Convention on Biological Diversity

JOINT EXPERT MEETING ON ADDRESSING
  BIODIVERSITY CONCERNS IN
  SUSTAINABLE FISHERY
Bergen, Norway, 7-9 December 2011

COMPILATION OF THE SCIENTIFIC INFORMATION ON THE IMPACTS ON MARINE AND COASTAL BIODIVERSITY OF PELAGIC FISHERIES OF LOWER TROPHIC LEVELS

Note by the Executive Secretary

1.   The Executive Secretary is circulating herewith a background document on the compilation of the scientific information on the impacts on marine and coastal biodiversity of pelagic fisheries of lower trophic levels, for the information of participants in the Joint Expert Meeting on Addressing Biodiversity Concerns in Sustainable Fishery, being convened in Bergen, Norway, from 7 to 9 December 2011.

2.   The research for this background document was undertaken by the Institute of Marine Research (Bergen, Norway) as part of the support for this meeting provided by the hosting country.

3.   The document is circulated in the form and language in which it was received by the Secretariat of the Convention on Biological Diversity.

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Background document for CBD Expert meeting, Bergen, 7-9 December 2011

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Ecological effects of fisheries on small pelagics

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Background

Under the agenda item on impacts of unsustainable fishing (such as destructive fishing practices, overfishing, and illegal, unreported and unregulated (IUU) fishing) on marine and coastal biodiversity, the Conference of the Parties to the UN Convention on Biological Diversity in COP Decision X/29, paragraph 53, asked for an expert meeting "*to review the extent to which biodiversity concerns, including the impacts on marine and coastal biodiversity of pelagic fisheries of lower trophic levels, are addressed in existing assessments and propose options to address biodiversity concerns*".

This background document for the expert meeting in Bergen, 7-9 December 2011 deals with the issue of fisheries of pelagic fish at lower trophic levels. The document summarizes information on the fisheries of 'pelagics' at global and regional levels and provides some perspectives on the ecological roles of pelagic fish in marine ecosystems. It is <u>not</u> a thorough review of the large body of recent literature on 'small pelagics' and the dynamics of the ecosystems in which they occur. This was not possible in the short time period available for the preparation of the document. It also does not address the issue of the ecological effects of fisheries of pelagic fish on other parts of the marine and coastal ecosystems. Some additional material on the effects issue will be prepared and presented at the expert meeting in Bergen.

Small pelagics - what are they?

Fish come in a wide variety of shapes and forms, from tiny small fish about one cm long (*Paedocypris*) to the large whale shark that can grow up to 20 m long. FishBase includes over 32.000 species worldwide from many different taxonomic categories. Fish belong to the phylum of vertebrates and are made up of three main groups (taxonomic classes): jawless fish (class Agnatha) with lampreys and hagfish, cartilaginous fish (class Chondrichthyes) with sharks, rays and chimaeras, and bony fish (class Osteichthyes) with lobe-finned (lungfish and coelacanths) and ray-finned fishes (sub-class Actinopterygii). The ray-finned fishes contain the majority of extent fish species (about 30.000) in a number of different taxonomic orders, including herrings (Clupeiformis), salmons (Salmoniformes), cods (Gadiformes), flatfishes (Pleuronenctiformes) and perch-like fishes (Perciformes). The latter group is the most diverse and species-rich with about 40 % of all fish species including types such as cichlids, gobies, mackerel, and wrasses.

Based on life history, the fishes are grouped in two broad categories: those that live at or associated with the seafloor, which are the *demersal* group of fish, and those that live mainly in the water

column above the seafloor, the *pelagic* group of fish. This separation works well for many fish. Thus herrings and anchovies are mainly found in the free water masses and classify well as typical pelagic species, while flounders and other flatfishes are clear examples of demersal species. However, the distinction between demersal and pelagic life styles and species is often not that clear. Many species considered demersal, such as Atlantic cod, may frequently leave the bottom to forage in the water column. In the opposite manner, many species considered pelagic may seek shelter close to the bottom, particularly in shallow water during day-time, and they may even dig into the sand to hide as sand eels or sand lances do.

Important pelagic species of fish include the groups of:
- herrings, anchovies and sardines (Clupeiformes),
- mackerel and tunas (family Scombridae),
- jacks and horse mackerels (family Carangidae),
- sand eels and sand lances (family Ammodytidae),
- cod fishes (family Gadidae, including Alaska pollock and blue whiting),
- pomfrets (family Bramidae),
- cutlassfishes (family Trichiuridae),
- needlefishes (family Belonidae),
- flyingfishes (family Exocoetidae),
- sauries (family Scomberesocidae),
- swordfishes (family Xiphiidae),
- herring smelts or argentines (family Argentinidae)
- deep-sea smelts (family Bathylagidae), and
- lanternfishes (family Myctophidae).

The pelagic fishes can be separated into categories of small and large. Anchovies, sardines and myctophid lanternfishes are clearly small fish in the group of *small pelagics*, while blue-fin tunas and swordfish are obviously *large pelagics*. Where the border between small and large pelagics is placed is a matter of practical convenience. In ecological terms, the small species of pelagics feed solely or predominantly on zooplankton, while larger species of pelagics feed on other but smaller pelagic fish. Species of intermediate size such as mackerels, Alaska pollock and pomfrets feed variously on zooplankton (notably larger forms such as krill) and smaller fish. Many will shift the diet from feeding mainly on zooplankton as juveniles to feed mostly on fish as they grow bigger. Small pelagics are often used in a restricted sense to denote small clupeoids (such as sardines, anchovies and herrings), sand eels, and other small fish (such as sand eels, jacks and mackerels) that are used primarily for production of fish meal and fish oil.

Overview of main groups and species of 'small pelagics'

The next section (Pelagic fisheries) identifies the main groups and species of small (and large) pelagic fish that contribute to fishery yields globally and regionally (see Table 1). Some information on the main groups and species of pelagic is given in the following. More information on the biology and ecology of pelagic fish species are given in later sections in general terms and as specific examples from upwelling and northern boreal ecosystems.

Herrings, sardines and anchovies

Small clupeoids (herring-like fishes of the taxonomic order Clupeiformis) constitute the most important component of small pelagics in terms of global fisheries (see next section) and possibly also in terms of ecological importance in many marine ecosystems. There are two main families of clupeoids: *Clupeidae* which includes herrings, sardines, shads, and menhadens, and *Engraulidae* which are the anchovies. Atlantic herring (*Clupea harengus*) and Pacific herring (*Clupea pallasii*) are two closely related (twin) species (maximum length about 40 cm) that form large migratory populations in the boreal ecosystems of the North Atlantic and North Pacific. Sardines, sardinellas and pilchards are small species of clupeoids (typically 20-25 cm in length) that are abundant in many temperate marine ecosystems. Pilchards are important in many upwelling systems with California pilchard (*Sardinops caeruleus*), South American pilchard (*Sardinops sagax*), Japanese pilchard (*Sardinops melanostictus*) and Southern African pilchard (*Sardinops ocellatus*) forming a species complex that should perhaps be considered to be only one species (*Sardinops sagax*) made up of three genetic lineages (Grant et al. 1998, FishBase). European pilchard or sardine (*Sardina pilchardus*) is a different species found from the upwelling region along northwest Africa north to the North Sea and also in the western Mediterranean Sea. Sardinellas (genus *Sardinella*) occur with many different species in coastal and shelf waters of temperate and warmer regions. Round sardinella (*Sardinella aurita*) has a wide distribution on both sides of the Atlantic, while Indian oil sardine (*Sardinella longiceps*) is found in the northwestern Indian Ocean.

Shads and menhadens belong to a subgroup of herrings (subfamily Alosinae). Many shads are anadromous fish that feed and grow in coastal and shelf waters and move into rivers and freshwater lakes to reproduce. Menhadens occur typically in coastal waters and estuaries mainly in the Atlantic (*Brevoortia* spp.). Gulf menhaden (*Brevoortia patronus*) supports a fairly large fishery in the northeastern Gulf of Mexico.

Anchovies are small slender fish typically 10-20 cm long. They occur with many species in the Atlantic, Indian and pacific oceans and are particularly abundant in temperate waters where they support some of the major fisheries in upwelling areas. By far the most important in total fisheries catch is the ancoveta or Peruvian anchovy (*Engraulis ringens*) found along western South America in Peru and Chile. Japanese anchovy (*Engraulis japonica*) is found in the western North Pacific from northern Japan and Korea south along China almost to Canton and Taiwan. European anchovy (Engraulis encrasicolus) is found along the eastern border of the Atlantic from western Europe south along western Africa and also in the western Mediterranean. Southern African anchovy (*Engraulis capensis*) is found in the Southeast Atlantic along Namibia and South Africa.

Mackerels, tunas, bonitos, jacks and horse mackerels

Two families of pelagic fish are important components of marine pelagic ecosystems and support important pelagic fisheries. These are the family of mackerels, tunas and bonitos (Scombridae) and the family of jacks, pompanos, horse mackerels and scads (Carangidae). These are fast-swimming schooling fish that feed variously on zooplankton and other small pelagic fish as well as squid. Both families occur with species ranging in size from relatively small to large (blue-fin tuna (*Thunnus thynnus*) can reach a maximum length of 4.5 m, while greater amberjack (*Seriola dumerili*) can be up to 2 m).

Chub mackerel (*Scomber japonicus*) has a wide dsitribution in the Pacific and Indian oceans, while Atlantic mackerel (*Scomber scombrus*) is found in the North Atlantic. These two mackerel species can grow to maximum length of about 60 cm but are commonly around 30 cm long. They support large commercial fisheries in the Pacific and North Atlantic, respectively. Jack or horse mackerels of different species in the genus *Trachurus* are found along continents with abundant species in temperate and upwelling areas. Chilean jack mackerel (*Trachurus murphy*) is found in the South Pacific where it supports a large fishery in the upwelling areas along South America. Japanese jack mackerel (*Trachurus japonicus*) is found around Japan south to the East China Sea in the western North Pacific, Atlantic horse mackerel (*Trachurus trachurus*) is distributed in the eastern Atlantic from western Europe south along Africa, while Cape horse mackerel (*Trachurus capensis*) is found along Southwest Africa. The distributions of these four jack or horse mackerels are broadly similar to those of the four species of anchovies described above. The jack or horse mackerels can grow to a maximum length of 50-70 cm depending on species, but they commonly are around 25-35 cm long.

Bonitos are medium-sized tunas, with several species in the genus *Sarda* (Atlantic bonito - *Sarda sarda*; Pacific bonito - *Sarda chilensis*; Australian bonito - *Sarda australis*; striped bonito - *Sarda orientalis*). These fish grow to a size of about 1 m in length and 10 kg in weight. The most important species in terms of fisheries is the ocean bonito, or skipjack tuna (*Katsuwonus pelamis*), which is a highly migratory species with cosmopolitan distribution in the warmer parts of the Atlantic, Indian and Pacific oceans. Tunas are large species with Pacific blue-fin tuna (*Thunnus orientalis*) growing up to 3 m in length and Atlantic blue-fin tuna (*Thunnus thynnus*) even larger (up to 4.5 m). Yellow-fin tuna (*Thunnus albacares*; up to 2.4 m and 200 kg) is the most important species in terms of global fisheries. It is a highly migratory species with a world-wide distribution in tropical and subtropical seas. The tunas are fast swimming fish that hunt other schooling pelagic fish. The related and more slender wahoo (*Acanthocybium solandri*; up to 2.5 m in length), also with a world-wide distribution in tropical and subtropical seas, is possibly the fastest of all fish with a maximum speed of about 80 km an hour.

Pelagic cod fishes

(to be filled in)

Sauries, sand eels and capelin

(to be filled in)

Small pelagics in global fisheries

FAO statistics

The Food and Agriculture Organization (FAO) of UNESCO compiles and reports on the development of fisheries catch statistics globally and for regions. FAO produces an annual report, the *FAO yearbook. Fishery and Aquaculture Statistics* (http://www.fao.org/fishery/publications/yearbooks/en). The most recent report is for the year 2008. Every second year, a comprehensive overview of fisheries and aquaculture is produced, the so-called SOFIA report. The most recent of these reports came last year: *The State of World Fisheries and Aquaculture 2010*, and is based on statistics up to the year 2008. An even more detailed *Review*

of the state of the world marine fishery resources was produced in 2005 with information on fisheries catch statistics up to and including 2002 (FAO 2005). In the following we are use information for 2002 to illustrate the global and regional patterns in fisheries of pelagic stocks.

FAO report on fish catches for the global oceans broken down into 19 geographical fishing areas for statistical purposes. These areas constitute major portions of the shelf regions and basins of the main oceans, such as the Northeast Atlantic, Western Indian Ocean, and Southeast Pacific (see map, Fig. A1.2 on page 2 in FAO 2005).

Catches are reported for major species of demersal and pelagic fish and also aggregated into groups of species (about 50 in total covering marine and freshwater fish, invertebrates, mammals, reptiles, plants, and more). Pelagic fish are reported in 3 of the species groups:
- herrings, sardines, anchovies (species group 35, comprising the clupeoids)
- tunas, bonitos, billfishes (species group 36), and
- miscellaneous pelagic fishes (species group 37).

The group of clupeoids are all 'small pelagics' and the group of tunas, bonitos etc are 'large pelagics'. The 'miscellaneous' group is a mixture of small and large fishes, with forms such as capelin and sand eels being clearly small, while pomfrets may grow up to a meter and is considered on the large side. Jack mackerels and scombrid mackerels are intermediate in size (typically about 30 cm) and are often included with the 'small pelagics' in aggregated representations.

Trends and patterns in global fisheries

The total global marine harvest has quadrupled since 1950, from about 20 million tons to around 80 million tons in the 2000s (FAO 2005, 2010). Excluding China, which is by far the largest fish-producing country, the world capture fishery is reported as 75 million tons in 2009 (67 million tons from marine waters and 8 million tons from freshwater), and the world aquaculture production contributing an additional 21 million tons (8 million marine and 13 million from freshwater). The total fisheries production (capture fisheries plus aquaculture) in 2009 (excluding China) was 96 million tons, with 75 million from the marine and 21 million from freshwaters. The figures for China in 2008 (using a revised statistical methodology) were 15 million tons from capture fisheries and 33 million tons from aquaculture (FAO 2010).

The total global marine capture fisheries increased steadily from 1950 up to around 1990 (Fig. 1; including China). The global marine harvest (but excluding China) has leveled off and shown a weak decline in the last part of the 2000s, from about 71 million tons in 2004 to about 67 million tons in 2009 (FAO 2010). Four of the geographical regions contributed 2/3 of the global capture fisheries harvest in 2002. These regions were the Northwest Pacific, Southeast Pacific, Western Central Pacific, and the Northeast Atlantic (Fig. 1).

The Northwest Pacific includes the western Bering Sea, the Sea of Okhotsk, the Sea of Japan, the Oyashio and Kuroshio Current systems, the Yellow Sea, the East China Sea, the northern portion of the South China Sea, and the adjacent part of the western North Pacific east to the 180 degrees longitude. In this region the fisheries have grown more or less steadily to about 21.5 million tons in 2002, which was about ¼ of the total global harvest from marine capture fisheries.

The Western Central Pacific is the region south of the Northwest Pacific, including the South China Sea, the Sulu-Celebes Sea, the Indonensian Sea, the Gulf of Thailand, the Bay of Bengal, the Coral Sea, and the adjacent part of the Pacific Ocean east to 180 degree longitude and south from 20 ^{o}N to 25 ^{o}S. The fisheries in this area has developed markedly since the 1950s to a recent level (2002) of about 10.5 million tons.

The Southeast Pacific area includes the upwelling regions off South America and the adjacent part of the Pacific west to 120 ^{o}W and between 5 ^{o}N and 60 ^{o}S. The fisheries in this area developed in the 1960s as a large-scale fishery in the upwelling area in the Humboldt Current off Peru and Chile. The fishery has fluctuated due to the nature of the upwelling system but was about 13.8 million tons in 2002, which represented about 15 % of the total global capture fisheries.

The Northeast Atlantic includes the Barents Sea, the Norwegian Sea, the North Sea, the waters around the Faroes and Iceland, the waters east of the British Isles, the Bay of Biscay, the Iberian Shelf, and the adjacent part of the North Atlantic west to 42 ^{o}W and south to 35 ^{o}N (Gibraltar). Extensive commercial fisheries have existed for a long time in this region and therefore the increase in fisheries harvest has been less than in many of the other regions. The fisheries in the Northeast Atlantic constituted about 1/3 of the global fisheries in the 1950s. The recent harvest (2002) was about 11 million tons, which is about 13 % of the total global harvest.
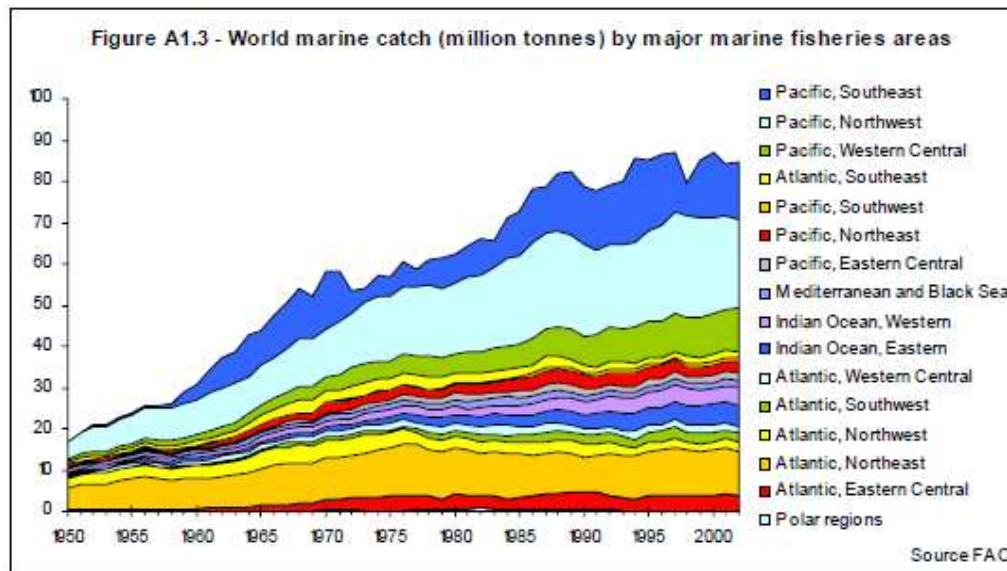
Fig. 1. Development from 1950 to 2002 of the World marine catch (in million tons) from capture fisheries by the major statistical fisheries areas. From FAO (2005).

The fisheries in the other regions give lower total catch levels and they show different patterns of development. The fisheries in the Indian Ocean has increased to recent (2002) levels of about 4.2 and

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5.1 million tons for the Western and Eastern Indian Ocean areas, respectively. In the Atlantic, the commercial fishery off Northwest Africa (in the Eastern Central Atlantic area) developed in the 1960s and the catch from this area was recently (2002) 3.4 million tons. The fisheries further south in the Southeast Atlantic, which includes the fisheries in the Benguela Current system, was high at about 2.5-3 million tons in the 1960s and 70s and has since decreased (due to better management?) to a recent level of about 1.7 million tons in 2002. Another region which has shown a decrease over recent decades is the Northwest Atlantic where the catch has decreased from about 4 million tons around 1970 to a recent level of 2.2 million tons in 2002. This decline reflects the collapse of the northern cod stock in Newfoundland.

The fisheries in the Northeast Pacific increased in the 1960s and 1970s but have since leveled off at around 3 million tons (2.7 million tons in 2002). This area includes the East Bering Sea, the Gulf of Alaska, the US coast south to 40 ^{o}N and the adjacent part of the North Pacific west to the 180 degree longitude.
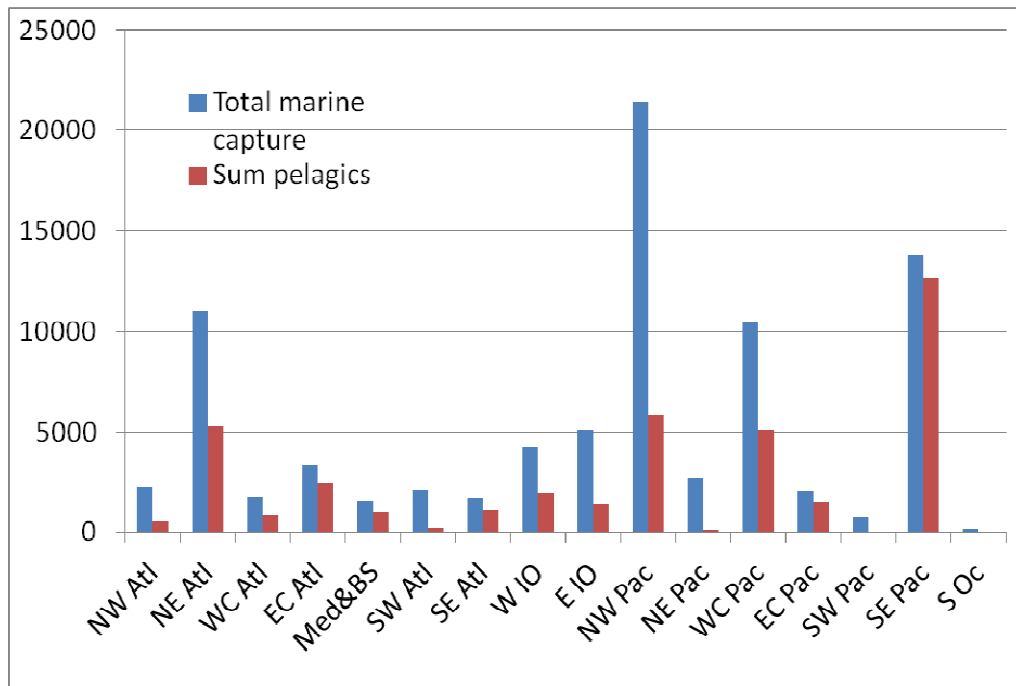
Fig. 2. Total fisheries catch and the contribution of pelagic fish (both small and large) for the different FAO statistical fisheries areas. Based on catch statistics for 2002 (FAO 2005).

The contribution of pelagic fish to the total fishery catches in the FAO fisheries areas is shown in Fig. 2. The break-down of pelagic fish into the three groups used in the FAO statistics (35 - Herrings etc; 36 - Tunas etc.; 37 - Miscellaneous) is shown in Fig. 3.

The total catch of pelagic fish in 2002 was 40 million tons, or about 47 % of the total global marine capture fisheries catch of 84.4 million tons. Clupeoids (herrings, sardines and anchovies) constituted more than half (56 %) of the catch of pelagic fish (22.5 million tons). The catch of large pelagics in the group of tunas, bonitos and billfishes made up 6 million tons, while the miscellaneous pelagic fish contributed 11.6 million tons.

The 4 FAO areas with the highest total fisheries catch are also the most important areas in terms of pelagic fish. However, the relative contribution by pelagics shows large variation among the regions (Fig. 2). The largest pelagic catch is in the Southeast Pacific where they made up the bulk of the total catch (12.7 million tons, which is 92 % of the total catch in this region, and 32 % of the total global catch of pelagics). In the 3 others of the top 4 regions, the catch of pelagics is at about the same level (5-6 million tons) but the relative contribution to the total differs. In the Northwest Pacific, the pelagics (with a catch of 5.9 million tons) made up about a quarter (28 %) of the total fisheries catch, while in the Western Central Pacific (pelagic catch 5.1 million tons) and the Northeast Atlantic (5.3 million tons) the pelagics made up almost half of the total catch (48-49 %).

The Eastern Central Atlantic and the Eastern Central Pacific had pelagic fisheries of 2.5 and 1.5 million tons, respectively. These two areas contain the Canary Current and California Current upwelling systems and in both regions the pelagics made up about ¾ of the total fishery catch (73-74 %). The Southeastern Atlantic area, which includes the Benguela Current upwelling system, had a catch of pelagic of 1.1 million tons, or 65 % of the total catch.

The catches of pelagics in the Western and Eastern Indian Ocean areas were 1.9 and 1.4 million tons in 2002, which made up 45 % and 27 % of the total fisheries catches in those two areas. The catch of pelagics in the Mediterranean Sea was 1 million ton (64 % of the total), while it was 0.9 million ton for the Western Central Atlantic (49 % of the total).

It is worth noting that the catch of pelagics in the Northeastern Pacific is very low (about 0.1 million ton in 2002). There are small pelagics in this area including capelin, Pacific sand lance, eulachon (a species of smelts), and others. However, these so-called 'forage fish' are left to be used by consumers such as marine mammals and birds in the ecosystem, and no or very limited fisheries for them occur. It should be noted that some of the small gadoids are more pelagic than demersal and could therefore more appropriately be counted among the pelagic than demersal components as they currently are in the FAO statistics. Thus, Alaska pollock made up more than half (55 %) of the total catch from the Northeastern Pacific in 2002, and the role of pelagic fish is therefore larger than suggested by the numbers shown in Figs 2 and 3.
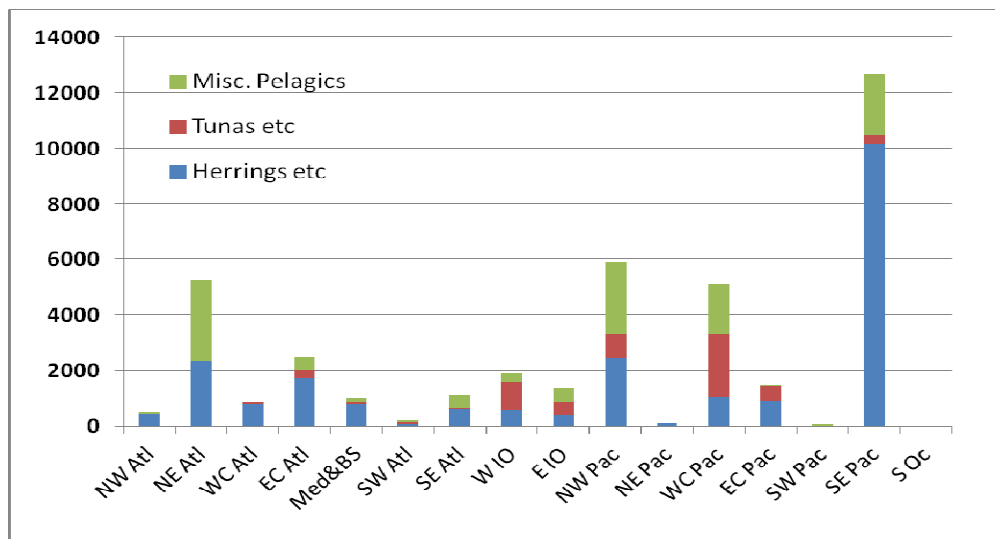
Fig. 3. The catch of pelagic fish in three categories for the different FAO statistical areas. The categories are: Herrings, sardines and anchovies (Clupeoids, FAO group code 35), Tunas, bonitos and billfishes (FAO code 36), and Miscellaneous pelagic fishes (FAO code 37, including scombrid and jack mackerels, pomfrets, sand eels, and others). Based on catch statistics for 2002 (FAO 2005).

The catch of clupeoids is by far largest in the Southeast Pacific reflecting the large fishery of anchoveta in the Humboldt Current upwelling system. The catch of clupeoids in this region was 10.2 million tons in 2002 (9.7 tons were anchoveta), which was 45% of the total global catch of herring-like fish (43 % for anchoveta alone). The catch of other pelagic fish in this region was dominated by Chilean jack mackerel with a catch of about 1.8 million tons.

The catch of clupeoids in the Northwest Pacific area was about 2.4 million tons in 2002, with the main part of this made up of Japanese anchovy (1.9 million tons). This species has increased during the 1990s, following a very pronounced decline of Japanese pilchard from catch levels around 5 million tons in the 1980s (FAO 2005). The catch of Alaska pollock in this area has also declined from levels of 3-5 million tons in the 1970s to the 90s, to a level of 1.1 million ton in 2002. The fisheries of the other pelagics (2.6 million tons) include chub mackerel with 0.9 million ton, Japanese jack mackerel (0.2 million ton), Pacific saury (0.3 million ton), and a mixed bag of others of 1.2 million ton.

The third most important area in terms of fisheries of clupeoids and also for the sum of pelagics is the Northeast Atlantic. The catch of clupeoids of 2.4 million tons in 2002 was dominated by Atlantic herring (1.6 million tons), while European sprat (0.6 million ton) made up most of the rest. The catch of miscellaneous pelagics of 2.9 million tons was predominantly capelin (1.9 million tons) from the Barents Sea and Iceland and Atlantic mackerel (0.7 million tons). In addition there was a fishery of 0.9 million tons of sand eels from the North Sea (reported under miscellaneous coastal fishes, code 33) and a fishery of blue whiting of 1.6 million tons (reported under Cods etc, code 32). The fisheries in several of the boreal ecosystems of this area undergo large fluctuations as will be illustrated in subsequent sections for the Barents Sea and Norwegian Sea ecosystems.

The catches of clupeoids in the Eastern central Atlantic (including the Canary Current system), the East Central Pacific (including the California Current system), and the Southeastern Atlantic (including the Benguela Current) are 1.7, 0.9 and 0.6 million tons, respectively. European pilchard (0.8 million ton) and California pilchard (0.7 million ton) contribute much or most of the catches in the two former areas.

The largest catches of tunas and bonitos are in the Pacific and Indian Ocean. Two oceanic species, both with wide distributions in tropical and subtropical seas, contribute about half to the total global catch of around 6 million tons of tunas and bonitos. These are skipjack tuna (or ocean bonito; 1.8 million ton) and yellow-fin tuna (1.3 million tons). The largest catches are reported from the western parts of the oceans, with 2.3 million tons caught in the Western Central Pacific, 1 million ton in the Western Indian Ocean, and 0.9 million tons in the Northwest Pacific Ocean (Fig. 3).

The top 10 species

Relatively few species make up a large proportion of the total global harvest from marine capture fisheries. FAO lists the top 10 species which in 2008 were (FAO 2010):

- Anchoveta   7.4 million tons
- Alaska pollock   2.7
- Atlantic herring   2.5
- Skipjack tuna   2.4
- Chub mackerel   1.9
- Largehead hairtail   1.4
- Blue whiting   1.3
- Chilean jack mackerel   1.3
- Japanese anchovy   1.3
- Yellowfin tuna   1.1

All of the top 10 species are pelagic and most are 'small pelagics' (except skipjack tuna, yellowfin tuna, and largehead hairtail, which are 'large pelagics'). The top 10 species have constituted around 30 % of the total global marine fisheries in the last 6 years (FAO 2010). They were the top species in 2002 (Table 1), except that capelin in that year was on third place with a catch of 2 million tons (the capelin stocks and fishery are very variable as we will illustrate for the Barents Sea in a later section).

Table 1 lists the top 15 or so species in the global fisheries statistics for 2002 and other pelagic fish species in decreasing order of catch. Twelve species had catches of more than one million tons. In addition to the 'top 10' and capelin mentioned above, European pilchard was number 12 on the list with a catch of 1.1 million ton. These 12 species made up about 34 % of the global marine capture fisheries in 2002. Another 18 species of small pelagics are included in Table 1 with catches larger than 0.2 million tons. Altogether the 30 species of fish made up 43 % of the global catch that year.

Anchoveta (or Peruvian anchovy) was by far the most important species with a catch of 9.7 million tons (11 % of the global marine catch). The catch of anchoveta has fluctuated much since the fishery started in the 1950s, but it has remained at a high level since a collapse in the stock in the 1970s and 80s (FAO 2010). Japenese anchovy was also among the important species with a catch of 1.9 million tons. Other anchovies contributed another million ton (European anchovy - 0.6 million ton, Southern African anchovy - 0.3 million ton). The total catch of anchovies was about 12.4 million tons in 2002, or around 15 % of the total marine catch.

Anchovies are generally linked to upwelling systems. Another group of small pelagic which contributes to the fisheries in upwelling areas is pilchards, sardines and sardinellas. European pilchard supported the largest catch in 2002 with 1.1 million tons, followed by California pilchard (0.7 million ton), sardinella species in the Western Central Pacific region (0.6 million ton), round sardinella from the Central Atlantic (0.4 million ton), Indian oil sardine (0.4 million ton), Southern African pilchard (0.3 million ton), and Japanese pilchard (0.2 million ton). The total catch of pilchards, sardines and sardinellas was about 3.8 million ton in 2002 (about 4 % of the total global marine catch).

Table 1 - Most important pelagic fish species - FAO statistics 2002

Species	Latin name	Catch (1000 tons)	FAO Fishing area
Anchoveta	*Engraulis ringens*	9703	SE Pac

Alaska pollock	*Gadus chalcogramma*	2655	NE/NW Pac
Capelin	*Mallotus villosus*	1958	NE Atl
Atlantic herring	*Clupea harengus*	1872	NE/NW Atl
Japanese anchovy	*Engraulis japonicus*	1854	NW Pac
Skipjack tuna	*Katsuwonus pelamis*	1776	WC/SE Pac, W Ind, EC Atl
Chilean jack mackerel	*Trachurus murphyi*	1750	SE Pac
Blue whiting	*Micromesistius poutassou*	1589	NE Atl
Chub mackerel	*Scomber japonicus*	1440	NW/SE Pac, EC Atl
Largehead hairtail	*Trichiurus lepturus*	1371	NW Pac
Yellowfin tuna	*Thunnus albacares*	1263	WC/EC/SE Pac, W Ind, EC Atl
European pilchard	*Sardina pilchardus*	1090	NE/EC Atl & Medit.
Sandeels	*Ammodytes spp.*	905	NE Atl
Atlantic mackerel	*Scomber scombrus*	758	NE/NW Atl
California pilchard	*Sardinops caeruleus*	683	EC Pac.
European anchovy	*Engraulis encrasicolus*	628	EC Atl & Medit.
European sprat	*Sprattus sprattus*	620	NE Atl.
Sardinella spp.	*Sardinella spp.*	608	WC Pac
Gulf menhaden	*Brevoortia patronus*	582	WC Atl
Round sardinella	*Sardinella aurita*	445	EC/WC Atl
Indian oil sardine	*Sardinella longiceps*	410	W Ind
Cape horse mackerel	*Trachurus capensis*	386	SE Atl
Pacific saury	*Cololabis saira*	335	NW Pac
Auracanian herring	*Strangomera bentincki*	347	SE Pac
Pacific herring	*Clupea pallasii*	317	NW/NE Pac
Southern African pilchard	*Sardinops ocellatus*	265	SE Atl
Southern African anchovy	*Engraulis capensis*	255	SE Atl
Japanese pilchard	*Sardinops melanostictus*	237	NW Pac
Japanese jack mackerel	*Trachurus japonicus*	230	NW Pac
Atlantic horse mackerel	*Trachurus trachurus*	209	NE Atl

A third group of fish that contributes to the fisheries of upwelling areas is the jack or horse mackerels. Chilean horse mackerel supported a catch of 1.8 million tons from the Humbold Current system in 2002. Other species in this group with fairly large catches were Cape horse mackerel (0.4 million ton), Atlantic horse mackerel (0.2 million ton), and Japanese jack mackerel (0.2 million ton). The total catch of horse mackerels was 2.6 million tons, or about 3 % of the global marine catch.

Chub mackerel is one of the major species in global fisheries with a catch of 1.4 million tons in 2004. The species has a wide distribution and most of the catch was from the Northwest Pacific and Southeast Pacific areas (0.9 and 0.4 million ton). The catch of Atlantic mackerel was also large with 0.8 million ton in 2002. Pacific saury resembles a mackerel but is more elongated in shape (it is sometimes called mackerel pike). It is fished with a catch of about 0.3 million ton in the Northwest Pacific area.

Atlantic herring was on forth place on the top 10 list in 2002 with a catch of 1.9 million tons. The catch increased to 2.5 million tons in 2008 when the species was on third place. The largest stock of this species (the Norwegian spring spawning stock) inhabits the Norwegian Sea and Barents Sea ecosystems and is considered in more detail in a later section. The closely related Pacific herring had a catch of 0.3 million ton. Other important clupeoids were European sprat caught in the North and Baltic seas (0.6 million ton), Gulf menhaden caught in the northwestern Gulf of Mexico (0.6 million ton), and Auracanian herring caught along the coast of Chile (0.3 million ton).

Capelin was caught with 2 million tons in 2002. It is caught in fisheries mainly in the Barents Sea and the Iceland Sea and the catches have shown large fluctuations over recent decades. Sand eels were caught with 0.9 million ton from the North Sea (predominantly lesser sandeel?).

Two species of codfishes are on the top 10 list: Alaska pollock with 2.7 million tons and blue whiting with 1.6 million tons in 2002. They are more pelagic than demersal in life history characteristics and are included here in the group of pelagics rather than with the group of demersals as they often are in statistical overviews by FAO. Alaska pollock and blue whiting are ecological equivalents as mesopelagic fish in boreal ecosystems in the North Pacific (including Bering Sea and Sea of Okhotsk) and the North Atlantic (including the Norwegian Sea).

Largehead hairtail was fished with a total catch of 1.4 million tons from the Northwest Pacific. This is a long, slender fish (typically about 1 m in length but can grow to a length of more than 2 m) with a bentho-pelagic life style. It feeds variously on plankton, small pelagic fish and squid and is best considered a large pelagic fish.

Skipjack tuna and yellowfin tuna are definitely large pelagics and are fished with large total catches of 1.8 and 1.3 million tons respectively. They are widely distributed and migratory species that are caught with the largest catches from the Western Central Pacific and Western Indian Ocean but with fairly large catches also from the Eastern Central and Southeastern Pacific and the Eastern Central Atlantic.

Temporal changes in catches of small pelagics

Time series of reported catches by species of pelagic fish are shown in Annex 1 for 5 species of anchovies, 7 species of pilchards and sardinellas, 3 species of herrings, 2 menhadens, 4 species of horse mackerels, 2 mackerels, and some others. These panels of time series of catches are taken from the FAO Fact Sheets for the species and are updated to 2007.

The temporal patterns show several features. One is that many fisheries of small pelagics developed from the 1950s (e.g. Peruvian anchoveta, round sardinella, Auracanian herring, capelin, blue whiting, Alaska pollock, and Chilean jack mackerel) and contributed thus to the pronounced increase in the overall catches of fish from the various regions as shown in Fig. 1. Another feature is the large fluctuation shown by many of these fisheries, with changes in catches by a factor of 2-5 or even more over the recent decades. Some of these changes are due to changes in fisheries patterns and regulations, but most of them reflect large fluctuations in the fish stocks themselves (as we will show with examples later in the report).

A third feature is the synchronous pattern of change for many species, with opposing trends for some species pairs of anchovies and sardines in some of the upwelling systems. This has been examined in a number of recent studies and reviews and appears to be closely related to climate oscillations (e.g. Lluch-Belda et al. 1992, Bakun and Broad 2002, Chaves et al. 2003, Checkley et al. 2009). The pattern of opposing changes is seen in comparisons of Japanese anchovy and Japanese pilchard, and of California anchovy and California pilchard. The fluctuations also involve other species in the upwelling areas such as Chilean and Japanese jack mackerels.

The catches at the species level usually come from several different stocks in geographical areas or ecosystems as we will show in the next sections. The changes at the individual stock level may therefore be more pronounced than the aggregate statistics for the species level as shown in Annex 1.

Small pelagics in food-webs

The 30 species of pelagic fish included in Table 1 eat basically the same things: zooplankton and fish. The diet is of course not exactly the same. Thus an achoveta eat small things, such as small zooplankton and fish eggs and larvae, while a skipjack tuna eats larger things, such as krill, jack mackerels and other pelagic fish.

Pelagic fish in general are generalists and opportunistic feeders that eat largely what prey is available in terms of size, catchability and abundance. This versatility allows them to use a broad range of prey types and species, which again leads to overlap and potential competition between different species of pelagic fish that occur in the same areas and ecosystems. The broad range of prey for pelagic fish includes other pelagic fish, even younger stages of their own kin. This feature means that pelagic fish may not only compete with each other for the same broad food base but they also act as predators on each other. The interactions between pelagic fish may therefore be complex.

In addition to being eaten by other pelagic fish, small pelagics are eaten by a wide range of predators in marine and coastal ecosystems, including demersal fish, seals, whales, dolphins and other small cetaceans, and seabirds. They therefore play key roles in the marine ecosystems, linking production at lower trophic levels with consumers at higher trophic levels.

The concept of 'trophic level' as introduced by Lindeman (1942) is in itself a tricky issue. It is a useful theoretical concept that has helped us to gain better understanding of the flows of energy and matter in food webs and of ecological energetics and efficiencies. However, trophic levels do not exist as such. You cannot go out and measure them directly. Any individual animal that has a varied diet has a trophic level which is some complex function of the diet it has eaten. The diet changes over time as the individual grows from young to older and also as the available prey field changes due to the dynamics and variability of the ecosystem. The trophic level of any species or population of pelagic fish can only be estimated as a rough approximation and should not be regarded as a constant but rather as a dynamic parameter changing with the condition of the stock (e.g. age composition) and with changes in the ecosystem.

Many pelagic fish can collect small prey by filter-feeding, using their gill system. They also feed by picking individual prey usually guided by vision. In contrast, filter-feeding does not depend on the fish

seeing the prey and can therefore be used as a foraging mechanism in the dark such as in the upper layer at nighttime. Filter-feeding usually requires dense concentrations of prey to be energetically possible or favorable. Many species of pelagic fish therefore shift between the two modes of feeding. A pattern seen in anchovies and pilchards is that they may start out being mainly raptorial predators picking individual prey when they are small juveniles, switching to a predominantly filter-feeding mode as they become adults.

Information on the food and feeding of pelagic fish species is given in Annex/Table (not included yet), based largely on information in the FAO Fact Sheets and FishBase.

The species of anchovies (*Engraulis* spp.) feed on various small zooplankton, notably copepods, invertebrate larvae, and also fish eggs and larvae. They also feed on phytoplankton by filter-feeding chain-forming diatoms and other large phytoplankton cells when they occur at high concentrations under bloom conditions in upwelling areas.

The species in the group of pilchards, sardines and sardinellas (*Sardina, Sardinella, Sardinops*; sardines for short) have similar diets that resemble those of the anchovies. They feed on various zooplankton with copepods often as the predominant prey. The sardines also feed on phytoplankton by filter-feeding, and for the Indian oil sardine phytoplankton (mainly diatoms) is said to be the main food item for both juveniles and adults (Sommer et al. 1996; FishBase). The sardines are generally somewhat larger than the anchovies (typically 20-25 cm in length) and they may also take larger zooplankton prey.

Atlantic and Pacific herrings feed on a wide range of zooplankton, often with copepods, krill and amphipods as predominant parts of the diet. Atlantic and Gulf menhadens feed by filter-feeding on small zooplankton, and phytoplankton may constitute an important part of their diet. The South American Auracanian herring is said also to have phytoplankton (diatoms) as a main part of their diet.

The species of horse or jack mackerels (*Trachurus* spp.) feed on various zooplankton including copepods and shrimps (krill?), and also on small fishes and squids. The scombrid mackerels (*Scombrus* spp.) have similar diets of zooplankton, small fish and squid. Atlantic mackerel is known to feed effectively by filter-feeding on small copepods and is also effective in feeding on larger prey such as krill and small pelagic fish (Iversen 2004).

The two pelagic (or benthopelagic) cod-fishes, Alaska pollock and blue whiting, take a broad range of prey including copepods, krill, small fish and squid. They tend to shift from small prey such as copepods when they are small juveniles to larger prey such as fish and squid when they are older. This is also a pattern shared by largehead hairtail which feeds on copepods and krill as juveniles shifting to become more piscivorous as adults when they take a wide range of fish prey including sardines, myctophids, jack mackerels and others.

Skipjack tuna also feeds on a variety of pelagic prey including many different species of fish, crustaceans and squid.

Small pelagics in ecosystems

Stocks or populations

Fish are swimmers (nekton) that control their positioning in the marine environment. This is in contrast to plankton which by definition are drifters, more or less at the mercy of the ocean currents that disperse and transports them around in the sea areas. (This generalization is only partly true since zooplankton may use their limited swimming capacity to move between different vertical layers and thereby indirectly influence their horizontal distribution by using the current regime.) Small pelagic fish are typically schooling organisms and occur together in smaller or larger aggregations. They are also typically migratory organisms that move around in their environment with a seasonal pattern in relation to the annual cycle of ocean productivity and their own life history and reproductive cycle.

Pelagic fish belong to more or less clearly defined populations or stocks. These are biological entities that are biologically and ecologically adapted to live in a given environment. Fish populations are faced with the need to close their life cycles geographically in relation to the pattern of currents and ocean circulation (Skjoldal 2004). There are typically spawning areas where the adult fish aggregate to spawn and fertilize their eggs. The eggs are usually spawned pelagically in the water mass or in some cases demersally on the seafloor, such as with Atlantic and Pacific herring. In either case the eggs hatch into pelagic larvae that drift and disperse with the currents to nursery areas where they feed and grow. As they do, the young fish develop their swimming ability and will soon school and move around in the environment. Dispersal and a more or less clearly defined seasonal feeding migration are a necessity for pelagic fish of large commercial stocks since they need to use the productivity over a large area to fulfill their nutritional needs. Larval drift from spawning areas and feeding migrations by juveniles and adult fish are components of the life cycle and annual cycle that need to be closed by a spawning migration of the mature fish back to the spawning area.

The geographical closure of the life cycle in relation to the ocean circulation is an important feature of fish populations. However, the populations may be more or less distinct as there may be more than one spawning area that adds complexity to the population structure. A population may exist with several spawning components and there may also be overlap and exchange between neighboring populations. The concept of metapopulation is therefore used to characterize situations where there are multiple spawning areas and population components in a geographical area.

Our knowledge of population structure is often not as good as one would wish, and management often has to proceed on the basis of pragmatic choices of what is considered a population as a practical management unit. Population structure of pelagic fish (and also other fish) is a very import research issue from both basic science and practical management point of views. There is a general need to better clarify and characterize the genetic, biological, and ecological properties of fish populations. This will help us understand their response and resilience to climate fluctuations and change and to exploitation.

The catch statistics summarized in Table 1 for the major species of pelagic fish are the aggregated sums for catches often from several populations in different areas and ecosystems. The FAO fishing areas from which the catches originate are included in Table 1. In the majority of cases (20 out of 30), the bulk of the catches originate from one region. This is particularly the case for anchovies and sardines that often are associated with the upwelling systems in various areas. For some of these

species, such as the Peruvian anchoveta, the catch is from just a few stocks or stock components, possibly making up one large population or metapopulation. Some of the boreal species that produce large total catches occur with several distinct populations both in the western and eastern parts of the North Atlantic (Atlantic herring) or North Pacific (Alaska pollock, Pacific herring). Chub mackerel has wide distribution in temperate waters and is represented presumably with different stocks in the Northwest and Southeast Pacific and the Eastern Central Atlantic. Skipjack tuna and yellowfin tuna among the large pelagics have wide distributions in warmer waters of the Pacific, Indian and Atlantic oceans where they occur with different stocks.

Table 2 gives a summary of catches for the major pelagic species (0.1 million tons or larger) from the various FAO Fisheries Areas.

Table 2. Catches from major pelagic fish stocks in the different FAO Fisheries areas.

PACIFIC OCEAN	
NW Pacific • Japanese anchovy – 1.9 • Japanese pilchard – 0.2 • Pacific herring – 0.3 • Chub mackerel – 0.9 • Japanese jack mackerel – 0.2 • Pacific saury – 0.3 • Alaska pollock – 1.1 • Largehead hairtail – 1.4	NE Pacific • Alaska pollock – 1.5
WC Pacific • Sardinella spp. – 0.6 • Skipjack tuna – 0.4 • Yellowfin tuna – 0.2	EC Pacific • Yellowfin tuna – 0.3 • California pilchard - 0.7
	SE Pacific • Anchoveta – 9.7 • Auracanian herring – 0.4 • Chilean jack mackerel – 1.8 • Chub mackerel – 0.4 • Skipjack tuna – 0.1 • Yellowfin tuna – 0.1
ATLANTIC OCEAN	INDIAN OCEAN
NE Atlantic • Atlantic herring – 1.6 • European sprat – 0.6 • Capelin – 1.9 • Sandeels – 0.9 • Blue whiting – 1.6 • Atlantic mackerel – 0.7	W Indian Ocean • Indian oil sardine – 0.4 • Skipjack tuna – 0.4 • Yellowfin tuna – 0.2
EC Atlantic • European pilchard – 0.8	

• Round sardinella – 0.3 • European anchovy – 0.15 • Chub mackerel – 0.2 • Skipjack tuna – 0.1 • Yellowfin tuna – 0.1	
SE Atlantic • Southern African anchovy – 0.3 • Southern African pilchard – 0.3 • Cape horse mackerel – 0.4	

Large Marine Ecosystems

Large Marine Ecosystems (LMEs) are geographical entities identified as ecosystems based on ecological criteria. The criteria are distinct bathymetry, hydrography and productivity, and trophic linkages within the ecosystem (Sherman 2008). Fish stocks and in particular those of small pelagics are important elements of the ecosystems in relation to the last criterion. The roles of small pelagics in linking lower and higher trophic levels give them special significance when it comes to identify LMEs, contributing to their system characteristics (Skjoldal and Misund 2008).

The world's shelf areas and the periphery of the ocean basins have been delineated into more than 60 LMEs. The LMEs contain the major fisheries areas that produce about 80 % of the global catch of fish (Sherman et al. 2009). The global fisheries catch statistics has been reprocessed and information on catches by dominant species and groups has been summarized for each of the more than 60 LMEs by the 'Sea Around Us' project at the University of British Columbia (Pauly et al. 2009; www.seaaroundus.org; Fig. 4). Catch profiles over time from 1950 to 2004 are included in the UNEP LME Report (Sherman and Hempel 2009; Note that the validity of some of the information in this report, e.g. the Stock-catch status plots, has been questioned).

The Humboldt Current LME includes the Peruvian upwelling system and provides the large catches of anchoveta, Chilean jack mackerel and the other pelagics fished in the Southeastern Pacific area (Table 2). The fisheries for anchoveta have had two periods with high catches. After the fishery developed in the 1950s it increased to a high level of 10-12 million tons in the late 1960s before it declined very much in the early 1970s when sardines (South American pilchard, *Sardinops sagax*) took over with peak catches of 4-5 million tons in the 1980s (Schwartzlose et al. 1999). Anchoveta catches increased again from the late 1980s to the recent high catches of 8-10 million tons (see Annex 1). The fishery for Chilean jack mackerel started around 1970 and increased to a peak of 4-5 million tons in the early 1990s. It has since declined to a recent level of somewhat less than 2 million tons.

The Benguela Current LME includes the upwelling system off southwestern Africa that supports the main fisheries in the Southeastern Atlantic area (Table 2). South African pilchard dominated the catches from this area into the 1970s with maximum of over 1 million tons in the late 1960s. After this there was a shift in dominance to anchovies with peak catches of more than 0.5 million tons in

the 1970s and 80s. The fishery for Cape horse mackerel increased in the 1970s to a level of around 0.6 million ton in the 1980s and early 90s and has since decreased to 0.4 million tons or less (see Annex 1).
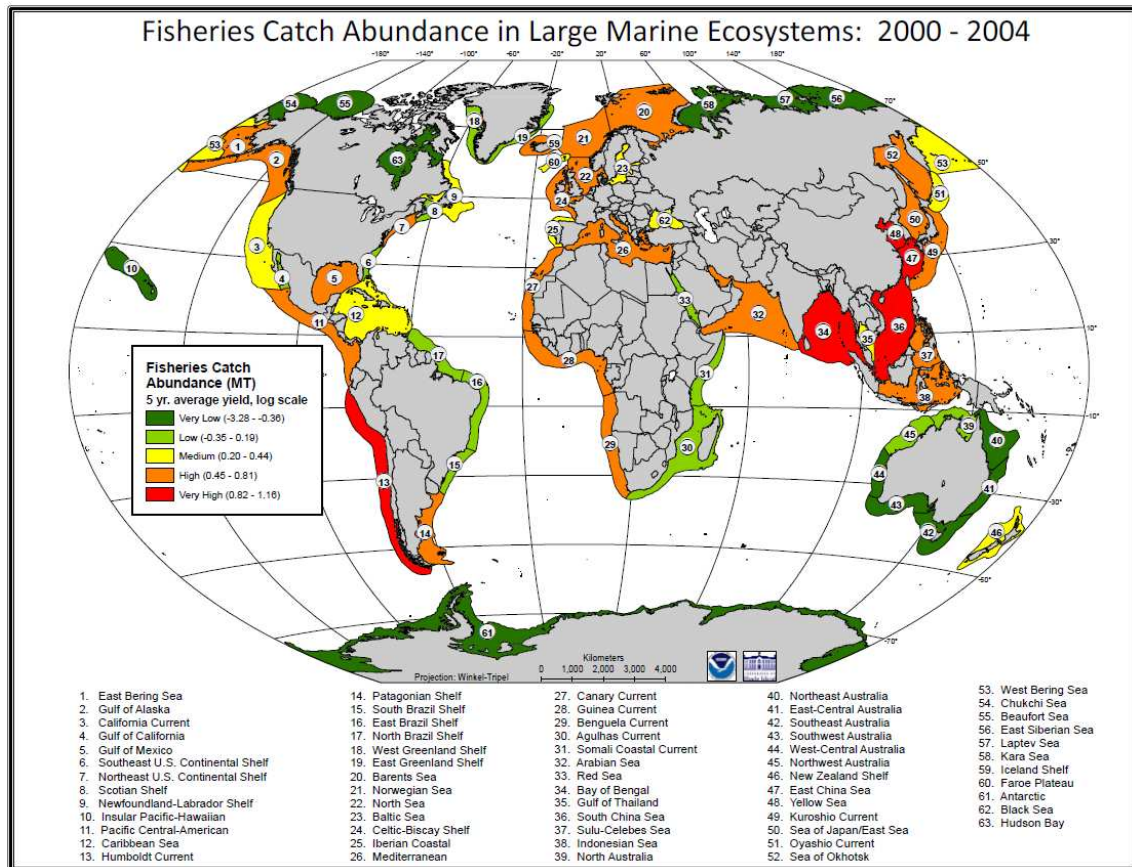
Fig. 4. Map of the LMEs of the world with fishery catch yields indicated by the color codes from low (green) to high (red). From: http://www.lme.noaa.gov/index.php?option=com_content&view=article&id=171&Itemid=74

The Canary Current LME includes the upwelling areas off Northwest Africa and supports the major catches from the Eastern Central Atlantic fisheries area (Table 2). European pilchard has been a dominant component in the fisheries in this LME with catches fluctuating at a level of 0.5-1 million ton since the 1970s. Round sardinella and also Madeiran sardinella are caught in this LME, as are European anchovy and chub mackerel.

The Arabian Sea LME is a productive system with seasonal upwelling along the coasts of Oman and Somalia during the period of southwest monsoon. This LME produces much of the yield of Indian oil sardine from the Western Indian Ocean area (Table 2).

The California Current LME is another upwelling system. This LME had a high yield of California pilchards in the first part of the last century with peak catches of 0.5-0.6 million ton in the 1930s and early 40s. California anchovy took over in the 1970s with a peak catch of about 0.4 million ton around 1980 (Schwartzlose et al. 1999).

The large fishery catches of several species of small and larger pelagics from the Northwestern Pacific area (Table 2) come from several different LMEs. This area includes the West Bering Sea LME, the Sea of Okhotsk LME, the Oyashio and Kuroshio LMEs, the Sea of Japan LME, the Yellow Sea LME, and the East China Sea LME. The catch of Alaska pollock comes mainly from the northern of these LMEs (Sea of Okhotsk and West Bering), while the large catches of Japanese anchovy come from the more southern of the LMEs including the East China Sea and the Yellow Sea.

The large fishery catches of pelagics from the Northeastern Atlantic (Table 2) also come from several LMEs. These are the Barents Sea, the Norwegian Sea, the North Sea, and the Iceland Shelf LMEs. The large catches of Atlantic herring come mainly from the Norwegian Sea and the North Sea LMEs. Blue whiting and Atlantic mackerel are fished in these two LMEs and also in the Celtic-Biscay LME. Sandeels and European sprat are fished mainly in the North Sea LME.

Ecosystem regulation

How marine ecosystems are regulated is an important issue from both scientific and management perspectives. It relates to how we perceive and understand the natural dynamics of the ecosystems driven by physical forcing and biological interactions, and how we as humans are influencing the ecosystems through fishery harvests and other disturbances such as coastal eutrophication, pollution and habitat deterioration and loss. The issue of ecosystem regulation was reviewed by Cury et al. (2003) from a fisheries perspective. They considered three different types of controls: bottom-up, top-down, and the so-called wasp-waist. Bottom-up is the physically-driven influence of lower trophic levels upwards in the food web, while top-down is regulation by predators downward in the food web. Wasp-waist denotes a situation where small pelagics have the dual roles of influencing both downward on prey and upward on their predators. Cury et al. (2003) considered that bottom-up was the predominant control, while top-down had a dampening effect on ecosystem fluctuations. Wasp-waist control was considered most probable in upwelling systems.

All marine ecosystems (in the meaning of LMEs) are open systems. Water flows through them and transport plankton into and out of the systems. Many species of fish, particularly large pelagics like tunas, will migrate at a larger scale and move into and out of defined LMEs. Stocks of small pelagics on the other hand should ideally be contained within the boundaries of an LME. With the whole life cycle carried out and closed inside the LME, such stocks of small pelagics may represent key species and key components of the ecosystem. By feeding on zooplankton and being themselves fed upon by other fish, mammals and birds, small pelagics provide important linkages and contribute to the system characteristics of the identified ecosystems. (If LMEs are defined so that they do not include stocks of small pelagics it may be that their boundaries should be revisited.)

The physical regime with winds, currents, water masses, hydrographic conditions and oceanographic processes sets the stage for and controls the plankton production. The growth of phytoplankton depends on input of nutrients, light and sufficient stratification to keep them in the upper lighted (euphotic) zone. Herbivorous zooplankton depends on the phytoplankton for reproduction and growth and constitutes food for other zooplankters that are omnivores or carnivores. The distribution and abundance of zooplankton depend also on the advective regime in relation to source populations. Fish are also directly influenced by the physics through dispersion and transport of fish larvae from spawning to nursery areas and for the migration of juveniles and adults. The bottom-up

control from the physics is therefore complex with a combination and interaction of direct effects on plankton, fish and other components, and indirect effects up through the food-web.

The recruitment variability of fish is a well-known and much studied phenomenon. Variable recruitment success can lead to variation in year-class strength of one order of magnitude or more. Periods of good or bad recruitment can drive large amplitude changes in the abundance of fish stocks. There are many examples from stocks of small pelagics that the resulting changes in stock levels may also be of one order of magnitude or more over a few decades. This is the case for anchovies and sardines in upwelling systems and for herring and other pelagic stocks in boreal ecosystems. Such pronounced changes are often called 'regime shifts' and have been shown to be related to large-scale oscillations in the physical regimes at inter-annual, decadal and multi-decadal time scales (e.g. Tourre et al. 2007, Checkley et al. 2009).

The observed synchrony in the fluctuations of pelagic fish stocks in different parts of the oceans is related to the large-scale physical forcing that operate at the ocean basin or even larger scale. A simple mechanism explaining the synchrony is the need for spatial life cycle closure by the various stocks of pelagic fish. They all respond to changes in the physical regime that influence the dispersion and transport of larvae and migrations of juveniles and adults in the dynamic spatial environment in which they live. Due to the continuity of the ocean circulation and of the atmosphere which forces the ocean, simultaneous responses of different stocks of fish may take place even though the responses may be of opposing directions (Skjoldal 2004).

Top-down control when predators influence populations of prey does occur and may have a dampening effect as suggested by Cury et al. (2003). Predator-prey interactions in food-webs are always there and may perhaps be best characterized as biological or ecological interactions since they can work both ways, downward and upward in the food-webs. Classical Lotka-Volterra predator-prey interactions work with time delay. A large prey population may lead to increased growth of a prey population, which subsequently may have a negative effect back on the prey. Density-dependent interactions are generally implied in all theoretical ecological work where encounter and feeding rates of grazers and predators are formulated as functions of the density of prey, while the mortality of prey is usually represented as dependent on the density of the predators.

Biological (predator-prey) interactions in food-webs and ecosystems should be expected to be both bottom-up and top-down at the same time, with the relative strength of the two varying over time as populations fluctuate. The branched and connected nature of food-webs, as distinct from linear food chains (which rarely exist other than as part of a web), adds complexity to the marine ecosystems. The branching represents the versatility in feeding mode (eating what is available) and also competition for food among different components of the food web. With broadly overlapping diets (they all eat zooplankton and small fish), there is inherent competition between the various pelagic fish species, as well as predator-prey relationships. Even simple systems with few species have a certain degree of complexity when they are represented as 'spaghetti' diagrams with simultaneous predator-prey interactions (bottom-up and top-down) and competition for food (see Fig. 4).

The wasp-waist regulation is a special case of the general where a small pelagic fish in a given time period may have a dominant role, effecting both its prey (zooplankton) and higher trophic level

consumers. It is possible that this represents a transient situation where good recruitment conditions replenish the stock of pelagic fish to counter the effects of increased predation.

The general situation in many marine ecosystems (at least upwelling and boreal systems) seems to be one where physical forcing on plankton and fish generates ecosystem variability, while biological interactions act to dampen the variability. Much of the ecosystem variability is generated through variable recruitment of fish. Strong or weak year-classes of fish (both pelagic and demersal) have impacts through biological interactions as they develop over the next years. Thus physical forcing in one season one year may cause a temporal development that set the stage for biological interactions in the ecosystem some years later. When recruitment conditions fluctuate with longer periods (such as multi-decadal) they may set the stage for more long term changes in the ecosystem ('regime shifts') resulting in build-up or decline in populations of birds and mammals with more stable demographic properties ('one-child' policy).

Whether a marine ecosystem is considered simple or complex is partly a matter of personal perspective and choice. However, there is an important aspect of this issue which is related to our ability to predict and to understand. Predicting what changes are likely to occur in an ecosystem in the future may require an ability to model the system with mathematical equations. This may be very difficult to do since the relationships relating predators, prey and competitors may not be known sufficiently well and the coefficients of those equations may be difficult to estimate. Thus from the perspective of prediction, the ecosystem may be seen as exceedingly complex. Interpreting and understanding what changes have taken place and are taking place in the ecosystem may be much easier given that we have sufficient observations of the key components of the ecosystem. Thus from the perspective of assessing recent changes and current status, the same ecosystem may be regarded as relatively simple.

A final point to note on the issue of how marine ecosystems function and are regulated is the fact that the types and species of small pelagics are limited in number. The various species of anchovies, sardines and horse mackerels are spatially separated but appear to be very similar from a functional ecological perspective. The ecosystems are also quite similar in the types of pelagic fish that occur in them. Thus, the upwelling systems have anchovies, sardines and horse mackerels as dominant components, while herrings, sandeels, pollock (or blue whiting), and capelin are common and important components of the boreal marine ecosystems in both the North Atlantic and the North Pacific. Knowledge and understanding should therefore to some extent (and with care) be extrapolable across ecosystems. Comparative studies of ecosystems (such as in the ESSAS program for the boreal and sub-arctic) is therefore a very relevant and important scientific enterprise.

Boreal ecosystems

The Barents Sea and the Norwegian Sea LMEs are two boreal and connected ecosystems. The Barents Sea is a shelf located between 70 and 80°N at the transition between the boreal and Arctic bioclimatic zones. The Norwegian Sea is a deep basin (3-4 km deep) located between about 60 and 75°N (Fig. 5). These two ecosystems have been described in recent books (Skjoldal et al. 2004, Sakshaug et al. 2009).
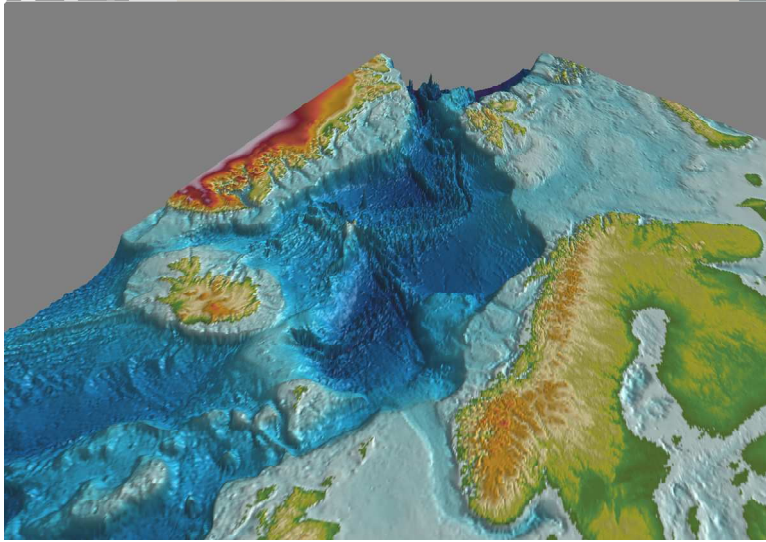
Fig. 5. Map of the Norwegian Sea and the Barents Sea ecosystems located west of Norway (basin) and north of Norway (shelf).

The Norwegian Sea is a productive marine area with high trophic transfer efficiency from phytoplankton to pelagic fish (Skjoldal et al. 2004). The deep basin provides a good wintering habitat for calanoid copepods (*Calanus finmarchicus* and *Calanus hyperboreus*). Other important zooplankton include various species of krill and pelagic amphipods.

Three species of pelagic fish have their main feeding areas in the Norwegian Sea. Atlantic herring (of the Norwegian spring spawning stock) recovered from a stock collapse in the late 1960s and came back as a major component in the Norwegian Sea in the late part of the 1990s (Holst et al. 2004). A fishery for blue whiting started in the 1970s after the herring stock collapsed, and the blue whiting stock also increased in the late 1990s due to good recruitment conditions. Finally, Atlantic mackerel of a large stock use the Norwegian Sea for summer feeding. All three species have a seasonal feeding migration into the Norwegian Sea where they feed on zooplankton and small fish. The biomass of the three stocks of pelagic fish increased to a level of almost 20 million tons in the first part of the 2000s. Information on the stock histories and fisheries of the 3 species is given in Annex 2.

A simplified representation of the food web of the Norwegian Sea ecosystem is shown in Fig. 6. Herring, blue whiting and mackerel are using broadly the same food base as plankton feeders, although blue whiting stays deeper and feeds more on krill (and also squid and mesopelagic fish) while herring to larger extent feeds on copepods.
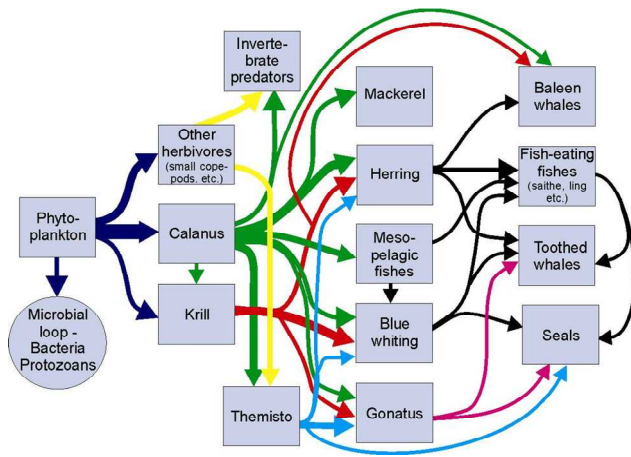
Fig. 6. A simplified representation of the food-web of the Norwegian Sea. From Skjoldal et al. (2004).

Zooplankton (dry weight biomass) has been surveyed annually since 1997. Over the last 10 years or so there has been a decline in the amount of zooplankton in the Norwegian Sea (Fig. 7; measured in the upper 200 m in May). The cause of this decline is still being investigated, but it is likely to have been caused by the predatory impact by the large stocks of pelagic fish (Skjoldal et al. 2004, Huse et al. in press).
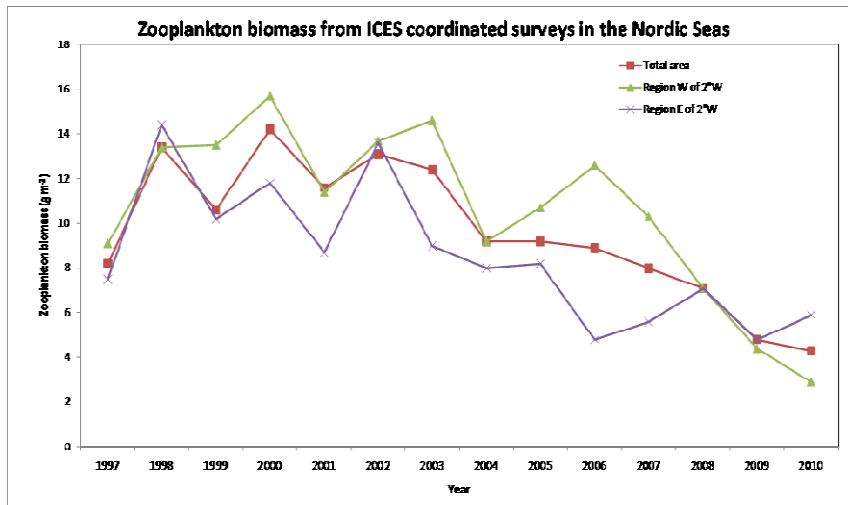
Fig. 7. Biomass (g dry weight m^{-2}) in the western and eastern parts of the Norwegian Sea ecosystem, 1997-2010.

The Barents Sea ecosystem has a zooplankton community of boreal origin in the southern part with *Calanus finmarchicus* as a dominant component, and Arctic zooplankton dominated by *Calanus glacialis* in the cold northern part. There are three main species of small pelagic fish: capelin, polar cod, and Atlantic herring. The herring is the juvenile component of the Norwegian spring spawning stock which has the southern Barents Sea as their nursery ground during the first 3-4 years of life. Polar cod (*Boreogadus saida*) is a small codfish that lives in the northern cold part, while capelin migrates seasonally from the warm part to feed in the cold part during the summer.

The stock developments since the 1970s for these three species and also for Atlantic cod, haddock, and blue whiting (from the same stock that uses the Norwegian Sea) are shown in Fig. 8. Capelin is a key species in this ecosystem and has undergone several cycles of population crashes and recoveries. The crashes are believed to be caused mainly by recruitment failure due to predation on the capelin larvae from juvenile herring. The consequences from the first collapse in the 1980s were dramatic, causing high mortality of seabirds and massive migrations and starvation-related mortality of harp seals (Skjoldal and Rey 1989, Blindheim and Skjoldal 1992). The ecological effects of the subsequent collapses in the 1990s and 2000s have been less pronounced due to different climatic and ecological situations (Gjøsæter et al. 2009).
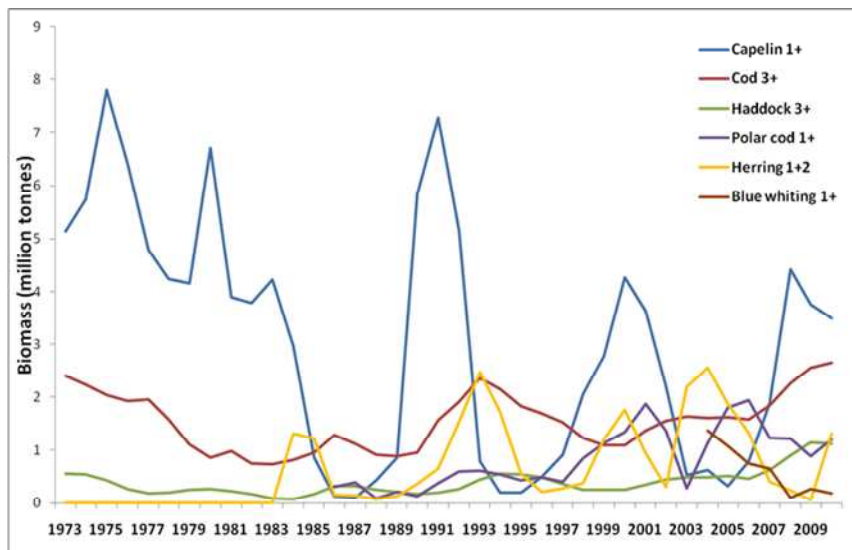
Fig. 8. Temporal development of capelin, juvenile herring and other fish stocks in the Barents Sea ecosystem.

Grazing impact from pelagic fish (notably capelin) on the amount of zooplankton in the Barents Sea has been documented (Skjoldal et al. 1992, Dalpadado et al. 2002). Large forms such as krill and pelagic amphipods have fluctuated opposite to the ups and downs of capelin but with a time delay. When capelin collapsed in the 1980s, krill and amphipods increased in abundance (by roughly a factor of 10). High abundance of large prey contributed to rapid growth and recovery of the capelin stock in the late 1980s (Skjoldal et al. 1992, Dalpadado and Skjoldal 1996, Dalpadado et al. 2002).

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Annex 1

Catch profiles for the most important small and large pelagics. From FAO Species Fact Sheets (downloaded 27 November 2011).

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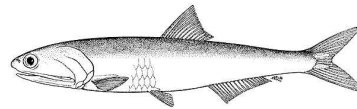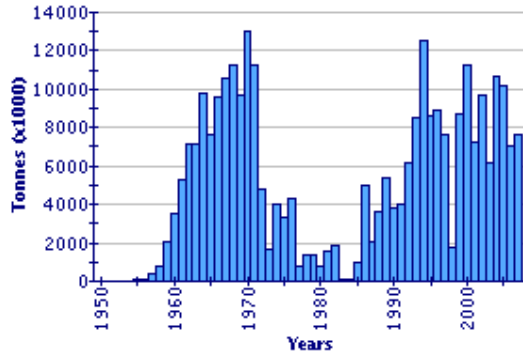
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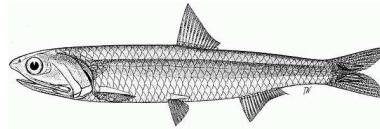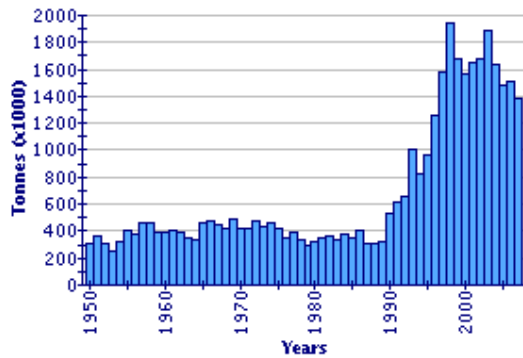
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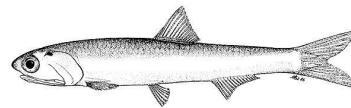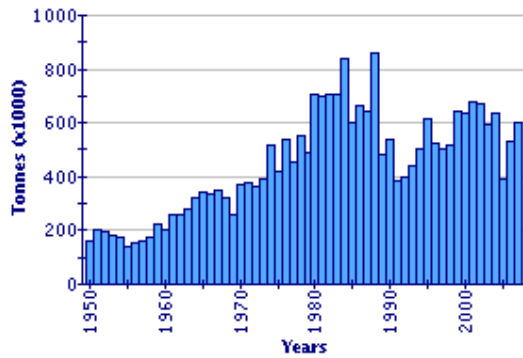
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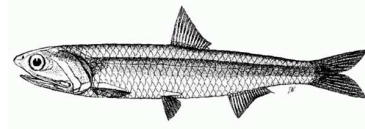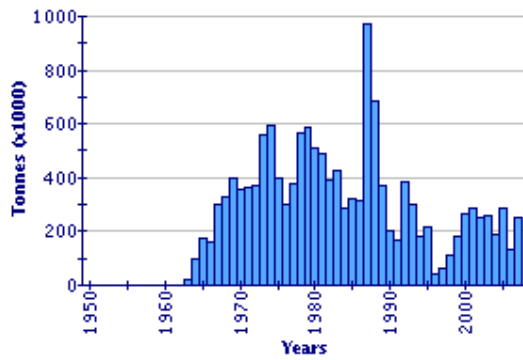
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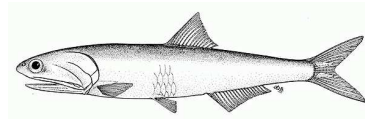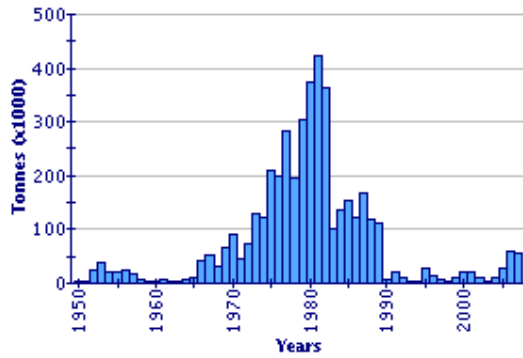
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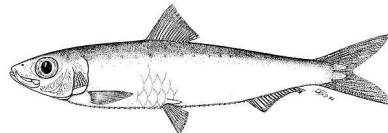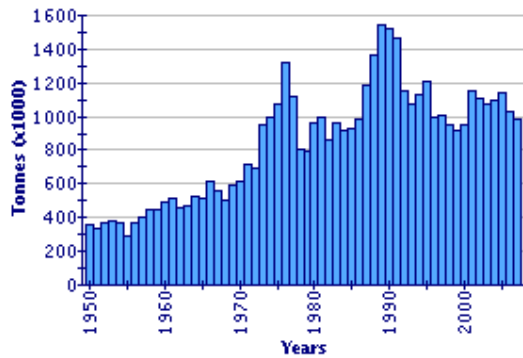
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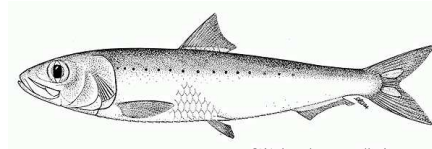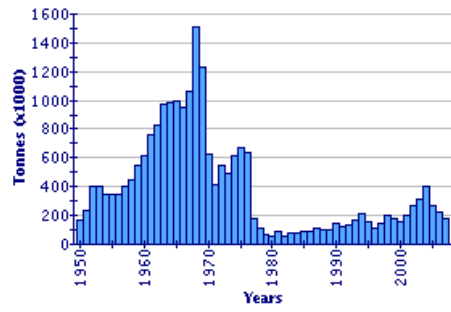
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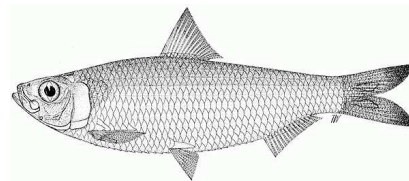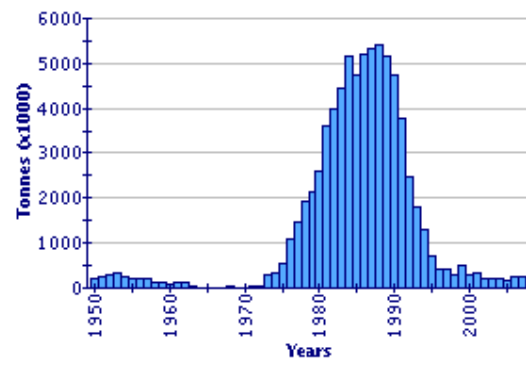
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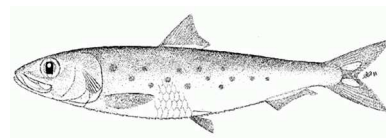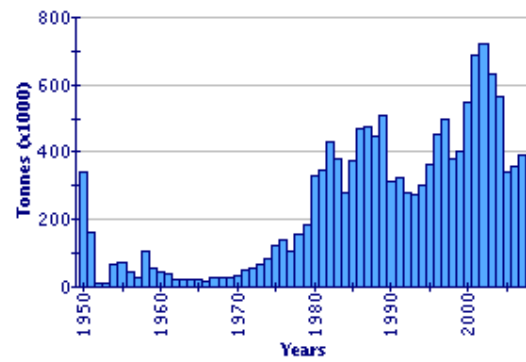
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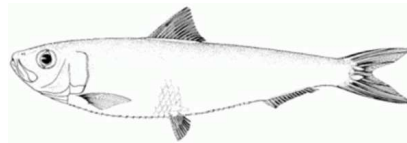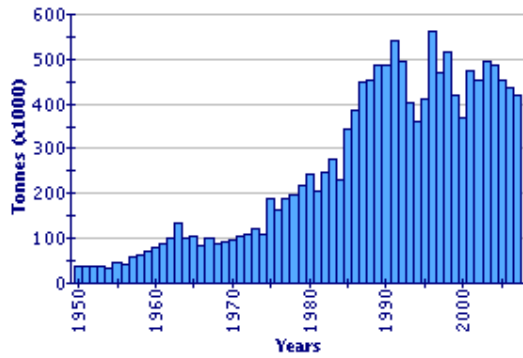
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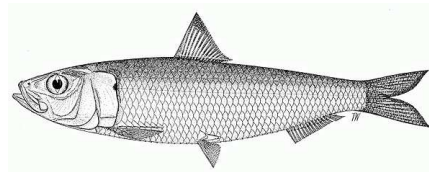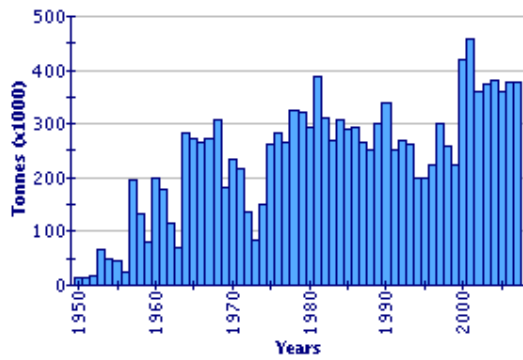
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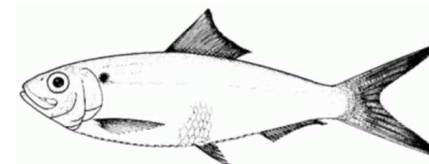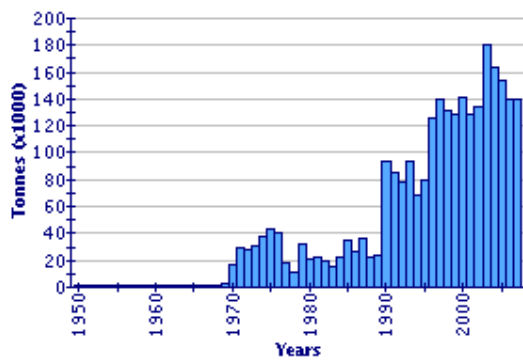
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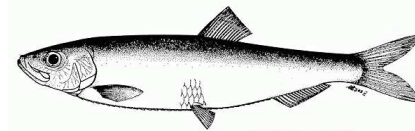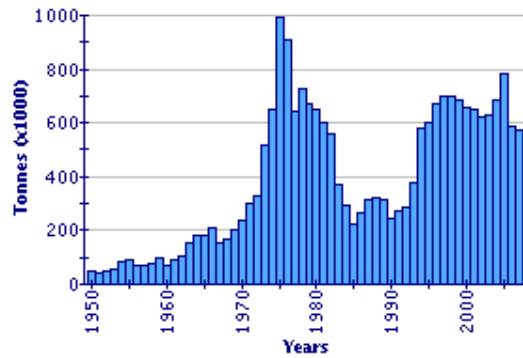
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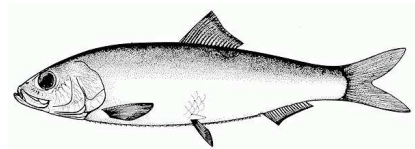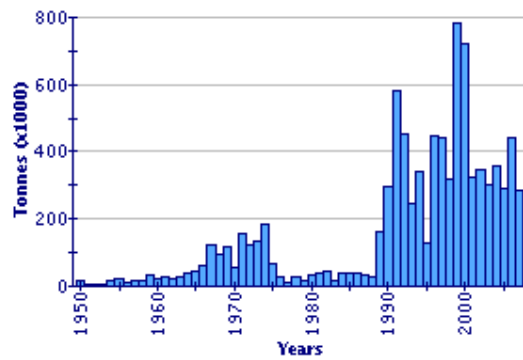
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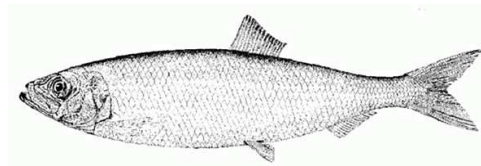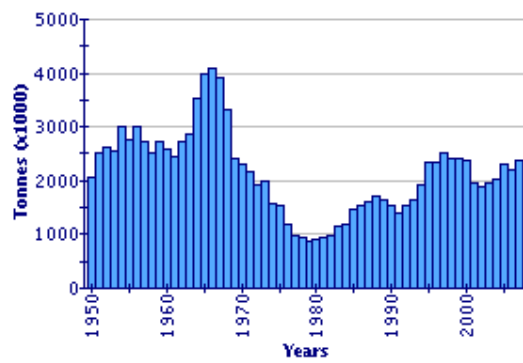
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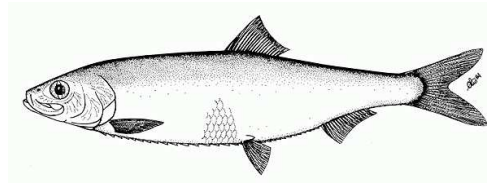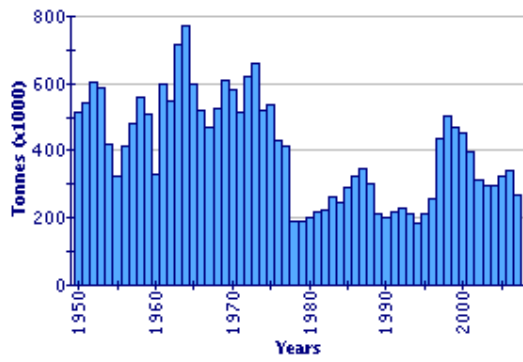
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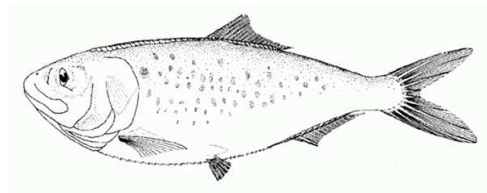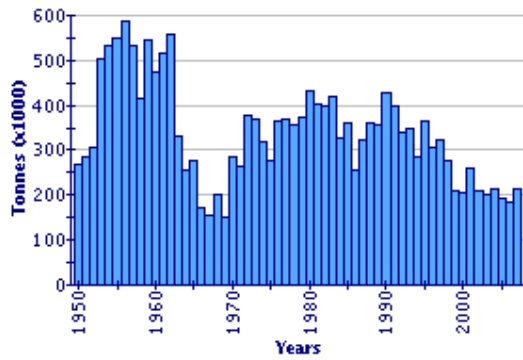
Brevoortia patronus - Gulf menhaden
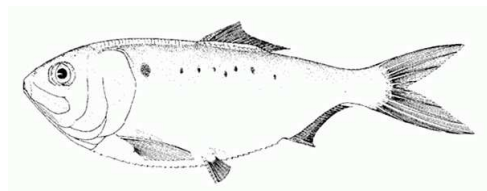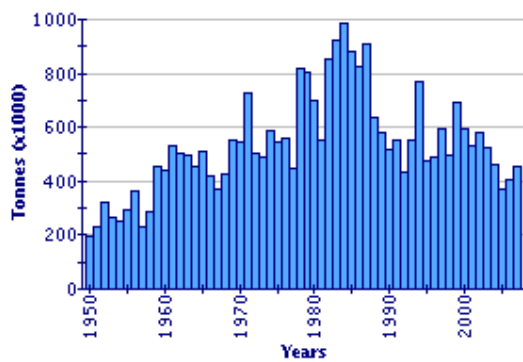
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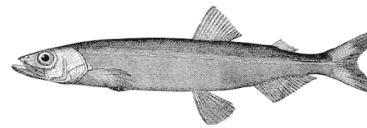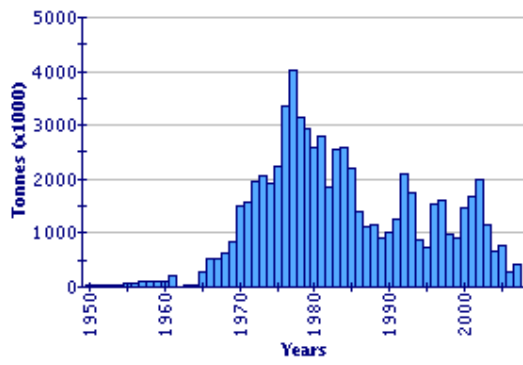
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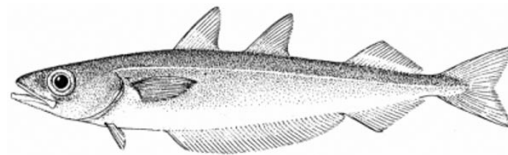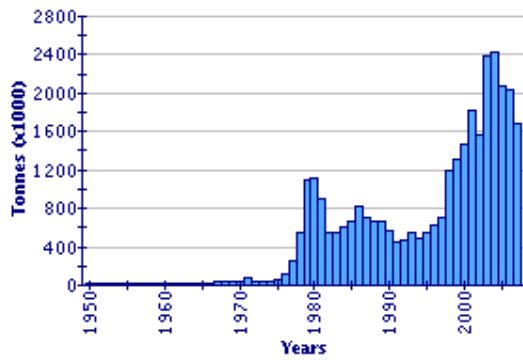
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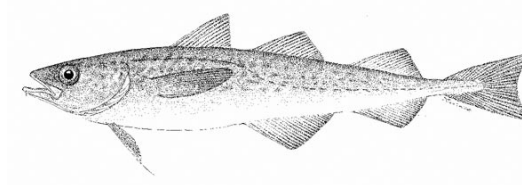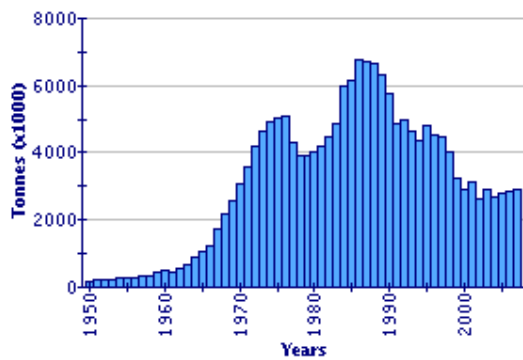
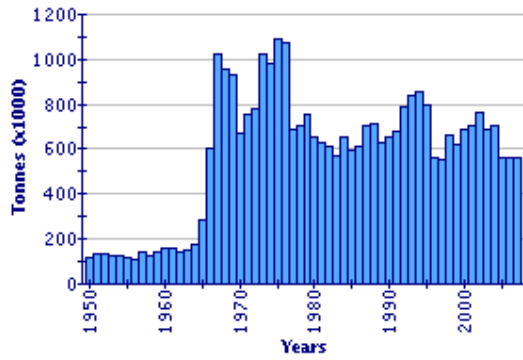*Trachurus murphyi* - Chilean jack mackerel
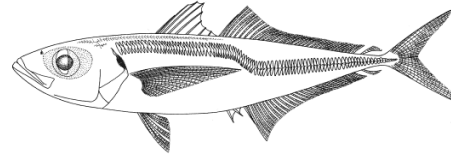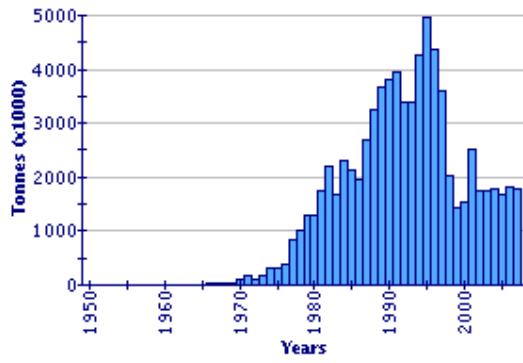
Trachurus japonicus - Japanese jack mackerel
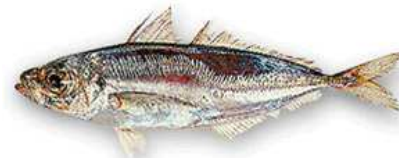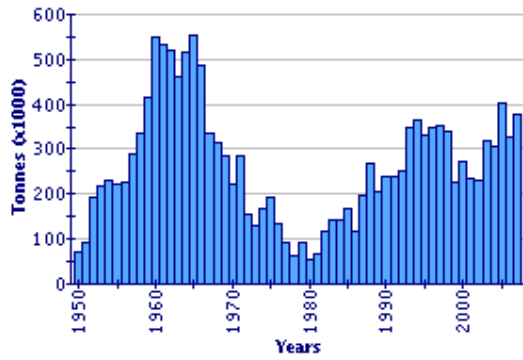
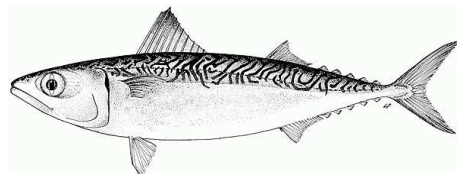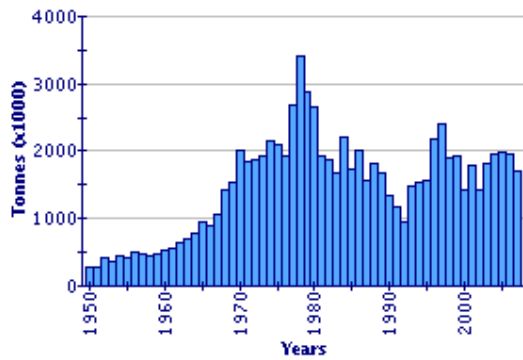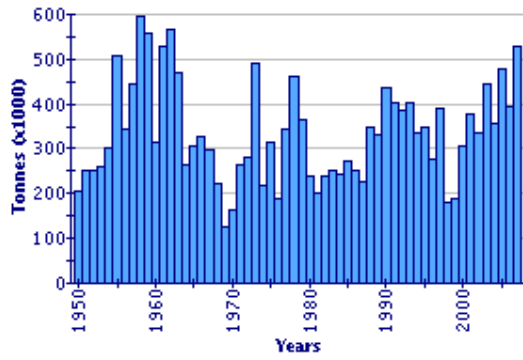*Trachurus trachurus -* Atlantic horse mackerel
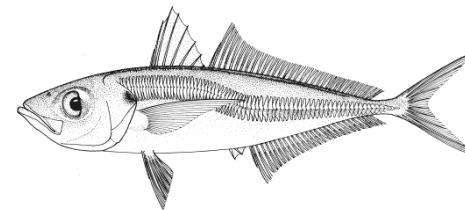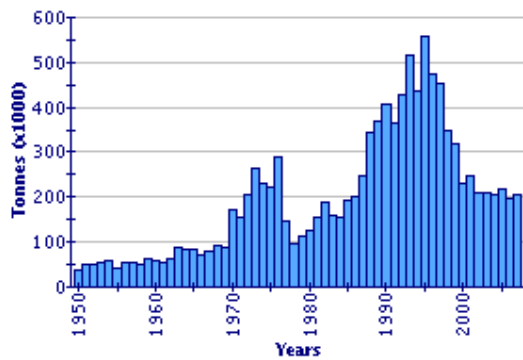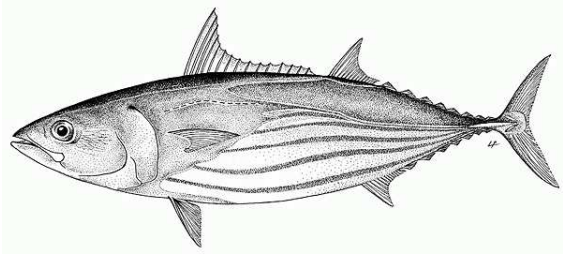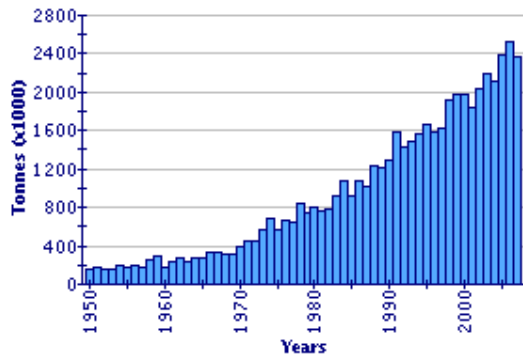
Trachurus capensis - Cape horse mackerel
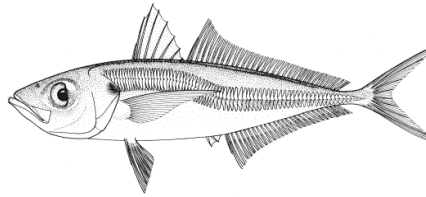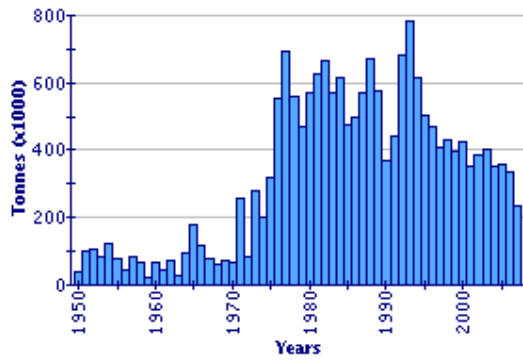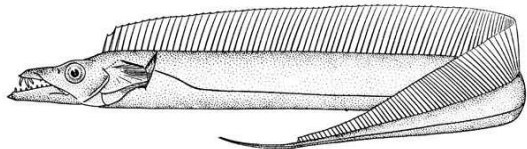

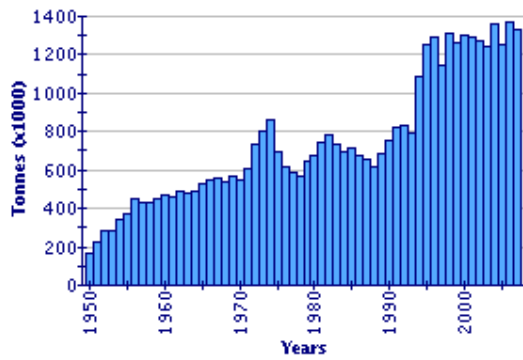*Scomber scombrus -* Atlantic mackerel
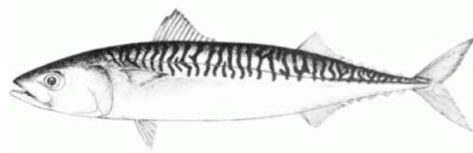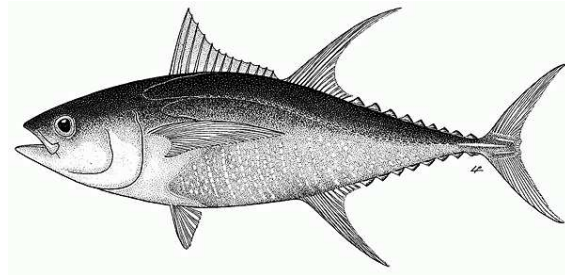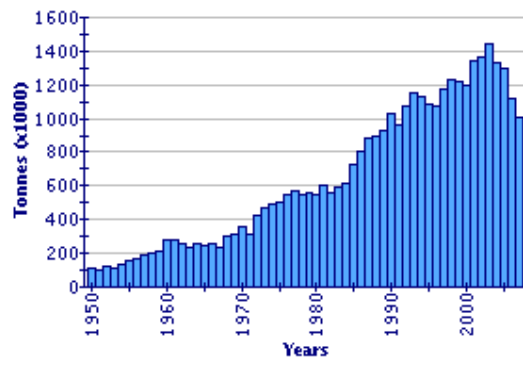

Scomber japonicus - Chub mackerel

Cololabis saira - Pacific saury

Trichiurus lepturus - Largehead hairtail

Thunnus albacares - Yellowfin tuna

Annex 2. Information on three pelagic fish stocks in the Norwegian Sea ecosystem.

Norwegian spring spawning herring (*Clupea harengus*)

Stock status
According to the International Council of the Exploration of the Seas (ICES)   the stock is considered to have full reproductive capacity and spawning stock biomass in 2011 is estimated to be 7.9 million tonnes, which is well above B_{pa}= MSY $B_{trigger}$ (5 million t). The stock is harvested sustainably, although the realized fishing mortality is estimated to be slightly above the target fishing mortality in 2010. Recruitment since 2004 has been low and the stock is declining and is expected to reach B_{pa} in 2014 or 2015 (ICES, 2011a).

Present management
A long-term management plan for Norwegian spring spawning herring (NSSH) was agreed by the coastal states EU, Faroe Islands, Iceland, Norway, and Russia in 1999. The plan includes a fishing mortality of 0.125 when the spawning stock biomass is above B_{pa} and a linear reduction in fishing morality to 0.05 when SSB is between B_{pa} and B_{lim} (2.5 mill t). ICES has evaluated the plan and concluded that it is consistent with the precautionary approach. The TAC for 2012 is set according to the management plan at 833 000 tonnes.

Biology
The NSSH belongs to the Atlanto-scandian herring together with Icelandic summer spawning and Icelandic spring-spawning herring. NSSH is the largest herring stock in the world with historic high spawning stock sizes estimated to be as high as 16 million tonnes (Holst et al., 2004). NSSH is a widely migrating stock. The feeding grounds of the adults are in the Norwegian Sea while spawning takes place in late winter and early spring along the Norwegian coast. In general, most juveniles occur in the Barents Sea and move to the Norwegian Sea when they mature. With its extensive migrations covering thousands of kilometers every year, NSSH is an important part of the ecosystem in the Nordic Seas both as a predator of zooplankton and as a prey for piscivorous predators.

Fishery and stock development
The history of this stock is known all the way back to the early 1900s. The NSSH stock has historically shown great dynamics both in migration pattern and in stock size, both related to environmental factors and fishery (Toresen and Østvedt, 2000). Huge variability in recruitment has been the general pattern. At the start of the 1900s, the stock was relatively small even with a limited fishery, but a number of strong year-classes from the 1920s onwards, built the spawning stock to very high levels during the 1930s-1950s. During this period, the fishery also increased and continued increasing to a record level of almost 2 mill tonnes in 1966. The stock was, however, declining rapidly at that time and collapsed in the late 1960s. From the record high catches in 1966, the catch was reduced to 68 000 tonnes in 1969. The collapse is related to a combination of negative environmental conditions and high fishing pressure, although the strong exploitation was considered to be the main reason for the collapse (Dragesund et al., 1980). The size of the stock has been found to be highly correlated

to the mean annual water temperature (Toresen and Østvedt, 2000). During cold periods, recruitment is low and low recruitment over a number of years will results in a reduction in SSB even without fishing. However, recent simulations (Røttingen and Tjelmeland, 2011) have supported that fishing was the major contributor to the collapse by showing that if the present management plan with a low fishing mortality had been in place from 1949, the collapse would have been avoided and the spawning stock would have stabilized at a much higher level than what was the case.

Strict regulations were enforced on the fishery during the collapse period to rebuild the stock. The stock still remained at very low levels until a new strong year-class was produced in 1983, and during the 1990s and early 2000s several strong year-classes built the stock up to recent high levels. Learning a lesson from the collapse, the main aim for management was to avoid a new collapse and a management plan was agreed among the coastal states in 1999 to restrict the fishing effort to minimize the risk of future collapse. Agreement among the coastal states to follow the management plan has been reached in all years since then.
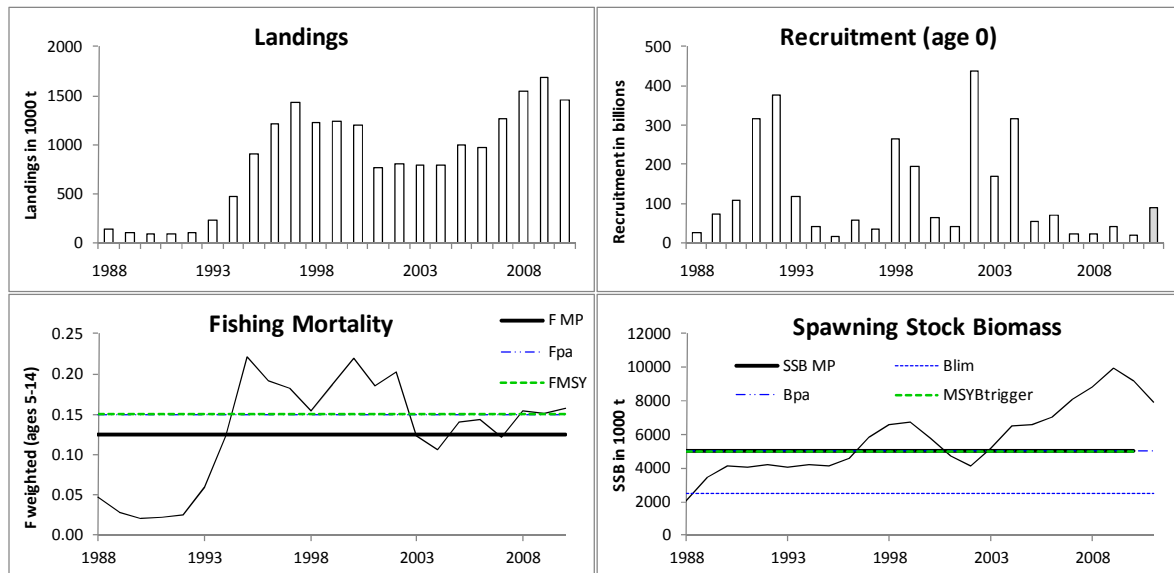

Figure 1. Norwegian spring spawning herring. Summary of stock assessment in 2011(the estimated shaded recruitment is the GM 1988–2007).
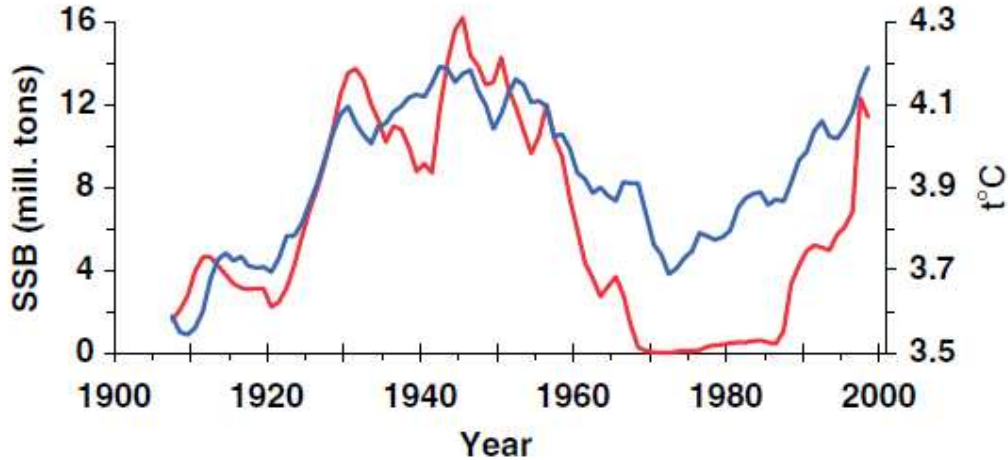
Figure 2. Spawning stock development (red line) and the mean annual (moving average over 19 years) temperature at the Kola section (blue line). From Toresen and Østvedt (2000).

Blue whiting (*Micromesistius poutassou*)

Stock status

According to ICES the stock is considered to have full reproductive capacity, but the spawning stock biomass in 2011 is estimated to be 2.3 million tonnes which is close to Bpa=MSY $B_{trigger}$= 2.25 million tonnes. The stock is harvested sustainably with a fishing mortality in 2010 of 0.18. All year classes from 2005 onward are estimated to be poor. SSB declined from a peak of 7.0 million tonnes in 2003 to 2.4 million tonnes (just above B_{pa}) at the beginning of 2011 (ICES, 2011b).

Present management

A management plan was agreed by the coastal states Norway, the EU, the Faroe Islands, and Iceland, and subsequently endorsed by NEAFC in 2008. The plan uses i) a target fishing mortality (F = 0.18) if SSB is above B_{pa}, ii) a linear reduction to F = 0.05 if SSB is between B_{pa} and B_{lim}, and iii) F = 0.05 if SSB is below B_{lim}. ICES has evaluated the plan in 2008 and concluded that it is in accordance with the precautionary approach. The TAC for 2012 is set according to the management plan at 391 000 tonnes

Biology

Blue whiting is widely distributed in the eastern part of the North Atlantic with the highest concentrations along the edge of the continental shelf between 300 and 600 m. Most spawning takes place along the shelf edge and on banks west of the British Isles. Juveniles are also widely distributed, including the Bay of Biscay, with the main nursery area believed to be in the Norwegian Sea. Ongoing work on stock identification suggests that there is likely to be more than one stock in the Northeast Atlantic. Blue whiting is a plankton feeder, and the main

prey is krill in addition to copepods, amphipods, mesopelagic fish and larvae of other fish species such as herring (Monstad, 2004).

Fishery and stock development

The known history of the blue whiting stock is short compared to NSSH (Monstad, 2004) and information on stock size is only available from the 1970s since there was no directed fishery on the stock before then. Since then both the spawning-stock biomass and recruitment to the stock have varied widely (Payne et al., in press). In the late 1970s the stock was large with a spawning stock biomass estimated to be close to 8 million tonnes (Monstad, 2004). During the late 1970s-early 1980s there was a considerable increase in the international fishery of blue whiting and the stock declined to a lower level and fluctuated around 2 million tonnes until the mid 1990s. Between 1995 and 2004 ten strong year-classes were produced resulting in a steep increase in spawning stock biomass until a maximum of 7 mill tonnes in 2004. This period of high recruitment could be associated with favorable environmental conditions since the position and strength of the North Atlantic sub-polar gyre (SPG) appears to influence the spawning distribution of blue whiting (ICES, 2009a) and this gyre may influence recruitment success through food availability and predation levels.

The fishery expanded rapidly in the late 1990s and catches peaked at nearly 2.5 million tonnes in 2004, making it one of the largest fisheries in the world at that time. Until 2006, the fishery was poorly regulated. In 2002, the Coastal States agreed to implement a long-term management plan for the fisheries of the blue whiting stock, which they considered consistent with the precautionary approach. However, this management plan was not implemented. In the absence of agreements on a TAC, the Coastal States and the Russian Federation each unilaterally implemented catch limits for these years making the combined total catch much higher than the advice from ICES. In 2006 to 2009 agreement on TAC was reached but the agreed TAC was set considerably higher than the advised TAC from ICES. The present management plan was agreed in 2008 and used for the first time in 2010. At that time the spawning stock was already declining.
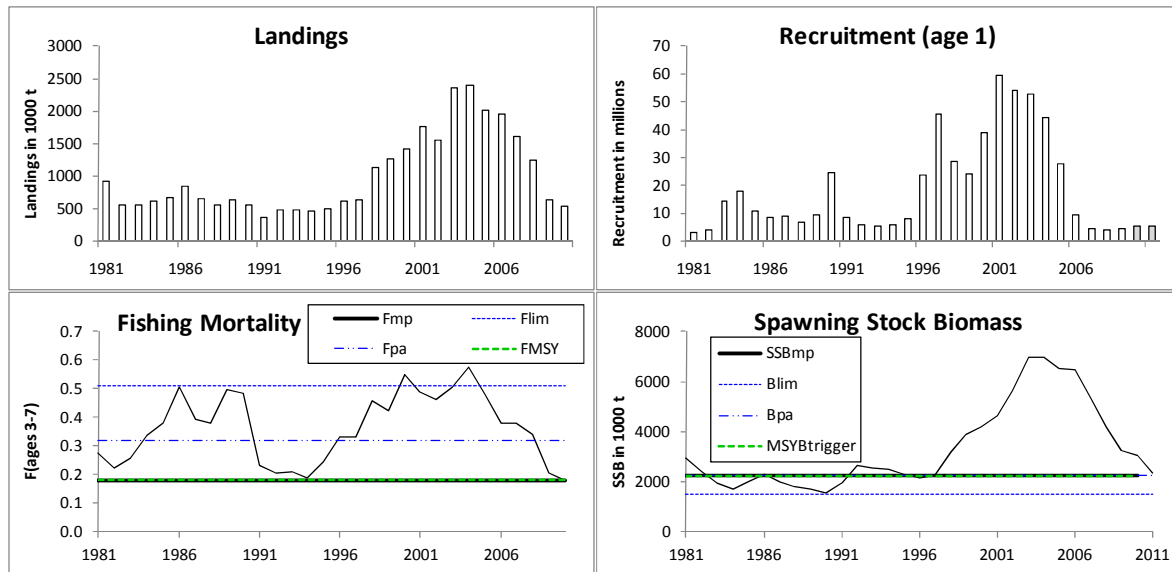
Figure 3. Blue whiting. Summary of stock assessment in 2011.

Atlantic mackerel (*Scomber scombrus*)

Stock status

According to ICES the stock is considered to have full reproductive capacity and the spawning stock biomass is estimated to be 2.9 million tonnes in 2011 which is above B_{pa}=MSY $B_{trigger}$= 2.2 million tonnes. However, the stock is harvested with a fishing mortality which is above the target fishing mortality and above the fishing mortality associated with maximum sustainable yield. Recruitment has, however, been high in recent years and the 2005 and 2006 year classes are the highest on record. The 2007 and 2008 year classes are about average. There is insufficient information to confirm the sizes of the 2009 and 2010 year classes (ICES, 2011c).

Present management

A management plan was agreed by Norway, Faroe Islands, and the EU in October 2008. ICES has evaluated the plan and concluded that it is precautionary. Following the management plan implies a TAC between 586 and 639 thousand tonnes in 2012. However, since 2009, the management plan has not been followed and there was no international agreement on TACs for 2010 and 2011.

Biology

The Atlantic mackerel is widely distributed on both sides of the North Atlantic Ocean (Iversen, 2004). The combined Northeast Atlantic mackerel is assessed as one stock but comprises three spawning components. Spawning areas of mackerel are widely spread from the Bay of Biscay and west of the British Iles to the North Sea, and only the North Sea component is sufficiently distinct to be clearly identified as a separate spawning component. Mackerel from the southern and western areas migrate to feed in the Nordic seas and the

North Sea during the second half of the year and then mix with the North Sea component. Mackerel prefers water with temperatures higher than 8°C, and can switch between particle feeding and filter feeding, preying mostly on zooplankton such as *Calanus finmarchicus*.

Fishery and stock development

In contrast to herring and blue whiting, the recruitment to the mackerel stock has been relatively stable throughout the period for which reliable data are available. This has lead to less variability in stock size of this species compared to the other two. Following that, total catches have also been relatively stable during the last 40 years. Due to recent lack of international agreement on TAC, the catch has increased substantially and is much higher than the advice from ICES both in 2010 and 2011.

Traditionally, the fishing areas with higher catches of mackerel have been in the northern North Sea, around the Shetland Isles, and off the west coast of Scotland and Ireland (ICES, 2011c). The southern fishery off Spain's northern coast has also accounted for significant catches. In recent years significant catches have also been taken in Icelandic and Faroese waters, areas where almost no catches were reported prior to 2008. In 2010, catches in this area constituted approximately 21% of the total reported landings. In the Icelandic and Faroese fisheries, in the north-western part of the distribution area, mackerel have been taken together with herring. In the southern part of the distribution area, Atlantic mackerel (*Scomber scombrus*) can be caught together with Spanish mackerel (*Scomber colias*). Catches of both species are reported separately.

Prior to the late 1960s, spawning biomass of North Sea mackerel was estimated to be above 3 million tonnes. Due to overexploitation, recruitment has failed since 1969, leading to a marked decline in the stock size of this component of mackerel. The measures advised by ICES have been aimed at protecting the North Sea spawning component and promoting stock recovery. The North Sea spawning component has increased since 1999, but continued protection is needed as the abundance remains low (ICES, 2011c).
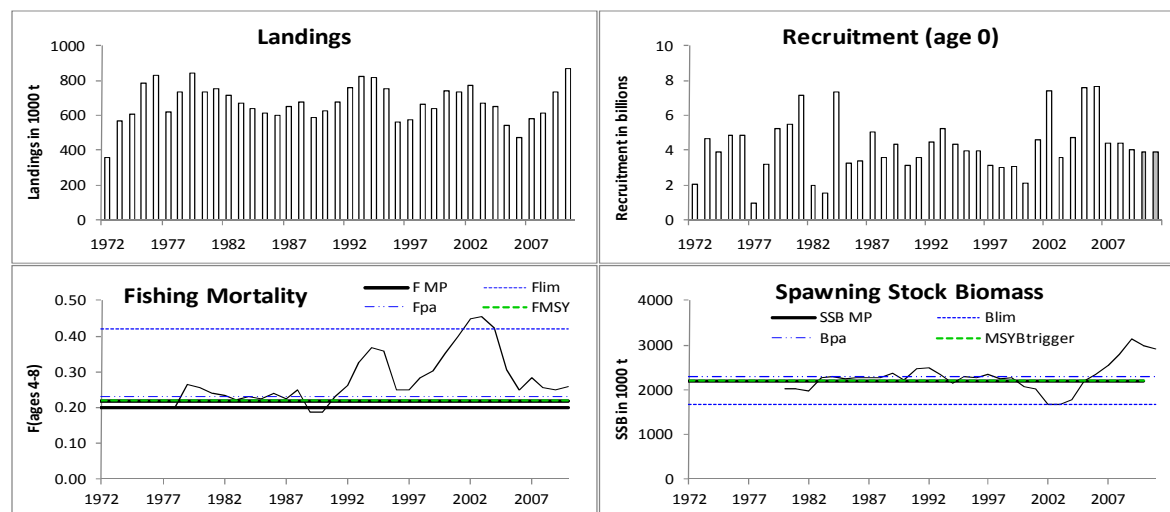

Figure 1. Atlantic mackerel. Summary of stock assessment in 2011.