Interactions between seals and commercial fisheries in the North-East Atlantic

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CONTENTS

EXECUTIVE SUMMARY

1. This report identifies the most important interactions between seals and commercial fisheries in the North-East Atlantic, summarises information on the abundance and diet of the three most numerous seal species, on the status of fish stocks that are believed to interact with these population either directly or indirectly, and reviews the methods that have been developed to analyse seal-fishery interactions.

2. The most important interactions involve grey seals and cod in the North Sea, grey seals, harbour seals and salmon in the North-East Atlantic, grey seals and salmon and whitefish fisheries in the Baltic, and grey seals and monkfish in the Celtic and Irish Seas and off South-West England. All but the first of these interactions primarily involve problems in the immediate vicinity of fishing gear rather than competition between seals and fisheries.

3. The grey seal is the most abundant species in the North-East Atlantic, although large numbers of harp seals may occasionally invade the area from further north. Grey seal numbers in the North-East Atlantic have been increasing steadily since at least the 1960s. There is some evidence that pup production at grey seal colonies off the west coast of Scotland is no longer increasing, but total population size will continue to increase for several decades. In the Baltic, there are approximately equal numbers of grey seals and ringed seals. There is some evidence that both populations are increasing, but the rate of increase is less certain than some accounts suggest. Bycatch levels are relatively high. Both populations are at or below 10% of their size at the beginning of the 20^{th} century. Most harbour seal populations have recovered from the effects of the 1988 phocine distemper epidemic, and many local populations are still increasing relatively rapidly.

4. Cod stocks througout the North-East Atlantic are considered to be outside safe biological limits. The current size and catches from North Sea, West Scotland and Irish Sea stocks are at historical lows. The most important predators (responsible for more than 10% of predation mortality) in the North Sea are believed to be gurnard and seals.

5. Whiting stocks in the North Sea are outside safe biological limits but are recovering. The Celtic Sea stock is above its long term average size. The most important predators (responsible for more than 10% of predation mortality) in the North Sea are believed to be whiting, gurnard and cod.

6. There is serious concern about the status of the northern stock of monkfish because of the high proportion of immature fish in the catch. There is no quantitative information on predation mortality.

7. Salmon stocks have suffered major declines but the northern stock in the North-East Atlantic is believed to be within safe biological limits. However, further reductions in exploitation rates are required for the southern stock. There are no good estimates of predation mortality, or of the contribution of different predators, at sea and on fish returning to spawn.

8. All eel stocks in the North-East Atlantic are at historic low levels. There are no reliable data on predation mortality, but birds and seals are believed to be important predators.

9. All haddock stocks are outside safe biological limits and catches are at, or close to, historic lows. There is some evidence of improved recruitment in 2000. The most important predators (responsible for more than 10% of predation mortality) in the North Sea are believed to be saithe, whiting and cod

10. Plaice stocks are outside safe biological limits and recruitment is below the long term average. Seals appear to be the only important predators on adult plaice.

11. Herring stocks in the North Sea are being exploited at a rate that is above the level recommended by ICES. In the Baltic, stocks are within safe biological limits but catches are low because of the preponderance of small fish in the catch. The most important predators (responsible for more than 10% of predation mortality) in the North Sea are believed to be whiting, mackerel, saithe and cod. In the Baltic, cod are the most important predator.

12. Sprat stocks in the North Sea are high but TACs have been set low to reduce the bycatch of herring. In the Baltic the stock is above its long-term average. The most important predators (responsible for more than 10% of predation mortality) in the North Sea are believed to be whiting and mackerel. In the Baltic, cod are the most important predator.

13. Sandeels in the North Sea are within safe biological limits. The most important predators (responsible for more than 10% of predation mortality) in the North Sea are believed to be mackerel, whiting and seals.

14. There is no agreed methodology for assessing the potential impact of a reduction in seal numbers on commercial catches of fish. A number of promising avenues have been explored but high levels of uncertainty are associated with the predictions obtained.

15. There is insufficient information on all of the interactions described in point 2. to fulfill the data requirements described in the UNEP Protocol for the Scientific Evaluation of Proposals to Cull Marine Mammals. However, most of the data required to evaluate the interactions between grey seals and cod in the North Sea are likely to become available over the next two years.

16. There are few instances of proposals to cull marine mammals to protect fisheries outside the North Atlantic, although there is growing concern about the potential impact of increasing marine mammal populations in many places. In the US a number of fisheries have been, or are likely to be, restricted because of concerns about their impact on the recovery of endangered seal species.

1. Introduction

1.1 General approach

Fish forms a large part of the diet of most seal species and, particularly at a time when many commercial fish stocks are declining or are at very low levels, it is not surprising that many fishers consider seals to be pests whose numbers should be drastically reduced. The perception of this problem has been exacerbated in recent decades because, following the cessation of centuries of exploitation, many European seal populations have been increasing in size.

The interactions between seals and commercial fisheries can be conveniently divided into two categories: **direct interactions**, which occur in the immediate vicinity of fishing gear and may involve damage to fish that have already been caught and to the gear itself, and **indirect interactions**, where the interaction is through a shared resource. The strength of indirect interactions are likely to be related in some way to the size of the seal population that is involved, but economically or ecologically important direct interactions can occur even when seal populations are at low levels. For example, the critically endangered Mediterranean monk seal (*Monachus monachus*) may cause considerable damage to fish caught in fine-mesh trammel nets in parts of Greece where it is most numerous, despite the fact that the total world population of the species is probably less than 500 individuals. Most of this report is concerned with the problems of evaluating indirect interactions, in which the estimated consumption of commercially important fish species is compared with the commercial catch of that species. However, we have only been able to identify two situations – the potential impact of predation by grey seals on North Sea cod, and by grey seals and harbour seals on Atlantic salmon in rivers and estuaries – in the North-East Atlantic and the Baltic Sea where indirect interactions are currently considered to be economically important. The other high profile interactions are essentially direct ones. Grey seals and harbour seals may also have an impact on the value of fisheries catches because they are the final host of the parasitic nematode worm *Pseudoterranove decipiens*, which used to have the common name "codworm" but is now more frequently referred to as "sealworm". A large number of commercially important fish species are used as intermediate hosts by this parasite and the presence of worms in their flesh can substantially reduce their resale value or require expensive processing. Sealworm is reported to be an economically important problem on the Atlantic coast of Canada and in some parts of Norway. Although there is some evidence that the prevalence of sealworm can be particularly high in areas where seals are locally abundant, this is not always the case. The expected relationship between worm burdens in fish and seal population size is complicated and we will not address it in this report.

The structure of this report largely follows the recommendations of a report of the Scientific Advisory Committee of the UNEP Marine Mammal Action Plan on the kinds of data that are required to evaluate proposal to cull marine mammal (UNEP 1999). These are summarised in Table 1.1. Although the UNEP Protocol was published in October 1999, it should be realised that it is based on discussions held at workshops in 1992 and 1994 and therefore does not reflect the results of research that have been published since 1994. In particular, the UNEP Protocol suggests that so-called minimum realistic models might be used to investigate the possible consequences of a cull of marine mammals under a range of different assumptions. Work since 1994 has indicated that it may be difficult to determine how many species need to be incorporated into such models before any confidence can be attached to the phrase "minimum realistic".

Table 1.1. Data for evaluation of proposals to cull marine mammals based on fishery impacts, from UNEP (1999, Table 2)

(i) Marine mammal:
- distribution and migration
- per capita food/energy consumption
- diet composition, including methods of sampling and estimation
- demographic parameters

(ii) Target fish species:
- distribution and migration
- demographic parameters (weight at age, age at spawning, etc., commercial catch per unit effort
- details of assessment models and results

(iii) Other predators and prey of the target species:
- abundance, amounts consumed, details of stock assessment if any

(iv) Other components of the ecosystem
- 2-way matrix of "who eats whom" with estimated or guessed annual consumptions
- estimated abundance by species

1.2 Seal populations in the North-East Atlantic and Baltic Sea

Three seal species (the grey seal *Halichoerus grypus*, the harbour (or common) seal *Phoca vitulina*, and the Baltic ringed seal *Phoca hispida botnica*) breed in the North-East Atlantic and Baltic Sea. All three are listed as species of Community interest in EU Habitats and Species Directive (92/43/EEC), and the Baltic ringed seal is listed as vulnerable to extinction by IUCN, the World Conservation Union. We will focus on these species in this report.

Two other species (the hooded seal *Cystophora cristata*, and the harp seal *Pagophilus (=Phoca) groenlandicus*) breed around Jan Mayen, in the Greenland Sea, and there is another breeding concentration of harp seals in the White Sea. Both species may enter North-East Atlantic waters in some numbers. In particular, substantial numbers of hooded seals are known to forage off the edge of the continental shelf in Irish and UK waters, but very little is known of their biology.

Three seal species (the bearded seal *Erignathus barbatus*, the Arctic ringed seal *Phoca hispida hispida*, and the walrus *Odobenus rosmarus*) occur as vagrants in the North-East Atlantic. They will not be considered in the main body of this report as their interactions with fisheries are generally trivial.

Bearded seals are found throughout the Arctic and sub-Arctic regions, although their distribution is patchy. Their normal range extends south from 88ºN to northern Norway and the north coast of Iceland, although individuals have been reported as far south as Portugal. Bearded seals have been observed almost annually along the North Sea coast of Britain for the last decade, particularly in Shetland. One emaciated individual was found on a beach in Lincolnshire in 1998 and subsequently released in Shetland. Another individual frequented the fish quay at Hartlepool on the east coast of England for most of January 1999. In the period April to June 2000 there were multiple sightings of a single animal on Yell, Shetland (Shetland Sea Mammal Group, 2001).

The ringed seal is predominantly an Arctic, ice-breeding species with a circumpolar distribution. Although it is generally non-migratory, ringed seals may make long distance movements following the distribution of pack ice. Occasionally young animals may move southward and there have been a number of records from the coasts of North Sea states. There were 14 records from the North Sea between 1970 and 1980, and 21 between 1980 and 1990 (Van Bree, 1997). Ringed seals are easily mistaken for harbour seals, and they may occur more frequently in the North Sea than the current records indicate since they were known to have been taken regularly by seal hunters operating in Shetland during the 1960's.

The walrus (*Odobenus rosmarus*) is normally found in shallow water around Arctic coasts. However, its distribution extended much further south in historical times and it has occurred in Germany, the Netherlands and Belgium, as well as the UK.

The endangered Saimaa seal (*Phoca hispida saimensis*) and the vulnerable Ladoga seal (*Phoca hispida ladogensis*) live in large bodies of freshwater adjacent to the Baltic Sea. However, neither subspecies occurs in the Baltic, and they will not be considered here.

1.3 Target fish stocks

There are four basic interactions between seals and commercial fisheries in the North-East Atlantic and Baltic which appear to be particularly important:

- The indirect effects of predation by grey seals on commercial catches, and the recovery, of cod stocks in the North Sea.
- The indirect effects of predation by grey seals and harbour seals in estuaries and in the open sea on the recovery of Atlantic salmon stocks.
- The direct effects of grey seals, and possibly harbour seals, on a range of different fisheries for salmon.
- The direct effects of grey seals on bottom-set gillnet fisheries for monkfish in the Celtic and Irish Seas, and off South-West England.

There may also be a direct interaction between grey seals and drift net fisheries for herring in the Baltic Sea.

Following the UNEP guidelines, we have considered not only the fish and seal stocks directly involved in these interactions but also (in the cases of North Sea and Baltic cod, and Baltic salmon) the stocks of the important predators and prey of these species. We have therefore also considered the current status of stocks of whiting, monkfish, eels, haddock, plaice, herring, sprat, and sandeels.

1.4 Relevant fisheries

Fisheries implicated in the first interaction include trawl and gillnet fisheries operated particularly by the UK, Denmark and Norway. Salmon fisheries that may be affected by interactions with seals include fixed net fisheries on the east coast of Scotland, and trap and gillnet fisheries in Ireland and the Baltic. We have not considered the impact of seal predation on non-commercial rod and line fisheries or on salmon aquaculture, although we recognise that such predation may have substantial economic effects.

2. Seal populations

2.1 Introduction

2.1.1 Methods for estimating population size

Seals spend most of their time at sea, and mostly underwater. As a result, it is difficult (and usually impossible) to census the whole of a seal population directly. Instead, some more accessible but well-defined component of the population is counted. Grey seals aggregate to breed, and their pups remain on the land or ice where they are born over a number of days or weeks. It is this component of the grey seal population that has traditionally been censused. Although harbour seals also aggregate to breed, their pups are often born on intertidal rocks or sandbanks, so they spend some of their time in the water from birth. For this species, a different component of the population, usually the number of seals hauled out during the annual moult in July or August, must be censused. In recent years, survey work in the Baltic Sea has also concentrated on this component of the grey seal population, because it has been difficult to locate ice-breeding aggregations. Ringed seals breed in sub-nivean lairs on ice, which are virtually impossible to detect from the air. However, adults spend a large proportion of their time on the ice at the end of the pupping season, when they can be counted in low-level aerial surveys.

In order to convert the estimate of the number of pups born in a particular year, or the number of seals counted out on a particular day, to an estimate of total population size, additional information on the life history and behaviour of the surveyed species is required. If pup counts are being used, the number of adult females can be estimated if the proportion of females that give birth each year is known. The number of subadult animals can be estimated in a number of ways. At the very least, we need to know annual survival rates from birth to first breeding. These rates will depend not only on the natural risks that young seals are exposed to, but also on how many are killed by hunters or taken as bycatch in fishing gear each year.

For counts of seals hauled out on rocks, sandbanks or ice, information on the proportion of time that animals spend out of the water is required. This can be obtained by attaching radio transmitters to individuals an monitoring their behaviour. However, sample sizes are likely to be small, and transmitters may become detached during the moulting process. Resightings of individually-recognizable animals – either those that have been deliberately marked by branding or which can be recognized by their unique markings – can also be used to provide this information. A number of studies have indicated that there are significant differences between the haul out behaviour of males and female harbour seals, and among age classes. These differences must be accounted for in converting counts to estimates of population size.

Resightings of individuals that can be recognized by their markings can also be used to estimate population size using mark-recapture analysis. This approach has been used to estimate the size of the grey seal population in the Baltic (Hiby et al. 2001), and is being developed for harbour seals (Hiby, pers. comm.).

2.1.2 Methods for estimating mortality and fecundity rates

The mortality suffered by a seal population can be conveniently divided into that resulting from natural causes and that resulting from human actions. Human-induced mortality includes seals deliberately killed as part of hunts or culls (including an allowance for seals that are killed but not recovered by hunters), and seals that die following entanglement in fishing gear. Clearly this mortality may vary substantially from year to year and needs to be explicitly documented. It is generally assumed that mortality from natural causes (such as disease, accident, starvation and predation) fluctuates around some long-term average and can be described by a single parameter. In populations that are not subject to large-scale human-induced mortality, natural mortality rates can be estimated from an examination of the number of animals in successive age categories. However, all of the seal species have a history of exploitation, culling or periodic mass mortalities that is reflected in their age structure. These perturbations have made it very difficult to estimate natural mortality from population age structure. In principal, mark-recapture analysis of the resightings of individually-recognizable animals can also be used to estimate mortality rates, but this approach has yet to be applied to seal populations in the North-East Atlantic.

If pregnancy and mortality rates remain constant over time, then the number of pups born each year in a seal population provides a reliable index of the total size of a seal population. However, if these rates vary over time, then trends in pup production can be misleading. In order to understand the dynamics of a seal population it is therefore necessary to monitor pregnancy rates. Since pregnant animals may lose their foetus at any time during pregnancy, pregnancy rates recorded during the later stages of gestation provide the most reliable link between pup production and the size of the adult female population. At present such information can only be obtained through post-mortem analysis, either of animals deliberately killed for scientific purposes or of animals that are bycaught or killed in hunts or culls.

2.1.3 Methods for estimating diet and prey consumption

Studies of the diet of seals in the North-East Atlantic have been based on the identification and measurement of prey remains (usually hard parts, such as fish otoliths) found in gut contents or faeces collected at haul-out sites. In some cases diet composition is simply estimated from the frequency with which different prey species are recorded. However, this can be misleading because the importance of prey species whose average size is small will be overestimated. It is preferable to estimate the weight and energy content of the original prey items and use these estimates as the basis for calculating the contribution that each prey species makes to the seal diet. Estimates of the total energy requirements of seals of different ages, based on laboratory or field studies, are then combined with estimates of the numbers of seals of the given ages in the population to calculate the total quantity of each prey species consumed.

The nature and direction of the biases in estimates of diet composition from stomachs or faeces are well known, and some allowance can be made for these in interpreting the data (e.g., Bowen and Harrison 1994). In particular, these techniques have been criticized for underestimating the importance of commercially important species in seal diets. However, they may also underestimate the importance of non-commercial species. Both methods, using stomach contents or faeces, rely on the presence of relatively undigested hard parts from prey in the samples and cannot account for prey without identifiable hard parts, or when hard parts are not ingested or are digested very rapidly. For example, it is often claimed that seals may eat only the bellies of large fish and that these size classes are therefore under-represented in the estimated diet. Diet quality is probably the largest source of calculable uncertainty in the estimates of consumption by seals (Shelton et al. 1997). Resampling methods (eg Hammond and Rothery 1996, Warren et al. 1997, Shelton et al. 1997) can, in principle, be used to provide confidence limits on estimates of diet compostion and quantities of fish consumed, but it is usually difficult to account for all sources of uncertainty. For example, to the best of our knowledge, no attempt has been made so far to account for uncertainties in the estimates of daily energy requirements, even though there is known to be large variation in published estimates of basic metabolic rate within individual seal species.

Other techniques which could be used for assessing seal diets include:

- Serological tests for the recent consumption of different prey species (Pierce et al. 1990). These can indicate whether or not seals have been consuming prey species whose identifiable hard parts are not ingested or are easily digested. However, they cannot be used to estimate the amounts of these species that have been consumed.

- Analysis of stable-isotope ratios provide information on the proportion of the diet which has come from different trophic levels (e.g., zooplankton, forage fishes, fish predators). This can give some insights into changes in food types over time (e.g., Lawson and Hobson 2000).
- Fatty acid "profiles". The kinds and amounts of different fatty acids in seal blubber or milk should reflect to the amounts of these fatty acids in the seals' prey and the quantities of the different prey species that have been consumed (Smith et al. 1997, Iverson et al. 1997). These fatty acid "profiles" provide a summary of an animal's diet over a considerable period of time, rather than reflecting the composition of one or two meals, as is the case with gut or faecal analysis. One potential problem with this method is that the fatty acid composition of a prey species may vary depending on the prey's own diet. However, Kirsch et al. (1998) fed captive seals with cod that had been fed either lean squid (*Loligo* sp.) or fatty mackerel (*Scomber scomber*) and found that "both cod and [its] prey . . . consumed by a larger predator [e.g., seals] can . . . still be distinguished from one another." Walton et al. (2000) carried out a preliminary analysis of the fatty acid composition of the blubber of British grey seal and found apparent differences in diet between seals foraging in the Atlantic and those foraging in the North Sea. However, it was not possible to identify which prey species were involved.

At the moment, only the analysis of prey remains in faeces or stomachs can provide quantitative estimates of diet composition and so it has been impossible to compare results obtained from these different methods.

2.2 Grey seal

2.2.1 Geographical distribution

Grey seals are confined to the North Atlantic, Baltic and Barents Seas. Grey seals haul out on land or ice for breeding and between foraging trips at sea. When breeding on land, they form large aggregations in which females give birth to a single pup, which is suckled for around 3 weeks. Females mate before returning to sea.

There are three recognised populations of grey seals which breed in the northwest Atlantic (primarily on Sable Island, Canada and in the Gulf of St Lawrence), in the Baltic Sea, and in the North-East Atlantic (primarily on offshore islands around the British Isles but also in Iceland, the Faeroe Islands, France, the Netherlands, central and northern Norway, and around the Kola peninsula in Russia). Historically, most of the pups in the Baltic were born on ice in the Bothnian Bay. However, in recent years, perhaps due to poor ice cover throughout the Baltic, a high proportion of pups have been born on islands off the coast of Estonia. The first successful breeding of grey seals in the Wadden Sea in the 20th century was recorded at Terschelling in the Netherlands in the 1980's. Pup numbers there have increased from just 2 in 1985 to more than 100 in 2000. Recent counts of older animals number around 500. The first firm evidence that grey seals breed on the west coast of Norway south of 62ºN was obtained in 2000, when 21 pups were tagged.

Timing of pupping differs throughout the range of the species. The North-East Atlantic population pups in the autumn, from September to December; in the Wadden Sea this period extends into January. In the Baltic, grey seals pup from January to March.

2.2.2 Population size

The North-East Atlantic population has been increasing in size by around 6% annually since the 1960's. It is currently estimated to consist of approximately 124,000 individuals. At the beginning of the 20th century it was much smaller: the grey seal was was the first mammal to be protected by British legislation, under an Act of Parliament passed in 1914. At that time, it was believed that there were only a few hundred grey seals left in the country. By the late 1950s, so many complaints had been received from fishermen about the effect of increasing grey seal numbers on their catches that the British Government established a Consultative Committee on Grey Seals and Fisheries. In 1963 this Committee recommended that grey seal numbers at the Farne Islands and in the Orkney islands, Scotland, should be reduced by a series of pup harvests. In practice, pups were taken from the Farne Islands only in 1963, 1964 and 1965. Pup hunting in Orkney continued from 1962 to 1982, with more than 1,000 pups being taken in some years, and was extended to the Outer Hebrides between 1972 to 1979. Smaller numbers of pups were also taken in Shetland over this period. Despite these actions, grey seal numbers continued to rise through the 1960s and early 1970s (Summers 1978). Nearly 2,000 adult grey seals were shot at the Farne Islands in 1972 (Bonner and Hickling 1974) and 1975 (Hickling et al. 1976) in an attempt to control numbers there. In 1977 a management plan to reduce the size of the Scottish grey seal population was instigated. The aim was to reduce mortality on fish stocks by killing 5,400 adult females and 24,000 pups over a five year period (Summers and Harwood 1979). In practice, only the first year of this plan was carried out, and it was abandoned in 1978 because of widespread public opposition (Harwood and Greenwood 1985). British fishermen have continued to call for a reduction in grey seal numbers since 1978, but no new action has been taken. In Norway, hunting of grey seals has recently (1998) been resumed, apparently in an effort to reduce perceived conflicts with fisheries (see Chapter 6), although the quota has not been taken in full. According to ICES (2001m, p6), the current quota of 400 seals on the coast south of 62°N "exceeds the documented population size", and only small numbers of grey seals have been taken (9 in 1999, 70 in 2000 – ICES 2001m).

The grey seal population in the Baltic is estimated to be 12,000 animals (Hiby et al. 2001), based on a photo-identification study conducted over six years. Historically the grey seal population of the Baltic was much larger than this: the population in 1900 is estimated to have been more than 100,000 (Hårding and Härkönen 1999), but numbers were reduced by over-hunting and the effects of pollutant-induced sterility. Hunting of grey seals has now been resumed in Sweden and Finland, again with the apparent intention of reducing damage to fisheries (see Chapter 6). The Swedish quota in 2001 was 150, of which 52 animals were taken (H. Westerberg, pers. comm.)

Counts on the Swedish coastline carried out during the moult have increased by 6-7% annually in recent years (Helander 2000), and the most recent comparison of coordinated counts throughout the Baltic (M Jüssi, pers. comm.) gives a total of 10,000 animals – very close to the estimate based on photo-identification. The observed increase in counts in Finish waters during the 1990s (from 400 in 1991 to 2,200 in 1999) reported in ICES (2000c) is too great to be the result of intrinsic growth and must, at least in part, have been the result of redistribution. Reported levels of bycatch are rather high (>500 animals per year, mostly caught in salmon gear – ICES 2000c). This represents an additional 4% mortality for a population of 12,000 animals. Hiby et al. (2001) calculated two values of annual survival for the Baltic population from their photo-identification data: a direct estimate of 0.9035, and an indirect estimate of 0.936 based on the assumption that the population was increasing at 6.5% per year. The second figure appears unlikely, because it implies that survival in the absence of bycatch would be around 0.98 (that is, only 2% of the grey seal population would die each year from natural causes!). The direct calculation of 0.9035 seems much more realistic and implies that the population is increasing by around 3% annually, rather than the

6-7% estimated from the moulting counts. The rate estimated from the counts may have been biased by, for example, improved counting efficiency in recent years.

Table 2.1 summarises information on the sizes of local populations. Abundance estimates are mainly based on counts of pups, but in the Baltic they are based on mark recapture analysis.

Table 2.1 Sizes of grey seal populations in the North-East Atlantic.

Area	**Population size (year)**	**Status**
Shetland	3,300 (1977)	Probably stable, but no systematic survey of all colonies has been conducted of all since 1977.
Outer Hebrides	40,200 (2000)	Pup production stable, total population still increasing
Inner Hebrides	9,700 (2000)	Pup production stable, total population still increasing
Ireland	2,000 (1997-99)	Unknown
Southwest Britain	4,700 (1999)	Stable
Orkney	48,000 (2000)	Increasing
UK North Sea coast	12,900 (2000)	Increasing
Norway	3,000-3,500 (1986)	Unknown
Germany	71 (1991)	Increasing
The Netherlands	500 (2000)	Increasing
Baltic	12,053 (2000)	Increasing

2.2.3 Diet

Estimates of the diet of grey seals are available from several sites around the UK (Hebrides, Orkney, Moray Firth and several sites on the North Sea coast), Ireland, Norway, and the Faroes. Most of the diet seems to be made up of fish that are commercially exploited, although some – such as sandeels – are of low commercial value. However, most of the UK estimates date from the mid-1980s, and there have been major changes in the abundance of many fish stocks since that time.

Hammond et al. (1994a) used faecal samples collected in 1985 to estimate that 40% of the diet, by weight, of grey seals in the Hebrides was made up of gadid fish (mainly ling, cod and whiting), flatfish made up 10-30% of the diet (depending on the locality and season), and sandeels (*Ammodytes* spp.) were an important component in the Outer Hebrides.

Hammond et al. (1994b) also used faecal samples collected in 1985 to estimate that sandeels accounted for almost half of the diet by weight of grey seals in Orkney. A further 25% of the diet was made up of gadids (mostly cod and ling).

At North Sea sites (Hammond et al. 1997), sandeels were the most important component in the diet, making up 10-30% by weight. Cod was the most important component for seals which hauled out at the Isle of May, making up around one third of the diet. Flatfish, particularly Dover sole, were more important at the southern sites. Thompson et al. (1996) obtained similar results from the analysis of faecal samples collected in the Moray Firth area, with sandeels making up 64% of the diet by weight, flatfish 11% and cephalopods (mostly octopus) 15%.

Arnett (2001) found that ling, scad and *Pollachius* spp. were the most important items in the diet of grey seals on the west coast of Ireland, based on faecal analysis. Gadids were the most important components of the diet estimated from the stomach contents of bycaught animals. Whiting appeared to be more important in the diet of these animals than in the faecal samples. No traces of monkfish remains were found in the Irish samples, and very few salmon remains have been found in samples collected from Ireland and the UK. This is a little surprising considering that seals are known to cause problems in the fisheries for these species.

Mikkelsen and Haug (1999) found that gadoids, sandeels and catfish made up 80% of the prey remains in a small sample of grey seal stomachs collected in Faroese waters.

There appear to be no recent data on the diet of grey seals in the Baltic (ICES 2000c).

2.2.4 Prey consumption

Hammond and Fedak (1994) estimated the quantities of commercial fish species consumed by grey seals in the North Sea in 1992, and also calculated 95% confidence limits on these estimates. The most important species consumed were sandeels (27,100-47,600 tonnes), cod (7,300-16,000 tonnes), ling (2,700-12,200 tonnes), and whiting (3,700-9,100 tonnes). Total fish consumption was 76,300 tonnes, more than 90% of this was fish species that are commercially exploited. In general, most of the fish consumed were smaller than those taken by the commercial fisheries, although there was substantial overlap. As noted above, most of the diet data on which these calculations are based was collected in 1985. A new round of sample collection from the North Sea and North-East Atlantic coasts of the UK is planned for 2002/2003.

2.3 Harbour (common) seal

2.3.1 Geographical distribution

Harbour seals are one of the most widespread pinniped species and have a practically circumpolar distribution. There are four sub-species, but only *Phoca vitulina vitulina* occurs in the North-East Atlantic and Baltic Sea. Its distribution extends as far north as Spitzbergen and there is a small population along the Barents Sea coast of Russia.

2.3.2 Population size

Population estimates for harbour seals are primarily based on counts made from aerial surveys conducted during the moult, when the largest proportion of animals is believed to haul out. However, in some areas (for example, the Moray Firth in Scotland) land and boat counts made at the end of the pupping season are considered to be more reliable.

The world population of this sub-species is estimated to be around 70,000 individuals, but this does not take account of animals in the water at the time the aerial surveys were conducted. Table 2.2 shows the size of different local populations. No estimates of the historical size of most populations are available, but ICES (2001m) suggests that, at the beginning of the 20th century there were 40,000 harbour seals in the Wadden Sea, 17,000 harbour seals in the Kattegat/Skagerrak, and less than 5,000 harbour seals in the Baltic. There has been a long history of hunting for most populations, and this was responsible for major declines in Shetland, the Wadden Sea, and the Baltic. Populations in the southern North Sea and the Kattegat/Skagerrak were severely affected by an outbreak of phocine distemper in 1988 which resulted in up to 60% mortality in some areas. However, most local populations have recovered to their pre-epidemic levels and many are still increasing. There appear to be genetically distinct populations within the Baltic. Both occur in Swedish and Danish waters (ie in the western part of the Baltic) but, somewhat confusingly, the most easterly of these populations (which occurs around the island of Kalmarsund) has traditionally been referred to as the East Baltic population. The Kalmarsund population was unaffected by the 1988 epizootic.

Table 2.2 Sizes and status of harbour seal populations in the North-East Atlantic and Baltic Sea.

Area	Population size (year)	Status
Ireland	900 (1978)	Unknown
Northern Ireland	400 (1997)	Decrease since 1970s
UK – Outer Hebrides	2,400 (1996-2000)	Increasing
UK – Scottish W coast	10,800 (1996-2000)	Increasing
UK - English E coast	4,250 (2000)	Increasing
UK - Scottish E coast	1,500 (1996-97)	Stable
UK – Shetland	6,000 (1996-2000)	Increasing
UK – Orkney	8,500 (1996-2000)	Possible decrease
Wadden Sea (Denmark)	2,100 (2000)	Increasing
Wadden Sea (Germany)	11,500 (2000)	Increasing
Wadden Sea (Netherlands)	3,300 (2000)	Increasing
Norway S of 62ºN	1,200 (1996-8)	Unknown
Limfjorden (Denmark)	1,000 (1998), 495 (2000)	Decrease since 1998
Kattegat/Skagerrak	9,752 (2000)	Increasing
West Baltic	315 (1998)	Small increase
Kalmarsund (East Baltic)	270 (1998)	Increasing

2.3.3 Diet

The most detailed data on the diet of harbour seals, and the way in which diet may be influenced by prey availability, comes from studies conducted by Thompson in the Moray Firth. He found that five species (sandeel, cod, whiting, herring and sprat) made up more than 85% of the diet by weight, and that the proportion of herring and sprat varied depending on the availability of these species (Thompson et al. 1997). Even though harbour seals are known to cause damage to salmon netting stations, there was very little evidence of salmon in the diet data.

Berg et al. (1999) found that saithe was the most important item in the diet of harbour seals in northern Norway. Olsen and Bjørge (1995) found that Norway pout was the most important species (by number) in the diet of harbour seals from southern and central Norway, with other gadids being well represented. They did not convert these values into estimates of consumption by weight.

Härkönen (1987, 1988) and Härkönen and Heide-Jørgensen (1991) found that cod and lemon sole made up 35% of the diet by weight of harbour seals in the Skagerrak, based on faecal samples collected between 1977 and 1979. However, in samples collected in 1989 herring was as important as cod by weight, and accounted for 38% of the total energy consumed. No confidence limits were presented.

2.3.4 Prey consumption

The only estimate of total prey consumption by harbour seals that we have been able to locate is that made by Härkönen and Heide-Jørgensen (1991) for harbour seals in the Skagerrak. They calculated that this population consumed 2,400 tonnes of fish in 1989, mostly herring and cod. About 25% of this consumption was of species that are not commercially exploited.

2.4 Baltic ringed seal

2.4.1 Geographical distribution

The Baltic ringed seal is, as its name suggests, confined to the Baltic. It breeds in sub-nivean lairs on sea ice in the Bothnian Bay, Gulf of Finland and Gulf of Riga.

2.4.2 Population size

Ringed seals were heavily exploited at the beginning of the 20th century, when the population was estimated to be of the order of 200,000 animals (Hårding and Härkönen 1999). Up to 16,000 animals being taken per year and the population declined rapidly from 1910 to 1940. This decline continued into the 1980s because a high proportion of female seals were rendered effectively sterile by occlusions in their uterine tracts, probably caused by high levels of organochlorine pollutants. Numbers of seals in the Bothnian Bay have been surveyed regularly since 1975. A decreasing trend was seen up to 1984, but counts have increased at an annual rate of 5% since 1988. The most recent published estimate is 3,954 in 1996 (ICES 2000c). Numbers in the Gulf of Finland were relatively high in the 1970s, with up to 8,000 animals being estimated in 1973. However, there appears to have been a mass mortality in this population in 1991, and counts since then have not exceeded 300 individuals. Up to 4,500 ringed seals were estimated to be in the Gulf of Riga in the early 1970s, but the most recent count is of 1,407 animals in 1996. Taken together these results suggest that the current population may be around 6,000 animals.

Bycatch rates in the Baltic are relatively high, and up to 150 animals may be taken each year, primarily in fyke nets and fish traps.

2.4.3 Diet

Most of the information on ringed seal diet comes from bycaught animals. Herring, smelt, stickleback and crustaceans appear to have been the main prey of these animals, but this may not be an accurate reflection of the diet of animals away from fishing gear.

2.4.4 Prey consumption

We have not found any estimates of the quantities of prey consumed by ringed seals in the Baltic.

2.5 Other seal species

2.5.1 Harp sea

The harp seal is a highly migratory and gregarious species which breeds in large aggregations on ice on the east coast of Canada, around Jan Mayen and in the White Sea. Outside the breeding season they are mainly found north of 65ºN, but in some years large scale southerly movements occur. In 1987 and 1988 over 70,000 seals were drowned in fishing nets along the north coast of Norway, and animals were observed as far south as France. These reports are summarised in Heide-Jørgensen et al. (1992). The invading seals consumed large quantities of herring, cod, saithe, haddock and Norway pout. Ugland et al. (1993) suggested that this predation may have contributed to the small size of the 1985 year-class of cod and the 1985 and 1986 year-classes of saithe. Another, smaller scale, invasion occurred in 1994 and 1995 (Van Bree, 1997). Both invasions are generally considered to have been a consequence of the collapse of the Barents Sea stock of capelin, which is the predominant species in the diet of harp seals in this area.

2.5.2 Hooded seal

Hooded seals are found throughout the northern part of the central and western North Atlantic. Three breeding aggregations are known: one to the north of Jan Mayen in the

Greenland Sea, another off Newfoundland and in the Gulf of St Lawrence, and the third in the Davis Strait. From September onwards hooded seals may make long excursions (Folkow and Blix, 1995, Folkow et al. 1996) to deep waters off the Faroe Islands, and these excursions may extend further south along the edge of the continental shelf off the west coast of Ireland and Scotland in April and May. Pups have been recorded as far south as Portugal. In June, the seals head for moulting sites in the Greenland Sea, north of Jan Mayen and east of Greenland and in the Denmark Strait. Hooded seals have been observed along the edge of the UK continental shelf by SAST observers (Tasker, pers. comm.). Given their preference for deep water on and beyond the edge of the continental shelf, it is not surprising that adult hooded seals are rarely observed in the North Sea. However, reports from the North Sea have increased steadily from four in the decade 1971-80, to 16 between 1991 and 1996 (Van Bree, 1997). Many of these reports are of pups that are brought in to seal rescue centres in southern England and the Netherlands.

The diet of hooded seals in the North-East Atlantic is not known, but in the North-West Atlantic they are known to consume cod, redfish, Greenland halibut and other flatfish (Hammill and Stenson 2000).

3. Fish information

3.1 Introduction

In order to regulate the fishing industry and control the rates of exploitation, fishery managers require information on the state of fish stocks. In general the information required on each stock is the numbers of fish or their total weight, the stock biomass, and some indication of the "health" of the stock. Four main characteristics are usually estimated: **spawning stock biomass** (the total weight of mature fish capable of spawning); **recruitment** (the number of young fish which survive to enter the adult, or fished, stock in a particular year); **landings** and **total catches** (the total tonnage landed by all fisheries exploiting the stock, and the total quantity actually removed by these fisheries); and **fishing mortality** (the proportion of fish taken each year by the fisheries).

Each year, researchers in the relevant countries investigate the changes in these characteristics and forecast the likely outcomes of different fishing regimes. The International Council for the Exploration of the Seas (ICES) coordinates the collection of data from the European fishing nations and these data is pooled for the process of stock assessment, which is carried out by relevant Working Groups and overseen by the Advisory Committee on Fisheries Management. It is the responsibility of the individual ICES member countries to actually collect the data. Data is basically of two types: fishery-dependent (catches, discards, fishing effort and sampling of commercial catches); and fishery-independent (research vessel surveys, tagging data, stomach content analysis, estimation of mortality from disease or pollution etc). Generally data on catch composition is collected by national statistical offices, while data on fish age, size and maturity is provided by Governmental fisheries institutes.

Pooled data are analysed to obtain estimates of stock size, recruitment, and fishing mortality, usually by Virtual (sometime called Sequential) Population Analysis (VPA), a method first described by Gulland (1965). VPA can only be applied to a single stock and takes no account of interactions between species. However, a multi-species version on VPA (MSVPA) has been developed and is applied periodically to data on all exploited fish species in the North Sea. There are problems with using the outputs of MSVPA to provide management advice, but it is particularly useful for obtaining estimates of natural mortality rates for key species.

3.1.1 Methods for estimating catch and population age structure

VPA requires information on the number of fish in each age class that are removed by the fishery each year. This information is obtained from market sampling, discard sampling and surveys by research vessels.

Landings at fish markets are regularly sampled, and the lengths of a large sample of the catch are measured. The age of a sub-sample of these fish, or of fish taken on research cruises (see below), is estimated from examination of the growth rings in scales or otoliths (ear bones). Otolith ageing is more difficult and time consuming than scale reading, so it is less adaptable to fisheries wide sampling programs. These data are then used to develop and age/length key which is used to convert the information on the length-structure of the catch to age-structure information.

Some caught fish are never landed, but are discarded at sea. Discarding rates are estimated by placing observers on selected fishing boats who record levels of discarding and collect fish samples for routine analysis. This information is then used to scale up the landings data to provide an estimate of total removals by the fishery, by species and age.

Information on recruitment is obtained from dedicated research cruises using nets with mesh sizes that are smaller than the minimum size used by commercial vessels. These catches provide information on the relative strengths of age-classes which have yet to be recruited to the fishery, and can be used to estimate recruitment rates. These cruises also provide additional information on abundance, which is used to calibrate the VPAs, and information on the distribution of stocks.

3.1.2 Methods for estimating stock sizes and status

There are two main approaches to stock assessments: VPA, using catch-at-age data; analysis of catch-at-length data; and "uninvolved" estimates of biomass (e.g. from acoustic surveys).

VPA is the most widely used method and requires information on the numbers of fish caught at each age on an individual cohort basis. The following two catch equations are then solved:

$$N_{y,a} = \exp(Z_{y,a}).N_{y+1,a+1}$$

$$C_{y,a} = (F_{y,a} / Z_{y,a}).[\exp(Z_{y,a})-1].N_{y+1,a+1}$$

Where $N_{y,a}$ is the number of fish in age class a caught in year y; $Z_{y,a}$ is the total mortality rate – made up of M_a, the natural mortality rate, and $F_{y,a}$, the fishing mortality rate; and $C_{y,a}$ is the total catch over the year. In principle, catch-at-length data could be analysed in the same way. This would avoid the necessity to convert these data to catches-at-age, and the biases and uncertainties that are associated with this transformation. However, the development of length based abundance estimates is still in its infancy.

For species such as herring and blue whiting, which aggregate in large single species shoals, abundance estimates over the distribution of the whole stock can be made from acoustic surveys.

In addition to total stock biomass (TSB), it is also important to be able to estimate the spawning stock biomass (SSB) - the abundance of reproductively-active fish. One way to estimate this is to determine the total number of eggs produced in each season by sampling surveys, and divide this figure by the average number of eggs per spawning female. This estimate is then divided by the proportion of females in the adult population to give a total number of spawning fish.

3.1.3 Methods for estimating diet

Diet is usually estimated by examining the stomach contents of fish of different age classes, collected from both commercial catches and from dedicated surveys. Attempts are made to identify the contents to the lowest taxon level, and to determine the size of each prey item. With some assumptions about the length of time it takes for prey to pass through the gut, it is possible to estimate average meal size and therefore to determine the total quantity of each prey species consumed by individual predators.

3.1.4 Methods for estimating and assigning mortality

Estimating natural mortality rates is difficult for most wild populations. Traditionally, a value of M=0.2 has been assumed in most VPAs. However, MSVPA has indicated that M may be substantially higher than this for some age-classes. Attempts to partition M into components due to predation and other factors, and the methods used for this, are described later in the report.

3.2 Cod (*Gadus morhua*)

3.2.1 Brief life history

The spawning period of cod varies with location being more prolonged in the Baltic than in the North Sea. Around the UK and Ireland, spawning generally takes place between January and April, whereas in the eastern and northern Baltic peak spawning occurs in June to July.

The average mature female carries about 500 eggs per g body weight, thus a 10 kg fish would release about 5 million eggs The eggs (which are ~1.4mm in diameter) float to the surface and are found over large areas. They hatch over a period of 2-3 weeks, at which stage the larvae are ~0.4 cm in length. By the end of June they have grown to 2-8 cm. Young cod live in the upper water layers until about August, when they move to the sea bed and adopt a demersal way of life. At end of their first winter they are 13-26 cm in length, after which they can grow rapidly and reach 80 cm by the time they are 4 years old. Young fish are often found close inshore, but as they grow older they move offshore to join adult stocks.

3.2.2Maximum size

Up to 150 cm (40 kg), but more usually 120 cm (11.3 kg).

3.2.3 Maturity ogive

The following table shows the percentage of fish mature at different ages in five different areas. Data are from ICES (2001a, 2001b, 2001c, 2001d).

1	**2**	**3**	**4**	**5**	**6**	**7+**	**Age**
0	52	86	100	100	100	100	North Sea & W. Scotland
0	38	100	100	100	100	100	Irish Sea
0	39	87	93	100	100	100	Celtic Sea
1	10	64	87	93	91	99	West Baltic
13	36	83	94	96	96	98	East Baltic

3.2.4 Weight at age

The following table shows the mean weight (in kg) at age, averaged over 20 years, for fish caught in five different areas. Data are from ICES (2001a, 2001b, 2001c, 2001d).

Age	**North Sea**	**W Scotland**	**Irish Sea**	**Celtic Sea**	**W Baltic**
1	0.613	0.654	0.823	0.814	0.405
2	0.969	1.237	1.818	2.250	0.680
3	2.147	2.717	3.704	4.699	1.084
4	4.053	4.653	5.687	7.169	1.696
5	6.327	6.396	7.38	8.909	2.618
6	8.418	7.946	8.959	11.345	3.683
7 or (7+)	10.071	(9.438)	(10.978)	(14.133)	(6.377)
8	11.183				
9	12.558				
10	13.693				
10+	14.777				

More detailed time series of weight-at-age data are given in Tables 3.2.1 (North Sea), 3.2.2 (W. Scotland), 3.2.3 (Irish Sea), 3.2.4 (Celtic Sea), and 3.2.5 (West Baltic).

3.2.5 Age at first spawning.
Small numbers of cod mature at age 2 years, but most do not spawn until they are 4-5 years (~70 cm long). All cod aged 6 years and above are assumed to be mature.

3.2.6 Age-specific natural mortality
The following table summarises available estimates of age-specific mortality rates derived from single species models (ICES 2001a) and multi-species models (ICES 1997).

Age	0	1	2	3	4	5	Source
M	2.70	0.80	0.35	0.25	0.20	0.20	Single species models
M	2.21	0.91	0.40	0.29	0.19	0.18	Multispecies models

3.2.7 ICES stocks
ICES recognises the following cod stocks:
North Sea + Skagerrak (ICES Areas IV +IIIa + VIId);
West of Scotland (ICES Area VIa);
Irish Sea (ICES Area VIIa);
South-west Britain / Celtic Sea (Area VIIe-k);
Eastern Baltic;
Western Baltic.

The International Baltic Sea Fisheries Commission (IBSFC) manages all cod in the Baltic as a single stock because of the practical difficulties caused by mixing of the two stocks around Bornholm Island.

There is little interchange of cod between the North Sea and the West of Scotland, but significant interchange occurs between the North Sea, the eastern English Channel and the Skagerrak. Thus ICES provides management advice on the cod in areas VIId, IIIa and IV as if they were a single stock. Young hatched fish are found concentrated in the eastern and northern parts of the North Sea. First-winter fish are mainly found in the shallow coastal waters of the eastern North Sea. Cod of age 1 and 2 years are found all over North Sea, but mainly towards the north when they are 3 years or older

There is a limited movement of cod between the east and west Irish Sea, and a large seasonal southward movement of adults from the spawning grounds, which are mainly in the area from County Down to the east of the Isle of Mann and south Ireland, into the western part of the Irish Sea.

Most cod in the eastern Celtic Sea spawn in an area off north Cornwall, but cod that have spawned in the Irish Sea are also found in the Celtic Sea. There is little movement east or west out of areas VIIe-k, but some limited movement north into the Irish Sea (ICES Area VIIa)

The two stocks in the Baltic have different morphometric and genetic characteristics. The western stock inhabits the area west of Bornholm Island including the Danish Straits. The eastern stock occurs in the central, eastern and northern part of the Baltic. The eastern stock is approximately nine times the size of the western one, although fluctuations in this ratio occur. In the Baltic, cod are usually confined to water 60-90 m deep. Successful egg development is affected by freshwater inflows into the sea. The western stock, being in more saline waters, is less affected by fluctuating salinity conditions.

3.2.8 Stock abundance
Time series of SSB, TSB, and recruitment levels are given in Tables 3.2.6 (North Sea), 3.2.7 (West Scotland), 3.2.8 (Irish Sea), 3.2.9 (SW Britain/Celtic Sea), 3.2.10 (West Baltic), and 3.2.11 (East Baltic). Time series of stock numbers at age are given in Tables 3.2.12 (North

Sea), 3.2.13 (West Scotland), 3.2.14 (Irish Sea), 3.2.15 (West Baltic), and 3.2.16 (East Baltic).

Summary statistics for TSB in 1000s of tonnes are:

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
North Sea	279 (2000)	619 (1963-00)	1180 (1971)	256 (1999)
W Scotland	11.7 (2000)			
Irish Sea	8.5 (2000)	20.1 (1968-00)	30.4 (1973)	8.5 (2000)
SW Britain/Celtic Sea	12.3 (2000)	17.7 (1971-00)	37.6 (1988)	9.1 (1974)
West Baltic	59.1 (2000)	69.0 (1970-2000)	101 (1971)	25.0 (1991)
East Baltic	148 (2000)	474 (1966-2000)	1036 (1982)	129 (1999)

Equivalent values for SSB, also in 1000s of tonnes, are:

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
North Sea	55 (2001)	152 (1963-01)	277 (1970)	54 (2000)
W Scotland	3.4 (2000)	24.1 (1966-00)	48.9 (1968)	3.4 (2000)
Irish Sea	4.4 (2000)	12.2 (1968-00)	20.7 (1973)	4.4 (2000)
SW Britain/Celtic Sea	6.9 (2000)	11.1 (1971-00)	24.8 (1989)	6.3 (1976)
West Baltic	40.0 (2000)	34.2 (1970-00)	56.1 (1980)	8.6 (1992)
East Baltic	135 (2000)	308 (1966-2000)	693 (1980)	97 (1992)

The quality of landing statistics in the Baltic was low in the early 1990s, but has improved since. However, there is still uncertainty in the estimates of stock size and level of fishing mortality especially for western population. IBSFC aims to maintain a minimum SSB >160,000 tonnes for the eastern stock and >9,000 tonnes for the western stock.

3.2.9 Current assessment of stocks

North Sea (IV +IIIa + VIId): Outside safe biological limits (ICES 2001a). The 2001 SSB was the lowest recorded level and the whole stock is in danger of collapse. There are too few parent fish left to spawn. The 1996 year-class of cod was the only plentiful one in the past decade and most of this class has now been caught.

W Scotland: Outside safe biological limits (ICES 2001b)

Irish Sea: Outside safe biological limits (ICES 2001b)

SW Britain/Celtic Sea: Outside safe biological limits (ICES 2001c)

West Baltic: Outside safe biological limits in 2000 (ICES 2001d), but SSB has increased from the low level in 1992.

East Baltic: Outside safe biological limits in 2000 (ICES 2001d). The SSB declined to the lowest level on record in 1992. It has now has increased but remains below the long term average.

3.2.10 Diet – estimates of consumption

In the North Sea about 75% of diet by weight is a mix of fish (mainly sandeels, Norway pout, whiting, haddock, herring, several flatfish species and some cod) and crustaceans. The remainder is molluscs (mainly *Cyprina islandica*) and worms (Adlerstein and Welleman

2000). The proportion of fish in the diet tends to increase as the fish gets older. Spatial variation is less important than seasonal differences. Cannibalism accounted for an estimated 4% of the diet by weight of North Sea cod in 1981 and 1.6% in 1991 (Palsson 1994).

In the Baltic, sprat and herring are the major food components. Predation mainly affects herring below 20 cm; larger herring in age groups 2+ are less affected. Cod is the main piscivore in the Baltic. The extent of cannibalism varies greatly between years and is affected by the relative and actual sizes of adult and juvenile populations of both cod and herring (Neuenfeldt and Koster 2000; Uzars and Pliksh 2000). In the 1980s, when cod stocks were high relative to the herring stocks, 25-38% of group-0 and 11-17% of group-1 cod in the Eastern stock were consumed by adult cod. Thus, between the ages of 0 and 2 there was a loss of 31-44% by cannibalism. In the western stock between the ages of 0 and 2 there was a loss of 24% by cannibalism. Currently estimates of losses due to cannibalism are considerably lower.

Christensen (1995) gives the following figures for the percentage composition of the diet of North Sea cod:

Other cod	1.7
Whiting	5.1
Haddock	5.8
Herring	2.3
Sprat	2.2
Norway pout	7.2
Sand eel	7.9
Other fish	18.8
Euphausiids	5.0
Other crustaceans	32.0
Echinoderms	0.9
Polychaetes	6.7
Other macrobenthos	2.2
Other invertebrates	2.2

3.2.11 Predators other than humans

The only other predators of cod in the Baltic are grey seals.

Based on a trophic interaction model, Christensen (1995) concluded that cod was the most important predator of cod in the North Sea, cod made up 1.7% of the diet. Cod constituted only 0.1% of the diet of whiting, 0.1% of the diet of saithe, and 0.3% of the diet of rays.

The ICES Multispecies Assessment Working Group (ICES 1997) used MSVPA to estimate that 4% of the predation on cod was due to other cod, 1% due to whiting, 71% due to gurnard (which were not considered by Christensen), 10% due to seals, 5% due to birds, and 8% due to other predators (see Table 3.2.17).

3.3 Whiting *(Merlangius merlangus)*

3.3.1 Brief life history

A mature female whiting releases around 400,000 eggs in a series of batches per season. Spawning takes place in February-May and the eggs take 10 days to hatch. The larvae start off life in mid-water, feeding on nauplii and copepods. They descend to the sea-bed in September and spend about 2 years as juveniles in shallow coastal and estuarine waters. Tagging experiments show that there is little movement away from the spawning areas. After the first year, growth is slow and variable: a 30 cm fish may be anything from 1- 6 years old.

3.3.2 Size

Up to 70 cm but usually 30-40 cm in the North Sea.

3.3.3 Maturity ogive

The following table shows the percentage of fish mature at different ages

Age	**1**	**2**	**3+**
% mature	11	92	100

Traditionally, all whiting were assumed to be mature at 2 years, but new evidence from the International Bottom Trawl Survey suggests that this may have to be revised, because only 90% of fish were observed to be mature at this age (ICES 2001a).

3.3.4 Weight at age

The following table shows the mean weight-at-age in g for fish caught in the North Sea between 1960 and 2000 (ICES 2001a).

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**7+**
	94	181	257	324	386	428	495	575

3.3.5 Age at first spawning.

Usually 3-4 years.

3.3.6 Age-specific natural mortality

The following table shows current estimates of mortality at age derived from single species models (ICES 2001a) and multi-species models (ICES 1997).

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8+**	**Model**
M	2.55	0.95	0.45	0.35	0.30	0.25	0.25	0.20	0.20	Single species
M	2.08	1.21	0.46	0.34	0.38	0.41				Multi species

3.3.7 ICES Stocks

ICES recognises the following stocks:

North Sea: spawning all over, but 0-group (3-5cm) fish occur mainly in northern the North Sea, Shetland. There may be different stocks north and south of the Dogger Bank

Celtic Sea : the main spawning areas are off Cornwall and South-East Ireland

3.3.8 Stock abundance

Time series of SSB, TSB, and recruitment levels are given in Tables 3.3.2 (North Sea), and 3.2.3 (Celtic Sea).

The following tables shows summary TSB and SSB statistics for the last 40 years.

Stock	**Most recent (year)**	**Mean (years)**	**Maximum (year)**	**Minimum (year)**
North Sea (TSB)	376 (2000)	630 (1960-00)	1308 (1968)	245 (1997)
Celtic Sea (TSB)	90.8 (2000)	53.5 (1982-00)	96.2 (1995)	23.4 (1982)

Stock	**Most recent (year)**	**Mean (years)**	**Maximum (year)**	**Minimum (year)**
North Sea (SSB)	234 (2000)	338 (1966-00)	576 (1977)	147 (1998)
Celtic Sea (SSB)	55 (2000)	39.5 (1982-00)	83.0 (1995)	15.0 (1983)

3.3.9 Current assessment of stocks

North Sea: Outside safe biological limits in 2000. The SSB declined in successive years from 1993 to 1998, but has recovered somewhat since then.

Celtic Sea: Inside safe biological limits. SSB is above long term average. Fishing mortality declined until 1997 and has since increased slightly. Recruitment has been below average since 1994.

3.3.10 Diet - estimates of consumption

In the northern North Sea, the diet is dominated by crustaceans and fish, but it is more variable in the south. The diet is mainly euphasids and craganoid shrimps, but also annelids and cephalopods at certain times. Whiting larger than 30 cm feed entirely on small fish (mainly Norway pout, sandeel, herring, cod and haddock). Because of their abundance, whiting are considered to be a major predator of commercial fish in the North Sea.

Seynon and Grove (1998) found that 0+ group whiting in the Celtic Sea consumed 0.41 g sprat, 0.14 g sandeels and 0.14 g crabs per day. The corresponding figures for 4 year old fish were 0.70 g of sprat, 0.80 g of sandeels, and 0.94 g of crab per day. The long term average consumption of these prey groups by whiting is around 820, 370 and 520 $g.km^{-2}.day^{-1}$.

Christensen (1995) estimated the percentage diet composition for North Sea whiting to be:

Cod	0.1
Whiting	1.8
Haddock	3.1
Herring	2.8
Sprat	7.7
Norway pout	11.8
Sandeel	25.3
Other fish	18.7
Euphausiids	9.9
Other crustaceans	9.9
Echinoderms	0.3

Polychaetes	2.5
Other macrobenthos	3.1
Other invertebrates	3.1

3.3.11 Predators other than humans

Christensen (1995) used a model of trophic interactions to estimate that North Sea whiting made up 5.1% of the diet of cod, 1.8% of the diet of whiting, 0.3% of the diet of saithe, and 1.1% of the diet of rays.

The ICES Multispecies Assessment Working Group (ICES 1997) attributed 12% of the predation mortality on whiting in the North Sea in 1995 to cod, 26% to whiting; 8% to saithe, 3% to rays, 32% to gurnard, 6% to seals, 2% to birds, and 10% to other predators (detailed figures in Table 3.2.17).

3.4 Monkfish/anglerfish (*Lophius piscatorius* and *L. budegassa*)

3.4.1 Brief life history

Two species of anglerfish are commonly called monkfish: the black-bellied monkfish *Lophius budegassa* and the white monkfish *Lophius piscatorius*. The basic biology of the two species is similar. The black-bellied is much rarer than the white monkfish in Northern European waters (north of latitude 55°N) but is sometime caught off South West England. They are not separated by species in landings data and the TAC is for both species combined. White monkfish are distributed in the north-east Atlantic from the south-west Barents Sea down to the west of Spain. Black monkfish have a more southerly distribution from southern British Isles to Senegal.

Knowledge of the location and timing of spawning is limited. Spawning occurs from mid-February to July, with a peak from March to July, usually in deep (>150m) water. Each female produces one batch of of up to 1 million eggs per season. After hatching the young spend 3-4 months in mid water before settling on the bottom at a size of 5-12 cm. They may drift considerable distances away from the spawning areas. Adults occur in a wide range of depths, from shallow to at least 1100m. Monkfish are slow growing and slow maturing.

3.4.2 Size

Up to 200 cm (30-40 kg) but rarely above 120 cm, average 40-60 cm.

3.4.3 Maturity ogive

The following table shows the percentage of fish that are mature at each age in ICES Areas VI and VII. Data are from ICES (2001b, 2001c).

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7+**	**ICES Area**
	0	0	2	24	80	97	100	VI
	0	0	0	0	0	54	100	VII

3.4.4 Weight and length at age

The following table shows mean weight at age (in kg) from fish caught in ICES Areas VI and VII over the period 1990-1999, taken from ICES (2001b, 2001c).

Age	2	3	4	5	6	7	8	9	10	11	12	12+
Area VI	0.4	0.7	1.2	2.0	2.9	4.3	5.7	7.9	10.5	18.4	18.4	18.4
Area VI	0.3	0.6	1.2	2.0	3.0	4.2	5.6	7.1	8.7	10.5	11.3	15.1

More detailed time series of weights-at-age are given in Table 3.4.1 (northern stock) and Table 3.4.2 (southern stock).

3.4.5 Age at first spawning

Some females become matures at age 7 (70cm), but majority do not mature until they are much older and are therefore likely to be caught before reaching full maturity. Mean length at maturity is 73 cm for females and 49 cm for males. Virtually all large monkfish are female. (Alfonso-Dias and Hislop 1996)

3.4.6 Age specific natural mortality

Assumed to be 15% at all ages.

3.4.7 ICES Stocks

ICES recognised the following stocks:

Northern (North Sea Area IV + West Scotland Area VI + Kattegat/Skagerrak Area IIIa)

Southern (SW Britain Areas VIIb-k + Bay of Biscay Areas VIIIa, b)

The North Sea, West Scotland, and Kattegat/Skagerrak areas used to be considered separately by ICES, but there is no evidence to indicate that these are separate stocks. However, this makes little difference to the conclusions that are drawn about stocks. Hislop et al (2001) used a particle tracking model to suggest that larvae caught west of the Hebrides probably originated from the west coast of Ireland and Rockall, whereas those caught in the northern North Sea probably originated from the Norwegian Deep and the shelf west and north of Scotland. Any quotas are precautionary only.

3.4.8 Stock abundance

Time series of spawning stock biomass (SSB), total stock biomass (TSB) together with recruitment levels are given in Table 3.4.3 (Northern); Table 3.4.4 (Southern).

Time series by age and year class are given in Table 3.4.5 for population numbers, TSB and SSB.

The most recently available, mean, maximum and minimum values of TSB for the different stocks (in thousand tonnes) are:

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
Northern	37.9 (1999)	39.6 (1992-99)	46.4 (1995)	35.7 (1992, 97)
Southern	65.4 (2000)	73.8 (1986-00)	90.4 (1995)	63.9 (1999)

For SSB they are:

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
Northern	24.3 (1999)	23.9 (1992-99)	27.5 (1995)	21.7 (1997)
Southern	27.7 (2000)	37.3 (1986-00)	52.0 (1986)	27.7 (2000)

3.4.9 Current assessment of Stocks

Northern: There are serious concerns about the state of this stock and uncertainty over current spawning stock levels. The fishing mortality is above the proposed precautionary level. ICES has proposed the precautionary level for fishing mortality (Fpa) should be 0.3. Currently there is no biological basis for defining the precautionary level for stock biomass. Thus, the stock is regarded as being outside safe biological limits. It is likely that, as the fisheries expanded in the 1980s into deeper waters, the increased catch levels were in areas believed to be refuges for adult monkfish. Immature fish have been heavily exploited for a number of years and thus only a few fish have survived to spawn. Around Shetland, Laurenson (1999) estimated that up to 95% of fish caught were immature. Only 8 out of 850 monkfish caught in a survey by the Scottish Fisheries Research Service were mature females. This has grave implications for the long-term future of the fishery.
Southern: ICES considers this stock to be within safe biological limits

3.4.10 Diet and estimated consumption
Monkfish larvae feed on copepods, crustacean larvae and arrow worms. Older fish feed on a wide variety of other fish, shellfish and occasionally seabirds.

3.4.11 Predators other than humans
Seals and, in Icelandic waters, sperm whales are known to prey on monkfish. Inshore netters in South-West England complain that seals frequently remove the tails and livers of fish caught in tangle nets (Wescott, 2000). The damage is reported to be worst around the Lizard, off Scilly, and around Looe, Newquay and Padstow. Their are similar reports from the West coast of Ireland (Arnett 2001).

3.5 Salmon *Salmo salar*

3.5.1 Brief Life history
Salmon spawn in freshwater rivers, generally between November-December in the UK and Ireland. A typical female salmon lays 450-750 eggs per g body weight. The eggs lie dormant amongst the riverbed gravel for approximately 90 days after fertilization, before hatching into the alevin stage, which still has the yolk sac attached. After about a month the yolk is absorbed and the young fish becomes known as a parr. Parr grow for the next 2 years until they attain a silvery sheen, at this point they are called smolts. The smolts, weighing around a 200g, then migrate to the sea. North-East Atlantic fish then head for feeding grounds off the Faeroe Islands. They feed voraciously on crustaceans and small fish for one year or more before returning to their natal rivers to spawn.

Adult fish are classified by the number of winters they have spent at sea before returning to freshwater. Fish that return after one year (1SW) are known as grilse, while larger salmon are 2SW or more. Salmon that spend several winter at sea are classed as multi-sea-winter (MSW) fish. Some fish will make the return journey to their natal river several times, growing in size year upon year. These fish tend to enter the river in the spring or autumn, while the first trip home of grilse usually occurs during the summer months.

3.5.2 Size
Males up to 150 cm (36 kg), females up to 120 cm (20 kg).

3.5.3 Maturity ogive
Not applicable.

3.5.5 Age at first spawning.
Two to three years.

3.5.6 Age-specific natural mortality
Annual survival of post-smolts is assumed to be 20%, though present evidence suggests that this value is an over estimate

3.5.7 Stocks
Salmon in the North-East Atlantic are divided into three main stocks:

Northern European (Finland, Norway, Russia, Sweden and Iceland);

Southern European (Ireland, France, England andWales, Northern Ireland and Scotland);

Baltic: The IBSFC manages salmon in the Gulf of Bothnia and the Main Basin, and those in the Gulf of Finland as two separates stocks.

3.5.8 Stock abundance
In contrast to most other species of fish, salmon stocks are usually assessed in terms of the number of fish rather than the total weight of the stock.

Time series of estimated pre-fishery abundances of salmon are given in Tables 3.5.1 (maturing 1SW), 3.5.2 (non-maturing 1SW), 3.5.3 (1 SW spawners), 3.5.4 (total 1SW).

3.5.9 Current assessment of stocks
Salmon populations are at their lowest recorded levels throughout the North Atlantic. There is evidence that this decrease is due more to problems in the seawater phase than in the freshwater phases (Anderson et al 2000). There is only very limited information on the movements of salmon in the seawater phase of their life. Better information is required to improve understanding of the effects of such variables as environmental conditions and food supplies on the survival of salmon. Concerns have also been raised about releases and escapes from fish farms. It has been suggested that this could lead to genetic dilution of the wild stock, by introducing genes that are poorly adapted for survival in natural conditions. as well as transmitting parasites and diseases.

Northern European stock: The escapement of 1SW salmon has been just within safe biological limits in recent years. However, data from Norway include farmed fish, so the size of the exploitable surplus is probably overestimated. The exploitable surplus has fallen from around 1 million recruits in the 1970s to about half this level in recent years. ICES (2001e) considers the stock to be within safe biological limits, although it is recognized that the status of individual stocks will vary considerably.

Southern European stocks: The spawning escapement of 1SW fish has fallen below the conservation limit for the past 10 years and recruitment of maturing 1SW salmon has been below any previously observed value throughout this period. In both 1999 and 2000 recruitment before exploitation was below the spawning escapement reserve. ICES (2001e) considers that reductions in exploitation rates are required for as many stocks as possible and that mixed-stock fisheries present particular threats to conservation. For MSW fish, ICES (2001e) considers that further reductions in exploitation rates are urgently required for as many stocks as possible, and that mixed stock fisheries present particular threats to conservation.

Baltic: The wild salmon stocks have been much depleted but they have been supplemented in recent years by the release of several million (6.5 million in 1999) hatchery reared salmon smolts per year. About 90% of the current recruitment to the Baltic stock is due to these released smolts. Thus it is difficult to assess the status of the wild stock alone. Some river stocks, especially of the smaller rivers, however face extinction. Some Baltic year-classes were badly affected by the M74 syndrome in mid 1990s, which affected yolk sacs and killed off many fry. Yields from smolt releases have been decreasing since 1994 and considered to be due to reduced survival in the post smolt phase. Most wild populations in the Gulf of Bothnia have improved in terms of parr densities from an all time low. Natural smolt production has increased in many rivers, particularly the larger ones, but many smaller rivers have alarmingly small smolt production. Survival of released smolts has been low, although the incidence of M74 syndrome decreased from 1999.

3.5.10 Diet - estimates of consumption

Salmon are considered to be opportunistic feeders. In the Baltic, they mainly feed on sprat and herring and, to a lesser extent, three spined stickleback. The mean size of sprat consumed in the 1990s was smaller than in the 1960s. Over the same period, herring increased in the diet while sprat decreased. It has been suggested that the M74 syndrome could have been caused by high thiaminase levels in these prey species leading to thiamine deficiency and consequent death in salmon fry.

A study of the stomach contents of nearly 3000 wild and 863 escaped salmon from around the Faeroes indicated that the most important food items in autumn were hyperiid amphipods *Thermisto genus,* euphasiids and mesopelagic shrimps. In late winter various mesopelagic fish (e.g. lantern fishes pearlsides and barracudinas) became equally important. Larger fish, such as herring, blue whiting and mackerel, were occasionally recorded but did not appear to be major food sources.

3.5.11 Predators other than humans

As wild salmon populations have diminished, concern has been expressed that present levels of predation could cause significant impacts upon the remaining fish. Known predators of salmon in sea water include seabirds (especially gannets), seals, cetaceans, gadoids and sharks. In fresh water, a variety of fish and birds, and some invertebrates, consume salmon eggs, fry and parr.

In comparison to many other fishes, salmon are rare in the open ocean. Therefore predators tend to encounter salmon by chance, and thus they only consume them incidentally. However, during migration runs in estuarine areas, predation may be more significant.

ICES (2001e) concluded that it would be extremely difficult to measure predation levels on salmon at sea, because salmon are rarely recorded in diet studies of marine predators. Even with greatly expanded sampling effort, it is doubtful that measurable levels of salmon consumption by most bird and mammal predators will be detected. However, it may be possible to measure levels of predation in freshwater on a river-specific basis, although the estimates are likely to have high variances.

Within the Baltic, increasing levels of seal predation on salmon fisheries have been reported. The main complaint is of damage to salmon around fishing gear. The damaged salmon and not included in catch statistics or in TACs. The overall effects of damage by seals are greatest in northern areas, and are considered to be insignificant in Denmark, Russia and Poland. No data are available from Germany or Lithuania.

3.6 EEL *Anguilla anguilla*

3.6.1 Brief life history

Eels are presumed to spawn in the Sargasso Sea. The hatched eels, known as leptocephali, are carried across the Atlantic to Europe in a journey, which can take three years. They are about 45 mm long by the time they reach European waters, where they metamorphose into elvers and then migrate into freshwater systems. The period in freshwater is in the region of 6-12 years for males and 9-20 years for females. Freshwater eels, known as yellow eels, are common in most rivers and estuaries and are mainly nocturnal in activity.

Mature eels (known as silver eels) migrate seaward in the autumn and are believed to return to the Sargasso Sea to spawn. However, no mature eels have been caught in the Atlantic en route to the Sargasso. The eel's digestive tract atrophies while it is at sea, so individuals must rely on stored energy reserves.

3.6.2 Size

Mature males are 30-50 cm, mature females are 40-100cm and weigh around 3.5 kg.

3.6.3 Maturity ogive

Not applicable

3.6.4 Weight at age

Maximum length is 133 cm and maximum weight 9 kg. The maximum reported age is 85 years.

3.6.5 Age at first spawning.

Age at first spawning varies with climate and latitude. Males become mature at 2-20 years, females at 5–50 years.

3.6.6 Age specific natural mortality

No information available.

3.6.7 ICES Stocks

The available genetic evidence supports the established view that there is a single spawning stock breeding in the Sargasso Sea, but distinct sub-groups may occur in the Mediterranean, western European and Baltic.

3.6.8 Stock abundance

Estimates of total spawning stock and total recruitment are not available for the entire distribution. The best indicator of oceanic spawning biomass is believed to be the number of silver eels leaving Europe, although they are more correctly termed pre-spawners. It is difficult to assess the losses that may occur en route from European freshwater systems to the Sargasso Sea.

FAO statistics show that the European catch of eels decreased by over 40% from 1988 to 1998, and only 7.5 tonnes were harvested in 1998. The declining eel stock is a serious threat to some inland and coastal fisheries in the Baltic Sea.

3.6.9 Current assessment of stocks

There are very few reliable time-series on the status of yellow and silver eel stocks and fisheries within the range of the European eel. All available information indicates that the stock levels are at a historic minimum. Fishing mortality is high in many waters for all stages of eels. Recruitment has been declining since 1980.

3.6.10 Diet - estimates of consumption

Elvers and immature eels feed on almost all aquatic fauna occurring in the eel's area.

3.6.11 Predators other than humans

Birds (e.g. cormorants) in some areas and seals

3.7 HADDOCK *Melanogrammus aeglefinus*

3.7.1 Brief life history

A mature female on average carries 500 eggs per g of body weight (equivalent to 300,000 eggs for a 4 year-old fish) which are laid in several batches during the spawning season, which extends from March to May. The eggs take 1-3 weeks to hatch. The length of the spawning season can vary with the size and age of the local population. Inshore waters usually contain younger, smaller fish compared to deeper waters. The two main spawning areas are the northern North Sea and west of the Outer Hebrides. Most larvae do not travel far from the spawning grounds. Young fish spend the first few months of life in the upper waters and then move to the sea bed where they take up a demersal life. Adult fish disperse after spawning and tend to concentrate around the Orkney and Shetland Isles, and in the central regions of the North Sea. They return to the spawning grounds in November or December, when they are usually found in water <300 m deep

3.7.2 Size

Up to 76 cm (4.5 kg) but usually 40-60 cm in the North Sea.

3.7.3 Maturity ogive

The percentage of fish mature at age are given in the following table, taken from ICES (2001a)

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6+**
	0	10	32	71	87	95	100

3.7.4 Weight at age

The following table shows the average weight at age (in kg) of fish caught between 1995 and 2000 (ICES 2001a)

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**
	0.02	0.14	0.26	0.37	0.51	0.66	0.86	1.02	1.41	1.84	2.10

The full time series of catch weight-at-age is given in Table 3.7.1

3.7.5 Age at first spawning.

About 20% of females spawn at 2 years, >50% at 3 years and nearly 100% at 4 years.

3.7.6 Age specific natural mortality

Estimates of age-specific natural mortality rates (M) calculated from single species (ICES 2001a) and multi-species models (ICES 1997) are:

Age	**0**	**1**	**2**	**3**	**4**	**5+**	**Model**
M	2.05	1.65	0.40	0.25	0.25	0.20	Single species
M	2.19	1.57	0.34	0.27	0.27	0.28	Multi species

3.7.7 ICES Stocks

North Sea and Skagerrak (ICES Areas IV and IIIa): Haddock are mainly found in the northern and central areas of the North Sea, but some found are found south of the Dogger Bank during summer..

West Scotland and Rockall (ICES Areas VIa and VIb). The major spawning areas are between the Outer Hebrides and Shetland. Tagging experiments indicate there may be some interchange between W Scotland and the North Sea.

3.7.8 Stock abundance

Time series of spawning stock biomass (SSB), total stock biomass (TSB) together with recruitment levels are given in Tables 3.7.2 (North Sea and Skagerrak) and 3.7.3 (W Scotland).

The following tables provide summary statistics in 1000s of tonnes for the period 1963-2000.

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
North Sea (TSB)	1535 (2000)	1176 (1963-00)	6700 (1968)	343 (1990)
W Scotland (TSB)	62 (2000)	88 (1965-00)	202 (1968)	34 (1990)

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
North Sea (SSB)	87 (2000)	250 (1963-00)	899 (1970)	63 (1991)
W Scotland (SSB)	20 (2000)	57 (1965-00)	163 (1970)	20 (2000)

3.7.9 Current assessment of stocks

North Sea: outside safe biological limits.

West Scotland: outside safe biological limits. The SSB for 2000 was below the precautionary level of 30000 t. Recruitment has been below average since 1995, but was high in 2000.

3.7.10 Diet - estimates of consumption

Haddock larvae feed on immature copepods. 0-group fish (3-14 cm long) feed on euphasiids, appendicularians, decapod larvae, copepods and fish. When the juveniles become demersal they still feed on pelagic organisms but also on slow-moving invertebrates. Larger fish feed on sand eels, Norway pout, long-rough dab, gobies, sprat and herring. Haddock tend to feed in shoals. The diet varies with season, fish size and location. The main diet of all haddock in winter is worms, molluscs, urchins and brittle stars. Fish prey become more important in spring and summer. Near to the Scottish coast and in the central North Sea, sand eels are the preferred prey whereas Norway pout is preferred in more northern areas. During the herring spawning season herring eggs are heavily predated by haddock.

The following table shows the estimated percentage composition of the diet of North Sea haddock as given by Christensen (1995).

Sprat	0.1
Norway pout	2.9
Sand eel	7.8
Other prey fish	28.6
Euphausiids	9.9
Other crustaceans	9.9
Echinoderms	13.9
Polychaetes	12.6
Other macrobenthos	7.2
Other invertebrates	7.2

3.7.11 Predators other than humans

Christensen (1995) estimated that, in the North Sea, haddock made up 2.2% of the diet of cod, 7.7% of the diet of whiting, 0.8% of the diet of saithe, 1.9% of the diet of mackerel, and 0.1% of the diet of other haddock.

The ICES Multispecies Working Group (ICES 1997) estimated that in 1995 14% of the predation mortality on North Sea haddock was caused by cod, 18% by whiting, 36% by saithe, 3% by gurnard, 1% by seals, 3% by birds, and 25% by other predators (see Table 3.2.17).

3.8 PLAICE *Pleuronectes platessa*

3.8.1 Brief life history

Spawning takes place between December and March, with a peak in January and February, at depths of 25-75 metres. The eggs and larvae are pelagic for 3-8 weeks and metamorphose into juveniles which move into coastal waters <20m deep. They remain there for a few years before moving into deeper waters.

3.8.2 Size

Plaice can grow up to 60 cm in length, but rarely reach this size in the North-East Atlantic.

3.8.3 Maturity ogive

The percentage of fish mature at different ages is given in the following table.

Age	**1**	**2**	**3**	**4+**
	0	50	50	100

3.8.4 Weight at age

Weight-at-age has varied significantly among year-classes over the past 40 years. (ICES 2001a). The mean weights (kg) at age over this period are shown below and the full time series is given in Table 3.8.1.

Age	weight		Age	weight
1	0.234		8	0.664
2	0.268		9	0.749
3	0.301		10	0.822
4	0.358		11	0.901
5	0.435		12	0.945
6	0.517		13	1.001
7	0.593		14+	1.079

3.8.5 Age at first spawning.

North Sea females spawn at around 42 cm (6-7 years), males at 35 cm (5-6 years).

3.8.6 Age specific natural mortality

Taken as 0.1 for all mature fish (ICES 2001a).

3.8.7 ICES Stocks

Two major stocks are recognised:

W English Channel (ICES Area VII) and **Celtic Sea**.

North Sea and Skagerrak.

Four major spawning groups are recognized in the North Sea:

Scottish east coast

Flamborough

Southern Bight and German Bight.

Central and southern North Sea

3.8.8 Stock abundance

Time series of SSB and TSB, together with recruitment levels for the North Sea and Skagerrak stock are given in Table 3.8.2. Summary statistics (in 1000s of tonnes) are given below:

Stock	**Most recent (year)**	**Mean (years)**	**Maximum (year)**	**Minimum (year)**
North Sea (TSB)	309 (2000)	483 (1957-00)	625 (1964)	261 (1996)
W English Channel (TSB)	3.01 (1999)	4.39 (1976-99)	6.96 (1989)	2.14 (1976)

Stock	**Most recent (year)**	**Mean (years)**	**Maximum (year)**	**Minimum (year)**
North Sea (SSB)	222 (1999)	332 (1957-00)	493 (1967)	150 (1997)
W English Channel (SSB)	1.71 (2000)	57 (1965-00)	4.16 (1989)	1.32 (1976)

3.8.9 Current assessment of stocks

North Sea: Outside safe biological limits. SSB and recruitment below long term average. SSB declined 1989-1997 but has increased slightly since 1998.

W English Channel/ Celtic Sea: Outside safe biological limits. SSB and recruitment below long term average.

3.8.10 Diet - estimates of consumption

Christensen (1995) provided the following estimates of the percentage composition of the diet of plaice in the North Sea:

Echinoderms	30
Polychaetes	50
Other macrobenthos	10
Other invertebrates	10

3.8.11 Predators other than humans

The only significant predators on adult plaice in the North Sea appears to be grey and harbour seals (Christensen 1995; ICES 1997).

3.9 HERRING *Clupea harengus*

3.9.1 Brief life history

The spawning period varies with location and race. A single female produces 20-50,000 eggs; after fertilization these sink to the bottom where they adhere to rocks etc. The eggs take about two weeks to hatch and the larvae rise to the surface. After a week the yolk sac is consumed and they start to feed on plankton. The larval stage lasts from 2-6 months. Juveniles spend their early life in shallow inshore waters, but move into deeper waters when they are about 10 cm in size. They are primarily pelagic fish found in offshore waters up to 200 m deep. Herring tend to spend the daytime in deeper water than at night when they rise to the surface.

3.9.2 Size

Up to 43 cm (0.68 kg) in the North Sea, but up to about 20 cm in the Baltic.

3.9.3 Maturity ogive

The percentage of fish mature at age in the Baltic and North Seas are given, based on ICES (2001g, 2001h, 2001i)

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	
	0	60	83	91	93	93	93	93	N Sea
	0	70	90	100	100	100	100	100	Baltic

3.9.4 Weight at age

Weight at age can vary greatly with stock. Weight at age (in g) in the catch of North Sea herring over the period 1983-2000 is shown below. The full time series (1960-2000) of catch weights at age are given in Table 3.9.1 (ICES 2001g)

Age	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	9	55	128	183	221	243	270	289	303

In the Baltic the mean weight at age has decreased (Kornilovs et al 2001), possibly because decreased predation by cod has led to greater survival of smaller herring. Weight at age (in g) for 2000 are shown below (ICES 2001h).

Age	0	1	2	3	4	5	6	7	8	9	10
	7	13	21	25	27	30	335	39	42	40	49

3.9.5 Age at first spawning.
Herring in the North Sea mature at 3-6 years, in the Baltic they mature at 2-3 years.

3.9.6 Age specific natural mortality
Mortality rates (M) derived from single and multi-species models are shown below for North Sea herring (ICES 1997).

Age	0	1	2	3	4	5	
M	2.00	1.00	0.30	0.20	0.10	0.10	Single species
M	0.82	0.74	0.50	0.32	0.18	0.17	Multispecies

for the Baltic they are (ICES 2001h, 2001i):

Age	1	2	3	4	5	6	7	8
M	0.30	0.23	0.22	0.21	0.21	0.21	0.21	0.20

3.9.7 ICES Stocks
Herring populations frequently show complex feeding and spawning migrations. They are divided into numerous localized races, which are often identified by the location and timing of spawning (e.g. North Sea spring-spawning herring) Morphological differences can sometimes be detected between races. In many cases there is considerable mixing of these races, both in nursery and feeding areas. Segregation occurs during spawning and early larval stages. The most important herring races in the North-East Atlantic are the White Sea, the Murman (Barents Sea), winter-spawning Norwegian, and the Baltic.

The North Sea stock is usually divided into three groups: northern North Sea summer-spawning; central North Sea autumn-spawning; and southern Bight winter-spawning. Favoured areas for the last group are the deeper waters in the southern North Sea to the south and east of the Dogger Bank. Larger, immature fish gradually move towards the northern North Sea. Mature adults move between the southern spawning and northern feeding areas on an annual basis.

For the Baltic, ICES (2001h) recently proposed the following two main divisions as assessment units: Gulf of Riga (Gulf herring); and Statistical Divisions (SD) 25, 27, 28 (excluding Gulf of Riga), 29 and 32. These are thought to be reasonably homogeneous internally, and migrations between them are believed to be of minor importance. Herring in SD25 and SD27 are believed to form two components (coastal herring and open sea herring) that should probably be assessed separately.

3.9.8 Stock abundance
Time series of SSB, TSB and recruitment levels are given in Tables 3.9.2 (North Sea and Skagerrak), 3.9.3 (all of Baltic but SD31), and 3.9.4 (Baltic SD31). Summary statistics (in millions of tonnes) are given in the following tables.

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
North Sea (TSB)	3.03 (2000)	2.41 (1960-00)	4.79 (1964)	0.21 (1977)
Baltic (excl SD31) (TSB)	0.92 (2000)	1.77 (1974-2000)	2.81 (1974)	0.81 (1999)
Baltic SD31 (TSB)	0.02 (2000)	0.03 (1980-2000)	0.05 (1980)	0.02 (1999)

Stock	Most recent (year)	Mean (years)	Maximum (year)	Minimum (year)
North Sea (SSB)	0.77 (2000)	0.70 (1960-00)	2.19 (1963)	0.47 (1977)
Baltic (excl SD31) (SSB)	0.49 (2000)	1.04 (1974-00)	1.59 (1974)	0.47 (1999)
Baltic SD31 (SSB)	0.01 (2000)	0.02 (1980-00)	0.04 (1980)	0.01 (1995)

3.9.9 Current assessment of stocks

North Sea: No designated stock status, but the stock is harvested above the recommended levels of fishing mortality (0.2 for adults and <0.1 for juveniles)..
Baltic : within safe biological limits.

3.9.10 Diet - estimates of consumption

Larval herring feed on plankton, mainly diatoms and flagellates, but also on the eggs and young of copepods. The diet of post-larval herring consists mainly of small copepods (*Calanus, Temora, Microcalanus*). First year herring mainly eat *Calanus*, mysid shrimps, various eggs and larvae, and young fish (principally sandeels). Adults have a varied diet of copepods, other crustacea (amphipods, euphasiids and mysid shrimps), young sandeels, gobies, whiting, herring, flatfishes and some invertebrates.

In the North Sea, Christensen (1995) estimated percentage composition of the diet to be:

Juvenile prey fish	11.1
Copepods	20.1
Euphausiids	57.5
Other crustaceans	11.3

In the Baltic the diet is mainly zooplankton and appears to have changed since the mid-1980s. The proportion of macrobenthos (mainly mysids *Mysidacrea*) and *Pseudocalanus* has decreased considerably, and the diet of herring has become more similar to that of sprat (see below). Thus, there is now increased competition between these two species. The present diet consists mainly of copepods (*Temora longicornis, Acartia* spp) and the cladocera *Bosmiona longispina.* In some years there is considerable consumption of cod eggs, but cod larvae are rarely eaten (Koster and Mollman 2000)

3.9.11 Predators other than humans

Christensen (1995) estimated that North Sea herring made up 7.2% of the diet of cod, 11.8% of the diet of whiting, 46.5%, of the diet of saithe 3.1% of the diet of mackerel, and 2.9% of the diet of haddock. The ICES Multispecies Working Group (ICES 1997) calculated that 12% of the predation mortality on herring in 1995 was caused by cod, 33% by whiting, 14% by saithe, 19% by mackerel, 2% by rays, 2% by birds and 15% by other predators (see Table

3.2.17).

The main predators of herring <20 cm in the Baltic are seals and cod. Levels of cod predation depend on the size of the stock, which is currently low.

3.10 SPRAT *Sprattus sprattus*

3.10.1 Brief Life history

Sprat are a small coastal species, usually found in large shoals in shallow water. During the winter it migrates inshore. Spawning occurs in spring and summer but can occur as early as January in the English Channel. It takes place in the open sea or near coastal slopes, mostly at depths of 10-20 m. Individual fish produce 6,000-10,000 eggs. The eggs float at the surface or in mid-water. They take 3-4 days to hatch after which the larvae drift inshore and the young fish stay in shallow water, often joining up with young herring. They are tolerant of freshwater and may even move into rivers. Mixed shoals are known as whitebait. During daytime shoals tend to stay close to the sea bottom, but at night they rise to the surface

3.10.2 Size

Sprat rarely grow larger than 15 cm.

3.10.3 Maturity ogive

The percentage of fish mature at age in the Baltic between 1997 and 1998 (taken from ICES 2001d) are

Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	32	91	97	97	98	99	98	97

3.10.4 Weight at age

Rarely grows larger than 15 cm, usually 11-12 cm at age 1, 13-14 at age 2 and 15 at 4 years.

3.10.5 Age at first spawning.

Occasionally spawns in the first year of life but usually in the second.

3.10.6 Age specific natural mortality

Assumed to be 0.2 (ICES 2001d), but likely to be lower in years when cod abundance is low.

3.10.7 ICES Stocks

North Sea (ICES Areas IV and IIa): Mainly inshore, but unevenly distributed. Principal spawning areas are the southeastern North Sea and Skagerrak.

Baltic : Sprats here are recognised as a separate sub-species *Sprattus sprattus balticus*

3.10.8 Stock abundance

Time series of SSB, TSB and recruitment levels are given in Table 3.10.1 (Baltic Sea). Total biomass in the North Sea in 2001 was estimated at 342,000 tonnes, in the Kattegat/Skagerrak it was estimated to be 2,000 tonnes. Total biomass in the Baltic in 2000 was estimated at 1,749,000 tonnes.

3.10.9 Current assessment of stocks

North Sea: Stock biomass is high, but the fishery is to be limited in order to reduced bycatch of herring.

Baltic : The SSB is well above the long-term average due to strong recruitment and low predation and hence can sustain high fishing mortality.

3.10.10 Diet - estimates of consumption

Young fish feed on diatoms, and eggs and young of copepods. Christensen (1995) estimated that the diet of adults in the North Sea was made up of 70% copepods (*Calanus, Pseudocalanus, Temora*), and 30% Euphausids.

In the Baltic the diet is mainly planktonic crustacea and benthos, mostly copepods (*Temora longicornis, Acartia spp*, the cladoceran *Bosmiona longispina,* and other small crustacea). Diet varies with season and prey abundance. In some years there is considerable consumption of cod eggs, but rarely of cod larvae (Koster and Mollman 2000).

3.10.11 Other predators

Cod, salmon and grey and harbour seals are known to prey on sprats. Christensen (1995) calculated that North Sea sprat make up 8% of the diet of cod, 25% of the diet of whiting, 5% of the diet of saithe, 19% of the diet of mackerel, and 8% of the diet of haddock.

3.5 SANDEELS *Ammodytidae*

3.11.1 Brief life history

Five species of sandeel are found in the North Sea, although most commercial landings are of the lesser sandeel *Ammodytes marinus*. Sandeels are a shoaling fish that hunt for prey in mid-water during the day and stay buried in the sand during the night. Spawning takes place mainly between November and February. The eggs are deposited as sticky clumps onto suitable sandy areas of the sea-bottom throughout much of the southern and central North Sea, but especially off the coasts of Denmark, northeastern England, eastern Scotland, and the Orkney Islands. After hatching, the larvae become planktonic and are liable to be transported to other areas by prevailing currents , resulting in a potentially wide distribution. The larvae metamorphose into juveniles, which migrate to suitable sandy areas where they settle and tend to remain. They burrow into, and over-winter in, the sandy substrate. Tagging experiments have shown that there is little movement between spawning and feeding grounds, indicating that fishing and spawning grounds may coincide.

3.11.2 Size

The lesser sandeel grows to 20 cm whereas the greater sandeel grows to 33 cm.

3.11.3 Maturity ogive

The percentage of fish mature at age (taken from ICES 2001a) are:

Age	**0**	**1**	**2**	**3**	**4+**
	0	0	100	100	100

3.11.4 Weight at age

Values for weight at age (in g) in 2000 provided by ICES (2001a) are

Age	**0**	**1**	**2**	**3**	**4+**
Jan-June	-	6.40	8.57	13.30	17.03
July-Dec	1.66	7.56	14.29	15.96	18.87

3.11.5 Age at first spawning.
Most fish spawn at two years of age.

3.11.6 Age specific natural mortality
Values for age-specific natural mortality (M) derived from single species and multispecies models (ICES 1997) are:

Age	**0**	**1**	**2**	**3**	**4**	**5**	
M	1.60	1.20	0.60	0.60	0.60	0.60	Single species
M	1.43	1.43	0.75	0.91	0.82	1.08	Multispecies

ICES (2001a) provided the following figures for seasonal mortality-at-age:

Age	**0**	**1**	**1**	**2+**	**2+**
Season	July-Dec	Jan-Jun	July-Dec	Jan-Jun	July-Dec
M	0.8	1.0	0.2	0.4	0.2

3.11.7 ICES Stocks
Once past the juvenile life-stage sandeels move very little, and so stock structure is regarded as being a complex of local populations. Until 1995, the European continental shelf was divided into four regions for assessment: Skagerrak (ICES Area IIIa), northern North Sea, southern North Sea and Shetland Isles. Since 1995 the two North Sea stocks have been regarded as a single stock even though this has little biological basis. Wright (1998) has suggested that the North Sea should be divided into three stocks: the region north of 55° 30'; the region south of 55° 30' and west of 4°E; and the region south of 55° 30' and east of 4°E

3.11.8 Stock abundance
Time series of SSB, TSB and recruitment levels are given in Table 3.11.1 for the North Sea and Skagerrak. North Sea TSB in 2000 was estimated to be 3,086,000 tonnes, and SSB as 707,000 tonnes. Mean TSB for the period 1976-2000 was 1,934,000 tonnes, and mean SSB 889,000 tonnes.

3.11.9 Current assessment of stocks

North Sea: within safe biological limits.

Shetland: safe biological limits have not been defined for this stock. Survey data suggests that the 2000 SSB is close to the lowest observed value and that recent recruitment has been weak. However, fishing mortality appears to be well below natural mortality.

3.11.10 Predators other than humans
Sandeels are important prey for many marine predators such as mackerel, whiting, cod, salmon, seabirds and seals. Whiting feed largely on 0-group sandeels, particularly between April and June. The ICES Multispecies Working Group (ICES 1997) estimated that 2% of the predation mortality on North Sea sandeels was due to cod, 22% due to whiting, 3% due to saithe, 39% due to mackerel, 6% due to haddock, 3% due to rays, 8% due to birds, and 12% due to other predators (including seals) (see Table 3.2.17).

Table 3.5.1 Atlantic Salmon Estimated abundance of maturing 1SW salmon by country and year *ICES 2000: WGNAS*

Year	Finland	France	Iceland	Ireland	Norway	Russia	Sweden	UK(EW)	UK(NI)	UK(Scot)	Southern Europe		Northern Europe		Total	
											Est.	SD	Est.	SD	Est.	SD
1971	14,275	34,137	44,862	265,435	596,979	225,393	4,349	190,032	28,154	1,179,189	**1,696,948**	178,217	**885,858**	83,404	**2,582,806**	196,768
1972	21,368	22,009	38,317	272,337	653,938	364,213	6,344	176,866	24,438	1,235,342	**1,730,993**	193,180	**1,084,179**	99,728	**2,815,172**	217,403
1973	20,781	13,907	30,535	298,119	608,182	330,001	4,674	182,253	24,722	1,021,934	**1,540,934**	154,063	**994,173**	92,757	**2,535,107**	179,831
1974	20,471	20,026	38,225	302,499	582,488	412,104	3,760	197,053	22,032	1,077,432	**1,619,042**	177,289	**1,057,049**	96,244	**2,676,091**	201,728
1975	17,614	16,881	29,340	225,956	564,548	346,718	3,806	129,908	15,140	740,757	**1,128,641**	120,402	**962,027**	90,503	**2,090,668**	150,624
1976	15,737	11,748	36,369	188,469	535,278	261,358	2,636	124,657	14,693	807,453	**1,147,019**	139,785	**851,378**	82,609	**1,998,397**	162,370
1977	10,036	12,948	47,881	174,014	383,997	181,723	2,182	138,909	19,918	957,810	**1,303,599**	169,081	**625,819**	58,968	**1,929,418**	179,069
1978	7,940	12,288	33,488	149,900	655,634	205,281	4,000	91,052	13,197	750,832	**1,017,268**	132,268	**906,342**	95,177	**1,923,611**	162,952
1979	10,647	24,737	42,734	182,064	701,428	325,310	8,361	113,922	16,222	925,886	**1,262,831**	151,452	**1,088,480**	100,659	**2,351,311**	181,852
1980	16,829	17,571	21,685	155,301	782,988	217,340	8,750	134,239	13,497	1,088,782	**1,409,390**	204,525	**1,047,592**	100,169	**2,456,982**	227,738
1981	18,468	12,293	21,418	96,814	654,750	216,104	11,006	90,817	17,644	835,106	**1,052,673**	145,660	**921,746**	80,855	**1,974,419**	166,596
1982	20,742	11,506	25,180	135,971	617,578	301,618	8,194	97,598	24,937	892,670	**1,162,681**	168,030	**973,313**	86,983	**2,135,994**	189,209
1983	16,452	17,430	25,782	118,862	606,599	302,599	7,503	81,191	10,441	658,615	**886,539**	126,468	**958,934**	90,501	**1,845,474**	155,514
1984	16,729	12,557	15,196	108,721	563,432	335,079	5,420	75,504	13,109	676,844	**886,735**	130,991	**935,856**	88,209	**1,822,591**	157,922
1985	11,373	15,100	27,162	126,203	659,902	372,969	5,857	107,036	14,611	1,101,508	**1,364,457**	256,252	**1,077,264**	102,916	**2,441,721**	276,146
1986	15,357	8,269	27,611	149,244	535,384	190,649	8,511	88,425	7,428	759,797	**1,013,162**	177,342	**777,511**	73,517	**1,790,674**	191,977
1987	12,042	19,703	22,335	124,693	408,572	195,297	6,563	110,906	19,509	808,656	**1,083,467**	193,840	**644,809**	60,607	**1,728,276**	203,094
1988	15,153	11,498	20,308	112,170	384,572	237,471	14,781	93,264	15,013	733,928	**965,872**	161,300	**672,285**	70,990	**1,638,157**	176,231
1989	15,873	9,135	22,169	52,923	425,237	232,523	10,913	72,859	13,734	585,591	**734,242**	136,576	**706,715**	69,848	**1,440,958**	153,400
1990	17,433	7,612	17,980	39,238	394,447	188,122	10,255	38,158	7,049	513,313	**605,369**	159,299	**628,236**	65,925	**1,233,605**	172,401
1991	17,798	10,587	24,265	71,198	409,446	166,818	12,384	38,980	15,864	674,754	**811,383**	212,748	**630,710**	68,983	**1,442,093**	223,652
1992	23,095	5,296	20,124	36,957	324,201	245,084	16,391	47,434	38,308	587,858	**715,854**	187,937	**628,894**	62,229	**1,344,748**	197,972
1993	17,513	9,460	21,788	74,478	345,889	213,161	12,296	78,247	13,486	679,602	**855,272**	223,038	**610,647**	61,362	**1,465,918**	231,325
1994	15,091	4,525	18,138	65,836	346,553	157,743	7,995	49,770	11,749	631,572	**763,452**	201,126	**545,520**	54,638	**1,308,973**	208,416
1995	9,402	8,131	16,336	47,868	337,507	241,890	10,035	61,238	13,200	564,795	**695,232**	191,095	**615,170**	72,118	**1,310,402**	204,251
1996	14,566	4,176	14,785	50,154	236,839	199,621	6,255	37,059	15,530	384,919	**491,838**	123,890	**472,066**	57,864	**963,904**	136,737
1997	12,877	3,493	16,180	55,996	281,631	196,985	3,451	24,315	21,509	417,310	**522,623**	112,766	**511,125**	63,504	**1,033,748**	129,418
1998	11,716	7,583	22,681	42,483	337,584	193,314	2,406	43,656	10,405	318,117	**422,244**	88,984	**567,701**	71,698	**989,945**	114,275
10yr Av.	15,501	7,409	19,523	59,027	347,628	206,612	9,742	53,180	15,986	553,796	**689,398**	559,756	**599,006**	217,643	**1,288,405**	600,579

Table 3.5.2 Atlantic Salmon Estimated abundance of non-maturing 1SW salmon by country and year *ICES 2000: WGNAS*

Year	Finland	France	Iceland	Ireland	Norway	Russia	Sweden	UK(EW)	UK(NI)	UK(Scot)	Southern Europe		Northern Europe		Total	
											Est.	SD	Est.	SD	Est.	SD
1971	8,532	58,869	47,904	1,415,594	577,799	133,724	13,016	168,074	143,211	1,466,207	**3,251,955**	340,515	**780,976**	83,274	**4,032,931**	350,550
1972	13,229	116,674	43,729	1,558,425	756,563	147,750	10,391	206,612	128,705	1,398,938	**3,409,354**	336,989	**971,661**	108,943	**4,381,015**	354,161
1973	19,971	70,743	44,589	1,670,373	830,476	247,158	12,935	204,528	111,849	1,626,312	**3,683,805**	376,896	**1,155,128**	120,038	**4,838,933**	395,550
1974	18,256	32,799	31,493	1,838,711	781,081	226,598	18,462	211,292	112,545	1,589,390	**3,784,737**	384,221	**1,075,890**	114,135	**4,860,627**	400,815
1975	18,116	65,511	45,093	1,919,466	737,692	241,535	19,787	250,114	100,583	1,232,776	**3,568,451**	319,110	**1,062,224**	107,485	**4,630,675**	336,726
1976	15,735	60,928	38,679	1,356,779	736,002	182,161	11,191	148,580	69,447	1,032,696	**2,668,431**	259,076	**983,768**	105,254	**3,652,199**	279,640
1977	13,996	45,900	43,028	1,190,070	713,351	153,417	5,294	166,409	67,403	1,075,566	**2,545,348**	249,000	**929,086**	99,888	**3,474,434**	268,289
1978	10,359	47,837	53,747	1,065,801	508,031	166,542	6,071	185,509	91,292	1,145,822	**2,536,261**	257,432	**744,750**	72,122	**3,281,012**	267,344
1979	10,693	54,259	52,597	954,356	876,247	189,504	6,381	127,287	60,601	1,032,596	**2,229,099**	244,906	**1,135,422**	128,225	**3,364,521**	276,442
1980	10,736	113,907	17,013	745,821	879,102	125,839	8,238	150,564	74,997	751,287	**1,836,577**	196,212	**1,040,928**	123,842	**2,877,505**	232,026
1981	10,098	91,140	34,634	451,872	604,012	89,857	14,904	194,995	62,372	946,665	**1,747,044**	240,536	**753,504**	84,566	**2,500,548**	254,969
1982	7,354	56,620	26,496	1,014,320	446,831	137,574	13,082	119,115	81,587	1,281,117	**2,552,760**	388,361	**631,336**	66,922	**3,184,097**	394,084
1983	10,919	60,604	35,744	1,499,645	754,956	202,247	17,322	151,840	114,875	1,302,361	**3,129,325**	353,966	**1,021,188**	111,780	**4,150,514**	371,196
1984	13,332	98,666	22,224	682,640	799,587	189,662	24,008	132,658	48,015	1,305,431	**2,267,409**	337,046	**1,048,813**	115,234	**3,316,222**	356,201
1985	16,796	36,703	44,665	1,276,618	814,526	253,882	28,452	131,630	60,378	977,198	**2,482,527**	275,388	**1,158,321**	119,129	**3,640,847**	300,051
1986	16,738	67,705	68,742	1,321,937	723,961	219,192	30,181	174,691	67,335	1,257,318	**2,888,985**	349,618	**1,058,815**	108,450	**3,947,799**	366,052
1987	23,508	117,554	45,425	904,710	640,712	356,089	24,495	152,547	34,507	1,004,217	**2,213,535**	283,881	**1,090,228**	103,887	**3,303,763**	302,293
1988	16,006	41,265	83,433	1,708,615	587,982	195,403	20,485	204,755	74,633	913,340	**2,942,607**	298,857	**903,309**	86,333	**3,845,917**	311,077
1989	23,561	21,917	45,392	783,424	801,507	287,008	6,607	155,278	69,662	1,259,838	**2,290,119**	415,571	**1,164,074**	131,163	**3,454,193**	435,779
1990	22,816	37,394	42,230	604,011	700,164	256,378	15,436	143,438	57,900	601,712	**1,444,456**	194,133	**1,037,024**	114,208	**2,481,480**	225,235
1991	20,683	26,613	50,666	485,446	642,044	248,399	18,452	81,589	32,498	523,481	**1,149,627**	165,745	**980,243**	101,887	**2,129,871**	194,557
1992	33,900	49,878	68,508	706,823	544,646	207,538	20,087	78,563	64,268	732,296	**1,631,828**	244,473	**874,679**	88,804	**2,506,507**	260,103
1993	25,185	70,986	65,500	561,990	455,818	170,839	21,571	138,237	77,221	691,784	**1,540,218**	227,069	**738,913**	68,631	**2,279,131**	237,214
1994	16,865	54,111	39,010	737,462	462,724	188,525	18,710	194,896	53,170	721,514	**1,761,154**	235,263	**725,833**	68,715	**2,486,986**	245,093
1995	17,732	17,257	57,329	599,956	408,654	169,280	26,634	94,812	50,907	676,096	**1,439,027**	210,426	**679,630**	60,622	**2,118,657**	218,985
1996	28,592	20,573	47,989	673,146	328,832	205,643	16,268	82,016	52,749	573,029	**1,401,513**	189,376	**627,324**	50,089	**2,028,837**	195,889
1997	25,218	10,513	47,573	669,534	375,697	193,381	7,535	73,234	59,461	405,886	**1,218,628**	156,185	**649,405**	56,570	**1,868,033**	166,114
1998	30,816	21,325	79,271	807,525	494,525	212,001	4,297	88,184	130,716	541,033	**1,588,784**	169,885	**820,910**	77,987	**2,409,695**	186,930
1999	37,860	6,932	52,941	390,483	549,911	146,833	5,152	73,789	36,142	229,017	**736,362**	75,318	**792,697**	84,735	**1,529,059**	113,370
0yr Av	25,748	30,682	54,219	638,164	524,047	207,802	14,613	109,458	62,245	632,335	**1,472,883**	737,295	**826,430**	283,888	**2,299,314**	790,061

Table 3.5.3 Atlantic Salmon Estimated abundance of 1SW spawning salmon by country and year *ICES 2000: WGNAS*

Year	Finland	France	Iceland	Ireland	Norway	Russia	Sweden	UK(EW)	UK(NI)	UK(Scot)	Southern Europe		Northern Europe		Total	
											Est.	SD	Est.	SD	Est.	SD
eggs/F	5,000	3,450	5,800	3,400	3,500	4,500	3,000	4,800	3,400	5,000	3996		4323		4296	
% Fem	12%	77%	47%	60%	40%	45%	50%	50%	60%	40%	42%		50%		48%	
1971	3,669	52,360	22,752	547,717	112,626	62,730	2,163	101,580	41,484	981,864	1,725,004	306,081	181,188	57,859	1,928,944	311,501
1972	5,692	103,852	20,714	601,458	146,913	69,067	1,743	124,702	37,200	934,028	1,801,239	300,520	223,416	77,175	2,045,369	310,271
1973	8,554	62,881	21,036	644,721	159,516	115,843	2,157	122,968	32,162	1,082,916	1,945,648	336,942	286,071	84,334	2,252,754	347,336
1974	7,806	29,124	14,819	709,537	148,983	106,034	3,097	126,894	32,264	1,055,539	1,953,357	344,262	265,921	80,920	2,234,097	353,644
1975	7,733	58,229	21,224	741,177	140,646	112,533	3,298	150,154	28,827	820,736	1,799,122	279,611	264,210	75,202	2,084,556	289,547
1976	6,788	54,224	18,297	524,802	142,175	84,843	1,828	88,275	20,020	684,686	1,372,007	230,632	235,635	74,121	1,625,938	242,250
1977	5,965	40,826	20,195	459,120	135,298	71,986	889	96,824	19,276	715,893	1,331,940	223,471	214,137	69,768	1,566,272	234,109
1978	4,465	42,598	25,407	413,013	97,830	77,698	1,021	106,882	26,306	765,212	1,354,010	231,994	181,014	49,990	1,560,430	237,319
1979	4,552	48,259	24,712	369,983	166,499	87,979	1,058	71,871	17,333	686,516	1,193,961	220,594	260,088	89,732	1,478,761	238,146
1980	4,535	101,267	8,028	288,534	168,954	58,587	1,340	79,144	21,538	537,504	1,027,987	177,425	233,416	85,465	1,269,430	196,936
1981	4,214	80,878	16,372	137,924	116,223	41,401	2,484	100,901	17,885	679,827	1,017,415	219,808	164,322	59,166	1,198,108	227,631
1982	3,044	50,155	12,544	340,332	86,288	76,726	2,148	60,593	23,485	915,223	1,389,788	336,392	168,206	48,568	1,570,539	339,880
1983	4,568	53,651	16,911	578,287	145,662	113,600	2,819	75,899	33,057	933,245	1,674,139	318,291	266,649	79,801	1,957,698	328,142
1984	5,684	87,773	10,495	224,430	153,652	105,813	3,974	64,180	13,775	932,338	1,322,497	308,507	269,123	81,534	1,602,114	319,099
1985	7,203	32,571	21,092	339,590	156,911	143,022	4,794	62,026	17,365	699,428	1,150,981	240,735	311,930	86,334	1,484,003	255,748
1986	7,198	58,761	32,572	387,783	140,563	122,144	5,134	82,355	19,431	900,188	1,448,518	308,448	275,039	78,155	1,756,130	318,196
1987	10,123	102,178	21,473	294,852	123,824	206,652	4,134	72,098	9,917	716,079	1,195,123	254,329	344,732	77,419	1,561,328	265,851
1988	6,834	35,777	39,340	798,924	112,627	113,492	3,438	97,473	24,494	652,607	1,609,275	262,377	236,391	61,998	1,885,006	269,603
1989	7,935	18,968	21,461	253,315	306,414	167,079	1,087	69,232	7,314	959,623	1,308,451	381,167	482,514	109,754	1,812,427	396,654
1990	7,685	32,450	19,958	281,118	267,588	148,201	2,656	62,536	20,374	461,146	857,624	177,359	426,131	95,297	1,303,713	201,339
1991	6,891	23,074	23,812	254,950	243,687	161,234	3,158	36,430	10,644	397,830	722,928	152,446	414,970	84,937	1,161,710	174,511
1992	11,527	43,423	32,471	318,904	209,036	134,642	3,374	37,238	26,256	558,456	984,278	224,696	358,579	74,851	1,375,328	236,836
1993	8,544	61,790	31,015	261,044	174,767	110,821	3,606	72,988	42,113	529,395	967,330	208,762	297,738	58,764	1,296,083	216,875
1994	5,660	47,005	18,383	335,067	176,291	122,351	5,002	106,098	14,792	550,602	1,053,564	215,306	309,304	58,180	1,381,250	223,028
1995	6,074	14,209	27,286	248,024	157,606	109,923	9,539	53,111	15,736	520,074	851,154	194,160	283,142	51,803	1,161,582	200,952
1996	12,308	16,869	22,610	304,281	125,136	133,323	5,723	49,685	21,145	452,479	844,458	173,985	276,490	42,889	1,143,559	179,193
1997	10,829	8,621	22,367	390,493	160,555	125,391	2,726	45,689	22,128	321,083	788,013	143,558	299,502	49,710	1,109,883	151,921
1998	13,444	17,574	37,517	487,999	213,605	137,579	1,147	58,066	90,900	437,732	1,092,270	155,619	365,776	68,769	1,495,563	170,137
1999	12,756	5,698	25,060	164,622	262,187	95,457	1,358	50,902	12,365	186,324	419,911	68,719	371,758	76,175	816,730	102,591
10yr.av.	8,885	29,069	26,929	357,647	195,210	133,094	3,769	62,595	26,900	531,002	1,007,213		340,958		1,375,100	
	5,331	77,222	73,409	729,600	273,294	269,516	5,653	150,228	54,875	1,062,005	553,794		2,073,930		2,701,133	

Table 3.5.4 Atlantic Salmon Estimated numbers (millions) of returning 1SW salmon by country and year *ICES 2000: WGNAS*

Year	Finland	France	Iceland	Ireland	Norway	Russia	Sweden	UK(EW)	UK(NI)	UK(Scot)	Southern E	Northern Eu	Total
											Est.	Est.	Est.
1979	0.29	0.66	0.68	0.56	1.75	0.37	2.87	0.51	1.08	0.47	**0.65**	**1.19**	**9.23**
1980	0.36	1.42	0.29	0.58	1.92	0.22	4.55	0.49	0.94	0.48	**0.78**	**1.47**	**11.25**
1981	0.39	1.13	0.40	0.41	1.50	0.22	10.59	0.40	1.07	0.54	**0.71**	**2.62**	**16.65**
1982	0.44	0.66	0.35	0.96	1.36	0.41	8.97	0.53	1.67	0.50	**0.86**	**2.30**	**15.84**
1983	0.51	0.39	0.37	1.51	1.87	0.60	7.26	0.42	0.72	0.52	**0.71**	**2.12**	**14.17**
1984	0.75	0.62	0.23	0.88	1.59	0.60	6.44	0.51	0.96	0.49	**0.69**	**1.92**	**13.08**
1985	0.71	0.45	0.54	2.08	1.55	0.60	6.80	0.69	0.73	0.45	**0.88**	**2.04**	**14.59**
1986	0.60	0.68	0.90	1.55	1.35	0.53	6.40	0.68	0.46	0.40	**0.75**	**1.96**	**13.54**
1987	0.49	0.78	0.72	0.81	1.24	0.64	4.50	0.86	1.47	0.38	**0.86**	**1.52**	**11.91**
1988	0.38	0.51	1.08	2.06	1.17	0.35	4.20	0.61	1.16	0.45	**0.96**	**1.44**	**11.98**
1989	0.46	0.25	0.68	0.87	1.44	0.37	2.02	0.44	0.91	0.24	**0.54**	**0.99**	**7.69**
1990	0.52	0.26	0.56	0.64	1.28	0.28	2.85	0.28	0.87	0.26	**0.46**	**1.10**	**7.81**
1991	0.55	0.31	0.59	0.47	1.23	0.25	3.28	0.29	1.05	0.31	**0.48**	**1.18**	**8.33**
1992	0.92	0.86	0.60	0.47	1.12	0.37	3.86	0.62	1.67	0.33	**0.79**	**1.38**	**10.83**
1993	0.66	1.09	0.63	0.77	1.06	0.36	3.14	0.92	0.87	0.38	**0.80**	**1.17**	**9.86**
1994	0.55	0.95	0.43	1.24	0.79	0.24	2.37	0.82	1.15	0.40	**0.91**	**0.88**	**8.97**
1995	0.47	0.27	0.67	1.00	0.61	0.28	2.90	0.51	0.51	0.29	**0.52**	**0.99**	**7.50**
1996	0.71	0.23	0.53	0.97	0.45	0.30	1.46	0.26	0.38	0.23	**0.41**	**0.69**	**5.52**
1997	0.59	0.13	0.48	1.10	0.54	0.31	0.62	0.33	1.92	0.23	**0.75**	**0.51**	**6.26**
0yr Av	1	0	1	1	1	0	3	0	1	0	1	1	8

Fig 3.1 Location of ICES Fishing Areas

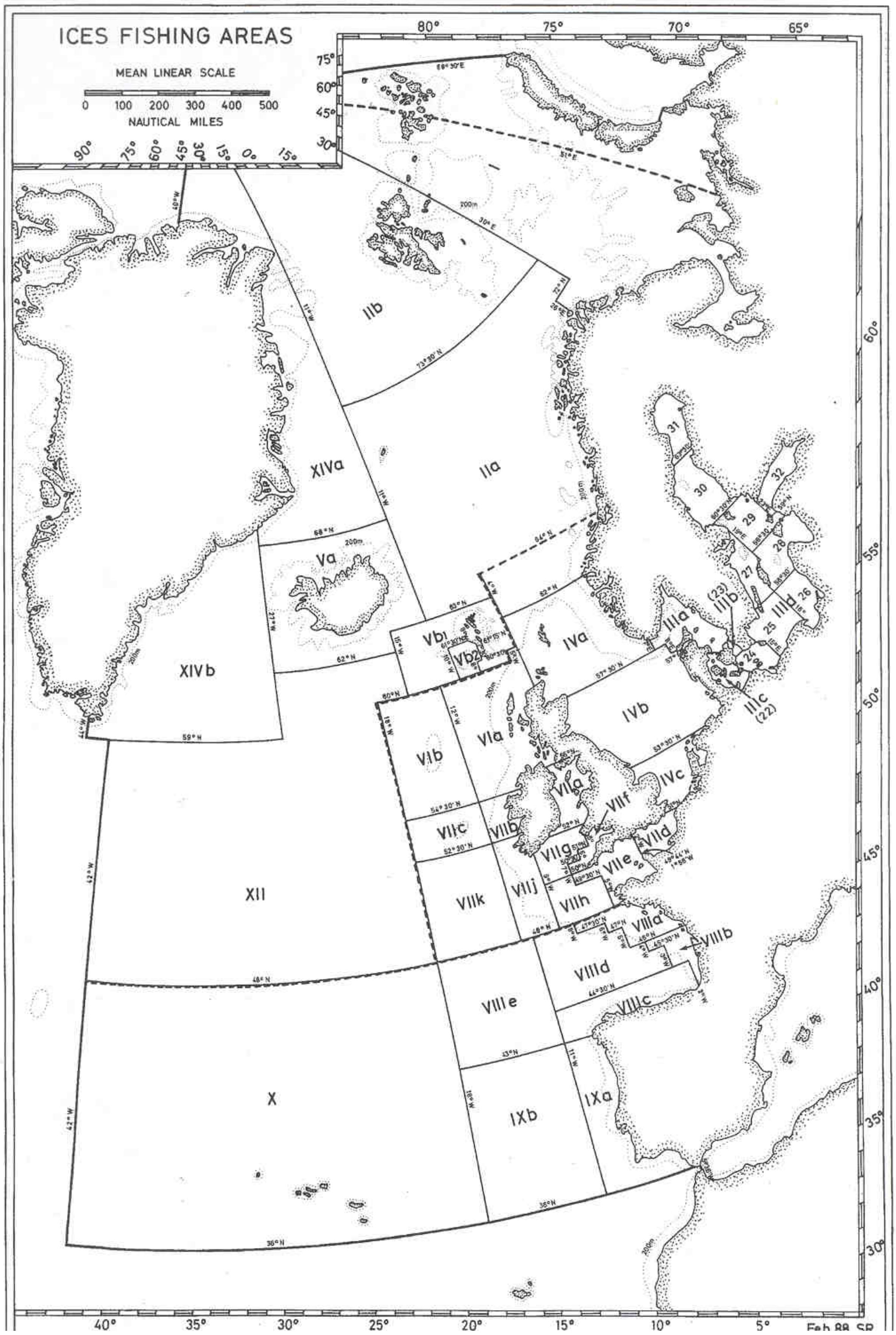
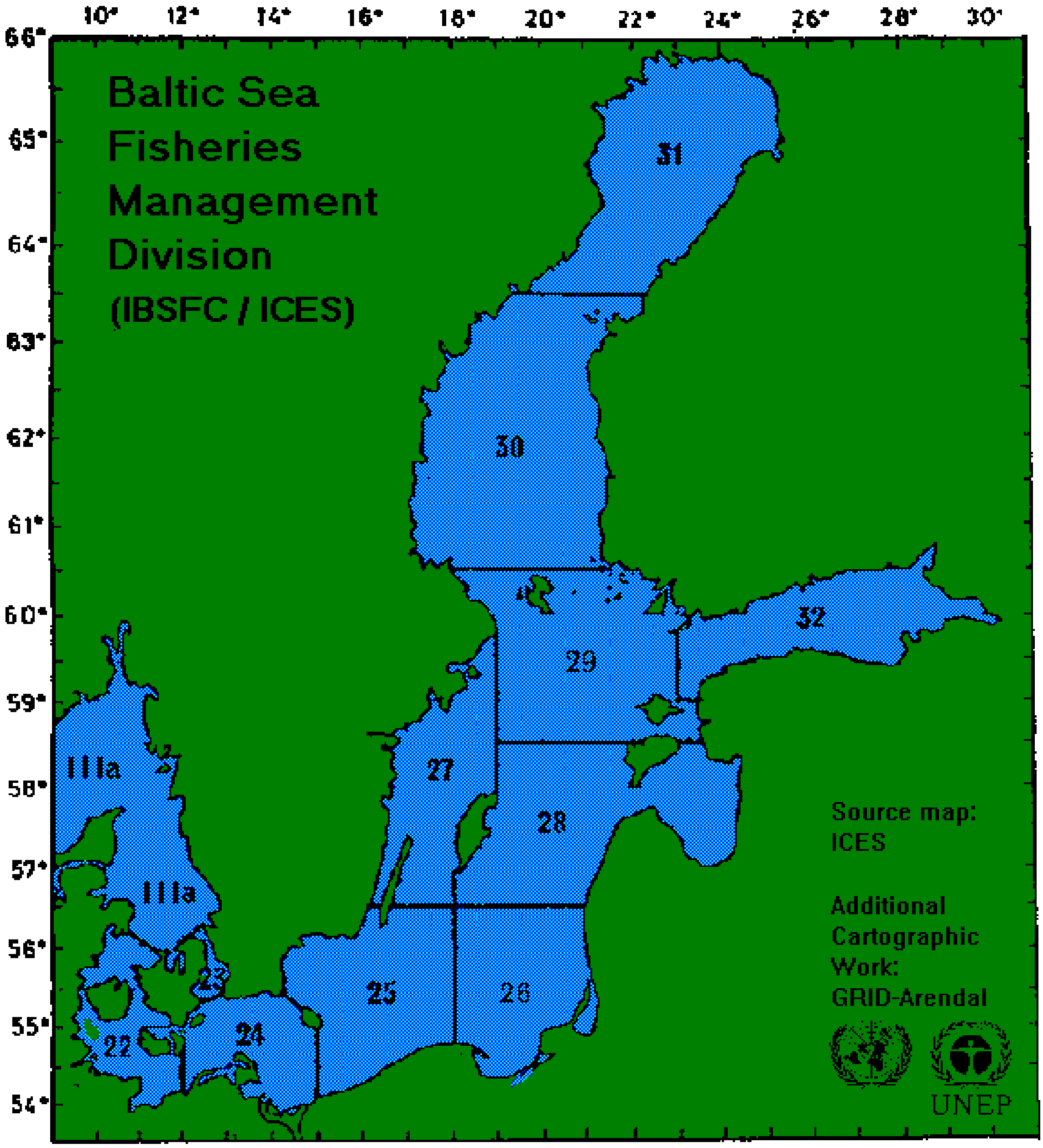


Fig 3.2 Location of Baltic Fisheries Management Division



4. Fisheries data

4.1 Introduction
Most stock production models require accurate catch data; ideally these data should be age specific, totalled over fleets and nations, and be available for a series of years.

4.1.1 Nature of the fisheries considered
Fisheries in the North-East Atlantic can be classified into demersal and pelagic fisheries, and into fisheries that catch fish for human consumption and industrial fisheries that catch fish for such purposes as the manufacture of fishmeal or fish oil. The demersal fisheries usually target mixtures of round fish (e.g. cod, whiting, and haddock) or flatfish (e.g. plaice). Pelagic fisheries tend to target herring or mackerel; these fish may be used both for human food and industrial purposes. Industrial fisheries usually target sandeels, sprat and Norway pout, but they may also by catch other species.

A wide variety of fishing gears is used by these fisheries e.g. otter trawls, seines, gillnets, beam trawls, pair trawls, pelagic trawls and purse seines.

4.1.2 Estimating landings and total catch
Official landings at fish markets are regularly recorded and monitored. Nominal catches are reported by national statistical offices. Usually the statistics are provided as annual landings classified by ICES subdivisions. However some catches are misreported or not-reported due to caught fish being landed unofficially or discarded because quota limits have been exceeded or because the catch has no commercial value. If these unrecorded catches are unaccounted for it would lead to biased estimates of biomass and TACs. Therefore estimates have to be made of their levels.

4.1.3 Estimating rates of discard and bycatch
Information can be obtained from fisheries logbooks, interviews with fishermen and by periodic surveys by sending out observers onto certain fishing boats. An international programme, funded by the EU, to collect data on sampling discards has been running in the Baltic since 1996. Data on discards is only used in a few single-species stock assessments, but for multi-species stock assessments estimates of all discards need to be included.

Discarding is particularly common in trawl fisheries and most discards are small fish. Hence expressing discard rates by number will represent a larger proportion of the total catch than expressing rates by weight.

4.2 COD *Gadus morhua*

4.2.1 Total Allowable Catch (TAC) in tonnes

Area	**2000**	**2001**
I	13494	395000
IIIa-Skaggerak	11600	7000
IIIa-Kattegat	7000	6200
IIIb-d	105000	105000
IIId(Estonia)	105000	105000
IIId(Latvia)	105000	105000
]IIId(Lithuania)	105000	105000
IIA,IV	81000	48600
Vb,VI,XII,XIV	7480	3700

VIIa	2100	2100
VIIb-K,VIII,IX,X	16000	10500
Total	**663674**	**893100**

4.2.2 Minimum landing size
35 cm in all EU areas apart from IIIa (Kattegat/ Skaggerak) where it is 30 cm. In Norwegian waters the minimum size is 40cm.

4.2.3 Minimum mesh size
100 cm for towed gear when targeting cod. 70 cm (with an 80 mm square mesh panel) for bycatches of cod in the *Nephrops* industry. 80 cm for bycatches of cod in the beam trawl fishery for sole. 120 mm for fixed nets.

From 1 January 2002 the minimum mesh size for towed gear and beam trawlers targeting demersal species in the North Sea will increase to 120 mm.

4.2.4 Fisheries
Cod is a key demersal species for many fisheries.

In the **North Sea** (ICES Area IV**)** Cod is usually caught by mixed fisheries together with haddock and whiting, mainly by otter trawl and gill net vessels. The gill netters are better able to target their catch to cod alone. Cod is also an important bycatch in beam trawlers targeting plaice and sole, and in otter trawl fisheries targeting prawns (*Nephrops*). In the **West of Scotland** (ICES Area VIa**)** large numbers of cod are removed each year before they reach maturity by bottom trawl gear in both inshore ands offshore areas. In the **Irish Sea (**ICES Area VIIa**)** cod are caught all year round in mixed fisheries, mainly by whitefish otter trawlers operating from UK and Irish ports, and French and UK pelagic trawlers. There is also some bycatch in *Nephrops* and flatfish fisheries. In the **Celtic Sea** cod are taken in mixed trawl fisheries (France 68%, Ireland 19%, England andWales 9%, Belgium 4%). In the **Baltic c**od are caught by demersal trawls, high opening trawls (both pelagic and demersal) and gillnets. There has been increasing use of gillnets and they now account for up to 50% of the total catch of cod. Cod is the most important commercially caught fish in the Baltic.

4.2.6 Time series of catches
Time series of catches are shown in Tables 3.2.6 (North Sea 1963-2000), Table 3.2.7 (West Scotland 1966-2000), Table 3.2.8 (Irish Sea 1968-2000), Table 3.2.9 (Celtic Sea 1971-2000), Table 3.2.10 (West Baltic 1970-1999), and Table 3.2.11 (East Baltic 1966-1999). Over these time periods, average landings (in 1000s of tonnes) have been:

Area	**Average**	**Maximum**	**Minimum**
North Sea	200	354 (1972)	71 (2000)
West Scotland	14.8	24.3 (1968)	3.1 (2000)
Irish Sea	8.9	14.9 (1981)	2.2 (2000)
Celtic Sea	8.8	20.3 (1989)	2.9 (1974)
West Baltic	38.7	54.4 (1973)	16.7 (1991)
East Baltic	179	392 (1984)	45 (1993)

4.2.6 Total quantities caught and levels of discard
Total catches of cod in the whole North-East Atlantic area by EEA (European Economic Area) countries declined from 1.49 million tonnes in 1970 to 0.89 million tonnes in 1997. Norway took 45% and Iceland 23% of the total 1997 catch.

In the **North Sea and Skaggerak** 97,000 tonnes (made up of 11,000 tonnes in ICES

Area IIIa, 78,300 tonnes in Area IV, and 6,900 tonnes in AreaVIId) were reported landed in 1999. The total figure declined to 71,000 tonnes in 2000. Full estimates of international discards are not available but from discard sampling studies the following estimates of the percentage discarded at age have been calculated (ICES 2001a).

Age	First Quarter	Second Quarter	Third Quarter	Fourth Quarter
1	56-99	66-100	57-100	57-79
2	11-46	10-51	9-67	1-11
3	5-6	7-37	3-6	1-6
4	0-6	0	0	0

Several factors affect discard rates. Inshore fisheries tend to discard more than offshore fisheries, which tend to use larger mesh nets. Also there are fewer juvenile fish offshore. Nephrops trawlers discard larger proportions of their catches of cod than pair trawls and otter trawls, but these other types also discard larger numbers of cod.

In the **West of Scotland** a total catch of 3,090 tonnes was reported in 2000. Existing information is that discarding of cod is at a relatively low level (ICES 2000b).

In the **Irish Sea** a total catch of 2,190 tonnes was reported in 2000. There are no time series of discards. Sampling of *Nephrops* trawls and pelagic trawls since 1997 show that the bulk of discards are 1-year old cod and that fishing mortality on landed and discarded 1-year olds is of equivalent magnitude. Sampling of otter and beam trawls indicates similarly low discard rates.

In the **Celtic Se**a a total catch of 6,990 tonnes was reported in 2000.

Catches in the **West Baltic** in 1999 were reported to be 42,150 tonnes, in the **East Baltic** they were 72,990 tonnes. For both of these stocks the quality of landing statistics was low in the early 1990s but has improved since. However there is still uncertainty in the estimates of stock size and level of fishing mortality. he exploitation rate is high and fishing pressure on young ages has increased. The quantities of discards are still largely unknown, but discards of fish below minimum size does occur. More than one third of the landings in 1996 were of 2-year old cod of which only 22% were mature. In all years landings have been far above levels recommended by ICES.

4.2.8 Catch at age and fishing mortality rates

At the minimum landing size of 35 cm cod are at age 2 years and upwards. Many fish are caught before that have the chance to spawn and less than 5% of 1-year olds survives to the age of 4. Time series of catch numbers at age are given in Table 4.2.1 (North Sea), Table 4.2.2 (West Scotland), Table 4.2.3 (Celtic Sea), Table 4.2.4 (Irish Sea), Table 4.2.5 (West Baltic), and Table 4.2.6 (East Baltic). Time series of fishing mortality rates for these areas are given in Tables 3.2.6 to 3.2.11. Over the time periods of the tables, average rates have been:

Area	Age-classes	Average	Maximum	Minimum
North Sea	2-8	0.812	1.064 (1982)	0.451 (1963)
West Scotland	2-5	0.785	1.060 (1997)	0.521 (1966)
Irish Sea	2-4	0.908	1.417 (1997)	0.578 (1970)
Celtic Sea	2-5	0.740	1.032 (1991)	0.399 (1977)
West Baltic	3-6	1.157	1.707 (1986)	0.805 (1984)
East Baltic	4-7	0.894	1.361 (1991)	0.320 (1993)

4.2.9 Seasonality of fishing

The fishery is all year round, although some fleets are seasonal. Within the North Sea, the highest catches in the first quarter of year are in southern areas, south of Dogger Bank and from the German Bight. In the second quarter of year the highest catches are in north-eastern areas, west of Jutland and south of Norway although significant landings are also made from the southern North Sea and German Bight. In the third quarter of year the catches are more evenly distributed over the North Sea but highest catches are in eastern areas. The fourth quarter of year is similar to the first quarter. In the Celtic Sea catches are highest in the winter months November to April.

4.3 WHITING *Merlangius merlangus*

4.3.1 Total Allowable Catch (TAC) in tonnes

Area	2000	2001
IIIa	4000	2500
IIa, IV	30000	29700
Vb, VI,XII,XIV	4300	4000
VIIa	2640	1390
VIIb-k	22500	21000
VIII	7000	5600
IX,X	2640	2100
Total	**73080**	**57335**

4.3.2 Minimum landing size

27 cm, except for the Skagerrak (ICES Area IIIa) where it is 23 cm.

4.3.3 Minimum mesh size

80 mm (otter and beam trawls) or 70 mm (*Nephrops* trawlers).

4.3.4 Fisheries

In the **North Sea**, whiting are fished by mixed demersal fisheries mainly by Scotland (seine and light trawl), England (seine and trawl) and France (inshore and offshore trawlers). Some are also caught by Dutch beam trawlers and German trawlers. French trawlers targeting saithe take a bycatch of whiting. It is also a bycatch in the industrial fisheries for Norway pout, sandeel and sprat.

In the **Celtic Sea w**hiting are fished by mixed trawls, otter trawls, seine and French *Nephrops* trawlers.

In the **Western Channel w**hiting are fished by otter trawls targeting a wide range of species, and beam trawlers targeting sole, monkfish and plaice.

4.3.5 Time series of catches

Time series of landings data are shown in Table 3.3.2 (North Sea 1960-2000) and Table 3.3.3 (Celtic Sea 1982-2000). Over these time periods, average landings (in 1000 tonnes) have been:

Area	Average	Maximum	Minimum
North Sea	177	360 (1976)	43 (1998)
Celtic Sea	15.2	22.7 (1995)	10 (1986)

4.3.6 Total quantities caught and levels of discard

In 2000 total catch was 55,300 tonnes (24,000 tonnes for human consumption, 22400 tonnes discarded and 8,900 as industrial bycatch). Human consumption and industrial landings are close to the lowest recorded levels and the level of discards is almost double the 1998 figure of 12,700 tonnes. ICES has recommended that technical measure be introduced to address the high rate of discarding because a reduction in fishing mortality cannot be achieved by TAC management alone. There is not thought to be a serious problem due to mis-recording in the catch data figures.

4.3.7 Catch at age and fishing mortality rates

The vast majority of 0, 1 and 2-age fish are caught in industrial fisheries or are discarded by human consumption fleets. Time series of mean fishing mortality rates are shown in Table 3.3.2 (North Sea) and Table 3.3.3 (Celtic Sea). Over the time periods of the tables, average rates have been:

Area	**Age-classes**	**Average**	**Maximum**	**Minimum**
North Sea	2-6	0.827	1.347 (1960)	0.412 (2000)
Celtic Sea	2-5	0.852	1.420 (1983)	0.354 (1996)

4.3.9 Seasonality of fishing

In the **North Sea** whiting are take all year over a wide area but especially in the north-western North Sea and in the eastern North Sea off the coasts of Germany, the Netherlands and Denmark. During the winter (October-March) months most of the catches are from the western and northern areas. In summer there is an increase in the catches from the south and east.

In the **Celtic Sea t**he bulk of landings (> 60%) are made from November to March

4.4 MONKFISH/ANGLERFISH *Lophius piscatorius* and *L.budegassa*

4.4.1 Total Allowable Catch (TAC) in tonnes

Area	**2000**	**2001**
IIa, IV	11660	14130
Vb,VI,XII,XIV	8000	6400
VII	23000	21700
VIIIa-e	6570	5900
Cecaf 34.1.1	6800	6000
Total	**62030**	**54130**

4.4.2 Minimum landing size

No minimum landing size. One reason given for this is that the large head size of fish which makes the imposition of a minimum size impracticable.

4.4.3 Minimum mesh size

None

4.4.4 Fisheries

For the Northern stock (North Sea, West Coast of Scotland and Skagerrak) monkfish are the fourth most abundant demersal species by weight caught by the Scottish fleet Until the mid-

1980s monkfish was mainly taken as a bycatch in bottom trawl.

For the southern stock (Celtic Sea), monkfish is an important component of mixed fisheries also taking hake, megrim, sole, cod, plaice and *Nephrops*. The fish is of great economic importance to fishermen. A trawl fishery by Spanish and French vessels developed in the Celtic Sea in the 1970s and 1980s, and these countries take about 75% of the total landings. Most of the remainder is taken by UK, Ireland and Belgium. French, Spanish and Irish vessels mainly use otter trawls, whereas 60% of the UK catch is by beam trawlers and gill netters. Monkfish are also taken by beam trawlers in deeper waters, usually as a bycatch in several types of fishery.

Off South-West England, local fishermen use both inshore gill nets and bottom set gill nets to catch monkfish. When set loosely bottom-set nets are called tangle nets and monkfish caught in these nets have been reported as suffering from seal damage, especially when nets remain unhauled for several days.

4.4.5 Time series of catches

These are shown in Table 3.4.2 (Northern stock 1973-1999) and Table 3.4.3 (Southern stock 1986-2000). Over these time periods, average landings (in 1000 tonnes) have been:

Area	**Average**	**Maximum**	**Minimum**
Northern	15.8	34.4 (1996)	5.8 (1981)
Southern	18.5	23.7 (1986)	12.8 (1992)

4.4.6 Total quantities caught and level of discard

In the North Sea and west of Scotland more than 98% of the catch is *L. piscatorius* compared to 2% *L. budegassa*.

In the Northern stock (North Sea, West of Scotland and Skagerrak), approximately 9,000 tonnes was caught annually from 1974-1983. Catches then rose gradually up to 34,000 tonnes in 1996. Since then there has been a steep decline to around 19,000 tonnes in 2000. Routine data on discards are not collected. However, it is known there is some discarding in targeted fisheries for monkfish and in other fisheries such as those for scallops. Recent observer trips on Scottish vessels indicate that discarding of monkfish only occurs at very low levels.

In the Southern Stock (Celtic Sea) landings for 2000 were 12,600 tonnes, a decrease from the 22,000 tonnes landed in 1996. This decline is for white monkfish, as catches of black monkfish have increased slightly. There is no systematic sampling of discards, but checks made on French, Irish and Spanish fleets indicated that there was only a low level of discarding and that any discards are limited to very small fish.

4.4.7 Catch at age and fishing mortality rates

Time series of catch at age are shown in Table 4.4.1 and time series of average fishing mortality rates are shown in Table 3.4.2 (Northern stock 1992-1999) and Table 3.4.3 (Southern stock 1986-2000) Over the time periods of the tables, average rates have been:

Area	**Age-classes**	**Average**	**Maximum**	**Minimum**
Northern	6-8	0.575	0.897 (1996)	0.413 (1999)
Southern	3-8	0.319	0.392 (1989)	0.213 (1993)

4.4.8 Seasonality of fishing

Year round, but off South-West England, tangle nets set in the vicinity of wrecks and reefs are more important in providing a winter fishery.

4.5 ATLANTIC SALMON *Salmo salar*

4.5.1 Total Allowable Catch (TAC) in numbers

Area	2000	2001
IIIb-d	450000	450000
IIId (Estonia)		450000
IIId (Latvia)	450000	450000
IIId (Lithuania)	450000	450000
Sub-div 32 of IBSFC	90000	70000
Total	1440000	1870000

4.5.2 Minimum landing size
Not applicable

4.5.3 Minimum mesh size
60 cm in the Baltic.

4.5.4 Fisheries
In the Baltic there is an offshore fishery using drift nets and long lines, in coastal waters trap nets are used, in rivers there is fishing with seine nets and sport fishing. From 1990-2000 there has been a shift from offshore fisheries towards coastal and river fisheries.

4.5.5 Time series of catches
Table 4.5.1 lists the catches of salmon caught in the open sea from 1973-1999. Over this time the catch has declined markedly from 4873 tonnes in 1973 to 46 tonnes in 1999. Table 4.5.2 lists estimated total catches of salmon from 1989-1999 in the North-East Atlantic categorised as either wild, farmed or ranched. Table 4.5.3 lists the catches of salmon in the Baltic from 1987-1999.

4.5.6 Catch at age and fishing mortality rates
Not applicable.

4.5.7 Total quantities caught and levels of discard
There is little knowledge on the nature and level of bycatches of post smolt or adult salmon in commercial fisheries. There are suspicions that both industrial and pelagic fisheries for human consumption pose a threat in this respect. Research fishing off Norway and North-West Scotland using surface trawling techniques have caught salmon and have provided evidence that they were exhibiting shoaling behaviour. Thus it is possible that similar commercial fisheries could cause major damage to certain year-class runs from a river.

In the late 1980s the offshore fisheries in the Baltic took more than 1 million salmon annually. The present quota is 450,000 fish (2000 tonnes). Only poor data on levels of discarding and reporting of undersized fish are available. Unreported catches in 2000 were estimated at 315 tonnes (equivalent to 56,397 fish), discards were estimated at 261 tonnes (48,441 fish). About 36,000 salmon were discarded in 2000 due to damage by seals in gears. In the Gulf of Finland there is increasing damage due to seal in Estonia and Finland. It has been estimated that seals damaged about 7% of the catch, equivalent to 50 tonnes of salmon catch in 1998. 78 tonnes (12,000 fish) were reported to have been discarded in 2000, approximately 95% of this was apparently due to seal damage. The most serious problems are reported to occur in SD29 (Åland Sea and Archipelago Sea), SD30 (Bothnian Sea), and

SD32 (Gulf of Finland) where seals destroy trap nets.

4.5.8 Seasonality of fishing
In the Baltic there is a closed season from June to August. The fishery in Denmark is divided into winter fishery (using long lines) and a spring and autumn fishery (using drift nets).

4.6 EEL *Anguilla anguilla*

4.6.1 Total Allowable Catch (TAC) in tonnes
There is no TAC because data on stock and recruitment relationships are not available for the different life stages of the eel, in addition TACs would be difficult both to monitor and to enforce.

4.6.2 Minimum landing size
There is no minimum landing size. Where elver recruitment is low, the commercial glass eel fishing is banned (Sweden, Denmark, Germany, Ireland, Netherlands, Belgium).

4.6.3 Minimum mesh size
There are restrictions on mesh size.

4.6.4 Fisheries
Eels are taken in trawls, on long lines and in traps of various types. The largest fisheries are for glass eels in the Bay of Biscay and South-West England. Eels are caught in Spain and Portugal by traps and hand nets, in France by small trawlers, and in the UK with hand nets. Yellow/ silver eels are caught in mainland Europe, Ireland and the Baltic using pound nets and similar passive devices, including traps. German fishermen are reported to be particularly concerned about the declining yields of the eel fishery.

4.6.5 Time series of catches
Reported catches of all age-classes of eels listed by area and fishery nation are given in Table 4.6.1.

4.6.6 Catch at age and fishing mortality rates
Not applicable.

4.6.7 Total quantities caught and levels of discard
In 1999, 827 tonnes of eels were caught.

4.6.8 Seasonality of fishing
Closed seasons are used in some countries to ensure unhindered migration of fish to the sea. These are timed according to local characteristics of the eels and the local fisheries.

4.7 HADDOCK *Melanogrammus aeglefinus*

4.7.1 Total Allowable Catch (TAC) in tonnes

Area	2000	2001
IIIa-d	4450	4000
IIa, IV	73000	61000
Vb, VI,XII,XIV	19000	13900
VII,VIII,IX,X	13200	12000
Total	**109650**	**90900**

4.7.2 Minimum landing size
30 cm, except for ICES Area IIIa where it is 27cm.

4.7.3 Minimum mesh size
100 mm (North Sea), but *Nephrops* trawlers can use 70 mm mesh with restrictions on the size of the bycatch of haddock.

4.7.4 Fisheries
In the North Sea haddock is taken as part of mixed demersal fishery, mostly by Scottish light trawlers, seiners and pair trawlers. Lesser quantities are taken as a bycatch by *Nephrops* trawlers. Haddock are also taken as a bycatch in Danish and Norwegian industrial fisheries. In the Kattegat/Skagerrak they are taken in mixed demersal and industrial fisheries.

4.7.5 Time series of catches
Time series of catches are given in Tables 3.7.2 (North Sea, 1963-2000) and 3.7.3 (West Scotland, 1965-2000). Over these time periods, average landings (in 1000 tonnes) have been

Stock	Average	Maximum	Minimum
North Sea	263	931 (1969)	93 (1990)
West Scotland	32.3	58.5 (1971)	15.3 (2000)

4.7.6 Catch at age and fishing mortality rates
A time series of catch numbers at age for the North Sea over the period 1985-2000 is given in Tables 4.7.1.Time series of mean fishing mortality rates are given in Tables 3.7.2 (North Sea, 1963-2000) and 3.7.3 (West Scotland, 1965-2000). Over the time periods of the tables, average fishing mortality rates have been

Stock	Age-classes	Average	Maximum	Minimum
North Sea	2-6	0.918	1.152 (1969)	0.620 (1968)
West Scotland	2-6	0.669	0.973 (1972)	0.384 (1981)

4.7.7 Total quantities caught and levels of discard
Landings in the North Sea in 2000 were 102,000 tonnes. In West Scotland, the total catch in 2000 was 15,300 tonnes of which 7,000 tonnes were official landings and 8,200 tonnes were discards. The levels of discarding in this sea area have been well monitored and a time series (1965-2000) is shown in Table 3.7.3.

4.8 PLAICE *Pleuronectes platessa*

4.8.1 Total Allowable Catch (TAC) in tonnes

Area	**2000**	**2001**
IIIa-Skaggerak	11220	9400
IIIa-Kattegat	2800	2350
IIa, IV	97000	78000
Vb,VI,XII,XIV	2400	1920
VIIa	2400	2000
VIIbc	300	240
VIIde	6500	6000
VIIfg	800	760
VIIh-k	1350	1215
VIII,IX,X	700	560
Total	**125470**	**102445**

4.8.2 Minimum landing size
22 cm, except for ICES Area IIIa where it is 27cm.

4.8.3 Minimum mesh size
100 mm for beam trawlers in the North Sea.

4.8.4 Fisheries
In the Celtic Sea and Western Channel (ICES Areas VIIe-g) the haddock fishery is mainly carried out by UK, French and Belgian otter trawlers, plus some Belgian beam trawlers. In the North Sea plaice are taken by beam trawlers in mixed fisheries with sole. In addition, there are seine and gillnet fisheries directed at plaice, and a mixed otter trawl fishery. In the Eastern Channel plaice are caught by Belgian and UK offshore beam trawlers, French and UK inshore trawlers, and by French otter trawlers in winter.

4.8.5 Time series of catches
A time series of landings for the North Sea in the period 1957-2000 is given in Table 3.8.2. Average landings were 117,800 tonnes with a maximum of 169,800 tonnes in 1989 and a minimum of 70,600 tonnes in 1957. In the Celtic Sea and Western Channel landings rose gradually from 1976 to reach a peak of over 5,500 tonnes in 1990; they have since declined to around 2,000 tonnes.

4.8.6 Total quantities caught and levels of discard
In the North Sea plaice discards can be very high and have been estimated at 50% for beam trawlers (CEFAS 2001).

4.8.7 Catch at age and fishing mortality rates
A time series of the numbers of fish caught at age is given in Table 3.8.1. A time series of mean fishery mortality rates for the period 1957-2000 in the North Sea is given in Table 3.8.2. Over the time periods of the tables, average rates have been:

Stock	**Age-classes**	**Average**	**Maximum**	**Minimum**
North Sea	2-10	0.366	0.540 (1994)	0.197 (1957)

4.8.8 Seasonality of fishing

In the Celtic Sea and Western Channel plaice are taken all year, but the highest landings are in February and March, and in September and October.

4.9 HERRING *Clupea harengus*

4.9.1 Total Allowable Catch (TAC) in tonnes

Area	**2000**	**2001**
Man Unit 3	85000	72000
I,II	1252000	851500
IIIa	80000	80000
IIIb,IIIc-d	405000	300000
IIId (Estonia)	405000	300000
IIId (Latvia)	405000	300000
IIId (Lithuania)	405000	300000
IIId (Poland)	405000	300000
North Sea	265000	265000
IVc, VIId	265000	265000
Vb, VIaN, VIb	42000	36360
VIaS, VIIbc	13900	13900
VIa, Clyde	1000	1000
VIIa	5350	6900
VIIef	1000	1000
VIIg-k	21000	20000
Total	**4056250**	**3112660**

4.9.2 Minimum landing size

20 cm, except for ICES Area IIIa where it is 18 cm

4.9.3 Minimum mesh size

Baltic Statistical Divisions 22-27: 32 mm; SDs 28-29 south of 59°30’: 28 mm; SDs 29-32 north of 59°30’: 16 mm.

4.9.4 Fisheries

In the North Sea herring are caught in drift nets, ring nets and trawls. In the Baltic, herring and sprat are caught in a mixed fishery which uses small-mesh trawls. Sprat fisheries have a bycatch of herring, and herring trawls yield a bycatch of sprat. A small fraction of the landed herring is taken with trap or pound nets during spawning time, the bycatch of sprat in this fishery is minimal. Sprat is managed by one TAC agreed for the whole Baltic, herring by two TACs. The herring TACs have been kept high despite decreasing stock size, but have not been taken in full since 1989. This fact, together with an increasing sprat stock, has created a strong incentive to misreport sprat as herring in order to utilize the quotas of both herring and sprat as much as possible. If this has happened, as the data seem to indicate, it will have influenced the assessments for both stocks. ICES (2001h) recommended that the species compositions of the landed pelagic fish should be reevaluated and revised at a national level.

4.9.5 Time series of catches
Time series of landings are shown in Tables 3.9.2 (North Sea, 1960-2000), 3.9.3 (Baltic except SD31, 1974-2000), and 3.9.4 (Baltic SD31, 1980-2000). Over these time periods, average landings (in 1000 tonnes) have been:

Stock	**Average**	**Maximum**	**Minimum**
North Sea	518	1169 (1965)	11 (1978)
Baltic (not SD31)	264	323 (1979)	178 (1999)
Baltic (SD31)	6.9	9.7 (1980)	3 (2000)

4.9.6 Total quantities caught and levels of discard
In the North Sea, 372,000 tonnes were landed in 2000. In the Baltic (excluding SD31) 208,000 tonnes were landed in 2000; 3,000 tonnes were landed in Baltic SD31.

4.9.7 Catch at age and fishing mortality rates
Time series of fishing mortality rates are given in Tables 3.9.2 (North Sea, 1960-2000), Table 3.9.3 (Baltic except SD31, 1974-2000) and Table 3.9.4 (Baltic SD31 only, 1980-2000). Over the time periods of the tables, average rates have been:

Stock	**Age-classes**	**Average**	**Maximum**	**Minimum**
North Sea	2-6	0.646	1.480 (1975)	0.053 (1978)
Baltic (not SD 31)	3-6	0.279	0.473 (2000)	0.186 (1977)
Baltic (SD31)	3-7	0.364	0.624 (1998)	0.174 (1980)

4.9.8 Seasonality of fishing
All year.

4.10 SPRAT Sprattus sprattus

4.10.1 Total Allowable Catch (TAC)

Area	**2000**	**2001**
IIIa	50000	50000
IIIb-d	400000	355000
IIId (Estonia)	400000	355000
IIId (Latvia)	400000	355000
IIId (Lithuania)	400000	355000
Iia, IV	225000	232000
VIIde	12000	12000
Total	**1887000**	**1714000**

4.10.2 Minimum landing size
None.

4.10.3 Minimum mesh size
16 mm in the Baltic.

4.10.4 Fisheries
There are important fisheries in the North Sea, Norwegian waters and in the Baltic. Inshore

fisheries mainly operate in the winter and use trawls and drift nets often from small boats. In the Baltic pelagic fisheries, using single and pair trawl, operate for industrial use by EU vessels and for human consumption by East Baltic countries.

4.10.5 Time series of catches
Time series of landings for the North Sea, Kattegat/Skagerrak and Baltic Sea are given in Tables 4.10.1. Over these time periods, average landings (in 1000 tonnes) have been:

Stock	Average	Maximum	Minimum
North Sea	171	641 (1975)	16 (1986)
Kattegat/Skagerrak	32	101 (1975)	2 (1992 and 93)
Baltic	174	529 (1997)	37 (1983)

4.10.6 Total quantities caught and levels of discard
In 1999 421,000 tonnes were landed in the Baltic.

4.10.7 Catch at age and fishing mortality rates
A time series (1974-1999) of average fishing mortality rates for the Baltic is given in Table 3.10.1. Over the time periods of the tables, average fishing mortality rates have been:

Stock	Age-classes	Average	Maximum	Minimum
Baltic	3-6	0.287	0.463 (1975)	0.129 (1992)

4.10.8 Seasonality of fishing
All year.

4.11 SANDEEL Ammodytes sp

4.11.1 Total Allowable Catch (TAC)

Area	2000	2001
IV (Norwegian)	Not applicable	Not applicable
IIa + IV (North Sea)	1020000	1020000

4.11.2 Minimum landing size
None.

4.11.3 Minimum mesh size
None.

4.11.4 Fisheries
Sandeels are taken by trawlers using small mesh gear. The fish are mainly taken for industrial purposes, principally by Denmark and Norway. Most of the catch consists of lesser sandeel *Ammodytes marinus.*

4.11.5 Time series of catches
Time series of landings are given in Table 3.11.1 (North Sea, 1983-2000), 4.11.1 (North Sea by area) and 4.11.2 (North Sea by fishing nation).

4.11.6 Total quantities caught and levels of discard

In 2000 699,000 tonnes were landed from the North Sea. Over the period 1983-2000 the mean annual landings were 798,000 tonnes the maximum was 1,138,000 tonnes in 1997, and the minimum was 537,000 tonnes in 1983.

4.11.7 Catch at age and fishing mortality rates

At current levels of fishing mortality, it is believed that the size of sandeel stocks is mainly determined by natural processes. A time series of average fishing mortality rates for fish aged 1-2 years in the North Sea is given in Table 3.11.1. During this period the average fishing mortality was 0.60, the maximum was 0.96 in 1985, and the minimum was 0.35 in 1984.

4.11.8 Seasonality of fishing

Peak catches are in spring and summer (April to June), only very low catches are taken in the period October to February.

5. Analysing interactions between seals and fisheries

5.1 Introduction

There is no doubt that marine mammals can be important influences in their ecosystems (Bowen 1997). The fact that, in some ecosystems, other taxonomic groups may be more important as predators of commercial fish species than marine mammals (e.g., Overholtz et al. 1991, Trites et al. 1997) does not necessarily imply that the effects of marine mammals are unimportant. The protocol in UNEP (1999) suggests that a formal "2-way matrix of who eats whom" be established before "deciding which species should provisionally be taken into account in an evaluation of the likely effects of a cull." Some of the information identified by UNEP (1999) as necessary for scientific evaluation of cull proposals requires extensive knowledge of multispecies interactions within which seals and commercial fish species operate. Multispecies approaches, despite many problems, are being actively promoted for fisheries science in general (e.g., ICES 1999), although total allowable catches (TACs) for exploited fishes are still largely based on single-species models.

Whipple et al. (2000) provide a useful discussion of the different methodologies that have been used to analyse predation mortality in aquatic ecosystems. They distinguished between static-flow models that provide a "snapshot" of the system at one moment in time, dynamic models that attempt to track variations in population size over time, and spatially explicit models that attempt to take account of variation in space as well as time. The simplest form of static-flow models simply involve calculations of the quantities of fish species consumed by seals, which are compared with the quantities taken by commercial fisheries. In simple "surplus yield" calculations it is then assumed that a reduction of the seal population by, say X%, will result in an equivalent reduction in the amount of fish consumed by seals and that, at least part, of this "surplus yield" will be available to commercial fisheries. More sophisticated static-flow models use mass-balance principles to estimate flows of organic matter or energy among components of an ecosystem using data on diets, estimated assimilation efficiencies, metabolic demands, etc. Formal implementations of this approach include the use of Ecopath software (Christensen and Pauly 1993, available at http://www.ecopath.org) and inverse-modelling (Savenkoff et al. 2001). This approach is particularly useful for identifying deficiencies in knowledge of the system. Some authors have attempted to use Ecopath to investigate the impacts of changes in one component of an ecosystem by manipulating the biomass of that component and re-balancing the system. However, Ecopath assumes that the interactions among the components of the system being modelled are linear, so that it cannot on its own be used to draw conclusions about effects of changes in exploitation rates or predation. Dynamic models, such as Ecosim (see below), are required for this. The Ecopath-with-Ecosim package also has an option (Ecospace) to incorporate spatially explicit variation in predator and prey dynamics.

ICES is planning a workshop on ecosystem models that will be run at the end of 2002, at the earliest (ICES 2001k) to compare the performance of a range of ecosystem models. Although this will, undoubtedly be an extremely useful exercise, its main purpose is to compare the performance of these models in predicting the effects of different fisheries activities on the entire marine ecosystem, rather than the role of predators in these systems.

Many model implementations have been hybrids of static-flow models for higher predators and dynamic models for prey populations. However, if such models are to be even moderately realistic it is important that they take account of the way in which the number of individuals of each prey species consumed by a predator varies with prey abundance (the predator's functional response), and the way the predator population responds to changes in overall prey availability (the numerical response of the predator population). In particular, very little attention has been paid to the way the functional response to one prey species may be affected by changes in the abundance of other prey (this is known as the predator's multispecies functional response).

The functional response can be very important in determining the way predator-induced mortality varies with prey abundance. Most predators do not have a linear functional response. Rather, the number of individuals of a particular prey species that are consumed may be relatively constant over a wide range of prey population sizes. As a result, over this range of prey abundances, the rate at which prey are consumed by the predator tends to increase as prey abundance falls. As a result, under certain circumstances, predator-induced mortality can rise to such a high level that the prey is "trapped" at a low level of abundance in what has been called a "predator pit". Such inverse density-dependent effects have been documented in some terrestrial predator-prey interactions and they have been proposed as an explanation for the failure of some fish stocks (eg northern cod in Canada, Norwegian spring spawning herring) to recover from the effects of over-exploitation.

Data on the functional responses of seals are equivocal. Stenson and Perry (2001) found no significant change in the proportion of Atlantic cod in the diet of harp seals off the east coast of Newfoundland over a period when the size of the cod stock declined by a factor of 100 times. This suggests that the functional response of harp seals to cod is highly non-linear. The Ecosim computer package has the facility to mimic the effects of predator functional responses by providing a "refuge" where some prey are unavailable to predators. Ironically, when this package was used to model interactions between cod and harp seals in the same area (see section 5.5.2) the best fit to the time series of fish abundance data was obtained when cod had no refuge from seal predation (Bundy 2001), implying a linear functional response.

Other authors have documented large changes in diet composition from region to region that appear to be related to the availability of prey, and there have been marked shifts in the diet of harp seals in the Barents Sea following changes in the abundance of capelin, their preferred prey (Bogstad et al. 2000). However, to date, there has been no systematic attempt to fit functional responses to these data.

Most dynamic models of multispecies populations have been extensions of "classical" prey-predator/competition models using differential or finite-difference equations. These have been used both to support and oppose the selective removal of one or another living component to influence the abundance or yield of another. For example, Flaaten (1988) used models of this kind to conclude that "sea mammals should be depleted to increase the surplus production of fish resources for man." Yodzis (1994) showed that this conclusion was a consequence of the structure of Flaaten's model, which was based on a few interacting species and linear interaction terms. Models with non-linear interaction terms provided very different conclusions. Yodzis concluded that "it remains frustratingly difficult to say just what functional form [of interaction] is the appropriate one for a given real population."

A recent exchange between Boyd (2001) and Yodzis (2001b) has highlighted the results of recent research on global-scale environmental shifts and consequent changes in prey-predator and fishery régimes: El Niño is a familiar example. Such events introduce additional uncertainty into the application of complex ecosystem models to particular situations.

Despite all these valuable multispecies approaches, a "common sense" view is that some effects of reducing seal predation should be predictable without resorting to multispecies analysis. Given the time lags that may be involved in the re-equilibration of whole systems, a sharp reduction of seal predation on fish of commercial size should lead to an increase in the size of the relevant fish stocks, at least in the short-term. Similarly, a reduction of predation on pre-recruit fish might give enough short-term relief to permit the stock to escape a "predator trap" caused by inverse density-dependent mortality. These possibilities are implicitly recognized by Yodzis (2001, p. 80), who notes "on a short time scale we might predominantly observe the effect from the shorter pathway (an increase in fisheries yield), with the contribution of the longer pathway making itself felt only on a longer timescale, possibly leading to a reversal of the response (a decrease in fishery yield)."

5.2 Surplus yield calculations

As noted above, surplus yield calculations may provide a reasonable estimate of the consequences of a change in predator abundance. However, such calculations are unlikely to provide a realistic estimate of the longer-term consequences of such a change. In addition, it is important to take account of the uncertainties involved at each stage of the calculation. When this is done, the potential benefits to fish stocks may be less clear cut than a simple calculation might imply. For example, MacLaren et al. (2001) calculated the potential effects on the northern cod stock of removing 750,000 harp seals from the North-West Atlantic stock over a five year period. The mean estimate was that this would reduce the quantities of cod consumed by around 4,000 tonnes per year. This is roughly equivalent to the effect of closing the current commercial fishery. However, the 95% confidence limits on this estimate were very wide (± 1,500 tonnes) and the consequences for the Canadian seal industry would be dramatic, with a high probability that this fishery would have to be closed following the reduction in seal numbers.

In an earlier example, Hammond and Fedak (1994) calculated that grey seals consumed 10,500 tonnes of cod in the North Sea in 1992. Again, the 95% confidence limits were wide (7,300-16,000 tonnes). The mean estimate of consumption was 10.7% of the commercial catch by all fisheries in that year. Since 1992 the TAC for cod has been substantially reduced (to 49,300 tonnes in 2002 compared with landings of 98,000 tonnes in 1992), and the grey seal population has increased by 60%. This might, and has, been interpreted as implying that grey seal predation is approaching the commercial catch. However, the grey seal diet estimates, particularly those for the Orkney islands where most of the population is concentrated, are based on samples collected in 1985 (Hammond and Fedak 1994). The size of North Sea cod stocks has declined very sharply since then (see section 3.2) and cod may now constitute a smaller proportion of the grey seal diet than in 1985.

5.3 Minimum realistic models

On way to improve the realism of simple surplus yield calculations is to incorporate predator mortality directly into models of the dynamics of target fish stocks. Such models have been referred to "minimum" realistic models (MRMs, for short). Such models may be fully dynamic (where continuous changes in the abundance of both predator and prey are modelled), or combine dynamic models of the fish stocks with static-flow models of predator consumption. There are now a number of examples of spatially-explicit models of this kind.

The incorporation of additional sources of predation may have counter-intuitive consequences for the predicted response of the target fish stock to a change in predator abundance. Perhaps the most oft-quoted example is an analysis conducted by Punt and Butterworth (1995) who developed an age-structured model of the interactions between Cape fur seals and the South African hake fishery. When they included only a single, cannibalistic hake species in their model, a decrease in fur seal numbers resulted in increased hake catches. However, when they took account of the fact that there are actually two hake species in South African waters, and that the species preferred by fur seals is a major predator on the younger stages of the species that is predominantly taken by the commercial fishery, they reached the opposite conclusion: a reduction in fur seal numbers had a negligible or negative effect on the commercial catch of hake. This is a classic example of what has been termed "mesopredator release" (see Crooks and Soulé 1999), where the reduction in predation on a species that is both prey and predator results in the "release" of this species and a substantial increase in predation on other prey species. Thus control of cat populations on islands may result in an increase, rather than the expected decrease, in seabird predation because of a consequent increase in the numbers of rats (Courchamp et al. 1999)

The results of Punt and Butterworth's analysis led UNEP (1999) to recommend the use of MRMs for evaluating the potential effects of culls of marine mammals on fisheries yields. In addition, UNEP suggested that MRMs should attempt to incorporate at least 80% of the natural predation on the target fish stock, although the basis for this value is not explained. There have been a number of attempts to apply MRMs to marine mammal-fisheries interactions since the 1992 and 1994 meetings that led to the UNEP guidelines and we review some of them below.

Hammond and O'Brien (2001) provide an amusing account of how Bayesian methods can be used to take account of uncertainty in the predictions of an MRM of the effects of grey seal and seabird predation on a hypothetical haddock stock.

5.3.1 MULTSPEC and BORMICON

MULTSPEC is a spatially-explicit, mixed static-flow and dynamic modelling package developed by Bogstad et al. (1997, with a more accessible account in Tjelmeland and Bogstad 1998) to investigate interactions between three fishes (capelin, herring, cod), harp seal, and minke whale (*Balaenoptera acutorostrata*) in the Barents and Norwegian Seas. Marine mammal numbers are assumed to remain constant over time, unless they are harvested. Bogstad et al. (1997) tentatively concluded that herring stocks would be reduced by increased whale numbers, whereas increased harp seal numbers would most heavily affect the capelin and cod stocks. These conclusions were generated by removing portions of the model fish and mammal populations and comparing the results with those from a "reference run." They claimed that the results were robust within broad specifications of the interactions. However, the lack of any functional response by either predator to changes in the relative abundance of alternative prey, the lack of any modelling of predator dynamics, and the fact that the dynamics of the system are largely driven by variations in spring-spawning herring which are controlled by events outside the Barents Sea suggests that alternative formulations of the model might produce rather different conclusions.

BORMICON (Bjoernsson 1997), like MULTSPEC, a spatially-explicit, mixed static-flow and dynamic modelling package. It's structure is more general than MULTSPEC and teh BORMICON framework is now being used as a replacement for MULTSPEC in the development of new models of the Barents Sea system. It was developed to investigate the effects of interactions among Icelandic cod, capelin, shrimp and baleen whales and fisheries yields. Preliminary application of this model (Stefánsson et al. 1997) suggested that "the impact of the three baleen whale species on the development of the cod stock is uncertain, but may be considerable".

5.3.2 Herring, mackerel, cod and grey seals in the southern Gulf of St Lawrence

Swain and Sinclair (2000) used an MRM to investigate how the abundance of herring and mackerel in the southern Gulf affects the recruitment of cod through predation of cod eggs and larvae. Swain and Sinclair suggest that seals may "have an indirect positive effect [on cod stocks] through predation on pelagic fishes." Indeed, their title suggests that they believe the argument might apply more widely to "the cod recruitment dilemma in the Northwest Atlantic." It is true that mackerel and herring are known elsewhere to consume eggs and larvae of cod and have been suggested to influence cod recruitment (references in Swain and Sinclair 2000). The one reference for herring in the Gulf of St. Lawrence (Messieh et al. 1979) is uninformative on proportions of cod among fish eggs (in 11% of stomachs) and larvae (a "trace") eaten. However, herring and mackerel undoubtedly do have opportunities to consume cod eggs and larvae during their heavy feeding period in summer.

The role of seals in this "triangular food web" is less certain. An estimated 3000 tonnes of herring were consumed by grey seals in the southern Gulf in 2000 (with very wide limits per Table 3 in Hammill et al. 2000). This estimated consumption is very much smaller than the estimated age 4+ biomasses of ~49 Kt for the spring spawning component and 415 Kt for the autumn spawning component of herring, and the combined fishery take of ~76 Kt (DFO 2001c). Hammill et al. (2000) do not estimate mackerel consumption in this region, but they did estimate that mackerel supplied only ~4% of the herring contribution to diet energy of grey seals (their Table 3). Taking individual herring and mackerel as energetically equivalent, this translates to ~120 tonnes of mackerel. This seems inconsequential from a spawning stock biomass (taken as an index) of ~2Mt in 2000 by Swain and Sinclair (2000, their Fig. 1), or even from the smaller current estimate of 366,022t in DFO (2001d). Thus, whereas Swain and Sinclair's (2000) hypothesis of a negative effect of pelagic fish biomass on cod recruitment appears generally convincing, there appears to be little evidence that seal predation on herring or mackerel is sufficient to reduce this effect.

5.3.3 Grey seals and cod on the Scotian Shelf, Canada

There have been two recent attempts to develop MRMs of the interactions between grey seals and Atlantic cod on the Scotian Shelf, off the east coast of Nova Scotia.

Mohn and Bowen (1996) modelled the functional response of the seals in two ways: a linear response and a “constant ration” model (which assumed that the proportion of cod in the seals’ diet was independent of cod abundance). They found that the model results were highly dependent on the form of the functional response, but concluded that “seals were not a major factor in the recent [1993] collapse of this stock”.

Fu et al. (2001) assumed that mortality on cod was proportional to grey seal abundance (which had been increasing exponentially over the 25 years of their modelling exercise) and used the same two functional responses as Mohn and Bowen (1996), but also allowed mortality from other causes to vary between years. They conclude that high natural mortality of immature and adult cod, much of which appears to be due to grey seal predation, and low recruitment since the mid-1990s have prevented the recovery of this stock.

5.3.4 Incorporation of marine mammal predation into Multispecies Virtual Population Analysis.

A number of studies have incorporated seal predation into the MSVPA framework. Livingston and Jurado-Molina (2000) developed an MSVPA model of the Bering Sea ecosystem involving six prey species and six predators, including northern fur seals. They found that the resulting estimates of total mortality for the prey species were higher than those obtained from single-species VPAs, but drew no conclusions about the importance of fur seal predation in prey dynamics.

The ICES Multispecies Working Group (ICES 1997) implemented an MSVPA model for the entire North Sea, involving a large number of fish prey species and their predators. Estimates of species- and size-specific fish consumption by grey seals, seabirds and cetaceans (mainly harbour porpoise and minke whales) were included in this analysis. The estimates of prey consumption by fish predators were based on large-scale stomach sampling programmes conducted in 1981, 1985-87 and 1991. They also obtained higher estimates of natural mortality, particularly for younger age-classes, than those obtained from conventional single-species VPAs. Hildén (1988) had shown that shifts in predators preference for prey over time could undermine the reliability of MSVPA calculations. However, the Working Group found very little evidence of this in the data from the North Sea studies. It concluded that the predictions of MSFOR (a multi-species model that uses values from MSVPA and assumptions about stock-recruitment relationships for individual fish species to predict future changes in stock sizes) were quite similar to those obtained from single species models, but that single species models may underestimate the time that depleted stocks may take to recover. They also noted that predator and prey stocks may follow very different trajectories as a system recovers from over-fishing. As noted in chapter 3, grey seals do not appear to be a particularly important source of mortality for most of the fish stocks considered by the Group. The Group also concluded that inadequacies in the available catch data were probably more important than inadequacies in the diet data, and therefore did not recommend another large-scale stomach sampling exercise in the North Sea.

ICES will host a workshop on MSVPA in the North Sea on 8-12 April 2002, but this will have to rely on seal consumption data that is now more than 15 years old, so it is unlikely to draw any new conclusions about the importance of grey seal predation in the North Sea ecosystem.

5.3.5 Steller sea lion and Alaskan pollock

Hollowed et al. (2000) developed a MRM of predation on pollock in the Gulf of Alaska incorporating three predators, one of which was the Steller sea lion, and pollock cannibalism. As with other MRMs, they obtained estimates of natural mortality on pollock that were higher than those from single species models.

5.4 Food web models

Pimm and Rice (1987) considered the usefulness of food web models for management of marine resources, and concluded that they were more useful for broad comparisons among ecosystems rather than for providing specific advice. They also noted that such models often had serious problems where may predators consumed the same prey species. However, there have been substantial improvements in the sophistication of marine food web models since their work.

Yodzis (1998, 2000, 2001a) has cautioned against the usefulness of MRMs. His extended food-web model of the Benguela Current ecosystem, of which the interaction of the fur seal with hakes studied by Punt and Butterworth (1995) is a part, included a wide range of components from bacteria to cetaceans. Yodzis used the model to investigate indirect interactions (for example the effects that fur seals might have on hakes via their predation on other fish species) from changing seal numbers, and to see if valid conclusions can be reached from using only a subset of species in the entire web. The uncertainty of total fish yields following a cull of fur seals in the context of the entire food web was summarized by Yodzis (2001a, Figure 2). He concluded that "the qualitative result, that a cull is more likely to be detrimental than beneficial to the total fishery, is robust with respect to underlying assumptions" about the inclusion of other prey effects and shape of the interaction functions. It is certainly true that the expected benefit to all fisheries is substantially less than the "surplus-yield" and that, for all fisheries combined, there is only a 25-39% probability that there will be any improvement to yield (Yodzis 1998, Table 1). However, this is not true for individual species. For hakes, the probability of an improvement in yield to the fishery is actually quite high (60-80%). The implication is that some fisheries will be winners and others will lose if a cull was implemented.

Yodzis (1998) also used his model system to investigate the robustness of conclusions drawn from MRPs. He found that he could capture most of the important features of the system if he excluded all links that represented less than 10% both by and of any species. In this way, he could ignore 91 of the 203 links in his system and still make similar predictions to those obtained with the full system. However, most of the data that are available to fisheries scientists only provide information on the proportions of different prey species in the diets of individual species in the system. He concluded that this was a less satisfactory way of identifying weak (that is, less important) links in the system, but he concluded that most of the important properties of the system could be preserved if all links that contributed less than 5% of a predators diet were ignored. This reduced the number of links in the system from 203 to 106. Unfortunately, this is still a much more complex system than any of the MRPs that have been used so far. These results also imply that MRPs which follow the guidelines in UNEP (1999) and account for 80% of the predation on the prey species of interest may not capture all of the important indirect interactions in the system.

5.5 Energy flux models

Given the enormous difficulties in obtaining enough information for the complex, age-structured population models of the kind developed by Yodzis, an alternative modelling approach for complete food webs is to use information on biomasses and the flow of organic matter among components. The Ecosim software (Walters et al. 1997, Pauly et al. 2000) provides a methodology for investigating the consequences of changes in fishing and predation ecosystems using this kind of information, although its limitations and assumptions must be clearly recognized. There have been a number of attempts to use Ecopath-with-Ecosim to investigate the consequences of changes in marine mammal numbers on commercial fish stock, some of which we describe here.

5.5.1 Steller sea lions and Alaskan pollock.

Trites et al. (1999 in Yodzis 2001a) used Ecosim to investigate the role of fisheries for Alaskan pollock and commercial whaling for fin whales on the decline of the Steller sea lion population in the Bering Sea. However, they were "unable to account for the differences between what was observed in that system in the 1980s and the best available reconstruction of the state of the system in the 1950s."

5.5.2 Harp seals and cod on the Newfoundland-Labrador shelf

Bundy et al. (2000), compiled available information and indirect estimates of biomass, consumption, production, and diet of major species and species groups on the Newfoundland-Labrador shelf during the period 1985-1987. These estimates produced considerable imbalances in the flows of organic matter within the overall system, at "a time of relatively constant biomass for the major commercial species." The biomasses and flows of organic matter among components were balanced using Ecopath. They found that the two most important predators of small cod were harp seals and large cod, although they concluded that the former was less important than the latter.

The system has changed radically since that time, most obviously through the great diminution of cod and other groundfish stocks and an approximate 70% increase in the harp seal population. The possible impact of these changes between 1985 and 2005 were explored by Bundy (2001) using Ecosim. She considered a number of different scenarios in which she simulated changes in fishing mortality on small (<35 cm) and large (>35 cm) cod, American plaice, and small (<40 cm) and large (>40 cm) Greenland halibut, each year from 1985 to the 1994 moratoria. She also simulated a potential rate of increase in the harp seal biomass by 5% per year. Vulnerabilities to predation were modelled by three situations: (1) all prey available to predators (top-down control); (2) predation completely constrained (bottom-up control); (3) only a proportion of prey available to predators (implying the existence of prey refugia). Given the unstructured pelagic and benthic habitats of eastern Newfoundland, the top-down situation was considered to be the most likely. This model, combined with a 5% annual increase in harp seal numbers, gave the best qualitative match to the observed changes in biomass of system components between 1985 and 2005. Bundy (2001) concluded that the results were consistent with the hypothesis that the collapse of the northern cod stocks was due to excess fishing, and "also support the hypothesis that the recovery of cod is currently being retarded by the increased biomass of harps seals due to predation by harp seals on cod." However, in the model simulations small and large cod in the model, unlike those in nature, had recovered to almost half their pre-collapse levels by the year 2000. In reality, no such recovery has occurred. It should be recognized that these simulations take no account of uncertainties in the estimates of energy flows between components of the system and that Ecosim is likely to be more effective at simulating the effects of small deviations from initial equilibrium conditions, rather than the very large changes that have occurred on the Newfoundland-Labrador shelf.

5.6 Application of the UNEP guidelines to interactions in the North-East Atlantic and Baltic Sea.

We have identified four basic interactions between seals and commercial fisheries in the North-East Atlantic and Baltic which appear to be particularly important to fishers:

- The indirect effects of predation by grey seals on commercial catches, and the recovery, of cod stocks in the North Sea.
- The indirect effects of predation by grey seals and harbour seals in estuaries and in the open sea on the recovery of Atlantic salmon stocks.
- The direct effects of grey seals, and possibly harbour seals, on a range of different fisheries for salmon.
- The direct effects of grey seals on bottom-set gillnet fisheries for monkfish in the Celtic and Irish Seas, and off South-West England.

In this chapter we will attempt to evaluate these interactions using the protocol for the scientific evaluation of proposals to cull marine mammals developed by the Scientific Advisory Committee of the Marine Mammals Action Plan of UNEP (UNEP 1999). In particular, we will see if the data that are available match those listed in Table 2 of the UNEP protocol. This identifies five areas where data are required: 1. basic information on the marine mammal populations, the target fish species, the fisheries involved, and the geographical area of concern; 2. cull objectives; 3. ecological information; 4. fisheries data on catches, bycatches, management systems and economics; and 5. the culling programme. As we have shown in Chapters 2 and 3, there is extensive basic information on the marine mammal and fish species involved in all of the interactions listed above, and we will not review this further here. Culls are being undertaken in relation to the perceived indirect effect of grey seals on fish stocks off the Norwegian coast, and in the Baltic to reduce damage to salmon and other whitefish fisheries. However, none of the detailed documentation relating to these culls is currently available in an English translation and we have not, therefore, been able to evaluate these plans against the criteria listed in Table 2 of the UNEP protocol.

5.6.1 Indirect effects of grey sealson cod in the North Sea

Fishermen in the UK and Norway have complained about the potential effects of increasing grey seal numbers on cod stocks in the North Sea for many years. The abortive attempt to reduce the size of the UK grey seal population in 1977 and 1978 was justified on the basis of these arguments, and fishermen's organisations in the UK are still lobbying for a renewal of these culls. Norway has recently increased the annual quotas for grey and harbour seals in its coastal waters by 30%. They now exceed the calculated replacement yield for these populations, and therefore these quotas must be regarded as an attempt to reduce the size of the population. We have not been able to locate any documentation justifying this increase, but the Norwegian fisheries minister has appeared on Scottish television claiming, at least in translation, that there is "no doubt that seals threaten the country's fish stocks".

For UK grey seals there are good data on grey seal population size, per capita food and energy consumption, and total food consumption. The available data on diet composition dates back to the mid-1980s when the composition of North Sea fish stocks was very different from what it is now. There is extensive information on the target fish species, and on other predators of this species but the development of a 2-way matrix of 'who eats whom' in this system is hampered by the quality of the seal diet information and the quality of the information on total catches (including bycatch and discards) of all of the fish species that interact with cod.

Estimates of the size of the Norwegian grey seal population and of the diet of these seals is much less extensive than for the UK.

We therefore conclude that all of the data required to evaluate any proposal to cull grey seals in the North Sea is not currently available. The situation, at least for UK seals, will be substantially improved when the results of new studies of grey seal diet become available (probably in 2004), and when the ICES MSVPA workshop has had an opportunity to evaluate the quality of the current information on total fisheries removals. For the Norwegian situation, better information on grey seal numbers and diet is required. However, Norwegian seals are a small component of the total North Sea stock, and it seems that the problems experienced in Norway are primarily local ones which are not easily analysed using any of the frameworks described in the earlier sections of this Chapter.

5.6.2 Indirect effects of seals on Atlantic salmon

Salmon fishermen have also complained for decades about the potential impact of seal predation, particularly in estuaries, on the recovery of salmon stocks. Indeed, the culls of UK grey seals that were instigated in the 1960s were primarily driven by complaints from salmon fishermen. There is no doubt that grey seals prey, often very visibly, on salmon in estuaries and the lower reaches of rivers, but there is almost no data on the levels of mortality caused by this predation. A more comprehensive evaluation of the causes and consequences of mortality on salmon at all stages of its life cycle, and of the likely benefits in terms of time to recovery from different management approaches, is required before all of the criteria listed in the UNEP protocol can be met for this interaction.

5.6.3 Direct effect of grey seals on salmon fisheries

The most detailed studies of the effects of grey seals around salmon fishing gear have been carried out along the Swedish coast, particularly looking at interactions around salmon traps. Lunneryd and Westerberg (1997) estimated levels of seal damage in this fishery and calculated that up to 50% of the catch was damaged. The economic costs of this damage and indirect costs through changes in fishing practice and damage to gear have been estimated at around 5 million Euros per year (Westerberg et al. 2000). Reports of damage have been increasing by approximately 15% per year; much faster than the rate of increase of the grey seal population. Attempts to reduce the problem by shooting seals in the immediate vicinity of fish traps resulted in no significant reduction in seal damage, but scaring devices were more effective (Westerberg 2001). Gear modifications to reduce the vulnerability of salmon to attacks by seals in and around traps have, however, been very effective (Lunneryd et al., in press; Westerberg 2001). However, these modifications cannot be applied to drift net fisheries for salmon and herring which also suffer from seal damage.

As noted in Chapter 2, both Sweden and Finland have begun issuing licences for seal hunting. In Sweden, regional quotas are related to the reported levels of damage to fisheries rather than the size of the local seal population. They must therefore be regarded as culls. However, there appears to have been no evaluation of the likely effects of these culls on fisheries damage. If the results of Westerberg's experiments apply generally, any benefits are unlikely to be detectable.

The UNEP protocol was not designed for the analysis of direct interactions between seals and local fisheries, and it is impossible to use the data requirements listed in the protocol to evaluate the available evidence on this interaction. However, we note that there are no published data on the current diet of grey seals in the Baltic, although some work on fatty acid signatures has been conducted (M. Biuw, pers. comm.).

5.6.4 Direct effects of grey seals on monkfish fisheries

Arnett (2001) and Westcott (2000) report high levels of damage in gillnet fisheries for monkfish off the west coast of Ireland and South-West England, respectively, which are believed to be caused by grey seals. There is no evidence that monkfish form a major part of the diet of gey seals in either area, but hard parts of this species will be difficult to detect in stomachs or faeces. This is another direct interaction which is difficult to analyse under the UNEP protocol. However, we note that the available information on the diet and size of the grey seal populations in these two areas is of much poorer quality than that available for other parts of the grey seal's range in the North-East Atlantic.

6. Interactions between marine mammals and fisheries in other parts of the world.

UNEP (1999) lists nearly 30 instances of then current or historical culls of marine mammals due to interactions with fisheries. Nearly half of these are in the North-East Atlantic. There have been few additions to this list since it was compiled in the mid-1990s. The Canadian government has sometimes claimed that the commercial harvest of harp seals is, at least in part, designed to reduce predation on fish stocks, particularly cod. However, the aim of that management is to take the replacement yield of seals (that is, maintain the population at its current level), and so it is unlikely to **reduce** predation. Claims that the current quota exceeds the replacement yield because it does not take adequate account of animals killed but not landed do not seem to be justified (see MacLaren et al. 2002).

Although there is growing concern elsewhere in the world about the potential effects of marine mammal predation on fisheries yields (see references in Yodzis 2001a), no culls have yet been implemented to address these concerns.

However, in at least two cases, modifications in fisheries practice to protect endangered species or populations from the indirect effects of fisheries. In particular, the US National Marine Fisheries Service has recently published a series of Biological Opinions which conclude that the fisheries for Alaskan pollock, Atka mackerel and Pacific cod in the Berring Sea and Gulf of Alaska are adversely modifying habitat for the endangered western stock of Steller sea lions. As a result the North Pacific Fisheries Management Council has been required to develop “reasonable and prudent” alternative management approaches for these fisheries aimed at reducing this adverse modification. Similar advice is being considered about lobster fisheries around Hawaiian because of their potential role in the decline of the critically endangered Hawaiian monk seal.

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