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Environmental information for stock evaluation and management advice purposes

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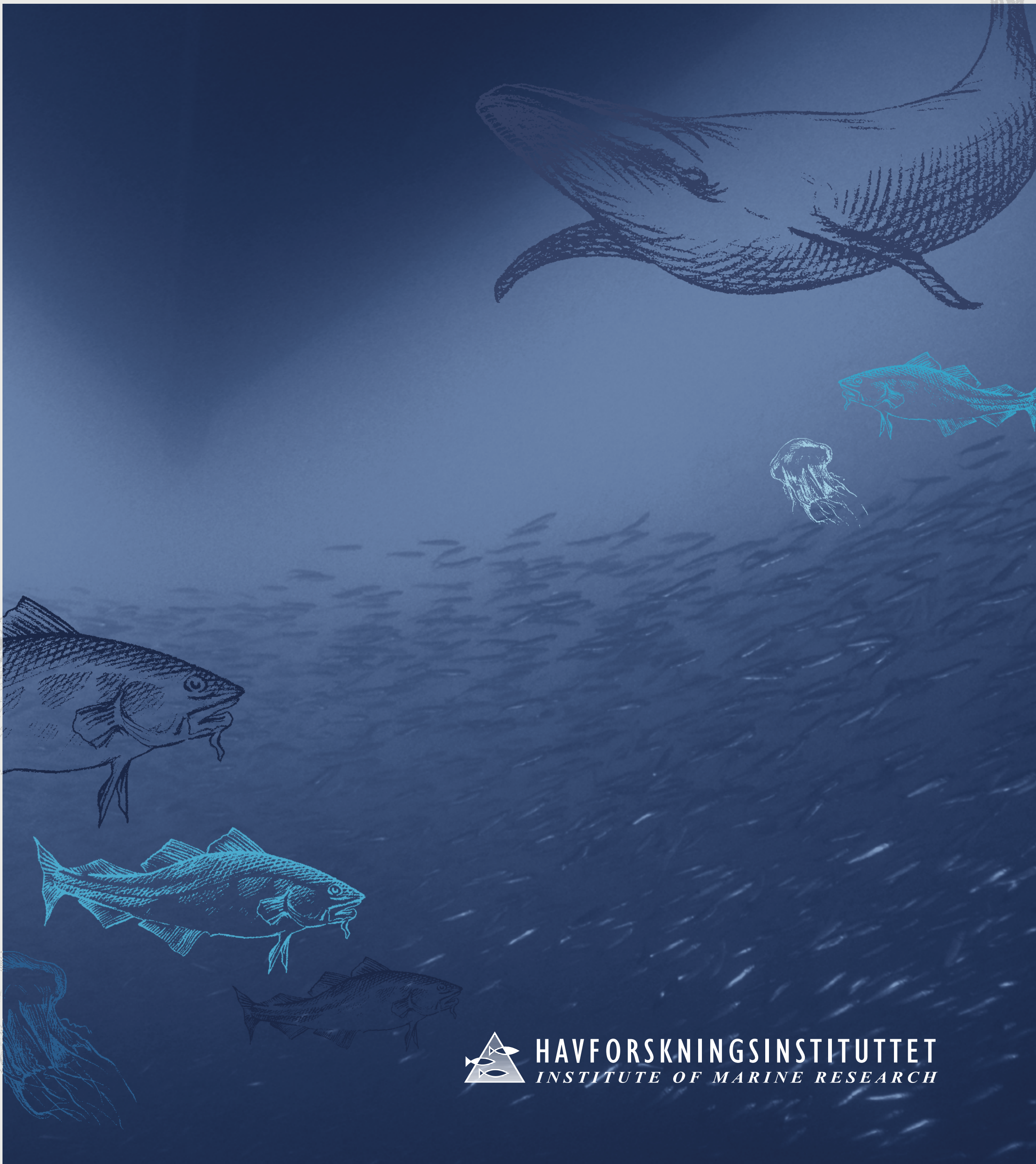

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Sammendrag (norsk):
Rapporten sammenfatter arbeidet til et utvalg nedsatt av ledergruppen ved Havforskningsinstituttet for å evaluere bruk av miljøinformasjon i bestandsvurdering og rådgivning. Rapporten diskuterer dagens- og potensiell bruk av miljøinformasjon og gir konkrete anbefalinger for hvordan Havforskningsinstituttet kan øke bruken av miljøinformasjon i bestandsvurderinger og rådgivning.

Summary (English):
This report summarizes the work of an internal working group appointed by the Institute of Marine Research's management group to evaluate inclusion of environmental parameters in stock evaluation. The report discusses the current and potential usage of environmental information and presents specific recommendation on how to increase the usage of environmental information for stock evaluation and management advice purposes.

Emneord (norsk):	Subject heading (English):
1. Bestandsvurdering	1. Fisheries assessment
2. Miljøinformasjon	2. Environmental information
3. Økosystemdynamikk	3. Ecosystem dynamics

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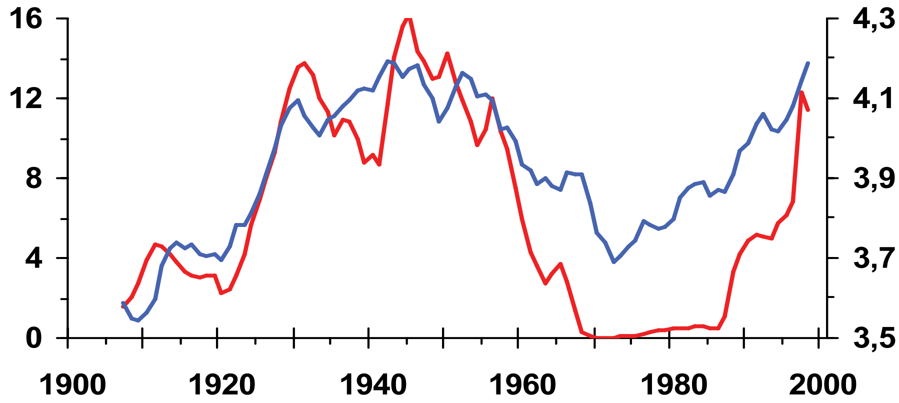
faggruppeleder

Environmental information for stock evaluation and management advice purposes



By

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November 2006

HAVFORSKNINGSINSTITUTTET
INSTITUTE OF MARINE RESEARCH

1. Recommendations

With a view to increasing the utilisation of environmental information for stock evaluation and management advice purposes, we offer the following recommendations:

1. Establish ecosystem-defined stock-advice projects staffed with a wide range of expertise in order to increase knowledge transfer and the robustness of the advice offered, and to capture common ecosystem processes.

2. Improve the flow, operationality and availability of data derived from observations and model simulations.

3. Identify and establish operational and quantitative relationships between environmental factors and stock variables such as growth, recruitment and natural mortality in our most important species.

4. Quantify potential improvements in historical stock evaluation and advisory situations by including environmental information.

5. Review environment-dependent reference points for fish mortality and spawning stock biomass.

6. Develop and implement environmental and behaviour-based models for correcting acoustic and trawl surveys.

7. Draw up a new data-gathering strategy aimed at meeting the requirements of ecosystem-based advice provision.

8. Continue to develop and improve the utilisation of environmental information in existing multi-stock models (*BIFROST, GADGET, SYSTMOD)*.

9. Finalise the numerical model for copepods, improve monitoring processes and initiate efforts to estimate zooplankton stocks.

10. Develop individual-based models of migration, growth and maturation for our most important stocks, particularly with the aim of estimating predator-prey overlaps, and study monitoring and management strategies.

2. Contents

3. Mandate

Following an initiative from Harald Loeng (sak Lg 66/2006), the Institute of Marine Research's management group appointed a group to evaluate the inclusion of environmental parameters in stock evaluations. The mandate of the group was to consider the following:

- Current status
  - Which climate parameters are being used?
  - How are these parameters utilised?
  - Which climate/fish relationships do we understand at present, either qualitatively and/or quantitatively?
- Why can we not use everything that we know for stock evaluation purposes?
- How can we integrate climate parameters into stock estimates and stock prognoses?
- What sort of climate information is relevant for use in the future?
- How can we obtain such information, and what are our requirements as regards format and operationality?

The first meeting of the group agreed to slightly modify the conceptual framework of the mandate. It was decided to adopt a broader perspective and to look at environment-fish relationships (including stock interactions) as a whole, rather than in the narrow sense of the concept. The group also agreed to employ the concepts of "stock evaluation" and "provision of stock advice" in place of "stock estimates" and "stock prognoses". This would give the study more room for manoeuvre than if it had kept to the more narrowly defined initial set of concepts. The structure of the report was also freed somewhat from the structure set out in the mandate, while the group sought to cover the original set of topics. In all other respects, the group stayed within the terms of its mandate.

The group comprises a wide range of expertise and includes scientists working on stock estimation, climatic effects, oceanography and behaviour/ecology:

Geir Huse, chair
Dankert Skagen
Sigurd Tjelmeland
Kathrine Michalsen
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Harald Loeng
Jan Erik Stiansen
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The group submitted its report to the Institute of Marine Research's management team on 15 November 2006.

4. Introduction

4.1 Background

Knowledge of ecosystem dynamics is essential if we are to be able to understand, evaluate and predict how environmental change and changes in fishing practices will affect the marine ecosystem. In this connection, two fundamental challenges will be those of identifying interactions and distinguishing between major natural variations and human impacts. Stock evaluations and provision of advice regarding living marine resources (fish, crustaceans, marine mammals) are currently based almost entirely on commercial catch data and trawl and acoustic data from research surveys. These estimates are essentially descriptive, telling us how stocks and harvesting rates have evolved over time, and how the future development of a stock will be affected by harvesting rates, but say little or nothing about why a stock has evolved as it has done, apart from shedding some light on the role played by harvesting. Without a broader understanding of the driving forces behind changes in stocks, we can make only extremely limited predictions about how they will evolve in the future.

This report concretises the problems involved in incorporating environmental information, used in the broadest sense of the term, into stock evaluation and advisory processes. In the course of time, we have generated a great deal of knowledge of the structures and functions of marine ecosystems, and climate change may prove to be just as important as the fisheries in bringing about changes in the state of our ecosystems, including the size of fish stocks. The report covers to only a limited extent the considerable knowledge that we already possess about our marine ecosystems; however in what follows we offer a brief description of natural variations in ecosystems, in order to be able to say something about the potential benefits of environmental information. This is followed by some examples of environmental information used in the provision of advice, and of known relationships that are potentially capable of being employed, but which have not been used to date. We then present and discuss an analysis in which we outline how environmental information could be incorporated into stock evaluation and advisory processes. Finally, on the basis of this analysis, we offer some specific recommendations (see above) regarding what the Institute of Marine Research ought to do in terms of incorporating environmental information into its stock evaluation and advisory processes.

4.2 Ecosystem dynamics

Norwegian fisheries areas, from the Barents Sea in the north to the Norwegian Sea, the coast of Norway and the North Sea in the south, span different types of marine ecosystems. The Barents Sea is an Arctic ecosystem. As we move south towards the North Sea, temperatures rise, and the species composition changes in favour of more temperate species. We move from an “arctic” ecosystem in the north to an "arctic-boreal" system in the Norwegian Sea and a "boreal-temperate" ecosystem in the North Sea. Within each of these ecosystems we can identify a considerable degree of natural variation. This is reflected to a certain extent by fisheries data and surveys, but in many cases there is a great deal to be gained by looking at several components of the ecosystem, rather than focusing purely on current stock levels. Climatic variations are a fundamental source of variation in other parts of the ecosystem, but it can be useful to look at responses in many parts of the ecosystem, because the latter is affected by climate in so many ways. Climate affects, for example, production and transport at lower trophic levels, the distribution of fish, mutual interactions among fish stocks, and the structure of the ecosystem itself. This last will be particularly relevant in the future because of the major changes that are taking place in the ecosystems of the North Sea and the Barents Sea.

Temperature is an important variable in the ocean climate because it affects every link in the food chain, from phytoplankton to fish. Organisms at these levels are all poikilotherms, which means that temperature has a direct influence on their metabolism. Any change in temperature will thus affect fish both directly and also indirectly via all organisms at lower levels of the food chain. However, the marine climate is not simply a matter of temperature; light levels, which are modified by cloud conditions, and turbulence, which is affected by the winds, are ocean climate variables that affect organisms at individual level, and it is particularly the lower links in the food chain, i.e. plankton, that are affected by light and turbulence. Current systems also affect the transport and dispersal of freely drifting plankton at population level. There are thus a large number of potential indirect effects of ocean climate change on, for example, cod in the marine ecosystem. In correlations between temperature and growth rates of a fish stock, a known temperature relationship may actually be a surrogate for a series of other ocean climate variables. Figure 1 illustrates the effects of various links in the food chain at individual and population level. Climate change also takes place on a range of different time-scales, ranging from annual to decadal and multidecadal (Figure 2).

An example of the effect of climate on fish stocks is shown in Figure 3, where variations in the size of the Norwegian spring spawning (NSS) herring stock partially correlate with long-period temperature oscillations in the Kola Section. The collapse of the herring stock at the end of the 60s was primarily the result of high fishing pressure, but the low biomass of the stock at the beginning of the previous century can scarcely have been due to the herring fishery. The build-up of the stock in the 30s was probably largely climate-driven; the result of several good recruitment years and good growth conditions for the spawning stock.

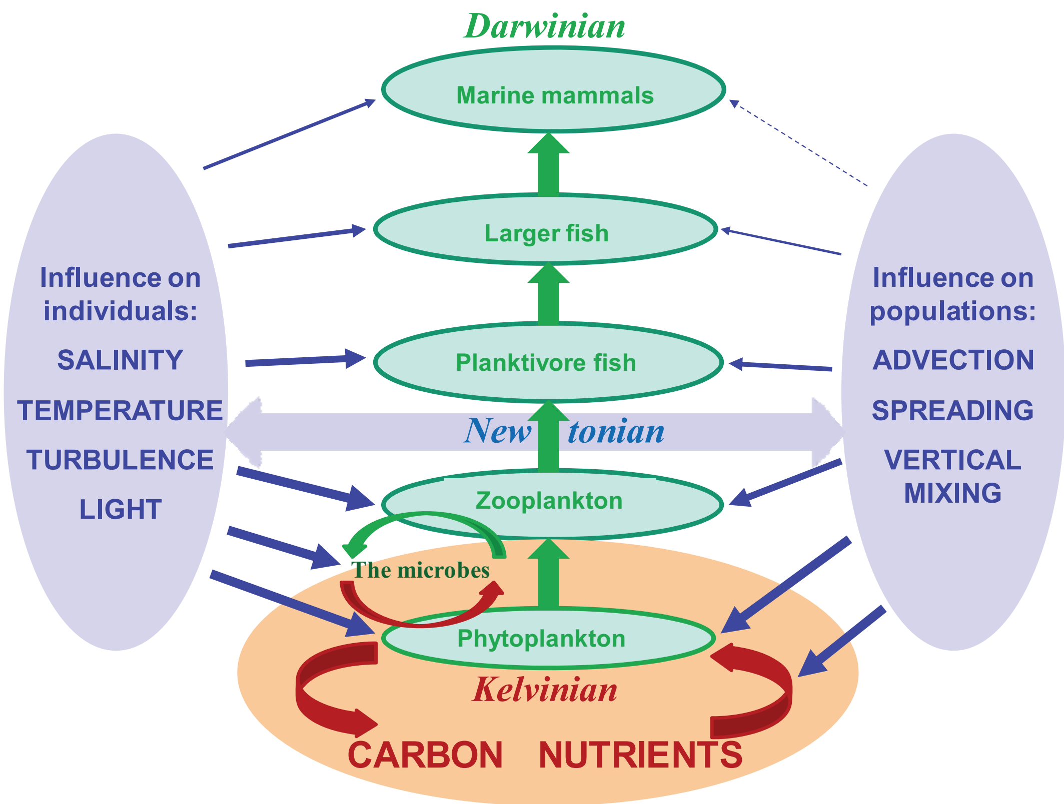

Figure 1. Effects of climate on the marine ecosystem. The ocean climate variables of salinity, temperature, light and turbulence affect marine organisms at individual level. These variables are included in individual-based models of marine organisms. The ocean climate processes of advection, diffusion and vertical mixing affect marine organisms, particularly plankton, at population level. These processes are included in numerical current models. From Sundby (2006a).

The dynamics of herring stocks, which are affected by the climate, are just one example of the obvious effects of the environment on fish. Climate also has major effects on other fish stocks, and it also produces cascade effects; rises in temperature, for example, increase recruitment to herring stocks, which in turn means more herring predation on capelin fry and thus a collapse in capelin stocks. In many cases, we are also able to quantify environmental effects on growth, for example, but this is only taken into account to a limited extent in stock evaluation and advice provision. One exception is the relationship between the North Atlantic Oscillation (NAO) and herring condition (Holst *et al.* 2004), which is used in providing advice about NSS herring.

In spite of these clear effects, we may still ask ourselves why we ought to implement knowledge of the environment in the advisory process. Put simply, this ought to be done if it enables us to improve the accuracy and/or robustness of our stock estimates and the advice we offer. This is obviously an absolute requirement for such an expansion of current methodology. In any case, it will be important to make major efforts in research if we wish to improve our understanding of ecosystems, and such efforts do not therefore need to be justified in terms of their direct applicability to stock evaluation and advice provision. Nevertheless, it is a problem that research results of relevance to stock evaluation and provision of advice are not utilised because the adaptation of the results needed to turn them into a form that would render them directly suitable for these tasks is not being done. Responsibility for ensuring that it is done must lie both with those who produce the research results and with those who work on the stock models that employ them.

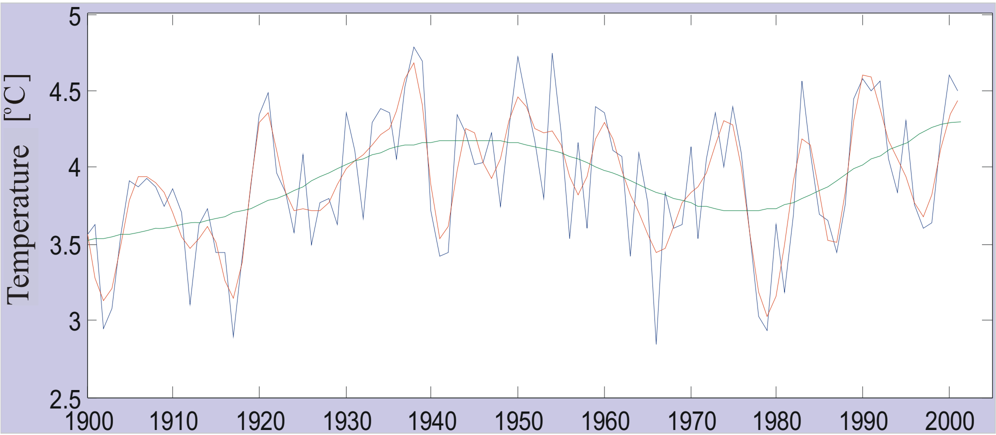

Figure 2. Temperatures in the Atlantic segment of the Kola Section (0–200 m, stations 3–7). 1) Blue curve: annual mean. 2) Red curve: 3-year running annual mean. This clearly shows the decadal oscillations. 3) Green curve: Long-term average produced with the aid of a 30-year low-pass filter. This clearly shows the multidecadal oscillations. Original data from PINRO, Murmansk.

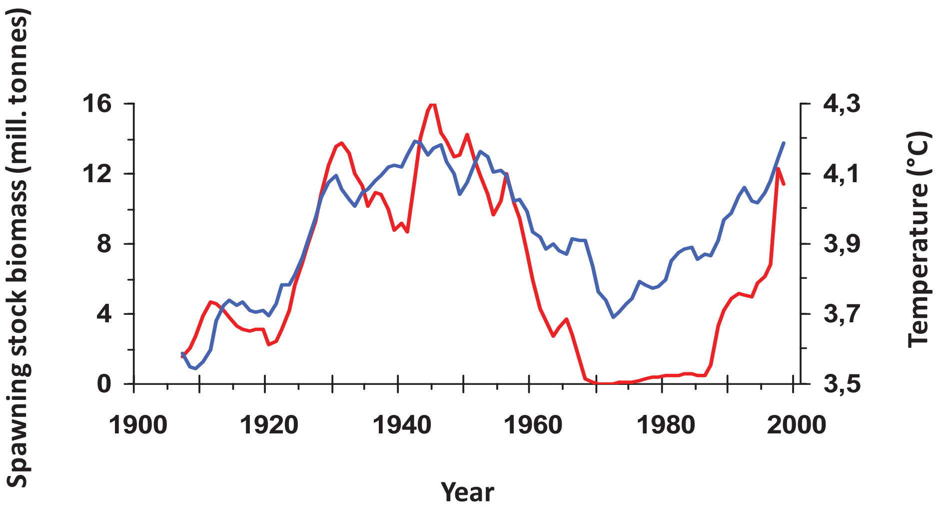

Figure 3. Biomass of spawning stocks of herring (red) and long-term mean temperatures in the Kola Section (blue). The temperature curve is in most respects similar to the green curve in Figure 2, but the averaging method is somewhat different. From Toresen & Østvedt (2000).

4.3 Climatic prognoses

The Institute of Marine Research is well to the forefront in the development of coupled hydrodynamic ocean climate models, and is a member of an international group that is developing the ROMS model system, a concept that is particularly suitable for linking with models of biological processes and individual-based models. We have recently completed the running of a 50-year "hindcast" time series for a global ROMS model, with high resolution in the North Atlantic. In the future, this will place us in a better position to study the underlying mechanisms of the well-established relationships between ocean climate and fish stocks. However, there is still a long way to go before such models can be used for general climate prediction purposes. All coupled ocean climate models (ocean/ice/atmosphere) are influenced by the atmosphere, which means that predictions of the ocean climate can never be better than the potential predictive capacity of our atmospheric models. Generally speaking, changes in the future climate can be divided into two components:

1. Natural climatic variations, which take place over a cascade of periods ranging from seasonal oscillations to thousands of years (e.g. the Milankovitch Cycle of 26,000 years).
2. Anthropogenic climate change, resulting from the rise in concentrations of greenhouse gases in the atmosphere.

It is actually much easier to predict global anthropogenic climate changes than natural changes. This is because the rise in CO_2 levels in the atmosphere produces quite specific, simple alterations in the global radiation budget, which is the relationship between incoming short-wavelength solar radiation and the longer-wavelength radiation that leaves the Earth for space. At present, there are twenty or so global coupled climate models capable of simulating rises in atmospheric CO_2. Most of them produce fairly similar results: a doubling of atmospheric CO_2 concentrations will raise the mean atmospheric temperature by 2–4 ^{o}C. The Bergen Climate Model (BCM), which is used by the Bjerknes Centre, is one such model. For the North Atlantic Ocean region, including the North Sea, the Norwegian Sea and the Barents Sea, it estimates a rise of between 1 and 2 ^{o}C in the annual mean sea-surface temperature in winter by 2070, with a rise of around 1.5 ^{o}C in the central Barents Sea (Furevik *et al.* 2002). However, only the greenhouse effect is being simulated here. Natural variations, from interannual to multidecadal oscillations, cannot be predicted by this model, because we do not know the specific driving forces that cause these oscillations and thus cannot incorporate them into the model. On the basis of existing time series, however, such as those from the Kola Section in the Barents Sea (Figure 2), we know that both decadal and multidecadal climatic oscillations are very distinct in our waters, and these have furthermore been shown to have clear effects on ecosystems and fish stocks. There is no reason to believe that such oscillations will be absent from a future warmer climate. But on the basis of our time series, we know that these oscillations can suddenly change, both in amplitude and in frequency. The NAO, for example, has been extremely dominant from the sixties until the present day, as it also was at the beginning of the twentieth century, but during other parts of the twentieth century it was much less marked. The decadal oscillations in Norwegian waters appear to have weakened again during the past few years. In making predictions of ocean climate, therefore, we are left for the time being with statistical analyses of climatic periods, combined with our knowledge about how a climate signal in one part of the North Atlantic spreads throughout the system.

5. Examples of the application of environmental information for stock evaluation and management advice purposes

As mentioned above, the application of environmental information for stock evaluation and management advice purposes is extremely limited; however a few examples do exist. Environmental information is used, for example, in combination with survey estimates (e.g. of mackerel), in predation and/or production modelling (e.g. capelin in the Barents Sea, shrimps off Greenland), in statistics-based processes and in the form of qualitative indicators. The following sections offer some examples of such uses of environmental information for certain individual stocks.

5.1 Mackerel

The only fishery-independent measure of stock size currently in use consists of biomass estimates based on the tri-annual egg survey, which counts the number of eggs in the sea at their earliest stage of development. This number is converted to give the production of eggs per hen fish. The process of recalculation makes use of the time that an egg remains at the first stage, and is done on a routine basis together with the egg measurements, but more accurate estimates of the ambient temperature in which the eggs grow would improve production estimates. The use of the Continuous Underway Fish Egg Sampler (CUFES) in conjunction with a model of the vertical distribution of mackerel eggs (e.g. Sundby 1983) has the potential to raise the level of accuracy of estimates of egg production while enabling the egg survey itself to be carried out in a shorter time.

5.2 Cod, haddock and capelin

Stock estimates of capelin, cod and haddock take into account mortality arising from the predation of cod on these species by taking cod stomach samples, estimated environmental temperature and experimental data on the rate of digestion in cod. The experiments have shown that a rise in temperature of 1 ^{o}C raises the rate of digestion by 10–15 %. It is therefore very important to use a representative temperature in calculations of this sort, and efforts are being made to improve the methodology on this point. We are also considering incorporating the consumption by cod in our stock estimates of some of the other most important prey species of cod, e.g. shrimp.

In the capelin stock management process, expected predation by cod is used to predict the spawning stock biomass (SSB) of capelin from the capelin survey cruise in September–October until spawning the following spring, using a model based on cod stock estimates and stomach samples, and in this case too, correct environmental temperature estimates are important.

5.3 Norwegian spring-spawning herring

There is a close relationship between the observed NAO index in winter and the biomass of copepods in the following summer. There is also a close relationship between copepod biomass in the Norwegian Sea and herring condition after a feeding season with large amounts of copepods. Herring growth can therefore be predicted by estimating plankton biomass in the year after the observed winter NAO index (Holst *et al.* 2004). In providing advice for herring, in connection with the zones to which they belong, the temperature and plankton distribution observed during the May ecosystem cruise is used to provide advice (internally within the Norwegian delegation) in connection with the negotiations regarding the zones to which Norwegian spring-spawning herring belong.

6. Examples of known environmental-fish relationships that are not utilised for stock evaluation and management advice purposes

There are also a good number of known environment–fish relationships that, for various reasons (see Discussion), are not utilised for stock evaluation and management advice purposes

6.1 Cod, capelin and herring

In the course of the past few years we have identified relationships (statistical models) that appear to be promising for making predictions of cod recruitment two to three years ahead, based on observations of temperature, capelin and cod (Huse & Ottersen 2002, Stiansen *et al.* 2002, Stiansen *et al.* 2005) and on models of water transport and primary production in the Barents Sea (Svendsen *et al.,* in press). We expect these to be particularly useful as a way of enabling us to provide early warning of recruitment failure.

One-year predictions of capelin recruitment (one-year-olds) appear to be possible on the basis of satellite measurements of sea-surface temperatures in the Barents Sea and biomass estimates of 0-group and maturing capelin (Stiansen *et al.* 2002, 2005).

On the basis of satellite measurements of Norwegian Sea surface temperature measurements and measured 0-group herring indices, herring recruitment (three-year-old) can be predicted three years ahead in time (Stiansen *et al.* 2002, 2005).

6.2 Anchovies in the Bay of Biscay

Anchovies are a short-lived species, in which recruitment has a decisive effect on the following year's fishery. There is a well-known relationship between recruitment and upwelling. An upwelling index was utilised for several years, but was abandoned after it resulted in completely unjustified advice to stop the fishery. "In-year monitoring" and acoustic and egg surveys are now utilised as indicators. A great deal of work has been put into understanding the relationship between distribution and ocean current/temperature, both in order to improve the interpretation of the results and as a basis for providing management advice.

6.3 Western horse mackerel

There is a good correlation between catches of horse mackerel in the North Sea in the autumn and inflows of Atlantic Water. A prognosis for the North Sea fishery is regularly reported to the working group, but is not used in developing its advice, partly because the Norwegian fishery in the North Sea is unregulated, partly because the regulation as a whole does not function particularly well, partly because the North Sea fishery is a relatively small part of the total fishery and finally, partly because we lack a reliable estimate for this stock. Tighter controls of this fishery are being developed, and horse mackerel are on the list of species for which Norway and the EU are trying to develop a joint management strategy. Relationships of this sort may come to be important in the future.

7. Integration of environmental parameters into current stock evaluation and management advice practices

The above survey is not exhaustive, but it does show that there are not so many applications of environmental information in stock assessment and advice provision, in spite of the fact that we know of, and can quantify, a good number of relationships. The reasons for this state of affairs are complex, and are partly historical and partly a natural consequence of the fact that fisheries data and quota advice should be integrated. At this point we do not intend to offer an in-depth analysis of why things have turned out as they have done, but will rather consider how we can improve stock assessment and advice provision by making more use of environmental information. In order to discuss this problem in more detail, it may be useful to divide this task into four facets:

- Stock estimates
- Short-term prognoses and provision of tactical advice
- Medium-term prognoses
- Design and evaluation of management strategies

The following sections describe the essence of these concepts and how we envisage that environmental information could be implemented to a greater extent, both on a general basis and for specific stocks.

7.1 Stock estimates

7.1.1 Description

These are estimates of stock size, usually in terms of age structure and harvesting rates, from the present day and as far back in time as we have data. Even though the tools that we use to make stock estimates often are described as models, they are really only analyses of observed data, which we try to make as independent as possible of modelling assumptions. We calculate how large the stock must have been back in time to allow the reported catches to have been taken, also taking other causes of mortality into account. The most central tool for this purpose is Virtual Population Analysis (VPA) and its equivalents, although other methods also exist. Cruise data (e.g. Catch Per Unit Effort: CPUE) is used to determine current stock levels relative to previous levels. This is quite different from modelling population dynamics, where we analyse mathematically how a population will behave, given certain assumptions about how production is dependent on the state of the stock. Production models, which are utilised when few data are available, lie somewhere between the two. The key is an assumption about how production (growth and recruitment minus mortality) is dependent on the size of the stock. The Institute of Marine Research has largely avoided using models of this type, as our philosophy has been that we prefer to base our estimates on direct observations of stocks and fisheries rather than on model assumptions, both because direct observations are available to us and because stocks do not always behave according to the textbooks.

7.1.2 Potential applications of environmental information

There have been few attempts to incorporate environmental information in stock the stock estimation process. Nevertheless, certain areas can be identified as potential areas for adopting the use of environmental information; these include the quantification of interannual variations in natural mortality (Recommendation 3) and the parameterisation of vertical distribution and angle of tilt in fish, in order to correct survey data (Recommendation 6).

Research has shown how acoustic target strength (TS) data for herring vary in the course of the day as a function of depth and tilt angle (Huse & Ona 1996, Huse & Korneliussen 2000, Vabø *et al.* 2002). This research, together with a study of the depth distribution of herring (of different year classes) in the historical acoustic time series could provide a basis for improving our observation model, which in turn would provide more reliable stock estimates. Similarly, there exist major differences between daytime and night-time acoustic measurements of biomass of fish in the

Barents Sea, where acoustic backscattering is only half as strong at night as it is during the day (Hjellvik *et al.* 2004). This is probably due to changes in the vertical distribution of the fish, and differences between day and night TS, but may also be a function of seasonal and environmental factors. An environment/behaviour-based correction might be one way of improving acoustic estimates in such cases.

Environmental information is not currently used in estimating capelin stocks, which are produced on the basis of direct acoustic measurements. A study of capelin migration related to environmental variables such as temperature and current could lead to improvements in survey design and thus to more reliable measurements for a given survey effort. Systematic variations in acoustic signal strength could also influence estimates (Jørgensen & Olsen 2002), as discussed above. This is particularly critical if there are major interannual variations in environmental factors.

The level of and variations in natural mortality can be important, particularly for short-lived species, but also for younger age-groups of other species. For example, shrimps are an important item of the diet of cod, particularly when capelin are scarce (Mehl 1989, Bogstad *et al.* 2000). It can be difficult to produce good estimates of natural mortality, but beyond the larval stage, predation is the major cause of fish mortality, and therefore there ought to be significant potential for developing better estimates of natural mortality if we increase our efforts in this direction.

7.2 Short-term prognoses and tactical advice

7.2.1 Description

These calculations are based on projecting stock estimates for a selection of fish mortalities, usually for one year ahead, in order to calculate what such mortalities are equivalent to in terms of catches. These form the basis of annual quota recommendations. Recommended quotas are the catches corresponding to what is regarded as responsible or desirable mortality on the basis of given criteria (precautionary principle and/or management regulations). The number of fish caught that is equivalent to the desirable mortality is converted into tonnes of catch, and the remaining stock is expressed in terms of spawning biomass, which is the measure of stocks which resources management usually refers to. The aim is usually that the spawning biomass should be maintained at a higher level than the reference points B_{PA} and B_{LIM} (see below). This calculation can be made stochastically (with bootstrapping) or deterministically; the latter method is more usual. The management authorities need a specific figure for the following year's quota, as they have problems in relating to distributions, while for our part, we are rather uncomfortable about the fact that the figures have fairly wide confidence intervals. These estimates are based on assumptions about natural mortality, growth, maturation and recruitment, as well as the estimated stock and fish mortality age profile. Recruitment plays an important role if mortality rates are high (short-lived species and/or high fishing pressure), otherwise it is not important (for single-year prognoses).

7.2.2 Potential applications of environmental information

Of the factors that are included in short-term prognoses and tactical advice provision, recruitment, natural mortality and growth/maturation are particularly important candidates for making estimates on the basis of environmental information (Recommendations 3 and 9), since all of these processes are controlled by environmental conditions, including stock interactions (Recommendation 8). The problem has been that of predicting these on the basis of known environmental information, and in this respect there is potential for further development; it is particularly important to be able to warn of changes.

Sætersdal & Loeng (1987) showed that cod, haddock and herring recruited better in warmer than in colder years. The best year classes occurred whenever there was a change from a cold to a warm regime. Ellertsen *et al.* (1989) showed that high temperatures in spawning and nursery grounds were a necessary but not a sufficient condition for good year classes of cod. It has also been shown that the environment has a greater influence on recruitment when cod stocks consist of few year classes than of many. This is related to the fact that when many year classes are spawning, the spawning process take place over a longer period of time and in a larger area, and there is a greater probability that some of the larvae will overlap with the copepod spawning period. We are thus aware of a range of different relationships, and for several species these have also been quantified and presented as predictions for several years ahead (e.g. Huse & Ottersen 2002, Stiansen *et al.* 2002, Stiansen *et al.* 2005, Svendsen *et al.*, in press).

Individual growth (and thus weight/maturation) is dependent on temperature and the availability of food. For some species, we use food availability data to provide prognoses of growth. Prognoses of the growth of herring in the quota year, for example, can be made on the basis of plankton biomass measured in the stock estimation year and on prognoses of plankton biomass (Holst *et al.* 2004).

Natural mortality will be dependent on the number of predators, the amount of other prey and the overlap between predators and prey. It is perhaps the last factor that will be most dependent on the environment in a short-term prognosis. In reality, estimating predator-prey overlap (continuously in time) can only be done by using numerical models of migration (with data assimilation), which in turn must be coupled with multispecies models with input data from biophysical models of lower trophic levels (physical factors, plankton, larvae). In this connection, we need to put much effort into completing ongoing work on a model of *Calanus finmarchicus*, and performing long-term simulations.

Natural mortality also forms part of an assumed quantity in making historical stock estimates, and it has a certain significance for estimates of current stock levels, i.e.

the point of departure for the short-term prognosis. For the following year's quota recommendations, the assumed level of natural mortality plays a lesser role than we might suppose. If natural mortality changes, however, the advice will be wrong. In this connection, therefore, changes in natural mortality are more important than the absolute level, and in one way or another, such changes will be based on environmental conditions.

The International Council for the Exploration of the Sea (ICES) is required to provide advice in accordance with the precautionary principle. This concept is not as well-defined as we might wish, and ICES has chosen to interpret it in its own way. The Institute of Marine Research usually supports the ICES interpretation. The core of this interpretation is that spawning stocks should not become so low that this in itself leads to reduced recruitment. There is also an assumption that recruitment is largely independent of biomass, as long as this is large enough.

ICES has established threshold values for biomass (B_{LIM}) that are assumed to represent the minimum biomass that is required to maintain "normal" recruitment. ICES has also estimated a maximum level of fish mortality (F_{LIM}) which (at least in principle) will produce a long-term biomass of B_{LIM} with normal recruitment. In order to allow room for the uncertainty of stock estimates and prognoses, ICES has chosen to make use of more conservative values (B_{PA} and F_{PA}). The idea is that if we estimate that the stock is or will be close to B_{PA}, it is unlikely that it will actually be B_{LIM}. A similar way of thinking applies to F_{PA} and F_{LIM}. Advice will usually be based on the idea that fish mortality should be no higher than F_{PA} if the stock after fishing is expected to be greater than B_{PA}. If it is not, a mortality rate low enough to bring it up again to B_{PA} in the course of one or two years will be recommended. For a few stocks, using this as a basis for advice is not suitable for various reasons, and other criteria have to be used. The capelin stock is one example of this (see below).

This basis for advice provision has several problematic aspects. These concern both how the reference values can be derived in a statistically acceptable way and whether there exists a well-defined biomass threshold that will guarantee a "normal" recruitment level, however static such a threshold might be. One current problem is whether B_{LIM} and B_{PA} should be fixed or functions of environmental conditions. It is also an open question whether fish mortality should be modified as stock productivity changes. There is a great deal to be said for the idea that the same level of mortality is optimal even if production rates change, but this question is the subject of discussion.

Developments are now moving in the direction of long-term management strategies (see below), a main feature of which is rational exploitation of the productivity of the stock. In such a connection, other indicators than current points of reference could be relevant, and we can envisage that most reference points would become superfluous as this strategy develops.

The capelin quota is set on the basis of acoustic biomass measurements and on prognoses of cod predation on capelin. The quota is set on the basis of probabilistic estimates and B_{LIM}, without the use of B_{PA}. This makes it easier to incorporate environmental information in a logically consistent way. The most important contribution is made by including a prognosis of young herring in the Barents Sea in the quota year, based on measurements in the stock estimation year, and basing quota recommendations on expected capelin recruitment instead of on minimum spawning biomass. Expected predation by harp seals can also be incorporated. Here, the overlap between predator and capelin is a central element, and this can be used in prognoses when we have good models of migration. Like capelin, shrimp are also prey for a number of predators, and predation is a decisive factor in determining the evolution and population dynamics of stocks. Predation by cod is included in estimates of shrimp stocks off Greenland (Hvingel & Kingsley 2006), and could certainly also be implemented elsewhere.

7.3 Medium-term prognoses

7.3.1 Description

This is where stock projections, typically for 2–10 years ahead, are made. For each year, a new year-class must be incorporated and weights and maturation estimated. Projections of this sort are always made stochastically, typically by bootstrapping, where recruitment and growth rates and any other parameters are drawn from distributions. These distributions are usually derived from historical stock estimates, and unless changes are incorporated the distributions are assumed to be stationary over time. Medium-term prognoses are primarily used in the evaluation of management regulations, to examine long-term yields, risk, and to assess the prospects of rebuilding stocks in poor condition. How many years ahead simulations of this sort are meaningful depends on how long the fish usually live, the quality of the stock estimates, and the degree to which the methods employed take multispecies interactions and environmental factors into account.

7.3.2 Potential applications of environmental information

Within this framework there are ample opportunities to utilise environmental information, which needs to be translated into probability distributions for recruitment, growth and natural mortality. For 2–3-year prognoses, however, we can utilise environmental information, such as recruitment predictions for cod. It will be particularly important to be able to shed light on long-term changes in recruitment, because stocks and yields over time are proportional to average recruitment and natural mortality (Recommendations 3, 8 and 9).

There exists an apparatus for probabilistic projections for five and ten years ahead, but this has not been utilised during the past few years. There exist spawning stock–recruitment relationships based on temperature, and a methodology for incorporating model uncertainty. For certain stocks, such as capelin and shrimp, changes in natural mortality can be obtained by means of multispecies models.

In connection with the change from managing capelin according to B_{LIM} to managing the species according to expected recruitment, it would be natural for the standard product to be a probabilistic projection for three to five years ahead. There exists a model (BIFROST) that does this in a consistent multispecies context, but harp seal predation has not yet been implemented. The Institute of Marine Research should further develop its methodology for projecting all of our most important stocks in consistent multispecies contexts, and the models GADGET (minke whale–cod–herring–capelin; same type of model as MULTSPEC, (Bogstad *et al.* 1997)) and SYSTMOD (cod–herring–capelin) (Hamre 2003) could be good points of departure for the Barents Sea (Recommendation 8).

Ocean climate and plankton production data have so far only been utilised to a limited extent in the prediction of fish stocks in the medium to long term. However, more goal-oriented research offers a significant potential for development in spite of the fact that we are still unable to predict the development of the ocean climate from one year to the next. The reason for this is that it takes time from when a climatic pulse influences production at lower trophic levels (planktonic levels) until it has an effect in terms of fish production and recruitment (see Figure 1). Examples of this are the relationship between the NAO index and herring condition one and a half years later (Holst *et al.* 2004) and the significance of climate for the survival of cod fry, which offers three-year predictions of recruitment levels of three-year-old fish (Stiansen *et al.* 2002, Stiansen *et al.* 2005, Svendsen *et al.*, in press), (because the year-class strength is largely determined at the larval/fry stage).

On a longer time-scale, biological multispecies interactions enable us to make predictions, for example when a strong year class of herring grazes down the capelin stock, in turn creating problems for cod. It also now seems clear that multi-decade climate signals have a long-lasting effect on the productivity of marine ecosystems (Toresen & Østvedt 2000, Drinkwater 2006). This results in longer (multi-decadal) periods during which an ecosystem can tolerate greater or lower fishing pressure, depending on the phase of the climatic period in which we find ourselves (Sundby 2006b). This is illustrated in Figure 4, which shows that blue whiting recruitment has risen dramatically and has completely changed during the past few years, in spite of very high outtakes of up to two million tonnes. Similarly, the condition of Norwegian spring-spawning herring has varied rather widely in the course of the years (Figure 5). Some of these changes are dependent on stock biomass, but there is probably also a significant environmental component here that says something about the productivity of the ecosystem at different times. We ought to be able to use this to estimate growth and recruitment rates. There are indications that the long-cyclic productivity of zooplankton is the key to this. For this reason, it is important that we should start making stock estimates of zooplankton similar to those that we make of fish stocks (Recommendation 9).

It will often be difficult to predict ecosystem changes, as is the case with the rise in blue whiting recruitment. However, it is important that we should be able to capture these changes at an early stage and commit resources to determine causal relationships and how such changes should be reflected in the advice we give. The Institute of Marine Research faces an important challenge in this respect. The quarterly series of situation reports for the North Sea that are issued by the NORth SEa Pilot Project (NORSEPP), which are edited and promoted by Hein Rune Skjoldal (Skjoldal 2006) is an example of an operation ecosystem evaluation that could be used to rapidly capture changes in ecosystems.

Even though environmental information is not directly numerically utilised in management instruments, its most important application may be to provide early warning of major changes in ecosystems. When such changes are observed or modelled in the climate, plankton or at early stages in the life cycle, we need to possess adequate knowledge and methods that will enable us to warn of the likely effects on fish stocks, so that these can be taken into account in the advice that we offer (precautionary principle).

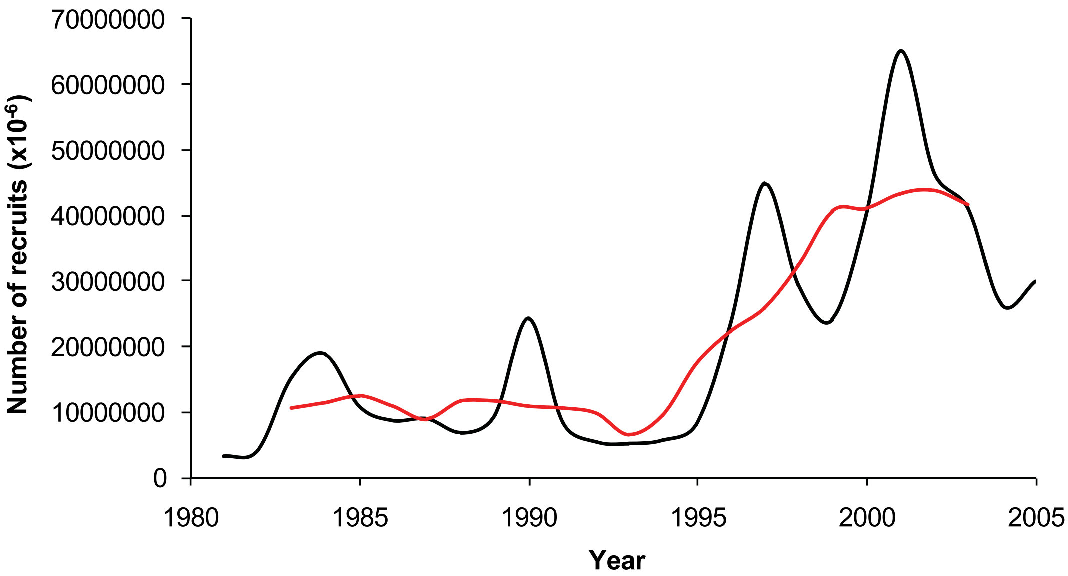

Figure 4. Blue whiting recruitment. Black curve: annual number of one-year-old fish. Red curve: five-year running average. From ICES (2006).

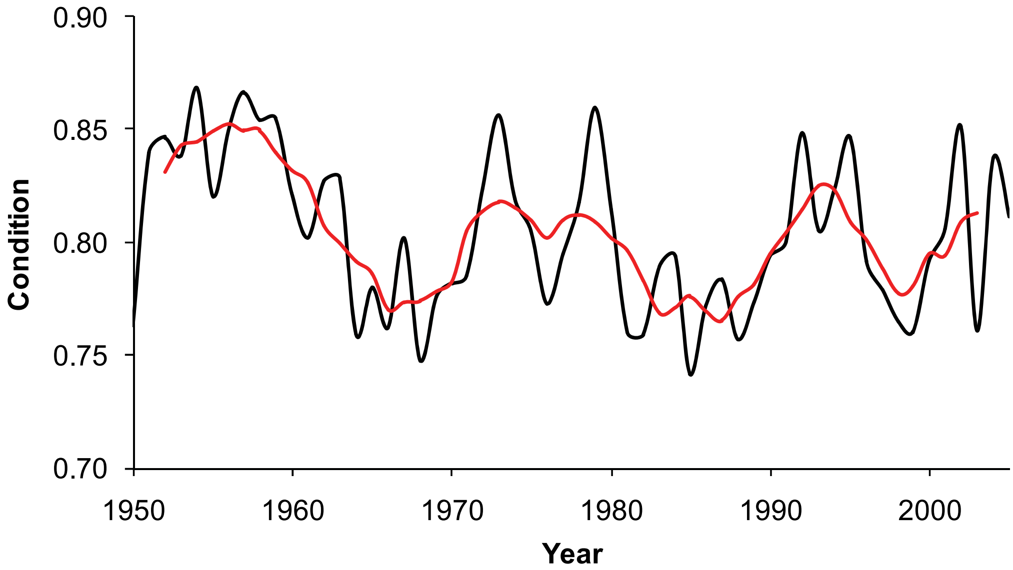

Figure 5. Condition of Norwegian spring-spawning herring. Black curve: annual condition. Red curve: five-year running average.

7.4 Design and evaluation of management strategies

7.4.1 Description

The basic prerequisite for any management regime is that it should not remove – in the course of time – more from the stock than it is capable of producing. In simple terms, production is the increase in biomass due to the growth of individual fish and the recruitment of new fish, less mortality losses. A complete evaluation of management strategies is a comprehensive process that may also involve socio-economic factors, but at this point we will consider only the purely biological parts of this process. In an evaluation of this sort we typically use the same type of tools as for medium-term prognoses, but often over a longer period of time. With the aid of numerical tools of this type, we can simulate a range of management strategies (fish mortalities, patterns of fishing, etc). Part of the evaluation process consists of checking how well a strategy can tolerate deviations from ideal conditions, such as differences between actual stocks and assumed stocks when decisions are taken, permitted vs. actual outtakes, variations in productivity resulting from changes in environmental conditions or climatic scenarios. The results will be evaluated with respect to one or more criteria, the most usual of which are the probability of exceeding a biological reference point (e.g. that the spawning stock falls below B_{LIM}), average yield (in tonnes or economic value), and interannual variation in catches.

7.4.2 Factors that determine how stocks evolve

The evolution of a stock is dependent both on management measures and how these are actually implemented, and on natural driving forces, which are what we usually associate with the concept of "environment" (Figure 6). There are effects on recruitment, growth and mortality, and these can take place either immediately or after some delay. For example, a lower level of recruitment will result in a reduction in total biomass and spawning biomass after several years, and several more years may pass before effective management measures are implemented.

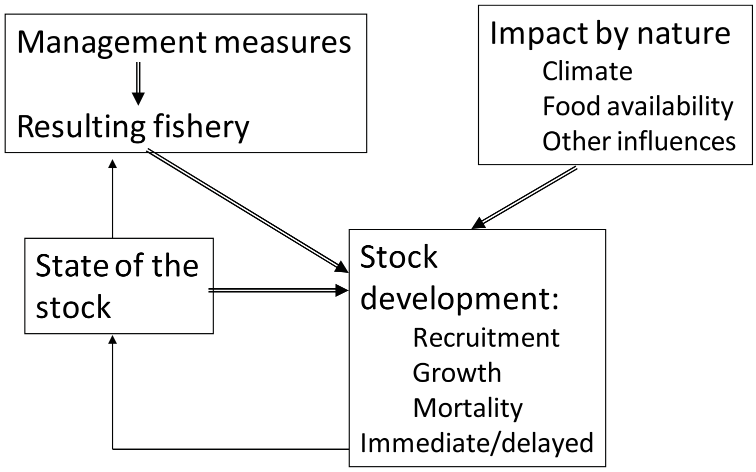

Figure 6. The most important factors affecting the evolution of a stock.

The internal relevance of these factors varies from one stock to another. Natural forces are occasionally blamed for a fall in a stock – sometimes justifiably – but we would be wrong to believe that fisheries are of no importance. On the contrary, the point should be to modify fishing pressure according to changes in natural conditions. If we can say anything about how natural conditions are likely to evolve, we can make recommendations that take these into account. If not, we must try to adopt management strategies that are capable of adjusting to changes in the productivity of a stock as these occur. To date, the latter has been the most usual way of designing management strategies. Such a robust adaptive strategy requires us to be capable of recognising changes in good time, and experience has shown that this is much more difficult if we do not understand the underlying mechanisms involved. This is perhaps part of the reason that the advice regarding blue whiting was far too late in taking into account the fact that recruitment had changed dramatically.

7.4.3 Potential applications of environmental information

Environmental information ought to play an important role in the design of management strategies. We can take environmental impact into account either in the design of management strategies and/or by including environmental impact in the evaluation of a management strategy (Recommendations 4, 5, 8, 10). We can use environmental information either to exploit a stock either more efficiently or more carefully, according to the prevailing environmental conditions. For each stock, we need to assess whether we are capable of using environmental information (or more environmental information) in such a way that it actually contributes to achieving our management aims (Recommendations 3, 4, 7, 10).

We have a number of alternatives available when we are designing management strategies:

We can attempt to take environmental impact into account in the decision rule, by:

- "Baking it into" the rule (for example that capelin should be managed on the basis of the food requirements of cod). This is based on the goal of exploiting resources in the best possible way and on accepting that the management strategy for one stock may also affect other stocks (predators, competitors, mixed fisheries, etc.).
- Environmental impact can be expressed in terms of one or more indicators, and these form part of the decision rule itself. In this case, there must be defined threshold values for the indicators, and rules need to be drawn up for the consequences that will ensue when the threshold values are exceeded. In all probability, this could only be used when the aim is to take extra good care of a stock. This method is not utilised today.

Ad hoc:

- In cases where scientists are worried about a stock because of an environmental factor. This will not be expressed in the "quantitative" advice, but the scientists will request the management authorities to be particularly careful in setting a quota. Such a warning would not be expressed in the form of a rule, but rather in the form of a statement that we ought to depart from the rule and be more conservative than the quantitative advice suggests. The management authorities themselves must work out how the recommendation should be implemented. This is done occasionally in practice.

The reference points on which the harvesting rule is based are dependent on the environment (this is not used today; Recommendation 5):

- Defining reference points whose aim is to maintain a given spawning stock structure (problem: genetic changes resulting from high fishing pressure).
- The productivity of the spawning stock is dependent on environmental factors (skipped spawning, condition factor).
- Movable reference point is dependent on environmental factors that affect the fish before they are recruited to the fishable stock.
- Harvesting rules are occasionally evaluated while a single environmental condition is modified. This can be done without the rule itself taking environmental factors into account.

At the present time, major changes are taking place in the ecosystem, with fairly large displacements of fish stocks and long-term changes in recruitment, for example of blue whiting (Figure 4). This needs to be taken into account in the provision of strategic advice, since it affects ecosystem carrying capacity. A range of different scenarios in terms of prey, predators and climate ought therefore to be studied, ideally using multi-stock models resolved in spatial terms.

8. New stock-evaluation and advisory concepts

The above analysis shows how environmental information can be incorporated into current stock evaluations and advice provision. In spite of the fact that the current system has evolved in the course of time, the foundations of the methodologies it employs were laid more than 50 years ago. Since then, there have been dramatic technological developments that offer us quite different possibilities than we used to have. At the same, the extent of management has dramatically changed, and in principle it now covers the whole ecosystem. It may therefore be useful to briefly mention some new angles of attack that differ conceptually from current stock evaluation and advice provision processes.

Giske *et al.* (2001) considered the prospects of developing spatially based, fishery-independent monitoring systems. They evaluated five different concepts and concluded that such systems could be developed using existing technology and that they could provide significant inputs to stock evaluation and advice provision. But this would require significant new investments in observation platforms for both physical and biological variables.

In spite of the fact that the AMOEBE project (Svendsen *et al.* 2002), which was given a very good international evaluation, was put into cold storage, the effort involved in describing the project laid the foundations for envisaging how a fully operational spatially based modelling system for marine research and fisheries management could be developed. The AMOEBE project was largely based on a system of models based on observations, and in which significant investments would be made in the observation infrastructure in the form of the operationalisation of data flows from vessels, remote measurements, and various types of moored and drifting buoys.

The system was based on the recognition that an ecologically based approach to marine management in accordance with the precautionary principle requires access to much more information than does traditional single-stock management. This can only be achieved by putting significant efforts into national and international cooperation aimed at integrating existing and new multidisciplinary knowledge and data via the extensive use of models, with the assimilation of observations. The understanding, quantification and prediction of recruitment, growth, maturation and natural mortality will require (more or less) three-dimensional “continuous” knowledge of physics, plankton, larvae and fry, migrations and distributions of fish and marine mammals, overlaps between predators and prey, and who eats whom and how much. However, this would require the development of an operational system of spatially resolved multispecies models with data assimilation (overlapping in time and space between predators and prey) and three-dimensional biophysical models of ocean climate and lower trophic levels (physics, plankton and fish larvae).

The spatial 3-D systems described above are conceptually completely different from today's advice system. Such 3-D systems would be capable of providing us with significant amounts of knowledge about the marine ecosystem, and they would also have the potential to improve our advice. However, the development of such systems would be extremely expensive, and it was estimated that the AMOEBE project would have cost NOK 1 billion. We see no prospect of financing such a system without significant additional funding, and have therefore not evaluated systems of this type in more detail here, since our primary task has been to evaluate the incorporation of environmental information into the existing advisory system.

9. Operational information

By its very nature, advice provision is operational. This means that we are involved in supplying products and/or services at more or less regular intervals, in a format that the user can understand and make use of. If they are to be useful, the sources of environmental information need to be extremely reliable and long-term in nature. The ability to utilise information rapidly when it arrives is a challenge that has scarcely been met by the existing system. In this respect, the KULT project at the Institute of Marine Research is an important initiative in terms of optimising the flow and availability of relevant data. At present, together with ICES, we are fairly operational with respect to counting fish and advising on individual stocks, but we still have a long way to go before we can become operational on the relevant environmental information that is needed for a useful operational ecosystem-based approach. Nevertheless, there is much to be gained from improving the flow and availability of data at the Institute of Marine Research (Recommendation 2). One example of this are acoustic data, which are currently scarcely available in online databases, and which require major efforts to access. One means of improving this situation might be to increase the capacity of NMD to take on this sort of work, so that all data from the Institute of Marine Research would actually be collected there.

For several years, the EU and ESA (European Space Agency) have been developing GMES (Global Monitoring for the Environment and Security), which will be the European framework for operational environmental information. (On a global scale GEOSS (Global Earth Observation System of Systems) has since been set up (mostly by the USA) and GMES might well be regarded as part of GEOSS). GMES will form a central part of the EU's 7th Framework Programme, and the programme is particularly interested in having someone deliver a range of operational marine core services (MCS) about the state of the environment (past, present and future, on global and regional scales) that will be accessible to everyone. The Institute of Marine Research should play an active role here in ensuring that the flow of environmental information will be useful in achieving the Institute's general objectives. In the first instance, the core services will deal with climate and physics, probably primary production, and possibly the drift of fish larvae.

We also need to do more to consider which essential processes ought to be studied (in the laboratory and in the field) and monitored, and to what extent there are nodal points in the ocean where key parameters can be monitored with sufficiently high frequency. Do we need to develop new technology or simply resources that will enable us to make better use of existing modern technology? An example is our ARGO profiling buoys in the Norwegian Sea which, fitted with some simple acoustic or possibly optical capabilities, could be used to monitor wintering zooplankton stocks. Models can be used to a much greater extent than they are at present to define optimised observation systems.

10. Discussion

10.1 Quantification of ecosystem dynamics

As we mentioned in the Introduction, clear relationships exist between climate and ecosystem productivity. Fish biomass, in particular, is correlated with long-cycle climatic oscillations, since climate has so many different direct and indirect effects on the ecosystem. Longer-lasting climate changes will thus result in more easily detectable effects. Nevertheless, the medium-term effects are very important for our understanding of changes in recruitment to fish stocks, and a better understanding of such relationships can be useful in providing better stock prognoses. Climatic variations and related ecosystem effects are thus to be found on most time-scales, and they may occur fairly rapidly. In the course of the past couple of years, for example, snake pipefish (*Entelurus aequoreus*) have established themselves in large areas of the North Sea, the Norwegian Sea and the Barents Sea. It is important that management should be operational on this time-scale, and there is a job to be done here in implementing environmental factors in our stock evaluations and advice provision, particularly in providing early warnings of changes that are taking place.

In the name of the "ecosystem approach" to management, a good deal of effort is being put into identifying indicators that describe the state of the ecosystem (in some connection or other). It is quite natural for ecosystems to change in the course of time. If we are to make significant advance in our use of such indicators, it will be important that we should be able to evaluate integrated effects and to differentiate to a certain extent between climate-driven changes and alterations that are due to human activity. This is far from being as simple as it sounds, because there is every reason to believe that there are interactive effects between the climate and human activity (for certain periods, the ecosystem can "tolerate" greater impacts than during others). For this reason, it is important to identify operational and quantitative relationships between environmental factors and stock parameters such as growth, recruitment and natural mortality (Recommendation 3). We may hope that establishing such relationships will increase the accuracy and reduce the uncertainty of our annual advice, and possibly allow us to adopt a precautionary approach if we anticipate reduced growth rates. Even if such correlations are not based on an understanding of the processes involved, they can be useful tools that will enable us to utilise information about the environment to say something about the future evolution of stocks that will be better than having an expected average value. Where we also possess understanding, process-based models are obviously preferable. Multispecies models are partly process-based, and the further development of such models in terms of environmental information will improve our utilisation of process understanding in stock evaluation and advice provision (Recommendation 8). For short-lived species with high natural mortality rates, such as sand-eels, we are faced with a number of interesting challenges, to deal with which climatic variables may turn out to be useful. However, the situation is different for long-lived species, for example the current year's estimate of numbers of three-year-old North Arctic cod. This year class is the 2003 year class, which has been (at the time of evaluation) observed six times (11 times if we differentiate between trawl and acoustic indices).

Today, the reference points on which the harvesting rules are based are constant, and independent of the state of the ecosystem. If we see a long-lasting change in the productivity of the ecosystem or are able to identify good qualitative relationships between environmental factors and growth or recruitment, we may imagine that the points of reference will be set as a function of the state of the environment (Recommendation 5). This would allow stocks to be harvested more heavily in more productive periods than in poor periods.

Virtual ecosystems are computer-simulated ecosystems in which we attempt to represent the most important elements of the system in terms of the interactions, growth, survival and reproduction of a set of species. Such a system, if it emphasised important fish stocks, would be a good point of departure for making thorough analyses of the relationships between stocks, data collection and advice (Recommendation 10): The system could then be managed in the same way as real stocks and ecosystems, with the difference that in the virtual system, we could enter all the components at all times. We could thus sail cruises in the virtual system and study the effects of various degrees of cruise coverage on stock estimates and on how different types of advice and outtakes of fish would affect the stock in the course of time. We would also be able to study accumulated errors over time and the consequences of different spatial patterns of fishing. This approach is already well-known in fisheries modelling, but only with either no or highly simplified spatial resolutions and long time-steps (monthly, quarterly, annual). Developing such a system will require a fair amount of effort, but would be quite possible with currently available technology. Systems of this sort were a central element of the AMOEBE project application (Svendsen *et al.* 2002).

10.2 Organisation of stock advice provision

An important organisational trend at the Institute of Marine Research, aimed at increasing the use of environmental information, involves establishing ecosystem-defined stock advice projects based on a wide range of expertise, staffed by people who work on stock advice provision, statistics, ecology, oceanography and plankton (Recommendation 1). This will also increase knowledge transfer and the robustness of the advice we provide, since more people will be directly involved in the process. This way of organising our advice will also enable us to better able to capture ecosystem processes that have shared effects on geographically overlapping stocks than the current system permits. In certain cases, the geographical aspect is already established, but we lack the multiplicity of expertise needed. This type of organisation will mean that more people are informed about the state of the stocks and the ecosystem, and will feel that they are part of the advisory process.

We may hope that this will contribute to stronger connections between research projects at the Institute of Marine Research and the advisory process than we have today, a situation that would be fruitful for individual scientists, the advice process and the Institute of Marine Research as a research-based advisory institution. Such an organisational trend would also be a natural step to take in connection with the current reorganisation in the direction of ecosystem-based stock management.

10.3 Environmental information

In the course of the past few years the Institute of Marine Research has begun to sail annual ecosystem cruises, in the course of which we cover the ecosystems of the Barents Sea and the Norwegian Sea synoptically. This is an important step on the way to ecosystem-based management, but it might nevertheless be useful to develop a strategy for monitoring ecosystems with a view to determining what sort of environmental information is needed for ecosystem-based management (Recommendation 7). In the field of survey methodology, there is also the possibility of improving stock estimates by incorporating environmental information, for example by correcting for how different environmental conditions produce variations in fish behaviour (Recommendation 5).

The philosophy of basing stock estimates on catch data may act as a barrier to making rapid progress in an ecosystem-based approach to fish stock management, while we can also see a growth in the uncertainty of the catch data on which traditional VPA analyses are based. The problem with such a strategy is that the methodology is extremely limited in terms of looking ahead in time, since we do not have data for the future. This means that we will need to develop and maintain a very different methodology for evaluating the past in terms of the future. By their very nature, advice and strategies are based on being to evaluate the future (on the basis of knowledge and model assumptions based on observations from the past). The various methods involved are complementary, but a great deal could be gained from being able to agree on common methods of evaluating stocks in the past, the present and the future. We mentioned at the beginning of this report that the objective of using environmental information must be related to improving the accuracy or robustness of quota estimates. For this reason, it is important that new methodology should be introduced in such a way that we are able to test that this requirement is satisfied before we adopt it (Recommendation 4).

The Institute of Marine Research is currently running a number of relevant projects that could provide valuable input to effort to include environmental information in stock evaluation and advice provision, and it will be important to make use of this knowledge by actively seeking for information in these projects. The new programme managers, particularly those in charge of the ecosystem and climate–fish programmes, will play key roles in connecting up research and advisory projects. The KULT project will play a central role in improving the flow of data. We have said little about the availability of data in this report, since we have rather taken it for granted that such data as are gathered will rapidly become operational (Recommendation 2). This is not necessarily the case, and we must hope that the KULT project will lead to a more satisfactory flow and availability of data.

10.4 Zooplankton biomass measurement

Copepods are a central species in the ecosystems of the Norwegian Sea, the North Sea and the Barents Sea, and it has a major influence on the recruitment and growth of fish in these ecosystems. Copepod biomass is already used to predict the condition of Norwegian spring-spawning herring a year ahead in time. Because of the central position and influence of copepods on the rest of the ecosystem, we need to work for a better understanding of copepod dynamics (Recommendation 9). Performing regular stock estimates of the Norwegian Sea stock of this species could be a useful tool for the better understanding, quantification and prediction of growth and recruitment of many of our most important fish stocks. Long time-series for zooplankton, in addition to the ability to relate changes in zooplankton biomass to changes in other parts of the North Atlantic, would make an important contribution to such an understanding. The Sir Alistair Hardy Foundation (SAHFOS) runs a large-scale, world-wide plankton monitoring scheme using continuous plankton recorders (CPRs) installed on board ships of opportunity, usually ferries and liners. Their level of activity is particularly high in the North Atlantic and the North Sea, although the ocean region that is our specific responsibility is unfortunately *Mare incognitum* in this respect. The exception is a 20-year period that lasted until the 70s, when CPRs were operated by the weather ships "Polarfront I" and "Polarfront II", on the route between Bergen and Station M. We regard it as extremely important that this time series should be taken up again, and that we should also initiate measurements in the Barents Sea, by installing CPRs either on a supply vessel route to the offshore installations on the Tromsøflak or on a shipping route between Tromsø and Longyearbyen. SAHFOS can do this if Norway becomes a member of the Foundation. Norway is the only major marine research nation in the western world that is not currently a member of this foundation.

10.5 Relevant working groups of the ICES

A number of ICES working groups are working on topics that are relevant to the implementation of environmental information in stock management. Their efforts have tended to follow four main lines:

1. An ICES group (SGMAS) has produced guidelines for the design and evaluation of management strategies. To date, environmental information has not been incorporated into this work to any great extent, because the task of evaluating proposed strategies has been more urgent. The main task of this group has been to operationalise the thinking of scientists and the management authorities about strategic management as an alternative to annual *ad hoc* decision-making.
2. The WGRED working group performs annual assessments of the ecosystems within the area of interest of ICES. WGRED's primary task is to produce descriptions of various ecosystems as part of ACFM's annual report. WGRED also identifies changes that could have consequences for the management of fish stocks. Its individual evaluation working groups are asked to take information of this sort into account to the extent that they regard it as relevant. So far, such environmental descriptions have had little influence on the advice given, except in a few cases, some of which have been mentioned above. There may be a number of reasons for this, one of which is probably that the environmental information has been too qualitative, while the relationship between the environmental factors described and the evolution if stocks has not been made sufficiently clear. There is probably also an element of conservatism here, as changes in the basis for offering management advice need to be defended vis-à-vis the fishing industry and the authorities, which have a tendency to protest when well-established "standard" procedures are deviated from. The latter factor probably plays a certain role, for example, where benthic species in the Barents Sea are concerned.
3. Special working groups have been set up to look more closely at cases in which the productivity of a particular stock has changed. SGRECVAP is worth a special mention here, as this committee has examined the possible causes of recruitment failure in a number of planktivorous fish species in the North Sea, particularly herring.
4. In 2006, ICES set up a study group (SGRAMA: Study Group on Risk Assessment and Management) to examine the possibility of performing risk analyses. The group will attempt to integrate stock advice and risk evaluations for both stocks and ecosystems.

For 2007, the integration of environmental information has been detached from the SGMAS process and given its own study group. The idea is to make the use of environmental information more operational by working through some examples in which environmental conditions should have had some effect on managed areas, and to show how this information could have been used and what consequences it might have had for earlier decisions.

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