ECOSYSTEM-BASED
FISHERY MANAGEMENT

A Report to Congress

by the

Ecosystem Principles Advisory Panel

As mandated by the Sustainable Fisheries Act amendments to the

Magnuson-Stevens Fishery Conservation and Management Act 1996

NATIONAL MARINE FISHERIES SERVICE
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PREFACE

Seeking solutions to reverse the decline of New England's fisheries in 1871, Congress created the U.S. Commission of Fish and Fisheries (Hobart 1995). The first appointed Commissioner, Spencer Baird, initiated marine ecological studies as one of his first priorities. According to Baird, our understanding of fish "... would not be complete without a thorough knowledge of their associates in the sea, especially of such as prey upon them or constitute their food...." He understood that the presence or absence of fish was related not only to removal by fishing, but also to the dynamics of physical and chemical oceanography.

Despite this historical, fundamental understanding of fisheries as part of ecosystems, we have continued to struggle to manage fish harvests while simultaneously sustaining the ecosystem. Recognizing the need for a more holistic management approach, Congress charged the National Marine Fisheries Service (a direct descendant of the U.S. Commission of Fish and Fisheries) with establishing an Ecosystem Principles Advisory Panel to assess the extent that ecosystem principles are used in fisheries management and research, and to recommend how such principles can be further implemented to improve our Nation's management of living marine resources. The resulting Panel was composed of members of industry, academia, conservation organizations and fishery management agencies. The Panel's diversity played a substantial role in the development of a pragmatic approach to expand ecosystem-based fishery management within the context of the existing fishery management system.

The Panel attempted to build on the progress of past efforts, namely the 1996 Sustainable Fisheries Act's (SFA) amendments to the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) (NMFS 1996). The provisions of the SFA require the Regional Fishery Management Councils to set harvest rates at or below maximum sustained yield levels; develop rebuilding plans for those species that are currently below the long-term sustainable yield; better account for and minimize bycatch and discard of fish; identify essential fish habitat and take measures to protect it; and determine the effects of fishing on the environment. These actions are being implemented and are vital to achieving ecosystem-based management. Still, it will take years to decades before the results are fully realized.

The Panel forged a consensus on how to expand the use of ecosystem principles in fishery management. We do not have a magic formula, but we offer a practical combination of principles and actions that we believe will propel management onto ecologically sustainable pathways. By asking more encompassing questions about fisheries management such as, "What are the effects of fishing on other ecosystem components?" and "What are acceptable standards for fisheries removals from ecosystems?" we are broadening the scope of management and ultimately making fisheries sustainable.

Ecosystem-based fishery management is likely to contribute to increased abundance of those species that have been overfished. It may, however, require reduced harvest of species of critical importance to the ecosystem. We expect that ecosystem-based fishery management will contribute to the stability of employment and economic activity in the fishing industry and to the protection of marine biodiversity on which fisheries depend. As a society, we are recognizing the limits of the sea to provide resources and of our abilities to stay within those limits. What are acceptable levels of change in marine environments due to fishing? This Report does not answer that question for society, but it does set a framework for beginning to take actions based on the insight of Baird 125 years ago.

David Fluharty
Chair, Ecosystem Principles Advisory Panel
Seattle, Washington
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EXECUTIVE SUMMARY

Ecosystem-based management can be an important complement to existing fisheries management approaches. When fishery managers understand the complex ecological and socioeconomic environments in which fish and fisheries exist, they may be able to anticipate the effects that fishery management will have on the ecosystem and the effects that ecosystem change will have on fisheries. However ecosystem-based management cannot resolve all of the underlying problems of the existing fisheries management regimes. Absent the political will to stop overfishing, protect habitat, and support expanded research and monitoring programs, an ecosystem-based approach cannot be effective.

A comprehensive ecosystem-based fisheries management approach would require managers to consider all interactions that a target fish stock has with predators, competitors, and prey species; the effects of weather and climate on fisheries biology and ecology; the complex interactions between fishes and their habitat; and the effects of fishing on fish stocks and their habitat. However, the approach need not be endlessly complicated. An initial step may require only that managers consider how the harvesting of one species might impact other species in the ecosystem. Fishery management decisions made at this level of understanding can prevent significant and potentially irreversible changes in marine ecosystems caused by fishing.

Recognizing the potential of an ecosystem-based management approach to improve fisheries management, Congress requested that the National Marine Fisheries Service (NMFS) convene a panel of experts to: 1) assess the extent to which ecosystem principles are currently applied in fisheries research and management; and 2) recommend how best to integrate ecosystem principles into future fisheries management and research. In response, NMFS created the National Marine Fisheries Service Ecosystem Principles Advisory Panel (Panel).

WHAT BASIC ECOSYSTEM PRINCIPLES, GOALS AND POLICIES CAN BE APPLIED TO FISHERIES MANAGEMENT AND RESEARCH?

To guide our deliberations, we developed a set of eight ecosystem operating principles (Principles) with societal goals for ecosystems (Goals), and a set of six management policies (Policies). These Principles, Goals and Policies were used to evaluate the current application of ecosystem-based fisheries management and to develop recommendations for further implementation of such approaches.

BASIC ECOSYSTEM PRINCIPLES, GOALS AND POLICIES

Based on the Panel's experience and review of the fisheries ecosystem literature, we suggest that the following Principles, Goals and Policies embody key elements for ecosystem-based management of fisheries.

Principles

- The ability to predict ecosystem behavior is limited.
- Ecosystems have real thresholds and limits which, when exceeded, can effect major system restructuring.
- Once thresholds and limits have been exceeded, changes can be irreversible.
- Diversity is important to ecosystem functioning.
- Multiple scales interact within and among ecosystems.
- Components of ecosystems are linked.
- Ecosystem boundaries are open.
- Ecosystems change with time.

Goals

- Maintain ecosystem health and sustainability.

Policies

- Change the burden of proof.
- Apply the precautionary approach.
- Purchase "insurance" against unforeseen, adverse ecosystem impacts.
- Learn from management experiences.
- Make local incentives compatible with global goals.
- Promote participation, fairness and equity in policy and management.

TO WHAT EXTENT ARE ECOSYSTEM PRINCIPLES, GOALS AND POLICIES CURRENTLY APPLIED IN RESEARCH AND MANAGEMENT?

The Panel considered a management system based on the ecosystem Principles, Goals and Policies, as a framework with which to evaluate the current application in U.S. marine fisheries management and research. This model was then compared to the current state of research and management.

We conclude that NMFS and the Regional Fishery Management Councils (Councils) already consider and apply some of the Principles, Goals and Policies outlined above, but they are not applied comprehensively or evenly across Council jurisdictions, NMFS Regions, or ecosystems. The fact that the Principles are not applied consistently in U.S. fisheries management and research should not be interpreted as reluctance or intransigence on the part of these entities to adopt ecosystem approaches. Rather, these agencies lack both a clear mandate and resources from Congress to carry out this more comprehensive, but ultimately more sustainable approach. Furthermore, the ecosystem-based management of fisheries is a relatively new concept and there are considerable gaps in knowledge and practice.

HOW CAN WE EXPAND THE APPLICATION OF ECOSYSTEM PRINCIPLES, GOALS AND POLICIES TO FISHERIES RESEARCH AND MANAGEMENT?

Several practical measures can be implemented immediately to make U.S. fisheries management and research more consistent with the ecosystem Principles (see **Summary of Recommendations**). These measures comprise an incremental strategy for moving toward ecosystem-based fisheries research and management.

Councils should continue to use existing Fishery Management Plans (FMP) for single species or species complexes, but these should be amended to incorporate ecosystem approaches consistent with an overall Fisheries Ecosystem Plan (FEP). The FEP, to be developed for each major ecosystem under Council jurisdiction, is a mechanism for incorporating the Principles, Goals and Policies into the present regulatory structure. The objectives of FEPs are to:

- Provide Council members with a clear description and understanding of the fundamental physical, biological, and human/institutional context of ecosystems within which fisheries are managed;
- Direct how that information should be used in the context of FMPs; and
- Set policies by which management options would be developed and implemented.

Fisheries management based on the ecosystem Principles, Goals and Policies must be supported by comprehensive research. Significant ecosystem research is now conducted by the National Oceanic and Atmospheric Administration (NOAA) and other agencies, as well as the academic community. This research is critical and must continue, but must expand into several key areas. First, we must better understand the long-term dynamics of marine ecosystems and how they respond to human-induced change, particularly changes brought about by fishing. Second, we must develop governance systems which have ecosystem health and sustainability, rather than short-term economic gain, as their primary goals.

THE FUTURE OF ECOSYSTEM APPROACHES IN U.S. FISHERIES MANAGEMENT

Fisheries scientists and managers are beginning to grasp the potential of ecosystem-based fishery management to improve the sustainability of fisheries resources. Given the depressed state of many U.S. fisheries, this awareness must be expanded and actions taken to implement this approach. Our management recommendations and research actions provide a pragmatic framework within which to apply the ecosystem Principles, Goals and Policies. The success of this approach depends on full implementation of measures already underway as a result of the passage of the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA) (NMFS 1996), particularly the essential fish habitat (EFH) requirements and strengthened national standards. The recommendations contained in this report provide the required next steps.

While some of the recommended actions can start immediately, we believe that legislation is required to implement measures like the FEP. Given that legislative processes may require three to five years to enact the proposed regulations, we recommend interim actions by the Secretary of Commerce to develop demonstration FEPs and to encourage voluntary adoption by management Councils of the Principles, Goals and Policies proposed herein. We also are aware that these new tasks will require additional human and financial resources for full implementation.

The benefits of adopting ecosystem-based fishery management and research are more sustainable fisheries and marine ecosystems, as well as more economically-healthy coastal communities. We have identified the actions required to realize these benefits. We urge the Secretary and Congress to make those resources available.

SUMMARY OF RECOMMENDATIONS

Fisheries management and policy recommendations are directed toward Congress for implementation by NMFS and the Councils. Interim measures and research recommendations are directed toward the Secretary of Commerce for implementation by NMFS and other appropriate agencies.

Develop a Fisheries Ecosystem Plan (FEP)

Require each Council to develop an FEP for the ecosystem(s) under its jurisdiction. The FEP is an umbrella document containing information on the structure and function of the ecosystem in which fishing activities occur, so that managers can be aware of the effects their decisions have on the ecosystem, and the effects other components of the ecosystem may have on fisheries.

Each FEP should require the Councils to take, at least, the following eight actions:

1. **Delineate the geographic extent of the ecosystem(s) that occur(s) within Council authority, including characterization of the biological, chemical and physical dynamics of those ecosystems, and "zone" the area for alternative uses.**

The first step in using an ecosystem approach to management must be to identify and bound the ecosystem. Hydrography, bathymetry, productivity and trophic structure must be considered; as well as how climate influences the physical, chemical and biological oceanography of the ecosystem; and how, in turn, the food web structure and dynamics are affected. Transfers across ecosystem boundaries should be noted.

Within each identified ecosystem, Councils should use a zone-based management approach to designate geographic areas for prescribed uses. Such zones could include marine protected areas, areas particularly sensitive to gear impacts and areas where fishing is known to negatively affect the trophic food web.

2. **Develop a conceptual model of the food web.**

For each targeted species, there should be a corresponding description of both predator and prey species at each life history stage over time. FEPs can then address the anticipated effects of the allowed harvest on predator-prey dynamics.

3. **Describe the habitat needs of different life history stages for all plants and animals that represent the "significant food web" and how they are considered in conservation and management measures.**

Essential fish habitat (EFH) for target and non-target species at different life stages should be identified and described. Using habitat and other ecosystem information, Councils should develop zone-based management regimes, whereby geographic areas within an ecosystem would be reserved for prescribed uses. FEPs should identify existing and potential gear alternatives that would alleviate gear-induced damage to EFH, as well as restrict gears which have adverse affects. Further, FEPs should evaluate the use of harvest refugia as a management tool to satisfy habitat needs.

4. **Calculate total removals—including incidental mortality—and show how they relate to standing biomass, production, optimum yields, natural mortality and trophic structure.**

Total removals (i.e., reported landings, unreported landings, discards, and mortality to fish that come into contact with fishing gear but are not captured) should be incorporated into qualitative food web and quantitative stock assessment models. These models will allow managers to reduce uncertainty, monitor ecosystem health and better predict relative abundance of species affected by the harvest of target species.

5. Assess how uncertainty is characterized and what kind of buffers against uncertainty are included in conservation and management actions.

Given the variability associated with ecosystems, managers should be cognizant of the high likelihood for unanticipated outcomes. Management should acknowledge and account for this uncertainty by developing risk-averse management strategies that are flexible and adaptive.

6. Develop indices of ecosystem health as targets for management.

Ecosystem health refers to a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization that has evolved naturally. Provided that a healthy state can be determined or inferred, management should strive to generate and maintain such a state in a given ecosystem. Inherent in this management strategy would be specific goals for the ecosystem, including a description of "unhealthy" states to be avoided.

7. Describe available long-term monitoring data and how they are used.

Changes to the ecosystem cannot be determined without long-term monitoring of biological indices and climate. Long-term monitoring of chemical, physical and biological characteristics will provide a better understanding of oceanic variability and how climate changes affect the abundance of commercially important species and their corresponding food webs.

8. Assess the ecological, human, and institutional elements of the ecosystem which most significantly affect fisheries, and are outside Council/Department of Commerce (DOC) authority. Included should be a strategy to address those influences in order to achieve both FMP and FEP objectives.

Councils and DOC have authority over a limited range of the human, institutional and natural components of a marine ecosystem. It is important to recognize those components of the ecosystem over which fisheries managers have no direct control, and to develop strategies to address them in concert with appropriate international, Federal, State, Tribes and local entities.

Measures to Implement FEPs

The following are general recommendations to ensure effective development and implementation of FEPs:

1. Encourage the Councils to apply ecosystem Principles, Goals and Policies to ongoing activities.

In preparation for FEP implementation, Councils should begin to apply the ecosystem Principles, Goals and Policies to the conservation and management measures of existing and future FMPs. Three actions are particularly important; specifically, each FMP's conservation and management measures should:

- Consider predator-prey interactions affected by fishing allowed under the FMP.

- Consider bycatch taken during allowed fishing operations and the impacts such removals have on the affected species and the ecosystem as a whole, in terms of food web interactions and community structure.

- Minimize impacts of fisheries operations on EFH identified within the FEP.

2. Provide training to Council members and staff.

To facilitate an ecosystem approach and to aid the development and implementation of FEPs, NMFS should provide all Council members with basic instruction in ecological principles. Further, training materials should be made available to the fishing industry, environmental organizations and other interested parties.

3. Prepare guidelines for FEPs.

The Secretary of Commerce should charge NMFS and the Councils with establishing guidelines for FEP development, including an amendment process. NMFS and the Councils should conduct a deliberative process—similar to the process of developing National Standards Guidelines—to ensure that FEPs are realistic and adaptive.

4. Develop demonstration FEPs.

While encouraging all Councils to develop framework FEPs, the Secretary of Commerce should designate a Council or Councils to develop a demonstration FEP, as a model to facilitate rapid implementation of the full FEP when required in MSFCMA reauthorization.

5. Provide oversight to ensure development of and compliance with FEPs.

To ensure compliance with the development of FEPs, the Secretary of Commerce should establish a review panel for FEP implementation oversight. Implicit in this action is the establishment of a timetable for development of a draft FEP, its review by the panel, and any necessary revisions before the draft FEP becomes a basis for policy.

6. Enact legislation requiring FEPs.

To provide NMFS and the Councils with the mandated responsibility of designing and implementing FEPs, Congress should require full FEP implementation in the next reauthorization of the MSFCMA.

Research Required to Support Management

Require, and provide support for NMFS and other appropriate agencies to initiate or continue research on three critical research themes which will provide the information necessary to support ecosystem-based fisheries management. These themes are:

1. Determine the ecosystem effects of fishing.

Fishing affects target species, non-target species, habitat and potentially marine ecosystems as a whole. A directed program must be initiated to determine all effects of fishing on marine ecosystems.

2. Monitor trends and dynamics in marine ecosystems (ECOWATCH).

In order to detect, understand and react appropriately to ecosystem changes, a broad-scale ecosystem research and monitoring program must be undertaken based on the best available technology. We refer to this program as “ECOWATCH” because it will enable scientists and managers to observe ecosystem changes in a comprehensive manner.

3. Explore ecosystem-based approaches to governance.

Many of today’s fisheries problems stem from governance systems which create incentives that are incompatible with, or inimical to, ecosystem-level Goals (e.g., health and sustainability). Alternate governance systems must be identified which provide fishermen and others with incentives to consider the health and sustainability of the ecosystem as primary goals.

ECOSYSTEM-BASED FISHERY MANAGEMENT

SECTION ONE: INTRODUCTION

The National Marine Fisheries Service (NMFS) was charged by Congress to establish an Ecosystem Principles Advisory Panel (Panel) to identify ecosystem principles, evaluate how those principles are currently used in fishery management and research, and then to recommend measures that would expand their use in fishery management and research. Our Charter (Appendix A) describes the rationale for our effort and provides the charge to this Panel. Here we outline our views of the historical developments and current issues leading to this charge. We lay out a conceptual framework that includes management actions and research on marine resources and fisheries in an ecosystem context.

THE PROBLEM

The world's oceans are at or near maximum sustainable fishery yields. The number of overexploited stocks increased by 2.5 times between 1980 and 1990 (Alverson and Larkin 1994). Much of the global sustained yield is being accomplished by increased fishing for species at progressively lower trophic levels (Pauly et al. 1998). The prospect of increasing total sustained yield is unlikely (Pauly and Christensen 1995). Although fisheries provide direct or indirect employment to about 200 million people (Garcia and Newton 1997), overfishing is the most commonly observed result of fishery development. The consequences of overharvesting are expressed in social, economic, cultural and ecological changes. The ecological consequences of overfishing often are undocumented and may be poorly known or overlooked.

Since 1990, annual harvests by U.S. fleets have been slightly in excess of 4.5 million metric tons, with nearly half of that coming from two fisheries—menhaden and Alaska pollock. In its annual report to Congress on the status of the fisheries of the U. S., NMFS states that of the 727 managed stocks in the United States, 86 are overfished, 10 are approaching overfished status, and 183 are not overfished (NMFS 1997). This leaves 448 stocks, for which the status is virtually unknown. NMFS (1997) also indicates that "additional stocks will likely be identified as overfished" under the new definition of overfishing in the Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA).

While there are some encouraging recoveries (e.g., striped bass in the Atlantic and Pacific sardine), record-setting yields (e.g., Alaska salmon), and management successes (e.g., Pacific halibut), those cases are the exceptions rather than the rule. As in the global case, we should be concerned that overfishing will be a common consequence for most fisheries (Ludwig et al. 1993, Mooney 1998), although this need not be the case (Rosenberg et al. 1993).

This issue is urgent because the current harvest levels are high and because new fisheries will rise, be fully capitalized and reach unsustainable levels of catch levels before the management process can establish effective constraints. That, unfortunately, is the too-common lesson of history (Ludwig et al. 1993). In many cases, the ecological correlates of changing fish populations could have served as evidence of intensified exploitation effects. Frequently, the advent of a fishery and implementation of catch restrictions have unknown ecological consequences. Too often, we learn about ecological consequences after the fact, because we do not consider them in our decision-making, nor do we monitor ecosystem changes due to increased exploitation. Those lessons are not unique to fisheries. Many Federal, regional and State resource management agencies are now moving toward or considering an ecosystem approach in their attempt to provide a holistic framework for resource management. Fisheries must do so as well (Langton and Haedrich 1997).

FISHERIES IN AN ECOSYSTEM CONTEXT

Much of the foundation of fisheries science provides a basis for determining maximum yields so that fishing can safely remove surplus production (Hilborn and Walters 1992). However, when fishing is examined in an ecosystem context, the rationale for harvesting surplus production is unclear. Marine ecosystems are effective at capturing energy, cycling nutrients and producing biomass. Very little, if any of this biomass, is truly "surplus" to an ecosystem; before the advent of fisheries, it was recycled within the ecosystem. Consequently, our societal decision to harvest fish, induces ecological changes among competitors, prey and predators as the system responds to fishing and the trophically-induced changes fishing causes in ecosystems. These changes affect future levels of surplus production of the harvested population, including the possibility that there may be none.

We understand that fisheries must continue, because they provide food and desirable social and economic benefits and because the cultural traditions of fishing are highly valued. However, we also understand that overutilized fisheries are a serious threat to those traditions and benefits (National Research Council 1999). Conflict thus develops when management agencies (e.g., NMFS, Regional Fishery Management Councils, etc.) seek to implement sustainable yield policies for open-access resources, when fishery effects extend to animals protected by our Endangered Species Act or Marine Mammal Protection Act, and, most recently, when conservation and management interests assert that the burden of proof should be placed on the fishing industry (i.e., to demonstrate that exploitation does not produce large-scale and long-term ecological changes) (Dayton 1998). Finding the balance between competing interests is a difficult challenge, and each fishery will have its unique solutions. On the Federal level, NMFS will be expected to provide the ecological insights that are essential for long-term protection of fish stocks and their ecosystems.

Decisions regarding fishing practices derive from our social, economic, political and cultural context, and only secondarily from the ecological context that supports fisheries (Mooney 1998). A holistic view requires that we recognize fishery management and exploitation as a real and integral part of the marine ecosystem (Langton and Haedrich 1997). Because fishing actively removes a percentage of one or several species, it can affect the predators and prey of those species, their physical habitat, and it can change the growth and mortality rates of target and non-target species alike. In short, fishing can and is likely to alter the structure and function of marine ecosystems (Dayton 1998, Pauly et al. 1998). Humans are at the top of the global marine food chain. We thus have the obligation and opportunity to make choices to affect the marine environment positively.

While fishing has a long history, it is a relatively new force in the scales of evolutionary time. Fishing is typically a species-selective and size-selective agent of mortality and, therefore, is unlike the natural causes of mortality. Most of the fish removed by fishing activities are in the middle or near the tops of food webs in their habitats. Fishing can be viewed as a keystone predator; the ecological effects of fishing are therefore substantially greater and more complex than simply the biomass removed. Thus, we should expect that substantial changes have or could occur in those ecosystems due to fishing. We have witnessed changes in the landscape around us with the advent of technology evolved from the axe and the plow. We should expect equally profound ecological changes from modern, large-scale uses of the hook and net.

Nature has limits

If nature is a shifting mosaic or in essentially continuous flux, then it may be wrong to conclude that whatever societies choose to do in or to the natural world is fine. The question can be stated as, "If the state of nature is flux, then is any human-generated change okay?" ... The answer to this question is a resounding "No!" ... Human-generated changes must be constrained because nature has functional, historical, and evolutionary limits. Nature has a range of ways to be, but there is a limit to those ways, and therefore, human changes must be within those limits. (Pickett et al. 1992).

MANAGING FISHERIES IN AN ECOSYSTEM CONTEXT

Ecosystem-based fisheries management does not require that we understand all things about all components of the ecosystem. We know that the traditional single-species approach of fisheries management is tractable, but we also know that it may not be sufficient. We know that an ecosystem perspective is desirable, but it is complex and unpredictable. There simply is not enough money, time or talent to develop a synthetic and completely informed view of how fisheries operate in an ecosystem context. There will always be unmeasured entities, random effects, and substantial uncertainties, but these are not acceptable excuses to delay implementing an ecosystem-based management strategy.

Each fishery and each ecosystem is unique and yet, in all cases, we are confronted with four fundamental problems:

- We do not have a complete understanding of the ecological system that produces and supports fishes.
- We cannot forecast weather or climate and their effects on ecosystems.
- Systems evolve over time and knowing how the system works does not necessarily mean that an ecosystem would respond predictably to future changes in weather, climate or fisheries.
- Our institutions are not configured to manage at the ecosystem scale. Fish and the fisheries that pursue them are not easily aligned with our political and jurisdictional boundaries.

These constraints are not unique to fisheries, they confront all attempts to manage natural resources in an ecosystem context. We know that the removal of one species can and does affect others, but rarely have we developed management plans that adequately account for those direct and indirect effects. We know that ecosystems have a limited carrying capacity that results in bounds on fish yields. We know that habitat loss contributes to declines in species abundance, but too often we only regulate catch, gear or effort for one target species as a way to compensate for habitat loss and its effects on other species. We know that major, unexpected events (e.g., El Niño) can alter ecosystem processes, thus affecting species targeted by fisheries, but we have no method for integrating these events into our assessments of target species population trends (Mantua et al. 1997, Francis et al. 1998).

What are the potential gains of implementing an ecosystem approach to management, and how do we develop a holistic view that is both sufficient and tractable? In this report, we develop a strategy for implementing ecosystem-based management.

First, we develop a conceptual model that sets fisheries in the context of what we know about ecosystem theory (which is provided in the section on **Ecosystem Principles, Goals and Policies**). Second, we provide a brief assessment of the extent to which ecosystem principles, goals and policies are applied in U.S. fisheries research and management (**Current Applications of the Principles, Goals and Policies**). Third, we offer a series of specific recommendations for applying these principles to the operational context of NMFS, the Regional Fishery Management Councils (Councils), their administrative structure and their management activities (**Recommendations for Implementing the Ecosystem Principles, Goals and Policies in U.S. Fisheries Conservation, Management and Research**). Finally, we recommend a comprehensive research program to provide the ecological and governance underpinnings for ecosystem-based fishery management.

Taken as a whole, the report presents our best

Legal Authorities for Ecosystem Management of Fisheries

The Magnuson-Stevens Fishery Conservation and Management Act allows fishery managers to consider ecosystems in setting management objectives. National Standard 1 requires conservation and management measures to "prevent overfishing while achieving, on a continuing basis, the optimum yield from each fishery" (Sec. 301(a)(1)). The "optimum" yield is defined as providing "the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems" (Sec. 3(28)(A)). Moreover, the optimum yield is prescribed as "the maximum sustainable yield from each fishery, as reduced by any relevant economic, social or ecological factor" (Sec. 3(28)(B)). In addition, the Act states as one of its purposes "to promote the protection of essential fish habitat" (Sec. 2(b)(7)). To the extent that ecosystems are not being adequately considered in FMPs, it is not because of a lack of statutory authority so much as it is a lack of direction about what information is required and how it should be put into operation.

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advice about innovative approaches that can help set fisheries in an ecosystem context. Ecosystem-based management is an important new challenge. We expect that NMFS and Council managers and scientists will develop creative ways to help meet that challenge. But these new approaches cannot substitute for compliance with existing mandates. Ecosystem-based management will require re-evaluation of the institutional structure necessary for effective management. It will also demand a strong political will expressed through Congress, NMFS and the Councils—one based on a broader appreciation of the ecosystem context within which we prosecute our fisheries (Hutchings et al. 1997).

SECTION TWO: ECOSYSTEM PRINCIPLES, GOALS AND POLICIES

There are two requirements for managing human interactions with marine ecosystems. One is to develop an understanding of the basic characteristics and principles of these ecosystems—what patterns they exhibit and how they function in space and time. The second is to develop an ability to manage activities that impact marine ecosystems, consistent with both their basic principles and with societal goals concerning the kinds of behavior we would like ecosystems to exhibit (i.e., health and sustainability).

This section lists eight basic ecosystem principles (Principles) and their parallels in human systems that are part of marine ecosystems. A discussion of societal goals (Goals) for ecosystem-based management follows. Finally, a list of general management policies (Policies) to achieve the Goals is provided.

BASIC ECOSYSTEM PRINCIPLES

Marine ecosystems are complex, adaptive systems composed of interconnected groups of living organisms and their habitats. Living organisms are constantly adapting and evolving to their environment (both to the physical environment, which varies on multiple scales, and to other living organisms with which they co-exist); this evolution leads to complex, sometimes chaotic dynamics.

Marine ecosystems are generally extensive and open. Their fluid environments are subject to variability in both local and remote inputs of energy (a consequence of physics operating on many spatial and temporal scales) which may dominate such systems. Highly variable and chaotic dynamics of living resources are often observed as well.

Today, humans are a major component in most ecosystems. The human component of the ecosystem includes the humans themselves, their artifacts and manufactured goods (economies), and their institutions and cultures. The human imposition of fishing mortality, at rates often higher than natural mortality, can have major impacts not only on targeted species but on the ecosystem itself.

The following eight Principles have analogs in both the human and nonhuman aspect of ecosystems:

1. **The ability to predict ecosystem behavior is limited.**

   Uncertainty and indeterminacy are fundamental characteristics of the dynamics of complex adaptive systems. Predicting the behaviors of these systems cannot be done with absolute certainty, regardless of the amount of scientific effort invested. We can, however, learn the boundaries of expected behavior and improve our understanding of the underlying dynamics. Thus, while ecosystems are neither totally predictable nor totally unpredictable, they can be managed within the limits of their predictability.

Properties characterizing marine ecosystems may vary within wide bounds on decadal and longer time scales (Fig.1). For example, El Niño events and decadal climate changes may displace species, restructure communities and alter overall productivity in broad oceanic areas. Other phenomena, sometimes operating on smaller time scales, may precipitate regime shifts characterized by major fluctuations in constituent species (Steele 1996), but our ability to predict such events is only now evolving (Langton et al. 1996) and will always be shrouded in a degree of uncertainty. Nevertheless, management policies can be guided by the broad understanding we possess of marine ecosystem boundaries and production potential limits.

The ability to predict human behavior in fishery systems is also limited, but evolving. Many fishermen pass through rounds of fishing in regular annual patterns, markets respond in predictable ways to price changes, and fishermen often have predictable responses to policy proposals or regulatory changes. Fisheries systems respond to

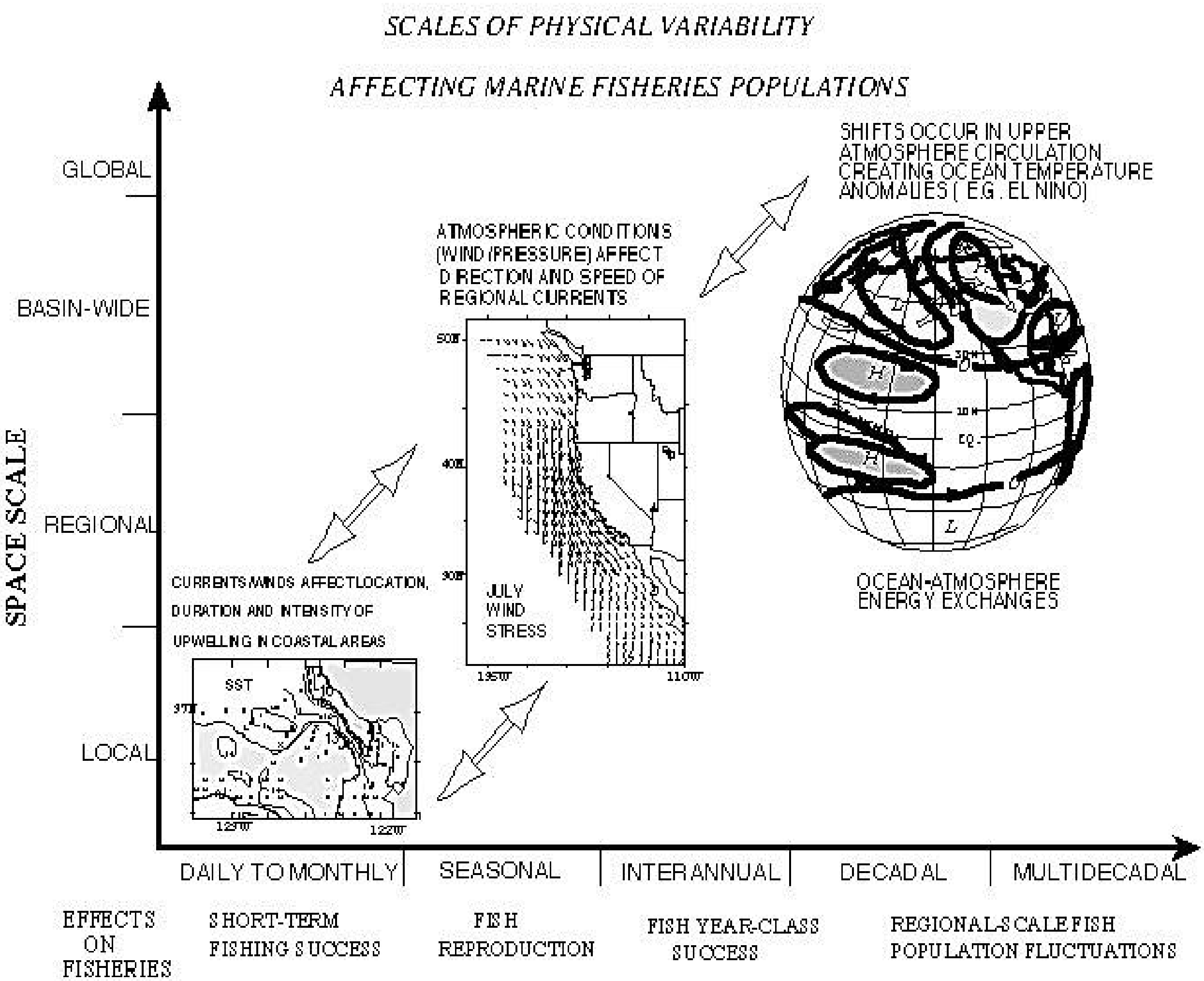

Figure 1. Scales of physical variability affecting marine resources. Variability in marine ecosystems is linked to variability in the physical environment on a continuum of time and space scales. We are often constrained to work on scales at which data are available, and long term monitoring must be carefully designed to address appropriate scales. Figure courtesy of NMFS Pacific Fisheries Environmental Laboratory.

global market trends and economic changes, social preferences and philosophies. The ability to describe, explain and predict these human behaviors, although the behaviors vary according to circumstance, is increasing with the growing body of social scientific data and information on fishery systems.

2. **Ecosystems have real thresholds and limits which, when exceeded, can effect major system restructuring (Holling and Meffe 1996).**

Ecosystems are finite and exhaustible, but they usually have a high buffering capacity and are fairly resilient to stress. Often, as stress is applied to an ecosystem, its structure and behavior may at first not change noticeably. Only after a critical threshold is passed does the system begin to deteriorate rapidly. Because there is little initial change in behavior with increasing stress, these thresholds are very difficult to predict. The nonlinear dynamics which cause this kind of behavior are a basic characteristic of ecosystems.

The concepts of limits and thresholds have been misused in single-species fishery management in the sense that they have been viewed as targets for fish catches rather than levels to be avoided. Because single-species management has prevailed, limits and thresholds rarely have been applied in a broader ecosystem context. Limits in fisheries management often have been biological reference points such as prescribed fishing mortality rates or yields, that are set without concern for other components in the ecosystem. Many limits are in fact thresholds that, when exceeded, challenge the resilience of the managed stock and associated species. Experience has shown that some past target levels used by managers, for example maximum sustainable yield, because they are too close to critical thresholds (Caddy and Mahon 1995), ultimately lead to stock declines or damage to ecological communities. Thresholds are to be avoided to maintain resilience at the species and community levels. Fishery targets should be set conservatively, well below the limits and critical thresholds that compromise the productive potential and stability of the ecosystem. Limits and thresholds of non-targeted organisms have only recently been considered through mandates of the Marine Mammal Protection Act, the Endangered Species Act, and in the new overfishing level definitions, bycatch and essential fish habitat (EFH) provisions of the MSFCMA.

Human systems (fishermen, their communities and fishery management systems) are both resilient and generally resistant to change. Thresholds of profitability, tolerance of regulatory conditions, and risk or uncertainty-induced stress on fishery-dependent human communities are real. Thresholds must be determined through both constituent advice and independent research on individual and group responses to stress. Identification of reference points for the limits of human resilience may be possible.

3. Once thresholds and limits have been exceeded, changes can be irreversible.

When an ecosystem is radically altered, it may never return to its original condition, even after the stress is removed. This phenomenon is common in many complex, adaptive systems.

It is probable that some estuaries, coral reefs (Hughes 1994), and mangrove ecosystems have been irreversibly altered by fishing, aquaculture, and other habitat-destructive activities. Farther offshore, effects of fishing itself on abundances of target and non-target organisms may radically alter communities and ecosystems. It is too soon to know whether heavily fished systems, such as Georges Bank, will return to their previous states when fishing effort is relaxed (Fogarty and Murawski 1998). Fisheries scientists and managers have demonstrated an abiding faith in the ability of fish stocks to compensate for fishing effects by increasing their level of productivity. Implicitly, that faith is extended to ecosystems which support exploited stocks. Up to a point, recoveries are possible. In some coastal ecosystems, however, resilience and limits have been exceeded, often by the combined effects of habitat destruction and fishing, and it is doubtful if they will return to their original condition.

Changes in ecosystems may permanently alter human behaviors. When a fisherman goes out of business, when an annual season of fishing is disturbed, or when market flow is interrupted, it is often not possible to reestablish the former business, pattern or market. Some aspects of human systems and behavior can be reestablished given enough time and attention, whereas changes in natural components of ecosystems are typically more enduring. In contrast, policy and management systems are continually subject to change and reversal.

4. Diversity is important to ecosystem functioning.

The diversity of components at the individual, species, and landscapes scales strongly affects ecosystem behavior. Although the overall productivity of ecosystems may not change significantly when particular species are added or removed, their stability and resilience may be affected.

Long-term consequences of diversity losses due to overfishing or poor fishing practices in marine systems are largely unknown. It is clear, however, that the economic value of specific components of catch change dramatically as some stocks are overfished, to be replaced in the ecosystem by lower-valued species (Deimling and Liss 1994, Fogarty and Murawski 1998). At the ecosystem level, drastic alterations of diversity certainly have occurred, and biological productivity has been redirected to alternative species, but it is not clear that these ecosystems are less productive or less efficient. However, such ecosystems are often valued less; witness the loss of tourist revenue in areas that have suffered damage to coral reef systems. It is prudent to presume that changes in biodiversity will decrease resiliency of species, communities and ecosystems, especially with perturbations that occur over long time scales (Boehlert 1996).

This principle also applies to the human element. An economy with more than one sector, a community with more than one industry, a fishing family with more than one income from different sources, or an industry large enough to foster technological innovation, are all aspects of the strength in diversity found in human society. Communities which lose such diversity are more susceptible to stress and unexpected sources of change.

5. Multiple scales interact within and among ecosystems.

Ecosystems cannot be understood from the perspective of a single time, space, or complexity scale. At minimum, both the next larger scale and the next lower scale of interest must be considered when effects of perturbations are analyzed.

Consequences of perturbations at one scale in marine systems may be magnified at larger and smaller scales (Langton et al. 1995). For example, destruction of a species' spawning habitat—typically a small fraction of its range—may translate into major impacts on species associations and trophic interactions in the broader feeding areas of recruited fish. Likewise, effects of fishing on a broad ecosystem scale may have profound impacts on components of ecosystems far removed in space and time—scientists are investigating the relationship between pollock fishing and the general decline of Steller sea lion populations in the eastern Bering Sea and Gulf of Alaska. Seemingly small human perturbations, applied at a point in time or in one part of a marine ecosystem, may have unforeseen impacts because of the open nature and fluid environment that characterize marine ecosystems. These features elevate the probability that a stress applied at one scale will be transmitted and may have unforeseen effects at other scales in the ecosystem.

Human impacts on ecosystems cannot be understood from the perspective of a single time, space, or complexity scale. A fishing community is subject to perturbations both from its own members and from outside forces. Fishery systems in one location are subject to environmental, social, economic and regulatory forces far removed in time and space, especially with respect to markets.

6. Components of ecosystems are linked.

The components within ecosystems are linked by flows of material, energy, and information in complex patterns.

Critical linkages in marine ecosystems are sustained by key predator-prey relationships. Large, long-lived predators and small, short-lived prey (e.g., forage fishes) both contribute in major ways to marine fish catches. Heavy fishing may precipitate species replacements, both at lower trophic levels (e.g., sand lance replacing herring and vice-versa) and at upper trophic levels (e.g., sharks and rays replacing Atlantic cod) (Fogarty and Murawski 1998). Loss from ecosystems of large and long-lived predators is of particular concern because they potentially exercise top-down control of processes at lower trophic levels. Global data sets have indicated that the mean trophic level of fish caught declined significantly from 1950-1994 (Pauly et al. 1998). Fishing down food webs (i.e., fishing at lower trophic levels) disrupts natural predator-prey relationships and may lead first to increasing catches, but then to stagnating or declining yields.

Disruption of ecosystem linkages clearly may have resounding impacts on human economies and, in the worst cases, ecosystem stability and productivity are compromised. Components of human systems are linked by flows of material, energy and information. The collapse of a market may drastically change fishing behavior. A technological innovation or entry of a new segment of a fishing fleet may cause far-reaching changes in dependent human communities.

7. Ecosystem boundaries are open.

Ecosystems are far from equilibrium and cannot be adequately understood without knowledge of their boundary conditions, energy flows, and internal cycling of nutrients and other materials. Environmental variability can alter spatial boundaries and energy

inputs to ecosystems.

Productive potential of marine ecosystems is especially sensitive to environmental variability over a spectrum of temporal and spatial scales. The unbounded structure of marine communities provides the backdrop for the high (relative to terrestrial) variability that is observed (Steele 1991). Boundaries of ecosystems, or productive regions, shift with weather and longer-term climate change. Species abundances and distributions vary in accord with annual to decadal shifts in ocean features (e.g., Pearcy and Schoener 1987, Polovina et al. 1995, Roemmich and McGowan 1995, Francis et al. 1998, McGowan et al. 1998). In open systems, local heavy fishing in combination with major changes in ocean conditions (e.g., El Niño), can lead to fishery collapses and associated shifts in the partitioning of energy or biomass among trophic levels (e.g., Walsh 1981, Barber and Chavez 1983).

Human behavioral systems are also subject to variability over a spectrum of temporal and spatial scales, and cannot be understood without knowledge of their boundary conditions. Certain components of human systems (people) are closely related and interact regularly over time; others are only sporadically in contact and interact in cyclical or irregular patterns. The more intermittent or sporadic the contact or interaction, the less stable the human system (Axelrod 1984).

8. Ecosystems change with time.

Ecosystems change with time in response to natural and anthropogenic influences. Different components of ecosystems change at different rates and can influence the overall structure of the ecosystem itself and affect the services provided to society in the form of fish catch, income and employment.

Marine ecosystems experience directional changes. Shifts in climate are responsible for many such changes, but the role of biological interactions in the absence of human influence are largely unknown. Dramatic changes in coastal and estuarine ecosystems, attributable to long-term geological and erosional processes are easily observed (e.g., Chesapeake Bay, see Mountford 1996). Anthropogenic changes are all too common, especially in neritic and estuarine ecosystems, or enclosed seas (e.g., San Francisco Bay (Nichols et al. 1986), Great Lakes, Black Sea, Aral Sea, Chesapeake Bay). Species introductions, excess nutrient loading, damming of tributaries, poor stewardship of bordering forests, bad agricultural practices, and poorly-managed fisheries are examples of factors that cause change. Rapid advances in fishing technologies (e.g., vessel power, navigation, sensing-locating and harvest efficiency), the propensity for fisheries to selectively remove species, failure to control bycatch, and unintended damage to the physical structure of ecosystems, have changed the character of heavily fished ecosystems (e.g., Georges Bank) (Fogarty and Murawski 1998). Selective fishing, that often targets long-lived predators, can have cascading effects on community structure (Marten 1979, Laws 1977), while heavy industrial fishing on forage species may have unintended impacts on top predators, especially those (e.g., marine mammals) unable to adapt quickly to changes in the forage base. Removal of large whales through past whaling practices, likewise, may have lingering effects on the nature of ecosystem structures today (National Research Council 1996). Deterioration of coastal ecosystems may also generate active attempts at remediation or enhancement through aquaculture and other means (Morikawa 1994), which can also generate pollution and wastes (Wu 1995).

Human activities dependent on ecosystems may change in response to environmental change and changes induced by fishing and other activities. In the short run, these impacts may be considered the normal consequences of a highly variable activity. However, humans adapt to long-term changes in composition of fisheries by stopping fishing or shifting effort to other species; changes which may produce adverse impacts. In addition, changes in perception, values, preferences, patterns of use, and accumulation of knowledge or expertise may cause changes over time in the ways humans interact within ecosystems. Human components of ecosystems (especially technology and institutions) can change rapidly in ways that outstrip the capacity for change of other ecosystem components. Communities may continue to grow and consumption rates increase, for example, yet the capacity of the seas to increase yields of living marine resources is limited. Thus, fishery management policies must be prepared to take into account these factors.

BROADENING SOCIETAL GOALS FOR ECOSYSTEMS

Traditionally, societal goals have emphasized benefits to humans resulting from extractive uses of ecosystem components. For example, fishery management has typically had revenues, employment, recreational fishing opportunities, and/or maintenance of traditional lifestyles as explicit or implicit goals. From an ecosystem perspective, these goals need to be broadened to include concepts of health and sustainability (Lubchenco et al. 1991, National Research Council 1999). Ecosystem health is the capability of an ecosystem to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity and functional organization comparable to that of the natural habitat of the region (Sparks 1995). This concept is also referred to as biotic integrity, which is defined as a system's wholeness, including the presence of all appropriate elements and occurrence of all processes at appropriate rates (Angermeier and Karr 1994, Angermeier 1997). While the concept of health applied to marine ecosystems is relatively new and untested, it has become a guiding framework in several areas, including forest ecosystems (Kolb et al. 1994), agroecosystems (Gallopin 1995), desert ecosystems (Whitford 1995) and others (Rapport et al. 1995).

A healthy ecosystem provides certain ecosystem goods and services, such as food, fiber, the capacity for assimilating and recycling wastes, potable water, clean air, etc. (International Society for Ecosystem Health, 1998). How do we extract from, and otherwise utilize ecosystems, while maintaining their health and the array of non-use services that they also provide (Costanza et al. 1997) into the indefinite future?

The challenge to scientists and managers is to develop useful, quantitative measures of ecosystem health which can guide management. What level of fishing, for example, can a "healthy" ecosystem sustain? How can vigor and resilience be expressed quantitatively so that managers can maintain them within healthy limits? These are difficult questions which will not be answered in their entirety in the foreseeable future, but incremental implementation of ecosystem-based fisheries management will begin to identify ecosystem variables (or indicators) that are unacceptable. These could be used to guide management away from unhealthy ecosystem states.

GENERAL ECOSYSTEM-BASED MANAGEMENT POLICIES

Ecosystem Principles to achieve societal Goals must be implemented through ecosystem-based management Policies. There are three overriding aspects of the Principles that are taken into account in the six Policies discussed below. These are the exhaustibility of ecosystems (reflected in Principles 2 and 3), uncertainty about ecosystems (reflected in Principles 1, 2, 4, and 8), and the role of humans within ecosystems (reflected in all of the Principles). The exhaustibility of the ecosystem requires a policy to change the burden of proof (Policy 1). Both the exhaustibility of ecosystems and uncertainty about ecosystems require policies to manage by a precautionary approach (Policy 2) and to "purchase insurance" (Policy 3) against adverse ecosystem impacts. Uncertainty about ecosystems also dictates that there is learning from management experiences (Policy 4). The role of humans within ecosystems requires policies to make incentives for human behavior consistent with societal goals for ecosystems (Policy 5). Acceptance and effective implementation of the policies and management is served by promoting participation, fairness and equity (Policy 6). Each of the Policies is discussed below.

1. Change the burden of proof.

We live in a world where humans are an important component of almost all ecosystems. Thus, it is reasonable to assume that human activities will impact ecosystems. The *modus operandi* for fisheries management should change from the traditional mode of restricting fishing activity only after it has demonstrated an unacceptable impact, to a future mode of only allowing fishing activity that can be reasonably expected to operate without unacceptable impacts.

To date, almost any type of fishing activity has been allowed until problems arise and regulations are established to solve them. Decision makers have to be convinced that management restrictions are needed. As W. F. Thompson (1919) wrote ". . . proof that seeks to change the way of commerce and sport must be overwhelming." Several authors have argued that a change is needed in this "burden of proof" (Sissenwine 1987, Mangel et al. 1996, Dayton 1998).

The key elements of the change are: 1) that future fishing activity should be allowed, if and only if it is explicitly provided for by fishing regulations which take into account risk and uncertainty and are promulgated to protect all elements of the ecosystem, and 2) that to a substantial degree the responsibility for providing the information and other support (e.g., the cost of management) necessary to manage fisheries in a sustainable manner, lies with participants in the fishery.

The first part of the change is analogous to changing the "null" hypothesis from "marine fisheries are inexhaustible" (Huxley 1883), to today's reality that marine fisheries will usually evolve to a state of overfishing unless they are carefully managed (Garcia and Newton 1997). The second element of the change makes clear that the direct beneficiaries from fishing should accept a greater share of the burden (i.e., costs) of fishery management. The standard of proof associated with the change (i.e., how much certainty is needed before a fishing activity is allowed) should be commensurate with the severity of the risk of a mistake. Applying the proper standard of proof is implicitly an element of the precautionary approach (see Policy 2).

In practice, changing the burden of proof will mean that, when the effects of fishing on either the target fish population, associated species, or the ecosystem are poorly known (relative to the severity of the potential outcome), fishery managers should not expand existing fisheries by increasing allowable catch levels or permitting the introduction of new effort and should not promote or develop new fisheries for so-called "underutilized species."

2. Apply the precautionary approach.

The precautionary approach is a key element of the United Nations Agreement for Straddling Stocks and Highly Migratory Species (United Nations 1996) and the Food and Agriculture Organization of the United Nations (FAO) Code of Conduct for Responsible Fisheries (FAO 1995). The U.S. is a signatory of both.

All ecosystems are complex and uncertainty is unavoidable. Within uncertainty, there is always a risk of undesirable consequences on fishery resources (e.g., overfishing) and/or on ecosystems. The precautionary approach was motivated by the widely accepted conclusion of scientists and fishery managers that many of the current problems of fisheries (i.e., a large number of overfished stocks) have been caused by the practice of making risk-prone fishery management decisions (i.e., to err toward overfishing) in the face of uncertainty (Garcia and Newton 1994). One approach to coping with uncertainty, which is widely applied to other human endeavors, is to encourage behaviors (often by enacting regulations) that reduce risk. Thus, the precautionary approach calls for risk averse decisions (i.e., to err toward conservation). FAO (1995) provides guidelines on the application of the precautionary approach.

3. Purchase "insurance" against unforeseen, adverse ecosystem impacts.

Even under the precautionary approach, there is a risk of unforeseen, adverse impacts on ecosystems. Insurance can be used to mitigate these impacts if and when they occur.

Insurance is a common method for guarding against the risks of unforeseen, adverse impacts of many human endeavors, and it has been proposed to guard against adverse ecosystem impacts (Costanza and Cornwell 1992). A requirement to purchase insurance provides an incentive to avoid risk-prone behavior (to reduce the cost of insurance). Thus, this management policy supports the precautionary approach.

Insurance can take many forms in addition to the traditional form of insurance policies or environmental bonds. Marine protected areas, for example, are a form of insurance. Protecting parts of the ecosystem from exploitation can insure future productivity and sustainability (Carr and Reed 1993, Dugan and Davis 1993, Agardy 1994, Bohnsack and Ault 1996, Roberts 1997, Lauck et al. 1998). Reserves also serve as baseline areas to evaluate natural variation in animal and plant populations that are free from fishing impacts.

Another form of insurance is a system to detect adverse impacts at an early stage so that actions can be taken to prevent further damage and/or to repair damage. This form of insurance is more effective if corrective actions have already been planned and adopted, such that there is minimal delay when a problem is detected.

Environmental bonding, marine protected areas and a system to detect and respond to adverse impacts can serve as both insurance and elements of a precautionary approach.

4. Learn from management experiences.

Management actions and policies can be considered as experiments and should be based upon hypotheses about the ecosystem response. This requires close monitoring of results to determine to what extent the hypotheses are supported.

Sustainable management of complex, adaptive ecosystems must itself be adaptive (Holling 1978). Management policies are experiments from which we can learn and improve, rather than absolute "solutions." Adaptive management in an "active" context would demand that hypotheses be put forward for testing and that alternative models be considered. Active, adaptive management often presumes that changes in fishing mortality rates will be imposed purposefully to induce a response in the fished stock or in the ecosystem under investigation (Walters 1986, Hilborn and Walters 1992). This "active" experimental approach to management is scientifically sound, but may have limited applicability in extensive marine ecosystems, at least within the time scales in which managers must act and in which fisheries operate. Walters (1997), while arguing eloquently about potential advantages of active adaptive management, recognizes the many arguments that detract from its adoption. For instance, modeling exercises and experiments required for the implementation of adaptive management have often been seen as excessively expensive or ecologically risky. A less aggressive form of the adaptive approach, however, is more generally acceptable and applicable. In this form, managers learn from actions to the greatest extent possible and respond expeditiously with alternative management actions. The willingness and institutional capability to respond are critical for this form of management to succeed.

5. Make local incentives compatible with global goals.

Changing human behavior is most easily accomplished by changing the local incentives to be consistent with broader social goals. The lack of consistency between local incentives and global goals is the root cause of many "social traps," including those in fisheries management (Costanza 1987). Changing incentives is complex and must be accomplished in culturally appropriate ways.

Global goals, such as long-term sustainability of a fish population or ecosystem health, are generally beyond the control of people at a local scale. Their incentive for conservation is diminished if they have no assurance that others will conserve or if they will not share in future benefits from conservation. This phenomenon is illustrated by the well known "race for the fish" which can lead to overfishing and wasteful overcapitalization (Graham 1935, Gordon 1954, Sissenwine and Rosenberg 1993).

A key element of making local incentives consistent with global goals is to allocate shares of the fishery such that people at local scales (down to the scale of individuals) have the incentive to use their shares efficiently (i.e., not wasting resources by racing for a share) and to conserve the entire resource to enhance the value of their shares in the future. Shares can take many forms such as a fraction of the total allowable catch (known as an individual quota), units of fishing effort, or exclusive rights to fish specific areas. Share-based allocation schemes might be broadened to take account of indirect impacts on ecosystems. There are several options for the local scale to which shares are allocated, such as to individuals or to communities. The most effective configuration of a share-based allocation scheme depends on the specific fishery and ecosystem that is being managed, but some form of share-based allocation will usually be necessary to fulfill this management policy.

6. Promote participation, fairness and equity in policy and management.

Ecosystem approaches to management rely on the participation, understanding and support of multiple constituencies. Policies that are developed and implemented with the full participation and consideration of all stakeholders, including the interests of future generations, are more likely to be fair and equitable, and to be perceived as such.

The level and quality of stakeholder participation in fishery management varies widely, as does the definition of “stakeholder.” Participation varies from passive consultation to shared decision making authority (Sen and Nielsen 1996). Systems organized to promote the maximum involvement of stakeholders, including the interests of future generations, and to emphasize the maximum appropriate delegation of responsibility and authority to the lowest possible levels of the management system (e.g., the local or regional level), tend to have the highest credibility among fishery constituents (Pinkerton 1989). This often leads to such effects as better data sharing and lower enforcement costs.

SECTION THREE: CURRENT APPLICATION OF THE ECOSYSTEM PRINCIPLES, GOALS AND POLICIES

We reviewed how the Councils and NMFS currently apply the ecosystem Principles, Goals, and Policies in order to help shape strategies for greater application in the future. We could not undertake a comprehensive fishery-by-fishery assessment of the application of the ecosystem Principles in current research and management activities. Such a task was beyond our scope given the limited time and resources available, and was certain to be incomplete. In addition, we saw little to be gained by evaluating the past performance of agencies relative to a set of ecosystem Principles, Goals, and Policies that were not known to the organizations whose performance might be judged. Most importantly, the 1996 amendments to the MSFCMA substantially changed the guidelines for certain management actions so that past practices are no longer relevant.

Information for the assessment was solicited from a number of sources, including NMFS Regional Offices and Fishery Science Centers. NMFS was asked to consult with Councils and other appropriate organizations to prepare this information. At our first meeting, representatives from each NMFS Fishery Science Center briefed us on the application of general ecosystem principles. Relying on that input and on our own knowledge and experience we then prepared regional overviews which served as the basis for this assessment.

To organize the assessment, we posed a series of questions that reflect the application of the Principles. These questions and our answers to each are given below.

Q: Have science-based ecosystem boundaries been identified, and are they used to specify resource management units?

A: Marine ecosystem boundaries are generally open, but bathymetric and other oceanographic features create biological discontinuities or shape gradients that allow marine ecosystems to be defined. On a regional scale, the Council jurisdictions reasonably correspond to such bathymetric and oceanographic features. Within these jurisdictions, management unit boundaries generally parallel the scientific information about the distribution of exploited fish stocks. Because fish distributions are also affected by the topographic and oceanographic features that are important to other biological components of ecosystems, it is often the case that management units corresponding to stock distributions also correspond to ecosystem boundaries. For example, this occurs with cod in the Gulf of Maine ecosystem, which are managed as a single stock by the New England Fishery Management Council. There are many situations where this is not the case, and many cases where the scientific basis for defining stock boundaries is minimal. Exchange rates across boundaries are seldom known or explicitly considered in management. This is particularly true for highly migratory species such as tunas, swordfish and billfishes. Exchange rates are important within ecosystems for some forms of management, such as area closures (including marine protected areas) that are used to conserve exploited stocks of fish, or more broadly, to conserve marine ecosystems.

The issue of ecosystem boundaries also has connections with human institutions. In some cases, the jurisdiction of management institutions does not match ecosystem boundaries or stock boundaries of some resources. This has led to various arrangements for interjurisdictional management of fisheries, such as international commissions, interstate fishery management commissions, and joint Fishery Management Plans (FMP) of two or more Councils. While some useful steps have been taken to deal with interjurisdictional issues, little consideration has been given to mobility of the fishing industry (both recreational and commercial) between jurisdictions, or to the diversity of people within the jurisdictions.

Another factor related to the definition of ecosystem boundaries is the impact that nonfishing sectors of society have on marine ecosystems. Management of coastal resources, agriculture and forestry, in addition to fisheries, is also required to effectively apply the ecosystem Principles, Goals and

Policies. If it is impractical to include these activities within ecosystem boundaries, exchanges across boundaries caused by these activities must be considered. In addition, institutional arrangements are needed to address cross-sectorial effects on ecosystems. Generally, such arrangements are lacking, although the recent MSFCMA amendment that calls for the identification of EFH should be an impetus for making such arrangements.

We conclude that ecosystem boundaries are generally defined and are reflected in management, but these definitions will have to be amended in order to integrate our recommendations for an ecosystem approach to management.

Q: Is scientific uncertainty in stock assessments and knowledge about marine ecosystems described to managers, and is this uncertainty considered in FMPs (such as by including buffers)?

A: Many sources of uncertainty affect stock assessments: 1) imperfections in catch statistics (sometimes from misreporting), 2) imprecise estimates of biological parameters, 3) variability in fishery independent resource surveys, and 4) natural variability in biological processes, particularly in recruitment. All these sources of uncertainty should be considered when determining the variance associated with estimates of current and future stock size. But, the uncertainty in stock assessment estimates is not always characterized, and even when it is, the true uncertainty is probably greater since it is difficult to account for all sources of uncertainty. Nevertheless, managers are usually made aware of at least some degree of uncertainty; their reaction to uncertainty varies among regions. For example, the North Pacific Fishery Management Council is noted for generally acting conservatively in the face of uncertainty (i.e., applying the precautionary approach), whereas some other Councils have consistently done the opposite (i.e., making risk-prone decisions) in the past. Recent changes in the MSFCMA and international agreements requiring the application of the precautionary approach should encourage risk-averse decisions by all Councils in the future.

Stock assessment uncertainty is only one of several areas of imprecision that should concern fishery managers. Uncertainty about fishery effects on ecosystems is high and generally is not characterized. There are some cases where fishery managers have attempted to account for ecological relationships in spite of uncertainty, such as prohibiting pollock trawling within 10-20 miles of islands that are occupied by endangered Steller sea lions, to minimize the risk that near-shore fishing will deplete their prey, however, these cases are rare.

Scientific uncertainty in stock assessments and ecosystems is an inherent reflection of highly complex systems that extend over vast areas and depths. We conclude that uncertainty is characterized to some degree. In the future, fishery managers need to consistently apply the precautionary approach in the face of uncertainty.

Q: Is there routine monitoring of ecosystems and are the results used to support management?

A: The fish component of marine ecosystems is monitored routinely for many stocks and in most U.S. regions. Standardized trawl surveys of the northeastern U.S., initiated in 1963 and now conducted three times per year, are the most extensive example of monitoring of the fish component, yet, some fish stocks are virtually unsampled by the current survey program. In other regions, fish stocks are only surveyed every third year. In addition, fishery-dependent monitoring is conducted.

Monitoring of fish is far more extensive than is the monitoring of other marine ecosystem components. Some systems such as San Francisco Bay, Chesapeake Bay and the Northeast U.S. have long-standing ecosystem monitoring programs which measure ecosystem components other than fish, but the use of such programs is not widespread for ecosystems and fisheries under the jurisdiction of NMFS and the Councils.

Other ecosystem components that might be monitored are human demographics, marine mammals, birds, benthos, zooplankton, phytoplankton, and physical and chemical factors. While there is a significant amount of human census data and other information about people, changes in the demographics and cultural aspects of participants in fisheries are not routinely monitored, nor are there studies of economics. As a result of the Marine Mammal Protection Act, many populations of marine mammals are monitored, although this monitoring is limited in extent. Coastal sea birds are monitored in some regions. There are long-term time-series of plankton data, such as California Cooperative Oceanic Fisheries Investigations data off of California, and Marine Resources Monitoring Assessment and Prediction and Continuous Plankton Recorder data in New England waters. With advances in satellite remote sensing, it is now possible to monitor primary production and some physical variables synoptically over vast regions. There has been very little monitoring of benthos, except for a few sites and generally for only a few years. Lack of time-series data on the benthos is an impediment to understanding the effects of mobile fishing gear on benthic habitats.

Monitoring data are used in a variety of ways in the management process. Fish monitoring results constitute a critical input to stock assessments, which are used to support fisheries management. Limited socioeconomic data are used for various impact analyses that accompany fishery management decisions. Information on other ecosystem components is sometimes considered to help explain variability in fishery resources, but such relationships are usually uncertain or speculative and therefore are seldom used by managers.

Q: Have the food webs of target species been identified and is this information used in FMPs?

A: There are extensive databases on the stomach content of fishes in some regions, such as the Northeast and Alaska where hundreds of thousands of fish of many species have been sampled over several decades. Some multispecies predator/prey models have been developed, but generally these models are better at explaining the effects that trophic relationships might have had, rather than predicting future patterns and variations.

To date, use of food web information in fisheries management has been limited. This reflects the limited predictive power of existing multispecies predator/prey models. Knowledge of food webs is considered qualitatively in some management decisions, such as the Pacific Fishery Management Council's FMP for anchovies which sets aside some of the population as forage.

Q: Are total removals, including discards, taken into account in stock assessments and management?

A: Total removals are made up of the reported landings, unreported landings, discards, and mortality to fish that come in contact with fishing gear but are not captured. Stock assessments are routinely based on reported landings and discard estimates, if available. Discard estimates are derived from fishing vessel logbook reports and/or from at-sea observers on fishing vessels. Larger groundfish vessels operating in the northeast Pacific are required to have 100% observer coverage, and this improves the quality of discard data for these fisheries. Observers in the Gulf of Mexico shrimp fishery estimate that discards of finfish are over four times larger than the catch of shrimp. For at least one important Gulf species, red snapper, discards are the largest component of mortality. But there are many species where there are virtually no discard data (although discarding exists). Estimates of unreported landings and/or mortality of fish that come in contact with fishing gear, but are not captured, are very rare. Stock assessments are robust to under estimates of total removals so long as the proportion not included in removal estimates is constant, which is a reasonable assumption under some circumstances.

There are alternative ways for fisheries management to account for total removals. When discards are estimated, they are usually included in the stock assessments which support fisheries management. For example, discards of juvenile swordfish are factored into the swordfish stock assessments conducted by the member countries of the International Commission for the Conservation of Atlantic Tunas. The discards may be taken into account by reducing the allowable catch based on the expected level of discards, or by counting estimates of discards against the allowable catch. Alternatively, management might use measures that are less dependent on knowing total removals, such as gear restrictions, effort controls or area closures.

We conclude that total removals are probably underestimated, and significantly so in some cases. Therefore, more effort is needed to estimate total removals and to apply management strategies that are robust in the face of uncertainty about total removals.

Q: Have the effects of fishing on the ecosystem been studied?

A: This is a relatively new research endeavor. There is clear evidence that fishing alters species composition (e.g., fishing on Georges Bank appears to have shifted the community from predominately Atlantic cod to sharks and skates (Fogarty and Murawski 1998)). Pauly et al. (1998) recently showed that there has been a significant worldwide reduction in mean trophic level of species fished. Several studies that have demonstrated that mobile fishing gear alters benthic habitat (Auster and Langton 1999), but little is known about the implications of these changes. Further, there has been even less research conducted on other fishing gears.

Q: Are the habitat needs of different life history stages of target and nontarget species known and are they considered in FMPs?

A: The habitats that are used by some or all of the life-history stages of many species of fish are known. But habitat utilization does not mean that the habitat is obligatory (i.e., the species must have that habitat to successfully complete its life-cycle). The mechanistic relationship between a fish species at a particular life history stage, and the type of habitat it occupies, is unknown for most species and life-history stages. It is most critical to understand the essential habitat needs of fish near shore, where anthropogenic effects on habitat are likely to be most significant.

The relationships between fish and habitat are summarized as a basis of EFH determinations to be included in FMP amendments, as required by the MSFCMA. These amendments require that the habitat needs of fish populations be given serious consideration in the future when government agencies make decisions that are likely to adversely affect EFH. Fishing itself is an activity that has the potential to affect EFH. Taking account of these potential effects is a major challenge facing Councils.

SECTION FOUR: RECOMMENDATIONS FOR IMPLEMENTING THE ECOSYSTEM PRINCIPLES, GOALS AND POLICIES IN U.S. FISHERIES CONSERVATION, MANAGEMENT AND RESEARCH

In this section, we describe approaches for incorporating the Principles, Goals and Policies established in Section II into the fisheries management and research processes of the current Council system. We strongly believe that the key to an effective ecosystem approach is to fish more conservatively. The depressed condition of many U.S. stocks is related primarily to unsustainable levels of fishing effort, rather than ecosystem effects. With few exceptions, scientists understand the levels of fishing effort required to produce sustainable yields, but fishery managers are challenged by a highly politicized process to exceed those levels for short-term gains. Setting maximum sustainable yield and optimum yield conservatively, and respecting these conservative goals in the face of political and economic pressure is essential in any ecosystem approach.

Many current U.S. fishery management problems such as overfishing, bycatch and protection of EFH are addressed in the Sustainable Fisheries Act (SFA) of 1996. Each of these SFA provisions is an important step toward the use of ecosystem principles in fishery management. However, these measures do not add up to an ecosystem approach.

FMPs for single species or species complexes should continue to be the basic tool of fisheries management for the foreseeable future. However, managements actions under FMPs alone are not sufficient to implement an ecosystem approach. A mechanism is required to integrate FMPs and include the ecosystem Principles, Goals, and Policies in a way that will be meaningful. That mechanism is the Fisheries Ecosystem Plan (FEP).

THE FISHERIES ECOSYSTEM PLAN (FEP)

Our primary recommendation is that each Council (including NMFS in the case of Atlantic highly migratory species) develop the FEP as a mechanism for incorporating ecosystem Principles, Goals and Policies into the present fisheries management structure. The objectives of FEPs are to:

- Provide Council members with a clear description and understanding of the fundamental physical, biological, and human/institutional context of ecosystems within which fisheries are managed;
- Direct how that information should be used in the context of FMPs; and
- Set policies by which management options would be developed and implemented.

Councils would develop FEPs for each major ecosystem under their jurisdiction. For example, the North Pacific Fishery Management Council might have two FEPs—one for the Bering Sea/Aleutian Islands and one for the Gulf of Alaska. Councils with overlapping ecosystems, or with significant species migration across ecosystem boundaries would work together on a joint FEP. In the event of transnational ecosystems, appropriate international arrangements would be sought to implement an ecosystem approach.

The FEP should be used as a metric against which all fishery-specific FMPs are measured to determine whether or not management effectively incorporates the ecosystem Principles, Goals and Policies. The FEP should also contain regulations or management measures which extend across individual FMPs. The FEP should serve as a nexus for existing FMPs and provide a context for considering Council management actions with respect to all living marine resources, whether managed or not.

FEPs must contain the information about ecosystem that allows managers to make informed decisions, but the primary purpose of the plans is to prescribe how fisheries will be managed from an ecosystem perspective. Careful consideration must be given to the structure and required content of an FEP to balance the needs for plans to be both substantive and realistic. It is appropriate that NMFS lead a deliberative and inclusive (of a broad range of interests and expertise) process to prepare guidelines for FEPs (analogous to the processes that have been used to prepare guidelines for implementing National Standards). Preparation of such specific guidelines was beyond the scope of our Panel Charter, but we did identify Council actions that must be taken when guidelines are prepared, to be consistent with the Panel's recommendations:

1. Delineate the geographic extent of the ecosystem(s) that occur(s) within Council authority, including characterization of the biological, chemical and physical dynamics of those ecosystems, and "zone" the area for alternative uses.

2. Develop a conceptual model of the food web.

3. Describe the habitat needs of different life history stages for all plants and animals that represent the "significant food web" and how they are considered in conservation and management measures.

4. Calculate total removals—including incidental mortality—and show how they relate to standing biomass, production, optimum yields, natural mortality and trophic structure.

5. Assess how uncertainty is characterized and what kind of buffers against uncertainty are included in conservation and management actions.

6. Develop indices of ecosystem health as targets for management.

7. Describe available long-term monitoring data and how they are used.

8. Assess the ecological, human, and institutional elements of the ecosystem which most significantly affect fisheries, and are outside Council/Department of Commerce (DOC) authority. Included should be a strategy to address those influences in order to achieve both FMP and FEP objectives.

The eight FEP actions are elaborated below:

1. Delineate the geographic extent of the ecosystem(s) that occur(s) within Council authority, including characterization of the biological, chemical, and physical dynamics of those ecosystems, and "zone" the area for alternative uses.

The ecosystems supporting fisheries in the United States vary markedly (Apollonio 1994), and the way in which fisheries are managed within them will vary according to their individual characteristics. Managers must be able to geographically delineate the systems under their authority, and have a scientific understanding of the structure, function, and processes that occur within their respective ecosystems, and between their systems and others. This delineation should include both ecological and human/institutional components and their interactions. This includes the extent of our knowledge of climate, how climate affects the physical and biological oceanography of the system, and how, in turn, these affect food web structure and dynamics.

Councils should use information from FEPs to develop zone-based management regimes. In a zoning approach, geographic areas within an ecosystem would be reserved for prescribed uses. For example, use of gears which are demonstrated to have an adverse effect on EFH could be limited to prescribed areas. Currently, FMPs are required to describe and mitigate gear effects on EFH, but FEPs should go further, not only identifying where habitat impacts occur, but also identifying specific zones where certain gears should be restricted. A zone-based approach could also limit fishing activities in areas where potential negative trophic impacts could occur. The North Pacific Fisheries Management Council's establishment of no-trawl zones in red king crab habitat is an example of such a measure. Zoning can also be used to limit bycatch, by restricting fishing activities in areas where high levels of bycatch are likely to occur.

A zoning approach should also include the establishment of marine protected areas. A species-specific approach to habitat protection, as currently practiced, may result in many small protected areas with occasionally conflicting regulations that are difficult to understand and often difficult to enforce. Complete protection of relatively large portions of marine ecosystems, in the form of harvest refugia, may provide the best way to characterize habitat needs and also serve as management tools (Bohnsack and Ault 1996, Roberts 1997). Each FEP should consider and evaluate the potential benefits of harvest refugia and support research to evaluate their use.

Marine Protected Areas

Marine Protected Areas (MPAs) offer promise as a means to implement the precautionary approach and mitigate the effects of fishing in an ecosystem (Yoklavich 1998). However, the utility of the approach depends on the way MPAs are defined and established. The concept of MPAs represents a continuum, from marine wilderness areas to areas in which only a few specific activities might be restricted. We use the term to mean the entire spectrum of usage, and suggest that managers carefully define their conservation and management objectives before determining the characteristics of a given MPA.

MPAs should be representative of the larger ecosystem and, as such, would serve as experimental sites for investigating processes and mechanisms that would be operable throughout the region. MPAs must be established with the understanding that ecosystems change over time and that research results have to be evaluated relative to this natural variability as distinct from variability resulting from human exploitation of a resource. MPAs represent a form of insurance against excessive exploitation. Although we aspire to a level of understanding that would allow for strategic management of our nation's fisheries, uncertainty and indeterminacy are fundamental ecosystem characteristics. Hence, research is needed on the optimal size of MPAs, sources and sinks for new recruits, and the social and management issues required for successful implementation.

2. Develop a conceptual model of the food web.

Fisheries managers cannot control the weather or long-term physical changes in the ecosystems that produce the managed resources. They can, however, control what species are fished and the total numbers and individual sizes of resources removed. Thus, managers should have a conceptual understanding of the food web, and should use that information in making decisions about harvest. For each species for which there is an FMP, there should be a description of both the prey species and the predators at each stage in the life cycle. Where information on certain species is not available for all life stages, managers should refer to species inhabiting similar ecological niches or their functional equivalents as the basis for defining trophic links. Following this, the FEP should contain an analysis of the anticipated impacts of the allowed harvest on predator-prey dynamics, even if data gaps force such a statement to be largely qualitative.

Ecosystem Modeling

Modeling is an essential scientific tool in developing ecosystem approaches for fishery management. Simple descriptions of prey and predator species and models of how they interrelate are good starting points but they are inadequate. What is required is a food-web based mathematical model. Such a model could examine factors that affect primary productivity and how changes in it affect the relationships that exist among all components of the ecosystem. Such a model could assist in assessing the trade-offs among harvests of fish species in different parts of the food web, how abundance of marine mammals relates to populations of its prey species, and how much of the total primary production is required to sustain ecosystem harvest. Recent models such as ECOPATH (Polovina 1984, Christensen and Pauly 1995, Pauly and Christensen 1995) have been applied and have provided insight into some fundamental ecosystem questions. ECOPATH provides a framework for summarizing natural rates of growth and consumption of marine populations. This allows small-scale studies or models (such as fish bioenergetics models or diet composition data) to be viewed in a common currency, in the context of the ecosystem as a whole.

Presently, dynamic mathematical models (e.g., ECOSIM (Walters et al. 1997)) are being developed but they have been applied only experimentally in actual fishery management situations. Using them as active parts of the FEP could facilitate model development and testing. Most importantly, models have the potential to provide managers with information about how ecosystems are likely to respond to changes in fishery management practices (Botsford et al. 1997). Like FEPs, these models will be unique to each system and its important attributes.

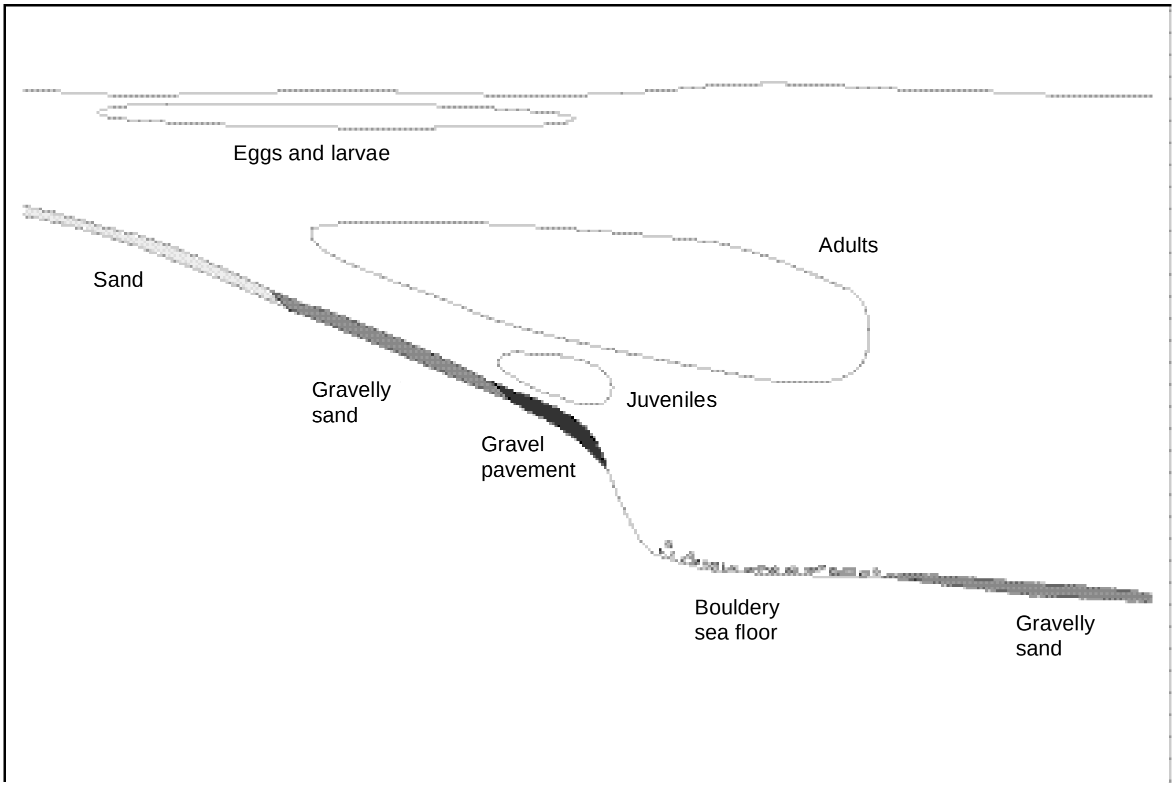

Figure 2. Life history stages of Atlantic cod versus habitat requirements as characterized for Georges Bank in the Northwest Atlantic (artwork by Dave Stanton, adapted from Lough 1989).

3. Describe the habitat needs of different life history stages for all plants and animals that represent the "significant food web" and how they are considered in conservation and management measures.

Marine organisms generally have different dietary and habitat requirements for each life cycle stage (e.g., Atlantic cod on Georges Bank; Fig. 2). Traditional management practices often limit fishing effort in an attempt to protect spawning stock while ignoring management strategies that would prevent negative effects on survivorship at each life cycle stage. In an effort to address this issue, FMPs are now required to include a description of EFH. This is probably best considered in a multiple-species context, including overlapping habitats of suites of species with similar life cycles that occupy similar habitats as well as their prey. Thus, each Council should include EFH considerations within the FEP, using the ecosystem approach to describe such habitat based on the EFH descriptions from existing FMPs.

4. Calculate total removals—including incidental mortality—and show how they relate to standing biomass, production, optimum yield, natural mortality and trophic structure.

Ecosystem overfishing occurs when fishing directly or indirectly results in a reduction of ecosystem health. Direct impacts on target species include changes in the total population status, age structure, and sex ratio within the population. Indirect impacts can occur on component species or on ecosystem health. Pauly et al. (1998) describe trophic effects of fishing which yield apparently nonlinear, unanticipated results with potential negative effects on sustainability. Thus, a measure of total removals of a target species should include fish landed and fish caught and released (with some determination of mortality rates of released fish), predation at each life history stage, and loss through incidental capture.

Mortality associated with bycatch can produce significant biological losses and ecological shifts in community structure within ecosystems (Alverson et al. 1994). To address bycatch issues, FEPs should: 1) identify potential shifts in community structure and their consequences, and indicate how they should be mitigated; 2) identify bycatch associated with particular gear types, not just by providing a list of species, but also by identifying how bycatch in a given species changes both spatially and temporally; and 3) identify existing or potential alternative gear types which would reduce bycatch.

5. Assess how uncertainty is characterized and what kind of buffers against uncertainty are included in conservation and management actions.

The more complex an ecosystem, the greater the unpredictability. The ultimate uncertainty and risk is associated with those practices that affect ecosystem equilibrium, such as significant changes in climate or hydrology that have potentially significant global effects. Therefore management actions that aim for specific outcomes should be accompanied by the anticipated probabilities associated with achieving those outcomes. Given the variability associated with ecosystem states and the general low precision, high variance, and unknown potential for bias in fisheries data—and thus in the models used to predict outcomes—managers must recognize the high likelihood for unanticipated results. Hence, decision-makers should account for this uncertainty with the development of flexible, adaptive, and risk-averse management strategies.

FEP should identify those factors or issues which are likely to bear the greatest degree of uncertainty within that ecosystem. Stock assessment reports, prepared for each new or continuing FMP, should characterize uncertainty and indicate how that uncertainty is incorporated into the assessment. The characterization of uncertainty in stock assessments is an example of how the policy of the precautionary approach should be incorporated into the FEP, and one of the best example of insurance against unknowable ecosystem dynamics.

Although uncertainty may render management strategies that are effective in one system ineffective in another, the application of the precautionary approach is a policy which can be implemented in any ecosystem. Because each ecosystem will have different levels of uncertainty and risk associated with it, managers must develop specific risk criteria for application of the precautionary approach within each system.

6. Develop indices of ecosystem health as targets for management.

The use of a goal such as ecosystem health to guide fishery management forces resource scientists and managers to define desired ecosystem states, typically based on historical information reflecting ecosystem structure and yield. Once this has been accomplished, management strategies can be developed to generate and maintain these healthy states. Defining a healthy ecosystem is problematic in practice, so we also recommend that managers identify “unhealthy” ecosystem states which should be avoided. For example, FEP goals could be to prevent the extinction of any ecosystem component, to maintain a specific, high mean trophic level in the ecosystem, or to maintain benthic biomass within the range of natural variability. Each Council should be charged to develop its own FEP goals and metrics based on unique ecosystem characteristics.

7. Describe available long-term monitoring data and how they are used.

Although most physical and biological databases represent relatively short periods of time and therefore do not characterize long-term variability, the amount and quality of physical data available relevant to fisheries have improved markedly in recent years (Boehlert and Schumacher 1997). These data are essential for the development of models to predict changes in oceanographic conditions. Biological baseline data often are difficult to evaluate, given the current impacts of fisheries on marine ecosystems and the largely unpredictable outcomes of these impacts. However, reasonable estimates of preexploitation conditions can be made in some cases (Pauly 1995).

Each FEP should include a prioritized long-term monitoring plan, designed to allow the assessment of the changing states of ecosystem health relative to established baseline conditions. This will be facilitated through the implementation of the research recommendations. As discussed by Christensen et al. (1996), monitoring programs should include ways to determine whether

Aquaculture and Stock Enhancement: Are Cautions being Heeded?

With declining fish stocks, there is growing pressure to artificially boost harvests, either through aquaculture in coastal waters or through stock enhancement. The potential benefits of aquaculture include: increased production of cultured fish which can contribute to food and economic security without placing additional pressure on wild stocks. In addition, stock enhancement may help rebuild or sustain depleted wild stocks.

However, many existing aquaculture programs have developed without attention to their impacts on marine ecosystems (Naylor et al. 1998). Salmon culture and ocean ranching provide good examples. Hatcheries have led to manifold problems, including interbreeding between native and non-native stocks (Lannan et al. 1989), decreases in genetic biodiversity (Ryman et al. 1995), introduced species problems, and threats to carrying capacity, even in the open ocean (Ogura and Ito 1994). Early calls to genetically "upgrade the wild stocks" (Moav et al. 1978) to improve production have given way to attention to the "usually negative" genetic impacts of aquaculture (Beveridge et al. 1994). Wilcove et al. (1992) captured this sentiment, stating "Introduced genes can be as harmful as introduced species, especially when hatchery-bred fish compete with wild populations."

Dramatic examples of human manipulation of coastal ecosystems are provided in Japan, where coastal fisheries have been maintained at a near constant level by increasing mariculture production and stock enhancement while natural production has declined (Morikawa 1994). Aside from potential genetic effects as noted above, high intensity coastal aquaculture decreases public access to the coastal ocean for recreation and other pursuits. Marine fish culture can also lead to additional pollution and wastes. Excess feed, feces and other organic matter from fish farms can accumulate in the benthos and result in a substantial alteration of the benthic community. (Wu 1995, Henderson and Ross 1995, Hansen 1994). In addition, some prophylactic chemicals and drugs used in fish culture have unknown impacts on marine ecosystems. Clearly, both stock enhancement and marine aquaculture must be approached carefully to maximize their benefits while ensuring the health of natural ecosystems and the continued production of wild stocks (Travis et al. 1998).

management actions effectively protect ecosystem function. Thus, these programs must be empirically sound and supported by rigorous statistical sampling that avoids bias. While the probability of accomplishing this is low—because replication is often unrealistic and sample sizes are, of necessity, quite small—it does not justify avoidance of establishing long-term monitoring programs (Walters 1986). In particular, the issue of cumulative impacts cannot be addressed without baseline data. Monitoring programs are essential to the success of fisheries management, particularly if we are to discern effects due to fishery policies from those due to other factors.

8. **Assess the ecological, human, and institutional elements of the ecosystem which most significantly affect fisheries, and are outside Council/DOC authority. Included should be a strategy to address those influences in order to achieve both FMP and FEP objectives.**

In many cases the preponderance of the ecosystem relevant to a particular fishery is under the jurisdiction of the Councils and DOC, but in many cases significant portions of the ecosystem will be outside of that jurisdiction. Examples include salmon, where inland water and habitat issues are paramount and under the jurisdiction of other Federal, State, local and tribal authorities; highly migratory species, where significant parts of the ecosystem are under the jurisdiction of different nations; or ecosystems as extensive as the Gulf of Mexico, where general water quality is critically affected by inflow from ecosystems as broad as the Mississippi River drainage area. Some elements of the ecosystem may be outside of Council/DOC jurisdiction; human constituents may move in and out of Council/DOC jurisdiction and many institutions other than the Councils/DOC may share authority over parts of the ecosystem.

Accounting for the effects of these external influences in the FEP is a two-stage process. First, Councils must identify the most significant elements which are outside Council/DOC authority. This list should include the most significant external effects on ecosystem health. Second, Councils should develop a strategic approach to mitigate each of the major impacts. This approach could include the development of agreements with other agencies to address significant ecosystem impacts, or increased research on ecosystem functions or processes which are affected by outside influences, and which may require mitigation.

Institutional and Human Ecologies—
The Case of Pacific Coast Salmon

The ecology of a Pacific coast salmon fishery includes not only the ocean environment but the rivers in which the fish spawn and the terrestrial habitat related to those rivers. The human ecology of that salmon fishery includes not only the commercial, tribal and recreational fishermen, but also their ancillary businesses and industries. There are also the businesses and industries which have direct effects on the ocean and the coastal riverine habitats (oil and gas, logging, hydroelectric power, development and construction, agriculture and other water diverters) and the citizens who are concerned about the salmon and their habitat even though they do not directly interact with the fish.

The institutional ecology of this salmon fishery includes NMFS, other Federal and State fishery agencies, Native American tribes, and all those institutions which govern the behavior of all of the constituent groups of the human ecology. In fact, 37 Federal agencies, in 9 executive level departments, have some authority over activities affecting marine fisheries and their habitat (Hinman and Safina 1992). Not only is it important to recognize the critical role of this broader set of institutions, but also the role of information, education, and involvement of all of the individuals and groups within the broader set of human constituents whose behaviors are governed by those institutions.

MEASURES TO IMPLEMENT FEPS

The following are general recommendations to ensure effective development and implementation of FEPs:

1. Encourage the Councils to apply ecosystem Principles, Goals and Policies to ongoing activities.

In preparation for FEP implementation, Councils should begin to apply the ecosystem Principles, Goals and Policies to the conservation and management measures of existing and future FMPs. Three actions are particularly important; specifically, each FMP's conservation and management measures should:

- **Consider predator-prey interactions affected by fishing allowed under the FMP.**

  Optimum yields should be set considering ecological factors and the integrity of the ecosystem, and total allowable catches should be justified with respect to total ecosystem biomass, production and interspecies relationships.

- **Consider bycatch taken during allowed fishing operations and the impacts such removals have on the affected species and the ecosystem as a whole, in terms of food web interactions and community structure.**

  FMPs should identify bycatch taken by gear types and should not just provide a list of species, but describe how bycatch changes temporally and spatially in a given fishery. Management actions should consider the implications of such removals and their consequences. FMPs should identify and consider existing or potential alternative gear types or fishing practices which could reduce such bycatch.

- **Minimize impacts of fisheries operations on EFH identified within the FEP.**

  Gear effects on habitat can be considerable. Gear used to harvest a particular species may directly or indirectly affect other species—managed or unmanaged—within the ecosystem. FMPs should not only identify such impacts but should also identify existing or potential alternative gear types or fishing patterns, such as area closures, which could alleviate these impacts.

2. Provide training to Council members and staff.

To facilitate an ecosystem approach and to aid the development and implementation of FEPs, NMFS should provide all Council members with basic instruction in ecological principles. Further, training materials should be made available to the fishing industry, environmental organizations and other interested parties.

3. Prepare guidelines for FEPs.

The Secretary of Commerce should charge NMFS and the Councils with establishing guidelines for FEP development, including an amendment process. NMFS and the Councils should conduct a deliberative process—similar to the process of developing National Standards Guidelines—to ensure that FEPs are realistic and adaptive.

4. Develop demonstration FEPs.

Choose one or more of the Councils to develop a demonstration FEP. Convene a workshop involving all Councils and other relevant participants which would help develop useful demonstration FEPs.

Encourage all Councils to develop framework FEPs, consisting of such information as can be collected with little additional effort, to facilitate rapid implementation of the full FEP when required by the next MSFCMA reauthorization.

5. Provide oversight to ensure development of and compliance with FEPs.

To ensure compliance with the development of FEPs, the Secretary of Commerce should establish a review panel for FEP implementation oversight. Implicit in this action is the establishment of a timetable for development of a draft FEP, its review by the panel, and any necessary revisions before the draft FEP becomes a basis for policy.

6. Enact legislation requiring FEPs.

To provide NMFS and the Councils with the mandated responsibility of designing and implementing FEPs, Congress should require full FEP implementation in the next reauthorization of the MSFCMA.

RESEARCH REQUIRED TO SUPPORT MANAGEMENT

Our identification of the Principles and associated management Policies reflects a vast amount of scientific knowledge about marine ecosystems and their relationship to humankind. This knowledge is the result of more than 125 years of scientific investment. Yet, the current state of scientific knowledge is not sufficient to fully implement the Principles and Policies. To more fully benefit from the application of the Principles and Policies, there is an urgent need for a better understanding of ecosystem processes in general, and about the state and dynamics of specific ecosystems.

The Panel did not attempt to develop an exhaustive set of research recommendations. That is better left to more specialized groups of scientists. Instead, we highlighted three research themes based on several criteria. First, we selected themes that were clearly related to the Principles and the Policies that form the basis of an ecosystem approach to fisheries management. Second, we placed a priority on identification of new research directions, compared to current research programs that support fisheries management. These new research directions are not recommended as alternatives to the current research programs, rather they are an additional requirement. Third, we highlighted themes for which NMFS has a unique responsibility.

The three recommended research themes are: 1) determine the ecosystem effects of fishing, 2) monitor trends and dynamics of marine ecosystems, and 3) explore ecosystem-based approaches to governance. Each of the themes is briefly described and discussed below.

1. Determine the ecosystem effects of fishing.

The effects of fishing on the species that are landed are generally understood, although the data that are necessary to assess specific stocks of fish are sometimes minimal. It is well known that the effect of fishing on a “target species” can be severe, with abundance reduced by a factor of 10 or more. Fishing is a form of directional selection on fished species that may alter not only population characteristics (i.e., age structure), but also the genetic makeup of the population. Research on genetic changes from fishing is appropriate. It is also known that fishing can have significant effects on nontarget species and, potentially, on marine ecosystems as a whole. These effects occur as a result of bycatch and discarding of non-target species (including marine mammals, reptiles and birds), trophic linkages between target and non-target species, and alteration of habitat caused by fishing gear. All three of these effects need to be studied. The research should consider how fishing changes ecosystems (i.e., abundance and diversity of species, food web dynamics, amount of various habitat types, and the functional significance of changes). An important element of this research will be to explore the utility of quantitative ecosystem health indices as a tool for managers. The research should also include consideration of strategies for applying the precautionary approach in light of uncertainty about ecosystem effects of fishing, and mitigation of undesirable effects. One particularly promising approach for risk-averse management is the establishment of marine protected areas and through traditional fisheries management techniques like time/area closures.

2. Monitor trends and dynamics in marine ecosystems (ECOWATCH).

We recommend the initiation of a significant new ecosystem monitoring program. We refer to the program as "ECOWATCH" because it will enable scientists and policy makers to observe natural and human-caused changes in marine ecosystems in a comprehensive manner. Target fish species are routinely monitored using landings data and resource surveys that apply standardized sampling methods. But even for some important exploited species, landings data and/or resource survey data are limited. Data on other components of marine ecosystems are even more limited, although there are some valuable time series of plankton data for a few ecosystems and for some marine mammal populations. For these reasons, ECOWATCH should be scientifically designed to provide data to improve existing models (i.e., stock assessments), but also for input for future ecosystem models. Research on ecosystem models based on current concepts of important ecosystem linkages is a useful application of ECOWATCH monitoring data.

We recommend substantial expansion of existing programs that collect data on trends and dynamics of marine ecosystems and which characterize the biological and physical relationships pertinent to ecosystem-based management. This expansion is needed to fill gaps in current data collection programs for some target species where data are limited, and systematically observe how other components of ecosystems vary. There are several reasons to observe marine ecosystems holistically. Such observations are needed to determine and understand indirect effects of fishing within marine ecosystems. In a sense, these observations are a form of ecosystem insurance. Because we cannot currently predict all of the ecosystem effects of fishing, we should be watching for evidence of such changes so that it is possible to react if the changes are adverse or positive. Ecosystem observations are also needed to distinguish human caused changes from natural changes. Large spatial and temporal scale (over ocean basins and decades) changes in ecosystems, called regime shifts, are known to occur. Routine monitoring and analysis of key ecosystem variables are needed in order to detect regime shifts and, if possible, to forecast them.

We envision that ECOWATCH will assess the productive capacity of marine ecosystems, including data on fish, shellfish, primary production, plankton, benthic communities (impacts on fishing sites versus control sites), marine mammals, birds, and physical and chemical factors. It will be necessary to make a major investment in new technology to make ECOWATCH feasible. It will be necessary to employ several different sampling "vehicles" including research vessels; dockside and sea sampling of fisheries; remote sensing from satellites, aircraft, and buoys; submersibles and autonomous underwater vehicles. It will be essential to develop modern data management systems so that variables can be related to each other and so that information is accessible. Models need to be developed to assimilate data and produce information products that enhance our ability to evaluate and make conscious decisions regarding marine ecosystems.

3. Explore ecosystem-based approaches to governance.

Many of today's fishery problems result from failed governance systems. One of the major shortcomings of past and most present governance systems is that they do not create incentives for humans to be prudent predators (i.e., efficient in the uses of natural resources and concerned about long-term conservation). A related problem is that members of the fishing industry and the concerned public often feel alienated from the institutions that govern fisheries. The challenge of achieving effective governance from an ecosystem perspective is even greater. From such a perspective, incentives for efficiency and conservation must apply to indirect effects of fishing on segments of society that are not directly concerned with fisheries, and to other industry sectors that indirectly affect fisheries. A broad array of stakeholders should have the opportunity to participate in the system of governance.

We envision a multifaceted research program including: 1) research on the social and economic importance of fisheries, and of other ecosystem uses that affect fisheries, to better understand social objectives, motivations for behavior, and options for creating effective incentive systems; 2) case studies and comparative studies (with other industry sectors) to identify factors that determine success or failure of governance systems; and 3) management experiments to test approaches for involving stakeholders in governance systems and for making decisions when faced with multiple objectives (i.e., from different societal perspectives and across sectors).

While NMFS clearly has lead responsibility for these themes, the research strategies should be developed and implemented as National, interagency programs, involving academic as well as government scientists. Because the ecosystem Principles apply globally, the U.S. should participate in, and initiate when necessary, international programs that further fisheries management objectives. A significant enhancement in resources (e.g., funding, staff, fishery research vessels) will be required if these research recommendations are to be fulfilled.

SECTION FIVE: SUMMARY AND CONCLUSIONS

Recognition of major problems in U.S. fisheries prompted Congress to legislate the Sustainable Fisheries Act (SFA) in 1996. This amendment strengthened the MSFCMA and gave new direction to NMFS and the Councils to halt overfishing, develop recovery plans for overfished fisheries, avoid and reduce bycatch mortality, identify and protect EFH, investigate ways to reduce fishing capacity, and implement numerous other conservation measures. These represent the beginnings of an ecosystem approach to fishery management. Rapid response and hard work by NMFS, the Councils, fishing industries, environmental groups and other interested parties will produce change that eventually will result in marked improvements in the status and management of our fisheries resources. Still, there is more to be done.

The appointment of the NMFS Ecosystem Principles Advisory Panel is a key provision of the SFA. Congress called for an assessment of the extent to which ecosystem principles are being applied in fishery conservation, management and research and for recommendations on how to use them further to improve management. Our review of the use of ecosystem principles finds some positive indications, but much room for further application. The fisheries ecosystem science being conducted is of high quality, but the types of research and assessments, and the geographic coverage are extremely limited and inadequate to inform fishery management. Where scientific information on fisheries ecosystems is produced, it is often used in the management process. However, it is inadequate relative to the scope of the problems and the geographic scale of our Nation's marine fisheries.

At present, NMFS and the Councils often are using the best available science to manage stocks on a single species or species-complex basis. If fishery management is to further incorporate ecosystem principles, Congress must provide a specific mandate to NMFS and the Councils to do so and must fund the scientific infrastructure required to support the decision-making process. Requiring Councils to prepare FEPs provides a mechanism to focus and inform fishery management, to measure progress toward implementation of ecosystem-based fishery management, to identify research needs and ultimately to insure healthy and productive ecosystems.

U.S. fisheries under an ecosystem-based management system are likely to be quite different than today's fisheries. New management tools will be employed including share-based systems. Fisheries and gear types that have significant adverse impacts on other ecosystem components may be modified or phased out and other types of fisheries and gears may replace them. In some cases, fish stocks may have to be exploited at lower harvest levels than presently indicated in order to sustain other ecosystem components. Some areas that are now fished may become fisheries reserves where harvests are restricted to protect a spawning stock or other sensitive life-history stages; this may result in changes to traditional fishing practices. The short-term consequences of such changes, which may be painful, must be balanced against future benefits in the form of sustainable fisheries and fishing communities.

The next ten years are critical for the future of U.S. fisheries. Already, important changes are underway as a result of the SFA, and the next round of legislation/reauthorization of the MSFCMA should provide additional impetus for reform. Implementation of an ecosystem-based approach will take time and there will be trials and errors. A great deal of education about this new approach will be required, and all involved must be prepared to learn. The two hardest lessons are likely to be shifting the burden of proof to the fishery to demonstrate that the ecosystem will not be damaged by fishing, and to develop a truly precautionary approach to fishery management. The learning curve will be steep for all involved; society as a whole, will be increasingly challenged to help define ecosystem health and the limits of acceptable change in marine ecosystems, while still allowing sustainable fishing practices.

GLOSSARY

Allowable Biological Catch—Catch that can be taken in a specific year that achieves the biological objectives, or avoids the biological constraints, of fishery management. Such objectives and constraints are usually set in terms of stock sizes that must be maintained and/or fishing mortality rates that shall not be exceeded. Estimates of allowable biological catch should be based on the best scientific advice available.

Burden Of Proof—The responsibility to demonstrate that a fishing activity will or will not lead to overfishing or negative effects on the ecosystem.

Bycatch—Unintentional catch; i.e., catch that occurs incidentally in a fishery that intends to catch fish with other characteristics (e.g., size, species).

Carrying Capacity—The numbers or biomass of resources that can be supported by an ecosystem.

Conservation and Management—The rules, regulations, conditions, methods, and other measures (A) which are required and useful to rebuild, restore, or maintain, any fishery resource and the marine environment; and (B) which are designed to ensure that: (i) a supply of food and other products may be taken, and that recreational benefits may be obtained, on a continuing basis; (ii) irreversible or long-term adverse effects on fishery resources and the marine environment are avoided; and (iii) there will be a multiplicity of options available with respect to future uses of these resources (NMFS 1996).

Discards—A portion of what is caught and returned to the sea unused. Discards may be either alive or dead. There are many types of discards, such as economic discards (when a portion of the catch that it is not economically rational to land is discarded), regulatory discards (when discarding occurs because of a prohibition on retaining some of the catch), highgrade discards (discarding of the portion of the catch with a lower value than the portion retained in order to comply with regulations that limit how much catch can be retained). Highgrading is a form of regulatory discarding.

Ecosystem-based Fishery Management—Fishery management actions aimed at conserving the structure and function of marine ecosystems, in addition to conserving the fishery resource.

Essential Fish Habitat—Those waters and substrate necessary for fish to spawn, breed, feed and grow to maturity (NMFS 1996).

Fish—Defined herein as finfish, mollusks, crustaceans, and all other forms of marine animal and plant life other than marine mammals and birds (NMFS 1996).

Fishery—(A) One or more stocks of fish which can be treated as a unit for purposes of conservation and management and which are identified on the basis of geographical, scientific, technical, recreational and economics characteristics; and (B) any fishing for such stocks (NMFS 1996).

Fishing—Any activity which can reasonably be expected to result in the catching, taking or harvesting of fish; or any operations at sea in support of, or in preparation for such activities.

Fishing Mortality—A measurement of the rate of mortality of fish in a population caused by fishing.

Fish Stock—A species, subspecies, geographical grouping, or other grouping of fish that is managed as a unit (NMFS 1996).

Maximum Sustainable Yield—A management goal specifying the largest long-term average catch or yield (in terms of weight of fish) that can be taken, continuously (sustained) from a stock or stock complex under prevailing ecological and environmental conditions, without reducing the size of the population.

Optimum Yield—(A) The amount of fish which will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems; (B) is prescribed as such on the basis of the maximum sustainable yield from the fishery, as reduced by any relevant economic, social, or ecological factor; and (C) in the case of an overfished fishery, provides for rebuilding to a level consistent with producing the maximum sustainable yield in such fishery (NMFS 1996).

Overfishing—Fishing at a rate or level that jeopardizes the capacity of a stock or stock complex to produce maximum sustainable yield on a continuing basis (NMFS 1996).

Primary Production—Creation of organic matter by plants through photosynthesis (using inorganic carbon, nutrients and an external energy source) to form the base of the food chain.

Recruitment—A measure of the weight or number of fish which enter a defined portion of the stock such as fishable stock (those fish above the minimum legal size) or spawning stock (those fish which are sexually mature).

Regime Shift—Major changes in levels of productivity and reorganization of ecological relationships over vast oceanic regions which could be caused by various sources including climate variability or overfishing.

Resilience—The ability of a population or ecosystem to withstand change and to recover from stress (natural or anthropogenic).

Significant Food Web—A predator/prey interaction that is important to either the predator or prey population.

Stock Assessment—An evaluation of a stock in terms of abundance and fishing mortality levels and trends, and relative to fishery management objectives and constraints if they have been specified.

Surplus Production—Total weight of fish that can be removed by fishing without changing the size of the population. It is calculated as the sum of the growth in weight of individuals in a population, plus the addition of biomass from new recruits, minus the biomass of mortality of animals lost to natural mortality, during a defined period (usually one year).

Target Species—Those fish explicitly sought by fishermen to meet social and economic needs. Their catch are the direct consequence of targeted fishing effort. **Non-target Species** include all others.

Total Allowable Catch—The annual catch from a stock that is allowed according to fishery management regulations.

Trophic Web—The network that represents the predator/prey interactions of an ecosystem.

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APPENDIX A: CHARTER—NATIONAL MARINE FISHERIES SERVICE ECOSYSTEM PRINCIPLES ADVISORY PANEL

The Charter was provided to the Panel as initial guidance from NMFS. It was subsequently modified after Panel review.

INTRODUCTION

Section 406 of the Magnuson-Stevens Fisheries Conservation and Management Act (MSFCMA) as amended through 1996 (Appendix B) requires the Secretary of Commerce to establish a Panel to provide advice to the Secretary and Congress on ways to incorporate ecosystem principles in fisheries conservation and management activities. The need for such a Panel has arisen from the perceived failure of traditional management approaches to ensure sustainable fisheries. Yields of many marine fisheries worldwide have declined in recent years; in the U.S., 42% of fish stocks are considered overutilized. The causes of these declines have been complex, and include overharvesting of target and non-target species, habitat alteration and loss, pollution and natural environmental change. Stocks in this condition are not able to provide the same sustained economic and social benefits as those in healthy fisheries.

A basic premise of ecosystem-based management is that the relationship between living marine resources and the ecosystem within which they exist must be well understood. This requires a more comprehensive approach to fisheries research than is necessary for traditional single-species management approaches, although single-species stock assessments have become increasingly sophisticated and some now incorporate environmental parameters. Successful implementation of ecosystem-based management will require consideration of, inter alia, essential habitat requirements, hydrography, trophic relationships and physical and biological processes. An important element of the Panel's duties will be to determine what information is essential to the task of ecosystem-based fisheries conservation and management, and how that information should be collected.

Managers must also understand the complex linkages between natural ecosystems and the economic, social and political dynamics of human systems. Humans are integral components of ecosystems and their interests, values and motivations must be understood and factored into resource management decisions. Information on human systems is as important as that from natural systems and must be included in any ecosystem research and management efforts.

Efficient use of existing information and information flow to management are important topics for Panel consideration. In developing an ecosystem approach to research and management, it is important to recognize that a great deal is already known about marine ecosystems, but that this information is not consistently applied in current management efforts. This is, in large part, because there is no agreed upon method or process for applying it. Therefore, emphasis must be placed not only on what new information is required, but also on how to apply existing information effectively. In addition, it must be recognized that both science and management are ongoing processes, and that mechanisms are required to incorporate new scientific, social, cultural, economic and institutional information into the management process as it becomes available. This may require managers to be trained in ecosystem approaches, so that valuable new information will be recognized and utilized where appropriate.

The complicated legislative and institutional framework that currently regulates resource management decision making poses a significant challenge to the implementation of ecosystem-based fisheries conservation and management. Although the MSFCMA is the principal legislation governing U.S. marine fisheries, other Federal legislation including the Marine Mammal Protection Act and the Endangered Species Act, as well as State laws and international agreements, provide for the conservation and management of marine resources. This geographic, legislative and institutional fragmentation of conservation and management responsibilities is not consistent with ecosystem principles, which ignore human boundaries and jurisdictions. It also indicates the need for an 'institutional ecology' and a 'legislative ecology' which parallel more closely the natural ecosystem. Coordination of these legislative and institutional responsibilities across jurisdictional lines, as well as the appropriate involvement of all stakeholders in the decision making process, will be a significant task in implementing ecosystem-based management.

The U.S. lacks a single and unifying legislative mandate or policy governing the use of resources from marine ecosystems. Consequently, decisions on resource management within marine ecosystems often are in conflict with one another. For example, it is axiomatic that fishery yields cannot be maximized for all species simultaneously. Likewise, the goal of protecting all marine mammals within an ecosystem may not be consistent with the goal of sustaining maximum fisheries yields, and vice versa. From the outset, resource managers must determine what values are placed on a marine ecosystem and its components, and which goods and services are expected to be produced from each ecosystem. The recommendations of this Panel regarding the development of such policies will be an important step towards improved fisheries conservation and management.

Numerous panels, committees and task forces have been constituted in the past to consider how ecosystem approaches should be applied to natural resource management issues. Many solid recommendations have emerged from these efforts, however few appear to be implemented in fisheries management, as evidenced by Congress' mandate for this Panel. While the reasons for this failure are probably multiple, an underlying cause may be that many of the recommendations have been more theoretical than practical, and have provided the practicing manager with little in the way of implementable management tools. Unlike these previous efforts, it is fully intended that the NMFS Ecosystem Principles Advisory Panel will develop specific, practical and implementable recommendations for the research, conservation and management of living marine resources, along with longer term goals and directions.

PURPOSE

The Panel's purpose is to advise NMFS and Congress on the application of ecosystem principles in fisheries conservation and management and research activities.

TERMS OF REFERENCE

The Panel will:

1. **Conduct an analysis of the extent to which ecosystem principles are being applied in fishery[1] conservation and management[2] activities, including research activities. The analysis should include the following:**

Conservation and management issues

A review of the extent to which ecosystem principles are being applied in: 1) the development of fishery management plans by the Councils; 2) the development of advice by NMFS to the Councils; and 3) other regulatory and rule-making activities of NMFS.

An identification and analysis of cases in which ecosystem principles have been successfully applied in fisheries conservation and management activities.

Research issues

A review of the status of ecosystem science

[1]The term "fishery" means — (A) one or more stocks of fish which can be treated as a unit for purposes of conservation and management and which are identified on the basis of geographical, scientific, technical, recreational and economics characteristics; and (B) any fishing for such stocks.

[2]The term "conservation and management" refers to all the rules, regulations, conditions, methods, and other measures (A) which are required and useful to rebuild, restore, or maintain, any fishery resource and the marine environment; and (B) which are designed to ensure that:

(i) a supply of food and other products may be taken, and that recreational benefits may be obtained, on a continuing basis;
(ii) irreversible or long-term adverse effects on fishery resources and the marine environment are avoided; and
(iii) there will be a multiplicity of options available with respect to future uses of these resources.

within NOAA and other entities involved with research in the marine environment (e.g., academic institutions, other Federal and State agencies).

An analysis of whether current research efforts within these agencies and institutions are adequate to support fisheries ecosystem conservation and management.

2. **Propose a specific, prioritized course of actions that the Secretary of Commerce, Congress and NMFS should undertake to expand the application of ecosystem principles in fishery conservation and management. For example, the following issues might be considered:**

Conservation and management issues

What specific, practical actions can be taken to apply ecosystem principles in fisheries conservation and management activities in the near term, before more complete information is available on ecosystem structure and function?

What barriers (scientific, social, institutional, economic, administrative, legislative) exist to the application of ecosystem principles in U.S. fisheries conservation and management activities? What solutions can be proposed?

Should changes be made to the Council structure or mission to better apply ecosystem principles in conservation and management activities? If so, what should the changes be?

Does the U.S. need additional legislation, or changes to current legislation, to improve the scientific and regulatory infrastructure to support ecosystem-based conservation and management?

Research issues

Which research topics should be priorities for the development of a long-term information base to support marine ecosystem management?

How can agencies and institutions involved in marine and fisheries science collaborate more effectively to take advantage of complementary research efforts, and synergize results from a broader ecosystem perspective?

What are the most meaningful time and space scales for marine ecosystem research which will directly support conservation and management efforts?

Is sufficient information available to determine the value of harvest refugia in fisheries ecosystem management? If not, what additional information is required?

3. **Produce a report to Congress by October 1998 which includes the above information, plus any other information as may be appropriate.**

The principal focus of the analyses in Section 1 above should be on conservation and management and research activities conducted within the U.S., including those marine ecosystems and their resources which are shared by the U.S. and other countries (e.g., transboundary stocks). However, the Panel should consider pertinent examples from other areas of the world where ecosystem approaches have been used. The Panel should focus on research, conservation and management activities which pertain to ecosystems or species under the jurisdiction of the MSFCMA.

Panel Membership

According to MSFCMA Section 406, the Advisory Panel shall consist of not more than 20 individuals and include:

Individuals with expertise in the structures, functions and physical and biological characteristics of ecosystems; and

Representatives from the Regional Fishery Management Councils, States, fishing industry, conservation organizations or others with expertise in the management of marine resources.

Nominations for panelists were solicited from the National Academy of Sciences, Councils, States, fishing industry and conservation organizations, as well as other appropriate regional and national stakeholders. The Panel membership is balanced geographically, so that regional issues can be addressed.

Travel Costs

Travel expenses for the panelists to attend panel meetings will be paid by the government at prevailing government rates.

Format and Panel Duration

The Panel will convene three two-day meetings in September 1997, November-December 1997, and February-March 1998. Additional meetings or conference calls may be held as required. The Panel may be requested to continue to advise NMFS on ecosystem issues after October 1998 if such advice is required.

All meetings will be open to the public, and each meeting will include a specific opportunity for public input. Members of the public wishing to make presentations or statements at the meetings must notify the NMFS Office of Science and Technology at least two weeks in advance of the meeting date, which will be published in the Register.

APPENDIX B: MSFCMA SECTION 406 FISHERIES SYSTEMS RESEARCH

(a) ESTABLISHMENT OF PANEL.—Not later than 180 days after the enactment of the Sustainable Fisheries Act, the Secretary shall establish an advisory panel under this Act to develop recommendations to expand the application of ecosystem principles in fishery conservation and management activities.

(b) PANEL MEMBERSHIP.—The advisory panel shall consist of not more than 20 individuals and include—

(1) individuals with expertise in the structures, functions, and physical and biological characteristics of ecosystems; and

(2) representatives from the Councils, States, fishing industry, conservation organizations, or others with expertise in the management of marine resources.

(c) RECOMMENDATIONS.—Prior to selecting advisory panel members, the Secretary shall, with respect to panel members described in subsection (b)(1), solicit recommendations from the National Academy of Sciences.

(d) ECOSYSTEM REPORT.—Within two years of the date of enactment of this Act, the Secretary shall submit to the Congress a completed report of the panel established under this section, which shall include—

(1) an analysis of the extent to which ecosystem principles are being applied in fishery conservation and management activities, including research activities;

(2) proposed actions by the Secretary and by the Congress that should be undertaken to expand the application of ecosystem principles in fishery conservation and management; and

(3) such other information as may be appropriate.

(e) PROCEDURAL MATTER.—The procedural matters under section 302(j) with respect to advisory panels shall apply to the Fisheries Ecosystem Management advisory panel..

APPENDIX C: MEETING PARTICIPANTS

First Meeting—September 9 & 10, 1997
Washington, DC

Presenters:

Dave Allison
Allison Associates

Larry Buckley
NMFS, Northeast Fisheries Science Center

David Evans
NMFS, Deputy Assistant Administrator

Karen Garrison
Natural Resources Defense Council

Craig Harrison
Pacific Seabird Group

Don Leedy
NMFS, Office of Sustainable Fisheries

Pat Livingston
NMFS, Alaska Fisheries Science Center

Jeff Polovina
NMFS, Southwest Fisheries Science Center

Mike Schiewe
NMFS, Northwest Fisheries Science Center

Jim Thomas
NMFS, Office of Habitat Protection

Nancy Thompson
NMFS, Southeast Fisheries Science Center

Guests:

Roger Griffis
NOAA, Office of Policy and Strategic Planning

Kate Wing
Staff, Senate Commerce Committee

Tom Eagle
NMFS, Office of Protected Resources

Second Meeting—December 15 & 16, 1997
Seattle, Washington

Presenters:

John Gauvin
Executive Director, Groundfish Forum

Chuck Fowler
NMFS, National Marine Mammal Lab

Lowell Fritz
NMFS, Alaska Fisheries Science Center

Peter Fricke
NMFS, Office of Sustainable Fisheries

Rod Fujita
Environmental Defense Fund

Tom Okey
Center for Marine Conservation

Ken Stump

Dave Witherell
North Pacific Fishery Management Council

Guests:

Kerim Aydin
University of Washington

Jim Balsiger
Director, NMFS Alaska Fisheries Science Center

Ed Casillas
NMFS, Northwest Fisheries Science Center

Tracy Collier
NMFS Alaska Fisheries Science Center

John Fell
University of Washington

Bill Hines
NMFS, Alaska Region

Loh-Lee Low
NMFS, Alaska Fisheries Science Center

Clarence Pautzke
Executive Director, North Pacific Fisheries Management Council

Mike Schiewe
NMFS, Northwest Fisheries Science Center

John Stein
NMFS, Northwest Fisheries Science Center

Usha Varanasi
Director, NMFS Northwest Fisheries Science Center

Kate Wing
Senate Commerce Committee

Third Meeting—February 26 & 27, 1998
Key Largo, Florida

Presenters:

Kimberly Davis
Center for Marine Conservation

Graeme Parks
Marine Resources Assessment Group Americas

Alexander Stone
Reefkeeper International

Guests:

Tom Eagle
NMFS, Office of Protected Resources

Chuck Fowler
NMFS, National Marine Mammal Lab

William Fox, Jr.
Director, NMFS Office of Science and Technology

Eduardo Martinez
NMFS, Southeast Fisheries Science Center