GETTING AHEAD OF THE CURVE

CONSERVING THE PACIFIC OCEAN'S TUNAS, SWORDFISH, BILLFISHES AND SHARKS

National Coalition for Marine Conservation
Leesburg, Virginia

Published by the
NATIONAL COALITION FOR MARINE CONSERVATION
3 North King Street
Leesburg, Virginia 20176 USA
www.savethefish.org

The papers contained in this volume were originally prepared for a symposium held at the **Monterey Bay Aquarium** in Monterey, California November 4-6, 1996.

The symposium was conceived, planned and organized by the **National Coalition for Marine Conservation** as part of its ***Marine Fisheries Symposium Series.***

Financial support provided by:

- ✓ **David & Lucile Packard Foundation**
- ✓ **National Marine Fisheries Service, NOAA, U.S. Department of Commerce**
- ✓ **Inter-American Tropical Tuna Commission**
- ✓ **United Anglers of California**
- ✓ **World Wildlife Fund**
- ✓ **Pacific Ocean Research Foundation**
- ✓ **San Pedro Fishermen's Marketing and Research Foundation**

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This volume should be referenced as follows:

Getting Ahead of the Curve. Conserving the Pacific Ocean's Tunas, Swordfish, Billfishes and Sharks. Ken Hinman, Editor. Marine Fisheries Symposium No. 16. National Coalition for Marine Conservation. Leesburg, Virginia. 2000.

INTEGRATED RESEARCH IN SUPPORT OF MANAGEMENT

John Sibert

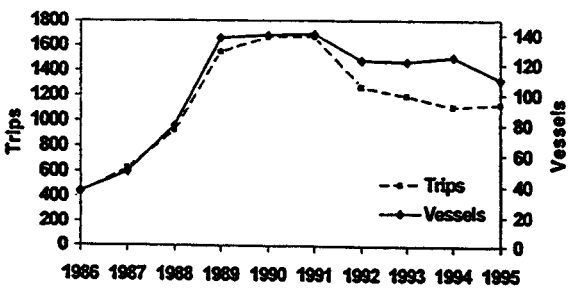
As we enter the 21st century, the Food and Agriculture Organization of the United Nations has assured the world that most major marine fish stocks are either fully-exploited or over-exploited. The tropical tuna stocks of the central and western Pacific Ocean are one of the few hopeful exceptions to this otherwise bleak situation. As pressure on the stocks increases, the task of fishery management will become even more challenging. We will be confronted with managing fisheries on the knife-edge between sustainability and disaster. This symposium and other recent events in national and international arenas imply a growing political commitment to sustainability. Given this commitment, it is timely to ask whether current tools for scientific analysis of fisheries and for development of effective management policies are adequate to the challenge. I would like to explore a strategy for the design of research programs to improve and apply these tools on a scale that encompasses about half of our planet.

Fishery management is really the practice of manipulating the fishing community to achieve some social or political goal. The manipulation is usually understood to be restrictions on the activities of fishers, and the goal is usually understood to be the conservation of the resource. I suspect this is a view of fishery management shared by many participants in this symposium. Other goals of fishery management may be equally important and legitimate, however. For instance, a coastal state may adopt a policy of restricting foreign access in order to increase the value of fishing licenses and thus increase revenues from foreign fishing. Or a coastal state may adopt policies that favor access to local fishers, perhaps even at the expense of the resource, in order to foster development of local fishing fleets. Or one resource user may adopt a goal that restricts activities of other resource users in order to reduce competition both in the market place and on the fishing grounds. Or, as in the US, the goal of fishery management may be "optimal use".

The goals of various user groups are often incompatible. Fishery management requires balancing conflicting values on the basis of incomplete and often faulty information. The information required to support management depends on the management goals. Integrated fishery research is a means to inserting additional information into the analysis of fisheries and supplying the results to managers in a useful format. In principal, the notion that policy makers and fishery managers should be completely informed in order to make important decisions is not a particularly profound or novel idea. In practice, however, it is extremely challenging to generate the required information and to present it to decision makers in a timely and useful form.

In 1992, a multidisciplinary research program, the Pelagic Fisheries Research Program (PFRP), was created at the University of Hawaii to provide scientific information for development of pelagic fishery management policies by the Western Pacific Fishery Management Council (WPFMC). I will present the recent history of the Honolulu-based longline fishery as an example of the management problems faced by the WPFMC. This example is not unique. Comparable examples can probably be cited from fisheries jurisdictions throughout the world. It illustrates the types of information required to manage fisheries and introduces a framework for guiding integrated multidisciplinary research on pelagic fisheries.

Figure 1 - Growth of the Honolulu-based longline fishery since 1986 (WPFMC 1996)

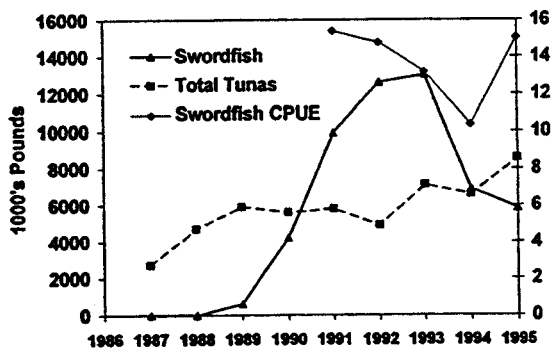


Finally, I will attempt to apply this framework to identify some key areas of research.

Hawaiian Longline Fishery

The longline fishery in Hawaii dates back to the 1940s. In the 1970s, catches by the Honolulu-based longline fleet began to increase, and in 1983 longline landings exceeded the previous historical high set in 1948. Further increases occurred in the late 1980s when size of the longline fleet increased by a factor of three (Boggs and Ito 1993; WPFMC 1996). Nearly 100 vessels and their crews migrated to Hawaii from other ports in the US, mainly from the Atlantic Ocean and the Gulf of Mexico (Figure 1). Broadbill swordfish was primary target of this fishery (see Fig. 2), and Honolulu quickly became the largest single domestic supplier of swordfish to the US.

Figure 2 - Tuna and swordfish landings and swordfish CPUE (per 1,000 hooks caught on directed trips) by Honolulu-based longline fishery. (WPFMC 1996)



This rapid influx of fishing power and fishing crews naturally caused problems for fishery managers. There were the usual resource questions: Is the swordfish resource capable of sustaining high levels of exploitation? (A particularly urgent question in consideration of the decline of the Atlantic swordfish fishery.) The longline fleet catches a significant amount of yellowfin and bigeye tuna. Are the tuna resources capable of sustaining higher levels of exploitation? Will harvesting by longliners impact the ability of the large numbers of small "commercial" trollers and handliners to catch tuna? If the swordfish stock declines, will the longliners begin to target tunas, further increasing pressures on "local" tuna stocks? (This question concerns the users of the resource as well as the resource itself) Are there "local" tuna stocks in the vicinity of Hawaii?

There were also social problems. "Local" longliners had an established historical relationship with other components of the pelagic fishing fleet. There were informal divisions of fishing grounds and few conflicts. The "foreign" longliners did not share these common cultural values, and there were confrontations.

This situation developed very rapidly, and the WPFMC took precautionary action in 1991. A moratorium on new entries to the fishery was imposed, and some areas were closed to longlining to minimize interactions with protected species (monk seals). These actions calmed the social situation and allowed time for development of more thoughtful management strategies. Unfortunately, there were few data on the north Pacific swordfish population, data available on tuna populations were fragmented, and there were no data on longline economic performance. Several research programs, including the PFRP, were launched to generate technical information on which to develop future policies.

Swordfish catches declined severely in 1994. This development reinforced the worst fears of many people associated with the fishery. The causes of the decline were not clear, however. Several scientists associated with the council felt the situation should be examined more closely before concluding that the swordfish population was on the verge of collapse. An *ad hoc* interdisciplinary group of researchers - biologists, economists, ocean-ographers - from the PFRP and the National Marine Fisheries Service (NMFS) Honolulu Laboratory assembled to examine the problem in more detail. The group posed three hypotheses to explain the decline in swordfish catch and then tested each of these hypotheses against the data that had accumulated since 1991.

Possible Causes of Swordfish Catch Decline
Decline in Absolute Abundance
Fishing pressure
Environmental (recruitment & mortality)
Decline in Availability
Large-scale distribution (migration)

Local distribution (depth)
Decline in Fishing Power
Change in participation
Change in targeting

The Honolulu-based longline fleet is not homogeneous. Economic data as well as analysis of catch composition reveal three relatively distinct modes of operation: (1) swordfish-directed, (2) tuna-directed, and (3) mixed. The catch-per-unit-effort (CPUE) of the swordfish directed segment of the longline fleet declined between 1992 and 1994, but then recovered sharply in 1995. The size distribution of the fish did not change in any way suggestive of high levels of exploitation. The group concluded that there may have been a reduction in overall abundance, but if so, the rapid recovery in 1995 is difficult to understand. Participation in the fishery has also changed significantly and partially accounts for the sustained decline in total catch and effort, but cannot account for the change in CPUE. The spatial distribution of the catch was also different in each year, further increasing the difficulty of reaching general conclusions. The most important factor in mediating the observed changes in CPUE during this period may have been the variability in the strength of the convergent oceanographic front near the fishing grounds. The *ad hoc* group concluded "the most likely explanation for the CPUE decline in 1994 appears to be a change in the environment which affected the availability and/or the catchability of swordfish" (WPFMC 1996). While this conclusion is offered with great caution, we now have on hand a multidisciplinary team capable of quickly applying biological, economic and oceanographic analyses to fishery management problems.

In 1993, the WPFMC amended the pelagic fisheries management plan (FMP). Area closures are maintained, a longline limited entry plan is in place, logbook reporting requirements have been established, and observers are in place on longline vessels. While this plan is practical and effective in regulating the fishery and minimizing conflict among sectors, it is based on limited information. Knowledge of the swordfish population is still less complete than necessary. The historical database pertinent to tuna populations has only been compiled recently and preliminary analyses completed. Collection of economic information about the longline fleet has been very successful and has already been useful in modifying observer programs. Collection of data on other sectors of the fishery is only beginning. Fortunately, the management plan is strongly supported by an active interdisciplinary research effort and contains provisions for revision as more complete information accumulates or as conditions change.

Fisheries As Globally Coupled Systems

The swordfish example shows how rapidly distant events may impact local conditions. In this case, longline vessels moved from one ocean to another. The move was not predicted and happened so rapidly that it was essentially complete before fishery managers could react. Migration of pelagic fishing fleets is common. In the early 1980s, large purse seiners moved from the eastern to western Pacific and from the Atlantic to the Indian Ocean. In each case, these large-scale fleet movements challenged local fishery managers with both social and resource problems and the challenges arrived as suddenly as the vessels. Management, at least with respect to pelagic fisheries, has acquired global dimensions.

The swordfish example also illustrates that analysis of fishery management problems is a multidisciplinary enterprise, a conclusion that should not surprise late 20th century observers. Social and economic changes in the fleet interact with environmental changes to cause changes in catches and catch rates that are difficult to understand. Fisheries inextricably couple human and natural systems. The productivity of fisheries resources depends on the dynamics of the species and the constraints imposed on natural production by the environment. The exploitation of fisheries resources depends on economic and cultural forces. The act of exploitation couples natural production systems to human social systems and induces additional layers of research problems. The task of fishery management is made more difficult by the fact that these systems and the nature of the coupling are incompletely under-stood. Further complications arise as the scope of these systems expands from local to global. Research programs supporting development of management policies for the next century must acknowledge the globally

coupled aspects of fishery systems. They must be multidisciplinary and explicitly include emergent complexities arising from the coupling of large-scale systems.

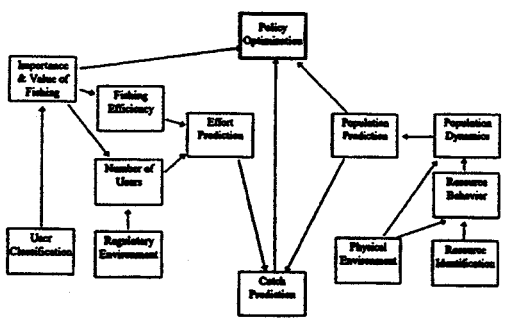
Policy development requires a means of discriminating among alternative policies in the context of management goals. Decisions will be made that some management scenarios are "better" or "worse" than others. The US Fishery Conservation and Management Act includes the notion of optimal use as a goal of fishery management. Optimality is an inherently quantitative notion. A minimum requirement for the development of optimal policy is a consistent yardstick that can be used to compare policies objectively. Although the goal of basing policy on an objectively determined optimum may be a naive hope and an impossible goal, the information required to make the attempt is essential. Science, after all, progresses most rapidly through the conflict between prediction and observation.

The information required to develop optimal policies is essentially the same as the information required to predict catch. Prediction of catch obviously requires the ability to make predictions about the resource, but catch ultimately depends on the users of the resource. Therefore, the prediction of catch also requires the ability to make predictions about the resource users. The information needed to make these two types of predictions should guide research for fishery management. Predicting effects of management actions on the resource and its users are essential components of any feasible policy evaluation metric. The ability to predict catch is a prerequisite to the development of optimal policy is therefore a potentially useful premise on which to construct an integrated research agenda. A unifying premise is the distinction between a research program that is merely multidisciplinary and a truly integrated approach. The need to make predictions about the resource leads to much of the research usually conducted under the rubric of "fisheries research". The need to make predictions about resource users leads to an agenda of social, cultural and economic studies that are *not* usually conducted under the rubric of "fisheries research".

Resource	Users
Forecast Population	Forecast Effort
Identify & Characterize Movement Between Fishing Grounds	Identify & Characterize Movement Between Fishing Grounds
Response to Exploitation	Response to Economic Conditions
	Response to Changes in Policy

These two branches of inquiry concern the resource on one side and the users of the resource on the other. Viewed in this way, fisheries research is a set of parallel inquiries directed at the resource and its users. Making quantitative forecasts about resources is part of the normal fisheries research agenda. Making quantitative forecasts about resource users is apparently a novel and challenging goal for the social science community.

Figure 3 - Information flow in a catch prediction and policy optimization model.



The usefulness of the "catch prediction" premise for policy development is becoming established. In Hawaii, one of the tools used by the WPFMC to evaluate the current pelagic fishery management plan was a simple catch prediction algorithm or model that computed hypothetical catch levels under different management policies. Although this model lacked population dynamics and used simplified fleet dynamics, it was a useful attempt to understand implications of allowing varying numbers and types of fishing vessels to participate in the longline fishery.

A Catch Prediction Model

Models are useful, some would say essential, components of scientific research. In the most general sense, models outline the conceptual understanding of the phenomenon under study. The use of a model to shape a research agenda for resource management focuses attention on processes rather than problems. Understanding of processes enables researchers and managers to anticipate problems before they occur instead of reacting to problems in an *ad hoc* way.

Figure 3 outlines a conceptual model for policy optimization and catch prediction. This model explicitly includes the idea that exploitation couples two rather complex and disparate systems and attempts to decompose the problem of catch prediction into component problems. Research activities begin to suggest themselves as decomposition proceeds and information requirements become more specific. This model is obviously an oversimplification, but it serves to point out how analysis of a general model leads to specific information requirements and ultimately suggests research topics to appropriate specialists. If the model were complete, research activities would simply consist of projects to estimate quantitative relationships between model components.

Each of the boxes and arrows in Figure 3 can be further decomposed to yield specific research problems. At this point, any formal process inevitably begins to break down, and knowledge and analysis must be applied. The University of Hawaii Pelagic Fisheries Research Program has implemented thirty-five different research projects addressing topics in most of the boxes in Figure 3.

Inspection of Figure 3 reveals two essential pieces of information required to predict catch: population density and fishing effort. In the past 10 years, considerable research has been directed to the creation of fish population dynamics models that explicitly include spatial structure and movement, for example, Sibert (1984), Hillborn (1990), Kleiber and Hampton (1994), Sibert *et al* (in press). These models appear to accurately predicting time and place of tag recapture. Further work, Mullen (in press) and Bertignac (in prep.), has extended this approach to modeling the age-structured population density on various spatial scales up to the scale of the Pacific Ocean basin. Population dynamics models that explicitly include movement and spatial structure of the habitat are extremely promising starting points for the development of complete catch prediction models. However, some substantial difficulties remain to be solved. It is at this point that models are of great value in shaping research priorities.

Measuring the Amount of Fishing.

The ability of the population movement models currently in use to predict catches depends on knowing the distribution and intensity of fishing. The population dynamics components of the models predict the general distribution of the population, but specific catch predictions depend on the amount of fishing at a particular time and place. These models "hindcast" catches provided adequate fishing effort data are available. The ability to "forecast" catches will depend on the ability to "forecast" fishing effort. This conclusion emphasizes the critical importance not only of *collecting detailed information from the fishery* on the time and place of fishing, but also of *research into fishing practices*. Understanding the complex interaction between fisheries policy, economic factors, social factors, and resource abundance in determining the time and place of fishing is a critical but sadly neglected research topic.

Ecology and Habitat.

Population movement models currently describe large-scale movements of fish in two fundamentally distinct modes. One movement description is most suited to the notion that fish have consistent, fixed migratory pathways. The tempo and direction of movement are strictly functions of season and locality. This method has proved useful in the analysis of skipjack and yellowfin tag recapture data. Alternatively movement can be considered to be a function of habitat quality in the sense of MacCall (1990). Preliminary attempts to model large scale movement of tunas as a function of the thermal properties of the ocean show that some of the features of large-scale movement and distribution can be attributed to sea surface temperature, thermocline depth and the gradients of these two variables (Sibert, unpublished). Tunas are also

sensitive to other features of their environment, such as forage abundance and oxygen. Incorporation of these variables has produced realistic models of skipjack distribution in the Pacific (Berignac in prep. and Lehody in prep.).

Summary

Beverton and Holt published their seminal book on the dynamics of exploited populations in the mid 1950s. Nearly every "new" idea in the analysis of fisheries data to appear in the last 40 years has its roots in this book. Of necessity, Beverton and Holt devoted a considerable amount of space to estimation of individual population dynamics parameters such as growth rate, mortality and catchability. The parameters were then inserted into various models to attempt to describe responses of a population to exploitation. Furthermore, Beverton and Holt developed their models to analyze fisheries operating in relatively small areas in which omission of movement caused few problems (perhaps). We now have computational and mathematical tools that were almost unimaginable 40 years ago. We have the task of managing fisheries on a huge geographic scale. It is possible to conceive of population models that integrate all important features of population dynamics with the realistic expectation of attempting to estimate these parameters directly from fisheries data. Thus we can test how our notions of growth, mortality, movement and exploitation interact. We can determine pragmatically where to invest our research dollars. We can extend ideas about the dynamics of exploited fish populations to embrace the dynamics of whole fishery systems. In short, we can begin to build a comprehensive theory of the dynamics of fisheries systems. The challenge of the 21st century will be to manage the world's fisheries at full exploitation. To meet this challenge we need tools that explicitly include the large-scale complexities inherent in coupling of global systems.

Acknowledgments

This paper is funded in part by Cooperative Agreement Number NA37RJ0199 from the National Oceanic and Atmospheric Administration. The views expressed herein are those of the author and do not necessarily reflect the views of NOAA or any of its subagencies. I would like to thank Kitty Simonds of the Western Pacific Fishery Management Council and Marc Miller of the University of Washington for their insights into the social dimensions of fishery management, Michel Bertignac and Patrick Lehody of the South Pacific Commission for allowing me to review their current research on environment-based movement models, and Karen Oppenheim Mason for comments on the manuscript. These kind folks bear no responsibility for my own particular interpretations of their ideas. I would particularly like to thank the National Coalition for Marine Conservation for the invitation to participate in this symposium and thus for providing me with the impetus to further develop the ideas in this paper.

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