October 2015

Final report

Assessment of the effects of oil exposure on the population dynamics and abundances of Atlantic cod and haddock using state-space models

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Project duration: 01.08.2012 – 31.08.2014 (operational funds to be used by 20.09.2015)
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Project number: 6159

1. Popular presentation of the project

This project was aimed at investigating how long-lived and economically important marine fish species such as Atlantic cod and haddock would respond to severe mortality events, as may be caused, for instance, by to acute oil exposure. We were particularly interested in the species' responses to increased mortality among the egg and larval life-stages, because some areas along the Norwegian coast that are close to the species' spawning grounds and larval drift areas are being considered for oil production. In addition, eggs and larvae are particularly vulnerable and cannot actively avoid exposure to toxic substances.

We used a modeling approach based on available historical data on fish eggs, larvae, juveniles and adults, and constructed a life-cycle model that could be used to simulate the impact of a hypothetical mortality event on the population as a whole.

We found that marine fishes such as cod can be remarkably resilient against extreme mortality events that affect the survival of a single year-class of eggs and larvae. Population recovery, which was determined by comparing simulated and historic abundance trends, was relatively fast. This is explained by a diverse population age-structure with several age-classes that constitute population biomass and contribute to future reproduction, as well as compensatory density dependence in juvenile survival, which partly offsets the loss of eggs and larvae due to increased subsequent survival. Nevertheless, our results suggest that the economic damage due to catch losses can be substantial.

Our simulations did not account for long-term sub-lethal effects on the population or indirect effects via food-web interactions, and these additional impacts need to be considered in future studies in order to gain a more comprehensive appreciation of the potential ecological and economic implications of catastrophic events such as oils spills in the marine environment.

2. Changes and achievements regarding the promised objective/goals of the project

We achieved the general goals outlined in the project description and followed the work schedule with only a slight delay; we gathered data on the two populations and developed Bayesian state-space models for both cod and haddock. These models account for extrinsic environmental effects and population-intrinsic density dependence and were developed as a basis for the simulation study that evaluated potential impacts of mass mortality events. We carried this work to completion for the cod, and developed the basic model for haddock. We ran mortality scenarios for the cod stock using a general approach by simulating a large range of potential catastrophic egg/larval die-offs (see below). Instead of running these scenarios for cod eggs and larvae under different climate scenarios, as previously envisioned, we adopted a hindcasting approach for our scenarios. This was done in order to avoid the large uncertainties associated with forecasts, which are inherently difficult and uncertain due to unknown climate conditions, population status, and fishing pressure in the future. The haddock model was used to study species interactions within the Barents Sea food web, as a first step towards building more complex models that go beyond single-species investigations and take into account food web dynamics. The remaining task of this project, a synthesis paper using population models for both species, could not be completed because the project period was shortened due to the scholars' early termination of the work contract in August 2014. Nevertheless, we continued the publication process throughout the past year, and we now have two manuscripts published and a third manuscript accepted for publication.

3. Publications

Ohlberger J, Rogers LA, & Stenseth NC (2014) Stochasticity and determinism: How density-independent and density-dependent processes affect population variability. *PLoS ONE* 9(6):e98940.

Ohlberger J, & Langangen Ø (2015). Population resilience to catastrophic mortality events during early life-stages. *Ecological Applications* 25(5):1348–1356

Patin R, Rogers L, & Ohlberger J (2015). Using a state-space population model to detect age-dependent species interactions. *Canadian Journal of Fisheries and Aquatic Sciences*. Accepted for publication.

4. Reflections on continuation of the project

We will ensure publication of the final manuscript (see above). Otherwise, the project has been completed successfully.