Fish populations in Swedish waters
How are they influenced by fishing, eutrophication and contaminants?

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Foreword

In the light of previous work by the Committee on Environment and Agriculture with a follow-up of fisheries policy measures, the Committee decided at its meeting of 1 November 2007 that a research review should be carried out of the fisheries area, primarily to illuminate the ecological consequences of fishing. The general objective of the review is to give members of the Committee more thorough background material for decision-making in relation to commercial fishing. The Committee decided that the review should be in two parts where part 1 would contain research about environmental factors having both direct and indirect effects on fish populations and part 2 would contain future scenarios showing how climate change and future fishing management may affect fish populations. Part 1 will be completed in 2008 and part 2 in 2009. Part 1 of the report, presented below, provides an overview of scientific publications, reports and interviews about the way in which fishing, eutrophication and contaminants have influenced our fish populations.

The review was carried out by Lisa Almesjö, Researcher at the Department of Systems Ecology, Stockholm University, and Senior Research Officer Helene Limén of the Parliamentary evaluation and research unit, Research Service at the Riksdag. The authors alone are responsible for the contents of the report. Rapporteur Anna-Lena Kileus of the Secretariat of the Committee on Environment and Agriculture and evaluator Christer Åström of the Evaluation and Research Function at the Riksdag assisted the authors in the assignment. In addition, Stockholm University trainees Carolina Enhus and Elias Drakenberg assisted the authors by preparing background materials.

Two reference groups were assigned to supervise the work; an all-party steering group and a group of experts. The all-party steering group had the remit of providing guidelines for the review and ensuring that it was carried out in accordance within the Committee’s terms of reference. The group had the following members: Sven Gunnar Persson (ChrDem), Jan-Olof Larsson (SocDem), Wiwi-Anne Johansson (Lft), Erik A. Eriksson (Cen), Tina Ehn (Grn), Rune Wikström (Mod) and Lars Tysklind (Lib).

The group of experts had the task of scrutinising the overview with regard to the quality and relevance of its content. The group had the following members: Sif Johansson (PhD, Swedish Environmental Protection Agency), Sture Hansson (Professor, Stockholm University), Henrik Svedäng (Researcher, Institute of Marine Research Laboratory of the Swedish Board of Fisheries), Agneta Andersson (Associate Professor, Umeå University), Gunilla Ericson (Head of Department, National Chemicals Inspectorate), Anders Alanärä (Researcher, Swedish University of Agricultural Sciences in Umeå), and Leif Pihl (Professor, Göteborg University).

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Anders Ygeman Björn Wessman
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Summary

As a whole, recent research shows that fishing is the single most important factor impacting the conditions of fish populations in Swedish lakes and marine areas. In addition to overfishing leading to a decline in entire fish populations, selective fishing for large individuals has also resulted in significant changes in the age structure of the remaining stocks. In turn this can cause impaired reproductive success and a reduced capacity of the different fish stocks to overcome natural fluctuations in their habitat. Research shows that fishing has had a considerable impact on both target species and the entire ecosystem, and for this reason it is imperative to ensure a sustainable management of our fish populations. It has been shown that management based on short-term decision-making leads to both ecological and financial losses. Aquaculture can be viewed as a supplement to fishing, and the industry has a significant potential for growth if it is developed in parallel with the sustainable management of our aquatic ecosystems. Studies also show that recreational and tourist fishing have a potential to generate considerable earnings both from an economic perspective and as a source of recreation.

The effects of eutrophication on fish populations are complex. Initially, eutrophication may have a positive impact on fish populations since the availability of food tends to increase. In the long-term, however, eutrophication may cause oxygen depletion, alter the characteristics of vital habitats, and cause changes in the species composition of prey, which may cause a decline in fish populations. The whole ecosystem must be considered when tackling the problems of eutrophication. For instance, recent research shows that the absence of predatory fish such as cod can worsen the effects of eutrophication. A decline of predatory fish may (in the same way as an increased discharge of nutrients) lead to a higher abundance of phytoplankton or macro-algae and in extension cause oxygen depletion and dead zones.

In Sweden, many fish populations have undergone substantial structural changes in which both high fishing pressure and eutrophication have been significant factors. In an ecosystem which has already undergone such large-scale changes, the effects of toxic compounds can potentially be important for the ability of fish populations to recover. The effects of diffuse discharges, both water-borne and air-borne, may have a greater effect on fish populations than indicated by our present knowledge. Ongoing environmental monitoring, screening and research are indispensable tools in our efforts to understand the impact of contaminants on our ecosystems.
1 Effects of fishing on fish populations

1.1 Introduction

Human activities have impacted lakes and seas and the life in them for many thousands of years. Since the mid-1900s, this impact has constantly increased as a consequence of population growth, technological development and the larger geographical scale on which exploitation is taking place (Jackson et al. 2001). In many of the world’s aquatic ecosystems, large-scale changes have occurred as a consequence of the decimation of marine mammals (e.g. seals, porpoises and sea otters), overfishing, eutrophication and the spread of contaminants (Elmgren 1989; Hansson and Rudstam 1990; Jackson et al. 2001; Myers and Worm 2003; Österblom et al. 2007). Declining populations of marine mammals and predators, which structure food chains in seas and lakes, frequently lead to ecosystems becoming more sensitive to other natural and human changes. For instance, in a number of locations it has been observed that overfished areas become more sensitive to eutrophication and the spread of diseases (Jackson et al. 2001; Casini et al. 2008). The introduction of alien species is a further factor contributing to large-scale changes in many aquatic ecosystems (this will be considered in the Committee’s Research Review, Part 2, 2009).

In Sweden’s marine areas, large changes also occurred during the 20th century, both as a result of human activities and changes in the climate and hydrography (Schinke and Matthäus 1998; MacKenzie and Schiedek 2007). During the 20th century, populations of grey seals and ringed seals in the Baltic Sea were decimated by almost 95% (Harding and Härkönen 1999) both as a result of intensive hunting (mainly between 1900 and 1940) and later contaminants that made reproduction more difficult for the seals (mainly between 1965 and 1975). In certain areas of the east coast of Sweden and of the west coast, the grey seal was completely extinct. After seal hunting was prohibited in 1988, the grey seal has increased by roughly 8% annually and it is estimated that there are now some 25,000 grey seals in the Baltic (Karlsson et al. 2007). This number can be compared with the 100,000 grey seals estimated to have lived in the Baltic in 1900 (Karlsson et al. 2007). Ringed seals, found principally in the Gulf of Bothnia, have increased by roughly 4% annually since 1988 to number around 5,000 in 2006 (Karlsson et al. 2007). This relatively modest increase is probably a consequence of ringed seals still being notably affected by contaminants, which leads to a reduced reproductive capacity in the female seals (Karlsson et al. 2007).

A number of fish species in the Baltic have shown large population fluctuations since the end of the 19th century and the beginning of the 20th century. We know that intensive fishing for herring took place in the western
Baltic and the Sound from the 12th century until the end of the 17th century (MacKenzie et al. 2002). Cod, on the other hand, appears to have been fished on a large scale only at certain periods between the 16th century and the mid-19th century (MacKenzie et al. 2002). The expansion of professional cod fishing in the Baltic began in the 1930s but did not have its big upswing until the 1950s (MacKenzie et al. 2002; Eero et al. 2007). Estimates of catches and fish biomass from the first half of the 20th century are generally speaking unreliable since standardised methods of measurement were not available and catches were not reported in the same way as they are by the same methods as they are today. Baltic stocks of cod, herring, and sprat appear to have been small in the early 20th century (Thurow 1997), probably as a consequence of a high level of predation by seals and porpoises, in combination with low levels of nutrients and thus lower production than today. With intensified agriculture in Sweden in the late 19th century and the beginning of the 20th century, the nutrient load into the sea increased. This stimulated primary production and probably also the production of fish (Thurow 1997). Stocks of cod, herring and sprat increased substantially between the 1950s and the 1970s. A number of years with favourable conditions for reproduction yielded uncommonly large year classes of cod between 1976 and 1982. These constituted the basis for the considerable growth of the cod fishery between 1980 and 1985, when more than twice as much cod was caught annually compared to the catches in the 1970s (Sjöstrand 2007). After this peak, both landings and abundance of cod in the Baltic Sea have steadily declined. In 2005 the eastern stocks were lower than ever previously recorded in the data series of the International Council for the Exploration of the Sea (1966–2005; ICES 2006). During the period 1967–1992 cod stocks in the Baltic varied dramatically, partly due to varying saltwater inflow. Fishing pressure also increased considerably during this period. The combination of these two factors led to the small cod stocks currently seen. Compared to cod, the abundance of sprat has developed in a diametrically opposite way, doubling their numbers from the mid-1980s up to the present (Sjöstrand 2007). This increase can partly be explained by the decrease in cod stocks, as cod is the most important sprat predator. Some years with favourable climatic conditions for sprat reproduction have, however, also contributed to the increase.

In Bohuslän on the west coast of Sweden, large-scale herring fishing has taken place since at least the 12th century (Alheit and Hagen 1997). There are documents describing the vast shoals of herring appearing in certain periods – known as herring years – which were of great socio-economic value. During the herring years large quantities of spawned herring spent the winter in the fjords of Bohuslän and supported a large-scale fishing industry. There are nine confirmed herring periods, varying from 20 up to 100 years. They are principally explained by unusually favourable climate for herring during these periods (Alheit and Hagen 1997). Until the beginning of the 1900s, the fjords of Bohuslän were fished using permanent nets or seine nets pulled out from
the beach. Big catches could therefore only be taken when the herring remained close to the shore.

Fish stocks in the Skagerrak and in the north eastern parts of the North Sea (also known as Jäderen) were primarily fished by Swedish fishermen during the 1800s, although Norwegian and Danish fishermen also participated to a certain extent (Poulsen et al. 2007). Species caught were ling, cod, tuskfish (“lubb”) and other demersal (bottom-dwelling) species, principally in shallow areas with a depth of between 80 and 300 metres. The fishing season started in February/March and lasted until August/September using long-line boats whose lines were equipped with hooks (Poulsen et al. 2007).

Advances, particularly in engine and fishing equipment technology, have been indispensable in the development of more intensive fishing. On the basis of log books and other early records researchers have estimated that the whole of the North Sea was being fished around 1900, and with the exception of the periods around the first and second world wars, fishing efforts have been increasing steadily since then (Rijnsdorp et al. 1996; Jennings et al. 1999). Many species in the North Sea have shown a tendency to decrease as a result of this intensive fishing. These are principally large, fish-eating species like cod, ling and haddock (Svedäng and Bardon 2003, Svedäng et al. 2004). Other long-lived species that are not fished commercially, e.g. lantern shark, rabbitfish, lesser redfish, grenadier and blue skate, have also become increasingly rare (Svedäng et al. 2004).

In Sweden’s largest lakes (Vänern, Mälaren, Hjälmaren and Vättern) professional fishing nowadays is dominated by catches of pike-perch, freshwater crayfish and vendace (www.fiskeriverket.se [Swedish Board of Fisheries]). The effects of contaminants are in general larger in lakes due to the restricted size of lakes and their limited water exchange. At the beginning of the 20th century Vänern was one of the world’s most mercury polluted lakes following large-scale discharges from paper and pulp factories (www.vanern.se). The Environment Protection Act (SFS 1969:387), which was adopted in 1969, was the first "real" environmental law to regulate activities deleterious to the environment, and the Act has been the basis for improvements in Sweden’s water environment since then. During the 1970s, sewage treatment was also improved in the towns around lake Vänern. The levels of a number of well-known toxic contaminants (PCB, DDT and mercury) and pesticides (herbicides and insecticides) are still too high in the sediments of lake Vänern and in its fish, although in general they are decreasing (Vätternvårdsförbundet 2003). In Vättern, too, fish species such as char, salmon and trout contain high levels of dioxin-like PCB and mercury.

Fish stocks in different marine areas

Sweden’s long coastline, extending for 11,500 km, borders on a number of fundamentally distinct marine areas (Fig. 1.1.1). In the northern Baltic, the water is characterized by almost limnic conditions, whereas the northern parts of the Skagerrak on the west coast of Sweden are almost completely marine.
Salinity is a very important factor as it structures the character of the marine area in question and the species that will be found there. The different areas therefore offer very different conditions for the pursuit of commercial and leisure-based fishing.

Fig. 1.1.1 Map of Sweden’s maritime territory where the area inside the baseline comprises internal waters and the area outside comprises territorial waters. The area beyond this within the dotted line constitutes Sweden’s economic zone.
The southern and central parts of the Baltic Sea, the Baltic Proper, are characterised by brackish water with a salinity around 6‰ in the surface water. The most important commercial fish species are cod, herring and sprat. Major changes in the fish community of the Baltic Proper have occurred during the latter half of the 20th century and the beginning of the 21st century. A fish community formerly dominated by cod has now become more dominated by sprat. After a period of decreasing fishing pressure, the populations of herring, which used to be heavily fished and showed a dramatic decline between the end of the 1970s and the late 1990s, have once again increased (Fig. 1.1.2).

Fig. 1.1.2 The biomass of cod, herring and sprat in the Baltic from 1974 to 2007. Data from ICES.

The salinity in the southern parts of the Gulf of Bothnia and in the bottom waters may reach 4.5 ‰, while the surface water becomes fresher in the north. The main species fished are herring, vendace and, to a certain extent, salmon. Since the early 1990s, a dramatic difference in the size distribution and abundance of herring has been observed. The numbers of young herring have increased greatly, while older fish over 20 cm have decreased in numbers. As a consequence it is now difficult to find the large sized herring required for preparing “surströmming” [fermented herring]. Herring have also in general become leaner (Sjöstrand 2007).

In the Gulf of Bothnia, vendace is one of the most important species for commercial fishing. Vendace is caught for its roe and is mainly fished during the spawning season. In the early 1990s, catches declined greatly, but stocks later recovered due to good recruitment, and catches were good in 2004 and 2005. This positive trend has now reversed and catches are diminishing again. Continued low recruitment in 2006 is expected to lead to a further reduction in stocks. The low proportion of older individuals, as well as the variations in
recruitment, make the stocks vulnerable to overfishing (Swedish Board of Fisheries 2007c).

The marine areas located to the west of Sweden are divided into the Sound, the Kattegat and the Skagerrak. The salinity in the Sound is around 10‰, and increases to roughly 30‰ near the Bohus coast. These marine areas are the most species rich and productive coastal regions in Sweden. It provides habitat for a great variety of commercially important fish species. Pelagic species like herring, sprat and mackerel are fished in these regions as are demersal species like cod, haddock and various flatfish. Norway lobster and shrimp are also fished on a large-scale. Several stocks of demersal fish, such as cod, haddock and ling have shown a tendency to decrease, particularly since the 1970s and the 1980s. In the case of cod, stocks have become so small that the recruitment has been negatively impacted, and some local stocks are likely to have become extinct (Svedäng and Badon 2003). In the cod stocks of the Kattegat and the North Sea/Skagerrak there remains very few large fish able to produce high quality eggs and larvae with good ability to survive (Marteinsdottir et al. 2005; Sjöstrand 2007).

Swedish fishing in numbers

The number of boats in the Swedish fishing fleet at the end of 2006 was 1,564, and 1,880 people held commercial fishing licences at this time (Swedish Board of Fisheries 2008a). However, not everyone working on fishing boats holds a licence, which means that the total number people employed in fishing is greater. The Swedish fishing fleet consists principally of smaller boats using passive gear together with a few larger boats using trawls and similar gear (Swedish Board of Fisheries 2008a).

Lake fishing is small-scale fishing primarily using passive gear. In addition to the biggest lakes where commercial fishing licences are required for fishing in common waters, fishing in smaller lakes may be pursued on the basis of private fishing rights. In addition to fishing in the five largest lakes, commercial fishing is carried out in 34 lakes throughout Sweden (Swedish Board of Fisheries 2008a). The number of lake fishermen with commercial fishing licences was 192 in the year 2006 (Swedish Board of Fisheries 2008a).

Both revenues and profitability in Swedish saltwater fishing declined in the early 21st century. Between 2002 and 2005 the landed value of fish decreased from SEK 1,174 to 888 million. After this, catches have increased by 4% and their value has increased by 15% (Swedish Board of Fisheries 2008a).

A branch with potential growth is the leisure-based fishing trade. Activities based on leisure fishing include goods and services sold in conjunction with fishing trips, such as accommodation, the sale of fishing gear, fishing package tours, guiding, renting of boats and fishing waters and training. In 2006, there were just over 1,300 businesses in Sweden which were fully or partially related to leisure fishing. Their total turnover was just under SEK 500 million.
A follow-up study shows, however that the real value probably is twice as much (Paulrud and Waldo 2008). Generally speaking, the companies had a positive view of their future development potential – with just over 50% assuming that their turnover would increase over the next three years. There is, however, widespread concern that poor fish numbers may be a threat to their businesses. Over 40% of the companies dealing with sea-based leisure fishing have reported that a shortage of fish has proved to be a large, or very large, obstacle to the further development of their activities (Paulrud and Waldo 2008).

1.2 Direct effects of fishing

**Fact box**

*Fish population*

A fish population is a group of fish of the same species living within a certain area at a certain point in time. Some species are divided into many small populations which may be completely or partially separated from one another even though they live in a rather limited area. This is because adult individuals of many species return to specific spawning areas. Salmon is an example of such a fish which always returns to spawn in the river where it was hatched. Herring and cod are also species in which different small populations have very specific spawning areas. In the management of fish resources it is very important to take into account the various populations within a species. Individual populations within a stock are otherwise at risk of becoming extinct by excessive fishing pressure. If there are many healthy populations of a species this helps to make the species more resilient to changes in its habitat (e.g. climate change). A fish population also uses various environments (habitats) during its life cycle. Eggs, larvae, juvenile fish and adults are therefore often not found in the same geographical area. A fish population can therefore be affected by a number of external factors, and in management it is important to preserve all the habitats that impact the fish’s life cycle.

*Fish community*

A fish community is a general term defining a number of populations of different species living together in a certain environment. The term community often indicates that the organisms present interact in some way (e.g. by way of predation or competition). A fish community comprises all the various kinds of fish in a particular area (e.g. a lake) affecting one another in some way. Cod, herring and sprat are considered to be the most important species in the fish community of the Baltic pelagic zone.
Fish stocks

A fish stock is a technical management term referring to the fish of the same species living within a limited area and comprising part of the amount of fish that can be removed by fishing. Examples of such stocks are the eastern and western stocks of cod in the Baltic or herring in the Gulf of Riga.

Natural mortality and fishing mortality

The primary effect of fishing is that the total mortality in a fish population increases when the removal of fish is added to the natural fish mortality (Beverton and Holt 1957). Above all, natural mortality includes predation by predatory fish and related species (cannibalism), predation by birds and seals, but also death resulting from disease, parasites and starvation. Compared with mammals and birds, fish have very high levels of fecundity, and a female can produce from tens of thousands to millions of eggs on one or more occasions during spawning. It was formerly believed that fish populations were more or less inexhaustible, since such great quantities of eggs and larvae were produced during spawning (Jackson et al. 2001). The mortality of eggs and larvae is, however, very high. Therefore only a very small proportion of eggs survive to become reproductive adults. The risk of dying often diminishes exponentially with the size and age of the fish but is also due to species-specific factors like absolute length, life span and behaviour. Determining the natural mortality of a population is difficult, but the information is crucial in the assessment of fish resources. Fish with a long life span (e.g. cod) have low natural mortality as adults, compared to naturally short-lived fish like sprat, whose natural mortality is high. Generally speaking, a species with low natural mortality will not endure as intensive fishing pressure as a species with high natural mortality (Hilborn et al. 2003). This is generally due to the slow regeneration of long-lived species since these reach sexual maturity late in life and do not attain full reproductive capacity until they have reached a substantial body size.

The correlation between parent fish, genetic variation and the number of juveniles

Fishing increases the total mortality of adult fish and leads to a reduction in the abundance of reproductive fish; the effective population size thereby diminishes. The effective population size is the part of the population which produces offspring which in turn survive to produce offspring. A small effective population size diminishes genetic variation and increases the risk of inbreeding. High genetic variation is in most cases indispensable for the ability of a stock or a population to adapt and survive changes in its habitat. A small effective population also means that few juvenile fish are produced, and in this way a population’s regeneration can be threatened.

Fisheries biology has developed theoretical correlations between the abundance of parental fish and the abundance of recruits – known as stock-recruitment curves. In this context the term “recruits” designates the number
of juvenile fish surviving until they are large enough to be caught. The theoretical curves are not always applicable to reality, and it is difficult to determine the exact correlation between parental fish and recruits since a number of other factors are also involved. Such factors are for example temperature and climate, diffusion by way of currents, access to suitable food and predation from other fish. It is however quite clear that if the abundance of parental fish falls below a certain limit, the number of juvenile fish living to become adult individuals will not be sufficient to ensure the population’s continued survival. A good example of this is the cod fishery in Newfoundland on the east coast of Canada, where intensive fishing for many years led to a complete collapse of the cod populations. Fishing was banned in 1992, but even today the cod show no sign of recovery (e.g. Hilborn et al. 2003). Factors like seal predation and poor recruitment have also been suggested as causes of the decline of Canadian cod, but there is no doubt that it was the overestimation of stocks and far too intensive fishing that caused the collapse (Myers et al. 1997). In Sweden too there are examples of overfishing causing drastic declines in fish stocks. The coastal cod populations of the Kattegat on the Swedish west coast have long been subjected to intensive fishing pressure, and these local populations are now on the brink of extinction (Cardinale and Svedäng 2004). For many years the abundance of cod in the Baltic has been below the biologically safe limit set by ICES.

Overfishing – a poor business strategy

Overfishing is caused by a too large part of the population being caught each year and as a consequence the fishing doesn’t harvest only the interest on its capital but also the capital itself. The precondition for sustainable fishery is that stocks are not reduced by more than they can produce each year. Overfishing is not just a poor business strategy from an ecological perspective but also from a economical one. The smaller the stocks, the longer it takes to find the fish, and in the end this means a higher cost for each fish landed. In overfished stocks the size of the individual fish usually decreases (see section on size-selective fishing), which also gives a smaller catch per effort. Well-managed stocks give a good economic return as well as a future for the species fished (Hilborn et al. 2003; Sjöstrand 2007). To avoid overfishing it is imperative to adjust the management of fish stocks to prevailing environmental conditions, e.g. by restricting fishing in periods of poor recruitment.

In fisheries biology a theoretical concept known as MSY – maximum sustainable yield is used. This may be defined as “additional production”, that is the amount of fish that would be present without any fishing and it estimates the size of catch providing the best long-term sustainable harvest. If a population should be left unfished for a number of years, it would grow until such factors as food, space or other resources became limiting. In this situation there would not be any “additional production”, and the population
would stop growing (at point B0 in Fig. 1.2.1). Somewhere midway between a fish population not containing any fish at all and the point at which the “additional production” becomes zero, there is a point where the additional production or sustainable catch is at its greatest – the maximum sustainable yield, MSY (Fig. 1.2.1).

Fig. 1.2.1 Schematic graph of how the MSY concept is estimated in a fish stock. B0 represents the average biomass of a completely unexploited stock. At B0 the additional production is zero. BMSY stands for biomass maximum sustainable yield. See text for details. (Based on a figure from www.fao.org)

From both a biological and an economic perspective it is advantageous to keep a fish stock at a higher biomass than that given by the MSY. There are a number of explanations: (i) a larger biomass in a stock constitutes a better buffer against changes in the environment (e.g. climate change), (ii) with a larger biomass the catch efficiency, and thus the economic yield of the fishing effort is higher, and (iii) when the target species has a larger biomass, the impact on the ecosystem as a whole is less (summary in Hilborn et al. 2003). The MEY – maximum economic yield occurs when the fishing effort gives the greatest profit margin in relation to the costs of the effort (Caddy and Mahon 1995) and this is achieved at a larger biomass than the MSY.

Size-selective fishing
High fishing mortality in a stock drastically diminishes the prospects of a fish living beyond maturity. Since most fish species keep growing throughout their lives, this also reduces the probability of individuals surviving long enough to become big. A clear indication of heavy fishing is therefore a downward shift in a stock’s size distribution – the fish continually become
smaller and the number of annual cohorts diminishes (Bianchi et al. 2000; Svedäng et al. 2004; Marteinsdottir et al. 2005).

Under natural conditions a long-lived species like cod can reach an age of 25 years and be almost 2 m long, but such large individuals are very rare in Swedish waters nowadays. In the Skagerrak on the west coast of Sweden the Swedish Board of Fisheries has compared the size distribution of a number of fish species between 1946–47 and 1999–2001 (Svedäng et al. 2004). The length distribution for cod, haddock, whiting and coalfish had changed completely between 1946–47 and 1999–2001 (Fig. 1.2.2). In the 1940s each species was represented by many annual cohorts, that is to say both juvenile and more mature fish. In the 1999–2001 studies, on the other hand, only juvenile (small) individuals were found. Most cod stocks in the North Atlantic show similar changes in their age structure (summary in Marteinsdottir et al. 2005).

For many years, researchers have observed that fished stocks with an altered age structure show a more significant variation in abundance than unfished stocks (Andersson et al. 2008). Large fluctuations in a stock are undesirable since they increase the risk of the stock becoming extinct. In a new study from California, researchers are studying why the biomass of fished stocks tends to vary so much (Andersson et al. 2008). The study indicates that a primary cause of the variability of exploited fish populations is that demographic variables in the fish stock, such as rate of growth and age of sexual maturity, are subject to change. This makes the stocks more sensitive to factors like variations in fishing pressure and environmental conditions. It also appears that species with late sexual maturity, long spawning periods and high fecundity are extra sensitive to this type of impact (Andersson et al. 2008). The researchers stress that it is especially important to preserve a natural age structure in fished stocks, in order to reduce the risk of stocks collapsing (Andersson et al. 2008).

Earlier sexual maturity in heavily fished stocks

In a number of heavily fished stocks it has been observed that females reach sexual maturity earlier and earlier (e.g. Trippel 1995; Mollet et al. 2007). The age changes in sexual maturity may be explained by two different mechanisms. Partly, the decrease of a stock’s size entails a diminution of competition for food. The individuals remaining in the sea thus have more to eat and grow more rapidly. The more rapid growth and the better condition of the fish may lead to earlier sexual maturity (Trippel 1995). This mechanism does not lead to any change in the genetic composition of the fish; when stocks increase in size and access to food diminishes, individuals once again reach sexual maturity later (Trippel 1995). The other mechanism is linked to the removal of large individuals. Within a stock there is a certain degree of natural genetic variation entailing that certain individuals reach sexual maturity earlier. Intensive fishing for large individuals leads to their genes for
later sexual maturity become increasingly rare in a population. After a number of generations, early sexual maturity becomes more common, and eventually these genes may completely dominate a population. In this way, by removing large individuals, fishing has induced an evolutionary change in the age of sexual maturity (Mollet et al. 2007). This type of genetic change takes longer for a stock to recover from – since it is necessary for the genes generating later sexual maturity to once more become predominant in a population.

Fig. 1.2.2 The relative length frequency distribution for cod and haddock in catches from 1946–1947 and 1991-2001. Data from Svedäng et al, Swedish Board of Fisheries.
The significance of large females

A shift in the age structure towards smaller and younger fish has a negative influence on a stock’s reproduction (Marteinsdottir et al. 2005). For instance, researchers have shown that poor recruitment in Icelandic cod stocks was due to a change in the age structure towards younger individuals (Marteinsdottir and Thorarinsson 1998). It also appears as if changes in age structure cause stocks to become more sensitive to natural changes, such as changes in climate (Ottersen et al. 1994).

The total number of reproducing individuals in a stock is a rather poor measure of how high its reproductive potential is, since large females generally speaking produce many times more eggs than small females (Trippel 1995). Put simply, a few large females would be able to produce more offspring than many small ones. For instance, a six-year-old cod female produces around four times as many eggs as a three-year-old female (Vallin and Nissling 2000). Older cod females also have a more prolonged spawning period and lay more batches of eggs in a season compared to younger females. A stock consisting of many age groups also means that the aggregated spawning period for the whole stock will be longer, since juvenile and older fish frequently have overlapping spawning periods. Young cod females spawn earlier in the season while older fish normally begin spawning somewhat later (Vallin et al. 1999). Since factors like water temperature and access to food vary from year to year, the length of the spawning period can play an important part in the total survival of juveniles. A long spawning period increases the chance that some batches of eggs will hatch under exactly the right conditions, while a brief spawning period may result in that the wrong temperature or poor access to food will annihilate the whole of a year’s reproduction.

In addition to producing more eggs, large females also produce larger eggs. This correlation is valid for most fish species, as well as for crustaceans like lobster and crab. Large eggs contain more energy and give rise to larger and more healthy juveniles (Trippel 1995; Vallin and Nissling 2000; et al.). Large juveniles also easier avoid being eaten, have a higher growth rate, and are able to eat more varied food (summarized in Vallien et al. 1999). In the Baltic, large cod eggs have a further advantage since they float at a lower salinity than small eggs (Vallin and Nissling 2000). In the Baltic, cod live at the limit of their geographical distribution, and the salinity is actually too low for cod reproduction. In the North Sea, cod eggs float closer to the surface, where the salinity exceeds 30% and access to oxygen is always good. In the Baltic, cod eggs will only float in water with a salinity above 14.5 ± 1.2‰ (Nissling et al. 1994), which usually occurs at 60 meters depth or deeper. At lower salinity, the eggs sink towards the bottom where the risk of being attacked by fungi and bacteria is great. At a depth of 60 m in the Baltic, however, the oxygen concentration in the water is a problem, since the eggs need oxygen levels greater than 2 mg/l to survive. Large, regular inflows of saline water from the North Sea are of major importance for cod spawning.
During periods with few inflows (stagnation periods) both salinity and oxygen concentration decreases in deep water and the volume of water with the right salinity and oxygen content for cod spawning (known as the reproductive volume) declines. Saltwater inflows influence many processes in the Baltic (see also the chapter on eutrophication) and are indispensable for successful cod reproduction and thus new recruitment with respect to fishing. The relative effects of the age and size of cod females are assumed to increase when spawning conditions deteriorate, i.e. when oxygen conditions in Baltic deepwater are bad. In such conditions, it is questionable if small females are at all capable of contributing to the rejuvenation of cod populations in the Baltic.

Many fish populations create stability

Many fish species are divided into smaller populations which are more or less separate from each other. Such populations or subpopulations originate and maintain their numbers by using specific spawning areas, but other differences in behaviour between these populations may also be observed. Perhaps the best known example of a fish species with many clearly delimited populations is salmon. Salmon eggs hatch in large rivers with strong currents, and the juveniles remain there from one to three years before migrating to the sea. For some years they live in the sea and increase in size, after which they return to their home river to spawn. Along Sweden’s coast there are around twenty wild salmon populations each of which has its own spawning area in a particular river.

In a large area of south-west Alaska the abundance of the North American sockeye salmon has been monitored in about a dozen pristine river and lake systems since the 1940s. It has been clearly shown that the total abundance of salmon during this period has hardly varied, but the abundance of salmon in the different rivers has varied all the more (Daniel Schindler, personal communication). It was shown that changes in climate, precipitation and other environmental factors produced different effects in different rivers. Every large river-specific salmon population thus has both good and bad periods. But since the bad periods do not coincide in every river, the total amount of salmon still remained relatively constant. Researchers who study sockeye salmon in these rivers stress the importance of preserving an area's biocomplexity and habitat complexity. Simply put this means that keeping high diversity of populations and habitats intact increases the ability of a species or a group of species to resist and survive changes produced by natural or human causes. This area is also interesting in that sockeye salmon are intensively fished here. The annual catch is about 1.8 million salmon, which can be compared with the 1.1 million salmon spawning in the area each year (Baker et al. 2006). Thus it is possible to engage in fairly heavy fishing at the same time as both habitats and fish populations are kept healthy and intact. A management committee with absolute powers can close down
fishing from one day to the next, if too few salmon have passed up into the rivers (Daniel Shindler, personal communication).

Cod too is a species with many small, genetically distinct populations which use specific spawning grounds (Marteinsdottir et al. 2005; Svedäng et al. 2007; Vitale et al. 2008). Many of the stocks considered as units in fisheries management may in themselves consist of a number of different populations. In the Baltic, the eastern and western stocks are distinguished. The larger, eastern stock stays east of the island of Bornholm and has its spawning grounds in the Bornholm Deep, the Gotland Deep and the Gdansk Deep. The western stock is smaller and stays to the west of Bornholm, in the Sound and in the Belt. It is considered, however, that both of these stocks consist of a number of populations. On the west coast of Sweden, fisheries management distinguishes between cod stocks in the Kattegat, the Skagerrak and the North Sea (www.ices.dk). Research, however, shows that cod in the coastal areas of the Kattegat and the Skagerrak comprises a number of populations, some of which stay near the coast and spawn there, while others move between different areas of the Kattegat, the Skagerrak and other parts of the North Sea (Svedäng and Svenson 2006; Svedäng et al. 2007). When it is time to spawn, the cod, like salmon, migrate back to the specific area where they were born. Above all, the various populations appear to maintain their numbers by way of differences in their behaviour – one might say that they have different cultures (Henrik Svedäng, personal communication). Formerly, researchers thought that cod populations primarily arose and maintained their numbers due to currents transporting their eggs and young fish to various parts of the sea. That populations are maintained due to differences in behaviour means that they are more sensitive to high fishing pressure than if their division occurred passively by way of marine currents. It is thus imperative that fisheries management takes all aspects of the population structure into account to preserve the diversity of cod populations. Otherwise they are at risk of disappearing as the recolonisation of an area seems to be a very slow process (Henrik Svedäng, personal communication).

How do we estimate the abundance of fish in the sea?

To fish a stock sustainably it is very important to estimate the stock’s size as accurately as possible. The best solution of all would be to count every fish in the sea, but this is an impossible task. Instead, the size and age structure of a stock are calculated using mathematical models. The models, in their turn, contain data from the fishing boats’ log books, from the samples taken by the Swedish Board of Fisheries on board the boats and in port, and from the data collected by research vessels (Swedish Board of Fisheries 2007b).

– Fishing boats’ log books contribute information about how much fish is caught, which species, and how long it takes to make the catch in a given geographical area. If you take into consideration how long it takes to make the catch, you obtain a measure of catch per unit effort. This is particularly important measure since it gives an idea of how much fish there is in different
parts of a species’ distribution area. With technical aids such as sonar, it is easier to catch large numbers of fish even when stocks are low. If the abundance of fish caught per unit of time decreases over the years, you can be relatively certain that a stock has become smaller.

– Sampling on board fishing boats made by the Swedish Board of Fisheries to record the size of the by-catch thrown back into the sea. The same applies to sea birds and marine mammals like seals and porpoises.

– Sampling in port made to gather data about a catch’s species composition, length and weight distribution and, in certain periods, the spawning maturity of the fish. Samples taken amount to about 200 fish per 1,000 tonnes of fish landed.

– Research vessels collect data not recorded by the fishing boats, such as the abundance of eggs and fish larvae. Research vessels do not endeavour to catch as much fish as possible. Instead, they fish in the same way and usually in the same location, year after year, in order to observe the changes of fish stocks over time. The Swedish Board of Fisheries also fish in coastal areas to estimate the abundance of coastal fish species like perch, pike and roach. In this too, standardised methods and nets are used to make it possible to monitor the development fish stocks.

From data collection to quotas recommended by ICES

The advice submitted to the EU by the International Council for the Exploration of the Sea (ICES) concerning fishing quotas is based on biological grounds and long-term agreements in the EU. No regard is paid to the fisheries industry at this stage. ICES bases its advice on minimum levels of sexually mature fish or a level for permitted fishing mortality (that is the proportion of breeding stock that can be removed through fishing). The minimum levels for biomass imply that a certain abundance of sexually mature fish should remain in the stock after natural mortality and fishing mortality have reduced the stock. As estimates of fish stock are uncertain, a minimum measurement is used called a precautionary biomass limit which is designated as $B_{pa}$. To keep the stock within “secure limits”, the breeding biomass may not be allowed to fall below $B_{pa}$. Another limit for estimating the size of stock is the biomass limit $B_{lim}$. $B_{lim}$ is the lowest level to which a particular stock may be allowed to fall. Below this level, the stock is estimated to be so low in numbers that the recruitment of young fish will be reduced, and the future of the stock may be threatened.

As from 2008, ICES’ recommendations for cod fishing in the Baltic will be based on a fishing mortality level instead of biomass levels. This decision has been made by ICES because the reference points previously used for the biomass of Baltic cod are considered to be too uncertain (ICES 2008). ICES’ recommendations for cod fishing in eastern stocks of the Baltic state that fishing mortality rates should not exceed 0.3, which in practice means that approximately 30% of all fish in the age group 4-7 years will be fished every
year. Ever since the mid-1960s, the fishing mortality rate among Baltic cod has often been well over 0.6 (Fig. 1.2.3; ICES 2008). ICES’ new recommendations agree with the management plan adopted by the European Commission in September 2007, in which the long-term goal is a fishing mortality rate of 0.3 (Council Regulation (EC) 1098/2007). Also included in the Commission’s management plan is that total allowable catches (TACs) should not increase by more than 15% a year, and neither should they decrease by more than 10% a year, provided that the fishing mortality rate is below 0.6. The reason is that fishing pressure should not be allowed to fluctuate too much from year to year.

The EU rarely follows the exact fishing quotas recommended by ICES, but in most cases establishes quotas at a level somewhat above ICES’ recommendations. Many researchers consider that it is these high quotas that have caused today’s stocks to be so decimated. If fishing had been carried out at the levels proposed by ICES, stocks would be at acceptable levels, complete with both economic and biological benefits (Sjöstrand 2007).

Figure 1.2.3 Cod mortality in the Baltic (unbroken line) between 1966 and 2006 in relation to the recently decided 0.3 level (broken line). Data from ICES.

Fishermen and researchers do not really disagree with each other

It is often said that fishermen and researchers do not agree on how much fish there actually is. This is due to the fact that they see fishing from different perspectives. The total amount of fish that is landed is a poor way of measuring fish abundance since this figure does not tell us how long time it has taken to find the fish. In simple terms, we can say that if a fisherman and a researcher are fishing the same reduced stock, data on each of their catches would appear to be quite different. The fisherman’s catches would remain at an even level while the researcher’s would decrease as time goes on (Fig. 1.2.3).
If instead we compare catch per unit effort for fishermen and researchers, it transpires that they are in fact quite similar (Fig. 1.2.5).

Fig. 1.2.4 Fishermen and researchers carry out their trawl fishing in different ways – which is quite natural as they have different objectives in their fishing. (According to Poul Degnbol FISK&HAV no 43.)

<table>
<thead>
<tr>
<th>Plenty of fish</th>
<th>Fisherman</th>
<th>Biologist</th>
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<tbody>
<tr>
<td>Good fishing</td>
<td>Good fishing</td>
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<td>Plenty of fish</td>
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<tr>
<th>Moderate fish abundance</th>
<th>Fisherman</th>
<th>Biologist</th>
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<tr>
<td>Good fishing</td>
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<td>Moderate fish abundance</td>
<td>Moderate fish abundance</td>
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<table>
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<tr>
<th>Few fish</th>
<th>Fisherman</th>
<th>Biologist</th>
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<tbody>
<tr>
<td>Still reasonable fishing but longer search time</td>
<td>Few fish</td>
<td>Few fish</td>
</tr>
</tbody>
</table>

- Trawl fishing
- Fish density
Protected areas

In a report from 2007 (Bergström et al. 2007), the Swedish Board of Fisheries evaluated the abundance of fish in a number of areas where they are completely protected (5 areas) or protected during their spawning period (5 areas), and in areas where the use of fishing gear is restricted throughout the year (6 areas). The report shows that all areas in which fishing was completely prohibited have denser stocks and larger individuals. In two of the areas, however, Lake Vättern and Gotska Sandön, the period of protection was too short for any noticeable effects to be seen. In Lake Vättern, the use of fishing gear was previously limited to a certain extent. A further restriction on the use of fishing nets was introduced in 2005, and in addition, an area consisting of approx. 250 km² (18% of the area of the lake) is completely protected from fishing (Bergström et al. 2007). The waters around Gotska Sandön have been a no-take zone (a fishing-free area) since May 2006. This was previously an area of intensive fishing, but fishing has been extremely limited in the last ten years. The no-take zone around Gotska Sandön stretches 4 nautical miles from the island and covers an area of approx. 350 km² (Bergström et al. 2007).

Positive effects of no-take zones all over the world

A major study of 89 no-take areas all over the world demonstrates similar results to those in the Swedish study – there are higher densities of fish, their total weight is greater, the fish are larger and the entire fish community has a higher diversity of species. The study also indicates that small, fishing-free areas also tend to show similar effects and that these effects often occur within a period as short as three years after closing (Halpern and Warner,
In the areas of the north-western Atlantic that were virtually closed for fishing after the collapse of cod stocks in the early 1990s, the abundance of haddock, flatfish and scallops increased after only five years (Murawski et al. 2000). On the other hand, the cod population had not recovered significantly, probably because other species had increased so much in number that they prevented the reestablishment of cod (Myers et al., 1997; see also the section on interaction between cod and sprat in the Baltic).

**Zones with gear restrictions**

In zones where gear restrictions are in force throughout the year, positive effects have been noted both in the size and in some cases in the density of fish (Bergström et al. 2007). The most common restriction is a ban on trawling, which applies along the entire coast of Sweden (4 nautical miles from the baseline), in the Havstensfjord and the inner regions of the Gullmarsfjord in Bohuslän in western Sweden and in the Öresund region of Skåne in southern Sweden. In Öresund, the Havstensfjord and the Gullmarsfjord, clear positive effects have been noted in the distribution of particularly cod, but also in species such as haddock, whiting, lemon sole and plaice. In these areas, the fish are larger and occur in some cases (above all cod) in higher densities than in areas subject to trawling (Bergström et al. 2007).

**Öresund a significant reference area in Sweden**

In most of Öresund, trawling and seine fishing have been banned since 1932, because of heavy shipping in the area. Fishing in Öresund is primarily carried out using gill nets, which allows a high degree of selectivity as regards size and species when fishing. One result of the ban on trawling has been that more species, higher densities and larger individuals are found in Öresund (Svedäng et al. 2004). Öresund can be regarded as a reference area in which the fish community is more "natural" in relation to areas where trawling occurs. Such reference areas are important when it comes to understanding how large-scale changes, for example climate change, affect natural fish communities, compared to those that are subject to heavy fishing pressure (Svedäng et al. 2004).

**Protection during spawning periods not effective if there is no reduction in total catches**

There are also a number of areas in Sweden where fish are protected during the spawning period. These protective measures include a total ban on fishing during the spawning of cod in the Bornholm Deep in the southern Baltic and Skälder Bay and Laholm Bay in Halland, a ban on targeted fishing inside the trawling limit on the west coast and in estuaries of streams and rivers in southern Sweden, as well as a complete fishing ban in 17 spawning bays for perch and pike in the Stockholm archipelago. Further bans on cod fishing during the spawning period have also been introduced in the Gdansk Deep and the Gotland Deep in 2008 (www.fiskeriverket.se). In cases where spawning areas have been protected for a sufficient period of time to enable
them to be evaluated (the Bornholm Deep and estuaries of rivers and streams in southern Sweden), positive effects have only been noted regarding the density of salmon and brown trout in southern Sweden. In order for protection during spawning to have a noticeable positive effect, it is important that the total fishing mortality is reduced – meaning that less fish is caught in total. If the fishing is merely moved to another area during the spawning period, without a reduction in total catches, the positive effects on the protected fish species will be very small or may be completely lacking (Bergström et al. 2007).

**New areas with permanent fishing bans**
A government decision in connection with the environmental quality objectives and the Government’s National Marine Environment publication entrusted the Swedish Board of Fisheries with the task of proposing, in consultation with the Environmental Protection Agency and the relevant County Administrative Boards, three areas with permanent fishing bans. These areas are to include both coastal and pelagic areas of the Baltic and the Skagerrak and Kattegat area and will be established by 2010 and evaluated by 2015 (Sköld et al. 2008). The Swedish Board of Fisheries (Sköld et al. 2008) has presented the pelagic areas that are proposed to be completely free of fishing.

The following fishing-free pelagic areas have been proposed:
- the south-eastern Kattegat for protection of cod;
- the southern Baltic for protection of maturing cod;
- the Gulf of Bothnia for protection of herring in coastal spawning grounds.

The following fishing-free coastal areas have been proposed:
- the Havsten Fjord in Bohuslän for protection of turbot, cod and plaice;
- the Brunskär-Tanneskär region west of Göteborg for protection of lobster and demersal fish;
- the Stockholm archipelago for protection of perch, pike and pikeperch.

With the exception of the southeastern Kattegat, the delimitations of these areas are unclear, identifying only stocks targeted for protection rather than geographical areas.

**New rules for cod fishing in the Skagerrak and Kattegat region**
From 1 October 2008, fishermen with fishing permits (“effort permits”) in the Skagerrak and Kattegat region are no longer allowed to transfer the permits. The decision means that those who already have effort permits may still change vessels, provided that they do not increase their fishing capacity. Every member state will have a pool of kilowatt days to distribute, as opposed to the case today when every vessel regardless of size is given a certain number of days. The use of kilowatt days is a more precise way of regulating fishing effort.
The purpose of the new rules is to reduce overcapacity in the fishing fleet and make fishing more sustainable. A consequence of the system is expected to be that the Swedish Board of Fisheries should be able to steer fishing towards fishing with less discard, better selectivity and more environmentally-friendly fishing methods. A similar decision has already been taken for the Baltic (www.fiskeriverket.se).

**Fact box – types of fishing gear**

**Net/twine**
Gill nets are equipped with floats along the top and weights along the bottom edge so that they always stand vertically in the water. Gill nets can be placed at different levels in the water or at the bottom. Depending on which species of fish are to be caught, different types of gill nets are used with different mesh sizes and different thicknesses of the twine. The species that are caught with gill nets include mackerel, cod and different kinds of flatfish.

**Trawling**
There are two main types of trawls; midwater trawls and bottom trawls. Midwater trawls are towed through the water column (the pelagic zone) by one or two boats and are used to catch species such as herring, sprat and mackerel. Bottom trawls are towed along the seabed and are used to fish for bottom-dwelling species (demersal species) such as cod, haddock and flatfish, as well as Norway lobster and shrimp.

The BACOMA trawl is a special type of bottom trawl used for Baltic cod. This trawl is equipped with diamond-shaped mesh in the cod-end, which allows small fish to escape if they happen to have come into the trawl.

When fishing for Norway lobster and shrimp on the west coast, a bottom trawl equipped with sorting devices is sometimes used that prevents larger fish from getting into the trawl, also known as a sorting grid. These trawls catch to a greater extent only the intended species, and there are significantly fewer by-catches than in the case of trawls without sorting grids.

**Danish seining**
Danish seining is similar to trawling, but the net is not dragged behind a boat, instead the fishing vessel proceeds from an anchored buoy. A few thousand metres of strong drag lines are placed in the water followed by the seine itself and then the same length of drag lines once again. The drag line and seine sink down into the water and are then hauled up from the boat. This method is mainly used to catch demersal fish such as cod, haddock and flatfish.

**Purse seine**
A purse seine is a long net with floats at the top and weights at the bottom. The seine is laid out in a circle around a school of fish (usually herring, sprat and mackerel) and is then drawn together into a “purse” using wires that run along the bottom of the net. A purse seine is a very effective form of fishing gear that can catch large schools of over 1,000 tonnes in a single cast. Purse
seines are used primarily on the west coast of Sweden and are common in what is called “light fishing” (that is the fish are lured to the boat with the help of lamps that illuminate the water) for herring or sprat.

**Fishing gear using hooks**

Longline fishing is a method consisting of a long line, onto which leaders (diagonally placed, approx. 2m lines) are fixed at regular intervals. Attached to these are hooks usually with some sort of bait on them. Longlines are used for fishing both pelagic fish (e.g. salmon) and demersal fish (e.g. cod and flatfish). Gear using hooks can also be dragged behind a boat at different levels in the water and is used for mackerel or for fish belonging to the salmon family.

**Fixed gear**

The various forms of fixed gear include traps and gill nets which are anchored or fixed in the seabed with piles. The gear consists of long “tentacles” that stretch out from land and lead the fish into a trap/capture receptacle. “Push-up” traps are used mainly in salmon fishing and consist of tentacles and a capture receptacle with double walls in order to protect from attack by seals. Below the capture receptacle there are pontoons that are inflated when the trap is to be emptied, so that the whole trap will float up to the surface.

**Pots/traps**

Pots are cages that are baited and are used chiefly for fishing lobster, crab, Norway lobster and freshwater crayfish. Catch specificity is regulated by the size of the entry hole and exit openings. For example, a lobster trap must have two circular exit openings with a diameter of at least 54 mm, while a crab trap should have at least one circular exit opening with a diameter of 75 mm. Traps and pots can also be used for catching fish, for example perch and eel.

**Hoop nets**

Hoop nets are used mainly when fishing for eel and consist of a conical net that is kept taut with bows. An arm leads the fish into a funnel-shaped opening, which is followed by more funnels that lead into the capture receptacle. The funnels make it more difficult for the eels to escape from the trap.

**By-catches in the Swedish fisheries industry**

By-catches of species other than the target species represent a major problem in commercial fishing throughout the world. The by-catches that constitute the greatest threat to biological diversity and ecosystems are those of species that become sexually mature at a high age and which have a low reproduction rate. These include sharks and rays, marine mammals such as porpoises and certain species of birds (Swedish Board of Fisheries 2007a). In addition, by-catches of juveniles of a species such as cod can be particularly sensitive in areas where the stocks are already severely overfished, for example off the west coast of Sweden. This may occur in the case of mixed fishing in which
the mesh sizes (for example in a trawl) are small in relation to the species in the by-catch. According to the Swedish Board of Fisheries (2007a), the knowledge of the possible effects of by-catches on the ecosystems is today inadequate. There is also a lack of information on the size of by-catches, particularly for certain parts of the fisheries industry.

**Management system crucial for discard problems**

The management of fisheries is of great significance when it comes to the problems connected with by-catches (Crean and Symes 1994). In cases where the control of catches is strict for example systems with total allowable catches (TACs), there are often high levels of by-catches (Graham *et al.* 2007). In mixed fishing with a number of target species, other species are fished once the quotas for the target species have been exhausted. The species with exhausted quotas must not be landed, and thus be thrown overboard. The regulations have the same effect in cases where only a certain percentage of the catch may consist of a specific species. The fishermen are often deeply dissatisfied when they are forced to throw dead fish into the sea, and this also undermines their confidence in the fishing management systems (Graham *et al.* 2007).

**By-catches – definitions and problem areas**

By-catches in their broadest sense can be defined as all catches of species other than the species that is/are being actively fished (Swedish Board of Fisheries 2007a). A distinction is often made between three different types of by-catches:

− unintentional catches of fish and other organisms (for example seabirds and marine mammals) with no commercial value;
− catches of commercial species that are too small to be landed or for which quotas have already been exhausted;
− catches of species other than the target species but that are commercially viable and landed.

Problems with by-catches differ greatly between different types of fisheries, depending on which gear is used and how selective they are in terms of separating unintended species from target species. The largest by-catches in quantitative terms occur in fisheries for small species such as shrimp and Norway lobster, where fine-meshed bottom trawls are used. By-catches of birds and marine mammals occur mainly in fisheries using twine (Swedish Board of Fisheries 2007a). Most of the knowledge about by-catches in Swedish pelagic fishing comes from the observation programme of the Swedish Board of Fisheries, which began in 1995/96 and annually monitors less than 1% of the total fishing effort (Swedish Board of Fisheries 2007a). In the case of certain rare species there is a voluntary reporting system, in which fishermen may report catches directly to the Swedish Board of Fisheries. The Swedish Board of Fisheries has also carried out telephone interviews in order to estimate the amount of seals and porpoises in by-catches in the Baltic and the North Sea (see e.g. Lunneryd *et al.* 2004).
**Trawling for crayfish and shrimp results in by-catches**

In trawling for Norway lobster in the Skagerrak, where the trawlers were not equipped with a sorting grid, by-catches of other fish (cod, plaice, American plaice, sand dab and haddock) and crayfish (below the minimum size stipulated for crayfish) amounted to 1,300 tonnes for the sampled catches in 2006 (Swedish Board of Fisheries 2007a). The landed catch of Norway lobster was 620 tonnes – less than half of the catch that was discarded. There were similar results for the Kattegat where the catch of Norway lobster was also 620 tonnes and the discarded catch 1,500 tonnes. In crayfish fishing with trawls equipped with a sorting grid, the catch amounted to 310 tonnes and the by-catch 500 tonnes. However, this by-catch consisted almost exclusively of crayfish below the minimum stipulated size.

There are also large by-catches in the case shrimp fisheries. It is mainly shrimp of the “wrong” size that are discarded, as a result of exhaustion of quotas of larger or smaller shrimp. The shrimp trawlers have low size selectivity which also entails large catches of small shrimp. Trawling for shrimp takes place in deep water, which results in by-catches of demersal species such as rabbit fish, lantern shark, piked dogfish and roundnose grenadier. A list of common species in by-catches in shrimp fisheries showed that 51 different species were discarded in 2004 and 2005 (Swedish Board of Fisheries 2007a).

**Other types of fishing resulting in by-catches**

North Sea cod is caught mainly by means of trawling (bottom trawling or midwater trawling), twine or hooks. Most of the by-catches of fish when trawling for cod are flounder and cod under the stipulated minimum size. By-catches of cod vary greatly from year to year and depend to a great extent on the stocks for that particular year. Years when there is a great deal of cod just under the minimum stipulated size (38 cm) usually produce large by-catches of these (Swedish Board of Fisheries 2007a).

Other fisheries that results in large by-catches of cod is light fishing for herring and sprat in fjords or areas close to the west coast of Sweden, and in some cases the use of hoop nets to catch eel (Swedish Board of Fisheries, 2002). Light fishing for herring carried on in wintertime close to the coast in parts of the Kattegat and Skagerrak has been identified as one of the possible causes of the depletion of stocks of coastal cod in these areas. The gear – the purse seine – that is used in this fishery has low species and size selectivity and can catch more than 1,000 tonnes of fish in a single throw. The Swedish Board of Fisheries has proposed that this type of light fishing should be banned during the first quarter of the year, which is when the cod spawns in these areas. There is already a similar ban at least in parts of the coastal areas of the Kattegat and Skagerrak (Bergström et al. 2007).

The Swedish Board of Fisheries has also stated that the species selectivity in trapping of eels must be improved (Swedish Board of Fisheries 2002), so that by-catches of cod can be avoided in this type of fishing.
By-catches of seals, porpoises and birds

In 2002, the Swedish Board of Fisheries carried out telephone interviews with 220 randomly selected professional fishermen. Based on the fishing effort of the professional fishermen interviewed, in relation to the fishing effort in the whole country, it was calculated that 462 grey seals, 52 ringed seals and 416 harbour seals drowned as a result of Swedish fishing in 2001 (Lunneryd et al. 2004). In the west coast waters 114 porpoises drowned in fishing gear, whereas there were no reports of by-catches of porpoises in the Baltic. The Swedish Board of Fisheries considers that these by-catches do not constitute a threat to seal populations, since all species have shown a positive stock development in recent years (Lunneryd et al. 2004). However, by-catches of marine mammals are troublesome for fishermen and in many cases ethically unacceptable (Swedish Board of Fisheries 2007a). By-catches of porpoises in the Baltic have been a major problem before, mainly as a result of fishing with drift-nets. According to statistics from the Swedish Board of Fisheries, 5 porpoises drowned as a result of fishing in the Baltic every year between 1989 and 1993 (Swedish Board of Fisheries 2007a). There are few official reports of by-catches of porpoises after this, which is presumably due to the fact that the number of porpoises is very small. Estimates indicate that there are between about one and a few hundred individuals left in the southern Baltic (Swedish Board of Fisheries 2007a).

By-catches of birds occur primarily in different kinds of twine and nets (Lunneryd et al. 2004). In the study carried out by the Swedish Board of Fisheries the most common species of bird to be caught in by-catches was the great cormorant. Other common species include the common eider, common guillemot, and long-tailed duck (Lunneryd et al. 2004). Based on the total fishing effort, the total number of birds caught in by-catches was estimated at approx. 18,000 individuals for 2001. By-catches of seabirds are a major problem all over the world and are considered to be one of the greatest threats to some species of seabirds (Tasker et al. 2000).

What are the policies of the EU and Sweden regarding by-catches?

The main goal of the EU’s Common Fisheries Policy (CFP) is to achieve sustainable development as regards fishing from an environmental, economic and social perspective. The CFP includes an action plan for limiting the environmental effects of fishing, protection measures for non-target species and a strategy to reduce by-catches and eliminate discards, which should gradually lead to a ban on discards. The CFP also contains a strategy for eliminating destructive fishing methods and encouraging development and use of selective fishing gear.

There are a number of EU projects working with the development of more selective fishing gear. One example is the BACOMA project (Baltic Cod Management), used for all trawling of cod in the Baltic, which has been developed within projects financed by the EU. Trawlers with sorting grids are used partly for fishing Norway lobster on the west coast of Sweden. All trawls used for crayfishing inside the trawling limit, for example, must be equipped with sorting grids.
The Marine Environmental Commission (Swedish Government Official Reports 2008:48) proposes that the Swedish Board of Fisheries should be given a clearer mandate to assume responsibility for the development of selective fishing gear and less destructive fishing methods. The Swedish Board of Fisheries is already working with the production of selective fishing gear – for example bottom trawlers equipped with sorting grids (see, e.g., Valentinsson and Ulmestrand 2008). However, the Swedish Board of Fisheries has pointed out that unless quotas and fishing efforts are in balance with fish stocks, selective fishing gear can generally only have a marginal effect. This is the case mainly in fisheries where several species are fished – known as mixed fishing (Swedish Board of Fisheries 2007a).

In order to address the problems of by-catches, it is of vital importance that a thorough analysis is made of which types of gear are used in which areas and which problems are encountered in each specific area. In many cases, it should be possible to create incentives to change over from using one particular type of gear to another, if the former type entails large by-catches and/or other types of environmental problems. This could for example be applied to the fishing of Norway lobster off the west coast of Sweden, where lobster caught in pots are both bigger and of better quality than trawled lobster and therefore fetch a higher price. Trawling of lobster entails large by-catches of cod and other demersal fish and causes great damage to the seabed (Leif Pihl, personal communication). It is also important, when quotas are determined for individual species, to take into account whether these species are common in by-catches in other types of fishing.

1.3 Other human activity that causes high fish mortality – examples from hydroelectric and nuclear power plants

Hydropower has been used to produce electric current in Sweden since the end of the 19th century. Today, hydropower produces approx. 65 TWh per year, which corresponds to approx. half of the country’s electricity production (Swedish Energy Agency www.energimyndigheten.se). Of these 65 TWh, 70% come from the four largest rivers: the Lule, the Ume, the Indal and the Ängerman river. Although there are about 1,200 hydroelectric power plants in Sweden altogether, most of these are relatively small. The Kalix and Torne Rivers are the only major Swedish rivers that are completely untouched and protected from exploitation, while there are similarly protected stretches in the Pite and Vindel Rivers and around ten smaller rivers.

Hydroelectric power is a renewable energy source with low environmental impact, but there are far-reaching consequences for the landscape and on various organisms. Apart from the fact that large areas of the original channel of the river are alternatively flooded and drained, the power plants and turbines constitute a great threat to species of fish that live in the rivers and above all for those species that use the rivers as migration paths. Migrating fish change their habitat completely when it is time to spawn and travel great
distances to reach their specific spawning grounds. Fish belonging to the salmon family such as salmon (*Salmo salar*) and sea trout (*Salmo trutta trutta*), are known as *anadromous* species that live their adult life in saltwater or brackish water (in the case of the Baltic) and spawn in freshwater streams. The eel (*Anguilla anguilla*), on the other hand, is one of the *catadromous* species that live in freshwater (lakes and smaller streams) but travels some 7,500 kilometres to the saltwater of the Sargasso Sea in the northwestern Atlantic to spawn. However, it appears that some eels live for at least part of their lives along the coasts of both the Baltic and the North Sea, since the yellow eel (adult but not yet sexually mature) can be caught along our coasts during much the year (Tzeng *et al.* 2000).

Measures intended to help the migrations of salmon species

On their way to and from their spawning and nursery grounds in rivers and streams, migrating fish are confronted with many obstacles that are both naturally occurring and created by man. In order to enable the fish to pass obstacles such as power plants, devices like fish passages and salmon steps etc. have been constructed. In spite of these efforts, it is uncertain how effective such passages are (Aarestrup *et al.* 2003). A major problem appears to be that they are only kept open at times when the greatest migrations of sexually mature fish are expected. One study of the migrations of trout between the sea and rivers indicated that trout also migrated to a great extent during periods not directly connected to the spawning period (Carlsson *et al.* 2004). The trout also tended to move more between different parts of the river than had previously been known. Migration paths for fish that are only kept open during the spawning period can thus disturb the natural migration pattern of the fish and result in fewer individuals reaching their spawning grounds. In the Ume River in northern Sweden, researchers marked and counted salmon migrating upstream at the Stornorrfors power plant between 1995 and 2005. Apart from the regulated tributary that carries the water through the turbines of the power plant, there is a “by-pass channel” for overflowing water that the fish can use. The result of the study indicates that on average only 30% of the sexually mature fish manage to find their way to the by-pass channel and from there continue to their spawning ground in the unregulated Vindel River (Lundqvist *et al.* 2008). Low water flow in the by-pass channel and/or high flow in the outflow from the turbines confuses the fish, and instead of finding their way up into the by-pass channel, many individuals swim towards the power plant turbines. A higher flow through the by-pass channel, however, made it easier for the fish to find the right way. It is thus not sufficient only to have one possible way for the fish to pass a power plant – a sufficient level of water flow is also necessary to safeguard the fish’s migration upstream. In the Ume River example the researchers showed that the potential population increase for salmon would be as much as 500% in a ten-year period, provided the proportion of salmon migrating upstream amounted to 75% instead of 30% (Lundqvist *et al.* 2008). This would be of major significance for the wild salmon population that spawns in the Vindel River.
A major part of the work connected to increasing salmon and trout stocks in Sweden involves improving the by-pass channels and salmon steps that already exist in exploited Swedish rivers (see, e.g., Elforsk 2006). Knowledge of the fish behaviour in these by-pass channels is a prerequisite for building systems that the fish can use. Technical solutions for fish passages are also an important building block for helping fish migrate up- and downstream.

Fish stocking

Wild salmon in Sweden has been severely affected by human influence on watercourses by building of dams, water power plants, pollution and other changes in habitat. This has caused the gradual disappearance of wild salmon populations from smaller watercourses since the 18th century, while major watercourses have lost their populations mainly in the 20th century. At the end of the 1990s there were less than 40 watercourses in Sweden where annual, natural reproduction of salmon occurred (www.art databanken.se).

Power plants restrict the upstream migration of salmonid species to their spawning grounds, and in addition around 15-20% of all smolt (young salmon) are killed in the turbines, when they migrate downstream (Elforsk, 2006). To restock fish that are lost, the power companies are, according to rulings from the water rights court, liable to raise fish and release them into rivers that are regulated. The number of young salmon and trout stocked by the company Vattenfall (a major Swedish power company) amounts to more than 1.8 million individuals annually. These are stocked downstream of the power plants in the Lule, Ångerman, Indal, Dal and Göta Rivers and into Lake Vänern. In total, the stocking of salmon in the Baltic region amounts to over 5 million young salmon annually, which can be compared with the 1.6 to 1.7 million young salmon that are produced in the wild (www.fiskeriverket.se).

The stocking of fish is partly problematic

Stocking of salmon can have negative effects on the genetic composition of the fish population and also on the behaviour of the fish. Fish species such as salmon and trout have a population structure with a large number of small subpopulations that are specifically adapted to their locality. When stocking fish, relatively few parent fish are used to produce a large amount of fry. Subpopulations in a watercourse are thereby brought together to form a cultivated population. When locally adapted subpopulations are mixed together, the characteristics of each particular subpopulation will disappear, resulting in a population that is not adapted to any specific area. Another problem is that the limited number of parent fish can result in a decline in genetic variation in the stocked population.

In the Baltic Sea as a whole, about 70% of the salmon are of stocked origin, but this proportion varies greatly between different rivers (McKinnell et al. 1994; Elforsk 2006). Today it appears that the mortality of stocked salmon is increasing, but the cause has as yet not been ascertained. The proportion of stocked salmon has varied greatly in the Baltic in the last 15 years. From having amounted to 10-30% of catches in the 1980s, adult fish originating from wild populations now constitute at least two thirds of
catches. The reduced fishing pressure in the Baltic has probably caused a relatively large increase in the production of natural smolt in unregulated water courses. However, it cannot be ruled out that this is an effect by a significantly lower survival of stocked smolt compared to wild smolt. According to the results of marking, catches resulting from the stocking of smolt have decreased in the fisheries of all the countries around the Baltic in the last few years (A. Alanärä, personal communication).

In the case of trout in the River Dalälven there are clear differences in behaviour between stocked fish that have lived their first year in captivity and wild fish (Järvi and Petersson 2004). Since stocked fish are bred in an environment with greater access to food, less space and without predatory fish, they are less skilled in searching for food and avoiding predatory fish when they are released into the river. On the other hand, there were no differences in behaviour between wild and stocked trout that was released into the river as roe.

**Eel – an endangered species with migration problems**

The eel is one of Sweden’s most endangered species. The proportion of juvenile eels reaching Swedish coasts is today just 1% of the levels in the 1970s, and there is a significant risk of extinction. Conceivable explanations for the decline of the eel are changes in sea currents in the northeastern Atlantic, excessively high fishing pressure, obstacles in watercourses hampering migration of eel both upstream and downstream, loss of areas suitable as nursery grounds, diseases and parasites and high levels of lipophilic contaminants (Art databanken [Swedish Species Information Centre] 2005). The relative importance of the various factors are however still unclear. Since the turn of the century, eel catches have been at a rather low level in Sweden (540-670 tonnes annually), if compared with catches in previous years of around 2,000 tonnes (Swedish Board of Fisheries 2006). Eel fishing has been prohibited in Sweden since 1 May 2007, but fishermen fishing for eel can be granted exemption for continued eel fishing if it is judged to be a significant part of their fishing income (www.fiskeriverket.se). In addition to this, fishing for eel is allowed in inland waters upstream of three hydroelectric power plants where mortality in any case is considered to be high (www.fiskeriverket.se).

Eels have a migratory pattern opposite to that of salmon and trout and they migrate upstream as juveniles and downstream towards the sea as adults. This leads to that eels have exceptionally severe problems passing power plants – because the by-pass channels and fish ladders are constructed mainly to help fish to find their way upstream. The length of the eels is also a problem, and it has been shown that the longer an eel is when it first migrates, the greater the risk that it may die (Winter et al. 2006; ICES 2007). The number of eels that die in the turbines of power plants varies greatly from year to year, depending on how each particular power plant is constructed and whether the eels have the possibility to find alternative paths. In many European studies, the mortality of eel migrating downstream at power plants is between 20% and 40% (ICES 2007). Since many watercourses have several power plants,
total mortality level may be as high as between 70% and 100% (ICES 2007). In Sweden, the annual migration upstream of juvenile eels is estimated to be between 5 and 25 million individuals (Håkan Wickström, personal communication). The number of eels killed in power plants while migrating downstream, is estimated to be between 100-200 tonnes per year (Håkan Wickström, personal communication).

Inflow of cooling water to nuclear power stations causes great loss of fish

Nuclear power plants need large amounts of water to cool their condensers. In, for instance, the Forsmark nuclear power plant approximately 135 m$^3$ per second is pumped through the power plant when running at full capacity (Sandström et al. 2002). The coastal laboratory of the Swedish Board of Fisheries performs annual studies at the nuclear power plants of Forsmark, Oskarshamn (Simpevarp) and Ringhals. The second reactor at Barsebäck was closed in 2005 and will not be considered in this overview. Studies were carried out with regard to fish communities in areas subjected to cooling water discharges and in reference areas and the losses of fish in cooling water intake screens were estimated. Quantitative measurements of fish losses in intake screens are usually made during a two-week period in the spring and in the autumn. It is during these periods that the loss of fish is the greatest, but the studies underestimate the total annual number of fish that die in cooling water intake screens.

In Forsmark, the loss of fish in intake screens amounted to more than 10 million individuals annually between 2004 and 2006 (Adill et al. 2006). These figures also agree with previous studies (Sandström et al. 2002). The main species of fish killed in the cooling water intake screens are three-spined stickleback, nine-spined stickleback and herring. Other species with a high level of mortality are perch, ruffe, pipefish, bleak and smelt. In the autumn it is mainly juveniles that get caught in the intake screens and in the spring one-year-old fish (Sandström et al. 2002). The number of eels that are killed in intake screens is generally higher during the autumn than in the spring. During the period 2004-06, losses of eel were between 179 and 383 individuals in the spring and between 672 and 1,019 individuals in the autumn (Adill et al. 2006). The average weight of eel in the intake screens is generally higher than for most other species, which means that the losses of eel are not insignificant (Sandström et al. 2002). It is overall difficult to estimate the significance of losses in intake screens for individual species. However, these losses can have a major significance for recruitment of certain species, especially those that are already exposed to targeted fishing such as perch and pike-perch (Sandström et al. 2002). It cannot be excluded that other species may also be affected, especially in the cases for stationary fish species (that is they stay in a limited geographic area).

At the Ringhals nuclear power plant on the west coast of Sweden, studies of the effluent outlet and the intake screens have been performed annually since 1979 (Fagerholm and Andersson 2005). The amount of cod roe and juvenile cod killed in the cooling water intake screens varies greatly from year to year - depending on the cod stock size in the particular year and how
many eggs and larvae drift with the currents into the power plant (Andersson et al. 1999; Fagerholm and Andersson 2005). Previously the loss of cod roe and juvenile cod in the power station was thought to be negligible, as the natural mortality of roe and juveniles is anyway high (Fagerholm and Andersson 2005). In recent years, however, cod populations in the North Sea have been subject to such high fishing pressure that they are now outside safe biological limits. In the light of this, losses in the power plant cannot be considered negligible for the recruitment of cod. These losses are however very small compared to the effect of fishing (Fagerholm and Andersson 2005). For coastal species such as shorthorn sculpin and rock gunnel, annual losses due to mortality in intake screens is considered to have some importance for local recruitment (Andersson et al. 1999).

### 1.4 Aquaculture

*Aquaculture in Sweden*

Fish farms are currently found in some 100 municipalities in Sweden. In addition to food fish Swedish farms also produce crayfish, mussels, oysters and fish and crayfish for stocking. Production levels have been relatively constant over the past 15 years in terms of the total amount of fish that is produced. There has, however, been a change in the species farmed. In 2005, 88% of farmed fish consisted of rainbow trout. Production levels for arctic char have increased, while levels for salmon have remained low. The total value of Sweden’s food fish production is estimated at SEK 156 million, and the value of fish for stocking is estimated at SEK 83 million (National Strategic Plan for the Fisheries Industry in Sweden 2007-2013, The Government Offices). This may be compared to Finland where the value of aquaculture production in 2007 totalled SEK 402 million (The Finnish Game and Fisheries Research Institute, www.rktl.fi).

An important prerequisite in the development of aquaculture is that it takes place alongside sustainable management of the natural aquatic systems. A commission of inquiry is currently analysing the conditions for and identifying the obstacles to the development of economically and ecologically sustainable Swedish aquaculture (Directive 2007:170). The findings of the inquiry will be presented on 28 February 2009 (2008:84). Since 1 January 2008, fish farms have been environmentally classified according to feed consumption rather than fish production. The purpose is to enable better control of the environmental impact of aquaculture.

*Smaller discharges from fish farms today*

In general, fish farms are responsible for smaller discharges from feed and faeces into the surroundings today, compared to the situation 20-30 years ago. A lower feed conversion ratio (FCR) means that feed discharges have decreased. In the mid-1970s, emissions of phosphorus and nitrogen amounted to 30 and 130 kg per ton of fish produced, while current levels are 5.5 and 55 kg per ton of cultivated fish (Swedish Board of Fisheries 2005). The effects of
emissions on the immediate environment are closely linked to the dynamics of the water and sediment in the area (Gyllenhammar and Håkansson 2005). Good water circulation reduces unwanted concentrations of phosphorus and nitrogen. The impact of fish farms on the surroundings should be estimated in relation to surface and distance from the fish farm. Roughly speaking, a fish farm’s footprint is equivalent to the size of a football field (50-100 m), if annual fish production is approximately 50 tons (Gyllenhammar and Håkansson 2005).

In cooperation with the Royal Institute of Technology and the Swedish University of Agricultural Sciences, a pilot study involving perch stocking in closed systems is currently being conducted in the Östergötland archipelago. Closed systems allow greatly enhanced purification of emissions, and therefore a heavily reduced impact on the environment. The commercial use of closed systems started in northern Europe, primarily in the Netherlands, Denmark and Germany in the early 1980s. Instead of releasing the used water it is recirculated after purification (mechanical and biological filtering and oxygen supply). Until now, cultivation in closed systems has not had a major economic impact, but with greater demands on efficient water use, combined with tougher environmental legislation, this technology may have a more important role in the future (Aquamedia, www.feap.info).

Better use of feed, fewer outbreaks of contagious diseases and fewer unsuitable species of fish in Swedish waters are other factors to be taken into account in aquaculture development. Another positive development is that the use of antibiotics has fallen by 90% since the mid-1990s (Swedish Board of Fisheries 2005).

**Shortage of fish-based feed – research on alternative feed sources**

Fish-based feed is widely used in salmon farming. To address the issue of decreasing stocks of feed fish in our seas, research is being conducted with the aim of finding alternatives to fish-based feed. Today’s feed consists of approximately 30% vegetable protein. There have also been attempts to substitute marine fats with vegetable oils. Use of vegetable oils however, changes the composition of fatty acids in the fish, and it is unclear what impact this has on fish health and in what way it affects the quality of fish for consumers (Pickova et al. 2007).

**Areas that are especially suitable for fish farms**

When estimating the environmental impact of fish farms it is important to consider all sources of nutrients to a waterbody – both natural and from fish farms (Gyllenhammar and Håkansson 2005). Nutrient-poor or nutritionally disturbed environments, such as hydro power reservoirs in regulated waterways are example of areas where it may be suitable to allow a certain increased exploitation of the water bodies in the form of fish farms (Swedish Board of Fisheries 2005). Criteria for areas of special importance for aquaculture have been drawn up and some examples are: the northern part of lake Vänern, hydro power reservoirs in regulated rivers in Norrland and the
maritime area at Höga kusten in Västernorrland (Swedish Board of Fisheries 2005).

Wild fish stocks throughout the world are overexploited, and alternatives are needed to provide humans with fish for consumption. Aquaculture is a rapidly growing industry which provides an important solution to an increasing need for fish products in the future (www.fao.org). At the regional level, fish farms can have a positive impact on the economy and can generate new jobs. In addition to positive effects on the economy, locally produced fish can also reduce the need to transport fish produced in other countries (Gyllenhammar and Håkansson 2005).

Åland is an example of where aquaculture has had a positive impact on the economy and has generated new jobs. In Åland the fish farms sector dominates the fisheries economy both as regards the first-hand value of production and in terms of direct and indirect employment. The business has an important role in the production of basic food products in the province, both for local consumption and for exports. Locally, the industry is of major industrial and social importance, since it offers employment opportunities and revenues in sparsely-populated and archipelago areas where alternative sources of income are limited. This, in turn, contributes to the objective of sustaining a flourishing archipelago, with a stable and permanent population and general local services (Åland’s Regional Government 2006).

**Mussels as “purification systems”**

Mussels eat by filtering large quantities of water. This means that they absorb considerable amounts of phytoplankton, and can thus serve as “purification systems” in areas with high levels of nutrients. A positive effect of mussel farming is thus that nitrogen is returned from water to land. A negative effect is that organic matter, for example, in the form of faeces, accumulates on the bottom. In areas with high concentrations of mussels, the accumulation of organic matter can lead to high oxygen consumption when the organic matter decomposes, leading in turn to a depletion of oxygen levels (Newell 2004; Lindahl et al. 2005). This can consequently result in a decline in biological diversity. If, however, there is a thin oxygenated sediment layer on top of the anoxic sediment, the sediment can help to transport nitrogen out of the system in the form of nitrogen gas – so-called denitrification (Newell 2004). In cases where there is still a negative effect on the bottom fauna, it should be seen in relation to the positive effects that mussel farming can have on coastal areas (Lindahl et al. 2005). As a complement to other measures to reduce nitrogen, mussel farming can be economically profitable on the west coast of Sweden, at least under certain conditions (Hart, 2003). It is estimated that net transports of nitrogen can be reduced by 20% where Gullmarnsöfjorden has its outflow with 25 farming stations and each station has 200 tonnes of mussels (Lindahl et al. 2005). An estimate shows that a harvest of one ton of blue mussels can remove 6.4 – 10.2 kg of nitrogen and 0.4 – 0.6 kg of phosphorus (Kjerulf Petersen and Loo 2004).

Mussel farms give society an ecosystem service by returning nitrogen from the marine environment to land. A system involving trading in emissions
rights for nutrients could be introduced in the same way as the current system of emissions rights for carbon dioxide. This means in practice that an industry, for example, could purchase the right to emit a certain amount of nutrients, in exchange for taking the same amount of nutrients from the sea, e.g. in the form of mussels (Lindahl et al. 2005).

Environmental and economic benefits

In addition to having a positive effect as a “purification system”, sea mussels are a nutritious food for humans and can be used in animal feed or as a fertilizer in agriculture (Lindahl et al. 2005). Preliminary studies also show that mussels can be suitable as feed for laying hens (Lindahl et al. 2005). It is estimated that two-thirds of all mussels are harvested for consumption, while other smaller and damaged mussels can be used in agriculture, a practice known as the agro-aqua recycling (Lindahl et al. 2005). Mussel farms can also generate employment opportunities and have a positive effect on the local economy.

Similarly, oyster farms can have a purifying effect on the environment and can generate economic gains. In August 2008, a large-scale oyster farm was opened in Sydkoster in the county of Västra Götaland. It is planned that the farm will, within five years, have an annual production of some 300 tonnes of oysters (www.ostrea.se).

Mussels as food

Mussel farms have existed in Sweden since the 1970s, and by the mid-1980s, production levels reached a peak of some 2,500 tonnes/year (Swedish Board of Fisheries 2004). In the 1980s there was a fall in production as a result of toxic algal blooms. The risks associated with consuming mussels are primarily connected with the presence of toxic algae, as well as pathogenic bacteria and viruses in the areas of cultivation (Rehnstam-Holm and Hernroth 2005). To ensure the quality of mussels as food, methods have been developed to test mussel toxicity and the presence of algal toxins in the water. In marine areas along the west coast where mussels are farmed and wild mussels are fished commercially mussels are tested weekly for toxins, and the presence of toxic algae in the water is monitored. If levels exceeding guidelines for maximum levels of bacteria, or if toxins are found in the mussels, the area is closed for harvesting and does not reopen until levels have fallen below maximum recommended levels (The National Food Administration 2006).
1.5 Indirect effects of fishing

Fact box

Trophic level

The trophic level (from the Greek trophos = food) denotes a species’ level in the food chain. Primary producers such as plants and phytoplankton are at the first (lowest) trophic level, herbivores at the second trophic level and predators at the third trophic level (Fig. 1.5.1).

Functional groups

A functional group consists of several species that perform the same “task” or have the same structural effect on a particular environment. For example, animals that feed by filtering water belong to the “filterers” group. This functional group includes mussels, tunicates and certain polychaetes. Another important functional group is decomposers that help to transform dead matter into accessible nutrients. A functional group can also consist of plants or animals that create a certain habitat for other plants or animals, such as perennial macroalgae like the bladder wrack.

Trophic cascades/cascade effect

A trophic cascade or cascade effect can be defined as a form of control of the food chain, which is regulated by the dynamics of for example a predator (e.g. seal or predatory fish). A cascade effect can also be defined as a series of events, each of which is prerequisite for the next event. These can have consequences that are very difficult to predict or prevent.

Fishing affects not only the specific species that is caught (the “target species”), but also other parts of the ecosystem. Such indirect effects, or ecosystem effects, affect the rest of the fish community as well as lower trophic levels including benthic crustaceans and zooplankton. Examples of indirect effects of fishing are changes in the interaction between predatory fish and their prey. These changes can persist even when fishing pressure on the predatory fish has ceased. Other effects are long-term genetic changes, for example, in the age of sexual maturity (as discussed in Ch. 1.2), effects on non-target species such as birds, marine mammals, sharks and rays, as well as disturbed habitats for demersal fish and animals as a result of, for instance, trawling.
The changes in an ecosystem as a result of intensive fishing depend largely on how many species there are in the specific area, how the species are distributed in terms of predatory fish and preyfish, and what the preyfish eat. In general, one can say that an ecosystem with many species of predatory fish, preyfish and smaller animals (benthic animals and zooplankton) is more resistant to change, as there are more species in each functional group. An example of such an ecosystem in Sweden is the Skagerrak/Kattegat/North Sea region. If a species of predatory fish decreases in number, another can take over its position so that the “function” of predatory fish is retained. There are, however, many interactions between the various species and it can be difficult to predict the long-term consequences of a particular type of fishing. Ecosystems with few species (e.g. the Baltic Sea) are in general more sensitive to change, as there are only a few species within each functional group.

*Changed interaction between predatory fish and their prey*

When large species of fish that feed on other fish (e.g. cod and pike) are fished selectively, predation on their prey (e.g. perch and sprat) declines. As a result, the natural mortality of the preyfish declines and they can increase in number. In areas with heavy fishing pressure, the composition of the fish community may change from containing several large, predatory species to one dominated by small, plankton-eating species. Such a change has been observed in large parts of the North Sea over the past 30 years. The number of...
small varieties of fish has increased significantly, both as regards pelagic and bottom-dwelling species (demersal) (Daan et al. 2005). In the Baltic Sea too, abundances of plankton-eating fish (primarily sprat) have increased considerably since the late 1980s, at least in part due to heavily-decimated cod stocks (MacKenzie et al. 2002; Österblom et al. 2007).

Changes further down in the food chain
The decline in demersal fish stocks along the west coast of Sweden has led to an increase in numbers of demersal crustaceans and prawn. Fishing for these species has thus increased steadily since the 1970s (www.ices.dk). In an international perspective, there have been considerable changes in fishing patterns over the past 50 years. From having been dominated by large, fish-eating fish, landings in recent years are largely dominated by plankton-eating fish and crustaceans such as prawns and crayfish (Pauly et al. 1998). The concept “fishing down the food web” was coined by the same Pauly, and describes the phenomenon of fishing taking place at increasingly lower trophic levels as a result of overfishing of larger, fish-eating species. Other researchers, on the other hand, claim that the phenomenon is exaggerated and that predatory fish, and fish and crustaceans at lower trophic levels are all fished today (Essington et al. 2006).

When the predatory pressure on species such as herring and sprat decreases and these populations increase in size, this can in turn have an impact on their food source – the zooplankton. More zooplankton-eating fish means fewer zooplankton and fewer zooplankton means a greater number of phytoplankton. In the Baltic Sea both the abundance of zooplankton and their species composition have changed (Möllmann et al. 2000), presumably because of the increase in the abundance of sprat (Casini et al. 2006; 2008). However, such changes are not always easy to interpret over time. Ecosystems are highly complex, and there are a number of factors that affect a course of events simultaneously. In the Baltic, climate change, eutrophication and overfishing have proceeded simultaneously, and it is therefore difficult to distinguish to what extent each of these factors affects the ecosystem.

Interaction between different species of fish in the Baltic Sea
As a result of overfishing and poor recruitment, the abundance of cod in the Baltic Sea (eastern stock) has fallen drastically (www.ices.dk). Overfishing of cod in the Baltic Sea is a known fact today, and spawning stocks have been below the precautionary reference point (Bpa) since the late 1980s and periodically even below the biomass limit reference point (Blim) since the mid 1990s. Fishing mortality has remained high, despite wavering stocks. As cod stocks have fallen, abundance of sprat has increased, which in turn has affected lower trophic levels (Casini et al. 2008).

In addition to the abundance of parent fish, the reproductive potential of cod is also dependent on saltwater inflow to the Baltic Sea. Few and weak saltwater inflows lead to poor oxygenation in deepwaters, and in such
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conditions it becomes more difficult for cod to reproduce successfully (see Section 1.2 on size-selective fishing). In the last 20 years, the intensity of saltwater inflows has been low, and in general has led to poorer conditions for cod reproduction compared to the late 1970s and early 1980s (Sjöstrand 2007). Even during periods of major inflows of saltwater (e.g. in early 1993; Matthäus and Lass 1995), cod reproduction has been poorer than expected, which has caused researchers to speculate whether other factors also affect the cod reproductive potential. Since the abundance of sprat in the Baltic has increased in the same period as cod abundance has decreased, it is suspected that sprat may have something to do with the situation. It has been shown that sprat and herring can be effective predators of cod eggs (Sparholt 1994; Köster and Möllmann 2000). Sprat and herring also compete with young cod for their common food source – zooplankton (Casini et al. 2008).

The abundance of the coastal predatory fish (perch and pike) has declined in outer coastal areas in the Baltic since the early 1990s (Andersson et al. 2000; Ljunggren et al. 2005). The reason for the decline in perch and pike stocks seems to be death by starvation among juveniles. Research shows that areas with low recruitment of perch and pike also have low abundance of the zooplankton that the juveniles prefer to eat. It may then be that sprat also affect coastal fish communities as a consequence of their predation on zooplankton.

To further examine the interaction between sprat, cod and zooplankton in pelagic areas and between sprat, perch, pike and zooplankton in coastal areas, a major project has been launched by the Swedish Board of Fisheries. The project runs from 2008 to 2013 and is being conducted in cooperation with a number of institutions in Sweden and abroad. Laboratory tests, field tests and ecological models will be used to provide a comprehensive picture of the way in which sprat interacts with cod and coastal stocks of perch and pike. The main purpose is to try to determine whether reduction of the sprat stocks can “help to restore the ecological balance in the Baltic Sea” (Swedish Board of Fisheries 2008b). The project is still in its infancy but will presumably produce a number of important pieces of the puzzle as to how various fish species affect each other and their food sources.

Trophic cascades in the Baltic Sea

New research indicates that the decline in cod stocks in the Baltic Sea has also affected the phytoplankton abundance (Casini et al. 2008). In the study, a number of changes in the Baltic’s food web between the mid 1970s and the early 2000s are identified. The decline in cod stocks which has led to an increase in sprat stocks and a reduction in the abundance of zooplankton, has also caused an increase in the abundance of phytoplankton (Casini et al. 2008). This can be explained by reduced grazing of phytoplankton by zooplankton. The study (Casini et al. 2008) demonstrates that increased supply of nutrients and hydrological factors were of secondary importance to phytoplankton dynamics. Instead it is changes at higher trophic levels (cod,
sprat and zooplankton) that have caused the increase in phytoplankton. The researchers conclude that it is extremely important to maintain the structural function of predatory fish in the ecosystem – not only for the sake of the fish stocks, but also to reduce the risk of large algal blooms.

Trophic cascades are generally difficult to identify in marine environments as interactions between the organisms involved are so complex. That is why only a couple of previous studies have shown examples of similar cascades. One example is from the Black Sea where researchers showed that intensive fishing for predatory fish had led to large changes in the entire ecosystem (Daskalov 2002; Daskalov et al. 2007). The other study shows how intensive cod fishing in parts of the North-West Atlantic has led to major changes at lower trophic levels (Frank et al. 2005). As in the Baltic and Black Seas, the decline in large, predatory fish has generated more zooplankton-eating fish, fewer zooplankton and more phytoplankton (Frank et al. 2005).

Seabirds' access to food is changing as a consequence of fishing

In many areas with heavily fished stocks, there have also been changes among land animals, in addition to changes in the marine animal communities. This kind of cascade effect often has consequences that could not initially be predicted. In many areas around the North Sea, the effect on several species of birds from fishing activities has been studied. Various species of gulls have, for example, benefited from intensive fishing, as they have specialised in following fishing boats and eating discards and offal (Tasker et al. 2000). Interaction between various species of fish caught for production of fishmeal (e.g. sand eels and sprat) and birds that feed mainly on these species can change as a result of fishing (Tasker and Furness 1996). Fishing of sand eels is periodically very heavy, and the fishing therefore competes with the birds for the same, limited food source. Breeding birds have reportedly been forced to fly increasingly longer distances to find food for their young, which has led to lower survival among chicks and parents alike (Monaghan et al. 1992). Researchers have also observed that great skuas (seabirds) have adapted their diet according to the abundance of sand eels in the area, and the size of discards from fishing boats. When abundance of sand eels and discards are low, the gulls eat a higher proportion of other seabirds (Votier et al. 2004). Declining fish stocks and fewer discards as a result of smaller by-catches can, in other words, have devastating effects for certain species of birds.

Decline in weight among Baltic guillemot chicks

A study of the weight of guillemot chicks was undertaken on the island of Stora Karlsö off Gotland in the Baltic Sea between 1989 and 2000 (Österblom et al. 2001). The chicks were caught, ringed and weighed when they left their nests to fly out to sea with their parents. Guillemots breed up to one chick per season, and the chicks feed almost exclusively on sprat (Österblom and Olsson 2002). The survey from Stora Karlsö shows that the weight of
guillemot chicks has declined steadily between 1989 and 2000. This is despite the fact that the abundance of sprat in the Baltic has increased during the same period. The mechanism behind this somewhat surprising result is that, while sprat are increasing in number, their age-specific weight has decreased (see e.g. Casini et al. 2006). Sprat have, in other words, become leaner, which means that each fish contains less energy (Hjelm et al. 2006). Even though the guillemot chicks have no quantitative lack of food, their body mass has decreased because the quality of their food is poorer.

Why has sprat body weight decreased?
Sprat is a species that lives in shoals and feeds on zooplankton throughout its life. Sprat are selective predators of zooplankton, which means that they actively choose certain species or stages of life (e.g. females with eggs) as their preferred diet (Casini et al. 2004). Zooplankton are small crustaceans that are transported with the current, however many of them can also swim considerable distances, e.g. between deepwater and the surface. Zooplankton exist in a variety of forms and sizes, from the smallest, unicellular plankton to larger crustaceans of up to two or three mm. Since the early 1990s, certain zooplankton species in the Baltic Sea have decreased in number (see e.g. Möllmann et al. 2000). It is primarily large species with a high fat content (e.g. *Pseudocalanus*) that have decreased in number while other species (e.g. *Acartia*) have increased (Möllmann et al. 2000). Some researchers have linked the decrease in zooplankton to increased freshwater run-off in the Baltic during the same period (Flinkman et al. 1998; Möllmann et al. 2000; Rönkönen et al. 2004). The less saline water has a negative impact on species better suited to more saline water (e.g. the above-mentioned *Pseudocalanus*) and leads to impaired growth and reproductivity. Other researchers explain the decline in certain species of zooplankton by the fact that sprat have increased in abundance and in total, consume more zooplankton than previously (Cardinale and Arrhenius 2000; Cardinale et al. 2002; Casini et al. 2006). What is certain is that a shortage of food has led to a decrease in bodyweight of sprat. However, it is unclear whether this food shortage is due primarily to increased freshwater run-off or to larger abundance of sprat.

Trawling changes the seabed and animal communities
Most trawling of demersal species of fish (e.g. cod, haddock and flatfish) and of crustaceans (e.g. Norway lobster and prawns) takes place in areas shallower than 200 m (Kaiser et al. 2002). It has been estimated that some 75% of the continental shelves (the part of the seabed that is closest to the continents) are trawled on a regular basis (Kaiser et al. 2002). Trawling is carried out above soft seabeeds, i.e., those with a soft sediment consisting of clay, sand or organic matter.

Large-scale effects
In addition to the direct effects on demersal animals and plants, trawling also changes the physical environment of the seabed. Perhaps the most obvious effect is on the seabed’s large-scale topography. Sonar images of seabeeds
show the typical “striping” that trawling causes. Large trawl doors that are dragged across the seabed cause ditches, leading to a courser topography in general. Water renewal is lower in these ditches, which may lead to depleted oxygen levels (Kaiser et al. 2002).

... and small-scale effects

The centre or catch section of a trawl consists, besides the actual net bag, of cables with reels, chains or a bar that is dragged across the seabed. These can be compared to a farmer’s harrow, as the trawl doors have a function similar to that of a plough. The centre section of the trawl therefore has a “smoothing” effect on the sediment surface. The greatest effect of trawling on demersal organisms seems, paradoxically enough, to be this smoothing effect, and not the ditches it produces. On a small spatial scale, mounds and ditches caused by digging organisms are very important, as they create complexity in the landscape of the seabed and promote high biological diversity. Such structures are also very important environments for juvenile fish giving access to food and hiding-places (see e.g. Auster et al. 1997). It may be expected that frequent trawling in a specific area will lead to a gradual deterioration of the habitat of fish and other creatures, which in turn may lead to a decline in the abundance of fish produced in the area (Kaiser et al. 2002).

Effects on bottom material

Another major effect of trawling is resuspension of the bottom sediment, which means that soft matter is stirred up. The effect of trawling can be considerably greater than the effect of the wind on the bottom sediment under the halocline (Floderus and Pihl 1990). Resuspension can have a number of consequences, including release of sediment-bound nutrients, exposure of oxygen-deficient layers deeper down in the sediment, an increase in the biological oxygen demand, release of contaminants, and blocking of various organisms’ feeding or respiratory organs (Kaiser et al. 2002).

Trawling affects demersal animals (e.g. crustaceans and mussels) by changing both structures and functions in such communities. Larger, slow-growing species are generally more sensitive to disruptions caused by trawling, while smaller individuals and species manage better (Dinmore et al. 2003). Areas that are trawled intensively are therefore often dominated by fast-growing individuals and species. These areas generally also have a lower biomass and production, compared with untrawled areas (Jennings et al. 2001).
2 Eutrophication

Fact box

*What is eutrophication?*

Eutrophication is in part a natural process whereby nitrogen and phosphorus accumulate in water and watercourses from surrounding land. However, various forms of human activity cause this accumulation to increase, leading to an eutrophication process with potentially drastic effects on plant and animal life. Examples of consequences include an increase of vegetation covering shallow bays, intensive algal blooms, turbid water and effects on higher trophic levels such as fish. Intensive eutrophication leads to an increased production of algae which – when they sediment on the bottom leads to oxygen deficiency, as oxygen is used when dead plants and animals decompose.

2.1 Introduction

Eutrophication is a global problem that is often manifested in coastal areas where human activity leads, in various ways, to increased nitrogen and phosphorus levels. Depending on a number of chemical, hydrological and biological factors, a sea can “react” in different ways to large accumulations of nitrogen and phosphorus.

The Baltic Sea is unique in many ways. It is one of the largest brackish seas in the world (413,000 km²) and borders 9 countries with a total population of just over 80 million. Furthermore, the Baltic is an inland sea with limited water exchange with the North Sea via Öresund and the Belt Sea. A considerable flow of freshwater into the northern Baltic, combined with an inflow of saline water from the North Sea leads to that the Baltic Sea has brackish water. The salinity of the water increases towards the south, but also with increasing depth. This gives rise to a strong vertical gradient (halocline) that divides more saline water at the bottom from less saline water above the halocline, leading to that the surface water and the deepwater are rarely mixed together. A natural consequence is that the water close to the bottom easily becomes anoxic. Mixing in the water column mainly occurs when saline, oxygen-rich water flows in from the North Sea. Major inflows are needed for oxygen to be supplied to the bottom waters of the deeper basins of the Baltic. This occurs at irregular time intervals, and in the last 20 years, the only major inflow took place in 1993, with two smaller inflows in 2003 and 2005 (www.helcom.fi and www.smhi.se). Few inflows of saline water and elevated nutrient inputs have caused large areas of anoxic sea bottoms. Concentrations of both nitrogen and phosphorus have increased dramatically in the last 100 years. It is estimated that the concentration of nitrogen in the Baltic Sea is at least four times as high and the concentration of phosphorus eight times as
high today as in the early 20th century (Larsson et al. 1985). For the Skagerrak, it is estimated that nitrogen concentrations have tripled compared with estimated levels before 1950 (Rosenberg et al. 1990). New model estimates show that the total inflow of nitrogen to the Baltic Sea has doubled since the beginning of the last century and that the total inflow of phosphorus has tripled. By comparing historical data of, for example, the Secchi (transparency) depth, these estimates can be confirmed (Savchuk et al. 2008).

There are large regional differences as regards eutrophication, as well as local differences between coastal and open sea areas. The Bay of Bothnia has good oxygen conditions and does not show any clear signs of eutrophication, whereas the situation in the Baltic proper’s open sea areas is serious, with poor oxygen supply and large areas with “dead bottoms”. A positive trend is that the situation in coastal areas of the Baltic proper has improved. On the west coast, eutrophication has resulted in depleted oxygen levels, as on the east coast. However a slightly positive trend in the Kattegat is emerging today, compared with the 1980s and 1990s (www.havet.nu).

2.2 Nitrogen and phosphorus the most important nutrients

Limit both nitrogen and phosphorus

In order to overcome the problem of eutrophication it is necessary to limit levels of both nitrogen and phosphorus (Vahtera et al. 2007). In management plans for the Baltic Sea, it is also important to take into account differences between various sea basins, coastal and open sea areas (Granéli et al. 1990). However, it has not yet been fully ascertained which measures produce the best results – to some extent because researchers do not yet completely understand how various factors influence the transformation and release of nutrients. This is a complex system that involves interaction between many different factors. There are also differences in the transformation of nitrogen and phosphorus, both regionally and between coastal and open sea areas.

It has been shown that oxygen conditions in the Baltic Sea’s deepwaters have a major impact on the way in which both nitrogen and phosphorus are transformed (Raateoja et al. 2005; Vahtera et al. 2007). One source of nitrogen and phosphorus is the settling organic matter (dead animals and plants) on the bottom. As the material decomposes both nitrogen and phosphorus are released. During algal blooms in the spring – mainly composed of diatoms – large volumes of organic matter settle on the bottom. When they decompose, oxygen levels fall in both the sediment and bottom waters. When oxygen levels are low, nitrogen is transported out of the system through a process known as denitrification. Denitrification means that nitrogen in the water is converted into nitrogen gas, which eventually enters the atmosphere. At the same time, a lack of oxygen results in phosphorus being released from the sediment and accumulating in the water (Conley et al. 2002). Human activity contributes to the inflow of nutrients into the aquatic
environment, both from the air (atmospheric deposition of nitrogen) and from the land (through run-off from, for example, agricultural areas or drains).

In order to reduce concentrations of nitrogen and phosphorus at the lowest possible cost, a better understanding of the way in which nutrients are transformed and released in our aquatic ecosystems is needed (Elmgren and Larsson 2001). As regards the nitrogen cycle, new research shows that there are many ways for nitrogen to be transported out of the system (Hannig et al. 2007), and that established knowledge about nitrogen needs to be revised (Brandes et al. 2007). At the same time, decisions about the management of our ecosystems cannot wait for scientific certainty to be reached. Decisions on the management of our environment may therefore be seen as experiments that need to be supervised, learned from and reassessed (Elmgren 2001).

2.3 General effects of eutrophication

**Increased abundance of plankton algae**

The growth and production of plankton algae is largely determined by the amount of available nitrogen and phosphorus, and by the proportions in which they occur. In general, phosphorus is the principal limiting nutrient in lakes, while nitrogen limits the production of plankton algae in the sea. The situation can also vary at different times of the year. In the Baltic Sea, plankton algae are limited during the spring primarily by nitrogen, while summer algal communities are mainly limited by availability of phosphorus (Granéli et al. 1990). This can be explained by differences in the species composition of the algal blooms in the Baltic in the spring and the summer. Supply of a limiting nutrient will lead to larger production of plankton algae. Since the 1980s, the primary production in the Baltic has almost doubled (Cederwall and Elmgren 1990; Wasmund et al. 2001). In many lakes the abundance of plankton algae has also increased as a result of increased input of nitrogen and phosphorus (see e.g. Willén 2001).

**Reduced Secchi depth**

More plankton algae leads to a larger abundance of particles in the water, which in turn affects the Secchi depth of the water. The Secchi depth is a rough measure of how deep in the water column the light reaches. A reduced Secchi depth means poorer light conditions for macroalgae attached to the bottom substrate (e.g. bladderwrack) and can lead to a reduction in their depth distribution (see Ch. 2.3 Changes in coastal zones). A clear deterioration in Secchi depth has been observed in the Baltic Sea over time, when comparing data from two periods: 1914-1939 and 1969-1991 (Sandén and Håkansson 1996).
Lack of oxygen

When organic matter that has sedimented on the bottom decomposes, oxygen is consumed, which can lead to a lack of oxygen in the sediment and bottom water. The lack of oxygen becomes especially extensive when the abundance of organic matter is high and the water column mixing is poor. A lack of oxygen can cause hydrogen sulphide to form, which is highly toxic for most organisms. A complete lack of oxygen also disturbs the nitrogen cycle. The potential for denitrification, when nitrate is converted into nitrogen gas and transported out of the system, is weakened. Anoxic sediments also releases phosphorus, which in conditions of oxygen-saturation, stays trapped in the sediment (Conley et al. 2002).

Lack of oxygen is considered as one of several main threats to coastal ecosystems globally (Diaz and Rosenberg 1995). In coastal zones, the number of dead zones has increased dramatically since 1960, and today more than 400 areas are affected by a serious lack of oxygen (Diaz and Rosenberg, 2008). The detrimental effects of a lack of oxygen on marine environments is widespread today and the exponential increase in the number of anoxic environments in a short period is alarming (Diaz and Rosenberg, 2008).

Summer cyanobacterial blooms in the Baltic Sea

In recent years summer blooms of cyanobacteria (blue-green algae) has been the subject of attention both in the media and among researchers. Summer cyanobacterial blooms are a natural phenomenon in the Baltic Sea and have occurred for over 7,000 years (Bianchi et al. 2000). Some factors are especially decisive for heavy blooms; high levels of phosphorus, low levels of nitrogen and warm, still waters (Wasmund 1997; Larsson et al. 2001). Cyanobacteria have a special ability which gives them competitive advantage over other phytoplankton species during the summer – they can use nitrogen gas soluble in the water. This is known as nitrogen fixation. Other plankton algae are dependent on nitrogen compounds, which generally exist in limited amounts in the water. The ability of cyanobacteria to bind nitrogen gas and convert it into nitrogen compounds leads to a large input of nitrogen into the Baltic Sea every year (Larsson et al. 2001; Rolff et al. 2007). The total amount of nitrogen that accumulates is difficult to estimate and undoubtedly varies from year to year. However, several studies show that it amounts to some 300,000 tonnes per year (Larsson et al. 2001; Rolff et al. 2007). This means that nitrogen fixation adds almost as much nitrogen to the Baltic Sea as water-borne sources, and more than atmospheric deposition (Rolff et al. 2007). It is unclear whether summer cyanobacterial blooms really have increased in the Baltic. A couple of studies show an increase from the 1950s and onwards, while other studies do not show any increase at all (Almesjö 2007, and references therein). Since the spread of cyanobacterial blooms varies greatly, both between different periods in the summer and from year to year, it is difficult to identify any clear-cut trends (Almesjö 2007).
Measures to limit the effects of eutrophication

In addition to reducing the actual supply of nitrogen and phosphorus in lakes and seas, more drastic methods are tested and discussed to reduce the effects of eutrophication.

For the Baltic Sea, summer cyanobacterial blooms have become the symbol of a eutrophicated sea, even if the problems are not limited to these blooms. The development in the Baltic Sea can be described as a vicious circle that has occurred because the increased abundance of nutrients has increased production of phytoplankton which, in turn, has caused poorer oxygen conditions. The low oxygen levels lead to nitrogen being transported from the system (denitrification), at the same time as phosphorus is released from the sediment. In times of oxygen deficiency the concentration of nitrogen in the deepwater therefore decreases, whereas the concentration of phosphorus increases. These factors create conditions for extensive cyanobacterial blooms. It is, in other words, largely an internal process that takes place and affects the relative availability of nitrogen and phosphorus, and thereby also the cyanobacterial blooms (Vahtra et al. 2007). In order to address, primarily, oxygen levels in the deepwater, two main measures have been proposed: precipitation of phosphorus and oxygenation of the bottom waters. These proposed measures are still at the planning stage and it has currently not been decided whether or not they will be used.

Precipitation of phosphorus

In order to reduce the amount of phosphorus, primarily in the Baltic proper, it is possible to induce precipitation of phosphorus in the sediment using chemicals (Blomqvist and Gunnars 2008). This has previously been done in lakes, but whether the conditions for this exist in a marine environment remains to be examined. To examine the consequences of such a measure, small-scale laboratory experiments are planned, in which various substances can be tested. On the basis of these experiments, the systems may eventually be tested in natural environments (Blomqvist and Gunnars 2008). A possible measure is to add aluminium, e.g. in combination with calcium, in order to precipitate the phosphorus (S. Blomqvist, personal communication). By precipitating phosphorus in shallow areas, it is also possible to limit the phosphorus load to the Baltic open sea area. The precipitation of phosphorus can, if it works, serve as one of several measures to reduce eutrophication and its effects in the Baltic proper. But a long-term strategy is also needed to reduce phosphorus leakage combined with reduced emissions of nitrogen. Lower levels of nitrogen would limit spring blooms, which would in turn reduce the release of phosphorus from the sediment. If phosphorus could also be trapped in coastal areas, the result of these combined measures should lead to reduced cyanobacterial summer blooms in the Baltic Sea (Blomqvist and Gunnars 2008).

Oxygenation of bottom waters

In order to oxygenate bottom waters that currently are oxygen deficient, there are proposals to pump oxygen-rich surface water down into the deepwaters
beneath the halocline. A new report from the Swedish Environmental Protection Agency (NV DNR: 806-390-06 and DNR: 304-5453-07 Nh) presents the results of a study commissioned by the Government and conducted in consultation with other participants, to examine possible measures, effects and costs of increasing oxygen levels in the Baltic’s deepwaters and reducing sediment leakage of phosphorus where needed.

The report emphasises that the biomanipulation methods presented do not address the problems, they are merely different ways of dealing with the symptoms. In order to address the problem of eutrophication in the Baltic Sea, it is necessarily, first and foremost to focus on sustainable cod fishery, and to reduce the load of phosphorus and nitrogen from land (NV DNR: 806-390-06 and DNR: 304-5453-07 Nh). The study also emphasizes that the basic conditions for restoration of the Baltic and coastal zones differ from lakes in many ways, partly owing to the size and salinity that causes separation of water layers in the Baltic Sea. Furthermore, there is a risk that the contaminants trapped in marine sediments will be released if oxygen is supplied to the deepwaters (NV DNR: 806-390-06 and DNR: 304-5453-07 Nh).

**Fish as a means of reducing eutrophication**

In order to obtain clearer water and better fisheries, a project was launched in Himmerfjärden in Stockholm’s southern archipelago in the autumn of 2008. Despite considerably reduced emissions of nutrients to the bay, the water is still cloudier than expected at the present level of nutrients (Hansson and Didrikas 2005; Larsson and Hansson 1993). Researchers believe that this may be because the large abundance of juvenile Baltic herring in the bay and that they consume large volumes of zooplankton. The lack of zooplankton leads, in turn to high volumes of phytoplankton, even though concentrations of nutrients have fallen. For three consecutive years, 290,000 juvenile pike-perch will be planted in the bay each year, with the aim of increasing predation on Baltic herring and in the long-term, increasing the volume of zooplankton, which can eat more phytoplankton.

Fishing of perch-pike in the area is intensive today, but by means of information to the public, it is hoped that the taking of pike-perch smaller than 45-50 cm can be avoided. In this way perch-pike will have a chance to grow and can continue to eat Baltic herring. The project will be followed up continuously, e.g. by means of sampling fish and phytoplankton. Similar projects have previously been conducted in lakes, e.g. Ringsjön in Skåne, where large abundances of zooplankton-eating carp were removed (Hamrin 1999). In the follow-up of the Ringsjö project, both clearer water and a reduced phytoplankton biomass were noted (Bergman et al. 1999). The Himmerfjärd project is the first of its kind to be conducted in a marine environment. If the results of the project are positive, this will be a good argument for reducing cod fishery in the Baltic and planting predatory fish to counteract the effects of eutrophication on a larger scale (Sture Hansson, personal communication).
2.4 The effects of eutrophication on fish communities

Higher fish production

Catches of the commercially important species cod, herring and sprat increased tenfold between the middle of the last century and the early 1990s (Hansson and Rudstam 1990). The large catches during the 1990s are linked to a more intensive fishing with more effective catch methods and reduced predation by seals. The higher fish production may however also be a result of eutrophication (Hansson and Rudstam 1990; Österblom et al. 2007). Even if eutrophication, in an initial phase, can lead to increased fish production, studies show that certain species are negatively affected. This is partly linked to poorer oxygen conditions. The effects of eutrophication are clearer among fish stocks that spend their entire lifecycles in coastal zones, compared with fish stocks in pelagic areas.

Eutrophication – an important structuring factor in the Baltic Sea

The Baltic Sea has undergone major changes in the last century, as reflected by changes in fish communities. In addition to decreasing seal populations and the high extraction of cod, eutrophication has had an important structuring effect on the Baltic ecosystem. The transition from a nutrient-poor to a nutrient-rich sea may be regarded as a regime shift because of the effects it has had on food webs (Österblom et al. 2007). A regime shift means that the prevailing conditions are relatively stable and that it can be difficult, or even impossible, to return to previous conditions in the Baltic Sea.

Lakes

Much of the knowledge we have about the link between eutrophication and its effects on fish communities comes from observations in lakes. In lakes it has, for example, been shown that a limited addition of nutrients benefits most species of fish. At high concentrations of nutrients an unfavourable change occurs, in which certain species are instead negatively affected. This applies, in particular, to species that are dependent on good oxygen conditions (Hansson and Rudstam 1990, and references therein).

Effects of eutrophication on commercially important fish species

The overall knowledge of how eutrophication affects fish populations is incomplete. The effects of changes among phyto- and zooplankton, are especially unclear. Below follows an overview of studies that show how a few commercially important species can be affected by eutrophication.

Cod

Eutrophication can have a negative effect on the reproductive potential of Baltic Sea cod. This is because cod are dependent on relatively high concentrations of oxygen (above 2 ml/l) in order to reproduce (see also Ch. 1.5, Interaction between different species of fish). The decline in cod populations since the mid-1980s is explained partly by intensive fishing, combined with low oxygen levels in the Baltic’s deep basins (Bagge and
Thurow 1994). Intensive cod fishing and eutrophication have had synergy effects. A poorer environment as a result of eutrophication has made the cod more sensitive to fishing, and high fishing mortality has in turn contributed to a greater sensitivity to a poorer living environment (Österblom et al. 2007).

Herring
For herring, the effects of eutrophication can be both positive and negative. Greater access to food in the form of zooplankton can benefit smaller herring, while fully-grown herring are often negatively affected. This is because they primarily feed on bottom-living crustaceans, which are sensitive to poor oxygen conditions (Hansson and Rudstam 1990). An increased occurrence of filamentous brown algae in eutrophic bays has been shown to have a negative impact on the survival of herring eggs. Brown algae release substances that can be toxic for herring eggs and juveniles (Aneer 1987).

Sprat
Catch quotas for sprat increased dramatically between the mid-1950s and the 1970s, possibly as a result of eutrophication (Hansson and Rudstam 1990 and references therein). The rise in the sprat population after 1990 has also been explained by a fall in predation by cod (Rudstam et al. 1994). Factors such as temperature and access to food are also important. Higher water temperatures promote sprat recruitment (MacKenzie and Köster 2004), as well as access to the crustaceans on which smaller sprat primarily feed (Alheit et al. 2005).

Plaice
Many flatfish are dependent on the coastal zone as a “nursery”, where both access to food and protection from predators are important factors in the survival of juveniles (Pihl et al. 2005 and references therein). Both the quality and the size of areas used for reproduction and recruitment are important in securing their survival. Studies have shown that small plaice prefer clean sediments to areas with algal growth (Wennhage and Pihl 1994). Eutrophication has led to an increase in fast-growing green algae in coastal zones, in areas that were previously free from growth. Locally this can have a very negative effect on plaice recruitment (Pihl et al. 2005).

Freshwater species
The effects of eutrophication are most evident among fish species of freshwater origin, which spend their entire lifecycle close to the coast. It has, for example, been seen that eutrophic coastal areas are favourable for both perch and carp, but have a negative impact on other species. Similar results have been observed along Sweden’s and Finland’s coasts (Paavilainen et al. 1985; Hansson 1987; Bonsdorff et al. 1997). Changes in coastal fish communities as regards species of freshwater origin are similar to the changes found in eutrophic lakes (Hansson and Rudstam 1990).
2.5 Changed phyto- and zooplankton composition

Changes in phytoplankton communities
An overview of changes in phytoplankton composition in the Baltic Sea shows that major changes took place in the 20-year period examined in the study (1979-1999; Wasmund and Uhlig 2003). These changes differed in different marine areas, for example, it can be mentioned that the total amount of phytoplankton in the Baltic proper increased during the period in the study. In the Baltic Sea as a whole, phytoplankton communities appear to have undergone a change in composition (Wasmund and Uhlig 2003). While both nitrogen and phosphorus levels have increased in the central parts of the Baltic Sea, concentrations of dissolved silica have decreased (Papush and Danielsson 2006). This has partly led to changes in the phytoplankton community. Diatoms which, in addition to nitrogen and phosphorus are also limited by the amount of silica, are less prevalent while another group of phytoplankton – dinoflagellates – have increased in number (Wasmund et al. 2001). This change may have an impact on the entire ecosystem, as dinoflagellates are generally less nutritious for zooplankton than diatoms (Van Nieuwerburgh et al. 2005; Pauline Snoeij, personal communication).

Changes in the coastal zone – effects on fish communities
Eutrophication can lead to changes in the composition of plants and smaller animals in the coastal zone, which in turn can affect the habitat of fish and other animals further up in the food chain. Among other things, changes have been noted in the distribution and composition of macroalgae attached to different substrates. A comparative study was made in the Baltic Sea between the vertical distribution of bladderwrack in the 1940s and 1980s. The study showed that the lower limit of the depth distribution of bladderwrack had moved upwards by approximately 3 metres in these 40 years, which can be explained by decreased transparency of the water column. The increased turbidity is, at least in part, a result of higher concentrations of nutrients. Less light penetration also means that the conditions for bladderwrack growth are limited to more shallow areas (Kautsky et al. 1986). Another effect of eutrophication is that it stimulates the growth of fast-growing algae in coastal zones. These filamentous algae can eliminate multi-year populations of macroalgae, such as bladderwrack (Norkko 1997). In recent years, however, both research studies and environmental observations have shown positive trends for bladderwrack. In the 1990s spread in depth of bladderwrack was increasing once again and in studies carried out in 2006, bladderwrack was found at the same depth as in the 1940s studies (Karlsson and Kautsky 2007).

Eelgrass beds are an important habitat for both demersal animals and fish. Large areas of eelgrass beds have disappeared in the 1980s and 1990s. Human activity such as eutrophication and physical disturbance on land and in the water can be important contributing factors to their declining distribution. These have contributed to poorer Secchi depth and consequently to a poorer light penetration and to increased growth of algae. However, it is believed that these changes cannot be attributed solely to eutrophication.
Intensive fishing may also have contributed to the increased amount of epiphytic filamentous algae. Owing to the depletion of larger predatory fish, such as cod, the abundance of smaller fish species have increased. These eat small crustaceans and molluscs, which are efficient grazers of adherent algae. The grazing crustaceans and molluscs can, under normal conditions, control both the production and the composition of adherent algae, despite the effects of eutrophication. Even if the link between fishing and greater amounts of adherent algae has not been entirely established, studies in the west-coast county of Bohuslän and in the Baltic Sea support that the number of small predators and grazing crustaceans has a bearing on the occurrence of algal mats in eelgrass beds. In Öresund, where trawling has been prohibited and the cod population is reasonably intact, the amount of grazing crustaceans (e.g. *Gammarus* and *Idotea*) are high in the eelgrass beds, and there are no mats of filamentous algae. Here, the growth rate of eelgrass is high and its distribution has remained unchanged in recent decades (www.marbipp.se).

It is estimated that the distribution of eelgrass beds has decreased by 60% in the Skagerrak in the last 20 years (Pihl *et al.* 2006). In a comparison between large areas with and without eelgrass (where eelgrass has previously grown), the number of species of fish was higher in eelgrass habitats and both the density and the biomass of fish was generally lower in areas without eelgrass. Many species were absent in the areas where eelgrass had disappeared. For example, the number of small cod was very low (Pihl *et al.* 2006).

Summer cyanobacterial blooms – effects on fish communities

Larger accumulations of cyanobacteria affect the quality of food for organisms in the water column and on the bottom, once the bacteria have sedimented. In addition to the effects of the toxins cyanobacteria can produce, researchers have found various indirect effects such as behavioural changes among fish and even changes in the surrounding plankton community.

Large accumulations of cyanobacteria in the summer can affect fish communities in different ways, partly through changes in the Secchi depth and through exposure to the toxins that are sometimes released in conjunction with heavy blooms. Toxins from cyanobacteria can accumulate in higher trophic levels through zooplankton (Engström-Öst *et al.* 2002). It is estimated that less than 1% of toxins from cyanobacteria are accumulated in higher trophic levels, but also very small amounts can affect organisms (Karjalainen *et al.* 2007). The reaction among smaller-sized fish may be more dramatic than among adult fish – embryonic development of herring has, for example, been seen to be negatively affected by accumulations of cyanobacteria (Ojaveer *et al.* 2003). Adult salmon trout can get serious liver damage from nodularin, which is one of the toxins produced by cyanobacteria. This damage has shown itself to be reversible once the fish are no longer exposed to the toxins (Kankaanpää *et al.* 2002).

Accumulations of non-toxic blooms have also been shown to affect the behaviour of fish. The search for food among juvenile pike has, for example, been seen to decrease during heavy blooms which may be because of both
poorer visibility and that their gills are blocked (Engström-Öst et al. 2006). Changes in the spawning behaviour of sticklebacks on account of increased turbidity have also been observed (Engström-Öst and Candolin 2007).

It must be regarded as uncertain whether large cyanobacterial blooms can have large-scale effects on fish and other organisms. Bearing in mind that cyanobacteria are rather large and are only grazed to a limited extent, it is, however, not very likely that they could cause damage on the same scale as dinoflagellates and other smaller, toxin-producing plankton algae.
Contaminants is a collective term for substances that are potentially harmful to biological life, including humans. Contaminants are normally divided into heavy metals and organic contaminants. Heavy metals are elements that occur naturally in our environment, but that become toxic in high concentrations. Some common heavy metals are mercury, lead and cadmium. Organic contaminants are various kinds of carbon compounds which, either artificially or through combustion, have formed compounds with for example, tin, chlorine or other halogens. The organic compounds are toxic, even at low levels, and are easily spread in the environment as they are fat-soluble and highly persistent. Known contaminants such as PCB, DDT and dioxins are examples of organic contaminants.

Environmental monitoring of contaminants

The national marine monitoring programme monitors a number of heavy metals and organic substances. Sampling is done at 10 stations in the Baltic Sea and the Skagerrak, Kattegatt and the Sound, and samples are collected from herring, cod, perch and viviparous blenny, as well as blue mussels and guillemot eggs (Bignert et al. 2007). The heavy metals monitored are mercury, lead, cadmium, nickel, chrome, copper and zinc. The monitored organic contaminants are divided into different groups, depending on the type of substance they belong to. These are:

- Industrial chemicals and unintentionally formed substances in industry (PCBs, HCB, dioxins and dibenzofurans, PAHs)
- Pesticides (DDT, HCHs, e.g. lindan)
- Brominated flame retardants (polybrominated diphenylethers (PDBEs), and hexabromocyclododecane (HBCDD))
- Perfluorinated substances (including PFOS used as impregnating agents in paper, textiles and leather).

In addition, annual overall analyses (“scanning”) are conducted in order to discover new, and hitherto unknown, substances. Sweden has very long time-series of contaminants in our biota, compared with other countries. These are of great help when assessing whether or not a substance should be banned, and the Swedish test-series have, in many cases, been decisive for EU decisions (Per Larsson, personal communication; Sandström et al. 2005).

Many contaminants have been reduced

Many “old” contaminants in Swedish biota are significantly lower today, compared with the 1970s and 1980s (e.g. Sandström et al. 2005; Bignert et al. 2007). These include the known substances PCB and DDT where, since the ban in the 1970s, levels have fallen markedly among fish, birds and seals. Lead levels in Baltic herring have decreased at all sampling stations since lead was banned in petrol. From the 1970s to the early 1990s, levels of...
brominated flame retardants in guillemot eggs from Stora Karlsö increased dramatically, but this trend has now been reversed for banned flame retardants. However, levels of certain brominated flame retardants (e.g. the highly brominated HBCDD) continue to rise. Another group of substances that has increased substantially since the 1970s is perfluorinated substances (PFCs). PFCs are very resistant to both chemical and biological breakdown and are primarily used for finishing in paper, textiles etc. (Bignert et al. 2007). In the year 2000, one of the largest manufacturers of PFCs introduced a voluntary suspension in production, which will hopefully lead to a reduction in the occurrence of such substances in the future (Bignert et al. 2007).

**TBT in harbours and marinas along the entire coastline**

Organic tin compounds such as tributyltin (TBT) have long been used in boat-bottom paints to prevent the growth of sea acorns, algae etc. Since TBT is toxic at very low doses and has been proven to cause hormonal disturbances and sterility in a number of marine organisms, its use in pleasure boats was banned in 1989 and for vessels taller than 25 m in 1993 (Cato et al. 2007). In the EU, TBT in smaller boats was banned in 1999 and on 17 September 2008, the International Convention on the Control of Harmful Anti-fouling systems on ships (AFS Convention) came into force with a ban on TBT in vessels (http://www.imo.org/conventions/mainframe.asp?topic_id=529). Since 2002, Geological Survey of Sweden (SGU) has conducted a project with the aim of identifying the occurrence of organic tin compounds in sediments along the Swedish coastline. The findings show that tin compounds occur in virtually all areas examined, and in certain areas (primarily marinas) levels can be classed as very high (Cato et al. 2007). It is however positive that levels of TBT in netted dogwhelks that have been examined in a number of exposed areas seem in most cases to be decreasing.

**Difficult to obtain a cohesive picture of contaminants**

There is no consistent and cohesive picture of the occurrence of contaminants and heavy metals in living organisms, as certain substances are increasing while others are decreasing. In most cases it does, however, seem that a ban on a substance actually leads to lower concentrations in environments and organisms. However, not all substances show the rate of decrease one could expect if all use and spread had stopped completely. Certain substances such as PCB, which was produced for use in, for example, transformers and in certain building materials, are still found in these, even though they were long since banned. The destruction of such substances is both technically complicated and very expensive, which means that the renovation of older buildings containing PCB is a long, drawn-out process (www.naturvardsverket.se/sv/Produkter-och-avfall/PCB-i-byggnader-och-produkter). Furthermore, when organic contaminants are broken down, other substances, which can be at least as harmful as the original ones, are formed. Damage to organisms can thus persist or even become worse a long time after a contaminant has been banned and taken out of production.
3.1 Contaminants are persistent and are enriched

Organic contaminants and heavy metals are stable compounds that are very resistant to decomposition, which means that their persistence in the environment is very long. In general, contaminants can easily bind to various kinds of biological molecules and can thus accumulate in sediment or in the organs of living organisms. Contaminants reach the organisms partly through “passive” absorption through their cell-walls (e.g. in phytoplankton), gills and skin (in fish) and through active absorption in the intestinal canal through food. Because of persistence and fat solubility and/or an ability to bind biological molecules, contaminants are enriched up the food-chain.

**Heavy metals**

Heavy metals, e.g. mercury, are not fat-soluble, but can still be stored in the body. By means of natural processes, mercury is converted into methyl mercury, which binds various molecules and is stored, for example, in the liver. Methyl mercury has a number of negative effects on living organisms. Damage to the nervous system, primarily at the foetal stage, is one of the most well-documented effects of mercury.

**Perfluorinated substances**

Perfluorinated substances such as PFOS and PFOA are used as water and fat-repellents. These substances are neither fat-soluble nor water-soluble but bind themselves to proteins in the body and are for example stored in the liver and blood. PFOS are highly persistent and thus have a long toxic effect in nature. PFOS also disturb reproduction and are toxic to marine organisms (www.kemikalieinspektionen.se).

**Organic contaminants**

Organic contaminants are fat-soluble, which means that they bind to and are stored in the fatty tissue of living organisms. This means that the highest concentrations normally accumulate among predators such as seals and sea-eagles, which are at the top of the food web. In fish, it is the fish-eating species such as salmon and cod that contain the highest concentrations. Levels of organic contaminants are not solely dependent on which trophic level a specific animal is at, but also how much fat it contains and how quickly it is growing. It has, for example, been shown that salmon contains more contaminants the fatter it is (Larsson et al. 1996), and slow-growing char in Lake Vättern contain more contaminants than fast-growing char (Vätternvärdsförbundet 2003). For human consumption of fish, the amount of fat in the actual fish flesh is of significance. In the case of cod, the flesh is lean and the level of contaminants fairly low. These are stored in the fatty cod liver instead. The flesh of salmon and Baltic herring, on the other hand, is rich in fat, which also binds contaminants. For this reason, the National Food Administration recommends limited consumption of fatty fish and cod liver from the Baltic Sea, primarily among pregnant women and women of reproductive age (www.livsmedelsverket.se).
3.2 Reproductive disturbances in fish

The effects of contaminants on organisms can be described as complex and
difficult to interpret as they seldom lead to immediate death among the
affected organisms. Instead, it is the organism’s ability to find food, grow and
reproduce that is adversely affected. It is often unknown what substance or
substances that cause an observed disturbance. The combined risks of the
spread and effects of contaminants are therefore difficult to estimate
(Sundberg 2005; Per Larsson, personal communication).

Contaminants can cause a number of disturbances

Contaminants can cause a number of deformities, genetic changes and
disturbances in the reproductive organs of fish. It is not the contaminants
themselves that cause these disturbances, but the biological responses they
cause in the organisms. The damage that arises depends on the pollutant’s
chemical composition, the concentration in which it occurs and the stage of
life of the organism in question (egg, juvenile or adult individual).

It is possible to distinguish three main kinds of damage to fish as a result
of exposure to contaminants: (i) various kinds of deformities (e.g. to gill
covers or fins) and genetic changes that may increase the risk of tumours, (ii)
hormonal changes leading to sterility, reduced fecundity or imposex (when
females develop male sexual characteristics or vice versa) and (iii) damage at
an early stage of life, often in connection with hatching or when the juveniles
leave the yolk-sac stage.

Point-source emissions cause clear damage

In marine areas and lakes with well-defined emissions from industries,
rubbish tips and other installations, the impact on fish populations can be very
clear. Chlorine bleaching of pulp produced a number of environmentally toxic
substances that were released in several areas along the Baltic coast. Several
studies reported adverse effects among fish, including enlarged livers,
increased EROD activity, stunted growth of sexual organs, decreased sex
hormone levels, damaged fins, skeletal change and deformed jawbones
(summarised in Naturvårdsverket 2008b). These disturbances led to poorer
production of juveniles, low density of, for example, perch and a displaced
balance between different species of fish (Neuman and Karås 1988; Karås
et al. 1991). The effects of emissions from the pulp industry were the greatest in
the immediate vicinity of the industries, but a more diffuse impact could also
be observed many kilometres from the point of emission. The use of chlorine
bleaching decreased successively in the 1980s and was stopped entirely in the
early 1990s. In the 1990s the health status of fish also improved in the
affected areas (Naturvårdsverket 2008b). It has not been possible to pinpoint
exactly which chemical substances caused such severe damage to fish in the
areas surrounding the pulp industries (Naturvårdsverket 2008b).

In Lake Molnbyggen in the county of Dalarna, a correlation between
severe reproductive disorders among several species of fish (perch, roach
and brown trout) and leachate from a municipal refuse dump in the vicinity has
been found (Noaksson 2003; Linderoth 2006). Just one fourth of female fish in Molnybyggen had reached sexual maturity, and in these, the roe sacks were diminished (Linderoth 2006). The diffuse leakage from the municipal refuse dump had, in other words, induced reproductive failure in female perch. Other signs of effects from various toxic substances in the perch were changes in blood and liver status (Noaksson et al. 2005). An extended study showed that female fish in other lakes had similar disorders (Linderoth 2006).

**Difficult to interpret diffuse effects**
Within the framework of national environmental monitoring, the health status of female perch from reference areas in the Baltic Sea has been examined annually since 1988 (Hansson et al. 2006a). An overview of the results so far shows a successive decrease in relative gonad size (gonads = sex glands in which fish roe are formed). In the same period there has been an increase in EROD activity – a broad measure of the health status of fish. These two factors together may be interpreted as effects of contaminants. However, there is no established correlation, as both gonad size and EROD activity can also be affected by factors such as water temperature and season (Hansson et al. 2006a). The health status of perch has also been studied in a gradient from Lake Mälaren out to Stockholm’s archipelago (Hansson et al. 2006b). Here too, the results show a diffuse effect of contaminants all along the gradient, with the greatest impact closest to the city (Hansson et al. 2006b).

**Better knowledge needed**
In a report from the Swedish Environmental Protection Agency (Naturvårdsverket 2008b), the authors note that there are several gaps in our knowledge of contaminants that need to be filled. These gaps include, inter alia, that new biomarkers need to be developed. A biomarker is a biological tool that shows a biological response as an indicator of the effects of a contaminant. The above-mentioned EROD activity is an example of a biomarker that is often used. The report from the Swedish Environmental Protection Agency also indicates that better knowledge is needed on how to relate a biomarker response of an individual to health effects at the population level. The report also mentions that the current environmental monitoring needs to be supplemented and developed, for example, by means of impact measurements. This is in order to increase opportunities to study effects on fish populations shown by environmental monitoring and that remain to be explained, for example, changes in gonad size and EROD activity among coastal perch populations.

**No indicators of effects at population level**
In a report from the Swedish Environmental Protection Agency (Naturvårdsverket 2008b), the authors draw the conclusion that there are no indicators today (2008) that individual contaminants or the combined burden of contaminants have effects at population level among fish. Local emissions can, however, have a negative impact on fish in the immediate vicinity (Naturvårdsverket 2008b).
3.3 Salmon and M74

In 1974 there were reports, for the first time, of an unusually high mortality among juvenile salmon at several hatcheries in Sweden (Börjeson et al. 1994). The disease was named M74, where M stands for environmental causes (“miljöbetingat” in Swedish) and 74 for the year it was first discovered. The disease affects Baltic juvenile salmon at the yolk-sac stage. M74 affects batches of juvenile from certain female fish and causes death of all juveniles in these batches, a couple of weeks after the first symptoms have been observed. Symptoms include hyperactivity, abnormal swimming activity, poor coordination and a low heart-rate. Mortality as a result of M74 among cultivated salmon has varied greatly from year to year and reached a peak in 1993, when 72% of all juvenile salmon in Sweden’s hatcheries died (Börjeson et al. 1994). In the 2000s, mortality rates have for the most part been considerably lower, but have varied greatly from river to river and from year to year (www.skogochfisk.se). Knowledge of M74 and wild salmon is limited but electrofishing studies have shown that wild salmon are also affected by M74 (Karström 1999).

M74 caused by vitamin B deficiency

M74 is caused by a thiamine (vitamin B1) deficiency both in eggs and female fish, and symptoms can be cured by bathing the eggs in thiamine. However, the underlying cause of thiamine deficiency is still unknown. Initially, it was thought that M74 was caused by changes in the diet of the salmon, as this would explain the thiamine deficiency. One possible explanation put forward is the large-scale changes in the Baltic Sea’s food web, which could result in low thiamine levels or a higher occurrence of enzymes that break down thiamine in the diet of salmon. There is, however, no evidence today to show that thiamine levels in the food consumed by salmon have changed since the 1970s (Karlsson et al. 1999). It has also been proven that oxidative stress and low levels of antioxidants (fat-soluble vitamins) such as astaxanthin, tocopherol and ubiquinon are significant in the development of M74 (summarised in Vuori and Nikinmaa 2007).

M74 a threat to wild salmon and salmon trout stocks

There is very little possibility of monitoring the entire wild salmon stock and or of treating females and eggs with thiamine in the same way as cultivated salmon. The same applies to sea trout which can also suffer from M74-like symptoms, if not to the same extent as salmon (Landergren et al. 1999). The wild stocks thus risk depletion in years with many cases of M74.

3.4 Pharmaceuticals and fish

There are currently some 7,600 pharmaceuticals in Sweden, 90% of which are for household use and the remaining 10% are used by healthcare facilities (Läkemedelsverket 2004). The largest volumes of used pharmaceuticals
belong to the categories painkillers and anti-inflammatory (e.g. paracetamol, ibuprofen and ketoprofen). Pharmaceuticals for treatment of gastric ulcers (ranitidine), cardiovascular disease (atenolol) and certain antibiotics (tetracycline) are also at the top of the list. Human medicines represent by far the biggest proportion of all medicines, while veterinary medicines made up barely 2% of total sales in 2006 (www.apoteket.se).

Pharmaceuticals differ from many other chemical substances in society, in that they are prepared with the aim of achieving a biological effect. In this respect they are similar to pesticides. To withstand long transportation and storage and to prevent them from breaking down in the “wrong” part of the body, pharmaceuticals are chemically stable (persistent). Pharmaceuticals can be water or fat-soluble, but they all end up in wastewater after passing through the body. Water-soluble pharmaceuticals are excreted directly in urine, while fat-soluble pharmaceuticals are first transformed before being excreted through urine or bile. When they are broken down in the body, metabolites, or residues of the original pharmaceutical are formed. The metabolites excreted vary from pharmaceutical to pharmaceutical, but are also linked to factors such as the gender, age etc. of the individual taking the medicine.

**Water treatment plants are not constructed to break down pharmaceuticals**

Many pharmaceuticals are broken down in water treatment plants, but there are great variations depending on the substance involved. In a study by the Stockholm Water Company (Naturvårdsverket 2008a), it emerged that concentrations of pharmaceuticals in incoming and outgoing wastewater varied between 0 and 100%. Some substances, in other words, are broken down completely, while others are not broken down at all. The water treatment plants are not primarily constructed to reduce pharmaceuticals and the degree of breaking down in a treatment plant depends, besides the characteristics of the substances, on the processes in the individual plant. With increasing residence time of sludge and high levels of nitrogen removal there is an increased breakdown of pharmaceuticals and pharmaceutical residues (Naturvårdsverket 2008a).

Knowledge of the effects of pharmaceuticals, and in particular metabolites on the environment is insufficient today (Naturvårdsverket 2008a). A first step is to analyse pharmaceutical residues in the environment, and this is currently being done in several parts of the country. In addition to the comprehensive report produced by the Stockholm Water Company at the request of the Swedish Environmental Protection Agency (Naturvårdsverket 2008a), studies are also being conducted in Region Skåne, Uppsala County Council, Östergötland County Council and Stockholm County Council.

**Effects on fish**

Until now no serious or widespread biological effects that can directly be linked to emissions of pharmaceuticals in Swedish waters have been proven (Naturvårdsverket 2008a). The effects observed in aquatic environments are primarily reproductive disturbances among fish in the immediate vicinity of
the water treatment plants (see, e.g. Larsson et al. 1999). In general it is difficult to link effects to specific substances since there are, apart from human oestrogen (hormones) and synthetic oestrogen, also a number of other hormone-disrupting substances. These include phthalates, which are used as a softener in plastic, and nonylphenol, which is used as a surfactant (cleaning agent) in paint and detergents. Nonylphenol is banned in Sweden but is still found in the environment as it is still contained in some imported products. For some substances, researchers have found clear effects in fish in laboratory tests. The effects are not acute toxic (i.e., the organisms do not die), but involve a sex-ratio imbalance as a result of long exposure to low levels. Laboratory tests have shown effects from pharmaceuticals in the form of abnormal swimming behaviour in marline crayfish (DeLange et al. 2006). At Stockholm University, researchers recently started to study the effect of certain pharmaceuticals on mussels. The tests have shown strong indications that the pharmaceutical substances ibuprofen (painkilling and anti-inflammatory), propanolol (heart medicine) and diclofenac (painkilling and anti-inflammatory) have an adverse effect on mussels. High doses led to fewer and weaker byssus threads (the threads that mussels use to adhere to the bed), and to a poorer scope for growth, i.e. less energy for growth and reproduction, which is also an indirect measure of stress. (Linda Kumblad, personal communication).

The longer-term impact of pharmaceuticals on aquatic organisms is still very unclear. Even though no definite link can be seen today, the possibility cannot be ruled out that pharmaceutical emissions in the environment involve risks to both humans and biota (Naturvårdsverket 2008a). Early life stages and certain development periods are more sensitive to effects from toxic or foreign substances. It has also been demonstrated that a combination of substances can lead to more forceful effects than individual substances, even at relatively low concentrations (see e.g. Fent et al. 2006).

3.5 Marine litter

A problem that has been highlighted since the 1970s, but that has acquired new relevance is the occurrence of marine litter along beaches and in the sea. The definition of marine litter is “any persistent, manufactured or processed solid material deliberately or indeliberately discarded, disposed of or abandoned in the marine and coastal environment” (OSPAR, 2007). Marine litter thus includes objects used by humans and that reach the sea or beach indirectly (e.g. from rivers and wastewater), or that have been left or dumped in the sea or on beaches. It also includes materials that are washed overboard in severe weather conditions from fishing boats and transport vessels (e.g. fishing equipment and goods of various kinds). Various kinds of plastic and polystyrene (styrofoam) are the most common form of marine litter, and make up some 75% of all litter in the studies conducted by the OSPAR Commission (OSPAR 2007). The biggest individual source of marine litter according to these studies was the fisheries industry, which leaves various kinds of rope,
twine and plastic containers. Shipping is also a major source of marine litter (OSPAR 2007). On the west coast of Sweden, Västkuststiftelsen collects 6000 m³ of rubbish every year that has been washed up on the beaches. It also collects large quantities of wood (www.vastkuststiftelsen.se).

In the 1970s, seabirds and marine mammals, primarily, were examined for traces of plastic in their crops, stomachs and faeces. As a result of human use of various plastics, these can be found in seabirds (Vlietstra and Parga 2002; Petry et al. 2007), fish (Carpenter et al. 1972) and marine mammals (Eriksson and Burton 2003). Researchers have also shown, in several studies, that the amount of microscopic plastic particles in water has increased significantly since the 1960s (Thompson et al. 2004). A Swedish study of the amount of plastic particles in water was conducted on the west coast in 2007, as part of the OSPAR Commission’s work with marine litter. The study showed that the number of plastic particles per cubic metre of water was between 150 and 2,400, which is up to 100,000 times greater than amounts measured in previous studies (Norén 2007). The large amount of particles found in this study is due to the use of a bag net with a smaller mesh (80 µm) compared with previous studies (450 µm). The plastic particles found in the sea are thus both smaller and greater in number than previously thought. No targeted studies of the occurrence of plastic particles along Sweden’s coasts have been conducted. A few foreign studies have shown the presence of plastics in fish stomachs (see e.g. Eriksson and Burton 2003) and in an early study it has also been shown that certain species of fish actively eat plastic particles (Carpenter et al. 1972). In studies performed in the Baltic Sea where the aim was to examine the diet of various species of fish, plastic particles have not been found (Sture Hansson, personal communication). It is unknown in what way the consumption of plastic affects fish, even if it is assumed that plastics may block the stomach and intestinal canal of small fish (Carpenter et al. 1972). This may lead to starvation or reduced growth rate. A Japanese study has shown that plastic particles can absorb organic contaminants such as PCBs and PAHs (Mato et al. 2001). Since the main raw material in plastic is oil, organic contaminants are easily absorbed by plastic particles. These can function as effective carriers of contaminants in the environment and even facilitate their transportation to organisms (Mato et al. 2001). However, it remains unclear how significant this is to the spread of contaminants and the extent to which it can affect various fish populations.
4 Conclusions

The fishing – the most important structuring factor

Altogether the research shows that fishing is the single most important factor impacting fish populations in Sweden’s lakes and marine environments. This applies primarily to fishing of commercially important species such as cod, herring and sprat. In addition to a substantial reduction of the cod populations by overfishing, selective fishing for large individuals has led to major changes in the age structure of the remaining stocks. This may lead to impaired reproductive potential and a reduced ability of the fish stock to cope with natural fluctuations in their habitat. Intensive fishing has also affected other organisms in the food web, which may have a far-reaching impact on the functioning of the entire ecosystem.

Certain types of fishing have a considerable impact on the rest of the ecosystem, because of by-catches of fish, birds and marine mammals. This primarily applies to fishing with fine-meshed bottom-trawls which involves large by-catches of fish, while birds and marine mammals are mainly caught in net-fishing. Increased use of selective gears would, in certain forms of fishing, reduce by-catches. Today, however, there are no strong incentives to use these gears to a greater extent. In addition to low selectivity, bottom-trawling also has a large impact on certain bottom-living animals and can cause the release of both nutrients and contaminants from the sediment.

In view of the major effect that fishing has on both target species and on the ecosystem as a whole, it is crucial that our fish populations are managed in a sustainable manner. It has been proven that management based on short-term decisions leads to both ecological and economic losses. Aquaculture can be regarded as a complement to fishing and the industry has the potential for growth, if this occurs in parallel with the sustainable management of our aquatic ecosystems. Recreational fishing and fishing tourism have considerable profits too, both economically and as a source of recreation. Studies show that industries linked to aquaculture, recreational fishing and fishing tourism can also have a major impact on rural economic development.

Eutrophication – long-term measures required

The effects of eutrophication on fish populations are complex and can, at an initial stage, be positive for many species since access to food tends to increase. However, a number of long-term effects of eutrophication have had a negative impact on our fish populations, including depleted oxygen levels, overgrowth in shallow archipelago areas and changes in the composition of species in the food web.

Long-term measures are needed to limit the effects of eutrophication. Reduced discharge of both phosphorus and nitrogen are needed and require both national and international measures. It is also crucial to take into account both external sources and internal processes in the sea. The dynamics of
nutrients are complex and we currently do not have a sufficient understanding of all the processes involved. It is also important to take into account the fact that different marine areas, coastal areas and lakes have different properties, and measures must be adapted to these specific conditions. The entire ecosystem must be considered when dealing with the problem of eutrophication. New research shows, for example, that a lack of predatory fish (e.g. cod) can aggravate the effects of eutrophication. A reduction in the amount of predatory fish can, like increased discharges of nutrients, lead to an increased amount of phytoplankton or macroalgae and, in the long term, lead to depleted oxygen levels and dead zones.

Contaminants - a cocktail of substances

Contaminants can cause many negative effects in fish, among those is a reduced reproductive potential. Such effects have been observed in areas surrounding industries or other sources of emissions. Pharmaceuticals in aquatic environments can also affect the reproductive potential of fish, a phenomenon observed in the immediate vicinity of water treatment plants. However, no large-scale effects on fish populations can currently be directly linked to contaminants or pharmaceuticals.

Many fish populations in Sweden have undergone major structural changes in which both heavy fishing pressure and eutrophication play an important role. In an ecosystem which has already undergone major change, contaminants can potentially affect the capacity of fish populations to recover. Diffuse emissions, both water-bound and air-bound, may impact fish populations more than we know today. Continued environmental monitoring, screening and research are important tools in our efforts to understand the effects of contaminants on our ecosystems.


