

## **Fisheries-induced evolution in Northeast Arctic cod**

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### **Abstract**

We explore the evolutionary effects of fisheries on North-East Arctic (NEA) cod. It has earlier been shown that fisheries can change the cod's age and size at maturation in two ways: first, by reducing the biomass, which may lead to faster individual growth and thereby earlier maturation (through phenotypic plasticity), and secondly, by altering the selective pressures so the stock evolves towards maturing at a smaller size and younger age (i.e., shifting the maturation reaction norm). Shifts in maturation reaction norms can be rapid and estimating them can help disentangle plastic and evolutionary changes in the age and size at maturation, which is important from a management perspective, as genetic changes are likely more difficult to reverse. Using an individual-based, eco-genetic model, we predict how fishing pressure influences the evolution of immature somatic growth rates, reproductive investment, and the maturation reaction norms of NEA cod. This modeling approach is chosen because it allows the merging of genetics and demography, both of which are important in the context of fisheries-induced change (i.e., Chambers 1993; Dunlop et al. 2005; Jager 2001). An individual-based approach also allows for modeling maturation as probabilistic, which is likely more realistic given the inherent stochasticity of the maturation process (Heino et al.

2002b). Effects of climate fluctuations and climate change are expected to affect recruitment, but at this moment these effects have not yet been included in the model. Hence, an important extension of this work will be to consider the large changes in the Barents Sea climate predicted to occur towards the middle of the 21st century.

We used an individual-based, eco-genetic stochastic model (Dunlop et al. 2005) to examine the fisheries-induced evolution of five quantitative traits: intercept of the maturation reaction norm, angle of the maturation reaction norm, width of the maturation reaction norm, gonadosomatic index (quantifying reproductive investment), and fraction of energy devoted to growth prior to maturation. A previously developed individual-based model by Dunlop et al. (2005) focused only on the evolution of the maturation reaction norm. Since recent research suggests that other traits such as growth (Conover and Munch 2002) and reproductive investment (e.g., Rijnsdorp et al. 2005) might also be affected by fisheries-induced evolution, we included this in our model. Simulations are run on yearly time steps with the processes of maturation, reproduction, growth, and mortality occurring on an annual basis. Individual growth is assumed to be density-dependent and linear prior to maturation. Following maturation, a component of the available energy will be devoted to reproduction and follows a von Bertalanffy growth curve (Lester et al. 2004). An individual's maturation status is based on its probabilistic maturation reaction norm (Heino et al. 2002a; Heino et al. 2002b), and reproduction occurs randomly between pairs of mature individuals. The evolving traits are passed on to offspring in dependence on the two parental trait values, using a normal recombination kernel (Roughgarden 1979). The density-dependent survival of newborns is based on a Beverton-Holt stock-recruitment function (Hjermann et al. in prep.). We then used basic VPA formulae for survival (Gulland 1965) and assumed a natural mortality of 0.2 in order to calculate the density-dependent mortality rate of newborns. In all simulations, a constant level of natural mortality is applied to individuals depending on their maturation status; this natural mortality is elevated for the mature individuals because they likely suffer from mortality when migrating to the spawning grounds (Jørgensen et al. 1992; Heino et al. 2002c). There is also a tradeoff between juvenile growth rate and survival because individuals that grow faster have less energy to devote to maintenance and may suffer a higher mortality as a result.

Initially, the modeled population is allowed to reach equilibrium (in the population abundance and evolving traits), after which time fishing is applied for 100 years. The harvest in the

model is size-selective in that only individuals above a length of 70 cm are exposed to fishing mortality. We mimic three different management strategies: constant harvest (harvest is always the same proportion of the stock abundance, but the total catch may vary), constant catch (catch is independent of population abundance), and constant escapement (a constant number of fish are left unharvested). Using the above framework, we can analyze the effects of different levels of harvest mortality (including the historic fishing rate of ~0.4, based on catch data for the years 1946-2003) and determine which (if any) management strategies are capable of reducing the evolutionary impacts of fishing.

In conclusion, harvesting does not only change the abundance but also causes more ‘invisible’ effects by changing the traits of the stock. Our preliminary results indicate that an evolutionary shift in the maturation reactions norm and in the other modeled life-history traits may be rapid and much faster than earlier believed. This is significant from a management perspective, as genetic changes are bound to be more difficult to reverse than demographic or phenotypically plastic changes (Law 2000). We find preliminary evidence that relaxing the fisheries-induced selection pressures halts the rapid evolution of key life-history traits in NEA cod, which indicates that this stock is an important target for the management of fisheries-induced evolutionary change.

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