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Last stop: The ocean –
polluting the seas



> Human society inevitably generates immense amounts of waste arising from the production and utilization of food as well as industrial and consumer goods. A considerable amount of this waste eventually ends up in the oceans. Fortunately, the pollution from oil has been decreasing in recent years. But the increasing load of nutrients and pollutants and general littering of the oceans are a growing cause for concern.



Over-fertilization of the seas

> Rivers convey agricultural nutrients and untreated wastewater to the oceans. In many areas this causes a massive proliferation of algae. In some regions entire habitats are altered. Efforts to curtail the flood of nutrients have been successful in some parts of Europe, but worldwide the situation is growing worse.

Rivers – the lifeblood of coastal waters

Coastal waters are among the most productive regions of the oceans. The greatest numbers of fish, shellfish and seafood in general are caught here. The high productivity is a result of nutrients that are transported by rivers from the land into the sea. These mainly comprise phosphate and nitrogen compounds, which plants require for growth. Phytoplankton in the ocean, microscopically small algae in particular, also utilizes these substances. Because of the high availability of nutrients, phytoplankton grows exceptionally well in coastal regions. It is consumed by zooplankton, small crustaceans, fish larvae, and other creatures, and thus forms the base of the food web in the ocean.

The high productivity of coastal waters also makes them increasingly attractive areas for aquaculture. The output of the aquaculture industry increased worldwide by a factor of fifteen between 1970 and 2005. But rivers

are not the only source of nutrients for coastal areas. On the west coast of Africa, for instance, ocean currents from greater depths bring nutrient-rich water up to the surface, where light can penetrate. In these **upwelling regions**, the nutrients also promote a rich growth of algae, increase productivity through the entire food web, and ultimately produce a greater yield for fisheries. A natural level of nutrients is therefore a positive factor and is essential for marine organisms in the coastal waters.

Too much of a good thing

In many densely populated regions of the Earth, however, excessive amounts of nutrients are finding their way into the coastal waters. A large proportion of these nutrients come from the intensive agricultural application of chemical fertilizers, which are washed by rain into the rivers.

Between 1970 and 2005 the amount of nitrogen fertilizer alone, applied globally, increased by almost a factor of three. Nitrogen and phosphate compounds are also transported to the sea by untreated wastewater, and via the atmosphere from the burning of fossil fuels. The production and decay of organic material are unnaturally intensified by the huge amounts of nutrients in coastal waters. Scientists call this process eutrophication. The availability of nutrients is so great that the phytoplankton population grows beyond normal levels, producing a classic algal bloom. In the North Sea and in the Wadden Sea, massive algal occurrences are occasionally whipped into a foam by the surf. These sometimes form piles up to a metre high, resembling giant meringues. A serious

4.1 > Eutrophication stimulates the growth of algae, which are sometimes pounded to foam in the surf, as seen here on the German North Sea coast.





4.2 > Over-fertilization of the seas usually first becomes apparent with the appearance of copious amounts of green algae. Prior to the start of the Olympic sailing competition in Qingdao in 2008, the algae had to be removed from the water surface by hand.

threat is presented by the propagation of toxic algae. These are poisonous to various organisms in the sea, such as fish and clams and if they enter the food chain, they may also be ingested by humans. Numerous cases have been reported of people dying after eating poisoned shellfish. Scientists have also verified the deaths of marine mammals from algal toxins that they ingested with their food. These toxic algal blooms occur along the coast of Texas, for example. Because they discolour the water they are commonly called “red tides” or “brown tides”.

The blooms of non-toxic algae can also create problems when the algae die. The dead algae sink to the bottom where they are broken down by microorganisms through a process that depletes oxygen in the seawater. Low oxygen concentrations in the water can lead to large-scale mortality of fish and crustaceans. When the oxygen levels begin to drop, the animals that can actively move, such as fish and crabs, leave the area first. Within the sea floor, the population of animals that require a healthy oxygen supply diminishes at the same time. If the oxy-

gen concentration continues to drop, then most of the other species living in the sea floor also disappear. Only a few species that can tolerate low oxygen levels remain. If the bottom water finally becomes completely depleted of oxygen, even these organisms will die off.

But eutrophication also causes blooms of other organisms besides phytoplankton. It has a significant effect on larger plants, and can often change entire coastal ecosystems. One example of this was the formation of a vast carpet of green algae on the Chinese coast at Qingdao in 2008, which disrupted the Olympic sailing competition. In other cases, eutrophication leads to the disappearance of seagrass beds (Chapter 5) or to changes in the species composition in certain habitats. In short, eutrophication is an illustration of how changes onshore can impact the ocean, because the oceans are connected to the land masses by rivers and the atmosphere. To counteract the negative effects of eutrophication, serious efforts are being made to reduce the input of phosphate and nitrogen compounds into coastal waters.

4.3 > When conditions are favourable for phytoplankton growth, algal blooms occur in the oceans, as here in the Baltic Sea. Through the massive reproduction of cyanobacteria, formerly called blue-green algae, the water in these areas turns green. Such phenomena are completely natural, but because of over-fertilization these blooms are occurring with unusually high frequency today.

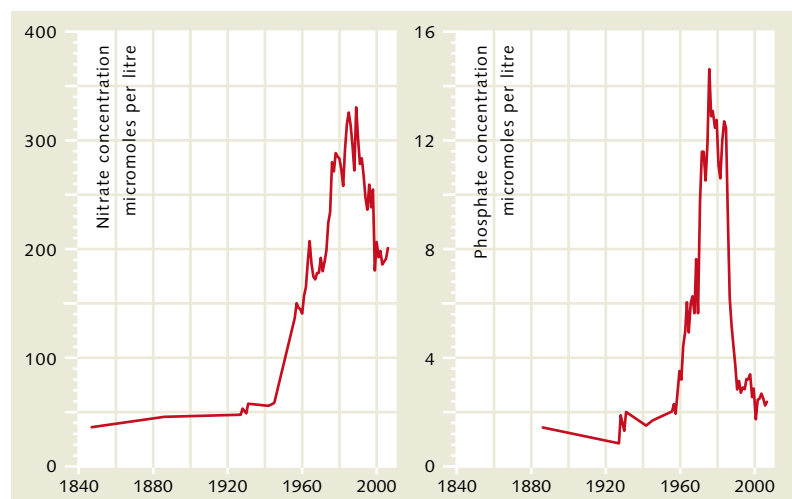


Reversing the trend

The Rhine River and North Sea present a good example illustrating how the input of nutrients by rivers into the ocean has evolved through time in European regions, because extensive data are available for both of these water bodies. The first observations were made as early as the mid 19th century. Water samples from the Rhine near the border of Germany and Holland were taken and analysed over several decades. Near the border town of Lobith, researchers documented a strong increase in phosphate and nitrate concentrations from the mid-20th century. Appropriate measures were taken that have succeeded in consistently reducing the concentrations since the mid-1980s.

The causes of the increase included a growing input from agriculture and industry as well as the discharge of untreated urban sewage. Laundry detergent with phosphate additives to decalcify the wash water was a significant source of phosphates. As early as the 1970s, a ban on this type of detergent had already begun to reduce the phosphate concentrations in the Rhine. Then, in the 1980s, the nitrogen levels in the river also began to drop. This can be attributed in part to improved fertilizing methods in agriculture that resulted in lesser amounts of nutrients being washed from the fields. Another reason is the improved treatment of industrial and domestic wastewater. In 1987, environmental ministers from the North Sea countries finally agreed to a goal of halving the amounts of phosphate and nitrogen transported by rivers. For phosphates this goal was reached quickly. For the nitrogen compounds it took almost 25 years. Despite decreasing phosphate and nitrogen concentrations in the water, however, the Rhine River still carries large amounts of nutrients to the North Sea, because it flows through a highly developed and intensively used agrarian region. The present nitrate loads are still higher than in the pre-industrial age 150 years ago. Similar situations exist in other European river regions and in the USA.

In some parts of Europe, political decisions have thus led to a reversal of the trends and a reduction of nutrient input into the oceans. But the opposite trend can be



4.4 > Eutrophication in coastal waters is primarily caused by an abundance of nitrates (nitrogen compounds) and phosphates that are washed into the ocean by large rivers. For example, since the middle of last century the concentration of nutrients in the Rhine River near the border town of Lobith has increased enormously. This is largely due to the intensive use of chemical fertilizers in agriculture and inadequate wastewater treatment. Counteractive measures such as a ban on phosphate detergents and improved fertilizing techniques have been successful in significantly reducing the input since the 1980s. But in many other coastal regions of the world the nutrient concentrations continue to increase.

observed globally. Computer models indicate that the use of fertilizer is increasing in many regions due to population growth and the intensification of agriculture. Accordingly, in many coastal regions, the amounts of phosphate and nitrogen being washed into the sea by the rivers are increasing. Particularly in Southeast Asia, rivers are carrying more and more nutrients to the sea, and experts expect this trend to continue.

A global problem

The effects of eutrophication have been coming to light since the 1960s. Researchers have noted more abundant algal blooms, oxygen-poor zones in coastal regions, and changes in coastal ecosystems. The causes of eutrophication have been thoroughly analysed in numerous studies, and there is certainly a direct connection between environmental changes and nutrient input. But for a long time researchers were in disagreement as to how the phos-

The Mississippi River and the Gulf of Mexico dead zone

No other North American river has a drainage basin as large as that of the Mississippi. The amount of nutrients it discharges into the Gulf of Mexico is correspondingly large. Because freshwater from the river is lighter than the salty seawater, it settles as a distinct layer above the seawater. This phenomenon is called stratification. The freshwater layer acts like a blanket to prevent the exchange of gases, oxygen for example, between the seawater and the atmosphere. This kind of stratification is also observed in other coastal areas, such as in the Baltic Sea between Denmark and Sweden, and in the Norwegian fjords. In the case of the Mississippi River, however, the situation is exacerbated by the especially high levels of nutrients it contains. The presence of the nutrients leads to profuse algal growth. When the algae die their remains sink into the lower water layer. There they are broken down by bacterial activity, a process that consumes oxygen. This causes the oxygen levels in the deep-lying saltwater layer to drop drastically. Free-swimming organisms flee the area due to the oxygen deficiency. Less mobile animals such as mussels die. For this reason, the low-oxygen areas off the coasts of Louisiana and Texas are called "dead zones". In 2002 an oxygen-deprived area of more than 20,000 square kilometres was observed. This is equal to half the area of Germany. There is considerable evidence that the oxygen problem associated with

stratification has only begun to occur more frequently since the middle of last century. The increase is probably due to the rising nutrient concentrations, especially nitrogen, which has trebled since the 1950s. Stratification in the northern Gulf of Mexico is, in fact, a natural phenomenon that is especially pronounced during years with high rainfall. Storm events like hurricanes can cause effective mixing of the water, and even counteract the effects of stratification. But the nutrient transport of the Mississippi River is still too great. A management plan has now been adopted to attempt to reduce the nutrient input, with an aim of limiting the maximum area of the dead zone to around 5000 square kilometres. The measures being applied include improved wastewater treatment, optimized fertilization practices, and the creation of flood-plain areas along the rivers, which would absorb significant amounts of the nutrients.

4.5 > The Mississippi River carries vast amounts of sediments (yellow-brown) and nutrients into the Gulf of Mexico, which are then transported westward along the coast by the wind. The nutrients cause a strong growth of algae (green). Oxygen is consumed in the deep water as bacteria break down the algae. This results in a completely oxygen-depleted dead zone along a broad strip of the US coast.



phates and nitrates interact as nutrients. Some experts accepted that the “law of the minimum”, formulated by the agronomist Carl Sprengel in 1828, was valid for algal growth. According to this theory, a plant requires several nutrients in order to thrive. If one nutrient is missing, then it cannot grow. This means that the growth of plants would always be limited by the one substance that is not available in sufficient quantity. This would suggest that it is sufficient to remove one nutrient, either phosphate or nitrogen, from the wastewater and rivers in order to stop the growth of algae. This would also significantly reduce the costs of water treatment.

This assumption, however, now appears to be too simplistic. Continuing experiments and observations show that multiple factors acting in concert are often responsible for limiting plant growth. Experts call this phenomenon co-limitation. Eutrophication can only be combated successfully if both phosphate and nitrogen are reduced. However, this is fraught with difficulty, primarily because nitrogen released by agricultural activity is not easily contained. This is also true of nitrogen released into the atmosphere by the burning of natural gas, oil or coal. Eutrophication is therefore likely to continue to occur in coastal waters in the future.

One example of a strongly eutrophic area is the German Bight. In the 1980s the oxygen concentration in its deep waters dropped to alarming levels. At the same time an increase in primary productivity in the form of enhanced algal growth was observed in the Wadden Sea. Seagrass, a plant that is the foundation for a unique habitat in the North Sea and Wadden Sea, disappeared. It was displaced by an excessive proliferation of green algae. All over the world, bays with limited water exchange are affected by eutrophication because nutrients are not effectively dispersed. These include Tokyo Bay, Long Island Sound in the USA, the Baltic Sea, and several of the fjords in Norway.

Eutrophication with an excessive growth of phytoplankton has also been observed in some areas in the Mediterranean Sea, such as the north-eastern Adriatic Sea or the bay at Athens. The Gulf of Mexico is a special case: here the Mississippi River discharges such a large

volume of nutrients that an extensive low-oxygen area has formed along the coast.

Any chance of recovery?

Through systematic measures such as the Water Framework Directive of 2000, or the Marine Strategy Framework Directive adopted in 2008, the European Union is striving to improve water quality in the European coastal waters. Key parameters for evaluating water quality are sufficient oxygen content, low nutrient levels, and the presence of certain algal species and bottom dwellers. Wherever possible the previously eutrophic waters should be restored to their natural condition, or at least to an only slightly impacted state. Improved monitoring for ongoing assessment should also be carried out in order to identify changes and their causes.

Due to world population growth, eutrophication will continue to be a problem for decades to come. There is presently little hope of a worldwide reduction in the amounts of nutrients being discharged into coastal waters. A true dilemma exists: humankind has a vital need for agriculture and the production of grain, but this results in vast amounts of fertilizers ending up in the rivers and oceans. Often costly abatement measures are therefore required to achieve a balance between the nutrient input from agriculture and the negative impact on the ecosystem. One particular problem is that it is impossible to completely restore a coastal ecosystem affected by eutrophication to its original state. Eutrophication is not fully reversible. Studies in several European coastal systems indicate that a long period of eutrophication produces lasting changes in the ecosystem that cannot simply be reversed by reducing the nutrient input. Nonetheless, the example of the Wadden Sea clearly illustrates that practical measures can be effective in decreasing the amount of nutrients and creating a general improvement in the marine environment. In the northern Wadden Sea, for instance, there are indications that the seagrass beds have recovered and are expanding again as a result of the reduction of nutrients and algal blooms.

Organic pollutants in the marine environment

> It has long been known that specific toxins accumulate in the natural environment and in living organisms, causing damage to health. As a result, the use of many of these chemicals is now prohibited. However, new toxic substances that were not initially recognized as a threat are frequently detected in the environment. Polyfluorinated compounds (PFCs) are one current example. There is still no solution to this problem.

The downside of consumption

Chemical-based products are found in plastic casing for computers, in athletic-hall flooring, in rubber soles for jogging shoes – the applications are endless. In consequence, a very wide range of chemicals is used in industry today. According to the Organisation for Economic Co-operation and Development (OECD), approximately 100,000 different chemical substances are currently on the market worldwide. In Europe alone, approximately 10,000 chemicals are produced and marketed annually in amounts of greater than 10 tonnes. It is estimated that between 1 and 3 per cent of these chemicals are problematical. These environmentally relevant pollutants include heavy metals such as lead and mercury, which are released into the environment by the burning of oil, mining activities, and industrial emissions and effluents. Persistent organic pollutants, known as POPs, are another problematical substance category.

Poisonous and persistent – POPs

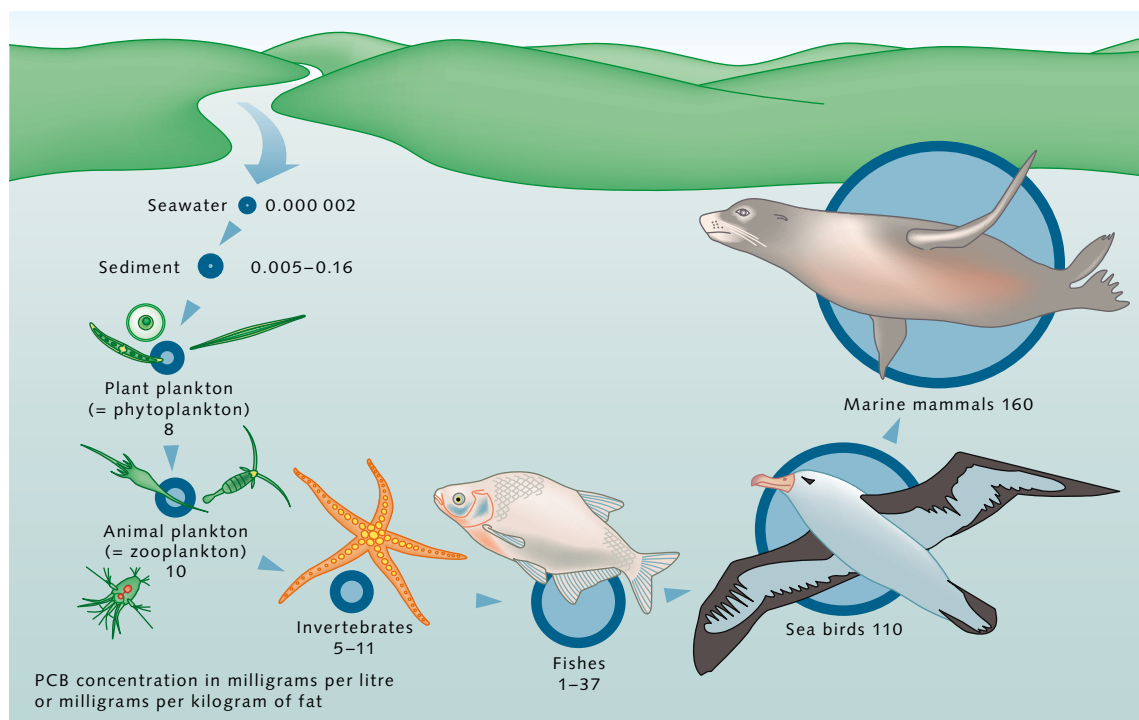
The Stockholm Convention on Persistent Organic Pollutants adopted in 2001 deals with persistent organic pollutants (POPs), i.e. substances that possess toxic properties and resist degradation. They include pesticides such as DDT and lindane, industrial chemicals such as polychlorinated biphenyls (PCBs), and substances such as dioxins, which are the unwanted by-products of manufacturing and combustion processes. As these substances are highly stable and therefore non-degradable to a large extent, they can be transported over long distances and accumulate in the environment.

POPs cause problems because they are stored in the fatty tissue or organs of animals, where they can have toxic effects. For example, they can disrupt the endocrine system, cause cancer or genetic defects, and weaken the immune system.

Various effects of POPs on marine mammals have been investigated. Studies of Baltic ringed seals (*Phoca hispida*) and grey seals (*Halichoerus grypus*) found uterine occlusions, stenoses and tumours, resulting in reduced reproductive ability. Other observed effects included colonic ulcers, as well as reduced bone density, which led to changes in the skeletal system. In seals and porpoises, researchers found indications that POPs depress the immune and endocrine systems. A further topic of discussion in this context is whether these pollutants and the weakening of the immune system affect the spread of epidemics, such as the disease that killed thousands of seals in the North Sea in 1988 and again in 2002 – probably an epidemic of the phocine distemper virus.

4.6 > During the phocine distemper virus (PDV) epidemics in 1988 and 2002, thousands of dead seals were washed up on German beaches and had to be collected and destroyed.





4.7 > Bioaccumulation of toxins in the marine food chain has long been recognized as a problem. The process illustrated here relates to polychlorinated biphenyls (PCBs), a typical environmental toxin.

Humans mainly ingest POPs from food and drinking water, but also from the air (mainly by breathing in dust particles) and through the skin (through direct contact with the chemicals). The highest concentrations of POPs are generally found in marine mammals and humans, both of which are at the top of the food chain.

Polyfluorinated compounds: a fresh cause for concern

Besides the “classic” POPs, mentioned above, new types of persistent toxic compounds of non-natural origin were identified in the environment at the end of the 1990s, which could not be detected before as the appropriate technology and analytical methods had not yet been developed. These include polyfluorinated compounds (PFCs), which have been used in a wide variety of everyday applications for more than 50 years. PFCs are mainly used as fluoropolymers in the textile industry, for example, in the manufacture of breathable membranes for out-

door clothing, and in the paper industry in the production of water-, stain- and grease-proof paper (e.g. fast-food packaging). They are also used for surface treatment of furniture, carpets and clothing textiles and in non-stick coatings for cookware (such as Teflon frying pans).

It is believed that a total of six manufacturers have produced around 4500 tonnes of PFCs every year over the past decade: a relatively small amount compared with other chemicals. This group of substances is significant nonetheless, due to its environmentally relevant properties, as some PFCs are highly bio-accumulative in organisms.

At present, more than 350 different PFCs are known to exist. The best-known is perfluorooctanesulfonic acid, more commonly known as PFOS. Based on animal experiments with PFOS, researchers conclude that repeated exposure can have an extremely adverse effect on human health; among other possible effects, it may cause damage to the liver. PFOS may also be carcinogenic, and it is also thought to impair the development of progeny. PFOS

therefore recently became the first PFC to be listed as a persistent organic compound (POP) under the Stockholm Convention, which means that it is now on the list of particularly hazardous chemicals for which a worldwide ban is to be imposed.

Occurrence of polyfluorinated compounds

Polyfluorinated compounds (PFCs) have been industrially manufactured for around half a century, but it has only recently been possible to detect their presence in the environment due to new chemical and analytical techniques. Natural origins of these chemicals are not known to exist, and yet today PFCs can be detected in water, soil, air and living organisms worldwide – including humans. High levels of PFCs have been found in numerous foods as well as in human blood and breast milk.

The distribution of PFOS in the environment is particularly well-researched. High concentrations of these substances have been detected in fish, seals and sea birds worldwide and, above all, in Arctic polar bears, which are at the top of the food chain. Researchers from

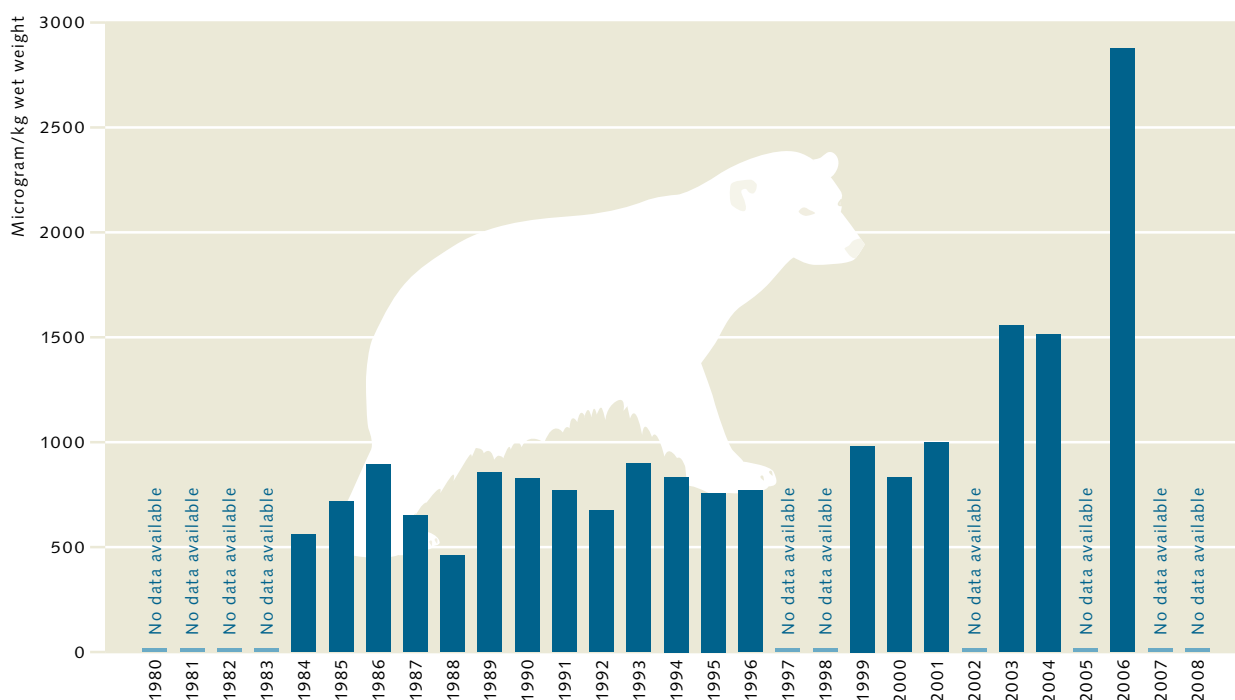
Canada and Denmark have reported a sharp rise in PFOS concentrations in liver samples taken from polar bears in Canada, Alaska and Greenland in recent decades.

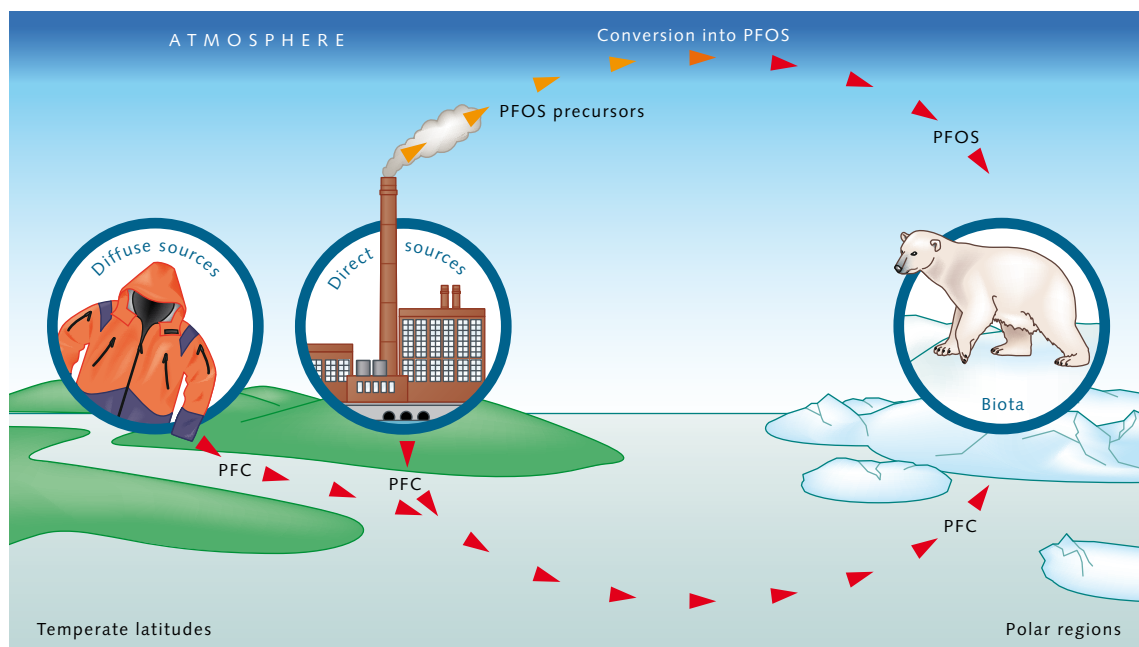
Compared to other environmentally relevant POPs, such as polychlorinated biphenyls, PFCs are found in much higher concentrations. In Swedish studies of human blood from 1994 to 2000, the mean PFC concentration was 20 to 50 times higher than the concentration of the polychlorinated biphenyls and about 300 to 450 times higher than that of hexachlorobenzene, two “classic” organic pollutants that have been recognised as hazardous for decades.

Transport of PFCs

The detection of PFCs and especially PFOS in marine mammals such as Arctic seals and polar bears, and even in the blood of the Arctic’s human inhabitants, the Inuit, raises the question of transportation: How did these substances end up in the sea and even in the Arctic? There are numerous different sources of PFCs. They are released, for example, during the use of the every-day con-

4.8 > PFOS concentrations in the livers of East Greenland polar bears have increased significantly in recent years. The measurements were obtained from deep-frozen liver samples.





4.9 > PFCs can travel great distances in water or air. Through a direct pathway, they enter the rivers in wastewater and are carried down to the sea. They can also be transported indirectly through the atmosphere. For example, volatile PFOS precursors are released into the atmosphere, where they are converted into PFOS, which is then deposited back on the Earth's surface at the place of origin or elsewhere in rainfall or in dust particles.

sumer durables mentioned above – from carpeting, outdoor clothing, cookware and fast-food packaging. However, in Germany, relatively large concentrations of PFCs also enter the rivers from municipal and industrial wastewater treatment plants, which cannot capture these substances. The rivers then wash these substances into the North Sea. From here, they are carried by the main North Sea and Atlantic Ocean currents to the Arctic, where they are ingested by microorganisms in the water and thus enter the food chain, bioaccumulating in larger organisms and finally in the organs of polar bears and humans.

PFCs are also transported long distances through the atmosphere by the movement of air masses. Compounds such as PFOS are not volatile, but volatile precursor compounds escape into the atmosphere during the manufacturing process. Physical and chemical processes that take place in the atmosphere then convert these chemical precursors into stable end products such as PFOS. These are removed from the air by precipitation and enter the seawater in soluble form or bound to dust particles, or are deposited on land or ice surfaces. PFCs can thus travel

great distances and can be detected in the environment a long way from their place of origin or use.

Protection from new pollutants

Today PFCs are distributed all over the world. They are found in water, in the air, in living organisms and even in our own bodies. They are likely to persist for generations. This group of substances clearly shows that it is impossible to predict all the environmental impacts, or the delayed effects, of new chemical substances. In the future too, it is likely that some substances that were initially regarded as harmless, but whose undesirable effects can only be discerned after some time has elapsed, will be detected in the marine environment. Nowadays, however, intensive efforts are being made to limit the further global spread of pollutants. For example, risk assessments are carried out before chemicals are licensed for use, in order to determine to what extent they could constitute a hazard. There are also various voluntary renunciation schemes for producers, as well as relevant legislation. In other words, a start has been made.

Litter – pervading the ocean

> Every year, large amounts of litter enter the sea. As plastics are particularly durable, the mass of plastic debris in the world's oceans is steadily increasing – often with fatal consequences for countless sea creatures. Microscopic breakdown products from plastics, which scientists have only recently started to study in detail, may also pose a threat. Although the problem has existed for some time, there is still no effective strategy in place to turn the tide on marine litter.

Litter: Where does it come from?

Take a stroll along any beach after a storm and you will get an idea of just how much litter is floating around in the world's oceans: the sand is strewn with plastic bottles, fish boxes, light bulbs, flip-flops, scraps of fishing net and timber. The scene is the same the world over, for the seas are full of garbage. The statistics are alarming: the National Academy of Sciences in the USA estimated in 1997 that around 6.4 million tonnes of litter enter the world's oceans each year. However, it is difficult to arrive at an accurate estimate of the amount of garbage in the oceans because it is constantly moving, making it almost impossible to quantify.

A further complicating factor is that the litter enters the marine environment by many different pathways. By far the majority originates from land-based sources. Some of it is sewage-related debris that is washed down rivers into the sea, or wind-blown waste from refuse dumps located on the coast, but some of it comes from careless beach visitors who leave their litter lying on the sand.

Shipping also contributes to the littering of the oceans: this includes waste from commercial vessels and leisure craft that is deliberately dumped or accidentally lost overboard and, above all, torn fishing nets. As most of the litter is plastic, which breaks down very slowly in water and may persist for decades or even centuries, the amount of debris in the marine environment is constantly increasing.

Scientific studies have revealed regional variations in the amount of litter in the sea. In many regions, researchers have reported quantities of floating plastic

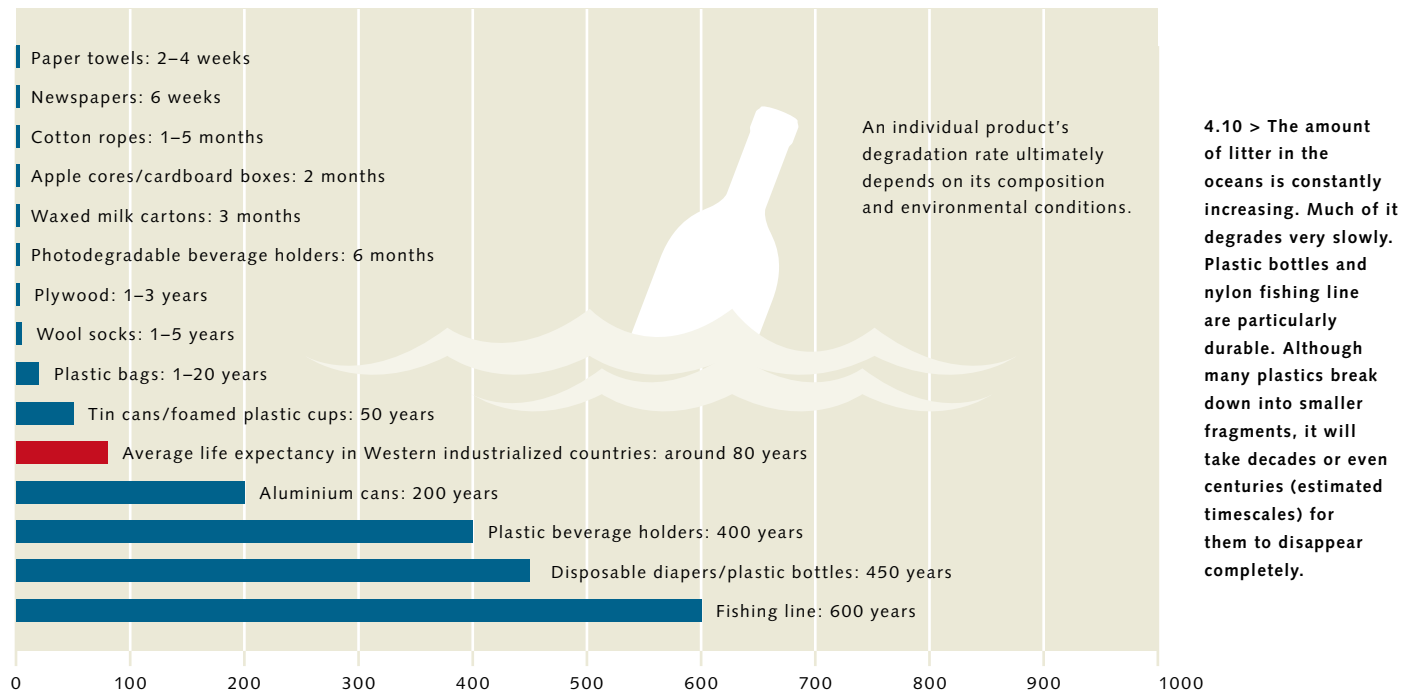
debris in the range of 0 to 10 items of debris per square kilometre. Higher values were reported in the English Channel (10 to 100 items/square kilometre), but in Indonesia's coastal waters, 4 items of debris in every square metre were reported – many orders of magnitude above the average.

The problem does not only affect the coastal areas, however. Propelled by the wind and ocean currents, the litter – which is highly persistent in the environment – travels very long distances and has become widely dispersed throughout the oceans. It can now even be found on remote beaches and uninhabited islands.

In 1997, researchers discovered that the floating debris accumulates in the middle of the oceans – in the North Pacific, for example, where massive quantities of water constantly circulate in a swirling vortex of ocean currents known as gyres, which extend for many hundreds of kilometres and are driven by light winds. The plastic debris ends its journey here. The litter circulates constantly, with new debris being added all the time. Environmental researchers call it the Great Pacific Garbage Patch. The concentration of litter is extremely high, which is particularly worrying if we consider that it is located in the open sea thousands of miles from the coast. Scientists have detected up to 1 million plastic particles per square kilometre here. Much of the debris consists of small fragments of plastic that were fished out of the water using fine-mesh nets. By contrast, studies in the English Channel, and many other surveys carried out elsewhere, are based on the visual method of quantification, which means that scientists simply count the pieces of debris that are visible as they pass by in their research vessels.

Top ten marine debris items:

- 1 Cigarettes/
cigarette filters
- 2 Bags (plastic)
- 3 Food wrappers/
containers
- 4 Caps/lids
- 5 Beverage bottles
(plastic)
- 6 Cups, plates,
forks, knives,
spoons (plastic)
- 7 Beverage bottles
(glass)
- 8 Beverage cans
- 9 Straws, stirrers
(plastic)
- 10 Bags (paper)



The amount of floating oceanic debris is immense. However, it is thought that around 70 per cent of the litter eventually sinks to the sea floor. The worst-affected areas are the coastal waters of densely populated regions or regions with a high level of tourism, such as Europe, the US, the Caribbean and Indonesia. In European waters, up to 100,000 pieces of litter visible to the naked eye were counted per square kilometre on the sea floor. In Indonesia, the figure was even higher – up to 690,000 pieces per square kilometre. Much of the litter is harmless, but some of it is responsible for marine mammal deaths. Seals and otters, for example, which feed on fish, crabs and sea urchins on the sea floor, are frequent casualties.

Tiny but still a threat – microplastics

For some years now, scientists have increasingly turned their attention to what remains of the plastic debris after prolonged exposure to wave action, saltwater and solar radiation. Over time, plastics break down into very tiny fragments, known as “microplastics”. Microplastics are

now being detected in ocean waters, sand and sea-floor sediments all over the world. These tiny particles, just 20 to 50 microns in diameter, are thinner than a human hair. Marine organisms such as mussels filter these particles out of the water. Experimental analyses have shown that the microplastics accumulate not only in the stomachs but also in the tissue and even the body fluids of shellfish. The implications are still unclear, but as many plastics contain toxic substances such as softeners, solvents and other chemicals, there is concern that microplastics could poison marine organisms and, if they enter the food chain, possibly humans as well.

The silent killers – ghost nets

Derelict fishing gear – known as “ghost nets” – poses a particular threat to marine wildlife. These are nets which have torn away and been lost during fishing activities, or old and damaged nets that have been deliberately discarded overboard. The nets can remain adrift in the sea and continue to function for years. They pose a threat to

fish, turtles, dolphins and other creatures, which can become trapped in the nets and die. The tangled mass then snags other nets, fishing lines and debris, so that over time, the ghost nets become “rafts”, which can grow to hundreds of metres in diameter. Some of these nets sink to the sea floor, where they can cause considerable environmental damage. Propelled by currents, they can tear up corals and damage other habitats such as sponge reefs.

Impacts on people

For a long time, marine litter was regarded as a purely aesthetic problem. Only coastal resorts attempted to tackle the problem by regularly clearing debris from the beaches. However, as the amount of litter has increased, so too have the problems. It is difficult to put a precise figure on the economic costs of oceanic debris, just as it is difficult to quantify exactly how much litter there is in the sea. In one study, however, British researchers showed that marine litter has very serious implications for humans, particularly for coastal communities. The main impacts include:

- risks to human health, including the threat of injury from broken glass, syringes from stranded medical waste, etc., or from exposure to chemicals;
- rising costs of clearing stranded debris from beaches, harbours and stretches of sea, together with the ongoing costs of operating adequate disposal facilities;
- deterrent effect on tourists, especially if sections of coastline are notoriously polluted. This results in loss of revenue from tourism;
- damage to ships, such as dented hulls and broken anchors and propellers from fouling by floating netting or fishing line;
- fishery losses: torn nets, polluted traps and contaminated catches; if nets become choked with debris, the catch may be reduced;
- adverse effects on near-coastal farming: numerous items of plastic waste and other forms of wind-borne marine debris may be strewn across fields and caught on fences; livestock may be poisoned if they ingest scraps of plastic or plastic bags.

Impacts on animals

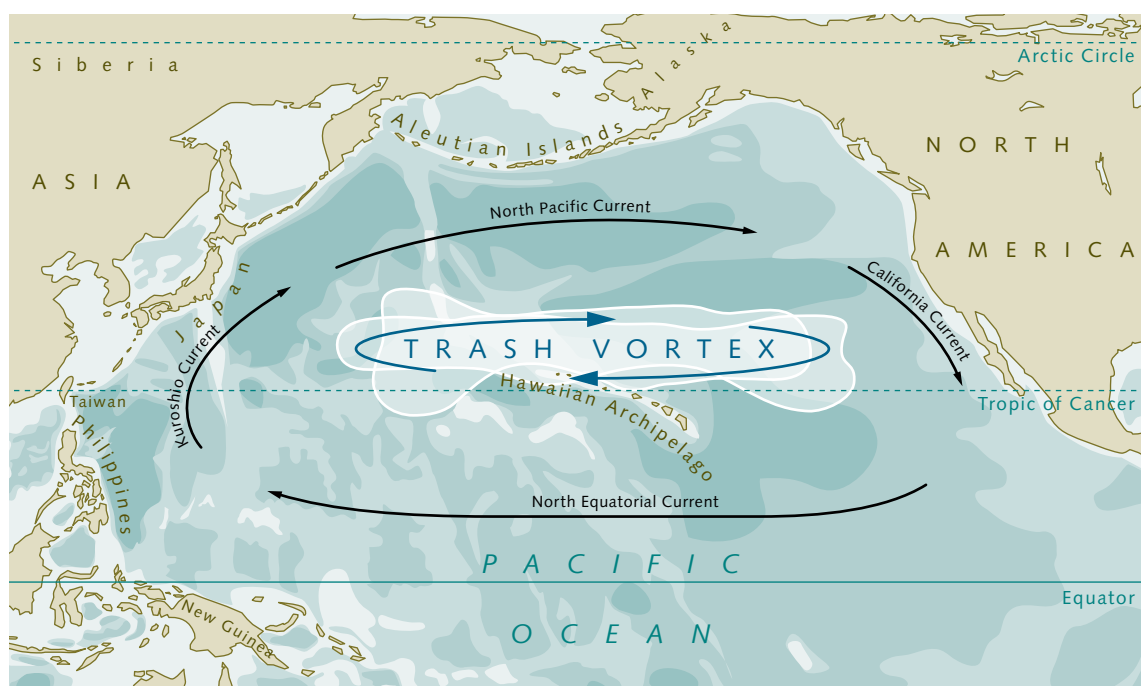
The presence of such large quantities of debris has a catastrophic effect on marine fauna. Seabirds such as the various species of albatross (*Diomedidae*) or the Northern fulmar (*Fulmarus glacialis*) pick up fragments of plastic from the sea surface, ingest them and then often pass them to their chicks in regurgitated food. It is by no means uncommon for birds to starve to death as their stomachs fill with debris rather than food. Analyses of the stomach contents of seabirds found that 111 out of 312 species have ingested plastic debris. In some cases, up to 80 per cent of a population were found to have ingested debris.

In another study, the stomach contents of 47 harbour porpoises (*Phocoena phocoena*) from the North Sea were investigated. Nylon thread and plastic material were found in the stomachs of two of these individuals. In other cases, the debris itself can become a death trap. Dolphins, turtles, seals and manatees can become entangled in netting or fishing line. Some of them drown; others suffer physical deformities when plastic netting, fishing line or rubber rings entwine the animal's limbs or body, inhibiting growth or development.

There is another threat associated with plastic debris as well: almost indestructible and persistent in the environment for many years, plastic items drift for thousands of miles and therefore make ideal “rafts” for many marine species. By “hitch-hiking” on floating debris, alien species can cross entire oceans and cover otherwise impossibly long distances. Plastic debris thus contributes to the spread of invasive species to new habitats, and can even destabilize habitat equilibrium in some cases (Chapter 5).

Raising awareness: The first step forward

The fact that marine litter is a problem that must be taken seriously is only gradually being recognized. The United Nations Environment Programme (UNEP) has therefore launched an intensive publicity campaign in an effort to raise awareness of this critical situation. Its main focus is



4.11 > In the Great Pacific Garbage Patch between Hawaii and North America, vast quantities of litter are constantly circulating. Many plastic items are transported thousands of kilometres across the sea before they are caught up in the gyre.

on working with non-governmental organizations and government agencies to improve the situation at the regional level. This includes promoting the introduction of regulations and practices that in many cases are already the norm in Western Europe, such as waste separation systems, recycling, and bottle deposit-refund schemes. Various litter surveys have shown that much of the debris found in the North Sea, for example, comes from shipping rather than from land-based sources. However, the situation is reversed in many countries of the world, where waste is often dumped into the natural environment without a thought for the consequences and, sooner or later, is washed into the sea. In these cases, shipping plays a less significant role. UNEP is therefore emphasizing the importance of efficient waste management systems.

UNEP also supports high-profile, media-friendly clean-up campaigns such as the annual International Coastal Cleanup (ICC). Every year, volunteers, especially including children and young people, clear litter from beaches and riverbanks. The main aim is to raise young people's

awareness of the problem of global marine litter. In 2009 alone, around 500,000 people from some 100 countries took part in the ICC. Before all the litter is disposed of onshore, each item is recorded. Although the data collection is carried out by laypersons and may therefore contain errors, the International Coastal Cleanup nonetheless provides a very detailed insight every year into the worldwide litter situation.

Indeed, surveying marine litter – i.e., regular monitoring – is an important tool in assessing how the situation is developing. In various regions of the world, professionals have been recording the debris found along the coasts for many years. In the north-east Atlantic region, for example, a standard methodology for monitoring marine litter was agreed to by the Contracting Parties to the Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR Convention), and this has been in effect for around 10 years. Using a common, standardized survey protocol, 100-metre stretches of around 50 regular reference beaches in the north-east Atlantic region are surveyed three to four



4.12 > The Laysan albatross (*Phoebastria immutabilis*) is also affected by the litter in the Pacific Ocean, as the birds mistake the brightly coloured plastic for food and ingest it. Here, the photographer has laid out stranded items of debris neatly on the beach. These types of objects are typically found among the stomach contents of albatross, and can cause the death of many of the affected birds.

times a year. It was this monitoring activity that found that the debris in the North Sea mainly comes from shipping.

International agreements lack teeth

For some years, efforts have been made to stem the tide of litter with international agreements. These include the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78). Since 1988, Annex V to the Convention has specified which types of waste must be collected on board and may not be discharged into the sea. For example, under the MARPOL Convention, disposal of food wastes into the sea is prohibited if the distance from the nearest land is less than 12 nautical miles. Disposal of all plastics into the sea is prohibited. For the EU, on the other hand, Directive 2000/59/EC of the European Parliament and of the Council of 27 November 2000 on port reception facilities for ship-generated waste and cargo residues requires ships to dispose of their waste before leaving port and obliges ports to ensure the provision of adequate reception facilities for such waste. Ships must contribute to the costs of the reception facilities through a system of fees.

If a ship has proceeded to sea without having disposed of its waste, the competent authority of the next port of call is informed and a more detailed assessment of factors relating to the ship's compliance with the Directive may be carried out. Critics point out that both the assessment itself and the communication between ports are inadequate. The fact that there has been no decrease in the amount of debris along the North Sea coast as yet also suggests that the international agreements lack teeth. Annex V of the MARPOL Convention is therefore being revised at present.

In any case, the agreements have no impact on the amount of waste entering the sea from land-based sources. It is hoped that the Marine Strategy Framework Directive (MSFD) – the European Union's tool to protect the marine environment and achieve good environmental status of the EU's marine waters by 2020 – will improve

the situation. Besides addressing topics such as marine pollution from contaminants and the effects of underwater noise on marine mammals, the MSFD in addition deals with the issue of waste. An initial assessment of the current environmental status of the waters concerned and the environmental impact of human activities is to be completed by 2012, and a programme of measures is to be developed by 2015. The necessary measures must then be taken by the year 2020 at the latest.

Turning the tide against litter: The future

Experts agree that the littering of the seas will only stop if the entry of waste from land-based sources can be controlled. According to UNEP, this means that numerous countries will have to develop effective waste avoidance and management plans. At present, the prospect of this happening seems somewhat bleak, especially given the vast quantities of waste involved. Environmental awareness-raising and education would therefore appear to be a more promising approach. The popularity of the International Coastal Cleanup programme is an encouraging sign that there is growing recognition, around the world, of the need to prevent littering of the seas.

To address the problem of ghost nets, UNEP is calling for stronger controls, which would involve fishermen being monitored and having to log the whereabouts of their nets. Work is also under way to develop acoustic deterrent devices for fishing gear that can, for example, alert dolphins to the presence of nets. The Fishing for Litter scheme being set up in Scotland and Scandinavia is another positive example of action being taken. Fishermen and port authorities have joined forces so that debris caught in fishing nets can be disposed off correctly onshore. Instead of throwing the litter back into the sea, the fishermen collect the debris on board and bring it back into port. Recycling schemes for old fishing nets are also being developed. In all probability, the global problem of marine litter can only be solved through numerous individual schemes such as these. However, without a concerted effort by the international community as a whole, the problem is likely to continue.

Oil pollution of marine habitats

> Oil pollution is one of the most conspicuous forms of damage to the marine environment. Oil enters the seas not only as a result of spectacular oil tanker or oil rig disasters, but also – and primarily – from diffuse sources, such as leaks during oil extraction, illegal tank-cleaning operations at sea, or discharges into the rivers which are then carried into the sea. The designation of marine protected areas, increased controls and the use of double hull tankers are just some of the measures now being deployed in an effort to curb marine oil pollution.

How oil enters the sea

The public generally takes notice of the problem of marine oil pollution when an oil tanker breaks up in heavy seas or a disaster occurs at an oil platform, one example being the Deepwater Horizon incident in the Gulf of Mexico in spring 2010. In such cases, oil slicks often drift towards the coasts and kill seabirds and marine mammals such as seals. Yet in reality, spectacular oil tanker disasters account for only around 10 per cent of global marine oil pollution.

Most of the oil enters the seas along less obvious pathways, making it correspondingly difficult to precisely estimate global oil inputs into the marine environment.

Around 5 per cent comes from natural sources, and approximately 35 per cent comes from tanker traffic and other shipping operations, including illegal discharges and tank cleaning. Oil inputs also include volatile oil constituents which are emitted into the atmosphere during various types of burning processes and then enter the water. This atmospheric share, together with inputs from municipal and industrial effluents and from oil rigs, accounts for 45 per cent. A further 5 per cent comes from undefined sources.

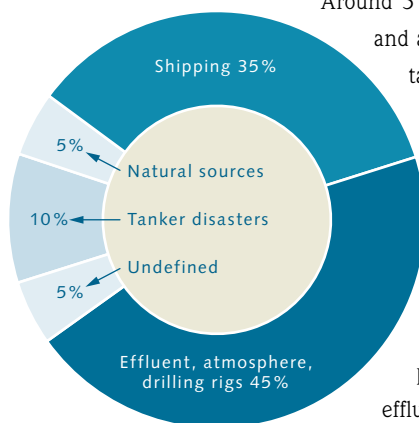
Although vegetable oils such as palm oil are now being produced in increasing quantities and are therefore also entering the atmosphere, oil pollution still mainly consists of various types of oil from fossil sources, created

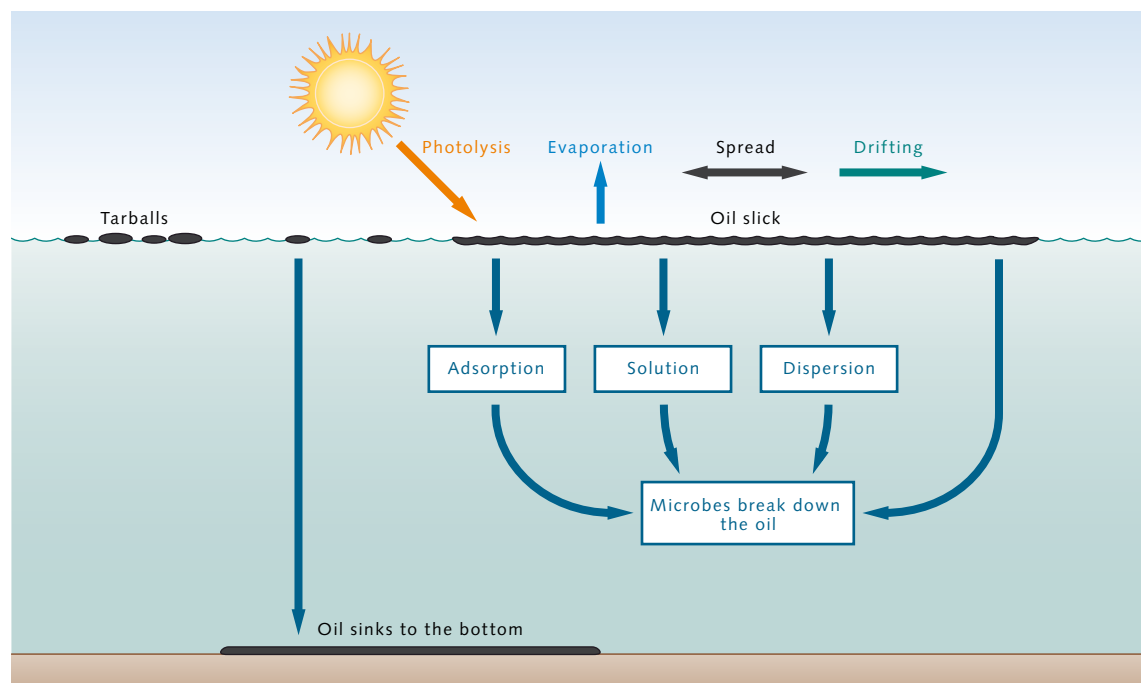
over millions of years from deposits of microscopically small marine organisms, mainly diatoms (Chapter 7). This crude oil consists of around 10,000 individual substances, with hydrocarbons being the main component (more than 95 per cent). However, the precise composition can vary considerably according to the place of origin. Crude oil also contains heavy metals and nitrogen compounds.

The extent to which mineral oils and their components adversely affect the various marine habitats and their flora and fauna varies considerably from case to case. Major oil spills have the greatest and most disruptive impact, although their effects are in most cases regionally limited. Since the *Torrey Canyon* tanker disaster in 1967, when around 115,000 tonnes of crude oil were spilled on a reef off the southern English coast, resulting in the largest oil pollution incident ever recorded up to that time, numerous field studies have been carried out which now provide a very clear overview of the impacts of various types of oil on organisms and habitats. However, one oil disaster is quite never the same as another, and the precise effects of an accidental oil spill depend on a variety of conditions.

A crucial factor, for example, is how quickly the oil breaks down or sinks from the surface of the sea to the lower depths, where the damage it causes is likely to be relatively limited. This breakdown is influenced by various physical, chemical and biological processes. Depending on a variety of different environmental conditions such as temperature, nutrient content in the water, wave action etc., the breakdown of the petroleum hydrocarbons may take shorter or longer periods of time. During

4.13 > Oil enters the sea along various pathways. Around one third comes from regular accident-free shipping operations.





4.14 > In the sea, oil is modified and broken down in a variety of ways. Generally, when an oil spill occurs, the oil immediately forms large slicks which float on the water's surface. A proportion of the oil evaporates or sinks, but other oil constituents are broken down by bacteria or destroyed by solar radiation. Finally, the oil solidifies into clumps (tarballs), which are more resistant to bacterial breakdown.

the first few hours or even during the first few weeks, the oil is modified by the following chemical and physical processes:

- evaporation of volatile constituents;
- spreading of the spilled oil in large oil slicks drifting on the surface waters;
- formation of dispersions (small oil droplets in the water column) and emulsions (larger droplets of oil-in-water or water-in-oil);
- photooxidation (molecular changes to the oil constituents caused by natural sunlight) and solution.

Processes such as sedimentation and breakdown by bacteria, on the other hand, may continue for months or even years, although in some cases, under favourable conditions, they may be completed within a matter of days.

The reason for this discrepancy is that, firstly, the various substance groups contained in the oil undergo biological breakdown at different rates. The speed of breakdown depends primarily on the molecular structure of the oil constituents. The more complex the hydrocarbon

molecules, the longer it takes for the oil to be broken down by microorganisms. Secondly, the rate at which the various hydrocarbons are broken down is increased by the following factors:

- high temperatures, promoting bacterial activity;
- a large surface area (if necessary, the surface area of the slick can be increased through the use of dispersants, i.e. surface-active agents [surfactants] which promote the formation of dispersions);
- good oxygen supply for the bacteria;
- good nutrient supply for the bacteria;
- low number of predator organisms which would reduce the number of bacteria.

Some of the above-mentioned processes have a very considerable influence on the extent of oil damage. Water-in-oil emulsions, for example, are a contributory factor in the formation of "chocolate mousse". This viscous emulsification can increase the original volume of the oil as much as fourfold, rendering the use of chemical dispersants impossible and making it far more difficult to pump the oil off the water surface.

How oil damages habitats

It is generally not possible to protect an entire coastline from the effects of a major oil spill, so the authorities have to set priorities for their oil spill response. It goes without saying that designated conservation areas, such as national parks, or sensitive marine areas are particularly worth protecting and are given high priority in clean-up efforts. As a rule, however, these areas are too large to be protected in their entirety. Here, sensitivity rankings can facilitate the oil spill response: these describe the general sensitivity of the various shoreline types to oil pollution. In exceptional cases, it may even be possible to define “sacrificial areas” which are less important from a nature conservation perspective and where no protective measures are taken.

When defining these sensitivity rankings, one factor which is taken into account is whether the section of coastline is a “high-energy” area, e.g. with rocky or sandy shores that are subjected to direct wave action, or whether they are relatively calm, “low-energy” areas such as the Wadden Sea, which are protected by sandbanks or offshore islands. Of course, within the major habitats described here, other more detailed sensitivity rankings can be defined for a targeted oil spill response.

EXPOSED ROCKY AND SANDY SHORES: Exposed rocky and sandy shores are classed as areas of relatively low sensitivity because the oil deposited by the sea is cleared very swiftly by wave action. Nonetheless, major oil spills can change the composition of biological communities in these habitats over the longer term. In such cases, populations of former dominant species such as crustaceans and molluscs may decline. In rocky crevices, rough gravel and on mussel beds, the oil pollution may persist for many years.

SANDY BEACHES: Here, a different situation applies. The extent to which the oil penetrates the ground and how long it remains there depend primarily on the structure of the beach. An extensive beach with little surf and with branching channels, for example, is far more vulnerable than a steep beach with a less diverse structure. Coarse-grained sediment facilitates oil penetration, makes

the clean-up process more difficult, and increases the risk of follow-up damage from re-surfacing oil. Beach areas used as habitats or breeding sites by endangered species, such as turtles, are classed as particularly sensitive.

CORAL REEFS: Corals are also highly sensitive to oil pollution. Various studies show that damaged coral reefs are very slow to regenerate. Oil pollution can also affect entire communities. For example, less sensitive species of algae can colonize oil-contaminated areas which were previously coral habitats. Very little research has so far been undertaken to investigate how oil spills affect the relationship between corals and the many species associated with them. The linkage between numerous specialized species and the great significance of symbioses within these ecosystems indicate that far-reaching and long-term impacts can be anticipated after major oil spills.

MANGROVES: Mangrove habitats react with particular sensitivity to oil pollution. Here, an oil spill can inflict severe damage on trees and the sensitive organisms living in them and in sediment. This damage is caused by toxic hydrocarbons, but can also occur as a result of oil cover, which shuts off the oxygen and freshwater supply. The regeneration of damaged populations of flora and fauna is a lengthy process. As the harmful hydrocarbons are removed from sediment very slowly in mangroves, habitat recovery is further delayed.

SOFT SUBSTRATES AND SANDBANKS: Sections of coastline with soft substrates and sandbanks, such as the Wadden Sea on the North Sea coast, are classed as particularly or highly sensitive. The organisms living at great density in and on the sediment provide the basic food supply for fish and birds. Although in most cases, very little oil penetrates the often water-saturated fine pores of muddy sediment, these areas are generally densely populated by burrowing organisms whose activities cause the oil to sink deeper into the ground. On the other hand, the stirring and mixing of sediment by these organisms – known as bioturbation – also help to break down the oil by churning up the sediment, exposing deeper layers to the air and bringing oily sediment to the surface. As this activity promotes a healthy oxygen supply, the oil is then

4.15 > A specially equipped ship deploys a boom, consisting of inflatable floats, in an attempt to contain the crude oil spilled at sea by the oil tanker *Sea Empress* after it went aground off the coast of Wales in 1996. In rough seas, however, the use of these skimmers has little effect.



Oiled and poisoned – the effects on flora and fauna

The damage caused to seabirds' plumage is probably the most notorious effect of oil pollution. As a result of oil contamination, the plumage can no longer perform its vital functions of repelling water and providing thermal insulation. If much of the plumage is covered in oil, the bird will lose body heat and die. A similar effect can be observed when marine mammals' fur is coated with oil. The fur can no longer insulate the mammal from cold air and water, which weakens it and may even cause death in extreme cases.

In plants, oil contamination of shoots interrupts gas transport from the leaves to the roots, which causes the plant to die. Filter-feeders such as mussels and organisms such as sea snails and worms which take up nutrients from the sea floor often ingest oil along with their food. The toxic hydrocarbons can then be passed along the food chain when the contaminated mussels are eaten by other animals. Birds and mammals often ingest oil when they attempt to clean their oil-coated feathers or fur. Soft-skinned creatures such as fish and many invertebrates mainly absorb petroleum hydrocarbons through the skin and especially through the gills, which process large quantities of water.

Petroleum hydrocarbons have many different effects according to the species. In many fauna, they mainly impair growth and metabolic activity. Studies show that lobsters and lug worms react by reducing their nutrient intake. In mussels and fish, studies show that growth is impaired by oil pollution. Researchers have repeatedly observed behavioural changes in response to exposure to oil. Seals are reported to be extremely lethargic, which scientists attribute to nerve damage caused by the intake of volatile petroleum hydrocarbons during respiration in the immediate aftermath of oil spills.

Reproduction of numerous marine organisms is also adversely affected. Poisoning by oil can cause genetic damage: in salmon, for example, increased ovum mortality was observed after an oil spill. In herring, numerous freshly hatched progeny were malformed. Scientists have also reported that the concentration of specific hydrocarbons in sediment increases the number of genetic mutations in mangrove trees. Often, toxic oil constituents can also damage the reproductive organs of marine organisms: an increase in the number of sterile shellfish, for example, was observed during the year following an oil spill. In the case of corals, scientists reported that the number of progeny decreases in chronically oil-polluted areas.

Furthermore, many marine fauna lose their sense of direction, as many of them use very fine concentrations of certain substances as a means of finding their way around their environment and identifying prey, predators or partners for reproduction. These natural substances are **biogenic** hydrocarbons whose molecular structure is similar to some hydrocarbons contained in crude oil. If large quantities of the alien hydrocarbons enter the water during an oil spill, the animals find it impossible to detect the natural substances, making it far more difficult for them to find food or identify a breeding partner.

4.16 > In San Francisco Bay, a stricken seabird attempts to clean oil from its plumage following an oil spill from the *Cosco Busan* container ship after it collided with a tower of a bridge in November 2007. Accidents such as this contribute to the chronic oil pollution of the seas.



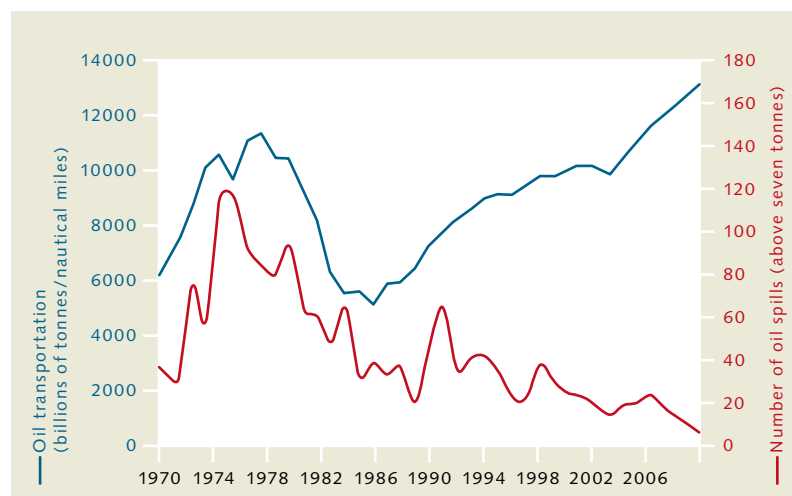
broken down more quickly by bacteria. If the organisms in the sediment have been killed by the oil, however, bioturbation ceases and the oil remains in the ground for longer, causing long-term habitat damage.

SALT MARSHES: Very few studies have been carried out to investigate how oil affects invertebrate organisms found in salt marshes, such as insects and worms. The vegetation, however, can suffer long-term damage from oil pollution, with major implications for breeding and resting birds in the salt marshes, whose plumage may be covered in oil or which could lose their basic food supply. To sum up, the following regeneration periods can be assumed:

- Exposed rocky and sandy shores: between a few months and 5 years;
- Protected rocky shores and coral reefs: between 2 and more than 10 years;
- Protected soft substrates, salt marshes, mangroves: between 2 and more than 20 years.

Responses to oil spills and pollution

In scenarios other than disasters that occur in deep waters, such as the explosion at the oil drilling rig in the Gulf of Mexico in spring 2010, an oil spill disaster response is most effective while the slick is still drifting on the water surface. From a technical perspective, some countries prefer to use exclusively mechanical methods to contain oil spills, such as oil skimmers or booms that form floating barriers on the water, while others opt for chemical methods, mainly involving the use of dispersants, which are usually dropped on the slick in large quantities from aircraft. The effectiveness of these chemicals is heavily dependent on the type and condition of the oil, however. A further limiting factor is that these dispersants can generally only be used for a short time after the spill has occurred, as the chemical and physical processes described above begin to impair their effectiveness after only a few hours. If the oil slicks are drifting towards sensitive sections of shoreline, using these agents may be a sensible option, however. The dispersants drive the oil from the surface down into deeper



4.17 > Although the quantities of oil being transported across the oceans have increased considerably since the 1970s, the amount of marine oil pollution caused by oil tanker disasters, technical defects or negligence has fallen dramatically. The sharp decrease in tanker traffic in the late 1970s was caused by the economic crisis which occurred during that period. The statistics cover oil spills above 7 tonnes; records of smaller spills are somewhat patchy.

waters, reducing the risk that seabirds or sensitive flora will become coated with oil. Following the explosion at the Deepwater Horizon drilling rig in 2010, however, the oil flowed out of the borehole at great depth and entered the entire water column, partly as a massive cloud of oil. Very little experience has been gained in responding to disasters of this type and on this scale. As an initial response, massive quantities of dispersants were deployed, with currently unforeseeable ecological consequences. Bioremediation can also be successfully deployed in suitable – i.e. nutrient-poor – marine areas. This involves seeding the water with nutrients to promote the growth of bacteria that break down oil.

No matter which strategy is deployed, it can only be successful and effective as part of a broader national contingency plan in which well-trained emergency teams implement a coherent and well-thought-out response. In the US, Germany, other North Sea states and certain other countries, such contingency plans have been in place for a number of years. In these countries, the days

4.18 > Workers on a beach at the popular Gulf Shores resort in the US remove sacks of oil-covered algae. The resort, along the coast of Alabama, is one of the communities in the Gulf of Mexico which have been polluted by oil from the Deepwater Horizon disaster in June 2010.



when the authorities often failed to adopt a prompt, effective or appropriate response to oil spills due to a lack of clear responsibilities, equipment and personnel are over. On their own, however, technical management strategies are not enough. Global and regional agreements are required to protect the sea from oil pollution, and mechanisms need to be in place to monitor compliance with them. A positive example is the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78), which from 1983 formed the basis for the designation of marine protected areas where tanker traffic is wholly or partly restricted. As a result of the Convention, there was a reduction in the number of oil tanker disasters during the 1980s. In addition to other provisions on operational discharges of oil, MARPOL 73/78 also paved the way for the introduction of double hull tankers. The United States' 1990 Oil Pollution Act and the International Management Code for the Safe Operation of Ships and for Pollution Prevention

(ISM Code) adopted by the **International Maritime Organization (IMO)** in 1998 also contributed to the further decrease in oil pollution over subsequent decades.

The outlook for the future – cautious optimism

Marine oil pollution has undoubtedly decreased in recent decades. International conventions, the designation of protected areas and the mandatory introduction of double hull tankers have all made a contribution here. At the same time, as the Deepwater Horizon disaster clearly demonstrates, the situation for the marine environment continues to give cause for concern. Furthermore, the illegal discharge of oil during tank-cleaning operations, which still accounts for one third of oil pollution, cannot be tackled effectively without more stringent controls and tough penalties. Combating oil pollution in shallow waters such as the Wadden Sea will also continue to be a problem in future as response vessels generally cannot operate in waters of less than 2 metres depth.

CONCLUSION

Much to be done ...

Humankind is still discharging millions of tonnes of problematical substances into the sea. Some enter the marine environment during the production or use of specific products, while others can be classed as litter, or contaminate the sea with oil. However, the present situation differs from the past in one crucial respect. Whereas humankind, until only a few decades ago, deliberately disposed of waste in the sea, by far the major share of litter and pollutants now enters the sea indirectly along many different pathways. This is exactly what makes it so difficult to combat pollution – for in order to improve the situation, a whole package of measures is required. For example, in order to curb nutrient overfertilization of the seas, treatment plants need to be built onshore and the amount of fertilizer used in agriculture must be reduced. The success achieved in improving water quality in Western European rivers shows that the nutrient load can indeed be decreased in this way. Ultimately, every individual nation has a responsibility to adopt appropriate measures to keep its marine environment clean. Substances which are dispersed into the environment from the atmosphere, however, are far more difficult to control. This applies to nitrogens from the burning of oil, gas and coal, and to industrial chemicals such as polyfluorinated compounds or other persistent molecules. Here, the pollutants need to be captured at source. In some cases, however, the origin of the substances is not yet properly understood. Robust risk assessments offer a promising solution here: these evaluate the potential hazards associated with a given substance before it is brought to market. In contrast to substances such as polyfluorinated compounds, which are difficult to monitor because they are released not only during

the production but also during the use of certain products, the solution to the littering of the oceans is obvious, and starts with correct disposal. In countries such as the Netherlands and Germany, recycling and bottle-deposit systems are well-established as a means of effectively managing the flow of disposable packaging. Many other countries, however, lack well-functioning waste recovery systems. However, waste management can only really work if the general public is sensitized to the problem of waste. There are now good examples of effective environmental awareness-raising all over the world.

In contrast to the marine litter situation, a more positive trend can be observed with regard to oil pollution. The amount of oil in the sea has been decreasing for years. It is difficult to say whether this is due to more stringent controls on commercial shipping, monitoring overflights or better ship safety. It is also unclear, at present, which measures would be effective in significantly reducing oil pollution in future. One thing is certain: the threat posed by major tanker disasters is taken far more seriously today than just a few years ago. Disasters such as the Deepwater Horizon drilling rig explosion in the Gulf of Mexico nonetheless demonstrate that humankind is often helpless in the face of the problems caused by oil. It is still unclear whether the trend towards oil extraction at ever greater depths will increase oil pollution in the oceans. However, as the most recent example shows, there are currently very few strategies in place to combat oil pollution in the deep seas. Oil clean-up technologies for use when emergencies occur in deep-sea oil extraction and drilling therefore need to be developed as a matter of urgency. The oil industry has announced that it plans to set up a voluntary rapid response force; however, such measures must be monitored by impartial agencies.

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