Chapter 8

Climate change, adaptation and the fisheries sector

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The fishing industry is a primary example for an industry subject to nature's variability, including climate change. Climate change affects fisheries along two main axes, changes in productivity in a given location and changes in fish migrations or the location of their habitats. Based on IPPC reports and other sources the paper summarizes expected changes in the marine environment. It then looks into potential fisheries productivity implications by drawing on examples from changes that occurred in the past. The paper also outlines the impacts of changing fish migration patterns of shared stocks, again illustrated by examples from the past. Those changes can influence the behaviour of the partners exploiting a shared stock, with critical consequences for the status of the stock and/or the relationships between the partners of an agreement. The paper further illustrates that if those changes affect stocks located entirely or partially in the high seas, shared management through RFMOs becomes even more challenging.

The paper concludes that the policy implications of climate change for fisheries will depend on the speed with which those changes occur. If change occurs gradually, management can be adjusted accordingly. If change occurs unpredictably, management adaptation requires better marine and climate change science to be able to react. Secondly, management systems need to be flexible as in the case of unpredictability they can only adapt once change has occurred.

The paper concludes that climatic changes have caused adjustment in the marine environment already in the past and will continue to do so, be in a predictable or rather unpredictable manner, causing reversible or irreversible changes. In any case, the climate change discussion provides momentum for refocusing on good fisheries management as the key issues are unlikely to change considerably with global warming. The challenge is to understand what adaptation to a fluctuating environment means for good governance.

Introduction: the issues

What are the key issues for fisheries arising from climate change? Most people probably associate climate change with global warming; that certainly is one of hottest issues of our times (no pun intended). Global warming will affect not just the atmosphere but the oceans as well, but how much, how rapidly, and even, for some areas, in what direction is unclear. In fact, even if global average temperature is rising, it will not necessarily rise uniformly in every location, and what evidence there is indicates that some areas, such as the Arctic and sub-Arctic, are warming more rapidly than others. Some areas might even become cooler. This is likely also to be the case in the world's oceans; climate change will manifest itself in changing ocean currents, and some areas might even get colder because of diversion or changing intensity of currents.

But climate change need not be due to global warming. In fact, the climate has always varied on long and short time scales and will undoubtedly continue to do so whether or not man-made global warming is occurring. Since global warming will occur as a trend around which there will be variations, perhaps substantial, many of the issues associated with it are much the same as the issues raised by climate variability in the past. Conversely, whatever lessons we can learn from climate variability in the past should definitely be of interest for the issues raised by global warming. Hence we shall devote considerable attention to some climate variations that have happened in the not too distant past (within a time horizon of a hundred years or so). How did they affect fisheries? How did the industry and society in which it was embedded respond?

So what are the issues? The fishing industry is a bit special, being essentially an advanced form of hunting.[1] It does not attempt to control nature, except indirectly through how it exploits the fish stocks. There are, with few exceptions (salmon hatcheries), no measures applied to enhance the productivity of the oceans, analogous to seeding, fertilisation, or ploughing and harrowing; the fisheries take what nature gives them, and nature responds in a niggardly way if the fisheries take too much. The productivity of the oceans depends on ocean climate; the upwelling of nutritional materials from the deep sea that occurs in certain areas depends on currents, which in turn depend on winds, and currents carry plankton to certain areas so the fish can thrive. The strength and even location of ocean currents can vary substantially over time, which in turn gives rise to fluctuations in the productivity of fish stocks, as well as in their migrations and location. This variability is further affected by predator-prey dynamics; a dearth of suitable prey fish due to changes in productivity lower down in the food chain will affect the growth of their predators, and abundance and migration of predators will affect the abundance of their prey.

Hence the fishing industry is a primary example of an industry that is subject to the vagaries of nature and so must adjust to nature and her variability; there is little or nothing that the industry can do to affect the natural processes. The first issue to arise, then, is can we predict changes in ocean climate? Unfortunately it is unclear whether we can, at least in a sufficiently precise and timely fashion to be of much help for the industry in the short term. The synthesis overviews of climate change predictions, such as those produced by the Intergovernmental Panel on Climate Change (IPCC), make few predictions on a spatial or temporal scale that would be useful for fisheries management. Other work on regional scales has the potential to produce more useful predictions, and these predictions are likely to improve as the methods are developed further. The fact remains, however, that there is substantial uncertainty in these models and their predictions, and their ability to predict non-linear or threshold responses might be particularly limited.

Whether or not we can predict in a sufficiently precise and timely fashion to meaningfully affect management raises the question of whether we really need predictions. If changes occur gradually it may be true that all we need is to adjust gradually; the necessary information will be revealed as it is required. This is not true if changes in fish migrations or productivity occur suddenly and on a major scale as certain "threshold values" of environmental variables are exceeded (Arnason, 2006). Such changes may be difficult to predict, and all the more so since they might occur even if the underlying change in ocean circulation and temperature is gradual; ocean conditions might suddenly reach a point where certain fish stocks can no longer survive, or radically change their migratory habits. We would only know what to expect if: (1) similar things had occurred in the past; and/or (2) if we had a strong understanding of the mechanisms and interactions underlying climate change and its impacts on oceans and ecosystems.

Then, being able to predict changes or not, what changes could we expect? It is useful to distinguish between two main types of changes that could occur: (i) changes in the productivity of the ocean in a given location and (ii) changes in fish migrations or the location of their habitats. Changes in productivity could go both ways; less intensive upwelling in the areas where this occurs would adversely affect the productivity in these areas. This is what occurs during the famous *El Niño* events when warm waters are carried towards the west coast of South America and the upwelling diminishes, adversely affecting the anchovy stocks in the area and the fisheries of Peru and Chile (see Annex 9.A1). Conversely, the blooming of plankton could increase and so could the intensity of currents carrying plankton to certain areas; this is what happened in the warm period in the 1920s and 30s in the north-east Atlantic, to be further discussed below. How fish stocks will be affected is a more complicated issue, depending on predator-prey interactions. As to the industry and society, changes in productivity of fish stocks may necessitate investment in new equipment or finding new markets, or cause obsolescence of real and human capital and loss of markets.

Changes in fish stock productivity, if they occur uniformly in a given area, would affect all countries sharing the stocks involved in a similar way. Changes that affect fish stock migrations or displace their habitat may on the other hand affect different countries differently. Some might be disadvantaged while others might gain. This could cause problems when fish stocks migrate between the exclusive economic zones (EEZs) of different countries. The countries involved might be affected differently, and so they would be if the habitat of a given fish stock is largely or wholly displaced from one country's EEZ to another's. This could upset existing agreements on sharing fish stocks.

These are the key issues to be further discussed below. We begin with what we might expect, drawing on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the Arctic Climate Impact Assessment (ACIA), and past experience ("What can we expect?"). We then move on to consider implications of changes in fish stock productivity, such as would not involve changes in migration and stock habitat ("Changes in fish stock productivity"). Thereafter we consider the consequences of changed stock migration or habitat location and what this means for stocks shared between two or more countries ("Changed fish migrations and shared stock") and those partly or wholly found on the high seas ("High seas fisheries"). After a concluding section on policy implications ("Conclusions and policy implications") there is an annex where there is a brief discussion of climate changes that have occurred in the north Atlantic and the eastern Pacific and their implications for the fisheries in these areas. These experiences are useful to keep in mind when we are dealing with the consequences of future climate change, and we have also drawn on them in various parts of this paper.

What can we expect?

Climate change has been a high profile international issue for about twenty years. For some time the average global temperature has been increasing, and most climate scientists have concluded that this is mainly due to emissions of greenhouse gases, particularly carbon dioxide. Since there is no way emissions of these gases could, in the medium term, be reduced to a level that would stabilise their concentrations in the atmosphere the global temperature is likely to rise further, although by how much is highly uncertain.

Global warming will affect not just the atmosphere but also the oceans. Emissions of greenhouse gases, in particular carbon dioxide, will affect the oceans in at least three ways: (i) warmer atmosphere will warm up the oceans; (ii) some of the carbon dioxide will be absorbed by the ocean (but some might in fact be released from the ocean to the atmosphere), which could affect ecosystems through acidification; (iii) increased melting of glaciers in the Arctic will release fresh water to the ocean, affecting its salinity, level and possibly its circulation. In addition, if global warming affects wind patterns and strength, this in turn will affect ocean currents. This could have two effects. First, changes in ocean currents would affect the distribution of plankton and hence migrations of fish stocks and location of their habitats. Second, changes in the winds that cause upwelling of nutritional material from the deep sea could affect the upwelling and hence the growth of fish stocks that depend on it. Some of the richest fisheries in the world exploit species that depend on upwelling (sardines and anchovy off southern Africa, California, Morocco and Peru and Chile).

These are complex effects and their magnitude and time profile highly uncertain. It is no wonder, therefore, that the voluminous Fourth Assessment Report of the IPCC has very little to say, at least very little that is definitive, about how world fisheries will be affected. It notes that changes in salinity, circulation and ice coverage that already have happened and may be expected to continue will affect primary production, fish growth and fish migration. In some cases the effects have been positive, but in others negative (IPCC, 2007b, pp. 234-236 and p. 333). The most definitive conclusions concern coral reefs and coastal areas, both of which are likely to be negatively affected (IPCC, 2007b, Chapter 6). Bleaching of coral reefs is likely to increase, both because of rising temperature and because of acidification of the ocean due to absorption of carbon dioxide. Acidification has wider implications, as it adversely affects animals with a hard shell, which would threaten ecosystems where such organisms play a pivotal role (IPCC, 2007b, p. 236).

More definitive predictions, but still fairly vague, were made in the Arctic Climate Impact Assessment (ACIA, 2005).[2] This was the result of work done by a group of scientists asked to assess the effects of global warming on the Arctic and sub-Arctic region. This assessment was based on a number of climate scenarios and models used in the Third Impact Assessment Report of the IPCC, but ACIA went into much greater detail about how the said region and its various parts might be affected. Fish stocks were predicted to move further north because of rising ocean temperature and melting of Arctic ice. These movements would not necessarily be displacements but also expansions, with new areas colonised by certain stocks, which thus would increase in abundance. The most northerly species (capelin and Greenland halibut, for example) would probably decline in abundance, while more southerly ones (cod, pollock, herring, and some flatfish) would probably increase. The melting of sea ice was expected to increase primary production by opening up new areas for the inflow of sunlight. This was expected to increase fish production, but it was pointed out that the latter would depend critically on fish larvae being carried by currents to the blooming of zooplankton at the right time (ACIA, 2005, Chapter 9). Overall, predictions were positive rather than negative, which agrees with the experience from the warm period in the north-east Atlantic in the 1920s and 30s. The ACIA report also dealt with possible economic effects of this, a subject we shall return to in the following section (ACIA, 2005, Chapter 13).

Given the rather uncertain predictions of the consequences of climate change for fisheries, we shall deal with changes in fish stock growth and migration in quite general terms. While in a number of cases it seems reasonably clear in what direction the growth and migrations of certain stocks will be affected, the speed and magnitude of these changes are much less clear. It is also unclear if these changes will be gradual, in response to a gradual increase in global average temperature, or whether they will be released when certain threshold values of environmental variables such as temperature and salinity will be hit, displacing stocks from their previous habitats or inciting them to change their migrations.

What we seem to be seeing is global warming occurring as a trend, but with swings, perhaps substantial ones, around the trend. Even if some of the warmest years ever recorded have occurred fairly recently, the warming seems to have come to a halt lately. On a longer time scale, the 1960s and 70s were a cool period in north-west Europe, compared to the 1920s and 30s and the last two decades. Even with global warming, all areas will not warm to the same extent; it appears that the Arctic and sub-Arctic are warming much more rapidly than the rest of the world.

As regards ocean climate, this is an even more appropriate description. The temperature in a specific area is highly dependent on ocean currents and can vary substantially from year to year or decade to decade, depending on the strength and direction of these currents (examples of this are discussed in the annex). This means that any trend towards warming will be overlaid with substantial variations around that trend. Some areas might even be going against the trend for a long and possibly indefinite period, due to a change that might permanently strengthen or switch on a cold current. As an example, substantial weakening of the Gulf Stream and the thermohaline circulation is a scenario that cannot be totally dismissed, even if it is considered unlikely (IPCC, 2007b, p. 797 and 802).

This has some important implications for the adjustment towards a changed climate in the ocean. First, how can we tell a permanent change from a temporary one? In the past we have had so-called regime shifts in various parts of the world which have been fairly long-lasting, such as the warm period in the north-east Atlantic in the 1920s and 30s (Vilhjálmsson, 1997; Drinkwater, 2006), the cooling off in the 1960s and 70s, and the shift to a warmer regime in the north Pacific in the late 1970s (Miller and Munro, 2004). It is not easy to distinguish such regime shifts from a more permanent change. On the other hand it can be argued that this does not much matter for practical purposes; from the point of view of investing in production equipment or finding new markets, a regime lasting 10-20 years is a regime lasting forever.

As a result of such regime shifts, partly at least, we have in the past seen fish stocks disappear and migrations being changed for long periods, and some have not returned to their previous state or patterns. The West Greenland cod stock was severely depleted in the 1960s and has been virtually non-existent since 1990, while the shrimp stock increased (ACIA, 2005, Chapter 13). The northern cod of Newfoundland disappeared in the early 1990s. Also here shrimp, as well as crab stocks, increased. Migrations of Norwegian spring-spawning herring to Iceland stopped when the waters north and east of Iceland became colder in the 1960s and have not fully resumed their previous pattern despite a warmer ocean and stock recovery after the mid-1980s. The Pacific sardine disappeared from the coast of California in the 1950s and was absent for decades (some of these changes are further discussed in the annex).

As was noted in the introduction, if the changes in ocean climate are incremental, they might not pose much of a problem. Adjustment could occur gradually, and sound expectations could be formed on the basis of past experience. But the changes just discussed seem to be due to the passing of certain environmental thresholds rather than dramatic, underlying climate changes. As the temperature rose, or cooled, nothing much happened until suddenly a certain fish species was seemingly unable to reproduce or find enough food to survive, or predators invaded and decimated a fish stock that earlier was thriving. Such changes are impossible or at least very difficult to predict. In order to know the threshold values involved they must have been passed at some time in the past, but then the fish would not be around anymore unless the change was reversible. Many such changes are in fact reversible; both the Norwegian spring-spawning herring and the Pacific sardine were almost wiped out at one point, but once the environmental conditions were appropriate they came back, although much later than the environmental conditions would seem to warrant (see annex).

As has been argued, global warming is certain to be a trend with inter-annual and perhaps even decadal variability, not least in the oceanic environment. This may mean that critical thresholds could be crossed in opposite directions from time to time. Does this mean that the ecosystem will return to its previous state? How quickly? These temporary setbacks are particularly likely to cause problems with shared fish stocks whose migrations might switch between different states' EEZs. We shall return to this problem later in this chapter.

Changes in fish stock productivity

As discussed in the previous section, climate change is likely to cause changes in fish stock abundance, albeit of uncertain magnitude and direction. Here we ignore international repercussions and assume that changes in fish stock abundance are confined to one nation's exclusive economic zone (EEZ) or, for stocks that move between the EEZs of different nations, affect them all in equal measure. This also covers the case where new stocks expand to new areas without declining in their traditional areas. Previous climatic variations provide examples of this latter effect. Cod and even herring began to spawn at Greenland during the warm period in the 1920s and 1930s. The area must have been seeded from somewhere, but not necessarily at the expense of those areas; adult fish probably migrated in search of food or larvae drifted with the currents and then settled at Greenland. Migrations or larval drift from other areas to which the adult fish return, like the cod at Iceland that drifts over to Greenland and then returns, is a different issue which would get us into the subject of shared stocks and how sharing agreements are affected by climate change, the subject of the following section.

Climate change, whether it is warming or cooling, will affect different fish species differently. Each fish species is found only within a certain temperature range, which may have as much to do with the availability of prey as with temperature as such. Any change in temperature is therefore likely to be beneficial for certain stocks and harmful to others. Disappearance of cod and booming shrimp and crab stocks at Newfoundland and Greenland as a result of climate change has already been noted. Change in ocean currents, which manifests itself as a change in temperature, may also affect upwelling of nutrients from the deep sea. Even small changes can apparently cause major disruptions, such as the switch from anchovy to sardine and *vice versa* which occurs in various upwelling areas around the world (Benguela, Humboldt, the California current) from time to time, for reasons that are not well understood.

Whether or not global warming will affect the productivity of the oceans negatively or positively depends on two things: how it will affect (i) primary production and (ii) upwelling (or runoff) of nutritional material. The Fourth Assessment Report of the IPCC leans towards thinking that primary production will be negatively affected (IPCC, 2007b, pp.234-5). Nutritional upwelling from the deep sea depends critically on the strength of winds and the currents they generate, and it seems difficult or impossible to make any definite forecasts about that. A given primary production will end up producing a different species mix at each trophic level, according to how changes in ocean currents affect the survival of different species. Whether we will end up with more or less valuable species mix as a result of global warming is very difficult to say.

How each particular country will be affected will depend on the composition of species within its EEZ (abstracting from any fishing the country could be involved in outside its own zone). It is unlikely that all its fisheries would be adversely affected; if, say, fish *X* that preys on fish *Y* will be adversely affected, fish *Y* is likely to survive better, and provided that there is enough food around for fish *Y*, the country in question could increase its catches of this fish. Whether the country in question gains or loses from the change will depend on, among other things, the value (monetary or otherwise) of fish *Y* relative to the value of fish *X* and the costs associated with taking them. As a case in point, consider what happened to the fisheries in Newfoundland after the collapse of the Northern cod in the early 1990s. A contributing factor to the collapse of this fishery was the cooling off of the waters around Newfoundland at the time. This fishery was both large and valuable, and its disappearance caused a major disruption to the economy and culture of Newfoundland. However, the abundance of crabs and shrimps increased in the wake of the collapse of the cod, probably due to less predation from cod on these species or their larvae. After a few years the value of fish catches (including crabs and shrimps) was higher than ever before.[3] However, the impacts on Newfoundland were serious: the benefits of the shrimp and crab fisheries were distributed among a much smaller segment of the population than were those of the cod fishery; the cod fishery was fundamental to the culture of Newfoundland; and there were substantial costs in helping thousands of fishers and processing workers make the transition to other industries.

Regardless of whether in the end a country would gain or lose from a climate change in the waters around its coasts, all changes, even those for the better, necessitate adjustments. Boats may need to be adapted to catch new species and new ones might need to be built. This, needless to say, is likely to be most demanding when new and very different species replace old ones. It was not too much of a problem in the herring fisheries of Norway and Iceland to switch to capelin when the herring stocks collapsed (these fisheries are discussed at a greater length in the annex), but switching from cod to crabs or shrimp is likely to be more problematic, as the fishing gear is quite different. On the processing and marketing side the problem of switching will depend on how similar the species are with respect to the processing equipment required and the markets they supply. The aforementioned switch from herring to capelin as raw material for the fish meal industry was unproblematic, both with respect to processing and marketing; the meal from both is very similar and the same processing equipment can be used for both. The situation would be different if, say, a herring fishery providing raw material for cured products collapses. Cured products of herring do not have perfect or maybe not even close substitutes and appeal to a specific and acquired taste among consumers. If a switch from Species *X* to Species *Y* is required and Species *Y* serves a totally different market, it will be necessary to find and make inroads on such markets and probably to invest in new processing equipment as well. In the end the country might end up with more valuable fish catches, but at a certain cost.

It is difficult to generalise about these points, other than to say that flexibility on all fronts will be helpful. Regulatory regimes should be such that the industry can switch its boats and processing equipment from the retreating species to the expanding one as needed. In regimes that rely on fish quotas or licenses there should be flexibility as required to switch from a quota or a license for species *X* to species *Y*, needless to say without unduly raising the exploitation pressure on species *Y*. This could be achieved with markets for licenses or quotas where the total amount for each type of fish is decided on sound biological and economic principles, allowing the industry to achieve maximum efficiency within those limits.

Likewise, easy market access would be helpful to cope with switches to new species and markets. Traditional supplies to a given market could dry up if the fish species involved can no longer be caught by the traditional suppliers, be they domestic fishermen or some specific exporting country. It would be in the interest both of the consumers in those markets and of the new potential suppliers emerging if imports of fish are unimpeded by tariffs and other trade restrictions, except those necessary for health and safety purposes.

In general, one would be tempted to conclude that the richer a country is, the better it will be able to cope with structural changes made necessary by climate change, in fisheries as in other industries. Rich countries certainly are in a better position to pay monetary compensation to those whose skill and capital equipment might be made obsolete by disappearing fish stocks. On the other hand, rich economies are often more demanding in terms of specific skills than poor ones; specialisation is indeed one of the factors behind economic growth. The skills acquired in an industry like fishing could, in a rich country, be less easily transferable to other industries relying on a different set of skills. Hence, reintegrating redundant fishermen into the labour market could be more difficult and expensive in rich countries than in poor countries.

The ACIA report mentioned earlier went into considerable detail about the possible economic effects of changes in fish abundance in the Arctic and sub-Arctic region (ACIA, 2005, Chapter 13). Of particular interest is the analysis of what might happen to the economies of Iceland and Greenland. This is so because in most countries fisheries are a very small part of the overall economy, but often important locally and possibly pivotal in certain regions. The impact of changes in fish stocks would therefore hardly be noticed in statistics at the national level, while regional statistics are often too rudimentary to evaluate such regional effects and may not exist at all. For the Icelandic economy a gradual change in fish stocks spread over 50 years would hardly have a discernable impact on the economy. However, a more sudden change for the worse – a decline of 25% over five years – would produce serious effects, producing a dip in GDP to 90% of a reference level, attained over a few years, and then a recovery.[4] The Greenland economy, being more fish-dependent, seems still more sensitive to changes in fish abundance, so even a moderate increase in fish abundance would have a significant impact on the economy. From this it appears clear that such gradual and moderate effects as foreseen by the ACIA scenarios would have a relatively minor impact, except in extremely fish-dependent communities with few opportunities, such as Greenland.[5]

Changed fish migrations and shared stocks

Some fish stocks traverse the great oceans; tuna is a primary example. This is most likely driven by a search for food. Some stocks migrate recurrently to certain locations to spawn; north-east Arctic cod and Norwegian spring-spawning herring are two examples, discussed at some length in the annex. Whatever the reason, the extensive migrations of some fish stocks take them across national boundaries at sea, and sometimes into what is left of the high seas.

The fact that one country cannot effectively control a stock that periodically migrates out of its EEZ and into that of another or into the high seas, has prompted some of the countries sharing a stock to agree on its management and control. All countries involved have an interest in avoiding overexploitation, but apart from that their interests and incentives may be different. Their goals might possibly differ, and even if they are only concerned with economic gain, the relevant parameters such as costs, prices, or discount rates might differ among them. But even if the said parameters were the same the incentives for avoiding overfishing could vary in strength.

Fish stock management involves the resolution of two questions: (i) how much fish should be caught from each stock at each point in time, and (ii) how that amount should be divided among the parties. Several principles have been invoked in the resolution of the latter question; some at least are based on what may loosely be called zonal attachment, *i.e.*, how much of the stock is within the EEZ of one particular country, or how much time the stock spends there (Engesæter, 1993). Both are essentially variations on the same principle.

But things could be less straightforward. If sovereign states are to agree to anything, they must fare better under the agreement than without it. This means that a state will only agree to limiting its fishing effort if this results in greater gain than it would get otherwise. This is only loosely related or not at all to zonal attachment. In Box 9.1 this is illustrated with a simple, numerical example. It is also illustrated how a sudden, unexpected and perhaps imperfectly understood change in the distribution of the stock might upset an existing agreement.

One example of how a scenario of the kind illustrated by the example in Box 9.1 can play out is the warming of the north-east Pacific after the late 1970s and its consequences for the salmon runs to the rivers of Canada and the United States. The runs to the rivers of Oregon and Washington were adversely affected, and so were the runs to the Fraser River in Canada, but the latter increasingly took a northerly route north and east of Vancouver Island instead of rounding its southern tip where they would have been temporarily available in US waters. The agreement between the US and Canada had sought an acceptable interference by Americans with the runs to the Fraser River and by Canadians with runs to Washington and Oregon. The warm regime kept the Fraser River salmon mostly in Canadian waters, while the runs to Washington and Oregon were severely down. Further north, salmon runs to Alaska increased greatly, and Alaskans were increasingly able to catch fish heading for rivers in Canada. This essentially led to the emergence of three players; Oregon and Washington together, Canada, and Alaska, all with different interests and differently affected by the climate change. The sharing agreement broke down in 1993, but was eventually renegotiated, with allowances for differential changes in salmon abundance and inclusion of side payments (Miller and Munro, 2004; Miller, 2007).

Box 8.1: Zonal attachment and the sharing of a fish stock

Suppose we have a stock 20% of which annually spills over from Country A’s EEZ to Country B’s EEZ. The reproduction of the stock from one year to the next depends on how much of the stock is left after fishing in both countries’ zones, the stock remaining in Country B’s zone after fishing returning to Country A’s zone. Suppose the stock reproduces according to the relationship R = Sa where 0 < a < 1, so that the size of the stock in the absence of fishing would be R = S = 1, and the sustained catch would be Sa – S in case we always leave S behind after fishing. Suppose, for simplicity, that both countries have the same economic parameters such that if one of them controlled the stock it would be interested in maximising the sustainable yield. That would in this simple example mean that it would maximise Sa – S, which would imply □S□ - 1 = 1. With □ = 0.5, we would get S = 0.25, so 25%of the stock would be left for breeding and growth, giving a total catch of □0.25 – 0.25 = 0.25. Would Country B be happy with getting 20% of this? This is, arguably, its zonal attachment of the stock. This would amount to 0.05. But what would country B do on its own? It knows that A would try to maximise its catch, given whatever amount of fish is left to migrate from B’s to A’s zone. Country A would maximise 0.8(SA + SB)□ - SA, that is, the share of the stock in its zone less what it leaves behind to breed and grow, the subscripts A and B denoting the stock levels left behind in the two countries’ respective zones. Country A can only determine what it leaves behind, and for any given stock that country B leaves behind, the solution to country A’s maximisation problem implies 0.8□(SA + SB)□ - 1 = 1, which gives us a solution for SA for any given SB. We get a similar result for Country B, 0.2□(SA + SB)□ - 1 =1, from which we can find a solution for SB for any given SA. The problem is, however, that for most stock levels that country A might leave behind, Country B would not want to leave behind anything at all, knowing that it would always get some fish to its zone due to A’s incentives to preserve the stock. The mutually consistent solution to both problems would be SA = 0.16 and SB = 0, resulting in a catch of 0.16 for A and 0.08 for B.a Country B would therefore not be satisfied with its zonal attachment share of the maximum sustainable yield, which we have seen is equal to 0.05; it could get 0.08 on its own, and this much it will demand as a minimum if it is to go along with an agreement about managing the stock. Suppose, then, that A and B have reached an agreement in their best mutual interest, so that the sum of what they leave behind is 0.25, producing a stock of 0.5 at the beginning of each season, of which 0.1 spills over into B’s zone. B takes 0.08, the minimum acceptable to it, leaving behind 0.02, with A leaving behind 0.23 and taking 0.17. Suddenly the tables are turned, with Country B now getting 80% of the stock and Country A only 20%. This may take some time to discover, at any rate with a sufficient degree of certainty. Country B would most likely consider itself entitled to a greater catch of fish, and A might be reluctant to recognise its present eroded position. A used to have a stock of 0.4 within its zone at the beginning of each season, but now it has only 0.1. There is no way Country A can catch 0.17 and leave behind 0.23 as it used to do. Suppose that, partly in ignorance and partly in frustration, A takes all the fish in its zone, and that Country B feasts on the bonanza and only leaves behind 0.02 as it used to do. In the next period a stock of only □0.02 = 0.1414 appears, instead of 0.5. A vicious downward spiral has begun. How quickly would the parties recognise and adjust to the new situation? Would the authorities in the two countries believe this is just a freak event or permanent? How long would it have to prevail before they accept it as permanent? How large losses would occur in meantime? Could the stock be fished to extinction? a With SA = 0.16 and SB = 0, the emerging stock is □0.16 = 0.4. Of this 80 percent, or 0.32, is in Country A’s zone, and Country A catches 0.16 if it leaves behind 0.16. Twenty percent of the stock, or 0.08, migrates to Country B’s zone, and Country B can take it all, knowing that Country A has an incentive to leave 0.16 behind in its zone. If we check the maximum condition for Country B, we find that 0.2x0.5/□0.16 = 0.25 instead of 1, which means that Country B would want to leave a negative amount of fish behind (- 0.15), which is not possible.

Changes in fish migrations due to climate change could thus put the existing agreements on sharing fish stocks under strain, or make it more difficult to reach agreement where none is in place. Some sinister outcomes are possible. Suppose, for example, that a stock has been confined to Country *A*'s EEZ. Climate change increasingly diverts the stock into Country *B*'s EEZ, while the growth and reproduction of the stock still depend on how much of the stock is left after fishing in the EEZs of both countries. Country *A*'s command over the stock will be steadily eroded and so will its previously strong incentives to protect it, while Country *B* will acquire an interest in the stock, at first fleeting but then a more substantial one. If things continue in this direction, *B* will ultimately acquire a stronger incentive than *A* to preserve the stock for reproduction and future growth, while *A* will become a player which only has a minor fraction of the stock and which in fact will be able to demand a disproportionate share of the stock, since it will in any case benefit from *B*'s conservation efforts without making much of a contribution itself. But how quickly will the players realise this reversal of roles and how timely will their adjustment to it be? This is likely to be a difficult issue, because global warming and the changes it leads to in ocean climate will be a trend around which will see substantial variations, similar to the climatic variability in the past. Changes in fish migrations are thus likely not to be smooth trends but trends with temporary reversals. How is Country *B* to know that the fish are shifting over to its zone on a long-term basis? With expectations formed on the basis of recent experience, Country *B* may see fluctuations without much of a long-term trend and may thus come to realise its pivotal role for the stock much too late. And when will Country *A* realise that the stock will leave its EEZ for good and that its days with a major interest in the stock are numbered? It is possible to think of a "twilight" period in which Country *B* has not yet realised that it has acquired a permanent, major interest in the stock while Country *A* will realise that it has no long-term interest in the stock any more. Country *A* may therefore decide that it serves no purpose to preserve the stock for future use and so neglect to leave any of it behind, while Country *B* has not yet realised that it would be in its interest to do so. As a result, the stock would be depleted, possibly once and for all.[6]

Are there examples of stocks which could be shifted permanently out of one country's zone into another? No stock seems to have undergone such radical permanent shifts, but there are stocks which have experienced major shifts as a result of depletion or climate change and possibly a combination of both. As the stock of the Pacific sardine collapsed, what remained of it was mainly within what is now the EEZ of Mexico, while in its heyday sardines were caught as far north as British Columbia. As the stock has grown in recent years it has again been found as far north as British Columbia. Prior to its collapse in the late 1960s, the Norwegian spring-spawning herring migrated towards Iceland during the summer and was caught in what is now the Icelandic EEZ in substantial quantities. After the collapse it became confined to what is now the Norwegian EEZ, although its changing habits were at least in part caused by a temporary cooling of the waters north and east of Iceland (Malmberg, 1969; Hamilton *et al.*, 2006). This was well before the EEZs became established, but in any case one may surmise that a sharing agreement based on the catch shares or "zonal attachment" back in the 1950s and early 1960s would hardly have survived these changes. A sharing agreement for the stock in fact broke down for a few years early this century because expectations about the stock migrations did not materialise.

Another example along similar lines is the North Sea herring. As the stock was decimated in the 1970s it became more and more concentrated in the EU-part of the North Sea. When the fishery was resumed in the 1980s Norway and the EU, within whose

EEZs the stock was located, negotiated a total quota and how it should be shared. The EU wanted to base the sharing on the zonal attachment of the stock, which had been found to be 4% in the Norwegian zone. The Norwegians argued that this low attachment was due to the concentration of a small stock in the EU-area and refused to accept the offer. They allowed their fishing fleet to fish at will within the Norwegian zone, resulting in a much greater Norwegian share of the catch than the 4% offered by the EU. The following year a sliding scale for sharing the total catch was agreed, with the Norwegian share being greater the larger the stock.

A warming of the Barents Sea could change the habitat of the north-east Arctic cod, which inhabits the EEZs of Norway and Russia. Its spawning grounds are off the coast of Norway, while the larvae drift towards Spitzbergen and into the Barents Sea. A warming of the ocean in this area is expected to shift the stock further east and north, into the Russian EEZ. Ever since the EEZs were established and a total quota imposed for the stock, the two countries have shared it evenly, apart from a minor allocation to third countries. A major relocation of the stock might undermine this sharing agreement for the reasons discussed above.[7]

It is possible that the picture being painted above is too gloomy. There are factors mitigating against dramatic fish stock depletion and breakdown of agreements as a result of climate change. One such is that fishing costs are sensitive to stock size. If the cost per unit of landed fish goes up as the stock is depleted, this provides some protection against a serious stock depletion resulting from a breakdown of sharing agreements. And the sharing agreements themselves could be resilient against variations in fish migrations. Oceanographic conditions vary a great deal from year to year, due to factors that are unlikely to be related to global warming, and so do fish migrations. Many of the existing sharing agreements seem to be quite resilient to these variations, even if no formal allowance is made for this. The sharing of the North Sea stocks between Norway and the EU is based on an investigation carried out in the early 1980s and has withstood the test of time, with the exception of the North Sea herring already discussed. But both the North Sea herring example and the north Pacific salmon runs indicate that if changes in fish migrations are too dramatic and long lasting, agreements on stock sharing will indeed come under pressure.

High seas fisheries

Changed fish migrations need not only affect the EEZs of individual countries, migrations between one or more EEZs and the high seas could become established or existing ones be affected, positively or negatively. Some stocks (straddling stocks) are mainly contained within the EEZ of one or more countries while others are predominantly or even exclusively in the high seas area. The example in the previous section about a stock migrating out of Country *A*'s area into Country *B*'s area is perhaps particularly pertinent to stocks straddling into the high seas, with the latter replacing Country *B*'s EEZ in this context. Not only would the conservation incentives for Country *A* be seriously eroded by the weak incentives the high seas players have to leave anything behind, the high seas players also face considerable difficulties in coordinating their actions and in finding a common interest.

There is no doubt that management of fish stocks that are partly or wholly within the high seas is a great deal more difficult than it is for stocks confined within the EEZs, even those that migrate between the EEZs of two or more countries. The reason is the absence of national jurisdiction on the high seas; boats fishing in this area are under the jurisdiction of their home countries. The UN fish stock agreement has given the role of fish stock management on the high seas to regional fisheries management organisations (RFMOs), and some experts are of the opinion that fishing in contravention of regulations by these organisations is in contravention of international law, even if the offending country is not a member of or does not accept the authority of the RFMO in question (*e.g.* Serdy, 2008). The enforcement of these regulations is still up to the individual countries whose boats fish in this area, an arrangement that is much less effective than if one single state had jurisdiction, as the case is within the EEZs. The attempts to deal with enforcement have therefore concentrated on access to markets or port services, denying access to markets for fish taken in contravention of RFMO regulations and services to boats engaged in such fishing. How successful this is depends on market concentration and how vigorously these measures are pursued by the countries where the major markets are.

It is very difficult to say anything in general about how global warming might affect fish migrations into the high seas versus containment within one or more countries' EEZ. To the extent that fish migrations into the high seas increase, fish stock management is bound to become more difficult. That difficulty is due to the fact that it is more difficult to reach agreement the more parties that must agree, and on the high seas there are more parties to be reckoned with than there are for stocks that stay within the EEZs. This problem is aggravated to the extent that the number of parties with an interest in a high seas stock is indeterminate, while the number of countries with an interest in stocks that stay within EEZs is either just one or at any rate defined by the migratory habits of the stock in question (and which may change as already argued). Traditionally, fishing on the high seas used to be open to any country, and it is still unclear to what extent the RFMOs can limit that number or whether, and in that case how, they must accommodate new, untraditional members.

Among the high seas stocks that could be affected by climate change the tuna stocks are the most important, partly because of their extensive migrations and partly because of their high value. Miller (2007) has discussed the effects of climate change on the tuna stocks and pointed out the need for flexible arrangements that could adjust automatically to the challenges of climate change. She mentions transferable catch or effort quotas that could be utilised irrespective of where the fish are taken. Such measures would require that the RFMOs involved have reached an agreement on allocation of quotas or fishing licenses among the parties involved and solved the new member problem so that an existing agreement could not be undermined by countries that suddenly might want to engage in the fishery. This is a taller order than it might seem; it is possible to imagine that those who now are engaged in these fisheries deliberately abstain from ambitious agreements that might appreciably improve the profitability of the fishery, as this might attract entrants that would not find it worthwhile to participate in the fisheries as they are at present.

It is possible that the strains climate change might put on the tuna fisheries, and other high seas fisheries for that matter, will depend on the shape and size of the EEZs involved versus the high seas. Both the Indian Ocean and the eastern Pacific have vast spaces of high seas in which much of the tuna fishing takes place, and there are relatively few national EEZs involved. The western Pacific is different in that it is interspersed with EEZs of many independent island countries, with high seas "holes" in between. The *El Niño* events are known to displace tuna migrations by hundreds or even thousands of miles (Miller, 2007). This has led to major shifts in catches taken by some of the Pacific island nations in the area. Migrations between the EEZs and the high seas are also affected. Such international agreements on tuna fishing as there are or might be attained in the Indian Ocean and the Eastern Pacific are therefore less likely to be upset by climate change, as the distribution of fish between the high seas and the EEZs will not change much, while in the western Pacific climate change might cause major shifts in the bargaining strength of the different nations involved.

Conclusions and policy implications

One thing is certain: there will be changes in the ocean climate, as there have been in the past, irrespective of whether global warming is happening or not. Global warming will add two complications. First, it will add a trend, around which ocean climate will fluctuate. Second, because of that trend, it is more likely than it used to be that changes in ecosystems will be irreversible. It is uncertain how great the associated changes in fish stocks will be, in what direction, and how quickly they will happen. They are also likely to differ from place to place, not only in magnitude but also in direction. Certain stocks may fade in certain areas, or may disappear altogether and in some cases be replaced by other stocks. Whether on balance this is for the better or for the worse will vary from place to place. Suffice it to say that all changes, be they for the better or for the worse, call for adjustments, and adjustments are always costly.

What are the implications for fisheries management? This depends on whether the effects of climate change occur gradually or not, and whether they can be predicted or not. If these effects take place in small, incremental steps they would not seem to be very problematic; adjustment could be made in similarly small, incremental steps. That climate change will occur as variations around a trend might seem to support the notion that its effect will also be gradual and at times even reversing direction, but this would be too hasty a conclusion. It is quite possible, and indeed likely, that there are certain threshold levels in terms of water temperature, salinity or flow of currents that make certain fish stocks unviable in their previous environment, or at least substantially affect their abundance. These effects could manifest themselves suddenly as the critical threshold levels are surpassed, even if the underlying climate change itself is incremental. Furthermore, it is highly uncertain whether fish stocks would bounce back from their depleted levels, even if the climate change that led to their demise was reversed.

Could sudden and possibly dramatic effects of climate change on fish stocks be predicted? If they could, management authorities could develop responses to cope with them. Unfortunately, it is uncertain whether or not these effects can be predicted sufficiently far in advance. To make such predictions, one would need either to have experienced similar changes in the past or to have a firm understanding of the mechanisms of climate change and its impacts on ocean ecosystems. It is worrying that none of the fisheries collapses that occurred in the past, some of which are discussed in the annex, were predicted; on the contrary they came as surprises. However, these collapses occurred before significant attention was focused on climate effects on fisheries. More recent developments and ongoing work suggest that there is hope to have fewer such surprises in the future, although the issue of possibly increasing climate variation will complicate the picture.

That the effects of climate change on fisheries cannot be predicted with much confidence and will sometimes occur suddenly has two implications for how to respond to them. First, a strengthening of marine science and its interface with climate science is needed. It is of obvious value to know what might happen, even if one cannot predict precisely when it will happen and on what scale. Such understanding can only come from a general advance in marine science; from oceanography, which tells us how ocean currents, salinity, temperature, upwelling and uptake of carbon dioxide in the ocean is likely to be affected, to fish ecology, which tells us how plankton, fish stocks and marine mammals interact, and how a change in one will affect the abundance of another.

The second implication is, in broad terms, the need for flexibility in response. If changes cannot be reliably predicted the only option we have is to respond to them after they have occurred. To do so in the fisheries context, flexibility is needed both in terms of market access and for adjustment in the use of labour and capital. Unnecessary barriers between different types of fisheries, some of which could expand while others must contract, should be avoided; this could be accomplished by transferable fishing licenses or quotas where the total number of licenses or quotas is based on sound biological principles applied to changing stocks. It is particularly important to avoid "preserving" work opportunities if this is achieved by maintaining a large and unsustainable catch from a dwindling stock. Instead, mobility out of a fishery that must rely on smaller catches because of worsening environmental conditions should be encouraged. In an economy with far-reaching specialisation and few opportunities for unskilled labour this would often necessitate support for retraining and perhaps geographic mobility as well. For capital equipment there may be second hand markets, especially once the world gets a grip on the global overcapacity problem. For markets, unimpeded access would facilitate switching to new sources for supplies when needed.

The changes that we have seen in world fisheries in the past and that appear related to climate change are suggestive of what might happen as a result of climate change and how we could or should respond. These changes have sometimes been of a magnitude to call forth adjectives such as "spectacular" and nouns such as "collapse". Over just a few years fisheries have collapsed, from hundreds of thousands of tonnes to nearly nil. These collapses are unlikely to have been caused solely by climate change; the primary reason is likely to have been in large part mismanagement, due to insufficient information, inappropriate interpretation of the information at hand, lack of appropriate institutions or measures, or short sighted lobbyism by industry. However, climate change may have added to the evils of bad management and helped bring about a collapse.

Several conclusions follow from this. The outcomes of future climate changes may in some ways be quite similar to those we have experienced in the past – there are some similarities between changes in ocean climate in the last century and what we expect to happen in the coming decades. The global temperature has in recent years reached a higher level than we have seen since the beginning of reliable measurements. Further increase could take us into an unchartered territory and, together with other stressors on marine eco-systems, cause unprecedented impacts. Second, what is critical is good management of stocks. The management of many of the stocks that have collapsed was either absent (Atlanto-Scandian herring, North Sea herring) or deficient (northern cod). Therefore, management, or the lack of it, is likely to have been the major cause of the collapse. How these stocks would have fared under better management we do not know, but it is not unlikely that the protracted absence of the herring could have been avoided, and the cod fishery of Newfoundland might have been saved.

Hence, climate change serves to strengthen further the arguments for good management, in particular avoiding such overfishing as typically results from open access. Global warming is unlikely to pose fundamentally new problems for fisheries management, but the present focus on it serves the good purpose of emphasising how dependent fisheries are and have always been on the variability in ocean climate. This has important, but unfortunately unclear implications for the sustainability of fisheries. The deterministic fisheries models, despite their usefulness as pedagogical devices, may have led some people to believe that sustainability of fisheries revolves around maintaining steady stock levels and steady catches over time. This is unlikely to be desirable for stocks the growth and reproduction of which depend critically on a fluctuating environment, and it may even be impossible to attain. Hence, if sustainability means anything, it means adaptation to a fluctuating environment. Unfortunately, it is not clear what that adaptation means. Does it mean preserving depleted fish stocks in the expectation that they will bounce back once the environmental conditions have returned to an advantageous state, or are some stocks doomed in certain areas because of irreversible changes in the ocean climate, so that we had better take them while they are still around? It is not easy to answer these questions, because of the difficulty to know whether climate changes are permanent and irreversible or part of a repetitive pattern.

Notes

1. This is not, of course, true for aquaculture, but it is capture fisheries that are the subject of this paper.
2. This report has been well summarised by Schrank (2007).
3. The value of total fish landings in Newfoundland in 1989-90, while the cod was still around, was about CAD 275 million per year (*Historical Statistics of Newfoundland and Labrador*, Vol. II (VII), 1994) published by the Government of Newfoundland and Labrador, Executive Council). In 2004-09 it was about CAD 470 million per year (Internet website of the Government of Newfoundland and Labrador: *http://www.fishaq.gov.nl.ca/stats/landings/index.html*). According to the consumer price index for Canada (*http://www40.statcan.gc.ca/l01/cst01/econ46a-eng.htm*), prices rose by 42% from 1990 to 2007, so allowing for inflation the value of fish landings was about 20% higher in 2005-2009 than in 1989-90. In the first years of this century the value of fish landings in Newfoundland was even higher (*http://www.dfo-mpo.gc.ca/stats/commercial/land-debarq/sea-maritimes/s2000av-eng.htm*).
4. This is about the same as the dip in GDP expected to occur in 2009 as a result of the collapse of the Icelandic banks.
5. The analysis of Iceland and Greenland is discussed from a more technical point of view in Arnason (2007).
6. This problem, with adaptive expectation, is considered formally in Hannesson (2007).
7. This problem is considered in a bioeconomic model in Hannesson (2006). This exercise illustrates the point made above that a decline in zonal attachment may up to a point strengthen the bargaining position of the country so affected.

Annex 8.A1

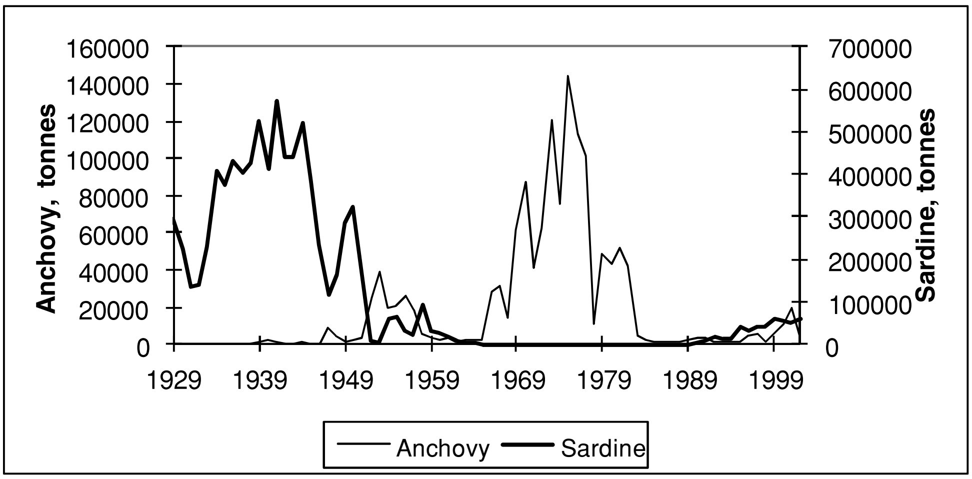
Examples of past climate changes and their consequences

In this annex we discuss several well known cases of fishery collapses and changes in the oceanic environment. It is recognised that the global temperature has in recent years reached a higher level than we have seen since the beginning of reliable measurements and that further increase could take us into an uncharted territory and, together with other stressors on marine eco-systems, cause unprecedented impacts.. However, it is valuable to review past experiences to identify potential lessons for the future. The environmental indicator used is ocean temperature, but the temperature is unlikely to have been the causal factor behind the collapses, even if any given fish species thrives within certain temperature limits and so could have been rendered unviable by passing critical thresholds. Rather the temperature is associated with other attributes of the water masses involved; such as salinity, higher concentrations of nutrients (upwellings), or transport of plankton and prey fish necessary for fish higher up in the food chain. Yet temperature is a convenient and widely used indicator for environmental changes in the ocean.

Another point to note is that the association between changes in ocean temperature and the collapse of fisheries is suggestive rather than a clearly established quantitative, causal relationship. Yet these associations appear to be widely accepted among fisheries biologists and oceanographers. The picture is further complicated by the fact that misinformed and inflexible fish stock management has also been involved in the fisheries collapses to be discussed.

Pacific sardine

Figure 8.A1.1. California landings of anchovy and sardine (1920-2002)

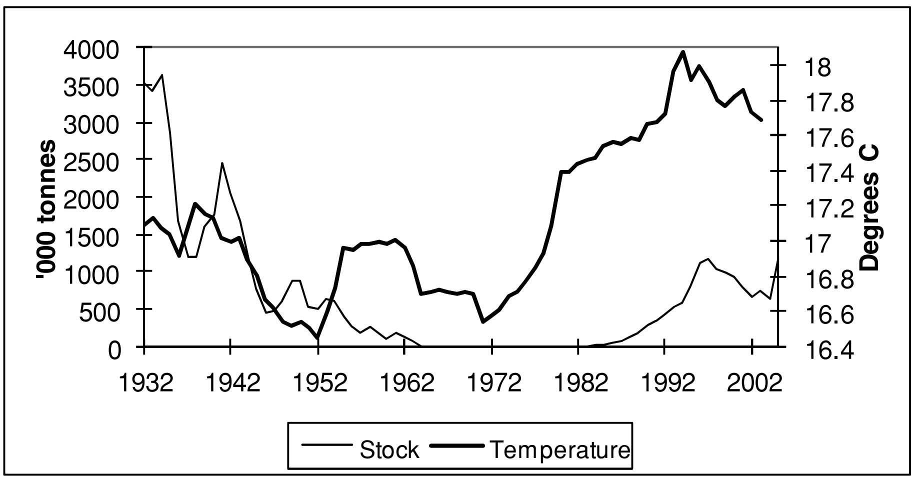


In the 1930s and 1940s, the Pacific sardine supported one of the largest fisheries in the world (*cf.* Figure 8.A1.1). Some fish was used for reduction to meal and oil and some by a large canning industry in California, made famous by John Steinbeck's novel "Cannery Row." In the 1950s the sardine fishery collapsed. The collapse was initially attributed to overfishing (Herrick *et al.*, 2006). Later, when marine biologists began analysing cores from sediments in the Santa Barbara channel, they found that sardine and anchovy appeared to have alternated in this area long before European colonisation and attributed this to climate changes (Baumgartner *et al.*, 1992). The collapse of the sardine fishery may thus have been partly due to a climate change. In the 1950s the North Pacific became cooler and entered a climate regime disadvantageous to the sardine, with anchovy taking its place in the ecosystem. As Figure 8.A1.1 shows, the anchovy fishery flourished in the period when the sardine was down (note that the scales for the two fisheries are different).

Figure 8.A1.2 shows the sardine stock and the nine-year moving average of the average annual temperature at the Scripps Pier in La Jolla, California. The figure suggests a positive correlation between temperature and the abundance of the sardine, although it is by no means perfect. The decline in the stock in the early 1940s coincided with a declining temperature, and the upswing in the 1990s coincided with a substantial rise in temperature. Due to a bulge of high temperatures in the late 1950s the temperature during the virtual absence of the sardine was not much lower than during the sardine heydays in the 1930s and early 40s, but certainly well below what it has been from the mid-1980s onwards.

As a result of the collapse of the sardine, people were thrown out of work, fishing boats became obsolete, and so did processing capital onshore such as fish meal factories and canneries. Some of the fishing and processing equipment was exported to countries where new and similar fisheries emerged, partly as a result of the collapse of the sardine fishery in California (Glanz, 1992). In the 1950s both the anchovy fishery in Peru and Chile and the sardine fishery in South and south-west Africa developed. Over a few years these became major suppliers of fish meal on the world market. Some of the cavernous sardine canneries in Monterey are now used by the Monterey aquarium.

Figure 8.A1.2. Spawning stock of Pacific sardine and temperature at Scripps Pier, La Jolla, California
(nine-year moving average)

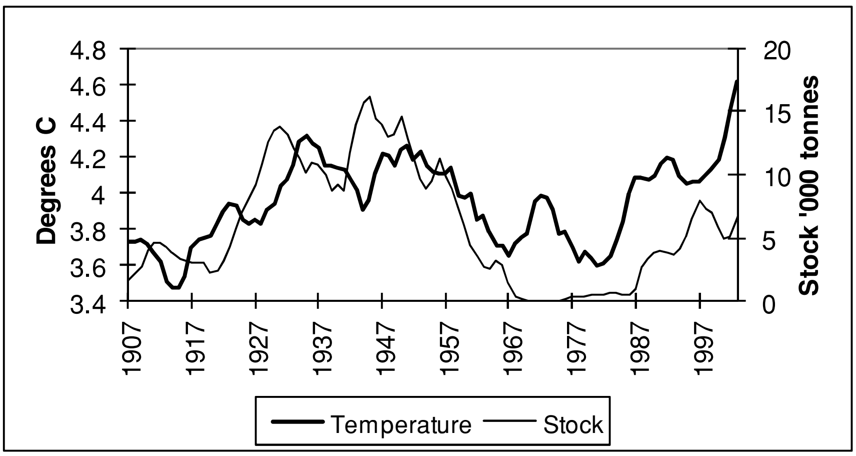


The Atlanto-Scandian herring

The collapse of the Atlanto-Scandian herring was no less spectacular than the collapse of the California sardine. The collapse has usually been attributed to overfishing, brought on by a major technological change that occurred in the fishery over just a few years (the introduction of a mechanical winch to haul in purse seines). At the time (late 1960s) the fishery was largely conducted in international waters, and an effective control of the fishery would have involved an international effort by Norway, Iceland and the Soviet Union and possibly others. This was not attempted. Apart from the difficulties in getting several parties to agree, it is doubtful if the problem was recognised in a timely enough fashion to do anything about it.

Lately attention has been drawn to the fact that there probably is a correlation between ocean temperature and the abundance of the herring stock (Toresen and Østvedt, 2000). Figure 8.A1.3 shows the size of the spawning stock of Norwegian spring-spawning herring and average annual temperature at the Kola section (nine-year moving average). The figure indicates a positive correlation between herring abundance and temperature; the period while the herring stock was down (1967-87) coincides with a period of lower temperature than before or after, and the recovery of the herring stock occurred after the temperature began to rise. While few would go as far as attributing the collapse of the stock to climate change only, it is certainly likely that some decline in the stock would have occurred as a result of cooling temperatures if the fishery had continued in the same fashion as it did before the technical change.

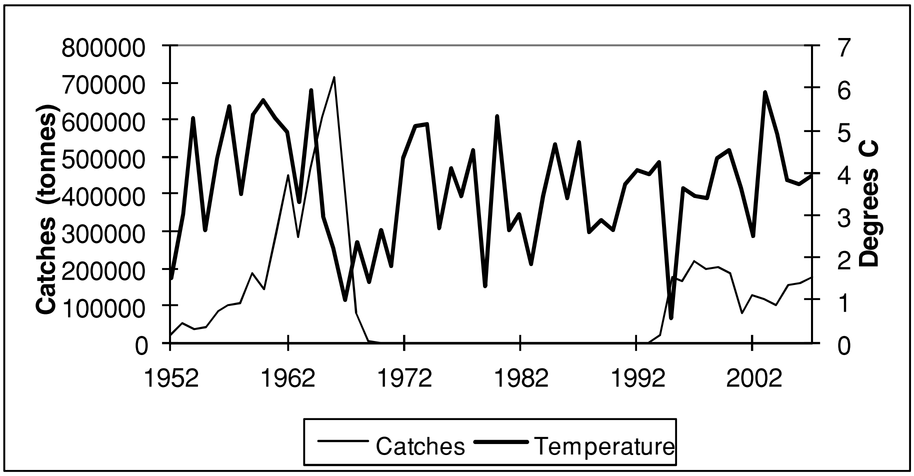
Figure 8.A1.3. Spawning stock of Norwegian spring-spawning herring and average annual temperature at the Kola Section
(nine-year moving average)



The decline in the herring fishery caused major disruption in the fishing industries of Norway and Iceland (Hamilton *et al.*, 2006; Lorentzen and Hannesson, 2006). In Iceland the gross domestic product fell, unemployment became a major problem, and many people emigrated in search of work. At the aggregate level these effects are much less visible in Norway, the Norwegian economy being much bigger and more diversified. In both countries the collapse of the herring fishery led to the development of new fisheries, especially the capelin fishery, which for a while was the major supplier of raw material for the fish meal factories in Norway and still is in Iceland. It is indeed possible that the capelin stock in the Barents Sea, exploited by Norway and Russia, came to occupy a part of the ecological niche left vacant by the herring.

What probably aggravated the herring collapse in the Icelandic fishery was a temporary cooling of the waters north of Iceland in the late 1960s (Figure 8.A1.4) (Malmberg, 1969; Hamilton *et al.*, 2006). This adversely affected primary production in the area and disrupted the traditional feeding migration of the herring to this area. In fact, a separate stock of spring-spawning herring that spawned at Iceland disappeared at this time, either due to overfishing or adverse climatic conditions. The same thing happened to the spring-spawning herring at the Faeroe Islands, so the Norwegian component is the only one remaining of what used to be called Atlanto-Scandian herring (an autumn-spawning herring stock still remains at Iceland). The importance of the temperature regime for the collapse in the catches of herring is masked by the fact that after the migrations to the traditional area north of Iceland stopped in 1963, the boats chased it further east and north towards Spitzbergen. The migrations did not resume after the temperature recovered in the mid-1970s, the reason probably being that there was very little left of the stock (*cf.* Figure 8.A1.3). These migrations still have not been fully re-established, but since the mid-1990s the Icelandic catches have been resumed, even if the Icelandic stock of spring spawners appears to have vanished.

Figure 8.A1.4. Icelandic catches of spring-spawning herring and spring ocean temperature at Siglunes



The north-east Arctic cod

Figure 8.A1.5. Stock of north-east Arctic cod and average annual temperature at the Kola Section (seven-year moving average)

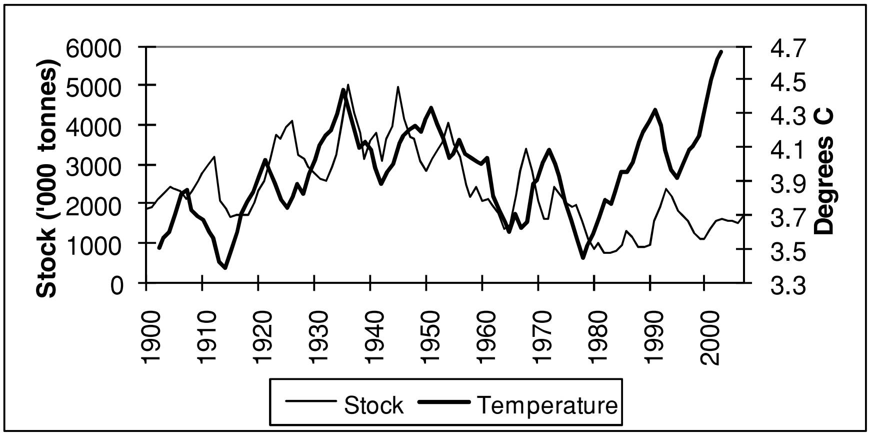


Figure 8.A1.5 shows the abundance of north-east Arctic cod and the average annual temperature in the Kola section (seven-year moving average). There figure suggests a positive correlation between stock abundance and temperature. The correlation is least convincing for the years after 1980. Since then the temperature has been on the rise, reaching in 2007 its highest level since 1900, but the stock abundance has been relatively low during that entire period, even if it did reach a local peak in 1994, about three years after a local peak in temperature. This is a long-lived stock; maturing at an age of six-seven years (later in earlier years) and recruited to the fishery at an age of three. If temperature primarily affects recruitment, a time lag of five years or more between temperature and the stock should be expected, and there is some indication of that. Unlike the herring and the sardine stocks, this stock has not collapsed, but the rate of exploitation increased very substantially in the 1960s and 70s, which could be the reason why the correlation between temperature and stock size is less convincing for the years after 1970.

Figure 8.A1.6. Recruitment of three-year olds to the north-east Arctic cod stock and temperature at the Kola Section three years earlier

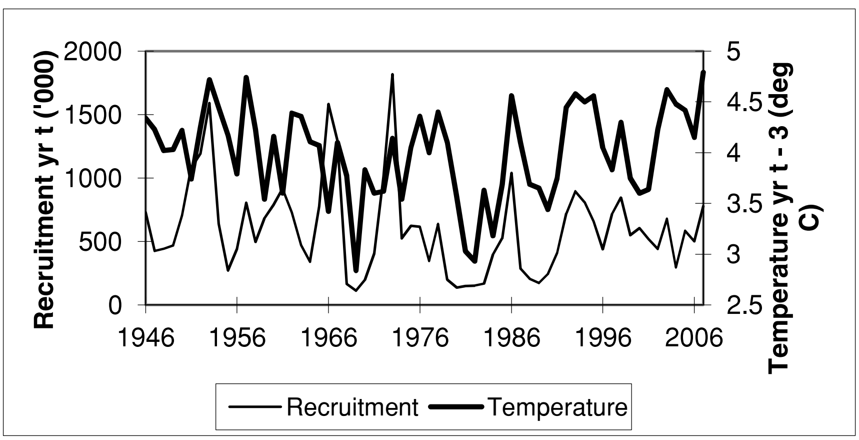
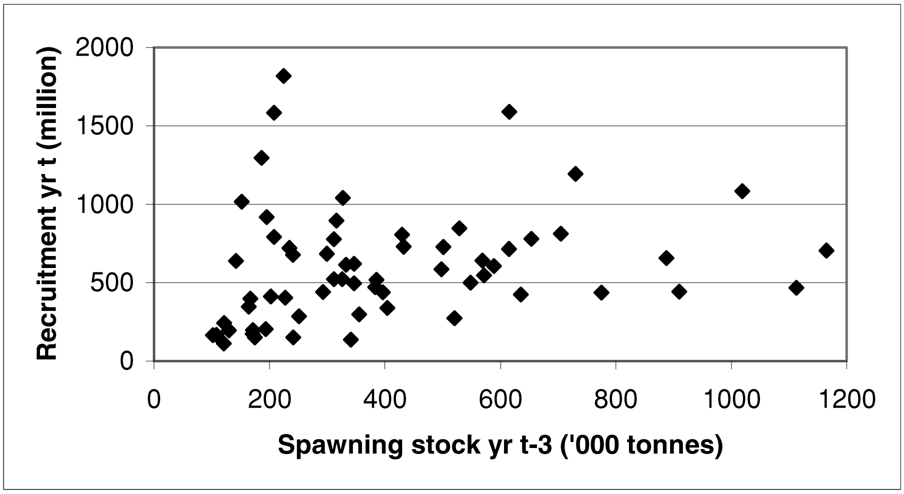


Figure 8.A1.7. Recruitment of three-year olds to the north-east Arctic cod stock and the spawning stock three years earlier



The ocean climate is probably particularly important for recruitment to the stock. Figure 8.A1.6 shows recruitment to the stock and the temperature at the Kola section three years earlier. The correlation between the two is not particularly high (0.27), but it is significant at the 5% level. Figure 8.A1.7 shows a scatter plot of recruitment and the spawning stock three years earlier. It is difficult to see any relationship between those two, except perhaps that a large spawning stock would not bring a large recruitment.

The northern cod of Newfoundland

The northern cod of Newfoundland is probably the only one among major commercial fish stocks that has been fished to extinction in an economic sense. The fishery was closed in 1992 and has not been reopened since, except on an experimental basis to help assessing the stock. This happened despite a management policy that was explicitly cautious (the $F_{0.1}$ criterion was used as a guideline). In hindsight the stock turned out to have been overexploited, due to erroneous stock assessment. Investigations have not uncovered serious methodological faults, but belatedly it was realised that the catch per unit of effort did not fall as much with the stock as expected, due in all probability to a herding behaviour of the stock in warm-water pockets on the Grand Banks during a cold ocean climate regime. The colder ocean climate may also have played a further role by retarding the growth and reproduction of the stock. The story illustrates well how difficult it can be to account for environmental variability despite well developed fisheries science and good intentions.

Figure 8.A1.8. Catches of northern cod (1850-1992)

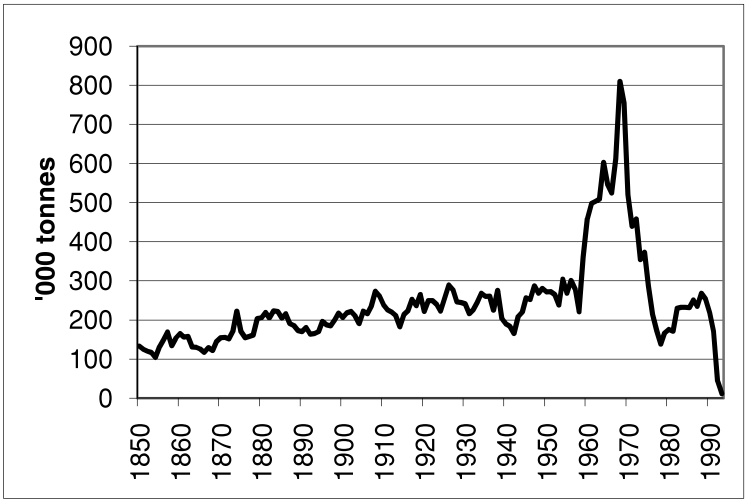
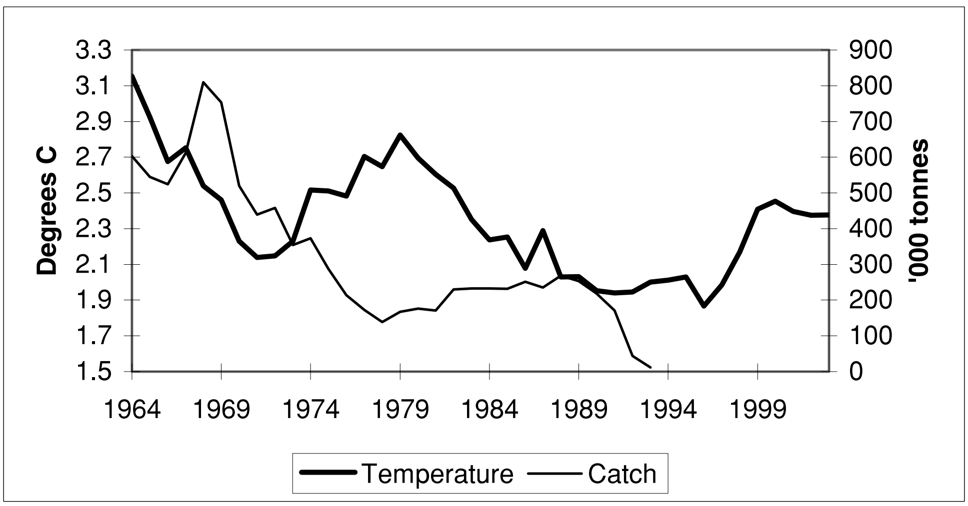


Figure 8.A1.8 shows the catches of northern cod from 1850; the high peak reached in the 1960s was due to the advent of large trawler fleets from various nations, which raised the rate of exploitation to an unsustainable level. After Canada established its exclusive economic zone in the late 1970s the catches fell to a level similar to what had prevailed before the international trawler fleets came along and continued in that fashion for about ten years, until the collapse in 1992. Figure 8.A1.9 shows that the collapse coincided with a cold ocean climate regime in the area.

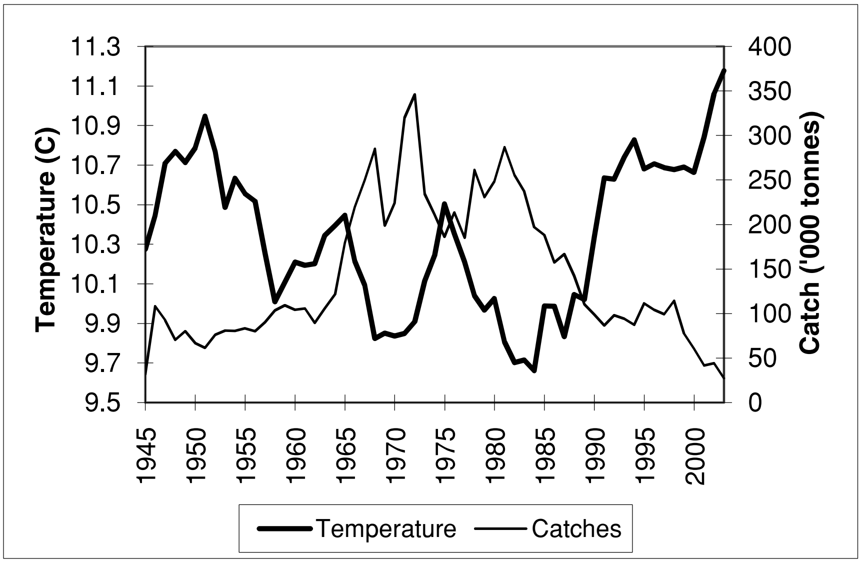
Figure 8.A1.9. Catches of northern cod and summer sea surface temperature at Newfoundland
(nine-year moving average)



The North Sea cod

It is generally acknowledged that the North Sea cod stock is not in good shape. This is typically attributed to overexploitation. This may indeed be true, but it is also true that the catches of North Sea cod are inversely related to ocean temperature, indicating that there may be more to the story than just overexploitation. Figure 8.A1.10 illustrates this, using temperatures from the northern fringe of the North Sea.

Figure 8.A1.10. Catches of North Sea cod and ocean temperature off the Sognefjord
(seven-year moving average)



If ocean climate plays such as large role as Figure 8.A1.10 indicates it raises some challenging questions. Is it possible to save the North Sea cod, or is it doomed to disappear because of adverse environmental changes? If so, it would not help much to cut back on fishing, and it might make most sense to catch it while it is still around. Similar questions can be asked about the Baltic cod. Both the Baltic and the North Sea are marginal areas for the cod, so that relatively small environmental changes threaten their survival.

The Peruvian anchovy

The fishery for anchovy in Peru developed in the late 1950s, partly as a response to the collapse of the Pacific sardine. A new fish meal industry was built on the basis of the Peruvian anchovy, and some of the equipment made redundant by the collapse of the California sardine was sold to the new Peruvian industry. Before the late 1950s hardly any anchovy was caught in Peru, and the anchovy was “harvested” indirectly by guano deposited on islands off Peru and Chile. The guano industry opposed the development of the anchovy fishery, fearing that its raw material base would disappear.

Figure 8.A1.11. Catches of anchovy and pilchard (sardine) in Chile and Peru

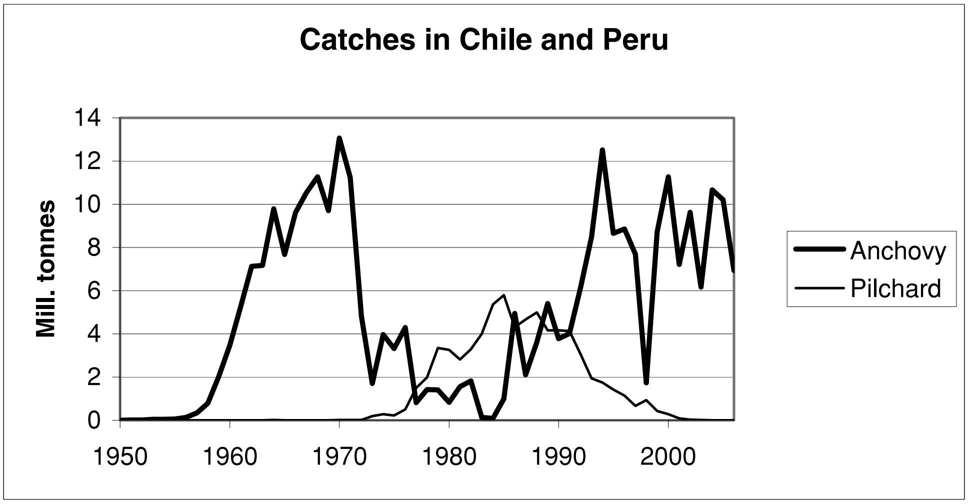


Figure 8.A1.11 shows the development of the anchovy and sardine (pilchard) fisheries in Peru and Chile. In 1972 there was a strong *El Niño* event, adversely affecting the catches of anchovy. Measures for cutting back the anchovy fishery were not taken in time, the stock collapsed, and the fishery did not regain its previous peak until 1994.

In 1997 there also was a strong *El Niño* event. This time measures were taken to reign in the fishery. The catches dropped precipitously in 1998, but recovered already next year. It appears that the lessons of the early 1970s had been learned, but prior to that time there was no experience of how the *El Niño* event might affect the anchovy fishery.

A noteworthy thing in Figure 8.A1.11 is the rise of the sardine fishery after the collapse of the anchovy, as well as its decline after the anchovy recovered. Sardine and anchovy occupy the same niche in the ecosystem and typically alternate in abundance, a phenomenon known to occur in several upwelling systems such as the California current, discussed above, the Benguela current, and the Canary current. So even if one species virtually disappears for a time, it is not necessarily the case that the primary production (plankton) goes unutilised.

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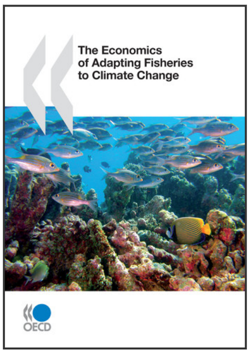

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