The evolutionary dimension of modern fishing

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Worldwide, three-quarters of fish stocks are maximally exploited or over-exploited. Wasteful practices, ineffective enforcement, and disregard for scientific advice on fishing quotas have contributed to this. IIASA has been at the forefront of research revealing that fishing not only reduces the number of fish, but also changes their heritable features. This previously overlooked evolutionary dimension of modern fishing has unexpected consequences for economic yields and for the ecological stability and recovery potential of exploited fish stocks.

While the accompanying presentation at the IIASA Conference 2007 on Global Development: Science and Policies for the Future, titled *The Global Fisheries Crisis: Acknowledged Causes and Elusive Cures*, provides an overview of both the ecological and evolutionary aspects of the current fisheries crisis, the summary and references below focus on the evolutionary dimension of modern fishing.

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 reveals that such fisheries-induced evolution is indeed occurring as predicted in exploited stocks around the world. In fact, these evolutionary changes have already been occurring for decades without being noticed.

According to the United Nation's Food and Agricultural Organization, world capture fisheries have reached a ceiling, with three stocks out of four being maximally exploited or over-exploited. 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.

Evolutionary processes have long been thought of as being too slow to impinge on the management of 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, and from bacteria quickly attaining antibiotic resistance. In all such instances, the speed of evolution, driven by the successive removal from populations of maladapted organisms, 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, say, at age 10 will leave hardly any offspring when their 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 all individuals each year, implying a probability of only $(1/2)^{10} \approx 0.001$ 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 longer), increased reproductive effort (to create more offspring per season), and certain morphological and behavioral adaptations (to avoid or escape fishing gear).

Indeed, many commercially exploited fish stocks have now been demonstrated to exhibit trends towards earlier maturation. 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, which means that each fish has available more food resources and can thus grow faster and mature earlier. To overcome the resultant ambiguity in interpreting observed maturation trends, a new method had to be developed for estimating so-called probabilistic reaction norms for age and size at maturation. Using this technique has allowed us to remove important confounding effects from maturation trends and to identify residual trends that are fully consistent with the predictions of evolutionary theory. 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.

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 over-exploitation). 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 practically impossible. To avoid further undesired fisheries-induced evolution, a new generation of fisheries scientists and managers will thus need to adopt an evolutionarily enlightened management approach. The new scientific tools thus required for monitoring and forecasting evolutionary changes are currently being developed at IIASA.

Further reading (with active weblinks to online reprints)

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