

Theme session: Evolutionary effects of exploitation on living marine resources (Session H)

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The Propensity of Marine Reserves to Slow the Evolutionary Effects of Fishing

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Introduction

Several recent theoretical (Baskett et al. 2005, Ernande et al. 2004) and empirical (Grift et al. 2003, Olsen et al. 2004) studies have provided evidence that fishing is capable of inducing evolutionary changes in key life-history traits. These evolutionary changes can have unwanted consequences, such as reduced body sizes in the catch and lowered population biomass, which

might lead to a deterioration of the quality of the fishery. Therefore, managers need viable options for mitigating the evolutionary consequences of fishing.

An important strategy of contemporary fisheries management is the implementation of marine reserves. By protecting a certain segment of a population from harvest, marine reserves might slow, stop, or reverse the evolutionary consequences of fishing. A recent study by Baskett et al. (2005) confirms this hypothesis. Based on the analysis of a quantitative genetics model, Baskett et al. (2005) predict that marine reserves slow evolution in the size at maturation. Furthermore, results suggest that marine reserves can protect against any scientific or management uncertainty that might lead to over-fishing (Baskett et al. 2005).

Although significantly improving our understanding of the effects of marine reserves on evolution induced by fishing, the model of Baskett et al. (2005) can be extended in several interesting directions. The first direction is the inclusion of density-dependent growth and mortality, which might play a critical role in the effectiveness of a reserve if crowding occurs. The second direction is the inclusion of multiple evolving traits, such as reproductive investment and somatic growth, in addition to the traditionally studied maturation schedule. The third direction is the inclusion of a more complex and spatially structured life cycle. For example, many commercially important species (e.g., Northeast Arctic cod, North Sea plaice, Norwegian spring spawning herring) undergo an annual migration between feeding and spawning grounds. In such species, the ideal placement and effects of a marine reserve are obviously not straightforward. Protection on the feeding grounds might dilute some of the benefits of implementing a marine reserve, because adults might fully mix in the spawning grounds. Conversely, protection of a portion of the spawning grounds might not do much to slow the evolutionary effects of fishing, because harvest of both immature and mature fish might still remain high on the feeding grounds.

In this study, we build an eco-genetic model to explore the effects of marine reserves on the evolutionary response to fishing in a species with an annual migration between feeding and spawning grounds. Our model advances previous theoretical approaches by including features such as phenotypic plasticity, density-dependent growth, and the evolution of multiple life history traits. We parameterize our model for a cod-like fish and examine the consequences of marine reserve location (either on the feeding grounds or on the spawning grounds) and of the proportion of area protected on the speed, direction, and eventual magnitude of fisheries-induced evolutionary responses.

Methods

We chose an eco-genetic modeling approach because it allows the intuitive merging of considerations based on ecology and genetics. Important ecological aspects include density-dependence and population structure, which are both pertinent to the evolutionary process. Important genetic aspects include the mode of inheritance of quantitative traits from parents to offspring, the population's genetic variance, and the phenotypic expression of genetically determined traits. All of these factors are essential because they influence the rate of evolution, something which must be of high significance to fisheries managers.

We implemented our eco-genetic model in an individual-based framework so that we could efficiently model the evolution of multiple traits (maturation reaction norm, reproductive investment, and somatic growth) in a population structured by age, size, and maturation status. We model a probabilistic maturation reaction norm (PMRN) to account for phenotypic plasticity in the maturation process (Heino et al. 2002). The PMRN of an individual describes its size- and age-based probabilities of maturation before the next year's spawning season. We parsimoni-

ously assume a linear PMRN with an evolving slope, intercept, and envelope width. The envelope width describes, for any given age, the range of sizes over which the probability of maturation rises from, say, 25% to 75%. For simplicity, we assume this envelope width to be constant across ages. Another evolving trait, reproductive investment, represents the fraction of available energy allocated to reproduction after maturation. The fifth evolving trait in our model, the somatic growth rate, describes an individual's intrinsic capacity for growth, and trades off with survival.

Space is implicit in our model and the marine reserve is implemented as a proportion of the pre-fished population protected. Each year, mature individuals undergo a migration from the feeding grounds to the spawning grounds; after reproduction occurs, newly born individuals drift to the feeding grounds where they remain until maturity. Size-selective fishing occurs in both the feeding and spawning grounds. The movement that occurs each year between the reserve and harvested area is a function of reserve size and a retention rate parameter. Density-dependence in growth is determined on the feeding grounds and, for a given individual, therefore depends on the average density of fish residing within the individual's location on the feeding grounds (this density naturally differs between the inside and the outside of the reserve). If the reserve is on the spawning grounds, reproduction occurs between individuals of similar location within the spawning grounds (individuals in the reserve mate with each other and individuals in the harvested area mate with each other); in this case, offspring inherit the reserve status of their parents (with movement). If there is no reserve on the spawning grounds, mating occurs randomly and the reserve status of offspring equals the fractional reserve area. We allow population abundance and evolving traits to reach a stable equilibrium before creation of the reserve and the onset of fishing. This allows us to evaluate the capacity of marine reserves for slowing or stopping the evolutionary response to fishing. Future work will analyze the propensity of marine reserves to

impact evolution in a population that has already been subject to harvest and that consequently has already undergone some genetic change.

Concluding remarks

Preliminary results indicate that implementation of a marine reserve on the feeding grounds can have positive effects: the evolutionary response to fishing in the modeled life history traits slows down as the area of the reserve increases; this is the case even when maintaining a constant catch in the fishery. However, the propensity of a marine reserve to slow evolution is diminished when the reserve is located on the spawning grounds. Therefore, the results of our model underscore the importance of adopting an evolutionary perspective when implementing management strategies aimed at protecting commercially important fish stocks.

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