Fishing at Lofoten, Norway.
Photograph: Stefan Rosengren, Naturbild

Fishing drives rapid evolution

Today, fishing is the dominant source of mortality in most commercially exploited fish stocks. Evolutionary theory predicts that increased mortality typically selects for fish that mature younger and smaller. Recent research by fisheries scientists in Europe and North America – orchestrated by the International Institute for Applied Systems Analysis in Laxenburg, Austria – reveals that the predicted fisheries-induced evolutionary changes are indeed occurring.

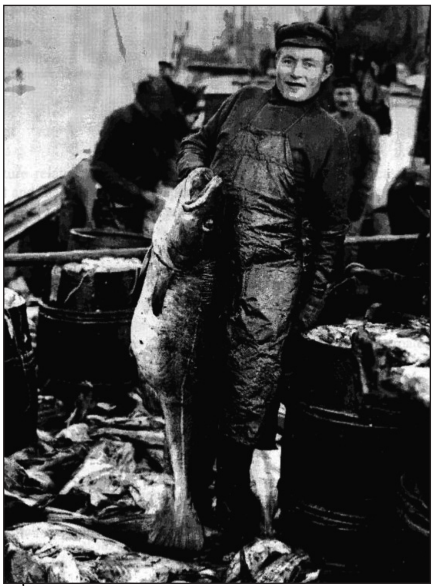
By Ulf Dieckmann & Mikko Heino

According to the United Nation's Food and Agricultural Organization, FAO, world capture fisheries have reached a ceiling. Three stocks out of four are being maximally exploited or overexploited. Since all fish species were genetically adapted to the environmental conditions experienced prior to intensive exploitation, the current, drastically altered conditions cannot possibly leave their life-history patterns unaffected. This means that fishing is not only changing the numbers of exploited fish, but also their genetic composition. It is only now that fisheries scientists and managers are gradually awakening to the formidable risks posed by further unmanaged fisheries-induced evolution.

Rapid changes

Evolutionary processes have long been thought of as being too slow to impinge on the management of extant populations. By contrast, a wealth of empirical studies have made it increasingly clear that evolution may rapidly change the properties of populations, on time scales as short as decades or even years.

Famous examples come from moths adapting their wing color to dust-covered tree trunks, from guppies adapting their patterns of growth and maturation to predation risks, or



Cod of this size are no longer found today. Large Northeast Arctic cod from the beginning of the 20th century. (Photograph by Anders Beer Wilse, courtesy of the Norsk Folkemuseum, Oslo, Norway.)

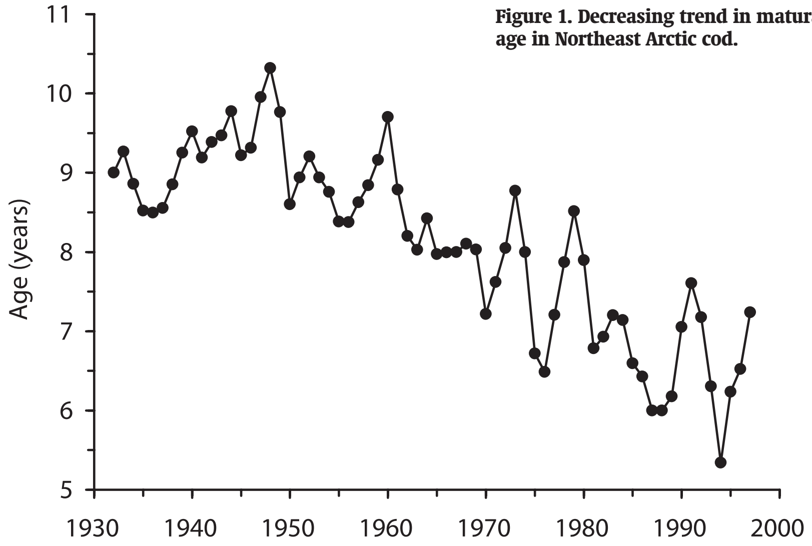


Figure 1. Decreasing trend in maturation age in Northeast Arctic cod.

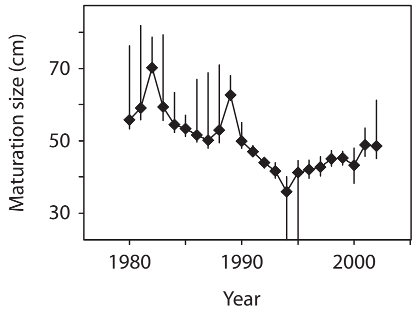


Figure 2. Decreasing trend in maturation size in northern cod, after removal of confounding factors.

from bacteria attaining antibiotic resistance. In all such instances the speed of evolution (driven by the successive removal of maladapted organisms from populations) is greatly accelerated, simply because the disadvantages suffered by maladapted organisms are so strong.

Strong selection pressures also apply in commercial fisheries. For example, fish that are genetically geared to reproduce for the first time at, say, age 10 (Figure 1) will leave hardly any offspring, when the chances to survive until such old age are negligible.

This situation applies in most exploited stocks today, where fishing often removes more than 50% of individuals each year, implying a probability of only $(1/2)^{10} = 0.001$ for a fish to survive until age 10. Under such conditions, procreating earlier in life is highly advantageous. Similarly strong fisheries-induced selection may result in reduced growth (to stay under mesh size for longer), increased reproductive effort (to create more offspring per season), and suitable behavioral adaptations (to escape fishing gear).

New method developed

Indeed, many commercially exploited fish stocks show trends towards earlier maturation (Figure 1). Why, then, have the problems associated with fisheries-induced evolution not been recognized earlier? One reason is that maturation trends can also be explained by factors other than evolution. When fishing mortality is high, less fish remain in the sea; this means that each fish has available more food resources, thus growing faster and maturing earlier.

To overcome the resulting ambiguity in interpreting observed maturation trends, a new method (for estimating so-called probabilistic reaction norms for age and size at maturation) had to be developed. Using this technique has recently allowed us to largely remove confounding effects from maturation trends and to identify residual trends that are fully consistent with the predictions of evolutionary theory (Figure 2). After having reached this same conclusion in independent case studies of several fish species in several geographical regions, we suggest that fisheries-induced evolution is a truly ubiquitous phenomenon.

Cause for concern

Implications for sustainable yield, stock stability, and recovery potential give cause for concern. Fish maturing earlier in life divert much energy to relatively inefficient reproduction. Consequently, they grow less (which is detrimental to the yield extractable from a stock) and contribute far less eggs than older and larger individuals would (thus rendering a stock more vulnerable to environmental fluctuations and less capable of recovering from overexploitation). These problems are aggravated by the fact that, once fisheries-induced evolution has occurred, it is usually very difficult and slow to revert. In many stocks such reversal many in fact be infeasible. To avoid further undesired fisheries-induced evolution, a new generation of fisheries scientists and managers will need to work with new scientific tools, which are currently under development. ●

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Further reading

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