Theme Session C

Advances in marine ecosystem research: what we have learned from GLOBEC and what we can carry forward in future climate-related programmes

ICES CM 2009/C:01

Ecological forecasting under climate change—the case of Baltic cod

Martin Lindegren, Christian Möllmann, Anders Nielsen, Keith Brander, and Brian MacKenzie

Good decision-making for fisheries and marine ecosystems requires a capacity to anticipate the consequences of management under different scenarios of climate change. The necessary ecological forecasting calls for ecosystem-based models capable of integrating multiple drivers across trophic levels and properly including uncertainty. The methodology presented here assesses the combined impacts of climate and fishing on marine foodweb dynamics and provides estimates of the confidence envelope of the forecasts. It is applied to cod (*Gadus morhua*) in the Baltic Sea, which is vulnerable to climate-related decline in salinity resulting from both direct and indirect effects (i.e. through species interactions) on early-life survival. A stochastic foodweb model driven by regional climate scenarios is used to produce quantitative forecasts of cod dynamics in the twenty-first century. The forecasts demonstrate how exploitation would have to be adjusted in order to reduce risks of future stock collapse under different climate scenarios.

Keywords: ecological forecasting, climate change, cod.

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ICES CM 2009/C:02

Comparative changes in fish communities in marine ecosystems

Ray Hilborn, Boris Worm *et al.*

A working group at the National Center for Ecological Analysis and Synthesis has evaluated the trends in a range of marine ecosystems in the North Atlantic (seven ecosystems) and seven other ecosystems around the world. We used stock assessment data, trawl surveys, and catch data to evaluate the impacts of fishing on the ecosystems and trends in abundance, mean length, fishing mortality, and status relative to reference points across the ecosystems. We also used ecosystem models to evaluate the trade-off between sustainable yield from the ecosystem and number of species that would be severely depleted from fishing. We found that for most ecosystems where these three types of data are available fishing mortality rates are now lower than the level that would produce ecosystem-wide maximum sustainable yield (MSY), but because of the history of past high fishing pressure about two-thirds of stocks examined were still below the biomass that would produce MSY. The proportion of severely depleted stocks is now about 20% and has demonstrated no sign of decline. We highlight that a major challenge for marine fishery management is finding ways to avoid less productive stocks while sustaining fisheries on more productive stocks. Much of the governing legislation for fishery management seems to ignore this fundamental issue.

Keywords: marine ecosystems, overfishing, world fisheries, ecosystem status.

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ICES CM 2009/C:03

Cod vs. shrimp dominance in West Greenland waters: can climate change reverse the regime shift from a cod- to a shrimp-dominated ecosystem off West Greenland?

Kai Wieland and Holger Hovgård

Relatively warm conditions prevailed in Greenland the first half of the twentieth century and in this period a self-sustaining and very abundant cod stock existed in West Greenland offshore waters. A prolonged period of decline in stock biomass was observed from 1950 to 1975 during intense fishing, and the West Greenland cod stock collapsed completely in the early 1990s when colder conditions prevailed and mean size-at-age declined drastically. Air and ocean temperatures increased again above average at the end of the 1990s but it was only in 2005 that initial signs of a rebuilding of the stock was seen. The condition of the cod appears to be poor compared with historical periods and a self-sustaining spawning stock has yet not been re-established. An offshore fishery for northern shrimp began in the 1970s and a threefold increase in stock biomass in West Greenland waters occurred from 1997 to 2003 at moderate fishing levels. In recent years, during which relatively high water temperatures have been recorded off southwest Greenland, the shrimp stocks have moved northward and the stock biomass has decreased considerably. Poor recruitment recorded in recent years has raised concerns that the current level of exploitation of the shrimp stock may not be maintained in future.

Keywords: cod, shrimp, regime shift, West Greenland.

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ICES CM 2009/C:04

Advances in marine ecosystem research: what we have learned from GLOBEC and what can we carry forwards in future climate-related programmes?

Why is haddock overtaking cod? Comparing the effects of temperature and habitat size on recruitment dynamics of both species across the North Atlantic

Irene Mantzouni and Brian R. MacKenzie

Demersal fish stocks in the North Atlantic have experienced serious declines and depletions mainly as a result of overfishing in recent decades. For some species, such as haddock (*Melanogrammus aeglefinus*), the situation seems to have changed and certain stocks are starting to recover. Other species, like cod (*Gadus morhua*), however, still remain at low levels despite restrictive management measures or even fishing closures. The main aim of our study is to investigate whether the differing responses of these species are related to differing sensitivities of their recruitment dynamics to environmental forcing, and especially temperature. We developed stock recruit (SR) models, in a hierarchical framework, combining data across sympatric populations. By allowing the SR parameters to depend on temperature and habitat size, it is possible (i) to determine patterns of productivity and carrying capacity in relation to these factors among and within species and (ii) to borrow strength and provide estimates of increased precision. Temperature during the spawning season was shown to have significant effects on the productivities of both species. Haddock, however, was found to be more resilient to warming conditions, and thus it had a higher reproductive rate than cod at increased temperature. We also found that for both species density-dependent regulation is determined by the available habitat size, although the relationship is stronger for haddock. Synthesizing these patterns can improve our understanding of environmental impacts on key population parameters and lead to more reliable forecasts under different exploitation and temperature scenarios.

Keywords: carrying capacity, cod, climate change, habitat size, haddock, hierarchical models, productivity, temperature.

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ICES CM 2009/C:05

Changes in cod management strategy that have resulted from warming scenarios for the Barents Sea

A. A. Filin

There is a high certainty that global warming is a reality. Future climate change scenarios from global circulation models indicate a rise in temperature and a decline in sea-ice coverage in the Barents Sea. Coupled biological–physical models project an increase in the plankton production as a response to climate change in the area. Model studies also demonstrate that a higher primary production tends to lead to an increase in cod recruitment in the Barents Sea. This, together with the expected acceleration of growth and maturation rates, will lead to an increase in cod stock productivity as a response to the warming. On the other hand, model analyses have demonstrated that cod predation in the Barents Sea ecosystem, including cannibalism, will grow as a result of increment in rations as water temperatures rise. Because of this, the question of how future management of cod may have to be adapted to account for climate change impacts is of interest. Simulation studies on the future management of cod in the Barents Sea under different warming scenarios have been carried out using the STOCOBAR cod–ecosystem coupled model. The results suggest that adjustment of the biological reference points used for management will be required because of changes in cod stock productivity.

Keywords: Barents Sea, biological reference points, climate change, cod, management, model, stock productivity.

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ICES CM 2009/C:06

Combining hydrographical particle-tracking models with spatial analyses to evaluate spatial dynamics of cod larvae and 0-group in the Barents Sea

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Recruitment ecology of cod has been an important focus within the framework of GLOBEC. A large part of this work has focused on understanding the spatio-temporal component of cod populations. For the early pelagic life stages, studies based on an individual have provided highly valuable insights, combining oceanographic, behavioural, and modelling approaches. The spatial modelling of observational data often fails to include density-dependent covariates, which for early pelagic life stages originate in the combination of circulation patterns and eggs coming from the spawning aggregations. We performed this task combining a hydrographical particle-tracking model with spatial statistical analyses to investigate the relative contribution of hydrographical variables on the spatial distribution of cod larvae and 0-group in the Barents Sea under two short-term climatic regimes in the period 1986–1991. The modelling approach was split into two life stage-based steps: (i) cod larvae distribution is modelled using eggs drifting from the spawning aggregations in the Lofoten Islands and (ii) 0-group distribution is modelled using larvae drifting information. We found that interannual variability of the spatial aggregations of the spawners influenced the distribution of larvae drifted. Results demonstrate different effects of spatial location and temperature over the two regimes (1986–1988 and 1989–1991), which can affect survival and growth. Temperature also affects 0-group distribution in the two regimes, and this effect depends on the mean length of fish. This approach can be useful for other fish populations to further understand the underlying processes shaping the seascape of early life stages.

Keywords: Barents Sea cod, larvae, 0-group, hydrographical particle-tracking models, spatial analyses.

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ICES CM 2009/C:07

Trophic interactions affecting a key ecosystem component: a multistage analysis of the recruitment of Barents Sea capelin

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In the Barents Sea, capelin is a key food item for the northeast Arctic cod stock. This capelin stock has had very unstable population dynamics since 1985, with recruitment failures leading to three major collapses of the stock (>90% reduction of the stock size), resulting in decreased growth and survival of cod. Here we analyse in detail how predation and harvest affects the recruitment of capelin using data on three different stages (i.e. larvae, 0-group, and 1-year-olds) through the first 1.5 years of the capelin's life. We demonstrate that both herring predation (on capelin larvae) and cod predation (both on spawners and on offspring) have had major negative effects on capelin recruitment. Mortality is also demonstrated to be strongly density-dependent, and is lower when temperatures are high—probably ascribable to higher food availability for capelin. Harvesting maturing capelin on the way to the spawning grounds did affect the production of larvae, at least during the first half of the 1980s. However, the reduced production of larvae appears to a large extent to have been compensated for by decreased density-dependent mortality at later life stages, resulting in only minor effects on the abundance of 1-year-olds. Altogether, our study points to the importance of trophic interactions in determining the dynamic structure in high-latitude marine ecosystems.

Keywords: stock collapse, predation, trophic interactions, harvesting, density-dependent mortality, generalized additive models (GAM).

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ICES CM 2009/ C:08

Enhancing stock–recruitment models for North Sea cod by including climate and zooplankton

Geir Ottersen, Esben M. Olsen, and Nils Chr. Stenseth

Intuitively, the size of a spawning stock should influence recruitment, but in practice the relationship found is often weak. There is thus a need to both enhance models and include other sources of data. Specifically, theoretical work suggests that the shape and the position of the stock–recruitment curve is influenced by the environmental conditions experienced by the fish larvae. Cushing and Horwood suggest strong density-dependent mortality of fish larvae, even with low observed densities. Their model demonstrates a positive link between the number of food organisms and the slope of the stock–recruitment relationship. More recent work suggests that a Ricker-type stock–recruitment relationship (i.e. overcompensation) could be expected at limited food levels, whereas as food availability improves the recruitment curve increases monotonically towards an upper limit (i.e. a Beverton–Holt type stock–recruitment relationship). Building upon these ideas, using unique continuous plankton recorder zooplankton data and temperature measurements, we here demonstrate novel stock–recruitment models for the once large North Sea cod stock. A model combining the Ricker and Beverton–Holt models has considerably more explanatory power than either model in isolation. In essence, food (zooplankton) availability determines whether the Ricker or Beverton–Holt model applies. Furthermore, temperature displaces the recruitment curve upwards (good recruitment) during cold years and downwards during warm years (poor recruitment). These findings shed new light on the recruitment problem in general, and specifically support earlier studies that have suggested that full recovery of the North Sea cod stock should not be expected until environmental conditions become more favourable.

Keywords: recruitment, cod, zooplankton, temperature, North Sea.

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ICES CM 2009/C:09

Controls on the ratio of mesozooplankton production to primary production in marine ecosystems

Charles A. Stock and John P. Dunne

An ecosystem model was used to determine the extent to which global trends in the ratio of mesozooplankton production to primary production (referred to as the "*z*-ratio") can be explained by nutrient enrichment, temperature, and euphotic zone depth. Equilibrium model solutions were first calibrated to global observed and empirically derived patterns in phytoplankton biomass and growth rates, mesozooplankton biomass, and growth rates, and the fraction of phytoplankton that are large (>5 μm ESD). Calibrated model solutions had no major biases and produced median *z*-ratios and ranges consistent with global estimates. However, much of the variability around the median values in the calibration dataset (72 points) could not be explained. Model results were then compared with an extended global compilation of *z*-ratio estimates (>10 000 points). This revealed a modest yet significant (r = 0.40) increasing trend in *z*-ratios from values ~0.01–0.04 to values of ~0.1–0.2 with increasing primary productivity, with the transition from low to high *z*-ratios occurring at lower primary productivity in cold-water ecosystems. Two mechanisms, both linked to increasing phytoplankton biomass, were responsible: (i) zooplankton gross growth efficiencies increased as their ingestion rates became much greater than basal metabolic rates and (ii) the trophic distance between primary producers and mesozooplankton shortened as primary production shifted toward large phytoplankton. Substantial regional *z*-ratio variability remained unexplained by the simple nutrient enrichment, temperature, and euphotic zone scalings considered herein and are currently being studied by integrating the ecosystem model with a global ocean circulation model.

Keywords: zooplankton, ecosystem modelling, energy flow, foodwebs, trophic levels, secondary production.

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ICES CM 2009/C:10 Poster

Influence of lipids and fatty acid composition in eastern Baltic cod (*Gadus morhua*) and its prey with emphasis on the timing of maturation and spawning

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The Baltic Sea experienced an ecosystem regime shift in the late 1980s with large changes in foodweb dynamics, and Baltic cod spawning-stock biomass decreased to historically low levels. These ecosystem alterations are thought to be related to climate-driven changes affecting phyto- and zooplankton assemblages, which contributed to reduced numbers of the clupeid prey of cod. The spawning time for eastern Baltic cod has shifted from April–June to the end of July since the early 1990s. The present study investigates whether the later spawning of Baltic cod could be caused by deficiencies in specific essential fatty acids (EFAs) resulting from the ecosystem changes, as EFAs originate from phytoplankton and are transmitted though the foodweb. The lipid contents and fatty acid compositions of the ovaries and livers of prespawning female Baltic cod were analysed and compared with those from North Sea cod that has an unchanged spawning time. Liver lipid levels were significantly higher in prespawning cod from the Baltic Sea than in North Sea cod, which ruled out poor energy reserves as the cause of the change in spawning time. The proportion of ω-3 EFAs in ovaries gradually increased with progressive oocyte development, whereas the ω-6 EFA arachidonic acid (ARA) proportion decreased. The proportion of ARA in mature females was significantly lower in Baltic cod than in North Sea cod. The prey of Baltic cod is thus rich in ω-3 EFAs, and it is suggested that insufficient supplies of ARA in prey during the maturation period could be a limiting factor causing the prolongation of ovarian maturation.

Keywords: cod, *Gadus morhua*, clupeids, lipid dynamics, fatty acid composition, maturation, spawning time, recruitment, Baltic Sea.

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ICES CM 2009/C:11 Poster

Biophysical properties of Norwegian coastal cod eggs from different local populations

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The vertical distribution of fish eggs and larvae is a key factor in the transport and retention of the offspring, affecting mixing/separation between populations, and hence mechanisms maintaining genetic differentiation among local populations, in combination with high site fidelity and natal homing of older cod. The vertical distribution is determined by the combined effects of the local salinity structure of the ambient water and the specific gravity of the eggs. The specific gravity of the eggs is determined by their biophysical characteristics. We have studied the biophysical properties of Norwegian coastal cod (*Gadus morhua*) eggs from different areas (Porsangen, Tysfjord, and Helgeland). Eggs used in the present experiment were collected from three groups of wild coastal cod raised as broodstock of the regions. The experiments were carried out during the spawning season, March–April in 2009, and we investigated the underlying biochemical characteristics causing different egg buoyancy by measuring neutral buoyancy, diameter, chorion thickness, wet and dry weight. These observations were further discussed in relation to vertical distribution and transport of the eggs and their relevance to the maintenance of local population structures along the Norwegian coast.

Keywords*: Gadus morhua*, egg, buoyancy, chorion thickness, local population.

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