

## Theme Session C

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

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The Cod and Climate Change programme (CCC) has stimulated a wide range of research on cod, the ecosystems in which it occurs and the physical, biological and human drivers which shape its life history and population dynamics. The Theme Session, which included ten oral presentations, was intended to be an opportunity to take stock of what we have learned and to ask what progress we have made in resolving some of the issues which provided the scientific and management impetus for the CCC programme. These include:

Research themes of the CCC programme	C:01	C:02	C:03	C:04	C:05	C:06	C:07	C:08	C:09	C:10
Recruitment and the role of environmental variability	*		*	*	*		*	*		
Linkages with zooplankton dynamics	*							*	*	
Growth, Maturation										*
Productivity and sustainability		*	*		*			*	*	
Transport and Biophysical modeling						*				
Trophic relationships	*		*				*		*	
Climate impacts – past present and future	*		*	*	*			*	*	
Analysis of time series	*	*	*	*	*		*	*		

The CCC programme was set up to take a broad ecological approach to issues in fisheries management and to widen the scientific community who attend and contribute to the work of ICES. Two of the speakers were new to ICES and the papers represented a range of scientific disciplines, from physiology to global climate models. We can learn from GLOBEC that collaboration across disciplinary boundaries can be readily achieved and new scientists brought into ICES work by a strategic plan that has well defined and tractable problems in which they can recognise how their special expertise will contribute to a solution. Several of the specific scientific advances reported at the Session (see details below) can clearly be carried forward in future fisheries and ecosystem assessment and management. However another lesson from GLOBEC is that integrating such knowledge is difficult and the advisory side of ICES has not been welcoming to the programme or to the results it has produced.

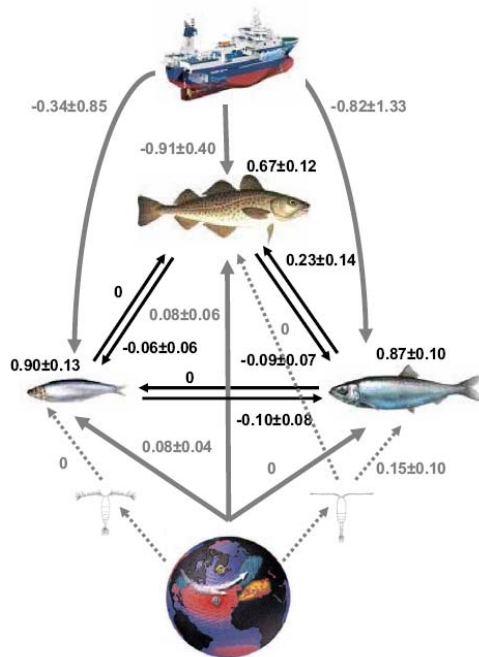


Fig. 1. A schematic view of the Baltic Sea upper-trophic food web. Black arrows and parameters represent species interactions between cod (Top), sprat (Left), and herring (Right). Gray arrows and parameters demonstrate the effects of fishing, climate, and zooplankton on the three species. Interactions with the key zooplankton species *Acartia* spp. (Left) and *P. acuspes* (Right) are illustrated by dotted arrows. Negative parameter values indicate negative effects on the biomass of the species and vice versa. Intraspecific parameters <1 indicate an increasing degree of density dependence in the population. Zero parameter values indicate interactions excluded during model selection. Note that even though it is statistically uncertain we decided to include the fishing effect on sprat and herring because they are heavily exploited by commercial fishing. Climate image is from [www.ideo.columbia.edu/res/pi/NAO](http://www.ideo.columbia.edu/res/pi/NAO).

Martin Lindegren's talk (C:01) on Ecological Forecasting under Climate Change – the case of Baltic cod argued that statistical food web models can represent interactions between species and effects of fishing and environmental factors with sufficient precision and confidence to provide a basis for fisheries management. Such ecological forecasting tools must account for uncertainties and provide quantitative assessments of the risks associated with management actions under different climate change scenarios. He showed using a multivariate autoregressive model for the Baltic Sea ecosystem (BALMAR – see Figure) how the risk of extinction of cod depends on adjusting the fishing mortality to the changes in salinity over the period to 2100. The model could also be adjusted to include new species, such as anchovy, which may become more abundant in the Baltic as it becomes warmer.

Ray Hilborn's talk (C:02) on Comparative changes in fish communities in marine ecosystems was based on an article (Boris Worm, et al Science 325, 578 (2009)) that analysed recent trends in 20 marine ecosystems around the world from a fisheries and conservation perspective. It arose from a wish to reconcile opposing views concerning the state of exploitation of global fisheries and the effectiveness of current fisheries management. While there is agreement that many stocks have been overfished and that fishing mortality remains high in many cases it is also clear that levels of fishing have been reduced in recent years and some ecosystems are showing evidence of recovery. Exaggerating the failures is unhelpful in dealing with the problem of overfishing and we can learn a great deal from the successes of fisheries management, rather than oversimplifying and calling for extensive protected areas (which are only one tool among many).

Kai Wieland (C:03) described the geographic changes that have taken place in the fisheries for cod and shrimps at Greenland since the 1920s. The question posed in the title is whether climate change can reverse the shift from cod to shrimp as the dominant fishery? He did not think we knew enough to answer this as it depends not only on the climate but also on geographic overlaps, predation by other species (although Greenland halibut predation is probably minor) and the rebuilding of cod stock biomass, probably with a major input of juvenile fish from Iceland.

Irene Mantzouni (C:04) extended the meta-analysis she presented a year ago to include haddock and to contrast their dynamics with cod. Her principal finding was that temperature has a positive effect on haddock recruitment across the ten stocks she studied and this effect is stronger than for cod (where the effect of temperature switches to negative above a median value of temperature). She found that density dependent regulation is related to the area of available habitat for both species. A questioner stated that the area occupied by haddock had greatly increased at Iceland and asked how habitat area is measured. It is the area within a fixed depth contour for each stock.

Anatoly Filin (C:05) developed a model (STOCOBAR) that predicts changes in cod biomass, growth and maturity and resilience to fishing pressure in the Barents Sea. Coupled physical-biological models predict an increase in plankton production and the rates of cod recruitment growth and maturation are expected to increase. However predation and cannibalism will likely also increase. Scenarios with a 1 and 2°C rise in temperature produced increases in cod yields in the model and increases in the fishing mortality that the stock could sustain (from 0.4 at status quo to 0.55 for a 1°C increase and 0.8 for 2°C). Recruitment is expected to increase in spite of a projected decrease in spawning biomass.

Manuel Hidalgo (C:06) combined particle tracking modelling with spatial analysis to explore the dynamics of cod larvae and 0-group in the Barents Sea during the period 1986-1991. Spawning biomass, inflows and NAO all varied during this period. Survival and growth were affected by spatial location of spawning and by temperature during two “regimes” (1986-88 and 1989-91). Future improvements to the model will include vertical movement, spatial variation of spawner by size and survival during the first weeks of life.

Dag Hjermann’s work (C:07) stemmed from an earlier paper that looked at the consequences on northeast Arctic cod stock of “competition between fishermen and fish” for the Barents Sea capelin and re-examined the roles of fishing and trophic interactions in causing capelin stock fluctuations. The time series extends back to 1970 and the analysis shows strong predation effects on capelin due to herring (on larvae) and cod (on spawners and offspring), but also strong density dependent mortality when other food is less abundant. Harvesting probably had quite a small effect on the 1990s collapse in capelin. The study identifies trophic interactions as important in determining the dynamic structure of high latitude marine ecosystems.

Geir Ottersen (C:08) fitted stock-recruit curves to North Sea cod and included both environmental (temperature) and biological (zooplankton) information. He concluded that the form of the relationship between spawning stock biomass and recruitment shifted from a more asymptotic (Beverton-Holt) shape when temperatures were low and zooplankton values high towards a more overcompensatory (Ricker) fit during the opposite conditions. This means that fisheries reference points such as  $F_{msy}$  change with the food and metabolic environment for larvae, probably due to effects on their survival. The conclusion is that “recovery” of the North Sea cod stock to earlier levels should not be expected unless the environmental (and biological) conditions become more favourable.

Charles Stock (C:09) questioned the traditional trophic pyramid view and sought to estimate how global variability in the ratio of mesozooplankton production to primary production (the z-ratio) may be affected by nutrient enrichment,

temperature and euphotic zone depth. The aim was to look for patterns in complex foodwebs and the data came from widely different ecosystems and included small and large phytoplankton groups. The z-ratio increased with primary productivity; low-productivity subtropical gyres had z-ratios an order of magnitude smaller than upwelling systems. The transition from low to high z-ratios occurs at lower primary productivity in cold-water ecosystems. The causes of this pattern in z-ratios is probably higher zooplankton gross growth efficiency once ingestion exceeded basal metabolic requirements and reduced trophic distance between primary producers and mesozooplankton when phytoplankton are bigger. The implication of this pattern in relation to increasing sea temperature is of concern for future marine productivity.

In the final talk (C:10) Jonna Tomkiewicz explored the relationship between changes in timing of cod spawning in the Baltic Sea and seasonal changes in the availability of essential fatty acids (EFA) in their diet. It appears that maturation of the ovaries of Baltic cod could be delayed because of lack of arachidonic acid (ARA) in their diet even though their total lipid levels are higher than North Sea fish, which have not changed their spawning time. Since EFAs originate from phytoplankton it is likely that the change in timing of cod spawning is caused by ecosystem changes that affect phytoplankton composition. Changes in the timing of cod spawning have occurred in other areas (e.g. the Scotian Shelf) and it would be interesting to investigate whether similar processes are at work.