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A bio-economic model of fisheries-induced evolution in Northeast Arctic cod

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Abstract

The Northeast Arctic (NEA) cod stock is currently the world's largest stock of Atlantic cod (*Gadus morhua*). Not only is it important ecologically, but also economically, sustaining large open-ocean trawling and conventional fishing gear on the Norwegian coast (Nakken 1998). In the 1940s, the stock experienced a substantial shift in fishing pressure when trawlers began fishing in the open-ocean feeding grounds. Before that time, the fishery was dominated by traditional harvest practices targeting cod in the spawning grounds off the Norwegian coast. Consequently, the fishing pressure switched from harvest experienced primarily by the adult population to a much higher harvest rate experienced by both juveniles and adults (ICES 2005). During the last

decade, there has been a growing body of evidence suggesting that strong fishing pressure may induce evolutionary changes in life-history traits. In particular, the NEA cod has experienced a considerable reduction in its mean age at maturation from 10 years to around 6 -7 years during the second half of the twentieth century.

The observed changes in the life-history traits of NEA cod might result from phenotypically plasticity and/or genetic adaptation in response to the changed harvest pressure imposed on the population. A phenotypically plastic response might come about through changes in food availability that may occur when a population's abundance is decreased by fishing: increased food availability improves conditions for somatic growth, thereby potentially triggering earlier maturation. In addition, fishing can exact high selective pressures on a population, often by selectively removing the larger, older, and/or mature individuals: such selective pressures are bound to induce a genetic response in life-history traits, because individuals with certain genotypes are more likely to survive and produce offspring than other genotypes (Heino *et al.* 2002a, 2002b; Barot *et al.* 2004; Olsen *et al.* 2004). Also recent experimental evidence suggests that harvesting can indeed induce noticeable genetic changes within only a few generations (Conover & Munch 2002; Reznick & Ghalambor 2005).

Distinguishing between plastic and genetic responses is important for fully understanding the impacts of fishing on a population (Rijnsdorp 1993). This distinction is also relevant from a management perspective, because genetic changes are bound to be more difficult to reverse than compensatory plastic responses (Law 2000). Genetic changes in life-history traits thus give rise to concerns (Olsen et al. 2004) – in particular, since the consequences of fishery-induced evolution can result in lower body sizes and lower sustainable yields (Law & Grey 1989; Law 2000; Conover & Munch 2002; Hutchings 2004), as well as reduced stock stability. For example, high fishing pressure often causes evolution towards maturation at earlier ages and smaller sizes (Heino *et al.* 2002b), which may imply a reduction in biomass and a decrease in the profit of the corresponding fishery.

Currently, there is a price premium of approximately 70% on fish above 3 kg compared with fish below 1 kg, and this premium will, in all likelihood, increase when the abundance of large fish in the stock is diminished. Considering that the total value of the Norwegian cod fisheries was 3 billion Norwegian Kroners (approximately 400 M€) in 2005, one can expect that fisheries-induced evolution may lead to considerable economic losses.

In this study, we aim to integrate and strengthen the interface between ecological, evolutionary, and economic modeling, in order to contribute to an improved understanding of the mid- to long-term effects of fishing. The biological component of this approach is based on an individual-based eco-genetic model (Dunlop 2005) for the Northeast Arctic cod (Eikeset *et al.* 2005). To advance the majority of previous studies that have focused on the evolution of a single life-history trait, we examine the propensity of harvest to induce evolution in multiple life-history traits: specifically, we consider the intrinsic somatic growth rate, the reproductive investment, and three parameters describing the probabilistic maturation reaction norm of individuals. In addition to characterizing the magnitude and rate of fisheries-induced adaptive change in NEA cod, we evaluate if and how different fishing regimes and fishing pressures alter the evolutionary response – and how their respective economic output differs.

First, we analyze the biological and economic repercussions of three different fishing regimes (constant harvest rate, constant catch, and constant escapement), of different minimum size limits, and of different harvest mortalities, in order to determine which harvest patterns, if any, are capable of reducing the evolutionary and economic impacts of fishing.

The cost function used in the economic component of our model is estimated from data collected by the National Norwegian Profitability in Fisheries Survey (Anonymous 2006). Cost data were available for the years 1998 to 2004. After adjusting the data for inflation, a quadratic cost function was estimated. No suitable demand schedules for cod were available in the literature; therefore, the demand function was estimated based on the reported landing price of 17 NOK per kilo in 2000. We hypothesize a cut-off price of 20 NOK per kilo as the maximum price that the market would be willing to pay before switching to substitutes and we let the demand be moderately elastic with respect to price below this level.

We explore the evolutionary effects in an open-access regime (an entirely unregulated system in which selfish decision taking prevails), to investigate its effects on social welfare. We also identify and analyze management scenarios that maximize the long-term profitability of the fishery, measured by the net present value of the fishery-generated cash flow. Preliminary results of the model quantify the costs of fisheries-induced evolution. We hope that making the economic and ecological costs of fisheries-induced evolution explicit in this way will serve as an important step forward in the development and implementation of improved management practices.

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