1 The importance of marine fish

> Fish are a vital component of marine habitats. They are complexly related to other organisms – through the food web and through other mechanisms. Intensive fishing therefore results not only in the decimation of fish species but also affects entire biological communities. The results are often unpredictable. Although industrial fisheries rarely cause the complete eradication of individual species, they may already be having an evolutionary impact on heavily fished species.

The role of fish in the ecosystem

> Economically important fish species have long been regarded in isolation from each other and their habitat. In order to comprehensively assess the impacts of fisheries the entire habitat must be considered. Only then will a sustainable and economic fishery system be possible. Methods now exist for these kinds of comprehensive analyses. Moreover, it is now known that not only the fisheries, but also changing environmental conditions can affect the size of fish populations.

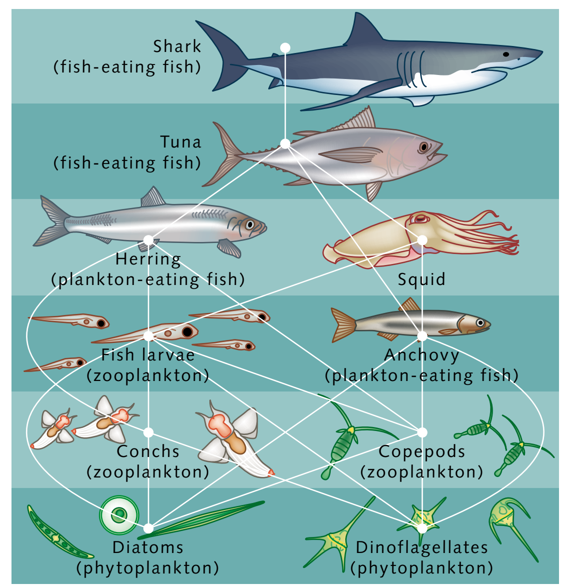
Fish and life in the sea

The ocean is tremendously diverse and species-rich. It is the home of countless organisms living in very different ecosystems. Mussels and worms thriving in the Wadden Sea are a food source for millions of migratory birds. Communities of tube worms, crustaceans and bacteria have developed at volcanic hydrothermal seeps in the deep sea. Elsewhere kelp forests sway with the currents while sea otters on the hunt swim through. Sea birds nest on rugged and rocky coasts while thousands of iridescent fish species frolic in reefs.

Fish are a key component of marine biotic communities. For millennia mankind has had an especially close bond with them because they provide people with food. Around 43 million people worldwide make their living directly from fishing or fish breeding. But people are careless with this natural resource. Over thousands of years too many fish have been taken. Many fishing grounds have been overfished. Furthermore, the ocean is being polluted by effluents from industry, settlements and agriculture. Some habitats such as mangrove forests are destroyed directly by construction. Considering the serious situation, it is important to investigate the present status of marine fish.

Fascinating diversity

The diversity is amazing: there are over 30,000 fish species in the world. Some are only a few centimetres long and live hidden among corals. Others, like the blue marlin in the Atlantic, are up to 3 metres long and roam the open sea. Herring glide through the North Sea in large schools, while anglerfish do their hunting in the darkness of the deep sea with a bioluminescent lure extending from their foreheads. Each of these fish types is part of a habitat, an ecosystem, and exists in complex interdependence with many other species in a food web.



1.1 > Interrelationships between organisms can be illustrated as a food web with various trophic levels.

Specialists arrange the organisms within the food web into different nutritional positions called trophic levels. At the bottom there is a myriad of microorganisms. These include microscopic single-celled algae such as diatoms, dinoflagellates and cyanobacteria, collectively known as phytoplankton, which drifts freely in the water. It carries out photosynthesis, which means that it uses sunlight and nutrients to synthesize sugar, and from this builds other energy-rich substances. Scientists refer to this biochemical development of biomass as primary production. Phytoplankton is the food source for small, free-swimming

1.2 > Sardines are also threatened by predators from the air. Cape gannets off South Africa can plunge up to 8 metres below the surface to grab their prey.

crustaceans or fish larvae, referred to as zooplankton. Zooplankton, in turn, is food for small fish and other organisms. The amount of fish that can exist in a given region is primarily determined by the activity and amount of primary producers; greater primary production can support larger fish stocks. The simple model of a food web in which smaller organisms are eaten by larger ones, however, is not sufficient for explaining the relationships in the ocean. What the larger animals do has an impact on the entire habitat. Many other interactions are also taking place.

Network thinking

The knowledge that the web of relationships among marine organisms is complex is not new. Similar connections are also known for many habitats on land. But for a long time in the fisheries there was a tendency to focus on individual commercially important species such as cod, herring or sardines. Only in the past ten years has the importance of looking at entire ecosystems become accepted for the long-term preservation of fish stocks and effective management of fisheries. The reason: numerous stocks have been overfished in many ocean regions in the past. In some cases this has resulted in serious changes to the habitats. It is gradually being recognized that the complexity of the marine system has to be considered in fishery management. Marine habitats are by no means influenced only by primary production at the base, but also by factors at the higher trophic levels, from the top down.

An example can be seen in the eastern Atlantic waters of the Benguela Current off Angola, Namibia and South Africa. Persistent winds in this region push the surface waters out to sea. This is replaced by nutrient-rich water

1.3 > Specimens of the jellyfish *Nemopilema nomurai* can reach a size of 2 metres and weigh up to 200 kilograms. A few years ago hundreds of these animals drifted into Japanese waters, seriously interfering with fisheries.

rising from below near the coast. These upwelling regions are enormously productive and rich in fish. Over many years mostly foreign fleets have fished intensively for sardines here. At the beginning of this century the stock collapsed. Since then the jellyfish population in this region has greatly increased. Experts believe that the decline of sardines represented the loss of an important food competitor because both sardines and jellyfish feed primarily on zooplankton. In addition, young jellyfish are eaten primarily by fish. The jellyfish scourge was unexpected. It was assumed that with the decline of the sardines the abundance of anchovies, another small fish species native to this region, would increase. The anchovy has a diet similar to that of the sardine and should have kept the jellyfish in check. But the anchovy does not appear to be a true competitor of the jellyfish, because so far the anchovy population has remained smaller than that of the sardines. Perhaps the very dynamic upwelling area is a less suitable habitat for anchovies.

There is a similar situation off the coast of Japan. The population of the jellyfish *Nemopilema nomurai* greatly increased there after the intensive fishing of sardines. Individuals of *Nemopilema* can reach a size of up to two metres. The fishery is now seriously impaired by the jellyfish because they clog up or even tear the nets. But jellyfish do not always proliferate to create this kind of disaster. In the 1970s, off Peru, the large stocks of South American anchovies collapsed. As a result, sardines flourished and a jellyfish plague was avoided. In other words, it is almost impossible to predict today what effects the overfishing of a population will have.

When the big ones land in the net, the small ones benefit

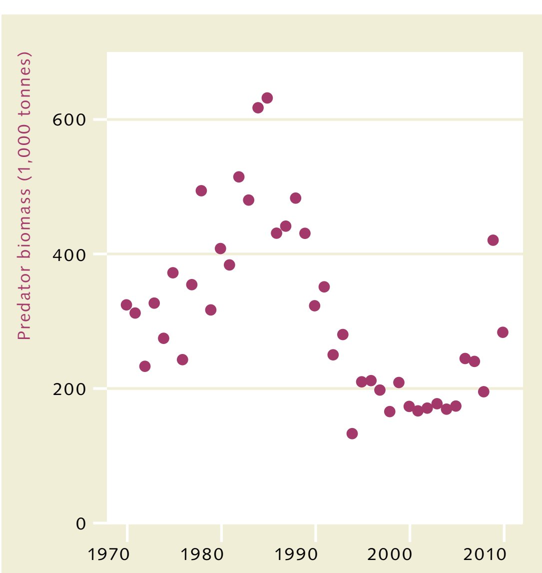
Overfishing has also altered the habitat in the waters off Nova Scotia on the east coast of Canada. For years cod and other bottom-living (demersal) predators such as coalfish have been heavily fished here. The stocks collapsed in the early 1990s. More than 40,000 fishermen lost their jobs. Although a ban on fishing was imposed relatively quickly, the stocks did not rebound even after many years. There is much concern that the habitat has been irreversibly altered.

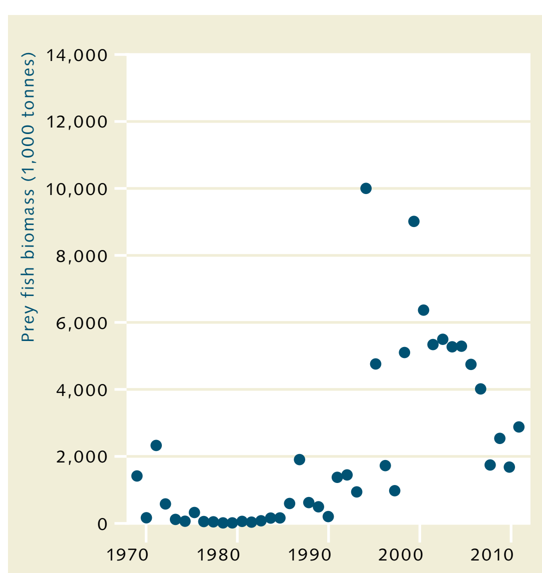
The cod is a predatory fish at a high trophic level that hunts small **planktivorous** species, plankton eaters such as the capelin and herring. As the cod disappeared the small planktivorous species became more abundant. Unfortunately, both the planktivorous fish and the larvae of the larger predators feed on zooplankton, which makes them competitors. In addition, the planktivores eat cod roe and larvae, which further increases pressure on the predators. The number of planktivores increased by a factor of nine, while predator stocks remained small.

The food fish therefore have a strong influence on their predators. Specialists use the term "predator-prey feedback". Because of this feedback, the stocks of cod, coalfish and other large predators off Nova Scotia have been slow to rebound. The planktivorous fish were thus able to predominate over the predators for a period of 20 years. But now the stocks of planktivores are declining. This is attributed to the fact that the capacity of this region is exhausted: there are so many planktivores that their food supply has become scarce. But a poorly nourished population produces fewer offspring, so the total biomass of the planktivorous fish stocks decreases. The predation pressure on the early life stages of the large predator fish off Nova Scotia has thus declined. As a result the stocks of some predators, for example the coalfish, have recovered. The warning status for cod stocks, however, cannot yet be lifted.

Similar interdependencies between predator and planktivorous fish are also known from other marine regions. In the Baltic Sea researchers refer to the "cod-sprat swing". After the general conditions for cod roe and larvae had deteriorated due to low salinity and oxygen deficiency, the cod stocks declined drastically. Because the cod fishery did not adjust to the situation and decrease the catch amounts rapidly enough, the stocks decreased even more. Thus the stocks of their prey, the planktivorous sprat, increased. Because the sprat diet also includes cod roe, pressure on the cod population was further increased. But in this case, temperature also had a crucial impact on the success of the population: slightly increased water temperatures enhanced development of the eggs and larvae of the sprat.

Now the "cod-sprat swing" is sweeping back because the fishery was adjusted: a reduction in cod fishing and





1.4 > "Predator-prey feedback": In the mid-1980s the stocks of the northwest Atlantic cod off Canada drastically declined (left figure). As a result the biomass of the smaller food fish increased (right). In recent years this trend seems to be turning around again.

interim increase in sprat fishing led to a moderate recovery of the cod stocks.

There is evidence that not only the planktivorous fish, but also algae benefit from the disappearance of large fish. Planktivorous fish feed on zooplankton, which, in turn, feed on the small free-floating algae, the phytoplankton. Increased numbers of planktivorous fish produce a drop in the amount of zooplankton, and phytoplankton can flourish. This can cause a problem, especially in the nutrient-rich coastal waters where phytoplankton can grow practically unchecked. The result is known as an algal bloom. When the algae die they sink to the bottom. There they are broken down by bacteria, which consume oxygen.

The formation of algal blooms is complex. It seems that a number of favourable conditions must be present at once. In addition to a sufficient supply of nutrients, moderate water temperatures are necessary. By adding the factor of overfishing of large predators, the problem is apparently exacerbated.

Greater amounts of algae sinking to greater depths results in increased bacterial activity there, and ultimately leads to a shortage of oxygen. Thus, oxygen-deficient dead zones develop in the ocean where neither fish, crustaceans, nor mussels can survive. Many scientists are therefore now urging fishery management to expand their focus from only the species being fished to consideration of the entire habitat. By recognizing the interdependencies among different species and the trophic levels, this ecosystem-based management should prevent the continued damage or drastic alteration of entire ocean regions caused by intensive fishing and consideration or monitoring of single species.

1.5 > Copepods are usually only a few hundred micrometres to a few millimetres in size. They are an important food staple for fish and for other crustaceans, and make up the largest share of the marine zooplankton.

The environment also influences stocks

Fluctuations in the size of fish stocks are not only caused by fisheries. Changes in environmental conditions also affect the stocks. For example, in cold, salty water the Baltic Sea cod produce more offspring than in warmer water with a lower salinity. On the other hand, the animals reach sexual maturity later in colder water. But water temperatures and other environmental parameters fluctuate over time in many marine regions. These are often triggered by natural climate cycles that produce regular changes in winds or ocean currents.

One example is the **North Atlantic Oscillation** (NAO), which influences the climate over parts of Europe and North America. The NAO is a fluctuation of the atmospheric pressure difference over the North Atlantic between the Azores high and the Icelandic low. Among its influences, the NAO affects the winter weather in Europe, and fluctuates with a 10-year rhythm. The wind and near-surface ocean currents in the North Atlantic also fluctuate with the atmospheric pressure.

In contrast, the **El Niño** climate phenomenon operates in the Pacific. It alters the current direction in upwelling regions, in this case between the west coast of South America and Indonesia. The large upwelling region off the coast of Chile and Peru is part of a powerful ocean current called the Humboldt Current. This brings cold water from the Antarctic northward along the west coast of South America. Here, like off southwest Africa, nutrient-rich, cold water rises to the surface. The engine for this upwelling is provided by the prevailing **trade winds** that push the warm surface water from South America westward towards Australia and Indonesia.

South American waters are among the world's richest in fish. Around 15 to 19 per cent of the world's catch comes from here, especially small species like sardines and anchovies. The larger horse mackerel, as well as wide-ranging species such as sharks and tuna, are also found here.

But in the years of the El Niño, the westward-blowing **trade winds** decline and may even reverse direction. This also changes the current direction of the water. Warm, nutrient-poor surface water now flows from the western Pacific towards Peru. These conditions inhibit the production of plankton off the coast of Peru. Food for the planktivorous fish thus becomes scarce, and the stocks collapse. The larger predatory fish and birds, including penguins, are affected, but also mammals such as seals, which rely on the fish as their main food source. In El Niño years they often produce fewer offspring.

Vital conditions for fish thus change more or less regularly. This can affect both the size of the stocks as well as their geographic extent. The cod population in the eastern Baltic Sea is highly dependent on incursions of salt water from the North Sea. These massive inflows of water occur only every few years under certain weather conditions. They have to be strong enough to override the Darss Sill, a kind of shallows off the coast of Mecklenburg-Western Pomerania. Under normal conditions the heavy salty North Sea water cannot pass over this sill. But during the massive salt-water incursions, enormous amounts of North Sea water flow over the sill and along the bottom of the Baltic Sea as far as Gdansk Bay, and even farther into the Gotland Basin between Latvia and Sweden. This salt-water influx is important because along with the cold saline water it also brings oxygen into the depths where

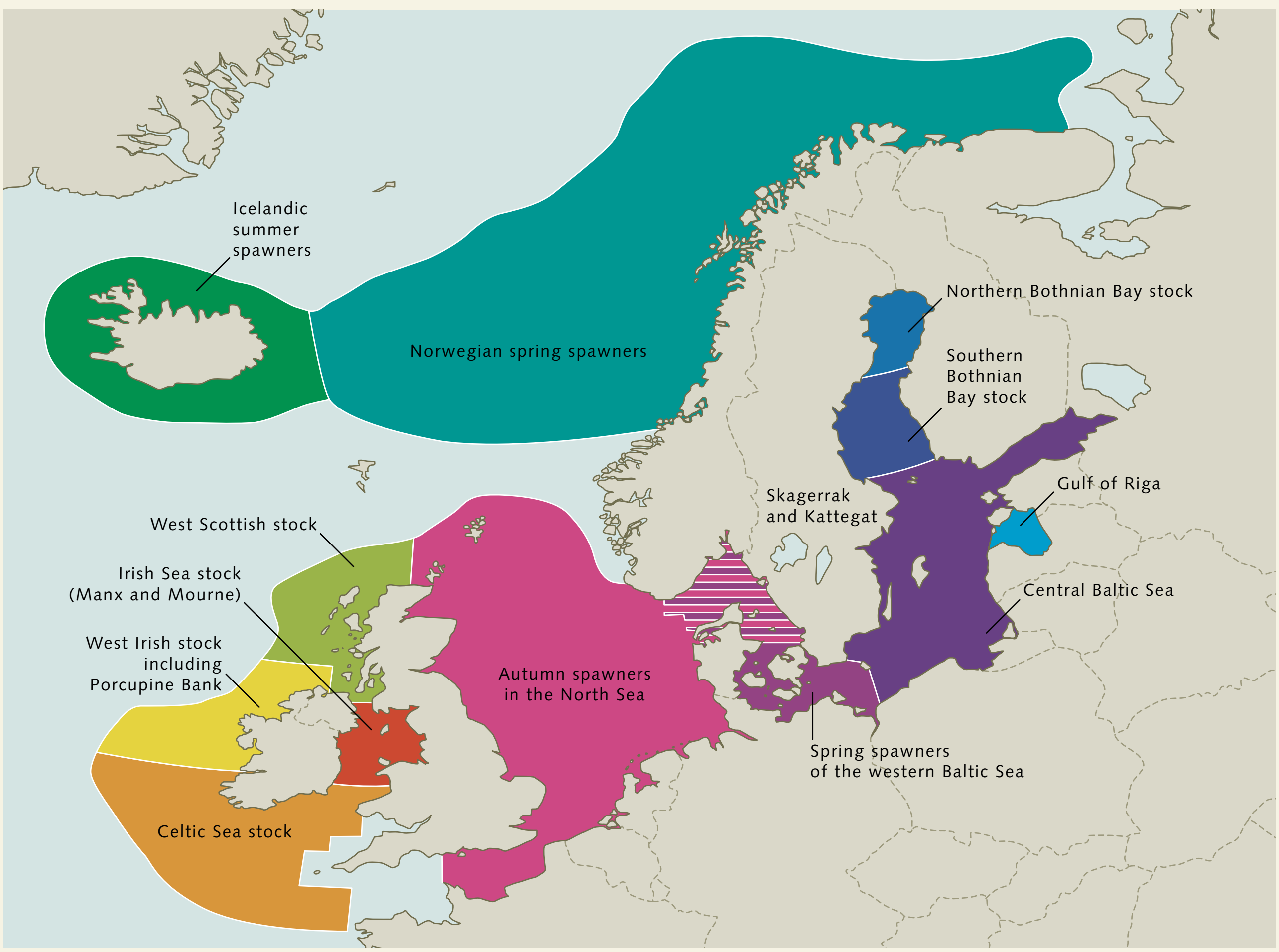
North Sea water for cod offspring

The Atlantic cod lays its eggs in the open water. The eggs do not sink, but float within the water column. They lie suspended at the "halocline". This is an abrupt boundary between a layer of light, lower-density fresh water floating above, and denser, more saline water below. The density of cod eggs is such that they sink in the fresh water but do not fall below into the denser salt water. For their optimal development the roe require salty and oxygen-rich water. In the Baltic Sea these parameters depend greatly on the influx of cool, saline and oxygen-rich North Sea water. If there is no inflow of North Sea water for an extended time, the Baltic Sea salinity decreases due to the input of river water, which also thickens the fresh-water layer above the halocline. The halocline thus deepens. But at greater depth the oxygen content decreases. In some cases the oxygen content is so low that the eggs develop poorly or not at all, especially in the deeper Baltic Basin. The conditions for development are improved again only with the next influx of fresh North Sea water.

One species – multiple stocks

A stock is a self-sustaining population of a species that occurs within a defined region of the ocean. As a rule, the different stocks of a fish species are spatially separated to such an extent that the individuals from one stock cannot breed with those of another, even though they belong to the same species. The herring provides an example.

The individuals in Norwegian waters spawn in the spring. Herring in the North Sea, however, spawn in autumn. Thus there is a very clear separation between the two stocks, which even has a biological manifestation. For fishery management and discussions of overexploitation of fish species, it is crucial to consider the stocks individually. Rarely is a species completely overfished, rather it is usually only a particular stock of the species. The herring stock of autumn spawners in the North Sea recovered after just five years, while the stock of spring spawners off Norway took almost 20 years to recover.



1.6 > Herring live in the transitional area between the northern temperate and polar zones. They occur not only in the North and Baltic Seas, but also throughout the North Atlantic, living at water depths up to 360 metres. Herring undertake extensive migrations between their feeding and spawning grounds and their winter stop-over areas. Different stocks spawn in different seasons.

cod spawn. If the salt-water influx does not occur for a long time the spawning conditions deteriorate. Furthermore, it is now known that long-term climate fluctuations impact cod stocks in the eastern Atlantic, the North Sea, and the Baltic Sea. In the 1980s the stocks of gadoids, the cod-like fish, increased greatly in these regions.

The environmental conditions that led to this "gadoid outburst" are still not known. There are a number of hypotheses. It may be that the cold winters of the 1960s and 1970s afforded ideal spawning conditions. In subsequent years the stocks decreased again, presumably not only due to fishing. It is generally true that when a population collapses it is usually associated with a combination of high fishery pressure and changes in environmental conditions.

More data for stock assessment

In order to determine the impact that fisheries have on different ocean regions or to assess the status of a fish species – for example, whether it is overfished or not – many more details are necessary beyond the usual information about the annual catch statistics for a species.

One factor of interest is how the stocks of other fish species in the same region develop, rather than focusing only on the species being fished. Special consideration should be given to the bycatch. This refers to the fish and other marine animals that are unintentionally caught along with the species of commercial interest such as cod or coalfish that are being fished for. As a rule, the bycatch is thrown back.

Because bycatch amounts have not been systematically recorded in the past, an important parameter is missing that would help to assess the population development of several species, as well as the status of the marine region. Fortunately, there are a number of regions today where discarding the bycatch is not allowed. The European Union also wants to make throwback illegal. This would make it possible in the future for fisheries to provide valuable data to scientists that would otherwise only be obtainable through expensive research cruises. There is continuing controversy among various specialists, not only about the status of individual species, but also about how the stocks of certain fish species can be best estimated. In any case, obtaining additional data would help a great deal.

In this regard, it would also be important to gather data on the primary producers, the algae and other single-celled organisms, whose quantities and composition substantially contribute to the biomass in the marine region. Such a multiple indicator approach, which considers all of these parameters, could be very important in establishing future catch limits. This kind of comprehensive data set is presently only available for a few fish species, because obtaining the data for all of these parameters is extremely expensive. Furthermore, it requires an intensive exchange of information among scientists of various disciplines, including fishery biologists, oceanographers, and plankton specialists, which has so far only been accomplished for a few stocks such as the Baltic Sea cod and the West Atlantic cod.

1.7 > Clupeids frequently form dense shoals, such as here off the Moluccas. They are an important food source for many marine organisms and very important for the ecosystem.

What does overfishing mean?

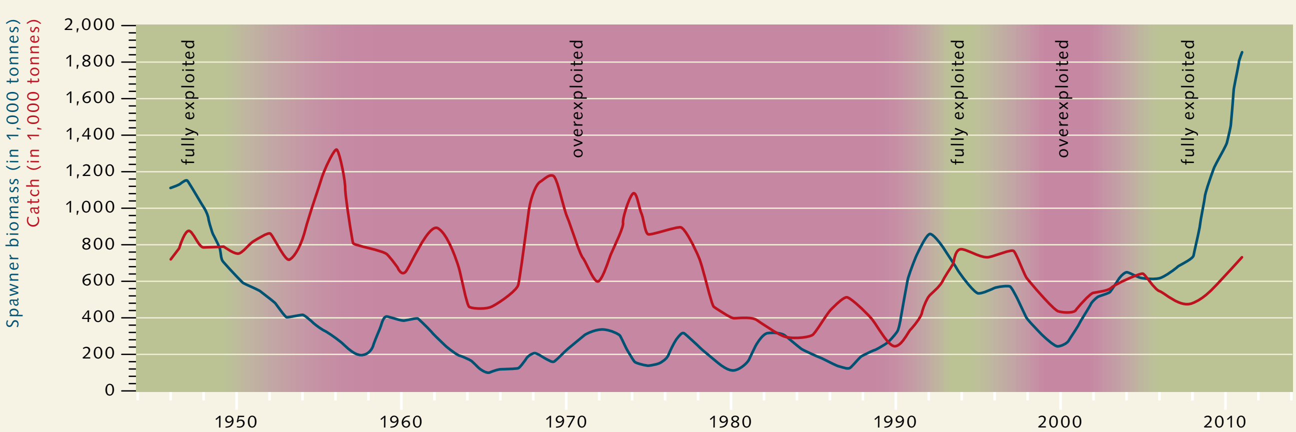
Fish cannot be counted like elephants in a national park. Fishery biologists therefore have to calculate the size of a stock based on specific parameters. The size of the annual catch is important. If this declines it could be a sign that the stock size is shrinking. The quantity of sexually mature adult fish, the spawners, is also important because they determine how many offspring are produced. After all, a stock can only sustain itself if the new offspring can compensate for the number of fish that are caught or die of natural causes. Fishery biologists commonly assign stocks to one of several categories: moderately exploited, fully exploited, overexploited, depleted, or recovering.

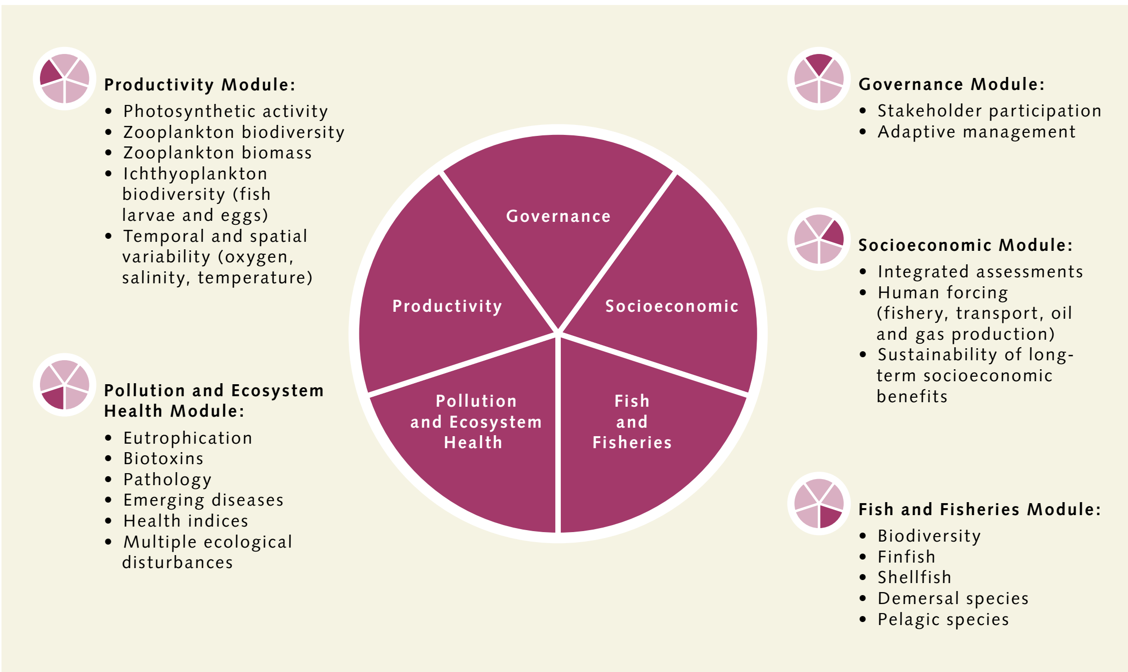
The transitions between these status classes, however, are not sharp, for example, the boundary between a fully exploited and overexploited stock. One reason for this is that different fish species react very differently to fishing pressure. Species that multiply in large numbers and reach sexual maturity early can react better to high catch volumes than species that produce fewer offspring and require several years before they can spawn.

But basically a stock is considered to be fully exploited when it is fished to the maximum and an increase in the catch is not possible. If the fishing is intensified at this point, the stock is then pushed into the overexploited status. This stock then continues to decline because there are not enough offspring being produced. The stock is considered to be depleted when the catch is significantly below the historically expected amounts. Many researchers define this situation as the point when only 10 per cent of the highest historical catch is achieved. When a stock is depleted the catch cannot be increased even with intensified fishing, which is referred to as an increase in fishing effort.

A stock is considered to be recovering when the catch begins to rise again after depletion. An example of this is the North Atlantic cod, whose stocks collapsed in the 1960s and recovered again after a fishing ban. The Food and Agriculture Organization of the United Nations (FAO) presently uses three categories to describe the status of the stocks: non-fully exploited, fully exploited, and overexploited.

1.8 > The example of the North Atlantic cod shows that a fish stock collapses when not enough mature fish (spawners) are present to produce offspring.





1.9 > The objective of the Large Marine Ecosystem concept is sustainable management of the oceans. Under this approach the status of marine regions is characterized in five different modules.

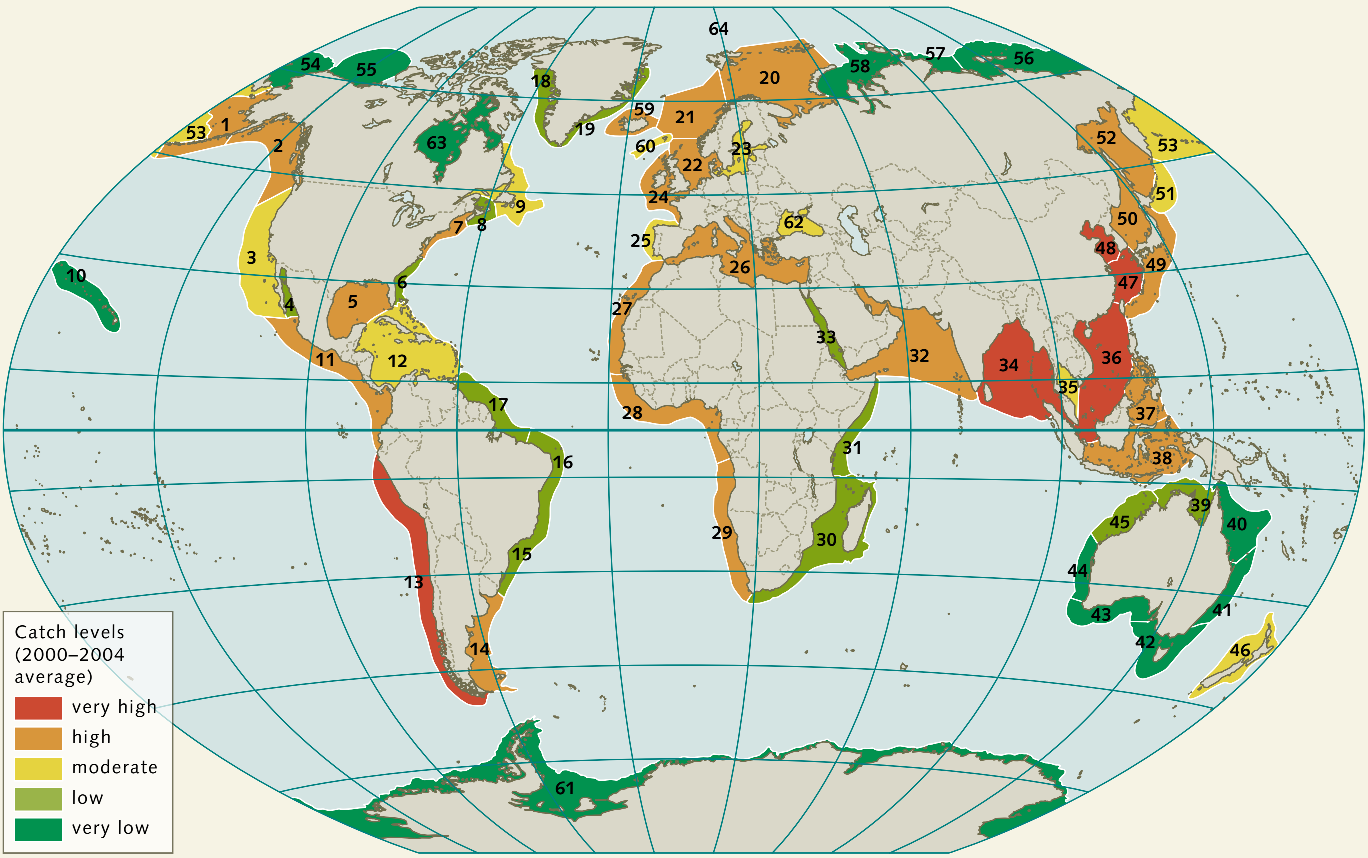
Large Marine Ecosystems

Most marine regions and habitats are so large that they extend across the coastal waters of multiple countries. Comprehensive conservation in these areas is only possible if the countries cooperate, for example, with regard to pollution of the ocean. Even larger fish stocks can only be sustained when the countries agree to joint policies of protective fishery management. For a long time, these kinds of international agreements regarding coastal regions had been lacking. For this reason the National Oceanic and Atmospheric Administration of the USA (NOAA) developed the concept of Large Marine Ecosystems (LMEs) in the 1990s. This divided the coastal marine regions of the Earth into 64 LMEs. Each LME is characterized by a typical flora and fauna. The LMEs extend along the coasts out to the continental slope, where the continental shelf ends and starts its downward incline towards the deep sea. The characterization of certain marine regions by large currents is also considered. For example, the upwelling regions off South America and Southwest Africa are each defined as an LME.

The LMEs comprise all of the coastal regions of the Earth. They are especially productive because they are well provided with nutrients from rivers or upwelling currents. The LMEs produce 95 per cent of the global fish biomass. These areas are also immensely important for humans. Hundreds of millions of people worldwide live near the coasts. Their existence depends more or less directly on fishing. Thus, in addition to the biological factors, the Large Marine Ecosystem concept also deals with socioeconomic aspects.

With the support of the World Bank and the United Nations Environment Programme (UNEP), an effort is being made to improve international cooperation towards protecting the joint ocean regions, particularly in the developing and newly industrialized countries. Researchers and politicians of the neighbouring countries meet at workshops and conferences. The major challenge is to achieve better protection of the marine environment in spite of differences in interests.

Economic aspects such as offshore oil production often have priority over protection of the environment. The concept of the LMEs should provide a counterbalance



1. East Bering Sea
2. Gulf of Alaska
3. California Current
4. Gulf of California
5. Gulf of Mexico
6. Southeast U.S. Continental Shelf
7. Northeast U.S. Continental Shelf
8. Scotian Shelf
9. Newfoundland-Labrador Shelf
10. Insular Pacific-Hawaiian
11. Pacific Central-American Coastal
12. Caribbean Sea
13. Humboldt Current
14. Patagonian Shelf
15. South Brazil Shelf
16. East Brazil Shelf
17. North Brazil Shelf
18. West Greenland Shelf
19. East Greenland Shelf
20. Barents Sea
21. Norwegian Shelf
22. North Sea
23. Baltic Sea
24. Celtic-Biscay Shelf
25. Iberian Coastal
26. Mediterranean Sea
27. Canary Current
28. Guinea Current
29. Benguela Current
30. Agulhas Current
31. Somali Coastal Current
32. Arabian Sea
33. Red Sea
34. Bay of Bengal
35. Gulf of Thailand
36. South China Sea
37. Sulu-Celebes Sea
38. Indonesian Sea
39. North Australian Shelf
40. Northeast Australian Shelf-Great Barrier Reef
41. East-Central Australian Shelf
42. Southeast Australian Shelf
43. Southwest Australian Shelf
44. West-Central Australian Shelf
45. Northwest Australian Shelf
46. New Zealand Shelf
47. East China Sea
48. Yellow Sea
49. Kuroshio Current
50. Sea of Japan
51. Oyashio Current
52. Okhotsk Sea
53. West Bering Sea
54. Chukchi Sea
55. Beaufort Sea
56. East Siberian Sea
57. Laptev Sea
58. Kara Sea
59. Iceland Shelf
60. Faroe Plateau
61. Antarctic
62. Black Sea
63. Hudson Bay
64. Arctic Ocean

1.10 > Near-coastal ocean regions have been divided into 64 Large Marine Ecosystems that cross geopolitical borders. This concept is expected to improve cooperation of countries with regard to international marine conservation. The individual LMEs are coloured to indicate the intensity of fishing from 2000 to 2004. In many marine regions the fishing pressure has not dropped since then.

and create an awareness of the importance of the marine habitat. Political crises and civil wars, however, like that in the Ivory Coast have continued to undermine cooperation in recent years.

One focus of the work is to educate qualified people locally. Together with international experts, native scientists are trained to record and competently analyse the stocks of fish, primary producers, and other marine organisms according to current standards. However, in the past many countries have lacked both the funds and sufficient specialists to carry out sustainable fishery management within their territorial waters. Technical knowledge is thus a critical prerequisite for future fishery conservation efforts.

Promising examples are illustrated by the two West African LMEs, the Benguela Current LME and the Guinea Current LME. Numerous courses, workshops and conferences have been held in the countries concerned.

One of the present goals is to find indicators for the various LMEs whereby the status of the marine regions can be assessed and described. A sustainable management of the seas should ultimately be achieved. Five working areas, referred to as modules, have been established for this purpose.

PRODUCTIVITY OF THE HABITAT: Record biodiversity of the phytoplankton and zooplankton and their biomasses, measure the photosynthetic activity, etc.

POLLUTION AND ECOSYSTEM HEALTH: Investigate the influences of biotoxins, eutrophication of the water, and the development of pathological changes in the marine organisms, etc.

FISH AND FISHERIES: Investigate the biodiversity and biology of finfish and shellfish, identify fish stocks and changes in their composition.

SOCIOECONOMY: Investigate the practical application of scientific findings for management of the ecosystems, assess diverse management methods based on economic and other criteria regarding the principle of sustainability.

GOVERNANCE: Consider ways in which various interest groups in the areas of fisheries, tourism, energy and environment can participate in the development of interregional management planning, etc.

The Large Marine Ecosystems programme has produced a series of studies in which scientists have investigated the development of the LMEs over recent decades. These have clearly illustrated the severe impact that fisheries can have on habitats, but in many cases it is still not clear to what extent natural processes have influenced the development of fish stocks.

In some years, large oxygen-deficient zones form in the Benguela Current. In these years the stocks of **pelagic** fish collapse, causing a shortage of food for many species of seabirds and seals. This results in a decline in the survival rates of their young.

Of course the upwelling areas generally exhibit low concentrations of oxygen at greater depths. But it is not yet known why the oxygen-poor areas sometimes extend nearly up to the surface.

There is some evidence that the oxygen deficiency occurs after periods of especially intense upwelling currents. This suggests an initial development of large amounts of phytoplankton that later die in large volumes and are subsequently broken down by bacteria. In some cases it appears that a change in current conditions causes expansion of the oxygen-poor areas.

This example illustrates again the importance of understanding the entire ecosystem in assessing the development of populations of marine organisms and ultimately also the fish stocks.

The concept of the Large Marine Ecosystems is important and necessary. But so far there is little indication that information gained from the international LME projects and activities have led to concrete political directives or national laws. Experts stress the need for action in the future. They agree, however, that LME activities are likely to lead to a greater awareness of marine protection and conservation of fish stocks for the future than has been the case up to now, even in developing and newly industrialized countries.

Diversity at risk

> Many stocks have been so strongly decimated by fisheries that it is no longer commercially profitable to fish for some species. Still, most species will survive thanks to their enormous reproductive capacity. But there are exceptions. Some species could actually be wiped out by humans. It is also alarming that the fisheries appear to influence evolution. Smaller fish often prevail while the larger ones become scarcer.

Are fish species facing extinction?

Although many stocks have been overfished by industrial fisheries, as a rule this does not result in the extinction of fish species. The classical notion of a species being wiped out by human activity, like the case of the dodo, a flightless bird on the island of Mauritius, cannot be directly applied to fisheries. There is an economic reason for this: long before the last fish is caught it would become unprofitable to fish for it, so it would no longer be pursued by the fishery in the affected region. Specialists refer to this kind of situation as commercial depletion.

Some fish stocks have been reduced by 50 to 80 per cent in the past. This would spell extinction for many terrestrial animals, especially for species that produce small numbers of offspring. The death of even low numbers of young animals by disease or predation could then completely wipe out such a species. This is not the case with fish. As a rule, the stocks recover. One important reason for the resilience of fish stocks is their high reproductive capacity. Cod can produce up to 10 million eggs each year. An additional factor is that a fish species is usually represented by multiple stocks.

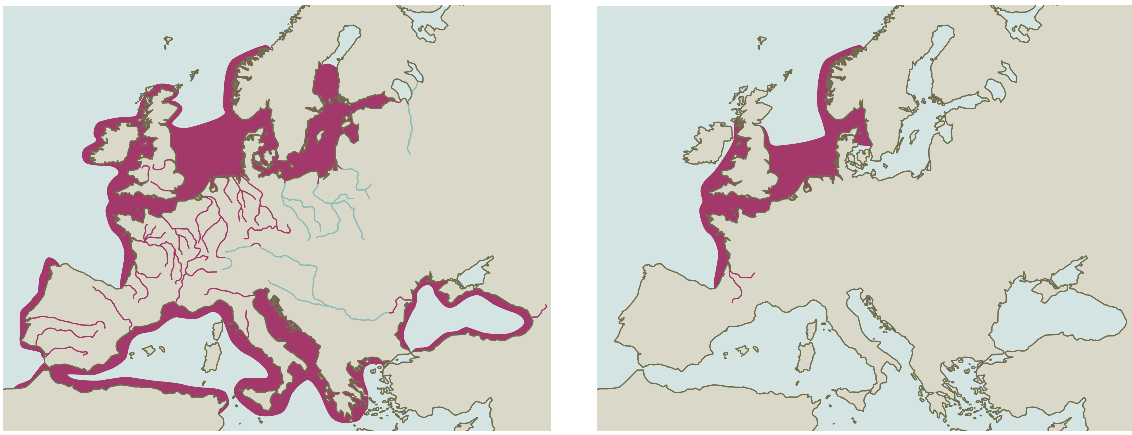
There is no question that intensive fishing has severely reduced the amount of fish, the fish biomass, in many marine regions. The higher trophic levels are especially affected. The large fish have been and still are the first to be depleted. But even these are usually not in danger of biological extinction. In order to draw conclusions about the status of a fish species, all of its stocks have to be assessed. For several years there has been some controversy about the best mathematical and statistical models to use for this.

The Food and Agriculture Organization of the United Nations (FAO) has established a general classification system. It classifies fish stocks as overexploited, fully exploited and non-fully exploited. According to the FAO, almost 30 per cent of all fish stocks are considered to be overexploited. As a rule, however, the species will be preserved.

1.11 > Animal conservationists have been trying for several years to reintroduce the sturgeon to German waters. A number of the animals released have yellow markers on their backs. Fishermen who catch one of these are requested to report the number on the marker to the conservation group and return the fish to the water.

Regrettable exceptions

There are, however, exceptions. Some species of tuna fish bring such high prices on the market that catching them is profitable even when their numbers are very limited. One fish can weigh up to 500 kilograms. Certain species, such as the bluefin tuna *(Thunnus thynnus),* which lives in the Atlantic, can bring a price of 100 dollars per kilogram. In Japan, hundreds of thousands of Euros may be paid for the first or best tuna of the season. Expensive fish is a mark of prestige there. Furthermore, the first tuna of the season are considered to be bringers of good luck, for which some customers will pay a lot of money. For practical purposes, fishing for such valuable specimens can be compared with



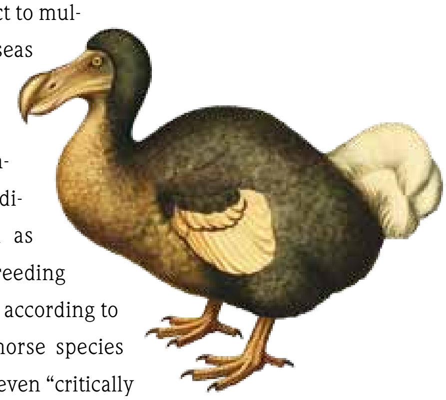
1.12 > Around the year 800 the European sturgeon was indigenous to many rivers and almost all of the coastal areas of Europe. Since then its marine distribution has shrunk significantly, and it is now limited to the region between Norway and France. The only remaining spawning area of the European sturgeon is the Gironde Estuary in France.

hunting rhinoceroses on land. As late as the 1920s bluefin tuna still appeared regularly in the nets of Norwegian mackerel fishers. Today this species has completely disappeared from the Kattegat and the North Sea. And in the Atlantic there are only very small numbers of bluefin tuna remaining.

Other species of fish are threatened with extinction because they are under multiple pressures at the same time, both from fisheries and destruction of their habitats. One example is the European sturgeon *(Acipenser sturio)*, whose distribution once extended from southern Spain to eastern Europe. The sturgeon spawns in rivers and grows to sexual maturity in the sea. Like salmon, the European sturgeon migrates back into the rivers to spawn. The species once inhabited the Eider, the Elbe, and small north German rivers like the Oste and the Stör. But over the past hundred years the stocks have greatly declined. Today there is only one remaining stock in Europe, in the Gironde Estuary in southwest France, but it has also been shrinking in recent years.

The decline of the sturgeon has multiple causes: river training, installation of weirs, pollution of the water, and fishing. Today, the remaining animals are threatened primarily with ending up in fishing nets as unintentional bycatch. The European sturgeon is classified as "Critically Endangered" on the **Red List** of the International Union for Conservation of Nature (IUCN). The release of juvenile individuals to rivers has therefore been ongoing for several years, in order to re-introduce the species into its various native regions of Europe, including Germany. In addition, attempts are being made to encourage the fish to spawn in their once-native waters by returning some stretches of river to their natural state or building fish steps around weirs. It is still uncertain whether these efforts can save the European sturgeon.

Some species of seahorse are also subject to multiple threats – including pollution of the seas and destruction of their habitats, the mangroves. There is also a large demand for them. They are fished on coral reefs, in mangroves or seagrass beds, and are sold as traditional medicine on Chinese markets and as ornamental fish for aquariums. There are breeding programs, in Vietnam for example. But still, according to the IUCN Red List, of 38 worldwide seahorse species seven are considered "endangered" and one even "critically endangered". The species primarily at risk are those that occur in a small, relatively limited geographic area. These are referred to as **endemic species**.



1.13 > The dodo died out at the end of the 17th century. Native exclusively to the islands of Mauritius and Réunion, the flightless bird had no natural predators before the arrival of humans. It was completely wiped out by imported rats, monkeys and pigs.

Examples such as these illustrate that humans need to be more responsible in using and protecting fish resources in the future. The fact remains, however, that for most fish species in the world there is no danger of extinction. The IUCN list was originally established for land organisms. These generally do not have the reproductive capacity of fish. Critics therefore say that the risk of extinction expressed in IUCN standards is exaggerated for many commercial fish species.

Other marine animals are also affected

Not only do fisheries alter the natural species structure of the fish that are being fished for; they also have an impact on the stocks of animals that are taken as bycatch. U.S. researchers have calculated that at least 200,000 loggerhead sea turtles and 50,000 leatherback turtles worldwide were caught incidentally in the year 2000 by tuna and swordfish fishers. The turtles are caught on the hooks of "longlines". These are usually several kilometres long and can be fitted with thousands of baited hooks. If the turtles snap at these they will be hooked. Some are able to free themselves and others are thrown live back into the ocean by the fishermen. But thousands die an agonizing death. Tests are now being carried out to shape the hooks so that the turtles will no longer be caught by them.

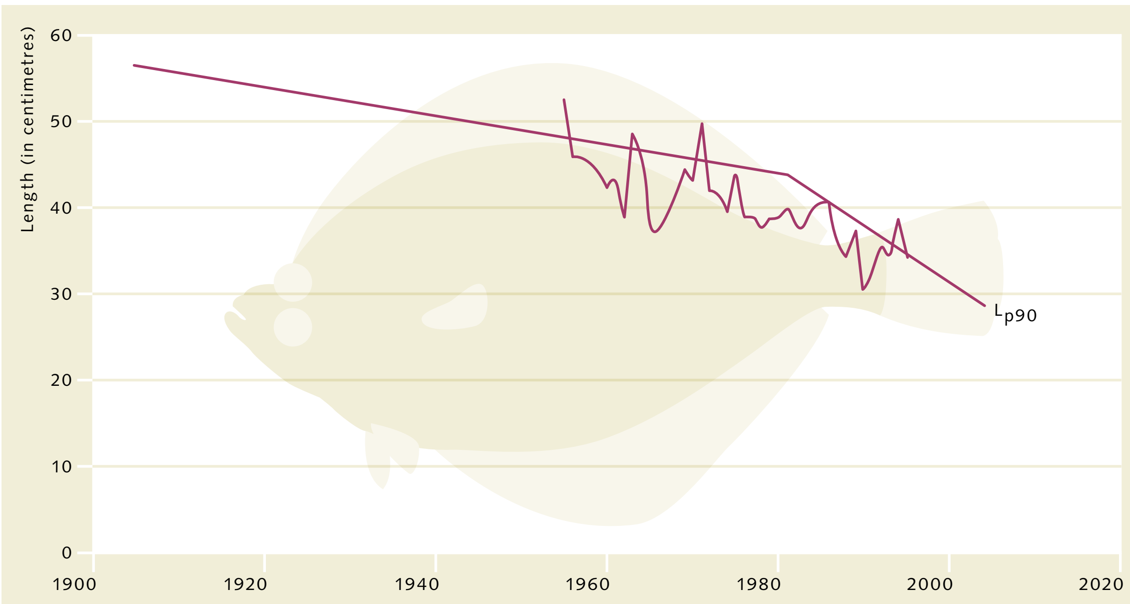
The longlines can also be fatal for albatrosses because they do not sink to the working depth immediately after being let out, rather they float for a while at the surface and attract the birds. Environmental organizations estimate that hundreds of thousands of sea birds are unintentionally killed annually worldwide by longline fishing. New methods are therefore also being tested by which longlines are deployed through tubes that extend up to 10 metres below the surface, so that albatrosses cannot see or reach the bait. In the Baltic Sea, the harbour porpoise is also endangered as bycatch. There are only an estimated 500 to 600 individuals remaining in the eastern Baltic Sea. The harbour porpoise was hunted here for decades. Severe icy winters are also a strain on them. Today, every unintentionally caught animal brings the stock closer to extermination. It is a near tragedy that the eastern Baltic Sea harbour seals very rarely mate with their relatives in the North Sea and western Baltic Sea. The North Sea stock is comparatively large. Researchers estimate it to be around 250,000 animals. Because the eastern animals do not mate with their western relatives, it is feared that the species could die out in the Baltic Sea. This would mean a loss of species diversity in the region.

The fisheries influence evolution

Intensive fishing, however, also changes the biological diversity in another way. Scientists are now discussing the phenomenon of fisheries-induced evolution. When the fisheries primarily catch large and older individuals, then, over time, smaller fish that produce offspring at an earlier age become more successful. The fisheries thus critically upset the natural situation. In natural habitats that are not affected by fisheries, larger fish that reach sexual maturity at a greater age are more dominant. Their eggs have lower mortality rates. The eggs and larvae can better survive phases of hunger in the beginning because they possess more reserve substance, more yolk, than the eggs and larvae of parents that reproduce at a younger age. The entire stock benefits from this because many offspring are regularly produced, which preserves the stock.

Under heavy fishing pressure, on the other hand, the animals that primarily reproduce are those that are sexually mature at a smaller size. But they produce fewer eggs, and their eggs have higher mortality rates. Through computer models and analyses of real catch data, and using the example of the northeast Arctic cod, researchers have been able to show that this fish stock has actually undergone genetic alteration through time. Fish with the genotypic trait of becoming sexually mature at a young age and small body size have become more successful. This is true for both males and females. To illustrate this, the researchers have employed catch data in their model that extend

1.14 > This bluefin tuna, weighing 268 kilograms, fetched a price of 566,000 Euros at a fish auction in Tokyo in January 2012. It was bought by Kiyoshi Kimura (left), president of a sushi gastronomy chain. In early 2013, Kimura even paid a full 1.3 million Euros for a tuna. That translates into a price per kilogram of more than 6000 Euros.



1.15 > Over decades of fishery, plaice in the North Sea that achieve sexual maturity with a smaller body size have gradually become predominant. This relationship can be clearly depicted by using different probabilities (p) in mathematical models. The body length (L) of 4-year-old plaice that will become sexually mature in the coming season with a 90 per cent probability (p90) is illustrated. As the graph shows, this body length (Lp90) has decreased significantly over recent years.

back to 1930 and document the gradual changes with respect to age, size, and reproductive capacity. The study was based on especially detailed data sets of the catches in Norwegian waters. Originally the northeast Arctic cod became sexually mature at an age of 9 to 10 years. In the northeast Atlantic today, the cod is sexually mature at 6 to 7 years old. It is notable that this fisheries-induced evolution has occurred over a period of just a few decades. Experts feel that one reason for this is that the fisheries exert a much greater pressure than natural selection factors such as predators or extreme environmental conditions, such as heat or cold. The computer models also indicate that it would take centuries for the effects of the fisheries-induced evolution to turn around – even if the fisheries were completely stopped. In actual practice, the effects may even be irreversible. Within the past 10 years fisheries-induced evolution has been verified for a number of species, including the North Sea plaice.

The effect of fisheries is thus exactly the opposite of what an animal breeder usually aims for. The animal breeder, as a rule, selects the largest and most productive animals in order to continue breeding with them. As a result of the fisheries, by contrast, precisely those older and larger animals with the highest reproductive capacity are killed.

Genetic impoverishment in fish?

In proportion to their body size, large and mature fish invest relatively more energy into the production of eggs than small, young animals that have considerably less body mass and volume. Older fish thus provide a kind of reproductive insurance. As long as enough older fish are present, sufficient offspring will be produced. But in stocks that consist of few age groups, and primarily of younger age groups, the danger of offspring deficiency increases when the reproductive conditions intermittently worsen, such as times of food scarcity. Stocks in which older fish predominate can more efficiently withstand these kinds of fluctuations, because the mature ones will reliably produce offspring in the following season. Stocks

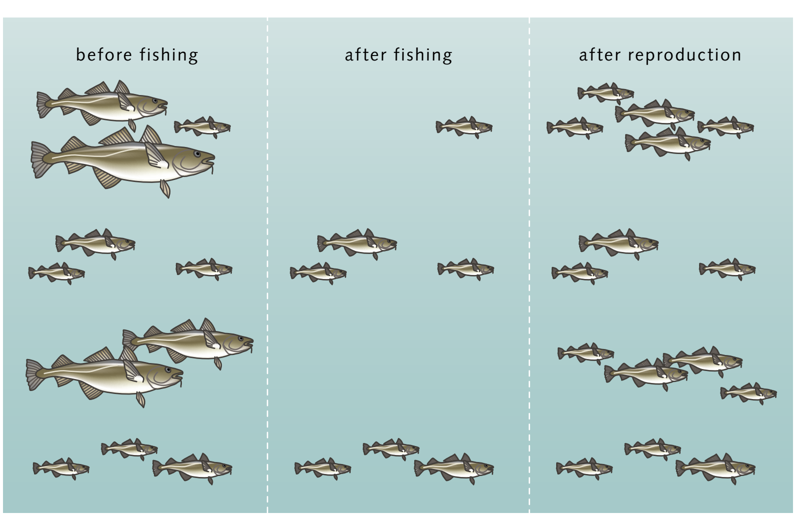
Genotype
Genotype refers to the total genetic information of an organism that is stored in the cell nucleus of each body cell. Among individuals of a species most of the genes are identical. But their combination is unique for every individual

Phenotype
The phenotype is expressed in the appearance of an individual: the observable characteristics of the individual genotype. Phenotypic attributes include eye colour, psychological traits, or genetically caused illnesses.

comprising different age groups also exhibit greater resilience because the spawning season of the fish varies with their age. There are thus a sufficient number of spawning animals at any given time in a mixed stock. Periods of unfavourable environmental conditions therefore have a less severe impact.

Warnings are now being raised that fisheries can also cause genetic impoverishment, or "genetic erosion" in the species being fished. This phenomenon is also recognized in land animals. With the destruction of habitats like rain forests, the distribution areas of species become critically limited. Many individuals die before they can mate. In addition to the species-specific genetic material, every organism possesses a small share of individual genetic attributes. If the animal dies without producing offspring, these individual attributes are lost and the population is genetically impoverished. Extreme genetic erosion is referred to as a genetic bottleneck. In this case, a species is reduced to a small number of individuals. This could occur as the result of a natural catastrophe such as a volcanic eruption or flooding. Intensive hunting of geographically restricted populations like the Siberian tiger can also lead to a genetic bottleneck. In extreme cases this leads to inbreeding. The animals produce offspring with genetic defects or that are susceptible to disease. Some scientists are concerned that genetic erosion leading to genetic bottlenecks occurs not only in land animals, but also in some fish species through overfishing. So far, however, this assumption is hypothetical and it is presumably not valid. For most of the commercially depleted fish stocks neither genetic erosion nor genetic bottlenecks can be statistically verified. Specialists believe that even fish stocks that have been commercially depleted still possess thousands of individuals capable of reproduction. The genetic variability thus probably remains great enough to preclude the erosion effects.

1.16 > A fish stock before fishing, after fishing, and after reproduction. The changes in body size are a result of fisheries-induced evolution.



Slowing down fisheries-induced evolution

Experts recommend giving more attention to the ecogenetic aspects of fishery management in the future. There is already a general consensus that fishery management should not consider a fish species independently of its habitat. Beyond this, however, ecogenetic models are necessary. These can be used to estimate which changes are caused by fisheries and to what degree genetic changes influence a stock, but also how these ultimately affect the future fishery harvests. Through responsible fishing, there is hope that fisheries-induced evolution can be reversed, or at least slowed down. It can probably not be completely stopped. Researchers also need to employ complex evolution models. Up to now, often only the age classes of a fish stock have been considered in detail for calculations of stock development. Fish sizes are entered into the calculation simply as the mean of an age class. This mean, in turn, has been calculated from long years of body-length measurements. An age class for a fish stock, therefore, always has a fixed, assigned average size. In fact, however, the mean size of an age class changes from year to year, depending mainly on the food supply. In years of scarce food supply immature animals grow more slowly. This variability has to be given greater consideration in the future. And, of course, there are always larger and smaller individuals within an age class. These fluctuations also have to be addressed. The mean value is not sufficient for an evolutionary model. Researchers therefore call for more intensive cooperation between fishery authorities, who have access to detailed data, and mathematicians and statisticians, who can develop powerful computer models.

Conclusion

The "big picture" in the ocean

Worldwide there are over 30,000 fish species. Several hundred of these are fished commercially. The species of commercial interest have long been regarded in isolation. The primary concerns for fisheries management have been merely the annual catch of a species and its presumed stock, from which the maximum catch for the next season is derived.

The web of relationships in the ocean, however, is complex. Catching huge volumes of fish changes the entire habitat. The idea that entire ecosystems have to be taken into account if fish stocks are to be preserved over the long term is gradually becoming accepted. An improved and more sustained management of fish stocks in the future will require much more extensive investigations than have been previously carried out.

One topic of interest is how phytoplankton, the basis of life in the ocean, proliferates in particular regions. The amount and composition of zooplankton, on which smaller fish species primarily feed, also play an important role. Although these kinds of complex ecosystem investigations have only been carried out for a few species so far, the gain in knowledge has been great.

Furthermore, scientists are calling for accurate data on bycatch to be recorded at last. "Bycatch" refers to those fish and marine animals that unintentionally end up in the nets while fishing for particular species, and are usually thrown overboard dead. The numbers and composition of the bycatch can provide further important information about the ecological status of a marine region.

The increase in joint international efforts to promote marine conservation in recent years is encouraging. The coastal regions of the world, for example, have been classified into Large Marine Ecosystems (LMEs), large-scale regions that span geopolitical borders. The LMEs produce 95 per cent of the global fish biomass. Hundreds of millions of people worldwide live near the coasts.

This initiative should be effective in bringing together international experts, especially from developing and newly industrialized countries. The first positive indications of international marine conservation projects between neighbouring countries have already been seen off south-west Africa and in the Gulf of Guinea.

Fortunately, people will not be able to completely eliminate most of the commercially fished species. Fishing will become unprofitable before the stock is reduced to the point at which a species disappears. There are, however, some possible exceptions such as the sturgeon and certain species of tuna. Although some protection measures have now been introduced, such species could be annihilated in the coming years. The stock of sturgeon, in particular, has already been so weakened by fishing and habitat degradation that the species probably cannot be saved.

It is also disturbing that industrial fishing probably alters the evolution of certain species. Large fish are fished out while small individuals become more predominant. Under intensive fishing, being small apparently gives the individual fish an evolutionary advantage. The consequences of this fisheries-induced evolution cannot be foreseen. There are strong indications that fish stocks of small, young-reproducing fish are less stable than stocks with large animals that reach sexual maturity later. Computer models indicate that these human-induced changes will take centuries to reverse, if at all. The precondition will be that humans catch fish with more foresight in the future, and reduce pressure on the species.

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All the graphics in the World Ocean Review were produced exclusively by Walther-Maria Scheid, Berlin. The list of illustrations states the original sources which were used as a basis for the preparation of the illustrations in some cases.

Publication details

Project manager: Jan Lehmköster
Editing and text: Tim Schröder
Copy editing: Dimitri Ladischensky
Coordinator at the Cluster of Excellence: Dr. Jörn Schmidt
Editorial team at the Cluster of Excellence: Dr. Jörn Schmidt, Dr. Rüdiger Voss, Dr. Kirsten Schäfer
Design and typesetting: Simone Hoschack
Photo-editing: Petra Kossmann, Peggy Wellerdt
Graphics: Walther-Maria Scheid
Printing: DBM Druckhaus Berlin-Mitte GmbH
Paper: Recysatin, FSC-certified

ISBN 978-3-86648-201-2

Published by: maribus gGmbH, Pickhuben 2, 20457 Hamburg

www.maribus.com

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