

On the History of Marine Fisheries

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SUMMARY

The Marine Policy Center of the Woods Hole Oceanographic Institution hosted a workshop entitled "On the History of Marine Fisheries" on August 26, 1998. Sponsored by the Sloan Foundation, the workshop was part of a larger Sloan effort to assess the feasibility of a large-scale program to improve the state of knowledge about the current and potential global diversity, abundance, and distribution of marine life.

The theme of the Woods Hole workshop was selected in light of the recommendations of an earlier Sloan-sponsored meeting held in Monterey in April 1998. Participants in the Monterey meeting had proposed an iterative process of modeling and observation, with a pilot observational phase that would concentrate on filling in large unknowns in existing ecosystem models, especially information about the diversity, abundance, and distribution of biomass at the upper trophic levels.

Participants in the Woods Hole workshop were asked to address two main questions:

- (1) What do modeling and observational studies tell us about the state of marine fisheries prior to, and in the early stages of, exploitation?
- (2) What further studies should be undertaken to improve the state of knowledge in this area?

Participants' responses to the first question converged on a few key themes. One was the estimate of roughly an order-of-magnitude reduction in fish biomass in intensively exploited fisheries of the Northwest Atlantic, relative to pre-exploitation or early exploitation levels, and signs of

similar trends elsewhere. Evidence supporting such an estimate comes from a broad range of observations, including qualitative accounts of fish sizes and abundances off New England in the 1600s; early fisheries records documenting enormous catches with unsophisticated fishing methods; contemporary reports of very high catch rates in newly developing fisheries; and traditional stock assessments based on scientific surveys, which indicate reductions in the spawner-recruit index by a factor of at least 5, often 10, and sometimes as high as 20.

A second theme concerned the implications of this estimated reduction in biomass for existing ecosystem models. Such models depict present systems at a steady-state and use either biomass fluxes or energy flow rates as the state variable to be conserved or balanced. Given the balancing requirement, the estimated reduction in biomass at the upper trophic levels suggests either that primary production must once have been much higher, or that energy flows across trophic levels have changed considerably.

The first scenario raises the possibility that environmental changes, rather than overfishing, may be responsible for the estimated declines in biomass, which is inconsistent with our understanding of some of the best-known cases of intensively exploited fish stocks. Models can account for the implied changes in energy flows, but because they are structured in terms of trophic levels and because data on intermediate levels of the system are scant, the models cannot distinguish the degree to which such changes are associated with changes in the age and size composition of exploited stocks vs. the species composition of affected systems. Moreover, both mass-balance and energy-flow models give a large role to the cycling of nutrients through the microbial loop, with a large reservoir of detritus that accounts for as much as 85% of the biomass in some systems and may transfer as little as 11% of that biomass to higher trophic levels. In order for such systems to have supported ten times more fish biomass in the past, detritus utilization rates must have been 6 to 7 times greater than the models of present systems indicate, which implies a basic change in energy flows between major parts of the system. In other words, models of present systems suggest that environment plays a far bigger role in stock dynamics, or that fish play a much larger role in the overall structure and functioning of the ecosystem, than has generally been understood to be the case.

These puzzles highlight the need for additional observational effort to fill in important gaps in the models and ultimately to confirm or disprove them. The appropriate scale and organization of such an effort received considerable discussion. For the most part, however, the discussion focused on the potential use of historical fisheries data for these purposes.

One promising possibility involves the use of fish egg and larval data, for which at least 20 datasets dating back to about 1910 are available. These provide indications that the eggs and larvae of commercial fish species on the Scotian Shelf, with the exception of herring, have indeed declined by a factor of 10. An unusual advantage of these datasets is that early survey methods are directly comparable to those presently in use, so they present few difficulties with respect to standardizing the data.

Other historical fisheries records promise to shed light more directly on the question of environmental change as a driver of steep stock declines. The record of sardine scales in sedimentary deposits in the California Current provides support for such an interpretation, at

least with respect to small, short-lived pelagic fish. The record dates back to about 400 AD, spanning major climate-driven contractions of sardine habitat as well as periods of intensive exploitation. The record shows that sardines are extremely sensitive both to overfishing and to natural environmental change, and that roughly 100-fold declines in abundance are possible even without fishing. Another research effort under way involves the use of spawner-recruit datasets to obtain a global picture of the relationship between fish production rates and geographical habitat, or ecosystem carrying capacity.

Specific Issues

I. Scales of Variability

One major "historical" issue concerns the amplitude and spatial scale of variability in fish populations before exploitation. Data from fish scales in sediment cores suggest that there may have been very large changes in abundance of particular species before fishing, implying that there were significant natural environmental effects on populations such as sardine and anchovy. However, because cores are at a few discrete sites, these data might represent only local variability.

This issue is important for our view of the spatial and temporal variability of unexploited populations and so of the sampling requirements for estimates of their dynamics.

II. Pre-exploitation Stock Assessments

There is substantial agreement within the fisheries community that the biomass of exploited stocks of demersal species such as cod and haddock was roughly an order of magnitude greater prior to exploitation. A wide range of evidence supports this conclusion, including qualitative accounts in the popular literature of 300 years ago; more formal historical accounts and early fisheries records documenting enormous catches with fairly unsophisticated techniques; and contemporary reports of catch rates in newly developing fisheries, such as New Zealand orange roughy. For some areas where deepwater exploration and exploitation began less than 20 years ago, the documentation traces the shift from very dense amounts of fish at the outset, followed by rapid declines as the fisheries started up.

It is important to recognize that in some cases there are probably major population aggregations at favored fishing locations, with densities that may not be at all applicable to entire populations over their whole geographic distribution. Nonetheless, the consistency of the evidence for a wide range of species and fisheries strongly supports the conclusion of an order-of-magnitude decline in biomass.

Modeling lends additional support. From traditional stock assessments, a tremendous number of examples have been summarized which indicate that, for most cases that we know about, we are fishing down the spawn-per-recruit index by a factor of at least 5, often 10, and sometimes 20. Suppose that reproduction stopped but all the fish currently living were allowed to remain in the population. Abundance levels would increase by 5 to 10 to 20 times, even ignoring what effects there might be on recruitment. In other words, just the rates of growth associated with current recruitment levels can produce huge increases.

From all these very different sources, then, we get estimates of order-of-magnitude differences (in biomass, not abundance). What about energy models? Some work for coastal areas indicates that one-third of the productivity is already accounted for; and work on Georges Bank shows that the system is even tighter than that, with 50% or more of productivity accounted for. This suggests that, unless the lower end of the food chain is radically changed--unless we had higher primary productivity before--how do we explain an order-of-magnitude difference? Clearly the answer must be that animals of today must have much higher production-to-biomass ratios and consumption-to-biomass ratios than the animals of earlier times. This is exactly what one would expect in terms of the age composition, with older, slow-growing fish dominating the pristine stocks compared to the huge growth rates characteristic of present stocks.

The question, then, is how much of the biomass decline is driven by change in age composition vs. fundamentally different species mixes. This is one of the most difficult questions. Is age composition sufficient to account for the change? It may be sufficient, but that does not mean it is the answer. There are many reasons to think that there has been an order-of-magnitude change, based on evidence from many sources. Yet the energetics tells us that although this may be the case with biomass, it cannot be true for production rates of the fish community.

III. Multi-species Effects

A striking feature of the recent historical data, based on fisheries statistics, are the loosely coupled, inverse shifts in abundances of different species. The best known are sardine/anchovy switches in abundance around the Pacific during this century. There are similar examples among herring, mackerel and pilchard in the north Atlantic. All of them involve pelagic species and could be considered as relatively explicable consequences of shifts in competitive advantage.

More interesting but less explicable are switches in abundance between pelagic and demersal stocks. Some of these have occurred in the last few decades and can be attributed largely, if not entirely, to overfishing. However, there is circumstantial evidence that, on the Scotian Shelf, Grand Banks, and Georges Bank, there were similar changes before overfishing. The two main pelagic species on the Scotian Shelf are capelin and sand lance. The sampling programs for both were very poor, but even so it is clear that very little was there to be caught back in the period when large amounts of groundfish were being caught. Then, when the haddock was eliminated, the catch of pelagics went up, and when there was a haddock recovery it went down, and so forth. One should be very skeptical of the data, but it is fairly convincing that there was an increase in the biomass of the pelagics.

In addition, there are egg and larval surveys that we can compare back at least to 1910 or 1914 for the same geographic area, which were conducted with methods that are directly comparable to methods used on surveys in the last few years. In eastern Canada, there are at least 20 separate egg and larval datasets on different species and populations. These provide indications that the eggs and larvae of everything on the Scotian Shelf except herring have declined by a factor of 10. These datasets are another rich source that could be rescued and used fairly easily.

No matter how you look at the data, the total biomass of demersal fishes is about one-tenth of what it was, and there are corresponding increases in pelagics. This leads one to think that there

have been major changes in the abundance of other fish stocks concomitant with the decline in demersal species.

IV. Intermediate Trophic Structure

The historical data raise serious concerns about the structure of fish stocks before the tenfold change in demersal species. But is this the only change that occurred?

At present, gelatinous plankton are considered a dominant component of many shelf ecosystems. In particular, they may be major predators of the herbivorous zooplankton and thus direct competitors with pelagic fish. Furthermore, many jellies, such as salps, are omnivorous and can consume both phytoplankton and heterotrophs. In particular, they could be principal consumers of "detritus."

If the pristine fish stocks needed significantly more energy input, this in turn would require a major diversion of energy flow from gelatinous to vertebrate species. One problem with this switch is that, in the unexploited open ocean, jellies appear to be a dominant component of the pelagic systems. This would imply that the previous reasoning is not valid or that the open ocean and continental shelf food webs are entirely different.

In either case, these speculations demand that studies of present or past unexploited systems must consider the intermediate as well as the top trophic levels.

V. Modeling Approaches

The two main ways to approach these questions are through observational studies and modeling. It really is not feasible to sample enough of the ocean that we could measure the abundance and distribution of marine life directly, but neither are the two approaches mutually exclusive. Both will be needed and should be used. We need several modeling approaches.

(1) The basic ecological knowledge of marine food webs is critical. The best example is the appreciation of the microbial loop as an integral part of these food webs. Another is the elucidation of the role of gelatinous organisms. A present gap is our relative lack of knowledge of the role of cephalopods within the oceanic webs, even though their importance is undoubted.

(2) The construction of quantitative energy flows through food webs can provide constraints on the total system through the need to achieve overall balance. In the North Sea, for example, it appears difficult to reconcile a major pathway through the microbial loop with a significant loss to invertebrate carnivores such as "jellies." On the other hand, these calculations show how the pelagic/demersal switch can be accommodated even if the ecological processes are unclear. Also, such calculations highlight the critical nature of the "detritus" terms in pristine versus overfished systems.

(3) Such bookkeeping does not help us to understand how the system can switch from one state to the other (pristine/exploited; pelagic/demersal; large/low detritus). If we require models that can "predict" past systems or that can propose strategies to observe open-ocean populations, then we would need dynamic models.

At present, however, such models would be difficult, if not impossible, to validate. The consensus is that they serve as means for defining problems rather than supplying answers: they help drive the design of the study, but they leave unresolved the question of exactly what form the field study should take. There was general agreement at the Woods Hole meeting that a field program would still be a quest for knowledge in a very broad exploratory sense--the *Challenger* 100 years later.