

Fisheries and Aquaculture

Lead Authors

Hjálmar Vilhjálmsson, Alf Håkon Hoel

Contributing Authors

Sveinn Agnarsson, Ragnar Arnason, James E. Carscadden, Arne Eide, David Fluharty, Geir Hønneland, Carsten Hvingel, Jakob Jakobsson, George Lilly, Odd Nakken, Vladimir Radchenko, Susanne Ramstad, William Schrank, Niels Vestergaard, Thomas Wilderbuer

Contents

Summary	692	13.4. Newfoundland and Labrador Seas, Northeastern Canada ..	731
13.1. Introduction	692	13.4.1. Ecosystem essentials	732
13.1.1. Biological and model uncertainties/ certainties	693	13.4.2. Fish stocks and fisheries	733
13.1.2. Societal uncertainties	694	13.4.3. Past climatic variations and their impact on commercial stocks ..	736
13.1.3. The global framework for managing living marine resources ..	694	13.4.4. Possible impacts of climate change on fish stocks	739
13.2. Northeast Atlantic – Barents and Norwegian Seas	695	13.4.5. The economic and social importance of fisheries	741
13.2.1. Ecosystem essentials	696	13.4.6. Past variations in the fishing industry and their economic and social impacts	742
13.2.2. Fish stocks and fisheries	696	13.4.7. Economic and social impacts of climate change: possible scenarios	744
13.2.3. Past climatic variations and their impact on commercial stocks	699	13.4.8. Ability to cope with change	745
13.2.4. Possible impacts of climate change on fish stocks	700	13.4.9. Concluding comments	745
13.2.5. The economic and social importance of fisheries	700	13.5. North Pacific – Bering Sea	746
13.2.6. Economic and social impacts of climate change on fisheries in the Northeast Atlantic	706	13.5.1. Ecosystem essentials	747
13.2.7. Ability to cope with change	709	13.5.2. Fish stocks and fisheries	747
13.2.8. Concluding comments	709	13.5.3. Past climatic variations and their impact on commercial stocks	753
13.3. Central North Atlantic – Iceland and Greenland	709	13.5.4. Possible impacts of climate change on fish stocks	757
13.3.1. Ecosystem essentials	710	13.5.5. The economic and social importance of fisheries	761
13.3.2. Fish stocks and fisheries	712	13.5.6. Variations in Bering Sea fisheries and socio-economic impacts: possible scenarios	766
13.3.3. Past climatic variations and their impact on commercial stocks	716	13.5.7. Ability to cope with change	768
13.3.4. Possible impacts of climate change on fish stocks	719	13.5.8. Concluding comments	768
13.3.5. The economic and social importance of fisheries	721	13.6. Synthesis and key findings	770
13.3.6. Economic and social impacts of climate change: possible scenarios	725	13.7. Research recommendations	771
13.3.7. Ability to cope with change	729	References	772
13.3.8. Concluding comments	730		

Summary

This chapter addresses fisheries and aquaculture in four large marine ecosystems, three in the northern North Atlantic and one in the North Pacific. The ecosystems around Greenland and off northeast Canada (east of Newfoundland and Labrador) are of a true arctic type. Owing to a greater influence of warm Atlantic or Pacific water, the other systems are of a cold-temperate type. Historical data are used to project the effects of a warming climate on commercial and other marine stocks native to these ecosystems.

Modeling studies show that it is difficult to simulate and project changes in climate resulting from the response to forces that can and have been measured and even monitored on a regular basis for considerable periods and on which the models are built. Furthermore, current climate models do not include scenarios for ocean temperatures, watermass mixing, upwelling, or other relevant ocean variables such as primary and secondary production, on either a global or regional basis. As fisheries typically depend on such variables, any predictions concerning fisheries in a changing climate can only be of a very tentative nature.

Commercial fisheries in arctic regions are based on a number of species belonging to physically different ecosystems. The dynamics of many of these ecosystems are not well understood and therefore it is often difficult to identify the relative importance of fishing and the environment on changes in fish populations and biology. Moreover, current fish populations differ in abundance and biology from those in the past due to anthropogenic effects (i.e., exploitation rates). As a result it is unclear whether current populations will respond to climate change as they may have done in the past. Thus the effects of climate change on marine fish stocks and the eventual socio-economic consequences of those effects for arctic fisheries cannot be accurately predicted.

In general, it is likely that a moderate warming will improve conditions for some of the most important commercial fish stocks, e.g., Atlantic cod, herring, and walleye pollock. This is most likely to be due to enhanced levels of primary and secondary production resulting from reduced sea-ice cover. Reduced sea ice would automatically improve recruitment to Atlantic cod, herring, and walleye pollock stocks, as well as to a number of other smaller stocks.

Such changes could also lead to extensive expansions of habitat areas for species such as cod and herring. The most spectacular examples are cod at Greenland and the Norwegian spring-spawning herring. Atlantic cod appear to be unable to propagate off West Greenland except under warm conditions when a very large self-sustaining cod stock has been observed. At the same time, there has sometimes been a large-scale drift of juvenile cod from Iceland to Greenland. Many of these cod have

returned to Iceland to spawn as adults, thus expanding the distribution range of Icelandic cod. In warm periods, the Norwegian spring-spawning herring forages for food westward across the Norwegian Sea to the north of Iceland, but is excluded from the western half of the Norwegian Sea and northern Icelandic waters during cold periods. This results in a loss of about a third of the summer feeding grounds for the largest single herring stock in the world.

Global warming is also likely to induce an ecosystem regime shift in some areas, resulting in a very different species composition. In such cases, relative population sizes, fish growth rates, and spatial distributions of fish stocks are likely to change. This will result in the need for adjustments in the commercial fisheries. However, unless there is a major climatic change, such adjustments are likely to be relatively minor and, although they may call for fresh negotiations of fishing rights and total allowable catches, such changes are unlikely to entail significant economic and social costs.

The total effect of a moderate warming of climate on fish stocks is likely to be of less importance than the effects of fisheries policies and their enforcement. The significant factor in determining the future of fisheries is sound resource management practices, which in large part depend upon the properties and effectiveness of resource management regimes and the underlying research. Examples supporting this statement are the collapse of the "northern cod" off Newfoundland and Labrador, the fall and rise of the Norwegian spring-spawning herring, and the stable condition of the Alaska pollock of the Bering Sea. However, all arctic countries are currently making efforts to implement management strategies based on precautionary approaches, with increasing emphasis on the inclusion of risk and uncertainty in all decision-making.

The economic and social impacts of altered environmental conditions depend on the ability of the social structures involved, including the fisheries management system, to generate the necessary adaptations to the changes. These impacts will be very different to those experienced in earlier times, when the concept of fisheries management was almost unknown. Furthermore, in previous times general poverty, weak infrastructure, and lack of alternative job opportunities meant that the ability of societies to adapt to change, whether at a national or local level, was far less than today. Thus, it is unlikely that the impact of the climate change projected for the 21st century (see Chapter 4) on arctic fisheries will have significant long-term economic or social impacts at a national level. Some arctic regions, especially those very dependent on fisheries may, however, be greatly affected.

13.1. Introduction

This chapter identifies the possible effects of climate change on selected fish stocks and their fisheries in the

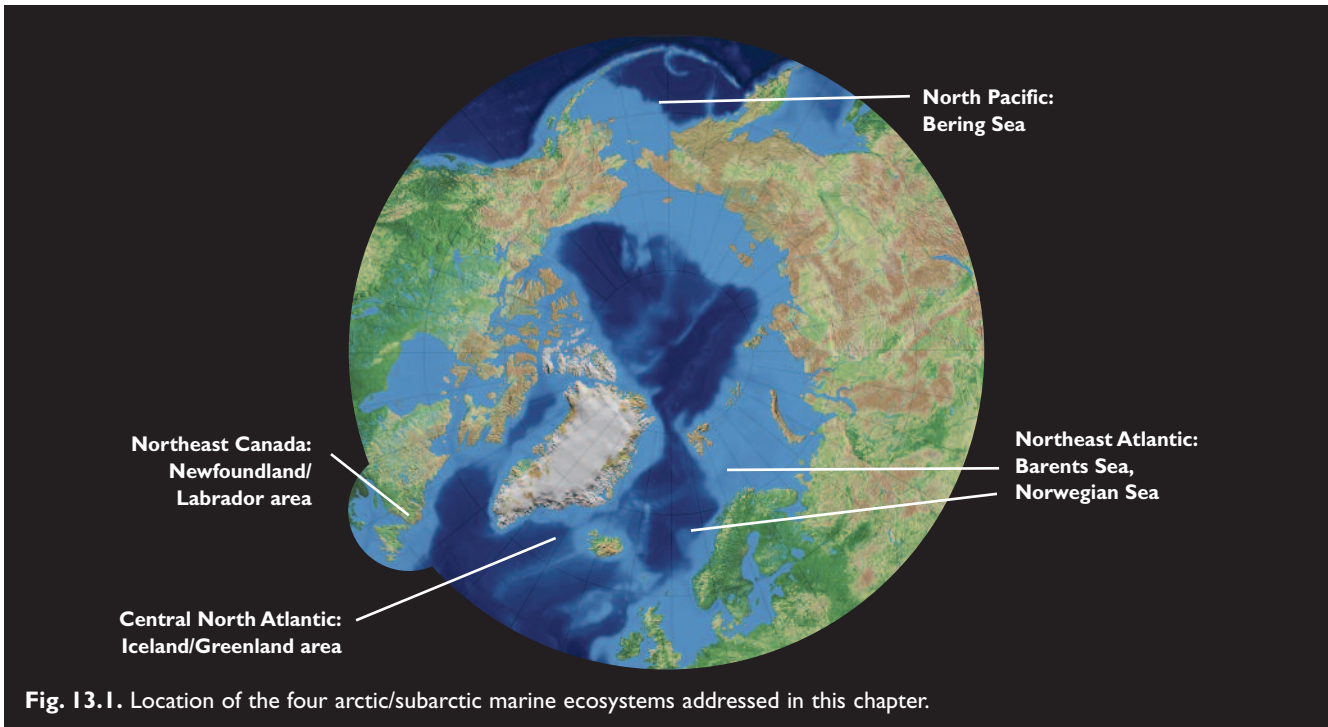


Fig. 13.1. Location of the four arctic/subarctic marine ecosystems addressed in this chapter.

Arctic. Arctic fisheries of selected species are described in the northeast Atlantic (i.e., the Barents and the Norwegian Seas), the waters around Iceland and Greenland, the waters off northeastern Canada, and the Bering Sea (Fig. 13.1). The species discussed are those few circumpolar species (capelin (*Mallotus villosus*), Greenland halibut (*Reinhardtius hippoglossoides*), northern shrimp (*Pandalus borealis*), and polar cod (*Boreogadus saida*)) and those of commercial importance in specific regions. The latter include Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), Alaska pollock (*Theragra chalcogramma*), Pacific cod (*Gadus macrocephalus*), snow crab (*Chionoecetes opilio*), plus a number of others. Marine mammals are also considered in this chapter as they form an important component of northern marine ecosystems and several are of commercial importance.

This chapter focuses on the effects of climate change on commercial fisheries and the impacts on society as a whole. Chapters 9, 10, and 12 address the implications of fisheries and aquaculture for indigenous peoples.

This chapter is organized such that for each of the four regions the discussion follows a standard format: introduction; ecosystem essentials; fish stocks and fisheries; past climatic variations and their impact on commercial stocks; possible impacts of global warming on fish stocks; the economic and social importance of fisheries; past economic and social impacts of climate change on fisheries; economic and social impacts of global warming: possible scenarios; and ability to cope with change. The chapter concludes with a synthesis of the regional assessments of the impacts of climate change on arctic fisheries and societies, and with research recommendations.

13.1.1. Biological and model uncertainties/certainties

Precise forecasts of changes in fish stocks and fisheries and their effects on society are not possible. The sources of uncertainty can be grouped into three categories: (1) uncertainties in identifying the reasons for past changes in fish biology, (2) uncertainties in the projections of potential changes in the ocean climate under climate change scenarios, and (3) uncertainties relating to the socio-economic effects of changes in fish stocks.

There are many biological characteristics of fish that change in response to natural variability in the physical environment. However, when fish stocks are heavily exploited, as many arctic stocks have been, it has proven difficult to identify the relative importance of fishing and environment on observed changes in biology. Also, many fish stocks are currently much less abundant than in the past and are showing extreme changes in population characteristics. Thus, even if historical observations of variability in fish biology could be associated with past changes in ocean climate, it is not known whether the present populations would respond in a manner similar to the historical response.

Some of the uncertainties surrounding the response of the ocean to the projected changes in global climate discussed in Chapter 4 were addressed in Chapter 9. One of the most important components of the arctic environment is the thermohaline circulation. Possible changes in the thermohaline circulation and their consequences are described in section 9.2.5.5. Present climate models are considered to generate reasonably reliable projections of climate change at a global scale but are considered to generate less reliable results at the regional level. This results in uncertainty in evalua-

tions of potential effects of climate change on the large marine ecosystems considered in this chapter.

Some key findings in Chapter 9 reflect a high degree of certainty about changes in the arctic seas. Although regional changes were not identified in Chapter 9, the chapter concludes that in most arctic areas *upper water column temperatures are very likely to increase, especially in areas with reduced sea-ice cover* and that *increased water temperatures are very likely to lead to a northward shift in the distribution of many species of fish, to changes in the timing of their migration, to a possible extension of their feeding areas, and to increased growth rates*. Chapter 9 also concludes that *most of the present ice-covered arctic areas are very likely to experience reductions in sea-ice extent and thickness, especially in summer* and that *in areas of reduced sea-ice cover, primary production is very likely to increase, which in turn is likely to increase zooplankton and possibly fish production*. In addition, Chapter 9 concludes that *increased areas and periods of open water are likely to be favorable for some whale species and the distribution of these species is very likely to move northward*. An expansion of their feeding grounds would presumably lead to an increase in their abundance. Thus, although the Chapter 9 conclusions are global in scale and do not identify specific changes in the four marine ecosystems considered here, they do provide, with a high degree of probability, a basis for considering these conclusions within the context of the fish stocks, fisheries, and possible effects on human societies resulting from the projected changes in the four areas.

13.1.2. Societal uncertainties

Once fish population changes have been evaluated, it becomes necessary to relate those changes to changes in society. This raises new difficulties. Even when changes in fish populations are predictable to a high degree of accuracy, there is no deterministic relationship between these changes and those in society. Social change is driven by a number of different forces; with climate change only one of a number of natural factors. Also, humans are important drivers of change, through economic and political activities. It is extremely difficult to isolate the relative impact of the various drivers of change. In addition, societies have the capacity to adapt to change. Changes in fish stocks, for example, are met by adjustments in fisheries management practices and the way fisheries are performed.

The result of these uncertainties is that there are few firm predictions in this chapter. Instead, changes in potential effects and likely outcomes are considered.

13.1.3. The global framework for managing living marine resources

A global framework for the management of living marine resources has been developed over recent decades, providing coastal states with extended jurisdiction over natural resources. The Third United Nations Law of the Sea Conference (UNCLOS) was convened in

1973 and ended nine years later with the adoption in 1982 of the United Nations Law of the Sea Convention, which lays down the rules and principles for the use and management of the natural resources in the ocean. The most important elements are the provisions that enable coastal states to establish exclusive economic zones (EEZs) up to 200 nautical miles (360 kilometers) from their coastal baselines. Coastal states have sovereign rights over the natural resources in their EEZs. The Convention also mandates that coastal states manage resources in a sustainable manner and that they be used optimally. Where fish stocks are shared among countries, they shall seek to cooperate on their management.

A country's authority to manage fish stocks is defined by its 200 mile EEZ. Within its EEZ, a coastal state has sovereign rights over the natural resources, and therefore the authority to manage the living marine resources there. During the 1980s it became evident that the framework provided by the Convention was inadequate to cope with two major developments in fisheries worldwide: the dramatic increase in fishing in the high seas beyond the EEZs and a corresponding increase in catches within the EEZs. Both developments were driven by rapidly growing fishing capacity. The consequence was that many stocks were overfished. A treaty was therefore negotiated under the auspices of the United Nations to supplement the Convention, seeking to provide a legal basis for restricting fisheries on the high seas and introducing more restrictive management principles, enhanced international cooperation in management, and improved enforcement of management measures. The Agreement for the Implementation of the Provisions of the United Nations Convention on the Law of the Sea of 10 December 1982 Relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks (The UN Fish Stocks Agreement) was thus adopted in 1995 and mandates the application of a precautionary approach to fisheries management. It also emphasizes the need for cooperation between countries at a regional level in this respect. These two elements have proved crucial in the development of international fisheries conservation and management policies since the mid-1990s, not least in arctic areas. Existing regional arrangements have been improved upon in order to implement the agreements. This applies to the Northwest Atlantic Fisheries Organization (NAFO), which covers the Northwest Atlantic, and the North East Atlantic Fisheries Commission (NEAFC), which covers the international waters in the Northeast Atlantic. An agreement placing a moratorium on fishing on the high seas in the Bering Sea has been in force since 1994.

The development of this global framework for fisheries management has been accompanied by a corresponding development of fisheries management regimes in individual countries. The design and performance of such regimes are crucial to the fate of fish stocks. At the global level, the major challenges to fisheries management are related to the need to reduce a substantial

overcapacity in the world's fishing fleets, and the need to introduce more sustainable management practices. To achieve the latter, countries are introducing precautionary approaches to fisheries management – a crucial requirement of the 1995 UN Fish Stocks Agreement. In addition, ecosystem-based approaches to the management of living marine resources, where natural factors such as climate change are taken into account in decision-making, are under development. The 2002 World Summit on Sustainable Development stated in its implementation plan that ecosystem-based approaches to management are to be in place by 2010.

All arctic countries with significant fisheries have well established resource management regimes with comprehensive systems for producing the knowledge base required for management, the promulgation of regulations to govern fishing activities, and arrangements to ensure compliance with regulations. While the various regimes vary considerably with regard to the design of management policies, the challenges they confront in attempting to reduce overcapacity and in introducing precautionary approaches to fisheries are similar.

For marine mammals there is a single international body at the global scale, and several regional bodies. At the global scale the 1946 International Convention for the Regulation of Whaling mandates an International Whaling Commission (IWC) to regulate the harvest of great whales. A moratorium on commercial whaling was adopted in 1982. A number of countries, among them Norway and Russia, availed themselves of their right

under the convention not to be bound by this decision. Canada and Iceland left the Commission due to the preservationist developments there. Iceland rejoined the Commission in 2003. The North Atlantic Marine Mammal Commission (NAMMCO) is tasked with the management of marine mammals in the North Atlantic.

13.2. Northeast Atlantic – Barents and Norwegian Seas

This section addresses the potential impacts of climate change on the fisheries in the arctic area of the Northeast Atlantic. The area comprises the northern and eastern parts of the Norwegian Sea to the south, and the north Norwegian and northwest Russian coasts and the Barents Sea to the east and north. The fisheries take place in areas under Norwegian and Russian jurisdictions as well as in international waters. The total fisheries in the area were around 2.1 million t in 2001 (based on data in Michalsen, 2003). Aquaculture is dominated by salmon and trout and produced 86000 t in 2001 (Fiskeridirektoratet, 2002a).

The legal and political setting of the fisheries in the Northeast Atlantic is complex. Norway and Russia established 200 nm EEZs in 1977, as a consequence of developments in international ocean law at the time. The waters around Svalbard come under a Fisheries Protection Zone set up by Norway, which according to the 1920 Svalbard Treaty holds sovereignty over the Svalbard archipelago. The waters around the Norwegian island of Jan Mayen, north of Iceland, are covered by a Fisheries Zone. Two areas occur on the high seas beyond the EEZs: in the Barents Sea the so-called “Loophole” and in the Norwegian Sea the so-called “Herring hole” (Fig. 13.2). Norway and Russia have long traditions of cooperation both in trade and management issues. In the 18th century, Norwegian fishermen in the north traded cod for commodities from Russian vessels – the so-called “Pomor-trade” (Berg, 1995). Joint management of the Barents Sea fish stocks has been negotiated since 1975. Since then, a comprehensive framework for managing the living marine resources in the area has been developed, including the high seas. The resources in the area are exploited with vessels from Norway and Russia, as well as from other countries.

Northern Norway includes three counties: Finnmark, Troms, and Nordland, and covers an area of 110000 km² – about the same size as Great Britain. The total population is 460000. Owing to the influence of the North Atlantic Current, the climate in this region is several degrees warmer than the average in other areas at the same latitude. While the Norwegian fishing industry occurs in many communities along the northern coast, the northwest Russian fishing fleet is concentrated in large cities, primarily Murmansk. In addition to the Murmansk Oblast, Russia's “northern fishery basin” comprises Arkhangelsk Oblast, the Republic of Karelia, and Nenets Autonomous Okrug (see Fig. 13.2). There is no significant commercial fishing activity east of these



Fig. 13.2. Map of the Norwegian EEZ, the Svalbard fisheries protection zone, and the Russian EEZ in the Barents and Norwegian Seas. The international areas in the central Norwegian and Barents Seas are often referred to as the “herring hole” and “loophole”, respectively.

regions until the far eastern fishery basin in the North Pacific. Since 1 January 2002, the population in the four federal subjects constituting Russia's northern fishery basin was 3.2 million people.

13.2.1. Ecosystem essentials

There are large seasonal variations in the upper water layers of the Barents Sea (see section 9.2.4.1). The spring bloom starts in the southwestern areas and spreads north- and eastward following the retreat of the sea ice. Fish and marine mammals also exhibit directed migrations: spawning migrations south- and westward in late autumn and winter, and feeding migrations north- and eastward in late spring and summer.

Relatively few species and stocks make up the bulk of the biomass at the various trophic levels. Fifteen to twenty species of whales and seals forage regularly in the area. Harp seals (*Phoca groenlandica*) and minke whales (*Balaenoptera acutorostrata*) are the two most important predators in the pelagic ecosystem. The harp seals breed in the southeastern parts of the Barents Sea, i.e., in the White Sea, and feed close to the ice edge, mainly on amphipods and capelin. In periods of low capelin abundance, harp seals feed on other fish, such as cod, haddock, and saithe (*Pollachius virens*), and migrate southward along the Norwegian coast (Nilssen K., 1995). Minke whales feed on various species of fish and over most of the area from May to September (Nordøy et al., 1995). During the winter the whales occur further south in the Atlantic Ocean.

The spawning grounds of most species are situated along the coast of Norway and Russia. Spawning normally occurs in winter and spring (February to May) and egg and larval drift routes are toward the north and east. Juveniles and adults feed in the area; polar cod in the north- and northeasternmost parts, saithe and herring (*Clupea harengus*) in the southwest, as well as the easternmost Norwegian Sea and off the Norwegian coast. Capelin reside mainly on the Atlantic side of the Polar Front during winter, but feed on the zooplankton production in the large ice-free areas north of the Polar Front in summer and autumn. Cod has the most extensive distribution. Adult cod spawn in Atlantic water far south along the coast of Norway in March to April, and then feed along the Polar Front and even far into arctic water masses during summer and autumn. All species exhibit seasonal migrations, which coincide with the formation and melting of sea ice: north- and eastward during spring and summer, south- and westward during autumn and winter.

Cod, saithe, haddock, and redfish (*Sebastes marinus* and *S. mentella*) have their main spawning grounds on the coastal banks and off the shelf edge (redfish only) of Norway between 62° and 70° N and return to the Barents Sea after spawning. Herring migrate out of the Barents Sea before maturing, feed as adults in the Norwegian Sea, and have their main spawning grounds far-

ther south along the Norwegian coast, between about 59° and 68° N. Capelin spawn in the northern coastal waters mainly between 20° and 35° E, while polar cod has two main spawning areas; one in Russian waters in the southeastern part of the Barents Sea and another in the northwest, close to the Svalbard archipelago. The capelin spawning schools are followed by predating immature cod, four to six years old. Adult Greenland halibut inhabit the slope waters at depths between 400 and 1000 m over the entire area. Northern shrimp occur over most of the area in regions with bottom depths of between 100 and 700 m on the "warm" side of the Polar Front. Individuals are four to seven years old when they change sex from male to female and spawning (hatching of eggs) occurs in summer and autumn over most of the area.

From simulations of interactions between capelin, herring, cod, harp seals, and minke whales, Bogstad et al. (1997) found the herring stock to be sensitive to changes in minke whale abundance because whale predation in the Barents Sea affects the number of recruits to the mature herring stock. They also found that an increasing harp seal stock will reduce the capelin and cod stocks, implying that an unexploited seal population would lead to a substantial loss of catch in the cod fishery.

Cod, capelin, and herring are considered key fish species in the ecosystem and interactions between them generate changes which also affect other fish stocks as well as marine mammals and birds (Bogstad et al., 1997). Recruitment of cod and herring is enhanced by inflows of Atlantic water carrying large amounts of suitable food (especially the "redfeed" copepod *Calanus finmarchicus*) for larvae and fry of these species. Consequently, survival increases, so that juvenile cod and herring become abundant in the area. However, since young and juvenile herring prey on capelin larvae in addition to zooplankton, capelin recruitment might be negatively affected and thus cause a temporal decline in the capelin stock, an occurrence that would affect most species in the area (fish, birds, and marine mammals) since capelin is their main forage fish. Predators would then prey on other small fish and shrimps. In particular, cod cannibalism may increase and thus affect future recruitment of cod to the fishery (Hamre, 2003).

In periods of low abundance or absence of capelin and/or herring, the top predators will have to feed somewhere else or shift to prey on the zooplankton group. For cod, such shifts have been observed twice in the past 15 years and were related to the collapses of the capelin stock in 1986–1988 and 1993–1994.

13.2.2. Fish stocks and fisheries

For the past thousand years, fishing for cod and herring has been important for coastal communities in Norway and northern Russia (Solhaug, 1983). Throughout the centuries, fishing was purely coastal and seasonal and based on the large amounts of adult cod and herring

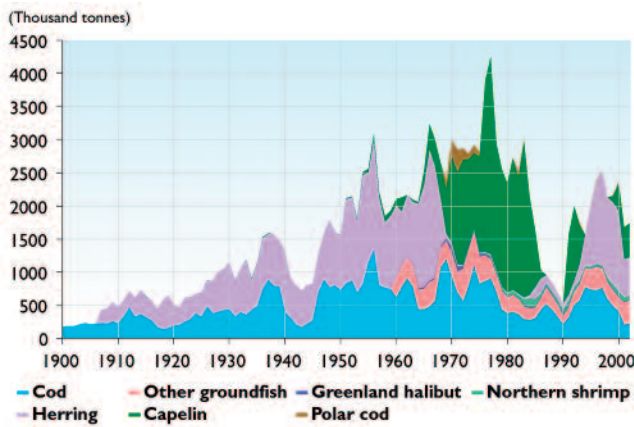


Fig. 13.3. Landings in Norway from the most important commercial catches taken in the Arctic (data from the Ministry of Fisheries and Coastal Affairs, Oslo).

migrating into near-shore waters for spawning during winter–spring and on the schools of immature cod feeding on spawning capelin along the northern coasts in April to June. A certain development toward offshore fishing took place at the end of the 19th century when cod were caught on the Svalbard banks and driftnetting of herring began off northern Iceland. However, the quantities caught in these “offshore” fisheries were small compared to the near-shore catches in the traditional fisheries for both species. Estimates of annual yields of cod and herring prior to 1900 were given by Øiestad (1994). For both species large fluctuations were experienced. The dominant feature is the 5- to 10-fold increases between 1820 and 1880 as compared to yields in previous centuries. For fish species other than cod and herring reliable estimates of yield prior to the 20th century are not available.

Landings for herring, capelin, polar cod, Greenland halibut, northern shrimp, and northeast Atlantic cod in the 20th century are shown in Fig. 13.3. Total fish landings from the area increased from about 0.5 million t at the beginning of the century to about 3 million t in the 1970s. This increase was mainly due to a series of major technological improvements of fishing vessels and gear, including electronic instruments for fish finding and positioning, which took place during the 20th century and dramatically increased the effectiveness of the fishing fleet. Furthermore, there was a growing market demand for fish products.

13.2.2.1. Capelin

When herring became scarce in the late 1960s the purse seine fleet targeted capelin and catches increased rapidly in the 1970s. Management measures such as minimum allowable catch size and closing of areas where undersized fish occurred, as well as limited fishing seasons, were introduced in the early 1970s, first by Norway and later jointly by Norway and Russia. Total allowable catches (TACs) have been enforced since 1978. Landings have fluctuated widely. In 2002, the total catch of capelin was 628 000 t (Fig. 13.3). During the 1980s, the

importance of capelin and juvenile herring as food sources for cod and other predators was fully realized (see Nakken, 1994 for references). As a consequence, there was increased research effort on species interactions and since 1990 the cod stock’s need for capelin as food has been taken into account in the scientific advice on management measures.

13.2.2.2. Polar cod

Russia and Norway started regular fisheries with bottom and pelagic trawls for polar cod in the late 1960s. The catches increased to approximately 350 000 t in 1971. The Norwegian fleet was active until 1973, when fishers lost interest because of declining catches. Since then landings have been exclusively Russian. Catches in 2001 were about 40 000 t.

13.2.2.3. Greenland halibut

Until the early 1960s, the Greenland halibut fishery (Fig. 13.3) was mainly pursued by coastal longliners off the coast of northern Norway. Annual landings were about 3000 t. An international trawl fishery developed in the area between 72° and 79° N and catches increased to about 80 000 t in the early 1970s. Landings decreased throughout the 1970s; the spawning stock biomass declined from more than 200 000 t in 1970 to about 40 000 t in the early 1990s and has since remained at this low level. Since 1992, only vessels less than 28 m in length using long lines or gillnets have been permitted to carry out a directed fishery. The rest of the fishing fleet has been restricted by by-catch rules. The total catch in 2002 was 13 000 t.

13.2.2.4. Northern shrimp

Prior to 1970, trawling for northern shrimp took place in the fjords of northern Norway and catches were low. During the 1970s offshore grounds were exploited. Catches increased until 1984 when 128 000 t were landed. Since then, catch levels have fluctuated (Fig. 13.3). Fisheries have been regulated by bycatch rules and closed areas since the mid-1980s. Areas are closed to fishing when the catch rates of young cod, haddock, and Greenland halibut exceed a certain limit. In later years, young redfish has also been included in the bycatch quota. Areas are also closed when the proportion of minimum-size shrimp (15 mm carapace length) is too high. In the Russian EEZ an annual TAC is also enforced. Estimated cod consumption of shrimp has since 1992 been approximately ten times higher than the landings, which were about 58 000 t in 2001.

13.2.2.5. Herring

Until the 1950s, herring fisheries remained largely seasonal and near shore. The bulk of the landings came from Norwegian vessels. In the 1950s Russian fishers developed a gillnet fishery in offshore waters in the Norwegian Sea, and in the early 1960s purse seiners

started using echo sounding equipment to locate herring. These technological developments resulted in a large increase in the total catches until 1966 (2 million t). Thereafter, catches decreased rapidly and the stock collapsed (Fig. 13.3, and see Box 13.1). Although individual scientists expressed concern about the stock, effective management measures were neither advised nor implemented until after the stock had collapsed completely. Minor catches in the early 1970s (between 7000 and 20000 t) removed most of the remaining spawning stock as well as juveniles and it was not until 1975 that the fishing pressure was brought to a level which permitted the stock to start recovering. For 25 years the stock was very small and remained in Norwegian coastal waters throughout the year. Norway introduced management measures including minimum allowable landing size and annual TACs. Furthermore, a complete ban on fishing herring was enforced for some

years. During the 1990s the stock recovered, started to make feeding migrations into the Norwegian Sea, and catch quotas and landings increased. In 2002 the total landings were 830000 t.

13.2.2.6. Northeast Atlantic cod

Prior to 1920, the bulk of the northeast Atlantic cod (*Gadus morhua*) catch was from two large seasonal and coastal fisheries: the fishery for immature cod feeding on spawning capelin along the northern coast of Norway and Russia and the fishery for spawning cod (“skrei”) further south off northern Norway (the Lofoten fishery). In the 1920s and 1930s an international bottom trawl fishery targeting cod as well as other species (haddock, redfish) developed in offshore areas of the Barents Sea and off Svalbard. Annual catches increased from about 400000 t in 1930 to 700000 to

Box 13.1. The fall and rise of the Norwegian spring-spawning herring

In the early 1950s, the spawning stock of Norwegian spring-spawning herring was estimated at 14 million t – one of the largest fish stocks in the world. Most of the adult stock migrated between Norwegian and Icelandic coastal waters to spawn in winter and feed in summer, respectively. The herring fishery was important for several countries, especially Norway, Iceland, Russia, and the Faroe Islands. However, after 15 years of over-exploitation and a decreasing spawning stock, the stock collapsed in the late 1960s.

Deteriorating climatic conditions north of Iceland and in the western Norwegian Sea are crucial in explaining changes of feeding areas and migration routes of these herring in the late 1960s. High fishing intensity was, however, the major factor behind the actual stock collapse. The breakdown had large social and economic consequences for those depending on the fishery. Nevertheless, the industry managed to redirect its effort to other pelagic species – primarily capelin.

Over the following decades, the remaining herring kept close to the Norwegian coast. The stock was strictly regulated and fishing was prohibited for several years. These regulations, probably in combination with favorable climatic conditions, contributed to a considerable increase in stock size from the mid-1980s, making it possible to resume fishing. By the late 1980s the spawning stock had reached a level of 3 to 4 million t, mainly due to above average recruitment by the 1983 year class.

By 1995, the spawning stock had reached 5 million t. As a consequence, the stock extended its feeding grounds by resuming its old migration pattern westward into the Norwegian Sea. It therefore became available for fishing beyond areas under Norwegian jurisdiction. The unilateral Norwegian management regime was no longer adequate to regulate fishing of the stock. Meanwhile, there was no arrangement to oversee the international management of the fishery. Negotiations between Norway, Russia, Iceland, and the Faroe Islands failed, and the total catch quota recommended by ICES was exceeded in the following year.

High economic values were at stake for all actors. Fishers and fisheries managers in all involved countries and in the EU were very engaged in the conflict. A first agreement was reached between Norway, Russia, Iceland, and the Faroe Islands in May 1996. In December 1996, the EU was included in the arrangement, where the five parties set and distribute TACs of Norwegian spring-spawning herring, based on ICES advice. The responsibility to manage the share of the stock in international waters is vested with the NEAFC, of which the aforementioned parties are members. Negotiations are held every year, but the percentage allocation key has not changed since the 1996 agreement. However, changes in the migration pattern may upset the present arrangement. The arrangement is, however, not currently functional due to disagreement over quota distribution.

This example shows that not only negative, but also positive changes in stock abundance may create management problems. If the parties had not reached agreement, there would have been devastating consequences for the exploitation and development of the Norwegian spring-spawning herring stock, almost certainly resulting in significant economic losses. This example shows the importance of political efforts to solve such conflicts.

800 000 t at the end of the decade. Landings also remained high after the Second World War until the end of the 1970s when catches declined sharply due to reduced stock size and the introduction of EEZs. Management advice was given by the International Council for the Exploration of the Sea (ICES) from the early 1960s. Increases in trawl mesh sizes were recommended in 1961 and in 1965 a variety of further conservation measures were recommended in order to increase yield per recruit and to limit the overall fishing mortality. From 1969 onward, ICES has expressed concern about the future size of the spawning stock, considering that at low levels of spawning stock biomass there would be an increased risk of poor recruitment to the stock. The first TAC for cod was set in 1975, but was far too high. Although minimum mesh size regulations had been in force for some years at that time, it is fair to conclude that no effective management measures were in operation for demersal fish in the area prior to the establishment of 200 nm EEZs in 1977.

The estimated average fishing mortality for the five-year period 1997 to 2001 is a record high (0.90) and about twice the fishing mortality corresponding to the precautionary approach (0.42). In the period 1998 to 2000 the spawning stock biomass was well below the recommended precautionary level of 500 000 t. However, despite relatively low recruitment in most recent years, the spawning stock has increased since 2000 and is now considered to be above precautionary levels. Landings have varied considerably over time and in 2002 were 430 000 t (Fig. 13.3).

13.2.2.7. Marine mammals

Three species of marine mammals are commercially exploited in the Northeast Atlantic by Norwegian and Russian fishers, i.e., minke whales, hooded seals (*Cystophora cristata*), and harp seals. In addition, grey seals (*Halichoerus grypus*) and harbour seals (*Phoca vitulina*) are exploited along the Norwegian coast by local hunters. Offshore exploitation of marine mammals in the area began in the 16th century. Basque and later Dutch and British vessels hunted Greenland right whales (*Balaena mysticetus*) and seals. Processing plants were established at shore stations as far north as north-western Spitzbergen (Arlov, 1996). Russian and Norwegian hunters have caught walrus (*Odobenus rosmarus*), polar bear (*Ursus maritimus*), and seals at the Svalbard archipelago since the 16th century. By the first decades of the 19th century the stocks of right whales had almost disappeared, and the walrus was so depleted that the hunt became unprofitable. A new era of offshore exploitation began around 1860 to 1870 when the use of smaller ice-going vessels (“sealers”) permitted Norwegian hunters to penetrate into the drift ice. At about the same time the invention of the grenade harpoon made hunting of great whales profitable. Catches of great whales increased between 1870 and 1900, but leveled off and decreased rapidly during the first decade of the 20th century.

Minke whales

Minke whales have been hunted in landlocked bays (“whaling bays”) along the coast of Norway since olden times. Offshore hunting, using small motorized vessels, developed prior to the Second World War, essentially as an extension of fishing activities. Catches increased until the 1950s, the mean annual take at that time being about 2300 animals. Since 1960, catches have decreased due to reductions in annual TACs. Between 1987 and 1992 no commercial hunting was allowed. In recent years annual catches have been 400 to 600 animals and the quota for 2002 is 674 minke whales. The stock in the area is estimated at 112 000 animals (Michalsen, 2003).

Harp seals and hooded seals

Two stocks of harp seal, in the West Ice (Greenland Sea) and the East Ice (White Sea – Barents Sea), and one stock of hooded seal in the West Ice are subject to offshore sealing; since about 1880 mainly by Norwegian and Russian hunters. The total annual catch from these stocks increased from about 120 000 animals around 1900 to an average of about 350 000 per year in the 1920s. Since then catches have declined, mainly because of catch regulations (i.e., TACs). In recent years the loss of markets has been the main limiting factor. In the 1990s, catches of harp seal in the West Ice were 8000 to 10 000 animals each year and 8000 to 9000 for hooded seal, while catches of harp seal in the East Ice ranged from 14 000 to 42 000 per year. Russian catches, which constitute about 82% of the total, are taken in the East Ice, while the Norwegian catches (about 18%) are taken in both the West Ice and East Ice.

Hooded seals are found in the North Atlantic between Novaya Zemlya, Svalbard, Jan Mayen, Greenland, and Labrador. All the Norwegian catch of hooded seal takes place in the West Ice (Greenland Sea). Russia has not caught hooded seals since 1995. The total catch in 2001 was 3820 animals. All seal stocks are assessed every second year by a joint ICES/NAFO working group, which provides ICES with sufficient information to give advice on stock status and catch potential. All three stocks are well within safe biological limits, and harvesting rates are sustainable.

13.2.3. Past climatic variations and their impact on commercial stocks

The relationship between the physical effects of climate change and effects on the ecosystem is complex. It is not possible to isolate, let alone quantify, the effects of climate change on biological resources. The following discussion is therefore of a tentative and qualitative nature.

A number of climate-related events have been observed in the Northeast Atlantic fisheries (see section 9.3.3.3). During the warming of the Nordic Seas between 1900 and 1940, there were substantial northward shifts in the geographical boundaries for a range of marine species

from plankton to commercial fish, as well as for terrestrial mammals and birds (Dickson, 1992). Recruitment of both cod and herring is positively related to inflows of Atlantic waters to the area and thus to temperature changes. Both stocks increased significantly between 1920 and 1940 when water temperatures increased (Hyllen, 2002; Toresen and Østvedt, 2000). The increase in stock size was probably an effect of enhanced recruitment, because catches increased in the same period. A similar development may have occurred between 1800 and 1870 (Øiestad, 1994). Øiestad (1994) also provided evidence that cod abundance was low during the cold period between 1650 and 1750.

Since the Second World War both cod and herring have been subject to overfishing. This resulted in a collapse of the herring stock in the 1960s, with serious consequences for other inhabitants of the ecosystem as well as man (see Box 13.1). For cod, the most likely result of the overfishing has been a far lower average annual yield since 1980 than the stock has potential to produce. Recruitment of cod depends heavily on parent stock size in addition to environmental factors (Ottersen and Sundby, 1995; Pope et al., 2001). For several decades heavy fishing pressure has prevented maintenance of the cod spawning stock at a level which optimizes recruitment levels in the long run. Therefore, management of these stocks is the key issue in assessing the effects of potential climate variations (Eide and Heen, 2002).

13.2.4. Possible impacts of climate change on fish stocks

Global models project an increase in surface temperature in the Northeast Atlantic area of 3 to 5 °C by 2070 (see Chapter 4). Regional models however, project that for surface temperatures in this area there will be “a cooling of between 0 and -1 °C” by 2020 (Furevik et al., 2002). By 2050 the area is projected to have become warmer and by 2070 surface temperatures are projected to have increased by 1 to 2 °C (Furevik et al., 2002).

Research over the last few decades shows that cod production increases with increasing water temperature for stocks inhabiting areas of mean annual temperature below 6 to 7 °C, while cod stocks in warmer waters exhibit reduced recruitment when the temperature increases (Sundby, 2000). The mean annual ambient temperature for northeast Atlantic cod is 2 to 4 °C (depending on age group) and the stock has experienced greatly improved recruitment during periods of higher temperature in the past (Sundby, 2000). A rise in mean annual temperature in the Barents Sea over the period to 2070 is therefore likely to favor cod recruitment and production, and result in an extended distribution area (i.e., spawning and feeding areas) to the north and east. A similar statement may be made for herring (see Chapter 9). This statement is based on the assumption that the production and distribution of animals at lower trophic levels (particularly copepods – the food for larvae) remain unchanged. The projection is also based on

the assumption that harvest rates are kept at levels that maintain spawning stock biomass above the level at which recruitment is adversely affected.

Experience indicates that it is likely that a rise in water temperature, as projected for the area, will result in large displacements to the north and east of the distribution ranges of resident marine organisms, including fish, shrimps, and marine mammals. Their boundaries are very likely to be extended as waters get warmer and sea-ice cover decreases. “Warm water” pelagic species, such as blue whiting (*Micromesistius poutassou*) and mackerel (*Scomber scombrus*), are likely to occur in the area in higher concentrations and more regularly than in the past. Eventually, these species will possibly inhabit the southwestern parts of the present “arctic area” on a permanent basis.

The effects of a temperature rise on the production by the stocks of fish and marine mammals presently inhabiting the area are more uncertain. These depend on how a temperature increase is accompanied by changes in ocean circulation patterns and thus plankton transport and production. In the past, recruitment to several fish stocks in the area, cod and herring in particular, has shown a positive correlation with increasing temperature. This was due to higher survival rates of larvae and fry, which in turn resulted from increased food availability. Food is transported into the area via inflows of Atlantic water, which have also caused the ocean temperature to increase. Hence, high recruitment in fish is associated with higher water temperature but is not caused by the higher water temperature itself (Sundby, 2000).

Provided that the fluctuations in Atlantic inflows to the area are maintained along with a general warming of the North Atlantic waters, it is likely that annual average recruitment of herring and cod will be at about the long-term average until around 2020 to 2030. This projection is also based on the assumption that harvest rates are kept at levels that maintain spawning stocks well above the level at which recruitment is impaired. How production will change further into the future is impossible to guess, since the projected temperatures, particularly for some of the global models, are so high that species composition and thus the interactions in the ecosystem may change completely.

13.2.5. The economic and social importance of fisheries

The fishery sector is of considerable economic significance in Norway, being among the country’s main export earners. Data used in this section are based on statistics from “Fisken og Havet” and the Norwegian Directorate of Fisheries, and include landings from catches taken in ICES statistical areas I, IIa, and IIb. In 2001, the export of fish products accounted for 14% of the total exports from mainland Norway (based on data from the Statistical Yearbook of Norway and infor-

mation from the Norwegian Seafood Exports Council). The fisheries constituted 1.5% of the Norwegian Gross National Product in 1999, excluding petroleum. In northwest Russia, fisheries are of less economic importance nationally. A substantial share of the catches taken in Russian fisheries in the north is landed abroad.

Most northern coastal communities are heavily dependent on the fisheries in economic terms, as well as being culturally and historically attached to fisheries. As early as AD 1000 an extensive trade in dried cod had developed in northern Norway, through the Hanseatic trade (Solhaug, 1983). The coastal fishery and trade made up the economic foundation for the communities along the northern coast. Since the early 1980s, aquaculture has become increasingly important, accounting for a significant part of the economic value of the fisheries sector (Ervik et al., 2003).

The total fishery in the arctic Northeast Atlantic yields about 2.1 million t and has a total annual value of around US\$ 2 billion. The resources occurring in the Arctic are also significant to fishery communities elsewhere. A substantial component of the catches in the Arctic is taken by fishers from outside the region, such as those from southern Norway and elsewhere in Europe.

13.2.5.1. Fish stocks and fisheries

Most of the Norwegian fish harvest is taken in the Norwegian EEZ (Fig. 13.2). Altogether, the waters under Norwegian jurisdiction cover around 2 million km² – more than six times the area of mainland Norway. The arctic fisheries occur in three main areas: the Barents Sea/Svalbard area, the north Norwegian coast, and around Jan Mayen.

In the Norwegian fisheries, northeast Atlantic cod is by far the most important stock in economic terms. The landed value was approximately US\$ 350 million in 2000, but had declined to just below US\$ 209 million

in 2002 (Fig. 13.4). The landed value of herring also increased considerably throughout the 1990s, to about US\$ 205 million in 2002. The third most valuable species is northern shrimp, of which the landed value was approximately US\$ 100 million in 2000, but had declined to about US\$ 85 million by 2002. Other important fisheries include those for capelin, Greenland halibut, king crab (*Paralithodes camtschaticus*), haddock, and saithe. These fisheries are important to the processing plants along the coast, and so to the viability of coastal communities.

For the northwest Russian fishing fleet, northeast Atlantic cod is also the most important fish stock. Catches are taken in Russian as well as Norwegian waters. Since the early 1990s, most of the cod caught by Russian fishers in the Barents Sea has been landed abroad, primarily in Norway. Only small quantities of mainly pelagic fish have been landed in Russia from the Barents Sea in recent years. The share of the total catch from the Northeast Atlantic has however increased. The northwest Russian fishing fleet, previously engaged mainly in distant water fishing, now works in the immediate northern vicinity. While only 234 000 t were taken in the Northeast Atlantic in 1990, catches have been over 500 000 t in all years since.

The economic value of the commercial exploitation of marine mammals in Norway and Russia is of minor direct significance nationally and regionally. But since marine mammals are major consumers of commercial fish species, their harvest is seen as an important contribution to maintaining a balance in the ecosystem. The marine mammal fishery also has a long tradition. Archeological excavations and early historical records clearly show that whaling has been conducted since ancient times and that whales were exploited before AD 1000 (Haug et al., 1998). In the 17th century, British and Dutch whalers killed an annual average of 250 Greenland right whales in the arctic and subarctic regions. These whales were processed at shore stations along the west coast of Spitsbergen (Arlov, 1996; Hacquebord, 2001).

13.2.5.2. Fishing fleets and fishers

The fishing fleet in northern Norway consists of around 1250 vessels operating on a year-round basis (Fiskeridirektoratet, 2002b). More than half are small vessels of 13 m or less. The fleet has been considerably reduced since the early 1970s. Small vessels fishing with conventional gear such as nets, lines, and jigs dominate. A large part of the fishery therefore occurs close to shore and in the fjords. Larger coastal vessels are ocean going. Trawlers and purse-seiners dominate the offshore fisheries. The vessels are required to carry a license to fish, and also need a fish quota to be admitted to a particular fishery. There are almost no open access fisheries in Norwegian waters. Most coastal communities have a number of vessels attached to them.

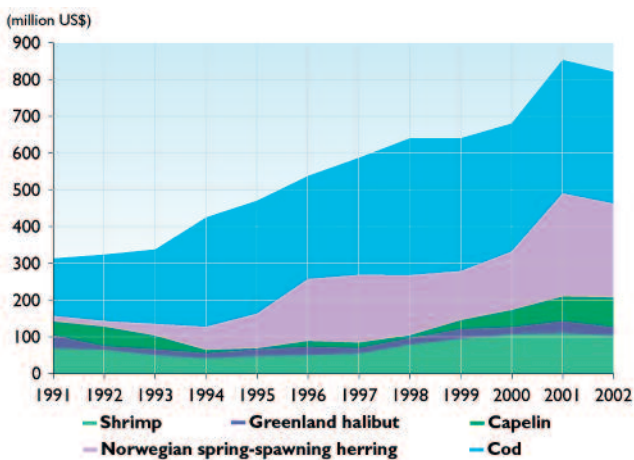


Fig. 13.4. Nominal value of the landings in Norway from the arctic fisheries, 1991–2002 (data from the Fisheries Directorate, Bergen, Norway).

Northwest Russian fisheries include a variety of fishery-related activities and participants. They are based in Murmansk and Arkhangelsk Oblasts, and in the Republic of Karelia (Hønneland and Nilssen, 2000; Nilssen F. and Hønneland, 2001). Most of the activity is located in the city of Murmansk, where most vessel owners, fish processing plants, and management authorities have their premises. The association of fishing companies in “the northern basin” of the Soviet Union, *Sevryba* (“North Fish”), was founded in 1965 and given the status of General Directorate of the Soviet Ministry of Fisheries in Northwestern Russia. *Sevryba* was made a private joint-stock company in 1992. The majority of the approximately 450 fishing vessels located in northwestern Russia are controlled by a handful of fishing companies (referred to henceforth as the “traditional” companies). The rest are distributed between *kolkhozy* (fishing collectives) and private fishing companies (referred to henceforth as the “new” companies). The total number of vessels has been stable since the early 1990s: few old vessels have been taken out of service and few new vessels have been purchased (Hønneland, 2004).

The “traditional” fishing companies are a legacy from the Soviet period. This fleet mainly consists of medium-sized (50 to 70 m) and large (over 70 m) vessels, and has around 250 to 300 ships. Before the dissolution of the Soviet Union, their main activity was the exploitation of pelagic species in distant waters and fisheries in the northern Atlantic Ocean. These companies now deploy a fleet of mid-sized factory trawlers for fishing and processing codfish. The collective fleet is significantly smaller in number, with some 80 to 100 vessels. Nearly all are of medium size (50 to 70 m). The fishing collectives are more diversified than other companies. Like the traditional companies, the collectives also aim at upgrading their fleet. The “new” companies (including the so-called coastal fishing fleet) have the smallest fleet, both in number and vessel size, limiting the range of the vessels and so the markets for the sale of the fish. The fleet comprises around 100 vessels, including around 30 coastal fishing vessels of less than 50 m in length.

The Russian perception of “coastal fishing” differs from that in neighboring countries. While a Norwegian “coastal” fishing vessel normally has a small crew and goes to port for daily delivery of catches, a northwest Russian “coastal” fishing vessel has a crew of more than a dozen and stays at sea for weeks before landing the catch. The reasons for this are two-fold. The fishing industry that was developed during the Soviet period was based on large-scale fishing and processing. Traditions, skills, and infrastructure for small-scale coastal fisheries are therefore non-existent in the main fishing regions of the Russian Federation. In addition, fish stocks for developing a viable coastal fishery are not available. Also, the financial status of the fishing companies is an obstacle to the development of coastal fisheries (Hønneland, 2004).

13.2.5.3. The land side of the fishing industry

More than 90% of the fish landed in Norway – by Norwegian, Russian, and other countries’ vessels – is exported. Changes in the international market for fish and fish products may thus have substantial effects on the processing plants as well as on the rest of the industry. Many fish processing plants are heavily dependent on landings by Russian vessels. In 2001, around 70% of the Russian cod quota was landed in Norway. This percentage has since decreased, with the increase in landings in other countries and trans-shipments in the open ocean. The fishing industry, especially the fillet-producing plants, has experienced low profitability and an increasing number of bankruptcies in recent years (Bendiksen and Isaksen, 2000). Increased competition for raw materials and high production costs in Norway help to explain the problems. In addition, the advantage of the Norwegian industry has been its location near the resources. New freezing and defrosting technologies, and infrastructure developments that make frozen products more valuable (Dreyer, 2000), reduce the advantage of proximity to the resource.

There are around 170 fish processing plants in northern Norway (Roger Richardsen, Fiskeriforskning, pers. comm., 2002 data). The size of the plants varies substantially. Most are engaged in producing traditional white-fish products, for example dried cod, salted fish, and stockfish. In Finnmark, a relatively large proportion of the plants concentrate on fillet production, while the shrimp industry is more important in Troms (NORUT, 2002). In Nordland, both fillet and traditional production is important.

Before the dissolution of the Soviet Union, Murmansk had the largest fish processing plant of the entire Union. Since fishing in distant waters has been reduced and catches from northern waters landed abroad, activities at the fish processing plants in Murmansk have been drastically reduced. The production of consumer products fell from 83 300 t in 1990, to 10 100 t in 1998 (Nilssen F. and Hønneland, 2001). Processing of fish outside Murmansk is insignificant.

13.2.5.4. Aquaculture

Since around 1980, Atlantic salmon (*Salmo salar*) and trout (*Oncorhynchus mykiss*)-based aquaculture has developed in Norway, making this country the world’s biggest farmed salmon producer. Total production in 2000 was 485 000 t, worth US\$ 1.6 billion. Of this, around 145 000 t of salmon and trout were produced in northern Norway, at a production (i.e., before sales) value of approximately US\$ 470 million. This makes salmon the single most important species in terms of economic value, both in northern Norway and in the Norwegian fishing industry as a whole.

In 2000, there were 854 licenses for salmon and trout production in Norway, of which some 30% were for

sites located in the three northern counties (Fiskeridirektoratet, 2001). The number of plants and sites in northern Norway is expected to increase considerably in the future (Hartvigsen et al., 2003). In addition to salmon, this development will also involve other fish species such as Atlantic halibut (*Hippoglossus hippoglossus*) and cod. Over time, aquaculture is expected to become more important to the north Norwegian economy than the combined marine fisheries.

An important aspect of the aquaculture industry is that it is dependent on a huge supply of pelagic fish species. Fishmeal and oils are important components of the diet of many species of farmed fish, including salmon and trout. The quantity needed is so high that the industry at a global level is sensitive to rapid fluctuations in important pelagic stocks. El Niño–Southern Oscillation (ENSO) events in the Pacific have already affected the industry through impacts on anchovy (*Engraulis* spp.) stocks. From 1997 to 1998, the global marine fishery was reduced by nearly 8 million t, mainly due to ENSO events (FAO, 2000). Reduced supply on the international market led to increased prices of fishmeal in this period. The latest assessment by the Intergovernmental Panel on Climate Change (IPCC, 2001) states that unless alternative sources of protein are found, aquaculture could in the future be limited by the supply of fishmeal and oils.

Aquaculture is in its infancy in northwest Russia and the total production is negligible. It is however likely to increase in the future.

13.2.5.5. Employment in the fisheries sector and the fisheries communities

There are approximately 17000 fishers in Norway, of which almost half live in the three northern counties. In northern Norway it is common to combine fishing with other trades to make a living, particularly in remote areas. Part-time fishers make up about a third of the total number of people in the profession. The number of fishers has been sharply reduced over recent decades. This reflects broader societal changes with a shift in the workforce from primary to secondary and tertiary occupations, as well as technological development in the industry. A total of 12420 persons worked in fish processing in Norway in 2000 (Ministry of Fisheries, 2002). About half of these worked in the northernmost counties.

In 2001, around 3600 people worked in aquaculture in Norway (Ministry of Fisheries, 2002). Of these about a third worked in the three northernmost counties. The combined direct employment in the fisheries sector in northern Norway is 16000 to 17000 people. The fisheries also generate substantial employment in related activities, such as shipbuilding, ship repairs, and gear production, as well as sales and exports. The number of people employed in the related industries has increased substantially over recent decades. The employment generated in related industries by the fish-

eries sector is 0.75 man-years per year in the fisheries (KPMG and SINTEF, 2003), amounting to some 12000 people in northern Norway. The total employment generated is therefore close to 30000 people. With a total population in northern Norway of 460000, this implies that the fisheries are crucial to employment and income in the region.

Corresponding data on employment in the fisheries sector for northwest Russia were not available.

According to Lindkvist (2000) there are 96 communities in Norway that can be characterized as fishing communities. Of these, 42 occur in the three northern counties. Of these, 31 may be defined as fisheries-dependent in the sense that more than 5% of the working population is employed in fisheries and fish processing (Lindkvist, 2000). These communities are typically small and located in remote areas. Most face depopulation and problems such as lack of qualified personnel to maintain public services, but at the same time have few alternative trades to fishing. In Finnmark county, about 10% of the total employment is in the fisheries sector (Hartvigsen et al., 2003). Remote, fisheries-dependent communities in northern Norway have the highest depopulation rates in the country. Since the 1980s, none of its municipalities have increased in population. On average the coastal municipalities have experienced a population reduction of around 30% (Hartvigsen et al., 2003).

Demographic pressure towards urbanization, which is expected to continue (IPCC, 2001), may be said to be one of the major driving forces behind this development. Other factors, such as lack of employment opportunities and inferior public services, may be seen both as a cause of the problem as well as a consequence. There is also the trend of fishing boats being sold out of the communities. These trends indicate that the small fishery-dependent societies are under continuous pressure. These societies are subject to a “double exposure” (O’Brien and Leichenko, 2000), where climate change occurs simultaneously with economic marginalization. The Norwegian government has for a long period run programs aimed at strengthening the viability of fishery-dependent societies in the north. In recent years these efforts have been directed towards market orientation, flexibility, and a more robust industrial structure, rather than towards subsidies to the industry. Some regional development programs are aimed at diversification of the economic activity in remote areas by supporting, among other things, female-run enterprises (Lotherington and Ellingsen, 2002).

Among the Russian Federation subjects in the northwest, the Murmansk Oblast is most important from the point of view of fisheries. This region is one of the most urbanized in Russia, with around 92% of the population living in cities and towns. Most of the northwest Russian fishing fleet is concentrated in the city of Murmansk. Some companies are located in the three other Russian Federation subjects: Arkhangelsk (Arkhangelsk Oblast),

Petrozavodsk (Republic of Karelia), and Narjan-Mar (Nenets Autonomous Okrug).

The fishing industry is important for several major cities in northwestern Russia, but these cannot be characterized as “fishing communities” in the sense that this concept is understood in the West. Their viability is not dependent on fisheries. Also, the significance of the fishing industry has been severely reduced in the post-Soviet period as the catches of Russian vessels are mainly delivered to the West. The redirection of landings to the home market has been one of the main ambitions of Russian fishery authorities at both the federal and regional level since the early 1990s. That this has not been achieved points to the relative impotency of these bodies. At the federal level, the State Committee for Fisheries has twice lost its status as an independent body of governance (subsumed into the Ministry of Agriculture in 1992–1993 and 1997–1998) and seen its traditional all-embracing influence over fisheries management significantly reduced. In 2000, the Ministry of Trade and Economic Development succeeded in introducing a system for quota auctions, against the will of the State Committee for Fisheries. Regional authorities increased their influence during the 1990s. This development has now been reversed owing to the re-centralization that began around 2000, commensurate with wider developments in Russia since President Putin came to power. Hence, while regional authorities in northwestern Russia have a declared aim of developing coastal fisheries, actual development in this sphere can only be considered minimal.

13.2.5.6. Markets

All data in this section are from the Norwegian Seafood Export Council (<http://www.seafood.no>).

Norway is one of the world's biggest fish exporters – more than 90% of the landings are exported (in 2001 Norway was the world's second largest fish exporter, after Thailand). There are two aspects to this. First, the income generated by fish exports is substantial – around US\$ 4 billion in 2001. As the production in aquaculture will increase, and the production of petroleum will decrease, exports of fish products can be expected to become more important in the future. The Ministry of Fisheries envisages that aquaculture will become a mainstay of the Norwegian economy in the years to come, and that the sales value in northern Norway will be nearly five times higher in 2020 than today. Second, Norway is a major supplier to many markets. The Norwegian imports are important to, for example, the EU market for seafood, which is therefore vulnerable to fluctuations in Norwegian fisheries.

The single most important species in terms of export value is salmon, which had an export value of US\$ 1.8 billion in 2000. The second most important category is whitefish, the exports of which (consisting mainly of cod, haddock, and saithe) are worth in the range of

US\$ 1.2 billion annually. Pelagic species, of which herring is the most important, had an export value of US\$ 920 million in 2001. The fourth most important species in terms of export value is northern shrimp.

Landings of Russian-caught cod in Norway have increased since 1990. During 1995 to 1997, landings were around 250 000 to 300 000 t per year. Since then, there has been a reduction in Russian landings of cod as well as other fish in Norway. Trans-shipments of fish at sea and landings in other countries are increasing while landings in Norway are decreasing. Catches landed in Russia mostly go to the Russian consumer market. Imports of fish to Russia from Norway are rapidly increasing.

13.2.5.7. The management regime

In addition to the EEZ, Norway also manages the resources in the Fishery Zone around Jan Mayen and in the Fishery Protection Zone around Svalbard. The Norwegian EEZ borders the EU zone to the south, the Faroe Islands to the southwest, and Russia to the east. A large area beyond the EEZ boundary in the Norwegian Sea and a smaller area in the Barents Sea are international waters. Most of the economically important stocks move between the zones of two or more states.

Cooperation between the owner countries in the management of these stocks is essential to ensure their sustainable use. A series of agreements has been negotiated among the countries in the Northeast Atlantic that establish bilateral and multilateral arrangements for cooperation on fisheries management. The most extensive management regime on arctic stocks in the Northeast Atlantic is that between Norway and Russia. A joint fisheries commission meets annually to agree on TACs and the allocation for the major fisheries in the Barents Sea: i.e., those for cod, haddock, and capelin (since 2001 a total quota has also been set for the king crab fishery). The total quotas set are shared between the two countries – the allocation key is 50-50 for cod and haddock, and 60-40 for capelin. A fixed additional quantity is traded to third countries. There are also agreements on mutual access to the EEZs and exchange of quotas through this arrangement (Hoel, 1994). An important aspect of the cooperation with Russia is that a substantial part of the Russian harvest in the Barents Sea is taken in the Norwegian zone and landed in Norway. The cooperation also entails joint efforts in fisheries research and in enforcement of fisheries regulations.

Despite disagreement between Norway and Russia on the delimitation of the boundary between their EEZ and the shelf in the Barents Sea, the cooperation on resource management between the two countries may generally be characterized as well functioning (Hønneland, 1993). However, agreed TACs by Norway and Russia have, in some years, exceeded those recommended by fisheries scientists. In addition, the actual catches have sometimes been larger than those agreed. Since the late 1990s, a

precautionary approach has been gradually implemented in the management of the most important fisheries. However, retrospective analyses have shown that ICES estimates of stock sizes have often been too high, thereby incorrectly estimating the effect of a proposed regulatory measure on the stock. This has had the unfortunate effect that stock sizes for a given year are adjusted downward in subsequent assessments, rendering adopted management strategies ineffective (Korsbrekke et al., 2001; Nakken, 1998). However, the Joint Norwegian–Russian Fisheries Commission has decided that from 2004 onward multi-annual quotas based on a precautionary approach will be applied. A new management strategy adopted in 2003 shall ensure that TACs for any three-year period shall be in line with the precautionary reference values provided by ICES.

A number of other agreements are also in effect in the area, notably a five-party agreement among the coastal states in the Northeast Atlantic to manage Atlanto-Scandian herring (Ramstad, 2001). Total quotas for the following year's herring fishery are set, and divided among the parties. A separate quota is set for the area on the high-seas in the Norwegian Sea. The high seas quota, most of which is given to the same coastal states, is formally managed by the NEAFC, which is mandated to manage the fishing on the high seas in the Northeast Atlantic. Norway also has an extensive cooperation with the EU on the management of shared stocks in the North Sea, as well as on the exchange of fish quotas, which entails access for EU vessels to north Norwegian waters. The EU is given a major share of the third country quota of cod in the Norwegian waters north of 62° N.

Management measures for marine mammals harvested in the area are decided by the IWC, NAMMCO, and the Joint Norwegian–Russian Fisheries Commission. The IWC has not been able to adopt a Revised Management Scheme and so does not set quotas. Since 1993, Norway has set unilateral quotas for the take of minke whales, on the basis of the work of the IWC Scientific Committee (Hoel, 1998). NAMMCO adopts management measures for cetaceans and seals in the northern Northeast Atlantic (Hoel, 1993).

A precondition for sound management of living marine resources is that sufficient knowledge about the resources is available. In Norway, the Institute of Marine Research is the main governmental research institution, while the Northern Institute of Marine Research (PINRO) plays the same role on the Russian side. ICES is the international institution for formulating scientific advice to the fisheries authorities in the North Atlantic countries. Its work is generally based on inputs from the research institutions in the member countries. The ICES advice is now based on a precautionary approach, which seeks to introduce a greater sensitivity to risk and uncertainty into management. Three of the challenges for fisheries management in the future are: a better understanding of species interac-

tions (multi-species management), more reliable data from scientific surveys, and a better understanding of the impact of physical factors – such as changing climatic conditions – on stocks. A major challenge is the development and implementation of an ecosystem-based approach to the management of living marine resources, where the effects of climate change are also considered when establishing management measures.

The management measures essentially fall into three categories:

- input regulations in the form of licensing schemes restricting access to a fishery;
- output regulations, consisting of the fish quotas given to various groups of fishers which limit the amount of fish they are entitled to in any given season; and
- technical measures specifying for example the type of fishing gear to be used in a particular fishery.

The objectives of fisheries management in Norway are related to conservation, efficiency, and regional considerations (Report to Parliament, 1998). Conservation of resources is seen as a precondition for the development of an efficient industry and maintenance of viable fishing communities. An important objective of the fisheries policy is to improve the economic efficiency of the industry. An important issue is therefore to reduce the capacity of the fishing fleet, which is much larger than needed to take the quotas available and therefore makes the costs of fishing too high. Attempts to remove excess capacity include scrapping of vessels, regulatory mechanisms, and vessel construction regulations. A quota arrangement allowing for merging two vessels' quotas while removing one of the vessels from the fishery gives vessel owners an incentive to remove excess fishing capacity, and can contribute to a more efficient fleet. However, this can result in coastal communities seeing their local fleet reduced or even disappearing, threatening the viability of that community.

The enforcement of the fisheries regulations in Norway is carried out both at sea and when the fish is landed. At sea, the Coast Guard is responsible for inspecting fishing vessels and checking their catch against vessel logbooks. Foreign vessels fishing in Norwegian waters are also inspected. The activity of the Coast Guard is vital for the functioning of the management regime as a whole. Ocean-going vessels are required to install and use a satellite-based vessel-monitoring system enabling the authorities to continually monitor their activities. The Directorate of Fisheries also inspects activities on the fishing grounds, as well as at the landing sites. When fish is landed, the sales organization buying the fish reports the landed quantity to the Fisheries Directorate, which is responsible for maintaining the fisheries statistics.

The regulation of Soviet fisheries in the Northeast Atlantic used to be the responsibility of the Sevryba

association. As this organization lost its status in fisheries regulation in the mid-1990s, the regulatory tasks were partly taken over by the enforcement body Murmanrybvod, partly by the fisheries departments of regional authorities in each federal subject in the area, and since 2000 to an increasing extent the regulatory tasks have been the remit of federal authorities. During the 1990s, the Russian share of the Barents Sea quotas was first divided among the four federal subjects of the region by the so-called Scientific Catch Council (formerly headed by Sevryba, since 2001 by the federal State Committee for Fisheries). Within each federal subject, a Fisheries Council (led by regional authorities) distributed quota shares among individual ship owners. The influence of both the Scientific Catch Council and the regional Fisheries Councils was reduced after the introduction of quota auctions in 2000/2001. Since then, an increasing share of the quotas has been sold at auctions, administered by the federal Ministry of Trade and Economic Development. In November 2003, the Russian Government decided to abolish the auctions and instead introduce a resource rent (a fee on quota shares). The quotas will from 2004 be distributed by an inter-ministerial commission at the federal level, so the regional authorities will also lose the influence of inter-regional quota allocation (Hønneland, 2004).

Apart from quotas, the Russians have fishery regulations similar to those in the Norwegian system: regulations pertaining to fishing gear, size of the fish, and composition of individual catches. In addition, the Russians have a more fine-meshed system than the Norwegians for closing and opening of fishing grounds. Individual inspectors from the enforcement body Murmanrybvod or researchers from the scientific institute PINRO can close a "rectangle" (a square nautical mile) on site for a period of three days. After three days, the "rectangle" is reopened if scientists make no objections, i.e., if the proportion of undersized fish in catches does not continue to exceed legal limits.

Traditionally, the civilian fishery inspection service Murmanrybvod, subordinate to the Russian State Committee for Fisheries, has been responsible for enforcing Russian fishery regulations in the Barents Sea. In 1998, responsibility for fisheries enforcement at sea in the Russian Federation was transferred to the Federal Border Service. In the northern fishery basin, the Murmansk State Inspection of the Arctic Regional Command of the Federal Border Service was established to take care of fisheries enforcement. However, this body is only responsible for physical inspections at sea, while inspection of landed catches has been transferred to the Border Guard. Murmanrybvod is still in charge of keeping track of how much of the quotas has been caught by individual ship owners at any one time. It has also retained its responsibility for the closing of fishing grounds in areas with excessive intermingling of undersized fish, a very important regulatory measure in both the Russian and Norwegian part of the Barents Sea. Finally, Murmanrybvod is still responsible for

enforcement in international convention areas. In practice, Murmanrybvod places its inspectors on board northwest Russian fishing vessels that fish in the NEAFC or NAFO areas.

The reorganization of the Russian enforcement system is generally believed to have led to a reduction in the system's effectiveness, at least from a short-term perspective. For example, officers in the Murmansk State Inspection of the Federal Border Service generally lack experience in fisheries management and enforcement. This has partly been compensated for by the transfer of some of Murmanrybvod's inspectors. More apparent is the lack of material resources to maintain a presence at sea. Contrary to the intentions of the reorganization of the enforcement system, the presence at sea by monitoring vessels has declined since the Border Guard took over this duty in 1998. Precise data for presence at sea and inspection frequency are not available, but Jørgensen (1999) estimated that the Border Guard performed around 160 inspections at sea in 1998, which represents a significant reduction compared to an estimated 700 to 1000 annual inspections at sea by Murmanrybvod prior to the reorganization. For periods of several months during 1998, not a single enforcement vessel was present on the fishing grounds in the Russian part of the Barents Sea. Officials of the Border Service explain this by a lack of funds to purchase fuel. Critics question the genuineness of the Border Service's will to play a role in fisheries management. The result of the reorganization has, in any event, so far led to a tangible reduction in the effectiveness of Russian enforcement in the Barents Sea.

13.2.6. Economic and social impacts of climate change on fisheries in the Northeast Atlantic

The economic importance of fisheries to northern Norway is substantial, cod being the most significant species. Problems related to profitability in the fishing industry have been evident for a long time, and have contributed to depopulation problems in remote, fishery-dependent areas. Aquaculture is, however, a growing industry and is expected to be important to the future viability of local communities in northern Norway. In northwest Russia, the fishing industry is based in big cities, Murmansk in particular, and is therefore not as significant to local communities as it is in Norway.

A study by Furevik et al. (2002) developing regional ocean surface temperature scenarios for the Northeast Atlantic concluded that for the 2020 scenario, no substantial change is likely in the physical parameters. The authors concluded that a slight cooling in ocean surface temperature is likely by 2020 with warming likely in the longer-term scenarios. For the near-term future, climate change is therefore not likely to have a major impact on the fisheries in the region. Uncertainties surrounding these scenarios are however considerable. These are amplified when the physical effects on biota are included, and amplified again when the effects

of climate change on society are added. In addition, social change is driven by a vast number of factors, of which climate change is only one. The rest of this section is therefore tentative and should be read more as discussions of likely patterns of change than predictions of future developments.

The effects of climate change are closely related to the vulnerability of industries and communities, and to their capability to adapt to change and mitigate the effects of change. Within this context vulnerability is defined as “the extent to which a natural or social system is susceptible to sustaining damage from climate change” (IPCC, 2001). It depends on the ability and capacity of society at the international, national, and regional level to cope with change and to remedy its negative effects. Climate change may also result in positive changes.

The fisheries sector is one in which the industry has always had to adapt to and cope with environmental change: the abundance of various species of fish and marine mammals has varied throughout history, often dramatically and also within short periods of time. Adapting to changing circumstances is therefore second nature to the fishing industry as well as to the communities that depend upon it. An important issue is thus whether climate change brings about changes at scales and rates that are unknown, and whether adaptation can be achieved within the existing institutional structures.

13.2.6.1. Resource management

Resource management is the key factor in deciding the biological and economic sustainability of the fisheries. The fishing opportunities are decided by the management regime. There are virtually no remaining fisheries where the economic result is decided by the industry itself. The design and operation of both the domestic and international management regimes are crucial to the sustainability and economic efficiency of the fisheries, and hence to the economic viability of the communities that depend upon them. The development and implementation of a precautionary approach, as well as the emergence of ecosystem-based management, may enhance the resilience of the stocks and therefore make the industry and communities more robust to future external shocks. As discussed in section 13.2.5.7, the main arrangements for managing living marine resources in the Northeast Atlantic are being modified in this direction, with the implementation of a precautionary approach and the development of an ecosystem-based approach to management.

A major challenge for the management regime is that of adjusting to the possible changes in migration patterns of stocks resulting from climate change. This finding is in conformity with that of the IPCC (2001) and Everett et al. (1996). Changes in migration patterns of fish stocks have previously upset established arrangements for resource management, and can trigger conflicts between countries. One example is that of

northeast Atlantic cod: in the early 1990s, the stock extended its range northward in the Barents Sea, into the high seas in the area (the so-called “loophole”). Vessels from a number of countries without fishing rights in the cod fishery took the opportunity to initiate an unregulated fishery in the area, thereby undermining the Norwegian–Russian management regime. This triggered a conflict between Norway and Russia on the one hand, and Iceland on the other. The conflict was later resolved through a trilateral agreement (Stokke, 2001). Another example is that of the Norwegian spring-spawning herring (Box 13.1): following more than two decades of effort at rebuilding the stock on the part of Norwegian authorities, in the mid-1990s the stock began to migrate from the Norwegian EEZ and into international waters for parts of the year. By doing so the stock became accessible to vessels from other countries, and in the absence of an effective management regime for the stock in the high seas, efforts at rebuilding the stock could prove futile. A regime securing a management scheme for the stock eventually came into place, but took several years to negotiate (Box 13.1). Thus, changes in migration patterns, which are likely to be triggered by changes in water temperatures, tend to result in unregulated fishing and conflicts among countries. The outcome of such conflicts may be conflicting management strategies, new distribution formulas, or even new management regimes.

Another important factor is that negative events tend to be a liability to the management regime. The so-called “cod crisis” in the late 1980s, for example, led to several modifications of the existing regime. The management regime is likely to be held responsible for social and economic consequences of climate change. This may in turn affect the legitimacy and authority of the regime, and its effectiveness in regulating the industry. An important aspect in that regard is the way decisions about resource management and allocation of resources are made. A regime that involves those interests that are affected by decisions in the decision-making processes tends to produce regulations that are considered more legitimate than regimes that do not involve stakeholders (Mikalsen and Jentoft, 2003).

Current fisheries management models are mainly based on general assumptions of constant environmental factors. The current methods applied in fisheries management can not accommodate environmental changes. A study by Eide and Heen (2002) investigated the economic output from the fisheries under different environmental scenarios and under different management regimes for the cod and capelin fisheries in the Barents Sea. Using the ECONMULT fleet model (Eide and Flaaten, 1998) and a regional impact model for the north Norwegian economy (Heen and Aanesen, 1993), they concluded that even a narrow range of management regimes has a variety of possible economic outcomes. Even though climate change may result in significant potential effects on catches, profitability, employment, and income, changes in the management regimes seem

to have an even larger impact. This conclusion sets the discussion of effects of global climate change in perspective. It implies that a large number of factors influence the economic activities and their output and, furthermore, that the operation of the management regime seems to be the most significant of these factors.

The crucial factor for resource management under conditions of climate change is therefore the development of robust and precautionary approaches and institutions for managing the resources. The decisive factor for the health of fish stocks, and therefore the fate of the fishing industry and its dependent communities, appears to be the resource management regime.

13.2.6.2. The fishing fleet

The ability to adapt to changes in migration patterns or stock size of commercially exploited species will vary between different vessel groups in the fishing fleet. The ocean-going fleet is capable of adjusting to changes in migration patterns, as it has a wide operating range. Small coastal vessels are more limited in that regard. Thus, northern communities with a strong dependency on small coastal vessels are likely to be more affected if migration patterns and availability of important fish stocks change significantly. If fish stocks move closer to the coast it is an advantage to the coastal fleet, while it is a disadvantage for this fleet if the stocks move more seaward. Such a development may be confounded by changing weather patterns with severe weather events becoming more prevalent. All vessel groups will be affected if changes lead to stocks crossing jurisdictional borders. That may imply a change in distribution of resources among countries.

Increased production and larger stocks of cod and herring are possible outcomes of climate change in the Northeast Atlantic. A question arises as to which fleet groups are most capable of making the best of such positive changes in the resource. Such changes may result in different availability of the resources between groups of fisheries (e.g., coastal versus ocean-going vessels), affecting the domestic allocation of resources. It may also lead to a greater political pressure to change the allocation of resources between the main groups of resource users.

Changes in stock abundance and migration patterns are not new to the industry. The availability of fish stocks and their accessibility to the coastal fleet has changed throughout recorded history, and the industry as well as the management regime is used to adapting to changing circumstances. The key question is whether climate change would amplify such variations and aggravate their effects beyond the scale with which the industry and the regulating authorities are familiar.

Changes in oceanic conditions may also affect the migrating ranges of marine mammals, and hence marine mammal–fisheries interactions. Such interactions could include marine mammals preying on fish, thus increasing

competition with fishers, or marine mammals interacting directly with the fishery, for example by interfering with fishing gear. Marine mammals are also vectors of parasites that may affect fish and fisheries.

13.2.6.3. Aquaculture

Higher water temperature generally has positive effects on aquaculture in terms of fish growth. The IPCC reported that warming and consequent lengthening of the growing season could have beneficial effects with respect to growth rates and feed conversion efficiency (IPCC, 2001). Warmer waters may also have negative effects on aquaculture since the presence of lice and diseases may be related to water temperature. In recent years high water temperatures in late summer have caused high mortality at farms rearing halibut and cod, the production of which is still at a pre-commercial stage. Salmon is also affected by high temperatures and farms may expect higher mortalities of salmon. A rise in sea temperatures may therefore favor a northward movement of production, to sites where the peak water temperatures are unlikely to be above levels at which fish become negatively affected.

An increase in severe weather events can be a cause of escapes from fish pens and consequent loss of production. Escapes are also a potential problem in terms of the spread of disease. However, technological developments may compensate for this.

The aquaculture industry is dependent on capture fish for salmon feed. Climate change may cause a lack of and/or variability in the market for such products, but this is also an area where research may lead to the development of other feed sources.

13.2.6.4. The processing industry, communities, and markets

The fish processing industry in the north faces challenges in the structural changes both in the first-hand market (from fisher to buyer) and in the export market. Increased international competition for scarce resources has left the processing side of the industry increasingly vulnerable to globalization pressures. At the same time many of the communities, depending on fisheries for their existence, experience economic marginalization and depopulation-related problems. The vulnerability of the fishing industry and fishing communities can therefore be considered as relatively high at the outset, rendering them particularly susceptible to any negative influences resulting from climate change. Such impacts may however be minor compared to that of other drivers of change. Furthermore, the fish processing industry is very varied. The size of fish processing plants is one aspect of this, their versatility and ability to vary production and adapt to changing circumstances is another. The ability of the particular type of industry to adapt to various earlier “crises”, whether in terms of demand or supply failures, could be an indicator of their future

“coping-capacity” for effects resulting from climate change. Another issue is that climate-induced changes elsewhere in the world may affect the situation for the north Norwegian fishing industry and fishing communities. Experience from, for example, the fisheries crisis in Canada in the 1990s indicates that such situations tend to intensify competition for further processing of the raw material. To the industry in Norway, with high labor costs, such a scenario is negative.

13.2.7. Ability to cope with change

Many factors contribute to a community’s “coping capacity” in relation to depopulation and to structural changes in the fisheries sector (Baerenholdt and Aarsaether, 2001). The future of these settlements may depend on their ability to adapt to increased competition, efficiency, deregulation, and liberalization of the markets, as much as on the accessibility of fishing resources for their local production systems (Lindkvist, 2000).

While the management regime can be seen as an instrument to ease negative effects of climate change, it is however also important to consider public measures beyond the fisheries management regime that affect the conditions of the fishing industry more broadly, as for example regional policies and the development of alternative means of employment. Measures for building infrastructure such as roads or to develop harbor facilities are but one example. Government support for fisheries in the form of direct subsidies is now effectively prohibited by international agreements. But in Norway in particular there is a strong tradition for supporting regional development in a broader sense, and programs to this end may enhance the resilience of northern communities.

In addition to adapting to possible changes in the resource resulting from climate change, the fishing communities will also need to adapt to possible other climate-related changes in their vicinity (e.g., weather events) and their effects on terrestrial biota and infrastructure. These may have indirect effects on the fishery sector, related economic activities, or on other aspects of life, valued by the people in the respective communities.

13.2.8. Concluding comments

The Northeast Atlantic area comprises the northern and eastern parts of the Norwegian Sea to the south, and the north Norwegian coast and the Barents Sea to the east and north. The total fisheries in the area amounted to 2.1 million t in 2001. Aquaculture production is dominated by salmon and trout and amounted to 86 000 t in 2001. Norway and Russia have long traditions for cooperating both in trade and management issues. Since 1975, a comprehensive framework for managing the living marine resources in the area has been developed, covering also the areas on the high seas. While the Norwegian fishing industry is located in numerous communities all along the northern coast, the northwest

Russian fishing fleet is concentrated in large cities, primarily Murmansk.

Owing to the influence of the North Atlantic Current, the climate in this region is several degrees warmer than the average in other areas at the same latitude. Historically, a number of climate-related events have been observed in the Northeast Atlantic fisheries. Since the Second World War both cod and herring, the two major fish stocks in the area, have been subject to overfishing. This has resulted in a far lower average annual yield than these stocks have the potential to produce. Therefore, the management of stocks is the key issue in assessing the effects of potential climate variations on fish stocks.

Provided that the fluctuations in Atlantic water inflows to the area are maintained along with a general warming of the North Atlantic waters, it is likely that the annual average recruitment in herring and cod will be at about the long-term average during the first two to three decades of the 21st century. This projection is based on the assumption that harvest rates are kept at levels that maintain spawning stocks well above the level at which recruitment is impaired. How production will change further in the future is impossible to guess, since the projected temperatures, particularly for some global models, are so high that species composition and thus the interactions in the ecosystem may change completely.

Resource management is the key factor in deciding the biological and economic sustainability of the fisheries. The design and operation of both the domestic and international management regimes are therefore crucial in determining sustainability and economic efficiency. The development and implementation of a precautionary approach, as well as the emergence of ecosystem-based management, may enhance the resilience of the stocks and thus lessen the vulnerability of the industry to future external shocks. A large number of factors influence economic activities and their output, and an effective rational management regime seems to be the most significant of these. The crucial factor for resource management under conditions of climate change is therefore the development of robust and precautionary approaches and institutions for resource management.

13.3. Central North Atlantic – Iceland and Greenland

This section deals with the marine ecosystems of Iceland and Greenland. Although there are large differences, both physical and biological, between these two ecosystems there are also many similarities. Seafood exports represent a major source of revenue for both countries. Figure 13.5 shows the locations of the sites referred to most frequently in the text.

The waters around Iceland are warmer than those around Greenland due to a greater Atlantic influence and are generally ice free under normal circumstances. Exceptions are infrequent and usually last for relatively

short periods in late winter and spring when drift ice may come close inshore and or even become landlocked off the north and east coasts. However, drift ice has been known to surround Iceland during cold periods, such as during the winter of 1918. Greenlandic waters are colder, sea-ice conditions more severe, and ports on the coastline commonly close for long periods due to the presence of winter sea ice and icebergs.

The reason for treating these apparently dissimilar ecosystems together is the link between the stocks of Atlantic cod at Iceland and Greenland. There is a documented drift of larval and 0-group cod (in its first year of life) from Iceland to Greenland with the western branch of the warm Irminger Current (Jensen, 1926). Spawning migrations in the reverse direction have been confirmed by tagging experiments (e.g., Hansen et al., 1935; Jónsson, 1996; Tåning, 1934, 1937). There are, however, large variations in the numbers of cod and other fish species, which drift from Iceland to Greenland and not all these fish return to Iceland as adults.

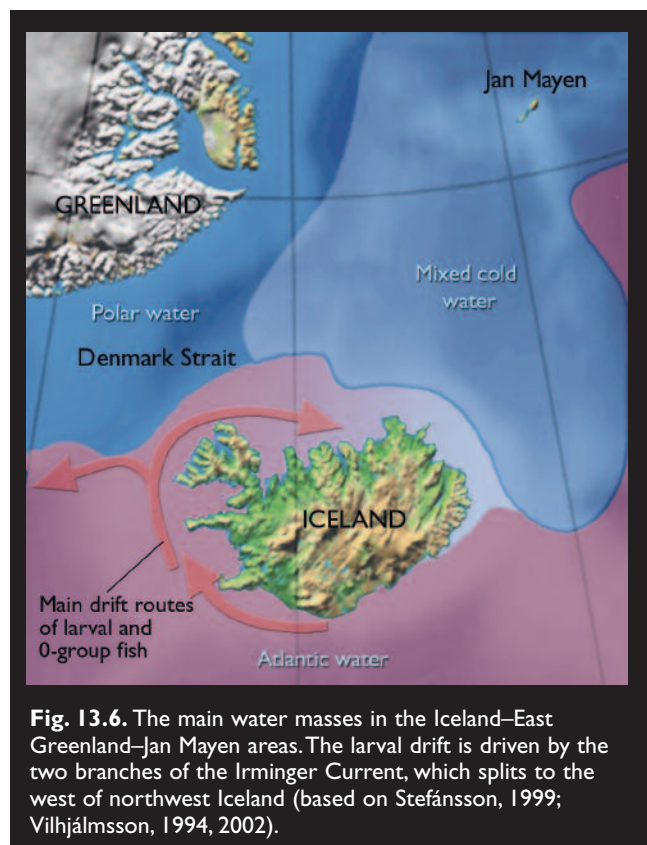
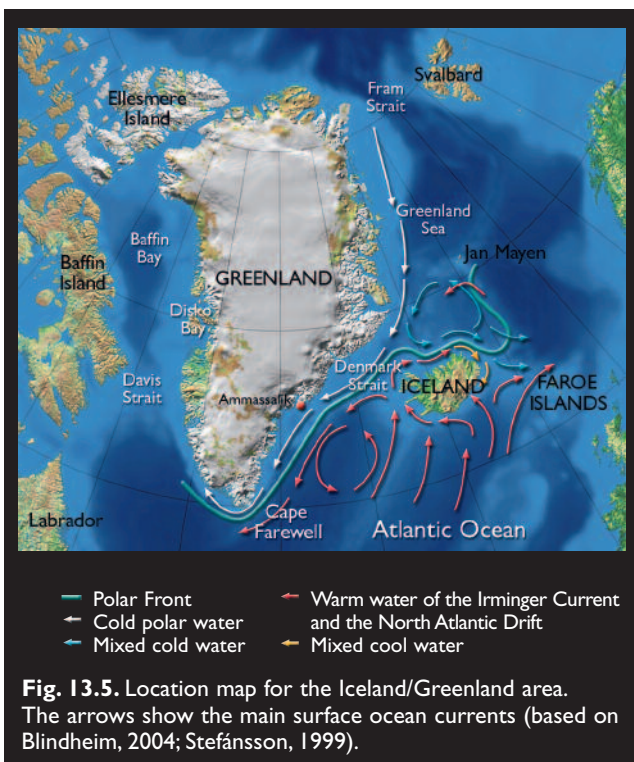
The history of fishing the waters around Iceland and Greenland dates back hundreds of years but is mainly centered on Atlantic cod, the preferred species in northern waters in olden times. Icelandic waters are usually of a cold/temperate nature and are therefore relatively species-rich. Consequently, with the diversification of fishing gear and vessel types in the late 19th century and the beginning of the 20th century, numerous other fish species, both demersal and pelagic, began to appear in catches from Icelandic waters. The Greenlandic marine environment is much colder and commercially exploitable species are therefore fewer. Present-day catches only comprise nine demersal fish species, two pelagic fish species, and three

species of invertebrates. There is currently almost no catch of cod at Greenland.

Whale products feature in Icelandic export records from 1948 until the whaling ban (zero quotas) was implemented in 1986, but their value was never a significant component of exported seafood. Iceland has a long history of hunting porpoises, seals, and seabirds, and gathering seabird eggs for domestic use. Although this hunting and gathering gradually decreased with time, it is still a traditional activity in some coastal communities. For Greenland, several species of marine mammals (at least five different whale species, five species of seals, plus walrus) and six species of seabird are listed in catch statistics. Catches of marine mammals and seabirds are still important in Greenland, culturally and socially, as well as in terms of the local economy.

13.3.1. Ecosystem essentials

The marine ecosystem around Iceland is located south of the Polar Front in the northern North Atlantic (Fig. 13.5). The area to the south and west of Iceland is dominated by the warm and saline Atlantic water of the North Atlantic Current, the most important component being its westernmost branch, the Irminger Current (Fig. 13.5). The Irminger Current bifurcates off the northern west coast of Iceland. The larger branch flows west across the northern Irminger Sea towards Greenland. The smaller branch is advected eastward onto the North Icelandic shelf where the Atlantic water mixes with the colder waters of the East Icelandic Current, an offshoot from the cold East Greenland Current. On the shelf north and east of Iceland the



degree of mixing increases in the direction of flow and the influence of Atlantic water is therefore lowest on the east Icelandic shelf as shown in Fig. 13.6. Hydrobiological conditions are relatively stable within the domain of the Atlantic water to the south and west of Iceland, while there may be large seasonal as well as interannual variations in the hydrography and levels of biological production in the mixed waters on the north and east Icelandic shelf (Anon, 2004b; Astthorsson and Gislason, 1995), depending on the intensity of the flow of Atlantic water and the proximity of the Polar Front. Large variations in the flow of Atlantic water onto the shelf area north of Iceland on longer timescales have also been demonstrated (Malmberg, 1988; Malmberg and Kristmannsson, 1992; Malmberg et al., 1999; Vilhjálmsson, 1997).

The East Greenland Current carries polar water south over the continental shelf off the east coast of Greenland and after rounding Cape Farewell (about 60° N; 43° W) continues north along the west coast. Off the east coast, the temperature of these cold polar waters may be ameliorated by the warmer Atlantic waters of the Irminger Current, especially near the shelf break and on the outer parts of the shelf (see Fig. 13.5). Off West Greenland, the surface layer is dominated by cold polar water, while relatively warm mixed water of Atlantic origin is found at depths between 150 and 800 m, north to about 64° N. Mixing and diffusion of heat between these two layers, as well as changes in the relative strength of their flow, are fundamental in determining the marine climatic conditions and the levels of primary and secondary production off West Greenland (e.g., Buch, 1993; Buch and Hansen, 1988; Buch et al., 1994, 2002).

The Irminger Current is also important as a transport mechanism for juvenile stages of various species of fish (Fig. 13.6). Thus, its eastern branch plays a dominant

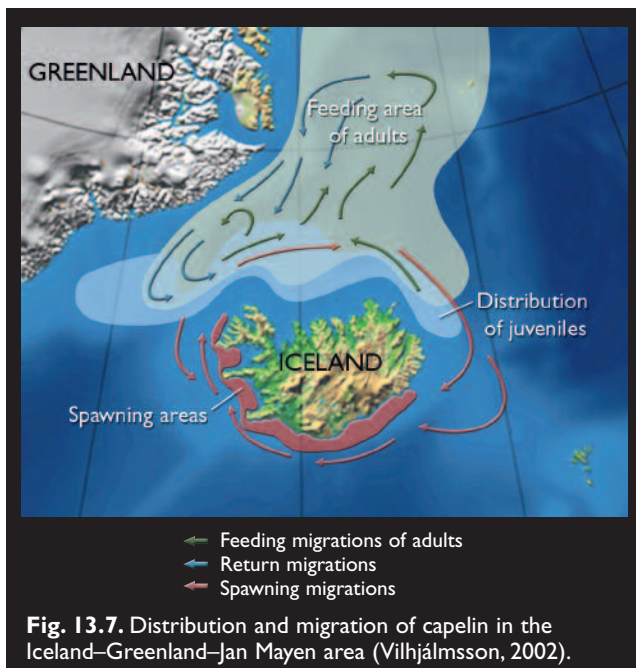
role in transporting fish fry and larvae from the southern spawning grounds to nursing areas on the shelf off northwest, north, and east Iceland, while the western branch may carry large numbers of larval and 0-group fish across the northern Irminger Sea to East Greenland and from there to nursery areas in southern West Greenland waters. The main ocean currents in the Iceland/Greenland area are shown in Fig. 13.5.

The Icelandic marine ecosystem contains large stocks of zooplankton such as calanoid copepods and krill, which are eaten by adult herring and capelin, adolescents of numerous other fish species, as well as by baleen whales. The larvae and juveniles of both pelagic and demersal fish also feed on eggs and juvenile stages of the zooplankton. Benthic animals are also important in the diet of many fish species, especially haddock, wolffish (*Anarhichas lupus lupus*), various species of flatfish, and cod.

Owing to the influence of warm Atlantic water, the fauna of Icelandic waters is relatively species-rich and contains over 25 commercially exploited stocks of fish and marine invertebrates. In contrast, there are only a few commercial fish and invertebrate species in Greenlandic waters (Muus et al., 1990) and these are characterized by cold water species such as Greenland halibut, northern shrimp, capelin, and snow crab. Redfish are also found, but mainly in Atlantic waters outside the cold waters of the East Greenland continental shelf and cod can be plentiful at West Greenland in warm periods.

Around Iceland, most fish species spawn in the warm Atlantic water off the south and southwest coasts. Larvae and 0-group fish drift westward and then northward from the spawning grounds to nursery areas on the shelf off northwest, north, and east Iceland, where they grow in a mixture of Atlantic and Arctic water (e.g., Schmidt, 1909). Larval and 0-group cod and capelin, as well as species such as haddock, wolffish, tusk (*Brosme brosme*), and ling (*Molva molva*) may also be carried by the western branch of the Irminger Current across to East Greenland and onward to West Greenland (e.g., Jensen, 1926, 1939; Tåning, 1937; see also Fig. 13.6). The drift of larval and 0-group cod to Greenland was especially extensive during the 1920s and 1940s.

Capelin is the largest fish stock in the Icelandic marine ecosystem. Unlike other commercial stocks, adult capelin undertake extensive feeding migrations northward into the cold waters of the Denmark Strait and the Iceland Sea during summer. The capelin return to the outer reaches of the north Iceland shelf in October/November from where they migrate to the spawning grounds south and west of Iceland in late December/early January (Fig. 13.7). Spawning is usually over by the end of March. Capelin are especially important in the diet of small and medium-sized cod (Pálsson, 1997). Most juvenile capelin aged 0, 1, and 2 years reside on or near the shelf off northern Iceland and on



the East Greenland plateau west of the Denmark Strait (Fig. 13.7). These components of the stock are therefore accessible to fish, marine mammals, and seabirds throughout the year. On the other hand, the summer feeding migrations of maturing capelin into the colder waters of the Denmark Strait and the Iceland Sea place the larger part of the adult stock out of reach of most fish, except Greenland halibut, for about five to six months. However, these capelin are then available to whales, seals, and seabirds. During the feeding migrations, adult capelin increase 3- to 4-fold in weight and their fat content increases from a few percentage points up to 15 to 20%. When the adult capelin return to the north Icelandic shelf in autumn they are preyed on intensively by a number of predators, apart from cod, until the end of spawning in the near-shore waters to the south and west of Iceland. Thus, adult capelin represent an enormous energy transfer from arctic regions to important commercial fish stocks in Icelandic waters proper (Vilhjálmsón, 1994, 2002).

Off West Greenland, northern shrimp and Greenland halibut spawn at the shelf edge off the west coast. This is also the case for the northern shrimp stock, which is found in the general area of the Dohrn Bank, about mid-way between East Greenland and northwest Iceland. Greenlandic waters also contain capelin populations that spawn at the heads of numerous fjords on the west and east coasts. These capelin populations appear to be self-sustaining and local, feeding at the mouths of their respective fjord systems and over the shallower parts of the shelf area outside these fjords (Friis-Rødel and Kannevorff, 2002). During the warm period from the early 1930s until the late 1960s there was also an extensive spawning of cod to the southeast, southwest, and west of Greenland (e.g., Buch et al., 1994).

In the pelagic ecosystem off Greenland the population dynamics of calanoid copepods and to some extent krill play a key role in the food web, being a direct link to fish stocks, baleen whales, and some important seabirds, such as little auk (*Alle alle*) and Brünnich's guillemot (*Uria lomvia*). But polar cod, capelin, sand eel (*Ammodytes* spp.), and squid (*Illex illecebrosus*) are probably the most important pelagic/semi-pelagic macrofauna acting as forage for fish such as Greenland halibut and cod, marine mammals, and seabirds. Benthic animals are also important. Northern shrimp is a major food item for Atlantic cod and many other species of fish and marine mammals (e.g., Jarre, 2002).

13.3.2. Fish stocks and fisheries

13.3.2.1. Atlantic cod

Historically, demersal fisheries at Iceland and Greenland fall into two categories: land-based fisheries conducted by local inhabitants and those of distant water foreign fleets. For centuries the main target species was cod. Until the late 19th century, the local fisheries were primarily conducted with open rowboats, while the distant

water fishing fleets consisted of much larger, decked ocean-going sailing vessels. Until the end of the 19th century, almost all fishing for demersal species, whether from small open rowboats or larger ocean going sailing vessels, was by hand lines.

Jónsson (1994) estimated that the combined landings by Icelandic, Dutch, and French fishing vessels were around 35 000 t per year for the period 1766 to 1777. One hundred years later, the combined French and Icelandic catches averaged about 55 000 t per year. From the subsequent development of fishing effort and knowledge of stock sizes and exploitation rates, it is obvious that even large fleets of several hundred sailing vessels and open rowboats, fishing with primitive hand lines, can not have had a serious effect on the abundant cod stock and other demersal species at Iceland.

This situation changed dramatically with the introduction of steam and combustion engines to the fishing fleet, and the adoption of active fishing gear at the turn of the 19th century. By the beginning of the 20th century the otter trawl had been adopted by the foreign fleet (e.g., Thor, 1992), while the smaller motor powered Icelandic boats began to use gill nets, long lines, and Danish seines. Landings from the Icelandic area were no longer almost exclusively cod, but species such as haddock, halibut, plaice (*Pleuronectes platessa*), and redfish (*Sebastes marinus*) also became common items of the catch. The demersal catch at Iceland is estimated to have increased from about 50 000 t in the 1880s to about 160 000 t in 1905, reaching 250 000 t just before the First World War. Although cod was still the most important species, the proportion of other demersal species landed had increased to about 30% (Fig. 13.8).

With the increasing effort and efficiency of the international distant water and local fishing fleets, cod catches in Icelandic waters increased to peak at 520 000 t in 1933, while the catch of other demersal species increased to about 200 000 t (Fig. 13.8).

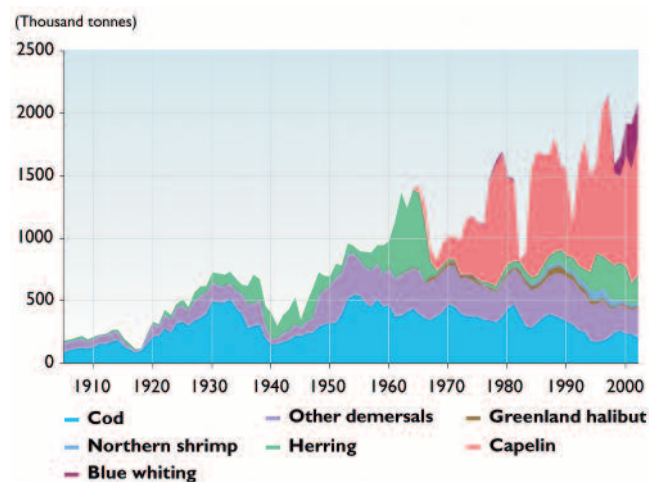


Fig. 13.8. Total catch from Icelandic fishing grounds, 1905–2002 (data from the Icelandic Directorate of Fisheries and the Marine Research Institute).

Catches declined during the late 1930s, while the exploitation rate increased until the fishing effort fell drastically due to the Second World War. Nevertheless, the exploitation rate of cod remained at a moderate level due to recruitment from the superabundant 1922 and 1924 year classes (Schopka, 1994). After the Second World War, catches of demersal fish from Icelandic grounds increased again. Landings peaked at about 860 000 t in 1954, with cod accounting for about 550 000 t (Fig. 13.8). Because of the very strong 1945 cod year class and good recruitment to other demersal stocks, the exploitation rate of cod and other demersal species remained at a low level, although almost 50% higher than during the late 1920s and early 1930s. From 1955, the exploitation rate of all demersal stocks at Iceland, but especially that of cod, increased rapidly and with few exceptions has since been far too high. Until 1976, this was due to the combined effort of Icelandic and foreign distant water fleets. However, since the extension of the Icelandic EEZ to 200 nautical miles in 1977, the high rate of fishing has continued due to the enhanced efficiency of Iceland's fishing fleet.

Although cod has been fished intermittently off West Greenland for centuries, the success of the cod fishery at Greenland has been variable. Despite patchy data from the 17th and 18th centuries, there is little doubt that cod abundance at West Greenland fluctuated widely (e.g., Buch et al., 1994). Information from the 19th century suggests that cod were plentiful in Greenlandic waters until about 1850. After that there seems to have been very few cod on the banks and in inshore waters off Greenland until the late 1910s to early 1920s, when a small increase in the occurrence of cod in inshore areas was noted (Hansen, 1949; Jensen, 1926, 1939). Cod were also registered in offshore regions off West Greenland in the late 1920s, where fisheries by foreign vessels expanded quickly and catches increased from about 5000 t in 1926 to 100 000 t in 1930. From then until the end of the Second World War in 1945, this fishery yielded annual catches between about 60 000 and 115 000 t (Fig. 13.9). The total cod catch reached

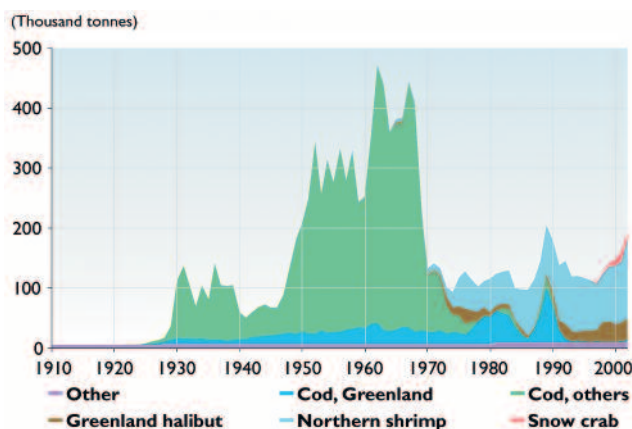


Fig. 13.9. Total catch off West Greenland, 1900–2002 (data from the Greenland Statistical Office and Directorate of Hunting and Fishing).

about 200 000 t by 1950 and then fluctuated around 300 000 t between 1952 and 1961. After that the cod catch increased dramatically and landings varied from about 380 000 to 480 000 t between 1962 and 1968. By 1970, the catch had fallen to 140 000 t and was, with large variations, within the range 10 000 to 150 000 t until the early 1990s (Fig. 13.9). Since 1993, almost no Atlantic cod has been caught in Greenlandic waters. Before the introduction of the 200 nm EEZ around Greenland in 1978 the cod fishery was mostly conducted by foreign fleets, but since then the Greenlandic fleet has dominated the fishery.

13.3.2.2. Greenland halibut

An Icelandic Greenland halibut fishery began in the early 1960s (Fig. 13.8). Initially, long line was the main fishing gear but this method was abandoned because killer whales (*Orcinus orca*) removed more than half the catch from the hooks. Since the early 1970s this fishery has been conducted using otter trawls.

At Greenland, a fishery for Greenland halibut began in a very modest way around 1915 and had by 1970 only reached an annual catch of about 2700 t, most of which was taken by Greenland. From 1970 to 1980 other countries participated in the Greenland halibut fishery, which peaked in 1976 at about 26 000 t. By 1980 the catch had fallen to about 7000 t. During the 1990s, the catch increased rapidly to about 25 000 t in 1992 and was in the range of 30 000 to 35 000 during 1998 to 2002. Since 1980, foreign vessels have not played a significant role in the Greenland halibut fishery off West Greenland. The total catch of Greenland halibut in West Greenland waters is shown in Fig. 13.9.

13.3.2.3. Northern shrimp

A small inshore fishery for northern shrimp began in Icelandic waters in the mid-1950s. Initially, this was a fjordic fishery of high value to local communities. An offshore shrimp fishery, which began in the mid-1970s on the outer shelf off the western north coast, soon expanded to more eastern areas. Annual landings from this fishery increased to between 25 000 and 35 000 t in the late 1980s and to between 45 000 and 75 000 t in the 1990s. Recently, catches have declined drastically, both in offshore and coastal areas (Fig. 13.8).

The catch of northern shrimp off West Greenland has increased steadily since its beginning in 1960. At the outset, this species was fished only by the Greenlandic fleet, but from 1972 large vessels from other countries joined this fishery. This led to a large increase in the total catch of northern shrimp, which peaked at about 61 000 t in 1976. Between 1976 and the early 1980s, the catch by other countries decreased and has been insignificant since. On the other hand, the Greenlandic catch increased steadily, from a total catch in 1960 of about 1800 t to 132 000 t in 2002 as shown in Fig. 13.9.

13.3.2.4. Herring

Commercial fishing for herring started at Iceland in the 1860s when Norwegian fishermen initiated a land-based fishery on the north and east coasts using traditional Scandinavian beach seines. This fishery proved very unstable and was abandoned in the late 1880s. Drift netting was introduced at the turn of the 19th century and purse seining in the early 20th century (1904). The latter proved very successful off the north coast, where the herring schools used to surface regularly, while drift nets had to be used off the south and west coasts where the herring rarely surfaced. The north coast herring fishery increased gradually during the 1920s and 1930s and had reached 150 000 to 200 000 t by the beginning of the 1940s (Fig. 13.8). During this period, the fishery was limited mainly by lack of processing facilities. Around 1945 the herring behavior pattern changed and as a result purse seining for surfacing schools north of Iceland became ineffective and catches declined. The reasons for this change in behavior have never been identified.

Horizontally ranging sonar, synthetic net fibers, and hydraulic power blocks for hauling the large seine nets were introduced to the herring fishery during the late 1950s and early 1960s (Jakobsson, 1964; see also Box 13.1). These technical innovations, as well as better knowledge of the migration routes of the great Atlanto-Scandian herring complex (i.e., Norwegian spring-spawning herring and much smaller stocks of Icelandic and Faroese spring-spawning herring), lead to an international herring boom in which Icelandic, Norwegian, Russian (USSR), and Faroese fishermen were the main participants (for Icelandic catches see Fig. 13.8). This extraordinary herring fishery ended with a collapse of the Atlanto-Scandian herring complex during the late 1960s due to overexploitation of both adults and juveniles (Box 13.1). Catches of Atlanto-Scandian herring (now called Norwegian spring-spawning herring since the Icelandic and Faroese components have not recovered) in the Icelandic area have been negligible since the late 1960s and Iceland's share of the TAC of this herring stock since the mid-1990s has mainly been taken outside Icelandic waters. There is no fishery for herring at Greenland.

It took the Norwegian spring-spawning stock about two and a half decades to recover despite severe catch restrictions (Box 13.1). Both the Icelandic spring- and summer-spawning herring suffered the same fate. Retrospective analysis of historical data shows that there were no more than 10 000 to 20 000 t left of the Icelandic summer-spawning herring stock in the late 1960s/early 1970s (Jakobsson, 1980). A fishing ban was introduced and since 1975 the fishery has been regulated, both by area closures and minimum landing size, as well as by having a catch rule corresponding to a TAC of roughly 20% of the estimated adult stock abundance in any given year. The stock recovered gradually, is at a historical high at present, and the annual yield over the 1980s and 1990s was on average about 100 000 t.

13.3.2.5. Capelin

An Icelandic capelin fishery began in the mid-1960s and within a few years replaced the rapidly dwindling herring fishery, as was also witnessed in the Barents Sea (Vilhjálmsón, 1994, 2002; Vilhjálmsón and Carscadden, 2002). The capelin fishery is conducted by the same high-technology fleet as used for catching herring. During the first eight to ten years, the fishery only pursued capelin spawning runs in near-shore waters off the southwest and south coasts of Iceland in February and March and annual yields increased to 275 000 t. In 1972, the fishery was extended to deep waters east of Iceland in January, resulting in an increase in the annual catch by about 200 000 t. In 1976, an oceanic summer fishery began north of Iceland and in the Denmark Strait. In 1978, the summer fishery became international as it extended north and northeast into the EEZs of Greenland and Jan Mayen (Norway). Within two years the total seasonal (July to March) capelin catch increased to more than one million t. Total annual international landings of capelin from this stock during 1964 to 2002 are shown in Fig. 13.8.

Historically, capelin have been caught at Greenland for domestic use and animal fodder. A small commercial fishery for roe-bearing females began at West Greenland in 1964 with a catch of 4000 t, which is also the largest catch on record. There were relatively large fluctuations in the capelin catch from 1964 to 1975, but since then the catch has been insignificant. This fishery is conducted by Greenlanders.

13.3.2.6. Blue whiting

The most recent addition to Icelandic fisheries is that of the semi-pelagic blue whiting. This is a straddling species commonly encountered in that part of the Icelandic ecosystem dominated by Atlantic water, i.e., off the west, south, and southern east coast. A small blue whiting fishery began in the early 1970s, increased to about 35 000 t in 1978 and then dwindled to 105 t in

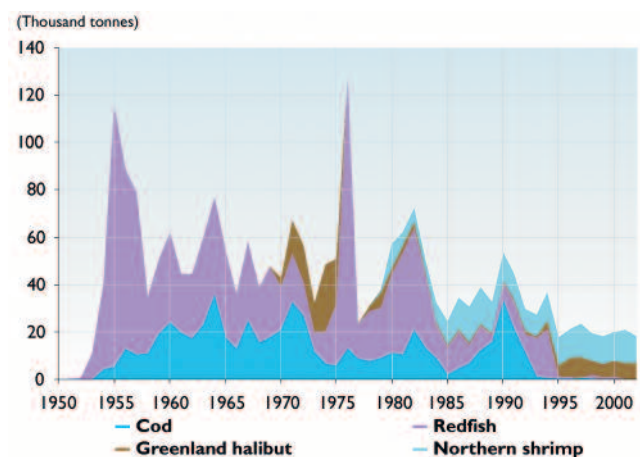


Fig. 13.10. Total catch off East Greenland, 1950–2002 (data from the Greenland Statistical Office and Directorate of Hunting and Fishing).

1984. There was renewed interest in this fishery in the mid-1990s and from 1997 to 2002 the blue whiting catch increased from 10 000 to 285 000 t (Fig. 13.8).

13.3.2.7. Fisheries off East Greenland

East Greenland waters have been fished commercially only since the Second World War (Fig. 13.10). The main reason for this is the rough bottom topography as well as the speed and irregularity of the ocean currents, especially near the edge of the continental shelf. These conditions render it difficult to fish East Greenland waters except with large powerful vessels and robust fishing gear. The main species that have been fished commercially off East Greenland are Greenland halibut, northern shrimp, cod, and redfish. With the exception of northern shrimp since the 1980s, the fisheries off East Greenland have almost exclusively been conducted by foreign fleets.

13.3.2.8. Marine mammals and seabirds

The Icelandic marine ecosystem contains a number of species of large and small whales, most of which are migratory. Commercial whaling has been conducted intermittently in Iceland for almost a century. Initially, large Norwegian whaling stations were operated from the mid-1880s until the First World War, first on the Vestfirðir peninsula (northwest Iceland) and later on the east coast. By about 1912, stocks had become depleted to the extent that whaling was no longer profitable and in 1916 the Icelandic Parliament passed an act prohibiting all whaling. In the following decades whale stocks gradually recovered and from 1948 until zero quotas on whaling were set in 1986, a small Icelandic company operated with four boats from a station on the west coast, just north of Reykjavík. The main target species were fin (*Balaenoptera physalus*), sei (*B. borealis*), and sperm (*Physeter catodon*) whales and the average yearly catches were 234, 68, and 76 animals respectively. In addition, 100 to 200 (average 183) minke whales were taken annually by small operators between 1974 and 1985. Although never commercially important at a national level, whaling was very profitable for those

engaged in the industry. Icelandic whale catches by species are shown in Fig. 13.11.

The numbers of seals in Icelandic waters are comparatively small. The populations of the two main species, harbour seals and grey seals, are estimated at 15 000 and 6000 animals, respectively (Anon, 2004c). Harbour seal abundance is stable while the numbers of grey seals have decreased. Sealing has never reached industrial proportions in Iceland, the total number of skins varying between 1000 and 7000 annually since the 1960s.

Although foreign fleets have pursued large-scale whaling in Greenlandic waters, native Greenlanders have hunted whales for domestic use only. Harvest of the main species has been modest and is unlikely to have had any effect on stocks. Five seal species are exploited in Greenland, with harp and ringed (*Phoca hispida*) seals by far the most important. Ringed seal catches increased from the mid-1940s until the late 1970s and then dropped until the mid-1980s after which they increased. The harp seal catches increased until the 1960s at which point they began to decrease and were very low during the 1970s. Since then, harp seal catches have increased continuously and at the time of writing were higher than ever.

Greenlandic catches of whales, seals, walrus, and seabirds between 1993 and 2000 are shown in Fig. 13.12. Sealskin prices were subsidized in Greenland when prices started to decline on the world market and sealskin campaigns are thought unlikely to have influenced hunting effort for seals in Greenland. There have, however, been indirect positive effects, in that Canadian catches (Labrador plus Newfoundland) of both species fell dramatically and the harp seal population increased to double its size within a relatively few years. The decrease in ringed seal catches during the early 1980s coincided with the sealskin campaign, but the underlying cause was probably population dynamics, triggered by climatic fluctuations (Rosing-Asvid, 2005).

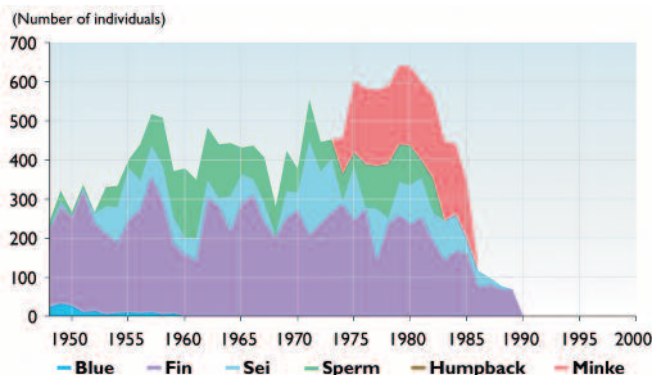


Fig. 13.11. Catch of large whales at Iceland, 1948–2000 (data from the Icelandic Directorate of Fisheries and the Marine Research Institute).

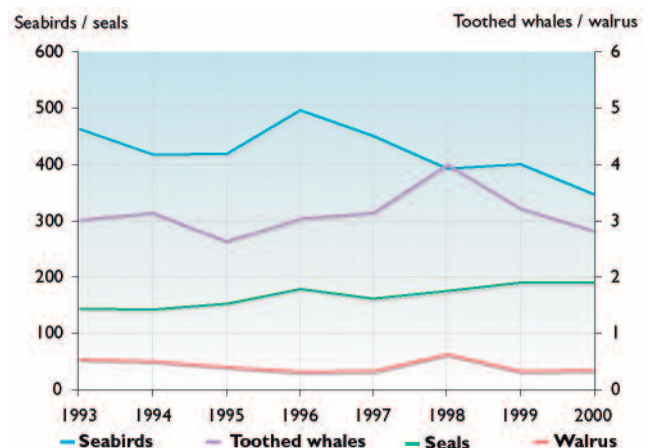


Fig. 13.12. Greenland catch of marine mammals and seabirds, 1993–2000 (data from the Greenland Statistical Office and Directorate of Hunting and Fishing).

13.3.2.9. Aquaculture

In the late 1970s and 1980s there was much interest in aquaculture in Iceland. A number of facilities were developed for the cultivation of salmon, rainbow trout (*Salmo gairdneri*), and Arctic char (*Salvelinus alpinus*) at various sites on the coast. Practically all failed, either for financial reasons or lack of expertise, or both. The few that survived, or were rebuilt on the ruins of others, have until recently not produced much more than necessary for the domestic market.

In comparative terms, aquaculture has therefore been of little economic importance for Iceland in the past. However, renewed interest began in the 1990s. Iceland is once again investing heavily in fish farming – but this time it is private capital rather than short-term loans or state funding which governs the progress. The largest quantitative increase will almost certainly be in salmon. Total production in 2001 was around 4000 t of salmon and related species. It is expected that by 2010 the production of these species will have increased to around 25 000 to 30 000 t. In addition, there is increased interest and success in the farming of Atlantic halibut, sea bass (*Dicentrarchus labrax*), turbot (*Psetta maxima*), cod, and some other marine fish, and recently there has been a considerable increase in the production of abalone (*Haliotis rufescens*) and blue mussel (*Mytilus edulis*).

Despite fish farmers working closely with the industry and with researchers to accelerate growth in production of both salmonids and whitefish species, it is expected to be a few more years before the industry is operating smoothly. Area conflicts with wild salmon have not been resolved, cod farming is still at the fry stage, and char – a high price product – has a limited market. Nevertheless, aquaculture is being developed to become more than an extra source of income and as a consequence, major fisheries companies are investing in development projects in this sector.

Aquaculture was attempted in Greenland in the 1980s. The experiment failed and aquaculture is not conducted in Greenland at the present time.

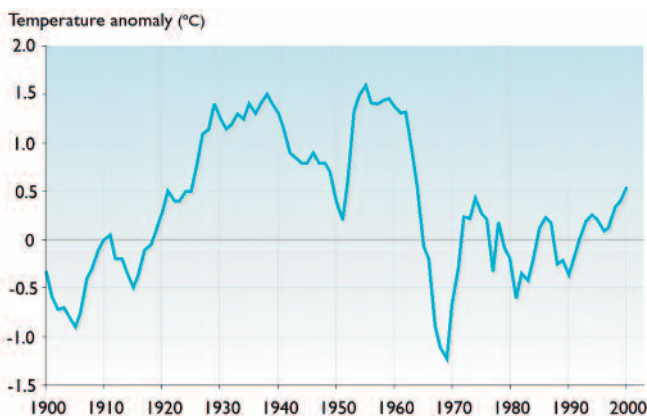


Fig. 13.13. Sea surface temperature anomalies north of Iceland (based on Anon, 2004b; Stefánsson, 1999). Five-year running means, 1900–2001.

13.3.3. Past climatic variations and their impact on commercial stocks

The main climate change over the Nordic Seas and in the northwest North Atlantic over the 20th century was a rise in air temperature during the 1920s and 1930s with a concurrent increase in sea temperature and a decrease in drift ice. There was distinct cooling in the 1940s and early 1950s followed by reversal to conditions similar to those of the 1920s and 1930s. These changes and their apparent effect on marine biota and commercial stocks in Icelandic and Greenlandic waters were studied and reported on by a number of contemporary researchers (e.g., Fridriksson, 1948; Jensen, 1926, 1939; Sæmundsson, 1934; Tåning, 1934, 1948). Summaries have been given by, for example, Buch et al. (1994) and Vilhjálmsón (1997).

Figure 13.13 shows five-year running averages of sea surface temperature anomalies off the central north coast of Iceland and illustrates trends in the physical marine environment of Icelandic waters over the 20th century. The main features are an increased flow of Atlantic water onto the shelf north of Iceland between 1920 and 1964 followed by a sudden cooling in 1965 to 1971 and more variable conditions since then. A strong presence of Atlantic water on the north and east Icelandic shelf promotes vertical mixing and thus favors both primary and secondary production, i.e., prolongs algal blooms and increases zooplankton biomass. Greenland also experienced a climatic warming in the 1920s probably with similar effects on the lowest levels of the food chain (Fig. 13.14).

At Iceland, one of the most striking examples of the effects of the climatic warming during the 1920s was a mass spawning of cod off the north and east coasts in addition to the usual spawning off south and west Iceland (Sæmundsson, 1934). Furthermore, there was large-scale drift of larval and 0-group cod across the northern Irminger Sea to Greenland in 1922 and 1924

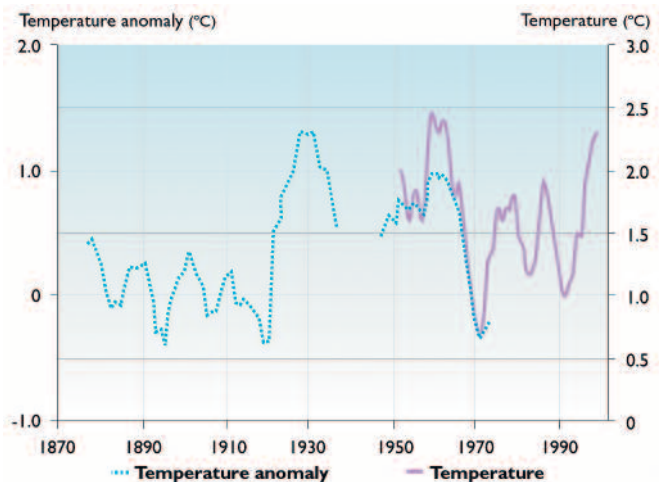


Fig. 13.14. Variations in sea temperature and temperature anomalies on the Fylla Bank off southwest Greenland (adapted from Buch et al., 1994, 2002). Five-year running means, 1875–2000.

(Jensen, 1926; Schopka, 1994). This is described in detail in Box 13.2.

Changes in the marine fish fauna off West Greenland were even more spectacular than those off Iceland. There was a large increase in cod abundance and catches in the 1920s (Fig. 13.15), and other gadids, such as saithe, haddock, tusk, and ling, previously rare or absent at Greenland, also appeared there in the 1920s and 1930s. Furthermore, herring appeared in large numbers off West Greenland in the 1930s and began to spawn there in the period July through September, mainly south of 65° N (Jensen, 1939). These herring spawned near beaches, similar to capelin in these waters. Like capelin, herring are bottom spawners with their eggs adhering to the substrate or even, as in this case, the fronds of seaweed. In 1937, the northernmost distribution of adult herring reached 72° N (Jensen, 1939). However, a herring fishery of commercial scale has never been pursued at Greenland.

In the early 1900s capelin were very common at West Greenland between Cape Farewell and Disko Bay (Fig. 13.5), but unknown further north (Jensen, 1939). In the 1920s and 1930s, the center of the West Greenland capelin populations gradually shifted north and capelin became rare in their former southern area of distribution. By the 1930s, the main spawning had shifted north by 400 nm to the Disko Bay region (Fig. 13.5). Off East Greenland capelin have gradually extended their distribution northward along the coast to Ammassalik (Jensen, 1939). However, capelin are an arctic species and have probably been common in that area for centuries since Ammassalik means “the place of capelin”.

During the latter half of the 1960s there was a sudden and severe climatic cooling with an associated drop in sea temperature, salinity, and plankton production (Fig. 13.16), and an increase in sea ice to the north and east of Iceland (e.g., Astthorsson and Gislason, 1995; Malmberg, 1988; Thórdardóttir, 1977, 1984). Temperatures increased again in the 1970s, but were

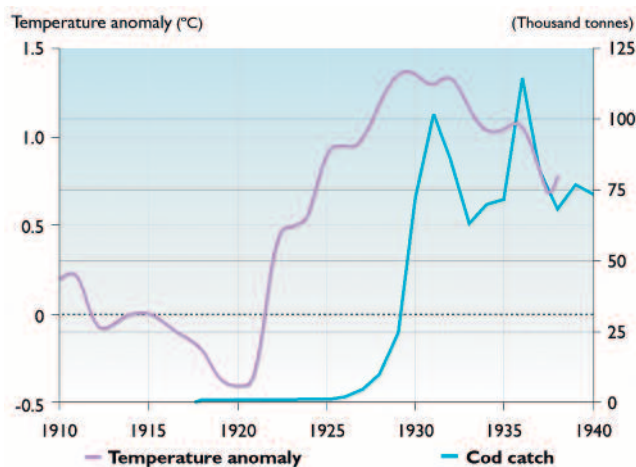


Fig. 13.15. Temperature anomaly and the catch of cod off West Greenland, 1910–1940 (Vilhjálmsson, 1997).

then more variable during the previous warm period. The low sea temperatures were also recorded in West Greenland waters (Fig. 13.14). This low temperature, low salinity water (the “Great Salinity Anomaly”) drifted around the North Atlantic and had noticeable, and in some cases serious, effects on marine ecosystems (reviewed e.g., by Jakobsson, 1992).

In the Icelandic area, herring was the fish species most affected by the cold conditions of the 1960s (Dragesund et al., 1980; Jakobsson, 1969, 1978, 1980; Jakobsson and Østvedt, 1999). This is not surprising as herring are plankton feeders and in north Icelandic waters are near their limit of distribution. This was manifested in large-scale changes in migrations and distribution (see Fig. 9.19) and a sudden and steep drop in abundance (which however was mostly brought about by overfishing – see Box 13.1). The abundance of the Norwegian spring-spawning herring stock increased dramatically in the 1990s (see section 13.2.2.5 and Box 13.1) and regained some semblance of its previous feeding pattern (for an overview of these changes see Chapter 9). Presently, Norwegian spring-spawning herring still overwinter in the Lofoten area on the northwest coast of Norway. Whether and when they revert completely to the “traditional” distribution and migration pattern cannot be predicted.

The two Icelandic herring stocks, i.e., the spring- and summer-spawning herring stocks, suffered the same

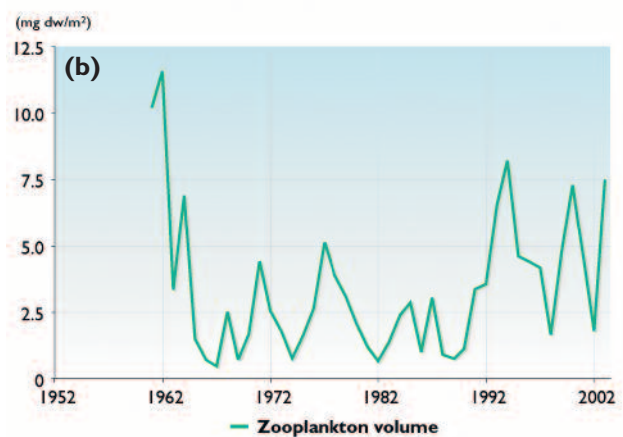
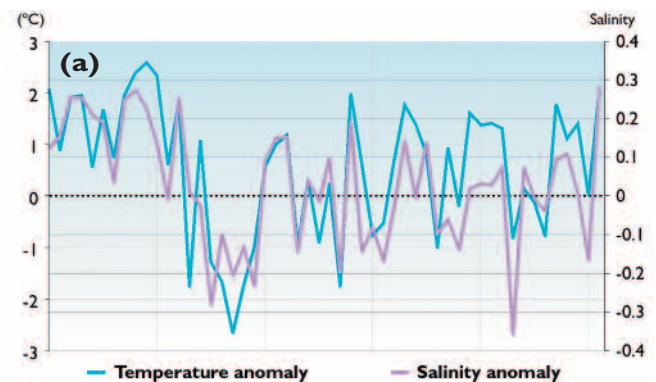


Fig. 13.16. Deviations of (a) temperature and salinity, and (b) zooplankton volume north of Iceland, spring 1952–2003 (Anon, 2004b).

Box 13.2. The Iceland/Greenland cod and climate variability

Although the abundance of the Icelandic cod stock prior to 1920 is not known, it was unquestionably large (e.g., Schmidt, 1909). Furthermore, the climatic warming of the 1920s and 1930s appears to have greatly increased reproductive success of Icelandic cod through extended spawning areas and increased primary and secondary production in the mixed waters north and east of Iceland compared to previous decades. In addition, huge amounts of larval and 0-group cod drifted west across the northern Irminger Sea in 1922 and 1924, grew off West Greenland, and returned to Iceland in large numbers to spawn (Schopka, 1994; Vilhjálmsón, 1997). Tagging experiments indicate that the majority of these fish then remained within the Icelandic marine ecosystem (Hansen, 1949; Hansen et al., 1935; Jakobsson, 2002; Jónsson, 1996; Tåning, 1934, 1937). Thus, the distribution area and biomass of cod in the Icelandic marine ecosystem can be enormously enlarged through larval drift and returning adults during warm periods.

The climatic warming in the 1920s (Fig. 13.14) resulted in far greater changes in the distribution and abundance of cod at Greenland than Iceland. Until the 1920s, cod occurred in scattered numbers in inshore waters near Cape Farewell, the southernmost promontory of Greenland (Jensen, 1926, 1939; Tåning, 1948). In the 1920s, cod appeared over wider areas and in increasing numbers. This is shown in the rapid rise in the international catch of cod at West Greenland in the late 1920s, which coincides with the time needed for the 1922 and 1924 year classes to grow to marketable size. Furthermore, cod extended their distribution northward along the west coast of Greenland by 600 to 800 nm in the 1920s and 1930s (Tåning, 1948). At East Greenland, cod appeared in small schools in the Ammassalik area around 1920 and became common around 1930 along the east coast south from Ammassalik (Schmidt, 1931). The drift of 0-group cod from Iceland to Greenland continued on and off from the 1930s to the mid-1960s, although on a smaller scale than for the superabundant year classes of 1922, 1924, and 1945 (Schopka, 1994).

By the early 1930s, West Greenland waters were warm enough for successful spawning of cod (Buch et al., 1994; Hansen, 1949; Hansen et al., 1935; Jensen, 1939; Tåning, 1937). Some members of the 1922 and 1924 year classes took advantage of this, spawned off West Greenland and, with the small inshore cod population, were instrumental in giving rise to a local self-sustaining component. The West Greenland cod stock became very large and sustained annual catches of 300 000 to 470 000 t throughout the 1950s and 1960s. From 1973 to 1993 the average annual catch off West Greenland was about 55 000 t. Peak catches in this period are associated with year classes which drifted as 0-group from Iceland to Greenland. At present, there are few cod at East and West Greenland and no local recruitment to the cod stock (Buch et al., 1994, 2002).

Although fishing mortalities at Greenland increased in the 1950s and 1960s and accelerated the crash of the Greenland cod in the 1970s, the spawning stock remained above 500 000 t until 1970 and produced large year

fate. The spring-spawning stock still shows no sign of recovery, while the summer-spawning stock recovered a few years after a fishing ban was imposed in the early 1970s (Jakobsson and Stefánsson 1999). It seems that, like the West Greenland cod, the Icelandic spring-spawning herring had difficulties in self propagation in cold periods and would probably have collapsed in the late 1960s and early 1970s, even without a fishery (Jakobsson, 1980). The summer-spawning herring, on the other hand, have adapted much better to variability in Icelandic waters. For all three stocks it can be concluded that environmental adversities placed them under reproductive stress and disrupted feeding and migration patterns. Environmental stress, coupled with far too high fishing pressure on both adults and juveniles, resulted in the actual collapses of these herring populations.

While the growth rate of Icelandic capelin has shown a significant positive correlation with temperature and salinity variations in the north Icelandic area since the mid-1970s, this relationship probably describes feeding

conditions in the Iceland Sea rather than a direct effect of temperature (Asthórsson and Vilhjálmsón, 2002; Vilhjálmsón, 1994, 2002). Results of attempts to relate recruitment of the Icelandic capelin stock to physical and biological variables, such as temperature, salinity, and zooplankton abundance, have been ambiguous. Nevertheless, judging by their stock size, the Icelandic capelin, which spawn in shallow waters off the south and west coasts of Iceland, seem to have been successful in recent decades and probably also in most years during the latter half of the 20th century.

However, at the peak of warming in the late 1920s and the first half of the 1930s, it was noted that capelin had ceased to spawn on the traditional grounds off the south and west coasts of Iceland and spawned instead off the easternmost part of the south coast as well as in fjords and inlets on the southeast and north coasts (Sæmundsson, 1934). Sæmundsson also noted that the cod had become unusually lean and attributed this to lower capelin abundance. Although there can be other causes of reduced growth of cod, e.g., competition due to a

classes until 1964. Like at Iceland, there was a severe cooling of the Greenlandic marine environment in the latter half of the 1960s and since then the only year classes of commercial significance at Greenland are those of 1973 and 1984, both of which drifted to Greenland as 0-group from Iceland. Despite warmer Greenlandic waters after the cooling of the late 1960s, no year classes of Greenlandic origin have appeared (Vilhjálmsón and Friðgeirsson, 1976; Vilhjálmsón and Magnússon, 1984; Schopka, 1994). This indicates that cod cannot reproduce efficiently at Greenland except under hydrographic conditions that are warmer than "normal".

The fishable part of the Icelandic cod stock (age 4+) declined from almost 2.5 million t in the early 1950s to below 600 000 t in 1986. The spawning stock decreased from about 1 260 to below 200 000 t over this period. The initial large stock size was due to low fishing pressure in and immediately after the Second World War and to the recruitment of the superabundant 1945 year class. A large part of this year class drifted across to Greenland as 0-group and grew in Greenlandic waters. Later, around 500 million members of this year class migrated back to Iceland for spawning and appear not to have left (Schopka, 1994). Despite the cold period of 1965 to 1971 and warmer but more variable conditions since then, recruitment remained at a normal level until 1985, with occasional boosts by immigrants from Greenland, although on a much smaller scale than in 1922, 1924, and 1945 (Schopka, 1994).

Compared to other cod stocks in arctic/subarctic areas, recruitment variability of cod which grow within the Icelandic ecosystem is low or about 1:4 in the period 1920 to 1984. Although it seems that the Icelandic ecosystem cannot support juvenile year classes much beyond sizes corresponding to 300 million recruits at age 3, it has easily accommodated very large numbers of adult cod migrating back from Greenland to their natal spawning grounds. Even the very cold period from 1965 to 1971, and the variable conditions since then, do not appear to have had much detrimental effect on recruitment to the cod stock by fish that grew locally. Average recruitment during 1920 to 1985 was 210 million age 3 cod per annum.

However, since 1985 there has been a large and protracted decline in recruitment, from 210 million to about 135 million age 3 cod per annum. A very small and young spawning stock in the range of 120 000 to 210 000 t is the only common denominator over this period. This is very likely to have resulted in lower quality eggs, shorter spawning time, smaller spawning grounds, and possibly different drift routes, and seems to be the most plausible explanation for the reduced recruitment (Marteinsdóttir and Begg, 2002; Marteinsdóttir and Steinarsson, 1998). The most likely explanation for the large year classes of 1983 and 1984, which derived from small spawning stocks, is that old fish from the abundant year classes of 1970 and 1973 were still present in the spawning stock in sufficient numbers to enhance recruitment.

large stock size, Sæmundsson's conclusion may have been correct. The change in capelin spawning areas he described is probably disadvantageous for this capelin stock. The reason being that suitable spawning areas would be much reduced compared to those previously and presently occupied by the stock. Furthermore, larval drift routes could be quite different and a proportion of the larvae would probably end up in the western Norwegian Sea and be spread to regions where their survival rate might be much lower.

The catch history and series of stock assessments of northern shrimp in deep waters northwest, north, and east of Iceland, as well as at Greenland are too short for establishing links with environmental variability. Being a frequent item in the diet of small and medium-sized cod, stocks of northern shrimp are likely to be larger when cod abundance is low. However, in general terms, the stock probably benefits from cooler sea temperatures, possibly through both enhanced recruitment and a reduced overlap of shrimp and cod distribution.

13.3.4. Possible impacts of climate change on fish stocks

To project the effects of climate change on marine ecosystems is a very difficult task, despite knowing the effects of previous climatic change. Previous sections described how the marine climate around Iceland changed over the 20th century, from a cold to a warm state in the 1920s, lasting with some deviations for about 45 years, with a sudden cooling in 1965 which lasted until 1971. Since then, conditions have been warmer but variable and temperatures have not risen to the 1925 to 1964 levels. Available evidence suggests that, as a general rule, primary and secondary production and thereby the carrying capacity of the Icelandic marine ecosystem is enhanced in warm periods, while lower temperatures have the reverse effect. Within limits, this is a reasonable assumption since the northern and eastern parts of the Icelandic marine ecosystem border the Polar Front, which may be located close to the coast in cold years but occurs far offshore in warm periods when levels of biological production are enhanced through nutrient

renewal and associated mixing processes, resulting from an increased flow of Atlantic water onto the north and east Icelandic plateau.

Over the last few years the salinity and temperature levels of Atlantic water off south and west Iceland have increased and approached those of the pre-1965 period. At the same time, there have been indications of increased flow of Atlantic water onto the mixed water areas over the shelf north and east of Iceland in spring and, in particular, in late summer and autumn. This may be the start of a period of increased presence of Atlantic water, resulting in higher temperatures and increased vertical mixing over the north Icelandic plateau, but the time series is still too short to enable firm conclusions.

However, there are many other parameters which can affect how an ecosystem and its components, especially those at the upper trophic levels, will react to changes in temperature, salinity, and levels of primary and secondary production. Two of the most important are stock sizes and fisheries, which are themselves connected. Owing to high fishing pressure since the early 1970s, most of the important commercial fish stocks in Icelandic waters are smaller than they used to be, and much smaller than at the onset of the warming period in the 1920s. Associated with this are changes in age and size distributions of spawning stocks; spawners are now fewer, younger, and smaller. These changes can affect reproductive success through decreased spawning areas and duration of spawning, smaller eggs of lower quality, and changes in larval drift routes and survival rates (Marteinsdottir and Begg, 2002; Marteinsdottir and Steinarsson, 1998). It is unlikely that the response of commercial fish stocks to a warming of the marine environment at Iceland, similar to that of the 1920s and 1930s, will be the same in scope, magnitude, and speed as occurred then. Nevertheless, a moderate warming is likely to improve survival of larvae and juveniles of most species and thereby contribute to increased abundance of commercial stocks in general. The magnitude of these changes will, however, be no less dependent on the success of future fishing policies in enlarging stock sizes in general and spawning stock biomasses in particular, since the carrying capacity of Icelandic waters is probably about two to three times greater than that needed by the biomass of commercial species in the area at present.

The following sections describe three possible scenarios of warming for the marine ecosystems of Iceland and Greenland and attempt to project the associated biological and socio-economic changes.

13.3.4.1. No climate change

Although the marine climate may dictate year-class success in some instances, there is little if any evidence to suggest that year-class failure and thereby stock propagation is primarily due to climate-related factors. Therefore, assuming no change from the ACIA baseline climate conditions of 1981–2000, the development and

potential yield in biomass of commercial stocks will in most cases depend on effective rational management, i.e., a management policy aimed at increasing the abundance of stocks through reduced fishing mortalities and protection of juveniles. This is the present Icelandic policy. Although it has not yet resulted in much tangible success, it should eventually do so and with a speed that largely depends on how well incoming year classes of better than average size can be protected from being fished as adolescents.

A successful fishing policy of this kind should ensure an increase in the abundance of many demersal fish stocks by around 2030. This would considerably increase the sustainable yield from these stocks compared to the present. This could also apply for the Icelandic summer-spawning herring, although that stock is already exceeding its historical maximum abundance. The increase in yield in tonnes is, however, not directly proportional to increase in stock abundance. Thus, a doubling of the fishable biomass of the Icelandic cod stock would probably increase its long-term sustainable yield in tonnes by about 20 to 30% compared to the present annual catch of about 200 000 t. Furthermore, due to natural variability in the size of recruiting year classes, increases in stock biomasses of the various species are most likely to occur in a stepwise fashion and the value of the catch would not necessarily increase proportionally.

However, on the negative side, it is likely that the northern shrimp catch would decrease due to increased predation by cod and that the capelin summer/autumn fishery would have to be reduced or stopped altogether, in order for the needs of their more valuable fish predators to be met and those of large whales, if whales remain subject to a moratorium on commercial whaling. Increases in abundance, but especially extended migrations of the Norwegian spring-spawning herring to feed in north Icelandic waters, will determine the value of the yield from that stock for Iceland. For this to occur on a long-term basis, the intensity of the cold East Icelandic Current must weaken and temperatures north of Iceland must increase. Such conditions are not envisaged under this scenario.

At Greenland, the no-change scenario will have little effect on the present situation, given that stocks are presently managed in a rational manner and that this is expected to continue.

13.3.4.2. Moderate warming

Most criteria in the no-change scenario are probably also valid for a moderate warming of 1 to 3 °C. However, due to greater primary and secondary production and a direct temperature effect *per se*, stock-rebuilding processes are likely to be accelerated in most cases. Nevertheless, as for the no-change scenario, a rational fishing policy must be maintained. Indeed, it is very likely that harvesting strategies can be used which would give higher returns from most of the major dem-

ersal stocks in the Icelandic area. As under the no-change scenario, a side effect of such a policy would be a rise in the mean age and number of older fish in the spawning stock of cod, which would further enhance larval production and survival.

Drift of larval and 0-group cod across the northern Irminger Sea to East Greenland and onward to West Greenland waters is likely to become more frequent and the number of individuals transported to increase compared to the latter half of the 20th century. Since sea temperature off West Greenland will also increase under this scenario, it is very likely that the drift of cod larvae and juveniles from Iceland will lead to the establishment of a self-sustaining Greenlandic cod stock. With a successful management strategy and in the light of past events, that cod stock could become very large and have enormous positive economic benefits for Greenland (see section 13.3.6.2). However, it is unlikely that this will contribute much to cod abundance at Iceland. This is because present fish finding and catch technologies are so effective that these cod can, and very likely will, be easily fished in Greenlandic waters before they could return to Iceland for spawning at the age of seven to eight years.

An increase in temperature of 1 to 3 °C in the north Icelandic area is large in comparative terms and will, among other things, be associated with a weakening of the East Icelandic Current and a considerable reduction in its domain. The degree of reduction is very likely to be sufficient to enable the Norwegian spring-spawning stock to again take advantage of the rich supply of *Calanus finmarchicus* over the north Icelandic shelf. This scenario would make it easier and cheaper for Iceland to take its share of this stock, and would also make the stock more valuable. The reason for this is a large increase in the proportion of the catch which could be processed for human consumption compared to the current situation where a large proportion must be reduced to the comparatively cheaper fishmeal and oil. It is also very likely that more southern species such as mackerel and tuna will enter Icelandic waters in sufficient concentrations for commercial fishing in late summer and autumn.

13.3.4.3. Considerable warming

According to the B2 emissions scenario, model results indicate that a rise in temperature beyond 2 to 3 °C in the Icelandic area in the 21st century is unlikely. However, should that happen, the high temperature is likely to lead to dramatic changes to the Icelandic marine ecosystem. Section 13.3.1 described the key role of capelin for the well-being of many demersal stocks, and highlighted the large reduction in weight-at-age of Icelandic cod during the two capelin stock collapses. Capelin spawning also ceased on their traditional grounds off the south and west coasts of Iceland in the late 1920s and early 1930s, occurring instead in fjords and inlets on the southeast and north coasts (Sæmunds-

son, 1934). Under such conditions the extent of capelin spawning grounds would reduce considerably. Should the rise in sea temperature increase beyond that of the 1920 to 1940 period, it is likely that capelin spawning might be even further reduced and limited to the north and east coasts of Iceland. This would result in major changes in larval drift routes and survival and, eventually, to a large reduction in, or even a complete collapse of, the Icelandic capelin stock.

Owing to the key role of capelin as forage fish in the Icelandic marine ecosystem this scenario would be very likely to have a considerable negative impact on most commercial stocks of fish, whales, and seabirds which are dominant in this ecosystem at present. Such a scenario is also very likely to result in species from more temperate areas moving into the area and at least partially replacing those most affected by a lack of capelin.

13.3.5. The economic and social importance of fisheries

13.3.5.1. The fishing industry and past economic fluctuations

Iceland

During the 20th century, the Icelandic gross domestic product (GDP) had an average annual growth of about 4% per year. This was largely driven by expansion in the fisheries and fish processing industries. Furthermore, fluctuations in aggregate economic output were highly correlated with variations in the fishing industry. Good catches and high export prices resulted in economic growth, while poor catches and adverse foreign market conditions led to economic slowdown and even depression. All five major economic depressions in the 20th century can be directly related to changes in the fortunes of the fishing sector, either wholly or partially (Agnarsson and Arnason, 2003).

The first of these major depressions covers the period of the First World War, which had catastrophic effects on Iceland, as it did on many other European countries. The first two years of the war were favorable for the fishing sector however, as increased demand pushed up foreign prices, but in 1916 the international trade structure broke down and Iceland had to accept harsh terms of trade with the Allies. In 1917, Iceland was forced to sell half its trawler fleet to France. This led to substantially reduced demersal fish and herring catches in 1917 and 1918. The result was a sharp drop in GDP and a depressed economy until 1920 (Fig. 13.17).

The effects of the “Great Depression” were first felt in Iceland in autumn 1930, and in the following two years GDP fell by 0.5% and 5% respectively as demand for maritime exports declined sharply. Following a brief recovery, the economy was hit again when the Spanish Civil War broke out in 1936 and closed Iceland’s most important market for fish products. Despite these

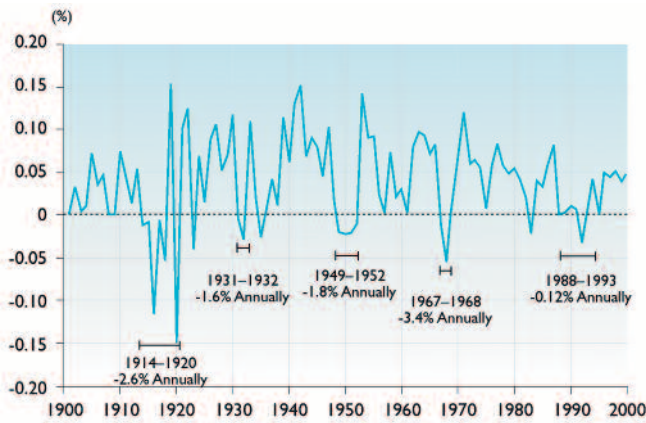


Fig. 13.17. GDP growth in Iceland, 1901–2000: showing major depressions (Agnarsson and Arnason, 2003).

events, economic growth still averaged 3% in the 1930s, mostly because of strong rebound in the fisheries, especially the herring fisheries, in 1933 to 1939. The strong performance of the fisheries in the 1930s appears to be the reason that the “Great Depression” was felt less in Iceland than most other countries of Western Europe.

The Second World War was a boom period for Iceland led by good catches and very favorable export prices. But in 1947 and subsequent years, herring catches fell considerably and real export prices subsided from the high wartime levels. The result was a prolonged economic recession from 1949 to 1952.

During the 1960s, the economy grew at an average rate of 4.8%. This was largely due to very good herring fisheries. When the herring stocks collapsed toward the end of the decade the result was a severe economic depression in 1968 and 1969, when the GDP declined by 1.3% and 5.5% respectively. Unemployment reached over 2% – a great shock for an economy used to excess demand for labor since the 1930s – and many households moved abroad in search of jobs. Net emigration amounted to 0.6% of the total population in 1969 and 0.8% in 1970.

High economic growth resumed between 1971 and 1980 with annual rates averaging 6.4%. However, just as during the 1960s, this growth was to a significant extent based on overexploitation of the most important fish stocks. Reduced fishing quotas and weak export prices reduced fishing profitability in the late 1980s. And, partly as a consequence of this, the Icelandic economy was stagnant between 1988 and 1993, with an average annual decline in GDP of 0.12%.

Since 1993, the Icelandic economy has shown steady and impressive annual growth rates. One reason for this is a recovery of some fish stocks. More important, however, are more favorable fish export prices and the impact of the individual transferable quota (ITQ) system. The ITQ system has enabled the fishing industry to increase and stabilize profits and more easily adjust to changing quotas and fish availability.

Thus, over the 20th century as a whole, it appears that major fluctuations in the Icelandic economy largely reflect changes in the fortunes of the fishing industry both in terms of harvest quantity and output prices. This implies that possible changes in fish stocks due to climate change may have similar macro-economic effects. However, it is very likely the macro-economic impact of any given change in fish availability will be smaller in the future than in the past. First, because the importance of the fishing industry for the Icelandic economy has declined substantially, and second, because the ITQ system has probably made the fishing industry more capable of adapting to changes in fish stocks. However, it must be noted that if the current depressed state of some of the most important fish stocks persists, adverse environmental changes may actually translate into larger biological shocks than those experienced in the past.

Greenland

Greenland does not offer the same overwhelming evidence of the national economic importance of the fishing industry as Iceland. This, however, does not mean that the economic importance of the Greenland fishing industry is any less than in Iceland. In fact it is probably much greater.

First, the Greenland fishing industry developed much later than that in Iceland. Thus, the Greenland fishing activity was relatively insignificant over the first half of the 20th century (see Fig. 13.9) even when compared to the rest of the Greenland economy. Second, being based on underexploited fish stocks, the Greenland fishing industry expanded relatively smoothly until the 1980s, resulting in far fewer of the dramatic fluctuations in fisheries output experienced in Iceland. Third, the Greenland economic statistics are less comprehensive than in Iceland, meaning fewer data.

Since 1970, there have been two major cycles in the Greenland economy (Fig. 13.18) both associated with changes in the fishing industry, more precisely the cod fishery.

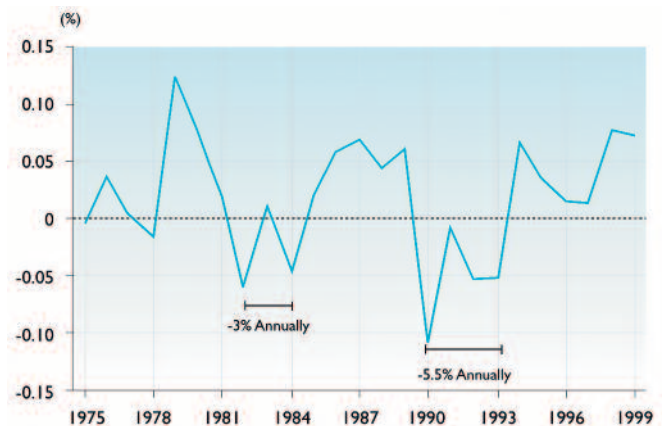


Fig. 13.18. GDP growth in Greenland, 1975–1999: showing major depressions (Anon, 2000).

Historically, the cod fishery has been Greenland's most important fishery (although this has now been superseded by the shrimp fishery). The cod fishery underwent a major expansion in the latter half of the 1970s due to reduction in foreign fishing following the extension of the Greenland fisheries jurisdiction to 200 nm and a greatly expanded Greenland fishing effort. This led to a period of good economic growth that reversed abruptly in 1981 with a major contraction of the cod fishery due to a combination of overfishing and low export prices. The subsequent period of economic depression lasted for three years during which the GDP decreased by 9% per year. Another short-lived boom in the cod fishery from about 1985 led to a corresponding boom and bust cycle in the economy with a five-year growth period followed by a sharp depression lasting four years during which GDP decreased by over 20%. Economic growth resumed in Greenland in 1995, not on the basis of cod, which has not reappeared, but shrimp fishing which expanded very rapidly during the latter half of the 1990s.

As in Iceland, historical evidence indicates a close connection between fluctuations in GDP and variations in the Greenland fishing industry.

13.3.5.2. The economic and social role of fisheries

Iceland

The relative importance of the fishing industry in the Icelandic economy seems to have peaked before the middle of the 20th century. Since then, both the share of fish products in merchandise exports and the fraction of the total labor force engaged in fishing have declined significantly. In 2000, the fishing industry employed 8% of the labor force, accounted for 63% of merchandise exports, and generated 42% of export earnings. Total export value of fish products in 2000 was about US\$ 1220 million.

National accounts estimates of the contribution of the fishing industry to GDP – available since 1980 – confirm this trend. Thus, in 1980 the direct contribution of the fishing industry to GDP was over 16%. In 2000, this had dropped to just over 11%, which corresponds to an added US\$ 900 million.

These aggregate statistics will understate the real contribution of the fishing industry to the Icelandic economy. There are two fundamental reasons for this. The first is that there are a number of economic activities closely linked to the fishing industry but not part of it. These comprise the production of inputs to the fishing industry, the so-called “backward linkages”, and the various secondary uses of fish products, the so-called “forward linkages” (Arnason, 1994). The backward linkages include activities such as shipbuilding and maintenance, fishing gear production, the production of fishing industry equipment and machinery, the fish packaging industry, fisheries research, and education. The forward link-

ages comprise the transport of fish products, the production of animal feed from fish products, the marketing of fish products, and retailing of fish products. According to Arnason (1994), these backward and forward linkages may add at least a quarter to the direct GDP contribution of the fishing industry.

The other reason why the national accounts may underestimate the contribution of the fishing industry to GDP is the role of the fishing industry as a disproportionately strong exchange earner. To the extent that the availability of foreign currency constrains economic output, the economic contribution of a disproportionately strong export earner may be greater than is apparent from the national accounts. While the size of this “multiplier effect” is not easy to measure, some studies suggest it may be quite significant (Agnarsson and Arnason, 2003; Arnason, 1994). If this is the case, the total contribution of the fishing industry to GDP may be much higher than estimates suggest, in the sense that removing the fishing industry would, with all other things remaining the same, lead to this reduction in GDP.

There are also economic reasons as to why a change in the conditions of the fishing industry due, for example, to climate change, might have a lesser economic impact than suggested by the direct (and indirect) contribution of the fishing industry to GDP. Most economies exhibit some resilience to exogenous shocks. This means that the initial impact of such shocks is at least partly counteracted by the movement of labor and capital to economic activities made comparatively more productive by the shock. Thus, a negative shock in the fishing industry would to a certain extent be offset by labor and capital moving from the fishing industry to alternative industries and vice versa. Thus, the long-term impact of such a shock may be much less than the initial impact. The extent to which this happens depends on the availability of alternative industries. However, with increased labor mobility, communication technology, and human capital this type of flexibility is probably much greater than in the past.

Regional importance

Analysis in terms of macro-economic aggregates does not take into account that the economic importance of the fishing industry varies from one region of the country to another. In 2000, when the fishing industry (harvesting and processing) employed only about 8% of the

Table 13.1. The importance of the fishing sectors to Icelandic communities in 1997.

Labor share of the fishing sectors (%)	Number of communities	Number of inhabitants	Percentage of total population
>40	24	12812	7.7
25–40	16	23063	8.6
10–25	14	36959	13.7
5–10	16	26832	10.0
<5	54	161922	60.1

national workforce, it provided jobs for over 35% of the working population in the western fjords and almost 30% of the working population in the eastern fjords. Both regions are sparsely populated and account for only a small proportion of the total Icelandic population. Near the capital, Reykjavík, where most of the alternative industries such as manufacturing and services are located, the fishing industry employed only about 3% of the working population.

The local importance of the fishing industry is even more apparent at the community level. In 1997, the fishing industry accounted for over 40% of the local employment in 24 out of a total of 124 municipalities in Iceland (Table 13.1). A typical example of a community totally dependent on fishing is Raufarhofn, a small community of 400 inhabitants in northeast Iceland. Almost 70% of the adult population worked in the fishing industry in 1997. In four other communities the fishing industry accounted for over 60% of total employment in 1997.

By contrast, in 54 communities the fishing industry accounted for less than 5% of total employment. Most of the largest municipalities in Iceland belong to this group. It is mainly the smaller, economically less developed communities that depend heavily on fisheries (see Table 13.1).

Thus, the effects of a significant reduction in fish availability around Iceland, or the benefits of fisheries expansion would be differently felt in the various regions and communities of Iceland. In general terms, a significant reduction in fish availability is liable to be economically and socially disastrous for the western and eastern fjord regions and for certain other smaller regions of Iceland, while in the more densely populated southwest of Iceland such a reduction would be felt mainly as an increased influx of labor from the outlying regions and the corresponding realignment of economic activity.

Although labor mobility is high in Iceland, it may not be easy for inhabitants of fishing villages to find jobs elsewhere following a decline in fisheries due to climate change, especially if the economy is already depressed. Also, as many of the employment opportunities in and around the capital require particular education and training, individuals transferring from the fishing industry may have to accept relatively inferior jobs. At the same time, reduced employment and movement out of the fisheries-dependent regions and communities of Iceland will decrease real estate values in these areas, meaning that these migrants may have to suffer a significant decrease in the value of their assets at the same time as moving to seek new employment.

Thus, a significant reduction in the Icelandic fishing industry would lead to noticeable social disruption. However, given the nature of Icelandic society, it would probably be resolved within five to ten years of the initial shock, although the disruption would impose a certain stress on the social and political system during this period of adjustment.

Greenland

The fishing industry is by far Greenland's most important production sector. In the 1960s and early 1970s fish and fish products accounted for between 80 and 90% of Greenland's total export value. In 1974, there was a very large increase in the export of lead and zinc, which increased GDP by about 50% and caused fish and fish products to fall to between 60 and 70% of total export value. The export of lead and zinc ceased in 1990. Since then, export of fish and fish products has accounted for about 90% of Greenland's total export value. In 2000, the export value of fish and fish products was about US\$ 270 million and the total export value about US\$ 285 million.

Exact statistics about the direct contribution of the fishing industry to the Greenland GDP are not available. However, the contribution to the gross national income (GNI) may be as high as 20%. This, however, does not tell the complete story. Greenland is part of Denmark with a "Home Rule" government. This means that Greenlanders can decide their own policies, except for foreign and defense policy. Every year, the Home Rule government receives economic support from the Danish State. In 2000 this amounted to about US\$ 350 million or almost 25% of GNI. Correcting for this indicates a direct contribution of the fishing industry to the Greenland GDP of 25 to 30%.

As for Iceland, however, the fishing industry also has an indirect contribution to the Greenland economy via forward and backward linkages as well as multiplier effects. Adding these may bring the total contribution of the fishing industry to the Greenland economy as a whole to over 50%.

Regional importance

Greenland as a whole is highly dependent on the fishing industry. This is even more the case in less populated communities along the coast. About 20% of Greenland's population lives in small villages and settlements with an average population of about 150 inhabitants. Many more live in small towns with less than a thousand inhabitants. The economic activity in these communities is almost exclusively based on the exploitation of living marine resources, i.e., through fishing and hunting. Also, the geographical isolation of many of these communities means alternative employment opportunities are few if any.

Thus, a significant drop in the fish stocks and other living marine resources would have a devastating impact on these communities. Most would decrease significantly and many would disappear altogether, causing those inhabitants that left to become economically and socially dispossessed. A secondary effect would be the substantial influx of these people to the more urban areas of Greenland and the problems that this would cause.

A significant increase in the stocks of fish and other living marine resources would cause the reverse effect and would strengthen the economic basis of Greenland's smaller communities. While larger towns may benefit disproportionately from such a change, the net effect would probably be to increase population in the smaller communities and to expand the geographical extent of habitation in Greenland.

13.3.6. Economic and social impacts of climate change: possible scenarios

From an economic point of view, climate change may impact on fisheries in at least two ways: by altering the availability of fish to fishers and by changing the price of fish products and fisheries inputs. Although both types of impact may be initiated by climate change, the former is a more direct consequence of climate change than the latter.

The possible impact of climate change on fish availability may occur through changes in the size of commercial fish stocks, changes in their geographical distribution, and changes in their catchability. These changes, if they occur, will affect the availability of fish for commercial harvesting. The direction of this impact is uncertain. It may be negative, and so reduce the maximum sustainable economic yield from the fish stocks, or positive, and so increase the maximum sustainable economic yield from the fish stocks. Also, the impact may vary for different fish stocks and for different regions. Irrespective of the direction of the impact, however, it is very likely that climate change will, at least temporarily, cause instability or fluctuations in harvesting possibilities while ecosystems adjust to new conditions. The adjustment period may be long, and may even continue after the period of climate change has ended.

The same applies to changes in economic value in that relative prices may continue to adjust after an exogenous shift, such as climate change, has been resolved. In fact, economic adjustments following climate change, being dependent on biological/ecological adjustments, will by necessity continue after the latter are complete.

This section speculates on the possible economic and social impacts in Iceland and Greenland of changes in fish availability. The possible impacts of relative price changes are not discussed. However, the economic and social impacts of price changes will be similar to those of changes in fish stock availability. In terms of drawing inferences from historical evidence, it is not important whether expansions and contractions in the fishing industry result from changes in prices or fish availability.

Empirical evidence of possible economic impacts of changes in fish stock availability is either qualitative historical evidence or quantitative evidence. Qualitative evidence (discussed in section 13.3.5.1) relates economic fluctuations to qualitative evidence of expansions and contractions in the fishing industry. Quantitative evi-

dence, in the form of time series for fisheries production and production values, provides a basis for statistical estimates of the relationship between the production value of the Icelandic and Greenland fishing industries and their respective GDP and Gross National Product (GNP) growth.

13.3.6.1. Iceland

Reliable time series data for the output and output value of the fishing industry are available since 1963. These data have been used to estimate the form and parameters of a relationship between economic growth rates and the output value of the fishing industry as well as other relevant economic variables such as capital and labor (Agnarsson and Arnason, 2003). The equation exhibits good statistical properties and actual and fitted GDP growth rates are illustrated in Fig. 13.19.

This equation can, with certain modifications, be used to predict the short- and long-term impact of a change in fish stock availability due to climate change. It is important to realize, however, that to use this equation it is necessary to project (1) the extent and timing of climate change, (2) the impact of global climate change on fish stock availability, and (3) the impact of changed fish stock availability on the value of fish production (which involves both the volume and price of fish production).

Impact on GDP

This section presents the outcome of calculations to estimate the possible impact on GDP of changed fish stock availability as a result of climate change. The impact of other variables on the value of fish production is ignored. The calculations are based on two key factors: the impact of future climate change on the value of fish production in Iceland and the estimated relationship between economic growth and the value of fish production (see Agnarsson and Arnason, 2003). Both are highly uncertain. Thus, the following calculations must not be regarded as predictions. They are intended to serve as

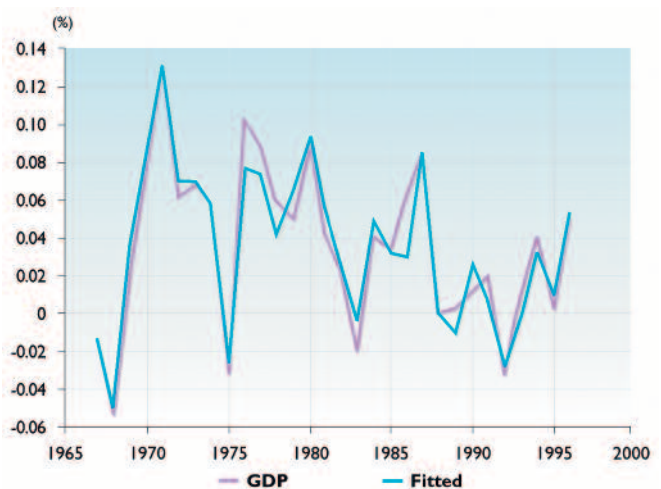


Fig. 13.19. GDP growth in Iceland, 1966–1997: actual and fitted values.

indications of the likely magnitudes of the impact on GDP in Iceland resulting from certain stated premises regarding changes in fish stock availability.

Available projections (see section 9.3.4.4) suggest that climate change over the next 50 to 100 years is (1) unlikely to have a great impact on fish stock availability in Icelandic waters and (2) is very likely to benefit the most valuable fish stocks. As a result, the overall effects of climate change on the Icelandic fisheries are likely to be positive. As these expectations are very uncertain, the rest of this section illustrates this point using three scenarios.

The first scenario assumes a gradual increase in fish stock availability of 20% over a period of 50 years. This is known as the “optimistic” scenario and corresponds to a 0.4% increase in the value of fish production annually. The second scenario assumes a gradual reduction in fish stock availability of 10% over 50 years. This is known as the “pessimistic” scenario and corresponds to an annual reduction in the value of fish production by 0.2%. The third scenario assumes a 25% reduction in fish stock availability over a relatively short period of five years. This corresponds to a collapse in the stock size of one major species or a group of important commercial species. In fact, there are some indications that the response of fish stocks to climatic change may be sudden and discontinuous rather than gradual. Owing to the magnitude and suddenness of this reduction it is known as the “dramatic” scenario.

These scenarios illustrate the likely range of economic impacts of climate change around Iceland. In interpreting their outcomes it is important to remember that these scenarios are restricted to the impact of climate change assuming all other variables affecting fish stocks and their economic contribution are unchanged. These outcomes do not incorporate the possibly simultaneous impact of improved fisheries management or other variables affecting the size of fish stocks and the value of the fisheries. In fact, given the currently depressed state of many of the most valuable fish stocks in Iceland, a better harvesting policy may easily contribute at least as much to the overall economic yield of the fisheries as the most optimistic climate scenario. However, such a policy will also improve the outcomes of the more pessimistic climate scenarios.

Optimistic scenario

In the optimistic scenario, fish stock availability is assumed to increase in equal steps by 20% over the next 50 years. The impact of this scenario on GDP relative to a benchmark GDP of unity is illustrated in Fig. 13.20. The figure illustrates that this quite considerable increase in fish stock availability has only a relatively minor impact on GDP. The maximum impact occurs in year 50, when increased fish stock availability has fully materialized. At this point GDP has increased (com-

pared to the initial level) by less than 4%. The long-term impact, after economic adjustment processes are complete, is even less at around 2.5%. The largest annual increase in GDP is small at under 0.2%, and is substantially less than the GDP measurement error. Thus it would be hardly noticeable. In the years following the end of the increase in fish production, growth rates decline as production factors (which move to the fishing industry) reduce economic production elsewhere. Long-term GDP growth rates are, of course, unchanged. The main conclusion to be drawn is that a 20% increase in the output of the fishing industry equally spread over 50 years has a very small, hardly noticeable, impact on the short-term economic growth rates in Iceland as well as on long-term GDP.

Pessimistic scenario

In the pessimistic scenario, fish stock availability is assumed to decrease in equal steps by 10% over the next 50 years. The impact of this scenario on GDP relative to a benchmark GDP of unity is also illustrated in Fig. 13.20. As in the optimistic scenario, it is apparent that this considerable decrease in fish stock availability has a relatively minor impact on long-term GDP. The maximum impact also occurs in year 50, at which point GDP has been reduced by less than 2%. The long-term impact, after economic adjustment processes are complete, is even less or just over 1%. The largest annual decrease in GDP is well over -0.1%. This occurs a few years after the decrease in fish stock availability begins. For most of the period, however, the impact on annual economic growth rates is much less. In the years following the end of the decrease in fish production, growth rates improve, as production factors (which move from the fishing industry) find productive employment elsewhere. All these deviations in annual GDP growth rates are well within GDP measurement errors. Long-term GDP growth rates are, of course, unchanged. As under the optimistic scenario, the main conclusion to be drawn is that a 10% decrease in output from the fishing industry equally spread over 50 years has a negligible impact on the short-term economic growth rates in Iceland as well as on long-term GDP.

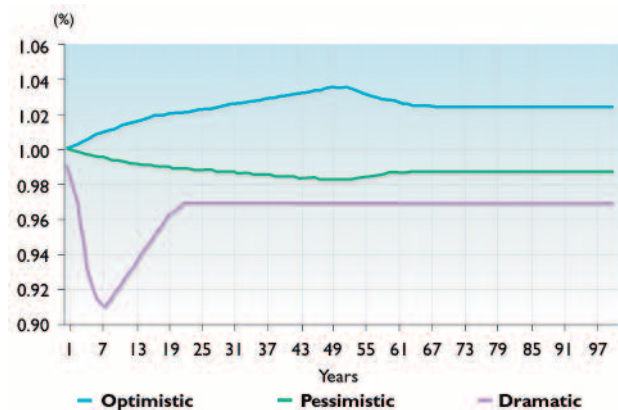


Fig. 13.20. Iceland: impact of different scenarios on GDP (benchmark GDP = 1.0).

Dramatic scenario

The dramatic scenario assumes a fairly substantial drop in fish stock availability and, hence, fish production of 25% over the next five years. The impact of the dramatic scenario on GDP relative to a benchmark GDP of unity is illustrated in the lowest curve in Fig. 13.20. This sudden drop in fish stock production has a significant negative impact on GDP in the short term. At its lowest point, in year eight, GDP is reduced by over 9% (compared to the initial level). The long-term negative impact, after economic adjustment processes are complete, is only about a 3% reduction in GDP. The decrease in annual GDP growth rates for the first seven years following the start of reduced fish stock production are significant or -1 to -2%. The maximum decline occurs toward the end of the reduction process in years four and five. However, only four years later, the contraction ends, and the deviation in annual GDP growth rates is reversed as production factors released from the fishing industry find productive employment elsewhere. According to these calculations, this adjustment process is complete by year 25 when growth rates have reverted to the underlying economic growth rate.

Social and political impacts

If the change in fishing industry output is gradual and the economic impact comparatively small (as in the “optimistic” and “pessimistic” scenarios), it is unlikely that the accompanying social and political impacts will be noticeable at a national level. Although over the long term, social and political impacts will undoubtedly occur, whether these will be large enough to be distinguished from the impact of other changes is uncertain. Regionally, however, the situation may be very different. In some parts of Iceland (see section 13.5.2) the economic and social role of the fishing industry is far above the national average. In these areas, the economic, social, and political impact of an expansion or contraction in the fishing industry will be much greater than for Iceland as a whole and in some areas undoubtedly quite dramatic.

If, on the other hand, the change is fairly sudden (as in the “dramatic” scenario) the short-term social and political impact may be quite drastic. In the long term, however, after the initial impact, social and political conditions will revert to the long-term scenario described by the “pessimistic” scenario. Whether the economic and social adjustments will then also revert to their initial state is not clear.

Impacts on fish markets

Reductions or increases in fish production in Iceland alone will not have a significant impact on global fish markets. Neither are they likely to have a large impact on the marketing of Icelandic fish products, provided the changes are gradual. If there is an overall decline in the global supply of species of fish that Iceland currently

exploits, the impact on marketing of these species is uncertain. Almost certainly the marketing of the species in reduced supply will become easier. Thus, prices will rise counteracting the decrease in volume. However, the marketing impact might actually be the opposite. For some species, a large and steady supply is required to maintain marketing channels. If this is threatened, these channels may close and alternative outlets will have to be found.

Discussion

The main conclusion to be drawn is that the changes in fish stock availability that seem most likely to be induced by climate change over the next 50 to 100 years are unlikely to have a significant long-term impact on GDP in Iceland and, consequently, on social and political conditions in Iceland. Also, it appears that any impact, small as it may be, is more likely to be positive than negative. However, if on the other hand, climate change results in sudden rather than gradual changes in fish stock availability, the short-term impact on GDP and economic growth rates may be quite significant. The impact seems very unlikely to be dramatic (i.e., over 5% change in GDP between years) however. Over the long term, the impact on GDP of a sudden change in fish stocks will be indistinguishable from the effects of more gradual change. Long-term social and political impacts may differ although there is no clear evidence to support this.

13.3.6.2. Greenland

Reliable time series data for the export value of the Greenland fishing industry are available since 1966. These data have been used to estimate the form and parameters of a relationship between GDP and the real export value of fish products (Vestergaard and Arnason, 2004). The equation exhibits reasonable statistical properties. Actual and fitted GDP growth rates according to this equation are illustrated in Fig. 13.21. It is projected that a 1% increase in the export value of fish products will lead to a 0.29% increase in the Greenland GDP. Subject to the same qualifications as for Iceland, this equation can be

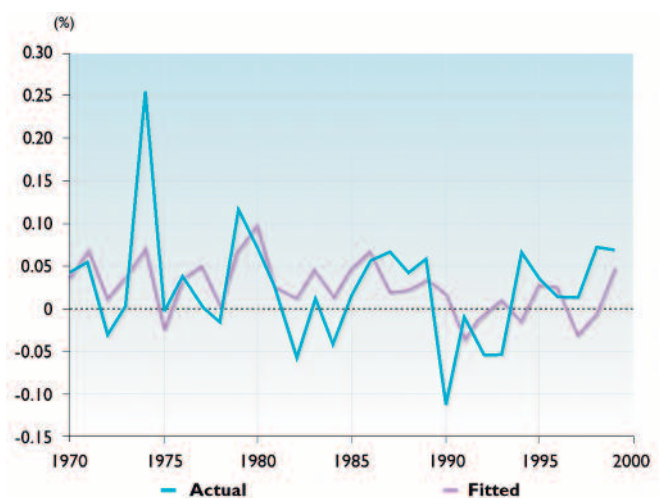


Fig. 13.21. GDP in Greenland, 1970–1999: actual and fitted values.

used to predict the economic impact of a change in fish stock availability resulting from climate change.

Impact on GDP

Available projections (see section 9.3.4.4 and sections 13.3.3.3, 13.3.3.4, and 13.3.4.1 to 13.3.4.3) suggest that climate change over the next 100 years is very likely to benefit the most valuable fish stocks at Greenland. This is particularly likely to be the case for the cod stock, which could experience a revival from its current extremely depressed state to a level, seen during warm periods of the 20th century, where it could yield up to 300 000 t on a sustainable basis. However, climate change and increased predation by cod could lead to a dramatic fall in the sustainable harvest of shrimp by up to 70 000 t (Fig. 13.22). The value of the increased cod harvest would, however, greatly exceed losses due to a possibly reduced harvest of shrimp. In fact, this change could lead to doubling or even tripling of the total production value of the Greenland fishing industry. Thus, the projected climate change could have a major positive impact on the Greenland fishing industry. However, this is highly uncertain. As was the case for Iceland this section continues on the basis of three scenarios.

The first scenario, termed the “pessimistic” scenario, assumes that despite more favorable habitat conditions, cod will not reestablish permanently in Greenland waters. Instead, there will be periodic bursts of cod availability accompanied by a corresponding drop in shrimp, based on occasional large-scale larval drift from Iceland similar to that seen in warmer periods in the past. The overall impact will be a slight average increase in fish harvests with some peaks and troughs. The second scenario, termed the “moderate” scenario, assumes a modest and gradual return of cod to Greenland which in 20 years would be capable of yielding 100 000 t per year on average. This would be accompanied by a corresponding decline in the shrimp stock. The third scenario, termed the “optimistic” scenario, assumes a return of the Greenland cod stock, initially generated by Icelandic cod larval drift, to the levels of the 1950s

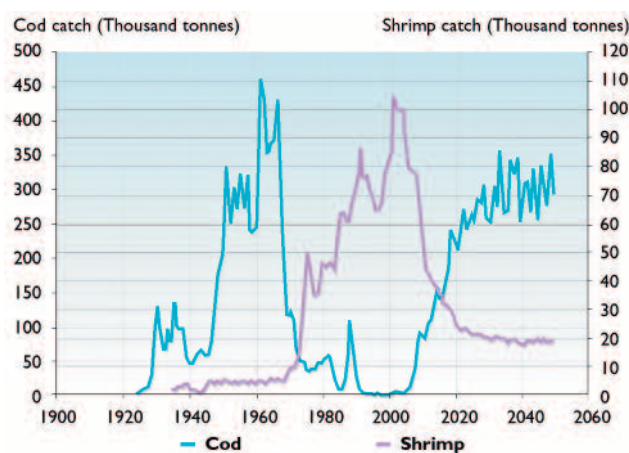


Fig. 13.22. The history and possible future development of cod and shrimp harvests in Greenland under global warming (Hvingel, in prep).

and 1960s. A full revival, however, would take some decades and would occur in a fluctuating manner. Ultimately, in about 30 years, the cod stock would be capable of producing an average yield of 300 000 t per year, compared to almost nothing at present. The average shrimp harvest, however, would be reduced from a current level of almost 100 000 t per year to about 20 000 t per year. Nevertheless, the overall value of the Greenland fish harvest would almost double. These scenarios illustrate the likely range of economic impacts of climate change around Greenland. The harvest projections are all based on a two-species fisheries model developed for the Greenland fisheries (Hvingel, 2003).

Pessimistic scenario

The pessimistic scenario assumes an insubstantial change in overall average fish stock availability. However, due to the occasional large-scale influx and survival of Icelandic cod larvae, periodic bursts in cod availability occur. This situation results in fluctuating fish production rates and GDP impacts over time (see lowest curve in Fig. 13.23) with a small average increase. The average increase in GDP after 50 years is about 2% higher than would otherwise have been the case.

Moderate scenario

In the moderate scenario, fish stock availability is assumed to increase gradually by about 20% over the next 100 years. The impact of this scenario on GDP relative to a benchmark GDP of unity is shown by the middle curve in Fig. 13.23. This increase in the availability of fish leads to a moderate long-term increase in GDP of 6% (compared to the initial level). However, as most of this increase is projected to occur over the first ten years (in fact the initial impact is projected to be greater than the long-term impact) there would be a significant addition to GDP of 1% per year during this initial period.

Optimistic scenario

In the optimistic scenario, fish stock availability is assumed to increase gradually, but in a fluctuating man-

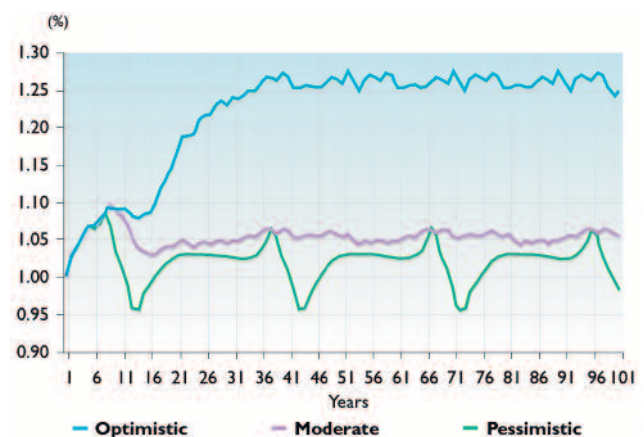


Fig. 13.23. Greenland: impact of different scenarios on GDP (benchmark GDP=1.0).

ner, by about 100% over the next 50 years. The projected relationship between the value of fish exports and GDP suggests that this will lead to an ultimate increase in GDP of 28% compared what would otherwise have been the case. This impact relative to a benchmark GDP of unity is illustrated in Fig. 13.23. Such an impact would be very noticeable. The addition to economic growth would be close to 0.8% per year over the first 30 years but would then decrease, stopping after 40 years.

Social and political impacts

If the optimistic scenario were to occur and the increased cod harvest was mainly caught and processed by Greenlanders there would be a dramatic improvement in the Greenland unemployment/underemployment situation and in the income of the large group of self-employed small-boat fishers/hunters. Everything else being the same, the current high level of unemployment would disappear and the total income of many families would increase markedly. This would have a major social impact in Greenland. Cod fishing of the magnitude projected under the optimistic scenario might easily lead to the establishment of large-scale fish processing factories in the more densely populated regions of Greenland.

Under the pessimistic and moderate scenarios employment and consequently social impact would be far more moderate, especially if the changes appeared gradually over a long period. If, however, the change is sudden (as in the “dramatic” scenario for Iceland), short-term social and political impacts may be drastic.

Discussion

The likely impacts of the possible changes in fish stock availability in Greenland waters resulting from climate change cover a wider range than for Iceland. At one extreme, they could lead to a 30% increase in GDP, while at the other extreme the impact on GDP could be negligible. This range in outcomes reflects (1) the greater importance of the fisheries sector in Greenland compared to Iceland and (2) that during warm periods the very large marine habitat around Greenland can accommodate a biomass of commercial species which is many times greater than that at present. Since the arctic influence is more pronounced in the Greenland marine environment than in that around Iceland, it follows that impacts resulting from a moderate climate change, if it occurs, are very likely to be more dramatic in the marine environment around Greenland.

13.3.7. Ability to cope with change

Climate change will almost certainly lead to changes in the relative sizes, biological productivity, and spatial distribution of commercial fish stocks. These changes may be predominantly advantageous or predominantly disadvantageous. They may be sudden or may emerge gradually.

The economic and social impacts of changes in fish stock availability depend on the direction, magnitude, and rapidity of these changes. The economic and social impacts also depend, possibly even more so, on the ability of the relevant social structures to adapt to altered conditions. Good social structures facilitate fast adjustments to new conditions and thus mitigate negative impacts. Weak or inappropriate social structures exhibit sluggish and possibly inappropriate responses and thus may exacerbate problems resulting from adverse environmental changes.

One of the most crucial social structures in this respect is the fisheries management system. This determines the extent to which the fisheries can adapt in an optimal manner to new conditions. Other important social structures relate to (1) the adaptability of the economic system – especially price flexibility, labor education and mobility, and the extent of economic entrepreneurship; (2) the ability to adjust macro-economic policies; and (3) the extent and nature of the social welfare system. These structures influence the form of the necessary adjustments to new conditions, for example whether they are smooth and quick or difficult and long-term.

The Icelandic fisheries management system is based on permanent harvest shares in the form of ITQs and so is inherently forward-looking and thus probably well-suited to adjust optimally to changes in the availability of fish, especially if these changes are to an extent foreseen. For any time path of fish stock productivity, ITQ-holders have a strong incentive to maximize the expected present value of the fishery as this will also maximize their expected wealth. As a result, there is a high likelihood that TACs and other stock size determinants will be adjusted optimally to altered conditions. In other words, with the Icelandic fisheries management system, there is little chance that the fishing activity will exacerbate a negative biological impact arising from climate change. Also, the opportunities generated by a positive biological impact will probably be close to fully exploited by the fishing sector. In Greenland, however, fishers’ rights to harvest shares are considerably weaker. As a result, Greenland seems less prepared than Iceland to adapt in an economically efficient manner to changed fish stock availability.

For the other relevant social structures, it also appears that those in Iceland are well-suited to facilitating adjustment to adverse environmental changes. First, Icelandic social structures are used to having to adapt to quite drastic fluctuations in the economy (see section 13.3.5.1), which implies that these institutions have evolved to cope with such fluctuations. Second, labor education and mobility is high in Iceland. High labor mobility refers to labor movements within Iceland as well as to between Iceland and other countries. This means that negative regional impacts resulting from climate change are unlikely to lead to permanently depressed unemployment areas or even persistent national unemployment. Third, the level of private and commercial entrepreneurship is

high in Iceland. This suggests that in the case of negative impacts, economic substitute activities are likely to be quickly spotted and exploited. Fourth, there is an extensive social welfare system in Iceland that would provide at least temporary compensation to individuals adversely affected by environmental change. Although this social "safety net" will tend to delay adjustments to new conditions, it will also ensure that the burden of adverse changes is shared among the total population and so prevents individual hardship.

Thus, broadly speaking, it appears that Icelandic social structures are well suited to cope with sudden changes in fish stock availability resulting from climate change. This means that adjustments to changes are likely to be fast and smooth. Adverse environmental changes will nevertheless be economically and socially costly. However, they are unlikely to be exacerbated by social and economic responses. On the other hand, although the Icelandic economy seems well prepared to deal with changes in fish stock availability, an adverse biological impact may be felt more strongly than in the past. This is because some of the most valuable commercial stocks are currently close to their historical minimum. Hence, if there is an adverse environmental change, the initial reduction in harvests may be more dramatic than previously experienced and, also, the risk of a long-term stock depression greater.

The ability of social structures in Greenland to adjust to new conditions is similar to the situation in Iceland. Greenlanders are used to variable environmental and economic conditions. Although perhaps not at the level of Iceland, general education and labor training is also high in Greenland. However, partly due to the size of Greenland and the isolation of many communities, labor mobility is considerably less than in Iceland. Most importantly, however, the degree of private and commercial entrepreneurship in Greenland seems much less than in Iceland.

Thus, while the Greenland social structure and institutions seem reasonably well placed to adjust to the changes in fish stock availability that might result from climate change, they presently appear less suited in this respect than those in Iceland.

13.3.8. Concluding comments

The ecosystems of Iceland and Greenland are very different. Icelandic waters occur to the south of the Polar Front under normal circumstances and are therefore under the influence of warm Atlantic water. Greenland waters are dominated by the cold East Greenland Current. This difference is reflected in higher numbers of exploited species at Iceland than at Greenland where there is also a dominance of arctic species of plankton, commercial invertebrates, and fish.

Both ecosystems were subject to large climatic changes in the 20th century. After a prolonged period of cold

conditions (lasting several decades), a warm period started around 1920 and peaked in the 1930s. Conditions were cooler in the 1940s, but warmed again and stayed warm for several years. There was a sudden cooling associated with decreased salinity and severe ice conditions in the mid-1960s. These changes reverberated around the North Atlantic at least twice during the next two decades. Conditions improved at Iceland in 1972 but remained variable for the next two and a half decades. Since the late 1990s, conditions have been persistently warmer at Iceland and even more so off West Greenland.

The warming of the 1920s and the early 1930s was followed by spectacular changes in the fish fauna of Icelandic and, in particular, Greenlandic waters. Cod and herring began to spawn in large numbers off the north coast of Iceland in addition to the traditional spawning areas in the Atlantic water off the south and west coasts. For some years, capelin were absent from their usual spawning areas to the south and west of Iceland, but spawned instead off southeast Iceland as well as in fjords and bays on the north and east coasts. Despite searches by Danish biologists and fishers, almost no cod were found to the south and west of Greenland between 1900 and 1920. However, after 1920 cod began to appear in increasing numbers in these areas and in the 1930s a cod fishery off West Greenland yielded on average about 100 000 t per year. This change is attributed to a massive drift of 0-group cod from Iceland across the northern Irminger Sea to the east and then west of Greenland.

Other changes associated with the warm period were manifested in a regular appearance of more southerly species such as mackerel and tuna at Iceland, while cold-temperate species such as haddock, saithe, and herring became fairly common at Greenland. In the latter case, cod extended their distribution northward to the west of Greenland for hundreds of kilometers to Disco Bay. Likewise, the center of capelin distribution shifted from off southwest Greenland to the Disco Bay area and the northern limit of their distribution reached as far as Thule.

Although many of the cod which had drifted across to Greenland as juveniles returned to spawn in their native areas off south and west Iceland, many did not, but spawned instead off West Greenland and eventually gave rise to a self-sustaining Greenlandic cod component. The Greenland cod were very successful for a number of decades and eventually formed a large local stock that supported catches in the hundreds of thousands of tonnes.

The cooling of the mid-1960s had a devastating effect, both at Iceland and Greenland. The spawning of cod at Greenland seems to have ceased completely and the stock crashed. At Iceland, the zooplankton community in the north and east changed from an atlantic to an arctic type. The most drastic effect was the disappearance of the Norwegian spring-spawning herring (the largest known

herring stock in the world) from its traditional feeding areas north of Iceland. In the following years the herring fed further east in the Norwegian Sea until the stock crashed in the late 1960s. The two local and much smaller Icelandic herring stocks suffered the same fate. These stocks were all subject to a large fishing pressure in the 1960s. While the collapses in the herring stocks can be traced to exploitation beyond sustainable levels, this is not the case for the Greenland cod stock. Although the stock was also heavily fished, and its downfall accelerated by the fishery, evidence suggests that cod cannot reproduce effectively at Greenland except under warm climatic conditions. On the other hand, the low temperatures of the latter 1960s and relatively cold but variable conditions of Icelandic waters since the early 1970s do not seem to have adversely affected the Icelandic cod stock. The relatively low abundance of cod at Iceland at present appears to be the result of overfishing.

From a socio-economic point of view, climate-driven changes in fish abundance at Iceland over the 20th century had very large effects. In particular, the disappearance of the Atlanto-Scandian herring had severe consequences at all levels of society. Iceland lost about half its foreign revenue from fish products almost instantly, resulting in severe economic depression. However, the depressed state did not last long. The herring sector of the fishery quickly targeted other local species and also shifted to fishing herring elsewhere, mainly in the North Sea and adjacent waters. The Icelandic fishery sector also adapted quickly to various fishing restrictions imposed during the last quarter of the 20th century.

The lucrative cod fishery, which started off West Greenland in the late 1920s and lasted until the stock collapse in the early 1970s, did not have much effect on

the Greenland economy. This was because the lack of suitable vessels and gear, as well as the necessary infrastructure, meant Greenland was unable to benefit from these conditions except on a very small scale.

Three scenarios of possible future climate change (no change, moderate warming (1–3°C), and considerable warming (4°C or more)) were used to examine likely outcomes for Iceland and Greenland. Changes in the size and distribution of commercial stocks are very unlikely under the no-change scenario. Thus, the Greenlandic fishing sector would mainly depend on cold water fish such as Greenland halibut and invertebrates such as northern shrimp and snow crab. At Iceland, fish species such as Atlantic cod, haddock, saithe, and redfish would dominate demersal fisheries, while capelin, local herring, and possibly blue whiting would dominate the pelagic fisheries. Catches of some species under the no-change scenario could be increased considerably through effective fisheries management, particularly in Iceland.

Moderate warming is likely to result in quite large positive changes in the catch of many species. Through larval drift from Iceland, a self-sustaining cod stock is likely to be established off West Greenland which could yield annual catches of around 300 000 t. If that happens, catches of northern shrimp are likely to decrease to about 30% of the present level, while catches of snow crab and Greenland halibut are not likely to alter much. Such changes would probably approximately double the export earnings of the Greenland fishing industry, which roughly translates into the sum presently paid by Denmark to subsidize the Greenland economy. Such dramatic changes are not likely in the Icelandic marine ecosystem. Nevertheless, it is likely that there will be an overall gain through larger catches of demersal species such as cod, and pelagic species such as herring, and new fisheries of more southern species such as mackerel. On the other hand, capelin catches are likely to decrease, both through diminished stock size and the necessity of conserving this important forage fish for other species. Effective fisheries management is very likely to continue to play a key role for Greenland and Iceland.

Little can be said about potential changes under the scenario of considerable warming. This is because such a situation is outside any recorded experience.

13.4. Newfoundland and Labrador Seas, Northeastern Canada

Fisheries in ACIA Region 4 may be subdivided into those near the coast of Greenland, those near the coast of Canada, and those in the deep waters of Baffin Bay and Davis Strait between Greenland and Canada. The whole area is within the fisheries convention area of NAFO (Fig. 13.24) and the stocks are currently managed by the coastal state or by NAFO.

Along the northeast coast of Canada the study area extends southward to the central Grand Bank (46° N) in

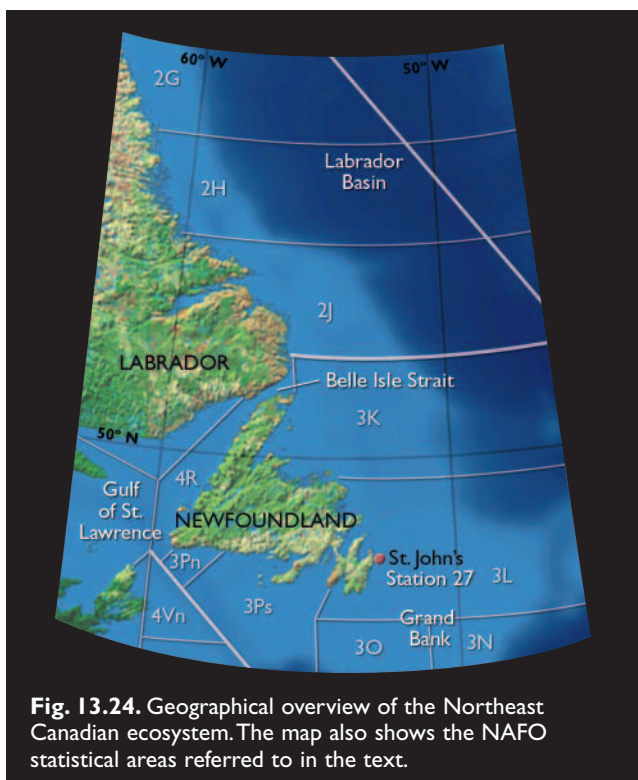


Fig. 13.24. Geographical overview of the Northeast Canadian ecosystem. The map also shows the NAFO statistical areas referred to in the text.

order to assess climate-driven impacts on marine ecosystems that are comparable to those considered for the northeast Atlantic (section 13.2) and around Iceland (section 13.3). This southward extension reflects the presence of the Labrador Current, which transports cold water southward from Davis Strait, the Canadian Archipelago, and Hudson Bay. The median southerly extent of sea ice is on the northern Grand Bank at approximately 47° N (Anon, 2001) and bottom water temperatures on the northern Grand Bank are below 0 °C for long periods. The southerly extent of cold conditions is also indicated by the regular presence of polar cod along the northeast coast of Newfoundland and their occasional occurrence on the northern Grand Bank (Lilly and Simpson, 2000; Lilly et al., 1994).

Fish has dominated the history of Newfoundland since the time of British colonization. The British interest in Newfoundland after its “discovery” during the Cabot voyage of 1497 was due to the incredibly large amounts of codfish. Exploitation of this fishery by the British reduced its dependence on Iceland for fish, a dependence that was creating difficulties. The French also saw the value of Newfoundland’s fishery, and possession of the island became an important part of the colonial wars of the 18th century (for the historical background of Newfoundland, see Chadwick, 1967; Innis, 1954; Lounsbury, 1934). As an inducement for France to enter the revolutionary war on the side of the American colonies, Benjamin Franklin offered a share of the Newfoundland fishery to the French as bounty once the war was won (Burnett, 1941). Indeed, until the late 1800s, when a cross-island railroad was built, fishing was Newfoundland’s only industry. There was then a series of diversification programs, which have continued in one form or another until the present day. Although in the early 1970s Newfoundland had the world’s largest hydroelectric plant (in Labrador), and despite many attempts to diversify the economy with both small-scale industries (e.g., cement production, knitting mills, a shoe factory, a chocolate factory) and numerous large-scale industries (e.g., the Churchill Falls hydroelectric station, a petroleum refinery, a third paper mill, iron mines in Labrador) in the twenty years following Confederation with Canada in 1949, none of these made any difference to the dominance of the fishery in Newfoundland (Letto, 1998). However, what did change in Newfoundland with Confederation, and after revisions in Canadian federal/provincial intergovernmental arrangements, was the emergence of extremely large government, health, and education sectors which, as shares of GDP, eclipsed the fishery. By 1971, the fish and fish processing sectors accounted for less than 5% of Newfoundland GDP. By 2001, their contribution was 3.5 %.

13.4.1. Ecosystem essentials

The ecosystem off northeastern Canada has been characterized by a relatively small number of species, a few of which have historically occurred in high abundance

(Bundy et al., 2000; Carscadden et al., 2001; Livingston and Tjelmeland, 2000). The dominant fodder fish has been capelin, with polar cod more prominent to the north and sand lance (*Ammodytes dubius*) more prominent to the south on the plateau of Grand Bank. Herring is found only in the bays and adjacent waters. These four species of planktivorous fish feed mainly on calanoid copepods and larger crustaceans, the latter predominantly hyperiid amphipods to the north and euphausiids to the south. The dominant piscivorous fish has been Atlantic cod, but Greenland halibut and American plaice (*Hippoglossoides platessoides*) have also been important. Snow crab and northern shrimp have been the dominant benthic crustaceans. The top predators are harp seals and hooded seals which migrate into the area from the north during late autumn and leave in spring. Other important predators include whales, most of which migrate into the area from the south during late spring and leave during autumn. The most important are humpback (*Megaptera novaeangliae*), fin, minke, sei, sperm, and pilot whales (*Globicephala melaena*). Additional immigrants from the north during the winter include many birds, such as thick-billed murre, northern fulmar (*Fulmarus glacialis*), and little auk. Additional immigrants from the south during summer include short-finned squid, fish such as mackerel and bluefin tuna (*Thunnus thynnus*), and birds such as greater shearwater (*Puffinus gravis*) and sooty shearwater (*P. griseus*).

The Labrador/Newfoundland ecosystem has experienced major changes since 1980. Atlantic cod and most other demersal fish, including species that were not targeted by commercial fishing, had declined to very low levels by the early 1990s (Atkinson, 1994; Gomes et al., 1995). In contrast, snow crab (DFO, 2002a) and especially northern shrimp (DFO, 2002b) increased considerably in abundance during the 1980s and 1990s and now support the most important fisheries in the area. Harp seals increased in abundance between the early 1970s and the mid-1990s (DFO, 2000c). Capelin have been found in much reduced quantities in offshore acoustic surveys since the early 1990s, but indices of capelin abundance in the inshore surveys have not shown similar declines, leaving the status of capelin uncertain and controversial (DFO, 2000b, 2001). Atlantic salmon, the major anadromous fish in the area, has declined in abundance, due in part to lower survival at sea (DFO, 2003b; Narayanan et al., 1995).

The waters of eastern Newfoundland have been fished for centuries, primarily for Atlantic cod but with an increasing emphasis on other species during the latter half of the 20th century. These fisheries have undoubtedly had an influence on both the absolute abundance of some species and the abundance of species relative to one another. However, the role of the fisheries in structuring the ecosystem is often difficult to distinguish from the role of changes in the physical environment. The area cooled during the last three decades of the 20th century, with particularly cold periods in the early 1970s, early to mid-1980s, and early 1990s. This cooling, which was

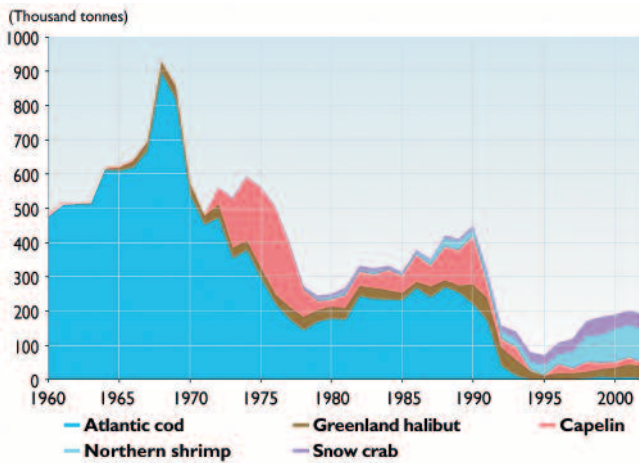


Fig. 13.25. Total catch of selected species off northeastern Canada, 1960–2002 (data from NAFO STATLANT 21A online database www.nafo.int/activities/FRAMES/AcFrFish.html; Anon, 2004a; Darby et al., 2004; Dawe et al., 2004; Hvingel, 2004; Lilly et al., 2003; Murphy and Bishop, 1995; Orr et al., 2003, 2004; Stenson et al., 2000).

associated with an intensification of the positive phase of the North Atlantic Oscillation (Colbourne and Anderson, 2003; Colbourne et al., 1994; Mann and Drinkwater, 1994; Narayanan et al., 1995), may have played an important role in the dramatic decline in Atlantic cod and other demersal fish, and the increase in crustaceans, especially northern shrimp.

13.4.2. Fish stocks and fisheries

Catches are from official NAFO statistics (as of February 2004) or from relevant assessment documents if there is a difference between the two (e.g., NAFO 2001a,b). Figure 13.25 provides an overview of developments in the main fisheries off Newfoundland and Labrador since 1960.

13.4.2.1. Atlantic cod

The distribution of Atlantic cod off Canada has historically been from the northern Labrador Shelf southward to beyond the limit of this study, although during the 1990s there were few cod off Labrador. Atlantic cod tends to occur on the continental shelf, but has been

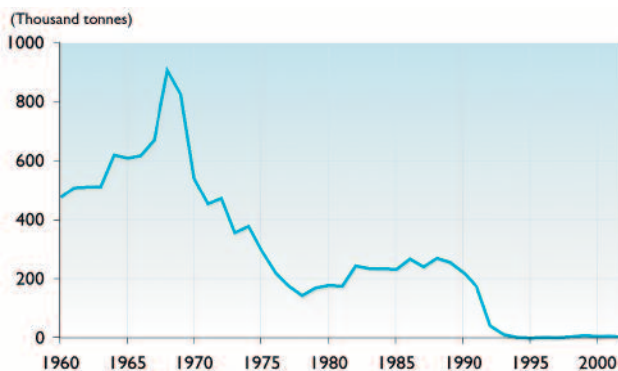


Fig. 13.26. Catch of Atlantic cod, 1960–2002 (data from Murphy and Bishop, 1995; Lilly et al., 2003).

found at depths of at least 850 m on the upper slope off eastern Newfoundland (Baird et al., 1992).

The European fishery for Atlantic cod off eastern Newfoundland began in the late 15th century. For the first few centuries fishing was by hook and line, so the cod were exploited only from late spring to early autumn and only in shallow water along the coast and on the plateau of Grand Bank to the southeast of the island. There is evidence that local inshore over-exploitation was occurring in the 19th century (Cadigan, 1999), but improvements in gear and an increase in the area fished tended to compensate for local reductions in catch rate. Annual landings increased through the 18th and 19th centuries to about 300 000 t in the early 20th century. The deep waters were refugia until the 1950s, when larger vessels with powered gurdys were introduced to exploit cod in deep coastal waters and European trawlers started to fish the deeper water on the banks. Landings increased dramatically in the 1960s as large numbers of trawlers located and exploited the overwintering aggregations on the edge of the Labrador Shelf and the Northeast Newfoundland Shelf. At the same time, the numbers of large cod in deep water near the coast of Newfoundland are thought to have declined quickly as the longliner fleet switched to synthetic gillnets. Catches peaked at 894 000 t in 1968, and then declined steadily to only 143 000 t in 1978. Following Canada's declaration of a 200 nm EEZ in 1977, the stock recovered slightly and catches were between 230 000 and 270 000 t for most of the 1980s. However, catches fell rapidly in the early 1990s as the stock declined to very low levels. A moratorium on directed fishing was declared in 1992 (Fig. 13.26). A small cod-directed inshore fishery was opened in 1998 but closed in 2003. Additional details on the history of the Atlantic cod fishery of Newfoundland and Labrador, including changes in technology and temporal variability in the spatial distribution of fishing effort, may be found in Templeman (1966), Lear and Parsons (1993), Hutchings and Myers (1995), Lear (1998), Neis et al. (1999), and Hutchings and Ferguson (2000).

13.4.2.2. Greenland halibut

Greenland halibut (also called Greenland turbot) is distributed off West Greenland from Cape Farewell northward to about 78° N and then southward off eastern Canada to beyond the limit of this study. It is a deep-water species, occurring at depths from about 200 m to at least 2200 m off West Greenland (Bowering and Brodie, 1995). The history of the fishery is complicated by temporal and spatial variation in effort and catch by different fleets and by alleged underreporting of landings. For details of the fisheries, refer to Bowering and Brodie (1995), Bowering and Nedreaas (2000), and NAFO (2001b).

The fishery off eastern Newfoundland dates back to the mid-19th century (Bowering and Brodie, 1995; Bowering and Nedreaas, 2000). Annual catches from

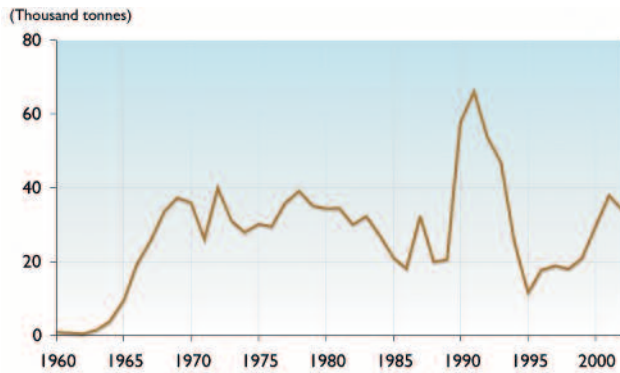


Fig. 13.27. Catch of Greenland halibut, 1960–2002 (data from NAFO STATLANT 21A online database www.nafo.int/activities/FRAMES/AcFrFish.html; Darby et al., 2004).

longlines were less than 1000 t until the early 1960s, when catches began to increase substantially. Landings from offshore trawlers, mainly from European countries, also increased after the mid-1960s. Catches in SA 2 + Div. 3KL fluctuated around 25 000 to 35 000 t from the late 1960s to the early 1980s, after which there was a gradual decline to about 15 000 t in 1986. Landings increased dramatically in 1990 with the arrival of many non-Canadian trawlers that fished deep waters on the northern Grand Bank (see Fig. 13.24 for location). Catches over the next four years were high (estimated at between 55 000 and 75 000 t in 1991; NAFO, 2001b), declined substantially in 1995 due to an international dispute, and increased again in the late 1990s under NAFO quotas that maintained catches well below those of the early 1990s (Fig. 13.27).

The fishery to the north (NAFO SA 0), which has been conducted primarily with otter trawlers in the second half of the year (Bowering and Brodie, 1995), reported an average annual catch of 2100 t between 1968 and 1989 (including a high of 10 000 t in 1972). Catches increased dramatically to 14 500 t in 1990 with increased effort by Canada, but declined to about 4000 t from 1994 onward. These landings came mainly from off southeastern Baffin Island. The fishery expanded even further north into Baffin Bay in the mid- to late 1990s (Treble and Bowering, 2002). This fishery, which extended to 73° N in 2002 (M.A. Treble, Fisheries and Oceans Canada, pers. comm., 2003), has been limited by sea-ice cover in September through November.

13.4.2.3. Capelin

Before the start of a commercial offshore fishery in the early 1970s, capelin were fished on or near the spawning beaches. Annual catches, used for local consumption, may have reached 20 000 to 25 000 t (Templeman, 1968). Offshore catches by foreign fleets increased rapidly, peaking in 1976 at about 250 000 t, and then declined rapidly. This offshore fishery continued at a low level until 1992. Catches in the offshore fishery were taken at different times of the year in different areas. The spring fishery was dominated by large midwater trawlers operating in Div. 3L. During the autumn, the offshore fishery first

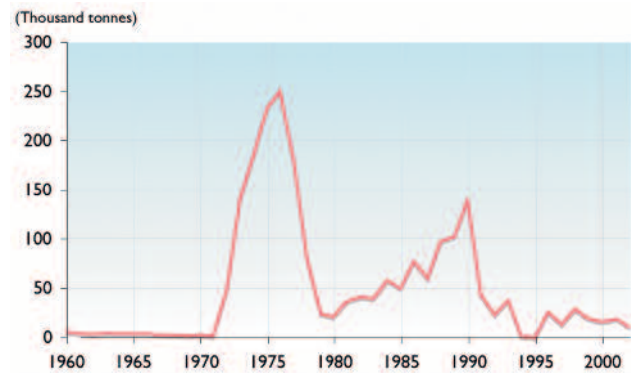


Fig. 13.28. Catch of capelin, 1960–2002 (data from NAFO STATLANT 21A online database www.nafo.int/activities/FRAMES/AcFrFish.html).

occurred in Div. 2J, off the coast of Labrador, and gradually moved south into Div. 3K as the capelin migrated toward their overwintering area (see Fig. 13.24 for NAFO statistical areas). This fishery was also dominated by large midwater trawlers, which mostly took feeding capelin that would spawn the following year. During the late 1970s, as the foreign fishery declined, Canadian fishers began fishing mature capelin near the spawning beaches to supply the Japanese market for roe-bearing females. This fishery expanded rapidly, exhibited highest catches during the 1980s, and declined over the 1990s. Catches in the inshore fishery have generally been lower than from the offshore fishery. The total international catch of capelin off Newfoundland and Labrador from 1960 to 2002 is shown in Fig. 13.28.

13.4.2.4. Herring

Herring in the Newfoundland and Labrador area are at the northern extent of their distribution. Stocks are coastal in distribution and stock abundance is low compared to other stocks in the Atlantic. A peak catch of 30 000 t occurred in 1979, supported by strong year classes from the 1960s. Recruitment since the 1960s has been lower. Stock sizes in the late 1990s were less than 90 000 t and annual catches less than 10 000 t (DFO, 2000a).

13.4.2.5. Polar cod

Polar cod is broadly distributed through the Arctic and in cold waters of adjacent seas. It occurs on the shelf from northern Labrador to eastern Newfoundland, with the average size of individuals and the size of aggregations decreasing from north to south (Lear, 1979). There has been no directed fishery for polar cod off eastern Canada, but a small bycatch was reported in the Romanian capelin fishery in 1979 (Maxim, 1980), and it is likely that small quantities were also taken in other years and by other countries.

13.4.2.6. Northern shrimp

Northern shrimp is distributed off West Greenland from Cape Farewell northward to about 74° N and then

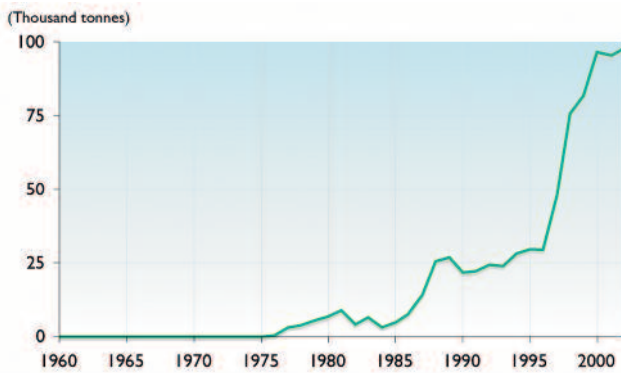


Fig. 13.29. Catch of northern shrimp, 1960–2002 (data from NAFO STATLANT 21A online database www.nafo.int/activities/FRAMES/AcFrFish.html; Hvingel, 2004; Orr et al., 2003, 2004).

southward off eastern Canada to beyond the limit of this study. The depth of highest concentration tends to vary from area to area but is generally between 200 to 600 m. A fishery with large trawlers began off north-eastern Canada in the late 1970s (Orr et al., 2001a). For the first decade most of the catch was taken from two channels in the central and southern Labrador Shelf, but in the late 1980s there was an increase in effort and landings both to the south on the Northeast Newfoundland Shelf and to the north off northern Labrador. Catches increased above 25 000 t by the mid-1990s. New survey technology introduced in 1995 indicated that commercial catches were very small relative to survey biomass, and quotas were increased considerably in the late 1990s. Total landings rose to more than 90 000 t by 2000 (Fig. 13.29). Much of the increase in catch from 1997 onward was from a new fleet of small (<100 feet) vessels that fished with bottom trawls mainly on the mid-shelf. In the 1990s fishing also expanded to Div. 3L (Orr et al., 2001b).

13.4.2.7. Snow crab

Snow crab is distributed from the central Labrador Shelf at approximately 55° N southward off eastern Canada to beyond the limit of this study. The depth distribution extends from approximately 50 to 1400 m, but most of the fishery occurs at 100 to 500 m. The fishery off eastern Newfoundland began in the late

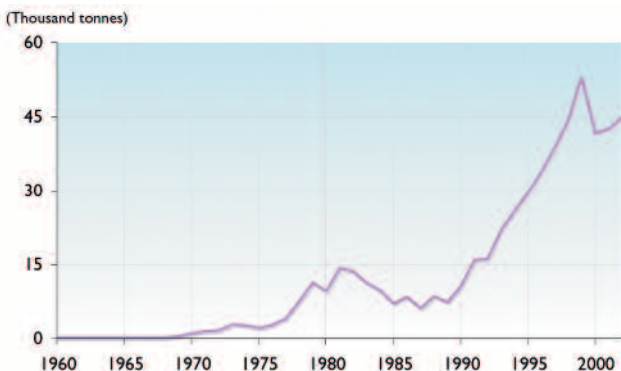


Fig. 13.30. Catch of snow crab, 1960–2002 (data from NAFO STATLANT 21A online database www.nafo.int/activities/FRAMES/AcFrFish.html; Hvingel, 2004; Orr et al., 2003, 2004).

1960s as a small bycatch fishery, but soon expanded into a directed fishery with crab traps (pots) along most of the inshore areas of eastern Newfoundland (Div. 3KL) (Taylor and O’Keefe, 1999). During the late 1970s and early 1980s there was an increase in effort and an expansion of fishing grounds. Catches in Div. 3KL reached almost 14 000 t in 1981, but then declined. In the mid-1980s there was expansion of the fishery to the area off southern Labrador (Div. 2J) and new entrants gained access to supplement declining incomes from the groundfish fisheries. The number of participants and the area fished expanded further during the 1990s, and total catches rose quickly, reaching almost 55 000 t in 1999. Quotas and landings were reduced for the next two years following concerns that the resource may have declined.

Commercial catch rates in Div. 3KL increased during the late 1970s to a peak in about 1981, declined to their lowest point by 1987, and then increased in the late 1980s and early 1990s to a level comparable to that in the early 1980s (DFO, 2002a). Catch rates remained high to the end of the 1990s, despite the substantial increase in fishing effort and landings (Fig. 13.30). This partly reflects an increase in the area fished, although there must also have been an increase in productivity.

13.4.2.8. Marine mammals

Harp seals summer in the Canadian Arctic or Greenland but winter and breed in Canadian Atlantic waters. There are two major breeding groups: the first breeding in the Gulf of St. Lawrence and the second breeding off southern Labrador and northeast Newfoundland (Bundy et al., 2000). The total population increased from less than 2 million in the early 1970s to more than 5 million in the mid-1990s (Healey and Stenson, 2000; Stenson et al., 2002). The increase was largely due to a reduction in the hunt after 1982 (Stenson et al., 2002). The population stabilized when the hunt was increased in the mid-1990s. Reported Canadian catches of harp seals include

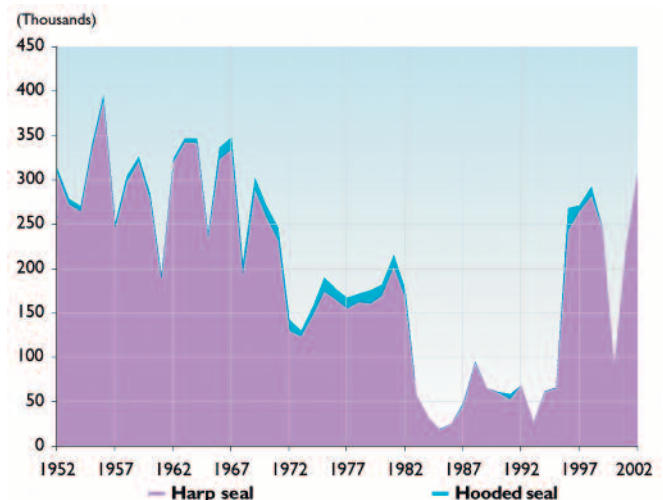


Fig. 13.31. Catch of harp and hooded seals, 1952–2002. The catches also include seals taken in the Gulf of St. Lawrence (data from Anon, 2004a; Stenson et al., 2000).

harvests off the coast of Newfoundland/Labrador (the “Front”) and in the Gulf of St. Lawrence. Seals caught in both areas belong to the same population: the Northwest Atlantic Harp Seals. The proportion of the population that occurs in the two areas varies among years, as does the relative number of seals caught in each area. Catches from both areas are combined in official statistics and so those presented here are combined “Front” and Gulf of St. Lawrence catches (Fig. 13.31).

Hooded seals are less abundant than harp seals. Whelping occurs on pack ice off northeast Newfoundland, in Davis Strait, and in the Gulf of St. Lawrence. Pups migrate into arctic waters and remain there as juveniles. Adults migrate south in the autumn and return to the Arctic in April (Bundy et al., 2000). The harvest of hooded seals (“Front” and Gulf of St. Lawrence combined) is shown in Fig. 13.31.

There has been no commercial whaling in the area since the late 1970s. Using north Atlantic population estimates, assumed growth rates, and an assumed proportion of the total population in the Newfoundland and Labrador area, Bundy et al. (2000) estimated population abundances of 33 000 for humpback whales, 1000 for fin whales, 5000 for minke whales, 1000 for sperm whales, 1000 for sei whales, and 9000 for pilot whales.

13.4.3. Past climatic variations and their impact on commercial stocks

13.4.3.1. Atlantic cod

The severe decline in Atlantic cod in the Newfoundland and Labrador area seems to have occurred from north to south. On the northern and central Labrador shelf (Div. 2GH), catches of 60 000 to 90 000 t were reported for the period 1965 to 1969, but catches declined to less than 5000 t for most of the 1970s and early 1980s, and to less than 1000 t in the latter half of the 1980s (Fig. 13.32). There are no analyses of factors that contributed to the decline in this area.

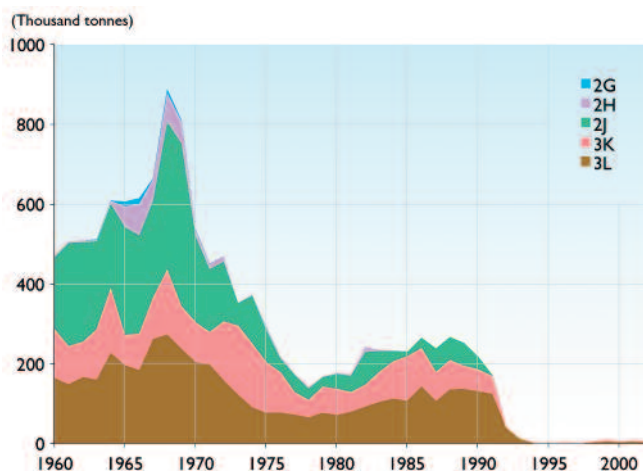


Fig. 13.32. Catch of Atlantic cod by NAFO statistical division, 1960–2000 (data from Murphy and Bishop, 1995; Lilly et al., 2003).

In the area from southern Labrador to the northern Grand Bank, the Div. 2J+3KL stock (the so-called “northern cod”) collapsed in the 1970s in response to severe overfishing. The stock recovered slightly in the 1980s but collapsed to even lower levels in the late 1980s and early 1990s. There is controversy as to whether there was a rapid but progressive decline from the mid-1980s onward or a precipitous decline in the early 1990s (Atkinson and Bennett, 1994; Shelton and Lilly, 2000). Many studies (e.g., Haedrich et al., 1997; Hutchings, 1996; Hutchings and Myers, 1994; Myers and Cadigan, 1995; Myers et al., 1996a,b, 1997a,b) have concluded that the final stock collapse was entirely due to fishing activity (landed catch plus discards). However, several authors have pointed to ways in which the decline in water temperature and increase in sea-ice cover might have contributed to the collapse, either directly by reducing productivity (Drinkwater, 2000, 2002; Mann and Drinkwater, 1994; Parsons L. and Lear, 2001) or indirectly by affecting distribution (Rose et al., 2000).

Despite many studies on this cod stock, there are few uncontested demonstrations of the influence of climate variability on stock dynamics. There is an expectation that recruitment might be positively influenced by warm temperatures, because the stock is at the northern limit of the species’ range in North America (Planque and Frédou, 1999). However, there have been conflicting reports of whether such a relationship can be detected (deYoung and Rose, 1993; Hutchings and Myers, 1994; Planque and Frédou, 1999; Taggart et al., 1994). Part of the problem is that recruitment is also positively influenced by the number and size of spawners in the population (the spawning stock biomass or SSB; Hutchings and Myers, 1994; Morgan et al., 2000; Myers et al., 1993; Rice and Evans, 1988; but see Drinkwater, 2002). Both temperature and SSB declined from the 1960s to the 1990s, increasing the difficulty of demonstrating a temperature effect. A reported positive relationship between recruitment and salinity (Sutcliffe et al., 1983) was subsequently supported (Myers et al., 1993) and later rejected (Hutchings and Myers, 1994; Shelton and Atkinson, 1994) as data for additional years became available. The negative effect of temperature on individual growth has been well documented (Krohn et al., 1997; Shelton et al., 1999). Additional aspects of cod biology that changed during the early 1990s, possibly in response to changes in the physical environment, include a delay in arrival on traditional inshore fishing grounds in early summer (Davis, 1992), a concentration of distribution toward the shelf break in autumn (Lilly, 1994; Taggart et al., 1994), a move to deeper water in winter (Baird et al., 1992), and an apparent southward shift in distribution (Kulka et al., 1995; Rose and Kulka, 1999; Rose et al., 1994).

Of much interest is the possibility that an increase in natural mortality contributed to the rapid disappearance of cod in the early 1990s. The sharp decline in survey abundance indices occurred during a period of

severe cold and extensive sea-ice cover. A considerable decline in the condition of the cod occurred at the same time, especially in the north (Bishop and Baird, 1994; Lilly, 2001). Steep declines in abundance also occurred among other groundfish in the 1980s and 1990s (Atkinson, 1994; Gomes et al., 1995), and while there have been some suggestions that these declines were caused by captures during fishing for cod and other species (Haedrich and Barnes, 1997; Haedrich and Fischer, 1996; Haedrich et al., 1997; Hutchings, 1996), there is no direct evidence of large removals. In the case of American plaice, a species studied in detail, Morgan et al. (2002) demonstrated that the declines were too large to have resulted from fishing alone. The contribution of increased natural mortality to the decline in cod and other demersal fish in this area during the last two decades of the 20th century, and particularly during the early 1990s, remains unresolved (Lilly, 2002; Rice, 2002).

The northern cod stock was still at a very low level a decade after the moratorium on directed fishing (DFO, 2003a; Lilly et al., 2001). Recruitment to ages 0 to 2 remained very low, possibly due in part to a very small spawning stock biomass; juveniles in the offshore areas appeared to show very high mortality, possibly due in part to predation by harp and hooded seals; and a directed fishery during 1998 to 2002 targeted the inshore aggregations, resulting in increased mortality on the larger fish. The unquantified impacts of low spawning stock biomass, high predation, and fishing make it difficult to establish whether some aspect of ocean climate has had a role in impeding recovery.

13.4.3.2. Greenland halibut

The status of Greenland halibut in the northwest Atlantic has been uncertain because the stock structure is still unclear, the fish have extensive ontogenetic migrations, there appear to have been shifts in distribution, the fisheries have undergone many changes in fleet composition and in areas and depths fished, and individual research surveys have only covered part of the distribution range. Nevertheless, evidence suggests that the biomass of Greenland halibut on the western side of the Labrador Sea declined substantially during the 1980s, with the decline off Baffin Island and northern Labrador (Div. 0B and 2GH) most pronounced in the first half of the decade and the decline off southern Labrador and eastern Newfoundland (Div. 2J3K) to the south most pronounced in the latter half of the 1980s and the early 1990s (Bowering and Brodie, 1995). Evidence for a decline in biomass in Div. 2J3K is also seen in the declining success of the gillnet fishery in the 1980s. The history of the fish exploited during the 1990s by the new deep-water trawler fishery to the south on the northern Grand Bank (Div. 3L) is less clear. At least some of these fish may have migrated into the area from the shelf to the north (Bowering and Brodie, 1995), in which case the decline in Div. 2J3K was partly due to a southward shift in distribution.

Reasons for the declines in biomass and shift in distribution remain unclear. Bowering and Brodie (1995) drew attention to the decline in water temperatures on the shelf in the early 1990s, but thought it unlikely that such a change would in itself have affected the distribution and abundance of Greenland halibut because this species occupies relatively deep water. Also, much of the shift in distribution must have occurred in the latter half of the 1980s, a period during which water temperatures were low but not as low as during the early 1990s.

Variability in the physical environment had no observed effect on either size at age (Bowering and Nedreaas, 2001) or maturity at size or age (Morgan and Bowering, 1997) between the late 1970s and mid-1990s.

13.4.3.3. Capelin

The relationship between capelin biology and the physical environment has been extensively studied in the Newfoundland and Labrador area. Of particular relevance to this assessment is the observation that many aspects of capelin biology changed during the 1990s and, initially, it appeared that these were the result of changes in water temperature. However, water temperatures in the latter half of the 1990s returned to normal while the biological changes exhibited by capelin did not revert to earlier patterns. There are many environmental variables that are linked to capelin biology which may be relevant in the event of global climate change and these are briefly described in the rest of this section.

Mean fish length of the mature population was smaller during the 1990s (Carscadden et al., 2002). These small sizes have been attributed to smaller fish sizes at age with fewer older and more younger fish in the population. Condition (calculated as a relationship between length and weight and regarded as a measure of “well-being”) of capelin was generally higher in the 1980s than the 1990s. Condition was not related to temperature (Carscadden and Frank, 2002).

Spawning occurs most often on fine gravel and grain size and beach orientation have been shown to explain 61% of the variation in egg concentration among beaches (Nakashima and Taggart, 2002; Vilhjálmsson, 1994). Water temperature is also a determinant of capelin spawning. The lowest and highest recorded temperatures for beach spawning in Newfoundland are 3.5 and 11.9 °C, with beach spawning ceasing when temperatures exceed 12.0 °C (Nakashima and Wheeler, 2002). Capelin eggs are very cold- and salinity-tolerant, surviving down to -5 °C and in salinities from 3.4 to 34 (Davenport, 1989; Davenport and Stene, 1986). The rate of egg development in the beach gravel is directly related to average incubation temperatures, which in turn are determined by water temperature, maximum and minimum air temperature, and hours of sunlight (Frank and Leggett, 1981).

Some capelin that move close to spawning beaches eventually spawn in deeper water adjacent to beaches. This demersal spawning can occur simultaneously with intertidal spawning when temperatures are suitable as well as when water temperatures at the beach–water interface become too warm. Egg mortality among these demersal eggs has been observed to be higher. Reproductive success may have been lower during the 1990s because the water temperatures encountered when the capelin reached the spawning beaches would have increased the incidence of demersal spawning (Nakashima and Wheeler, 2002). Historically, the spawning of capelin off Newfoundland beaches in June and July was a predictable event. In the early 1990s, spawning was later, and 80% of the variation in spawning time (1978–1994) was significantly and negatively related to mean fish size and sea temperatures experienced during gonadal maturation (Carscadden et al., 1997). Spawning on Newfoundland beaches continued to be delayed through 2000 despite sea temperatures having returned to normal. However, mean lengths of capelin continued to be small.

There are historical reports of capelin occurring outside their normal distribution range. Unusual appearances in the Bay of Fundy and on the Flemish Cap were attributed to cooler water temperatures while occurrences in Ungava Bay coincided with warming trends (summarized by Frank et al., 1996).

In the early 1990s, capelin distribution occurred more to the south, centered on the northern Grand Banks. Originally attributed to the colder water temperatures (Frank et al., 1996), this shift within the normal distribution area continued through 2000. Because capelin did not return to their usual pattern of seasonal distribution as water temperatures increased, this suggests that factors other than water temperature were also operating. Outside their normal distribution area, capelin occurred on the Flemish Cap and eastern Scotian Shelf in the early 1990s and occasionally during earlier cold periods. Capelin continued to appear on the Flemish Cap and on the eastern Scotian Shelf through 2000. In this case, capelin appear to be gradually declining in abundance as the waters warm. For mature capelin offshore during spring, Shackell et al. (1994) concluded that temperature was not a proximate cue during migration but that seasonal temperatures moderated offshore capelin migration patterns through the regulation of growth, maturation, food abundance, and distribution.

Capelin typically move up and disperse throughout the water column at night, descending and aggregating at greater depths during the day. However, during spring surveys throughout the 1990s they remained deeper in the water column and exhibited reduced vertical migration (Mowbray, 2002; Shackell et al., 1994). This change in vertical distribution was not related to the several factors tested, including temperature and predation, but may have been linked to feeding success (Mowbray, 2002).

Recruitment of beach-spawning capelin is partly determined by the frequency of onshore winds during larval residence in the beach gravel (Carscadden et al., 2000; Leggett et al., 1984). Capelin assessments have been especially problematic since the early 1990s, resulting in considerable uncertainty in the status of the stock. However, there is no evidence to indicate that exploitation has had a direct effect on population abundance (Carscadden et al., 2001), suggesting that any variations in abundance are due to environmental factors. It is not known whether some changes in biology such as condition and distribution have affected abundance, however, spawning time and increased demersal spawning may be contributing to poor survival.

Thus, exploitation has not been shown to affect any aspect of capelin biology in this area. Although there have been several changes in capelin biology beginning in the early 1990s, there is no clear indication of what external factor(s) has (have) influenced the changes. Earlier studies concluded that temperature was an important factor for some changes, but it now seems unlikely that temperature is the sole factor, given that water temperatures have returned to normal. There are suggestions that changes in food supply (zooplankton) may be affecting capelin biology but the exact mechanisms have not been identified.

13.4.3.4. Herring

Recruitment is positively related to warm overwintering water temperatures and high salinities (Winters and Wheeler, 1987); these conditions seldom exist in this region and so, large year classes rarely occur.

13.4.3.5. Polar cod

The distribution of polar cod off eastern Newfoundland expanded to the south and east during the cold period of the early 1990s (Lilly and Simpson, 2000; Lilly et al., 1994).

13.4.3.6. Northern shrimp

The shrimp resource off northeastern Canada has increased in density and expanded in distribution since the mid-1980s. There is no indication that increased catches have negatively affected the resource (DFO, 2002b).

There is much support for the hypothesis that the increase in northern shrimp off northeastern Canada was, at least in part, a consequence of a reduced predation pressure by Atlantic cod and other groundfish (Bundy, 2001; Lilly et al., 2000; Worm and Myers, 2003). Nevertheless, there is evidence that other factors were involved. For example, Lilly et al. (2000) noted that the increase in shrimp density on the Northeast Newfoundland Shelf might have started in the early 1980s, a time when the biomass of Atlantic cod was increasing following its first collapse in the 1970s. Parsons D. and Colbourne (2000) found that catch per

unit effort in the shrimp fishery on the central Labrador Shelf was positively correlated with sea-ice cover six years earlier. They suggested that cold water or sea-ice cover itself was beneficial to the early life history stages of shrimp in that area.

13.4.3.7. Snow crab

The increased productivity of snow crab in the 1990s may have been caused, at least in part, by the release in predation pressure from Atlantic cod and other demersal fish (Bundy, 2001). However, the relationships between Atlantic cod and snow crab have not yet been explored to the same extent as for Atlantic cod and northern shrimp. A preliminary examination of the influence of oceanographic conditions on snow crab productivity has shown a negative relationship between ocean temperature and lagged catch rates (DFO, 2002a). This has been interpreted to indicate that cold conditions early in the life cycle are associated with the production of strong year classes of snow crab in this area.

13.4.3.8. Marine mammals

Trends in populations of marine mammals over recent decades appear to be influenced mainly by the commercial harvest. As populations of harp seals have increased in abundance, changes in biological characteristics indicate that density-dependence may be operating (Stenson et al., 2002). Density-independent influences may also regulate harp seal populations. Harp seals whelp on sea ice and mortalities may vary according to sea-ice conditions in this critical period. Mortalities of newly whelped pups may also occur during winter storms.

Concerns regarding the impact of predation by seals on commercial fish species increased as seal populations increased. It has been estimated that 74% (about 3 million t) of the total annual consumption by four species of seals in eastern Canada occurred off southern Labrador and Newfoundland (Hammill and Stenson, 2000). Predation by harp seals has been implicated in the lack of recovery of the northern cod stock (DFO, 2003a), and predation on cod by hooded seals may be large (DFO, 2003a).

13.4.3.9. Aquaculture

Salmonid aquaculture does not occur in the ACIA part of Newfoundland because the water is too cold in winter. The main species cultured is blue mussel. Production of this species has grown over the last twenty years such that, in 2002, around 1700 t were raised in the whole of Newfoundland.

13.4.4. Possible impacts of climate change on fish stocks

Two recent papers (Frank et al., 1990; Shuter et al., 1999) discussed the possible influence of climate change on ecosystems and fisheries off eastern Canada. Frank

et al. (1990) predicted shifts in the ranges of several groundfish stocks because of redistribution of populations and changing recruitment patterns. Stocks at the southern limit of a species' distribution should retract northward, whereas those near the northern limit should expand northward. Frank et al. (1990) did not make predictions specifically for Labrador and eastern Newfoundland, but events during the decade following publication of their paper were in many respects opposite to these general predictions. The changes off Labrador and eastern Newfoundland were unprecedented and not predicted, and illustrate the uncertainty of predictions, even on a regional scale and in the relatively short term. Shuter et al. (1999) had the advantage of witnessing the dramatic changes that occurred in the physical and biotic environment during the 1990s. They concluded that greenhouse gas accumulation will lead to a warmer, drier climate and, for the fisheries of Atlantic Canada, this will result in a "decrease in overall sustainable harvests for coastal and estuarine populations due to decreases in freshwater discharge and consequent declines in ecosystem productivity". For fisheries in the Arctic, they predicted "increases in sustainable harvests for most fish populations due to increased ecosystem productivity, as shrinkage of ice cover permits greater nutrient recycling".

As the relative importance of fishing and environment is difficult to determine for any species or group of species, it is not surprising that the importance attributed to each has varied for different studies. It is also not surprising, given the differences among species in the magnitude of fishery removals relative to stock size, that opinion favors fishing as the dominant factor for some species and environment for others. For demersal fish, there are many statements to the effect that declines were caused entirely by overfishing, but there is evidence that changes in oceanographic properties contributed to changes in distribution and declines in productivity. For crab and especially shrimp, it has been suggested that increases in biomass were simply a consequence of a release in predation pressure from Atlantic cod and perhaps other demersal fish, but again there is evidence that changes in oceanographic factors contributed to an increase in reproductive success. For capelin, most information supports the hypothesis that fishing had little impact on population dynamics, and that environmental factors were the primary determinant of stock size, well-being (growth and condition), distribution, and timing of migrations. For polar cod, fishing may be dismissed as a contributor to changes in distribution and biomass.

An important constraint on predicting changes in fish stocks and the fisheries that exploit them off Labrador and eastern Newfoundland is uncertainty about the direction and magnitude of change in important oceanographic variables. For surface air temperature, some model outputs project a cooling over the central North Atlantic, and it is not clear where the Labrador/Newfoundland region lies within the gradation from

significant warming in the high Arctic to cooling over the central North Atlantic. In addition, there is no model for downscaling the output of general circulation models to specifics of the Labrador/Newfoundland area. As an example of the importance of regional models, many large-scale models project an increase in air temperature over the Norwegian and Barents Seas, while simulations with one specific regional model (Furevik et al., 2002) indicate that sea surface temperature in that area may decline in the next 20 years before increasing later in the century. Another concern is that natural variability in a specific region, such as the Labrador Shelf, may be greater than variability in the global mean (Furevik et al., 2002). Thus, a warming trend in shelf waters off Labrador and Newfoundland might be accompanied by substantial annual variability, such as was witnessed during the last three decades of the 20th century, and it is even possible that the amplitude of that variability could increase. For biota, extreme events associated with this variability might be at least as influential as any long-term trend. For the Labrador Shelf and Northeast Newfoundland Shelf, it is probably at least as important to know how the North Atlantic Oscillation will behave (especially the intensity and location of the Icelandic Low) as it is to know that global temperature will rise.

In the absence of region-specific information on likely future developments of climate, all predictions of climate-driven changes in the marine ecosystem off Newfoundland and Labrador can only be highly tentative. The following subsections describe the changes that seem most likely under three different scenarios: no change or even cooling of climate, moderate warming, and considerable warming.

13.4.4.1. No change

As temperatures were generally below the long-term average during the ACIA baseline period (1981–2000), no change from present conditions or even a cooling are likely to favor the current balance of species in the system. This implies a predominance of commercial invertebrates like northern shrimp and snow crab and cold water species of fish such as Greenland halibut, polar cod, and capelin.

13.4.4.2. Moderate warming

The moderate warming scenario (an increase of 1 to 3 °C) assumes that there will be a gradual warming of the shelf waters off Labrador and Newfoundland. Using the events in West Greenland during the first half of the 20th century (Vilhjálmsón, 1997) as a spatial/temporal analogue, there is likely to be better recruitment success and northward expansion of Atlantic cod and some other demersal fish that live mainly on the shelf. Capelin is also likely to shift northward. If zooplankton abundance is enhanced by warmer water, capelin growth is likely to improve. It is possible that many existing capelin spawning

beaches will disappear with the projected rise in sea level (Shaw et al., 1998). Depending on the increase in sea level, storm events, and the availability of glacial deposits, some beaches may move and new beaches be formed, while others may disappear completely. While beach-spawning capelin can adapt to spawning on suitable sediment in deeper water, survival of eggs and larvae appears to be adversely affected (Nakashima and Wheeler, 2002), suggesting that a rise in sea level is likely to result in reduced survival and recruitment for capelin. A warming of sea temperatures is likely to retard recruitment to snow crab and northern shrimp, so these species might experience gradual reductions in productivity. Thus, a gradual, moderate warming of sea temperature is likely to promote a change back to a cod–capelin system from the present system where snow crabs and northern shrimp are the major commercial species. In addition, both cod and capelin are also likely to become more prominent off central Labrador than they were during the 1980s.

A gradual warming of shelf waters is also likely to promote a shift of more southerly species into the area. For example, haddock is likely to become more abundant on the southern part of Grand Bank, and expand into the study area. Migrants from the south, such as short-finned squid, mackerel, and bluefin tuna, are likely to occur more regularly and in greater quantities than in the 1980s and early 1990s.

The simple scenario of a gradual change back to a cod–capelin system under moderate warming conditions is uncertain. This is because the influence of oceanographic variability in the past is still not clear, and because it is likely that the dynamics of some species are now dominated by a different suite of factors than was the case in the past. It is highly likely that the ecosystem off northeastern Canada changed substantially as a consequence of fishing during the first four centuries after the arrival of European fishers, changed even further with the increasingly intensive fishing of the 20th century, and has changed dramatically from the 1960s onward. The magnitude of these changes is such that it would be difficult to predict accurately the future state of this ecosystem even without the added complications of climate change. Thus, the system could remain in its current state, could revert to some semblance of an historic state (or at least the state of the early 1980s), or could evolve toward something previously unseen.

Changes in sea ice (see Tables 9.2 and 9.3) are likely to have a negative impact on harp seals, the most important marine mammal predator in the area. Sea-ice duration is projected to shorten and it is not known whether harp seals would be able to adjust their breeding time to accommodate this change. A decrease in sea-ice extent is unlikely to affect harp seals because they would probably shift their distribution with the sea ice. However, thinner sea ice may be deleterious, resulting in increased pup mortality. Increases in regional storm intensities (see Table 9.1) are likely to result in higher

pup mortalities if such storms occur during the critical period shortly after birth (G. Stenson, Fisheries and Oceans Canada, St. John's, pers. comm., 2003).

Changes in seal abundance are likely to cascade through the ecosystem, since seals are important predators on many fodder fish and commercially important groundfish (Bundy et al., 2000; Hammill and Stenson, 2000), and are thought by some to be important in impeding the recovery of cod (DFO, 2003a) and thus maintaining the present balance within the ecosystem.

In addition to uncertainty regarding the response of individual species and the ecosystem as a whole, there is uncertainty regarding the influence of changing sea-ice cover on the fisheries themselves. A reduction in the extent and duration of sea ice may permit fishing further to the north and would increase the period during which ships would have access to certain fishing grounds. In particular, these changes in sea-ice cover would affect the Greenland halibut and shrimp fisheries in Baffin Bay and Davis Strait. For example, an increased open water season and extended fishing period is thought to have the potential to increase the harvest of Greenland halibut at the time of spawning (late winter/spring).

A reduction in sea-ice cover (see Tables 9.2 and 9.3) is also likely to negatively impact upon Greenland halibut fisheries that are conducted through fast ice. For example, a fishery that was developed in Cumberland Sound on Baffin Island in the late 1980s has developed into a locally important enterprise (Crawford, 1992; Pike, 1994). The fishery is conducted with longlines set through ice over deep (600–1125 m) water, with the season extending in some years from mid-January to June. Since the mid-1990s, the season has been shorter, typically from early February to May (M.A. Treble, Fisheries and Oceans Canada, Winnipeg, pers. comm., 2003). To date, attempts at fishing during the open water season have not proved successful. The catches have been small and the fish appear dispersed. It is unclear whether the fish would be present in commercial concentrations in the winter/spring if sea ice were not present. Even if they were, the absence of sea ice would certainly affect the conduct of the fishery.

13.4.4.3. Considerable warming

Since a warming of 4 to 7 °C is beyond any recorded experience in the Newfoundland–Labrador area, a meaningful discussion of the considerable warming scenario is not practicable. In very general terms, such a shift could favor cold-temperate species such as cod, improve conditions for more southern species such as haddock and herring, and even lead to the formation of demersally spawning stocks of capelin in addition to beach spawning stocks. However, there are likely to be other changes, such as a freshening of the surface layer due to freshwater from melting sea ice further north, which would be likely to reduce primary production in the area.

13.4.5. The economic and social importance of fisheries

From an economy based primarily on the fishery, Newfoundland has, along with most of North America, moved to a service economy. By 1971, for instance, the fishing and fish processing sectors accounted for less than 5% of Newfoundland's GDP, whereas the service sector accounted for more than half. Mining accounted for 11% and construction 18% (although that included construction of some of the large diversification projects). Nearly twenty years later, in 1989, shortly before the groundfish collapse, the fishery harvesting and processing sectors together accounted for slightly more than 5%, service industries had grown to 68%, mining had fallen to less than 6%, and construction to 8% (for a more extensive discussion see Schrank et al., 1992). By 2001, the fishery harvesting and processing sectors accounted for only 3% of GDP, the service industries remained constant at 68%, construction had slipped to 4.7%, and conventional mining to 3%. Oil production, a new industry in Newfoundland, already accounted for 8.4% of the provincial GDP, with every prospect of growing (the 2001 data were from the Newfoundland Statistics Agency; www.nfstats.gov.nf.ca/statistics/GDP/GDP_Industry.asp). Mining was also expected to see resurgence with the potential opening of a large nickel mine in Labrador.

While the fishery may not be of great importance to the overall Newfoundland economy, it continues to dominate completely the economy in rural areas, and perhaps even more importantly, its culture. After fifty years, there is still a daily *Fisheries Broadcast* on radio and when the Canadian Broadcasting Company decided to cancel the weekly television program *Land and Sea*, which often focuses on the fishery, public pressure forced the crown corporation to continue the program. With the fishery in deep trouble in 1989, the dominant newspaper in the province, *The Evening Telegram*, commented in an editorial entitled "Too Many Fishermen?" on 1 June 1989, that "Newfoundland's fishery must eventually be expanded and diversified so that it can employ more people, not fewer..."

With the spectacular change in fisheries employment that accompanied the collapse of the northern cod stock, there has been a sharp reemphasis on economic diversification. The two areas paraded as holding the hope of the future are tourism and information technology (Government of Newfoundland and Labrador, 2001). Progress has been made in both areas (e.g., fishing vessels converted to tour boats for whale watching, and many bed and breakfast establishments), but has been uneven, and some government policies have been inconsistent with the promotion of these industries. For instance, despite its interest in developing tourism, the Newfoundland government decommissioned or privatized a substantial number of the parks in the province's extensive parks system (Overton, 2001). How many of those sold remain as parks is unknown.

The real problem with the emphasis on tourism and information technology is that it is happening at the time as it is happening throughout the world. Why should Newfoundland have an advantage over the rest of the world in either field? It is too early to tell whether this diversification will be successful.

The story of the Newfoundland fishery does not end with the collapse of the groundfishery, its catastrophic consequences for many families, and the serious pressures it placed on the government. Two critical sets of changes have occurred since 1992: (1) the fishery management process has evolved and (2) shellfish have replaced groundfish as the main components of fishery landings in Newfoundland.

Fishery management by restricting total allowable catches began in Newfoundland in the mid-1970s. Following a particularly dramatic race to the fish in 1981, the government imposed, at the industry's request, enterprise allocations on the offshore groundfish fleet in 1982. These allocations were divisible and transferable in the year in which they were assigned. Government emphasized that these were rights to fish as opposed to property rights, which could be permanently sold. By this time, gear and geographic restrictions had been imposed, as had limited entry to non-groundfish inshore fisheries. With the expansion of the crab fishery, enterprise allocations have also been assigned to this inshore sector. These allocations are not transferable. The federal government has relinquished the licensing of fishers in favor of the provincial Professional Fish Harvester's Certification Board. This board was established as part of a professionalization program and it licenses harvesters either as apprentices or in one of two professional classes. The federal government, in turn, in 1996 established "core" fishing enterprises for the inshore fisheries. Senior level professional fishers who met certain conditions were declared the heads of core fishing enterprises. Approximately 5500 of these were established and the government claimed that no additional core licenses would be issued; the only way that fishers could obtain such status would be to buy out the core license of an existing core fisher. In an attempt to reduce the number of fishers, the federal government bought approximately 1500 core licenses, claiming that these will not be reissued. The final major changes in the management system are that (1) species license fees (access fees) are no longer nominal, for most important species they are based on the anticipated gross income from the fishery; and (2) there is now an extensive system of public consultations before recommendations concerning total allowable catches are made to the Minister of Fisheries and Oceans. For a discussion of the current fishery management system, see Schrank and Skoda (2003).

The value of landings in all Newfoundland fisheries in 1991 was Can\$ 282 838 000. This fell during the first year of the moratorium to Can\$194745 000 and then doubled to Can\$ 388 700 000 by 2000. Viewed alternatively, the period of the northern cod moratorium saw

an increase of one-third in the real value of Newfoundland fish and shellfish landings. But, while in 1991 43% of the value of landings was for cod, in 2000 46% was accounted for by crab and a further 30% by shrimp. With some cod stocks reopened on a limited basis for commercial fishing, cod accounted for 9% of the total landings in 2000, although this had earlier (in 1996) fallen to less than one-half of one percent (www.dfo-mpo.gc.ca/communic/statistics/landings).

For environmental reasons, whether the lack of predation or favorable climatic conditions, the shellfish population has surged and there has been a nearly complete conversion of Newfoundland's fishing industry from groundfish to shellfish. The conversion took years to occur. Labor requirements for shellfish are lower than for groundfish and, having higher unit prices, the shellfish quantities that yield these landings figures are much smaller than for groundfish.

Since all major species are under quota, total allowable catches for shrimp and crab have been increasing rapidly, along with the number of harvesting and processing licenses for shrimp and crab. The number of shrimp harvesting licenses rose from 19 in 1986 and 57 in 1991 to 438 in 2000. The numbers of crab licenses for those years were 274, 721, and 3333 (Corbett, 2002). There has been much controversy as to whether the old error of issuing too many licenses has occurred for crab. Even with the exodus from the province, in February 2003 there was still a 17.5% seasonally adjusted unemployment rate in the province (where the national figure was 7.4%) with continued pressure to open closed plants and increase licenses for crab fishers. While the number of crab fishing licenses has increased substantially, the increase in the number of crab processing plants has been modest.

13.4.6. Past variations in the fishing industry and their economic and social impacts

The *Evening Telegram* editorial, referred to in section 13.4.5, appeared within the context of a fishery that had long been in trouble. In 1967, a provincially financed report supported the trend away from a seasonal inshore fishery in Newfoundland toward a capital-intensive year-round offshore fishery. The report also noted that the "number of people dependent on the fishery should be reduced" (Pushie, 1967, 185). This has been a recurring theme. In 1970, the federal fisheries department appealed to the Canadian cabinet to permit the department to establish regulations that would lead to a 50% reduction in the number of Atlantic Canadian (meaning mainly Newfoundland) fishers.

The authority to effect these changes was denied (Schrank, 1995). The fishery faced repeated crises, was repeatedly studied, and the conclusion was repeatedly drawn that too many people were dependent on it. One study estimated that of the then 35 000 licensed fishers, only 6000 could be supported unsubsidized by the fish-

ery at a better than poverty-level income. The same study concluded that for every dollar of fish landed, there was a dollar of subsidy (Schrank et al., 1986). In 1976, with the extension of coastal states' fishery jurisdiction to 200 nm from shore, the two Canadian departments concerned (fisheries and regional economic expansion) both published reports stating that there was sufficient extra capacity in the industry that no significant employment benefits could be expected from the expanded jurisdiction (Government of Canada, 1976a,b). Two years later, a provincial government report made a similar point by stating that the Canadianized fishery, when fully developed, could employ only 9000 inshore fishers (Government of Newfoundland and Labrador, 1978). Yet, in response to popular pressure, both federal departments, as well as the provincial government, licensed and subsidized a tremendous expansion in the physical capacity of the industry: from 13 636 registered fishers in 1975 to 33 640 in 1980; from 9517 registered inshore vessels in 1976 to 19 594 in 1980; from a fish freezing capacity of 181 000 t in 1974 to 467 000 t in 1980; from net fishers' unemployment insurance benefits of US\$ 30 724 000 in 1976/77 to US\$ 66 060 000 in 1980/81; and from outstanding loans of the provincial Fisheries Loan Board (to finance inshore vessels) from US\$ 36 869 000 in 1976/77 to US\$ 78 558 000 in 1980/81 (Schrank, 1995). By 1981 the expansion had stopped and the two federal departments agreed that no further expansion of fish processing facilities would be built with federal financing (LeBlanc and De Bané, 1981). However, the damage had already occurred and, in the face of the anti-inflation recession of the early 1980s in the United States (where most of the Newfoundland fish production was sold), the market for Newfoundland fish products shrank dramatically and most Newfoundland fish processing companies faced bankruptcy.

As a result, the industry was financially, but not structurally, reorganized and the massive industrial closures implicit in bankruptcy were averted (Kirby, 1982). Yet, starting in 1982, inshore groundfish catches fell and after 1986 offshore catches followed. By 1992, the situation was so bad that a moratorium on the commercial catching of the formerly massive northern cod stock was put into place. Shortly after, nearly all Newfoundland groundfisheries were closed and the moratorium was extended to non-commercial fishing (Schrank, 1995). The closure of most of these groundfisheries continues, in whole or in part, to the present. The closure of the Newfoundland groundfisheries is reputed to have involved the largest mass layoff of labor in Canadian history. In social terms (due to the mass layoff), in biological terms (due to the decimation of the fish stock), and in governmental financial terms (due to billions of dollars spent on income maintenance for fishers and fish plant workers) the moratoria were disasters.

The response of government, industry, and the public to the moratoria indicates what might happen with climate change. Although the cause of the stock

destruction in Newfoundland waters may be debated, the dramatic effect on the fish population is incontrovertible. Should significant changes in environmental conditions occur, and should these changes have substantial effects on commercial fish stocks, then the Newfoundland experience may provide a template for what might be expected to happen elsewhere. Moreover, the Newfoundland experience may also indicate the need for alternative policies.

The decline in the cod fisheries was better understood after the reports by Alverson (1987) and Harris L. (1989, 1990). That major problems were developing in the groundfishery was no longer debatable. In 1990, in response to the decline of the fishery, the federal government introduced the Atlantic Fisheries Adjustment Program (AFAP; see Schrank, 1997). The emphasis was on the word "adjustment". People were to be retired from the fishery, rural communities were to receive money to help them diversify their economies away from the fishery, and steps were to be taken to increase scientific understanding of the declining fish stocks. But only a few hundred fishers left the industry. With the shock of the total closure of the commercial northern cod fishery in July 1992, the federal government, anticipating that the fishery would revive in two years, created the Northern Cod Adjustment and Recovery Program (NCARP; see Schrank, 1997). Again there was an emphasis on people adjusting out of the fishery. This program called for early retirement of fishers, buybacks of fishing licenses, training of fishers for other trades, and income maintenance payments to fishers and fish plant workers. A third of the 9000 northern cod fishers and half the 10 000 plant workers affected by the northern cod shutdown were expected to leave the fishery. In fact, only 1436 took early retirement and 876 fishers sold their licenses. Fishers were not convinced that the shutdown would continue for long, and believed that the government would support them until the fishery reopened; the relatively uneducated, potential low end laborers did not see a need to leave an industry in which they were skilled and for which they were trained from an early age. One reason for low educational levels (until 1991, less than half Newfoundland's adult population had completed high school) was the fishing tradition. Boys started fishing with their fathers at a young age and looked forward to leaving school as soon as possible to join the family fishing enterprise. Boys and girls with little interest in fish harvesting could work for life in the local fish plant, in jobs which mostly required little formal education.

However, the fish did not return after two years, and have still not returned a decade after the start of the moratorium. As NCARP was ending, a new adjustment program began. The Atlantic Groundfish Strategy (TAGS; see Schrank, 1997) was to be a five-year program of income maintenance and adjustment (license buybacks and retirements) in which a 50% reduction in fishing capacity was anticipated. Again, there was very little movement of people out of the fishery. Their reluc-

tance to abandon the fishery was for the same reasons as under the NCARP program.

As TAGS drew to a close at the end of the 1990s, the government took a harder line. The post-TAGS program did not resemble its predecessors: income maintenance was severely cut and many people were removed from the program. With government financial support gone, or going, and the fish still not returned, an exodus from the fishery finally occurred.

Between 1986 and 1991, the Newfoundland population stagnated, at least partially from a dramatic drop in family size. From the highest birth rate of Canadian provinces, by 1991 Newfoundland had the lowest. Also, there had always been modest migration out of the province. But in the five years between 1991 and 1996 (from the year after the start of AFAP to halfway through TAGS) the population actually fell by 3%. With the continuing moratorium and the change in government policy, the exodus increased significantly and between 1996 and 2001 there was a further drop of 7%. Census figures for 2001 are from Statistics Canada (2002a), while those for 1991 and 1996 are from Statistics Canada (1999).

Even though such a population drop in a province over a decade is dramatic, this value of 10% actually hides the severity of the impact of the fishery collapse on Newfoundland's rural communities. Trepassey, on the southern shore of the Avalon Peninsula, was the location of a major groundfish processing plant. Newfoundland groundfish operators had been operating under an Enterprise Allocation scheme since 1982. With the drop in fish stocks toward the end of the 1980s, enterprise allocations were cut and, in response, a number of fish plants closed. One of the first to close, in 1990, was that in Trepassey. The result was that a town with 1375 inhabitants in 1991 had shrunk by more than 35% to 889 in 2001. Many rural communities in Newfoundland have seen population declines since 1990 of 15 to 30% (Statistics Canada, 2002b).

13.4.7. Economic and social impacts of climate change: possible scenarios

Climate change is likely to cause changes in the size of fish stocks. The effects are unlikely to be greater than the historical changes described in section 13.4.6. With human society, responses to impulses are not "natural" in the sense that a climatic change "causes" a human response. The human response is determined by the magnitude of the stimulus plus the political response of the society. In this sense, societal responses to climate change will not be qualitatively different from society's responses to past changes. The political system will respond, and the details of that response are impossible to predict. But models exist from past experience. However, many of the federal and provincial interventions in the fishery since 1992 have appeared ill thought out, often unfair, and have raised controversy.

A recent case provides an illustration. The groundfish plant in Twillingate was once owned by the largest fish company in Newfoundland, Fishery Products International, Ltd., but had been sold to another operator in the mid-1980s (Schrank et al., 1995). With the northern cod moratorium in 1992, the plant was shut and remained shut until 2002 when it opened as a shellfish plant with more technologically sophisticated equipment than had been used for groundfish. The Marine Institute, a branch of Memorial University, introduced a course to teach fish plant workers to use the new equipment, charging more than CAN\$ 400 per person. For unemployed people receiving (un)employment insurance the fee was paid by the federal government. Others had to pay for themselves. Most unemployed people without employment insurance could not afford the fee. Most working people, wanting higher paying jobs in the fish plant, or former fish plant workers wanting to return to the industry, would need to quit their jobs to take the course, unless they were granted time off, which is unlikely in unskilled trades. But if they quit their jobs and completed the course, there was no guarantee of a job in the Twillingate, or any other technologically advanced, fish plant (CBC, 2002). Thus, every aspect of the long adjustment process which started with the decline of the groundfishery in the 1980s has been characterized by a deep sense of unfairness.

The Newfoundland experience shows that a "catastrophic" event concerning the fishery leads to severe adjustment problems, and that the adjustment period may be very long, but that it also raises new potential for a successful industry. The issues seem to be:

- how to convince participants in the industry that there is a crisis;
- adjustments that need to be made;
- the role of government; and
- how to protect the new fishery from the mistakes of the failed fishery.

In terms of predicting the socio-economic effects of long-term climate change, this is one case where it is easier to prescribe than to predict. The Newfoundland experience has shown reactions to expanding fish populations and to shrinking fish populations. In neither case was the reaction, in terms of government action or political pressure, appropriate. During the expansion period of the late 1970s, the fishery expanded too much, with excessive and ultimately largely immobile labor and capital entering the industry. Whereas a properly managed fishery would have restricted the expansion of production factors, the expansion was almost without letup until stopped by a general economic crisis. It was understood at the time that employment expansion was an incorrect response. Should fish stocks off Newfoundland increase over the next 20 or 50 years, care should be taken (1) to restrict by government regulation the magnitude of any expansion of capital and labor in the fishery; or (2) to ensure that such economic incentives are in place that excessive growth does not occur; or (3) to combine the two.

Should fish stocks decrease over the next 20 or 50 years, then it should be clear from the start that endless subsidies will not be forthcoming. License buyouts, even generous license buyouts of core enterprises for instance, would help. While these payments are subsidies, they are limited in scope and time and would have the effect of permanently shrinking the factor base of the industry. In the 1990s, such a policy would have been much cheaper and much less stressful for the fishing families affected, than the offering of income maintenance payments.

A gradual warming of shelf waters is likely to lead to increased opportunity for aquaculture. Warmer temperatures and shorter periods of sea-ice cover are likely to enable mussel farming to be more productive. Warmer waters are also likely to promote the development of Atlantic cod farming. If inshore waters become sufficiently warm, it is likely to be possible to farm Atlantic salmon along the east coast of Newfoundland. This is presently impossible because water temperature in winter falls below the lethal temperature for salmon.

13.4.8. Ability to cope with change

Climate change will affect all aspects of the fishery: the range of existing species, the relative populations of different species, and the economic circumstances of people who depend on the fishery for a living. How ready the economic and social systems of Newfoundland are to cope with these changes is not clear. When the Newfoundland fishery was revitalized after the declaration of the 200 nm limit, its economic structure over-expanded with largely immobile capital and labor and resulted in disaster. When the cod fishery started to decline in the late 1980s, several years passed before many of the necessary adjustments occurred. Whether the situation will be any different in response to climate change depends on whether lessons have been learned, and whether the social and political systems are prepared to adjust. Both the expansion of the ground-fishery in the late 1970s and the failure of the fishery to adjust to decimated stocks in the early and mid-1990s were largely due to the subsidies. During the 1970s the expansion was mainly financed by the federal and provincial governments. Despite the efforts of the federal government to adjust fishers out of the industry in the 1990s, the adjustment programs became income maintenance programs, which in effect encouraged fishers to remain in the industry in the hope that the fish would return. It was only when the subsidies were substantially reduced after 1998 that a significant number of fishers left the industry (based on the assumption that departures from the fishery are reflected in the census figures).

Subsidies are not the results of whimsical acts of governments or politics but are responses to real social and economic concerns. As long as the government considers the survival of small rural communities a major priority, subsidies to the fishery (the primary industry in

these communities) will continue. While subsidies exist, the response of people to changes in the industry will be slow. Without subsidies, economic forces will require change, probably rapid change if the fishery is declining. If the biological base of the fishery is expanding, there is always the possibility that the industry will overexpand without government help. Government financial assistance would virtually ensure that over-expansion would occur.

To the extent that adjustments induced by climate change cause human suffering, the government can be expected to ameliorate the situation and ease the necessary transitions. But there is strong precedent for transition programs being transformed into short-run income maintenance programs. If that were to happen again, the process of adjustment is likely to be as long, painful, and wasteful as before.

Thus, it is impossible to predict how ready society is to cope with the effects of climate change. The response mechanisms are not automatic and political reactions will play a major role.

13.4.9. Concluding comments

The ecosystem off the northeast coast of Canada is under the influence of the Labrador Current, which carries cold water south from Davis Strait, the Canadian Archipelago, and Hudson Bay. As a result, climate impacts in this ecosystem can be compared to impacts on comparable ecosystems in the Northeast Atlantic and Iceland. Historically, the dominant demersal species were cod, Greenland halibut, and American plaice, the dominant invertebrates were northern shrimp and snow crabs, the dominant pelagic fish was capelin, and the dominant top predators were harp seals and whales.

The Labrador/Newfoundland ecosystem experienced major changes in the 1980s and 1990s. Atlantic cod and most other demersal fish, including species that were not targeted by commercial fishing, had declined to very low levels by the early 1990s. In contrast, snow crab and especially northern shrimp surged during the 1980s and 1990s and now support the most important fisheries in the area. Harp seals increased in abundance between the early 1970s and the mid-1990s. Capelin have been found in much reduced quantities in offshore acoustic surveys since the early 1990s, but indices of capelin abundance in the inshore surveys have not experienced similar declines, leaving the status of capelin uncertain and controversial.

The relative importance of overfishing and the environment on changes in cod and Greenland halibut has not been determined, although fishing is generally accepted as the most important factor affecting cod abundance. Ocean climate is thought to have had an impact on the lack of cod recovery, although this has not been quantified. Exploitation has not been shown to have affected any aspect of capelin biology in this area. Although there

have been several changes in capelin biology since the early 1990s, there is no clear indication of what external factor(s) has (have) influenced the changes. A combination of reduced predation and favorable environmental conditions probably contributed to the success of northern shrimp and snow crab. Harp seals increased because of reduced commercial harvesting.

Changes of the magnitude that have occurred in the biological components of the ecosystem since the early 1980s are unprecedented and together with the lack of regional predictions of changes in the ocean due to climate change, make predictions of biological responses to climate change highly speculative.

If there is no change from the present state or even a cooling, it is likely that the current balance of species will persist.

With a moderate, gradual warming, there is likely to be a change back to a cod–capelin system with a gradual decline in northern shrimp and snow crab. Cod and other demersal, shelf-dwelling species and capelin are likely to move north. Many existing capelin spawning beaches are likely to disappear as sea levels rise. If there is an increase in demersal spawning by capelin in the absence of new spawning beaches, capelin survival is likely to decline. Seals are likely to experience higher pup mortality as sea ice thins. Increases in regional storm intensities are also likely to result in higher pup mortality. A reduction in the extent and duration of sea ice is likely to permit fishing further to the north. A reduction in sea-ice cover is likely to shorten Greenland halibut fisheries that are conducted through fast ice.

If a more intense regional warming occurs as a consequence of extensive climatic warming, then predicting the responses of the biological community to these changes must occur in the absence of historic precedence and be completely speculative. Such an event is likely to improve conditions for cold-temperate species such as cod, improve conditions for more southern species such as haddock and herring, and even result in the formation of demersally spawning stocks of capelin.

Although the fishery in Newfoundland has accounted for 5% or less of provincial GDP since 1971, it dominates the economy and culture in rural areas. The cod fishery expanded rapidly in the 1980s and then contracted rapidly in the 1990s, the latter in response to the fishing moratorium. The social and economic effects of changes in fish stocks due to climate change are likely to be less than the historical changes experienced in the latter part of the 20th century in Newfoundland and Labrador.

Past experience suggests that the political system will respond but that the details of the response are impossible to predict. It is, however, possible to prescribe directions that governments should follow in the event of expansions or contractions of fish stocks resulting from climate change. If fish stocks off Newfoundland increase

over the next 20 or 50 years, care should be taken (1) to restrict by government regulation the magnitude of any expansion of capital and labor in the fishery; (2) to ensure that such economic incentives are in place that excessive growth does not occur; or (3) to combine the two. If fish stocks decrease over the next 20 or 50 years, then it should be clear from the start that endless subsidies will not be forthcoming. License buyouts, even generous license buyouts of core enterprises for instance, would help. While these payments are subsidies, they are limited in scope and time and would have the effect of permanently shrinking the factor base of the industry.

Aquaculture in Newfoundland and Labrador is relatively small but there is interest in expansion, especially with the lack of recovery of cod stocks. A gradual warming of shelf waters is likely to lead to increased opportunity for aquaculture. Warmer temperatures and shorter periods of sea-ice cover are likely to enable mussel farming to be more productive. Warmer waters are also likely to promote the development of Atlantic cod farming and the farming of Atlantic salmon along the east coast of Newfoundland.

13.5. North Pacific – Bering Sea

The continental shelves of the eastern and western Bering Sea together produce one of the world's largest and most productive fishing areas (Fig. 13.33). They contain some of the largest populations of marine mammals, birds, crabs, and groundfish in the world (Overland, 1981). A quarter of the total global yield of fish came from here in the 1970s. The central Bering Sea contains a deep basin that separates the shelves on the Russian and American sides and falls partly outside the 200 nm EEZs of the two countries. Prior to extended fishing zones, a complex set of bi- and multilateral fisheries agreements was established for the area. These range from agreements on northern fur seal (*Callorhinus ursinus*) harvests and Canada/US fisheries for Pacific salmon (*Oncorhynchus* spp.) and Pacific halibut (*Hippoglossus stenolepis*), to the multilateral International

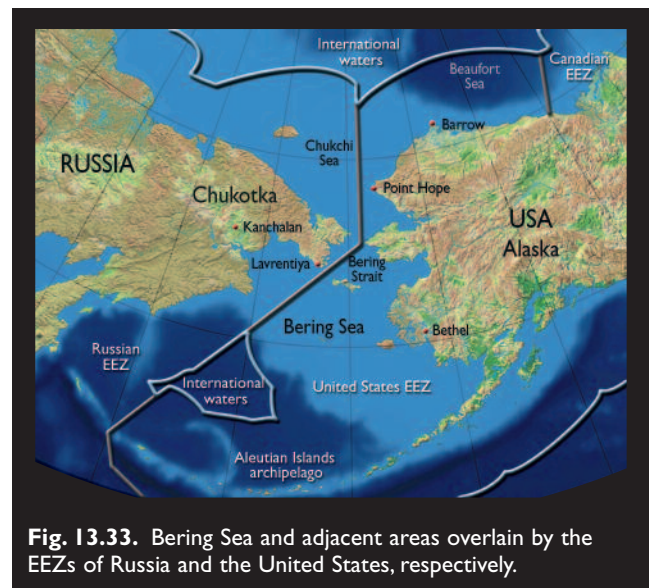


Fig. 13.33. Bering Sea and adjacent areas overlain by the EEZs of Russia and the United States, respectively.

North Pacific Fisheries Convention for the development and use of scientific information for managing fisheries on the high seas (Miles et al., 1982a,b). (Various post-EEZ license agreements have permitted fishing by non-Russian and US fleets. At present such fishing is precluded in the US EEZ and is much reduced in waters of the Russian Federation.) In the so-called “Donut Hole”, a pocket of high seas area surrounded by US and Russian EEZs, scientific research and commercial fishing are carried out in accordance with the Convention on the Conservation and Management of Pollock Resources in the Central Bering Sea by the two coastal states and Japan, Korea, Poland, and China. The North Pacific Science Organization and the North Pacific Anadromous Fish Commission were established to facilitate fisheries and ecosystem research in the North Pacific region, including the Bering Sea.

Commercial fisheries in the Bering Sea are generally large-scale trawl fisheries for groundfish of which about 30% of the total catch is processed at sea and the rest delivered to shoreside processing plants in Russia and the United States. Home port for many of the Bering Sea vessels is outside the ACIA region reflecting the comparative advantage of supply and service available in lower cost regions. Small coastal communities have a strong complement of indigenous peoples with subsistence fishing interests. They depend on coastal species, especially salmon, herring, and halibut, but the overlap with commercial activities is generally small. Anadromous species extend far inland via the complex river systems and are critical resources for indigenous peoples. The chief indigenous involvement in the marine commercial sector is the Community Development Program in the Northeast Pacific where 10% of TACs are allocated to coastal communities and their chosen partners (Ginter, 1995). Because the eastern Bering Sea is within the EEZ of the United States, harvest levels of commercially important species of fish and invertebrates are regulated through federal laws. Management plans exist for the major target species that specify target fishing mortality levels calculated to maintain the long-term female spawning stock levels at 40% of the unfished equilibrium level for fully exploited species. In the western Bering Sea, within the Russian EEZ, fishery management is executed on the basis of an annual TAC established for all commercial stocks of fish, invertebrates, and marine mammals. Allowable catch is calculated as a percentage of the fishable stock. Percentages for individual stocks and species were based on early scientific studies and do not exhibit annual change. However, since 1997, these harvest percentages have been revised by government research institutes, using new modeling applications and adaptive management approaches. The recommended TACs are approved by the special federal agency and issued as a governmental decree.

Annual catches of all commercial groundfish species between 1990 and 2001 in the US eastern Bering Sea EEZ ranged from 1.3 to 1.8 million t and averaged 1.6 million t. The walleye pollock (*Theragra chalcogramma*)

catch averaged 1.2 million t and ranged from 0.99 to 1.45 million t (Hiatt et al., 2002). In the western Bering Sea, the total groundfish catch reached 1.45 million t in 1988 of which walleye pollock contributed 1.29 million t. The annual catch of walleye pollock between 1990 and 2001 averaged 0.73 million t ranging from 0.45 to 1.06 million t. Walleye pollock comprised 89% of the catch, on average, over the 11-year period.

Aquaculture is not a particularly important activity in the Bering Sea region. In the eastern Bering Sea region, Alaska has adopted policies that prohibit aquaculture but enable some land-based hatcheries that produce salmon for release into the sea to supplement at times of low escapement. Some of these salmon pass through the eastern Bering Sea and may have some effect on larvae, for example red king crab (*Paralithodes camtschaticus*) larvae, but this has not been demonstrated. None of the hatcheries operate in the western Bering Sea region (NPAFC, 2001).

13.5.1. Ecosystem essentials

The Bering Sea is a subpolar sea bounded by the Bering Strait to the north and the Aleutian Islands archipelago to the south (Fig. 13.33). Geographically, the Bering Sea lies between 52° and 66° N, and 162° E and 157° W. The narrow (85 km long) and shallow (<42 m deep) passage of the Bering Strait connects the Bering Sea to the more northern Chukchi Sea and the Arctic Ocean to the north. The sea area covers almost 3 million km² and is divided almost equally between a deep basin in the southwest and a large, extensive continental shelf in the east and north. The eastern continental shelf is 1200 km in length, exceeds 500 km in width at its narrowest point, and is the widest continental shelf outside the Arctic Ocean (Coachman, 1986). The shelf is a featureless plain that deepens gradually from its extensive shoreline to the shelf break at about 170 m depth. There are very limited commercial fisheries in the Chukchi Sea or the Arctic Ocean north of the Bering Strait due to a known lack of resources, operating difficulties, and distance from markets. Marine mammal populations are locally important for subsistence use.

13.5.2. Fish stocks and fisheries

This section describes the life history characteristics, distribution, and trends in abundance and fisheries for the main species which are or have been the subject of important fisheries or which are important as forage fish for such species. Catch records for the major groundfish species of the eastern and western Bering Sea are shown by species in Figs. 13.34 and 13.35 respectively.

13.5.2.1. Capelin

In the Bering Sea, adult capelin only occur near shore during the month surrounding the spawning run. In other months they occur far offshore. In the eastern Bering Sea capelin occur in the vicinity of the Pribilof

Islands and the continental shelf break; in the western Bering Sea they occur in the northern Anadyr Gulf and near the northwestern Kamchatka coast. The seasonal migration may be associated with the advancing and retreating sea-ice edge. In the eastern Bering Sea, sea ice retreats during summer. As a coldwater species, capelin may migrate in close association with the retreating ice edge resulting in the summer capelin biomass located in the northern Bering Sea, an area not covered by surveys and with very little commercial fishing. Capelin aggregations near the northwestern Kamchatka coast have a stable distribution over the warm season. It is reported that the biomass of capelin and smelt grows in periods of climatic transition, when the abundance of other common pelagic fish (walleye pollock and herring) are low in the western Bering Sea (Naumenko et al., 1990). Capelin biomass was estimated at 200 000 t on the western Bering Sea shelf between 1986 and 1990. Their biomass may be much larger on the expanded eastern shelf. Nevertheless, capelin are not commercially exploited in the Bering Sea. In Russia, some attempts were made to include capelin and polar cod in a commercial fishery in the mid-1990s. Capelin are a major component of the diets of marine mammals feeding along the ice edge in winter (Wespestad, 1987) and of seabirds in spring.

13.5.2.2. Greenland halibut

In the Bering Sea, Greenland halibut (commonly known as Greenland turbot) spend the first three or four years of life on the continental shelf after which they migrate to deep waters of the continental slope where they live as adults (Alton et al., 1988; Shuntov, 1970; Templeman, 1973). Although tagging studies show that they undergo feeding and spawning migrations in the North Atlantic Ocean, it is unknown to what extent this happens in the Bering Sea. A slow-growing and long-lived species, Greenland halibut reach over 100 cm in length and 20 years of age in the Bering Sea. Greenland halibut are a valuable commercial product and have been caught in trawling operations and by longlines. Catches of Greenland halibut and arrowtooth flounder were reported together in

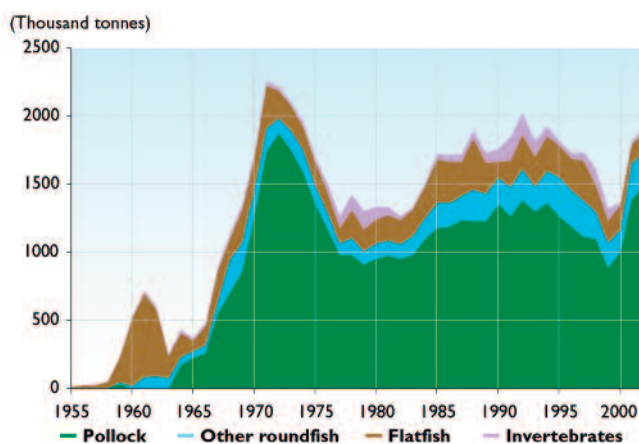


Fig. 13.34. Catch by species from the eastern Bering Sea, 1955–2002 (NPFMC, 2004).

the 1960s; combined catches ranged from 10 000 to 58 000 t per year with an average annual catch of 33 700 t. The Greenland halibut fishery intensified in the 1970s with catches of this species peaking between 1972 and 1976 at 63 000 to 78 000 t per year, primarily taken by distant-water trawl fleets from Japan. Catches declined after implementation of the Magnuson Fishery Conservation and Management Act (FCMA) in 1977, where the US fisheries jurisdiction was extended to 200 nm from the coast. However, catches were still relatively high in 1980 to 1983 with an annual range of 48 000 to 57 000 t. After that, trawl harvest declined steadily and averaged 8000 t between 1989 and 2000. This decline is mainly due to catch restrictions placed on the fishery because of declining recruitment and market conditions. In the western Bering Sea, Greenland halibut were lightly exploited due to low stock abundance before the FCMA took effect in the eastern Bering Sea. In 1978, a Greenland halibut fishery began on the northwestern continental slope, mostly by longlines. Annual harvest varied from 2010 to 6589 t between 1978 and 1990 with part of the harvest resulting from bycatch in the Pacific cod longline fishery. Since the early 1990s, Greenland halibut stock abundance and catches have declined. Resource assessment surveys on the continental shelf in 1975 and between 1979 and 2002 showed that intermediate size Greenland halibut (40–55 cm) were present throughout the region from 50 to 200 m depth during the late 1970s and early 1980s (Alton et al., 1988). By 1985 and 1986 the distribution range had decreased such that Greenland halibut were only encountered in the area to the west and south of St. Matthew Island and at much reduced densities. Since then, fish of this size range have only been caught in small quantities in the northern part of the survey area. It is unknown whether environmental conditions in the late 1970s and early 1980s were favorable for strong recruitment of Greenland halibut and levels have since returned to more normal recruitment levels, or whether there has been reduced recruitment to

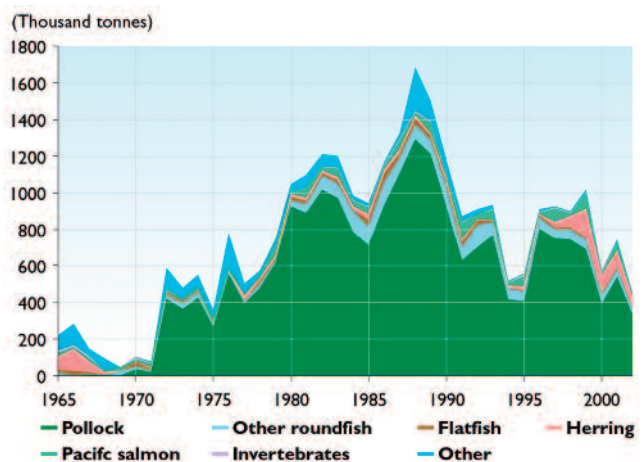


Fig. 13.35. Catch by species from the western Bering Sea, 1965–2002 (1965–1993 data from Committee on the Bering Sea Ecosystem, 1996; 1994–2003 data from the TINRO-Center archive, Vladivostok, Russia).

this stock since the mid-1980s. However, stock assessment models suggest a declining population since 1985 (Ianelli et al., 2001). Greenland halibut are widely distributed in the western Bering Sea but are not abundant there. The most significant Greenland halibut aggregations occur on the outer continental shelf and slope along the Korjak coast (Borets, 1997; Novikov, 1974). Survey results indicate that Greenland halibut abundance was higher in the northern Bering Sea in the 1990s than in the 1980s. However, the total biomass and overall distribution of this flatfish decreased in the Bering Sea region as a whole.

13.5.2.3. Shrimp

Pandalid shrimp (primarily *Pandalus jordani*) are widely distributed along the outer third of the eastern continental shelf where they are consistently caught in resource assessment trawl catches in small numbers. Humpy shrimp (*P. goniurus*) are distributed throughout the northern Bering Sea shelf and the Anadyr Gulf, in contrast to northern shrimp (*P. borealis*), which are much less abundant. Northern shrimp were the first commercially exploited shrimp in the Bering Sea after aggregations were discovered on the outer shelf north of the Pribilof Islands in 1960 (Ivanov, 1970). This fishery was conducted by Japanese vessels and peaked at 31 600 t in 1963. After that the northern shrimp stock declined sharply and commercial fishing ceased after 1967. Since then there has been no fishery for pandalid shrimp in the Bering Sea. Humpy shrimp aggregations were discovered in the Anadyr Gulf in 1967. A large-scale Russian trawl fishery harvested humpy shrimp in the northern Bering Sea in late 1960s to 1970s until they too became less abundant. Individual trawl catches of Humpy shrimp reached 10 t per 15 minute haul in the Anadyr Gulf, which became the catch value record in the world shrimp fishery. Humpy shrimp biomass was estimated at 350 000 t in the Anadyr Gulf in 1975. The annual Russian harvest of humpy shrimp exceeded 11 200 t in 1978 (Ivanov, 2001) but then declined due to the lack of a market for small-sized shrimp. Other pandalid shrimp species were also caught as bycatch in the pursuit of other target species.

13.5.2.4. Polar cod

Polar cod are caught in small amounts in resource assessment surveys at the northernmost survey stations on the eastern Bering Sea shelf. The southern extent of their summer distribution is related to bottom water temperature where they have been found to range from 59° N in 1999 (coldest year) to 62° N in 1996 (warmest survey year on record, except 2003). Since polar cod are found at such high latitudes, little information is available on their life history characteristics in the eastern Bering Sea and they are not pursued as a commercial species due to their low abundance. In the northwestern Bering Sea and the Chukchi Sea, polar cod are distributed at depths from 15 to 251 m (Tuponogov, 2001). A local fishery on polar cod exist-

ed there during years of high abundance (1967–1970; see Tuponogov, 2001).

13.5.2.5. Crabs

Snow crab and Tanner crab (*Chionoecetes bairdi*) are distributed throughout the eastern Bering Sea shelf with the exception of the shallow waters of Bristol Bay (Otto, 1998). The abundance of commercial size males was estimated at 183.5 million crabs in 1988 (Stevens et al., 1993). The distribution extends beyond the study area to the north and west, and to a small extent into the Gulf of Alaska. Owing to the relatively narrow shelf area of the western Bering Sea, snow crab abundance is notably less there. In 1969 the number of commercial size males was estimated at 25 million crabs (Slizkin and Fedoseev, 1989). An intensive directed fishery began for snow crab in the Bering Sea in the 1980s. They were initially caught incidental to the pursuit of red king crab until 1964 when both Japan and Russia increased their effort for this species due to a bilateral agreement with the United States to limit king crab catches (Davis, 1982). The combined Japanese–Russian catch of snow and Tanner crab increased until 1970 to 22 844 t (ADF&G, 2002), after which quotas were established for these nations' fishing fleets and the catch was sharply reduced. The American pot fishery (non trawl) began shortly after and catches increased during the 1980s to a peak in 1991 at 172 588 t. Catches rapidly declined with stock decrease but increased again in the mid-1990s as the snow crab stock condition improved. Since 2000, the stock has again declined and the commercial fishery is presently operating under reduced quotas. The Tanner crab fishery has been closed since 1997 in the eastern Bering Sea (NPFMC, 2002). In the western Bering Sea, there was no commercial snow crab or Tanner crab fishery in 2000 and 2001. Only insignificant catches (250 t) were allowed during research surveys. The results indicated some improvement in stock condition and a small commercial fishery was allowed in 2002.

13.5.2.6. Pollock

Walleye pollock (hereafter referred to as pollock) is the most abundant species within the Bering Sea and is widely distributed throughout the North Pacific Ocean in temperate and subarctic waters (Shuntov et al., 1993; Wolotira et al., 1993). Pollock are a semi-demersal schooling fish, which become increasingly demersal with age. They are a relatively short-lived (natural mortality estimated at 0.3) and fast-growing fish, females usually become sexually mature at four years of age. The maximum recorded age is about 22 years. The stock structure of Bering Sea pollock is not well defined. In the US part of the Bering Sea, pollock are considered to form three stocks for management purposes: the eastern Bering Sea stock (which comprises pollock occurring on the eastern Bering Sea shelf from Unimak Pass and to the US–Russian Convention line), the Aleutian Islands Region stock

(which occurs within the Aleutian Islands shelf region from 170° W to the US–Russian Convention line), and the Central Bering Sea stock (known as the Bogoslof Island pollock, and which are thought to be a mixture of pollock that migrate from the US and Russian shelves to the Aleutian Basin around the time of maturity). There are only two stocks in the Russian EEZ. Pollock currently support the largest fishery in US waters and comprise 75 to 80% of the annual catch in the eastern Bering Sea and around the Aleutian Islands. From 1954 to 1963, pollock were only harvested at low levels in the eastern Bering Sea. Directed foreign fisheries first began in 1964 after which catches increased rapidly during the late 1960s, and peaked in 1970 to 1975 when they ranged from 1.3 to 1.9 million t per year. Following a peak catch of 1.9 million t in 1972, catches were reduced through bilateral agreements with Japan and Russia. Since the US claim to extended jurisdiction in 1977, the annual average eastern Bering Sea pollock catch has been 1.2 million t, ranging from 0.9 million t in 1987 to nearly 1.5 million t (including the Bogoslof Islands area catch in 1990), while stock biomass has ranged from a low of 4 to 5 million t to highs of 10 to 12 million t (NPFMC, 2002). In 1980, US vessels began fishing for pollock and by 1987 were able to take 99% of the quota. Since 1988, only US vessels have been operating in this fishery and by 1991, the current domestic observer program for this fishery was fully operational. In the southwestern Bering Sea, the pollock fishery developed slowly during the mid-1960s stabilizing at 200 000 to 300 000 t in the latter half of the 1970s and the 1980s. After 1995, there was a reduction in harvest due to a decline in pollock stocks in the western Bering Sea. After that, the total pollock catch in the Russian EEZ was maintained by increasing fishing activity in the Navarin region between 1996 and 1999, and ranged from 596 000 to 753 000 t. The pollock catch subsequently declined in the northern region due to poor stock condition as well as to the application of precautionary approaches in pollock fishery management. The total pollock catch in the Russian EEZ declined from 1 327 000 t in 1988 to 393 180 t in 2000. Vessels of “third countries” began fishing in the mid-1980s in the international zone of the Bering Sea (commonly referred to as the “Donut Hole”). The Donut Hole is located in the deep water of the Aleutian Basin and is distinct from the customary areas of pollock fisheries, namely the continental shelves and slopes. Japanese scientists began reporting the presence of large quantities of pollock in the Aleutian Basin in the mid- to late 1970s, but large-scale fisheries did not begin until the mid-1980s. Thus, the Donut Hole catch was only 181 000 t in 1984, but grew rapidly and by 1987 exceeded the catch within the US Bering Sea EEZ. The outside-of-EEZ catch peaked in 1989 at 1.45 million t and then declined sharply. By 1991, the Donut Hole catch was 80% less than the peak value, with subsequent low catches in 1992 and 1993. A moratorium was enforced in 1993 and since then only minimal pollock catches have been harvested from the Aleutian Basin by resource assessment fisheries.

In response to continuing concerns over the possible impacts groundfish fisheries may have on rebuilding populations of Steller sea lions (listed as an endangered species after four decades of decline), changes have been made in regulations of the pollock fisheries in the eastern Bering Sea and at the Aleutian Islands. Pollock are important prey items for Steller sea lions and these changes were designed to reduce the possibility of competitive interaction of the fishery with Steller sea lions. For the fisheries, comparisons of seasonal fishery catch and pollock biomass distributions in the eastern Bering Sea led to the conclusion that the fishery had disproportionately high seasonal harvest rates within critical sea lion habitat which could lead to reduced sea lion prey densities. Consequently, management measures were designed to redistribute the fishery both temporally and spatially according to pollock biomass distributions (the underlying assumption being that the independently derived area-wide and annual exploitation rate for pollock would not reduce local prey densities for sea lions).

13.5.2.7. Pacific cod

Pacific cod are widely distributed from southern California to the Bering Sea, although the Bering Sea is the center of greatest abundance for this species. Tagging studies have shown that they migrate seasonally over large areas. In late winter, Pacific cod converge in large spawning concentrations over relatively small areas. Spawning takes place over a wide depth range (40–290 m) near the bottom. Eggs are demersal and adhesive. Estimates of natural mortality range from 0.29 to 0.99, while a value of 0.37 is used in the stock assessment model. Pacific cod have been found aged up to 19 years and females are estimated to reach 50% maturity at 5.7 years, corresponding to an average length of 67 cm. Pacific cod are the second largest Bering Sea groundfish fishery. Beginning in 1964, the Japanese trawl fishery for pollock expanded and cod became an important bycatch species and an occasional target species during pollock operations (in the early 1960s, a Japanese longline fishery harvested Bering Sea Pacific cod for the frozen fish market). By 1977, foreign catches of Pacific cod had consistently been in the 30 000 to 70 000 t range for a full decade (Thompson and Dorn, 2001). The foreign and joint venture sectors dominated catches through 1988, when a US domestic trawl fishery and several joint venture fisheries began operations. By 1989, the domestic sector was dominant and by 1991 the foreign and joint venture operations had been displaced entirely. Catches of Pacific cod since 1978 have ranged from 33 000 t in 1979 to 232 600 t in 1997 with an average of about 141 900 t. At present, the Pacific cod stock is exploited by a multiple-gear fishery, including trawl, longline, pot, and jig components (with the exception of 1992, the trawl catch was the largest component of the fishery (in terms of catch weight) between 1978 and 1996. Since 1997, the longline fleet has taken the greatest proportion of Pacific cod). Pacific cod were estimated

to be at low abundance levels in 1978 but experienced strong recruitment (age 3) in the early 1980s, which built the stock to high levels. The population biomass peaked at 2.5 million t in 1987 and then declined gradually to about half the peak value in 2001. In the western Bering Sea, the Russian cod fishery developed slowly and was mostly unsuccessful until the late 1960s. Several attempts were undertaken by Japanese and local fishermen in longline and trawl fisheries development in the 1920s and 1930s. Meanwhile, commercially significant Pacific cod concentrations were described by scientific expeditions. In particular, dense aggregations were found in the northwestern area in 1950 to 1952 near the Navarin Cape (Gordeev, 1954). This led to the organization of a special cod fishery expedition in 1968 (Vinnikov, 1996). Pacific cod harvest from this area ranged from 6500 to 24 500 t in the first years, and peaked at 117 650 t in 1986. In the 1990s, catches declined due to a restructuring of the fishery and, in recent years, from decreases in cod abundance in the North Pacific. Pacific cod biomass was estimated at 766 000 t in 1989 (Vinnikov, 1996) and had declined to 172 000 t by 2000.

13.5.2.8. Flatfish

The flatfish harvest and resource is much smaller in the southwestern Bering Sea with its relatively narrow shelf than in the eastern Bering Sea. A directed flatfish fishery began in the mid-1950s in the southwestern Bering Sea. This is a small-scale land-based fishery using Danish seines and, to a lesser extent, trawls. Yellowfin sole (*Limanda aspera*) comprise the main part of the flatfish harvest in the southwestern Bering Sea (72.7% of the predicted flatfish TAC for 2002 and about 74% in Danish seine catches in recent years) and its biomass is estimated at 78 000 t on the southwestern shelf compared to 1.6 million t in the eastern Bering Sea. Maximum catches in the southwestern Bering Sea, 32 000 and 20 000 t respectively, were registered in 1958 and 1959. The situation changed dramatically in 1960 and 1961 when the flatfish harvest fell to its lowest ever values (100 to 160 t). The stock condition improved over the following decades. By the mid-1960s catches had stabilized at approximately 6000 t per year which continued through 1974, after which they declined until the early 1980s. During 1996 to 2002, the flatfish catch in the southwestern Bering Sea varied from 6000 to 13 500 t. In terms of other flatfish species, Alaska plaice (*Pleuronectes quadrituberculatus*), rock sole (*Lepidopsetta bilineata*), and northern flathead sole (*Hippoglossoides robustus*) are the most important in the southwestern Bering Sea.

The abundance of yellowfin sole is low in the northwestern Bering Sea. The most important flatfish species is northern flathead sole, which accounts for about two-thirds of the total flatfish biomass, followed by Alaska plaice, and rock sole. A directed flatfish fishery did not begin in the northwestern region until the 1990s and never developed extensively. However, the

flatfish bycatch sometimes reached significant levels and between 1965 and 1984 ranged from 2440 to 29 140 t in the northwestern Bering Sea. The flatfish bycatch increased to 33 460 t in 1985 and 39 900 t in 1986, leveling off at 24 000 to 29 000 t over the next six years, and then declining to an average of 9700 t after 1993. A target flatfish fishery did not develop extensively, and the target catches remained less than the bycatch in the large cod and pollock fisheries.

In the eastern Bering Sea, yellowfin sole is distributed from British Columbia to the Chukchi Sea, into the western Bering Sea, and south along the Asian coast to about 35° N off the South Korean coast (Hart, 1973). In the Bering Sea, it is the most abundant flatfish species and is the target of the largest flatfish fishery in the United States. While also found in the Aleutian Islands region and the Gulf of Alaska, the center of abundance for this stock is on the eastern Bering Sea shelf. Adults are benthic and occupy separate winter and spring/summer spawning and feeding grounds. They overwinter near the shelf break at approximately 200 m depth and move into nearshore spawning areas as the shelf ice recedes (Nichol, 1997). Spawning is protracted and variable, beginning as early as May and continuing through August, occurring primarily in shallow water at depths less than 30 m (Wilderbuer et al., 1992). Eggs, larvae, and juveniles are pelagic and usually found in shallow areas. The estimated age at 50% maturity is 10.5 years with a length of about 29 cm (Nichol, 1994). The natural mortality rate is likely to be within the range 0.12 to 0.16, with a maximum recorded age of 33 years (Wilderbuer, 1997). Yellowfin sole have been caught with bottom trawls on the Bering Sea shelf every year since the fishery began in 1954. Between 1959 and 1962 yellowfin sole was overexploited by Japanese and Russian trawl fisheries when catches averaged 404 000 t annually. As a result stock abundance declined. Catches also declined to an annual average of 117 800 t between 1963 and 1971, declining further to an annual average of 50 700 t between 1972 and 1977. The yield in this latter period was partially due to the discontinuation of the Russian fishery. In the early 1980s, catches increased peaking at over 227 000 t in 1985. In the 1980s, there was a major transition in the characteristics of the fishery in the eastern Bering Sea. Before this, yellowfin sole were taken exclusively by non-US fisheries and these fisheries continued to dominate through 1984. However, US fisheries developed rapidly in the 1980s, and foreign fisheries were phased out. Since 1990, only domestic harvesting and processing has occurred. The 1997 catch of 181 389 t was the largest since the fishery became completely domestic, but decreased to 101 201 t in 1998. The 2000 catch totaled 83 850 t and the 2001 catch was 63 400 t. For many years in the 1990s the yellowfin sole fishery was constrained by closures in order to attain the bycatch limit of Pacific halibut allowed in the yellowfin sole directed fishery. Stock biomass has declined by 1 million t from the peak biomass observed in 1985 and was estimated at 1.6 million t in 2002.

13.5.2.9. Salmon

The Bering Sea is important habitat for many stocks comprising the five species of Pacific salmon during the ocean phase of their life history. Here, the various stocks intermingle from origins in Siberia, Alaska, the Aleutian Islands, Japan, Canada, and the US west coast. The earliest fisheries for salmon were probably indigenous subsistence fisheries in which salmon were captured returning to their native streams to spawn. During the 20th century there were three main fisheries for salmon in the Bering Sea: the Russian and Alaskan domestic fisheries, the Japanese high-seas gillnet and longline fishery, and the bycatch of salmon in the groundfish fisheries.

Salmon canneries first appeared on the Alaskan side of the Bering Sea in the late 1890s to process fish returning to Bristol Bay. It is reported that between 1894 and 1917 the Kvichak and Nushagak rivers flowing into Bristol Bay produced 10 million sockeye salmon (*Oncorhynchus nerka*) annually (Netboy, 1974). Purse seines and gill nets were the primary fishing gear in the early days of the fishery. Gill nets were hauled from the beach using horses, which were later replaced by engines, whereas the purse seine fishery started around 1915 with the advent of powered fishing craft. Purse seining continues to the present as the primary gear in a highly mobile fleet fishing near-shore, which assures the targeting of specific salmon stocks. Although all five species of Pacific salmon are present in Bristol Bay, sockeye salmon are the most abundant and have dominated the salmon catch for years. The Bristol Bay salmon catch for all species totaled 42 million fish in 1993, of which 41 million were sockeye salmon, the largest catch on record (fishery statistics from the Pacific salmon fishery on the western Bering Sea coast (eastern Kamchatka region) are available since 1906). On average, pink salmon (*O. gorbuscha*) contributed 73.8% of the Russian salmon catch in the western Bering Sea between 1952 and 1993, chum salmon (*O. keta*) 24.2%, sockeye salmon 1.3%, chinook salmon (*O. tshawytscha*) 0.6%, and coho salmon (*O. kisutch*) only 0.1% (Chigirinsky, 1994). Since 1989, the runs of pink salmon to the eastern Kamchatka coast have been in good condition in odd years. The historical highest catch totaled 83 640 t in 1999. The average pink salmon catch (38 390 t) for 1989 to 2001 is more than twice the average level of 15 996 t for 1952 to 1993 (Chigirinsky, 1994). Similarly, chum salmon catches were stable at 11 000 to 12 000 t in 2000 to 2001 compared to 5250 t for 1952 to 1993. The recent improved stock conditions coincide with new fishery regulations, which limit the chum salmon bycatch during the pink salmon fishery. The main sockeye salmon fishery in eastern Kamchatka results from the productive Kamchatka River, slightly south of the Bering Sea.

The Japanese high-seas gillnet and longline salmon fishery expanded into the Bering Sea in 1952 with three motherships and 57 catcher boats, which

increased to 14 motherships and 407 catcher boats by 1956 (Netboy, 1974). (Motherships are large vessels to which catcher boats deliver their catches and where the fish are processed for human consumption or reduced to meal and oil, they also carry fuel and other provisions for the catcher fleet.) The peak catch of 116 200 t occurred in 1955 and annual catches ranged from 71 000 to 87 000 t between 1957 and 1977 (Harris C., 1989). Sockeye, chum, and pink salmon comprised 95% of the catch in this fishery, which ceased operations in 1983. The bycatch of salmon in the commercial groundfish fisheries is of less importance than for the directed fisheries, but still accounts for fishing mortality important to resource managers. Observer sampling of the groundfish fishery indicates that chinook salmon are more frequent in bottom trawls and the other species more frequent in the pelagic trawls (Queirolo et al., 1995). In the western Bering Sea, primarily chinook and chum salmon were present in the bottom trawl catches during research surveys in 1974 to 1991 (Radchenko and Glebov, 1998).

13.5.2.10. Marine mammals

The Bering Sea contains a rich and diverse assemblage of marine mammals, including north temperate, arctic and subarctic species. Twenty-six species from the orders Pinnipedia (sea lions, walrus, and seals), Cetacea (whales, dolphins, and porpoises), and Carnivora (sea otter), and polar bears are present at varying times of the year (Lowry and Frost, 1985). Some species are resident throughout the year (e.g., harbour seal, Steller sea lion, sea otter (*Enhydra lutris*), beluga whale (*Delphinapterus leucas*), and Dall's porpoise (*Phocoenoides dalli*)) while others migrate into the Bering Sea during the summer on feeding excursions. Arctic species including polar bears, walrus, ringed and bearded seals (*Erignathus barbatus*), and bowhead whales (*Balaena mysticetus*) mostly occur in the Bering Sea during autumn and winter and are associated with the presence of seasonal sea ice. Most of the marine mammal species are found over the continental shelf and in coastal areas, although five whale species reside in the deep/oceanic waters of the Bering Sea basin (Lowry et al., 1982).

Harvesting of marine mammals has occurred since at least 1790, the first year when northern fur seal harvests were recorded (Langer, 1980). The harvest peaked in the 1870s at over 100 000 animals and was at levels exceeding 40 000 males annually until 1985 when the northern fur seal commercial harvest was stopped and only subsistence hunting by Aleuts was allowed in the Pribilof Islands. In the Russian EEZ, fur seal hunting has seen many changes since the mid-1980s. Since 1987, the experimental hunting of "silver" fur seals (aged 3–4 months) has been conducted on the Commander Islands (Boltnev, 1996). The harvest rate was established at 60% from the average annual male abundance for 1987 to 1989. Actually, significantly less than 50% were killed, which has further decreased to

less than 30% since 1989. The number of animals killed decreased from 6700 in 1995 to 3000 in 1999 and 2180 in 2000. The declining harvest is related to the decline in the fur seal population and the negative effect of disturbance by hunters on seal reproduction. All fur seal hunting is presently restricted to Bering Island. Bachelor males aged from two to five years were hunted on Medny Island until the mid-1990s (2134 animals were killed in 1994) and this area was then closed to harvesting in 1995. Whaling spread to the Bering Sea in the mid-19th century when large numbers (2500 in 1853) of bowhead whales were taken (NMFS, 1999). This harvest continued for 50 years until the bowhead whale population became depleted. The current subsistence harvest totals 60 to 70 whales annually. Some species, such as humpback and grey whales (*Eschrichtius robustus*), which are present in the Bering Sea in summer, were historically harvested during the winter near Hawaii and California and in waters off the Chukotski Peninsula (about 130 to 135 whales). Kenyon (1962) reported that Steller sea lions were very abundant in the Pribilof Islands when discovered in 1786, but were soon overhunted. After protective measures were taken, numbers grew from a few hundred in 1914 to about 6000 in 1960. The population has since declined to low numbers and has been the subject of extensive research to find the cause of the decline.

In the United States, stock assessment information on the 39 stocks of the 24 species of marine mammals in the Bering Sea are used to classify each stock as either strategic, non-strategic, or not available (Angliss et al., 2001). Strategic stocks are those considered threatened, endangered, or depleted under US law. The strategic stocks include: northern fur seal, sperm whale, humpback whale, fin whale, the North Pacific right whale (*Eubalaena japonica*), and the bowhead whale. Three Bering Sea stocks also have further designations: northern fur seals are designated as depleted under the Marine Mammal Protection Act, and the western stock of Steller sea lion is listed as endangered under the Endangered Species Act, as is the bowhead whale. Nine of the 39 marine mammal stocks are estimated to be increasing, five are stable, three are declining, and the status of the others is unknown. Subsistence harvest is allowed for three species: northern fur seals, beluga, and bowhead whales. In Russia, marine mammal populations are classified as commercial, non-commercial, or protected. Protected species include all whales and dolphins (with the exception of grey whales, whaled by indigenous people for subsistence), sea otter, and polar bear. Some commercial quota is established for beluga whales, but is not taken. Walrus, spotted seal (*Phoca largha*), ringed seal, and ribbon seal (*P. fasciata*) are hunted in the north-western Bering Sea. However, their harvest has been relatively low since the cessation of ship-based hunting operations. In 1998 to 2000, the harvest was less than 60% of the established TAC on different seal species and averaged 32.8%.

13.5.3. Past climatic variations and their impact on commercial stocks

Climate change primarily influences ocean water temperatures through the regulation of synoptic atmospheric processes and water exchange between the western Bering Sea and the Pacific Ocean. Four physical processes determine the change in ocean climate regimes in the North Pacific (Schumacher, 2000): the lunar tidal cycle, variations in solar radiation (Davydov, 1972; Van Loon and Shea, 1999), changes in the North Pacific circulation that affect air–sea exchange of heat and, finally, changes in the momentum of the Aleutian Low atmospheric pressure pattern. These processes generate a subset of basin-scale factors, each of which contributes to the oceanographic conditions of the Bering Sea. The Aleutian Low is an example of an atmospheric activity center in the northern-hemisphere (Beamish and Bouillon, 1993; Francis et al., 1998; Hollowed and Wooster, 1992; Latif and Barnett, 1994; Luchin et al., 2002; Wooster and Hollowed, 1995). Water inflow and atmospheric forcing appear to serve as links in the signal transfer chain for the Bering Sea region. Their functioning reflects the direct effect of the atmosphere on the marine environment through the temperature regime of shelf waters, and the undirected oceanographic phenomena offshore. The signal propagates through changes in the general current pattern and tidal wave parameters, which determine the intensity of the water exchange between the shelf and open sea regions.

The direct effects of atmospheric forcing resulting from climate variations are very important to the physical oceanographic dynamics of the eastern Bering Sea shelf, which has a characteristically sluggish mean flow and is separated from any direct oceanographic connection to the North Pacific Ocean by the Alaska Peninsula. Therefore, linkages between the eastern Bering Sea shelf and the climate system are mainly a result of the ocean–atmosphere interaction (Stabeno et al., 2001). Climate variations in this region are directly linked to the location and intensity of the Aleutian Low pressure center which affects winds, surface heat fluxes, and the formation of sea ice (Hollowed and Wooster 1995). The pressure index shows eight statistically significant

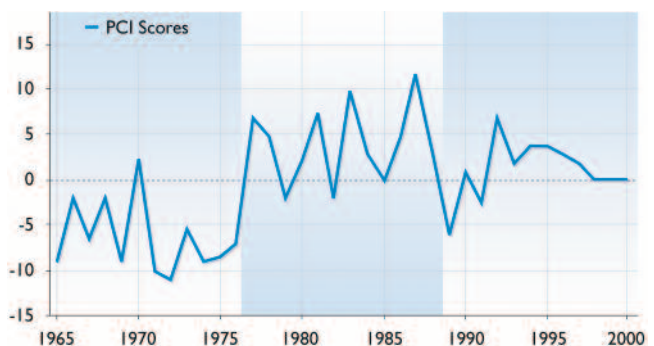


Fig. 13.36. Regime shifts in the Bering Sea, 1968–2000 (composite of 31 physical indicators: Hare and Mantua, 2000).

shifts, alternating between cool and warm periods, over the 20th century, which occurred on roughly decadal time scales (Overland et al., 1999). A well-documented shift (Trenberth 1990; Hare and Mantua, 2000) from a cool to a warm period occurred between 1977 and 1989, which coincided with the commencement of fishery-independent sampling programs and fishery catch monitoring of major groundfish species. Information from the contrast between this period and the prior and subsequent cool periods (1960–1976 and 1989–2000) forms the basis of the following discussion of the response of eastern Bering Sea species to climate-induced system changes (Fig. 13.36).

13.5.3.1. Effects on primary productivity

The influx of Pacific waters northward into the western Bering Sea results in a warming effect. The dynamics of the environmental conditions of the Bering Sea offshore zone and the relatively narrow western shelf are largely determined by the periodic behavior of current patterns (Shuntov and Radchenko, 1999). The direction and velocity of these currents coincide with changes in the atmospheric circulation pattern, effects which are manifested through the change in intensity of the inflow of North Pacific Ocean water. From 1977 to 1989, a period of enhanced atmospheric transport, an intensification of currents into the Bering Sea resulted in enhanced fluctuations in the thermal properties of the system towards a warmer state. During those years, the effect of horizontal water movement and mixing on primary production was almost as important as vertical mixing due to the renewed supply of nutrients necessary for phytoplankton blooms. According to long-term data series, the highest concentrations of spring-time nutrients in the upper mixed layer were observed in the Aleutian straits, over the continental slope, and in areas where the influx of North Pacific water was present. The enhanced rate of primary production may be as much as 10 to 13 g C/m² per day (Sapozhnikov et al., 1993), which is more than can be used by the zooplankton and microheterotrophs (especially in the western Bering Sea shelf). The unutilized primary production accumulates at the upper boundary of subsurface waters, which is relatively cold for microheterotrophs, and the organic matter gradually rises into the upper layers in divergence zones and cyclonic eddies during the warm season. Therefore, favorable conditions for plankton development during spring, both from heating and nutrient supply from Pacific waters, may cascade through higher trophic levels and play a large role in determining the total biological productivity for the year (Radchenko et al., 2001).

Changes in atmospheric climate are mainly transmitted through the eastern Bering Sea physical environment to the biota through wind stress (Francis et al., 1998) and annual variation in sea-ice extent (Niebauer et al., 1999; Stabeno et al., 2001). These mechanisms directly alter the timing and abundance of primary and secondary production through changes in salinity, mixed-layer depth,

upwelling, nutrient supply, and vertical mixing. These environmental changes vary at a decadal scale and resulted in higher levels of primary and secondary production during the warm period of 1977 to 1988 than in the earlier cool period (Brodeur and Ware, 1992; Hollowed et al., 2001; Luchin et al., 2002; Minobe, 1999; Polovina et al., 1995; Sugimoto and Tadokoro, 1997). During periods of low summer storm activity in the Bering Sea region, as in 1993 to 1998, water column stratification increases. Heating of a thin surface layer above the seasonal thermocline prevents vertical nutrient transport from the underlying, stratified layers, which reduces levels of primary production and biological productivity in the Bering Sea (Shuntov et al., 1997), despite warmer surface water temperature. This is consistent with the total heat budget of the upper layer of the Bering Sea, which was lower in 2002 than in the warmer period of the previous decade (Fig. 13.37).

In the relatively warm years of 1997 to 1998, there was significant growth in euphausiid biomass in the western Bering Sea (Radchenko et al., 2001) suggesting that warmer waters provide favorable conditions for the survival and growth of some subarctic zooplankton species. Crustacean growth rates have also been found to be above average in warm conditions (Vinogradov and Shushkina, 1987; Zaika, 1983). This enhanced growth rate allows for a longer maturation period and spawning season. A meta-analysis of marine copepod species indicates that growth rate is positively correlated with increasing temperature and that generation time decreases, allowing more productivity in warmer climates (Huntley and Lopez, 1992). The oceanographic conditions in the epipelagic layer are not considered crucial for copepod reproduction in the Bering Sea, since copepod species reproduce in relatively stable deeper layers below 500 m. However, calanoid copepod biomass was much higher in the eastern Bering Sea

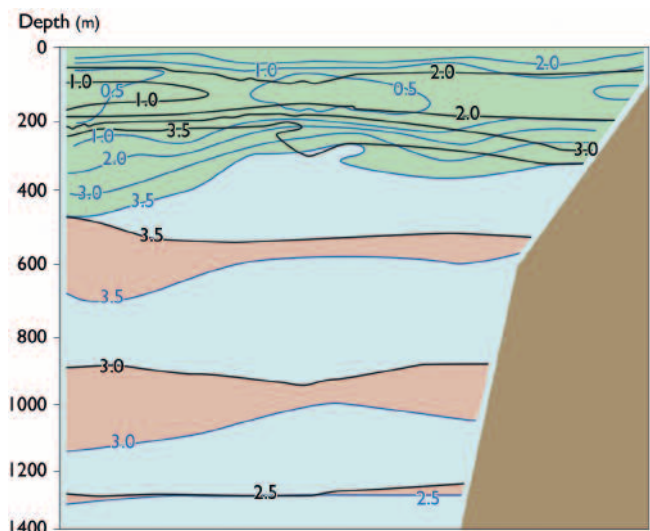


Fig. 13.37. Comparison of vertical temperature (°C) sections across the Kamchatka Strait on August 13–14, 1991 (black lines, after Stabeno et al., 2001) and June 27, 2002 (blue lines, TINRO-Center data, Vladivostok). Pink area indicates the layers where the water temperature was higher in 2002, green area – in 1991.

middle shelf in warm years (Smith and Vidal, 1986), probably due to higher growth rates. These findings suggest that climate change to a warm period enhances ecosystem productivity from the lower trophic levels, particularly for planktonic crustaceans.

13.5.3.2. Effects on sea-ice formation, distribution, and longevity

If it is assumed that any future climate change maintains the scale and periodicity of recent climate change events in the Bering Sea, then the period of meridional-type predominance in the wind transport above the Bering Sea, which began in the early 1990s, may last for 10 to 12 years before changing to a period of enhanced zonal transport. During the warm 1980s the zonal pattern of atmospheric circulation predominated (Luchin et al., 1998), as was the case in the 1920s and 1930s (Shuntov and Vasilkov, 1982). Periods of decreased zonal atmospheric circulation index (Girs, 1974) are characterized by colder arctic air masses over the Bering Sea region and a decrease in air temperature. The transitional 1989 to 1990 years were also characterized by a decrease in the zonal atmospheric circulation pattern above the far-eastern seas (Glebova, 2001; Overland, 2004).

Sea-ice distribution and residence time are frequently regarded as integral with the thermal regime of the Bering Sea pelagic zone (Ikeda, 1991; Khen, 1997; Luchin et al., 2002; Niebauer et al., 1999; Overland, 1991; Wyllie-Echeverria and Ohtani, 1999). The dynamics of sea-ice conditions directly depend on the intensity of the shelf water cooling in winter, wind direction, and water exchange between the shelf and the open sea. Similarly, ice conditions determine the intensity and degree of winter convection, the formation of cold near-bottom shelf waters, and the temperature distribution of surface and intermediate layers. The extent and timing of the sea ice also determine the area where cold bottom water temperatures will persist throughout the following spring and summer. This area of cold water, known as the “cold pool”, varies with the annual extent and duration of the ice pack, and can influence fish distributions. For example, adult pollock have shown a preference for warmer water and exhibit an avoidance of the cold pool (Wyllie-Echeverria, 1995) such that in colder years they utilize a smaller proportion of the shelf waters and in warm years have been observed as far north as the Bering Strait and the Chukchi Sea.

13.5.3.3. Oscillating control hypothesis

During warm periods, favorable environmental conditions after the seasonal sea-ice retreat can result in a significant increase in the Bering Sea biological productivity. In contrast, physical factors during cold periods adversely affect zooplankton growth and biomass, and thus the viability of the pelagic fish juveniles feeding on this production. The “oscillating control hypothesis”

proposes that the southeastern Bering Sea pelagic ecosystem alternates between primarily bottom-up control in cold regimes and primarily top-down control in warm regimes (Hunt et al., 2002). Late ice retreat (late March or later) leads to an early, ice-associated bloom in cold water (as occurred in 1995, 1997, and 1999), whereas no sea ice, or early ice retreat before mid-March, leads to an open-water bloom in May or June in warm water (as occurred in 1996, 1998, and 2000). Zooplankton, particularly crustaceans, are sensitive to water temperature. In years when the spring bloom occurs in cold water, low temperatures limit the production of zooplankton, the survival of larval and juvenile fish, and their recruitment. Such a phenomenon may be important for large piscivorous fish, such as walleye pollock, Pacific cod, and arrowtooth flounder. When continued over decadal scales, this situation leads to bottom-up limitation and a decreased biomass of piscivorous fish. Alternatively, in periods when the bloom occurs in warm water, zooplankton populations should grow rapidly, providing plentiful prey for larval and juvenile fish. In the southeastern Bering Sea, important changes in the biota since the mid-1970s include a marked increase in the biomass of large piscivorous fish and a concurrent decline (due to predation) in the biomass of forage fish, including age-1 walleye pollock, particularly over the southern part of the shelf (Hunt et al., 2002).

13.5.3.4. Effects on forage fish

Spatial distributions of forage fishes including herring, capelin, eulachon (*Thaleichthys pacificus*), and juvenile cod and pollock indicate temperature-related differences (Brodeur et al., 1999; Wyllie-Echeverria and Ohtani, 1999). Annual capelin distributions exhibit an expanded range in years with a larger cold pool and contract in years of reduced sea-ice cover. Although the productivity of capelin stocks in relation to temperature is not known, population growth of this relatively cold-water dwelling fish is not expected under the conditions of a warm regime. As discussed, capelin biomass increased when the abundance of walleye pollock and Pacific herring were low in the western Bering Sea (Naumenko et al., 1990), possibly due to a reduction in predation pressure of these species on capelin larvae. The eastern Bering Sea herring stocks showed improved recruitment in warm years (Williams and Quinn, 2000), similar to herring stocks on the Pacific coast of the United States where the timing of spawning is also temperature related (Zebdi and Collie, 1995). In the western Bering Sea, Pacific herring have also demonstrated a dependence on reproductive success related to the thermal conditions of coastal waters. However, herring stock increase and large-scale fishery restoration are related to the “historically most abundant” (Naumenko, 2001) year class, which appeared in the anomalously cold year of 1993. Generally, strong herring year classes have appeared in the western Bering Sea in years with high sea surface temperatures in May but the lowest sea surface temperatures in June

(Naumenko, 2001). After 2000, herring biomass decreased in the western Bering Sea but still exceeds the average level for the last warm period (1977–1989). In general, the distributions of all forage species from trawl surveys in a cold year (1986) were more widespread and with greater overlap among species than in a warm year (1987) (Brodeur et al., 1999).

13.5.3.5. Effects on pollock stocks

Pollock larvae concentrate in the water mass under the seasonal thermocline (Nishiyama et al., 1986). More productive year classes of pollock coincided with better nursery conditions for their larvae, which were related to a well-developed thermocline (pycnocline), large biomass of copepod nauplii, and low abundance of predators (Bailey et al., 1986; Nishiyama et al., 1986; Shuntov et al., 1993). The first two factors are related to warm conditions in the Bering Sea epipelagic layer. Age-1 pollock may also be distributed throughout the cold pool and move between water masses. During cold conditions, predation pressure on age-1 pollock is intense by their major piscine predators (adult pollock, arrowtooth flounder, and Pacific cod). As the cold pool reduced, predation on age-1 pollock increased due to overlapping distributions of Greenland halibut, yellow Irish lords (*Hemilepidotus jordani*), and thorny sculpins (*Icelus spiniger*) (Wyllie-Echeverria and Ohtani, 1999). The total biomass of the first group of predators was much higher in the 1980s than the second group (Aydin et al., 2002) and has remained higher until the present, despite some declines in western Bering Sea walleye pollock and cod stocks. In addition, the second group of predators comprises relatively small-sized fish (except Greenland halibut) and age-1 pollock could avoid predation through higher growth rates during warm conditions. In the relatively warm 1980s, strong year classes of pollock occurred synchronously throughout the Bering Sea (Bulatov, 1995) and coincided with above-normal air and bottom temperatures and reduced sea-ice cover (Decker et al., 1995; Quinn and Niebauer, 1995). These favorable years of production were due to high juvenile survival and are related to how much cold water habitat is present (Ohtani and Azumaya, 1995), the distribution of juveniles relative to the adult population to avoid predation (Wespestad et al., 2000), and enhanced rates of embryonic development in warmer water (Haynes and Ingell, 1983). Strong year classes of pollock were also observed in the eastern Bering Sea in the 1990s (Stepanenko, 2001), which may be related to the higher frequency of ENSO events, which contributed to heat transport throughout the region (Hollowed et al., 2001). However, there were no strong year classes of pollock in the western Bering Sea in the 1990s. This could be due to a general cooling of the Bering Sea climate and the oceanographic regime in a period of less intensive Pacific water inflow in the 1990s. The pelagic layer heat budget may need to be similar to that of the late 1970s and 1980s for the pollock reproduction conditions to improve in the Bering Sea as a whole.

13.5.3.6. Effects on other groundfish

Time series of recruitment and stock biomass have been examined for evidence that climate shifts induce responses in the production of groundfish species in the Bering Sea and North Pacific Ocean (Hollowed and Wooster, 1995; Hollowed et al., 2001). Even though results from these studies can be highly variable, strong autocorrelation in recruitment, associated with the significant change in climate in 1977, was observed for salmonids and some winter-spawning flatfish species. Substantial increases in the abundance of Pacific cod, skates, flatfish, and non-crab benthic invertebrates also occurred on the Bering Sea shelf in the 1980s as evidenced from trawl survey CPUE (Connors et al., 2002). This warm period was characterized by larger research catches and a change in the benthic invertebrate species composition from a system largely dominated by crabs to a more diverse mix of starfish, ascidians, and sponges.

In the southwestern Bering Sea, transition from the relatively warm period of 1977 to 1989 to the subsequent cool period was also evident in the groundfish community. The proportion of Pacific cod decreased from 80% in 1985 to 12 to 26.3% in the 1990s, while sculpin (8.2% in 1985) and flatfish (9.3% in 1985) proportions increased by 15.1 to 31.5% and 24.2 to 39.6%, respectively (Gavrilov and Glebov, 2002). Anthropogenic factors can also affect the state and dynamics of benthic communities. For example, large fishery removals of red king crab occurred in the 1970s and may have contributed to the reorganization of the benthos in the eastern Bering Sea. The climatic change related to recruitment success for winter-spawning flatfish may be associated with cross-shelf advection of larvae to favorable nursery areas, instead of with water temperature (Wilderbuer et al., 2002).

Sea-ice conditions and water temperatures can influence fishery effectiveness in addition to fish stock distributions and abundance. Coldwater effects have been observed in the behavior of flatfish species that may cause changes in the annual operation of the fishery. Because cold water causes slower metabolism in high latitude fish stocks, spawning migrations of yellowfin sole may be delayed in cooler years (Wilderbuer and Nichol, 2001), which can alter the temporal and spatial characteristics of the fishery. In addition, high catch rates have been obtained by targeting yellowfin sole close to the retreating ice edge, which has a high temporal variability and in warm years only occurs in areas north of the spring distribution of yellowfin sole. The catch process can also be affected as it is believed that flatfish bury themselves in muddy substrate during cold years and so become less vulnerable to herding by the sweep lines of bottom trawls (Somerton and Munro, 2001). This would result in lower catch rates in cold years for shelf flatfish species. These temperature-related behavior effects may also occur in other commercial species, particularly in pelagic fish, which react to avoid capture (Sogard and Olla, 1998).

13.5.3.7. Effects on salmon

Throughout their century-long exploitation, Alaskan salmon stocks have had periods of high and low production which persist for many consecutive years before abruptly reversing to the opposite production state. These production regimes coincide with low frequency climate changes in the North Pacific Ocean and the subarctic Bering Sea (i.e., the Pacific Decadal Oscillation and the Aleutian Low Pressure Index). In the 1930s and early 1940s, and then again in the late 1970s, Bering Sea salmon catches reached high levels during warm temperature regimes in their oceanic habitat. It is hypothesized that improved feeding conditions may prevail during warm oceanic regimes (Hare and Francis, 1995). There is also evidence of an upper thermal tolerance for salmon species that has set limits on their distributions (Welch et al., 1995), but it is doubtful that this effect would occur in the Bering Sea because the historical temperature range there is much lower.

13.5.3.8. Effects on crab stocks

The three species of crab that inhabit the eastern Bering Sea shelf (red king crab, Tanner crab, and snow crab) exhibit highly periodic patterns of increased abundance. Rosenkranz et al. (2001) investigated five hypotheses on factors affecting year class strength of Tanner crab in Bristol Bay in order to understand these patterns. They determined that anomalously cold bottom temperatures may adversely affect the Tanner crab reproductive cycle and that northeast winds may promote coastal upwelling, which advects larvae to regions of fine sediments favorable for survival upon settling. Incze et al. (1987) linked low densities of copepods inside the 70 m isobath of Bristol Bay with low abundance of Tanner crab larvae. An examination of recruitment patterns of red king crab in relation to decadal shifts in climate indicates that the Bristol Bay stocks are negatively correlated with the deepening of the Aleutian Low and warmer water temperatures (Zheng and Kruse, 2000). Red king crabs were also moderately exploited during the late 1970s, which contributed to the population decline.

13.5.4. Possible impacts of climate change on fish stocks

Given the present state of knowledge of complex marine ecosystems such as in the Bering Sea, it is not possible to predict with any certainty the effects of future atmospheric forcing, in this case increased sea surface temperature, on commercial fish and invertebrate species. Evaluation of a future state of nature would require knowledge of the future values of many ocean-atmosphere parameters to describe how these changes would be manifested in upper trophic level commercial stocks. These parameters include storm activity and frequency, wind direction and intensity, shelf stratification characteristics, effects on circulation and transport activity, sea level pressure (location and intensity of the

Aleutian Low pressure system), and precipitation as well as projections of sea surface temperature.

Three future climate scenarios are considered for the Bering Sea: no change from present conditions; moderate warming; and considerable warming.

13.5.4.1. No change

Under the no-change scenario the Bering Sea climate will continue to exhibit decadal-scale shifts alternating between warm and cool periods. These shifts in temperature regime have been shown to favor some species while their effect on others is unclear (section 13.5.3.4 to 13.5.3.8).

Under the present US and Russian management systems, it is expected that fish and invertebrate populations would be at or rebuilt to target spawning biomass levels as dictated by the management plans. This should result in an increase in total catches from the Bering Sea. Over the long term, however, a large total average increase is unlikely, but could nevertheless be considerable in individual cases.

13.5.4.2. Moderate warming

A moderate warming scenario can be developed by extrapolating trends characterizing the decadal-scale variability in the key physical factors influencing the Bering Sea ecosystem. On the basis of a moderate increase in air temperature (of 1 to 3 °C) and a general warming of the upper pelagic zone, several changes are likely:

- an increase in the zonal type repetition of atmospheric circulation for the early 2000s and for the period of the next 11-year cycle of solar radiation;
- an increase in storm activity and wind-induced turbulence for the same period;
- a gradual increase in water exchange with the Pacific Ocean, reaching a maximum in 2015 to 2020; and
- reduced sea ice, accelerated by an increase in air temperature, for the next 10 to 20 years after which time sea ice might increase again.

Variability in solar radiation correlates with many phenomena (Schumacher, 2000). It is a potential forcing mechanism for decadal-period oscillations of the coupled air-ice-sea system in the northern-hemisphere (Ikeda, 1990). Changes in solar fluxes correlate with change in the height of an atmospheric pressure surface in the troposphere of the northern-hemisphere (correlation coefficient = 0.72; Van Loon and Shea, 1999). Spectral maxima occur roughly every 7–17 (with an average of 11) and 22 years. The North Pacific Index also has phases similar to those noted for changes in solar radiation (Minobe, 1999). Storm activity and wind-induced turbulence of the sea surface layer are determined by the tracks and strength of cyclones, which are in turn deter-

mined by the nature of the pressure field. In the Bering Sea, a strong Aleutian Low is the source of most of the storm energy, and results in intense mixing of the sea surface layer in winter. Strengthening of the Aleutian Low occurs in years of zonal air transfer predominance (Shuntov, 2001). Such interrelations enable a prediction of high storm activity and wind-induced turbulence for all of the next 11-year cycle of solar activity.

Available information for the recent warm period in the Bering Sea suggests that primary productivity, and thus carrying capacity, would be enhanced under the warming scenario. However, because mixed-layer depth and water movements are not available for this scenario, the extent of this increase cannot be predicted owing to uncertainties concerning the renewal of the nutrient supply essential for sustaining the phytoplankton and zooplankton blooms. Also, as spring blooms are associated with the ice edge, a decrease in sea-ice extent associated with climate warming could

delay the onset of primary production in spring (Hunt et al., 2002). High water-column stability, which occurs at the ice edge during ice retreat, also supports intense phytoplankton blooms.

Recent studies on phytoplankton sinking velocities show that diatom cells sink more quickly than flagellates, which are lighter (Huisman and Sommeijer, 2002). Thus, it is possible that iceless winters could create unfavorable conditions for diatom blooms. This implies that climate warming could result in decreased biological production in the Bering Sea until the start of the projected increase in sea-ice cover after 2010. The dynamics of the Bering Sea sea-ice conditions are characterized by several periods of cyclic recurrence, ranging from 2–3 to 50 years (Plotnikov, 1996; Plotnikov and Yurasov, 1994; Ustinova and Sorokin, 1999). Obviously, this series is short for an exact tracking of the 50-year cycle. However, dramatic shifts in ice-cover anomalies were noted in the Bering and Chukchi Seas between 1976 and 1979, which divide

Table 13.2. Changes to stocks in the western Bering Sea and projected stock dynamics in response to a moderate warming (+ positive effect evident, - negative effect evident, 0 no effect evident or unclear effect).

Group	Increase in water temperature in upper pelagic layer	Increase in wind stress, zonal transport oscillation	Increase in water exchange with Pacific Ocean	Mild sea-ice conditions	Prevalent biological effects related to the physical environment changes	Key reference
Adult pollock	+	0	+	+	+ (food supply)	Shuntov et al. 1993
Juvenile pollock	+	-	+	+	- (predation)	Nishiyama et al. 1986
Pacific cod	+	0	+	0	+ (food supply)	Bakkala 1993
Pacific herring, WBS	-	0	-	+	- (competition)	Naumenko 2001
Pacific herring, EBS	+	0	-	+	- (competition)	Wespestad 1987
Pacific salmon	+	-	+	0	+ (food supply)	Hollowed et al. 2001
Cephalopods	-	0	+	0	- (predation)	Sinclair et al. 1999
Capelin	-	-	-	-	- (predation)	Wespestad 1987
Arctic cod	-	+	-	-	- (competition)	Wyllie-Echeverria and Ohtani 1999
Pacific halibut	-	0	0	0	-	Clark et al. 1999
Greenland halibut	-	0	-	0	- (competition)	Livingston et al. 1999
Arrowtooth flounder	0	+	0	0	+ (food supply)	Wilderbuer et al. 2002
Small flatfish	+	+	0	-	+ (food supply)	Wilderbuer et al. 2002
Skates	0	0	0	0	+ (food supply)	Borets 1997
Sculpins	+	0	0	-	- (competition)	Borets 1997
Atka mackerel	+	-	+	+	+ (food supply)	Shuntov et al. 1994
Mesopelagic fish	0	0	+	0	- (predation)	Radchenko 1994
Tanner crab	+	+	0	-	+ (food supply)	Rosenkranz et al. 2001
King crab	+	+	0	-	- (predation by flatfishes)	Haflinger and McRoy 1983
Shrimp	+	-	0	-	- (predation)	Ivanov 2001
Benthic epifauna	+	0	+	-	- (predation)	Connors et al. 2002
Benthic infauna	+	0	+	-	- (predation)	Livingston et al. 1999
Jellyfish	+	-	+	0	- (competition)	Brodeur et al. 1999
Euphausiids	+	0	+	+	- (predation)	Shuntov 2001
Copepods	+	0	+	+	- (predation)	Shuntov 2001
Phytoplankton	+	+	+	-	- (grazing)	Shuntov 2001

positive trend in stock abundance

negative trend in stock abundance

no trend expected or uncertain trend

the 1952–1994 data series into two distinct periods, which differ by 5.4% in average values (Niebauer et al., 1999). Alternatively, a warmer period could increase thermal stratification such that the bloom, which is not ice-dependent, would start sooner. However, it could also be that the nutrient supply is quickly depleted during a short and intense bloom and that photosynthesis is slowed. In addition to upwelling and nutrient recycling in the pelagic layer, Pacific water inflow is also a source of nitrogen and phosphorus. Intensification of water exchange with the Pacific Ocean under climate warming is thus likely to result in increased primary production in the Bering Sea (Shuntov et al., 2002, 2003; Ustinova, and Sorokin, 1999). Increased levels of primary production are usually associated with improved survival for juveniles of most fish species (Cushing, 1969) and subsequent contribution to the adult spawning stock.

Predictions of the relationship between climate change and commercial species distribution, abundance, and harvest patterns are based on the assumption that future management policies will be the same as at present. Namely, that target fishing mortality values will be designed to maintain the female spawning stock at a minimum of 40 to 60% of the unfished level (depending on species). Also, that when stocks are assessed to be below this level, harvest is reduced proportionally to rebuild the spawning stock to the target level. This approach is likely to result in fisheries for species which respond favorably to warmer conditions realizing greater catches and possibly shifting to areas of increased abundance or expanded habitat, while fisheries for species which are negatively affected by a warmer climate are likely to have smaller quotas, reduced areas of operation, and even vastly different areas.

Literature documenting changes in the Bering Sea ecosystem under the previous warm period suggests that increases in the abundance of many groundfish species are very likely under future warming. Pollock, Pacific cod, Pacific halibut (Clark and Hare, 2002), skates, some flatfish species, salmon, eastern Bering Sea herring, and Tanner crab are all likely to benefit under warmer conditions (Table 13.2), although the mechanisms underlying the increase are not clear in most cases. Strickland and Sibley (1984) proposed a possible northward expansion of pollock feeding and spawning habitat under a warming scenario due to reduced sea-ice cover, water column stratification, and increased food supply.

There are very likely to be many changes in the Bering Sea ecosystem following a change to warmer conditions from those at present. Centers of capelin distribution are likely to move northward to colder waters and forego the large areas of spawning habitat that would be available in colder years. Polar cod and five species of marine mammals that are associated with the ice edge (harbour seal, Steller sea lion, sea otter, beluga whale, and Dall's porpoise) are likely to be restricted to the Chukchi Sea for large parts of the year. Red king crab, which decreased in abundance during the past warming

period, is unlikely to do well under future warming. Deep-water species such as Greenland halibut are unlikely to be affected during their larval and juvenile stages, except when they are present in shallow water. Greenland halibut recruitment is likely to be enhanced in colder years, perhaps due to a decrease in overlap with adult pollock (Livingston et al., 1999). Similarly, predation by large piscivorous fish is likely to affect the pandalid shrimp stocks; these shrimp species are among the preferred prey of Pacific cod during summer feeding in the northern Bering Sea, especially for new recruits (Napazakov et al., 2001). Predation on shrimp stocks is likely to increase with increased recruitment of Pacific cod. Annual consumption of gonatid squid species was estimated at 4.2 million t in the Bering Sea for the late 1980s (Radchenko, 1992). A growth in squid stocks is unlikely under a warming regime due to predicted increases in the abundance of their main predators (except for Greenland halibut). Increased abundance of sculpins and western Bering Sea herring in the 1990s was attributed to the weakening of inter-specific competition in the pelagic and benthic fish communities by Naumenko et al. (2001). These stocks are likely to experience future decreases due to increases in pollock stock size.

Although some flatfish species on the Bering Sea shelf have shown increased productivity under warmer conditions, their distributions are unlikely to shift in response to ocean temperature. These species migrate to deeper, warmer waters in winter (where some spawn) and then migrate to the mid-shelf area in spring and early summer where they feed on the benthic infauna. Site fidelity is important for feeding purposes and these species are likely to tolerate moderate thermal changes. Habitat specialists, which have successfully developed niche preferences, are much less likely to be affected by climate change than "colonizing" species which have a more diverse diet so might be inclined to shift with the changing conditions. Such characteristics are expected to influence the extent to which fisheries would change under a warmer climate. However, the total fishery catch occurring under a climate change scenario would only increase to the extent allowable under current management practices. This also corresponds to historical data for the western Bering Sea fishery (Fig. 13.35). Attempts to forecast this increase, as described in the rest of this section, are based on the previously achieved maximum fishery harvest and assume that current management philosophies continue.

The maximum pollock catch in the Bering Sea was 4.07 million t in 1988, and averaged 3.55 million t between 1986 and 1990 (Fadeev and Weststad, 2001). The total walleye pollock biomass in the Bering Sea over that period was about 20 million t (Shuntov et al., 1997). Conventional wisdom assumes that the 1990s stock reduction was due to a decrease in productivity in response to environmental conditions rather than to overfishing. This means that the pollock harvest in the favorable period of the late 1980s can be used as the ref-

reference point for predicting future catch for the projected warm period. As a rule, an increase in the pollock fishery stock is due to several average and strong year classes, as in the latter 1960s, or one super-strong year class. A super-strong generation appeared in the Bering Sea in 1978 and ensured a stabilization of stock abundance and the development of the large-scale pollock fishery at the end of the 1980s (Stepanenko, 2001). The eastern Bering Sea population of pollock almost doubled between 1995 and 2001 and supports an annual catch of more than 1 million t with strict regulations. The stable condition of this population provides for the likely increase in future abundance associated with a moderate climatic warming. However, the 1978 year class occurred 13 years after the first strong year class in 1965 (Wespestad, 1993) and no cohorts of this strength have been observed since. Thus, a swift increase in stock size and catch of pollock in the near future is unlikely.

The annual Pacific cod harvest ranged from 33 100 to 117 650 t and averaged 65 210 t in the western Bering Sea during the period of Dutch seine trawls and, to a lesser degree, longline fisheries between 1981 and 2001. The catch for the whole Bering Sea for that period totaled 207 110 t. This is a relatively low catch compared to an estimated cod biomass of 3.27 million t. Adult Pacific cod are the main predator for some commercially important fish (e.g., pollock and herring) and crustaceans, particularly Tanner crab and shrimp. Relative to their weight, one unit of Pacific cod biomass consumes about 1.11 biomass units of Tanner crab juveniles, 1.12 of shrimp, 0.8 of walleye pollock, 0.39 of squid, and 0.31 of herring on the western Kamchatka shelf during the six months of the warm season (Chuchukalo et al., 1999). Whether an assumed increase in fishing pressure is justifiable for the purpose of decreasing predation by Pacific cod on other species in the ecosystem is under investigation. If the Pacific cod stock attains the same abundance in the Bering Sea as in the mid-1980s, it is likely that the total harvest could be increased (in both the western and eastern Bering Sea) to the level experienced in the 1980s and 1990s, i.e., around 350 000 t.

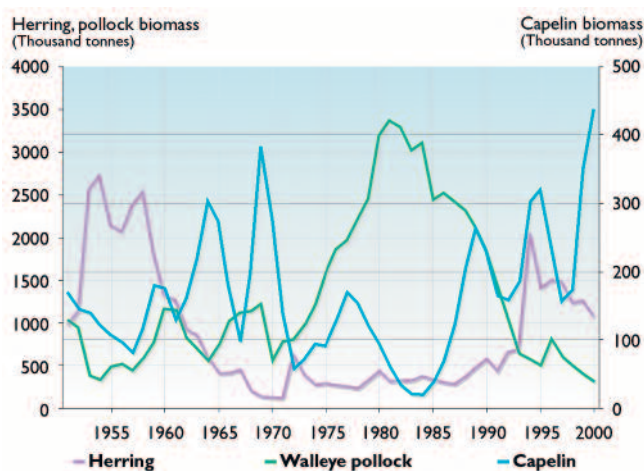


Fig. 13.38. Long-term changes in pelagic fish biomass in the western Bering Sea, 1951–2000 (after Naumenko et al., 2001).

Between 1981 and 1991, herring fisheries in the southeastern Bering Sea, in the vicinity of the Alaskan coast, harvested around 30 000 t, while harvests in the southwestern part of the Bering Sea (Fig. 13.38) were around 17 000 t over this period, relative to a total biomass level of nearly 500 000 t. The same level of harvest is likely for the next warm period. The western Bering Sea “fat herring” fishery is very likely to decline during the next decade, but the Alaskan roe-sac herring fishery is likely to increase.

The Pacific salmon fishery recently surpassed its top harvest level in the northeastern Kamchatka area due to the record pink salmon catches in 1997 (82 300 t) and 1999 (83 600 t). However, some decline is likely to occur there since the local stocks of other Pacific salmon species are not as abundant. The chum salmon coastal catch did not exceed 12 200 t, while the sockeye salmon catch did not exceed 7000 t for these years. However, these relatively high catches were made in the latter half of the 1990s. On the basis of the 5-years rate of increase in the 1990s, the total chum and sockeye salmon harvest could reach a surplus of 20 and 12%, respectively, by the end of the 2020s. Eastern Bering Sea salmon production is dominated by sockeye salmon which contributed 41 million fish from a total catch of 42 million Pacific salmon in Bristol Bay in 1993. This was a historical record and followed the previous record of 37 million fish (101 550 t) in 1983 (National Research Council, 1996). The Bristol Bay sockeye stock has since declined and is presently in a period of low production. Stock dynamics observed over the 1960s to 1990s (Chigirinsky, 1994) suggest that periods of low productivity can last for 15 to 20 years and with an average annual sockeye catch of about 20 000 t. However, if moderate climatic warming is favorable for Pacific salmon growth and survival during the marine part of its life cycle, it is likely that the annual catch will approach that of the previous warm period (1977 to 1993), i.e., about 110 000 t. The proportion of sockeye salmon is very likely to increase from the mid-2000s to the 2020s from 25 to 30%, to 50 to 55% of the total and the proportion of pink salmon will decrease accordingly. Chum salmon are very likely to take third place, chinook salmon fourth, and coho salmon fifth.

Although flatfish biomass will possibly increase in future warm periods, the catch is likely to remain low due to bycatch and market constraints. The Atka mackerel (*Pleurogrammus monopterygius*) of the Aleutian Islands, skates, smelt, and saffron cod (*Eleginus gracilis*) of the southeastern shelf are other potential stocks in good condition. Development of new markets for these fishery products could increase future harvests. Comments concerning a future crab fishery in the Bering Sea cannot be made as it is not well understood which environmental conditions would enable better survival and growth of crab larvae and juvenile stages. Also, the reasons for the sharp crab stock decrease in the Bering Sea in the 1980s are not known and there is debate as to whether the decline was due to overfishing or environmental

change. Polar cod, capelin, sculpin, mesopelagic fish, shrimp, and squid fisheries are presently undeveloped in the Bering Sea, and no precondition exists to develop these fisheries under a warmer climate regime. Some bycatch of commander squid (*Berryteuthis magister magister*) and sculpins in the trawl fishery for pollock in the Dutch seine fishery on groundfish is used, but the total value of this harvest is insignificant.

13.5.4.3. Considerable warming

Since a warming of >4 °C has not previously been observed, it is not possible to comment on changes which might occur in the marine ecosystem based on past cause and effects. It is likely that the distributions of many species would shift poleward and that there would be significant changes in the arctic ecosystem. Ice-associated species would encounter a shrinking habitat and there would be greater potential for stock collapse for species forced to forego past areas of desirable spawning and nursery habitats due to thermal intolerance. The species succession likely under a scenario of considerable warming is not known, but a sudden reduction in the economic potential of Bering Sea fisheries is possible.

13.5.5. The economic and social importance of fisheries

In comparison to other areas of the Arctic, the commercial fisheries of the North Pacific, including the Sea of Okhotsk, and the Bering Sea, are relative newcomers. Near-shore artisanal fisheries by indigenous peoples have occurred for centuries in the Bering Sea (Frost, 2003; Ray and McCormick-Ray, 2004; see also Chapters 3 and 12). The first documented commercial exploitation of groundfish dates back to 1864, when a single schooner fished for Pacific cod in the Bering Sea (Cobb, 1927), although salmon were part of commerce during earlier times. In 1882, American sailing schooners began a regular handline cod fishery. As recorded in Russian literature, the California-based fishers ceased to sail to fish in the Sea of Okhotsk after the cod shoals near the Shumagin Islands in the Gulf of Alaska were discovered. In the western Bering Sea, the early Russian fisheries were poorly developed and limited to near shore subsistence fishing by indigenous peoples and settlers (Ray and McCormick-Ray, 2004). However, even at this early date the Bering Sea was known to contain a rich resource of fish. The herring fishery area expanded northward to the Bering Strait and operated during two weeks in May when herring migrated near the coasts. The Pacific salmon fishery yielded 12 million fish each year of which 2 to 4 million fish were from the Yukon Delta area, while the remainder were caught by Russian development companies and Japanese corporations operating concessions on Russian rivers (Netboy, 1974).

In contrast to the slow development of the early fisheries, the hunting of marine mammals developed rapidly. In the western Bering Sea, the fur seal harvest

ranged from 20000 to 50000 animals on the Commander Islands. A Russian–American Company was mainly responsible for the hunting and fur purchase operations in the eastern Bering Sea, Gulf of Alaska, and Aleutian Archipelago regions between 1786 and 1862. The sea otter harvest totaled 201 403 animals during the time of the Russian–American Company of which nearly a third was purchased by merchants from the indigenous peoples. Other marine mammal harvests included sea lion hunting on St. George Island (on the Pribilof Archipelago), which yielded 2000 animals per year, and walrus hunting, which yielded 300 to 2000 animals per year until the harvest was reduced in the 1830s due to a declining population. Owing to overexploitation, the fur seal breeding grounds disappeared from the Pribilof Islands, Unalashka Island, and adjacent areas in 1830 to 1840. From 1743 to 1823, 2 324 364 fur seals, 200 839 sea otters, about 44.2 t of walrus tusk, and 47.8 t of baleen were harvested from the Aleutian Arc, other islands, and the Alaskan coast. The first protective measures on fur seal populations from Japanese and American illegal sealers were set by Russia in 1893. There is an illustration of this in the Rudyard Kipling ballad *The Rhyme of the Three Sealers*:

Now this is the Law of the Muscovite, that he proves with shot and steel

When ye come by his isles in the Smoky Sea ye must not take the seal.

In 1911, a three-sided treaty was concluded between Russia, the United States, and Japan, which established a sealing prohibition on the high seas in exchange for compensation paid from harvests in the rookeries (Miles et al., 1982a,b).

Large-scale commercial exploitation of the Bering Sea fish stocks developed slowly. Between 1915 and 1920, as many as 24 US vessels fished Pacific cod. Annual harvests ranged from 12 000 to 14 000 t (Pereyra et al., 1976). Small and infrequent halibut landings were made by US and Canadian fishers between 1928 and 1950, which increased sharply and exceeded 3300 t between 1958 and 1962 (Dunlop et al., 1964). In the early 1970s, the halibut catch fell to a low of 130 t before recovering to a high in 1987, and then slowly declined. The International Pacific Halibut Commission, established by Canada and the United States in 1923 to manage the halibut resource, determined that factors such as over-exploitation by the setline fishery, juvenile halibut bycatch, and adverse environmental conditions led to the decline in abundance (National Research Council, 1996). In the western Bering Sea, the exploitation of groundfish resources was mainly by small-scale coastal operations. Information on groundfish abundance was lacking until the first Soviet Pacific Integrated Expedition in 1932 to 1933. This covered the entire Bering Sea and found the eastern shelf and continental slope to be more productive fishing grounds than the narrower western ones. As a result, Soviet fish-

eries concentrated their efforts in the eastern Bering Sea after 1959. By the mid-1960s, newly organized Soviet fishing on the eastern Bering Sea shelf and in the Gulf of Alaska yielded about 600 000 t of Pacific ocean perch, yellowfin sole, herring, cod, crabs, and shrimps (Zilanov et al., 1989).

The Japanese and Russian fleets expanded rapidly between 1959 and 1965, with vessels from the Republic of Korea and other nations also participating in later years. These fishery efforts were added to the solely Japanese fishery efforts, which have actively operated in the Bering Sea since the 1930s, especially after the Second World War. By 1960, 169 vessels from Japan were present on the Bering Sea fishing grounds along with 50 to 200 vessels from the Soviet Union (Alverson et al., 1964). Significant growth in fishing effort led to overfishing of several stocks. The Soviet walleye pollock fishery began in the early 1970s after the decline of some commercially valuable fish stocks. Before that, walleye pollock was not regarded in the Soviet fishery as a target species. The Japanese mothership operations had three to five conventional catcher/trawlers and as many as eight pairs of trawlers associated with each mothership (Alverson et al., 1964). The catch was processed at sea with the frozen products transported ashore for food. Japanese catches were mostly processed aboard motherships into fishmeal, with livers extracted for vitamin oil. Female walleye pollock in spawning condition soon became an important source of roe-bearing fish, which were processed into valuable products such as different kinds of fish roe and surimi. The increase in product value, combined with an increase in pollock abundance after the latter half of the 1960s led to the gradual increase in catch: up to 550 000 t in 1967 and 1 307 000 t in 1970 (Fadeev and Weststad, 2001). Groundfish catches were mainly by vessels from Japan and the Soviet Union until 1986, when US fishing vessels participating

in joint ventures with foreign processing vessels took a larger proportion of the catch. By 1990, the distant water fleets were phased out of the eastern Bering Sea (the US EEZ) and US fishing vessels became the sole participants in the fishery. Some fishing occurs under license from the Russian Federation in its EEZ.

13.5.5.1. Fisheries

United States fisheries off Alaska constitute more than half of landings and about half the value of national landings of fish and shellfish from federal waters (NMFS, 2003a). Depending on species, approximately 90% of the landings in Alaska are from the Bering Sea/Aleutian Islands area. All the groundfish, crab, and salmon in the US EEZ of the Bering Sea are caught by domestic fishing bodies (Hiatt et al., 2002). In the Russian EEZ the majority of the harvests are taken by domestic fleets with a decreasing amount harvested under agreements with neighboring states. In 1997 it is estimated that the Russian Far East fisheries accounted for 70% of the Russian Federation total fisheries production (Conover, 1999; Zilanov, 1999), however this proportion may be decreasing due to the declines in pollock, crab, herring, and other species not being offset by the increases in Pacific salmon.

In the Bering Sea, walleye pollock is the major harvest by volume and value, with Pacific cod, flatfish, salmon, and crabs constituting most of the rest (Table 13.3). The total wholesale (raw fish landings) value for groundfish harvests in the eastern Bering Sea was approximately US\$ 426 million in 2001. The total primary processed value was approximately US\$ 1.4 billion. Crab harvests, mainly from the Bering Sea/Aleutian Islands area, amounted to US\$ 124 million even at the low population abundances noted earlier (Hiatt et al., 2002). Pacific salmon, a large amount of which comes from the Bristol

Table 13.3. Trends in abundance and value of major Alaskan fisheries (inflation-adjusted US dollars) (Alaska Department of Fish and Game, as cited by Pacific Fishing, January 2002).

Species	Stock 1977	Value 1977	Stock 2001	Value 2001	Discussion
Salmon	200 million fish	US\$ 500 million with peak value in 1988 of US\$ 1.18 billion	175 million fish	US\$ 205 million	A small decrease in total catch but a large decrease in price due to competition with farmed fish
Groundfish	Very small US harvest	US\$ 2–3 million but rapidly increasing to US\$ 1.0 billion in 1988 as a result of Americanization	1.65 million t harvested	US\$ 400 million	Whitefish markets strong yet price weak but US dollar also weak
Shellfish (primarily crab species but some shrimp in early years)	Red king crab strong, other species small harvests	US\$ 440 million. Drops when red king crab bubble bursts but Opilio crab takes over	Most species at low levels	US\$ 125 million	Strong competition in Opilio fishery from Eastern Canada but weak competition from Russia
Pacific halibut	Low catch most likely due to foreign fleet bycatch	Less than US\$ 30 million	High abundance	US\$ 150 million	Strong stocks and good price vis a vis other white fish
Herring	Low abundance	Less than US\$ 30 million although value increased in mid-1980s/mid-1990s to US\$ >50 million	Low abundance	Less than US\$ 30 million	Herring in same situation in 1977 and 2001

Bay and Yukon River areas, had a Bering Sea catch value of between US\$ 122 million (2001) and US\$ 179 million (2000) (Link et al., 2003). The Community Development Quota (CDQ) Program, which allocates 10% of the total Bering Sea TAC to 65 coastal communities organized into six CDQ corporations, earns more than US\$ 40 million annually (NPFMC, 2003a). A separate value is not assigned in this study to recreation or subsistence harvests in the Bering Sea due to lack of adequate analyses, despite their local and cultural significance. Economic value data for the Russian Far East are difficult to locate (Pautzke, 1997). Press reports for product value estimate the total 2001 production to account for US\$ 3.0 billion (Pacific Rim Fisheries Update, May 2002). Since the transition to a market economy began in the early 1990s and the Soviet style management of fisheries has changed, it appears that there are significant tracking and reporting difficulties with less fish being landed to avoid taxation and fees. Instead, harvests may be transferred at sea or transported directly to foreign markets by fishing vessels (Velegjanin, 1999). Thus, production and value data must be treated with caution until a more robust accounting system is developed.

13.5.5.2. Fishing fleet and fishers

Almost every fishing vessel in the Bering Sea fleet is registered outside the region. Vessels must be of requisite size to weather the environmental conditions and to have adequate scale efficiencies to operate in the area. These factors plus the lack of deepwater moorings and other support services make the eastern North Pacific a largely “distant water” fishery. Overall, the number of vessels eligible to fish for the increasing stocks of groundfish in the federal waters of the Bering Sea has decreased since the mid-1990s from 464 vessels in 1995 to 398 in 2001. This is the case for all groundfish vessel classes and types. In 2001, there were 163 hook and line (longline) vessels, 81 pot vessels, and 162 trawl vessels fishing, of which around 20 were at-sea capture/processors for pollock. The overall decrease in number results from rationalization programs for pollock under the American Fisheries Act 1998 and the North Pacific Fishery Management Council’s license limitation program for all species (although this figure does not include halibut/sablefish vessels which have Individual Fishing Quota qualification) (Hiatt et al., 2002). For other sectors, there were around 274 eligible Bering Sea/Aleutian Islands crab fishing vessels, 2500 catcher longliners (including Alaska state-water vessels) mostly involved in halibut/sablefish and Pacific cod fisheries, and some 5200 salmon fishing vessels of various types (Natural Resources Consultants, 1999).

Employment in the groundfish harvesting sector (at-sea catching and processing on land as well as motherships) in 2001 amounted to 4000 full-time equivalent jobs including skippers, fishing crew, processing crew, and home office staff (NMFS, 2003b). With few exceptions, most of this employment is in relatively small corporations. North Pacific Fishery Management Council license

limitation regulations limit the size and ability to grow of existing catching bodies. Thus, few large integrated harvesting and processing companies exist. Still, even the smaller organizations deal in multi-million dollar investments with substantial annual operating expenses, e.g., a typical catcher vessel of about 35 to 40 m in length would require a family owner or small business to have a fair market value of US\$ 2.5 million to 3.5 million (Natural Resources Consultants, 1999).

In the western Bering Sea, the situation is similar to that in the Alaskan EEZ. A large part of the harvesting capacity is located in the southern parts of the area, as are the financial and supply and repair services. The number of fishing vessels has declined drastically since the end of the Soviet era distant water fishing, owing to other nations extending their EEZs and to efforts to renew the fishing fleet and to reorganize it on market economy terms (Zilanov, 1999). Between 1990 and 1999 the Russian fishing fleet decreased by nearly 44% in number. Most of the fleet was privatized in the form of joint stock companies (56.7%), or transferred to cooperatives (*kolkhozes*; 23.7%), private companies (12.5%), or joint Russian–foreign ventures (2.4%) (Zilanov, 1999). In the Russian Far East, this has enabled small and mid-scale fisheries to develop while some large entities under Soviet style fisheries have changed and remained dominant forces. Likewise, total employment in the fisheries sector fell from 550 000 in 1990 to 398 000 in 1998. Contributing to the decline in employment in the Russian Far East was an exodus of people assigned to duties there returning to families and friends in their home regions.

13.5.5.3. The land side of the fishing industry

Approximately 70% of the Bering Sea harvests are processed on shore in a relatively small number (8) of groundfish processing plants near Dutch Harbor/Onalaska (NMFS, 2003b). Recent efforts have been made to locate processing facilities on Adak Island in the western Aleutians. Crabs are processed on the Pribilof Islands during periods of high abundance of red king crabs and snow crab in the Bering Sea. Salmon tendering and processing is focused around Bristol Bay although not exclusively. Sites where processing occurs require significant infrastructure for processing as well as for providing services to the fishing fleet. Given the remote nature of the Bering Sea fish processing activities, the communities in which these occur are highly dependent on the fishing industry for economic activity, with government services and tourism distant rivals. Most of the groundfish processing occurs adjacent to the densest aggregations of groundfish and where catcher vessels with refrigerated sea-water holds can make relatively rapid trips to maintain product quality. However, for some species and products (e.g., high grade surimi) it is difficult for shoreside processors to compete.

Employment in Alaskan shoreside processing for groundfish is estimated at 3525 full-time equivalents (NMFS,

2003b). The number of processing jobs onshore in the Bering Sea has increased by as much as 50% between the early 1990s and the present because of policies decreasing the amount allocated to at-sea processing versus onshore processing. Much of the work force is an ethnically diverse group of work permit holders from other parts of the world, mostly west coast United States, Mexico, and the Philippines. Over time, Alaskan communities in the Bering Sea region are being transformed as workers stay on and climb the corporate ladder.

In the Russian Far East a significant proportion of the catches have been processed at sea with the rest processed on shore or kept in cold storage, etc. With domestic demand low in terms of the ability to compete with global market price and other tax and regulatory issues onshore, there is a substantial incentive to process offshore and export directly (Velegjanin, 1999). This has contributed to a sizeable decrease in domestic consumption and employment in shoreside processing and other services to the fishing industry. The transition to a market economy has been difficult but the learning curve is trending upward with new management institutions and experience. However, without the full cooperation of the fishing industry and management, and tensions over the allocation of revenue between the Far East and Moscow, it will be some time before the industry stabilizes.

13.5.5.4. Fisheries communities

The North Pacific fishing communities surrounding the Bering Sea are different to those of the North Atlantic. There is no history of small coastal fishing communities developing commercial fishing on the currently harvested large stocks of pollock, Pacific cod, etc. In the eastern Bering Sea some 65 communities exist with a total population of around 27 500. They are frequently inhabited by a large percentage of indigenous Alaskans, but not exclusively (NPFMC, 2003a). Until they became participants in the CDQ program, they had limited coastal subsistence fisheries as well as some small-scale commercial fisheries for salmon and halibut. Involvement in the groundfish and crab fisheries has provided valuable income and employment as well as a role in management of the offshore fisheries. The main location of the fish processing on Akutan and Dutch Harbor/Onalaska had been important for crab, halibut, and some salmon fisheries. It was not until foreign and domestic investment was encouraged in shoreside processing of groundfish in the late 1980s that these communities were transformed. Loss of access to fishing in the US EEZ prompted Japanese investment in processing so that raw fish could be purchased at low prices and benefits gained in value-added processing from shore-based plants.

The history of the purchase of Alaska from Russia in 1867 and its status as a territory until Statehood in 1959 was that of a domestic colony. In particular, fishing interests in western Washington and Oregon were some of

the prime early investors in Alaskan fisheries. Ownership of the highly seasonal Alaskan canneries was mostly outside Alaska. Salmon fishing brought labor from the south. Halibut fisheries were developed as soon as ice-making and refrigeration technologies permitted catching and transport of fish to southern markets. Early crab fishing interests were based out of Seattle. Thus, the fisheries of Alaska have strong personal, financial, and service connections to Seattle due to the laws of comparative advantage. Alaska is a high cost area for living and carrying out a business (Natural Resources Consultants, 1999). In the federal water fisheries, residents of other states must not be discriminated against in management regulations, which further enforces the long, mostly cooperative, relationship between fishing interests in Washington and Oregon and those in Alaska. Overall dependence on fisheries varies by community but in Alaska as a whole, fisheries is a distant second to oil production in terms of revenue from resource extraction and for some cities with onshore processing, fisheries are the prime source of local landing tax revenue.

Similar to Alaska, small indigenous Russian settlements existed around the western Bering Sea. With the colonization by Russians, larger towns developed and during the Soviet era these grew as bases for resource development and national defense. Population in the seven administrative regions of the Far East is concentrated in coastal cities and declined slowly throughout the 1990s (Zilanov, 1999). Several large cities account for the majority of the population such that much of the Russian coastline is undeveloped. Fisheries are dominated by fishing interests in Vladivostok and Nakhodka. Increasingly stronger demands are being made by other regional fishing bases for more autonomy in management and greater allocations to proximate users.

13.5.5.5. Markets

The relatively low populations of the Bering Sea region do not constitute a very large local market for the large-scale fisheries. Thus, both Alaska and the Russian Far East look to distant markets at home and abroad. For Alaska, the prime markets are Japan, Korea, and China with Europe providing entry for some products. Over 90% of Alaskan fish is exported. Korea and now China with their relatively low wage labor have served as processing centers for some products that are re-exported, i.e., imported back in some value-added form. For the Russian Far East, exports have started to play an increasing role in the fisheries economy. During the Soviet era up to 80% of the Far Eastern fish products were processed and sent on to domestic markets in the western more populous parts of the country. The rest was exported or taken under fisheries agreements with neighboring states to obtain hard currencies needed by the central government. While low effective demand (i.e., domestic consumers) is not able to pay international prices for seafood products, many of the higher value species are exported and low value species and products are imported so that around 50% of the

seafood harvested is destined for export (Zilanov, 1999). Thus, the remote Bering Sea is a major player in terms of global seafood markets where declines in abundance of Atlantic cod, for example, open markets for fillets of pollock at the same time demand for pollock surimi products seems to be slackening as a result of weak Japanese and Korean markets. Similarly, high abundance of snow crab in Canada causes market erosion for this species in the eastern Bering Sea.

Owing to the significant price competition from farmed Atlantic salmon, the wild salmon dependent fishing enterprises and communities are facing major adjustments. Even though North Pacific wild salmon stocks are abundant at present, the large quantity of farm raised salmon and its method of sale and delivery reduce the price that can be obtained. There is some consideration in Alaska and Russia about starting aquaculture but it is recognized that the investment, organization, and technology may be significant hurdles (Link et al., 2003). Given the experience with salmon, there is also concern over the farming of halibut, sablefish, and cod becoming competitive with wild stock harvests.

13.5.5.6. Management regime

The US and Russian EEZs are the major management jurisdictions in the Bering Sea although the multilateral conventions for management of the “Donut Hole” fishery outside these boundaries also has an important role in fisheries management. Similarly, the Convention for a North Pacific Marine Science Organization and the Convention for the Conservation of Anadromous Stocks in the North Pacific Ocean provide frameworks for scientific exchange and cooperation. Even though the major activities covered by these conventions occur to the south of the ACIA boundary, the Wellington Convention for the Prohibition of Fishing with Large Driftnets constrains fisheries on the high seas with potential to intercept salmon of Russian and US origin as well to have negative bycatch effects on Dall’s porpoise and some seabird species. Bilateral agreements, such as between Canada and the United States for salmon and halibut management and between Russia and Japan for salmon, also exist.

At the national level, the Magnuson-Stevens Fishery Conservation and Management Act is the prime legislation guiding fisheries management in federal waters. In Alaska, this means that all waters between 3 nm from the state’s baselines and 200 nm is under federal jurisdiction. Other relationships exist, such as federal management for halibut in all waters due to the Convention between Canada and the United States for the Preservation of the Halibut Fishery of the Northern Pacific Ocean and Bering Sea, and Alaskan state jurisdiction (with federal oversight) over crabs as creatures of the continental shelf and salmon that are harvested within state waters (Miles et al., 1982a). The waters off Alaska constitute one of the nation’s eight fishery management regions. This is administered by the regional office of

the National Marine Fisheries Service, with management decision-making taking place in the North Pacific Fishery Management Council – an advisory body to the regional director and thereby to the Secretary of Commerce. The federal regulations aim to develop a decision process that is comprehensive, transparent, and open to participation by all interested parties (NMFS, 2003b).

The main tools for fishery management are Fishery Management Plans that set out the rules and regulations for management of each species or species complexes. Under the current management approach, TAC is set on an annual basis in the Stock Assessment Fishery Evaluation process (e.g., NPFMC, 2002). As part of this process, ecosystem considerations are made explicit in the form of a chapter of the Stock Assessment Fishery Evaluation document that addresses ecosystem trends and relationships to fishing, as well as in the environmental assessments required in accordance with the National Environmental Policy Act. All meetings of the Council and its Advisory Committee and Scientific and Statistical Committee are open to the public. Thus, any interested party can observe and participate in deliberations of Plan Development Teams setting TACs.

The North Pacific Fishery Management Council has developed innovative approaches to management. Scientific advice is rigorously adhered to in the setting of TACs and conservative harvest limits are applied. A cap of two million tonnes has been set on total removals in the fishery even when allowable catches might be considerably higher. Bycatch is counted against TAC and target fisheries can be closed if the bycatch limit is reached before the target fishery TAC. Larger boats are required to carry and pay for one or more observers to gather scientific information about harvests. Species such as halibut, salmon, and herring are considered prohibited species in the groundfish and other non-target species fisheries. Finally, significant areas of the fishing grounds are closed to trawling to protect habitat necessary for other species, e.g., red king crab savings area (Witherell et al., 2000). In addition, much of the present work of the North Pacific Fishery Management Council is on developing spatially explicit relationships between fisheries and fish habitats under the Essential Fish Habitat Provisions of the Magnuson-Stevens Fishery Conservation and Management Act (NPFMC, 2003b). There is also a Council emphasis on rationalization of fisheries through share-based management systems such as the Individual Fishing Quota program for halibut and sablefish (and as proposed for Bering Sea and Aleutian Islands crabs) or through using a cooperative approach as for pollock under the American Fisheries Act, 1999.

In the EEZ of the Russian Far East, the issues and basic management system are similar to those in the Northeast Atlantic (see section 13.2.5) with the exception of the reciprocal fishing agreements. The regional administration is subject to central control for setting allocations and for Border Guard enforcement. From comments about the implementation of enforcement in

western Russia, it seems the US Coast Guard and the Border Guards have developed a more effective cooperation on enforcement in the Bering Sea, particularly with respect to the fishing zone boundary and high seas driftnet fishing. The scientific basis for setting allocations in Russia is similar to that of Alaska. Significant concerns have been expressed about how well such allocations are being followed and enforced (Velegjanin, 1999). Similarly, the role of the central as opposed to the regional fishery administrations in the setting and allocation of quotas is being challenged. For several years, significant proportions of the total allowable harvest are being auctioned to the highest bidders. This innovative effort has been controversial.

13.5.6. Variations in Bering Sea fisheries and socio-economic impacts: possible scenarios

The major changes in the commercial fisheries of the Bering Sea have been in the distribution of the harvests among nations and sub-nation user groups. Changes in the species composition of the catch due to changes in environmental conditions and fishing pressures have also affected those employed in the fishing industry and their communities. However, while the latter are of considerable interest in the present assessment, it is important to note that the adjustments to changing claims to jurisdiction in the Bering Sea have been extensive (Miles et al., 1982a). The enormous dislocation of fishing fleets from Japan and then the Soviet Union post-EEZ extension, shows that major adjustments can be made but with considerable hardship. Similarly, the response of the US fishing industry assisted by favorable government incentives shows how quickly it can respond to opportunity. The question thus is how fully occupied fisheries can respond to sustainable and precautionary management.

Fisheries in the Bering Sea are largely a post Second World War phenomenon in terms of the technology and scale of enterprise necessary to fish the inhospitable and enormous expanses of the remote Bering Sea shelf. With the developments in mothership operations and food processing technology came the development of new markets for species such as walleye pollock that despite being available in large quantities had not previously been considered a target species. Little is known about the fisheries ecosystem of the Bering Sea prior to the development of the intensive industrial-scale fisheries. Attention has been given to the early whaling activity in the North Pacific as this affected the more valuable and easier to harvest species. The effects of removing this biomass of whales on controls in the Bering Sea ecosystem is not clear (National Research Council, 1996) but cannot have been insignificant. The decline in the North Pacific whaling was offset by effort directed toward other areas, including the Southern Ocean. For communities where rendering and processing occurred onshore, the displacement of effort meant the end of whaling as a source of employment and income.

Fisheries development after the Second World War tended to target the highest value species first. Despite efforts to develop sufficient scientific information and international management under the International Convention for High Sea Fisheries of the North Pacific Ocean, some stocks such as Pacific ocean perch and other longer-lived, high value species were overfished. The opportunity to fish on previously unfished stocks of very large size and extent resulted in significant employment and income benefits. With the development of coastal state management came the need to manage these large-scale fisheries properly. Most observers do not consider the harvests reported for the early period to be an accurate representation of catches. The valuable but limited joint scientific survey of stocks, performed by Canada, Japan, and the United States under the Convention, provides some information. This results in the period of record being extremely limited. Another factor is that the Bering Sea is a large, remote, and difficult area to characterize and monitor. Thus, the linking of scientific advice to fisheries management objectives has been a process of successive refinement. The ability to assess the range in natural variability in stock sizes is very imprecise and how the ecosystems function is only now being modeled with a significant degree of sophistication to begin to understand some of the issues involved (National Research Council, 2003).

Eight periods of alternating cold/warm sea temperatures are evident in the instrumental record. The extent to which these have altered population sizes and concentrations is difficult to establish for the reasons mentioned. Furthermore, population sizes may have been affected by high levels of fishing for some high value species, and low levels of fishing for species with low market value or with high levels of bycatch. Fishery management is generally thought to mediate for overfishing and to manage to maintain abundance of desired species. Since the mid- to late 1970s warmer temperatures and the associated patterns of atmospheric and sea surface circulation may have favored salmonids, winter-spawning flatfish, walleye pollock, Pacific cod, and Pacific halibut, and have been detrimental to capelin, Pacific herring, shrimps, and several species of large crab. Fisheries have developed on those species that are at high levels of abundance and left those whose abundance is low (NMFS, 2003b).

The US fishing industry in the Bering Sea survived changes in the relative abundance of particular species during the growth phase by, for example, shifting from crab fishing to walleye pollock fishing and Pacific cod fisheries. This has altered conditions for traditional crab processing ports in the Pribilof Islands but has contributed to the growth of groundfish processing in Dutch Harbor/Onalaska and Akutan. The question is what would happen to the industry under a pronounced shift to a coldwater period. Fisheries management is attempting to rationalize effort in these fisheries to increase efficiency, to reduce bycatch of prohibited

species, and to increase capture value through higher quality products and utilization rates. This tends to reduce flexibility of movement, as occurred when the domestic fisheries developed. There is little planning in place for how fishery management could operate in a transition between cold and warm regimes. For most of the groundfish species management under quotas, the expectation is that small or large year classes would be detected in the assessments and that quotas would rise and fall to prevent overfishing. For species with short lifespans this approach may be less effective, although high natural variability is considered by managers. For exceptionally long-lived species such as rockfish (*Sebastes* spp.), experience shows that very conservative harvest rates may need to be used and no-take marine reserves have been suggested as a tool to insure against loss of older highly productive fish.

This is an important issue, as is evident from the massive buildup of the red king crab fleet in the late 1970s to harvest anomalously large quantities of a Bristol Bay stock that subsequently crashed – probably due to recruitment failure following changes in environmental conditions. Additional effort entered the crab fleet with the strong stocks of snow crabs in the 1980s and 1990s. A sharp decline in these fisheries, again associated with changes in environmental conditions, caused severe problems for operators with high debt service and relatively few assets. These problems in the eastern Bering Sea crab fisheries provided an incentive to find other pot gear fishing opportunities and so other fixed gear operators in Pacific cod are now being squeezed by the entry of crab vessels into their traditional fisheries. This domino effect is highly predictable even if the underlying phenomena driving the process are not.

Warmer conditions are less favorable for pinnipeds. This appears to be an indirect food web effect rather than a direct effect through predation, although there may be interacting effects. This complex interaction between climate and pinniped survival has a pronounced effect on major commercial fisheries in the eastern Bering Sea under US jurisdiction. The spatial extent and timing of walleye pollock, Atka mackerel, and Pacific cod fisheries have been modified as a precautionary measure to protect Steller sea lions (National Research Council, 2003). In this way, changes in environmental conditions that result in effects on non-target species can be sufficiently significant in terms of the management of endangered and threatened species that they result in increased fishing costs and thus reduced profits.

The many subsistence fishing villages on the shores of the Bering Sea experience climate variability directly. The 65 CDQ communities in the eastern Bering Sea region have direct connections with climate variability through subsistence fishery activities and participation in the industrial fisheries through their partners. Industrial fisheries in the Bering Sea are dependent on large-scale shore-based processing plants that can operate, like the

fishery itself, under difficult conditions. This is because catcher vessels that deliver to the shoreside plants must now operate further offshore because of the closed areas to buffer sea lion competition for prey. At-sea processors are more adaptable to changing environmental conditions because they can follow the fish and fishing conditions and can deliver to various ports.

Salmonids have well-documented aggregate north/south shifts in production under warm and cold periods (Beamish and Bouillon, 1993; Hare and Francis, 1995; Mantua et al., 1997). Although this does not explain all sources of variability it has been used successfully to gain a better management understanding. These trends are now being exacerbated by the decrease in market price following the decline in the Asian market and competition from farmed sources of Atlantic salmon. Even at high levels of abundance fishing for wild salmonids in the Bering Sea is at best marginal. This may force fundamental change in the structure and practices of salmon fishing. Also, extremely low returns to the Yukon River make survival of the Alaskan and Canadian indigenous peoples dependent on the abundance of migrating salmonids precarious. This has brought disaster relief in the form of federal and state loans and welfare programs. Recent studies (Kocan et al., 2001) suggest that the decline in Yukon stocks may be due to warmer environmental conditions and so beyond the control of fishery managers. The low levels of salmon have already resulted in renewed calls for reducing the salmon bycatch in Bering Sea trawl fisheries. Even though salmon bycatch rates have been reduced, more salmon are wanted by Yukon and other peoples. The trawl industry that has been pushed from low to higher bycatch areas due to measures for Steller sea lion protection has taken proactive real time measures to avoid salmon bycatch.

The location of the sea-ice edge and of the extent and timing of the melting of the sea ice as well as the development of the “cold pool” can have positive and negative effects on fisheries through their tendency to concentrate or disperse certain species or to contribute to increased levels of primary and secondary production within the Bering Sea ecosystem. Direct impacts on crab pot loss resulting from shifts in the position of the ice edge have been noted in the opilio fisheries in some cold years. The economic consequences of these types of variability are considered part of the risks of fishing in the Bering Sea. At present, it is possible to make only general comments about the effects of climate variability on fisheries in the Bering Sea from a socio-economic perspective. Better analyses require a better scientific understanding of ecosystem dynamics within the Bering Sea and a better ability to predict. A complicating factor is the difficulty of understanding the dynamics within the fisheries due to the very short period of record. Also, external market forces are currently affecting the value of the fisheries to a very significant extent and this may be more important than variability in landings or overall fish abundance.

At the industrial scale of fishing and processing that is characteristic of groundfish and crab fisheries in the Bering Sea, the social effects reflect broader economic trends. Lower prices and quantities generate fewer and less well paid jobs. However, high world market prices for species such as red king crab may offset declines in stocks when other sources of supply decrease (e.g., in Russian waters), or increase (e.g., red king crab in northern Norway). Rationalization through the economic system or fishery management systems may allow greater long-term stability with less overall investment in harvesting and processing. Fewer operators earning a greater return on investment are more likely to absorb swings in abundance due to changes in environmental or other conditions. It is difficult to assess impacts on consumers as the world trade in fisheries tends to find ways to satisfy market demands. However, impacts on fishery dependent communities and small family-owned enterprises can be devastating as the high costs of fishing may exceed the price available (Link et al., 2003). Having most assets tied up in ownership of a fishing vessel and gear, a limited entry area permit, and nowhere to sell is a formula for disaster. Many operations face bankruptcy and in communities with many such entities, there are few alternatives.

13.5.7. Ability to cope with change

Over the past few decades Bering Sea fisheries have been built around fairly consistent warm water species although there are some differences between the western and eastern Bering Sea. Coastal states have benefited more in recent years than distant water fishing nations. However, the management response to a transition to a cold phase has not been adequately considered nor has the response to continued warm periods. Changes to stocks in the western Bering Sea and projected stock dynamics in response to a moderate warming are explored in Table 13.2. Assuming a shift between a cold and warm regime in the mid-1970s, which for the Bering Sea is only ± 1 °C (see section 13.5.4.2), could result in many effects and other coincident changes. For example: salmon increase in number but the world market price declines; groundfish abundance increases but the Asian market is weak owing to other economic factors; US snow crab stocks decline but Canadian stocks increase due to possible unfavorable or favorable environmental conditions.

A very small difference in ocean conditions can be detected as a cold or warm phase in the Bering Sea. Although a global climate change scenario for the Bering Sea *per se* does not exist, this shift between cold and warm periods provides some working hypotheses about what could be expected. At a minimum, it is likely that the conditions that have prevailed over the past few decades might constitute a baseline for slightly warmer conditions. Which means there is unlikely to be a resurgence of crab or shrimp populations or herring and capelin and other small pelagic species. The ecosystem would continue to be dominated by walleye

pollock, Pacific cod, and flatfish. Walleye pollock juveniles may continue to occupy the role of coldwater forage fish. Salmonids would probably remain abundant in the aggregate in northern waters but in the south off British Columbia and Washington and Oregon stocks would decrease.

Socio-economically this baseline case would replicate the current system in terms of production of fish commodities. Through improvements in fishery management, it may be possible to increase the harvests of certain stocks by managing for recovery to levels of former abundance. However, it is just as likely that unforeseen events or interactions may result in management mistakes that offset such gains. Exploitation of underutilized species may be feasible to some degree. There may be some gains in catching the whole TAC due to changes in gear and fishing practices to generate lower bycatch rates. To attain increases in value added and utilization rates, it may be necessary to further rationalize the industry.

Additional factors to be included in the scenario of a continuation of prevailing conditions are declines in marine mammal and seabird populations. In some cases, fishery interactions, while modest and indirect, may justify further efforts to protect the numbers of seabirds and marine mammals under an adverse environmental regime, and such requirements may constrain fisheries more than would be the case if the stock was the sole interest of management. Similarly, environmental groups may change the level of performance that they expect fishery management to attain, i.e., no detectable impact standard or negligible effect standard and this would alter the management "field of play".

With continued warming, there is likely to be a range of sea temperatures that would continue to generate positive recruitment and growth scenarios for some of the warm water species (Table 13.2). This is likely to result in unfavorable conditions (i.e., increased predation) for pandalid shrimp and most crab species. If walleye pollock stocks increase, their impact as a predator on fish may also increase with unpredictable outcomes. Migration paths, timing of spawning, timing of the start of primary production, and species composition are very unlikely to remain the same. Similarly, reduced sea ice is likely to change the early spring ecosystem processes but greater surface exposure to winter storm conditions is likely to increase nutrient cycling and resuspension from shallower waters. To date, there are no credible published predictions of changes to fisheries north of the Bering Strait under a no or low sea ice scenario.

13.5.8. Concluding comments

In comparison to fisheries in other areas of the Arctic, commercial fisheries of the North Pacific, including the Sea of Okhotsk and the Bering Sea, are relative newcomers. Commercial fishing for groundfish stocks other than Pacific halibut began in the Bering Sea in the 1950s by fleets from Japan and Russia and soon developed into

large-scale operations involving many nations. These fleets primarily harvested walleye pollock, Pacific cod, flatfish, sablefish, Atka mackerel, crab, herring, and salmon stocks. In the late 1970s, EEZs were established 200 nm seaward from the coast by Russia and the United States and fisheries management plans were established. By 1990, the distant water fleets were phased out of the eastern Bering Sea (i.e., the US EEZ). US fisheries off Alaska constitute more than half the landings and about half the value of national landings of fish and shellfish from federal waters. In the Russian EEZ, most catches are taken by domestic fleets with a decreasing proportion harvested under agreements with neighboring states.

Well-documented climate regime shifts occurred in the Bering Sea over the 20th century at roughly decadal time scales, alternating between warm and cool periods. A climate regime shift in the Bering Sea in 1977 changed the marine environment from a cool to a warm state. The warming-induced ecosystem shifts favored recruitment to herring stocks and enhanced productivity for Pacific cod, skates, flatfish, and non-crustacean invertebrates. The species composition of the benthic community changed from a crab-dominated assemblage to a more diverse mix of starfish, ascidians, and sponges. Pacific salmon production was found to be positively correlated with warmer temperatures. Consecutive strong year classes were established and historically high commercial catches were taken. Levels of walleye pollock biomass were low in the 1960s and 1970s (2 to 6 million t) but subsequently increased to levels greater than 10 million t and have remained large in most years since 1980.

Information from the contrast between the 1977 to 1989 warm period and the prior and subsequent cool periods (1960–1976 and 1989–2000) form the basis of the predicted response of the Bering Sea ecosystem to scenarios of future warming. Predictions include increased primary and secondary productivity with a greater carrying capacity, increased catches for species favored by a warm regime, poleward shifts in the distributions of some cold-water species, and possible negative effects on ice-associated species.

Walleye pollock is the major harvest species by volume and value, with Pacific cod, flatfish, salmon, and crabs constituting most of the rest. Total wholesale value for groundfish harvests in the eastern Bering Sea is approximately US\$ 426 million, while the total primary processed value is approximately US\$ 1.4 billion. The North Pacific fishing communities surrounding the Bering Sea are different from those of the North Atlantic. On the coast of the eastern Bering Sea there are some 65 communities with a total population of around 27 500 inhabitants, but these do not have a long history of fishing.

Fishery Management Plans are the main tool for fishery management in US waters. These set forth the rules and regulations for the management of each species or

species complexes. Under the current management approach, TACs are set on an annual basis in the Stock Assessment Fishery Evaluation process. Ecosystem considerations are explicitly made available at the time of the TAC setting process. The North Pacific Fishery Management Council has developed some fairly innovative approaches to management. In the EEZ of the Russian Far East, the regional administration is subject to central control for setting TAC allocations and for Border Guard enforcement.

The main changes over the years in the commercial fisheries of the Bering Sea have been in the distribution of the harvests among nations and sub-national user groups. There have been extensive adjustments to changing claims to jurisdiction in the Bering Sea. The tremendous dislocation of fishing fleets from Japan and Russia (then the Soviet Union) after the EEZ extension to 200 nm shows that major adjustments can be made but with considerable hardship. Similarly, the response of the US fishing industry, assisted by favorable government incentives, shows how quickly the fishery can respond to changed opportunities.

Eight periods of alternating cold/warm sea temperatures are evident in the instrumental record. Population sizes may have been affected by both high levels of fishing for some high-value species and low levels of fishing for species with low market value or with high levels of bycatch. Fishery management is generally intended to prevent overfishing and maintain the abundance of desired species. Since the mid- to late 1970s, warmer temperatures and associated atmospheric and sea surface circulation may have favored salmonids, winter-spawning flatfish, walleye pollock, Pacific cod, and Pacific halibut but have been detrimental to capelin, Pacific herring, shrimps, and several species of large crab. Fisheries are fully developed on those species that are at high levels of abundance, but have essentially ceased on those whose abundance is low. The last few decades of Bering Sea fisheries have been built around species that consistently favor warm water. However, there are some contradictions between the western and eastern Bering Sea. There is no question that coastal states have benefited more in recent years than distant water fishing nations. However, the management response to a transition to a cold phase has not been adequately considered, nor has it for the opposite, i.e., continued prevailing warm conditions.

Previous sections of this chapter have demonstrated that a very small difference in ocean environmental conditions can be detected as a cold or warm phase in the Bering Sea. While there is not a global climate change scenario for the Bering Sea per se, this shift between cold and warm periods does provide a basis for some working hypotheses about what to expect in the area in future. At a minimum, it is likely that the conditions which have prevailed over the last few decades might constitute a baseline for slightly warmer conditions. Therefore, there is not likely to be a resurgence of crab or shrimp populations, or herring and

capelin and other small pelagic fish species. The ecosystem is likely to continue to be dominated by walleye pollock, Pacific cod, and flatfish. Walleye pollock juveniles are likely to continue their role as cold-water forage fish. Salmonids are likely to remain abundant in the aggregate in northern waters, but south off British Columbia and Washington and Oregon stock abundance would be depressed.

Socio-economically this baseline case would replicate the current system in terms of production of fish commodities. Through improvements in fisheries management, it may be possible to increase harvests of certain stocks by managing for recovery to levels of former abundance. However, it is probably just as likely that unforeseen events or interactions may produce management mistakes that offset such gains in a dynamic ocean system. Exploitation of underutilized species may be feasible to some degree. Some gains in catching the whole TAC might be possible due to improvements in gear and fishing practices to lower bycatch rates. In order to attain increases in value added and in utilization rates, the industry may need to be further rationalized.

Under a continued warming scenario, it is very likely that there could be a range of temperatures that would continue to generate positive recruitment and growth scenarios for some of the warm advantaged species. These conditions would be negative for pandalid shrimp and most crab species. If walleye pollock stocks increase, their impact as a predator on fish may also increase with unpredictable outcomes. It is very unlikely that migration paths, timing of spawning, timing of start of primary production, and composition of species would remain the same. Similarly, loss of sea ice may result in changes to the early spring bloom and associated ecosystem processes, however greater surface exposure to winter storm conditions might increase nutrient circulation and resuspension in shallower waters. To date, there are no credible published data on what could happen in the waters north of the Bering Strait with respect to fisheries under a change to a significantly warmer climate.

13.6. Synthesis and key findings

Modeling experiments show that it is not easy to project changes in climate due to forces, which can and have been measured and even monitored on a regular basis for considerable periods of time and are the data upon which such models are built. The main reason being that major natural events occur over time scales greater than decades or even centuries and the period of regular monitoring of potentially important forcing events is relatively short. Also, current climate models do not include scenarios for ocean temperatures, watermass mixing, upwelling, and other relevant ocean variables such as primary and secondary production, neither globally nor regionally. Thus, it is not possible to predict the effects of climate change on marine fish stocks with any degree of certainty and so the eventual socio-economic consequences of these effects for arctic fisheries.

Nevertheless, and despite these difficulties, the scientific community should still rise to the challenge of predicting reactions of marine stocks in or near the Arctic to climate change, basing initial studies on past records of apparent interactions, however imperfect and inconclusive. It is on such bases – and such bases only – that effective future research can and should be planned and undertaken.

Commercial fisheries in arctic regions are based on a number of species belonging to physically different ecosystems. The dynamics of many of these ecosystems are not well understood. This adds a significant degree of uncertainty to attempts to predict the response of individual species and stocks to climate change. Indeed, to date it has been difficult to identify the relative importance of fishing and the environment on changes in fish populations and biology. Moreover, current fish populations differ in abundance and biology from past populations due to anthropogenic effects (i.e., exploitation rates). As a result it is unclear whether current populations will respond to climate change as they may have done in the past.

Nevertheless, it does appear likely that a moderate warming will improve the conditions for some of the most important commercial fish stocks, as well as for aquaculture. This is most likely to be due to enhanced levels of primary and secondary production resulting from reduced sea-ice cover and more extensive habitat areas for subarctic species such as cod and herring. Global warming is also likely to induce an ecosystem regime shift in some areas, resulting in a very different species composition. Changing environmental conditions are likely to be deleterious for some species and beneficial for others. Thus, relative population sizes, fish growth rates, and spatial distributions of fish stocks are likely to change (see Table 9.11). This will result in the need for adjustments in the commercial fisheries. However, unless there is a major climatic change over a very short period, these adjustments are likely to be relatively minor and are unlikely to entail significant economic and social costs.

The total effect of climate change on fish stocks is probably going to be of less importance than the effects of fisheries policies and their enforcement. The significant factor in determining the future of fisheries is sound resource management practices, which in large part depend upon the properties and effectiveness of resource management regimes. All arctic countries are currently making efforts to implement management strategies based on precautionary approaches, with increasing emphasis on ecosystem characteristics, effects of climate changes, and including risk and uncertainty analyses in decision-making. Ongoing adjustments to management regimes are likely to enhance the ability of societies to adapt to the effects of climate change.

The economic and social impacts of altered environmental conditions depend on the ability of the social

structures involved, including the fisheries management system, to generate the necessary adaptations to the changes. It is unlikely that the impact of the climate change projected for the 21st century (see Chapter 4) on arctic fisheries will have significant long-term economic or social impacts at a national level. Some arctic regions, especially those very dependent on fisheries or marine mammals and birds in direct competition with a fishery may, however, be greatly affected. Local communities in the north are exposed to a number of forces of change. Economic marginalization, depopulation, globalization-related factors, and public policies in the different countries are very likely to have a stronger impact on the future development of northern communities than climate change, at least over the next few decades.

This chapter considers the possible effects of projected climate change on four major ecosystems: the North-east Atlantic (Barents Sea), the central North Atlantic (Iceland/Greenland), Northeast Canada (Newfoundland/Labrador), and the North Pacific (Bering Sea). There are substantial differences between these regions in that the Barents Sea and Icelandic waters are of a subarctic/temperate type, while the arctic influence is much greater in Greenland waters, the waters off northeast Canada, and the Bering Sea. It follows, therefore, that climate change need not affect these areas in the same or a similar manner. Also, the length of useful time series on past environmental variability and associated changes in hydrobiological conditions, fish abundance, and migrations varies greatly among regions. Finally, there are differences in species interactions and variable fishing pressure, which must also be considered.

Owing to heavy fishing pressure and stock depletions, the Barents Sea, Icelandic waters, and possibly also the Bering Sea could, through more efficient management, yield larger catches of many fish species. For that to happen research must increase, and more cautious management strategies must be developed and enforced. However, a moderate warming could enhance the rebuilding of stocks and could also result in higher sustainable yields of most stocks, among others, through enlarged distribution areas and increased availability of food in general. On the other hand, warming could also cause fish stocks to change their migratory range and area of distribution. This could (as history has shown) trigger conflict among nations over distribution of fishing opportunities and would require tough negotiations to generate viable solutions regarding international cooperation in fisheries management.

The waters around Greenland and off northeast Canada are very different from the above. These regions are more arctic in nature. Greenland appears unable to support subarctic species such as cod and herring except during warm periods. Examples from the 20th century prove this point. For example, there were no cod in the first two and a half decades, but a large local self-sustaining cod stock from 1930 until the late 1960s, apparently

initiated by larval and 0-group drift from Iceland. If current climate conditions remain unchanged little change is likely around Greenland. On the other hand, a “moderate warming” such as that between 1920 and the late 1960s is likely to result in dramatic changes in species composition – a scenario where cod would play the major role. The northeast Canadian case is an extreme example of a situation where a stock of Atlantic cod (the so-called “northern” cod), which had sustained a large fishery for at least two centuries, is suddenly gone. Opinion differs as to how this has happened; most people believe that the decline was due entirely to overfishing, whereas others think that adverse environmental factors were significant contributors. In the present situation, however, the northern cod stock is so depleted that it is very likely to take decades to rebuild – even under the conditions of a warming climate.

An evaluation of what could happen to marine fisheries and aquaculture in the Arctic should the climate warm by more than 1 to 3 °C is not attempted in the present assessment. This is beyond the range of available data and would be of limited value. In general terms, however, it is likely that at least some of the ecosystems would experience reductions in present-day commercial stocks which might be replaced partially or in full by species from warmer waters.

13.7. Research recommendations

Past experience shows that marine living resources are not unlimited and must be harvested with caution. Although management practices have improved in recent decades, the present situation still leaves much room for improvement. More and better research is required to fill this gap.

1. Present monitoring of the physical and biological marine environment must be continued and in many cases increased. Basic research is often considered a burden, but is a prerequisite for understanding biological processes. Modern technology enables the automation of many of the time consuming tasks previously conducted from expensive research vessels. For example, buoys can now be deployed in strategic locations on land and at sea for continuous measurement of many variables required in marine biological studies. The monitoring of commercial stocks must also continue, applying new technologies as these become available. There is a general shortage of ship time for sea-based work. Administrators (governments) are often unaware of this, also that despite computers enabling more extensive and deeper analyses of existing datasets, people are still required to operate and program the computers.
2. Although the modeling of marine processes, particularly the modeling of climate variability, is still in its infancy, such work is the key to increasing understanding of the effects of the projected climate change scenarios (see Chapter 4). The devel-

opment of regional applications is particularly important. Regional effects might differ substantially from those considered average global effects. In order to relate physical changes in the atmosphere and oceans to changes within specific ecosystems, the modeling of regional effects is essential.

Current fisheries management models are based on general assumptions of constant environmental factors. The use of ecosystem-based approaches for fisheries management will require that physical and biological factors that do not directly affect the target species are also taken into account.

- It is extremely difficult to estimate the economic consequences of climate change on the world fisheries or the fisheries for any given region. It is important to invest in the development of better methods for examining the economic and social consequences of climate change, at both the global and regional level, and at the national and local level.

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