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Arne Eide, Ann-Christin Ese and
Alf Håkon Hoel (eds.)

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Nordic Council of Ministers
Ved Stranden 18
DK-1061 Copenhagen K
Phone (+45) 3396 0200

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Content

Foreword

Climate change is a reality, and the effects will be increasingly apparent in the future. One of the fields where we will have to adjust our current practices in order to meet the challenges of a changing climate is in the harvesting of marine resources.

The current management regime for fish stocks is based on a combination of political objectives, scientific knowledge, and bilateral agreements between resource owners. There are, however, a number of gaps in our understanding of how climate change will affect the biology and economy of fisheries. Consequently, it is not obvious what the best possible management practice should be in the future.

The aim of the FIMAGLOW project has been to fill the knowledge gaps. What do we know today, and what new knowledge do we have to develop in order to continue the successful management of the fisheries in our region? Researchers from the Nordic countries, with backgrounds covering a range of different disciplines, have shared their knowledge and concerns regarding the new challenges in the management of Nordic fisheries through a series of FIMAGLOW workshops. This report illustrates the complexity and many aspects involved in fisheries management. The challenges are formidable, but existing management experience, combined with new research achievements, give reason for optimism and belief in our ability to cope with the changes we will have to face in our future fisheries.

The University of Tromsø has had the honour of hosting the FIMAGLOW project. Fisheries management has been a key area for the University of Tromsø since it was established in 1968, and it will continue to be a key area for us in the future. We therefore encourage our researchers to continue the important Nordic cooperation, and to continue contributing in this important area of multidisciplinary research to the benefit of us all.

Jarle Aarbakke
Rector, University of Tromsø

1. Introduction

The FIMAGLOW project is a Nordic project including partners from Norway, Iceland, Denmark and Sweden. The project ran from 2008–2010, and the aim has been to study possible drivers and impacts of global warming on Arctic fisheries. The original project idea was to initiate a process in the Nordic community of fisheries scientists to identify and prepare a common Nordic initiative on a larger interdisciplinary research program addressing fisheries management in the Arctic under climate change.

As it unfolded, it became clear that the project should be seen as a first step in that direction, rather than fulfilling the initial ambition. As is often the case in new areas of research, new work tends to reveal the vast reach of our ignorance and open up new agendas for research, rather than providing firm answers to our initial questions.

Two workshops has been held, serving to identify the relevant set of institutions and people, updating the research community on on-going research projects and initiatives in this realm, and pointing to some critical issues for further research. The material presented in the workshops is collected in this report, which hopefully then may serve as a stepping stone for further explorations of this important issue.

A web site for the FIMAGLOW program has been set up and is available at the URL: http://fimaglow.maremacentre.com. The website includes program information and tentative programs for the workshops. MaReMA Centre at Norwegian College of Fisheries Science is organizing the program, Alf Håkon Hoel and Arne Eide being the project managers.

Tromsø, 21 April 2010

Arne Eide	*Alf Håkon Hoel*
Project leader	Project leader
University of Tromsø	Institute of Marine Research

2. The FIMAGLOW project

By Alf Håkon Hoel, Institute of Marine Research, alf.haakon.hoel@imr.no and Ann-Christin Ese, University of Tromsø, ann.christin.ese@gmail.no

Two-thirds of the Arctic is ocean. The marine ecosystems of the Arctic provide a range of ecosystem and climate services of fundamental importance for the arctic coastal areas (ACIA 2005, Goodstein *et al*. 2010). While there are no commercial fisheries in the Arctic Ocean to the north of the continents, the surrounding seas are globally significant in this respect (Hoel and Vilhjamsson 2005). The effects of climate change on living marine resources in the North, and the questions this raise for resource management and dependent communities, is therefore an issue of great importance.

The overall aim of the FIMAGLOW project is to study drivers and impacts of global warming on Arctic fisheries. The project was motivated by an interest in developing a multidisciplinary, Nordic community of fisheries scientists to identify and address fisheries management issues relating to climate change. The inspiration for the work has been the fisheries chapter of the Arctic Climate Impact Assessment (ACIA 2005), where a number of climate-related challenges to the fisheries sector where identified. Prominent findings here included possible changes in migration patterns, in-migration of new species from southern latitudes, and the need to ensure that resource management regimes are robust and well functioning.

The objective for the project is to enhance our understanding on how climate change is likely to affect fisheries, and bring us closer to an understanding of potential mitigation and adaptation strategies and measures. Further the objective is to update data, methods and analysis of the fisheries chapter of the Arctic Climate Impact Assessment.

The target groups for this project are the Nordic marine research community, including researchers, research administrators and policy-makers stand to gain from the project.

The primary means of work in the project has been through workshops, bringing together relevant researchers and institutions. The first workshop took place in Tromsø 31 March – 01 April 2009, the second in

Stockholm 17–18 September the same year. The first workshop addressed current physical and ecological environmental situation and existing management systems in the North-Atlantic and the Arctic, the fisheries chapters in the ACIA-report, shortcomings and needs of updating, the new scenarios of the IPCC, and natural variations vs. fluctuations caused by global warming. The second workshop shifted attention to impacts of change and strategies for mitigation and adaptation. Harvest control rules, including precautionary approach and ecosystem-based management in the light of climatic change are central to this.

The project has included scientists from a number of scientific disciplines with experience from the entire North Atlantic region, particularly emphasizing the Nordic region, but the project also benefits from inputs from Russian and North American scientists.

The workshops were divided into three main issues: variability, management and socioeconomic aspects:

Variability

- Øystein Skagseth (IMR): "Observed oceanic variations – natural fluctuations or climate change."
- Sigurd Tjelmeland (IMR): "Seeing climate change through assessment models."
- Christian Wexels Riser (UiT): "Ecosystem dynamics and production in the Arctic."
- Geir Odd Johansen (IMR): "Fish stock distribution in the future: the approach in FishExChange and NorExChange."
- Geir Odd Johansen (IMR): "Expected Change in Fisheries in the Barents Sea: preliminary results on the relationship between climate and the spatial distribution of commercial fish species."
- Bjørn Birnir: "Changes in Migration Patterns of the Capelin as an Indicator of Temperature Changes in the Arctic Ocean – Seen from an Icelandic point of view."

Management

- Arne Eide (UiT): "On the evolution of the fisheries management and new challenges – Towards a new management paradigm?"
- Jørgen Schou Christiansen (UiT): "Challenge for Arctic marine fishes and fisheries – a few biological viewpoints."
- Alf Håkon Hoel (UiT): "Fisheries management and climate change."
- Arne Eide (UiT): "Fisheries management and climate change: an introduction."
- Arne Eide (UiT): "Possible bio-economic modelling approaches to fisheries management under global warming."

- Knut Heen and Øystein Hermansen (UiT): "Aquaculture and Global warming: The case of Salmonid Aquaculture in Norway."
- Thorsten Bleckner (SU): "The ICES/HELCOM working group on integrated assessment of the Baltic Sea."
- Andreas Stokseth (NMR): "Support for Nordic fisheries research – climate related activities."

Socioeconomic aspects

- Grete Kaare Hovelsrud (CICERO): "Fisheries in the content of climate change."
- Jan Idar Solbakken (SUC): "The ACIA process and indigenous participation."
- Eirik Mikkelsen and Arild Buanes (NORUT): "Predicting the societal impact of the climate change on fisheries. Preliminary results from the NorAcia-project."
- Eirik Mikkelsen and Arild Buanes (NORUT): "Climate change and fisheries in the Norwegian Arctic. Societal impacts and adaptation"
- Alf Håkon Hoel (UiT): "Arctic tipping points."
- Anne-Sophie Crepin (Beijer Intstitute): "The Arctic tipping point project."

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3. Workshop I

At University of Tromsø, 31 March – 1 April 2009

3.1 On the evolution of the fisheries management and new challenges – Towards a new management paradigm?

By Arne Eide, Norwegian College of Fisheries Science, University of Tromsø, arne.eide@maremacentre.com

Going from subsistence to commercial fisheries had different consequences: labour was substituted by capital, as capital became more available, labour more expensive, and the market failure of open access to the natural resources became critical.

There has been a shift of paradigms through the evolution within fisheries management, in ways of protection, from protection of the fishery (first by protecting the fisher, later the resource base of the fishery), to protection of the nature as such. The evolution also shows different trends in managing the North Atlantic fish stock resources: from market access developing by improved infrastructure, through technological development, to different types of regulations, and eventually EEZs and other international agreements, leading up to the precautionary approach, protecting the biodiversity and the ecosystem-based management.

Despite new approaches towards protecting fisheries, fish stocks collapsed during the late 1960s. As a result of the collapse, available stock assessment methodology and theories of optimal exploitation, were introduced to fisheries management. Followed by the Convention of the Sea, the EEZs, limited entry and quota regulations were introduced in most North Atlantic commercial fisheries. The resent concept of precautionary approach management and the use of indicators as management measures, have to be understood within this framework. Indicators should however cover more than the reference points of the former approaches, also adding social and economic indicators. Furthermore, indicators may be snap-shots or reflect long term processes, and cover variability and trends. The indicators can be used in several ways; implement the precautionary approach, handle different principles and objectives, operationalise the ecosystem approach, and to include fisheries on different development stages in the same framework.

Identifying useful and necessary actions related to each possible set of indicator values is the crucial management challenge, the choice of indicators also becomes critical and good indicators are yet to be developed. A relevant control system is the fuzzy logic approach identifying management actions following each set of indicator values. Such sets may include different fisheries, ecosystem properties, social structures and economic conditions.

3.2 Fisheries in the context of climate change

By Grete Kaare Hovelsrud, CICERO, g.k.hovelsrud@cicero.uio.no

Temperature variability, ocean warming and broader environmental regime shifts are important variables when considering fisheries in the context of climate change. Studies show that spawning locations and stock distribution are partially correlated with ocean temperature changes. However there are many non-climatic factors which affect fisheries and it is essential to distinguish between these, climate variability and climate change.

The societal outcomes of anthropogenic climate change on fisheries are difficult to predict as there exists considerable variation in relative levels of social, economic and cultural fisheries dependency, both geographically and at different administrative levels. National fisheries policy, regional policy and climate mitigation and adaptation policy may generate heterogeneous outcomes in terms of local fisher and community livelihoods.

Fishers are well versed in coping with natural climatic and past regulatory variability. The pertinent question regarding the impact of anthropogenic climate change is whether fisheries, and wider social and economic policy, will impede or augment fisher adaptation strategies. Further, would such policy disproportionately affect or disadvantage one fisheries sector or actor over another, such as coastal fishers, compared to the off shore fleet. A more widely distributed and distant target fish stock is likely to require increased vessel capacity investment, both with regard to safety (rougher seas, and fishing further from shore) and gear, in order to reach deeper and a more varied catch composition. New species have already been documented by our respondents in Northern fishery areas. Investment decisions will be determined by a set of cost and utility variables, informed by broader fleet strategies, risk and uncertainty. Uncertainty may be conditioned by concern relating to the stability of management initiatives, for example catch quotas, input restrictions, as well as consumer tastes, and anthropogenic climate change.

Climate change is not recognized as a prominent concern for fishers in our case studies, as profitability and livelihood outcomes are more immediately and tangibly affected by fisheries regulation, focused on fleet profitability, efficiency and sustainable stock management, and wider social and economic dynamics. Irrespective of the recognition or not of climate change as an important variable affecting fisher's livelihoods, fisheries policy will be influenced by evidence of climatic impact on fish stocks. Climate change mitigation policies, such as fuel taxes and pollution taxes, affect fishers directly. For the individual fisher the degree of impact is a function of vessel efficiency and distance travelled. However input taxation is likely to unevenly affect fleet profit functions, and thus impact fleet segments differently, creating relative advantages and disadvantages. Increased trip length, and consequent costs incurred may affect decisions as to landing facility, thus having subsequent effects upon secondary industries and market access. Fuel taxes are likely to lead to increased returns to more fuel efficient vessels; however some segments of fishers may be unable or unwilling, to secure finance for further capacity investment.

Impacts on secondary industries from both diminishing catches and movement or consolidation of landing sites have been revealed in the Lofoten and Vesterålen cod processing industries. Traditional fish inputs have proved unreliable, due to a change in the distribution of the cod spawning stock, and thus inputs have needed to be sourced from wider afield, predominantly further north. There has also been a question raised as to the optimality of outdoor cod drying conditions in these regions. Location optimality and consequent product premiums are most likely to be affected by factors such as increased precipitation, earlier seasonal warming and dislocation between fish harvest and optimal hanging conditions.

Wider demographic and economic trends, particularly outmigration to larger centres, threaten the viability of smaller peripheral communities. The consequences and characterization of this need to be further investigated, but voiced concerns relate to future employment potential in the fisheries industry and infrastructure and service provision. How this affects climate change adaptation capacity is to be further investigated, but much rests on the unit of analysis, industry, community or individual.

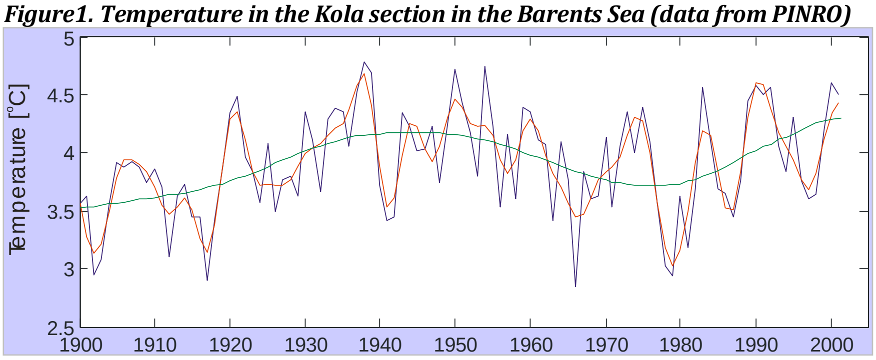
Fisheries communities capacity and capability to devise their own adaptation strategies needs to be supported so as to be best placed to respond to observed and projected climate change impacts. This implies firstly the acknowledgement of alternative local perspectives and solutions and secondly, community engagement in resource management policy, as well as nationally determined mitigation and adaptation strategies, thus ensuring community responses and viability are not unnecessarily constrained and undermined.

3.3 Observed oceanic variations – natural fluctuations or climate change

By Øystein Skagseth, Institute of Marine Research, oystein.skagseth@imr.no

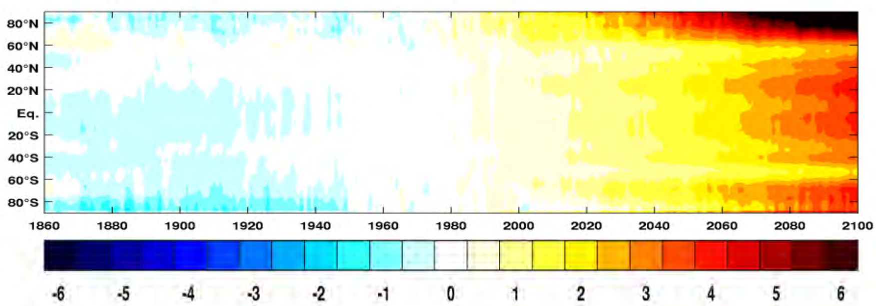
The instrumental record going back to the beginning of the 19th century shows variability over a broad range of time scales (Fig.1). The associated spatial scale increase with longer time scales. The longest scale resolved in the Kola section (Fig.1), a ~60–70 year oscillation, is associated with the Atlantic Multi-decadal oscillation (AMO) that represents the Atlantic sector sea mean surface temperature (SST) variability north of equator. The amplitude of the variability is the largest for the year to year variability and decrease with the longer time scales. The short term natural variability act to mask a general climate change, and the recent warm period is only slightly warmer than the 1930ies warm period. However, based on climate model simulation of the A2 scenario (the most likely emission scenario) it is in the next century that we will have the major changes (Fig. 2).

Figure1. Temperature in the Kola section in the Barents Sea (data from PINRO)



For the Nordic countries the faith of the Norwegian Atlantic Current (NwAC) in a general increased greenhouse is of major importance. There are a number of driving forces for the NwAC; on time scales from days and longer the direct wind forcing a key player, on seasonal and inter-annual scale thermohaline forcing becomes important, an additionally the freshwater loading to the Arctic Mediterranean that entrain water before exiting the basin plays a role. The interactions between these mechanisms occur over a broad range of scales, including feedback mechanisms. There is little evidence for a halt in the NwAC, but the range of the variability is not well known. To identify and understand feedback mechanisms in the climate system is of major importance to assess the projection regionally of climate change.

Figure 2. Ensemble mean air surface temperature for the IPCC 4AR scenario A2



3.4 Seeing climate change through assessment models

By Sigurd Tjelmeland, Institute of Marine Research, sigurd.tjelmeland@imr.no

An important word of warning when trying to infer climate-induced changes in fish stocks is that apparent long-term dynamics in e.g. spawning stock biomass may in fact may be due to pure stochastic recruitment, because one strong year class may affect the spawning stock for a long time, and will diminish following year classes through cannibalism. The result is seemingly dynamics on time scales comparable with the life span of the fish.

We cannot as a rule measure the stock directly, and must therefore construct a simple population model. The model is fitted to yearly data to give the same trend as observed, neglecting differences in absolute abundance. In the North-east Atlantic, only the Barents Sea capelin stock is managed based on direct measurements.

The management of fish stocks is increasingly based on harvest rules that are tested against precautionarity through long term simulations using an operative model that more often than not does not incorporate other biological mechanisms than those that are modelled in the assessment model. This is the case for the most important demersal species in the Barents Sea. In the context of climate change the most important question is whether the operative model used for testing the harvest rule is adequate for the future stock dynamics, i.e. in a strategic context it is more a question of the climate changing the stock dynamics than changing the stock abundance, and whether we are able to detect climate-induced changes in stock dynamics.

Possibilities investigated are gradual change in population dynamics, and abrupt change in population dynamics. The ability to detect changes depends on the uncertainty in stock models, catch statistics and survey indices. A simplifying assumption is that change takes place in the stock-recruitment dynamics. Management centres on the stock-recruitment relation because our influence on the future is through our influence on the spawning stock and thus detecting climate change induced changes in the spawning stock – recruitment relation is essential for management to cope with climate change.

Lessons from simulation exercises presented show that if the contrast in the data stems from recruitment variability, changes in the recruitment relation cannot be estimated. With CVs in surveys, catches and measured recruitment of about 0.5, changes in recruitment model parameters can only be estimated within a confidence interval of 70% from a data series of 60 years. Suggestions for possible extensions to the present simulation work are to run population model and operative model together, exploring the population dynamic space. Another extension is exploring the estimated uncertainty space and further expand the work to include the biological models and operative models actually used for different commercial stocks in the North-east Atlantic.

3.5 Challenges for Arctic marine fishes and fisheries – a few biological viewpoints

By Jørgen Schou Christiansen, University of Tromsø, jorgen.s.christiansen@uit.no

The improved access to Arctic waters due to the ongoing retreat of the summer sea ice has accelerated a growing interest in exploiting Arctic marine ecosystems and expanding fisheries also in the Arctic Ocean proper. Inevitably, the combination of climate and human stressors will affect the Arctic ecosystem profoundly although the magnitude of impact is unknown. In future, an Arctic fishery may broadly rely on two groups of fishes, i.e. those which are already commercially harvested and of boreal origin and the fish fauna native to Arctic waters.

A firm focus on the biological status, the vulnerability, and the commercial potential of the native Arctic marine fishes is both timely and imperative (Christiansen *et al*. 2008). However, it is striking and essential to realise that there is an almost complete lack of biological knowledge and understanding regarding the species diversity, phylogeny, and the fundamental ecology of the Arctic marine fish fauna. This is well illustrated by the fact that all but a few Arctic marine fish species are classified as data deficient, i.e. within the DD-category of the Norwegian Red List (http://www.artsdatabanken.no). Parallel to the indisputable thinning of the Arctic sea ice (Walsh 2008; http://www.noaa.gov), human activities increase rapidly into hitherto pristine parts of the Arctic Ocean: The petroleum exploration has begun, commercial fisheries are planned, the ecological effects of invasive species are poorly understood, and new shipping routes across the Arctic Ocean are within reach. Grounds for particular concern and attention relate to marine bioprospecting, which eagerly extract commercially valuable compounds from little known Arctic organisms. Hence, the native fishes of the marine Arctic deserve special attention for a number of reasons.

Arctic marine fishes are taxonomically complex and, in the light of the molecular revolution, several genera are ripe for major revisions. Genomic bar-coding has become a major tool for identification of fish taxa (Ward *et al*. 2009), but molecular techniques are no substitute to morphologic studies. For example, strong intra-specific phenotypic variations exist among Arctic fishes (Byrkjedal *et al*. 2007), and the combination of classic taxonomy (phenotype) and a molecular approach (the underlying genotype) will provide not only information but also knowledge about the phylogeny of Arctic marine fishes and their environment (Naish & Hard 2008).

Due to the environmental constraints of Arctic waters, e.g. low temperature and seasonal food shortage, the marine fishes are believed to grow and reproduce slowly and this make them particularly vulnerable to harvesting. However, even fundamental size-at-age data (e.g. Von Bertalanffy Growth Functions) and knowledge of the demographic structuring are lacking for most of the Arctic marine fishes. Concerning the Arctic ecosystems, the vertical energy fluxes (i.e. pelagic-benthic couplings) low in the food chain are relatively well studied (e.g. Wassmann 2006). This is in marked contrast to the Arctic fish fauna, although Arctic fishes are believed to play a key role in the transfer of bio-available energy from the lower trophic levels (plankton) to the bird/mammal predators. In this respect, it is important to realise that the pelagic polar cod *Boreogadus saida* is the only true Arctic fish species presently known to undertake major migrations and, thus, drive the horizontal energy flux across ecosystems, e.g. from fjords to shelf areas and vice versa (Christiansen unpublished). Below a list of selected key issues related to climate and human stressors:

Climate

- Arctic marine fishes are believed to be extremely temperature sensitive and even minor changes in sea temperature may have profound effects on their spatial distribution and survival (Christiansen *et al*. 1997). Furthermore, fishes respond differently to ocean warming which again may significantly alter the composition of extant fish communities.
- The polar cod is undeniably the key fish species in Arctic ecosystems. It uses the sea ice as a habitat for feeding, in protection from predators, and as a spawning substrate. Therefore, the diminishing sea ice cover will most likely have severe adverse effects on the

survival of this important species resulting in a regime shift of the Arctic marine ecosystem.

- Several fundamental questions arise when boreal fishes invade Arctic waters. Many commercial fishes (e.g. cod *Gadus morhua*, capelin *Mallotus villosus*, herring *Clupea harengus*, mackerel *Scomber scombrus* , blue whiting *Micromesistius poutassou*) are now found north of their traditional distribution areas, and the expected increase in the abundance of boreal fishes in Arctic waters is likely to disrupt existing and create novel trophic links. Furthermore, how do native and boreal fishes interact and how does that affect the population dynamics for both groups of fishes?

Man

- The potential conflicts between fisheries and petroleum exploitation within the Arctic region are of critical importance. Whereas the direct effect of petroleum spills in subarctic fishes is relatively well studied, the damaging effects of the preceding seismic activities in cold waters are largely unknown, in particularly with regard to the communication physiology of fishes.
- Arctic fishes have evolved an array of unique physiological and biochemical adaptations to sustain subzero temperatures (DeVries & Cheng 2005). Many compounds (e.g. biological antifreezes, lipids, enzymes) hold a great potential for marine bio-prospecting and biotechnology. On the other hand, the specialized physiology of Arctic marine fishes may also hamper detoxification of environmental pollutants (Christiansen *et al*. 1996).
- Most Arctic marine fishes are believed to be bottom dwelling and substrate spawning, i.e. with demersal eggs (Christiansen *et al*. 1998). This would make them particularly vulnerable to habitat destruction caused by bottom trawling and traditional fishing gears. Hence, appropriate gears for Arctic fisheries have to be developed.

The Arctic societies are by far based on living natural resources and the socio-economic progress is inevitably rooted in sound ecosystems. Clearly, the lack of knowledge concerning proper identification and demography of most Arctic marine fishes and the ecological interactions between native and invasive fishes presently represents severe shortcomings for a sustainable management of Arctic waters. Traditional ecological knowledge (TEKs) may be implemented in inter-disciplinary discussions to a much larger extend, and a common vocabulary should be employed to facilitate the exchange of ideas and knowledge across economics, social and biological sciences.

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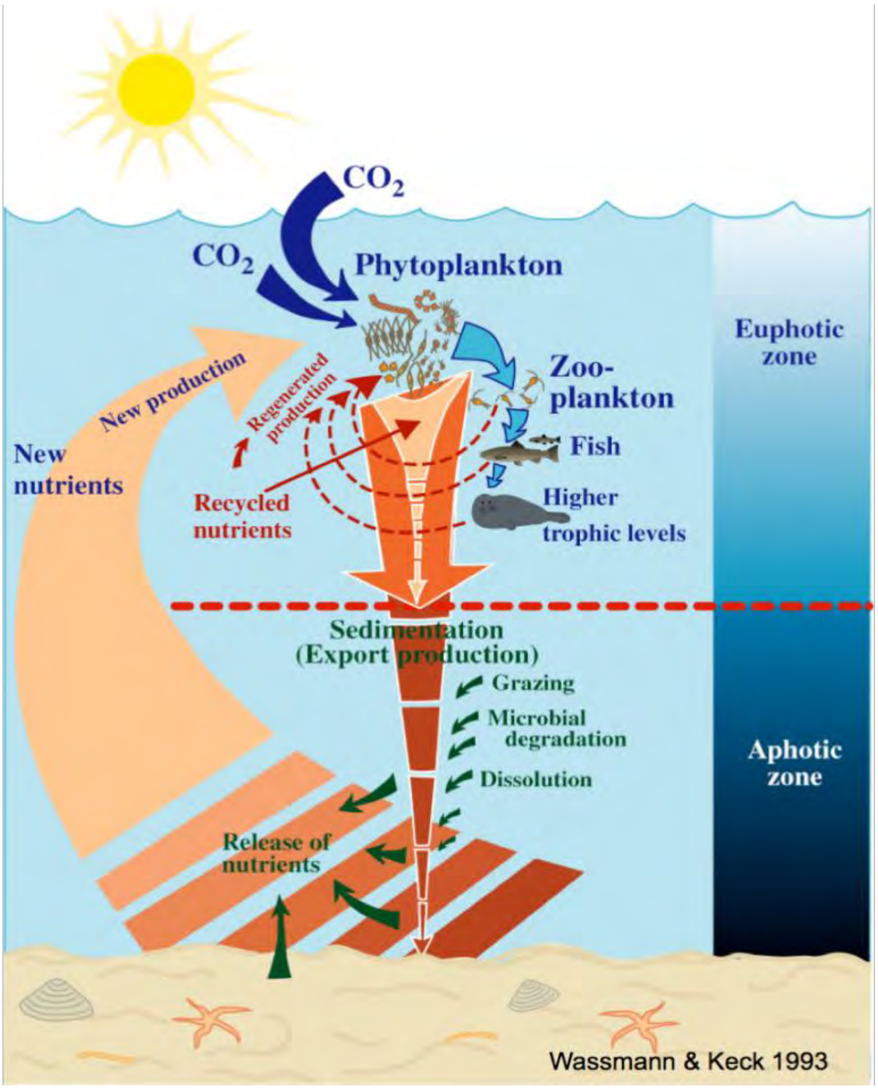
3.7 Ecosystem dynamics and production in the Arctic

By Christian Wexels Riser, University of Tromsø, Christian.Wexels.Riser@nfh.uit.no

The presentation aimed at giving the audience an introduction to Arctic marine ecosystems, with focus on the lower trophic levels. As the "sedimentation group" at University of Tromsø have been working a lot on the energy/carbon flow through the lower trophic levels of the food web. Questions such as: What is the fate of the primary producers? How much biomass is kept in the system and how much is leaving the system through gravitational sinking (or vertical flux) have been addressed by our research group.



As part of the Norwegian IPY-initiative, The Research Council of Norway funded the project integrated Arctic Ocean Observing system (*i*AOOS-Norway: closing the loop). The University of Tromsø and the "sedimentation group" are taking part in the biological sampling and have been involved in fieldwork conducted in the Fram Strait during 2 consecutive years (2007–2008). 80% of the Arctic Ocean water exchange through the Fram Strait, making it an ideal site for long-term studies of natural variability and climate change. Few biological studies have been conducted in the Western Farm Strait as the area is difficult to reach due to heavy ice cover during most of the year, so biological baseline data are needed in this area. We are particularly interested in the timing of the productive season and to study the energy flow through the pelagic food web.

Most of the biomass in marine systems is made up by organisms, which are less than 1mm in size, including bacteria, phytoplankton and mesozooplankton. Most of the carbon cycling takes place within the small unicellular organisms– here our knowledge is still limited, especially in the Arctic.

Marine ecosystems can be defined as: the sum of the biological community and its physical environment. Environmental conditions can affect the species composition and their distribution and primary production. Physical factors and biological interactions are all factors affecting the energy flow in marine ecosystems. Primary producers need light in order to grow and the light conditions are highly variable in the Arctic, on seasonal as well as special scale (e.g. ice cover). Physical factors such as temperature and salinity affect stratification versus mixing of nutrients. If stratification is weak, primary production becomes sensitive to wind as nutrients can be mixed up into the euphotic zone. Strong stratification will lead to nutrient depletion in the surface layer and phytoplankton production will be reduced. Studies of biological interactions, needs to look at match/mismatch between producers and consumers, species compositions and diversity, residence time of organic material and vertically migrating species.

Arctic ecosystems are adapted to large variations in environmental conditions. With long life cycles, abilities to build up lipid reserves, rapid responses to food and overwintering strategies: resisting spores, hibernation, migration to depth or other regions. The presence of the organisms is marginal with regard to niche and habitat needs. The organisms are closely "linked," some being specialist and others generalists. Many organisms are robust considering seasonal variation, but vulnerable to permanent change in habitat or niche.

Take home messages:

- The Arctic ecosystem will change when new species adapt to a new climate replace presently adapted species.
- Productivity might increase, in Arctic regions due to less sea ice, but depends on nutrient supply.
- Arctic ecosystems are complex system: this challenge robust predictions.

3.8 Fish stock distribution in the future: the approach in FishExChange and NorExChange

By Geir Odd Johansen, Institute of Marine Research, geir.odd.johansen@imr.no

Two large projects aimed at studying climate – fish interactions at the Institute of Marine Research, Norway were presented. "Expected change in fisheries in the Barents Sea" (FishExChange) focuses on several demersal and pelagic fish species in the Barents Sea and "Effects of climate change on pelagic fish stocks in the Norwegian Sea" (NorExChange) focuses on commercially important pelagic fish stocks in the Norwegian Sea.

The principal objective of these two projects is to evaluate the effects of future climate change on fish stocks in the Barents Sea and the Norwegian Sea. The approach is based on spatially referenced data on hydrography, fish sampled at standard surveys and catches and fishing activity from the fisheries statistics. The main aim is to study historical geographical distributions of fish and catches related to climate variability, assess the mechanisms governing this, and construct scenarios for future climate change effects on fish and fisheries. In addition, FishExChange produces Arctic climate scenarios and study consequences of climate change on the fisheries and related economy. The economical part of FishExChange looks at the climate change effects in economy of fisheries and fishing industry, effects of climate change on quota distributions, changes in costs and net revenues for the industry, and changes in fleet structure and landing patterns. The projects have joint administration including one project leader, common staff and joint meetings.

One of the major challenges for these projects is data heterogeneity in space and time. We need to integrate data like hydrography and model output, fish survey data, and catch data, with varying spatial and temporal structure in a common framework. To meet this challenge, a spatial database for storage of spatially referenced data from the different sources is developed. This database will contain both historical data and model scenarios.

Some preliminary results from FishExChange are presented. Climate scenarios of the Barents Sea show that the polar front in the west, may disappear from the Central Bank and move northwards in the east. Climate related change in the spatial distribution of juvenile fish is demonstrated.

3.9 The ACIA process and indigenous participation

By Jan Idar Solbakken, Saami University College, Kautokeino, Jan-Idar.Solbakken@samiskhs.no

In 1993, AEPS Ministers requested AMAP to review the integrated results, to identify gaps in the scope of monitoring and research, and ensuring that specific issues related to the arctic region are placed in the agenda of the appropriate international bodies. This request was addressed by publication of the AMAP Assessment report in 1998, the Arctic pollution Issues and the AMAP symposium in 1997. AMAP assessment recommended further research and monitoring and AEPS Ministerial conference in Alta asked AMAP to continue mandate climate and contaminants.

Later on, the AEPS becomes the Arctic Council (AC) and has its first meeting in 1998. The Ministers asked the Program for the Conservation of Arctic Flora and Fauna (CAFF) to continue to monitor and assess in collaboration with AMAP, the effects of climate change and UV radiation on Arctic ecosystems. This also included human health and indigenous people (AMAP first assessment had also focused on these issues). AMAP, CAFF and IASC establishes an Assessment Steering Committee (ASC), and arranges workshops in 1998/1999 to document activities in the arctic region with respect to observation and assessment of CC and UV. In 2000 the AC Ministerial endorses, adopts and establishes the Arctic Climate Impact Assessment (ACIA), and requested it to evaluate and synthesize knowledge in climate variability and change and increased UV radiation, and support policy making processes and the work of IPCC. They further requested that the assessment addressed environmental, human health, social, cultural and economic impacts and consequences, including policy recommendations.

The ASC had two representatives from AMAP, CAFF and IASC and a person representing the Arctic indigenous peoples. Later lead authors became member of this group. The ASC should oversee the ACIA process and coordinate all work related to the preparation of the assessment reports, foster cooperation and cross-fertilization, ensure circulation of draft reports and ensure independent peer review of final drafts. The ministers requested three documents: science document, synthesis document and policy document. Late in this ACIA-process USA stopped the policy document work. The responsibility to make a policy document was moved to the SAO.

The synthesis document was written in a layman language based on the more technical scientific document. This report was translates to several languages, including Sámi language.

ACIA's unique approach is the interaction between science insights and indigenous perspectives, and the integrating insights and knowledge from these perspectives. The goal for indigenous knowledge is to use the knowledge that makes the assessment as good as possible. One challenge here is that knowledge can be very local and closely connected to local language, which makes it difficult for outsiders to understand. It is therefore necessary to involve local people in the research. This will require training and education of local people. The result will hopefully be capacity building in local communities and better communication between scientists and local communities.

The indigenous observations show more persistent clouds, warm weather, warmer winter and extreme weather. The observations also shows less snow, less ice with later freeze-up and earlier break-up. Furthermore, it shows that the water levels are lower and the tree line is moving north.

The indigenous observations show the same results of climate change as the scientific based knowledge. But the indigenous knowledge is not communicated by graphics, charts and confidence limits.

Findings

Based on the experiences in the AMAP and ACIA processes – indigenous peoples and local residents should be involved in research projects. Involvement means real involvement and not only finding persons who give information to scientists.

3.10 Predicting the societal impact of climate change on fisheries. Preliminary results from the NorAcia-project

By Eirik Mikkelsen and Arild Buanes, NORUT, eirik.mikkelsen@norut.no, arildb@samf.norut.no

NorACIA was designed to build on the outcomes of ACIA (*Arctic Climate Impact Assessment*), and represents the Norwegian follow-up to this larger project/programme. Core elements of the action plan for NorACIA for 2006–2009 was to downscale regional climate models, update climate scenarios, look at physical and biogeochemical processes, as well as at effects on vulnerable societal sectors and ecosystems, and further necessary adaptation, institutional changes and mitigation. NORUT has been responsible for the reports on climate change effects on people and society, and adaptation and mitigation (Buanes, Riseth & Mikkelsen 2009a, 2009b).

The overall picture is quite complex when considering possible societal impacts of climate change on fisheries. Climate change has both direct and indirect effects at all levels, and climate change interacts, at the local and regional levels, with changes in economy and governance, as well as with the effects of mitigation measures, and also with super-regional changes from national to global levels. Thus, there are complex causal relationships and non-climate drivers of societal change to consider. AICA concluded that, due to uncertainties in CC modelling, it is not possible to predict the effects of climate change on marine fish stocks with any degree of certainty. The socio-economic consequences of these effects for arctic fisheries are therefore highly uncertain at the more detailed level of regional studies (cf. Loeng 2008). Despite these difficulties, the ACIA report recommended the scientific community to rise to the challenge.

As a general approach the following equation can serve a heuristic function: *Social climate vulnerability = exposure + sensitivity – adaptation*. Climate-vulnerability studies look at natural, socio-economic and institutional vulnerability of sectors and communities. It is important to take a broad approach to studying societal impacts, as this will facilitate mapping where vulnerability is (or, given rather high uncertainty, *seems* to be) largest; to identify data and knowledge gaps; and to further develop methods for vulnerability assessments.

The NorACIA approach is built upon a regional climate vulnerability analysis for Northern Norway. Local vulnerability to climate change is also studied, demonstrating methods for mapping institutional vulnerability at the municipality level. However, although NorACIA is based on regional climate models (RCMs) with higher spatial resolution, it is not necessarily more certain in its assessment of socio-economic climate change effects.

Historical examples are essential to learn about the actual adaptive capacity of persons, industrial sectors and communities, and hence, of institutions, adaptation as a strategy seeks to reduce vulnerability, and the socio-economic work produced as part of NorACIA has identified three classes of vulnerability: natural, socio-economic and institutional vulnerability. To measure vulnerability we need to know what the unit of analysis is – who/what is vulnerable at what scale? West and Hovelsrud (2008) have tried to identify fisheries-dependent communities, based upon the relative importance of fisheries as measured by employment and key economic figures, trying to identify the municipalities potentially most vulnerable to climate change. West and Hovelsrud has also identified potential indicators of vulnerability to climate change for fisheries, looking at number of part- and full-time fishermen, catch of fish by species and place of landing, fishing ground and place of registration of the vessel, number and type of fishing vessel, fish processing and aquaculture. These indicators discussed are not on their own sufficient to evaluate vulnerability to climate change related to fisheries, yet they could be used to screen the municipalities to identify municipalities that could/should be further evaluated with a set of additional, local factors and information.

The complex issue of societal impact of climate change on fisheries needs a broad approach and a combination of top-down and bottom-up research processes for its evaluation. The current situation is that the usual assemblage of fisheries data is not satisfactory. Additional methods and factors to consider conducting assessments of local vulnerability in fisheries-dependent regions are needed, like

- qualitative and quantitative assessments of alternative sources of local employment and income sources
- degree of local entrepreneurship
- assessment of unemployment levels among fishermen
- mapping of local managerial and institutional competence and assessment of awareness, perception and interpretations of climate change at the local level
- preparedness for dealing with changes.

Furthermore, the complexities of processes are not captured well in aggregated data, and we see a need for perspective analysis. The contextualization is important. Climate change and its societal impacts and effects needs to be seen in a broader perspective, looking at social, political and economic contexts.

3.11 Fisheries management and climate change

By Alf Håkon Hoel, University of Tromsø, ahhoel@gmail.com

The Arctic Climate Impact Assessment (ACIA 2005) concluded that good resource management regimes are essential to the climate challenge, and that capacity reduction is the single most important contribution from fisheries. Furthermore, climate change is one of the most pressing issues of our time with an increased attention to economic, political and social implications.

A policy in a given issue area can be defined as objectives with associated policy measures. In fisheries, there are three elements of good regimes: scientific knowledge, regulations and enforcement (Christy 1973). Scientific knowledge is critical to understand the resource dynamics, the effects of exploitation and the interaction between the resource in question and its natural environment. Regulations are the means by which the activity of those exploiting the resource is constrained, by limiting how much, where, when and how it can be fished of a given resource. Enforcement is about ensuring that regulations are complied with. To perform these three functions, elaborate governance mechanisms have been developed over the last decades.

The policy context of marine management is one of multilevel governance with global treaties and processes, regional RFMOs and other arrangements and domestic sector-ministries and agencies (Ebbin *et al*. 2005). In the context of fisheries management, fisheries are increasingly regarded as an environmental issue due to increasing influence of global environmental principles like the ecosystem approach (Morishita 2007) and the power of consumers, manifesting itself in eco-labelling schemes (Hoel 2006).

The first generation of the fisheries management toolbox looked at access restriction, catch limits and technical restrictions on when, where and how fisheries could take place. The second generation is looking at the precautionary approach, the level of risk, and ecosystem based management, with interaction between fisheries and climate, and integration of different types of knowledge and concerns.

There are two major issues dealing with policy implications and climate: mitigation and adaptation (Hoel 2008). Mitigation is looking at how fisheries affect the climate, and adaptation refers to how climate affects the fisheries. The management tool for mitigation, according to the Kyoto Protocol is emission targets, clean development mechanisms, joint implementation and emission quota trading (xxx). For adaption climate change has implications for fisheries policy at the international as well as the domestic level. Domestic adaptation is adjusting the industry to changing circumstances, an area of expertise of the fishing industry and managers. Furthermore, the policy measures include so-called good governance, risk management and more integrated approaches to knowledge and regulation. Good fisheries management means reduction of effort and good climate policy means less fuel consumption. In other words, good fisheries policy is good climate policy and is a win-win situation (Hoel 2008).

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4. Workshop II

At the Beijer Institute, Stockholm 17–18 September 2009

4.1 Fisheries management and climate change: an introduction

By Arne Eide, University of Tromsø, arne.eide@maremacentre.com

Management is to set constrains on dynamic systems, usually by governmental intervention. Two dynamic systems meet in fisheries, the economic and fish population (or ecosystem) dynamics. All social engagement evolves here. From an economic point of view, management may have two motivations: resolving market failures and introducing market failures. Ecosystems are affected by economic activities (such as fisheries), and harvest and fleet activities are constrained by management measures and economic condition. Open access to a valuable common pool stock resource represents a market failure since the price (free) does not reflect the real value of the resource. Currently available stock resources are functions not only of population dynamics but also of previous exploitation levels, possibly determined by open access to the resource. The two input factors in fish harvest production, fishing effort and fish stock biomass, then are interrelated and substitution between the two could only be carried out over time.

Climate change does not represent a significant new situation in the management of fisheries, apart from introducing a possible new management motivation – global warming mitigation. Global warming may affect ecosystem composition, performance and distribution, growth rates and capacity levels, distribution areas, migration patterns and seasonal profiles. It may also affect economic activities related to the ecosystem: cost of input factors in fishing, weather conditions and uncertainties, demand for fish products, coastal livelihood and demographic structures.

The main tasks however, remain: mapping possibilities and constraints, establishing long- and short- term objectives, identifying possible and preferable paths and developing ability to adapt to new knowledge (adaptive management). We are at the end of a long lasting attempt of understanding system dynamics before implementing proper management. Future management system will be more based on managing under uncertainty, acknowledging that important knowledge is missing. This will lead to management based on the most robust rules in order to cope with changes that we are not able to predict, instead of having a management regime assuming perfect knowledge.

4.2 Climate change and fisheries in the Norwegian Arctic. Societal impacts and adaption

By Eirik Mikkelsen and Arne Buanes, NORUT, eirik.mikkelsen@norut.no, arildb@samf.norut.no

This presentation was also based on NorACIA (see text about NorACIA in presentation by Buanes/Mikkelsen at Workshop I). The presentation described and explained the concept of climate change vulnerability and different methods to assess such vulnerability at different scales and for different types of actors. Further it presented fisheries-related climate change studies on/including the Norwegian Arctic, both ecosystem-based and sector-/community-based. The presentation summed up by presenting knowledge gaps and research needs.

The climate-vulnerability of an actor, industry, municipality or region depends on *exposure* to climate change, how *sensitive* it is, and its *adaptive* capacity. These links to studying *natural vulnerability* (exposure to climate change and occurrence of natural processes affected by climate change), *societal vulnerability* (the degree to which processes, infrastructure, industries etc affected by climate change is important for this actor/region), and *institutional vulnerability* (the institutional capacity there is to handle climate change and its implications, to carry out adaptive measures).

One method for evaluating vulnerability to climate change is a top-down approach using statistical data at the municipal level, to consider community/sector vulnerability, like in Groven *et al*. (2006). In bottom-up studies, local vulnerability is explored and evaluated *together* with local stakeholders, using both quantitative and qualitative data, as in West and Hovelsrud (2009). The top-down method is useful for screening a large number of municipalities or sectors to decide where further studies of vulnerability should be prioritized. The bottom-up vulnerability studies have a larger potential for activating local stakeholders for adaptive action, and for identifying concrete and appropriate adaptive measures fitting for the local context.

Climate change studies for fisheries must include a number of climate variables not usually included for terrestrial studies, including salinity, current, ice-conditions, water-height, waves, turbulence and light. Studies of climate change in fisheries have been of two major types: Those focused on a marine ecosystem, like the Barents Sea (Loeng 2008), and those focused on a fisheries sector (e.g. whitefish or pelagic fisheries) or a region/municipality (e.g. Northern Norway or Hammerfest municipality).

The study by Loeng *et al*. (2008) on climate change effects in the Barents Sea ecosystem underline that there are large uncertainties for the projections on climate change. In particular the climate models for the Barents Sea do not include sea-ice in a satisfactory manner. Fish stocks will likely move north and east due to temperature increases, but this will also depend on i.e. availability of food (match/mismatch in space and time), and alternative spawning grounds for the smaller species of fish. Transnational expansion may lead to international (re-) negotiations on quotas and fishing rights. Production may increase, but this will depend on the ecosystem effects of climate change. The societal effects based on these highly uncertain ecological effects, are even more uncertain.

Looking at adaptation in fisheries at a general level, it is necessary to have strong knowledge base and good methods for analysis and to understand complex multi-factor situations. At the national level good management of fish stocks, good institutions, and procedures for international fisheries management is needed. At the sector level and regional/local level adaptation might be limited by external factors like market conditions and higher level governance decisions. It is important to have a multi-stressor perspective on the effects of climate change. Some sectors and regions may also be doubly climate-sensitive, both to the direct effects of climate change, and to the effects of mitigation measures (like CO2-taxes on emissions). The knowledge gaps in societal impact studies are especially on connections between climate, environment and society. The gaps also include how to calculate economic effects, how to develop socio-economic scenarios, and methodology for coupling such scenarios with climate scenarios.

Major findings from NorACIA

The NorACIA scenarios have showed that marine downscaling models are still too poor. The ecosystem and fish stock impacts of climate change is highly uncertain, regional societal impacts depend on several factors and vulnerability assessment methods are generally not good enough. For the Norwegian Arctic a comprehensive local/regional fisheries-study is needed. It should link ecosystem and fish stock climate change scenarios with economic and societal scenarios. The scenarios should focus on sectors within fisheries, local impacts given local fisheries sector structure and identify local adaptation options. It is important to merge the different types of scenarios and combine the different objectives. Some adaptive measures work in different fields and adaptive measure in one community may affect another community in a negative may. Hence adaptive measures should be coordinated.

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4.4 Changes in Migration Patterns of the Capelin as an Indicator of Temperature Changes in the Arctic Ocean (Seen from an Icelandic point of view)

By Bjørn Birnir, University of California, Santa Barbara, birnirb@gmail.com

The capelin is important for both the ecosystem and the economy. The capelin feeds of the plankton that has increased dramatically in the Arctic because of hot summers and abundance of zooplankton. The feeding migration for the capelin is around 1000 km each way and the spawning migration circles Iceland.

The mathematical model is based on biological testing, using three different zones around the particle, see figure below. If there is another fish in the zone of repulsion, they go separate ways. In the zone of attraction they swing towards each other. If there are many fish in the same area, the different zones must be grouped together.

The predictions are also determined by temperature. It has to be built into the model and balance the capelin's tendency to orientate towards the direction of the school and its ideal temperature. The acoustic data in the model shows where the particle goes, using thousands of particles, making simulations with a scaling theory that shows parameters compared with biological parameters.

In 2008, the ice initially blocked the capelin, and then the warm Gulf Stream obstructed the capelin from spawning in traditional grounds, forcing them to stay where they were exactly as the acoustic data showed. In 2008 there were two migrations. In the second migration, the capelin travelled along an unusual route. The migration appeared to have stopped altogether, but in fact it went deeper than usual, stopped and then surfaced exactly where the fleet was waiting. The simulations of this route made it possible to get the destination but not the timing right. The second migration did not appear at the exact time predicted. They went deeper, and into an underwater fjord to gain time, making the timing of arrival slightly different than in the simulations.

During the spawning season the fat of the capelin is turned into roe. The rate at which roe is produced is dependent on temperature. When roe content increases above 10%, the swimming speed increases, and warm temperature tolerance increases. The increase in tolerance is what makes them survive the hotter water. To get the timing right we need two variables, the internal energy (fat content) and weight. With the energy budget incorporated, we can time the run and the migration, as the schools come into the continental shelf.

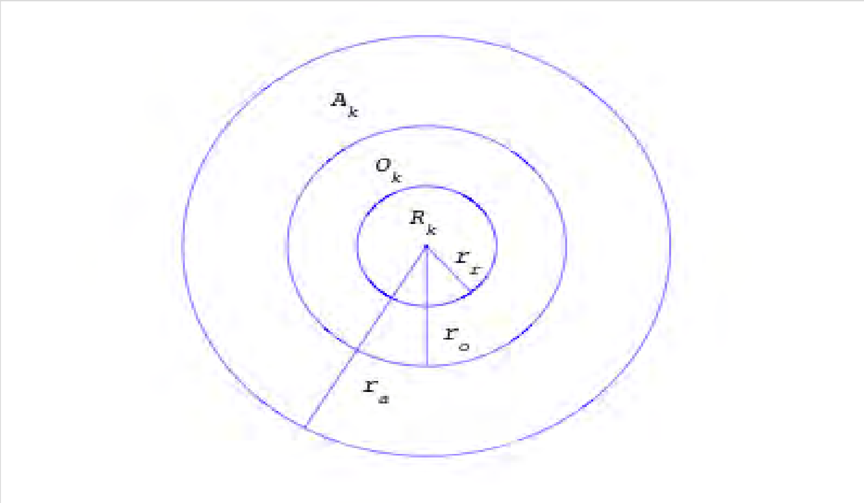
In 2009 there was no second migration of the capelin and the capelin fisheries were suspended for the first time in history. It remains to be seen if this change is permanent or cause by a temporary low in the capelin population. However, the spawning grounds seem to be the same as before and have not moved north.

Studying 40 years of acoustic data, it is possible to look for trends and sensitivities in the different migration patterns, and compare it to different climate parameters, such as increase in sea temperature. The current status is that we need a better model for currents; we need to couple a current-model to temperature- and stock-models. It is possible to build other species into the mathematical model as well. Once you have this model, you have a foundation, and the model can be used in the end to determine possible harvest outcomes.

Results

Given the form of landmasses, currents and food distribution in the oceans the migrations of the capelins is determined by only one parameter; the temperature distribution in the oceans. This makes the simulation of the migrations possible both with respect to location and timing. Fluctuations in the migrations over time can reflect temperature changes in the ocean, probing global change, and a multi-species model can be developed to optimize the harvest.

Figure 1. The figure shows the three zones. The innermost is the zone of repulsion with radius r_r. Then comes the zone of orientation with radius r_o. The outmost zone is the zone of attraction with radius r_a



4.5 Expected Change in Fisheries in the Barents Sea: preliminary results on the relationship between climate and the spatial distribution of commercial fish species

By Geir Odd Johansen, Institute of Marine Research, geir.odd.johansen@imr.no

Results from the project Expected Change in Fisheries in the Barents Sea (FishExChange) were presented. The principal objective is to evaluate the effect of climate change in the Barents Sea and adjacent areas, looking at distribution of fish stocks in the perspective of national marine areas. The aim is to evaluate what effect this will have in division of national fish quotas and economical consequences for the fisheries, all with a spatial approach.

The results presented are based on analysis of data stored in a spatial database covering the period from 1980 and onwards, including fish surveys, fisheries and climate data stored in predefined steps in space (horizontally and vertically) and time.

The temperature time series from the Barents Sea show an increase of about 2 °C in the period 1980 and onwards, with considerable year-to-year variation. In FishExChange we investigate if this temperature increase has resulted in an accompanying trend in the time series of spatial characteristics of the geographical distributions of fish, using the data stored in the spatial database. A simple spatial analysis of density indices of cod ≥ 45 cm (~ catchable size) from the winter bottom trawl survey in the Barents Sea in 1981–2009 controlled for varying survey coverage was presented. This shows no clear trends in the spatial pattern in accordance with the increasing temperature in this period. It is less likely that geographic distribution of fish respond directly to temperature, but that factors like life history stage, stock size and food availability plays equally important roles. Similar studies will be done on survey and catch data on several species in the Barents Sea.

The time series of geographical distribution data of high quality are limited in a climate change time perspective. An alternative to approach is to look at data as realizations of several distribution outcomes under the prevailing climate conditions, instead of looking at time trends. Sensitivity of the geographical distributions to environmental conditions, both biotic and abiotic, can then be studied using the combined data. This may hold information about the expected geographic distribution effects of climate change.

Two important findings/points/products

- Spatial databases covering the Barents and Norwegian Seas in period from 1980 and onwards integrating spatially referenced data like hydrography and model output, fish survey data, and catch data, are developed. The data are stored in stored in predefined steps in space (horizontally and vertically) and time. This system enables integration of data from different sources and with varying spatial and temporal structure in a common framework to facilitate analyses across the different data types. The developed system is general, based on open source software and capable of storing several other types of ecosystem data. It is foreseen as an important foundation for future marine climate research.
- A simple relationship between geographic distribution of fish and temperature is less likely. Several factors govern the geographical distribution of fish, e.g. stock size, life history stage, localization of spawning areas and prey availability. To enable scenarios of future fish distributions in a global warming regime, elaborate analysis taking several factors into consideration is necessary.

4.6 Aquaculture and Global Warming: The case of Salmonid Aquaculture in Norway

By Knut Heen and Øystein Hermansen, University of Tromsø, knut.Heen@nfh.uit.no, oystein.hermansen@nofima.no

Farming of salmonids includes three main species, Atlantic, Salmon trout and Coho. The spatial distribution depends on license allocation and physical conditions, with politicians defining where the licenses are handed out. Currently, movement of concessions between counties is not allowed. Some of the scenarios in this model explore greater liberalization.

With an expected temperature increase in Norwegian waters, the main objectives for this study are: influence on productivity in salmonid culture and spatial distribution of production and employment. The production results are measured over 30 years and four scenarios are investigated:

- Stable management and stable temperature.
- Stable management and increased temperature.
- Liberalized management and stable temperature.
- Liberalized management and increased temperature.

Management refers to the ability to relocate licenses, where stable and liberalized respectively implies fixed and free distribution of existing licenses.

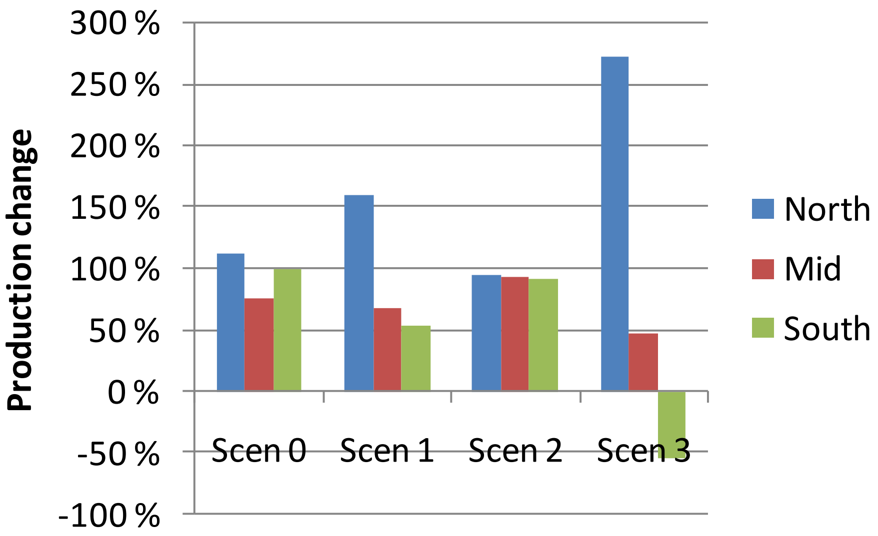
Temperature has a major effect on fish growth. The relationship between productivity and temperature is complex and difficult to model, with lack of data, vary timing of stocking, legal constraints and other variables like weight, O2, daylight, maturation etc. The production model predicts annual salmon production per year and county. This is a product of county averages of productivity that are temperature dependent, and number of licenses. *Production per county (productivity model) + Licenses pr yeas (relocalization model) + market growth (residual) = Total production (market projection).* Total production is based on a model that assumes linear market growth. Productivity per county is determined in a temperature-driven model. An annual scalar is employed to ensure that the market restriction is not violated. Furthermore, high organic load capacity, a restriction concerning capacity, is not assumed restrictive in any counties.

A simplified model for prediction of the relocalization of licenses is employed. In this model the removal of licenses has a linear relationship with relative productivity, and adding is done subjectively based on productivity and the size of the county.

Measurements of industrial statistics like value added (the contribution to the labour and the capital in the economy) and employment, are important when looking at the economy. An input-output model captures not only the direct effect, but also the indirect effects on other industries.

Preliminary findings indicate substantially differing effects on the spatial distribution of production and hence value adding and employment. In the baseline scenario, production growth is relatively equal among the northern, middle and southern parts of Norway. Increased temperature yield shifts production considerably north, both in case of stable and liberalized management.

Figure 1. The production change in the three regions within the different scenarios



4.7 Possible bio-economic modelling approaches to fisheries management under global warming

By Arne Eide, University of Tromsø, arne.eide@maremacentre.com

Partly due to the crisis and fish stocks collapses in the late 1960, a new toolbox of fisheries management became available. The main objective from the early years of ICES was to understand the great fluctuations in fish stocks, in particular focusing the problem of recruitment dynamics. The final toolbox for fisheries management, as it was introduced in the 70ies and up to recently, included models omitting the recruitment problem (yield per recruit optimisation and virtual population analyses). The new idea of precautionary approach to fisheries management represents also a reintroduction of the difficult dynamics of recruitment and other factors causing unexplained fluctuations. The idea is first to observe the system (by indicators), base the management decisions on the best (uncertain) knowledge, rather than explain the system and base the decisions on accurate system knowledge. The "traffic light cod harvest model" still is a very static approach, including the former reference points rather than useful indicators.

4.8 The ICES/HELCOM working group on integrated assessment of the Baltic Sea

By Thorsten Bleckner, Baltic Nest Institute, Stockholm Resilience Centre, Stockholm University

The ICES/HELCOM working group on integrated assessment of the Baltic Sea (WGIAB) was setup in 2007 as a forum for developing and combining ecosystem-based management efforts for the Baltic Sea. WGIAB has given itself 3 main tasks:

- to conduct holistic ecosystem assessments based on large multivariate datasets
- to consider the use of ecosystem modelling in the assessment framework
- to develop adaptive management strategies for the different Baltic Sea ecosystems.

WGIAB concentrated on the past two years on the collection and analyses of large multivariate datasets. This effort resulted in ecosystem assessment for 7 subsystems of the Baltic Sea. These ecosystem assessments demonstrated dramatic changes (i.e. regime shifts) during the last 3 decades on all trophic levels of the ecosystems related to climate variability and human exploitation.

Furthermore, WGIAB performed food-web and single species modelling. This ensemble modelling approach used allowed a straightforward comparison of the range of possible outcomes projected by the diverse models used. WGIAB started to develop a strategy on the use of ecosystem modelling in the future assessment framework, which will be continued in 2010 to develop adaptive management strategies.

4.9 Arctic tipping points

By Alf Håkon Hoel, University of Tromsø, ahhoel@gmail.com

The Arctic tipping point project looks at abrupt changes and the effects it may have on Arctic systems. One of the objectives is to examine the socioeconomic implications; that is – effects on administration, politics and institutions.

The governance of marine ecosystems are characterized by multilevel institutions: global, regional, and domestic regimes (Ebbin *et al*. 2005). Major interests are at stake in managing fisheries, making power over who gets what, when and how, an important driver in the development of governance in fisheries (Hoel and Kvalvik 2006). The multilevel governance system in fisheries that the project will explore effects of possible tipping points on can be briefly described as follows:

- The global institutional framework for marine ecosystem governance emerging in the 1970's in negotiations under UN auspices (the Law of the Sea Convention, adopted in 1982 and in force in 1994) was a tipping point in managing the world oceans. While Exclusive Economic Zones (200 nautical miles) are under coastal state jurisdiction, the high seas are essentially governed through international mechanisms. This regime has later been expanded upon both by additional United Nations treaties, as well as a number of soft law mechanisms (FAO and others). The allocation of living marine resource between different countries is basically decided by this regime, as are the principles whereby resources and ecosystems are to be managed.

In the Northeast Atlantic, the International Council for the Exploration of the Sea (ICES) plays a critical role in providing scientific advice for the management of the marine environment in general and the fisheries in particular. ICES can be considered a role model for the organization of the relationship between science and politics, in particular as it provides for a clear division of labour and the insulation of the scientific process from political concerns.

For fish stocks that are shared between countries, allowable catches are set in international negotiations among the relevant countries. In the Northeast Atlantic, there are a range of such arrangements, covering virtually all transboundary fisheries. The fisheries on the high seas in the region are regulated by agreements between the coastal states and the Northeast Atlantic Fisheries Commission (NEAFC).

At the domestic level (Norway as an example), the issue of distribution is basically between vessel groups (Mikalsen and Jentoft 2003). It is an important political issue to settle, in order to manage sustainable in the long run. Without resolving distributional issues, conservation is difficult. For most fisheries there are now long-standing allocation arrangements in place. Virtually no fisheries have open access.

When exploring the robustness and resilience of this system in a tipping point situation, analysis of historical examples will be important. An initial hypothesis is that the institutional system described above is quite robust, having evolved over time in response to various external influences, and able to withstand substantial shocks.

An example of this is the fishery of Atlanto-Scandic herring, which was a major international fishery before collapsing in the early 1970s. The fleets and communities that were dependent upon this fishery to a large extent were able to compensate by shifting to other fisheries. The regime set up to rebuild the stock was a domestic Norwegian regime until the mid-1990s, when the stock had grown so large as to re-establish its transboundary nature. This necessitated a major redesign of the management regime, involving a coastal state agreement as well as NEAFC. This regime has been quite successful, with the herring stock now sustaining one of the world's largest fisheries.

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4.11 The Arctic tipping point project

By Anne-Sophie Crepin, The Beijer Institute, asc@beijer.kva.se

The Arctic Tipping Point (ATP) is an EU project within the 7th framework programme. The project includes several work packages to structure findings and studies from and of the Arctic. The work packages involve administration, data collection, experiments, data analysis, modelling, socio-economic impact assessment and dissemination. The ATP includes different fields of studies and different expertise, all trying to understand the same problem. Hence, the ATP is a multi-disciplinary approach, linking up findings from one discipline with others. The ATP integrates links, disciplines, and institutions to gather data from different field studies and experiments, with the aim to merge them together in a common model to simulate scenarios that will serve as starting points for the socio-economic impact assessment of climate change in the Arctic.

The ATP's main objective is to focus on climate change, and its consequences for the Arctic environment and for people in the Arctic in general. In particular, the project aims at assessing whether or not tipping points can be expected to occur in the marine environment as temperature is rising.

Within the ATP project, the work package 6 that deals with socioeconomic consequences of tipping points in the Arctic is divided into three tasks: fisheries, oil and gas and governance issues. This work package also deals with general findings regarding the socioeconomic consequences of tipping points in ecosystems like the Arctic.

An important issue is to find rules for good decision making in a world with uncertainty and tipping points. The economic literature shows that in the presence of irreversible outcomes and uncertainty, it is optimal to take a precautionary approach. However, it is still important to find a balance between being precautionary and being too precautionary. There is always a trade off between being precautionary with foregone exploitation opportunities and realising the exploitation opportunities at the risk of crossing a tipping point implying very bad outcomes. Precaution should be seen in an option value framework: it helps to buy time, to get more information and research about what the uncertainties looks like, and how we can handle them.

It is important to deal with uncertainty seriously by having a strategy that takes into account the uncertainty issues coupled with the tipping point issue. It is particularly important to do so in relation to tipping points and the Arctic because some possible scenarios imply really bad outcomes and we want to deal with that even if the probability is very low. A decision maker should first assess how much precaution he/she needs to take in order to buy time to get more information. The decision maker should then use that time to actively gather information by e.g. monitoring key variables and using scenario analysis. Such a scenario analysis could for example find out what will happen and what is the best strategy under different uncertainty outcome like the worst case, the best case and a few scenarios in between.

4.12 Support for Nordic fisheries research – climate related activities

By Andreas Stokseth, Nordic Council of Ministers, Andreas.Stokseth@fkd.dep.no

The Nordic Council of Ministers is one of the world's most extensive regional cooperations, and provides funding for project activities which can contribute to improved Nordic cooperation. The main funding criteria and mantra is "nordisk nytte", meaning that all projects supported by NCM have to include participants from at least three Nordic countries.

There are two major Nordic bodies involved in support for fisheries research; NordForsk and the Fisheries Cooperation under the Council for Agriculture, Forestry, Nutrition and Fisheries. NordForsk was relatively recently established. It is a meta-regional research board and was established in 2005 by the Nordic Council of Ministers as one of the pillars of The Nordic Research and Innovation Area (NORIA). The goal is to strengthen the Nordic region in Europe and globally. The establishing of Nordforsk represents a strategy shift in the way NCM is organized as this organization is designed to be the central research funding, coordinating and research policy advice unit of the NCM.

The Working Group on Fisheries was reorganized in 2009, with a two-tiered structure; policy level and operative level. It includes the Nordic countries with representation from fisheries administration, research councils and research institutions. The group is currently implementing a strategic shift in focus from support of research to more policy relevant activities, surveys, and consultancy work. The group operates in partnership and cooperation with NordForsk, NICE and other international organizations.

In addition to FIMAGLOW, other climate related projects funded by the Council are: NISE 2004, Norwegian-Iceland Sea Experiment, Bergen Conference on Climate and Fisheries Management 2008 (FAO, EU, Norway), Codlog I–II: studies in the historical distribution of cod stocks as result of climate variations 2005–2009, NorFishExchange 2008–2010, FIMAGLOW 2008, Freon reduction in Fishing Vessels 2008–2009 and Variation in the cycle if deep water prawns along a temperature gradient in the north-east Atlantic 2009.

The Fisheries Cooperation in cooperation with NordForsk has also experimented with scenarios as a tool for planning and strategy development, and gained some insight into the benefits and pitfalls of such planning techniques. It is envisaged that such tools will be useful when working with social, economical and political impacts of climate change in the future and that the first hand experience gained through the scenario project has prepared the two organizations for further exploration of this field.

5. Climate Change: Policy Implications to Norway in the High North

By Alf Håkon Hoel, Institute of Marine Research, alf.haakon.hoel@imr.no

The reduction of sea ice in the central Arctic Ocean in recent years has spurred a writings predicting an imminent race to the Arctic Ocean, with geopolitical consequences.[1] The Arctic region is portrayed as an international legal void that is up for grabs, and that international conflict is likely to ensue.

This line of reasoning is fundamentally wrong: the Arctic Ocean, as any ocean in the world, subject to the global oceans regime, the centrepiece of which is the 1982 Law of the Sea Convention. The Convention, which entered into force in 1994, provides a comprehensive set of rules regulating virtually every aspects of the oceans and their use. Equally important, the five littoral states in the region are playing by those rules.

Climate change do however pose a number of serious challenges, both in terms of mitigation, or reductions of emissions of climate gases, and in terms of adaptation to change. the political challenges of climate change to the coastal states in the arctic, is however not so much about conflict and disorder, as it is about addressing the challenges in a constructive manner in accordance with the rules of the game laid down by international law.

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[1] See, for example, Borgerson 2008, Harrington 2008, or WWF 2008.

5.1 Norway and the Arctic

Norway is one of five states bordering the Arctic ocean.[2] Its ocean areas amounts to 2,2 million square kilometres – an area more than six times its landmass, or seven times the size of Italy. Its waters range from 56 degrees S in the North Sea to 84 degrees N north of the Svalbard Archipelago, some 3,200 kilometres north south. Due to the warming influence of the Atlantic current, the climate in Norway is 6–8 degrees C warmer than at corresponding latitudes in Siberia in North America. All of the Norwegian mainland is therefore south of the 10 C degrees in July isotherm, which is usually regarded as the boundary between boreal and Arctic areas.

The two Norwegian landmasses in the Arctic is the Svalbard archipelago separated from the Norwegian mainland by the Barents Sea, and the island of Jan Mayen. Most of the Norwegian Arctic is oceans. Svalbard came under Norwegian jurisdiction by the 1920 Svalbard Treaty, enacted in the 1925 Svalbard Act. Jan Mayen became Norwegian by occupation in 1929 (1930 Jan Mayen Act). It should also be noted that Norway is the only country in the world with territories both in the Arctic and the Antarctic, where Queen Maud Land on the Antarctic continent (occupied 1939), Peter I island, and Bouvet island. The former two are south of the 60th parallel and thus subject to the provisions of the 1959 Antarctic Treaty. While the Arctic islands are part of the Kingdom of Norway, the Antarctic possessions have the status of provinces ("biland").

Norway's Arctic Oceans can be defined as the areas to the north and east of the mainland. It is also common to include the ocean areas to the west of North Norway from Lofoten archipelago northwards in what is considered "Arctic waters", since the migratory range of important fish stocks can span the entire region.

The natural resources in its oceans and on the continental shelf are the mainstay of Norway's economy. Petroleum production amounts to 250 million Sm3 oil equivalents (2006) and constitutes some 25% of GDP and 50% of the country's exports. While the North Sea remains its most important petroleum province, production is gradually moving northwards. In 2007 the first field in Arctic waters off North Norway started production. A gas field, "Snøhvit", produces liquefied natural gas

[2] The others are Russia, USA, Canada, and Denmark/Greenland.

(LNG) destined for the US and European market. Expectations are high for further developments in the petroleum industry in the North.

The by far most important natural resource in the Norwegian high north are the fisheries resources. Fisheries is a nationally significant industry, contributing 5% to the country's exports, and it is vital to the economy of the coastal communities. The annual landings of marine fish is about 2,5 million tons, and aquaculture production (mainly Atlantic salmon) amounts to 600,000 tons, making Norway one of the world's major fishing nations. The fisheries are particularly important in the north, where cod, haddock, herring and capelin are among the most important fish stocks. Also minke whales and harbour seals are hunted. An important aspect of these resources are that they are largely shared with other countries, Russia in particular (see below).

5.2 The rules of the game

The governance system for the world oceans, the fundamentals of which is laid down in the 1982 Law of the Sea Convention, provides a comprehensive set of principles and rules for how the oceans are to be governed and used. When considering the effects of global warming and policy implications of those, these rules defines how countries can work in relation to mitigation and adaptation to change in the marine realm.

The perhaps most important provision of the ocean law regime is that coastal states are entitled to a 200 nautical mile (370 kilometres) Exclusive Economic Zone (EEZ) where they have sovereign rights over the natural resources. That includes rights over petroleum resources in the continental shelves, also beyond the EEZs. The sovereign rights implies that it is up to the coastal state to decide how resources are to be managed and used. Norway, along with inter alia the US, Canada, and Russia, were among the main beneficiaries from this development, leaving it with a major share of the oceans in Europe.

In Norway the developments in ocean law during the last decades have been the basis for the development of a comprehensive regime for the management of the oceans, the marine environment, and the marine natural resources. Norway established an EEZ in 1977, and neighbouring Russia followed suit the year after. To protect the fish stocks to the North of its economic zone off the mainland, Norway also established a Fisheries Protection Zone around Svalbard.

As regards fisheries, an important aspect is that many of the most important stocks have a geographical range spanning also the EEZs of other countries and in some cases also international waters. In the south, a number of fish stocks are shared with the European Union, which also enjoy fishing rights in the north as part of an exchange of fishing rights and by virtue of historical fishing activity. In the North Norway and Russia share the major fish stocks. Those resources are managed jointly by the two countries, by a Joint Fisheries Commission set up in 1975. Generally, the management regime established by Norway and Russia functions relatively well, with most stocks being fished at sustainable levels. In some years overfishing is a problem, and in recent years substantial amounts of cod have been caught in addition to the agreed quota.

As to the continental shelf and the petroleum resources, the management of these resources are decided on by the coastal state only, also where the continental shelf extends beyond the EEZ. A process under the auspices of the UN is underway to determine the outer limits of the continental shelves beyond EEZs globally.

5.3 Climate change and probable effects

During the past century, global temperatures have risen at rates of change that are unprecedented for millennia (Dessler and Parson 2006). Warming of the atmosphere has been particularly pronounced in the Arctic (ACIA 2005). In recent decades, average temperatures here have risen at rates twice that of the rest of the world.

The catalogue of possible effects of climate change is long and complex, and subject to considerable uncertainty. The Intergovernmental Panel on Climate Change (IPCC 2007) has pointed to a number of potential effects, including continued increase in temperatures throughout this century, a rise in sea levels, disturbances in oceanic circulation patterns, shifts in the geographic distribution of animal species, and increased frequency of storms.

The most recent comprehensive, scientific assessment of global warming in the Arctic (ACIA 2005) indicates that atmospheric temperatures in the Arctic as a whole are increasing at about twice the rate of the global average, to 4–7 °C in this century. This is likely to affect the natural environment, people and societies in the region in a number of ways. Increased temperatures will bring shorter and warmer winters, and snow and ice cover will continue to decrease. Vegetation zones will shift, with the tree line moving northwards. The productivity of ecosystems will change, as will the geographical distribution and diversity of species. Sea-ice extent and thickness will decrease.

The Arctic is a vast region – the area to the North of the Arctic Circle is more than 21 million km2 (five times the EU) – and an important aspect of climate change in the Arctic is that while some areas experience severe change (e.g. Alaska), others seem less affected. Also, the Arctic region is climatically diverse.

Confronting the challenges brought by climate change essentially involves two issues: mitigation and adaptation. Mitigation is about reduction of emissions of the climate gases that contribute to global warming, and occurs under the global climate regime (see below). Adaptation deals with the question of how societies can adjust to changes in the environment stemming from climate change, and entails a wide range of policy issues at all levels of governance.

5.4 Mitigation: the global climate regime

The possible consequences of climate change have spurred major institutional responses at the global level. Since 1988, the Intergovernmental Panel on Climate Change (IPCC) has produced assessments of the status of science in this realm, last in 2007 (IPCC 2007). In 1992, the UN Framework Convention on Climate Change (UNFCCC) was adopted, attracting virtually global membership. It was followed up by the Kyoto Protocol in 1997, which contains specific objectives and measures for reductions in emissions of climate gases and timetables for achieving them.

The 1992 UN Framework Convention on Climate Change (UNFCCC) constitutes the institutional response to the climate challenge. In the 1997 Kyoto Protocol (in force in 2005) developed countries (with some exceptions, notably the US) agreed to reduce their emissions of climate gases by 5.2 per cent on average in the period 2008–2012 relative to a 1990 baseline.

The Arctic nations, except the US, work through the Kyoto Protocol to confront the challenges posed by global warming. The Arctic countries are major contributors to global emissions of climate gases, with the US only accounting for about one quarter of the global discharges. After 1990, Canada, Finland, USA, Norway, and Denmark have seen an increase in emissions. Sweden, Iceland, and Russia have decreasing emissions.

Norway, like Russia, is a major petroleum-exporting country, but its steadily increasing emission levels have brought it about 10 per cent over 1990 levels. Norway is generally supportive of the global climate regime, and the government has adopted ambitious long term goals for the reduction of climate gases, and aims for carbon neutrality by 2030. Norway will also use other mechanisms provided for in the Kyoto Protocol, such as the quota trading. The public debate on mitigation issues have centred on the balance between policy tools: emission cuts and quota trading. One the one hand it is argued that climate change is a global issue and that buying emission credits in developing countries would be a more cost effective way of reducing emissions than cutting emissions at home. On the other hand it is claimed that Norway as a rich country has a moral obligation to take substantial cuts at home.

A major policy challenge – shared with a number of other Arctic nations – is to reconcile the fact that Norway is a major beneficiary of the income generated by petroleum resources, which is a major source of CO2. This constitutes something of an ethical dilemma which has not really been subject to public debate yet.

5.5 Adaptation

Temperatures in the Barents Sea fluctuate in long-term cycles, and have increased during the last three decades. Current models (ACIA 2005) predict an increase in surface temperatures of 1–2 degrees by 2070. Beyond the Barents Sea, in the Arctic Ocean proper, rates of change as well as change may be bigger (NSDIC 2008). The areas of possible consequences of temperature increases in the high north include less sea ice, changes in geographical distribution of fish and other animals in the ocean, sea level rise and ocean acidification.

Reductions in sea ice will affect the northern part of the Barents Sea, as well as the areas to the north of the Norwegian zone around the Svalbard archipelago. In recent years the Barents Sea have been ice free in summer and in winter the ice does not extent south of 75 degrees N. To the north of the Barents Sea, recent predictions indicate continued reductions in sea ice, with larger areas becoming ice free in late summer. The lowest amount of ice in the Arctic Ocean was measured in September 2007. The series of satellite based measurements goes back only three decades, however.

Warming of the oceans may also have consequences for marine ecosystems and living marine resources. In general, warmer waters may increase biological productivity in the ocean. For a number of fish species in Norwegian waters, this means that they may have more food and grow faster. On the other hand, waters may also become too warm, and ecosystems may be disturbed in a way that limits productivity. For that reason fish may move to areas where temperatures conform to their comfort zone. In practice this means that the migratory range of important fish species to Norway like cod, haddock and herring may expand, with fish moving northwards to cooler waters. A possible instance of this appears to be occurring off North Norway, where cod appears to be spawning further north than a few decades ago. By the same token, also new species may come into an ecosystem as a consequence of rising temperatures.

Adapting to such changes fundamentally is about developing robust resource management regimes that incorporate changes in ecosystems in management strategies (ACIA 2005). In Norway, an important step in this direction has been taken with the Management Plan for the Barents Sea, which provides a platform for considering all uses and stresses on the marine ecosystem in an comprehensive manner. Such integrated approaches to oceans management are now emerging in a number of countries, including the European Union.

Still another possible consequence of increasing temperatures is sea level rise. Warming causes water to expand, which means that the sea level may increase. Also, the melting of glaciers, the Greenland and the Antarctic icecaps in particular, may add to sea levels. These are processes that take place on very long time scales, and in Scandinavia they are compensated by the fact that the landmass is still rising following the withdrawal of the icecap of the last glaciations 10,000 years ago. The IPCC predicts sea level rise 19–58 cm at the global level in this century. While Norway's coasts are generally steep and rocky, the country is likely to be affected by sea level rise in this century (Drange *et al*. 2007).

5.6 Conclusions

Climate change brings a number of challenges to the Arctic countries, and Norway among them. These challenges are basically related to two issues: mitigation and adaptation. Mitigation deals with the reduction of climate gases, where Norway has major challenges looming in meeting its Kyoto targets as well as its long term ambitions in moving towards a carbon neutral society. In terms of adaptation, the major issue in the high north is developing management regimes for marine ecosystems and living marine resources that take the effects of climate change into account. Integrated oceans management is critical in this regard.

Contrary to what appears to be a popular understanding, the Arctic is not a vast, unregulated territory with major international conflicts over natural resources looming in the face of reductions in ice cover. Rather, the oceans are regulated by global agreements that can provide for an orderly development of the region.

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6. On the issue of economic impact of climate change in Arctic fisheries

By Arne Eide, Norwegian College of Fisheries Science, University of Tromsø, arne.eide@maremacentre.com

Climate change has been on the international agenda the last decades and global warming issues are now among the most important political challenges of our time. Evidently global temperatures are increasing and human impact is believed to play a significant role in these processes. The latter represents by far the most difficult political challenge, as binding agreements on reducing emission of climate gasses on a global scale, are not easy to reach. The scope of this chapter is however not to discuss further the possibilities of agreeing on international actions aiming to mitigate global warming, but rather focusing on adapting strategies when facing the consequences of climate change in the future, focusing Northern fisheries.

In the following I will discuss issues related to adaptation to climate change, focusing fisheries performances from an economic perspective. What are the economic consequences of global warming? To which degree is it possible to reduce negative consequences by adapting strategies? What is the cost of adapting and how could we identify possible unintended consequences of actions and decisions motivated by adaptation to climate change? And in particular, how is this in the Nordic fisheries and fishing communities?

6.1 Adapting capacities

Living in the high north has always been related to coping strategies towards changing environmental conditions. People utilising natural resources in these areas have always been prepared to adapt to natural fluctuations between seasons and years, similarly to the exploited natural resources. Fish stock resources in the Arctic accordingly have developed migration patterns, recruitment strategies and other stock properties, adapting to a life in extreme environments facing significant fluctuations between and within years. One should therefore expect those living in the Arctic – plants, animals, fish and people – to be particularly able to cope with fluctuations; also beyond what is often referred to as *natural fluctuations*. Changes in the geographical distribution (or range) of existing ecosystems therefore is an expected consequence of global warming, rather than abrupt shifts in ecosystem structure and content. Locally this may however appear as significant changes even by minor changes in distribution areas compared with the situation of today. Regardless if this could be characterised as a minor ecosystem perturbation, the economic consequences may be significant on a community level, though not necessarily on a larger regional scale. Climatic changes may affect local economic activities dramatically. Forecasting such dramatic events is challenging on regional scale and turns out to be rather speculative on community levels.

Adapting strategies related to climate change is as we understand not new phenomena in the Nordic context, and particularly not in the high north fisheries. Survival in this region has been dependent of utilising different resources in different periods, good planning, necessary infrastructure, also in order to reach markets far away, together substituting a successful set of coping and adaptive strategies. In this perspective inhabitants of this region should be expected to have a higher ability of adapting to climate change than economies elsewhere, it is simply a necessary condition for living in this region.

Sjögren (2009) describes how climate changes over the last 2500 years have influenced human life along the North-Norwegian coast, measured indirectly through human impacts over the investigated period. Obviously people in the region developed different adapting strategies in different climate periods. Some periods of reduced or almost no human impact reflect that the coping strategies also included migration to other areas where the conditions were more favourable. Similarly McGovern (1991) gives many references to correlations between climatic change and cultural change in the Arctic and Subarctic, particularly focusing the Northeast Atlantic region. These correlations reflect cultural sensitivities to climate changes, but also a long tradition of building capacity of adapting to such changes.

Does the current climate change represent a qualitative new situation than what we have seen in the past? Are possible consequences of the global warming of our time of such nature that the previously developed adapting capacity, both in human systems and ecosystems, will fail to cope with the new situation? The answer depends both on the time frame considered and what we should characterise as successful adaptation to climate change.

In a thousand years perspective the current changes in the north still are within the ranges of previously experienced variation (Dahl-Jensen *et al*., 1998). The bigger changes have been on the human society side. The development of modern civilisations the last centuries has in some relations reduced human vulnerability towards environmental changes, but also increased vulnerability for example by being more dependent on complex technological systems and devises. Previously important coping strategies, as for example seasonal migrations and rotation between utilising different natural resources (Berkes and Jolly, 2001), has become less apparent as a consequence of human life being less exposed to natural environmental variations. Hence such societies are less dependent on natural resilience, being to a large degree protected against natural threats, but also becoming estranged from nature and less able to adapt to unavoidable natural changes. Changes in the human society therefore have made the society both more vulnerable (related to economic and technological complexity) and less vulnerable than before (by providing access to measures capable of reducing negative impact of environmental changes).

6.2 Managing use of nature

Human life has always been based on the exploitation of natural resources and all economic activities relates to natural resource use. This is not changed by the development of modern civilisation. The share of the total economic activity directly linked to natural resource exploitation has however been significantly reduced, relatively few people are involved in harvesting natural resources. The total amount harvested has however probably never been as high as today, but labour has to a large degree been substituted by capital in these production processes. Nevertheless extraction of natural resources is still essential for all societies and natural changes affecting the rate of extraction also affect the economy. But economic activities may also affect nature and by that future economic activities.

This is the basic reasoning behind modern natural resource management, including fisheries. The last fifty years emphasis has been put on adjusting today's catches in order to reduce the negative effects on future resource exploitation. The new management principle of sustainable use introduced the idea of equilibrium catches and constant exploitation rates. By the later development, focusing precautionary use and management under uncertainty, a management approach towards unpredictable fluctuations and lack of full information regarding stock-harvest interactions has been introduced.

The precautionary principle was introduced to international agreements and treaties in the 1980s and confirmed by the UN Rio Declaration on Environment and Development in 1992. The aim of a precautionary approach is to reduce the probability of unwanted events, acknowledging the fact that decisions have to be taken on the basis of poor knowledge. The precautionary approach is included in the FAO Code of Conduct for Responsible Fisheries. The idea is to create a buffer zone where the probability of harmful decisions is acceptably low.

This reasoning introduces some quite new ideas to fisheries management. Setting quota values should for example include uncertainties regarding the state of the stock, in order to be within safe exploitation limits. Quota setting routines may be defined on the basis of critical limits and quota setting may be automated based on such routines or rules. Such rules, now commonly referred to as harvest control rules (HCR) in fisheries, may include precautionary approach but also other economic reasoning. A set of relevant indicators needs to be activated and the control system could be implemented similarly to fuzzy logic control. The learned effect of different previous decisions could be utilised in refining the predefined rules and by that implementing adaptive management. The new concept of HCR also opens for new methods to include other ecosystem effects not fully understood, as year-to-year and seasonal fluctuations, multispecies relations, ecosystem dynamics, but also economic dynamics as fisher behaviour, fleet dynamics, skill and technical differences, etc.

The new management tools based on HCR are design for making qualified decisions under uncertainty, reducing the risk of negative consequences based on limited information. This management technology is also valid if distributions areas of risk, uncertainty or knowledge changes, as might be the case of global warming. Climate change therefore does not represent an entirely new situation to management of fisheries. It may introduce a new reason of management-global warming mitigation, while the previous reasons remain.

The main tasks of fisheries management therefore still include: Mapping possibilities and constraints; establishing long- and short-term objectives; identifying possible and preferable paths and developing ability to adapt to new knowledge; making management adaptive. The long lasting attempt of trying to base management decisions of full knowledge has been replaced by precautionary approach to uncertainty we acknowledge could never be removed. The new management paradigm includes ideas on how to manage under uncertainty, which is the necessary approach towards unknown consequences of global warming. The approach may be new in modern fisheries management, but is also in line with adapting strategies of the past, aiming to manage and adapt under uncertainty. The challenge is to find the most robust management rules in order to cope with changes we are not able to predict, not to establish a management regime based on perfect rules. Even if the latter had been theoretical possible, the cost would be far exceeded the benefit of obtaining full knowledge.

6.3 Possible economic impacts on Arctic fisheries from climate change

Physical environment and ecosystems of the Arctic are characterised by significant fluctuations, both within and between years. Biological systems have developed a vast number of mechanisms to cope with seasonal variation and other fluctuating environmental conditions. Fish stocks show migratory patterns, cannibalistic behaviour, dynamic maturation, density dependent recruitment and other methods of compensating for, and coping with, these fluctuations. The exploitation of renewable natural resources in the Arctic is constrained by the same fluctuating environmental conditions and has also developed adaptive strategies to these.

Physical environment defines the possibilities of biological growth and the abundance of commercial species. Changes in physical environment elsewhere can change the world demand for this species and opportunity costs of exploitation. Increased fluctuations, which could be a consequence of climate changes, might also change exploitation patterns. The crossover areas between current knowledge about changes in physical environment and the biology, and biology and economic exploitation, become essential areas of research if the goal is to implement climate related knowledge into fisheries management. The fundamental problem of management seems however to remain the same even if uncertainty increases. Climate change caused by global warming is not likely to alter the main characteristics of the Arctic system as a highly fluctuating system, but may influence the fluctuating properties of both physical and biological systems, and, hence, economic activities related to these.

Global warming may however affect ecosystem composition, performance and distribution, growth rates and capacity levels, distribution areas, migration patterns and seasonal profiles. It may also affect economic activities related to the ecosystem: cost of input factors in fishing, weather conditions and uncertainties, demand for fish products, coastal livelihood and demographic structure.

Impacts of climatic change on fisheries could be listed in this way:

- Changes in stock availabilities affect cost of harvest. New fisheries may emerge while others may vanish in some areas, due to ecological changes (shift in migration patterns and distribution areas).
- Changes in weather conditions changes cost of effort (reduced occurrence of polar lows may reduce costs while more extreme weather may increase costs).
- Availability of other input factors in production of fishing effort may be affected (reflected in price on oil, capital and labour).
- Climatic change may also change the demand for fish and fish products regionally and globally (due to increased environmental concern and consumer caution).
- The changes may cause changes in management which also have cost consequences.

The points above could be discussed in economic terms as matters of changes in supply and demand for fish products. The supply side covers changes in cost of producing catches, while the demand side naturally reflects changes in demand for such products. Changes in demand come from changes in preferences, relative changes in prices on other products and changes in income. Adding the spatial dimension discussed previously (local and regional scale), the complexity involved in predicting aggregated effects becomes apparent. Studies aiming to investigate economic impact of global warming therefore usually cover regional or larger scale partial analyses.

There has been carried out one fully integrated study on the management of and economic impact on the Barents Sea cod fishery (Eide, 2008). The study is based on the IPCC's SRES scenario B2 atmospheric data downscaled by REMO5.1 and utilised by the 3D ocean circulation model SinMod giving inputs to the Barents Sea multispecies-multifleet model EconSimp2000. The finding is that management constraints may have a greater economic and biological impact than the effect of climate change in a highly fluctuating system as the Barents Sea ecosystem. This study confirms the findings of other studies with less model integration between natural and social systems, but wider ranges of variations (Eide and Heen, 2002 and Eide, 2007). Figure 1 (from Eide, 2007) illustrates the different impacts in terms of cod population biomass (the Northeast Atlantic cod stock) and resource rent obtained from the cod fishery.

Figure 1

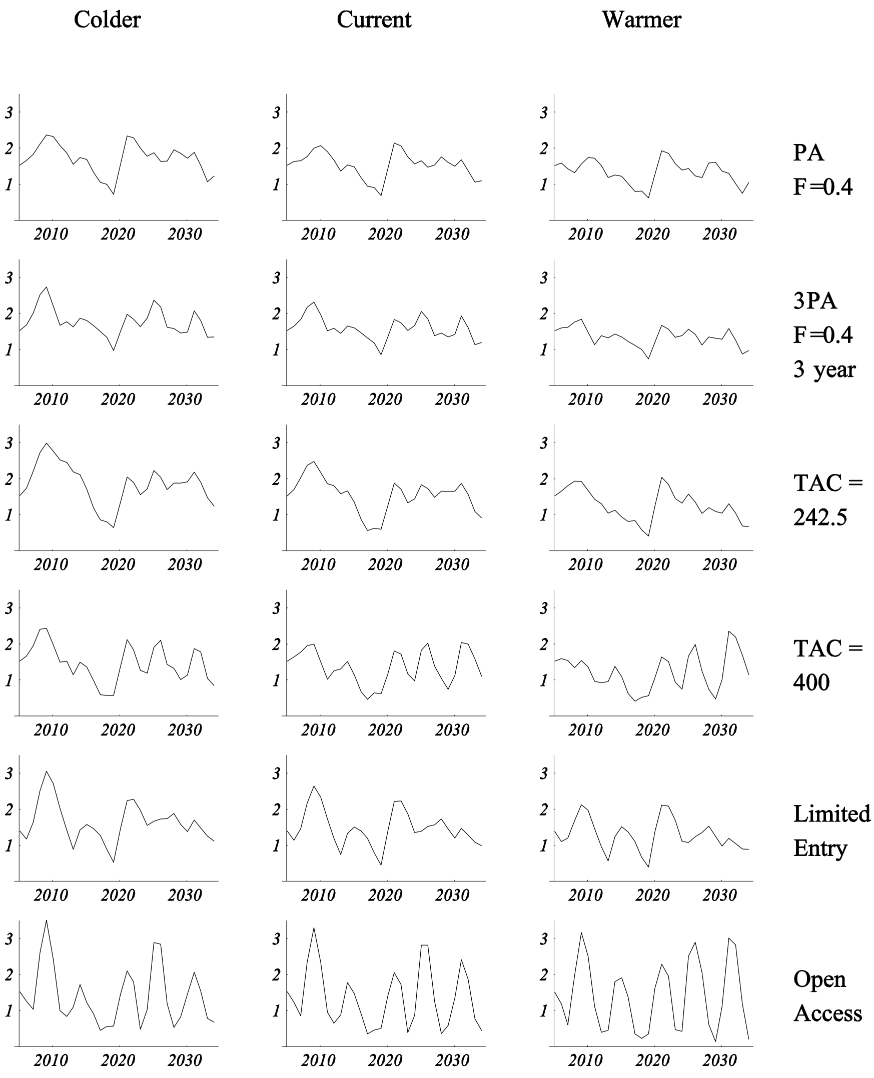
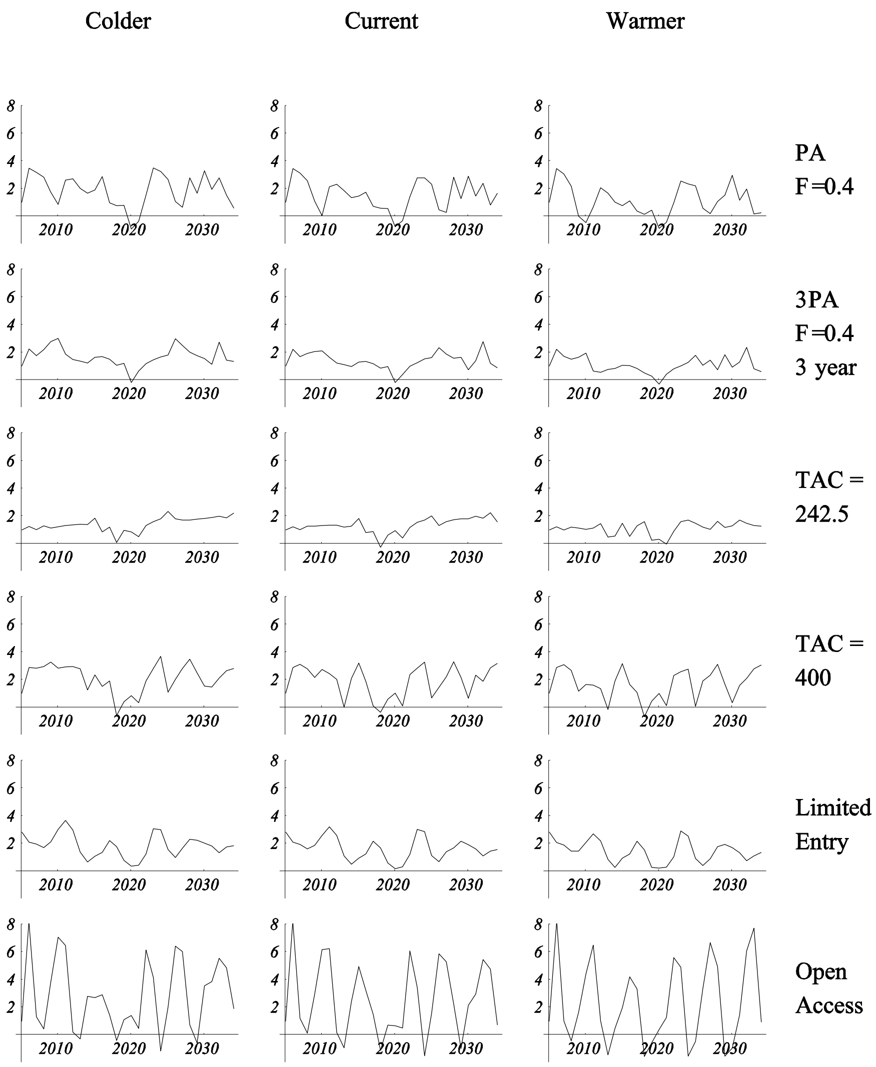


Figure 1 (continued)



Simulation results from Eide (2007) based on three climate scenarios for the Barents Sea ecosystem (colder, current and warmer) and six approaches to fisheries management, of which one being no management (open access). Of the six remaining management regimes two represent previous and current implementations of precautionary approach to fisheries management (PA, two include fixed annual quota values (TACs) and the last fixed fleet size (limited entry). The two panels to the left show simulations results for total cod population biomasses in million tonnes over a simulation period of 30 years (top panel) and corresponding resource rent in billion NOK. Further information could be obtained in Eide (2007).

All the mentioned studies assume the Barents Sea ecosystem to adapt to climate change without major structural shifts, based on the same reasoning as presented above. The change may cause the Barents Sea to be colder or warmer, depending on the total effect of two counterworking components: The heating of Atlantic water and the reduced inflow of Atlantic water into the Barents Sea basin. The studies include no market effects of the types described above, beyond the biological impact of global warming and rational fisher behaviour within the constraints defined by different management regimes.

The studies include a wide range of possible environmental and ecological impact from global warming and test the performance of different management strategies in the different climate scenarios. A robust finding in all studies is that impacts on economic performance due to choices of management regimes by far surpass the assumed impacts of global warming.

A further development of harvest control rules (HCR) is believed to have the greatest potential of improving management performance, by identifying proper sets of indicators suitable as inputs in HCRs focusing fluctuating fish stock. Quasi rent obtained on the exploitation of such fluctuating stocks may be quite considerable and even increase by increasing fluctuations, being one of the possible impacts of global warming. The current HCRs in the Northeast Atlantic cod fishery is however not suited to deal with a strongly fluctuating fish population, as the chosen indicators are based on a more static approach to fisheries management.

The best investment in reducing negative impacts of global warming on the northern fisheries therefore seems to be developing further HCRs to make them more flexible, adapting them to deal with fluctuating stock populations under uncertainty.

6.4 Conclusion

Fisheries around the world are characterised by heterogeneous fleets, spanning from small boats to large ships including a wide range of different gears utilised at different seasons targeting different species throughout the year. This is not a least the case in the Arctic fisheries, though the number of targeted species is rather limited. The heterogeneous fishing fleet could be interpreted as an adaptation to uncertainties and stock fluctuations, each participant aiming to increase their expected benefits from the fishery. This is obtained by taking advantage of flexible fishing methodology and changing between different seasonal fisheries. This kind of flexibility is easily reduced by modern fisheries management, since the regulation parameters include vessel size, gear, targeted species in addition to catch quotas and limited entry regulation.

Consequently one of the most powerful adapting strategies of the fishing fleet is lost or significantly reduced. If the natural fluctuations at the same time increases or becomes less predictable, this could dramatically affect the economic performance of the fleet.

By this reason and simply by the existence of unpredictable natural fluctuations alone, suitable management means allowing some of the above described flexibility to remain in the fishing fleet, is needed to ensure a sustainable, profitable and viable fishery in the Arctic. One of the expected consequences of global warming in this region may very well be increased fluctuations, emphasising the importance of developing management strategies robust to such changes and to utilise the stabilising property of fleet flexibility.

The new situation of global warming therefore does not represent an essentially new management challenge, it reemphasise the importance of developing management means capable of dealing with uncertainty and significant fluctuations. The new development of harvest control rules is promising, but there is still a long way to go in order to find more useful indicators and to develop ways of converting it into dynamic rules and thereby increase the capacity of learning and to take previous experience into use. Based on this reasoning the northern fisheries may be more prepared to tackle environmental challenges than many other industries despite of being more dependent on nature, or simply because it always has been dependent on adapting to natural variations.

6.5 References

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7. Sammenfatning

FIMAGLOW-prosjektet representerte en videreutvikling av det nordisk samarbeid omkring fiskeri, forvaltning og klimavirkninger som ble påbegynt under arbeidet med ACIA-rapporten (Arctic Climate Impact Assessment). Klimaendringer gir nye utfordringer også innen fiskeri og havbruk og for forvaltning av disse naturressursene.

FIMAGLOW-arbeidet besto av to arbeidsmøter hvor den første tok opp tråden fra ACIA-rapporten med nye studier og oppdaterte klimascenarier. Det andre arbeidsmøtet vendte blikket mot tilpasnings-strategier og hvordan forvaltningsregler kan tilpasses økt usikkerhet og endringer.

FIMAGLOW-rapporten gir et resymé over de faglige innleggene på arbeidsmøtene og (seksjon 3 og 4). Presentasjonene fordeler seg på tre ulike områder: Systemendringer og variasjoner, Forvaltning og Sosioøkonomiske aspekter. Forvaltningsrelevans og politikk-implikasjoner er temaene i seksjon 5, mens den avsluttende seksjon 6 tar opp de økonomiske implikasjonene klimaendringer kan ha på de nordiske fiskerier.

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Nordic Council of Ministers

Ved Stranden 18
DK-1061 Copenhagen K
www.norden.org

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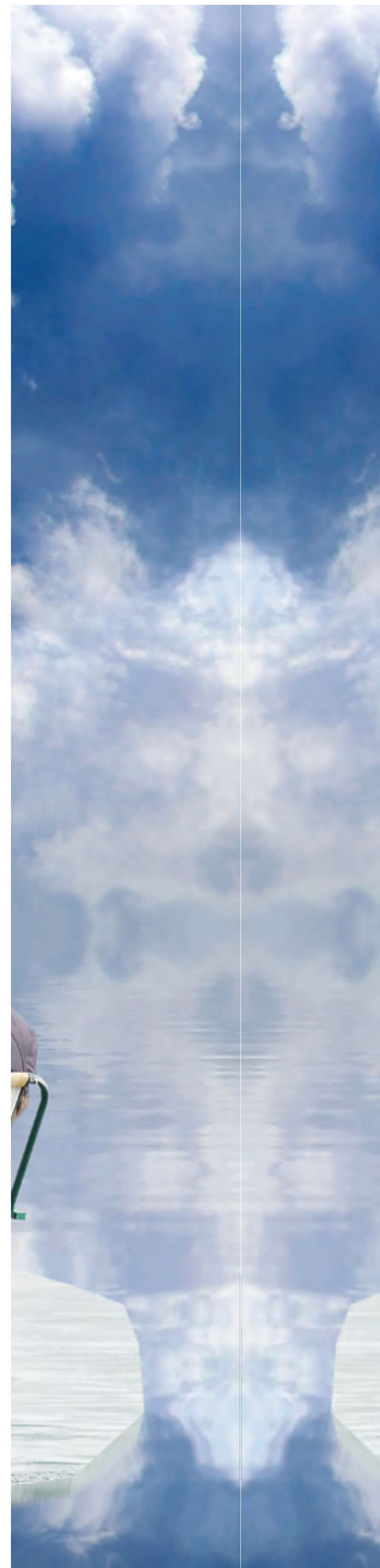
Fisheries Management and Global Warming

The FIMAGLOW project is a Nordic project with the aim to study possible drivers and impacts of global warming on Arctic fisheries. Two workshops has been held, serving to identify the relevant set of institutions and people, updating the research community on on-going research projects and initiatives in this realm, and pointing to some critical issues for further research.

The material presented in the workshops is collected in this report, which hopefully then may serve as a stepping stone for further explorations of this important issue.

A web site for the FIMAGLOW program has been set up and is available at the URL: http://fimaglow.maremacentre.com. The website includes program information and tentative programs for the workshops. MaReMA Centre at Norwegian College of Fisheries Science is organizing the program, Alf Håkon Hoel and Arne Eide being the project managers.



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