Report from NORACIA workshop on Biophysical modelling and climate change

Place/Time: Solstrand Hotel & Bad 13-14 desember 2006

Participants:
Dag Slagstad
Einar Svendsen
Frode Vikebø
Geir Huse
Ingrid Ellingsen
Morten Skogen
Svein Sundby
Webjørn Melle

Seminar

The seminar was organised as five introductory talks on climate change applications of biophysical models followed by a discussion of the usage of biophysical models for predicting the impact of global warming on ecosystem structure and functioning of the Barents and Nordic Seas. The following presentations were given:

Dag Slagstad/Ingrid Ellingsen: Impact of present and future climatic conditions on the physical and biological environment of the Barents Sea and a structured model of *Calanus finmarchicus*.

Morten Skogen: Inter annual variability of the Nordic Seas primary production.

Geir Huse: An individual based model for Calanus finmarchicus in the Norwegian Sea/ Capelin migrations and climate change - a modelling analysis.

Frode Vikebø: Inter-annual variations in drift, growth and survival of Arcto-Norwegian cod eggs and larvae.

Recommendations

A general point in the discussions were that best practice in model development was particularly important when using biophysical models for running climate change scenarios since there are so many other uncertainties associated with such simulations. The following recommendations emerged from the discussions:

1) There should be particular considerations of what is sufficient or optimal spatial and temporal resolution of the model.
2) Model validation for present day situation is particularly important for credible forecasts of consequences of climate change.
3) Model development needs to focus on mechanistic representation of processes (first principles) rather than statistically based parameterisation.
4) Biological models should preferably have a fine resolution in life history and physiology.
5) Biophysical models should be parameterised to separate likely responses of the *Calanus* sp. complex including *C. finmarchicus*, *C. helgolandicus*, *C. hyperboreus* and *C. glacialis*, which are dominant in different water masses.

6) Timing of life history events are likely to be particularly sensitive to climate change and ideally models should be able to include plastic responses for key life history traits of zooplankton and higher trophic levels.
7) There are a number of issues related to the downscaling process in itself and we recommend that BCCR develop code for best practice of downscaling climate predictions to regional scale.

The discussion centred around atmospheric, ocean and biophysical models respectively, and below some highlights are given.

Atmospheric models

Atmospheric models have a rather rough spatial resolution, and increased resolution particularly in near shore areas would most likely improve the wind fields and thus the ocean models. Slagstad and Ellingsen attributed some of the discrepancies of their biophysical model to an offset in the atmospheric model. Validation of atmospheric models with regards to positioning of large-scale pressure patterns such as the Arctic high pressure zone is therefore important before using models for climate change scenario simulation. In order to determine what is the sufficient resolution for atmospheric models, water transport at strategic locations such as the inflow to the Barents and North Seas, and outflow from the Fram strait should investigated.

Ocean models

There is need for substantial validation of ocean models before credible applications for climate change scenarios can be undertaken. In particular with regard to: mixed layer depth, onset of stratification, resolving important topographical features, large-scale transports, coastal circulation, cross-shelf transportation, and ice. Sufficient and optimal spatial resolution should be determined for ocean circulation models as well by sensitivity analyses of how different spatial resolution affects transport at strategic locations (see above).

Biophysical models

Key physical variables that are expected to be sensitive to climate change are temperature, ice cover and advection. There is a range potential usage for biophysical models. These include: prediction of changes in distribution/migration, recruitment, growth, fecundity and mortality of fish and primary production and zooplankton productivity. Global warming is expected to result in major changes in the structure of ecosystems, and it is therefore important both to use models to find out what are plausible changes in ecosystem structure from global warming and what are the consequences for biophysical modelling of the community changes. For example how does the establishment of different major grazers in the Barents Sea affect phytoplankton dynamics or the productivity of planktivorous fish? There is a general need for developing models able to predict community responses to climate change for different trophic levels, e.g. phytoplankton, zooplankton and fish. A related issue is the changes in spatial overlap and species interactions resulting from climate changes.

All these biological variables may therefore be studied using biophysical models. It is important to parameterise and validate models for present day climate simulations. In this respect models that are process based are likely to better predict how the organism responds to a climatic change. Statistically based models on the other hand, which are parameterised for the present climatic situation is less suited for addressing climate change.

The long-term biophysical model simulations for the Barents Sea ecosystem reported in Ellingsen et al (conditionally accepted, see abstract below) are a valuable starting point for future model studies of likely ecosystem consequences of climate change. These simulations generated a lot of discussion and there are specific plans for future follow up simulations based on the lessons learned from this initial study. Huse and Ellingsen (conditionally accepted, see abstract below) utilised the output from the biophysical model (Ellingsen et al.) to simulate likely effects of climate change on the space use of the Barents Sea capelin. This model simulates the entire life cycle of the capelin from egg until spawning using an individual based modelling approach. The model predicted a delay in spawning of capelin and a shift in spawning area from the coast of Northern Norway to areas along Novaya Zemlya as a consequence of global warming. It will be important to further develop these biophysical modelling tools over the next years if we are to understand ecosystem consequences of climatic change.

While there is a need for performing long term simulations as in the case of Ellingsen et al, we also need to perform sensitivity analyses of anticipated physical changes, for example increased temperature, reduced ice cover or changes in advection.

Future seminar

The group found the seminar valuable and productive and suggests that a follow up seminar is arranged next year. It would be valuable to broaden the spectre of modelling competence, and for a potential future seminar we wish to invite a few more researchers including a leading international expert.

Abstract of presentations

Impact of present and future climatic conditions on the physical and biological environment of the Barents Sea

Ingrid H. Ellingsen, Padmini Dalpadado, Dag Slagstad & Harald Loeng

A coupled physical and biological ocean model has been used to study the impact of potential future climatic changes on the physical and biological oceanography of the Barents Sea. A baseline run has been carried out for the period 1990 to 2004, and model results are compared to observations. Observations showed that the water in the Barents Sea became warmer the recent years, and that the ice cover correspondingly decreased. A climate simulation with the coupled model system applying forcing from a regional climate model is run for 70 years. Results from this simulation show that the warming of the Barents Sea will continue in the future. This warming results from a significant increase in temperature of the water flow into the western Barents Sea. As a result of this, the composition of water masses in the region changes and the ice cover in the Barents Sea decreases. These changes in physical properties have an impact on the biological environment. On average, the simulated primary production increases about 8 % over a 65 year period, partly due to an increased production in the northern Barents Sea. The zooplankton biomass distribution and composition depends on the annual primary production as well as on transports by currents and on the water temperature. The climate simulation presented predicts that in the future the Atlantic species will increase slightly in production and expand more towards the east and to the north, while the total biomass of Arctic species decreases.

Structured, Eulerian *Calanus* models

Dag Slagstad

A coupled hydrodynamic and ecological model has been used to study the formation of the overwintering distribution and its stability during the winter months when *C. finmarchicus* stay at the overwintering depth. The ecological model contains state variables for nutrients, phytoplankton and microzooplankton in addition to a stage structured model of *C. finmarchicus*. An Eulerian approach is used to represent the structured model in a 3D physical space. The model simulates the life cycle strategy og *C. finmarchicus* ensures downward migration after reaching a late copepodite stage V. Thus, the date for downward migration will depend on the onset of primary production, food concentration and temperature during the growth season. The model was initiated with a an overwintering stock, evenly distributed in the oceanic regions of the Norwegian Sea, i.e. depth > 600 m. Spawning and development of the new generation took place in a dynamic relationship with vertical mixing and phytoplankton development. After spending some time in as stage V, just before potential moulting into the adult stage, animals went into the overwintering stage and started to descend to the overwintering depth (700 to 1000 m). In late summer high concentration of overwintering animals were found near the shelf break north of the North Sea, North eastern part of the Vøring Plateau and in the eastern part of the Lofoten Basin just outside slope of the Barents Sea shelf.

Inter annual variability of the Nordic Seas primary production

Morten D. Skogen, W.Paul Budgell and Francisco Rey

Phytoplankton represents the primary trophic level in the marine pelagic ecosystems, where most of the biological material produced by photosynthesis is further channeled through the food web via grazing by zooplankton. Therefore, the level and variability of primary production is believed to be an important factor for fish recruitment and growth The Nordic Seas are important feeding areas for large and important commercial fish stocks, but due to scarcity of measurements only few estimates of the primary production exists. In addition, it is highly variable due to the wide variations in light, temperature and nutrient supply at a given time and location. In the present work primary production in the Nordic Seas is studied using a coupled 3D physical, chemical and biological ocean model (NORWECOM). The study shows large variations in primary production in both space and time. The model gives a mean annual production of 73 gC/m^2/year and a 20% variation in phytoplankton biomass between the years of highest and lowest production. The inter annual variability is linked to the North Atlantic Oscillation (NAO) and to the transport of water into the Nordic Seas. The strong control of phytoplankton production from the physics, suggest one possible mechanism for how climate can be an important factor for available biological material in the food webs.

Capelin migrations and climate change - a modelling analysis

Geir Huse and Ingrid Ellingsen

Capelin is a small abundant pelagic fish that performs long distance migrations between feeding, overwintering and spawning locations. There is considerable variability on several time scales in the physical and biological characteristics of the Barents Sea, and the migration pattern of capelin is adapted to this variability. In order to investigate consequences of a permanent climate change on the spatial dynamics of capelin, an individual-based model has been developed. The model relies on fine scale environmental information on temperature, currents, zooplankton and predation risk. The output generated by the model is capelin distribution, growth and biomass. The entire life cycle of the capelin including spawning, larval drift and adult movement is simulated. Timing of spawning and adult movement strategies are adapted by a genetic algorithm. Given present day climate the model evolves a spatial distribution resembling the present spatial dynamics of capelin. When this simulation is contrasted with a climate change scenario with increased temperature, the capelin is predicted to periodically take up new spawning areas along Novaya Zemlya and spend a greater part of the year in the northeastern part of the Barents Sea. Spawning is also found to occur over a month earlier in the warmer climate compared to the present day simulation.

A 3D super-individual model with emergent life history and behaviour for *Calanus finmarchicus* in the Norwegian Sea

Geir Huse, Paul Budgell, Webjørn Melle, Morten Skogen, Einar Svendsen

The copepod *Calanus finmarchicus* is the dominant species of the mesoplankton in the Norwegian Sea. The species is largely herbivorous and constitutes an important link between the phytoplankton to the abundant fish resources in the Norwegian Sea including Norwegian spring spawning herring, blue whiting, and mackerel. Spatially explicit models are key tools for understanding the zooplankton dynamics of the heterogeneous Norwegian Sea with warm Atlantic water masses to the south and east and cold Arctic water masses to the North. Here we present an individual based model with emergent life history and behaviour for *C. finmarchicus.* The objectives of this paper are to validate the approach, investigate the importance of the simulated adaptive process on retention and fitness of *Calanus* and investigate the importance of interannual variability on the distribution and production of *C. finmarchicus* in the Norwegian Sea. The results show that the simulated population is able to remain productive within the Norwegian Sea basin for hundreds of years. The evolved life history resembles that observed for *C. finmarchicus*. Long term simulations show that there in considerable inter annual variability in Calanus production, biomass and advection. The advection of *C. finmarchicus* into the Norwegian Sea is on average 2% of the production in the Norwegian Sea.

Inter-annual variations in drift, growth and survival of Arcto-Norwegian cod eggs and larvae

Frode Vikebø

Laboratory experiments and process-based modelling enable a mechanistic understanding of key factors of larval fish. Recent studies under the project ECOBE have compiled such knowledge in a coupled bio-physical model system for growth, drift and spatial distribution of pelagic Northeast Arctic cod (*Gadus morhua*). The model system describes individual, virtual larvae advected from their respective spawning grounds by temporal and spatial varying flow fields from the ocean circulation model ROMS. However, by vertical migration the larvae and juveniles are able to affect their drift route due to vertical variations in circulation. By allowing larvae and juveniles to choose depth according to an individual-specific risk sensitivity, we are able to investigate how this affect the resulting horizontal distribution, growth and survival. Locally, depth selection affects instantaneous mortality and growth rates, leading to higher survival through the larval period compared to larvae that were forced to stay in fixed depths. However, the strategy for depth selection also has long-term and large-scale consequences. First, since vertical behaviour interacts with ocean circulation, the strategy influences which drift trajectory a larva will follow and thereby the physical environment the larva experiences along its way. Second, the area or region where the larvae end up after the drift phase can have important consequences for later life stages