Hierarchical modelling of temperature and habitat size effects on population dynamics of North Atlantic cod

Understanding how temperature affects cod (Gadus morhua) ecology is important for forecasting how populations will develop as climate changes in future. The effects of spawning-season temperature and habitat size on cod recruitment dynamics have been investigated across the North Atlantic. Ricker and Beverton and Holt stock–recruitment (SR) models were extended by applying hierarchical methods, mixed-effects models, and Bayesian inference to incorporate the influence of these ecosystem factors on model parameters representing cod maximum reproductive rate and carrying capacity. We identified the pattern of temperature effects on cod productivity at the species level and estimated SR model parameters with increased precision. Temperature impacts vary geographically, being positive in areas where temperatures are
Meta-analysis of carrying capacity and abundance-area relationships in marine fish species

General information
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Organisations: Section for Ocean Ecology and Climate, National Institute of Aquatic Resources
Authors: Mantzouni, I. (Intern)
Productivity responses of a widespread marine piscivore, Gadus morhua, to oceanic thermal extremes and trends
Climate change will have major consequences for population dynamics and life histories of marine biota as it progresses in the twenty-first century. These impacts will differ in magnitude and direction for populations within individual marine species whose geographical ranges span large gradients in latitude and temperature. Here we use meta-analytical methods to investigate how recruitment (i.e. the number of new fish produced by spawners in a given year which subsequently grow and survive to become vulnerable to fishing gear) has reacted to temperature fluctuations, and in particular to extremes of temperature, in cod populations throughout the north Atlantic. Temperature has geographically explicit effects on cod recruitment. Impacts differ depending on whether populations are located in the upper (negative effects) or in the lower (positive effects) thermal range. The probabilities of successful year-classes in populations living in warm areas is on average 34 per cent higher in cold compared with warm seasons, whereas opposite patterns exist for populations living in cold areas. These results have implications for cod dynamics, distributions and phenologies under the influence of ocean warming, particularly related to not only changes in the mean temperature, but also its variability (e.g. frequency of exceptionally cold or warm seasons).
Why is haddock overtaking cod? Comparing the effects of temperature and habitat size on recruitment dynamics of both species across the N Atlantic

Productivity patterns and abundance-area relationships in 3 marine fish species (cod, herring and haddock); meta-analyses on the effects of temperature, life-history and habitat size across the N Atlantic

Stock status evaluation and recovery policies in fisheries management rely largely on reference points derived from spawner-recruit (SR) models. The key-parameters of these models, representing productivity and carrying capacity, have been shown to be sensitive to environmental forcing and to depend on the biological and ecological characteristics of the stocks. Our aim was to identify the patterns of the temperature, habitat size and life-history effects on the SR dynamics across the N Atlantic range of 3 species; cod (21 stocks), herring (16 stocks) and haddock (7 stocks). Using hierarchical, Bayesian SR models, we combined the data across the distribution of the species in order (i) to determine the functional forms of the SR parameters dependence on these factors among and within stocks and (ii) to borrow strength and provide estimates of increased precision. Temperature during the spawning season was found to have significant effects on the...
productivities of all species, while carrying capacity was shown to depend also on the available habitat size. Using the derived relationships, it was possible to predict the expected changes in population-specific dynamics resulting from temperature increases. Synthesizing these patterns can improve our understanding of environmental impacts on key population parameters, which is required for an ecosystem approach to management.

**General information**

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Authors: Mantzouni, I. (Intern), MacKenzie, B. (Intern)
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**Comparative dynamics of cod populations in the Baltic Sea, the Gulf of St. Lawrence**

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Authors: Brander, K. (Intern), Chouinard, G. (Ekstern), Mantzouni, I. (Intern), Mohn, B. (Ekstern)
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**Hierarchical modeling of temperature and habitat effects on carrying capacity and maximum reproductive rate of North Atlantic cod in the Baltic Sea, Gulf of St. Lawrence and throughout the North Atlantic**

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Organisations: Section for Ocean Ecology and Climate, National Institute of Aquatic Resources
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**Projects:**

**Centre for Macroecology, Evolution and Climate (CMEC) (38784)**

This project investigated large scale patterns and variations of life in the ocean, focusing primarily on fishes. The theme used fishes to investigate how processes associated with climate change and human impacts (e.g., fishing and eutrophication) influence fish life histories, biodiversity and the dynamics of populations and species over large time and space scales. Studies have focused on key processes affecting life histories and distribution of populations and species, including reproduction, mortality, and migration.
The project had one full-time PhD student, and 5 postdoctoral scientists. The relatively high number of postdocs in a short period was due to their success at finding permanent jobs as tenure-track assistant professors, or as research scientists or managers in either industry or academia.

Key results by DTU Aqua colleagues in the project include the following:
- A pan-Atlantic analysis and discovery of how temperature affects reproductive timing in cod, with evidence for local adaptation of cod thermal physiology and counter-gradient evolution. Our ongoing work is now investigating the consequences of this adaptation for match-mismatch of cod larval production with the timing of the peak production of major zooplankton prey species (e.g., Calanus finmarchicus, Pseudocalanus sp.).
- New estimates of the numbers, locations and volumes of the mesopelagic provinces of the world's oceans, and based for the first time on the dynamics of ocean primary productivity, C sedimentation and photic zones. These new habitat descriptors of the mesopelagic ocean will provide new contexts for studies of ocean biodiversity, and the distribution and productivity of mesopelagic fishes and other biota.
- New models of fish lifetime reproductive output which demonstrated that a fish's annual reproductive output was strongly related to maximum body size. Moreover, indeterminate spawners had ca. 10-fold higher reproductive output per unit weight than determinate spawners suggesting possible differences in survival rates among the early life history stages between these two groups of fishes.
- Estimates of how climate change will affect the spawning locations and timing for herring in the North Sea, based on climate change scenarios, lab studies of temperature effects on egg survival rate and substrate requirements for herring egg deposition.
- Global patterns in taxonomic and functional descriptors of fish biodiversity and how these are inter-related and affected by ocean conditions (e.g., primary production, ecosystem size). Ongoing work is relating these patterns to biodiversity protection (e.g., MPA coverage).

The project was coordinated by University of Copenhagen, Denmark. The project was funded by the Danish National Research Foundation.

National Institute of Aquatic Resources
Section for Marine Ecology and Oceanography
University of Copenhagen
Period: 01/01/2010 → 31/12/2015
Number of participants: 7
Research areas: Oceanography & Marine Populations and Ecosystem Dynamics
Contact person:
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Project participant:
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Elucidating the structure and functioning of marine ecosystems through synthesis and comparative analysis (META-OCEANS) (38154)
This project was an EU Marie Curie Early Stage Training PhD network. The project was designed to improve and apply meta-analytical methods to oceanographic and fishery research questions.

There are significant gaps in knowledge regarding the structure of marine food webs, the ecological roles of taxa of different sizes and the factors controlling linkages between different functional groups. Moreover, marine ecosystems continue to suffer from the impacts of human society superimposed on naturally and anthropogenically induced climate variability. These impacts include exploitation, eutrophication, pollution, species transfers and habitat alteration; they cause changes in the structure, function and biodiversity of marine ecosystems. However, the ability of marine scientists to predict the magnitude and direction of how marine taxa, functional groups and entire ecosystems respond to these changes, remains fragmentary. As a result, when asked by society for advice about how marine ecosystems will respond to different kinds of perturbations (including management actions), the marine science community can often only provide answers with high levels of uncertainty.

Students were trained in the use of meta-analysis techniques for marine ecological problems. The statistical methods were comparative and involved regression analysis, time series analysis, Bayesian analysis and trophic modelling. Students attended seminars organized by network scientists and visited scientists in partner institutes to attain additional training.
Meta-analyses approaches make use of existing data, produced in the context of different specific analyses, but which gain new value when assembled and reanalysed in a broader perspective. Meta-analyses involve several stages: (1) data mining; (2) quality control, (3) data analysis, and (4) validation. Students were trained in all these steps.

DTU Aqua had two PhD students involved in the project. These projects used Bayesian and meta-analytical methods to show that standardized estimates of maximum population growth rate for all assessed cod stocks vary spatially across the Atlantic and in a dome-shaped relationship with temperature, and that extremely good or bad recruitment occurs in years with extreme temperatures. In addition, new time series-based ways of forecasting cod population dynamics under climate change-exploitation scenarios were developed and the role of a trawling ban on a local cod population was shown to override temperature or other climate effects on stock productivity. Both projects produced papers in high impact journals (2 in Proc. Roy. Soc., 1 in PNAS), as well as in other leading fishery-marine ecology journals (MEPS, ICES, JMS, etc.)

This project was coordinated by AZTI Tecnalia, Spain.

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Centre for Ocean Life
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Plymouth Marine Laboratory
National Center for Scientific Research
CSIC
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Period: 01/03/2006 → 09/12/2011
Number of participants: 3
Research areas: Oceanography & Marine Populations and Ecosystem Dynamics
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