Strategic Guidance for Implementing an Ecosystem-based Approach to Fisheries Management[a]

Prepared for the
Marine Fisheries Advisory Committee[b]
by the
Ecosystem Approach Task Force

May 2003
Silver Spring, MD

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[a] The Atlantic States Marine Fisheries Commission was pleased to contribute resources to the development of this document; however, the final recommendations have not been submitted or reviewed through the Commission process.

[b] The creation of the Marine Fisheries Advisory Committee (MAFAC) was chartered under the Federal Advisory Committee Act, 5 U.S.C. App.2, on February 17, 1971, to provide advice to NOAA Fisheries. Information concerning MAFAC can be found at: http://www.nmfs.noaa.gov/MAFAC_Info

Strategic Guidance for Implementing an Ecosystem-based Approach to Fisheries Management[c]

Prepared for the
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Edited by

Wolf-Dieter N. Busch[d]
Atlantic States Marine Fisheries Commission
Washington, DC 20005

Bonnie L. Brown
Virginia Commonwealth University
Richmond, VA 23112

Garry F. Mayer
NOAA Fisheries (HC)
Silver Spring, MD 20910

May 2003
Silver Spring, MD

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[d] ASMFC until June 30, 2002; current address: Ecosystems Initiatives Advisory Services, 1705 Angelina Ct., Crownsville, MD 21032-1935

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Name	Affiliation
Busch, W. Dieter (Co-Chair and Coordinator)	Atlantic States Marine Fisheries Commission through June 2002, and NOAA Fisheries Contractor
Brown, Bonnie (Co-Chair)	Virginia Commonwealth University
Brown, Virdin	Caribbean Fishery Management Council
DiLernia, Anthony	Kingsborough Community College
Gilmore, Jim	At-Sea Processors Association
Iudicello-Marley, Suzanne	Junkyard Dogfish Consulting
Kaplan, Ilene	Union College
Maharaj, Vishwanie	South Atlantic Fishery Management Council
Mayer, Garry	NOAA Fisheries (F/HC)
Moon, Melvin	Quileute Natural Resources
Ragster, Laverne	University of the Virgin Islands
Rayburn, Ralph	Texas Sea-Grant College Program
Scavia, Don	NOAA – NOS
Sheehan, Elizabeth	Coastal Enterprises, Inc.
Sissenwine, Mike	NOAA Fisheries (F/NEC)
Stuart, Beth	Aleutians E. Borough
Washington, Percy	GAIA Northwest, Inc.
Wynne, Kate	University of Alaska, Fairbanks

In addition to the above, a *Technical Committee* was created by the Task Force to increase access to technical advice. The following have contributed:

Anderson, Emory	NOAA Fisheries (F/ST2)
Bigford, Tom	NOAA Fisheries (F/HC)
Boreman, John	NOAA Fisheries (F/NEC)
Chambers, Val	NOAA Fisheries (F/SWR)
Cyr, Ned	NOAA Fisheries (F/ST)
Detlor, David	NOAA Fisheries (F/ST)
Fabrizio, Mary	NOAA Fisheries (F/NEC)
Fluharty, David	University of Washington
Gilford, James	Mid Atlantic Fishery Management Council (Ret)
Koonce, Joseph	Case Western Reserve University
Lang, Judith	Environmental Consultant
Matlock, Gary	NOAA – NOS
Millikin, Mark	NOAA Fisheries (SF)
Orner, Derek	NOAA Fisheries (CBP)
Pugliese, Roger	South Atlantic Fishery Management Council
Richardson, Ed	At-Sea Processors Association

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Name	Affiliation
Burroughs, Richard	University of Rhode Island
Christensen, Villy	University of British Columbia
Kline, Lisa	Atlantic States Marine Fisheries Commission
Link, Jason	NOAA Fisheries (F/NEC)

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TABLE OF CONTENTS

PREFACE

The Marine Fisheries Advisory Committee's Ecosystem Approach Task Force was created in November 2001 to identify issues that must be addressed before meaningful ecosystem-based fisheries management is feasible. This document was prepared as an outline to assist the various marine management and regulatory agencies (with a primary focus on fishery resources and their habitats) in long-term planning to transition towards ecosystem-based management. The guidance statements made in this document, therefore, are directed to NOAA Fisheries and their Fisheries Management Councils, States, Interstate Commissions, tribes, and other fisheries managers.

Maintaining brevity and concise objectives was not easy since many of the important steps in moving towards an ecosystem approach to fisheries management are complex and often misunderstood. As a result, this document is broad in its sociological and environmental coverage, light in specific details, and not limited to the responsibilities of any individual agency or its divisions. More specific Strategic Guidance should / will be developed and coordinated within the applicable agencies, as discipline or agency subsets. In fact, the Task Force presents here various issues of concern and suggests that NOAA develop a "game plan" for addressing these issues, including estimating what financial and human resources are required to move beyond "harvest-regulation" management of single species.

The need for strategic planning cannot be overemphasized. The Task Force and Technical Committee members agree that implementation of an ecosystem-based approach to fisheries must take place incrementally and will require additional topic-specific development beyond this report, such as identifying ecosystem boundaries at various scales, use of Geographic Information System (GIS) data for marine resource management, identifying general and specific goals for specific coastal reaches, and mechanisms for advancing interagency cooperation. Nevertheless, while these additional tools are being developed, significant short-term progress can be made in advancing ecosystem approaches to management by moving to the goals-driven process encouraged in this Strategic Guidance document. This process, which requires defining, achieving, and maintaining socially desirable long-term *Goals* and *Objectives* as targets in management, constitutes an approach that differs significantly from the current state of affairs in marine fisheries management.

Introduction

Ecosystem-based Fisheries Management occurs when personal, social, political, and management decisions are made considering ecological information.

Ecosystem-based decisions acknowledge that the environment changes, even in the absence of anthropogenic influence.

Ecosystem approach decisions are three-dimensional because they:

1. include stakeholders, perspectives, and human goals,
2. consider the health and vitality of ecosystems into the indefinite future, and
3. include the larger landscape and connections among other landscapes.

An ecosystem-based approach requires attention to ecosystem integrity, interagency cooperation, spatially explicit management measures, and time-series data for multiple species and habitats.

Ecosystem-based approaches have the potential to significantly enhance and evolve marine fisheries management. This valuable alternative to traditional management of marine resources (e.g., species-by-species using simple parameters such as Optimum Yield [OY]) elicits various reactions because the approach is, by definition, multi- and interdisciplinary. Ecosystem-based management requires that the intent of such management be defined (goals) and a process be implemented within management agencies. The Task Force outlines in this document its vision of the essential elements of ecosystem-based fishery management and provides strategic advice in terms of policies, goals, and processes that will enable marine resource management groups to implement this multidisciplinary type of approach.

One criterion of an ecosystem-based approach that causes it to have far-reaching effects is that it requires an accounting of natural environmental fluctuations including global climate (also catastrophic events) and natural oscillations in the abundance/dominance of species. In many cases, data are insufficient to accurately predict these fluctuations. As a consequence, the Task Force has endeavored to emphasize that we must not be attempting to manage ecosystems, but rather, we must manage people's behavior with regard to the natural resource goals and objectives publicly established for those ecosystems in which they conduct their lives, in the context of a naturally varying environment.

A novel aspect of an ecosystem approach to fisheries management is that it provides for the examination of the different components of the marine environment and must take into account, by the very nature of systems theory, human and non-human elements of the marine environment and the inter-relationships that emerge (Ward et al. 2002). Although sociological data have not traditionally been considered as components of fishery management plans, contemporary environmental concerns clearly demonstrate that biological and social systems are not discrete, but intertwined. Systems-based approaches focus on inter-relationships that emerge on social, natural, and physical or technological levels. People are both actors and reactors within the marine environment; they can create change and also be changed by social, economic, political, and biological forces. The connections among components of a system are manifest as change in one component results in change in another component. Environmental stress, for instance, is not limited to marine resources that may be threatened by human activity; humans may undergo health, mental, and financial stress as they face fluctuations, not only with regard to marine resources, but with regulatory changes that create economic pressures and hardships that disrupt

Action Items:

- Identify and set goals with reference to the larger environment, including ecosystem parameters or environmental conditions (e.g., water quality) that limit fishery management options
- Focus on interactions among constituents and understanding of the problem, team building, and trust
- Put emphasis on "coordination and cooperation" as opposed to "control"
- Access and incorporate local and regional expertise (regionalize)
- Categorize current and proposed ocean zoning measures according to ecosystem relevance
- Report on efforts to ensure compliance with NEPA and other federal laws, and determine what, if any, additional federal action is needed beyond NEPA to foster an ecosystem-based approach
- Match elements of current FMPs to the suggested elements of FEPs to determine what's missing and whether activities that do match up can be enhanced
- Examine efforts to apply an ecosystem-based approach (e.g., Great Lakes, Chesapeake Bay, Hawaiian Islands) to determine coverage of suggested FEP elements.
- Undertake limited scale pilot projects.
- Promote development of graduate level curricula in support of ecosystem-based approach to fisheries management and implement with scholarship incentives.

family and community life. Conversely, regulatory changes may result in increased benefits to one group while another group is subject to economic loss and negative social impacts. Such tradeoffs can have both short and long-term consequences.

A further challenge in ecosystem-based management approaches is that static ecological boundaries for marine ecosystems are not always available. The Large Marine Ecosystems (LME) classification (Sherman and Gold 1993) identifies ecological systems for the various oceans that are influenced by their respective land masses. However, ecological boundaries for subsets within an LME are mostly lacking. Such hierarchal subsets need to be identified, preferably linked to ecological parameters and management responsibilities. Potential LME subsets may be coastal watersheds, estuaries, large embayments, coastal eco-reaches, and/or specific offshore/deepwater areas with specific physical/ecological attributes that can be inventoried and mapped. A review of the science of ecological classification is available from Grossman et al. (1999) and its application to management was reviewed by Carpenter et al. (1999). The boundaries of these ecosystem units frequently will not include the total range of some organisms, such as highly migratory fishes. Such species may, therefore, be included in more than one ecosystem during the period when they are seasonal or temporary residents.

Successful implementation of ecosystem-based approaches will require unprecedented changes in communication. First, since "environmental" management is shared among agencies and levels of government and further separated by various specialized disciplines, effective and proactive interagency cooperation is a requirement. It is desirable, and may be cost-effective, for agencies to compare and prioritize environmental management problems and efforts needed to resolve them, through a process that avoids circumstances that create adversarial relationships. Second, effective management requires public understanding, trust, and support, especially when resources are to be rebuilt and/or when competing users desire the same resources. Essentially, implementing an ecosystem-based approach requires an open process that actively seeks interagency and public input and support. Therefore, a key element in this guidance is the need for greatly improved interagency coordination and to enhance the exchange of information between regulators and constituents during all stages of management.

In addition to substantial changes in the lines of communication among agencies and constituents, the Task Force emphasizes the need to quantify ecosystem status, function, and changes as well as socio-economic implications of various conservation or restoration strategies and alternatives. The Task Force also recommends the use of trend analysis to improve understanding of cause/effect relationships. Therefore, indicators need to be identified and employed to better define the condition and the level of historic, current, and sustainable exploitation of the ecosystems. To promote these activities, the Task Force has listed various tools and processes that have been documented to be of use in resource management. One of the most significant is preparation of Fisheries Ecosystem Plans (EPAP 1999) that include natural resource goals and specific objectives relevant to describing the desired future conditions for each ecosystem. It is the hope of the Task Force that use of this guidance in application of an ecosystem-based approach to management will increase the degree of standardization of data collection, promote use of ecological indicators, and normalize language and acronyms among regions and agencies, thereby assisting in improving public understanding of, and participation in, the process of resource management.

During the spring of 2002, Busch et al. (2002) provided nine ecosystem-process related questions to the NOAA Fisheries Management Councils (FMC). Responses were received from all and some key elements are summarized as follows:

- Seven FMCs have tried or are attempting to use an ecosystem-based approach in addressing some of their management responsibilities. The NPFMC and WPRFMC (in Busch et al. 2002), indicated strong support, while one FMC is focusing more on improving its single-species management.
- All the FMCs acknowledged that more data and directions are needed. They expressed concern that the estimated cost of implementing ecosystem-based management would be high if the activity was mandated to be accomplished quickly and comprehensively.
- The NPFMC indicated that moving towards the use of an ecosystem-based approach "is a process and can be started regardless of the level of information on hand." The PFMC suggested a need for "regulatory flexibility in order to adjust to short and long-term environmental variability."

Ultimately, implementation of ecosystem-based management is an incremental and adaptive process. Since ecosystems, eco-regions, and other subsets come in various dimensions, have been under various degrees of anthropogenic stress, and are continually evolving, this guidance maintains flexibility in its application.

Successful planning and pilot projects will elicit a final, yet essential, element in progressing toward ecosystem-based management. Congress must be provided the information necessary to understand funding and staffing needs associated with implementing ecosystem-based management. In advising Congress, NOAA and the Councils should provide assessments of the research, staffing, training, funding, and timelines they expect to be necessary to implement ecosystem-based management on a comprehensive scale. As part of this activity, the framework should be documented regarding how ecosystem-based management helps satisfy existing mandates of NEPA, M-S, SFA, Reg. Flexibility Act, E.O. 12866, etc.

Transition to ecosystem-based management payoffs include, but are not limited to:

- Conserves natural resources and protects biodiversity
- Optimizes social and economic benefits and minimizes negative social and economic impacts to communities
- Improves public understanding of and participation in the management process
- Ensures fisheries comply with existing laws by setting management goals with respect to fish community effects, forage, and habitat, thereby reducing the incidence of unintended consequences of management

KEY ELEMENTS OF ECOSYSTEM-BASED FISHERIES MANAGEMENT

The backbone of historic fishery management has been assessment of the status of individual species abundance and calculating and enforcing allowable harvest limits. Some management interests have been exploring advancing this management concept to include multi-species while a few management identities are attempting to implement an ecosystem approach. A cursory review of these approaches may result in the impression that moving from single species, to multi-species, and on to an ecosystem approach is progress on a continuum. This is not necessarily true. The various approaches can serve different, complementary purposes. For example, single-species approaches may be needed for tactical management, whereas ecosystem approaches may be applied to strategic management where there is good information from stock assessment(s). Therefore, the processes can be complementary, expanding the scope/interest of management, and providing a continuum of options for management responses:

Single Species
Single-species management remains a viable approach in some cases where the focus is on the status and trends of a particular species and its harvest techniques, as driven by its economic value. Because of the particular focus, this approach will continue to have value. However, this focus can be improved to fit into an ecosystem approach if the management objectives for the species are expanded to include indicators of population health such as maintenance (or restoration) of geographic distribution and depth in the range of size/age classes, in addition to sustainable stock abundance. Furthermore, when the management agencies have achieved a strong understanding of the species habitat requirements and are able to communicate these needs to the environmental regulator agencies, other ecosystem objectives will be reached. When the management agencies can include considerations of the availability of forage and trophic balances in setting objectives for the desired abundance of this species, the management process will have made significant progress towards the use of an ecosystem approach even though the focus is on a single species.

Multi-Species
The term multi-species management frequently is used to imply a more comprehensive management approach than single-species management. This is true when predator/prey species are co-managed. It would also be true if desired abundance levels of competing species, such as predator species in the same trophic guild, were set jointly at a level of sustainability that includes considering the shared forage, habitat, etc. However, when multi-species management applies only to the number of species managed concurrently, without any efforts to balance the fish community or its use of forage, habitat, etc., the benefits expected from multi-species management are not achieved nor are the principles of an ecosystem approach being applied.

Ecosystem
Ecosystem approaches may be applied when single species are of primary interest or under the heading of true multi-species management. Greatest progress can be made when the management focus is on the robustness of the ecological functions supported in a specific geographic area. Ecosystem models developed to help understand the varies interactions draw from a variety of disciplines such as anthropology, biology, economics, geography,

public health and sociology. A systems-based approach focuses on the interrelationships that emerge on social, biological, and physical or technological levels; thus, ecosystem models, by their very nature, must deal with systemic changes that result from the interconnectedness of the biological, physical, and social environments. The application of an ecosystem approach, although flexible, requires a more comprehensive process.

Scholarly studies and case studies relating ecosystem approaches to management have ballooned in the past few years. A number of seminal works have examined ecosystem-based fisheries management and have made recommendations that are generally accepted as unimpeachable. These include:

Interagency Ecosystem Management Task Force (IEMTF 1995)
*"An **ecosystem** is an interconnected community of living things, including humans, and the physical and chemical environments within which they interact…The ecosystem-based **approach** is a method for sustaining or restoring natural systems and their functions and values. It is goal driven and it is based on a collaboratively developed vision of desired future conditions that integrates ecological, economic, and social factors. It is applied within a geographic framework defined primarily by ecological boundaries…The **desired outcome** of the ecosystem approach is to restore and sustain the health, productivity, and biological diversity of ecosystems and the overall quality of human (added for clarification) life through a natural resource management approach that is fully integrated with social and economic goals."*

Ecosystem-Based Fishery Management Report to Congress (EPAP 1999)
"*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)…"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 (Kolp et al. 1994), agroecosystems (Gallopin 1995), desert ecosystems (Whitford 1995), aquatic (Rapport and Constanza 2002), and other applications (Rapport et al. 1995)."*

Marine Fisheries Advisory Committee (MAFAC) Summary Report (November 2001)
"A working definition of "Sustainability" … must be categorically defined along four separate axioms: biology, society, economic, and legal.

> ***Biology** - harvest is managed to maintain populations at sizes within defined ranges that take into account natural environmental stochasticity and observed effects of management and other human activities.*
>
> ***Society** - maintain or enhance diverse societal attributes of the fishery (cultural, aesthetic, spiritual, religious) for a specified planning time horizon (may include but not*

be limited to ceremonial use, viewing aquatic species, fishing community heritage, dietary benefits, community diversity, ecosystem benefits, subsistence harvesting, area closures, promote environmental justice);

***Economic -** the fishery constitutes a viable economic endeavor for a specified planning time horizon and yields a positive return to society measured as cumulative economic output that remains within a defined range; and*

***Legal -** the fishery must exist within a governance structure that ensures system integrity, including but not limited to regulatory authorities, treaties, constraints, requirements and infrastructure."*

FAO Guidelines on the Ecosystem Approach to Fisheries (FAO Guidelines 2002)
*"The **purpose** of an ecosystem approach is to plan, develop, and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generations to benefit from the full range of goods and services provided by marine ecosystems…*[Thus, an ecosystem approach to fisheries is defined as:] *An Ecosystem Approach to Fisheries strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic, and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecological meaningful boundaries."*

TASK FORCE RECOMMENDATIONS FOR ISSUES THAT MUST BE ADDRESSED

After reviewing and considering these seminal works, the following elements were identified by participants at a January 2002 Workshop and also through feedback at an August 2002 Symposium (AFS Annual Meeting) as requiring clarification to successfully implement ecosystem-based management. These five key issues constitute the predominant focus of the Task Force activities and are considered to be the foundation necessary to implement ecosystem-based fisheries management as it has been described in those seminal publications.

Enhancing Intra- and Inter-Agency Cooperation and Communication

An ecosystem approach is, by design, interdisciplinary and should benefit from the coordination and cooperation of numerous agencies at all levels of government (Schrope 2002). The good news is that many agencies already are collecting and processing information that would provide major building blocks for implementing the ecosystem approach. However, most marine resource agencies or departments within these agencies, still focus mostly on their direct responsibilities. For example, in a recent U.S. state survey of fish and wildlife agencies, only 64 percent cooperated with their state's environmental agency (Fisher and Burroughs 2003). A positive example in reporting interagency management cooperation dealing with marine resource is the biannual "National Coastal Condition Report (EPA 2001); the addition of a few more trends in physical habitat and biological resources would make it even more complete.

STRATEGY

Integrate ecological, political, legal, and administrative information that is collected by the various local, state, and federal agencies in performing their missions and affects fishery management options through proactive interagency coordination and cooperation.

> Cooperation involves working towards shared environmental goals and objectives, including:
> - Physical and chemical settings supportive of natural aquatic resource abundance and distribution
> - Aquatic community structure (species, age/size distribution) resulting in robust and sustainable resources
> - Coordinating inter/intra-agency research, data collection, and use.

BACKGROUND

As fishery managers move toward ecosystem approaches to management, integration of ecological information across disciplines becomes increasingly important (Juda and Hennessey 2001). The fishery management planning process must begin looking outward. Managers must examine societal goals in terms of the larger environment, including ecosystem parameters or environmental conditions such as water quality/quantity that limit fishery management options. The natural sciences, however, are not the only arena where information-sharing and integration are important. Natural resource management in the marine environment—especially at the ecosystem level—crosses political, legal, and administrative boundaries, as well as scientific and ecological ones.

PRINCIPLES AND POLICIES

Both institutional and ecological boundaries must be examined to identify legal mandates, potential conflicts, and possible partners.

- Councils and Interstate Commissions must examine their fishery goals and objectives in terms of the larger environment [e.g., ecosystem parameters and/or environmental conditions that limit fishery management options such as adequacy of forage and habitat areas of particular concern (HAPC), water quality/quantity, etc.].

- Councils and Interstate Commissions should proactively consider living marine resources in the ecosystem that are not managed by them (e.g., seabirds, some marine mammals, some marine reptiles) or are not the target/managed harvest (i.e. forage fish, invertebrates).
- The fishery management planning process should be inclusive, having as an objective the health of the ecosystem and focusing on non-quota based management actions in addition to traditional harvest quotas.

PROCESS

- Expand the scope of management to include the societal goal for the desired future condition for the ecosystem.
- Identify and define partners (institutional and non-governmental) and their roles within the ecosystem.
- Consult interagency liaisons early in the planning process, organized around specific issues or ecosystem problems (FWS, EPA, Corps, USDA, USGS, tribes, states, counties, municipalities, commissions, watershed authorities, NGO, academia, other countries)
- Improve internal communication within NOAA.
- Recognize various mandates and instances of “conflicting mandates.”
- Obtain mortality estimates from other environmental sources (e.g., NOS, EPA, FWS, states, etc.).
- Consider prey allocations to other marine resources (e.g., mammals, fish, birds).
- Add other agency liaisons at council meetings to provide CZMA, MPRSA and other appropriate information (e.g. coastal, oceanographic, and climatic information).

Delineating Geographic Area(s) of the Ecosystem

Most management units are identified by political boundaries. However, to delineate ecosystem boundaries, it will be important to identify the geographic ranges/areas using ecological metrics. The following process may be applicable.

STRATEGY

Identify and describe the geographical area of the ecosystem or eco-region subset to be addressed, using biological, chemical, and physical parameters to the extent possible.

> Delineating an ecosystem requires a hierarchal approach. It is reasonable to start with the LME classification and step the area down as necessary using metrics such as:
>
> - Range of key species and the physical conditions that limit this range
> - Political boundaries of responsible jurisdictions
>
> *(Ensure that mechanisms are in place to address common management of interjurisdictional resources.)*

BACKGROUND

Political boundaries usually do not match ecological boundaries, leaving the management and assessment of a system disjointed. Compounding this problem, organizations, due to their jurisdictions and mandates, operate at different temporal and spatial scales (e.g., local, state, and federal management systems). Ecosystem-based initiatives may need to include significant focus on the condition, restoration (if needed), and sustainability of ecological metrics within the geographic area of responsibility. This would be in addition to the more common focus on sustainability of individual fish populations. The varieties of ecosystem-based activities are more easily illustrated when applied to terrestrial or hydrologically-defined areas or watersheds. However, a similar approach also is needed for eco-regions or subregions of the marine environment.

PRINCIPLES AND POLICIES

Given that marine ecosystems extend across jurisdictional boundaries and can be dependent on watershed and estuarine areas, consideration needs to be given to mechanisms for coordination among local, state, tribal, and federal jurisdictions. One essential mechanism is geographic delineation of eco-regions. Current fisheries management strategies make extensive use of geographically restricted zones for such purposes as regulation of gear conflicts, protection of nursery and spawning areas, protection of habitats, species specific measures, reduction of gear impacts, avoidance of by-catch, marine no-take areas, etc. These management measures constitute real and *de facto* marine reserves that range in size from small (e.g., Edgecumbe Pinnacles 4 sq.n.mi.) to large (e.g., SE Alaska no-trawl zone 43,000 sq.n.mi.) that have many positive spill-over effects in conservation and protection of marine biodiversity besides the immediate fishery management objective.

The identification of Essential Fish Habitat (EFH) and its use in effective management has been frustrating while the more limited range included in Habitat Areas of Particular Concern (HAPC) has been more successful. The total range of a species is the area that should be included in the effort to apply the ecosystem approach to the management of the species. This effort to identify habitat areas utilized by fish throughout their life cycle and taking measures to conserve those areas through consultative procedures is an essential component of ecosystem approach to management and is an integral part of applying the EFH concepts. Better understanding of the spatially explicit nature of management areas, transition to multiple species and habitat models, and better interjurisdictional coordination for activities within the specific geographic area will be some outcomes of this activity. The process described below is a reasonable approach to coming into compliance with the EFH provisions of the Sustainable Fisheries Act and with NEPA-mandated EISs for EFH.

PROCESS

- Identify the geographic area to be addressed - natural ecological boundaries are preferred; however, political boundaries may have to suffice in initial stages.
- Eco-region: Identify and describe the geographical extent of the ecosystem(s) under regional or Council authority and coordinate among institutions with overlapping jurisdictions.
- Describe habitat needs of different life-history stages and delineate straddling and transboundary stocks.
- Sub-region: Partition the ecosystem into applicable ecological units (range of fish species, climatic units, etc.) to provide the foundation for prioritization, sequencing, and creation of logical management, preservation and/or restoration area units.
- Select metrics to inventory and describe the area(s) for determining goals, criteria, and implementation strategies (e.g., document and map using GIS).

Preparation of Quantified Natural Resource Goals and Objectives (Description of Desired Future Conditions)

Public support and understanding will be improved when management decisions are clear, are based on quality information, and require accountability. Accountability requires specific and quantifiable objectives. Such accountability is coming into use for terrestrial natural resources, but is not yet common in aquatic resource management.

STRATEGY

- Use an open and public process to develop general goals and specific objectives that describe the "desired future condition" of the ecosystem and its major component parts (Sissenwine and Mace 2002).
- Identify and define tolerance limits for the evolving or functional ecosystem within an acceptable range of fluctuations similar to natural historic conditions.
- Develop a process for evolving policy, direction, and resource objectives as well as an institutional process for evolving implementation strategies, integrating inputs, and evaluating outcomes.

BACKGROUND

The current metrics used to describe the conditions of heavily harvested fish stocks, to determine if they are being overfished or that overfishing is occurring, have limited application if these metrics are applied using only the current or recent population data (Conoven and Munch 2002; Pauly et al. 2002). It has been suggested for some fisheries that each generation of resource managers appears to set for their goals and objectives the level of abundance and distribution of fish recorded during their contemporary studies, seemingly ignoring the information that current numbers have been significantly reduced from those recorded by the previous generation (Pauly 1995). Although descriptions and quantification of historic conditions are important in terrestrial ecology, they are not fully utilized in marine ecology because the historic references are assumed to be unreliable (Holthauser et al. 1999), but progress is being made (Link et al. 2002; Link and Brodziak 2002).

PRINCIPLES AND POLICIES

An ecosystem approach requires that all major actions be measured against the impact these actions will have on important metrics that have been developed to describe "desired future conditions." Therefore, a public process must be employed to describe the desired future conditions. To assist in this process and to identify historic limits, the historic conditions must be documented, including abundance and distribution of key resources.

PROCESS

- Identify the geographic area to be addressed - natural ecological boundaries would be preferred, however, political boundaries may need to suffice over the near term.
- Perform a technical analysis to investigate, evaluate, and use in trend analysis, historic data on species mix, relative abundance of key species, geographical distribution, age/size ranges of key species, etc.
- Perform similar analyses to describe current conditions.
- Identify and, if possible, quantify the differences between the historical description and current conditions.

- Through an open and public process, communicate the findings and results to the stakeholders, agencies, public officials, and the media.
- Implement a public process that will identify and describe the societal goals for the desired future conditions using two relevant time frames (short term: 3 to 5 years, and long term: 20 years plus).

Four Categories of *Ecological* Indicators:

- Diversity & functioning indicators: diversity and similarity indices, richness, evenness, dominance, keystone, redundancy, community importance, functional indices (similarity, redundancy, complementarily, impact, and strength)
- Multivariate methods: ordination, Tree, PCA, CA, other statistical analyses
- Aggregated indicators e.g., size spectra
- Emergent property indicators: food web from mass balanced models, primary production required to sustain the fisheries, mean trophic level, transfer efficiency between exploited trophic levels, FIB index…

Identify and Apply Specific Indicators

The process of determining the goals and objectives (future desired conditions) of an ecosystem-approach to marine fisheries management requires the use of measurable characteristics related to structure, composition or functioning of an ecological system (Boehlert 1996). Because ecosystems are dynamic and can be unpredictable, a precautionary approach (FAO #2 1996) must be implemented to accommodate natural variability, our incomplete understanding of ecosystem structure and function, and other uncertainties encountered in setting ecosystem reference points and in assessing the direct and indirect effects of anthropogenic stressors, including fishing, on natural ecosystems (Caddy and Regier 2002). Once selected, the effectiveness of these characteristics in identifying, describing, and conserving ecosystems and their natural resources must be reviewed with respect to uncertainties and unpredictability of responses to management actions.

Recent efforts to advance the ecosystem approach to fisheries have been stymied by the challenges involved with developing ecosystem indicators (environment, habitat, species, size, trophodynamic, or integrated) that would have near universal applicability (Miller and Cury 2002). Although it may be tempting to call this a "bottom-up" approach, this term has been preempted for use in energy / trophic applications. However, a term that might be usable and descriptive is "stress-symptom" indicators since the focus appears to be on the identification of metrics to quantify various types of ecosystem degradation. Further progress in the identification and description of stress-symptom indicators, addressing for example the topics identified by Miller and Cury (2002), will provide additional management tools.

STRATEGY

Identify specific indicators of ecosystem condition and integrity and evaluate their effectiveness in conserving ecosystems and their natural resources (FAO #8 1999; Jamieson et al. 2001). Those indicators are part of a precautionary approach that accommodates natural variability, our

Characteristics of Ecosystem Indicators include:

- Be reasonably simple to compute and understand
- Have an intuitively reasonable interpretation
- Be discussed and argued in a comprehensive way (statistically, mathematically and/or ecologically)
- Have some appropriate foundation in terms of an ecological theory, statistics or mathematics
- Be applicable to marine ecosystems, including the open oceans, the EEZ and continental shelf, and also the near-shore and its watersheds

incomplete understanding of ecosystem structure and function, and the direct and indirect effects of fishing on natural ecosystems. Use this information to create an institutional definition and interpretation of the "precautionary approach" and how it should be employed in ecosystem-based management approaches. Assess how (or whether) the precautionary approach currently is being employed and make recommendations to Congress on the need for legislation.

BACKGROUND

Single-species management has been effective in rebuilding some overfished stocks of marine fishes. However, the process of single-species management does not address possible direct and indirect adverse effects of the management plan on other components of the biological community or the integrity of the ecosystem itself. The outcome of the ecosystem approach to management is to achieve and maintain a desired level of stock abundance without imposing undesired effects on other living marine resources or disrupting the integrity of the ecosystem(s) (Caddy and Regier 2002). Various indicators (e.g., similarity to historic natural, efficiency in energy transfer between trophic levels, robustness, etc.) of ecosystem "health" and integrity can be used to select targets for the desired level of protection of the fishery ecosystem, to assess the current condition of the ecosystem, and to monitor the effectiveness of ecosystem management. Some of these indicators are available; others are conceptually sound but have not been tested. Of those that are available, few have been quantitatively related (calibrated) to various levels of abundance of a fishery's primary species.

Environmental indicators using satellite imagery (particularly in upwelling and coastal areas):

- Spatialized statistics of the upwelling event/region/system
- Habitat structure (heterogeneity and complexity at different scales)
- Triad indicators (i.e., quantify retention, concentration and production processes)

PRINCIPLES AND POLICIES

Improved availability and more comprehensive use of information addressing ecological conditions is a prerequisite for effective decision making about ecological resources. Basic needs:

- Assessing ecosystem health in sufficient detail to understand the general causes of impairments is complex, although broad comparisons with historic conditions can be accomplished.
- Addressing the prevailing lack of a comprehensive and consistent list of ecological characteristics and data on ecological conditions.
- Ecosystems are not totally predictable but progress can be made in trying to manage the human impact on them within the limits of their predictability.
- Species in an ecosystem are linked by energy and material flows in complex patterns.

Fishery indicators include:

- Catch Time Series: Changing regimes in ecosystem dynamics (changes in means and variance structure and ratios)
- Fishing effort: Characterize fishery activities, catch per effort, and catch distribution
- Acoustic survey: Characterize biomass distribution and overlap between biomass distribution and catch
- Historical trends in geographic distribution and size / age ranges

Disrupted patterns may affect the energy flow, productivity, stability and associated economies.

- Even ecosystems may change appreciably when native species are removed beyond long-term sustainability or non-native species are added and, furthermore, the stability and resilience of the ecosystem may be adversely affected.
- Excessive harvest of living resources changes conditions within the ecosystem.
- Reference conditions should be defined against which measured values for ecological indicators can be compared and should take into account that ecosystems are dynamic and variable.

PROCESS

Identify and characterize on the basis of available information, and consistent with a precautionary approach, the historical and current conditions of the fishery of interest, and its marine ecosystem setting, using an appropriate selection of ecological attributes and biotic indicators.

- Select biological indicators (e.g., species diversity, trophic structure, habitat requirements, community demographics, genetic diversity) and abiotic attributes (e.g., substrate, physicochemical, energy flow, nutrient cycling) to characterize the condition of specific ecosystems. Some are qualitative in nature, others are quantitative, but few as yet have been calibrated to reveal cause-and-effect relationships within and among components of an ecosystem.
- Identify societal goals (reference conditions) for the future of the fishery and its marine ecosystem and assess the initial and long-term impact of various anthropogenic stressors and management on the ecosystem. Apply precautionary principles to account for uncertainties and variability of data.
- Assess effectiveness of management plan in achieving goals and objectives using a variety of data sources (e.g., ecosystem indicators, landings, stock assessments, fisheries independent data) and accounting for data quality (natural variability, sampling strategies, lacking or limited information).

Socio-economic indicators include:

- Ecosystem value / fisheries value
- Ecosystem services
- Economic value of non-consumptive versus consumptive uses
- Ecosystem health and ecosystem integrity

Examples of Metrics Associated with Relevant Processes

Environment (Physio-chemical)	Bottom/surface temperature, Bottom/surface salinity, delta Sigma-T, difference between Bottom & Surface Temp, Water Volume from Scotian Shelf, Current velocities, etc.
Habitat (Benthos)	Percent of bottom that is gravel, sand, mud; distribution of hangs/snags; distribution of bolders, bedrock and/or other high rugosity sites; distribution of corals and unique other biotic habitat, multi-beam sonar maps, etc.
Contaminants	Concentration of organic hydrocarbons, concentration of (polyvalent) metals, concentration of Nitrogen, P, S, concentrations of the above in tissues of key spp., etc.
Diversity (i.e., biomass allocation)	Percentage of fish biomass in various aggregate groupings, guilds, trophic levels; size spectra; community diversity indices (e.g., richness, evenness), etc.
Productivity (& cybernetics)	chl *a*, phytoplantkon community composition, zooplankton biomass and community composition; growth rates, mortality rates, production rates of key species, total system production (by TL), total system biomass, ascendancy, redundancy, etc.
Trophodynamics	Number of Species interactions, diet composition of major species, mean TL, % Omnivory, % Cannibalism, Connectivity, Linkage Density, Cycling, etc.
Canary Populations	Incidence of disease/parasites, biomass/abundance of non-economic but ecologically valuable spp., etc.
Human	Total number of vessels, DAS, Total Landings by species, Total Income, Income per vessel, Landings by port, Bycatch rates, etc.
Pulse perturbations (e.g. hurricanes)	Likely same as above

Socio-Economic Data to Evaluate Management Tradeoffs

There must be a better understanding of the human dimension of fisheries management (ICGPSIA 1994). Under the National Environmental Policy Act (NEPA), federal agencies are

Characteristics of *Social and Economic* Indicators should:

- Be manageable and relevant to human ecology
- Be reasonably simple to compute and understand
- Have an intuitively reasonable interpretation
- Be discussed and argued in a comprehensive way (statistically, mathematically, and/or ecologically)
- Have appropriate foundation in terms of economics, sociology, or public health theory
- Examine systemic changes that result from interconnectedness of marine and human environments.

required to examine the impacts of government actions on the human environment. In addition, the Council on Environmental Quality (CEQ) defines the human environment to “include the natural and physical environment and the relationship of people with that environment” (40 CFR 1508.14). The Magnuson-Stevens Fishery Conservation and Management Act (MSA) states that fishery management plans should “take into account the social and economic needs of the States.” MSA also provides for the consideration of social needs and social impacts on fishing communities through National Standard 8 which states “Conservation and management measures shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities.” The cumulative impacts on fishing communities must also be assessed, thus emphasizing the importance of base-line and longitudinal data. Social and economic concerns of special interest groups and targeted economic groups are also protected. Environmental justice and cumulative impacts on fishing communities must also be taken into account. In addition, Executive Order (EO) 12898 requires federal agencies to examine the effects that federal actions will have on minority and low-income groups, and requires federal agencies to examine human health and the social and economic effects associated with federal actions. And, the Regulatory Flexibility Act (RFA) requires economic assessments for small entities that are directly affected by a proposed federal action. Thus, assessments that include ecological, social, and economic indicators are *all* required to satisfy various key federal acts. Efforts to develop ecosystem approach to fisheries management plans need to consider this entire range of assessments.

Mandates require collection and assessment of social and economic data. NEPA, CEQ, MSA, RFA require that management plans and other federal actions:

- Consider social and economic needs of the States
- Provide for sustained participation of fishing communities
- Minimize adverse economic impacts on fishing communities
- Evaluate environmental justice
- Assess cumulative impacts on fishing communities
- Consider effects on human health
- Perform economic assessment for directly affected public entities (even small)

STRATEGY

While conserving natural resources and protecting biodiversity, optimize social and economic benefits, and minimize negative social and economic impacts to communities through a better understanding and integration of the human dimension of fisheries management.

BACKGROUND

Ecosystem models draw from a variety of disciplines such as anthropology, biology, economics, geography, public health and sociology. A systems-based approach focuses on the interrelationships that emerge on social, natural and physical or technological levels; thus, ecosystem models, by their very nature, must deal with systemic changes that result from the interconnectedness of the natural, physical and human environments. Ecology itself is not a field subject to biological reductionism. Human and cultural ecology are established disciplines and the development of ecology as a science included, from the onset, the recognition that humans are key parts of ecosystems and need to be included in ecological models (for further discussion see: NRC 1999; Buttel and Humphrey 2000; Hawley 1950,1984).

Restrictive regulations in the short term could result in long term increased economic benefits; but short term social and economic hardships that occur need to be immediately addressed and not dismissed merely on the basis of possible long-term gains. A better understanding of behavioral adaptations in response to short-term economic hardship and social stress is critical because such behavior has often refuted management goals. Furthermore, cumulative impacts, uncertainty in predicting future behavior or resource conditions, and other unforeseen events can reduce or negate long-term benefits (or even result in unexpected benefits). Increases in the uncertainties that people face also may contribute to a reluctance to accept demands for immediate sacrifices. People must be convinced that they will have long-term benefits—thus increasing the need for better predictive economic and social impact models. Data collection and analysis is of primary importance for better achieving the goals of ecosystem management. Resources to generate these analyses are limited yet must, by law, be provided.

PRINCIPLES AND POLICIES

Federal law requires the collection and assessment of social and economic data to appropriately manage marine resources. The mandates include:

- Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires that social and economic analyses be conducted. For example, National Standard 8 calls for analysis of impacts on fishing dependent communities and directs the Secretary of Commerce to minimize adverse economic effects while still achieving conservation goals.
- Regulatory Flexibility Act (RFA) requires economic assessments for small entities that are directly affected by a proposed Federal rule.
- National Environmental Policy Act (NEPA) calls for social and economic impact assessments and also emphasizes the importance of environmental justice and cumulative impact considerations.
- Executive Order 12866 requires an analysis of economic costs and benefits of any proposed management action.

PROCESS

- Monitor and evaluate socio-cultural and economic interactions that contribute to and that occur as a result of ecosystem based fisheries management, e.g., work and occupational opportunities, unemployment trends, distributive impacts of policies.
- Provide adequate funds for social and economic information and analysis to meet the requirements of ecosystem based fisheries management.
- Improve regulatory and management policies to promote cooperation and reduce conflict

Ten-Step Social Impact Assessment

1. Develop a public involvement plan
2. Describe proposed actions and identify alternatives
3. Describe the relevant human environment
4. Identify probable impacts
5. Investigate probable impacts
6. Determine probable responses of affected public entities
7. Estimate indirect and cumulative impacts
8. Recommend changes in proposed action
9. Develop and implement a mitigation plan
10. Develop and implement a monitoring program

among stakeholders, managers, and government officials.

- Examine appropriate national and international case studies of interdisciplinary ecosystem approaches, co-management techniques, communities' rights and rights-based management techniques, and human response to management choices (*cf*. Ebbin 2002).
- Improve communication among government groups outside and within NOAA Fisheries (in particular, from committees that work on social and economic aspects of marine resource management).

POTENTIAL ANTHROPOGENIC STRESSES NOT ADDRESSED

Aquaculture

Approximately one-third of seafood for world-wide human consumption is generated through aquaculture (Goldburg et al. 2001) and the demand for these products continues to increase (FAO 2000). Concurrently, environmental and fisheries management agencies are identifying procedures to limit the potential negative environmental impacts of aquaculture (FAO 1991; FAO #5 1997; ASMFC 2002). Although planning is underway, (e.g., "New Initiative in Marine Aquaculture," NOAA 2002 and "Guidance Relative to Development of Responsible Aquaculture Activities in Atlantic Coast States" AMFC 2002), proactive implementation and enforcement of such guidance is needed. This can best be accomplished by working closely with experts to understand the production and ecosystem processes associated with marine aquaculture.

Anthropogenic stressors can be alleviated by (in alphabetical order):

- Aquaculture licensing, including requirements for waste treatment and performance bonds to prevent release or escapes of strains or species not native to the location.
- Identification of potential harmful species to provide focused transfer prevention.
- Imports of live products licensed with requirement that they will not be released unless appropriately authorized.
- Intentional introductions require approval and documentation on the risks and trade-offs.
- Mandatory ballast water treatment when crossing eco-regions.
- Restoring the natural biodiversity and abundance of native species to limit opportunities for exotics.

Exotic Species

Although non-native or exotic species have been of concern for decades (Galil 2000; Leppaekoski and Olenin 2000), the introduction of zebra mussels to the Great Lakes resulted in increased concern that encouraged the passage of the National Invasive Species Act (1996). A range of non-native classifications are included in the "exotic" label from genetic strains different from the native wild species to the truly exotic "from a far off or different location." The key to limiting the future impacts of exotic species appears to be in the prevention of their escape or release into the wild (Busch et al. 1999). However, policies and regulations are not yet in place in most jurisdictions.

SPECIFIC MANAGEMENT CONCEPTS

A number of concepts should be explored and applied, where appropriate, to elaborate on sustainable fisheries issues and to drive the basic components of ecosystem-based management. The following are recommended by numerous sources:

Advancing Understanding through Modeling
It is widely recognized that modeling can be a very important tool in describing ecological relationships (Larkin 1996). In data-rich and data-moderate cases, modeling is an indispensable tool for effective resource management. For example, a multidimensional model has been used for developing and monitoring strategies in Chesapeake Bay that affect plankton, benthos, and Submerged Aquatic Vegetation (Cerco et al. 2002). Recent trophic models (e.g., ECOPATH) are now being used to predict fishery outcomes for some near-shore and estuarine systems. For some offshore, deep-water fisheries however, inadequate data limit quality of model outputs. Therefore, modeling is at present a tool best used to assist identifying and interpreting cause / effect relationships for potential management actions. Ultimately, modeling is an essential component of progressing from precautionary single-species management to proactive and more holistic ecosystem fishery management. Therefore, modeling is a second or higher-level application that may best follow the basic initial steps identified in this Strategic Guidance and deserves special review beyond the scope of this document.

Adequately Measure Total Removals
Adequately measuring total removals is a basic first step in implementing ecosystem-based fisheries management. Existing catch accounting systems must be examined for effectiveness and must take into account bycatch. NOAA Fisheries' view of current observer programs and other monitoring and enforcement mechanisms, including Vessel Monitoring systems (VMS), must be clearly stated. A detailed examination of accounting systems and bycatch rules will be helpful to policy makers and fisheries managers in planning strategies for moving towards ecosystem-based fisheries management.

Rights-based Management
Numerous reports call for using rights-based fisheries management as a tool for addressing overcapacity and fostering widespread use of total allowable catch (TAC) levels. Various options are available to limit the conflicts and consequences of continuing the open access to fisheries (Charles 2002). Some of the options include assigning territorial rights to fish in certain locations, limiting entry to a certain number of individuals or vessels, and/or limiting effort rights or setting catch quotas. Each approach has advantages and disadvantages and its application and effectiveness depends on the ecological, social, economic, and political setting. It would be useful for NOAA Fisheries and the Councils to assess their accomplishments to date in meeting the SFA mandate to prevent overfishing. From these assessments, the most appropriate "next steps" outlined in this guide could be selected.

Research
Ecosystem-based management calls for understanding interactions among target species, prey, predators, and competitors. These ecological interactions are accompanied by a daunting list of other research needs to better understand the ecosystem. Currently, there is concern about the

quality and quantity of fisheries independent and fisheries dependent research as well as widespread dissatisfaction with the quality of, or lack of, social and economic data. NOAA Fisheries and the Councils should provide an assessment of research needs, by category, and the resources required to undertake a progressive research program needed to support ecosystem-based fisheries management.

Use of Social and Economic Data

Social and economic indicators are not new to ecological models. However, social and economic analyses are distinct from one another. They often examine related issues, because they focus on different aspects of the human dimension and the disciplines use different methodologies and techniques of analysis. Detailed lists of social and economic indicators have been prepared in the development of SAFE (Stock Assessment and Fishery Evaluation) reports (under the "Guidelines for Fishery Management Plans" (50 CFR 602), as well as in other Government and Fisheries Management Council initiatives such as those recommended by the Social Science Advisory Committee to the New England Fisheries Management Council and government reports on social and economic impact assessments. The question of manageable and relevant lists of indicators has also been discussed in FAO #8 (1999), Gruenwald et al. (1997), Kusel (1996), Doak et al. (1996), McCay and Cieri (2000), and Dunlop and Michelson (2002). These papers draw on fisheries and other resource management plans that are applicable to ecosystem approaches.

Human Communities and Demographics Categories

- Family stability
- Health: mental and physical
- Self esteem
- Social stress
- Crime levels
- Income levels
- Socio-economic condition of the community:
  - Housing, education, poverty, divorce, single-parent households, substance abuse
- Social profile of the community:
  - Historical trends, ethnicity, education, employment, housing, family life, gender roles, cultural and religious values
- Quality of life attitudes
- Hopefulness for the future

Fishery related occupation categories:

- Community revenues
- Regional revenues
- Market structure
- Market pricing
- Price fluctuation
- Business expenses and total costs
- Employment trends:
  - Full time, part time, seasonal
- Sector:
  - Owner, crew, processor, dealer, servicer, etc.
- Income trends or earnings changes:
  - Family income, salaries, payment schedules

Geographic Use Restriction through Ocean Zoning

Ocean zoning is the authoritative regulation (and allocation) of access and use to specific marine geographic areas. Its objective is to increase the use of spatially explicit management measures in fisheries using ocean zoning and coordinate with other managers of non-fisheries uses and activities to place fisheries within a larger ocean management area program.

Ocean zoning is the marine analogy to terrestrial zoning. Many federal and state agencies have jurisdiction over activities on/in the water column and the seabed [USDC (NMFS, NOS) USDOI

(NPS, FWS, MMS), DOD, EPA, etc.]. Frequently these authorities are for single-use regulation for non-fisheries uses of the ocean such as oil and gas production, ocean mining, ecotourism, marine transportation, marine defense and water-quality protection measures. Sometimes they may overlap with use by fisheries. No comprehensive authority for ocean zoning exists in the United States. However, fishery managers have used this tool for many years for a variety of conservation and management purposes (Bohnsack 1999; Rubec et al. 2001). When set in context, the patchwork of fisheries management areas, if adequately coordinated with jurisdictions of other agencies, and when designed to meet societal objectives, could be a tool in implementation of ecosystem approaches to fisheries management.

Fisheries management makes extensive use of zoning for such purposes as regulation of gear conflicts (Johnson 2002), protection of nursery and spawning areas, protection of habitats, species specific measures, reduction of gear impacts, avoidance of by-catch, marine no-take areas, etc. This effort constitutes a potential building block for ecosystem approach to fishery management (Rubec et al. 1999). Identification of habitat areas utilized by fish throughout their life cycle and taking measures to protect these areas, through consultative procedures, is one component of this activity that focuses on fish/habitat interactions. A second component is identification and mediation of fishing effects on the marine environment.

In the context of ocean zoning, consideration should be given to the issue of Marine Protected Areas (MPAs; Grittings et al. 2002) and the effects of E.O. 13158 directing relevant federal agencies to promote MPAs. NOAA’s recently formed MPA Advisory Committee is charged with, among other things, defining what constitutes an MPA. In collaboration with the MPA Advisory Committee, NMFS should review existing MPAs, including National Marine Sanctuaries, with respect to time/area closures and restrictions intended to avoid interactions with endangered, threatened, or protected species. Size, placement, and the number of MPAs for nearshore fishery management should be reviewed with respect to the extent to which they meet the goals and objectives that they were intended to accomplish. A particular review of the efficacy of MPAs to achieve the following ecosystem-based management objectives will be necessary:

- Ecosystem conservation and consideration for non-consumptive uses,
- Allowing for stock rebuilding, increased reproductive potential, and restoration of more natural age structures,
- Protecting marine species and sensitive, unique habitats, and
- Taking a precautionary approach to account for scientific uncertainty.

To this end, a critical analysis of experiences in the Florida Keys NMS, the Dry Tortugas, Channel Islands NMS/NP, and the U.S. Virgin Islands process may be instructive.

Fisheries managers may increasingly need to form partnerships with other agencies with marine management jurisdictions (Ward et al. 2002). Examples of potential cooperation (in some cases expanding on existing relationships, e.g., consultative requirements under the FWCA, NEPA, with MMS, EPA) are many and can be explored. Given that marine ecosystems extend across federal and state boundaries and can be dependent on watershed and estuarine areas, consideration needs to be given to mechanisms for coordination among local, state, tribal and federal jurisdictions. Some states already have developed zoning for their territorial seas. The

Oceans Commission 2000 has on its agenda the investigation of marine zoning. Internationally, Integrated Coastal and Ocean Management (ICOM) is gaining ground as a concept for management of competing uses in marine areas. It employs ocean zoning as a major tool.

Identification and systematic assessment of the existing use of geographically based fishery management measures in the US, including EFH, should be conducted at multi-national, federal, regional/interstate, Council, state, and local levels. Areas should be documented and mapped using GIS (Rubec et al. 1998). Assessment could consider how areas and habitats are protected from fishing and other impacts as well as consider how fisheries are given priorities in certain areas [e.g., gear limited areas] such as:

- Examination of state-level and foreign country experience with ocean area zoning for multiple uses, including fisheries and for fisheries within comprehensive ocean plans (e.g., Australia, Philippines, South Africa) for possible models.
- Research on hierarchical relationships/ marine zoning on different spatial scales.
- Research on spatially explicit management measures for fishing in areas adjacent to marine reserves (fully-protected, partially protected).
- Development of technologies required to implement large-scale spatially explicit fisheries management, e.g., GIS tools, vessel tracking and positioning equipment.
- Explore social patterns of use and social components of geographic-based management measures.
- Examine interagency (state, local, and tribal, including domestic/international, and task forces) coordination efforts for multiple zoning instances.

Tangible, measurable, or monitorable outcomes that should result when ocean zoning is applied as a component of ecosystem-based fisheries management have yet to be developed.

Regulatory Process Using Fishery Control Rules

Fishery Control Rules are the primary mechanism for achieving management: e.g., sustainable use, preventing overfishing, preserving habitat, rebuilding depressed stocks, and recognizing the importance of non-consumptive uses (Kaufman et al. in press; California Department of Fish and Game 2000). In federal fisheries management, formulae in FMPs often provide for the direct calculation of total allowable catch (TAC, fishing mortality) but usually not for other aspects of resource management (habitat quality, ecosystem integrity).

Fishery Control Rules do not have to be cast in terms of fishing mortality rates or biomass levels. Simply put, a Control Rule seeks to identify measures of "good" and "bad" stock condition (by comparing perceived stock status with biological reference points), as well as the actions that will make the stock condition change from "bad" to "good." In general, Control Rules help identify key management measures appropriate to the fishery. In addition, Control Rules must be based on objective, measurable criteria that indicate integrity or resilience of the ecosystem. Examples of such criteria include population size, recruitment, productivity, demographics, density, diseases, fishing income, etc.

There are many possible approaches to developing Fishery Control Rules. Choice of appropriate rules for a fishery depends on the management objectives for that fishery; the kind, amount, and quality of Essential Fishery Information (EFI) available; and the pros and cons of different Control Rule approaches. Different Control Rule approaches that are available for management of the nearshore fishery are described in this section (modified from Kaufman et al. in press; see also California Department of Fish and Game 2000). The recommended approach is presented.

The preferred Control Rule, which incorporates and blends different approaches, has three objectives:

- Maintain healthy populations of target species (or achieve the rebuilding schedule if applicable).
- Avoid extreme fishery effects on the ecosystem.
- Anticipate effects of environmental changes that affect the fishery- positively or negatively.

To accomplish those objectives, the control rule integrates:

- Essential fishery information about the demographics of target species, ecosystem effects of the fishery, and the effects of environmental change on the fishery.
- Different levels of availability of essential fishery information (data-poor, data-moderate, or data–rich circumstances).
- Management strategies that include more or less precaution, depending on the levels of essential fishery information.

Ecosystem Condition Categories

Land based activities
- Abundance and access to wetlands
- Restrictions to watershed access
- Abundance and condition of nearshore habitat
- Runoff and nutrient loading
- Toxic chemical loading
- Impingement/entrainment
- Aquaculture inputs including exotics
- Beach nourishment and dredging at borrow sites
- Electro-magnetic disturbance (power lines)

Harvest activities
- Bycatch/discards
- Physical habitat disruption

Imbalance in trophic structure
- Marine mammals guild – state of diversity compared to normal level of abundance
- Primary predator guild – state of diversity compared to normal level of abundance
- Secondary predator guild – state of diversity compared to normal level of abundance
- Forage guild – state of diversity compared to normal level of abundance
- Crustacean guild – state of diversity compared to normal, level of abundance
- Shellfish guild – state of diversity compared to normal, level of abundance
- Zooplankton guild – state of diversity compared to normal, level of abundance
- Phytoplankton guild – state of diversity compared to normal, level of abundance
- Introduction/establishment of exotics in any of the above trophic categories

Climatic changes
- Changes in migration patterns
- Changes in occupied range
- Recruitment changes, availability of food
- Changes in estuary salinity

Other
- Noise pollution (underwater)

The framework for the control rule includes three general categories:

- Stage I – Data-poor circumstances with precaution as the primary basis for setting TACs.
- Stage II – Data-moderate, improved single-species management and a transition from strictly precautionary management to risk management.
- Stage III – Data-rich, ecosystem approach to management.

For example, the current level of ecosystem knowledge for nearshore habitats is primitive. In Stage I and Stage II, only crude precautionary adjustments are available to address uncertainty about ecosystem effects of fisheries. Details of Stage III management must be developed and refined as it becomes clearer what types of relevant information can be successfully collected, as more of that information becomes available, and as models and other analyses are developed to apply hydrodynamic and living resources data using the full range of management measures.

In developing the Control Rules, a few underlying principles are evident:

- There are irreducible uncertainties that never will be resolved. Consequently, the need for precaution can be reduced with improved information but never eliminated.
- Single-species management has commonly tended toward inadvertent over-exploitation.
- In Stage II and Stage III, better information can result in higher TACs.

Although these three stages imply a stepwise progression, the boundary between stages is well-defined only between Stage I and the other two. Application of elements of Stage II and Stage III management may vary in degree and time among species and regions; as usable information of different types becomes available, it can be incorporated into management models. This Control Rule approach provides for changing the trigger points for regulatory action as information improves.

INDICATORS TO DESCRIBE AT VARIOUS SCALES ECOSYSTEM HABITAT CONDITIONS AND HISTORIC TRENDS

Physical / Chemical Parameters	Coast	Region	Estuary	Watershed
Wetlands (hectares)	X	X	X	X
SAV (hectares)	X	X	X	X
Live shell reefs (hectares)	X	X	X	
Historic (dead) Shell Reefs (hectares)	X	X	X	
Stream Access, Natural (historic, kilometers)	X	X	X	X
Stream Current Access / passage (kilometers)		X	X	X
Nutrient Loadings (annual metric tons; pt. source)	X	X	X	X
Beach Maintenance (annual cu. meters; kilometers)	X	X	X	
Sand/Gravel Mining (annual cu. meters)	X	X	X	X
Harbor / Channel Dredging (annual cu. meters)	X	X	X	X
Shoreline Armoring (kilometers)	X	X	X	X
Water Withdrawal (megaliters)	X	X	X	
Marine Protected Areas (hectares)	X	X	X	
Biological Parameters				
Species Overfished (number)	X	X	X	X
Exotic Species (number)	X	X	X	X
Extinct Species (number)	X	X	X	X
T or E Species (number)	X	X	X	X

An Example of Ecosystem-based Exploitation Strategies

Anthropogenic impact on the nearshore environment has been documented in much greater detail compared to offshore; yet, many species access both areas during their life cycle. Current management strategies separate nearshore and offshore waters, often by state and federal jurisdiction, seemingly stepping away from ecosystem approaches to fisheries management. However, due to the often profound differences between the nearshore and offshore ecosystems, including the range of environmental data available for these areas, it may be beneficial to acknowledge those differences in creating fishery management strategies allowing for incremental incorporation of ecosystem data. Such an approach has been taken within state waters in a Nearshore Fisheries Management Plan created under the California Marine Life Management Act (MLMA; Kaufman et al. in press; California Department of Fish and Game 2000) and is described in Appendix 3 in its three stages of application. The MLMA provides a preliminary example of how management can progress through various stages as data become available for a fishery ecosystem. This instance also illustrated the importance of both the advisory and regulatory responsibilities of a management agency and the need to have interagency cooperation.

ECOSYSTEM-BASED MANAGEMENT RECOMMENDATIONS - PILOT PROJECTS

Several types of pilot projects should be undertaken to illustrate the benefits and challenges likely to accrue when undertaking the preparation of Ecosystem-based Management Plans.

Ø One pilot project is to evaluate a limited number of current Fishery Management Plans with regard to ecosystem issues (delineate boundaries, establish indicators for measuring ecosystem effects; set natural resource goals; compile social and economic data; establish interagency cooperation) and recommended management tools. The outcomes would include improved understanding of the more common ecosystem issues that are adequately included while also identifying those challenges that are not being addressed. NOAA Fisheries or Congress should provide funding for several such projects.

Ø A limited number of regional, interagency, and interdisciplinary workshops should be supported to improve interagency communications, sharing of existing data, and guiding and funding high priority research. A limited number of successful examples of proactive interagency cooperation, identification and sharing of available data, and development of common resource Goals and Objectives could greatly advance the implementation of an ecosystem-based approach to resource management.

Ø Another pilot project should consider the benefits and costs of Fishery Ecosystem Plans and the projected shifts in effort and staffing required to create and implement FEPs. Although most existing management activities can be modified to be more in line with the ecosystem approach, proactive implementation requires a framework. Because boundaries for specific ecosystems have not been identified, flexibility must be exercised in addressing the scale of coverage. A Fishery Ecosystem Plan (FEP) may be prepared at different scales such as on a broad scale for an LME or with more specific data for smaller geographic areas. The development of these FEPs should encourage the collection of all relevant information (biological, physical, and socioeconomic), processed through a logical sequence of analyses, leading to solid options. The following are guiding principles:

- Document the status and trends of major biological resources and relevant chemical, economic, physical, and social metrics, moving towards a 4-d GIS system.
- Assess the ecological, social, and economic causes and consequences of those trends.
- Predict potential futures under various policy/management scenarios.
- Provide guidance on implementation of the options (without selecting one).

A comprehensive outline for preparation of an FEP follows and suggested specific indicators also are provided to aid in identifying the topics (and suggested methods) applicable to the ecosystem approach to marine resources management. FEPs must be, by design, interdisciplinary and broad in coverage and can be created only through interagency coordination. The overall requirements also could be used to identify agency-specific responsibilities and the team effort required to provide the desired environmental stewardship for specific geographic marine areas and their resources. NOAA Fisheries and the Councils must examine the ecosystem-based process, particularly with respect to costs, staffing, implementation timelines, and existing mandates under NEPA, the Regulatory Flexibility Act, E.O. 12866, etc.

SUGGESTED TABLE OF CONTENTS FOR A COMPREHENSIVE FEP

1. Introduction
   a. Agencies (lead, participating, supporting, interested)
   b. Laws being implemented
   c. Public consultation process
   d. Time period covered by this plan

2. Description of the geographic area of coverage
   a. Identification of significant political boundaries
   b. Identification of significant ecological units, subsets (may need to consider a hierarchical approach, stepping down from large to small scale as needed), and boundaries
   c. Base maps (created/obtained):
      Large scale of the ecoregion and small scale overlays for specific areas such as HAPCs
      Inventory and obtain GIS data available from other agencies
      Identify GIS data storage for security and accessibility

3. Description of current natural resource and socio-economic conditions using categories that are potentially developed/discussed in the Fisheries Ecosystem Plan to provide status and trends of all stressors affecting the natural resource and its system. The categories may include:
   a. Quantification of key environmental parameters
   b. Identification of the structure and relative abundance of each trophic guild
   c. Identification of abundance, geographic range, and age-class representation of key species
   d. Description and historic antecedents of the relevant fishing communities and related socio-economic setting
   e. Models used and results to present the integrated picture
   f. Issues of special concern (T&E, catastrophic events, etc.)
   g. May focus on details at each tropic level and representative guilds, species, and environmental parameters

4. Description of the historic ecosystem through trend mapping for the metrics used to describe the current natural resources and socio-economic conditions in addition to descriptive information such as traditional knowledge.

5. Description of the Desired State of the Natural Ecosystem expressed in the goal statements for the ecoregion and stepped down into sub-goals and quantifiable objectives as necessary. These would be similar to the current conditions in lightly perturbed reaches but would have to include rebuilding/restoration in highly disturbed/over harvested systems. The goals and objectives may be separated into short-term (2 to 5 yrs.) and long-term ($\geq$20 yrs.) goals and objectives. The desired state must be linked to the long-term desired socio-economic conditions.

6. Description of the Desired State of the Socio-Economic Ecosystem conditions expressed in the goal statements for the ecoregion and stepped down into sub-goals and quantifiable objectives as necessary. These also could be separated into short-term (2 to 5 yrs.) and long-term ($\geq$20 yrs.) goals and objectives. The desired state must be linked to the long-term desired ecological conditions.

7. Description of Ecosystem Management Options presented in terms of pros and cons of various management options to correct or mitigate the effects of adverse anthropogenic stressors and to accommodate natural cycles, to encourage resource abundance and health, to attain the desired resource and socio-economic goals.

8. Apply the selected indicators for ecosystem "health," for example, species and/or community, environmental, and/or societal descriptive metrics.

9. Evaluation and Follow-up via a clear process that institutionalizes periodic follow-ups on progress, and implements needed corrections.

10. Identification and prioritization of crucial information needs – In many applications, implementation will be limited by lack of information. These needs should be revisited periodically and considered during annual budget planning.

EVALUATING IMPLEMENTATION

A profound shift in agency operations as proposed will require assessing the effectiveness of changes implemented when applying ecosystem-based management. The following questions provide a nominal evaluation plan to assess progress in applying an ecosystem approach to fisheries.

1. Was a sound, interdisciplinary, ecosystem assessment conducted or is one underway that describes the current conditions and the major natural and anthropogenic (if any) stressors and constraints for a geographically/politically defined area?
2. Were goals and objectives (or are they being) collaboratively developed, describing a vision of desired future conditions, limited by historic restrictions and irreversible changes, including:

   <u>Marine resources</u>

   Key environmental parameters;
   Structure and relative abundance for each trophic guild;
   Abundance, geographic range, and age-class representation of indicator species;
   Tangible measurable (or monitorable) outcomes.

   <u>Socio-economic issues</u>

   Public process in place to make resource allocation decisions;
   Ability to use economic incentives and/or disincentives to match fishing capacity to sustainable harvest of resources;
   Pursue conservation measures that pose the fewest socio-economic problems.
3. Were the calculation and presentation of the trends, in the measurements/metrics selected for use in item #2 above, done for at least three time periods (a past period with relatively light disturbance/natural conditions, present, and desired future)?
4. Has interagency collaboration and coordination of activities and data sharing and reporting been implemented?
5. Does the Fisheries Ecosystem Plan identify and prioritize management actions to address the natural and anthropogenic stressors and the socio-economic tradeoffs limiting the achievement of the goals and objectives?
6. Are periodic interagency follow-up assessment meetings, open to the public, part of the standard operating procedures?

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GLOSSARY

BIODIVERSITY is the variety of *genes, species, and ecosystems* in a region. Each category describes different aspects of a living system and is scientifically measured in different ways to characterize the composition (identity and variety of living forms), structure (physical organization), and function (ecological and evolutionary processes) of the system – usually referenced to the natural variation in the region of interest. (See http://www.biodiv.org and http://ceres.ca.gov/ceres/calweb/biodiversity/what_is.html)

ECOREACH refers to a subunit of an ecoregion, determined based on gradients, barriers, and other physical, chemical, and biological features of the ecoregion.

ECOREGION refers to a unit determined by hydrology, plant and animal community structure, and substrate (if any). This unit is used both for assessing the quality of a resource relative to appropriate reference conditions and for conservation of natural resources while supporting local economies and culture for the lasting benefit of people living in or associated with the ecoregion.

ECOSYSTEM refers to the complex set of relationships among living resources, habitats, and residents of a region. An ecosystem includes people, wildlife, fish, shellfish, plants, wetlands, water, and any other living and non-living entities that are necessary for the ecosystem to function over the long-term.

ECOSYSTEM-BASED FISHERIES MANAGEMENT refers to personal, social, political, and management decisions that are made considering ecological information. Ecosystem-based decisions acknowledge that the environment, even in the absence of anthropogenic influence, is always changing. Ecosystem approach decisions are three-dimensional because they (1) include stakeholders, perspectives, and human goals, (2) consider the health and vitality of ecosystems into the indefinite future, and (3) include the larger landscape and connections among other landscapes. This approach requires attention to ecosystem integrity, interagency cooperation, spatially explicit management measures, and time-series data for multiple species and habitats. The goal of the ecosystem approach to fisheries management is to conserve natural resources and protect biodiversity while optimizing social and economic benefits and minimizing negative social and economic impacts to communities. Ecosystem goals are set with reference to the larger environment, including ecosystem parameters or environmental conditions (e.g., water quality) that limit fishery management options.

ESTUARINE refers to the deepwater tidal habitats and adjacent tidal wetlands, semi-enclosed by land, but with open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land. Estuarine systems extend upstream to a point where oceanic salts measure less than 0.5 ‰ during average low flow (although salinity periodically may rise above that of the open ocean by evaporation) and downstream to an imaginary line across the mouth of a river, bay, or sound, and seaward to the point where wetland emergents, shrubs, or trees are no longer present. (see http://www.npwrc.usgs.gov/resource/1998/classwet/estuarin.htm)

EXOTICS refers to species or strains of organisms introduced beyond their native ranges. Also known as "alien," "invading," "non-native," or "nonindigenous," these species may be intentionally or non-intentionally introduced and may include the introduced organism (generally plants, invertebrates, and vertebrates) as well as associated pests and parasites (viruses, bacteria, protozoans).

GIS is the acronym for "geographic information system" which refers to the organized activity by which people measure aspects of geographic phenomena and processes; represent the measurements (e.g., in a computer database) to emphasize spatial themes, entities, and relationships; operate upon these representations by integrating unrelated data to predict and discover new relationships; and transform these representations to conform to other frameworks of entities and relationships. Successfully implemented GIS aids goal setting, data analysis, and monitoring ecosystem integrity.
(see http://faculty.washington.edu/chrisman/explor/toc.html)

GUILD refers to a group of species that perform more-or-less the same ecological role, making similar use of the same resource. Having more species per guild may increase the stability, and hence the productivity over time, of a marine community. Conversely, a loss of a number of species per guild, could render a marine community more vulnerable to wild swings in stock sizes and productivity.

INDICATOR SPECIES refers to a species, that by virtue of its reliable occurrence in a specific substrate, community, or ecosystem, is used as a gauge for the condition of that ecosystem.

KEY SPECIES refers to ecologically and/or economically important organisms that usually also are numerically abundant.

LONG TERM refers to the fact that an ecosystem approach time frame extends beyond the next year, budget cycle, or election, to ensure that ecosystem dynamics occur within ranges that do not exceed the resilience of the system.

MARINE refers to the sea realm, comprising more than 99% of Earth's biosphere, and housing 31 of the 32 known animal phyla. Many conservation concepts developed for terrestrial systems must be considerably modified for marine systems due to the distinct physicochemical, biological, and valuation differences between the two types of systems.

MPA is the acronym for "marine protected area" which is a spatially explicit management classification that includes any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws, regulations, or customs to provide lasting protection for part or all of the natural and cultural resources therein.

MULTIVARIATE is the term that describes statistical, mathematical, or graphical techniques that consider multiple variables simultaneously.

NUTRIENT LOADINGS refer primarily to nitrogen and phosphorus pollution derived from municipal and industrial wastewater (point sources) and in agricultural runoff (non-point source).

OCEAN ZONING the authoritative regulation [and allocation] of access and use to specific marine geographic areas.

OVERFISHED refers to harvesting greater numbers of a species than are replenished by natural reproduction. The definition of overfishing should include at a minimum seven elements that define management targets and thresholds (status determination criteria, maximum fishing mortality threshold, minimum biomass threshold, biomass target, optimum yield, maximum rebuilding time period, control law or fishing mortality management strategy). (see Murawski, S.A. 2000. Definitions of Overfishing from an Ecosystem Perspective ICES Journal of Marine Sciences 57:649-658)

PRECAUTIONARY APPROACH as defined by FAO #2 (1996) refers to application of prudent foresight, taking into account the uncertainties in a fishery ecosystem and the need to take action despite incomplete knowledge. Components of a precautionary approach include addressing the needs of future generations, avoidance of irreversible changes, prior identification of undesirable outcomes and instituting measures to circumvent those occurrences, taking necessary corrective measures without delay, conserving the productive capacity of the resource, adjusting harvest and processing capacity to be commensurate with estimated sustainable levels of the resource, ensuring appropriate legal and institutional framework exists for management, conducting periodic review of management measures, and ensuring appropriate placement of the burden of proof.

PRIMARY PREDATORS refers to the main consumers of the prey in question or within in an eco-reach; the term usually is applied to the most significant competing piscivores as opposed to other consumers.

QUOTA defines a specified numerical objective for landings (excluding discard mortality), the attainment (or expected attainment) of which may cause closure of a fishery.

SAV is the acronym for “submerged aquatic vegetation.”

SECONDARY PREDATOR refers to the second most abundant or ecological important consumer of the prey in question or within in an eco-reach; the term usually is applied to the second most significant piscivore as opposed to other consumers.

SHORT TERM refers to the fact that many traditional management decisions are confined to a yearly, budgetary, or political cycle. Ecosystem processes occur on the scale of lifespans of the ecosystem inhabitants, often on the order of decades or even centuries.

STANDARDIZATION refers to the need to have consistent usage of data format, ecological indicators, and language and acronyms across regions and agencies. It is necessary to instill conformity of accepted measurements or values that are applied to fisheries management through the use of similar indicators for data collection, data processing, and reporting such as with Geographic Information Systems.

STRESS (STRESSOR) refers to a factor, environmental or anthropogenic, that causes or drives a behavior or outcome.

SUSTAINABILITY of a fishery must be defined in terms of goals within four separate categories**.** Together, these science and policy components interact transparently to form a dynamic and adaptive process:

Biology – harvest is managed to maintain populations at sizes within defined ranges that take into account natural environmental stochasticity and observed effects of management and other human activities;

Society – maintain or enhance diverse societal attributes of the fishery (cultural, aesthetic, spiritual, religious) for a specified planning time horizon (may include but not limited to ceremonial use, viewing aquatic species, fishing community heritage, dietary benefits, community diversity, ecosystem benefits, subsistence harvesting, area closures, promoting environmental justice);

Economic – the fishery constitutes a viable economic endeavor for a specified planning time horizon and yields a positive return to society measured as cumulative economic output that remains within a defined range; and

Legal – the fishery must exist within a governance structure that ensures system integrity, including but not limited to regulatory authorities, treaties, constraints, requirements and infrastructure.

TROPHIC (GUILD) refers to a group of species (or particular life stages of a group of species) that feed on the same types of prey.

TOTAL ALLOWABLE CATCH (TAC) is a specified numerical objective for catch (including discard mortality), the attainment (or expected attainment) of which may cause closure of the fishery. In Stage I, TAC is equivalent to a proxy for optimum yield of a species (OY). In Stages II and III, TAC is equivalent to OY.

WATERSHED refers to all of the land area that contributes surface run-off to the water supply of a body of water such as a river, stream, or lake.

WETLAND refers to an area where saturation or repeated inundation with water determines the nature of the soils, the plants, and the animals of the area. Wetlands include wet meadows, lake and river banks, swamps, bogs, marshes, embayments, bayous, river flood plains, and estuaries.

ABSTRACT FROM THE FAO FISHERIES ATLAS

SECTION 3.2.8 "BASIC PRINCIPLES OF ECOSYSTEM MANAGEMENT"

> *"The overarching principles of ecosystem-based management of fisheries are an extension of the conventional principles for sustainable fisheries development to cover the ecosystem as a whole. They aim to ensure that, despite variability, uncertainty and likely natural changes in the ecosystem, the capacity of the aquatic ecosystems to produce fish food, revenues, employment and, more generally, other essential services and livelihood, is maintained indefinitely for the benefit of the present and future generations.*
> *The main implication is the need to cater both for human as well as ecosystem well-being. This implies conservation of ecosystem structures, processes and interactions through sustainable use. This implies consideration of a range of frequently conflicting objectives and the needed consensus may not be achievable without equitable distribution of benefits."*

These needs are widely recognized and accepted by fisheries management agencies and interest groups worldwide, but there is still great uncertainty as to how to implement an effective ecosystem management system in practice. Conventional fisheries management focuses on a single species or stock and generally assumes that the productivity of that stock is a function only of its inherent population dynamics characteristics. However, even under this paradigm, fisheries management has been, at best, only partially successful and major problems have emerged because of uncertainty about the status and dynamics of the stock, a tendency to give priority to the short-term social and economic needs at the expense of the longer-term sustainability of the stock; poorly defined objectives; and institutional weaknesses, particularly in relation to the absence of long-term rights amongst the different key stakeholders and decision-making structures and processes.

As management expands its focus from target stock to ecosystem, all of these problems increase in an exponential way and biological uncertainty becomes ecological uncertainty that is even more complex, the number of competing users increases as do the resulting conflicts of interest, objectives become more complex and conflicting, and the number of stakeholders is expanded to include all the users of all the different ecosystem components. Of course, this expanding complexity is a result of recognizing the reality of the inter-dependence of all ecosystem components, instead of the false assumption that stocks are independent. However, while it is a major conceptual advance, the practical problems raised by this recognition are immense. This is apparent from the list of 30 elements comprising the foundations and components of ecosystem management suggested by the 5th Conference of the Parties of the Convention on Biological Diversity.

Nevertheless, there are pragmatic ways in which to begin implementation of ecosystem approach to fisheries management, even as we strive for greater knowledge of ecosystem functioning and how to deal with complex human institutions and societies. Among the immediate steps that should be taken in moving towards ecosystem approach in fisheries are the following:

1. Fisheries management agencies and others involved in use of aquatic resources need to identify the different ecosystems under their jurisdiction, the boundaries of those ecosystems and their characteristics.
2. In consultation with all legitimate stakeholders and interest groups, objectives must be agreed upon for each ecosystem, and potential conflicts and inconsistencies in those objectives recognized and addressed. This will require involvement of both fishery and non-fishery stakeholders and will include setting objectives for each of the fisheries taking into account the constraints of the ecosystem and the objectives of other stakeholders. Objectives should include both long-term and short-term objectives and would normally cover biological, ecological, economic, social and institutional issues.
3. In accordance with the FAO Code of Conduct for Responsible Fisheries (7.2.2) biological and ecological (collectively ecosystem) objectives should include conservation of biodiversity and protection of endangered species, consideration of "adverse environmental impacts on the resources" and minimization of "pollution, waste, discards, catch by lost or abandoned gear, catch of non-target species… and impacts on associated or dependent species…"
4. As a part of setting the objectives, sustainability indicators (see FAO #8, 1999) need to be established for each ecosystem. These serve both to facilitate communication, transparency and accountability in management, and to help assess the status of ecosystem elements and hence to guide management actions. There is a clear link between sustainability indicators and reference points, the latter describing either targets to be aimed for in the sustainability indicators or limits to be avoided.
5. Suitable management strategies, typically consisting of a suite of management measures, should be designed to achieve the set of objectives. Typically the management measures will encompass a combination of technical measures, closed areas and seasons, input and/or output controls, and a suitable system of access rights for all users. Closed areas are recognized to have an important role to play in ecosystem management.
6. Given the high levels of uncertainty concerning the status and dynamics of ecosystems and their response to perturbation, application of the precautionary approach is particularly important in implementation of an ecosystem approach to fisheries management.
7. An ecosystem monitoring system needs to be designed and implemented to ensure that the information necessary for tracking the sustainability indicators is collected in a reliable and timely manner.
8. An effective consultation and decision-making process must be established to ensure that all legitimate stakeholders can be consulted about any changes in the management strategy that may be required to respond to changes in the ecosystem, including changes in the nature and pattern of human usage. This forms part of the essential adaptive control system to respond to inevitable change and variability in ecosystems.
9. An appropriate and effective enforcement system must be impartially implemented.

Simultaneously, with implementation of robust and pragmatic ecosystem approach management systems, states and other management bodies should undertake further research to help to reduce the existing uncertainties concerning the ecosystem approach and hence to facilitate improved resource allocation. Such research should include the following:

1. Develop conceptual models of the food web of each discrete ecosystem to facilitate consideration of possible ecosystem responses to different management actions.
2. Through monitoring ecosystem interactions, e.g., diet composition and population dynamics of key species, improve knowledge where there are key gaps in the conceptual model of the foodweb.
3. Identify critical habitats for the key species in the ecosystem and identifying and address any threats to these.
4. Improve monitoring of bycatch and discards in all fisheries.
5. Improve data collection and analysis for socio-economic conditions of fishing communities.
6. Consider improved methods for consultation and joint-decision making to improve ecosystem governance.

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Ted Munn

Policies for Sustainable and Responsible Fisheries

John Caddy[1] and Henry Regier[2]
[1]Imperial College, London, and CINVESTAV, Merida, Mexico
[2]University of Toronto, Toronto, Canada

For millennia, human populations have changed planetary ecosystems; and hydrological basins and adjacent coastal seas have accumulated the consequences of human upstream alterations to terrestrial and aquatic ecosystems within these watershed or marine catchment basins. In addition to direct and indirect effects of fishing, communities or assemblages offish species must adapt to the aquatic effects on fish habitats of ecologically stressful human practices on land and along shore. Some fish species cannot tolerate these habitat changes. Climax assemblages of native species, or even the persistence of species components locally, cannot be sustained under intense stress to them and their habitat.

Some efforts to limit ecologically harmful practices date back many centuries. They are reflected in religious taboos, cultural mores, traditional knowledge and legal regimes. But as humans have became more numerous, and especially with industrialization, urbanization and impoverishment of fishers, most attempts to limit adverse ecological effects have eventually failed. Contemporaneously, the stress regime on ecosystems generated by humans has grown inexorably. Degradation of aquatic ecosystems may not be apparent to the casual observer but can be inferred from fisheries and other ecosystemic data.

Over recent millennia, humans have harvested fish, mostly for food for humans and their domestic animals, and to a much lesser extent for recreational and ceremonial purposes. When the demand for fish was less intense, fishers selectively removed taxa that were highly valued locally and in trade, i.e., premium fish or target species. Taxa that were not valued for human food, i.e., coarse fish, were often discarded where they were caught, or transformed into animal feed. A main conclusion is that a major challenge in governance of fisheries is managing the fishers and not just the fish stocks.

CURRENT ISSUES IN THE GROWING DEPLETION OF WORLD FISH STOCKS

In recent decades, a progressively broader spectrum of fish species has been harvested by commercial fishers. New technologies in preserving and processing fish for human consumption, animal feed and pet food have resulted in increases in the value of incidentally captured species in the by-catch that were once discarded. Anglers have diversified to target a broader array of sport fish. Poor people, with access to fish near human settlements where diets are short of protein, may harvest all species almost unselectively.

The destructiveness to fish habitat of some fishing methods, such as trawling, has become increasingly evident. Ecosystem stresses from fishing have generally increased in phase with impacts on fish habitat from other human activities. Empirical study has shown that some fish species populations are suppressed and even extirpated by such a combination of stresses while other populations may react positively and increase. Both types of anthropogenic stresses, fishing and indirect impacts of human activities on fish habitat, may act synergistically, and there is often confusion as to proximate causes in any given situation. Qualitative and quantitative characteristics of a fish association or community are altered further by human-induced changes to the association of higher vertebrate populations (reptiles, birds and mammals) which depend on fish for their diet. Thus, humans have long acted in ways that were unsustainable from both a fisheries and an ecosystem perspective.

From scattered evidence we infer tentatively that fish population extirpations occur more frequently through habitat destruction than through direct over-fishing, although extreme vulnerability, longevity and/or low fecundity exacerbate the risks of extinction by capture. The occurrences of fish population or stock extirpation, and much less frequently of species extinction, apparently increased progressively during the 19th and 20th centuries. The emphasis in management now seems less on the actual extinction of fish species than on the more immediate loss of genetic diversity through elimination of local stocks or races, especially for freshwater, estuarine and anadromous species, and those occupying specialized and restricted habitats such as estuaries, coral reefs or sea mounts. Nonetheless, currently few of the world's ecological associations of fish populations are not affected adversely by habitat abuses and/or improper fishing. Fishers can now take fish anywhere in the world's waters; for example, the recent ability to exploit economically extremely slow- growing, long-lived deep water species of oceanic slopes, ridges or sea mounts such as the orange roughy, is a deep concern. Given the few restraints that exist on overharvesting in international waters, many deep water stocks may be effectively eliminated before they can be studied.

Technological progress in industrial fishing of ocean resources has outstripped the ability of international regulatory bodies, hampered by inadequate powers allocated to them by coastal states, to counter the negative effects of overfishing in an environment where fishing power has grown continuously over recent decades. New technologies such as synthetic fibers for netting, echo location of schools, satellite navigation, and improved processing, transportation and marketing of fish, have all contributed to a frightening efficiency of harvesting and a greater range, versatility and speed of redeployment of fishing fleets.

Atmospheric, hydrological and ecological processes carry hazardous chemicals everywhere, and especially to higher latitudes. Climate change is altering the current patterns and temperatures of water bodies. Stratospheric ozone depletion is changing the spectrum of the sun's irradiation at the water surface, particularly off the Antarctic coast. Exotic species are transported widely in the ballast water of ships and through the fish culture and aquarium trades. The genie of genetically modified organisms is also now out of the bottle as far as fish culture is concerned, with likely effects of escaped cage-reared salmon strains on reproduction of native stocks. In developed countries, local and regional ecosystemic stresses may be abating while global stresses are intensifying. In less developed countries all stresses may be expanding and intensifying.

PROSPECTS

So what might a new global commitment to sustainable and responsible fisheries mean in practice? Pessimists may fear that the sustainability concept relates to an historic ideal that has become progressively less realistic over the centuries. Late in the 18th century, Condorcet and Malthus initiated a debate that has continued since then between technological optimists and ecological pessimists. Two centuries later, the optimists may appear to be winning this debate; with each passing decade, natural features of ecosystems are less capable of satisfying the growing human wants and needs, and we are relying on increasingly artificial ecosystems using increasingly artificial techniques. Pessimists question if these artificial systems, with expanding loss of natural features, can exist independently of a healthy biosphere with the integrity of its natural life-support capabilities persisting unchallenged.

In the 1880s European fisheries experts debated whether or not serious over-fishing of oceanic fish populations did, or even could, occur. That debate was not resolved finally until the 1990s, when the collapse of several well-studied and supposedly well-managed groundfish stocks in the north Atlantic cast doubt on the efficacy of current risk- adverse type of science-based management regimes.

We note in retrospect that during the intervening 20th Century, much of the science and politics of fishing was captured by this debate about the reality of overfishing. Rational resolution may have been hindered because commercial interests and their client nations sought to maintain the freedom of the sea in order to exploit commercial opportunities. At the same time, scientific advisors working for governments placed too much emphasis on the concept of ‘equilibrium conditions’ and the mistaken idea that fisheries were ‘sustainable’ at levels at or around maximum sustainable yield (MSY) (see *Maximum Sustainable Yield (MSY)*, Volume 4).

The politically weaker conservationists or ecological pessimists bore the onus of proof, in a case-by-case basis. Most management measures tended to be short-term, palliative, and fraught with problems due to unresolved differences about allocating catches between fleets and states. In consequence, management was not sufficiently rigorous or sustained to lead to stock rebuilding. Powerful interests, i.e., exploitive technological optimists, dictated that fishing practices should not be constrained unless and until clear evidence of over-fishing was presented to, and accepted by the fishing industry. Exploiters often resisted reporting data that could prove useful to the conservationists, or reported false data on landings or their provenance.

In the 1990s a different debate was joined at a global level, with a revaluation of the proposition that commercial fisheries or other forms of exploitation of wild natural resource can be managed sustainably, and if so with what constraints? This debate has led to the extension of the precautionary principle (see *Precautionary Principle*, Volume 5) from its original application in pollution science, to fisheries management. An attempt is now beginning to reverse the burden of proof to rest on exploiters rather than on conservationists, and require an assessment of fisheries impacts before authorizing new technological applications or increases in exploitation rate.

New interrelated global initiatives in ethics, law and science, applied to the shared use of fish and other ecosystem goods and services, began in the 1990s. There is as yet only scant empirical evidence that these noble commitments, which the two of us helped to foster, are being success fully put into practice. Optimists may argue that organisms that resemble wild fish, from a commercial perspective, can be reared economically in fish culture facilities. They admit that there will be adverse effects on the natural habitat, on the wild fish genome, etc. But it is better, they may say, to rear standardized, genetically-modified fish in abundance than to rely on stocks of variable wild fish that will likely fade away in any case. While the issues of fish culture, restocking and sea ranching are not addressed further in this essay, we have noted the dangers of genetic modifications to the fitness of wild stocks that they may pose. Among currently unresolved dangers of intensive and semi-intensive fish culture are: importation of diseases; local pollution of inshore environments and lagoons; and dependence on a limited supply of foodstuffs derived from harvesting wild stocks.

EARLIER SCIENTIFIC AND TECHNICAL APPROACHES

In this essay we mainly consider fisheries on fish (family Pisces) as such, but the aquatic realm provides somewhat similar opportunities and constraints to the ecological production, harvesting and relevant policies for other kinds of aquatic animals. Thus, much of our text is directly relevant to policies on harvesting of invertebrates and marine mammals.

During the 20th century a number of different approaches to population dynamics were employed for understanding, modeling and managing of fisheries. From roughly the 1950s onwards, these approaches were being applied in a rather widespread fashion to the management of commercial fisheries by industrialized nations. The primary focus was on the maximization of physical yield, using MSY as a target reference point sanctioned eventually by the Law of the Sea. Much later, and still inadequately, the focus shifted to the optimization of economic returns.

A problem with setting targets for catch or fishing rate is that fisheries data are rarely adequate to ensure a precision of greater than +30% in optimal yield estimates, hence overshoots were frequent with subsequent recovery difficult. As a result, fishing effort tends to continuously increase, following the ‘ratchet principle’, aided by hidden effects of technological improvements not contemplated during the formulation of fisheries regulations. Much more recently, the specification and avoidance of the risk of over- fishing has begun to be given priority in some fisheries, associated with the concept of precaution. As an example, the use of MSY as a limit reference point, rather than as a target, requires that managers take into account the variance in the data when seeking to avoid exceeding MSY, and prenegotiate an immediate effort reduction, should such an overshoot occur.

Within a particular ecosystem — river, lake, coastal sea, ocean — attention was focused mostly on populations of the fish species favored by the fishers, with little concern for the inevitably high discards and other impacts on species caught incidentally by relatively unselective fishing gear. With commercial fisheries, such target species brought increasingly higher prices on an international market. Since the l960s that market, in turn, has been increasingly efficient at linking hard-currency consumers anywhere, with fish resources harvested anywhere else in the world. Valued target species have shown an apparently unconstrained upward mobility in price, in turn increasing incentives for overharvesting. With ease of harvest and rudimentary regulatory systems, target species tended to be the first depleted in the local fish community. A bioeconomic model for a particular fish species might even have been fitted to data on catch and cost of fishing, but rarely was the concept of *economically optimal yield* used as a benchmark for deter mining harvest rate.

The abstractions from reality provided by simple single species models, that are often the best possible, given the limited information available, offer an illusion of certainty to fisheries managers. However, there is a growing awareness that aspects of the complex ecosystems in which the fish live, and of the societal and market complexities within which fishers operate, may better be described by chaos theory. Through time, a single species model's drift from realism is difficult to spot, and the inadequacies of information often means that decisions are made on yesteryear's information.

Numerous empirical generalizations or rules of thumb have been inferred from meta-analyses of population dynamics analyses over the years. Some examples are:

- The MSY of target species occurs when the total mass of the exploited fish population in the ecosystem is of the order of 50% of the biomass of that population in its historic pristine or 'virgin' state; unlike a virgin stock dominated by slow-growing older fish, an exploited population is dominated by more productive younger fish, posing a danger that excessive exploitation will cut into the population's spawning potential.
- The mean age in a population drops as fishing rate in a conventional fishery increases, so that the main possibilities for regulating fishing are either postponing age at first capture by gear regulations (e.g., using larger meshes in the net), by avoiding fishing on juvenile nursery or adult spawning aggregations, and/or by reducing the fishing intensity, fleet size and the individual fishing power of boats.
- As fishing intensity increases, longer-lived species (e.g., cods, halibuts, sturgeons) are replaced by shorter lived species (such as low-value forage fish and invertebrates), with consequent impacts on ecosystem balance.
- Species show an innate preferred temperature range; populations near the latitudinal mode of that temperature range are most productive while those at either the cold, high latitude or warm, low latitude extremes are smaller and produce less surplus for fisheries harvest perhaps due to irregular recruitment.
- In monetary units, net economic returns from commercial fisheries are usually maximized when harvests of individual populations are some 10-20% less than the MSY in mass units; this level of exploitation often corresponds roughly to the *optimal sustainable yield* or the *Maximum Economic Yield* in particular.

Current regulatory approaches often assume that the resource can be exploited throughout the year and throughout its range. Evidence is accumulating however, that such simplicity involves dangers because of the high seasonal vulnerability of some stocks due to a lack of effort control engendered by unresolved allocation issues. A more pre cautionary approach would be to start from the perspective that exploitation is prohibited, except for those time—area windows when established access holders are authorized to take a safe proportion of the stock, using selective, and tested harvesting methodologies with minimal discarding.

Because of the intractable unpredictability of nature and human activities that influence exploited fish populations, in practice the population dynamics approach can mainly be used to construct accountancy models for fish currently in the waters, as a basis for allocation. Such models have little explanatory or predictive power with respect to what yield can reliably be expected some years in the future.

The population dynamics approach alone has seldom provided appropriate information directly relevant to the management of recreational fisheries. Generally anglers appreciate a natural setting and enjoy the prospect of capturing a large fish, at least occasionally. This implies that a low overall rate of harvest must apply in order to allow survival of that statistically improbable phenomenon, the large, older or ‘record’ fish. The gustatory pleasure and dietary benefit of actually consuming the fish may not now rank as highly as in Isaac Walton’s day, and catch-and-release angling has gradually become more popular than angling for food. Aesthetic more than utilitarian considerations come into play with respect to considerations of sustainable angling pressure.

Artisanal or domestic fishers, who are often the poorer people of a region, tend to be opportunistic with respect to fish to which they have access. In North America, old treaties with some Native Peoples recognized usufructuary rights to harvest fish and other natural features in large areas beyond their immediate core reserves. Some of these treaties have been interpreted recently to imply that a Tribe is entitled to half the optimal sustainable yield of valued target species within its Treaty area. Often an artisanal fishery does not specialize just on a few valued species in its locale. Instead, fishers may remove fish of any size of numerous species. In many parts of the world a concept like sustainable fishing has seldom been applied to such artisanal fisheries. The poorest of the poor capture what they can where, when and however they can do so. Commercial and angling fishers may complain that artisanal fisheries are unsustainable, perhaps because some immature fish may be taken, but in general, artisanal fisheries provide more employment per ton of harvest, low wastage, and much of the catch goes for human food in local communities where fishers play an important economic role, as opposed to industrial fleets which may not employ local labor, and where the owners are not necessarily vessel operators.

Aboriginal peoples who live in ecosystems that retain some features of wilderness may capture fish in ritualized ways for ceremonial purposes. In North America, for example, Aboriginal peoples who were not assimilated fully in Western culture have been re-instituting ancient ceremonial practices that relate to the spiritual interrelationships.

of humans with nature. Relatively few fish may be taken, so that there is no direct threat to sustainability. But ceremonial fishing may be deemed to exacerbate harm done by commercial fishers who are, or may be fishing such populations intensely. Or anglers may resent the removal of the scarce large fish valued both for recreational and ceremonial purposes.

Within an interdisciplinary ecosystem approach, there may often be a role for a population dynamics approach within a broader ecosystem perspective, but a scientist should take care to relate the more limited assessments to a more comprehensive ecosystem-based approach (see *Ecosystem Approach*, Volume 2). Sustainability of fisheries then becomes a facet of the joint sustainability of a mix of uses, both direct and indirect, of an aquatic ecosystem.

Integrated Coastal Area Management and watershed management are becoming more relevant, linking fisheries with other users of the aquatic environment through concepts such as zonation by priority use of subareas, and the employment of tools such as Geographical Information

Systems now being widely used for planning user interactions and access rights (see *Geographic(al) Information Systems (GIS)*, Volume 4).

A multi-stakeholder commitment to sustainability relates, in turn, to some politically agreed vision of selected features of an ecosystem which are to be sustained. Any such vision will be tentative and subject to periodic revision as an ecosystem evolves in ways that are not fully predictable. Heretofore, few such shared visions have been negotiated and thus few are available to serve as case studies to guide further efforts to achieve joint sustainability. Any fishery of more than low intensity causes the ecosystem and the fish association to adapt irreversibly to some extent; thus a pristine state cannot provide a practical vision for a sustainable fishery. A debate between biodiversity preservationists and those favoring sustainable use in all waters continues, with the former slowly gaining in some countries through the adoption of marine parks or conservation areas in which commercial fishing may be banned.

OWNERSHIP REGIMES AND SUSTAINABLE FISHING

In many contexts, the management and transaction costs that come with private ownership of wild fish and their habitat may exceed the benefits to the owner of such ownership. In such cases, effective exercise of such ownership may not be worth the effort. Quasi-ownership regimes, involving a less formal balance of privileges and obligations, may be less expensive to administer. Common property resources may be formally owned in common by groups of people. The term may also be used loosely where access by fishers is open because no person or group holds formal ownership rights to the fish. The recent history of fishery policies is full of accounts of unsustainable exploitation of valued fish, in such open-access situations where no specific allocation of user access rights seems to mean that no duty of care for the resource is exercised.

A kind of Gordian knot is perceived by some fisheries analysts. It involves: both habitat and fish that are a commons; open access situations for fishers; fishing anywhere at any time of the year; unrestricted use of any kind of capture gear; rent-free harvesting; and willing consent of all harvesters prior to imposition of any constraints on extant fishing conventions and practices. This policy syndrome may seldom occur in full bloom in the real world, but is an interesting abstraction of what could happen where people have no commitment to intelligent joint action or to civic ethics.

Poorly-managed fisheries, with some features of the common property syndrome, may be complicated further by subsidies from governments to some fishers to help them to compete more effectively in such free enterprise. These subsidies, often rooted in political patronage, may be justified as efforts to assist poor fishers by supplying new technology to make their fishing more effective, or to reduce the costs of fishing. In fact, this may lead to further reduction of the level of fish abundance at which an economic breakeven point for fishing is realized, thus further increasing stock depletion. When external subsidies are not accompanied by compensatory constraints on fishery practices, they may well result in the intensification of existing unsustainable fishery practices, and promote further impoverishment.

Historically, many kinds of policy arrangements have emerged to guide the harvest of fish populations in situations where legal ownership, with a broad roster of enforce able rights, is not in place. In fact, in marine and some freshwater fisheries, ownership of a fish does not precede capture, and even where rights-based systems such as Individual Transferable Quota systems apply, it is more usual to speak of stewardship by the stakeholders over the resource, than ownership of a portion of the stock. As such, there may be few if any fish populations in the wild — other than in ponds, lakes and rivers on private estates — for which legal ownership of wild fish stocks can be invoked and enjoyed in practice. Ecosystems are by nature open systems, thus local, regional and global cultural stresses cannot be prevented from impacting at the local level. Thus, indirect effects of distant interests cannot be excluded from local ecosystems, however clear local legislation on exclusive ownership may appear to be.

Locally, some form of negotiation may lead to a balanced combination of privileges and obligations for each legitimate fisher and other users of the ecosystem. All stakeholders who enjoy some privilege of access are then constrained by some shared view of a preferred state of particular ecosystemic features, including those of the fish community or assemblage to be sustained. All local stakeholders' interests are also constrained by an ecosystem's subsequent responses to continuing regional and global stresses acting on it.

As is also the case with some mammals and birds, some fish species have populations that are strongly migratory with an annual cycle or space—time path. Policy issues, such as those concerning sustainable use, as related to highly migratory animals, are usually more difficult than those related to sedentary populations, since there are many points of harvest along the migration route. These are often in different jurisdictions or in international waters where legal constraints to overharvest are minimal. To limit harm to the habitat of highly migratory fish (as tunas and other large migrators are termed in the Law of the Sea), and to limit harvests to sustainable levels requires prior agreement among all those political entities scattered along the migratory path or with access to it.

Many inter-jurisdictional agreements have been negotiated over the decades to share sustainable yields of designated migratory stocks and to limit the harm done through abuse of habitats and bad fishing practices. Few of these agreements have served to protect the relevant stocks for long. In particular, enforcement of regulations in a multi-jurisdictional species range is a major weak point: the negotiation of a sustainable *Total Allowable Catch*, and fair allocations from it are other obstacles where agreement is not easily reached.

In ocean waters outside of national extended economic zones (EEZs), neither the fish nor their habitats are owned by any group or nation. Currently the global regime of governance is not developed to a stage at which such ownership in the open ocean has been legitimized through fisheries commissions, special (e.g., bilateral) arrangements, or by the United Nations and its specialized agencies. A 1995 agreement on how the Law of the Sea provisions will apply to Straddling Fish Stocks (i.e., those lying across boundaries between EEZs and the High Seas), and Highly Migratory Fish Stocks, was not yet ratified at the turn of the century. Some measure of law and order with respect to hopes for sustainability may however be exercised jointly in specific areas through multinational or bilateral treaty arrangements among powerful fishing nations, expressed in the form of fishery commissions set up to provide for a discussion between member nations. Common provisions for monitoring, control and surveillance (MCS) and enforcement capabilities are rarely ceded by states to these commissions. Responsibilities for MCS and prosecution of fishers who offend outside the EEZs remain largely with the flag states of an offender's vessel. Non-tariff barriers with respect to trade are beginning to be used, but are not especially effective given the magnitude of unsatisfied demand for fish internationally. More recently, ecocertification with labeling of fish products from properly managed fisheries has begun, and is aimed at giving the consumer a role in choosing products from areas where healthy fish stocks are maintained by proper management.

SUSTAINABLE FISHERY REGIMES FROM AN ECOSYSTEM PERSPECTIVE

Every natural aquatic ecosystem together with its cultural system of human users is unique in some important ways. A universal analysis that ignores such uniqueness would not likely suffice for practical and political purposes within a particular ecosystem.

With ecosystems generally, intensification of some mix of ecological stresses has proceeded more rapidly than the creation of appropriate science to understand what then happens in particular ecosystems. Current efforts to innovate scientifically, with an ecosystem approach that takes account of all stresses, have mostly focused separately on rivers, large lakes, enclosed coastal seas and shelf seas. Comparative studies or ecosystemic meta-analyses have been initiated within all four, with beginnings of studies interrelating all four types. The new science relies more on narrative and contextual case studies that have testable features, rather than on time-independent universalistic analyses also with testable features.

A favorite place for human settlements has always been along a river, near its mouth with a lake or sea. The waters near such settlements are often a particularly important habitat, at least seasonally, for valued fish species. With many exceptions, fishers have generally preferred to exploit large individuals of near-shore sedentary populations or of populations that performed predictable migrations through waters near settlements where they could be accessed easily during known seasons. Unless careful environmental stewardship was practiced, human settlements as onshore centers of cultural organization induced disorganization of ecosystems in adjacent nearshore waters. In terms of economic accounting, the environmental costs and con sequences of settlements were externalized to the natural aquatic system and its human users. Such degraded waters have often been zoned tacitly as being closed to fishers, in part because of the high concentration of hazardous chemicals and pathogenic organisms in the fish flesh. Increasingly strong programs to rehabilitate such locales are being initiated, with some successes.

One feature of the generally high fecundity of exploitable marine species is that a high level of attrition of juveniles naturally occurs due to predation, before the mortality of individuals drops to a much lower steady rate for adults. This means that a fish becoming large and mature even in a virgin population is a statistically rare occurrence, with probability of survival from egg to spawner of the order of one in a million in some cases. Thus, fisheries managers must make difficult decisions between: (a) harvesting juvenile fish (for which there is a good market in many countries) and conserving the few adult survivors; or (b) conserving the juveniles through closures of nursery areas and large mesh size and limiting harvesting of adults such that an adequate spawning stock survives. A fishing strategy which harvests all age groups intensively is rarely sustainable.

Centuries ago, fishing did not need to become very intense before some adverse effects of highgrading by discarding juveniles (which were dead in most cases) and by-catch became apparent, even in the absence of any noticeable habitat degradation. Fewer large fish were caught; annual recruitment of young fish failed in many years, more effort was needed to take the usual harvest, etc. If the fishing method involved barring the way to spawning habitat, then the population waned over the years due to inadequate recruitment.

Aristocrats or wealthy angler naturalists have tradition ally acted to regulate commercial fishing locally and to protect the aquatic habitat in order to preserve near-pristine sports fishing opportunities. A common method was to have such habitat and riparian lands declared a preserve and to make capture of the preferred fish illegal other than in small numbers by the owners. Anadromous salmonids are prime examples of such conserved sports fish resources. Nevertheless, of the uncounted thousands of anadromous salmonid stocks that existed three centuries ago, only a few percent have retained optimal sustainability.

Unintended habitat changes due to moderately intensive human activities in the ecosystem's hydrological basin or in the aquatic habitat itself may lead to increases in populations of small pelagic fish and other low-value forage fish, and thus to increases in their MSYs. The opposite may occur with large fish of demersal/benthic populations. With poorly managed or inappropriately regulated fisheries, fishing down the food web often occurs. Populations of apical predators — the large fish at the peak of the food chain such as groupers, pike, lake trout and halibut — were over-fished, with a reduction in annual catches leading to a reduction of predatory pressure and expansion of populations of smaller prey species, which in turn attracted fishing pressure.

The effects on an aquatic ecosystem of habitat degradation, together with overexploitation, interact in a common direction to produce a system dominated by lower trophic levels and small fish. This has often been labeled loosely with the code word cultural eutrophication, since the combined effects show some similarities to those caused by true eutrophication as with excessive nutrient runoff from land to aquatic systems. In turn, the combined effect of remediating a suite of cultural abuses has been termed cultural oligotrophication: an ecosystem is rehabilitated to a state showing some similarities to that which applied in pristine water bodies with low inflows of nutrients. Pristine oligotrophic systems contained clean water, low plankton density and dominance by apical or climax species in the food web (see *Oligotrophic/Heterotrophic/ Eutrophic*, Volume 2). For both cultural eutrophication and cultural oligotrophication, a strongly artificial ecosystem may result, as for example in large lakes. Ecosystems have their ways of self-organizing beyond our full control. Thus the distinction between a culturally-stressed aquatic system and extensive aquaculture is blurred, now that some 30% or more of the products of photosynthesis in marine coastal waters eventually reach the human table.

An ecosystem adapts to an externally-applied stress regime, always. It may however be capable of self-organizing into more than one phase. Thus, the ecosystem may appear in an oligotrophic or eutrophic state, depending on the external regime of natural factors and cultural stresses. In such cases — in the past confined mostly to fresh waters, but now increasingly evident in coastal lagoons and semi-enclosed seas — the human community in the region may then take terrestrial and aquatic subsystems into account and opt politically for one of these states of nature. The stakeholders or managers might then formulate a qualitative/quantitative vision with benchmarks including preferred features of a past state of nature which are to be sustained in the face of the mix of legitimated human activities, that are themselves always evolving. They may use selected features of a fish association typical of the preferred state, e.g., oligotrophic or eutrophic, as an integrative indicator appropriate for assessing the state of sustainability.

During the 19th and 20th centuries, a common approach to mitigating the effects of habitat and fishery abuses has been to introduce selected exotic species that may have some innate tolerance of the ecological effects of extant ecological abuses. Or it may have been inferred that the reproductive capabilities of diminished native or introduced species have been severely harmed, which might justify the use of fish hatcheries to counteract such inferred effects. These may be perceived as examples of artificially upgrading a currently degraded fish association. This approach has sometimes been spectacularly successful, at least from a perspective of some anglers. Mostly it doesn't work very well, or has unexpected side effects.

The use of exotics and hatcheries has usually brought with it a new set of difficulties, some of which may be perceived to be disastrous. Some jurisdictions are now interpreting sustainability, in the context of rehabilitation from past abuses, as relating mostly to natural reproduction of valued native fish species, and are discontinuing reliance on exotics and hatcheries.

If the stress regime is extremely intense, the adaptation may involve systemic disintegration into a near-chaotic state of a few tolerant species, and ultimately death of all. The concept of sustainability as commonly applied in practice seems to presuppose that the ecosystem under consideration has not been forced to sacrifice many of its desirable features in adapting to the extant stress regime.

Current use of the sustainability concept also presupposes that the living part of an aquatic ecosystem can and does self-organize to a state of health or integrity, and con tributes some degree of homeostatic capability with respect to the incessant fluctuations characteristic of a stressed regime (see Monitoring in Support of Policy: an Adaptive Ecosystem Approach, Volume 4). In other words, sustainability implies that an ecosystem and fish association can take care of itself, to an important degree. Management costs can be constrained as a result of healthy ecosystem processes.

The shared vision of a preferred ecosystemic state, with its fish association, usually implies discontinuation of the more egregious ecological abuses and some rehabilitation to correct unacceptable effects of past abuses. In such cases it is this vision of a rehabilitated state to which a sustainability policy must relate and move towards through a long-term integrated-use policy. It may seldom be a matter of restoring a previous state, or preserving a current state which is already unacceptably degraded. The latter condition is still manifest in many parts of large lakes and coastal seas near industrialized cities.

Early in the 21st century there may be no fish population in the world that is not stressed by humans in one or more ways. Hence the concept of sustainability must always relate to a complex of natural and cultural processes. Relevant policies to foster sustainability must in turn exhibit an appropriate or requisite measure of complexity.

REFORMS OF THE 1990s

A global movement to reform human practices in our biosphere and be more responsible has been growing since the late 1960s. It was then that Sweden put in motion activities that led to the 1972 United Nations Conference on the Human Environment convened in Stockholm. Grossly unsustainable practices that degraded aquatic habitats and overfished valued stocks, though discussed at Stockholm, were generally neglected in the oceans until two or three decades after that.

In the 1990s, several initiatives by the United Nations or its specialized agencies have created a formal set of inter-related documents that is providing the conceptual framework for the emergence of the new global regime on fish and fishing. These include:

- the United Nations Conference on Environment and Development in Rio de Janeiro in 1992 from which came Agenda 21 with chapters on Aboriginal rights, biodiversity and its sustainability, the oceans and climate change;
- the United Nations Conference on Straddling and Highly Migratory Fish Stocks of 1995 which closed a major gap in the 1982 United Nations Law of the Sea Convention;
- the United Nations Food and Agriculture Organization's Code of Conduct for Responsible Fisheries of 1995 with some six specialized appendices.

A strong theme in these initiatives was on the ocean but the agreements, suitably interpreted, are also relevant to closed seas, lakes and rivers.

For a particular ecosystem, although the transition has only begun, these reforms imply a change in emphasis from:

- maximal sustainable and independent use of each resource in the ecosystem by its own set of opportunistic stakeholders, to
- optimal responsible and shared use of the whole eco logical web and aquatic habitat by an interacting net work of sets of legitimate stakeholders.

Note that one aspect of this change is the shift in emphasis from ***sustainability of use to responsibility of use.***

Responsibility by an ecosystem's users, including fishers, implies that each user and group of users bears an onus to take a precautionary approach to that use. A fisher's rights/privileges are balanced by a set of responsibilities/obligations to provide evidence ***a priori*** that the fisher's use will not induce ecosystemic changes that are impermissible with respect to the ecosystemic vision shared by all the ecosystem's users. During use, the fisher dutifully reports correct data relevant to accountability commitments and submits to sanctions for improper practices. This may be because the fisher is driven by considerations of 'intergenerational equity', and the wish to leave his children's generation an ecosystem that will provide the same livelihood, food potential and aesthetic pleasure as he has enjoyed. Or the fisher may be driven by deeper ethical commitments. From this it is evident that the search for sustainability inevitably takes us into the field of civics and ethics in a search for responsible behavior on the part of users, emphasizing the importance of this subject in future educational curricula from the earliest ages.

As a governance paradigm, the reform process is generating compatible information services and implementation features at all the levels in the nested hierarchy from individual users within groups of similar users, to the relevant level of formal governance within a nation, to a regional international commission.

Experts in international law were much involved in the 1990s' negotiations, together with experts in large- scale economic, ecological and technological systems. An emphasis is emerging on the methods of transdisciplinary discourse appropriate for negotiating and accountability processes, with respect to this new interactive set of international commitments. Versions of such appropriate discourse include: natural justice; communicative action; ethical discourse; post-normal participatory science (see *Post-normal Science*, Volume 5); and action research. A broadened scientific approach may still have a place for the reductionist population dynamics approach that dominated the earlier regime as it has for bioeconomic modeling, but that role is clearly subservient now. In fact, the application of games theory, developed by the military, to modeling competing fisheries makes it clear that the major challenge in governance of fisheries is managing the fishers and not just the fish stocks. Games theory also outlines the formidable obstacles in the face of reaching a sustainable harvest regime in situations where competition for resources occurs and allocations are not agreed to early on in the process.

Nonetheless, in recent decades, numerous innovators in the science and management of fisheries and other uses of aquatic ecosystems in various parts of the world have already begun local and regional reforms that have some of the features of those mandated by the 1990s United Nations reforms. These include developing tools and concepts such as integrated coastal area management, large marine ecosystem approaches, appropriate scaling of human actions through marine catchment basins, and ecosystem approaches in large freshwater basins. Some innovators are now meshing their own regional efforts within global initiatives to foster feedback mechanisms that might expedite implementation of the reforms.

Once proper management policies are developed, inefficiencies in traditional governance institutions are a serious impediment to the successful implementation of the policies. One fundamental weakness is that such institutions and their old mandates rarely encompass fully the real problem in all its dimensions. Fishery-induced and other anthropogenic causes are often intertwined in such a way that Ministries of Agriculture, Environment, Rural Affairs and others would have to cooperate in arriving at solutions which would then have repercussions for other Ministries, not least of which would be the Ministry of Finance.

People practicing governance in obsolescent ways may be offered few if any incentives to effect change. If an interdepartmental committee is struck to deal with fisheries, in the context of the health of aquatic environments, it may: be dominated by non-innovative persons; be given inadequate resources; be allowed an extended time frame that may invite postponement of urgent problems; and may eventually provide advice that is weakened with compromises. Another approach is to allocate rights to the private sector or to devolve responsibility to lower governmental entities such as provinces, municipalities and co-operatives. Here the incentive of ownership, and ready recourse to the courts that this implies, may provide a more prompt means of correcting imbalances. By following this latter course, the number of jurisdictional disputes may in turn become more frequent and intense.

In the international arena, the problem of shared stocks and their management has been assigned by the Law of the Sea to Fisheries Commissions and Arrangements. To date, states have rarely turned over to these bodies enough of their jealously guarded rights to allow them to con duct surveillance and exercise control effectively, especially with respect to allocations of catch. Multinational entities at the government-industry interface could be established with full powers to jointly manage shared stocks and national fleets, providing, for example, joint marketing services and dividends to the countries whose fleets are participating in the fishery.

The challenges to governance with respect to responsible fisheries — in freshwaters, in EEZs, in coastal marine waters, and in international oceanic waters — are daunting. Deliberate efforts directed toward quick learning would seem to be in order. Attractive incentives to innovate might speed such learning.

We fear that it may be decades before these 1990s responsibility reforms will be well in place in much of the world. Sustainability of some desirable ecosystemic features that will be extant at those times may then be more certain. Perhaps our responsible successors will then have transcended the centuries-long conflict between ecological pessimists and technological optimists.

Regretfully, the nature of fisheries for wild resources that will be conducted sustainably a few decades hence cannot now be predicted. Without a dramatic paradigm shift towards a revaluation of renewable resources through precautionary thinking, the prospect is for further ecosystem degradation and loss of biodiversity through human impacts. A necessary, but not necessarily adequate, precondition for avoiding further declines is that the fine words, principles and agreements developed laboriously in the 1990s be implemented swiftly.

FURTHER READING

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Example of the Incremental Application of Ecosystem Principles (the MLMA)

Stage I: Precautionary Management in a Data-Poor Environment

When catch history is the only reliable information available and little or no information is available for demographics, ecological effects of the fishery, or the effects of environmental change on the fishery, precaution should be the primary basis for setting TACs (Caddy and Regier 2002). A limit should be placed on catches of all target species, equal to a fraction of the average catch of some series of years when there was evidence that abundance was not declining. In the absence of information to the contrary, the fraction could be 50%, which assumes that the stock is below the target biomass but above the overfished threshold. In cases where it is not possible to target individual species to the exclusion of others (e.g., rockfish), identification of catch to species level is unreliable. For these taxa, a pooled TAC should be defined for the most vulnerable species (or stock) in the complex. Discards should be allocated according to fishing sector, so that allocations to each sector can be adjusted depending on their discard rates, thereby providing an incentive to reduce discards. As the information improves, TAC's can be revised upwards or downwards accordingly. Fishery regulations should provide fishery participants an opportunity to catch the TAC, but not exceed it, and to allow as close to a year-round fishery as possible. No rollover of “unused” portions of the TAC to the next season should be allowed for Stage I fisheries, due to uncertainty about population stability and catch sustainability. During Stage I management, it is important to increase the quality and quantity of data necessary for more informed and less precautionary management (moving towards Stage II and Stage III), primarily in eight areas:

- Improvements to accuracy and completeness of the fishery-dependent data base
- Implementation of fishery independent surveys
- Improved life history information (track changes with time and environmental conditions), especially at reproduction phase
- Selection and comparative studies of study areas subject to varied fishing effort
- High-resolution mapping of habitats
- Discard survival studies of the captured species
- Identify the position and role of the targeted species within its ecosystem
- Incorporation of existing and new ecosystem information into fishery models

Stage II: Improved Single-Species Management in a Data-Moderate Environment

Improved single-species management can be implemented once data for the seven categories listed above become available. Stage II management is possible with adequate data and modeling, including risk analysis, allowing regional TACs to be set for species or species complexes. TACs under Stage II management incorporate population modeling and other analyses in place of the strictly precautionary approach in Stage I; however, precautionary adjustments to TACs are necessary because of minimal information about ecosystem effects of the harvest and the effects of environmental change on the fishery. Where data are still weak, techniques such as sensitivity analysis and Bayesian probability estimation should be applied to clarify decision making. The Stage II approach differs from the traditional adoption of a stock-specific optimum yield (OY) in one major respect. The calculation of OY assumes equilibrium population dynamics while the Stage II approach does not. Stage II employs the terms $B_{Unfished}$ (unfished biomass – the estimate of the biomass or stock size that would exist if there had been no fishing during several recent generations) and TAC instead of OY. Based on the estimated $B_{Unfished}$, a TAC would be calculated for each stock, including downward adjustments made for social, economic, or ecological factors, or if abundance is determined to be lower than the level that would achieve 0.6 $B_{Unfished}$. As Stage II management progresses, one of the most important advances will be that data become spatially explicit at increasingly higher resolution.

Stage III: Ecosystem Approach to Management in a Data-Rich Environment

Because Stage III management is data driven, it is reasonable to expect that its full implementation, although presently possible for some nearshore invertebrate or kelp fisheries, is years in the future for most nearshore finfish and offshore fisheries. The threshold for shifting to Stage III management includes two conditions:

- The comparison of study areas subject to varied fishing effort provides data on alteration of food web and other aspects of ecosystem function that are attributable to fishing
- Comparisons of protected reference areas with areas open to fishing provide data on the impact of fluctuating climate regime (or other forces extrinsic to the status of the stocks) on fishery productivity, which in turn permits raising TACs during periods of high productivity, and requires reducing TACs to protect populations when they are under stress.

Stage III focuses initially on the harvested species, using ecosystem-related parameters in addition to the species-specific life history and population parameters that form the backbone of Stage II. In Stage III, the data for management are expanded to encompass non-target species and the habitat setting. Triggers that raise or lower TACs in Stage III include indicators of fishery-caused alteration to bioenergetics and community structure (e.g., a switch in prey base, change in productivity at one or more trophic levels, or changes in the connectance (a measure of complexity) or resilience of the food web). In addition to life history, which already is incorporated into the control rules for Stage II management, other ecosystem parameters are employed in Stage III management:

- Trophic Parameters (e.g., effective trophic level, maximum food chain length, and connectance)
- Functional Diversity (e.g., species richness, evenness, and redundancy)
- Existing or anticipated effects of environmental change (e.g., el Niño or la Niña, shift in Pacific Decadal Oscillation, sea surface temperature, co-variance of target and non-target species)