Behavioral changes in response to trawl fishing:
A case study on the Northeast Arctic cod

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Goal

To develop a model for estimating behavioral profiles of trawl avoidance and to use such a model to assess the potential for evolutionary adaptation in trawl-avoidance behavior.

Background

The stock assessment of Northeast Arctic cod (*Gadus morhua* L.) and haddock (*Melanogrammus aeglefinus* L.) is based on virtual population analysis (VPA). Landing statistics and relative abundance indices from scientific surveys, the swept area, and acoustic indices are the basic input data used for this analysis. In the tuning of the VPA, the two survey indices of fish density are used independently of each other. Both indices are assumed to reflect total stock abundance, but neither of the two survey methods samples the complete vertical distribution of the stock.

It is therefore desirable to combine the two estimates into one absolute abundance estimate, covering the whole water column (Godø and Wespestad, 1993, Michalsen 1999). In order to achieve this goal, several problems must be overcome, necessitating more knowledge on trawl performance (Engås *et al*. xx), fish behavior in response to trawling (Fernö & Olsen 1994), and trawl efficiency (Aglen *et al*. 1999, Ona 1988).

Research questions

The main question for this project is whether and how the fishing mortality on Northeast Arctic cod has affected behavioral patterns of individuals in this stock.

A change in the adaptive behavior to vessel and gear could introduce biases in the indices, since the indices rely on the catchability of fish to remain constant. In order to achieve absolute abundance estimation for a species, the reaction of fish to the approaching trawl gear is of importance. Such a reaction could change adaptively, either on a short-term scale (individual learning processes) or on a long-term scale (changes in the gene pool of the population).

Methods and work plan

This project is divided into three sub-tasks, focusing, first, on estimating the profile that describes the behavioral response of Northeast Arctic cod to trawling and, second, on understanding whether the estimated profile is compatible with predictions based on evolutionary modeling.

Step 1: Establish behavioral profile

The first step is to investigate behavioral data from experiments conducted by the Institute of Marine Research, Bergen, Norway, in order to determine a snapshot of the behavioral profile of the northeast Arctic cod in response to modern trawl gear.

The behavioral data is recorded by an echo sound beamer. The echo sounder is attached to a buoy and launched in front of the vessel. Then the vessel passes the buoy and the reaction for the individuals are recorded. Each individual is detected and tracked via the echo signal and a three-dimensional trajectory for each individual is obtained. From this information it is possible to extract swimming velocities and diving angles for the detected individuals.

The first step is to extract all fish trajectories from the buoy data. In addition, the estimated sound profile of the survey ship is used to determine the loudness or volume l of the noise generated by the vessel at the location of the focal fish.

Then the velocities of individual fish are estimated by the following linear model,

$$v = w_z(l)\, z + w_s(l)\, s \,,$$

where v is the observed velocity vector of the focal fish, z is the unit vector pointing vertically downwards, and s is the unit vector pointing away from the source of the sound. The weights $w_z(l)$ and $w_s(l)$ of these two velocity components are dependent on loudness and constitute the behavioral profile of the fish.

One extension of this simple model incorporates the rate of change in loudness, c, in addition to the loudness l itself,

$$v = w_z(l,c)\, z + w_s(l,c)\, s \,,$$

another extension incorporates either the direction of the local gradient in fish concentration or, alternatively, the direction towards the global centre-of-mass of the school,

$$v = w_z(l)\, z + w_s(l)\, s + w_g(l)\, g,$$

where g is a unit vector pointing in this direction and $w_g(l)$ is the weight associated with this component of the velocity v. For this extension to be feasible, the vector g must be estimated from the available data.

Since the linear systems above will be highly over-determined, we expect that these estimates can be obtained from the data through a technique known as singular value decomposition.

Another approach may be to divide each observed velocity vector into components that point, a, horizontally away from the vessel, *b*, vertically away from the vessel and, *c*, horizontally perpendicular to *a*. Then each observed velocity can be fitted to the following model,

$$v = w_a(l)\, a + w_b(l)\, b + w_c(l)\, c,$$

The weight functions estimated through these models provide a snapshot of the behavioural profile that describes the response to the approaching vessel. This profile is needed to proceed with Step 2 below.

Step 2: Compare observed and predicted profiles

In a second step we will try to explore whether the reconstructed behavioral profile or reaction norm is compatible with predictions obtained from individual-based simulations of fish schools exposed to trawling, shaped by the selection pressure for increasing escape probabilities.

The model estimated above already describes, to the extent it is valid, the individual-based three-dimensional movement behavior of schools in response to trawling. Combined with a three-dimensional model of trawl types (including information on average trawl speed), it should be possible to incrementally adjust the shapes of the weight functions to maximize escape probabilities for modern trawl gear. It will then be interesting to see how much the profiles that are obtained via this evolutionary optimization coincide with those directly reconstructed from the data.

The model uses the escape of the trawl as a selection pressure. Modeling the fish reaction to vessel and gear will make the foundation of such a model. The fish reacts to the vessel, warps, otter boards, and trawl. A model based on repulsion of these sources of stimuli has to be incorporated. The reaction thresholds of these stimuli are sensitive for the result (Handegard, in press), and most likely variable.

Step 3: Assess effects of different gear

If step 2 provides a significant result, a further step would be to carry out the same evolutionary optimization for the physical characteristics of traditional trawl gears and vessels. We will then "mismatch" a particular trawl gear with reaction norms adapted to a different gear and evaluate the expected loss in catchability that results from various such combinations. This will be a first step towards predicting the catch of a traditional gear operating on today's stock.

Relevance and link to ADN's research plan

Scientists at the Adaptive Dynamics Network (ADN) project at IIASA are experienced in the development and application of complex adaptive models. The Institute of Marine Research (IMR) has experience in analyzing the dynamics of fish stocks, including new techniques for examining fish behavior.

In this project I will try to connect the data from the experiments with an adaptive model of how the behavior of Northeast Arctic cod has evolved in response to sustained exploitation by trawling vessels. To connect empirical evidence with theory is essential for validation of the theory, and, at the same time, an underlying theory is valuable in order to explain the observed behavior. This is a two-way street. The first question is highly relevant for ADN, and the second is of value for the IMR.

Expected output and publications

If Step 1 above generates significant results, this project should lead to an interesting publication on the probability of vessel-induced behavioral changes resulting from high fishing mortality.

The investigation of behavioral patterns from buoy data developed in Step 1 could also help to define a more standardized post-processing routine for the buoy data. With such a tool, a more thorough study of the behavioral database could be carried out. This work could possibly lead to an additional publication.

References

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