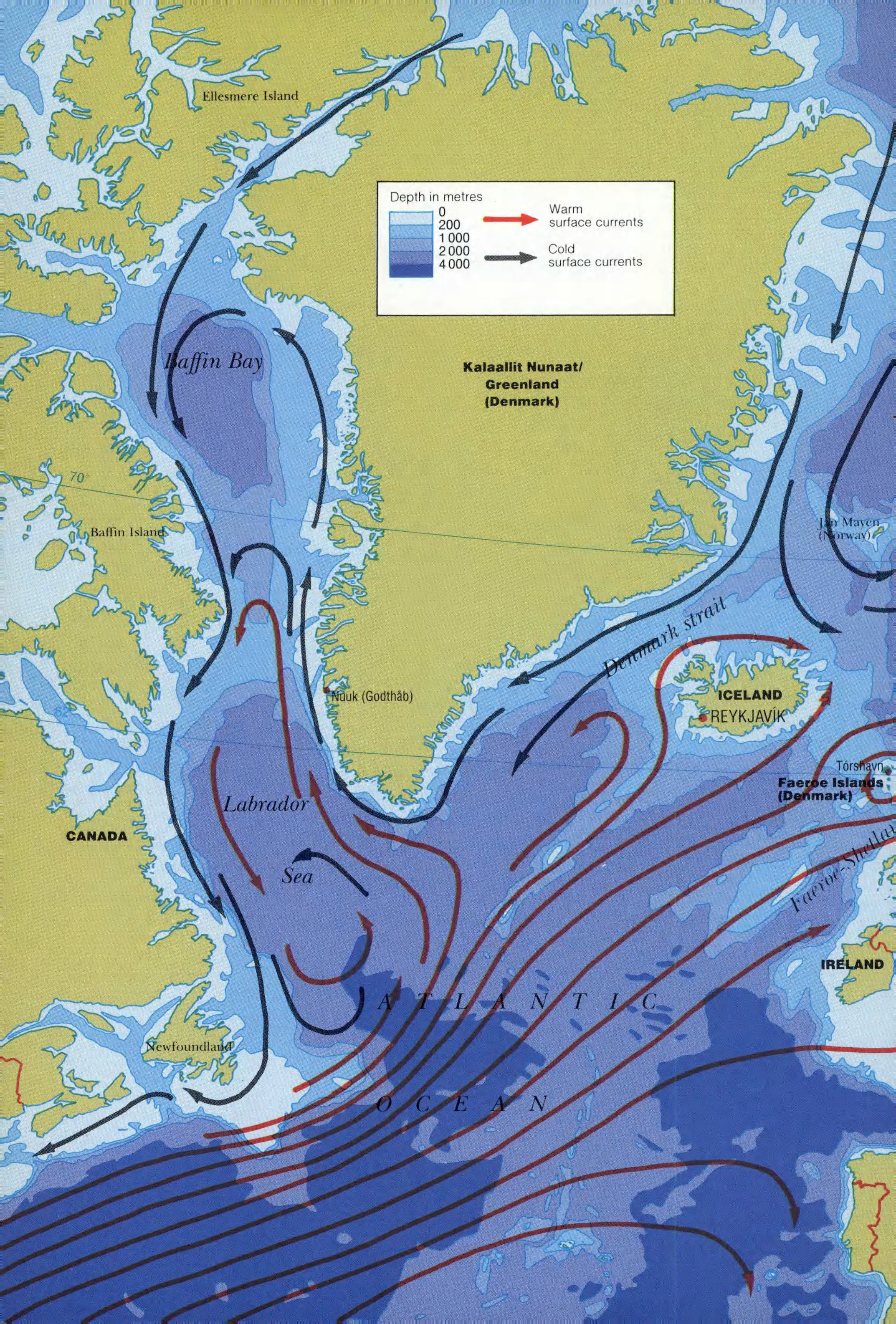
Water, currents and circulation

The water in the Norwegian Sea comes from the Atlantic via the Gulf Stream, from the North Sea with the Norwegian Current and in the form of fresh water from the Norwegian fiords and rivers. Basically, the water flows southwards, but its flow pattern is also affected by wind and pressure conditions.

The water in the Barents Sea is both Atlantic water with a temperature exceeding 0°C and of high salinity and subzero polar water of low salinity. Atlantic water is borne northwards in the Norwegian Current and the Norwegian Atlantic Current (the end of the Gulf Stream). It divides into two currents, of which one goes west of

Figure 24. Depths and major surface currents in the North Atlantic, Norwegian Sea and Barents Sea. This schematic figure outlines the large-scale current systems of the North Atlantic (around the Faeroes, Iceland, Greenland etc.) and how they interact with and influence the systems of the North Sea and Baltic Sea areas. At a more detailed level, the currents are naturally far more complex than can be shown here. The diagram indicates the decisive influence of the Gulf Stream on climate and conditions for life in northern Europe and adjoining areas.

Illustration: Stig Söderlind.


Ellesmere Island
Depth in metres
0
200
1 000
2 000
4 000
Warm
surface currents
Cold
surface currents
Baffin Bay
Kalaallit Nunaat/
Greenland
(Denmark)
70°
Baffin Island
Jan Mayen
(Norway)
Denmark strait
Nuuk (Godthåb)
ICELAND
REYKJAVÍK
62°
Tórshavn
Faeroe Islands
(Denmark)
Labrador
Sea
CANADA
Faeroe-Shetlan
IRELAND
ATLANTIC
OCEAN
Newfoundland


ARCTIC OCEAN
Franz Josef Land
(Soviet Union)
Svalbard
(Norway)
Longyearbyen
BARENTS
SEA
Kara
Sea
Novaya Zemlya
Bjørnøya
(Norway)
Tromsø-
flaket
70°
Tromsø
Kirkenes
Murmansk
NORWEGIAN
SEA
▼3960
Narvik
Glomfjord
Ranafjorden
Vefsnfjorden
Halten-
banken
Trondheims-
fjorden
Sunndals-
fjorden
White Sea
Arkhangelsk
62°
FINLAND
HELSINKI/
HELSINGFORS
Channel
Kråkenes
NORWAY
OSLO
SWEDEN
STOCKHOLM
BALTIC SEA
NORTH
SEA
DENMARK
COPENHAGEN
SOVIET UNION
GREAT
BRITAIN
NETHERL.
BELG.
L.
FRG
GDR
POLAND
CZECHO-
SLOVAKIA
FRANCE
SWITZER-
LAND
Black Sea
THE MEDITERRANEAN

Svalbard and one into the Barents Sea. Polar water flows southwards and westwards. The extent of the polar ice-cap depends on the season. In the late winter, there is ice far south of Svalbard, while the edge of the ice in the summer has receded as far north as the north-east side of Svalbard and the north of Novaya Zemlya.

Figure 24 shows the prevailing surface currents in the Norwegian Sea and the Barents Sea.

Rich fauna, extensive fisheries and potential oil resources

Norwegian Sea

The coastal areas of the Norwegian Sea are particularly rich in such fish as cod, pollack and haddock – where the former two are concerned, among the richest fisheries in the world. Herring also used to be fished on a large scale, and the herring may possibly be returning. There is also a wealth of sea birds, attracting amateur ornithologists from all over the world; and the sea is part of the migration route of several whale species.

The natural resources of the coastal area set a strong stamp on human economic activity. Many hundreds of fish farms – roughly half the Norwegian total – are located along the coast between Sogn og Fjordane and Troms.

The area is sparsely populated and such major towns as there are have developed around fishing, mining and heavy industry inside the fiords along the coast. A great deal of shipping traffic departs from the area, especially ore vessels to and from Narvik, freight vessels and fishing boats. In addition, there is transit traffic to and from the Russian harbours to the north.

The continental shelf is being surveyed for oil and gas deposits. Exploratory drilling is under way, but no commercial production has yet begun. There are plans to commence production at Halten Bank in 1990. There are gas deposits at Tromsøflaket, but even if they are worth drilling for, production will not start until around the year 2000.

Barents Sea

In the Barents Sea, the summer flow of water varying in temperature and salinity, the shallowness and the intensive summer sunlight add up to virtually optimal conditions for life during the six summer months. The edge of the polar ice-cap, in particular, is an important production area.

During the winter, nutrients are concentrated in the water below the ice as a result of the freezing-out of salt, which leads to an efficient vertical mixing of the water. When the ice melts, a nutrient-rich surface layer forms. This, combined with the fact that the water column is stable, means that phytoplankton grow very rapidly and in large quantities. Zooplankton come next in the food chain, and they are the staple food of herring and capelin. A high density of phytoplankton, zooplankton and plankton-eating fish is the basis of the rich fauna of the area. There are few species, but a large number of each species.

In the Barents Sea there are large stocks of fish, especially capelin, herring, Arctic cod and cod, as well as vast numbers of sea birds – some of the largest populations in the world – and such mammals as the grey seal, common (or harbour) seal and harp seal, walrus, humpback whale, minke whale, fin whale and polar bear. Sea birds play a key role as the link between the marine and land ecosystems, by taking up large amounts of biomass from the sea and transporting it to land.

The Barents Sea is a reproduction area for large numbers of fish, including capelin. Capelin in particular are necessary for the transfer of energy to higher trophic levels in the distinctive food chain of the area. In the last few years, however, fishing has depleted the Barents Sea of capelin, almost entirely eliminating the species. Since 1986, there has been a ban on capelin fishing.

The scarcity of capelin has affected sea-bird populations. Similarly, cod have been deprived of their staple food, and this has caused them to move westward to some extent, where they subsists on krill. However, this is nothing new in the area: here, there have always been cod feeding on krill.

Harp seals, which normally live entirely on capelin, are invading the coastal areas of Finnmark. Large numbers of harp seals are caught in fishing nets and drown. A disruption in the balance of nature in the Barents Sea is thus causing fish and mammals to move to other areas and also provoking an inevitable conflict between fishing interests – the fishermen cannot catch any fish when the seals consume them and also ruin expensive fishing equipment – and the animal-protection lobby that aims to save the seals.

The landmasses in the Barents Sea are sparsely populated. Apart from a few small Norwegian towns and a number of fishing villages, there is the Russian Murmansk area, with a massive naval base and heavy industry. The most important industry in the area by far is fishing – both along the coast and in the open sea.

In the last few years, there has been an expansion of interest in oil and gas production on the continental shelf of the Barents Sea. The Norwegian sector stretches from Tromsøflaket to Bjørnøya. Exploratory drilling has been carried out at Troms and Finnmark, but to date no deposits worth drilling for have been found. The USSR is also conducting test drilling, in the eastern parts of the Barents Sea.

Present and future marine environmental problems

Norwegian Sea

Human activities leave their mark along the Norwegian coast. Illegal oil discharges from ships are on the increase, as is the dumping of garbage. Oil discharges come mainly from the big ore vessels heading for Narvik and further north, but also from fishing boats and other vessels. The most severe effect of oil is on sea-bird populations.

Discharges of nutrients and industrial discharges in the fiords result mainly in local problems. However, little is known of the dispersion by sea currents of metals and stable organic substances in the area.

Mines and industrial installations in the fiords are point sources, the fiords with the heaviest pollution load being Sunndalsfjorden, Trondheimsfjorden, Vefsnfjorden, Ranafjorden and Glomfjorden.

The numerous fish farms produce constantly increasing quantities of organic material, which causes local nutrient and eutrophication problems.

Exploratory drilling on the continental shelf, like all such activity, entails a risk of acute oil discharges. Some drilling activity with oil-based (drilling) muds has taken place, although they are not yet used on a large scale and a shift to water-based muds is in progress.

The Norwegian portion of the Norwegian Sea is an area in which conflicts between economic and environmental interests are inherent. Development must therefore be monitored closely.

Barents Sea

An area like the Barents Sea, with its rich fauna and food chains well adapted to the environment, is ecologically vulnerable. External influences can have serious effects.

There are no major problems of nutrients and eutrophication in the Barents Sea, although there may possibly be indications of overfertilization in individual fiord areas.

Discharges from heavy industry in the Murmansk area have caused water and air pollution by heavy metals and stable organic substances, especially at Kirkenes. The forest round Murmansk is badly damaged by pollutants.

The ever increasing scale of shipping – both civil and military – along the coast involves risks of oil discharges and other pollution. Nuclear-powered vessels, both ships and submarines, are another potential environmental hazard.

Oil production is in its infancy in the area. There are gas finds on the Tromsøflaket shelf, but it is doubtful whether they are worth drilling for (see the section on the Norwegian Sea). Nevertheless, in the long run there is a danger of acute oil discharges in conjunction with oil production – both exploratory drilling and commercial operations. A major acute oil spill in the area is feared since it would cause widespread damage to the ecosystem. So far, the risk has been considered small, but substantial efforts are nonetheless being made with a view to establishing oil production in the area.

All types of oil discharge threaten sea-bird populations, especially the species living mainly on the surface of the sea and diving for their food.

Oil damage to fur-bearing animals can be lethal, since it destroys the animals' thermal insulation.

Oil is also a threat to fish-breeding areas. Eggs and fry, above all, are sensitive to oil.

It has not been established how the edge of the polar ice-cap – biologically, by far the most productive area in the Barents Sea – would function if an oil discharge took place in the area. As mentioned previously, oil discharges in cold waters are not necessarily more harmful to the environment than corresponding discharges in warmer waters; the decisive factor is whether the oil enters the open sea or areas with ice and narrow straits, or directly affects areas with large animal populations. If oil in the Barents Sea came into contact with ice before any major degradation or dissolution had taken place, the oil would probably be deposited on the upper or lower side of the ice and thereby break down more slowly. If so, flora and fauna beneath the ice would probably be killed immediately or noticeably affected in some other way, and this in turn would have repercussions on the production necessary to sustain life on the edge of the ice-cap throughout the area. The Barents Sea is regarded as particularly sensitive to pollutants with the same dispersion patterns as oil. Major efforts must therefore be made to forestall conflicts between humankind and human interests, on the one hand, and nature on the other.

The North Atlantic around the Faeroe Islands, Iceland and Greenland

Faeroe Islands

The Faeroe Islands are situated on the ocean ridge that links Greenland with Scotland and separates the warmer Atlantic water from the colder seas to the north. The ridge, which lies at a depth of some 500–600 m, is intersected by two channels through which deep-sea water can flow. The Faeroe Islands form a microcontinent between Iceland and Scotland, and the south-west portion of the sea area is dominated by this plateau, typically about 1 000 m deep. There are also a number of banks which almost reach the surface of the water. The sea area north-east of the Faeroes is part of the Norwegian Sea, with depths of over 3 000 m. Thus, there is a shelf sea surrounding the Faeroes, but this gives way to a deep sea further out (*figure 24*).

Iceland

The continental shelf around Iceland is linked by ocean ridges to the shelves surrounding Greenland, the Faeroes and Jan Mayen. Deep-sea basins up to 3 000 m deep lie between the ridges. Conditions on the seabed affect the circulation and mixing of the water masses.

Iceland is surrounded by a platform measuring 115 000 km^2, inside the line marking depths of less than 200 m. The depth of the ridge leading to Greenland is just over 600 m, while the ridge leading to the Faeroes is less than 400 m deep and that leading to Jan Mayen is less than 1 000 m deep, as is the ridge leading to Reykjanes.

Iceland's territorial waters measure 758 000 km^2 (*figure 24*).

Greenland

The seabed around Greenland has characteristics similar to those of the mainland. There are very wide variations in depth, even in limited areas. This is particularly true of the waters outside the archipelago, where the depth may vary from ten to several hundred metres. Further out from the coast lie the Greenland fishing banks, with depths of 20–100 m and a fairly even seabed. Ocean ridges 600 m deep link Greenland with both the North American continent and Iceland, the Faeroes and Scotland.

Greenland is thus situated on the continental shelf, but the deep-sea boundary is a sharp one. The extent of Greenland's waters is shown in *figure 24.*

Large-scale current patterns in the big ocean

Faeroe Islands

Circulation in the peripheral area around the Faeroes is complex. The surface water is dominated by relatively warm and saline water from the Atlantic, flowing in the North Atlantic Current. This water flows on both sides of the Faeroes, directly and indirectly towards the Norwegian Sea with its lower water temperature. There, the Atlantic water joins the colder and less saline water from the East Iceland Current, forming a sharp front. Along this front, warm water is transported into the Norwegian Sea, while the colder water from the north passes into the Atlantic deep down in the channels (a phenomenon known as 'overflow'). The current pattern is partly shown in *figure 24.*

Iceland

At Iceland, the Arctic (East Greenland) Current branches off from the warmer Gulf Stream. Iceland's northern and eastern coasts are periodically blocked by drift ice from the north. The warmer Atlantic water moves west, beneath and outside the polar water. To the east, the Arctic water gives way to the East Iceland Current, which flows in the direction of the Faeroes. In the winter, there are deep vertical convection currents north of Iceland, in the Iceland Sea, as in the Norwegian Sea. As a result, a deep layer of Arctic water forms, and oxygen and carbon dioxide are transported down to this deep, cold water, which constitutes overflow and is a predominant portion of the North Atlantic deep-sea water that flows southwards. In areas with deep convection currents, transport routes for large quantities of carbon dioxide are thus formed, and this can have climatic effects.

Along the entire Iceland coast, there is also a coastal current fed by fresh water from the land. The main currents around Iceland are shown in *figure 24.*

Greenland

The seawater is dominated by the East Greenland polar current from the Arctic. A warmer, more saline portion comes via Iceland from the Gulf Stream (the Irminger Current) and joins the polar current along the west Greenland coast – though the colder current remains closer to land all the way. In the interface between the two currents there is massive water mixing. The large-scale current system around Greenland is outlined in figure 24.

Fishing crucial to the economy

Faeroe Islands

The Faeroes are heavily dependent on a clean marine environment, since fish and fish products make up 95–99% of the country's exports. Everyday life in the Faeroes is connected with the sea in almost every way. The sea around the Faeroes is still among the least polluted, but there is no guarantee that it will remain so.

Fishing – of cod, haddock, pollack and redfish – is thus the main economic activity. Cod-fishing takes place in the shelf sea and on the banks. In deeper water, redfish is fished. Extensive fishing trials are also under way to find deep-water species that may become commercially important in the future. The dominant species of pelagic fish is whiting, which is a major export item. The fishing industry is, however, beginning to be affected by pollution and overfishing, the latter being the biggest threat so far. Fish stocks are, accordingly, becoming more vulnerable to disturbances.

Mariculture – the cultivation of such species as salmon and salmon trout – is also becoming more widespread, and is expected to assume greater economic importance for the Faeroe Islands. However, steps have been taken to prevent the uncontrolled development of fish farms, since pollution of vulnerable coastal areas is undesirable.

Iceland

The distinctive currents around Iceland provide the natural preconditions of highly productive fishing and mariculture, as well as large stocks of sea birds. Fishing is the main economic activity, accounting for some 80% of the country's export revenues. The main fish species are cod, redfish, haddock and coalfish, plus such pelagic species as capelin and herring. In the last few years, prawns have become the second most important species from the economic point of view. Mariculture has also become more important. The total annual catch of fish in the waters around Iceland is roughly 1,5 million tonnes.

Overexploitation of fish also takes place in Icelandic waters. Combined with natural stress resulting from climatic variations and a shift in the oceanic polar front, this imposes a severe strain on the sea's living resources.

Greenland

Fishing forms the basis for 90 % of Greenland's exports and is thus the paramount economic activity. Fishing is carried on along both the eastern and western coasts. In recent years, prawn fishing in particular has undergone strong development. Since the mid-1980s, cod fishing off West Greenland has receded markedly, but new generations of cod are now expected and the species may thereby recover. Salmon is another important species. Redfish and catfish, as well as capelin, are caught in small numbers. The fish-processing industry exists alongside fishing. Greenland also has some mining, but no agriculture.

In addition to fish, Greenland's waters contain walrus, some seal species and several species of whale. Marine mammals are caught here for local consumption only.

Current and future marine environmental problems

Faeroe Islands

Pollution of the coastal waters around the Faeroes is, compared with other marine areas, relatively slight. Despite their geographical proximity, the surrounding littoral nations seem to have left very little mark on the environment. One example is the radioactive discharges from Sellafield in the UK, which have had more repercussions on East Greenland and Iceland than on the Faeroes. Nor does shipping appear to have caused any major problems.

In individual fiords that are separated from the open sea, there are certain eutrophication problems, especially if aquaculture is carried on.

Future environmental problems may be created by pollutants from oil production and new exploratory drilling, as from major oil discharges from ships. In particular, there are apprehensions concerning the dumping of various kinds of waste, including industrial waste, in the open sea. In the highly stable, clockwise currents, the pollutants can then be transported straight into the Faeroe fishery banks. Sooner or latter, the deep-sea currents will disperse dumped waste over large areas.

The ecosystem of the deep sea is, in many respects, considerably more vulnerable than the systems in the upper water masses. In the deep sea there are stable low-oxygen levels, and these do not tolerate the same degree of pollution stress as the surface water.

Iceland

Pollutants in Icelandic waters are mostly derived direct from the fishing industry, for example the flushing of holds, oil spills, waste from vessels and lost fishing equipment. Local pollution may occur as a result of industrial discharges (from the fishing industry), mariculture, agriculture, waste water, etc. Other pollutants come from land, with currents, and via atmospheric deposition.

Radioactive fallout from the Chernobyl accident and radioactivity from Sellafield are registered in Iceland. Measurable radioactivity comes from these two sources with the East Greenland Current and, to a lesser extent, the East Iceland current. Sellafield radioactivity is transported northwards out of the North Sea, along the Norwegian coast, to Spitsbergen; from there, it turns towards the territorial waters of East Greenland and Iceland. The circulation time is 6–8 years, and the concentration in Icelandic waters is one-hundredth of the original concentration in the North Sea. Other components of North Sea water can be traced off Iceland 4–6 years later.

One future marine threat is the considerable traffic of military nuclear-powered vessels, and vessels bearing nuclear weapons, from the North Atlantic via the Arctic Ocean. In the event of an accident, these could cause severe radioactive contamination of the sea. The same applies to civil and military flights over the area. The East Greenland, Iceland and Norway marine area is already classified as among the most dangerous in the world.

Greenland

Where marine pollution is concerned, Greenland is not particularly hard hit. The strong currents remove residual waste from the fishing industry. The small oil discharges that take place from vessels have not caused any appreciable damage. Before the new Marine Environment Act comes into force, a number of waste-oil installations are being established.

Since Greenland has neither agriculture nor heavy industry, there is hardly any marine pollution caused by land run-off or other land-based sources.

Nevertheless, Greenland is probably the recipient of air pollution from remote areas. Inexplicably high levels of mercury have been found in marine mammals around Greenland, and the only possible explanation is that the metal has been transported there in winds from industrialized areas. There is speculation as to whether the mercury comes from mining operations in North America.

The Greenlandic marine ecosystems are vulnerable because of the ice in cold water. If pollutants are carried to Greenland by sea currents or winds, these inputs may constitute threats in future.

The Baltic Sea and the Kattegat

The Baltic Sea is the largest brackish water sea area in the world. It is a small, intracontinental mediterranean sea, and a shallow sea on the European continental shelf (*figure 25*).

The Baltic area comprises several sea areas that are together called the Baltic Sea. These areas are:

- the Gulf of Bothnia (the Åland Sea, the Archipelago Sea, the Bothnian Sea and the Bothnian Bay)
- the Gulf of Finland
- the Gulf of Riga
- the Baltic Proper
- the Sound
- the Belt Sea (the Great and Little Belts, the Kiel Bight and the Mecklenburg Bight)
- the Kattegat (up to 57°N, where it meets the Skagerrak).

In what follows, the area referred to as the Baltic is the whole of this area, unless otherwise indicated.

The Baltic Sea has a mean depth of only 55 m. In the Baltic proper, there are a number of deep basins, separated by shallow sills. The Baltic is divided into three major basins:

- the Baltic Proper with the Gulf of Finland
- the Bothnian Sea with the Åland Sea
- the Bothnian Bay.

Figure 25. The Baltic Sea: major population centres, rivers, industrial areas and other discharge and emission sources in its drainage basin.

Illustration: Stig Söderlind.


Depth in metres
0
25
50
100
200
500
1 000
2 000
4 000
Baltic Sea area and its drainage area
0
100
200 km
BARENTS SEA
NORWEGIAN
SEA
White Sea
Tornionjoki
Torne älv
Kalix älv
Lule älv
Kemijoki
Kemi
Skellefte älv
Ångermanälven
Oulu
Oulujoki
Skellefteå
Bothnian Bay
FINLAND
Indalsälven
Örnsköldsvik
Vaasa/Vasa
Härnösand
Ulvö Deep
Sundsvall
Onega
NORWAY
SWEDEN
Bothnian Sea
Kokemäenjoki
Päijänne
Saimaa
Kymijoki
Ladoga
Svir
Klarälven
Gävle
Turku/Åbo
HELSINKI/
HELSINGFORS
Leningrad
Dalälven
Landsort Deep
Åland
Åland Sea
Gulf of Finland
Neva
Mälaren
STOCKHOLM
Tallinn
Russian SFSR
Vänern
Narva
725
Motala ström
459
Hiiumaa
Estonian SSR
Peipsi-järv
Norwegian Trench
Skagerrak
Göta älv
Landsort Deep
Fårö Deep
Saaremaa
Võrts-järv
Gulf of Riga
SOVIET UNION
Frederikshavn
Gothenburg
Gotland
Gotland Deep
Ålborg
Kattegat
Ventspils
Latvian SSR
Jutland
Riga
Århus
Öland
Venta
Daugava
NORTH SEA
DENMARK
Helsingør
Helsingborg
COPENHAGEN
BALTIC SEA
Lithuanian SSR
Odense
Store Bælt
Øresund
Malmö
Klaipėda
Lille Bælt
Funen
Zealand
Dvina
Kiel Bight
Falster
Bornholm
Nemunas
Russian SFSR
Rügen
Vilnius
Kiel
Saßnitz
Gulf of Gdańsk
Kaliningrad
Travemünde
Rostock
Gdynia
Lübeck
Mecklenburg Bight
Gdańsk
FEDERAL
Swinoujście
Belorussian SSR
Neman
Szczecin
GERMAN
Oder
Odra
Vistula
Bug
BERLIN
Poznań
POLAND
REPUBLIC
DEMOCRATIC
WARSAW
Chernobyl
Wrocław
REPUBLIC
Ukranian SSR
OF GERMANY
Katowice
Kraków
CZECHOSLOVAKIA


Depth in metres
0
25
50
100
200
500
1 000
2 000
4 000
Surface currents
Baltic Sea area and its drainage area
0
100
200 km
BARENTS SEA
NORWEGIAN SEA
White Sea
Kalix älv
Torne älv
Tornionjoki
Kemijoki
Lule älv
Skellefte älv
Ångermanälven
Oulujoki
Bothnian Bay
FINLAND
Indalsälven
Ulvö Deep
Onega
NORWAY
SWEDEN
Bothnian Sea
Kokemäen-joki
Kymijoki
Saimaa
Ladoga
Svir
Klarälven
Dalälven
Lågskär Deep
Åland
Åland Sea
Gulf of Finland
Neva
Mälaren
Russian SFSR
Narva
Vänern
Motala ström
459
Landsort Deep
Fårö Deep
Hiiumaa
Estonian SSR
Peipsi-järv
Võrts-järv
725
Norwegian Trench
Skagerrak
Göta älv
The Skaw
Saaremaa
Gulf of Riga
SOVIET UNION
Kattegat
Gotland
Gotland Deep
Latvian SSR
Jutland
Öland
Venta
Daugava
NORTH SEA
DENMARK
Zealand
Funen
Lille Bælt
Store Bælt
Öresund
BALTIC SEA
Lithuanian SSR
Dvina
Bornholm
Falster
Kiel Bight
Rügen
Gulf of Gdansk
Nemunas
Russian SFSR
Mecklenburg Bight
FEDERAL REPUBLIC OF GERMANY
GERMAN DEMOCRATIC REPUBLIC
Belorussian SSR
Neman
Oder
Odra
Vistula
Bug
POLAND
Ukranian SSR
CZECHOSLOVAKIA

The areas of greatest depth are shown in *figures 26 and 27,* notably the Landsort Deep (459 m) and the Gotland Deep (249 m), but the rest of the Baltic area also contains a number of deeps and basins dropping to a depth of around 200 m. The basin areas are large, with individual deeps. In the Gulf of Bothnia, for example, the mean depth is 55 m and the greatest depth just over 300 m. The mean depths of the two parts of the Gulf of Bothnia – the Bothnian Bay and the Bothnian Sea – are 41 and 66 m, and their greatest depths 146 and 294 m, respectively.

The Danish Straits (a term embracing both the Sound and the Belt Sea) are also, with their mean depth of 25 m, very shallow. In the Sound, too, the mean water depth is about 25 m, but it increases to 30–40 m at the narrowest part, between Helsingør and Helsingborg.

The mean depth in the southern and western Kattegat is 20–25 m.

The total area of the Baltic sea is just over 400 000 km^2, and the aggregate water volume almost 22 000 km^3. As a sea, the Baltic is a very shallow, stationary inland sea. It is sometimes described as a 'super-estuary' rather than a sea, since the water consists mainly of the inflows from the surrounding countries' rivers.

An almost stagnant sea

The Kattegat is the portion of the Baltic which is most in contact with more open marine areas. *Figure 26* shows how the major currents to and from the Skagerrak and the North Sea also to some extent affect the water and flows in the Kattegat and thus, ultimately, throughout the Baltic.

The Jutland Current moves along the west Danish coast from the North Sea, turns off along the west coast of Sweden at the Kattegat and, broadly speaking, continues along the south coast of Norway, where it joins the Norwegian Current. The characteristics of the water in the Kattegat are determined mainly by water flowing in from the Baltic.

The denser, more saline North Sea water from the Jutland Current joins the Baltic Current, containing fresher water of lower density. The denser water sinks downwards, forming a halocline about 15 m deep in the Kattegat. Most of the inflowing North Sea water mixes with the outflowing Baltic water in the Straits and

Figure 26. Depths and prevailing surface currents in the Baltic.
Illustration: Stig Söderlind.

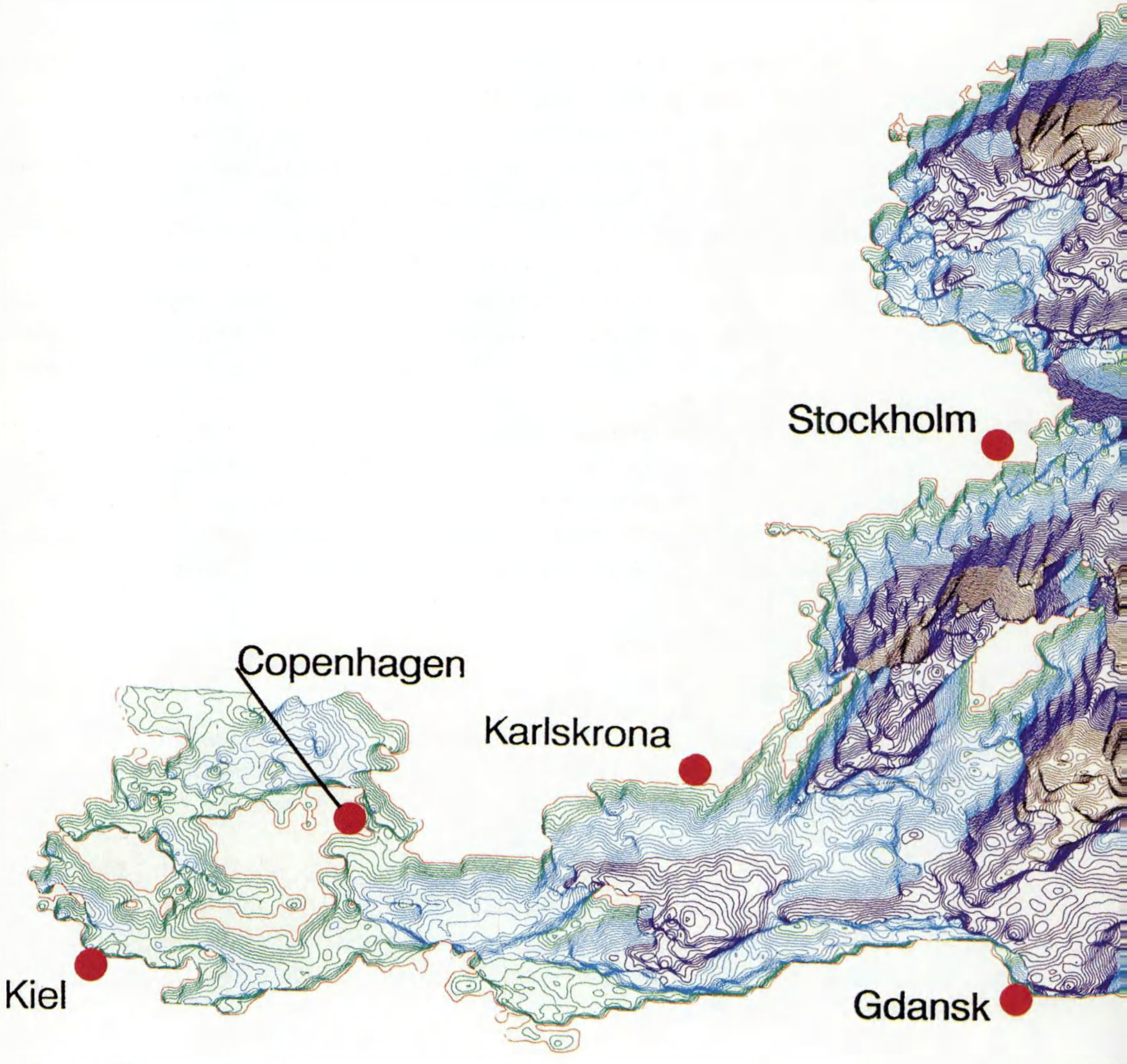

Stockholm
Copenhagen
Karlskrona
Kiel
Gdansk

Figure 27. Using a computer, researchers at the Askö Laboratory in the southern Stockholm archipelago have produced a three-dimensional depth chart of the Baltic Sea. The large basins with their deeps are shown, together with other features of bottom topography characteristic of the Baltic.

Depths: light green, 0—30 m; light blue, 30—60 m; dark blue, 60—120 m; black, over 120 m.

From Wulff, Stigebrandt and Rahm: 'Nutrient Dynamic of the Baltic Sea', *Ambio*, in print, 1989.

the Kattegat, and returns northwards with the Baltic Current. However, some saline water flows south, into a deeper trench through the Straits and into the Baltic.

The Great Belt is the widest of the three possible passages between the Kattegat and the Baltic Proper. Of the saline water that can enter the Baltic Sea at all, roughly 70% flows through the Great Belt. A very small proportion enters through the Little Belt. Broadly speaking, the entire remaining portion (30%) flows in through the Sound. The Danish Straits are thus the Baltic's only link with more open seas and more saline water. If a certain, albeit small, influx of salt water through the Straits were not possible, the Baltic would long ago have been transformed into a gigantic freshwater lake.

Sills mark the passages and bottom topography of all the areas of the Baltic. North Sea water flowing in from the Kattegat must cross the Darsser rise between the island of Falster and the East German coast. Here, the greatest water depth is 18 m. Salt water intrusions, when noticeable amounts of salt water enter the Baltic and contribute to water exchange there, take place only when there are strong west winds blowing. Air and water pressures then change, piling up water in the North Sea, Skagerrak and Kattegat against the west coast of Sweden while water in the Baltic is simultaneously driven back towards the Soviet coast. As a result, the water level in the Danish Straits is then higher than usual on the northern side, but lower than usual to the south. The outflow of Baltic water is halted for a while, preventing exchange and debouchment (see above). Instead, saline water can flow southwards into the Baltic, both in the surface layer and along the bottom. Easterly winds have the reverse effect: an increased outflow of Baltic water and no inflow of salt water from the North Sea.

These currents moving back and forth, 'sloshing' the water to and fro, account for most of the water interchange that takes place. Only true storms, in the autumn and winter, can give rise to major saltwater intrusions, and these may be years or even decades apart. On average, it takes an estimated 30–50 years for all the bottom and surface water in the Baltic to be exchanged. This explains the serious problems of anoxic sea bottoms. The supply of new, oxygenated saline water is not in proportion to the oxygen consumption and the formation of anoxic areas.

The physical characteristics of the Baltic provide natural preconditions for oxygen depletion in the bottom water and the resulting development of anoxic, dead bottom areas. The slow water exchange, the sills and pronounced halocline in the Baltic Proper are natural obstacles. Any consideration of the problem of the ever expanding deoxygenated areas must be based on these facts. The risk of oxygen depletion, hydrogen-sulphide formation and benthic death is an ever-present one in a sea such as the Baltic, but the situation has been greatly exacerbated by overfertilization.

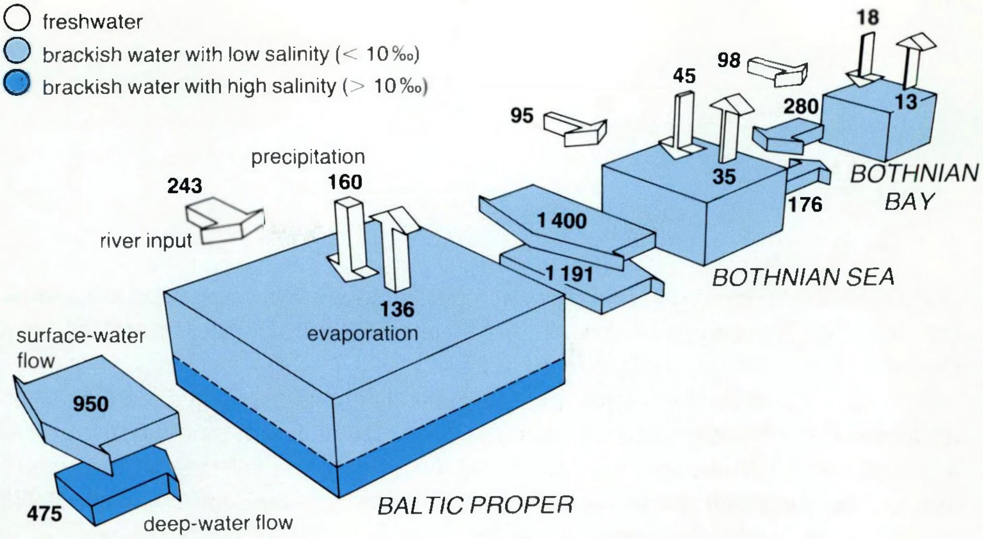


Figure 28. Water exchange in the Baltic. The majority of the fresh water reaching the Baltic Sea gets there via streams and rivers. Precipitation on the surface of the sea is largely offset by evaporation. Surplus fresh water passes out through the Danish Straits (including the Sound), but in addition large quantities of salt water flow into the Baltic. The total flow of water from the Baltic is therefore considerably higher than the net outflow. The water in the Gulf of Bothnia is entirely renewed in around four years, whereas it probably takes some 25 years for all the water in the Baltic to be exchanged.

Illustration: Claes Bernes. From *Sweden's marine environment — ecosystems under pressure* (Monitor 1988), National Environmental Protection Agency, Solna, Sweden.

A marked halocline has developed at a depth of 60–80 m in the Baltic Proper, and it almost entirely prevents oxygenated water from more superficial layers of water from mixing downwards in the water column. Nature's only means of oxygenating the deep-sea water is therefore by supplying oxygen-rich, saline water from outside. The saline water that enters must, however, be truly saline – and thus dense enough – to sink down into the Baltic depressions. If the water is mixed, and thus somewhat lighter than the truly saline seawater, it settles some way above and the old bottom water remains, deoxygenated and dense.

Water exchange varies from one part of the Baltic to another. The difference in salinity between the surface and bottom water is small in the northern parts of the Baltic, the Bothnian Sea and the Bothnian Bay. There, strong winds can break up the weak halocline and mix the water. In the Bothnian Bay, it therefore takes only about four years for the water to be exchanged; in the Bothnian Sea it takes about six years (owing to more marked stratification); in the Kattegat it takes a few months; and in the Danish Straits, with their narrow passages, water exchange takes only a matter of days or weeks. The most stagnant (stationary) water conditions thus prevail in the basin areas of the Baltic Proper. It takes some six months for inflowing water from the Belt Sea to reach the Gotland Deep.

The water balance in different parts of the Baltic is shown in *figure 28*. In general, the Baltic receives a larger amount of fresh water via rivers and precipitation than it loses via evaporation, with a surplus of fresh water as a result. This is what gives Baltic water its distinctive properties. Overall, the influx of water is also larger than the outflow, giving a net outflow from the area. The influx of salt water from the Kattegat and the Belts is in the order of 475 km^3 a year, while the surface-water flow of brackish water out of the Baltic – mainly through the Sound – is about 960 km^3. Thus, the influx is roughly half as large as the outflow.

Water in the Baltic is markedly stratified, with both thermoclines and haloclines. This stratification, combined with conditions on the seabed – where the numerous sills prevent free flows and the depressions, mainly in the Baltic Proper, retain water – and other meteorological and hydrological conditions, makes water exchange slow and often spasmodic.

The Baltic Sea is a sample-card of varying salinities, with a gradient from the Bothnian Bay to the Kattegat. In the northernmost part of the Bothnian Bay, salinity in the bottom water is some 3–4 ‰, in the Bothnian Sea it is 4–6 ‰, in the Gulf of Finland 5–9 ‰ and in the Baltic Proper 6–8 ‰. Salinity then rises steeply in the Straits and the Kattegat, from 8 to 20, and at the dividing line between the Kattegat and the Skagerrak the water is almost oceanic, i.e. just under 35 ‰.

Few species in large numbers

Biologically and geologically, the Baltic is a young sea and the result of the gradual retreat of the ice cap in the last Ice Age. The Baltic area has had its present size and shape for some 10 000 years.

The ecology of the Baltic is the explanation for the sea's pronounced vulnerability to pollution and other external influences. As pointed out above, it is a unique area with its salinity gradient from virtual fresh water in the Bothnian Bay to what is almost ocean water in the Kattegat/Skagerrak border area. The sea is steadily, but very slowly, becoming somewhat more saline. The Danish Straits are gradually becoming deeper; theoretically, more saline water can then flow in. The halocline is also being progressively raised: it is some 10 m higher now than at the turn of the century. Some marine animal species, such as common mussel and cod, are spreading northwards. But the rise in salinity is taking place extremely slowly, and the phenomena that disturb and destroy the Baltic environment are still overwhelmingly predominant.

The Baltic is also a sea with a very small number of plant and animal species.

There are considerably fewer species than in more saline waters; moreover, many Baltic species occupy the periphery of their range. The water of the Baltic is, in fact, an impossible environment for most plant and animal species – both marine and freshwater species. The water is too fresh for the true marine species, and too saline for the true freshwater species. Since fluctuations between fresh and brackish water ceased after the ice melted, relatively few animal and plant species have succeeded in colonizing the Baltic. It now contains species that have adapted themselves to a stressful life in an adverse environment. One could perhaps call them rudimentary brackish species, but in fact they are saltwater or freshwater species that have adjusted to an environment that, basically, is the wrong one for them.

Many animal species in the brackish water of the Baltic have great difficulties in retaining their internal fluid balance. This is because of differences in salinity between the ambient water and the animal's tissues. Merely staying alive can thus demand a great deal of energy for an animal or a plant in Baltic water. Furthermore, the water is relatively cold – the Bothnian Bay may, for example, be regarded as a sub-Arctic marine region – and this slows metabolism. At these latitudes, light is in short supply for long periods, both beneath the ice and in the open sea; this, too, affects living conditions for plants. (There are numerous interesting phenomena in the Baltic, such as the coexistence, and even co-reproduction, of saltwater and freshwater plants.)

There are about 100 species of brown algae in the North Sea; in the Baltic, there are about 20 at most. The North Sea has 200 different species of bivalve mollusc, while there are only four on the Finnish coast. The number of macroscopic and microscopic animal species west of Sweden is roughly 1 500; in the southern Baltic there are only about 150, in the water around Gotland only about 80, in the Åland region some 50 and in the Bothnian Bay a mere handful. The same applies to fish: the Kattegat has around 80 marine fish species, while the Sound has only 55 and the Archipelago Sea only about 20.

One consequence of the relative paucity of species is that the food chains are simple, and easy to disrupt and destroy. If one species disappears, the effects are far-reaching. In general, there are no species – or only a single one – that can replace the species that has disappeared. The whole ecosystem thus becomes imbalanced if species are wiped out by changed ecological conditions – both natural and due to pollution. If, for example, bladder wrack, which now serves as food for certain species and shelter (breeding ground) for myriads of organisms, were to disappear, all these species would be affected. Bladder-wrack communities are already disturbed: the increasing turbidity of the water means that light can no longer penetrate as deeply as it used to. Formerly, bladder wrack in the Baltic grew down to a depth of 11 m. Now, it is not found more than 8 m deep, and it is apparently being forced up into even shallower waters.

The capacity of the Baltic to withstand severe environmental disturbances is inferior to that of other marine environments. Several species are already struggling against fairly poor odds for their survival and range. Admittedly, they have developed in naturally stressful surroundings and they may possibly, for that reason, be somewhat hardier than they would normally be. The species in the Kattegat and Skagerrak have been able to develop in a considerably more stable environment, and are therefore easily eliminated if anything unexpected takes place. Stresses in the Baltic are, however, so heavy that the plants and animals need their slightly raised capacity (if any) to withstand stress.

The Baltic has both hard (rock) bottoms and soft (sediment) bottoms. The rock bottoms are more common to the north. Coastal contours also vary greatly. To the south, in Schleswig-Holstein and Mecklenburg, there are low, gently undulating moraines. In the eastern parts of the south coast, low, bank-like islands and sand dunes may be seen. Here, too, are shallow coastal lakes and lagoons. The Soviet coast is varied and somewhat more 'jagged', with numerous inlets and headlands. The northern part of the Gulf of Finland is a uniform archipelago zone, and further north as well the coast has the characteristics of an archipelago. Even further north, on the Finnish side, the terrain is characterized by rivers and dunes. Shallow and stony shores may be seen in the interior of the Bothnian Bay and here again there is an archipelago area. The Swedish coast is broken by archipelagos and estuaries. The east coast of Denmark is, in parts, steep. The numerous archipelago areas, with their thousands of small islands, are typical of the Baltic. These areas are also very rich in bird life, with respect to both species and numbers of sea birds.

Herring, cod and sprat fishing in the Baltic has increased sharply during the twentieth century. Altogether, the annual catch in the Baltic is in the order of one million tonnes of fish, both saltwater and freshwater species. Since fishermen of the Baltic nations have been steadily driven away from their traditional fishing waters in the North Sea and the north-east Atlantic – a result of the littoral nations there claiming sole rights in a 200-mile zone – the Baltic has become ever more important for its fisheries. Conflicts arise and fishing is conducted efficiently. Certain species are threatened by overfishing. Researchers are also concerned about the future survival of both salmon and cod.

Towns, rivers and landmasses

Figure 25 shows the drainage area of the Baltic. A distinction must be drawn between the rivers' total run-off and the amount of water actually reaching the Baltic. In round figures, 140 million people inhabit the seven countries surrounding the Baltic, but the rivers' drainage basin includes some 70 million of the total population. The drainage area measures approximately 1 650 000 km^2. The German Democratic Republic (GDR), whose only coastline is entirely on the Baltic, has for example a relatively small river flow to this sea. Instead, the North Sea, via the Elbe, is affected by most of the pollutants added to the river in the GDR portion of its course.

There is heavy industry in several Baltic nations, and the area also has abundant sea traffic – tankers and cargo vessels carrying oil and other raw materials, large container ships and ferries. Intensive agriculture is carried on in large areas. Figure 25 also shows schematically the rivers and the major population centres affecting the Baltic. In addition, there are industries, agricultural areas and other pollution sources.

Serious threats to the Baltic environment

The Baltic is a sea in poor health. Its fauna and flora are threatened by various pollutants and by disturbances of the sensitive ecosystems. Much has improved since the 1950s and '60s, but the threats are far from averted.

- In almost half of the seabed of the Baltic proper – an area measuring close to 100 000 km^2 – the benthic fauna has been virtually eliminated. These areas of seabed are almost entirely dead. Over large areas, in the depressions, the oxygen is entirely depleted and has been replaced by poisonous hydrogen sulphide. In other parts of the Baltic, too, the oxygen situation is alarming. In the Kattegat, for example, a severe oxygen deficiency now arises every autumn.
- Major algal blooms are becoming ever more frequent in the Kattegat and the Danish Straits, and most of the evidence suggests that widespread eutrophication is taking place. There has been a massive increase in nutrients since the 1960s.
- High concentrations of heavy metals have been measured in sediments, although discharges have decreased.
- Chlorinated organic material in the bleaching-plant discharge of pulp mills has proved to be widely dispersed. These substances disperse hundreds of times more widely than DDT or PCBs have ever done. Bleaching substances are found in sediments and have also caused severe damage to fish and benthic fauna in areas surrounding the discharges.
- Dioxin concentrations in fatty fish from the Baltic and in fat tissues of shellfish from the Kattegat/Skagerrak are so high that even moderate consumption of these entails a larger dioxin intake than is probably acceptable for humans in the long term.
- Oil production is already taking place on a certain scale in the southern Baltic. Large-scale exploration is now being carried out by Sweden and other countries. There is concern about the environmental risks of expanded oil production in an ecosystem as vulnerable as the Baltic.

Anoxic seabed expanding ...

An area of seabed in the Baltic proper measuring almost 100 000 km^2 is virtually lifeless. The occurrence of layered (stratified) sediments covering large areas in the Baltic is regarded as proof of this. In normal bottoms, sediments are stirred by benthic organisms (bioturbation), giving homogeneous sediments where no distinct layers are visible. If the benthos has disappeared, i.e. the bottoms are more or less dead, no bioturbation can take place and the sediments then remain as they were once deposited, layer upon layer. Here, so much organic material has been decomposed over a long period that the oxygen once contained in the deep water has been depleted. Over large areas, the next stage of oxygen depletion has begun: the stage at which the toxic gas hydrogen sulphide has formed. In the past decade, hydrogen sulphide has been almost continuously present in the bottom water of the Gotland Deep (*figure 29*).

Below a water depth of 60–80 m, i.e. beneath the halocline, there is virtually permanent anoxia. In the depressions, at depths of more than 130 m, hydrogen sulphide is usually present. Oxygen depletion also occurs in, for example, Hanö Bay, an area no deeper than 60 m and where the halocline is considerably higher than in the Baltic proper.

This development is alarming, and clearly indicates that conditions in the deeper portions of the Baltic proper are, ecologically, under severe pressure. There has not been enough – and dense enough – salt water entering the Baltic from the North Sea via the Skagerrak and the Kattegat to oxygenate the bottom water in the depressions. There, the water has not been exchanged for the past ten years or so. The large input of nutrients to the sea has almost certainly generated increased production, with the concomitant decomposition of organic material. The expansion of anoxic bottoms is thus an effect of eutrophication and adverse natural conditions combined. As mentioned above, there is always a considerable natural risk of oxygen depletion in a marine area with the characteristics of the Baltic. This is the reason why the Baltic is so vulnerable to further, similar influences caused by human activities.

One additional 'nitrogen factor' in the Baltic proper is the blue-green algae and their capacity to transform atmospheric nitrogen into nitrogen accessible to plant life, to store this nitrogen and to release it when required. This means that, as well as measurable nitrogen concentrations in the water and the dead organic material, the Baltic also has another, unpredictable nitrogen reserve that may begin circulating. Sedimentation (fixing) of phosphorus is also extensive in this sea. The larger the area affected by oxygen depletion, the more of this fixed phosphorus will be released and enter primary production.

Figure 29. In the deeper parts of the Baltic proper, oxygen levels are now so low that about 100 000 km^2 of the seabed is virtually devoid of life. In a sea area like the Baltic, the natural prerequisites for oxygen depletion and hence benthic death — slow water exchange, a halocline and deeps — are always present. However, the developments now occurring are far more dramatic than they probably would have been without the impact of human activities.

Illustration: Claes Bernes. From *Sweden's marine environment — ecosystems under pressure* (Monitor 1988), National Environmental Protection Agency, Solna, Sweden.

. . . owing to eutrophication and algal blooms

One phenomenon that probably proves that the wide extent of anoxic bottoms is primarily due to eutrophication is benthic developments on shallow and deep bottoms in the Baltic proper. Above the halocline, where there is ample oxygen in the water, the benthic biomass has quintupled since the 1920s. On the deep bottoms, on the other hand, the benthos has been eliminated. The proliferation of benthic fauna in an oxygen-rich habitat suggests that they have a good food supply – in other words, that primary production has increased markedly. In the Kattegat, too, benthic fauna has increased a great deal in shallow areas but died out in deeper ones. The effects of eutrophication, then, are noticeable here, as they are in the Bothnian Sea.

Fish catches in the Baltic have also increased sharply, but this cannot be seen as proof of eutrophication. Rather, fishing methods have become more efficient.

In the Bothnian Sea, the oxygen situation is better than in the Baltic proper, but in these northern waters too the oxygen content has declined gradually during the twentieth century. In the Kattegat, there has been a marked deterioration in recent years. During most of the year, there is enough oxygen in the bottom water, but in the autumn the oxygen content regularly falls to very low levels – and these levels are becoming steadily lower. Constantly recurring oxygen depletion of the water thus suggests that the system is in imbalance.

Table 6 is the Helsinki Commission's summary of the pollution load in the Baltic area. This shows clearly that nitrogen and phosphorus entering the Baltic come mainly via rivers and in the form of atmospheric deposition (*figure 30*).

At the turn of the century, the annual input of nitrogen to the Baltic is estimated to have been 250 000 tonnes and that of phosphorus some 10 000 tonnes. The nitrogen input has thus quadrupled, and the input of phosphorus has increased eightfold. In the Kattegat, nitrogen has risen sixfold, from around 26 000 tonnes at the turn of the century, and phosphorus has increased 10–20 times to its current level of roughly 8 000 tonnes a year.

In the Bothnian Bay, no actual eutrophication seems to have taken place. Unlike other parts of the Baltic, phosphorus is probably the growth-limiting factor in the Bay. Formerly, however, there were extensive bottom areas with oxygen depletion as a result of the discharge of large quantities of organic material by the pulp and paper industry. Large 'fibre banks' were formed immediately outside the mills' outfalls. These discharges have now decreased and the situation has improved, but the benthic fauna has still not returned to certain areas.

During the 1980s, areas in the Kattegat between Denmark's east coast and the west coast of Sweden have had major problems with recurrent algal blooms and

Table 6. Estimated annual inputs of pollutants to the Baltic (tonnes per year)[1]

Substance	Urban areas	Rivers	Industry	Land based sources total	Atmospheric deposition	Total input (rounded figures)
Nitrogen	67 652	449 150	11 549	528 351	413 000	940 000
Phosphorus	11 801	28 321	8 397	48 519 (42 000)	6 000	54 000
BOD	196 610	1 212 400	295 440	1 640 000		1 640 000
Mercury	1,1	3,7	0,2	5		5
Cadmium	3,2	46,3	9,3	59	80	140
Zinc	460	6 709	1 765	8 934	3 200	12 200
Lead	18	239	8	265 (300)	2 900	3 200
Copper	133	3 962	101	4 200	380	4 580
Oil	8 977	26 021	576	35 574		36 000
Arsenic	4	72	101	177		180
Nickel	10	0	96	106 (110)		110
Vanadium	0	0	290	290		290
Chromium	–	0,1	0,08	0,2		0,2

[1] The data in the table are taken from *The Baltic Sea Environment Proceedings no. 20, First Baltic Sea Pollution Load Compilation*, published in January 1987 by HELCOM, Helsinki, Finland.

In the report it is emphasised that the data are very heterogenous and that data used have av varying degree of certainty and are from different years. A new compilation will be done by the Commission and it is hoped that this will rely on a better set of data.

Figures should be regarded as preliminary and not as giving an accurate picture of inputs to the Baltic. In the table values are rounded off in accordance with the presentation made by HELCOM.

benthic death. These marine areas are severely affected by nutrient run-off from the intensively cultivated farmland. In the Kattegat, fishing for Norwegian lobster was highly profitable for some years. The lobsters were driven out of their seabed hollows by the lack of oxygen and were, as a result, easily caught. The situation as such was an abnormal one: Norwegian lobsters do not normally stand on the seabed, literally waiting to be caught. Fishing trials in 1989 have shown that there are now no longer any Norwegian lobster in the area. Recurrent oxygen depletion and heavy catches are the causes. In the Kattegat, there is also a lack of young cod, which suggests a disturbance in the system.

One effect of oxygen depletion in the Baltic proper is reproduction difficulties for cod. Cod must lay their eggs in the water beneath the halocline, where the salinity

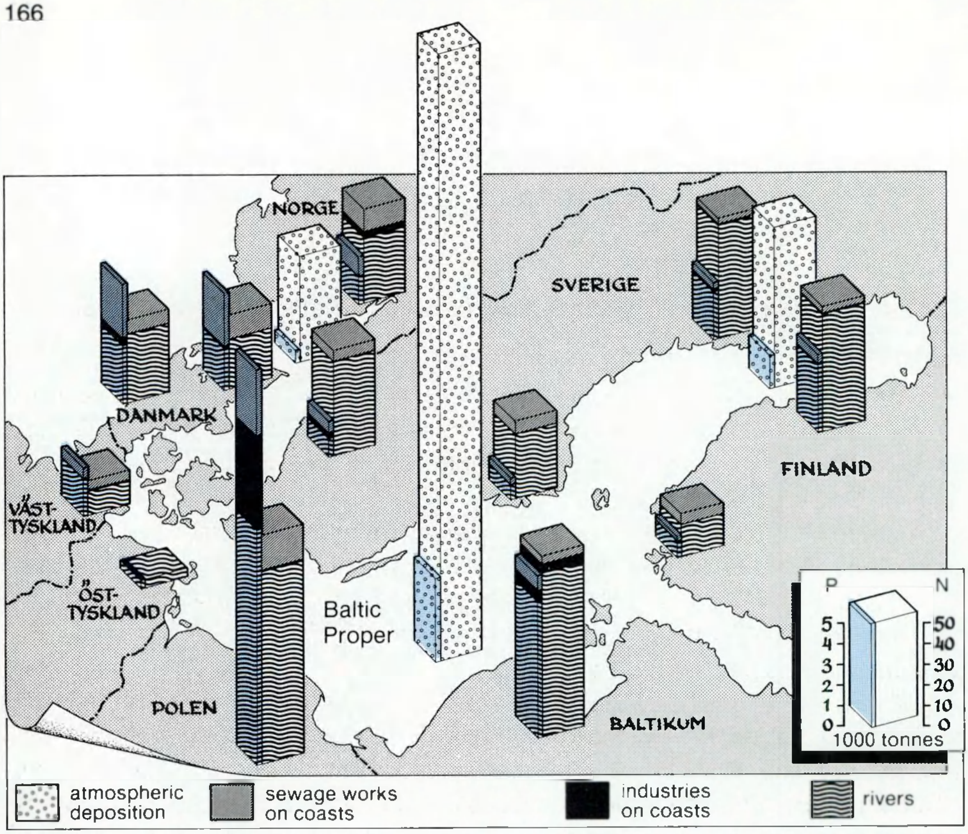


Figure 30. Every year the Baltic receives a total nitrogen input of around 940 000–1 000 000 tonnes and a total phosphorus input of some 55 000 tonnes from the seven Baltic Sea states. The most important routes are rivers and the atmosphere.

Illustration: Hans Nilsson.

exceeds 10 ‰. The eggs are too heavy to stay afloat in fresher water. Now that the saline bottom water is increasingly anoxic, the cod eggs cannot survive, and this is particularly true if they come to rest in areas containing hydrogen sulphide. Adult cod are, moreover, demersal and seek their food on the bottoms where a great deal of the fauna has been destroyed. During the 1980s, Baltic cod have had difficulty in reproducing, and researchers fear a continued deterioration in future generations.

In water with high primary production and increasing turbidity, it is more difficult for light to penetrate to great depths. This is now the situation in the Baltic. One effect of this is the increased incidence of attached algae, especially filamentous green algae. These choke other macroalgae, including bladder wrack, with major ecological consequences. The large-scale growth of ‘slimy’ green algae also makes cliffs and other shore areas unpleasant for humans, destroying their value for bathing and recreation purposes.

Large amounts of unknown stable organic substances worrying

DDT/DDE and PCBs, as well as toxaphene in recent years, are 'classic' environmental toxicants in the Baltic area. DDT is now banned in all the Baltic nations and the use of PCBs has diminished considerably – both as a result of work within the Helsinki Commission.

Owing to DDT/DDE, certain predator species (osprey, white-tailed eagle, eagle owl) on the Baltic coast were heading for extinction, but the birds now seem to be recovering. In some countries, the sale for human consumption of liver from cod caught in the Baltic is still banned: such liver contains excessive concentrations of such substances as DDT/DDE and PCBs.

PCB concentrations have decreased, but not at the same rate as DDT/DDE. The mammals of the Baltic – the common (or harbour) seal, the grey seal, the ringed seal and the sea otter – are still severely affected by environmental toxicants, including PCBs. The reproductive success of the seals is still impaired, and the number of fertile females is too small for any guarantee of the stocks' survival to be made.

Concentrations of toxaphene and chlordane are found in Baltic animals, although neither of these substances is used any more in northern Europe on any appreciable scale.

DDT/DDE, PCBs and toxaphene are fairly well known. A disturbing new discovery is the fact that chlorinated organic substances from the bleaching process in the pulp and paper industry are very widely dispersed in the marine environment. First, it used not to be known how this dispersion took place; secondly, it has not hitherto been clear how little is actually known of the countless components of these complex effluents. Each year 150 000 tonnes of chlorinated material from bleaching plants is discharged into the northern parts of the Baltic, and large quantities of chlorinated substances are deposited in the sediments, both in the immediate vicinity of pulp mills and far out to sea.

Of the chlorinated substances that researchers have been able to extract from the tissues of fish, they have succeeded in identifying only a small proportion. This means that uncertainty is considerable where present and future environmental effects are concerned. Researchers are concerned about the extensive distribution of these substances: future damage will be very difficult to remedy if they are widely dispersed in the ecosystems.

A Swedish research project on the biological effects of bleaching-plant effluents has recently been concluded. Its findings include changes in the number of species, in the numbers and distribution of invertebrates and also in plant communities. Both bottom-living animals and fish have been damaged. Chlorinated material is also bound in sediment. In the vicinity of pulp mills, fish have been found with deformed or reduced fins, skeletal damage such as spinal curvature in four-horned sculpin and bleak, reduced numbers of larvae and fry in the water several kilometres from the point of discharge, deformed gills, impaired immune system, disturbed salt balance, deformed jaws, 'upnose' skull deformation and skin lesions. These chlorinated substances are also believed to affect the survival of common mussels and amphipods and to cause changes in algal communities.

Baltic herring have been analysed to ascertain dioxin levels. Concentrations appear to be in the range of 2–20 picogram (pg) of TCDD (tetrachlorodibenzo-p-dioxin) equivalent per gram wet weight. Fatty fish, such as salmon, have higher concentrations. Mammals, too, accumulate high concentrations since dioxins, like other chlorinated substances, are soluble in fat. Dioxin levels in Baltic salmon and seals are 10–100 pg of TCDD equivalent.

Crab and lobster from the west coast of Sweden also contain notably high dioxin levels. Over 100 pg of TCDD equivalent has been measured in crab hepatopancreas.

Dioxins and other chlorinated substances have been found in sediments outside the pulp mills in the Bothnian Sea.

High heavy-metal concentrations in Baltic sediments

Although the inputs of mercury and other heavy metals have been reduced, high concentrations remain in sediments. Many areas are heavily polluted. These metals may be brought back into circulation as a result of both altered chemical conditions and the churning of sediments during dredging, for example.

Future oil production in the Baltic?

The problems of oil in the Baltic are still connected with the diffuse input from land-based sources and the risks of major oil spills resulting from shipping accidents. Large-tanker traffic is limited owing to the Baltic's shallowness: in practice, vessels exceeding about 120 000 tonnes cannot ply the Baltic. However, oil can leak from other types of vessel operating in the Baltic as well.

Broadly speaking, the annual inputs of oil to the Baltic are via rivers, sewage-treatment plants and the discharge of untreated waste water from urban areas, as well as from the air and as a result of small, diffuse discharges at sea (operational discharges from ships; see *table 7*). This input is hard to remedy as long as sources cannot be confined to certain areas and measures adopted there. Undoubtedly, however, the diffuse discharges are the most important ones to tackle, both because large quantities are involved and because it is not known how, in the long run, the beleaguered marine environment of the Baltic will react to a continuous input of petroleum hydrocarbons.

As yet, no systematic oil production can be said to be in progress in the Baltic. The FRG has one oil platform in the southern Baltic. The USSR has suspended an oil-drilling project off the Lithuanian coast for the time being. Sweden is now, however, surveying and prospecting potential resources in the Swedish sector of the Baltic. At the Helsinki Commission's meeting in 1989, future oil operations in the Baltic were discussed. No decisions were taken to attempt to stop such operations; instead, the discussions were more concerned with attempts to regulate any oil production carried out, in order to minimize the risks.

Table 7. Annual input of oil to the Baltic Sea Area (tonnes per year)[1]

Municipal effluents	3 000 – 9 000
Stormwater	1 000 – 5 000
Refineries	163
Steel rolling mills	307
Other industry	400 – 1 000
Oil terminals	100 – 200
Shipping	160 – 6 500
Ship accidents	200 – 9 000
Oil/gas platforms	<5
Rivers	14 000 – 25 000
Atmospheric input	1 000 – 10 000
Total	21 000 – 66 000

[1] The table is from *Sweden's marine environment – ecosystems under pressure* (Monitor 1988) National Environment Protection Agency, Solna, Sweden.

5 Policy and technology enable discharges to be reduced

In discussions on how to reduce the discharges of various substances to the sea – and atmosphere – interest tends to focus on technical matters. Control technology is, admittedly, crucial; but it is equally important to discuss policies, instruments of control and systems' solutions. Discharges of proven or potential detriment to the environment are, ultimately, a question of a community's policies regarding energy, industry, transport, agriculture and forestry, consumer issues and so on. The scope for reducing discharges of stable organic substances, heavy metals, nutrients, oil and other substances to the sea is thus closely bound up with society's political decisions in several fields. Environmental thinking must permeate other political decisions if essential environmental targets are to be met. Control technology is a tool and a supplement with which to reduce, on as large a scale as possible, those discharges that cannot be avoided with the imperfect process technology and the free flows of products and substances that characterize industrial society.

Chapter 6 gives a brief description of the marine conventions and political efforts to date to safeguard the marine environment. It is evident that, in the political arena, there has already been a realization of the extent of the problem, and also an attempt to define the areas in which measures must be taken. The following is a discussion of existing control technology, the need for technological development and, ultimately, the necessity of far- reaching changes in the human activities that cause unacceptable environmental effects.

Technical and political measures – when, where and how?

As stated previously, the main inputs to the sea are:

- via direct discharges to seawater from industrial installations, urban areas or shipping
- via inflowing rivers and land run-off, when the water carries substances from industrial installations, urban areas, agriculture and forestry
- via atmospheric deposition of pollutants from industrial installations, urban areas, agriculture and forestry, as well as from marine activities.

There are several main principles for tackling the discharges:

- to plan, even before the process or activity has started, to produce the smallest possible quantity of pollutants; this planning includes choice of systems' solutions, raw materials and processes
- as far as possible, to reduce the input of substances to water, air and perhaps land as well, during the process or activity
- to clean polluted water, air and land after an activity; this includes the disposal of solid waste and waste from purification processes
- if possible, to desist entirely from processes or activities producing severely contaminating discharges.

Virtually all human activities in an industrial society produce substances that must be disposed of in some way in order to prevent adverse environmental effects and health risks. Society can then take various decisions as to how these substances and discharges, as well as other problems connected with them, should be dealt with:

- technical solutions: control technology, technical development, process modifications, etc.
- political and economic instruments: legislation, financial levies, government financial support for alternatives, etc.
- thoroughgoing changes in the entire policy concerning a social activity (this being the most drastic measure).

One basic principle in industrial activity is that raw materials, water, air and energy are included in the process, and that its output comprises the desired product plus polluted water and air, as well as waste products. The same theoretical reasoning applies, of course, to activities in urban areas – human consumption and waste management, road traffic, energy production, etc.

If waste water and flue gases are cleaned in one way or another, or otherwise treated outside the scope of the industrial production process or other activity, the term used is external purification. Instead of installing clean-up devices in the final phase, the actual production process or activity can be modified, the raw materials replaced, etc. A solution of this kind is an example of an internal process measure.

In industry, the solution adopted is most often a combination of both external and internal measures.

As shown below, many methods of purification are the same for several industrial sectors and for activities in urban areas, such as sewage-treatment plants, power-generating plants and road traffic. Singly or in combination, methods may be used in order to:

- treat waste water (liquid flows) after the process
- reduce water consumption during the process
- treat flue gases and other air flows after the process
- modify the combustion technique used in the process
- keep various systems (air and water flows) well apart, during and after the process, in order to facilitate monitoring of inputs to them and their post-treatment (purification)
- replace 'hazardous' raw materials with less 'hazardous' ones before the process (i.e., in non-industrial contexts, ban the use of unsuitable products or substances or, in some other way, promote the increased use of less environmentally harmful products)
- recycle substances from liquid and gas flows, or remove undesirable substances from these flows, during the process
- take active steps to recycle products and materials after they are used, and to reuse their components (or ensure that the product or material is entirely removed from the circulation of the substances concerned in society)
- convert waste after the process (make it less 'hazardous' or use it in products or processes in which it is stabilized and remains 'non-hazardous' to the environment)
- dispose of waste by tipping or incinerating it after the process
- dispose of environmentally hazardous or otherwise hard-to-handle waste after the process, preferably by depositing it in a safe manner or delivering it to special treatment or incineration facilities.

And how much does it cost?

It is extremely difficult to make general estimates of the costs of the various conservation measures required to protect the marine environment in Northern Europe. Discussions on future measures touch on a large number of countries that vary with respect to social system and industrial and energy-production structure, and evince widely contrasting consumption patterns and major disparities in raw-material resources and economic conditions.

Since the question of costs versus benefit is, nevertheless, what ultimately determines which measures are taken in the various countries, it is nevertheless of paramount importance for long-term, detailed estimates of this kind to be carried out on a national basis and discussed internationally. One fundamental principle of environmental conservation is that measures should be adopted where they do most good, i.e. where they are most cost-effective. To reduce the load on a marine area shared by several countries, unconventional means of distributing costs may well, in the long run, prove to be by far the most cost-effective. In this situation the end result – maximum protection of the marine environment – must serve as guide.

In the following, a whole series of possible measures are described – both political decisions and technical methods of purification – but their costs are not specified. Based on the long list of options, however, one can perform the necessary estimates in each country. Ultimately, what each individual nation considers a healthy environment is worth, in pecuniary terms, is an overall political assessment.

Political decisions (legislation, limit values and emission standards, financial levies, etc.), the degree of technological development and economic priorities on the part of society and business then determine how far an industry, an individual company or society at large considers itself willing or able to implement measures to limit discharges.

Requirements concerning environmental protection have, in a number of situations, proved capable of generating solutions that are highly profitable to businesses, thus safeguarding employment in the long term. As environmental standards and legislation are tightened up in more and more countries, a capacity to meet them also becomes a weapon in the competition. Environmental technology is a product that can be sold at a good profit. Industries required to develop such technology are now in the vanguard of their respective sectors, and their extensive knowledge of such technology confers both financial gains and goodwill.

Technology to reduce marine pollution: A small selection

It is an impossible task to summarize and simultaneously describe in some detail all discharge routes from the whole of industry, all urban areas, farmland and forest land, plus all shipping and oil production in countries in the northern hemisphere, and to list all conceivable political and technical means of reducing these discharges. The following is therefore a very general summary of the basic methods that are most important, currently available and both technically and economically feasible – methods of:

- cleaning waste water from industrial processes and sewage from urban areas
- cleaning flue gases from industrial processes, energy production and road traffic
- handling waste from industrial processes, urban areas and purification processes.

Some examples are also given of existing specific technology to reduce discharges of stable organic substances, heavy metals, etc. from some industrial sectors that are often mentioned in connection with the marine environment, namely:

- the pulp and paper industry
- the chlor-alkali industry
- iron, steel and other non-ferrous metal works, the engineering industry and mining
- parts of the chemical industry.

Mention is also made of some feasible methods of reducing nutrient discharges from:

- agriculture, forestry and mariculture

and some possible measures to reduce pollution from

- the handling of e.g. oil in ports
- the transportation of oil at sea.

Treating sewage in treatment plants

The water entering urban sewer systems may comprise several different kinds of sewage:

- waste water from households
- stormwater (rain and melt water from hard surfaces, such as buildings and streets)
- drainage water (water diverted by drainage from land)
- industrial waste water.

Sewage reflects the society producing it. The water contains residues of all the chemical substances we use, as well as large quantities of solid contaminants, organic degradable material, nutrients and pathogenic substances (bacteria, viruses, parasites, etc.). Metals, acids, alkalis, cyanides, organic compounds that are not readily degradable, solvents, pesticides and other toxic substances can also enter sewage from both communities and industrial installations.

Sewage treatment plants – installations for treating municipal sewage and industrial waste water – can vary a great deal. The most advanced works use all the technically feasible processes, while others have a lower degree of purification and fewer stages.

A treatment plant can have the equipment and technology for either or all of these stages:

- mechanical (primary) treatment
- biological (secondary) treatment
- chemical (tertiary) treatment
- nitrogen removal.

The plant may be said to produce two things: cleaner water and contaminated sludge. The purity of the water and degree of contamination of the sludge may vary.

In rough figures, a sewage treatment plant with mechanical treatment only is estimated to reduce the biochemical oxygen demand (BOD) of the sewage by some 30 %. Biological treatment alone attains a 90 % purification rate, in terms of BOD, a 25 % rate where phosphorus is concerned and a 10–20 % rate with respect to total nitrogen. Chemical treatment alone is estimated to remove 60–70 % of BOD, about 90 % of total phosphorus and roughly 20 % of total nitrogen. A certain nitrogen reduction is also attained by means of mechanical and chemical treatment but this is incidental and due to the removal of the sludge.

Apart from the reduction of BOD, total phosphorus and total nitrogen, a chemical-biological treatment plant also removes at least 90 % of the suspended material and 50–90 % of the commonest metals. Moreover, 90–99 % of most bacterium species is also removed from the water.

With special nitrogen removal methods, it should be possible to reduce the nitrogen content of sewage by 70–80 %. Thus, a technically advanced treatment plant can purify incoming sewage to a very high degree. Certain stable organic substances and metals are, however, not broken down but removed with the sludge, or pass straight through the plants and out into the receiving water.

Mechanical treatment

Mechanical treatment often takes place in sedimentation basins, in which particles settle on the bottom in a layer of sediment.

A simpler form of mechanical treatment can take place if the water passes through a bar screen, a strainer or some other kind of coarse filter that traps large particles. In this case, unlike cleaning in a sedimentation basin, no compensation effect is achieved.

Biological treatment

Biological treatment can be either aerobic or anaerobic, i.e. take place with or without a supply of oxygen. In both cases, micro-organisms break down organic substances in the water. The primary purpose of the biological treatment is to reduce the quantity of organic material that consumes oxygen.

Various methods and installations exist for biological treatment. Examples are:

- aerated pond (tank)
- activated sludge plant
- trickling filters (bacterial beds)
- biorotors.

These installations have both advantages and disadvantages. A method may be highly efficient at cleaning the water but, at the same time, sensitive to uneven load or foreign substances (toxic substances in the water). The treatment can proceed at different rates and the end result may be a great deal or a small amount of sludge. Thus, any choice of treatment plant must take into account the type of sewage to be treated, operating conditions and the balance of priorities between efficiency, speed and durability.

A stabilization pond is a large pond in which, broadly speaking, nature's own way of cleaning water is simulated. The water contains certain micro-organisms in 'free' form. To enhance the cleaning capacity of a biological pond, air is blown into the water, raising the oxygen content and creating what is known as an aerated stabilization pond. Treatment processes are difficult to control in stabilization ponds, and the technique is therefore fairly uncommon if a high degree of treatment effect is sought.

In an activated sludge plant, treatment takes place in a bacterial culture that is

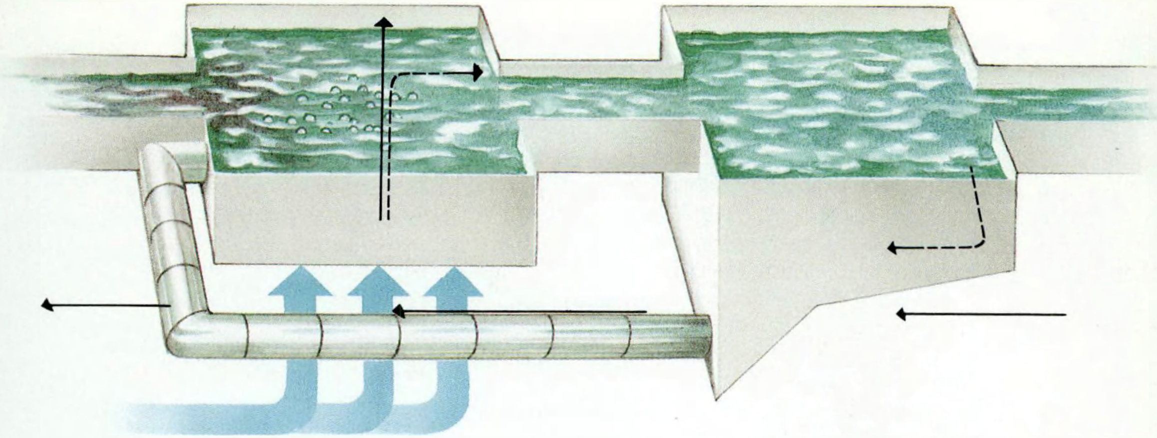


Figure 31. Treatment of sewage in sewage works can involve several stages: mechanical (primary), biological (secondary) and chemical (tertiary) treatment, and also processes specifically to remove nitrogen (figure 32). Treatment is carried out in different tanks, in which separated material settles out. To put it simply, a sewage treatment plant has two end products: cleaner water and a certain amount of polluted sludge.

These photographs show a sewage works in an average-sized Swedish town and a close-up of an activated sludge process tank at a normal sewage treatment plant. The diagram outlines the basics of the activated-sludge process. This biological treatment process is primarily designed to reduce the amount of organic, oxygen-consuming material. Special bacterial cultures are added to the water to break down the organic substances it contains.

Photographs: Lennart Norström, Naturfotograferna (bird's-eye view); Hans Ring, Naturfotograferna (close-up).

Diagram: Bosse Falk.

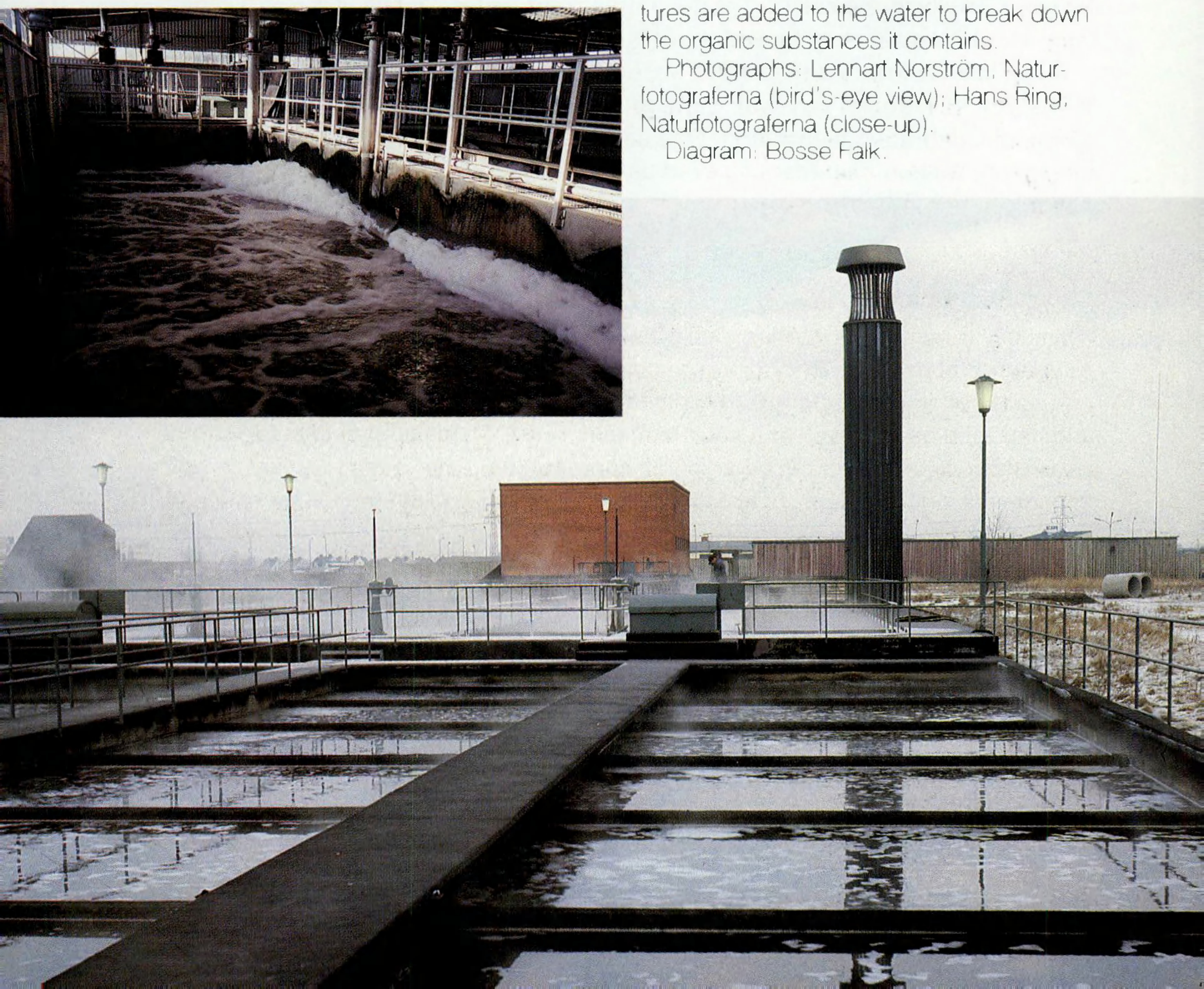


Figure 32. Processes specifically to remove nitrogen from sewage are complex and sensitive and are still uncommon throughout much of Europe. Several technical difficulties have yet to be resolved, and research is still going on. If they work properly, these processes markedly reduce levels of nitrogen in sewage effluent, in turn cutting inputs of nitrogen compounds to the sea.

The photograph shows the nitrogen removal stage in one of the tanks at the Henriksdal works in Stockholm. The diagram outlines nitrogen removal using the nitrification/denitrification process.

Photograph: Anders Kjellander.
Diagram: Bosse Falk.

kept suspended in the basin by means of air that is pumped in and oxygenates the water (*figure 31*). A sedimentation stage then follows. Part of the sludge is returned to the aeration basin in order to maintain a suitable concentration of bacteria there. An activated sludge plant has a high concentration of micro-organisms, and hence a large treatment capacity. However, it is sensitive to toxic substances that may be contained in the waste water and kill micro-organisms.

In trickling filters, sewage is sprayed over carrying material containing micro-organisms. The biobed is not as efficient as the activated sludge process neither, however, is it as sensitive to disturbances. One variant of trickling filters is a biorotor, in which the carrying material (the rotor plates) containing micro-organisms slowly circulates in the water.

Anaerobic biological treatment is based on the same principle as the denitrification stage of nitrogen removal: sewage containing a large proportion of organic material is degraded by bacteria. One advantage of this method is a lower rate of sludge production than that achieved using other forms of biological water purification.

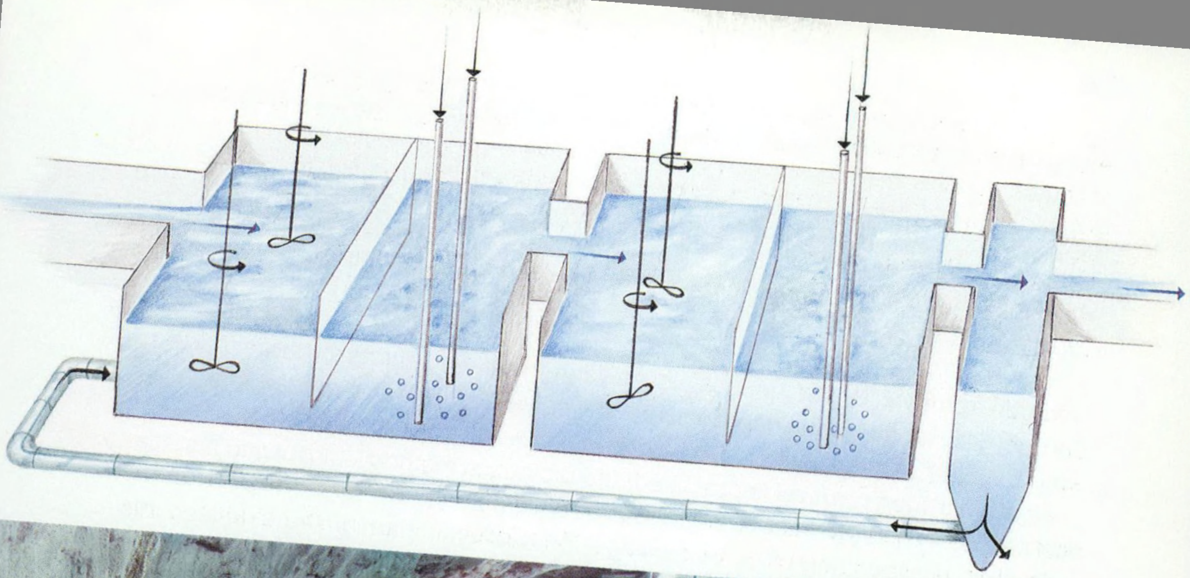
Chemical treatment

Chemical treatment is carried out mainly in order to remove phosphorus compounds from sewage. By adding precipitation chemicals, such as aluminium and iron salts, or lime, substances dissolved in the water are bound. They flocculate, and can then be removed in a sedimentation basin. Chemical precipitation can be carried out before or after other purification stages. One technique that is both economical and efficient in terms of results is multi-point precipitation, where precipitation chemicals are added at several points.

Chemical precipitation is also used to treat industrial waste water containing metals. Such waste water is treated with a solution of sodium or potassium hydroxide, or lime, causing the metals to form metal hydroxides and precipitate.

Nitrogen removal

Nitrogen removal may be carried out in several different ways. Some possible methods are:



- biological treatment with nitrification and denitrification in several consecutive stages
- degassing of ammonia
- ion-exchange technology
- assimilation of nitrogen by algae or plants (a kind of aquaculture).

Nitrogen removal is still unusual in sewage-treatment plants in large parts of Europe. Not all the technical problems are solved as yet, and research is under way.

Where nitrogen removal is practised, the biological method – involving nitrification and denitrification (*figure 32*) – is predominant.

Organic nitrogen must first be oxidized, producing ammonium ions, unless this has already occurred in the sewer system on the way to the treatment plant (nitrogen in sewage occurs mainly in the form of nitrate or ammonium ions). Municipal sewage contains large quantities of ammonium ions from urine and other substances. In an aerobic environment, these ions are converted by means of micro-organisms (bacteria) into nitrate ions. The next stage is anoxic, i.e. there is no free oxygen present. Special bacteria use oxygen in nitrate ions instead; what remains is 'pure' nitrogen, i.e. nitrogen gas, which may be released straight into the atmosphere.

Nitrogen removal is a complex and sensitive process. The organic material added must, for example, be appropriate for each stage: the content must be low in the nitrification stage and high in the denitrification stage.

In ammonia degassing, water is fed upwards into a cylindrical tower. Inside the tower are a large number of horizontal, perforated plates through which the water can run down. These divide the water into drops, giving a large total water surface. Large amounts of air are blown into the tower, upwards or straight in. The result is that ammonia gas is blown out through the tower, removing the nitrogen from the waste water. For method to succeed, the water to be treated must have a pH value exceeding 11.5. Merely allowing large quantities of ammonia to enter the air is, environmentally, quite unacceptable – ammonia is a major environmental problem. For this method to be acceptable from the environmental point of view, the ammonia emitted must therefore be collected in the installation.

Ion-exchange technology is used in numerous technical contexts. Expressed simply, it uses solid substances made up of large molecules which have a capacity to release certain of their own ions, taking up other ions from the surrounding media. Depending on which substance is added, it can be made to extract metal ions (recycling, for example, nickel, chromium or zinc from electroplating baths or iron ions from drinking water), calcium ions or ions of nitrogen compounds from contaminated water.

An ordinary water softener works on the ion-exchange principle. Hard, calcareous water passes through a bed composed of nitrolite (or ordinary table salt, sodium chloride). The nitrolite or salt binds calcium ions in the water, simultaneously giving off its own sodium ions and thereby making the hard water soft. On the same principle, one can add an appropriate ion-exchange substance to waste water so that it extracts and binds nitrogen (ammonium and nitrate ions), instead releasing other ions that do not cause environmental problems.

Using algae or plants to absorb the nitrogen compounds in waste water is another form of biological nitrogen removal. Living organisms are thus allowed to grow and flourish in the water, and a kind of ordinary nitrogen fixation takes place. Since the organisms are under control, there is no risk of the absorbed nitrogen leaching out, as it can do in land and water in natural surroundings. When the nitrogen has been consumed, the algae or plants can quite simply be strained from the water.

Sewage sludge – asset and burden

Sewage contains virtually all the chemicals and substances our society uses. Purification in treatment plants removes a large proportion of these substances, but in the 10–20% of organic material that remains after decomposition – the sludge – substances collect that do not readily decompose. Sludge may arise from the first stage, the preliminary sedimentation, or from biological or chemical treatment.

About half the sludge from municipal sewage treatment plants is composed of organic material. It also contains the plant nutrients phosphorus and nitrogen, as well as a number of trace metals which make it attractive as a fertilizer and soil conditioner for agricultural purposes. There are a number of objections to the agricultural use of sludge, connected with its concentrations of substances that are undesirable on farmland. The most important of these undesirable substances are heavy metals, especially cadmium. Sludge also contains stable organic compounds, albeit in considerably lower concentrations than the heavy metals. Examples of important stable organic compounds are nonyl phenols (degradation products from certain detergents), phthalates (softeners in plastics) and PCB compounds. These substances can be gradually decomposed in the soil if the sludge is used to improve soil quality. The heavy metals, on the other hand, remain stable.

Anaerobic digestion involves the degradation by micro-organisms, in anoxic conditions, of sewage sludge and the production of e.g. methane gas. Roughly half the organic material in the sludge decomposes during the 2–4 weeks that anaerobic digestion of municipal sludge usually takes. The process means that the sludge is stabilized while, at the same time, mineralization of nutrients occurs. Anaerobic digestion can take place in both sealed and open digestion chambers, and the sludge can also be stabilized with lime. Sometimes the sludge is placed in beds, or 'sludge lagoons', to be dewatered.

Sewage sludge has various uses. Some is used as a soil conditioner in agriculture. Some is dumped (this is permitted in the North Sea). Sludge from sewage treatment plants can also be used as a landfill and land-improvement material. Large quantities of sludge are, however, deposited on ordinary tips: sooner or later, this means that its substances are leached out and find their way into surface water and groundwater.

Another way of using sewage sludge is to dig it into the soil. Large quantities of sludge are ploughed into a special area, surrounded by a protective ditch, in which energy crops, for example, are then cultivated. This entails a turnover of the substances constituting sludge, but the ground is contaminated. Drainage water from these areas contains elevated concentrations of nutrients and can, theoretically, be used as liquid fertilizer; it is being experimentally used for this purpose in Denmark, the USA and other countries.

In Sweden, an attempt is to be made to produce biogas – methane – from sewage sludge. Large digestion chambers are planned in which something in the order of 30 % of the sludge should break down and give off methane gas. The rest of the sludge is pumped down into large rock shelters for final storage.

Treating polluted stormwater from urban areas

A glance at a street on a rainy day, or when snow is thawing, reveals how stormwater is formed. Hard surfaces, such as the walls of buildings, roofs, streets and car parks, are covered with particles, dust, oil, dry-deposited gases and other substances. When rain or other precipitation washes them off, the water becomes contaminated with oil, soot, heavy metals, acids, salts and ordinary dirt. This polluted stormwater, as it is called, can either be dealt with and cleaned or released, without cleaning, straight into a watercourse or the sea. Large amounts of water are involved each year. If this water is regularly discharged, in an unpurified state, into the sea, this input accounts for heavy pollution. Basically, stormwater reflects the degree of pollution in the area in which it collects. The larger the quantity of airborne and other substances deposited on the hard surfaces, the more is in due course found in the stormwater.

Sewer systems may be constructed in such a way that sewage, stormwater and drainage water are collected and carried to the treatment plant. This may involve capacity problems for the plant in the event of heavy rainfall, and hence large quantities of water in a short time. Stormwater mixed with sewage must then be discharged in untreated form: this is called overflow. To reduce the risk of overflow, the system can be supplemented by a compensation basin in which the 'surplus' water is stored pending available capacity.

In many sewer systems, separate pipes for stormwater and sewage are more common. Stormwater enters a sealed conduit and can, if it is fairly clean, be fed straight into a watercourse. Heavily polluted stormwater should be conducted to a treatment plant via a compensation basin.

Another method of treating stormwater is local treatment by means of infiltration. This represents a return to nature's own way of filtering water through vegetation, and is based on the slow seeping of stormwater through permeable ground covered with plants. Less polluted stormwater may be diverted to areas covered with grass and trees, where it can permeate the ground and be absorbed by the plants. If the ground is impermeable, a 'percolation reservoir', filled with gravel or some other material that allows the water to seep through, may be installed. The tank can also serve as a compensation basin when water flows are heavy.

Manifold methods for reducing air pollution

Air is polluted by industrial processes (the handling of chemicals and production of process energy), by power production in urban areas (combustion of oil and coal), by vehicle exhausts and by several other human activities. A portion of airborne contaminants ends up in the sea. As mentioned previously, nitrogen oxides, hydrocarbons (stable organic substances, such as DDT and PCB compounds, dioxins, etc.) and heavy metals pose major problems.

Atmospheric industrial emissions may contain sulphur and nitrogen oxides, carbon monoxide, hydrocarbons, carbon dioxide, dioxins, heavy metals, solvents and various other compounds. Urban areas produce large quantities of vehicle exhaust gases (hydrocarbons, carbon monoxide, nitrogen oxides, soot) and flue gases from energy production (sulphur and nitrogen oxides, carbon monoxide, carbon dioxide, heavy metals and soot). Pesticides (stable compounds) are dispersed via atmospheric emissions from industrial installations, private gardens, farms and forest land.

To deal with the polluting gases formed in the combustion of fossil fuels in stationary installations for power production, several types of control technology may be used, including:

- cleaning of fuels before combustion, or opting for another, cleaner fuel (e.g. natural gas)
- choice of an advanced combustion technique, staged combustion or gasification technology
- binding of substances, or minimization of their formation during combustion
- treatment of flue gases after combustion, before they are emitted.

Emissions from petrol and diesel vehicle engines require technology to:

- develop cleaner fuels, unleaded petrol, etc.
- modify engine design so that combustion becomes less harmful to the environment
- clean the exhaust gases formed before they are emitted.

Combustion technology and desulphurization

There are several methods for preventing the formation of nitrogen oxides during the combustion process itself. The important principles in the context are to reduce the combustion temperature – the higher the temperature, the more nitrogen oxide is formed. A lower combustion temperature is achieved by means of a gradual air supply, which in turn requires a modified design of the burner itself and of the combustion chamber. Modifications in the combustion process, such as two-stage combustion or gasification, also reduce the formation of nitrogen oxide.

Three examples of technology to reduce the formation of sulphur and nitrogen oxides during combustion in stationary installations (such as power and heating plants, or industrial process-energy plants) are:

- low NO_x burners, based on the principle of a gradual air supply
- SO_2 sorbents (usually lime or limestone)
- fluidized bed combustion.

Flue gas treatment to reduce emissions of sulphur and nitrogen oxides can be performed in several ways:

- flue gas denitrification, especially selective catalytic reduction (SCR), whereby nitrogen oxides in the flue gases are made to react with ammonia in the presence of a catalyst; the end products are nitrogen gas and water
- flue gas scrubbing with calcium compounds, whereby the flue gases react with a lime or limestone slurry or lime dissolved in water, the end products then being gypsum, water and carbon dioxide.

Dust emissions must also be reduced, especially since dust particles transport such substances as heavy metals and stable organic substances over long distances. Some methods of removing particles from air are mentioned below, in the section on the iron, steel and non-ferrous metal industries.

Reduced or cleaner vehicle-exhaust emissions

Both petrol and diesel vehicle engines emit considerable quantities of air pollutants – in particular, nitrogen oxides, carbon monoxide, hydrocarbons, lead and soot particles have been seen as the contribution by traffic to environmental destruction and damage to human health (*figure 33*). In many Western European countries, road traffic now accounts for 40–80% of the total emissions of nitrogen oxides to the air. Substantial amounts of these nitrogen oxides are in due course deposited in the sea, either direct on the water surface or transported by rivers and in land run-off.

The effects of regulations introduced to date with the aim of reducing vehicle-exhaust emissions have been, on the whole, offset by the increasing number of cars. The net effect has therefore been not to reduce nitrogen, hydrocarbon and

Figure 33. Vehicle exhausts are a major marine environment problem. Airborne pollutants account for a substantial proportion of the total load of pollutants reaching our coastal sea areas every year. Nitrogen oxides, hydrocarbons and heavy metals are perhaps the most important airborne substances affecting the marine environment. Rough estimates of nitrogen and heavy metal inputs to the Baltic and North Seas show that up to 50 % are atmospheric. In many West European countries, road traffic now accounts for 40—80 % of total emissions of nitrogen oxides to the atmosphere. Considerable quantities of these nitrogen oxides (and also heavy metals, e.g. lead from leaded petrol) eventually end up in the sea, either by direct deposition on the water surface or via rivers and land run-off.

Photograph: Klas Rune, Naturfotograferna.

carbon monoxide emissions but rather, at best, to keep their levels constant. However, there are few reasons for hoping that there will be any improvement in the situation in the near future, since the reductions decided on are too small to keep up with the increasing emissions.

Catalytic conversion of exhaust gases from petrol-driven vehicles has been in full commercial use for more than a decade in the USA and Japan. In Europe progress is slower, although several countries have taken far-reaching decisions concerning exhaust gas cleaning requirements. Research and development are under way to clean exhaust gases from diesel-driven vehicles as well.

A three-way catalytic converter reduces emissions of carbon monoxide and hydrocarbons by 80 – 95 % and nitrogen oxides by 70 – 75 % compared with existing conventional petrol-driven vehicles. With regular maintenance, a converter can have an cleaning efficiency of up to 80 %. The difficulty is that effective catalytic cleaning of exhaust gases can only be introduced in new cars, and it will therefore take a long time before the measure achieves its full effect. The technology also requires unleaded fuels and regular maintenance for its functioning.

A system for catalytic conversion of vehicle exhaust gases comprises three parts. A Lambda sensor measures the amount of oxygen in the exhaust gases and sends a signal to an electronically regulated carburettor or a fuel injection system. Then the actual three-way catalytic converter is activated: in it, carbon monoxide and hydrocarbons are oxidized, forming carbon dioxide and water, and nitrogen oxides are reduced to nitrogen gas. The catalytic converter is composed of ceramic material coated, for example, with the precious metals platinum and rhodium. The converter needs unleaded petrol since lead blocks the catalytic effect of the precious metals.

Another technical solution to vehicle exhaust problems has been mooted in recent years. Research has been conducted to construct a new type of engine using 'lean burn' technology. Such an engine, supplemented with an oxidation catalytic converter, would meet high abatement requirements. The principle for a lean burn engine is that more air is fed into the engine in relation to the amount of fuel than in an ordinary car engine. A strong but controlled eddying movement of the mixture of air and fuel is induced, making combustion faster and more complete. It is because of incomplete combustion that ordinary engines produce 'waste' carbon monoxide and hydrocarbons. The excess air in a lean burn engine cools the cylinders, making the engine work with a lean mixture of petrol and air. This results in cleaner exhaust gases, especially where carbon monoxide and nitrogen oxides are concerned.

It will probably be a long time before this engine has been developed. Until then, three-way catalytic conversion is the only technique of efficiently reducing emissions from vehicles. It should also be borne in mind that it will take many years before Europe's entire vehicle fleet has been renewed and the old vehicles are replaced by new ones fitted with catalytic converters. Thus, there will be a long time-lag between action taken today and any noticeable effects on the environment.

One way of reducing nitrogen-oxide emissions immediately is for motorists to slow down. There is a direct link between speed and nitrogen oxide formation. This applies particularly to speeds exceeding 60 km/h. Nitrogen oxide emissions from a car maintaining a constant speed of 120 km/h are more than four times as high as from one driving at 60 km/h. Driving more slowly is then, in a sense, an emission control technique – and one that everyone can start applying immediately, at no cost. In a few years' time, motorists' reduced speeds would be as significant in reducing nitrogen oxide emissions from vehicles as the various decisions to improve emission control.

Reduced discharges, more recycling of metals and hydrocarbons

Industrial activities give rise to considerable heavy metal discharges. Metals are released into both air and water from mining and iron-, steel- and other metalworks. The surface-treatment industry discharges copper, chromium and zinc. Large quantities of iron, cadmium, copper and zinc come from mining and mining waste. Metalworks discharge arsenic, lead, cadmium, copper, mercury and zinc. Iron- and steelworks contribute metalliferous dust which represents inputs of iron, lead, chromium, nickel, zinc, etc. to the environment. Pickling in the metal-processing industry releases metals with the pickling liquids used to remove oxidized layers on metal surfaces before galvanization. Metals and other substances in particle form can be removed after the process by means of cyclones, scrubbers, electrostatic precipitators or suppression (bag) filters. Electrostatic precipitators and suppression filters are highly effective, but require large and relatively expensive plants. Cyclones are less effective cleaning devices, but cheaper to install and operate. A scrubber purifies air both of particles and of certain gaseous substances, but has the disadvantage of producing wet waste that must be disposed of.

Iron-, steel- and non-ferrous metalworks can also release solvents that have been used for 'degreasing' before surface treatment. Degreasing tanks can be cleaned and components recycled by means of internal cleaning techniques. Using a method known as ultrafiltration, oil and grease can be removed from the waste water from degreasing tanks. The water passes through a membrane that allows the passage of water and salts, but not oil and grease. On the other side of the membrane, the tank liquid emerges with a large proportion of its detergent chemicals, which can then be fed back into the degreasing tank and used again.

The surface-treatment industry can use enclosed nickel-plating and chromium-plating processes. An investment of this kind is worthwhile since it avoids the need for, respectively, cleaning of metalliferous waste water by chemical precipitation and disposal of sludge containing metal hydroxides (see above). It is also possible to enclose other industrial processes, greatly reducing discharges and enhancing opportunities of recycling valuable auxiliary chemicals and raw materials.

Solvents used and released from a number of different industrial sectors can be recycled using an activated-carbon filter (adsorption on carbon) or a plastic material (adsorption on polymer material), in both water and gas flows. Hydrocarbons become 'attached' to the carbon and can be recycled. Other ways of using measures extraneous to the actual processes to clean outgoing polluted industrial air from gases are condensation, combustion (in fire or by a catalytic process) and absorption in a liquid.

Substitutes now exist for PCBs as flame retardants, insulators and heat carriers, and in other areas of application. If PCBs are still used, they should be kept in enclosed systems. Discharges of PCBs take place in conjunction with the scrapping of decommissioned transformers, condensors and other, similar devices, as well as with the burning of old PCB oil. In addition, if an installation containing PCBs is damaged or mismanaged, PCBs can be released into the environment. Since there are now a large number of installations which, sooner or later, will need scrapping and replacing, methods are being developed to dismantle and strip installations, removing the PCBs they contain.

Dioxins can be formed in many different combustion processes, including combustion in iron-, steel- and other metalworks, the chemical and forest industries, coal-fired power stations, hospital furnaces, incineration of environmentally hazardous waste and the burning of garbage. Vehicle-exhaust gases, too, have been shown to contain dioxins. In stationary incineration plants, it is mainly combustion processes and other operating conditions that need changing to reduce the quantity of dioxins formed. The burning of chlorinated substances in waste can be prevented if waste is sorted. Plastic materials are softened by means, for example, of chloroparaffins. Thus, chlorinated substances are used both in the plastics industry and in waste management.

Tensides are substances that reduce surface tension in water and are included in detergents, emulsifiers and foam-quenching preparations. In ordinary soaps and detergents used on an everyday basis, tensides are usually fatty alcohols. Industrial chemicals contain other kinds of tenside. When certain tensides – alkyl-phenolic ethoxylates – are partially degraded, in nature or in municipal sewage treatment plants, an environmentally hazardous degradation product can be formed. This can withstand both aerobic and anaerobic biological degradation, and is highly toxic to aquatic organisms. In Switzerland and the Federal Republic of Germany (FRG), there are special regulations or agreements to restrict the use of alkyl-phenolic ethoxylates.

Responsible waste management reduces discharges to the sea

Society's waste management is an environmental issue very much affecting the sea. The basic objectives of all waste management should, for all environmental and health reasons, be to

- reduce the amount of waste produced
- recycle materials and energy from the waste
- decrease the quantity of environmentally hazardous substances in the waste
- concentrate on safe treatment methods to deal with the waste we nonetheless produce.

By using raw materials and products better (resource conservation, recycling), separating various types of waste and striving to find long-term solutions to waste problems, we can reduce environmental effects. In industry, it is a matter of replacing raw materials and auxiliary chemicals by other products; this is also important as a general measure of reducing the environmental impact of industrial processes. Where possible, industry should be made to seek enclosed processes permitting the highest possible degree of recycling (internal process measures) and reuse. Waste can be processed to make recycling feasible.

The main methods of processing household waste and some forms of industrial waste (not classed as environmentally hazardous) are:

- land-filling
- incineration
- composting.

The wastes from incineration processes contain heavy metals. Fly ash, which is the ash from pulverized coal, contains the heavy metals that were contained in the coal. After incineration, both material from the fuel – ash (material that has not undergone a chemical reaction or remained unburnt) – and products formed during the cleaning of flue gases generally remain. This waste must be disposed of. If disposal is carried out in the wrong way, heavy metals and other substances can leak out and pollute the land, the groundwater and, in due course, the sea as well.

Incineration of household waste generates energy, but also entails risks of dispersion of heavy metals (especially mercury and cadmium), stable chlorinated substances including dioxins, and hydrochloric acid (hydrogen chloride) to air and water. When waste is deposited, there is an evident risk that leachate will in due course contaminate land and water. Various substances, including mercury, are

also emitted in gaseous form from a waste tip. Dioxins are spread by spontaneous fires on tips – something that is very common.

Garbage incineration is acceptable as a method of handling waste only if the burning is effective and advanced flue gas cleaning technology is used. The most environmentally acceptable way of tackling the growing mountain of refuse in urban areas is, first, to try to reduce the quantity of waste (fewer disposable articles, more recycling and collecting) and, secondly, to sort the refuse at the site of production, in households and industrial installations. Such sorting at source means the separation of plastic, paper and glass waste, wet organic waste, batteries and other environmentally hazardous waste, etc. The less mixed the waste is, the easier it is to dispose of.

Tipping of household waste and solid industrial waste is, in general, a method that may involve long-term environmental hazards, even if efforts are made to surround the tips with protective barriers and, as far as possible, to divert the leachate. Tips and land-fills are literally a growing problem in urban areas, and ordinary land-fills will probably remain the commonest method of disposing of both household and industrial waste for a long time to come (*figure 34*).

Environmentally hazardous waste and high-risk waste (from hospitals and other institutions whose work involves pathogenic infectious matter) must be treated with extra care. High-risk waste is burnt, but environmentally hazardous waste – mainly from industrial processes – is either dealt with by the company producing it internally or delivered to special treatment plants.

Examples of environmentally hazardous waste are oil residues, solvents, paints

Figure 34. Waste management is, literally, a growing problem throughout the world. The way we deal with our solid and liquid wastes, from industry, power stations and urban areas, is ultimately a matter of considerable importance to the marine as well as the terrestrial environment. At present most urban household refuse and some industrial waste is disposed of by tipping or landfill. The mountains of rubbish are growing, with an ever increasing danger of polluted leachates eventually reaching soil and rivers. Mercury can vaporize and thus leak from tips in gaseous form. Spontaneous fires often break out on large waste tips, producing dioxin-polluted smoke.

Incineration and composting are other ways of disposing of household and industrial wastes. These methods, too, result in environmentally disruptive substances escaping into soil, water and the air. Hazardous wastes are another complex problem facing modern society.

The only responsible approach to waste management is to reduce the amounts of waste produced, recover as much material and energy as possible from the waste that does arise, minimize the quantities of hazardous substances used and invest in truly safe methods of processing wastes. In Denmark, systematic sorting of domestic refuse at source has been introduced and has proved very successful. The photographs show the system of separate containers for glass, paper, wet refuse etc.

Photographs: Björn-Eyvind Swahn, Naturfotograferna (tip); Renovdan Systemtransport, Gentofte, Denmark (sorting at source).

and lacquers, glues, waste products containing heavy metals, waste containing cyanide or PCBs, pesticides, chemical residues and laboratory waste. Hazardous waste is derived not only from industrial activities but also from public transport and various types of public service, agriculture and forestry; electric-power plants, gasworks, waterworks and heating plants; building sites, etc.

Figure 35. Incineration of environmentally hazardous industrial wastes on board special incineration vessels on the open North Sea has evoked strong emotions among both scientists and the general public. Widely diverging views are held as to how efficient this incineration is and hence how environmentally acceptable it can be considered to be. If combustion is incomplete (temperatures below 1 250°C), toxic compounds are produced, and these end up in the sea. Ocean incineration will in all probability be discontinued. At the 1987 North Sea Conference, participating countries were called on to cut ocean incineration by at least 65 % by 1991 and to stop the practice altogether by the end of 1994.

Photograph: Greenpeace.

There are technical means of transforming certain kinds of environmentally hazardous waste into natural compounds that may be released or deposited without any risk. Waste containing cyanide can, for example, be oxidized to give carbon dioxide and nitrogen gas as end products. If a transformation of this kind is not feasible, it is nevertheless in some cases possible to treat environmentally hazardous compounds to make them somewhat less harmful, whereupon they can be deposited in controlled ways. Metals can be precipitated as metal hydroxides, producing a sludge that must then be disposed of. Controlled deposition at special sites is carried out at purpose-built installations. Waste can then, for example, be surrounded by protective embankments, rest on a base that is sealed against the ground and be covered by material that prevents rainfall and surface water from penetrating the waste and leaching it out.

Incineration of industrial waste at sea is a controversial method of disposal, and researchers' opinions are divided as to how effective incineration really is as a method of destruction. Proponents claim that more than 99 % of the substances involved are destroyed, becoming environmentally harmless. From this point of view, incineration – given optimal functioning – is an efficient method of destruction. Opponents assert, however, that technical deficiencies rule out complete incineration at the maximum temperature (1 250°C) for a maximum period. If incineration is inadequate, toxic compounds are formed and dispersed, especially various halogenated organic compounds, including dioxins. Another objection to incineration at sea is that incineration vessels are not equipped with the supplementary, multi-stage cleaning installations that are required for optimal cleaning of flue gases – cleaning devices that must exist when the corresponding incineration takes place on land. Incineration at sea is also an activity that cannot easily be monitored and surveyed on a continuous basis, as can be done with a stationary land-based facility. Accordingly, incineration at sea has come to be regarded as a form of waste disposal that is, largely speaking, outside the ordinary scope of society's control (*figure 35*).

When halogenated substances in waste are completely destroyed in incineration, hydrochloric acid is formed. Substantial amounts can therefore be dispersed to air and water. Some researchers consider that hydrochloric acid can change the sea surface microlayer, and this would increase the bioavailability of the stable substances that collect there.

Environmentally less harmful production of pulp and paper possible

The forest industry, which makes paper pulp and finished paper products, causes discharges to water of the following main substances:

- suspended solid organic and inorganic substances (fibres, bark, sand, clay, lime, etc.)
- dissolved organic and inorganic substances (lignin, stable organic substances including chlorinated compounds, acids, bases, nutrients, etc.).

The manufacture of pulp and paper, from timber to finished product, is a complicated process comprising a series of different stages. The following is a very concise description of their course (*figure 36*).

There are two main types of pulp – mechanical and chemical pulp. Mechanical pulp is produced when the timber is ground. Chemical pulp is produced when wood chips are cooked, at high pressure, in a liquid containing sodium hydroxide and sodium sulphide (yielding sulphate pulp), or hydrogen sulphide and sulphite or sulphur dioxide (yielding sulphite pulp). Sulphate pulp is the commonest type of chemical pulp.

The cooking process dissolves lignin – a substance holding the cellulose fibres together – from the raw material. The residual lignin in the sulphate pulp imparts to it a characteristic brown colour. To obtain white paper pulp, the remaining lignin

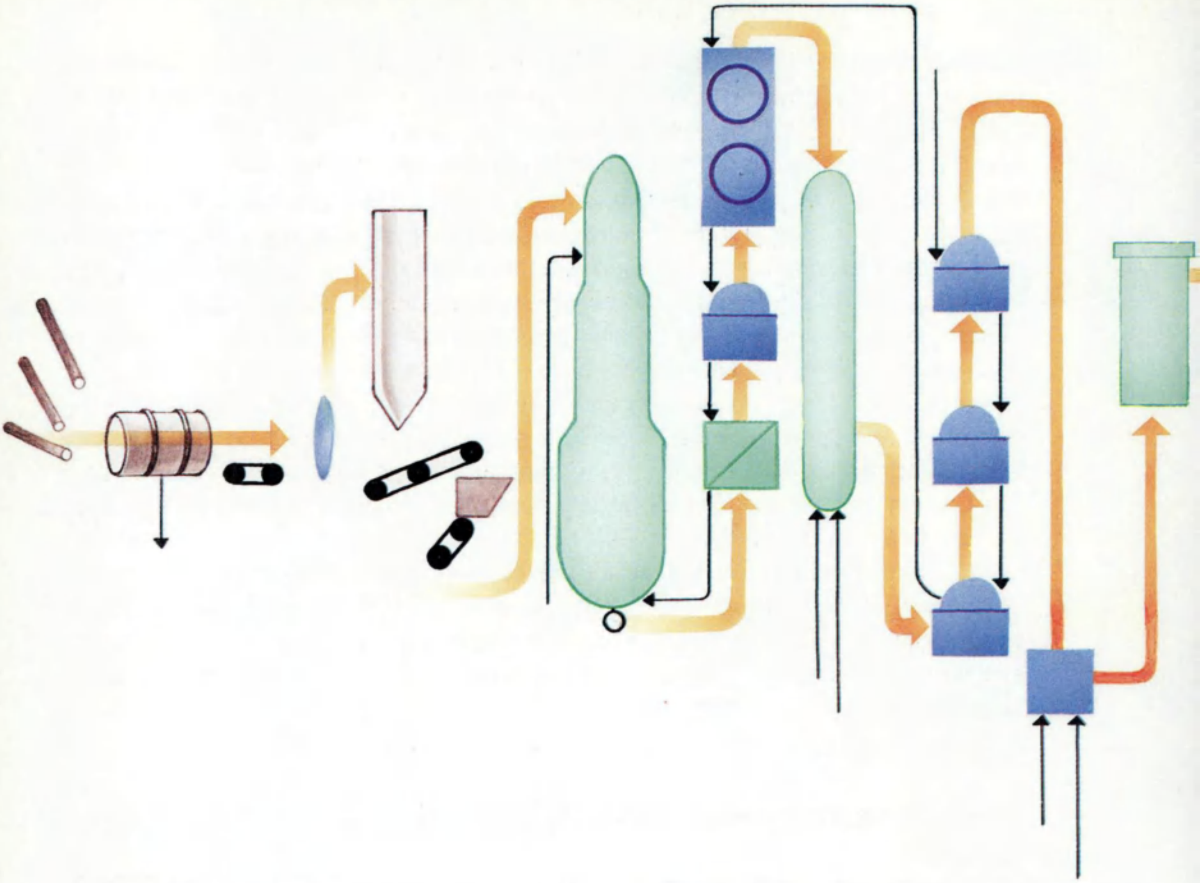
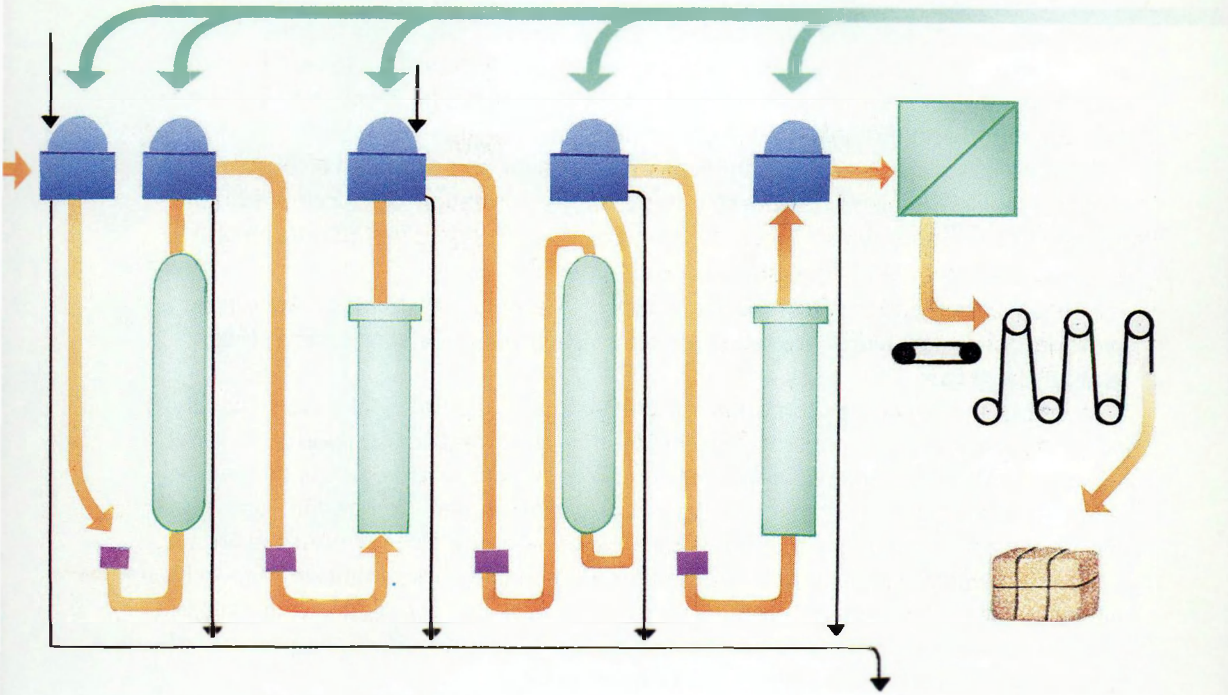


Figure 36. The manufacture of chlorine-bleached pulp is a complicated process involving many stages. Chemical pulp is produced by boiling wood chips in a solution of sodium hydroxide and sodium sulphide. This dissolves lignin, a wood component binding together the cellulose fibres in the wood. Lignin residues in sulphate pulp give it a characteristic brown colour. To make the pulp white, as much as possible of the lignin and coloured lignin compounds has to be removed. Bleaching of chemical pulp is not in fact a 'dyeing' operation, but a process to break down lignin molecules chemically and thus eliminate lignin. It would be more apposite, therefore, to call it 'further lignin removal'. Chlorine compounds are added during the bleaching process precisely with a view to achieving chemical breakdown of the lignin.

To reduce the use of chlorine as far as possible, modern pulp and paper mills are making boiling and pre-bleaching washing of pulp more efficient and treating pulp with oxygen. Producers are trying to reduce chlorine consumption to the minimum that is technically feasible. In several West European countries, companies are now seeking to compete on the basis of being able to offer customers paper and other pulp products not bleached with chlorine.

Illustration: Bosse Falk.



and the coloured lignin compounds must be dissolved. The bleaching of pulp should, in fact, be called 'further lignin removal', since it is a matter of using chemicals to transform the remaining lignin and then wash it out of the pulp. The chlorine compounds used in the bleaching react chemically with the lignin and other molecules, breaking down chemical bonds.

The chlorinated substances are discharged in the water with the lignin that is released. The key to reducing these discharges is thus, as far as possible, to decrease the lignin content in the pulp at an early stage – which lessens the need for further lignin elimination, i.e. bleaching. Waste water containing chlorinated material can be treated biologically, but also by other methods, such as ultrafiltration. Discharges of chlorinated substances to water can be reduced if:

- delignification progresses further before the final bleaching, e.g. by longer cooking of the pulp and treatment with oxygen gas
- the pulp is washed effectively before the final bleaching
- the use of chlorine gas in the bleaching process is reduced; chlorine gas should, as far as possible, be replaced by chlorine dioxide
- good process control is maintained
- partial waste-water streams in the bleaching plant are treated internally
- waste water is treated externally.

Cooking pulp more efficiently and pretreating the pulp with oxygen gas are two ways of reducing the lignin content and thereby decreasing the need of bleaching in subsequent stages. The pulp should also be washed effectively before bleaching. Oxygen-gas bleaching can lower the lignin content by 35–45%. However, such measures cannot be pursued to any length whatsoever, since the fibres are then damaged and the final pulp is of deficient quality.

Chlorine gas as a bleaching chemical should, as far as possible, be replaced by chlorine dioxide, which considerably reduces the formation of chlorinated compounds in the waste water. Nevertheless, chlorine dioxide gives rise to chlorate, which is toxic to brown algae such as bladder wrack.

Kitchen paper and lavatory paper in which the pulp has been bleached with hydrogen peroxide alone are now available. Such paper is almost white, with a faint yellow tinge.

Attempts are now made to permit the pretreatment of pulp so far before bleaching (at such a low lignin content) that the chlorine gas need not be used at all. Until this is technically feasible, a shift from chlorine gas to chlorine dioxide is then a first stage in reducing environmentally hazardous discharges. For certain types of chemical pulp, bleaching without the use of chlorine gas is already possible today.

Fibres in waste water can be separated by mechanical treatment. In pulp mills with this form of treatment, discharges of fibre materials that make water turbid and consume oxygen have been reduced by 90%. This prevents the problem of fibre banks on the bottoms outside mills from arising.

As mentioned previously, discharges from the pulp and paper industry to water contain a large number of unidentified chlorinated substances and other compounds. By efficient reuse of the water used in the manufacturing process, internal treatment of the water, separate conduit systems for different types of water and highly efficient external treatment, combined with changed utilization of chemicals, it should be possible to reduce the negative environmental effects of the waste water to a low level.

Chlorine and alkali can be produced without mercury

In the chlor-alkali industry, chlorine gas and sodium hydroxide (alkali, or caustic soda) are produced – industrial chemicals used for a number of industrial purposes. In the process, water and sodium chloride (table salt) react to form chlorine gas, sodium hydroxide and hydrogen gas.

The chlor-alkali industry is a key one for the forest industry, but also for other sectors that use chlorine and alkali as raw materials and auxiliary chemicals.

The chlor-alkali industry has become a problem in the context of marine pollution, since large discharges of mercury are made from the conventional production methods.

At present, there are three different processes for making chlorine and sodium hydroxide:

- the mercury-cell (amalgam) method
- the diaphragm method
- the membrane method.

Chlorine gas and sodium hydroxide must be separated to prevent them from reacting and forming by-products. In the mercury-cell method, this takes place when chlorine gas and sodium hydroxide are formed in two different cells (primary and secondary cells, see *figure 37*). In the primary cell, chlorine gas is formed. The sodium metal alloys with the mercury in the cell, forming an amalgam, which is then transferred to the secondary cell in which sodium hydroxide, hydrogen gas and pure mercury are formed. The mercury is then returned to the primary cell.

Atmospheric emissions of mercury from the chlor-alkali industry arise from a diffuse leakage from the cells, and from the handling of mercury in the manufacturing process. Mercury emissions can be remedied by means of improved work routines, such as a kind of extractor-fan device in the buildings where the cells are located. The hydrogen gas produced also contains mercury, but this mercury can be removed by cooling the gas and conducting it through carbon filters. The gas can also be washed with an oxidizing solution.

In the diaphragm method, chlorine gas and sodium hydroxide are separated by means of a porous 'wall' of asbestos. The brine is fed into the part of the cell known as the anode compartment. There, chlorine gas is formed and the liquid is then diverted into the cathode compartment, where sodium hydroxide and hydrogen gas are formed. The diaphragm method has the advantage of being mercury-free, but it also has certain disadvantages: the sodium hydroxide solution has a low concentration, and contains sodium chloride.

The membrane method is based on the separation of chlorine and sodium hydroxide by means of an ion-selective membrane. This dividing 'wall' or 'skin' thus lets only certain ions through. The brine is fed into the anode compartment, where chlorine gas develops. The negatively charged sodium ions pass into the cathode compartment, where water is added and sodium hydroxide and hydrogen gas can form. The membrane method, too, is free of mercury but has the same disadvantage as the diaphragm method with respect to the concentration of the alkali.

Sodium hydroxide is a raw material or auxiliary chemical in the production of, for example, glass, ceramics, soap, aluminium products and textiles, as well as in the bleaching of paper pulp.

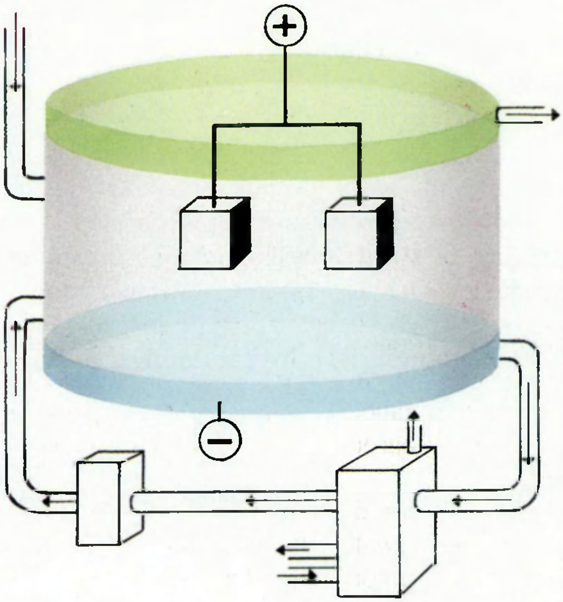
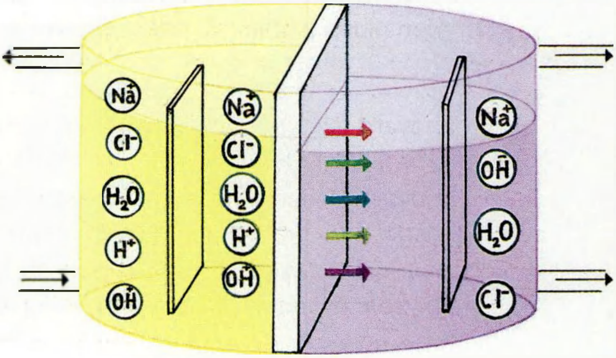


Figure 37. The chlor-alkali industry produces a range of industrial chemicals, including those used in the pulp and paper industry — chiefly chlorine and alkali (sodium hydroxide, or caustic soda). The main products of the chlor-alkali process are chlorine gas, sodium hydroxide and hydrogen gas. The raw material of the process is common salt, sodium chloride, which is broken down by electrolysis into differently charged atoms or groups of atoms (ions). Environmental problems have arisen because the chlor-alkali industry, which uses the mercury-cell (or amalgam) method, discharges large amounts of mercury in effluents.

The mercury-cell method (diagram above) is based on chlorine gas and sodium hydroxide being produced in two different cells. Chlorine gas forms in one of them. The sodium forms an amalgam (i.e. an alloy) with the mercury, which is then transferred to the other cell, where sodium hydroxide, hydrogen gas and pure mercury form. Mercury discharges arise from diffuse cell leakage and mercury handling during production.

The diaphragm and membrane methods are mercury-free. Instead of a mercury electrode (which attracts the positive sodium and hydrogen ions and hence concentrates these substances), they use materials which selectively permit different ions to pass through. In the diaphragm method (outlined in diagram below), chlorine gas and the alkali are separated by a diaphragm, a porous 'wall' of asbestos. The membrane method separates the chlorine and sodium hydroxide by means of an ion-selective membrane, this too a type of dividing 'wall' or 'skin' which only lets through certain ions. This achieves the desired separation and production of pure substances.

Illustration: Bosse Falk.



Reduced nutrient leaching with better handling of fertilizers and better land use

Leaching of nutrients – nitrogen and to some extent phosphorus as well – takes place in intensively cultivated farmland and forest land. The role of nitrogen versus phosphorus in the overfertilization of coastal seas is debatable, but there is every reason why the leaching of nitrogen, in particular, from farmland and forest land should be stopped.

Excess nitrogen also causes pollution of groundwater (high nitrate concentrations in drinking water are a health problem) and contributes to soil acidification. Moreover, it is economically unfortunate from the viewpoint of farmers and society that nutrients are literally washed away to no purpose. Another environmental problem in arable land is that artificial phosphate fertilizer and digested sludge add cadmium to soil.

Agricultural losses of nitrogen take place in various ways, the main ones being:

- leaching
- denitrification
- run-off
- ammonia release.

Ammonia release and run-off apply mainly to farmyard manure that has been stored in the wrong way or spread at an unsuitable time (*figure 38*). If farmyard manure is spread on fields in the autumn, when no plant cover remains, surface run-off removes a large amount of fertilizer. Chemical processes in the fertilizer cause it to give off nitrogen in the form of gas, straight into the atmosphere. Farmyard manure that is spread on the ground without being ploughed in, and moreover at a time when there are no plants whose roots can take up the nutrients in the manure, is thus largely wasted.

- Farmyard manure should be spread only during the spring and the growing season, when crops' uptake of nutrients is at a maximum.
- Farmyard manure that is not spread on growing crops should be ploughed into the soil, rather than spread on the surface.
- On farms, farmyard manure should be stored in a way that prevents nitrogen both from evaporating and from being leached out and washed away.

Figure 38. Large amounts of nitrogen and some phosphorus are leached from intensively cultivated farmland (and also forests). The role of these elements in the eutrophication of coastal seas is debated — in some areas nitrogen is the cause of eutrophication, in others phosphorus, depending on nutrient concentrations in the receiving waters. However, there is every reason to put a stop to nutrient leaching from cultivated land. Nitrogen losses not only result in over-fertilization of lakes, watercourses and seas, but also produce high nitrate levels in groundwater, which are a health hazard. What is more, the fact that these nutrients are doing no good (but a lot of harm) when they are washed away like this does not make economic sense to farmers or to the community as a whole.

The emission of ammonia from farmyard manure — nitrogen 'evaporating' into the atmosphere — is an air and water pollution problem that is attracting growing attention. Spreading manure on bare or frozen soil causes nitrogen losses in run-off. Correct storage and use of farmyard manure are thus important factors in reducing nitrogen inputs into seas and lakes. Artificial fertilizers also have to be used with care — they too must be applied to the soil when it has a crop cover that is able to utilize them.

Photograph: Klas Rune, Naturfotograferna.

It is important to note that nitrogen leaching results from the fact that nutrients circulate without being taken up by any plant roots. The type of fertilizer used does not really matter – the nitrogen in farmyard manure can be leached out as much as that in artificial fertilizer. However, on intensively cultivated cereal producing farms, where there are hardly any animals, it is mainly artificial fertilizer that is used. Animal husbandry automatically produces farmyard manure, thus increasing the proportion of nutrients provided by this form of fertilizer.

Farmland is fertilized in the spring. The crops take up virtually all this fertilizer, plus the nutrients stored in the ground. During this intensive growth period, hardly any nitrogen at all is lost. There may possibly be a risk of denitrification (bacterial conversion of nitrate into nitrogen gas) if the ground is very damp, warm and biologically active.

After harvesting, the risk of nitrogen losses increases steadily. Immediately before the harvest, the soil is deficient in nitrogen since most of it has been taken up by the crops. When the farmer harvests the crops, the plant roots and stubble remain. Straw and stalks may also remain on the field, but nowadays these remains from harvesting are increasingly used for other purposes. Then comes the autumn rain, the ground becomes soaked and the micro-organisms start working to break down the remaining organic material. The nutrient substances contained therein are released (mineralization) and the nitrification process starts. Nitrogen in the form of mobile nitrate ions enters the soil solution, and it is now that the risk of leaching begins to assume really serious proportions. No plants that take up this free nitrogen, and the nitrogen starts to leach out and flow in the soil solution into watercourses and seas.

Bare – fallow – land thus greatly promotes nitrogen leaching. As soon as the remains from harvesting, such as straw, with a low nitrogen content, are ploughed into the ground after the harvest, the risk of nitrogen leaching diminishes slightly. This is because, in decomposing, these plant parts consume a large number of ammonia and nitrate ions and thus prevent them from leaching out.

The warmer the autumn and winter, the larger the risk of nitrogen leaching. When the ground is saturated with water and there is no frost in the ground to bind substances there, the nitrate ions are literally washed away.

Nevertheless, it is possible to offset nitrogen losses and, by the same token, the nitrogen load in the environment. Agricultural policy should be oriented towards making it feasible and profitable for the individual farmer to keep land under cultivation and to:

- grow autumn-sown crops (autumn-sown grain and oil-yielding plants)
- grow winter pasture crops (on farms with livestock)
- grow intermediate or catch crops (that take up nitrogen)
- reduce soil scarification (less ploughing, harrowing, etc.).

The principle is the same for the cultivation of all these crops: they must be present to absorb the mobile nitrogen in the form of nitrate when it is released in the soil in the autumn and winter. Leaving farmland fallow is by far the least environmentally sound form of agricultural land use.

Modern, highly efficient and intensive agriculture has altered crop rotation and thus the turnover of plant nutrients. On farms with both animal husbandry and crop cultivation, part of the land needs to be devoted to grass, pasture and other coarse fodder plants. Livestock management concentrating on pigs instead of cattle usually means that large areas are cultivated with feeding grain. On cereal farms without livestock, only cereals are cultivated and the land therefore lies fallow during the winter months. In 'mixed' cultivation, with varied crop rotation, nitrogen leaching is unusual. In monocultures, with periods when the land is bare, nitrogen leaching has become common. Ultimately, this is the result of society's agricultural policy. Individual farmers are subject to heavy economic pressure and cannot afford to make such environmental concessions as, for example, planting catch crops in the cereals. If this were encouraged, both politically and economically, it would probably be done on a larger scale.

Demands for large harvests have also resulted in the large-scale use of fertilizer. Many farmers apply fertilizer in amounts that are larger than necessary, 'to be on the safe side'. This is unprofitable for the farmer, since nutrients are washed away to a large extent, and for society, which incurs more severe environmental problems. Economically, the larger harvests can hardly justify the shift towards a technique of cultivation that creates environmental problems. In the last resort, it is society that must foot the bill. It is not individual farmers who should be blamed: they are merely acting in accordance with what is favoured and encouraged by society and its agricultural policy.

Nitrogen leaching is greatest in bare, light (sandy) soils, in areas of heavy rainfall. These are the same features that are conducive to cultivation, which may explain why fertile, intensively used land also tends to suffer heavy nitrogen leaching.

Phosphorus is not leached as easily as nitrogen. This is because, chemically, phosphorus has a greater propensity to become bound in the soil. Phosphorus remains largely in the upper layers of soil; some may be flushed away by melting snow or a heavy rainfall, entering the surface run-off. The quantity of phosphorus lost from farmland is relatively smaller than the amount of nitrogen lost, but even small quantities of leached phosphorus lead to marked environmental effects in lakes and in the sea.

At present, there are researchers who argue that the active restoration of wetlands should be recommenced in agricultural areas, in the border areas between arable land and the littoral zone. Ditch-digging to bring larger areas under cultivation has meant that the wetlands of former times have disappeared. These wetland areas served as 'nitrogen-removal plants': large amounts of inflowing nitrogen were consumed by plants in the wetlands. Ditch-digging and the construction of culverts in modern farming – and also forestry – have caused the destruction of natural watercourse systems and mean that the water, with its content of leached-out nitrogen, flows rapidly through and out into the sea. If some land is utilized to restore former wetlands and pools, a portion of the nitrogen can be retained instead of leaching out into lakes and seawater.

In areas of intensive forestry, especially where rapidly growing tree species are cultivated, nitrogen leaching has become a new problem. The forest is now fertilized from the air, via the heavy atmospheric deposition of nitrogen. In addition, some active forest fertilization takes place. Both these additional sources can lead to nitrogen saturation of the soil, whereupon nitrogen is leached out into the water. The more acidified forest land then becomes, the more the phosphorus is fixed and the nitrogen leached. Active loosening of topsoil in the forest – including large-scale drainage of former wetlands for afforestation – also enables nutrient substances in the surface layer to be converted (mineralized) and released more easily.

Removal of nitrogen from industrial effluents and fish farms

As well as from farms and urban areas, nutrients enter watercourses and seas from industrial effluents and fish farms.

Large discharges of nutrients from industry are derived mainly from the food industry – dairies, slaughterhouses, breweries, fish processing, sugar refineries, starch factories, etc. – and from the industrial manufacture of fertilizers, explosives and paper pulp. This kind of waste water is sometimes fed into municipal sewage treatment plants, but since large quantities of water are involved the plants can become somewhat overloaded. Moreover, as mentioned above, the capacity to remove nitrogen from waste water is relatively small. Waste water must therefore be treated internally – in the course of the industrial processes – or externally in order for nutrient discharges to be checked.

Iron- and steelworks discharge nutrients with pickling liquids in the waste water. Pickling is the treatment before galvanization of oxidized metal surfaces. Pickling is carried out with liquids containing nitric acid, which produces nitrogen, and phosphoric acid, which produces phosphorus. These pickling liquors can be recycled.

Nutrients are also released from coking and by-product plants. Bound ammonia can be removed from coking-plant water by processes of nitrification and denitrification, or by treating the water with sodium hydroxide, causing ammonia to evaporate in the form of gas (which can be recycled).

The estimated input of nutrients from a large fish farm to a marine area is as large as that from a medium-sized town (approx. 25,000 inhabitants). It is therefore essential for fish farms – cage installations – to be localized in areas that have not already become severely overloaded with nutrients from land-based sources.

Like other intensive farming operations, large-scale aquaculture entails discharges of nutrients and organic material (*figure 39*). Techniques exist both for feeding fish with less wastage and for collecting waste products from the fish, but in practice they do not work particularly well. Effluents can only be treated properly if fish farms are enclosed systems; in practice, this means that they must be sited on land. Enclosed fish farms are still, however, so expensive that the profitability of the operation is jeopardized. Large amounts of water must be handled; only the removal of particles, therefore, is feasible. A substantial portion of nutrients, especially nitrogen, will therefore continue, in future as at present, to be discharged from fish farms. Aquaculture is an expanding industry, and a massive future increase in its effluents must therefore be expected.

Another substantial problem in aquaculture is the use of antibiotics and pesticides, which enter water. Diseases that break out in a cage farm are swiftly dispersed on a large scale, and fish are therefore sometimes given preventive treatment and sometimes treated when a disease has already broken out. The use of antibiotics has increased, and these are a harmful addition to the marine environment. Free-living fish outside the 'densely populated' fish farms can also sometimes be infected by diseases, and this itself is an environmental impact.

Enclosed installations might help to reduce discharges of antibiotics and pesticides to surrounding waters as well. The infection risk would diminish, and effective cleaning of effluents would be possible.

Oil and chemical residues must be disposed of in reception facilities

Large quantities of oil, chemicals and other products are handled both in oil ports and at other ports (*figure 40*). This entails various types of effluent that, sooner or later, may enter seawater.

Oil-containing water of various types originating in oil ports and from tankers must be dealt with and cleaned.

In oil ports, especially, the stormwater has a high oil content since it is contaminated by waste from the handling process. Particularly sensitive points, such as valves, pumps, loading ramps for vehicles and railway carriages, as well as quays, should therefore be equipped with anti-spill devices. One such device may be a plate or a trough to prevent stormwater from infiltrating the ground or reaching the ordinary urban stormwater system.

Ballast water from tankers can amount to 20–30% of the vessel's deadweight. How oil-contaminated this water is depends on whether the vessel has special ballast tanks and what the cargo has been. In many tankers, ballast water is always carried in the same tanks in which oil has been freighted. The water is

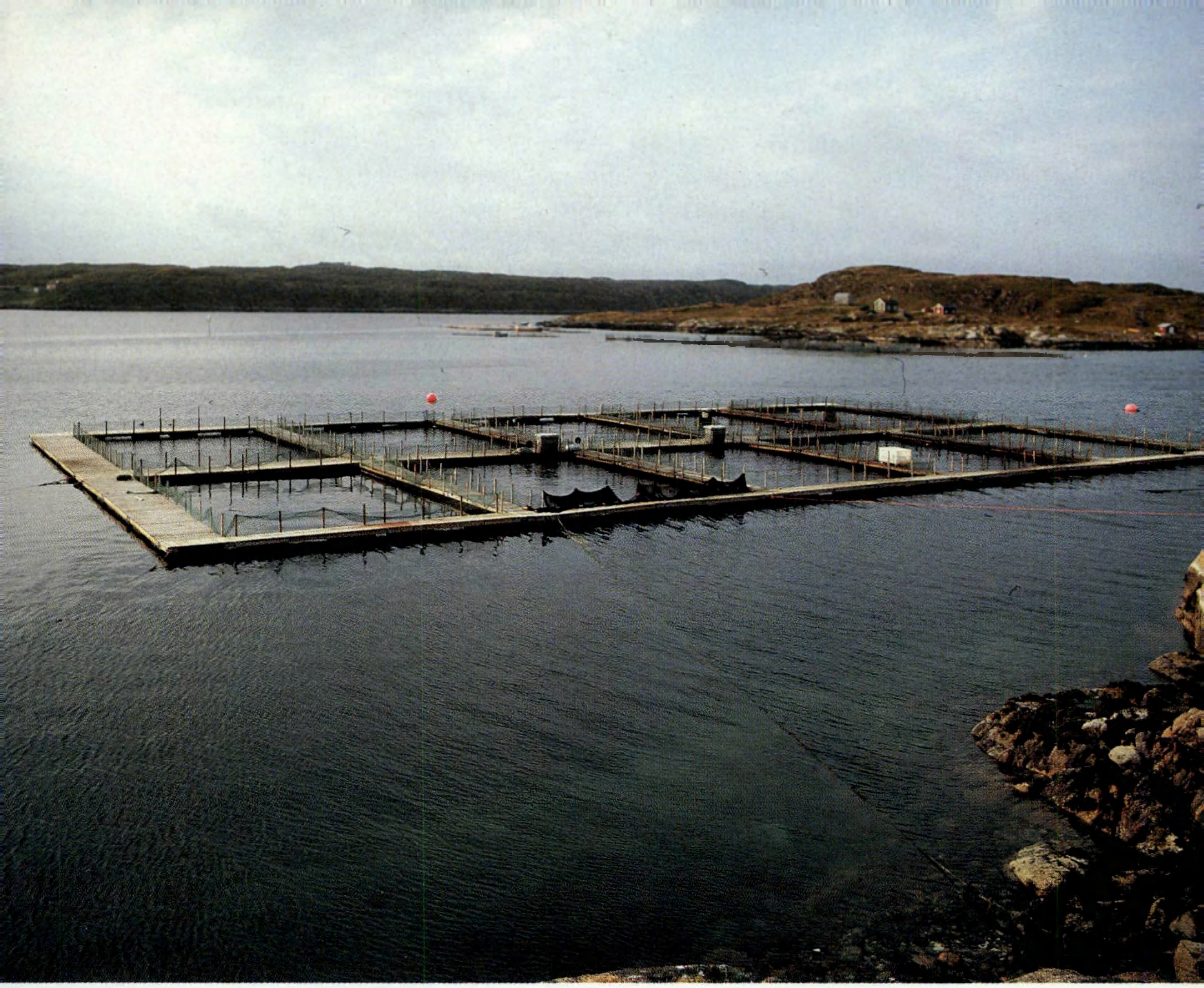


Figure 39. A large fish farm in a sensitive sea area can be a significant source of inputs of nutrients and organic, oxygen-consuming material. Such installations should therefore be sited away from areas already receiving large amounts of nutrients from land-based sources or where there is already a risk of oxygen depletion on the seabed. Another problem with large-scale fish farms is the use of antibiotics and other chemicals to control diseases and parasites. The use of such agents has increased and is disturbing the marine environment. Also, wild fish populations can become infected with diseases from floating cage installations, again an undesirable environmental impact.

Photograph: Åke W. Engman, Naturfotograferna.

always contaminated with oil in such a 'cleaned ballast tank' (CBT). With a 'segregated ballast tank' (SBT), the problem can be alleviated since the water in such tanks never comes into contact with oil and hence remains clean. This considerably simplifies handling in port.

Water used in washing the tanker's oil tanks is contaminated with oil to a varying degree. One method of reducing oil discharges when tanks are cleaned is the 'load-on-top' method. In simple terms, this means that one tank at a time is cleaned, and the oil content of the water gradually increases; water used for cleaning the tanks is then transferred to a special 'slop tank'.

Another type of oil-contaminated water that must be dealt with in ports is bilge water, i.e. water contaminated by oil in drainage channels and outlets in the engine room. The water may contain lubricating oil, detergents and emulsifiers. Lubricating oils, in particular, are difficult to handle and clean since they contain zinc, chromium, polyaromatic hydrocarbons and other environmentally hazardous compounds. Both on its own and in contaminated water, lubricating oil should be handled in such a way that it can never be released into any drains. Such oils should be handled in such a way as to keep them separate from the sewage system, and spilt oil should be collected in special tanks.

Like oil-contaminated water and oil residues, chemically polluted water and chemical residues must be handled carefully and responsibly on ships and at ports. The more, and the more efficient, reception facilities are constructed at ports, the greater will be the scope for preventing intentional discharges, spillage and unnecessary pollution of waste water and, ultimately, seawater.

Large amounts of hydrocarbons are emitted to the atmosphere in oil ports, where there is large-scale handling of oil, petrol and other fuels, both as cargo and as ship fuel. The technology for recovering of gases in the course of loading petrol into road tankers is used in some harbours: the fumes are converted into liquid form and mixed into the petrol.

The technology also exists to reduce discharges of hydrocarbons from refineries. An installation of this kind can discharge thousands of tonnes of hydrocarbons a year by leakage alone.

Can oil tankers be made wreck-proof?

When a large oil tanker runs aground, massive amounts of the oil on board pour out before the leak can be sealed and the vessel pulled afloat and towed away from the site of the accident. Oil has been spilt, and damage to fauna, flora and beaches can never be avoided.

Are oil spills, then, inevitable? Must marine transportation of oil in tankers constitute a potential environmental hazard? Over the years, numerous ideas and theories have been presented as to how the wreck-proof oil tanker should be constructed. One example is tankers with double bottoms: in the event of the vessel running aground, the outer hull would protect the inner, oil-filled tanks. Nevertheless, for various technical and economic reasons, no ideal vessel for carrying oil exists as yet. Nor can other cargoes be transported safely – in severe mishaps, even enclosed cargoes end up in the water. A recent example of this is the accident in the English Channel in April 1989, when a large number of barrels containing the pesticide Lindane sank and could not be located. It is uncertain what will happen to the barrels after a long time in seawater and what the consequences for the marine environment will be if large amounts of Lindane are dispersed in the water mass.

Figure 40. Handling of fuels and cargoes — including oil and chemicals — in ports is a potential environmental problem unless proper preventive action is taken. Oil-contaminated storm water, ballast water, bilge water and tank washings are some of the sources of pollution. Careless handling of these types of water, oil and many other chemicals can result in substantial amounts of pollutants 'spilling' into the sea.

In both the Baltic and the North Sea area, pressure is mounting for reception facilities for oil- and chemical-bearing residues from ships. Technology is also being developed to prevent leakage in connection with fuel handling (emissions to both water and air) and other operations that can cause oil and chemical spills. If reception facilities and other technical arrangements to cut discharges are to be effective, account has to be taken of the terms on which ships operate, e.g. the need to keep turn-round times to a minimum. Reception and other facilities must therefore operate efficiently and at low cost to shipping.

Illustrated is the Scanraff reception facility at Lysekil in Sweden. On the left are tanks for chemical, biological and other treatment; to the right, one of the facility's three 10 000 m^3 ballast tanks.

Photograph: Rustan Olsson, Scanraff.

Norwegian and Swedish technicians have developed a technique for loading oil with low pressure in the tanks — that is, the direct opposite of the technique used today. With low pressure in tanks, oil does not run out if the vessel is damaged and a hole torn in a tank.

Modern oil tankers have overpressure in their tanks. The pressure is regulated by a valve that releases gas at excess overpressure and admits air when low pressure develops. This makes it easier for oil to pour out into the water when an accident occurs. Moreover, in the event of extremely low pressure the regulatory valve serves to give the oil an even bigger 'push' out of the compartment: thousands of litres of oil can be discharged into the sea in just a few minutes.

If the oil tank has low pressure from the start, this is also retained if the tank breaks. The oil remains, in a kind of vacuum. Some will pour out, but only a fraction of the amount that would leak as a result of a conventional accident.

Oil from one or more damaged tanks can then be pumped out by means of a special pumping device that can be transported to the damaged vessel and temporarily mounted on the cleaning hatch. The low pressure is still retained during the pumping operation. Instead of the oil that has been pumped out, the vessel is then made to take water into the damaged tank.

This method has been presented internationally, but it has not gained acceptance. Old vessels must be rebuilt with reinforced hulls in order to withstand the low pressure. In the short run this may seem unduly expensive, and this is why many countries reject the new method. In the longer run, however, the financial gains from avoided accidents should far exceed the investment costs, if the method fulfils its promise. Many experienced experts are, however, still sceptical regarding the whole idea.

Photograph: Stefan Rosengren, Naturbild.

6 20 years of marine conventions and political initiatives — do they protect the marine environment?

The marine environment came into focus during the United Nations (UN) Conference on the Human Environment, held in Stockholm, Sweden, in June 1972. More than 20 resolutions and decisions dealt with the protection of the marine environment, globally as well as regionally. The threats to the marine environment had become obvious at a much earlier stage than the understanding of e.g. the effects of air pollution and other large scale environmental problems.

Basic reseach and fishing quotas

International cooperation on marine issues has existed for many years. The International Council for the Exploration of the Sea, ICES, was established early in this century. The Intergovernmental Oceanographic Commission, IOC, (a body within UNESCO, the UN Educational, Scientific and Cultural Organisation) was set up in the late 1940s.

The main task of ICES from the outset was to coordinate and promote reseach on the study of the sea, with particular attention on marine living resources and their utilisation, i.e. the yield from various fish stocks. Gradually, however, ICES has become more and more involved in marine environmental problems.

IOC was established with a mandate to promote and coordinate marine research – the physics, chemistry and biology of the sea. IOC has, step by step, during the years also developed a more pronounced environmental profile, especially in its cooperation with UNEP (the UN Environment Programme) within the framework of the UNEP Regional Seas Programme.

The International Law of the Sea

International cooperation concerning the utilisation of marine living resources led during the 1960s to the establishment of a number of international fisheries conventions. The overall purpose was to regulate fishing and establish catch quotas that would prevent overfishing. With the adoption of the UN Law of the Sea Convention and the establishment of Exclusive Economic Zones, the working methods of these fisheries conventions were changed during the 1980s.

The Law of the Sea – the international conventions and the custumary law dividing the sea and its resources, from the seabed upwards – was formally established during the period 1958 till the end of the 1970s. The United Nations held its first conference on the Law of the Sea in 1958. 86 states participated in the conference and four conventions were agreed:

- The Convention on the Territorial Seas and the Contiguous zone, which regulates the rights of states to the marine areas off there own coasts. It gives a state the right to adopt rules regulating navigation and customs, and exclusive fishing rights within the territorial waters. It also establishes certain obligations, including that of the right to innocent passage for merchant ships from other states.
- The Convention on the High Seas, which regulates the rights and obligations of states in areas outside national jurisdiction. These rights include the right of free navigation, the right to fish and to place underwater cables and pipelines on the sea-bed. All of these rights should, however, be performed with due respect to the interests of other states. Within the framework of this convention the right was established to register ships under so called flag of convenience.
- The Convention on Fishing on the High Seas and the Conservation of the Marine Living Resources, which recognized the rights of the coastal states to act in favour of the conservation of fishstocks also outside their respective territorial waters. The obligation of other states to cooperate with this aim were also laid down in this convention. The coastal states were given the right to impose non-discriminatory catchlimits.
- The Convention on the Continental Shelf, which regulates the rights of coastal states to non-living resources on the shelf from the base-line to the edge of the shelf, or to a depth of at least 200 meters (660 feet) whichever is greater. If technical means allow it, also resources to a depth below 200 meters on the continental shelf may be utilised.

In 1969 the International Court of Justice in the Hague decided that the North Sea States may 'exploit the natural extension of their landmasses below the sea surface'. Somes states claimed a right to the whole continental shelf pointing at a number of geophysical and topographical factors to support their claims. Today the North Sea has been divided into sectors – one British, one Norwegian, one German, one Danish and one Dutch – where the resources are being exploited according to availability and access to technology.

Exploitation of resources on the sea bed and the subsoil requires access to advanced technology and possibilities to finance this very special form of 'mining'. Such technology is expensive and, as a consequence, poor countries cannot participate. Poor countries have also very little to put up against the fishing fleets of the large industrialised countries, which more or less 'vacuum' the seas in their fishing efforts. Such fishing operations have destroyed the livelihood for several coastal fishing communites.

A third aspect of the Law of the Sea is the risk of accidents with ships carrying products hazardous to the environment. The right to innocent passage gives the right to take supertankers even through narrow waterways. Developed countries can build up a capacity to deal with emergencies, for instance if a large tanker runs aground or through another accident of some sort, pollute the environment with large quantities of oil, chemicals or radioactive substances. A poor country lacking these resources is more or less forced to become a passive spectator while its marine environment is being destroyed.

The United Nations has organised two more conferences on the Law of the Sea. At the third one, which began in 1973 , the participating states agreed to cooperate, but at the same time worked to a large extent for national interests. Already in 1970 the UN General Assembly adopted a declaration of principle according to which and the sea bed and the subsoil thereof, outside the national jurisdiction of the coastal states, was declared as being 'the Common Heritage of Mankind' which could only be exploited under international control. The 1973 conference was held with the purpose of developing a comprehensive convention on the marine environment. Soon, however, the 148 participating states split into a number of distinct interest groups and the conference was more or less stalled. Three main committees was set up to continue the work within broad substantive areas.

One result from this Law of the Sea Conference and the negotiations following it was the establishment of the then non-written practice, which since then has been put into practice by almost all countries having the possibility to do so – namely the 200 mile zone, or the right to establish Exclusive Economic Zones (EEZs). This gives every coastal state the right to extend its fishing zone up to 200 nautical miles from their coasts. The 12-mile zone nearest to the coast is regarded as territorial water. The 200-mile zone is not regarded as part of the high seas and the continental shelf is, according to the verdict of the International Court of Justice, defined as 'the natural extension of the landmass'. A number of conflicts have emerged between countries as a result of some states unilaterally declaring economic zones.

The Convention on the Law of the Sea was signed by 154 states in 1984. It will enter into force one year after it has been ratified by 60 of the signatories. 35 countries had ratified by the end of 1988. The ratification process is thus rather slow. One reason for this is thought to be that a ratification means recognition of the competence and authority of the Internationa Sea Bed Authority. The Authority is established through the convention as licensing authority for mining and drilling activities on the sea bed – outside the exclusive economic zones – and is supposed to receive part of the possible profits from such operations. The income from these operations is among other things supposed to be channelled to the Third World in order to build up marine competence in these countries. However, a number of important countries like USA, the United Kingdom, the Federal Republic of Germany and Japan have still not ratified the Law of the Sea Convention.

The new Law of the Sea puts approximately 40 percent of the oceans under national jurisdiction.

Conventions for the protection of the marine environment

The international environmental debate started in earnest at the end of the 1960s when the negative effects of the modern industrial society on the environment, natural resources and human health became apparent. It was realised that the oceans and seas had not functioned as large basins for the dilution of pollution. Instead nature had started to strike back.

A strong public opinion was created against the emission of pollutants into the environment, against oil spills and against the dumping of wastes into the North Sea. It was slowly realised that the emissions from landbased sources – from industries, urban areas, agriculture or through rivers – were the predominant sources of pollution, although at first the main attention was given to more spectacular incidents at sea. Accidents in which oiltankers spill thousands of tons of oil into the seas do not happen every day. But the emissions of environmentally hazardous substances from ordinary, 'non-dramatic' activities in our societies take place continously day after day, year after year. Dumping or incineration of wastes at sea can be stopped virtually from one day to the next. It is, however, much more difficult to take fast and effective decisions to stop immediately the emissions of nutrients or the deposition of air pollutants.

Awareness of the magnitude of pollution of the marine environment and the scope of the problem was followed by an awareness that a single country could not solve the problems around its coasts purely through national action and measures. It was clear that regional and international cooperation had to be initiated in order to deal effectively with the pollution of the seas. Many of the efforts within the various marine conventions are of a regional nature – countries sharing a sea area also try to share the responsibilities for the protection of the environment of that area. Some issues are however global in nature and must be dealt with on a global basis. Maritime activities with an impact on the environment, such as oil pollution from ships, are global problems as shipping is a truly global industry, involving vessels from virtually all countries of the world.

Gouache: Bengt-Erik Bengtsson, National Environmental Protection Agency, Section for Aquatic Toxicology, Studsvik, Sweden.

The 1972 UN Conference adopted a number of resolutions concerning the marine environment. These recommendations dealt with, for instance, research and monitoring and the negotiation of global conventions on dumping of wastes and pollution from ships. Of special importance with regard to both marine pollution and air pollution is article 21 of the Stockholm Declaration. According to this article all states have a responsibility to ensure that activities within their jurisdiction do not cause pollution in other states or in areas outside national jurisdiction. In the positive spirit of international cooperation that prevailed during the first part of the 1970s, a number of global, regional and subregional conventions and agreements were negotiated and signed for the protection of the marine environment. It should, however, be noted that the first global convention against pollution – the OILPOL – had already been signed in 1954.

For obvious reasons international cooperation developed first in sea areas like the Baltic and the North Sea, which are surrounded by heavily industrialised and densely populated regions. Such conventions encompassing mainly industrialised countries have been followed during the 1980s by a number of Action Plans and Conventions for the protection of the marine environment in the developing regions of the world. About ten such agreements have been concluded within the framework of the UNEP Regional Seas Programme.

The most important conventions for the protection of the marine areas of Northern Europe are two global conventions:

- **The London Dumping Convention** (The Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter) dealing with dumping of wastes from ships and incineration of wastes at sea
- **The MARPOL Convention** (The International Convention for the Prevention of Pollution from Ships) on pollution from ships.

and four regional conventions:

- **The Paris Convention** for the Prevention of Marine Pollution from Land-based Sources
- **The Oslo Convention** for the Prevention of Marine Pollution by Dumping from Ships and Aircraft
- **The Helsinki Convention** on the Protection of the Marine Environment of the Baltic Sea Area
- **The Bonn Agreement** on cooperation to combat spills of oil and chemicals.

These six conventions are briefly described in this chapter. Since 1984 one additional forum for international cooperation has been added, namely

- **The North Sea Conferences** 1984, 1987 and 1990.

In addition there are an number of bilateral agreements between countries sharing a particular sea area.

Principles and Annexes

The following short description of the conventions does not make them full justice, but aims at giving a general idea of purpose, scope, functions and results achieved so far.

The Conventions have several common caracteristics. They are written as framework conventions, where the basic obligations of the contracting parties are laid down. These basic obligations include an expression of the common responsibility to protect the marine environment and the willingness to cooperate in solving the problems affecting the geographical area covered by the convention. These principles include measures for the protection of the marine environment, the establishment of joint monitoring programmes, reporting etc.

Regulations regarding emissions, or measures to completely stop certain discharges are specified in more detail in special annexes to the conventions. The annexes seek to regulate certain activities or the handling of certain substances or groups of substances. The polluting or contaminating substances are generally classified into three different groups:

- **Blacklisted substances.** In principle these substances must not be discharged or dumped into the marine environment. Mercury, cadmium, stable halogenated organic substances and high-level radioactive waste generally belong to this group.
- **Greylisted substances.** These substances are only allowed to be discharged with special – case by case – permission from the competent authorities in the relevant countries. Greylisted substances generally include heavy metals as well as medium and low-level radioactive waste.
- **Other substances** are those which can be emitted into the marine environment in accordance with more general permits.

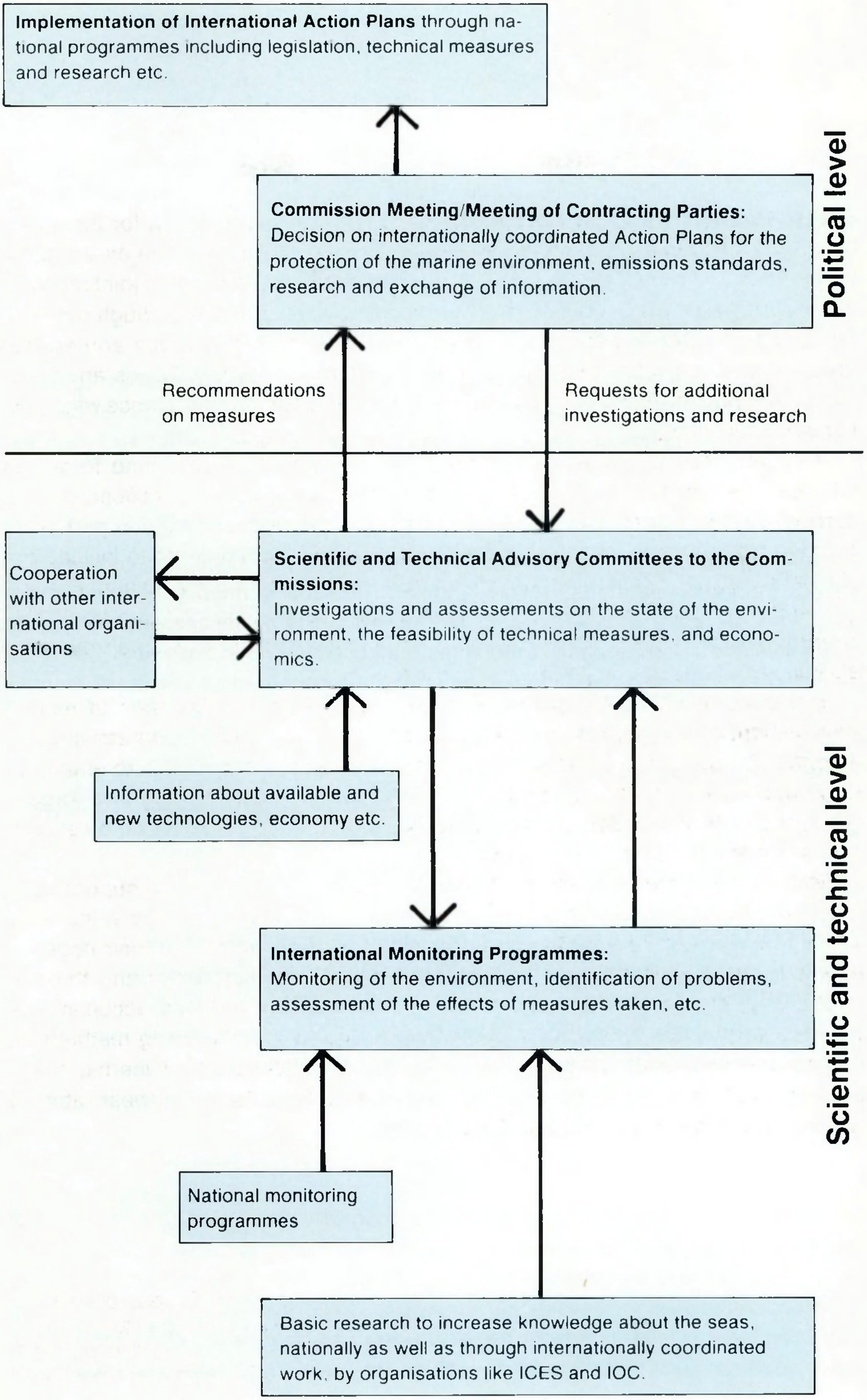
The Annexes to the conventions also generally contain regulations for the selection of dumping sites (if relevant) as well as articles dealing with the exchange of information and scientific cooperation, including the establishment of joint monitoring programmes. As is spelt out below, the conventions operate through commissions, which have secretariats to assist them, and working groups and ad hoc groups that can give greater attention to the details of various issues and problems. This system allows for the development of substantial competence within the various conventions.

In many cases it has taken years for the conventions to enter into force. An international agreement of this kind enters into force after the ratification by a certain number of the signatory states, which thus become contracting parties. In practice ratification means that the state has made a commitment to include the aims and purposes of the convention into national policies and legislation. Formally, ratification takes place when the highest political decision-making body of a country – generally the parliament or a corresponding body – has approved the agreement signed by the government of that country.

To a certain extent it is possible to see how fully the obligations of marine environmental conventions penetrate into the economic and industrial structure of a country by studying how long it has taken for a certain convention to enter into force and how it is implemented. It is much more difficult to bring into force a convention which includes measures that will have a strong impact and be expensive to implement than a less effective one.

Figure 41 illustrates in a schematic way how a marine convention is supposed to function. The strong belief emerged in the environmental discussions in the early 1970s that it would be possible to detect polluting substances and their negative effects in the marine environment through statistics on discharges and through monitoring programmes. It would thus be possible to take remedial action in time to avoid large-scale, possibly irreversible, damage. But the working methods of the conventions, with a built-in scientific, practical and political inertia, have, however, resulted in a situation where the conventions have not been able to function in the way originally intended.

Figure 41. The basic principles of how a marine convention is intended to function: areas of responsibility, interaction and feedback between different parts of the system.


Implementation of International Action Plans through national programmes including legislation, technical measures and research etc.
Political level
Commission Meeting/Meeting of Contracting Parties: Decision on internationally coordinated Action Plans for the protection of the marine environment, emissions standards, research and exchange of information.
Recommendations on measures
Requests for additional investigations and research
Cooperation with other international organisations
Scientific and Technical Advisory Committees to the Commissions: Investigations and assessements on the state of the environment, the feasibility of technical measures, and economics.
Information about available and new technologies, economy etc.
Scientific and technical level
International Monitoring Programmes: Monitoring of the environment, identification of problems, assessment of the effects of measures taken, etc.
National monitoring programmes
Basic research to increase knowledge about the seas, nationally as well as through internationally coordinated work, by organisations like ICES and IOC.

Global Marine Conventions

MARPOL 1973/78

MARPOL 1973/78 is the international convention on pollution from ships (International Convention for the Prevention of Pollution from Ships). It is a global convention – covering all oceans and seas – and it has so far been ratified by 49 states.

Objectives:

International rules for the prevention of pollution from ships are contained in several marine conventions. However, the MARPOL convention is the most important. The objective of MARPOL is to prevent polluting discharges of oil and chemicals, and also garbage, from ships in operation and in harbours. MARPOL also contains detailed regulations concerning the construction and equipment of ships.

Results and important issues:

- *Annex 1* deals with oil. Entered into force in October 1983.
- *Annex 2* regulates chemicals transported in bulk. Entered into force in April 1987.
- *Annex 3* applies to the transport, in packaged form, of solid as well as liquid hazardous substances . Has not yet entered into force, but is expected to do so during 1990.
- *Annex 4* regulates the disposal of sewage. Has not yet entered into force and no estimated time for the entry into force has been established.
- *Annex 5* concerns garbage, especially plastics and other non-biodegradable materials. Entered into force in January 1989.

As mentioned earlier it has been difficult to bring MARPOL into force, because of the global character of international shipping. One demand for which acceptance has been especially difficult to obtain is for the construction and above all the use of reception facilities for oil and chemical wastes in ports of loading and unloading. The Ministerial Declaration from the North Sea Conference in 1987 stressed the great need for such installations as well as for measures to stimulate their use.

This requirement has existed within the Helsinki Convention for a long time. The use of reception facilities should be stimulated through reasonable fees and without specific demands on the ships *per se*. It costs time and money to stay in port to clean oil tanks and unload wastes, and the reception facilities must thus function smoothly and efficiently.

Illegal discharge of oil is still a major problem, especially in the North Sea, despite the MARPOL rules. Airplanes are now used for surveillance and a considerable number of illegal discharges have been discovered. There is agreement that this surveillance should be strengthened. At the North Sea Conference 1987 the importance of bringing Annex 5 (on garbage) into force for the North Sea as soon as possible was emphasised. It was also proposed to have the North Sea, through IMO, designated a so called Special Area (see below) with regard to garbage. Such a decision would make it mandatory for garbage to be unloaded in port.

Another burning issue to be adressed in the context of MARPOL, in cooperation with other conventions, is the use of bunker oil as fuel. The burning of dirty bunker oil causes large emissions of sulphur and nitrogen oxides from the ships. The bunker oil is a great potential threat to the marine environment, as well as to air quality. Such oil has a high content of particles, sulphur and in some cases hazardous liquid wastes, which have been added to the oil. Another problem arises because an increasing number of ships is equipped with on board incinerators for wastes and sludge. These incinerators constitute a threat to the environment because the wastes burned contain, among other things, plastics and other chemical products.

Other issues that fall within MARPOL include action against substances that deplete the ozone layer, the identification of particularly sensitive sea areas (not included in the Special Area concept), the classification of chemical cargoes and global emergency planning to deal with major discharges from ships (accidents).

Organotin compounds, used as antifouling paints on the bottom of ships, is another environmental problem. Agreement within IMO is necessary to prohibit the use of such paints on large ships. However, for use on boats shorter than 25 metres, on harbour constructions and on certain other equipment, there is already a recommendation within the Paris Convention to prohibit the use of these paints. The Helsinki Commission has also decided on a similar prohibition.

There is also a proposal that Annex 1 (on oil) should be made applicable also to ships smaller than 400 GRT and that the implementation should not be related to the volume of the ships but instead to the size of the engine. (The regulations should then be adjusted taking into account the size of the fishing fleets of the various countries.) Today Annex 1 is applicable to tankers bigger than 150 GRT and to other ships bigger than 400 GRT.

Through the Helsinki Convention special rules regulate the discharge of oil in the Baltic Sea Area. Before Annexes1 and 2 of MARPOL entered into force these rules have been the only rules that regulate shipping operations in the Baltic. The Baltic Area is designated as a Special Area within MARPOL. Stricter rules are applicable in such especially sensitive areas because of 'recognized environmental reasons in relation to their special conditions and to the particular character of their traffic'. Thus, the discharge of oil and chemicals from ships in the Baltic has already been almost completely prohibited. Only some minor operational discharges are allowed. Other pollutants (Annexes 3,4 and 5) are still regulated through the Helsinki Convention. In principle it can be stated that MARPOL is fully implemented in the Baltic although two of its Annexes have not entered into force in other areas of the world.

Structure:

The Marine Environment Protection Committee (MEPC) is the decision-making body for MARPOL. MEPC meets approximately every ninth month. The MARPOL secretariat is located in London within the headquarters of IMO (the International Maritime Organisation, the United Nations agency for maritime technical issues.)

The MARPOL 73/78 Convention was signed in 1973 and revised through a protocol in 1978. It has entered into force in stages.

MARPOL operates relatively smoothly. Amendments decided by the MEPC enter into force globally within 15 months after a decision by the MEPC. The Annexes, and especially Annex 2, are revised on a continuous basis.

The London Dumping Convention

The London Dumping Convention (the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter) – the LDC – is also a global convention. It covers all oceans and territorial seas of the coastal states. The LDC has so far been ratified by 64 countries.

Objectives and results:

The LDC regulates dumping of wastes and pollution at sea from ships and aircraft, including the incineration of wastes at sea (which is adminstratively regarded as a form of dumping).

The global LDC and the regional Oslo Convention show many similarities. They both regulate dumping of a number of specific environmentally hazardous substances from ships and aircraft. These include halogenated, non-biodegradable organic substances, carcenogenic compounds and certain heavy metals. Both conventions also deal with incineration of wastes at sea.

The main difference between them is that the LDC includes regulations on the dumping of radioactive wastes and the implacement of such wastes in the seabed. The dumping of radioactive wastes has created very strong feelings in the general public in a number of countries and political complications for governments supporting such dumping.

Since 1972 the dumping of high-level radioactive waste (an Annex 1 substance) has been prohibited. Such waste must be taken care of on land. The controversy has been over the dumping of low- and medium-level waste. In 1983 the LDC decided in favour of a two year moratorium on the dumping of such wastes pending the outcome of further investigations. Expert groups were given the task of making scientific assessments during this period. However, the results from these studies were not conclusive.

In 1985 the issue was discussed again and since then the moratorium has been extended. At the LDC meeting in October 1988 the moratorium was extended for an additional five years. No radioactive waste is presently being dumped – or should not be dumped – until a final decision has been made. In the meantime a number of scientific, political, economic and social considerations will be further investigated. However, the moratorium can be seen as a kind of preliminary decision.

Nor should high-level radioactive waste be buried in the seabed until this issue has been decided internationally and the environmental consequences assessed.

The LDC shares responsibility for regulating dumping of wastes with the Oslo Convention and the regulation of discharges of radioactive substances with the Paris Convention. Radioactive substances are also released into the marine environment from land-based sources including nuclear power plants, reprocessing plants and from other stages of the nuclear enery cycle. However, the LDC has to a large extent become the representative organisation where the principal discussions are taking place about how we should deal with the hazardous waste (waste that is difficult to handle on land) produced in our society.

At its meeting in October 1988 the LDC decided to ban the incineration of wastes at sea globally from December 1994.

Structure:

The decision-making body of the LDC is the annual Consultative Meeting of the Contracting Parties. These meetings correspond to the Commission meetings of other conventions. The LDC secretariat is located along with the MARPOL secretariat at IMO headquarters. The Consultative Meetings are prepared by the LDC Scientific Group on Dumping, which is composed of experts from contracting parties and observers.

The LDC was signed in 1972 by 73 states, including the Contracting Parties to the Oslo Convention, and it entered into force in 1975.

Regional Marine Conventions

The Paris Convention

The Paris Convention – The Convention for the Prevention of Marine Pollution from Land-based Sources – is a regional convention. Its geographical coverage is shown in *figure 42.* The Paris Convention, like the Oslo Convention, covers the Northeast Atlantic and the North Sea area (with the Skagerrak and the Kattegat); the one difference is that the Paris Convention also covers the internal waters of the Contracting Parties.

Objectives:

The Paris Convention seeks to prevent pollution of the marine environment by virtually all substances that can reach the sea from land-based sources All types of land-based sources are covered in the convention – discharges directly into the sea, discharges into rivers, through land run-off or into the air. Efforts are made to limit discharges from industries and urban areas along the coasts (discharges of waste waters directly or through pipelines) and emissions from factories and urban areas inland, which are transported to the sea via rivers or in the air. Basically all types of human activities are regulated within the framework of the convention: industry, energy production (including nuclear energy), traffic, urban life, agriculture etc.

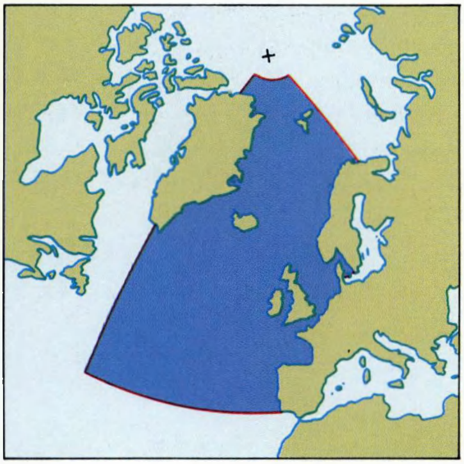


Figure 42. Sketch map of the geographical area covered by the Paris Convention (the 'Convention area').
Illustration: Stig Söderlind.

Important issues and results:

Within the Paris Convention priority has been given to the following substances:

- Cadmium, mercury, persistent and environmentally hazardous chlorinated substances – e.g. PCBs, DDT, petroleum based persistent oils and hydrocarbons, and liquid synthetic materials (Annex1; blacklisted substances).
- Organophosphorous compounds, organosilicon compunds, organotin compounds, phosphorous, non persistent petroleum based oils and hydrocarbons, arsenic, copper, chromium, lead, nickel and zinc. In addition, substances that can affect the taste or smell of fish and other organisms used for human consumption are also included (Annex 2; greylisted substances)

Radioactive substances, including radioactive waste, constitutes a separate group.

Nutrients are not included in any of the lists of priority substances, but work has begun within the convention to reduce substantially the emissions of nutrients into sensitive areas of the seas.

Despite the gigantic task laid down in the convention, quite a few practical results have been achieved over the years. The various working groups that have been established have, for exemple, done a great deal of in-depth preparatory work as a basis for discussions and decisions by the Commission.

At its meeting in June 1988 the Paris Commission adopted the Declaration from the 1987 North Sea Conference (see below) concerning a 50 per cent reduction by 1995 of the emissions of non-biodegradable organic substances, metals and nutrients to vulnerable sea areas within the convention area. The Working Group on nutrients has been given the task to assess and propose measures to reduce the emissions from sewage treatment plants, agriculture, industry, energy production plants, traffic and aquaculture. On the other hand it was this working group within the Paris Commission that developed the background material on nutrients for the North Sea Conference and thus made it possible for the North Sea states to make their decision at that conference.

The Paris Commission has given certain issues priority, including the reduction of emissions of substances listed below. A general approach used in this work is to follow the total flow of a substance through the system – a so called 'waste stream approach'.

Emission reductions from the following activities has been targetted:

- Mercury from the chlor-alkali industry and from the use of mercury containing products.
- Oil from refineries, oil platforms and reception facilities.
- Chemicals from the off-shore industry.
- Waste from the titanium dioxide industry.
- PCBs from various operations and products.
- Cadmium from various operations and products.
- Chlorinated pesticides, such as aldrine, endrine and dieldrine etc.
- Radioactive substances.
- Liquid plastic materials.
- Organotin compounds from antifouling paints used on boats and facilities related to shipping and fishing.
- Air pollutants.

Efforts concerning heavy metals, air pollutants in general and nutrients have been given increased priority within the Paris Commission.

With regard to mercury, it has been recommended that new industrial plants for chlor-alkali production should use mercury free processes. It has also been generally recommended that the use of products containing mercury should be reduced throughout society and that the standards laid down in the directive from the European Commission (the EC) on industries using mercury should be followed.

The Working Group on Oil Pollution is actively adressing off-shore issues. Standards have been set concerning discharges of oil from platforms and oil in production water. Regulations have been agreed to limit the discharges of oil-contaminated rock cuttings. Presently the Paris Commission is making a survey of the discharges of chemicals from oil drilling and these problems were discussed at the 1989 Commission meeting and should be finalised in 1990.

Agreement has been reached within the Paris Commission to prohibit the use and marketing of PCBs. However, the EC has objected to such a formal decision being made within the Paris Convention.

With regard to radioactive substances the Paris Commission has concentrated mainly on reprocessing plants and nuclear power plants. Discussions have also been held regarding cooperation with the OECD on these matters.

The possibility of prohibiting the use of organotin compounds is also under discussion. Recommendations have already been made on prohibiting the use of antifouling paints containing such substances on leisure crafts (boats shorter than 25 metres) and certain fishing gear. The Paris Commission has also recommended the development of technologies for the prevention of emissions of organotin compounds from operations in harbour docks.

Air pollution has already been given high priority within the Paris Commission, and will be given even higher priority in the future. Research has shown that airborne fallout is a dominant source of pollution. Air pollution relates closely to a number of those problem areas already adressed by the Commission, and has been given renewed attention following the decisions taken by the 1987 North Sea Conference and through other international cooperation.

In 1986 the Paris Commission adopted a protocol, i.e. a regulatory framework, to be able to deal with the deposition of airborne pollutants on the sea. This protocol implies an expansion of the work within the Convention and must have the support of the Contracting Parties. The North Sea Conference in 1987 urged those member states that had not already done so to ratify the protocol.

PARCOM held its 11th session in June 1989. The Commission adopted a recommendation on the Principle of Precautionary Action stating that the Contracting Parties to the Paris Convention 'Accept the principle of safeguarding the marine ecosystem of the Paris Convention area by reducing at source polluting emissions of substances that are persistent, toxic and liable to bioaccumulate by the use of the best available technology and other appropriate measures. This applies especially when there is reason to assume that certain damage or harmful effects on the living resources of the sea are likely to be caused by such substances, even when there is no scientific evidence to prove a causal link between emissions and effects (the principle of precautionary action).

However, on other more specific issues the Commission failed to reach the consensus necessary for the adoption of decisions. Such issues were e.g. the reduction of discharges of chlorinated hydrocarbons from the pulp and paper industry, and the limiting of mercury emissions from the chlor-alkali industry.

In order to give more political impetus to the work of the PARCOM and OSCOM, the 1989 Joint Meeting between the two Commissions decided to hold their meetings in 1992 at a ministerial level.

Structure:

The decision-making body is the Paris Commission (PARCOM). The PARCOM secretariat has been established jointly with the Oslo Commission and the Bonn Agreement (see below) in London.

PARCOM has formed a number of working groups. Two of these – the Technical Working Group (TWG), and the Joint Monitoring Group (JMG), established together with OSCOM and ICES) – are permanent. There are a number of ad hoc groups as well.

PARCOM meets annually, generally in June. The 1989 Meeting was the 11th session.

The Paris Convention was signed in 1974 and entered into force in 1978. It has 13 member states : Belgium, Denmark, the Federal Republic of Germany, France, Ireland, Luxemburg, the Netherlands, Norway, Portugal, Spain, Sweden, the United Kingdom. All countries except Luxemburg have ratified the convention.The EC is also a Contracting Party to the Paris Convention.

The Paris Convention has almost the same membership as the Oslo Convention, with the exception of Finland, which is a member of the Oslo Convention but not of the Paris Convention, but participates in the work of PARCOM as an observer. Neither Luxemburg nor the the EC participate in the work of the Oslo Commission.

The Oslo Convention

The Oslo Convention – the Convention for the Prevention of Marine Pollution by Dumping from Ships and Aircraft – is a regional convention. The geographical coverage of the convention is shown in *figure 43*. The convention area includes the Northeast Atlantic and the North Sea area (with Skagerack and Kattegatt) – i.e. the same area as the Paris Convention with the exception of the internal waters of the coastal states.

Objectives:

The Oslo Convention seeks to reduce, and preferably prevent, the dumping and incineration of environmentally hazardous substances at sea. The convention regulates pollution by dumping of wastes from ships and aircraft, and the incineration of hazardous wastes at sea. As mentioned above, radioactive wastes are not included in the Oslo Convention.

Results and important issues:

Chlorinated hydrocarbons, carcenogenic substances, mercury and cadmium are all on the black list (Annex 1) of the Oslo Convention. Dumping of other kind of materials and substances is only permitted pending the issue of special permits – on a case by case basis – by competent national authorities (Annex 2).

Figure 43. Sketch map of the geographical area covered by the Oslo Convention (the 'Convention area').
Illustration: Stig Söderlind.

- The dumping of hazardous substances listed on Annex 1 is prohibited, except in those cases where these substance occur as trace contaminants in other materials and substances. The prohibition against dumping is also lifted in the case emergency situations, when a ship is in distress and the crew and ship are in immediate danger.
- Special regulations are applicable to the dumping of a number of other substances, listed on the grey list (Annex 2).
- A number of conditions must be satisfied before a permit for dumping can be issued, including that there are no of alternative ways to dispose of the waste (Annex 3).
- Special rules are applicable to the incineration of wastes at sea.

Industrial waste, sewage sludge, dregded spoils, scrapped ships and other contaminated materials are dumped into the sea. Some 5,3 million tonnes of industrial waste and 7,5 million tonnes of sewage sludge were dumped within the convention area in 1987.

One issue that has been the focus for much public attention in recent years is the incineration of hazardous wastes at sea. At the meeting of the Oslo Commission in 1988 it was decided that this practice should be phased out before the end of 1994. A special working group has been established with the task to facilitate the implementation of the decision made by the 1987 North Sea Conference. This decision states that the incineration of wastes should be reduced by at least 65 per cent by 1 January 1991 and be totally phased out by the end of 1994. The incineration of wastes at sea will thus end by not later than the end of 1994. However, the issue at stake is whether this can not in fact happen sooner.

Ocean incineration has become an issue of principle, putting the overall issue of how we use the oceans as a garbage dump into sharp focus. The development not only of techniques and processes that will produce smaller quantities of waste and less hazardous wastes, but at the same time of alternative, environmentally sound land-based disposal facilities, is a basic principle that underlies all discussions about dumping, incineration and 'normal' discharges of environmentally hazardous substances into the marine environment.

Even if the incineration of wastes at sea has attracted the greatest public attention, the dumping of sewage sludge and industrial wastes as well as dredged spoils, constitute at least as great and serious an issue.The Oslo Convention has certainly over the years had som success – the general trend points towards a decrease in the amount of wastes dumped at sea. However, the overall goal of many member countries is to achieve nothing less than a total stop for all dumping.

The 1987 North Sea Conference adopted the principle that dumping of polluting materials and substances in the North Sea should be stopped. The Declaration from the Conference states that dumping of industrial wastes should not be allowed after 1989, unless there are no practical alternatives for disposal on land. If there are no such alternatives the country concerned must be able to show to the Oslo Commission that the material to be dumped will cause no harm in the marine environment.

The dumping of dredged spoils is without comparison the largest dumping operation in the area covered by the Oslo Convention. In 1987 approximately 91 million tonnes were dumped within that area. The dumping of sewage sludge is seemingly less frequent. In 1987 only two countries within the convention area dumped any sludge, the total amount being 7,5 million tonnes.

At its 15th session, in June 1989, OSCOM took a number of decisions to further implement the 1987 North Sea Declaration. Regarding the dumping of industrial wastes the Contracting Parties agreed that such dumping in the North Sea should cease by 31 December 1989, and in other parts of the convention waters by 31 December 1995, except for inert materials of natural origin, and except for those industrial wastes for which it can be shown to the Commission through the Prior Justification Procedure (PJP; see below) that there are no practical alternatives on land and that the materials cause no harm in the marine environment.

As a consequence the Commission also took a decision on the establishment of the Prior Justification Procedure. The PJP spells out the information that shall be sent to the Secretary of the Commission at least four months in advance of the envisaged dumping operation, whenever a Contracting Party proposes to issue a permit for the dumping of industrial wastes at sea in accordance with the provsions of the decision outlined above. This information will be circulated to all other Contracting Parties for comments and/or objections within one month.

Structure:

The decision-making body is the Oslo Commission (OSCOM). As mentioned earlier, OSCOM shares a secretariat in London with PARCOM and the Bonn Agreement.

The Oslo Commission has two permanent working groups – the Standing Advisory Committee for Scientific Advice (SACSA), and the Joint Monitoring Group (JMG; with PARCOM and ICES). In addition there are a number of subsidiary groups.

OSCOM meets annually, generally in June. The 1989 meeting was the 15th session.

OSCOM was signed in 1972 and entered into force in 1974. The Contracting Parties are: Belgium, Denmark, the Federal Republic of Germany, Finland, France, Ireland, Iceland, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom.

The Bonn Agreement

Objective:

The Bonn Agreement is an agreement among states to cooperate in combatting pollution – e.g. oil or other substances harmful to the marine environment – in cases of accidents or other major spills. The agreement has created a framework for such cooperation among those authorities in the various North Sea states that are responsible for dealing directly with major spills. These spills can range from blow-outs on oil platforms to major illegal oil spills. The agreement contains a system for mutual warnings in the case of accidents and cooperation and assistance in the practical work in cleaning up after a spill has occurred. The Bonn Agreement also covers chemicals and other hazardous substances that can enter the marine environment in large quantities.

The Bonn Agreement also allows for aerial surveillance of the convention area as a deterrent, with a view to prevent, as far as possible, illegal discharges. These operations are presently under development.

Structure:

The Contracting Parties are Belgium, Denmark, the Federal Republic of Germany, France, Ireland, the Netherlands, Norway, Sweden and the United Kingdom. The EC participates as an observer,

The Bonn Agreement was signed in 1969 and entered into force in 1970.

It has, as mentioned above, a joint secretariat with OSCOM and PARCOM located in London.

Photograph: Björn-Eyvind Swahn, Naturfotograferna.

The Helsinki Convention

The Helsinki Convention – the Convention on the Protection of the Marine Environment of the Baltic Sea Area – is a regional convention. The Helsinki Convention covers the Baltic Proper, the Gulf of Bothnia, the Gulf of Finland, the sounds between the Danish Isles and between Sweden and Denmark, the Kattegat and the Skagerrak up to a parallell through Skagen in Denmark at latitude 57 degrees north (*figure 44*).

Objectives:

The objectives of the Helsinki Convention is to protect the Baltic marine environment against all forms of pollution – emissions from land-based sources (including discharges of radioactive substances from land-based facilities), discharges from ships, atmospheric fall-out, dumping and pollution caused by exploration or exploitation of resources on the seabed.

The Contracting Parties have agreed to prevent, as far as possible, or at least to reduce substantially the pollution of the Baltic and to take active measures to protect and enhance the marine environment within the convention area. In practice, this has meant a commitment to take those measures that are technically and economically feasible. Already from the beginning it was decided to prohibit all dumping of wastes in the Baltic. The only exception applies to non-contaminated dredge spoils.

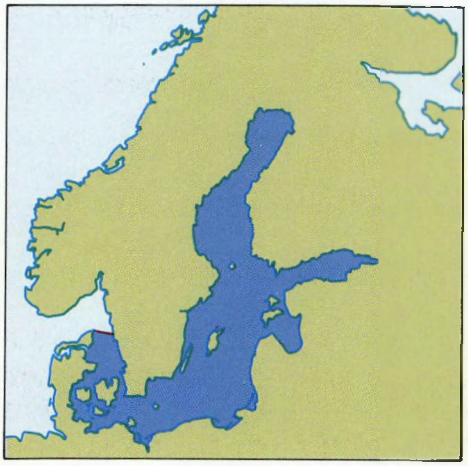


Figure 44. Sketch map of the geographical area covered by the Helsinki Convention (the 'Convention area').
Illustration: Stig Söderlind.

Results and important issues:

- The use of DDT is prohibited in all Baltic Sea states.
- The use of PCBs has been drastically reduced and will be phased out.
- PCT-substances (closely related to PCBs) have been added to the black list of the convention (Annex 1).
- A programme for the reduction of the discharges of mercury from the chlor-alkali industry has been adopted.
- The meeting of HELCOM in 1988 was held at a ministerial level and a Ministerial Declaration was adopted. It was agreed to reduce substantially the emissions of nutrients, heavy metals and persistent organic substances, for exemple by 50 per cent as soon as possible, but no later than by 1995.
- The discharges from ships have been greatly reduced.
- The Baltic is a Special Area within MARPOL.
- Reception facilities for oil and chemical residues have been established in most harbours where such substances are being handled.
- International rules for 'safe waterways' for large vessels (especially large tankers and ships carrying environmentally hazardous cargoes) have been established.
- Rules and guidelines for cooperation in combatting oil or chemical spills in connection with accidents have been agreed.
- A reporting system has been established for ships carrying dangerous cargoes in the Baltic (the Baltic Sea Ship Reporting System).
- The prohibition on dumping has forced countries to find alternative disposal methods, including the construction of reception facilities and the building of treatment plants for hazardous wastes.

The black list (Annex 1) of the Helsinki Convention contains DDT and its derivatives DDE and DDD, as well as PCB and PCT compounds, and mercury.

The grey list (Annex 2) contains several so called priority substances, including heavy metals like cadmium, lead, copper and zinc. In addition persistent organic substances not contained in Annex1 are included in Annex 2, together with lignine from the pulp and paper industry, oil, radioactive substances and number of other harmful substances and materials. Much attention is paid to what is called 'new contaminants', especially chlorinated organic substances that are discharged in the complex sewage waters coming from many industries. At present not much is known about these substances.

So far the Helsinki Commission has been concentrating particularly on assessments of the Baltic environment, compilations of the pollution load and measures to reduce the emissions of pollutants.

Compilations have been made of marine ecological conditions in the Baltic. Serious concern has been expressed about the continouos decrease in the concentrations of oxygen in the deep basins, about the steady increase in nutrients especially in coastal areas, and that emissions from the pulp and paper industries have not been surveyed and reduced or stopped. Further concern has been expressed about 'new contaminants' being released into the marine environment and causing serious damage, and that even small quantities of oil cause damage to birds, bottom-dwelling organisms as well as pelagic organisms. Increased eutrophication has been noted in several areas within the Baltic. On the positive side it has been noted that concentrations of DDT and PCBs are decreasing.

Since 1979 the Helsinki Convention has operated a coordinated monitoring programme – the Baltic Monitoring Programme (BMP) – which comprises hydrographical, chemical and biological investigations. During recent years investigations have been undertaken in order to estimate the size of the contribution from airborne fall-out to the pollution of the Baltic. In addition, the emissions of radioactive substances are monitored and investigated. A first pollution load compilation was made in 1986 (see *table 6*).

Measures against emissions of pollutants will concentrate on single substances as well as on broad sectors of industy and society. The efforts to reduce emissions of priority substances (Annexes1 and 2) will continue.

So far priority has been given to agriculture, urban activities and the forest industry. In the future also the pulp and paper industry, chemical industry, the surface treatment industry and the iron and steel industry will be included.

The HELCOM Ministerial meeting in 1988 expressed a clear aim to reduce the emissions of nutrients by e.g. 50 per cent not later than 1995. The Commissions recommendations with regard to the emissions of nitrogen and phosphorous from agriculture and urban areas include directives on the handling and spreading of manure and the use of catch crops. For urban areas it is recommended that towns or cities having more than 10 000 inhabitants should be using biological sewage treament plants by no later than 1998.

The Helsinki Commission has, like PARCOM, adopted recommendations to prohibit the use of organotin compounds in antifouling paints for leisure crafts and fishing gear. A decision on the elimination of pollution from such substances will be taken not later than 1991.

In 1988 the Commission adopted a recommendation to prohibit the discharge of drilling mud from off-shore activities containing oil or chemicals, and recommendations for tighter regulations regarding the concentration of oil in production (formation) water.

Oil refineries should, as of 1990, have biological or equally efficient treatment facilities for their wastewaters.

The Ministerial Declaration from the 1988 meeting contained, as mentioned, a commitment to reduce substantially the emissions of pollutants (nutrients, heavy metals and persistent organic substances) to the Baltic, e.g. by 50 per cent by no later than 1995. The ministers declared their determination to 'make further provisions for reducing discharges from point sources, such as industrial installations and urban wastewater treatment plants, of toxic or persistent substances, nutrients, heavy metals, and hydrocarbons by contruction and operation of installations and equipment in conformity with the best available technology. In this context it is noted that actions concerning non-point sources will also be needed.'

The Ministerial Declaration also deals with the need for intensified research and development as well as the exchange of information in order to increase the knowledge of the degree of marine pollution in the Baltic. There is a need to strengthen the monitoring of the conditions of the sea and its ecosystems. Techniques that gives rise to small or no discharges should be introduced. One specific item dealt with the use of best available technology in order to minimise or eliminate radioactive discharges from all nuclear power plants including reprocessing plants.

The ministers further called for close cooperation between the Helsinki Commission, the WMO (the World Meteorological Organisation) and the Executive Body for the Convention on Long-range Transboundary Air-Pollution, about the deposition of air-pollutants in the marine environment. The Declaration also dealt with issues such as increased efforts in coastal areas, further measures to improve the safety of tanker traffic, an expansion of the capacity of reception facilities in ports, cooperation with other international organisations to promote the development of better fuels for ships (and to counteract the use of heavy, dirty fuel oil, e.g. bunker oil), further work to counteract leakage and oil spills especially during winter, to strengthen air surveillance and other measures to help uncover violations of the prohibition on the discharge of oil.

In 1989 the Helsinki Commission decided to set up an early warning system between the states in order to facilitate the rapid exchange of information in the event that an acute environmental problem, such as the algal blooms in the North

Sea, Skagerrak and Kattegat during the early summer of 1988, would occur in the Baltic. As a first step the existing alarm system for oil and chemical accidents (POLREP) would be used.

At the 1989 meeting the Commission also decided to undertake an intensive study during1990 for the purpose of collecting information about all sources of pollution in Baltic and the magnitude of the problem. The material will be used in a second pollution load compilation, which in turn will be used as a basis for future decisions.

The next Ministerial meeting within the Helsinki Commission will take place in 1994. At that meeting an assessment will be made of the implementation of the recommendations, and decisions will be taken about further measures for the long-term protection of the Baltic environment.

Structure:

The decision-making body of the Helsinki Convention is the Helsinki Commission (HELCOM), and its secretariat is located in Helsinki.

HELCOM has three permanent committees – the Scientfic and Technical Committee (STC), the Maritime Committee (MC), and the Combatting Committee (CC). In addition there is a number of working groups.

HELCOM meets annually, usually in February. The 1989 meeting was the 10th session.

The Helsinki Convention was signed in 1974 and entered into force in 1980. All seven Baltic Countries – Denmark, the Federal Republic of Germany, the German Democratic Republic, Poland, the Soviet Union, and Sweden – have ratified the convention and are its Contracting Parties.

The North Sea Conferences

So far two North Sea Conferences have been held, in 1984 and 1987, both of them at a ministerial level. Also the third North Sea Conference, scheduled to be held in the Netherlands in March 1990, will be at a ministerial level.

The Conferences – The International Conferences on Protection of the North Sea – have dealt with the same issues and problems that are regularly discussed within the framework of the various marine conventions. Why then have these high-level meetings been held?

Following a number of reports in which concerns were expressed about the state of the environment in the Helgoland and German Bights and other coastal areas around the North Sea, the government of the Federal Republic of Germany invited all North Sea States to participate in special discussions about the marine environment of the North Sea in general and about the most affected areas in particular. Various factors influenced the form and timing of the meeting, but in general it can be stated that the German initiative was the result of a serious concern and a need to bring the North Sea issues and problems in a very 'concentrated' way to the political/ministerial level.

The First North Sea Conference, in 1984

The first North Sea Conference was held in the city of Bremen in the Federal Republic of Germany between 31 October and 1 November 1984.

A relatively detailed Ministerial declaration – the Bremen Declaration – was adopted at the meeting. Several of the recommendations and decisions from the meeting directly influenced the work of OSCOM, PARCOM and IMO. The Conference was unusual in that as it was organized outside the framework of the regular work within the conventions. However, it was more or less clear from the outset that the decisions and conclusions adopted by the ministers would automatically be transferred to the conventions as they are the international fora in which internationally legally binding decisions can be made by the Contracting Parties.

The Bremen Declaration was signed by the ministers from Belgium, Denmark, the Federal Republic of Germany, France , the Netherlands, Norway, Sweden and the United Kingdom – in other words by all participating states. The EC was also a signatory.

The main points contained in the First North Sea Declaration were:

- Dumping of wastes at sea. The Conference could not agree on a general prohibition on dumping.
- Reseach on environmentally sound technologies. A decision was taken to exchange information and to cooperate for the development of new and environmentally sound chemical products and processes.
- Pollution from ships. A number of decisions were taken on subjects such as oil pollution and the transportation of chemicals in bulk, and on noxious products transported in packaged form. Decisions were also made on increased information exchange in cases of accidents or illegal discharges.
- Airborne surveillance within the North Sea area. These issues had previously been adressed within the Bonn Agreement. Technical and practical cooperation were discussed at the conference.
- Emissions from off-shore platforms. A number of issues were discussed and some decisions made.
- A joint monitoring programme. The marine conventions are supported by a joint monitoring programme including comprehensive measurement programmes. The importance of this programme was underlined by the conference.
- The protection of marine marshland (salt marshes). A decision calling for increased protection of sentitive areas like the Wadden Seas and other marine marshlands was adopted.

The Second North Sea Conference, in 1987

The Second North Sea Conference was held in London on 24 – 25 November 1987.

One important element in the Ministerial Declaration from the meeting is the emphasis on the need to take an early preventive and precautionary approach to measures for the prevention of emissions and negative effects to the environment, even if absolute scientific evidence is not available. This approach is expressed in paragraph 7 of the preambular part of the Declaration which states: '*Accepting that, in order to protect the North Sea from possibly damaging effects of the most dangerous substances, a precautionary approach is necessary which may require action to control inputs of such substances even before a causal link has been established by absolutely clear scientific evidence.*'

The Declaration further establishes that best available technology should be used in all cases in which pollution can occur, that it is important to define the pollution sources, that the control of the production of hazardous substances must be intensified and that research and monitoring are important elements in a continouos accumulation of knowledge about these issues.

The Second North Sea Conference not only adopted recommendations but also took a number of far-reaching decisions which, to a large extent, guide the work carried out under the marine conventions and by national authorities.

According to the Declaration special measures have to be taken within the following sectors and activities for the protection of the environment of the North Sea:

- Input via rivers and estuaries of substances that are persistent, toxic and liable to bioaccumulate
- Input of nutrients
- Input of pollutants via the atmosphere
- Dumping and incineration at sea
- Pollution from ships
- Pollution from off-shore installations
- Discharges and disposal of radioactive wastes
- Co-operation on airborne surveillance
- Initiate action within IMO for the designation of the North Sea as a Special Area for the purpose of Annex 5 of MARPOL 73/78;
- Further research within areas of priority.

In addition the Declaration stresses the need for special protection of the Wadden Seas because of its particular vulnerability. The Wadden Seas states – Denmark, the Federal Republic of Germany and the Netherlands – made a joint statement at the conference further emphasising the importance of protecting the area because of its importance to the whole of the North Sea area.

With regard to the input via rivers and estuaries of substances that are persistent, toxic and liable to bioaccumulate, governments agreed to take measures to reduce urgently and drastically the total quantity of such substances reaching the North Sea, with the aim of achieving a reduction around 50 per cent in total inputs from these sources between1985 and 1995.

The countries should intensify their efforts to reduce emissions and inputs of substances like mercury, cadmium, PCB and DDT-compounds, carbon tetrachloride (CTC), organotin compounds, biocides like HCH, DDT, PCP, PCC and drins, wastes from the titanium dioxide industry and oil from refineries and reception facilities. With regard to potentially hazardous substances countries are urged to set up concrete goals for their reduction. This group of substances includes e.g. persistent halogenated substances from the organo-chemical industry, the pulp and paper industry and the manufacturing of pesticides and metals – all listed on the greylist of the conventions.

The input of nutrients should, according to the declaration, also be reduced substantially. The North Sea states are urged to take effective national action against the discharges of nitrogen and phosphorous aiming at a reduction of 50 per cent between 1985 and 1995. Particular efforts should be made to reduce emissions to sensitive areas that can be damaged, directly or indirectly, by high nutrient concentrations. The conference decided to pursue detailed elaboration of possible measures to reduce nutrient inputs within the framework of the Paris Commission Working Group on Nutrients.

Air pollutants are increasingly recognized as a major problem in the marine environment. The Conference urged those countries that had not already done so to ratify the Protocol on Air Pollution to the Paris Commission. The Paris Commission was further encouraged to develop its monitoring programme into a comprehensive programme for the monitoring of the role of air pollutants in the pollution of the marine environment. The emission of air pollutants should be reduced from key industrial and other sectors if practicable within four years (until 1991).

With regard to dumping and incineration of wastes at sea it was agreed in principle that these activities should be discontinued as soon as practicable in the North Sea. As from 1 January 1989, no material should be dumped in the North Sea unless there are no practical alternatives on land and it can be shown to the competent international organisation that the materials pose no risk to the marine environment.

It was further decided that the dumping of industrial wastes in the North Sea should be phased out by 31 December 1989, except for inert materials of natural origin or other materials which can be shown to the competent international organisation to cause no harm in the marine environment. The Conference also urged countries to take action in order to ensure that the dredged spoils that are disposed of in the North Sea are not heavily contaminated with persistent, toxic and bioaccumulable materials. Those countries that allow the dumping of sewage sludge should take urgent action to reduce the contamination of such sludge by substances hazardous to the environment.

The Conference wanted to end the incineration of wastes at sea, and welcomed the fact that several countries had already stopped the burning of their wastes at sea. Other countries were urged to minimise, by not less than 65 per cent, the use of marine incineration by 1 January 1991. It was agreed that all incineration operations at sea should be phased out not later than 31 December 1994 and that the waste should not be exported for incineration in marine waters outside the North Sea or allowed to be disposed of in other ways harmful to the environment.

The North Sea Conference decided to initiate action within the IMO to have the North Sea designated as a Special Area for the purpose of Annex 5 of MARPOL 73/78 (concerning garbage). If such a step is taken it would mean that ships would not be allowed to discharge garbage and refuse into the North Sea. Instead reception facilities for garbage and oil residues would have to be built in ports and their use promoted. The monitoring and control of discharges from ships would need improving.

Through the North Sea Conference the issue of air pollution from ships was put on the international agenda.

The Meeting agreed that discharges from offshore drilling in the North Sea should be reduced. The Paris Commission was urged to consider and, if necessary, to tighten the criteria for the use of oil-based muds. The Commission was also invited to establish strict standards to reduce the environmental impact of discharged oil-contaminated cuttings. The Conference decided to prohibit or limit severely the discharge, by off-shore industry, of chemicals with a potential risk to the marine environment.

Best available technology should be used to minimise pollution caused by radioactive discharges from all nuclear industries, including reprocessing plants. It was also agreed that the design and construction of repositories for the disposal of radioactive wastes should aim to preclude pollution of the North Sea.

The North Sea Conference endorsed the concept of shared responsibility of the North Sea littoral states to protect the Wadden Seas against pollution. The Conference welcomed the Joint Statement of the Wadden Seas States to increase their efforts to protect this area of importance to the whole of the North Sea.

It was agreed to increase the cooperation with regard to airborne surveillance for the detection of illegal discharges etc, and to increase research, monitoring, modelling and environmental assessment at national as well as international levels.

... and the Third North Sea Conference, in 1990

The Third North Sea Conference is scheduled to be held in the Netherlands in March 1990.

At the request of the Second North Sea Conference, OSCOM, PARCOM and ICES have established a **North Sea Task Force,** with a mandate to organize a harmonised programme of studies for monitoring, modelling and assessment of environmental conditions in the North Sea. The work of the group is geared to filling a gap in knowledge as identified in the preparations for the 1987 conference (in the Quality Status Report), and to coordinate and initiate further reseach of relevance to the North Sea.

The 1990s – a revitalisation of the marine conventions ?

Increasing awareness about marine pollution and threats to the marine environment – in the oceans in general and in coastal waters in particular – has created a renewed interest for the sea. The high-level political initiatives that have been taken during recent years are one of the signs of a revitalisation of international cooperation.

The change of attitudes is very evident among politicians at various levels. Problems and issues are discussed in terms of preventive measures being taken, and the concept that measures can be taken without 100 per cent scientific certainty is being accepted. Another step in the right direction would be taken if it became politically possible to apply the principle generally accepted by scientists about many substances – that for example heavy metals and persistent organic substances *per se* are dangerous to the environment because of the fact that they are stable and practically non-biodegradable. Scientists maintain that we may only have seen the tip of the iceberg and that the coming decades may bring new and even more serious negative environmental effects caused by these persistent substances.

The priciple that the responsibility and the burden of proof rests with those who want to exploit resources, or run an operation that has an environmental impact, may gradually become accepted nationally as well as internationally also in the field of the marine environment. This would imply a clear change from the present practice which requires authorities and other interested 'parties' to show that an operation, activity or discharge has a negative effect, before demands can be raised against those who are responsible for the operation.

During recent years awareness has increased about the wide variety of pollutants that reach the marine environment. The number of marine pollution issues has thus grown, become more interconnected and at the same time more difficult to handle within existing structures. The marine conventions certainly have an important future role in efforts to protect the marine environment. But so far the precautionary and the preventive principles have not been made fully concrete within these cooperative structures. It is a political responsibility to ensure that this will happen. The protection of the marine environment cannot be guaranteed without comprehensive national responsibility and international cooperation. The existing conventions have great potentials to develop as the fora in which these important issues are discussed and where effective measures are agreed.

No agreements are, however, better than the wishes and ambitions of the Contracting Parties. Only if there, behind the many declarations adopted and political initiatives taken during recent years, is real concern and an honest willingness to protect the marine environment, will progress be made to protect the marine environment during the 1990s and into the next millenium. It remains to be seen how much substance there is behind the verbal commitments. The parliamentarians of Europe have a key role to play in this respect, to push forward and to monitor the performance of their respective governments. International rules must be implemented through national legislation and regulations. As the ones ultimately responsible for the legislation and thus for the results achieved the parliamentarians have a very important task.

The recognition that the ocean in reality is a great lake, and that its selfcleaning capacity today is an illusion with the heavy pollution load that it receives, will hopefully lead to the adoption of far-reaching political decisions for the protection of the marine environment.

'Intet er så rommeligt som havet, intet så tålmodigt. På sin brede rygg bærer det lik en godslig elefant de små puslinger som bebor jorden; og i sitt store, kjølige dyp eier det plass for all verdens jammer. Det er ikke sant at havet er troløst; for det har aldri lovet noe; uten krav, uten forpliktelser, fritt, rent og uforfalsket banker det store hjertet — det siste sunne i den syke verden.'

(From the novel *Garman & Worse*, by Norwegian writer Alexander Kielland, 1849–1906)

'There is nothing as spacious as the ocean; nothing as patient. Like a friendly elephant it carries, upon its broad back, those little manikins who inhabit the earth; and in its great, cold depths it has room for all the sorrows of the world. It is not true that the ocean is unfaithful, for it has never made any promises; without demands, without obligations, free, pure and unadulterated, the big heart pounds — the last thing sound in a sick world.'
(Free translation of the Norwegian text above)

Photograph: Stefan Rosengren, Naturbild.

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