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Report of the PICES/NPRB Workshop on Integration of Ecological Indicators of the North Pacific with Emphasis on the Bering Sea

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Executive Summary

Ecosystem indicators are part of a larger process that considers policy-level goals for an ecosystem. Other elements include operational objectives and performance criteria. The eastern Bering Sea is advanced in application of ecosystem-based considerations to the management of marine resources. For instance, an *Ecosystem Considerations* appendix is prepared by the Alaska Fisheries Science Center (AFSC) each year for the annual Stock Assessment and Fishery Evaluation (SAFE) reports published by the North Pacific Fishery Management Council (NPFMC). This report is reviewed annually by NPFMC's plan teams and Scientific and Statistical Committee, and scientific advice is provided annually to managers based on ecosystem trends relative to managed fish species. Similarly, the North Pacific Marine Science Organization (PICES) prepared a North Pacific Ecosystem Status report in 2004 and is beginning to plan for an updated version of this report. Both reports can be improved by developing consensus on operational objectives and appropriate indicators.

Progress toward operational objectives and development of appropriate indicators was made by conducting the following four activities during an international workshop held on June 1–3, 2006, in Seattle (Washington, U.S.A.):

1. Involve the Bering Sea and international communities in developing of a set of operational objectives for the southeastern Bering Sea ecosystem;
2. Evaluate two status reports with the goal of integrating results and streamlining the presentation. The two reports are:
    a. NPFMC. 2005. Appendix C: Ecosystem Considerations for 2006. North Pacific Fishery Management Council, Anchorage, Alaska (http://access.afsc.noaa.gov/reem/EcoWeb /index.cfm);
    b. PICES. 2004. Marine Ecosystems of the North Pacific, PICES Special Publication 1, 280 p. (http://www.pices.int/publications/special_publications/NPESR/2005/npesr_2005.aspx);
3. Investigate methodologies that monitor system-wide structural changes within the marine ecosystem;
4. Identify steps to validate indicator performance, improve the monitoring network, and integrate into predictive models.

In preparing the workshop a focus was on the southeastern Bering Sea because it represents the center of the Bering Sea/Aleutian Islands large marine ecosystem (LME), one of three LMEs (the other two are the Gulf of Alaska and Arctic Ocean) defining the North Pacific Research Board's (NPRB) research region. This endeavour was funded by NPRB. Although the project focused on the southeastern Bering Sea, the intent of this exercise was to provide insights, findings, and recommendations more broadly applicable to the North Pacific and its adjacent seas, a larger area representing the PICES region, including waters bordering China, Japan, South Korea, Russia, Canada, and the United States.

Workshop presentations included three white papers on (1) development of operational objectives for the southeastern Bering Sea ecosystem; (2) ecosystem-based management for the oceans: a perspective for fisheries in the Bering Sea; and (3) ecological indicators: software development. These papers were followed by presentations on indicator use in other regions with advice for the North Pacific and reports on the status of the southeastern Bering Sea. A series of break-out groups was then convened to discuss the *Ecosystem Considerations* appendix of the SAFE report and PICES North Pacific Ecosystem Status report, objectives and use of indicators, matching indicators to objectives, methods to monitor ecosystem-wide structural changes, and means toward communicating results. Although this project was ambitious, substantial progress was made, and the following recommendations resulted from the workshop:

Ecosystem Objectives and Indicators

1. Ecosystem-level and community-level conservation thresholds are relatively new ideas in marine conservation. Since they will require new kinds of indicators, research is needed for their development and application to the Bering Sea.
2. New research is needed to understand how to synthesize the large set of Bering Sea data records into a reasonable number of ecosystem status indicators.
3. A formal process of evaluating and selecting ecosystem indicators is a general requirement. The Alaska Fisheries Science Center should consider developing and applying such a process to the indicators in its *Ecosystem Considerations* appendix.
4. Enhancements to the ocean/ecosystem monitoring network are needed to fill data gaps at ecological pulse points (plankton, benthic infauna and epifauna, seasonal species interactions and movements, small pelagics, and cephalopods) to improve predictive models and the development of ecosystem indicators.
5. More collaboration between modelers at the Alaska Fisheries Science Center and the Pacific Marine Environmental Laboratory, and elsewhere is encouraged to link various climate/ecosystem and conservation/assessment models, and to use these models to evaluate management strategies.

Socio-economics

While the workshop did not address socio-economic operational objectives for the Bering Sea and North Pacific, linkages between the well-being of people and healthy marine ecosystems require a level of attention comparable to those for ecosystem conservation objectives:

6. Socio-economic objectives related with the marine environment should be developed for the region, along with their indicators and reference points.
7. The North Pacific Fishery Management Council should play a central role in shepherding the development of these socio-economic objectives and indicators for the southeastern Bering Sea and Gulf of Alaska ecosystems;
8. There is a need to conduct scientific and policy analyses of pathways to achieve socio-economic objectives while remaining within ecosystem-level conservation limits.

Communication

9. Plans should be developed at an early stage on how the information from indicators can best be communicated to scientists, policy and decision makers, and the general public. The plans should include publishing concise, attractive executive summaries of major ecosystem status reports that will describe important trends and patterns in marine ecosystems for non-scientists.
10. To reach policy makers and the public in Asian countries, future iterations of the Synthesis chapter in the PICES North Pacific Ecosystem Status report should be published in multiple languages.
11. The development by the National Marine Fisheries Service of an *Ecosystem Considerations* website greatly increased access to time series of ecosystem indicators for the Alaska region, and should be maintained and enhanced.
12. An overview of the status of the Bering Sea ecosystem(s) should be presented at the annual *Marine Science in Alaska* Symposium to foster broader communication among the diversity of regional scientists, managers and the public.

Specific recommendations from individuals/groups can be found under Discussion Group Results in this report.

Foreword

This project entitled "*Integration of ecological indicators for the North Pacific with emphasis on the Bering Sea: A workshop approach*" was developed from a proposal submitted in response to the North Pacific Research Board's (NPRB's) request for proposals for 2005, specifically Project Need 1, Item 2, as stated below:

> ***Evaluate the Utility of Ecosystem Indicators in Explaining Processes underlying Marine Production.*** *Processes related to physical (e.g., atmospheric forcing, ocean temperature, salinity, sea level, freshwater discharges, transport of planktonic life history stages, sea ice extent and duration, turbulence and cold pool extent), chemical (e.g., nutrient/micronutrient availability to phytoplankton), and biological (e.g., predation, timing of plankton/zooplankton production, commercial catch composition, biomass/abundance trends) phenomena provide indicators of ecosystem status. The project would report on the current understanding of ecosystem indicators in the Bering Sea and Aleutian Islands, evaluate pros and cons of existing indicators, and identify next steps toward developing and/or validating indicators and evaluating their performance (e.g., using hind-casts of indicators and various marine populations). In addition, the report will describe how indicators can best be used as a tool for resource managers. The approach would include a workshop of regional experts to address the challenge of developing indicators and interpreting their utility.*

The North Pacific Marine Science Organization (PICES) appreciates NPRB funding for this work, which attempts to further the development of integrated ecosystem indicators for the Bering Sea.

The following four objectives/activities were central for the PICES/NPRB Indicators Workshop held on June 1–3, 2006, in Seattle (Washington, U.S.A.):

1. Involve the Bering Sea and international communities in developing a set of operational objectives for the southeastern Bering Sea ecosystem;
2. Evaluate two status reports with a goal of integrating results and streamlining the presentation:
    a. NPFMC. 2005. Appendix C: Ecosystem Considerations for 2006. North Pacific Fishery Management Council, Anchorage, Alaska (http://access.afsc.noaa.gov/reem/EcoWeb /index.cfm);
    b. PICES. 2004. Marine Ecosystems of the North Pacific, PICES Special Publication 1, 280 p. (http://www.pices.int/publications/special_publications/NPESR/2005/npesr_2005.aspx)
3. Investigate methodologies to monitor system-wide structural changes within the marine ecosystem;
4. Identify steps to validate indicator performance, improve the monitoring network, and integrate into predictive models.

In conducting these activities there was a focus on the southeastern Bering Sea because it represents the center of the Bering Sea/Aleutian Islands large marine ecosystem (LME), one of three LMEs (the other two are the Gulf of Alaska and Arctic Ocean) defining the NPRB research region (NPRB, 2005). Although the project focused on the southeastern Bering Sea, the intent was to provide insights, findings, and recommendations more broadly applicable to the North Pacific and adjacent seas, a larger area representing the PICES region, including waters bordering China, Japan, South Korea, Russia, Canada, and the United States.

The primary product of the project is this *PICES Scientific Report*, which includes three white papers developed for the Indicators workshop, and a summary of workshop discussions, outcomes, and recommendations. Outcomes of the workshop has also been used by NPRB to prepare an integrated ecosystem research plan for the Bering Sea.

WHITE PAPERS PREPARED FOR THE WORKSHOP

Development of operational objectives for the southeastern Bering Sea ecosystem

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Introduction

According to the United Nations Convention on Biological Diversity, an ecosystem approach [to management, EAM] is *a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable use in an equitable way* (http://www.biodiv.org/default.shtml). In the northeastern Pacific Ocean, contemporary conservation and management issues include fisheries, mariculture and ocean ranching, invasive species (including rats and foxes on the Aleutian Islands), preservation of heritage sites, coastal development, coastal erosion from rising sea level, oil and gas exploration and development, oil spill prevention and response, and risks associated with toxic waste sites from defunct military facilities. Among these concerns, management plans have been most fully developed for commercial fisheries. Therefore, while we maintain the broader view of EAM, we focus on fisheries management for the purposes of this workshop.

Traditional fisheries management compares the status of an exploited fish stock to the well-being of users of that resource. Since the 1990s, fisheries managers have been advised to broaden their scope of awareness beyond single-species considerations owing to a greater appreciation of the following (FAO, 2003):

- General poor performance of single-species fishery management worldwide;
- Heightened awareness of interactions among fisheries and ecosystems;
- Better understanding of the functional value of ecosystems to humans;
- Recognition of the wide range of societal objectives associated with marine fishery resources and ecosystems.

As a result, fisheries management has been moving slowly toward multispecies and ecosystem approaches. That is, within the broader context of EAM, fisheries have been shifting toward an ecosystem-based fisheries management (EBFM), also called an ecosystem approach to fisheries (EAF). An EAF *strives to balance diverse societal objectives by taking into account the knowledge and uncertainties of biotic, abiotic, and human components of ecosystems and their interactions and applying an integrated approach to fisheries within ecologically meaningful boundaries* (Garcia *et al.*, 2003).

An appreciation of diverse societal objectives recognizes that benefits arising from fish harvests form just one of the "services" that humans derive from marine ecosystems. Instead, an EAM approach strives to balance the suite of ecosystem services according to objectives and priorities set by society. Ecosystem services may be categorized into the following types (MEA, 2005):

- *Provisioning*: food, water, fuel, fiber, biochemicals, and genetic resources;
- *Regulating*: climate, disease, water purification, and floods;
- *Cultural*: spiritual, recreational, ecotourism, aesthetic, and educational;
- *Supporting*: necessary for production of all other ecosystem services, *e.g.*, primary production, nutrient cycling, and ecological value.

Making EAF operational

To make EAF operational, there is a need to establish a policy, management, monitoring and assessment framework for a system with measurable operational objectives. An operational objective might consist of a verb (*e.g.*, reduce), a specific measurable indicator (*e.g.*, bycatch mortality), and a reference point (*e.g.*, 1% of standing biomass) (Jamieson *et al.*, 2001). Indicators are used to quantify the performance of management with respect to these objectives (Fig. 1).

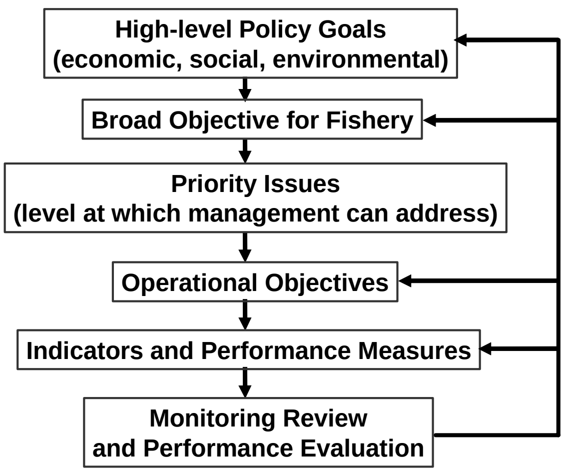

Fig. 1 Relationship between policy goals, broad fishery objectives, operational objectives, and indicators and performance measures for an ecosystem approach to fisheries (EAF). Adapted from FAO (2003).

The following is a simple example of how such a framework might be developed for a groundfish fishery. A high-level policy goal is to maintain ecosystem structure and function. While noble and perhaps somewhat naive, this goal is too vague to allow if unequivocal determination has been attained. So a broad objective for a groundfish fishery, that is consistent with the policy goal, may be to maintain the community of predators within ecologically viable levels. Some might consider that this objective is still too broad to allow definitive measurement of management success. So operational objectives with increasing levels of specificity can be developed, such as maintaining the spawning biomass of the predators (*e.g.*, sharks, cod and halibut) at 35% or more of their unfished levels while banning the harvest of forage species (*e.g.*, capelin, eulachon, and sand lance) to maintain natural fluctuations in prey abundance. An objective becomes operational only if there are agreed-upon target and limit reference points associated with the objective, as well as a routinely monitored indicator that, when compared to the limit and target reference points, provides a performance measure showing how well management is achieving the objective (Fig. 2).

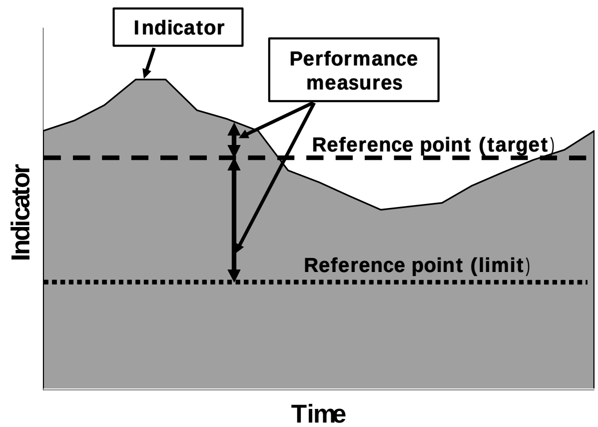

Fig. 2 Illustration of an indicator, reference points, and performance measures relative to an ecosystem operational objective. Modified after FAO (2003).

Ecosystem considerations in fisheries management in the eastern Bering Sea

The U.S. North Pacific Fishery Management Council (NPFMC) recommends regulations for federally managed fisheries in the U.S. Exclusive Economic Zone (EEZ, 3–200 nautical miles, nm) in the Gulf of Alaska, Aleutian Islands, and eastern Bering Sea; federal regulations are implemented and enforced by NOAA/Fisheries. For state-managed fisheries, regulations are set and fisheries are managed by the Alaska Board of Fisheries and Alaska Department of Fish and Game, respectively. The State of Alaska manages fisheries within state waters (0–3 nm), and management authority for some fisheries in the EEZ is delegated to the State of Alaska (*e.g.*, crabs, lingcod, and some rockfishes in the Gulf of Alaska), whereas still others (*e.g.*, crabs in the Bering Sea and Aleutian Islands, and scallops and salmon throughout Alaska) are managed under cooperative state–federal management plans.

Fisheries off the coast of Alaska tend to be conservatively managed, and exploited fish stocks have fared much better in this region than many other areas of the world (POC, 2003). NPFMC has a long track record of setting precautionary catch limits (Witherell *et al.*, 2000; Witherell, 2004). Conservative estimates of overfishing limits (OFLs) and acceptable biological catches (ABCs; where ABC < OFL) are recommended to NPFMC by their Scientific and Statistical Committee (Fig. 3). Moreover, total allowable catches (TACs) are always set at or below ABC levels and fishery removals are managed in-season so as not to exceed the TACs (Fig. 3). In addition, total catch for the Bering Sea/Aleutian Islands groundfish complex is constrained to 2 million mt, so that the sum of TACs for individual groundfish species is considerably less than the sum of ABCs. This limit provides a buffer against the uncertainties of single species harvest targets.

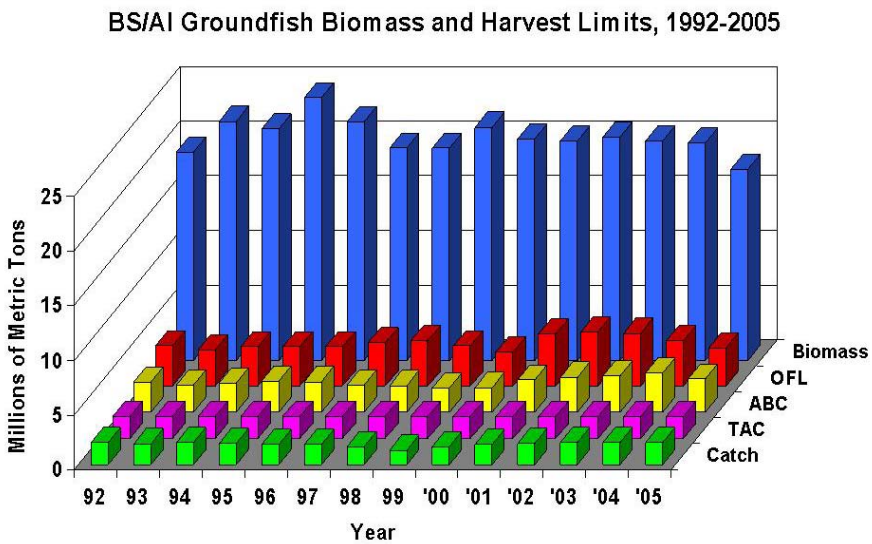

Fig. 3 Estimates of biomass, overfishing level (OFL), acceptable biological catch (ABC), and total allowable catch (TAC), and actual catch in millions of tons for groundfish in the Bering Sea/Aleutian Islands (BSAI) region from 1992–2005 (source: NPFMC).

Other conservative single-species aspects of federal fishery management in Alaska include capacity reduction programs for most fisheries, individual transferable quotas for crab, sablefish and halibut, and excellent data-collection programs, including fishery-independent surveys and an at-sea observer program. Likewise, the State of Alaska constrains groundfish and invertebrate catches by guideline harvest levels (similar to TACs) and does not allow commercial fisheries to be prosecuted if stocks fall below a precautionary threshold level of abundance.

NPFMC incorporates many ecosystem considerations into fishery management (Witherell *et al.*, 2000; Witherell, 2004). Examples include limits on bycatch and discards in the Bering Sea groundfish fisheries. Prohibited species catch (PSC) limits are established as a small fraction of crab and herring biomass and chinook and chum salmon abundance; when PSC limits are attained, specific areas close to fishing (Witherell and Pautzke, 1997). Other ecosystem approaches include large area closures to bottom trawling and dredging to protect corals and sponges, crabs, and other bottom habitats. Ninety-five percent of the Aleutian Islands management area (~277,100 nm^2) has been closed to bottom trawling since 2005 (Witherell, 2005). Some state waters have been closed to trawling by the State of Alaska since the late 1960s in efforts to protect crab habitats. Presently, nearly all state waters in the Gulf of Alaska and southeastern Bering Sea are closed to trawling, where only fixed gears (*e.g.*, pots, longlines, and jigs) are allowed for groundfish (Kruse *et al.*, 2000). Other ecosystem approaches include numerous measures to protect Steller sea lions and reduce seabird bycatch, full retention standards for pollock and cod fisheries to reduce discards, and a prohibition on forage fish fisheries throughout the Gulf of Alaska, Aleutian Islands, and Bering Sea, with the exception of ongoing commercial fisheries for Pacific herring.

Need for further development of EAF for the Bering Sea

Despite the healthy status of many fished stocks, some fish and wildlife populations have undergone significant declines in recent decades. In 2004, no overfishing occurred in any of the 58 assessed marine fish and invertebrate stocks, but four of 32 assessed stocks were determined to be overfished (NMFS, 2005). The four stocks listed as overfished in 2004 were snow crabs (Bering Sea), blue king crabs (Pribilof Islands), blue king crabs (St. Matthew Island), and Tanner crabs (eastern Bering Sea). As many scientists attribute the cause of these low crab abundances to climate change, the term "depleted" may be more appropriate than "overfished." In the Gulf of Alaska, where the State of Alaska manages invertebrate stocks without a federal fishery management plan, most crab and shrimp stocks collapsed in the 1980s, and abundance continues at low levels despite fishery closures for more than 20 years (Kruse *et al.*, 2000). Significant declines in great whales, the western stock of Steller sea lions, fur seals, sea otters, and some seabirds, such as spectacled eider and Steller's eider, are of much concern. Whereas the role of humans is clear in some declines (*e.g.*, historical whaling, predation of seabird eggs by human-introduced rats and foxes on Aleutian Islands), others are less clear, but may involve a stronger role of climate (*e.g.*, recent decline of fur seals, lack of recovery of crabs and shrimps). A better understanding of the roles of humans and climate on these changes is necessary to strengthen EAF, refine management objectives, and to develop useful indicators, reference points, and performance measures.

Goals and objectives for the Bering Sea

In 2004, the National Marine Fisheries Service (NMFS) completed an Alaska Groundfish Fisheries Programmatic Supplemental Environmental Impact Statement (PSEIS), a comprehensive assessment of the overarching conservation and management policies and objectives of the Alaska groundfish fishery management plans (NMFS, 2004). This PSEIS assessment was conducted through the environmental review process established by the National Environmental Policy Act. Original, revised, and final versions of PSEIS were developed and reviewed during a series of public hearings, as well as during meetings of NPFMC from 2001 to 2004. As a consequence, NPFMC recommended amendments to the fishery management plans for the Bering Sea/Aleutian Islands and Gulf of Alaska groundfish fisheries. The revised plans include a high-level policy statement, a broad goal and objectives for the fishery, a set of priority issues, and a more specific set of objectives within each priority issue (NPFMC, 2005; see Appendix 1 excerpted from the revised fishery management plan for the Bering Sea/Aleutian Islands).

NPFMC's high-level policy statement for both the Bering Sea/Aleutian Islands groundfish fishery management plan and Gulf of Alaska fishery management plan is:

…to apply judicious and responsible fisheries management practices, based on sound scientific research and analysis, proactively rather than reactively, to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future, as well as current generations.

NPFMC developed a set of broad objectives for the fishery, which are to:
1. provide sound conservation of the living marine resources;
2. provide socially and economically viable fisheries for the well-being of fishing communities;
3. minimize human-caused threats to protected species;
4. maintain a healthy marine resource habitat; and
5. incorporate ecosystem-based considerations into management decisions.

The Council identified nine priority issues:
1. prevent overfishing;
2. promote sustainable fisheries and communities;

3. preserve the food web;
4. manage incidental catch and reduce bycatch and waste;
5. avoid impacts to seabirds and marine mammals;
6. reduce and avoid impacts to habitat;
7. promote equitable and efficient use of fishery resources;
8. increase Alaska Native consultation;
9. improve data quality, monitoring and enforcement.

Within these nine issues, 45 specific objectives (*i.e.*, "tasks") were adopted and grouped into those already included in the groundfish management program, those related to actions currently under Council consideration, those related to actions currently on hold or not initiated, and those that apply to all management actions (see Appendix 2 for details). NPFMC has developed a work plan to address these priority issues and objectives (Appendix 3). Progress on the work plan is reviewed during each Council meeting.

Following the approach recommended during a workshop on objectives and indicators in Canada (Jamieson *et al.*, 2001), for purposes of our workshop, we will not consider issues that primarily concern *economic and social dimensions of human use* (*i.e.*, issues 2, 7, 8, and 9). Instead, we focus on the remaining five issues that address *conservation of species and habitats* (*i.e.*, issues 1, 3, 4, 5, and 6).

Priority conservation issues with examples of operational objectives and indicators

The following are the five broad priority conservation issues identified by NPFMC. For each conservation issue, an example of an hypothetical operational objective and an associated indicator is provided.

Prevent overfishing

- *Operational objective:* maintain harvest rates below those defined to be overfishing, F_{OFL}, for each exploited fish and invertebrate stock. Whereas the exact definition and value of F_{OFL} varies by stock based on the level of available data and stock-specific life history parameters, for most groundfish stocks managed by NPFMC, F_{OFL} is based on $F_{35\%}$, a rate that will, on average, reduce spawning stock biomass to 35% of the unfished level.
- *Indicator:* estimated annual fishing mortality based on the sum of landings, discards, and bycatch mortality divided by fishery-independent estimates of stock biomass.

Preserve the food web

- *Operational objective:* do not "fish down the food web" by maintaining trophic-level balance in the eastern Bering Sea relative to the mean trophic-level range (3.32 to 3.77, mean 3.61) observed during the base period, 1954–1984.
- *Indicator:* estimated annual mean trophic level of the catch of all groundfish and crabs from the eastern Bering Sea.

Manage incidental catch and reduce bycatch and waste

- *Operational objective:* reduce discarded bycatch by 40% from levels estimated from 1994–1997.
- *Indicator:* estimated discards as a percentage of total groundfish catch.

Avoid impacts to seabirds and marine mammals

- *Operational objective:* reduce total seabird bycatch on longline vessels by 30% from levels from 1994–1997.
- *Indicator:* Estimated seabird bycatch based on counts on vessels with observers extrapolated to the total longline fleet based on the proportion of observed to estimated total fishing effort.

Reduce and avoid impacts to habitat

- *Operational objective:* Reduce bottom habitat disturbance by 25% from the base period 1990–1999.
- *Indicator:* annual bottom trawl effort (days fished).

Food for thought: Input from two pre-workshops on objectives for Alaska

In preparing for the Indicators workshop in Seattle, two preliminary events were held, one on January 25, 2006, in Anchorage and the other on February 8, 2006, in Seattle. The former was held as an afternoon session at the conclusion of the annual *Marine Science in Alaska* Symposium and the latter was held as an evening session during the meeting of NPFMC. The first workshop was attended by approximately 75 participants, whereas the latter was attended by 20 participants.

A report on these two workshops was prepared by Gordon Kruse and has been posted on the PICES website at http://www.pices.int/projects/Bering_Indicators/project_documents.aspx for this workshop. However, a few of the more intriguing comments and questions are:

- We know the Bering Sea is a dynamic system and we also know that some reference points (*e.g.*, crab biological reference points) are not always robust, so how do we manage for performance measures in a dynamic system? The idea to "maintain" might not be the appropriate term.
- Objectives that include the phrase "to maintain" and those dealing with "ecosystem structure" are vague. There is a need to consider ecosystem states that may change over time (multiple states of the system) and there is a need to allow ecosystem indicators to fluctuate over time. There has been considerable work on the benthic intertidal zone that indicates the existence of multiple steady states.
- Consider species that are indicators of various kinds of ecosystem change: secular, cyclical, and decadal.
- Consider the possibility that indicators themselves may change. For instance, if sea ice ultimately disappears from the Bering Sea, it would no longer be a useful indicator for the Bering Sea, but could remain useful for the Arctic Ocean.
- Often we can only see ecosystem shifts in hindsight (*i.e.*, note that we are still arguing over the last El Niño), so it may be naive to say when we see an ecosystem change we will respond accordingly.
- There is a focus on the use of single, sentinel species as indicators of ecosystem-level changes. It may be useful to broaden our consideration by looking at aggregate indicators, such as the biomass of a class of consumers.
- We are entrenched in methods that try to maintain the mean but eliminate the variance. What if the most important feature for sustaining variability is maintaining the variance and not the mean?
- It is important to consider the need to examine aspects of variability over time. Consider focusing on things for which we understand the variance structure well.
- Consider diversity *versus* richness as an indicator. Also, consider the spatial distribution of biodiversity.
- Are there desirable upper limits on species, such as particular marine mammal abundances? For example, how high does arrowtooth flounder need to reach to trigger a halt to the pollock fishery or to hold the fishery harmless for their crab and halibut bycatch to foster removal of arrowtooth flounder from the system?
- Consider statistical *versus* functional methods to render indicators. For the latter, consider exploring groupings of species in the system by functional groups, such as winter spawners *versus* summer spawners, or predators of copepods *versus* predators of other plankton, *etc*.
- Consider using species with which we do not interact directly – *e.g.*, walrus in the Bering Sea that feed on clams – as indicators. Then, use these species to compare to those species that are affected by fisheries to try to sort out our effects.
- There are other views regarding the role of the human population in the system, such as Chuck Fowler's (NMFS/National Marine Mammal

Laboratory) approach that argues that harvests are an order of magnitude too high relative to other similar trophic-level consumers.

- Some indicators are common across systems. Consider looking at degraded systems to see what indicators may have shown a change in those systems and adopt those.
- Consider focusing on indicators that motivate management decisions. Sea ice indicators are nice, but what management decision hinges on this indicator?

Opportunity: Development of a Fishery Ecosystem Plan for the Aleutian Islands

Since 2005, NPFMC has been considering a Fishery Ecosystem Plan (FEP) for the Aleutian Islands management area as a more explicit EAF. NPFMC has committed to developing FEP, and has created a scientific Ecosystem Team to assist with its formulation.

Interest in establishing the first North Pacific FEP in the Aleutian Islands stems from several considerations. The area has attracted more interest in recent years concerning fisheries for walleye pollock, Pacific cod and Atka mackerel. To date, the Aleutian Islands has been lumped together with the Bering Sea under one fishery management plan for groundfish, however, some evidence suggests that stock structure for some commercial species may require separate management units.

Also, in recent years, NPFMC has recognized the Aleutian Islands as a region containing unique ecological values that the Council wishes to preserve. The Aleutian Islands have been a focus for Steller sea lion protection measures and conservation of benthic habitats to protect coldwater corals and sponges.

The Aleutian Islands ecosystem was the focus of a special issue of the journal *Fisheries Oceanography* (Schumacher *et al.*, 2005). Many papers in this issue indicated that the Aleutian Islands themselves may involve more than one region. For example, the Aleutian passes east of Samalga Pass are more shelf-like in nature, whereas those to the west are more oceanic. Significant differences in ecology are associated with these features.

The Aleutian Islands marine ecosystem remains an area of severely limited knowledge due, in part, to its remoteness. Schumacher and Kruse (2005) identified the need for increased funding for ecosystem research as well as the need to broaden management objectives to encompass a wider set of ecosystem services in an integrated ecosystem management plan. Quite possibly, timing may now be ripe for such progress.

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Appendix 1 Excerpt from Chapter 2 of the BSAI [GOA] Groundfish FMPs, "*Management Approach for the BSAI [GOA] Groundfish Fisheries*"

The Council's policy is to apply judicious and responsible fisheries management practices, based on sound scientific research and analysis, proactively rather than reactively, to ensure the sustainability of fishery resources and associated ecosystems for the benefit of future, as well as current generations. The productivity of the North Pacific ecosystem is acknowledged to be among the highest in the world. For the past 25 years, the Council management approach has incorporated forward looking conservation measures that address differing levels of uncertainty. This management approach has in recent years been labelled the precautionary approach. Recognizing that potential changes in productivity may be caused by fluctuations in natural oceanographic conditions, fisheries, and other, non-fishing activities, the Council intends to continue to take appropriate measures to insure the continued sustainability of the managed species. It will carry out this objective by considering reasonable, adaptive management measures, as described in the Magnuson-Stevens Act and in conformance with the National Standards, the Endangered Species Act (ESA), the National Environmental Policy Act, and other applicable law. This management approach takes into account the National Academy of Science's recommendations on Sustainable Fisheries Policy.

As part of its policy, the Council intends to consider and adopt, as appropriate, measures that accelerate the Council's precautionary, adaptive management approach through community-based or rights-based management, ecosystem-based management principles that protect managed species from overfishing, and where appropriate and practicable, increase habitat protection and bycatch constraints. All management measures will be based on the best scientific information available. Given this intent, the fishery management goal is to provide sound conservation of the living marine resources; provide socially and economically viable fisheries for the well-being of fishing communities; minimize human-caused threats to protected species; maintain a healthy marine resource habitat; and incorporate ecosystem-based considerations into management decisions.

This management approach recognizes the need to balance many competing uses of marine resources and different social and economic goals for sustainable fishery management, including protection of the long-term health of the resource and the optimization of yield. This policy will use and improve upon the Council's existing open and transparent process of public involvement in decision-making.

Appendix 2 Management objectives from the groundfish FMPs.

Goal	Objectives relating to actions already established as part of groundfish management program (does not preclude further actions under these objectives)	Objectives relating to actions currently under Council consideration	Objectives relating to actions that are on hold from Council consideration, or have not yet been initiated	Objectives relating to considerations that are applied to all management actions
Prevent Overfishing	2. Use existing OY caps. 3. Specify OY as a range.	*4. Periodic reviews of F_{40} and adopt improvements. *5. Improve management through species categories.		1. Adopt conservative harvest levels
Promote Sustainable Fisheries and Communities				6. Promote conservation while providing for OY 7. Promote management measures that avoid social and economic disruption 8. Promote fair and equitable allocation 9. Promote safety
Preserve Food Web	12. Limit harvest on forage species.	*10. Develop indices of ecosystem health. *11. Improve ABC calculations to account for uncertainty and ecosystem.		13. Incorporate ecosystem considerations in fishery management
Manage Incidental Catch and Reduce Bycatch and Waste	14. Continue and improve current incidental catch and bycatch program. 18. Continue to manage incidental catch and bycatch through seasons and areas. 19. Account for bycatch mortality in TAC accounting. *20. Control prohibited species bycatch through PSC limits.	*15. Develop incentive programs for bycatch reduction. *17. Develop management measures that encourage techniques to reduce bycatch.	16. Encourage research for non-target species population estimates.	21. Reduce waste to biologically and socially acceptable levels
Avoid Impacts to Seabirds and Marine Mammals	22. Continue to protect ESA-listed and other seabirds. *23. Maintain or adjust SSL protection measures.	24. Encourage review of marine mammal and fishery interactions.		

Appendix 2 Continued

Goal	Objectives relating to actions already established as part of groundfish management program (does not preclude further actions under these objectives)	Objectives relating to actions currently under Council consideration	Objectives relating to actions that are on hold from Council consideration, or have not yet been initiated	Objectives relating to considerations that are applied to all management actions
Avoid Impacts to Seabirds and Marine Mammals	25. Continue to protect ESA-listed and other marine mammals.			
Reduce and Avoid Impacts to Habitat	27. Identify EFH and HAPC, and mitigate fishery impacts as necessary. *29. Encourage research on baseline habitat mapping.		*26. Review and evaluate efficacy of habitat protection measures for managed species. 28. Develop MPA policy. *30. Develop goals and criteria for MPAs; implement as appropriate.	
Promote Equitable and Efficient Use of Fishery Resources		*32. Maintain LLP and initiate rights-based management programs.	33. Periodically evaluate effectiveness of rights-based management programs.	31. Provide economic and community stability through fair allocation 34. Consider efficiency when adopting management measures
Increase Alaska Native Consultation			36. Consider ways to enhance local and traditional knowledge collection. 37. Increase Alaska Native participation in fishery management.	35. Incorporate local and traditional knowledge into fishery management
Improve Data Quality, Monitoring, and Enforcement		*38. Increase utility of observer data. *39. Develop equitable funding mechanisms for the NPGOP.	*40. Increase economic data reporting requirements. *41. Improve technology for monitoring and enforcement. 42. Encourage development of an ecosystem monitoring program.	43. Cooperate with NPRB to identify needed research 44. Promote enforceability 45. Coordinate management and enforcement programs with Federal, State, international, and local partners

* indicates that objective is reflected on Council's work plan.

Legend:

ABC	acceptable biological catches	LLP	license limitation program	OY	optimal yield
EFH	essential fish habitat	MPA	marine protected area	PSC	prohibited species catch
ESA	Endangered Species Act	NPGOP	North Pacific Groundfish Observer Program	SSL	Steller sea lion
HAPC	habitat of particular concern	NPRB	North Pacific Research Board	TAC	total allowable catch

Appendix 3 NPFMC work plan (May 2006) for implementing groundfish management policy.

General Priority (in no particular order of importance)		Specific priority actions	Related to management objective:	Status (updated 5-4-06)	2006 Jun	2006 Oct	2006 Dec	2007 Feb	2007 Apr	2007 Jun	2007 Oct	2007 Dec
Protection of Habitat	a.	complete EFH action as scheduled	**27**	**Amendment approved by Council**								
	b.	recommend to NOAA Fisheries increased mapping of benthic environment	**29**	part of Council's research priorities, approved in April 06								
	c.	develop and adopt definitions of MPAs, marine reserves, etc.	**30**	discussion paper presented in Feb 05								
	d.	review all existing closures to see if these areas qualify for MPAs under established criteria	**30**	discussion paper presented in Feb 05								
	e.	evaluate effectiveness of existing closures	**26**	discussion paper presented in Feb 05								
Bycatch Reduction	a.	complete rationalization of GOA fisheries	**17 (32)**	rockfish demonstration program approved; analysis ongoing for broader rationalization								
	b.	complete rationalization of BSAI non-pollock fisheries	**17 (32)**	partially addressed through IRIU Amd 80 (final action Jun 06); also Pacific cod sector allocations (approved)								
	c.	explore incentive-based bycatch reduction programs	**15**	partially to be addressed through GOA rationalization and BSAI salmon vessel bycatch accountability analyses								
	d.	explore mortality rate-based approach to setting PSC limits	**20**									
	e.	consider new management strategies to reduce incidental rockfish bycatch and discards	**17**	revised ranking system for species of concern								
Protection of Steller Sea Lions	a.	continue to participate in development of mitigation measures to protect SSL including development of an EIS and participation in the ESA jeopardy consultation process	**23**	consider revisions to SSL management measures in 2006-07								
	b.	recommend to NOAA Fisheries and participate in reconsideration of SSL critical habitat	**23**	NMFS requested to re-initiate FMP-level Section 7 consultation on DoC species								
Prevent Overfishing	a.	continue to participate in the development of "lumping and splitting" criteria	**5**	GOA 'other species' amd approved; 'other species' breakout analysis initiated								
	b.	consider new harvest strategies for rockfish	**4**	MSE of rockfish harvest strategy								
	c.	set TAC at or < ABC	**1**	**Amendment approved by Council**								
Ecosystem Management	a.	revisit calculation of OY caps	**11, 4**	research paper presented to SSC in Feb 05								
	b.	recommend to NOAA Fisheries and participate in the development and implementation of ecosystem indicators as part of stock assessment process	**10**	development ongoing; ecosystem SAFE to be presented each year; PICES workshop to develop indicators for the BS (Jun 06)								
Improve Data Quality and Management	a.	expand or modify observer coverage and sampling methods based on scientific data and compliance needs	**38, 39**	analysis reviews alternatives; final action scheduled for Jun 06								
	b.	develop programs for economic data collection that aggregate data	**40**	partially addressed through GOA rationalization								
	c.	modify VMS to incorporate new technology and system providers	**41**	global VMS analysis initial review in Jun 06								

Legend:

ABC	acceptable biological catches	NMFS	National Marine Fisheries Service
BS	Bering Sea	NOAA	National Oceanic and Atmospheric Administration
BSAI	Bering Sea/Aleutian Islands	OY	optimal yield
EFH	essential fish habitat	PICES	North Pacific Marine Science Organization
ESA	Endangered Species Act	PSC	prohibited species catch
FMP	Fisheries Management Plan	SAFE	Stock Assessment and Fishery Evaluation
GOA	Gulf of Alaska	SSC	Scientific and Statistical Committee
IRIU	improved retention/improved utilization	SSL	Steller sea lion
MPA	marine protected area	TAC	total allowable catches
MSE	Management Strategy Evaluation	VMS	Virtual Monitoring System

Toward ecosystem-based management for the oceans: A perspective for fisheries in the Bering Sea

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Abstract

A large effort has advanced an ecosystem approach to fisheries management in Alaska and a framework has been developed to provide ecosystem-based information to support management decisions (Livingston, 2005). This framework uses status and trend data of ecosystem components and information on human effects to assess impacts of individual fisheries on ecosystem components, ecosystem effects on particular stocks, and ecosystem-level impacts of both fishing and climate stressors. Efforts are ongoing to develop associated ecosystem-level objectives, indicators and thresholds. The continuing challenge is to define regional management objectives at an operational level and use ecosystem indicators to measure progress towards achieving management goals.

In addition to identifying management objectives for a region, we also need a better understanding of the complex mechanisms underlying ecosystem function and structure linking climate variability, oceanographic processes, and ecology/fisheries. Accounting for the emergent properties of ecosystems (Carpenter and Folke, 2006) and deriving measures that provide a balance between diversity, productivity, stability and resilience, (Steele, 2006) will be important parts of a framework for sustainable ecosystem approach to management.

We review objectives of ecosystem approaches to management and ecosystem approaches to fisheries management from a variety of organizations. In addition, we review indicators in the Alaskan *Ecosystem Considerations* appendix in view of these objectives. Gaps in the existing indicator framework are outlined and future work to improve indicators is outlined.

Introduction

In many cases fisheries management has focused on single species targets and management objectives, thereby ignoring many of the ecosystem components, processes and interactions (Pikitch *et al*., 2004). In recent years there has been a global call for the implementation of an Ecosystem Approach to Management (EAM) and an Ecosystem Approach to Fisheries (EAF) to focus on different management priorities and to consider the ecosystem as a whole rather than single target species. The overall objective of EAM is an integrated approach to management of land, water, and living resources that promotes conservation and sustainable use over a broad range of human uses in an ecosystem. EAF is an integrated approach to fisheries management that takes ecosystem interactions and processes into account.

There has been a large effort to advance an ecosystem approach to fisheries management in Alaska and a framework has been developed to provide ecosystem-based information to support management decisions (Livingston *et al*., 2005). This framework uses status and trend data of ecosystem components and information on human effects to assess impacts of individual fisheries on ecosystem components, ecosystem effects on particular stocks, and ecosystem-level impacts of both fishing and climate stressors. Efforts are ongoing to develop ecosystem-level objectives, indicators and thresholds. The continuing challenge is to account for the emergent properties of ecosystems (Carpenter and Folke, 2006), *e.g.*, vulnerabilities, uncertainties, and biogeochemical cycles linked to biodiversity and fisheries production, and to provide a balance between diversity, productivity, stability and resilience, (Steele, 2006) to formulate a framework for adopting a sustainable ecosystem management strategy.

In a recent article, Steele (2006) pointed out that, although an ecosystem-based management (EBM) approach to marine resources is a "worthy ideal," there are shortcomings to be addressed. The major task ahead of us is to untangle the complexity underlying the rates of ecological change (Jackson *et al.*, 2001), and link it to patterns and policy (Fowler, 1999), and climate change (Hsieh *et al.*, 2005). In other words, how does ecosystem science relate to ecosystem-based fishery management?

In the current literature there is a wealth of information regarding management of ecosystems and resources (Christensen *et al.*, 1996; Mangel *et al.*, 1996), and some theoretical frameworks have been proposed to translate ecosystems indicators to ecosystems-based fisheries management policies (Pikitch *et al.*, 2004; Link, 2005; Livingston *et al.*, 2005; Rice and Rochet, 2005; Rochet and Rice, 2005).

In particular, we need to develop ecosystem indicators that can match and address each management action toward a specific goal (*e.g.*, the reduction of bycatch). Management actions also need to be placed in the context of climate change. Major ecosystem shifts in the Bering Sea at the ecological level can be related to shifts in regional atmospheric and hydrographic forcing (Grebmeier *et al.*, 2006; Overland and Stabeno, 2004), and the response to quasi-decadal climate variability has been linked to the recruitment of commercially-exploited fishes in the northeast Pacific Ocean (Hollowed *et al.*, 2001; Duffy-Anderson *et al.*, 2005), the eastern Bering Sea (Wilderbuer *et al.*, 2002) and the Gulf of Alaska (Bailey *et al.*, 2005; Ciannelli *et al.*, 2005).

In this review we evaluate the range of objectives being expressed by various international, national and regional groups with regard to EAF and EBM and evaluate the current indicators/indices for the Bering Sea proposed by current research programs, governmental agencies (National Oceanic and Atmospheric Administration, NOAA), and non-governmental organizations (NGOs), *e.g.*, North Pacific Research Board (NPRB), and NGOs relative to these objectives. We will identify gaps or shortcomings with the existing indicators and provide suggestions for improvement.

Ecosystem indicators/indices will be grouped in different domains: climate/oceanography (*e.g.*, climate/atmosphere, hydrographic and physico-chemical processes, climate regime shifts); ecological (*e.g.*, primary producers, zooplankton, fish, food web and population dynamics, life history parameters, natural genetic variation, resilience); fisheries (*e.g.*, catch per unit effort (CPUE), spawning biomass, recruitment, fish catch and fisheries mortality); and management and conservation (*e.g.*, EAM, adaptive management, social-ecological system, and native knowledge of the ecosystem). We will propose an aggregation of the existing ecosystem indicators/indices based on ecological information from correlative studies in retrospective analyses, model simulation and ongoing monitoring programs. We will suggest types of statistical analyses that can be performed to provide a better understanding of the current use of the ecosystem indicators/indices, and outline current gaps in our knowledge of the Bering Sea ecosystem.

Background information and terminology

Here, we review some of the definitions, principles, goals and objectives described in recent reports from different agencies, and emphasize common objectives regarding how to implement an EAF.

EAM can be defined according to the Communication Partnership for Science and the Sea (COMPASS; McLeod *et al.*, 2005) as "*an integrated approach to management that considers the entire ecosystem including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors. Specifically, ecosystem-based management:*

- *Emphasizes the protection of ecosystem structure, functioning, and key processes;*

- *Is placed-based (e.g., specific geographic location) in focusing on a specific ecosystem and the range of activities affecting it;*
- *Explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species;*
- *Acknowledges interconnectedness among systems, such as between air, land and sea; and*
- *Integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependences.*"

McLeod *et al.* (2005) also defined as EAM and EAF as being complementary but different. "*Managing individual sectors, such as fishing, in an ecosystem context is necessary but not sufficient to ensure the continued productivity and resilience of an ecosystem. Individual human activities should be managed in a fashion that considers the impacts of the sector on the entire ecosystem as well as on other sectors. The longer-term, integrated, cumulative impacts of all relevant sectors on an ecosystem must be evaluated, with a mechanism for adjusting impacts of individual sectors.*"

FAO (FAO 2001, 2003a,b, 2005) has described the main goal of EAF as: "*to plan, develop and manage fisheries in a manner that addresses the multiple needs and desires of societies, without jeopardizing the options for future generation to benefit from the full range of goods and services provided by marine ecosystems.*" The FAO (2005) listed the following principles that should be addressed by EAF:

- "*Fisheries should be managed to limit their impact on the ecosystem to an acceptable level;*
- *Ecological relationships between species should be maintained;*
- *Management measures should be compatible across the entire distribution of the resource;*
- *Precaution in decision-making and action is needed because the knowledge on ecosystems is incomplete;*
- *Governance should ensure both human and ecosystem well-being and equity.*"

These principles are also consistent with the principles outlined by the UN Convention on Biological Diversity. The EAF approach has to be initiated by fishery agencies; however, its implementation needs a wider support from other entities involved in the management of aquatic resources. In this respect, the North Pacific Fishery Management Council (NPFMC, 2006) recognizes the importance of implementing an EAF and in June 2000, based on different guidelines, proposed a definition for Ecosystem-based Fishery Management as "*the regulation of human activity toward maintaining a long-term system sustainability (within the range of natural variability as we understand it) of the North Pacific covering the Gulf of Alaska, the Eastern and Western Bering Sea and the Aleutian Islands region.*" This definition is based on previous guidelines provided by NOAA and from a review by the Pacific States Marine Fisheries Commission (PSMFC).

NOAA's EAM:

- Is adaptive;
- Is regionally directed;
- Takes account of ecosystem knowledge;
- Considers multiple external influences;
- Strives to balance diverse societal objectives.

PSMFC's EAF:

- Employs spatial representation;
- Recognizes the significance of climate/ocean conditions;
- Emphasizes food web interactions;
- Ensures broader societal goals are taken into account (possibly by incorporating broader stakeholder representation);
- Utilizes and expanded scope of monitoring (total removal, cumulative effects, non-target species, environmental covariates);
- Acknowledges and responds to higher levels of uncertainty;
- Pursues ecosystem modeling/research;
- Seeks improved habitat information (target and non-target species).

The Ecosystem Principles Advisory Panel (EPAP) produced a report for the Congress in 1999 to describe the Fishery Ecosystem Plan (FEP). As reported by NPFMC (2006), the EPAP's main goal was to "*Maintain ecosystem health and* *sustainability…*" based on the following principles:

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

These goals, objectives and definitions are in line with the FEP's mission goals proposed by NOAA in their strategic plan for 2006–2011 (NOAA, 2005). The goals and priorities of NOAA for 2006–2011 are focused on five NOAA Mission Goals and below are the first two of these goals more closely related with the implementation of an EAF:

- *"Protect, restore, and manage the use of coastal and ocean resources through an Ecosystem Approach to Management;*
- *Understand climate variability and change to enhance society's ability to plan and respond."*

NOAA defines the following outcomes:

- *"Healthy and productive coastal marine ecosystems that benefit society;*
- *A well-informed public that acts as a steward of coastal and marine ecosystems."*

In order to achieve these outcomes, NOAA listed a number of performance objectives:

- *"Increase number of fish stocks managed at sustainable levels;*
- *Increase the number of protected species that reach stable or increasing population levels;*
- *Increase the number of regional coastal and marine ecosystems delineated with approved indicators of ecological health and socioeconomic benefits that are monitored and understood;*
- *Increase the number of invasive species populations eradicated, contained, or mitigated;*
- *Increase the number of habitat acres conserved or restored;*
- *Increase the portion of population that is knowledgeable of and acting as stewards for coastal and marine ecosystems;*
- *Increase environmentally sound aquaculture production;*
- *Increase the number of coastal communities incorporating ecosystem and sustainable development principles into planning and management."*

The Alaska Fishery Science Center (AFSC) develops and implements research programs to address the NOAA Fisheries objectives under NOAA Mission Goals 1 and 2 (*Ecosystem Considerations*, Boldt, 2005).

These types of information are used to describe in more detail the Fishery Ecosystem Plans as reported by the EPAP (1999). Further, the Pacific States Marine Fisheries Commission provided information for NPFMC and the Pacific Fishery Management Council on how to use an EBM approach within their fishery management programs. The EPAP provided a list of recommendations for developing an FEP and the PSMFC (2005) provided a list of actions from the National Marine Fishery Service (NMFS, 1999) and recommendations for implementing those actions, some of which are listed here:

- *"Define management goals to reflect the societal objectives;*
- *Develop a conceptual model of the influence of oceanographic and climatic factors;*
- *Expand/modify the conceptual of the ecosystem to include life history characteristics and spatial variation;*
- *Develop a numerical representation combining the food web model (which include dynamic model of managed species), the oceanographic model, and explicit representation of management measures and quantities that have been identified as metrics of attainment of the management goals;*
- *Use models to identify indices that are relevant for the stated goals. Identify which indices can*

be used for the basis of decision making. 'Traffic light' approaches may be useful."

From the analysis of these different sources of information, NPFMC (2006) provided some broad objectives for a management approach for the Bering Sea/Aleutian Islands Gulf of Alaska (BSAI [GOA]) Groundfish Fisheries as follows:

- *"Prevent overfishing;*
- *Promote sustainable fisheries and communities;*
- *Preserve the food web;*
- *Manage incidental catch and reduce bycatch and waste;*
- *Avoid impacts to seabirds and marine mammals;*
- *Reduce and avoid impacts to habitat;*
- *Promote equitable and efficient use of fishery resources;*
- *Increase Alaska Native consultation;*
- *Improve data quality, monitoring and enforcement."*

From NOAA's Goals and Priorities emerge the need to develop an EAF and EAM at a regional scale and allow inter-regional comparison. For the implementation of this type of research plan, agencies such as NOAA will benefit from the research presented by independent organizations like the Pew Oceans Commission (2003), the World Wildlife Fund (WWF) and The Nature Conservancy (2004), COMPASS (McLeod *et al.*, 2005), North Pacific Marine Science Organization (PICES, 2004), as well as the U.S. Commission on Ocean Policy (2004). Further information on policy and science related to EAF and EAM is discussed in Field and Francis (2006), and Scandol *et al.* (2005).

A comparison of the broad-level objectives outlined by various groups for an EAM is shown in Table 1. Similar objectives emerge from this comparison. All acknowledge the need to: (1) protect ecosystem structure, functioning and key processes, including diversity and habitat, (2) account for food web interactions, (3) manage regionally, (4) incorporate precaution into decisions, (5) integrate broad societal goals, and (6) acknowledge multiple, external influences, including climate. Sometimes diversity or habitat is not explicitly mentioned in the objectives but is inferred from the broad objective to protect ecosystem structure and functioning.

Within this framework we need to develop regional research programs for place-based EAF and EAM. In this respect, a framework of an ecosystem impacts assessment for the BSAI and GOA was developed (Livingston *et al.*, 2005), which pointed out the need to define better ecosystem indicators that can be used to address the following goals and objectives:

Goal: Maintain predator–prey relationships
Objectives:

- Maintain pelagic forage availability;
- Reduce spatial and temporal concentration of fishery impact on forage fish;
- Reduce removals of top predators;
- Reduce introduction of non-native species.

Goal: Maintain energy flow and balance
Objectives:

- Reduce human-induced energy redirection;
- Reduce system impacts due to energy removal.

Goal: Maintain diversity
Objectives:

- Maintain species diversity;
- Maintain functional (trophic, structural habitat) diversity;
- Maintain genetic diversity.

An annual *Ecosystem Considerations* appendix (Boldt, 2005) organizes knowledge of ecosystem change at a variety of levels and provides a scientific assessment of the roles of humans and climate in producing change and whether we are achieving the above goals and objectives.

As pointed out by Scandol *et al.* (2005), EAF is closely connected to policies related to Ecologically Sustainable Development (ESD), but the science community has difficulties translating policy statements to specific ecosystem targeted studies directed toward the implementation of an EAF (Browman and Stergiu, 2004). We will discuss and compare in more detail the need for an integration of ecological indicators in view of the goals and objectives proposed and discuss a subset of potential ecosystem indicators according to different domains.

Table 1 Comparison of broad-level ecosystem protection objectives.

Food and Agriculture (FAO)	**Communication Partnership for Science and the Sea (COMPASS)**	**NOAA Ecosystem Approach to Management (EAM)**	**Pacific States Marine Fisheries Commission (PSMFC)**	**Ecosystem Principles Advisory Panel (EPAP)**	**North Pacific Fishery Management Council (NPFMC)**	***Ecosystem Considerations* appendix**
Limit ecosystem impacts	Protect ecosystem structure, functioning, and key processes	Take ecosystem knowledge into account	Broad scope of monitoring, pursue ecosystem modeling research	Ecosystems have real thresholds and limits	Prevent overfishing, manage incidental catch and reduce bycatch, waste, avoid seabird and marine mammal impacts, avoid habitat impacts	Maintain energy flow and balance
Maintain ecological relationships between species	Account for species interactions	Take ecosystem knowledge into account	Emphasize food web interactions	Diversity is important, components are linked	Preserve food web	Maintain predator prey relationships
Management measures compatible across entire resource distribution	Place-based	Regionally directed	Employ spatial representation	Multiple scales interact among and within ecosystems, boundaries are open	(regional measures)	(divided into regions)
Precaution in decisions due to ecosystem uncertainty		Incremental and adaptive	Acknowledge high levels of uncertainty	Prediction of ecosystem behavior is limited, change may be irreversible, ecosystems change with time	Improve data quality, monitoring, and enforcement	Maintain diversity
Governance ensures both human and ecosystem well-being and equity	Integrates ecological, social, and economic perspectives	Balance diverse societal objectives, collaborative	Account for broad societal goals		Promote sustainable fisheries and communities, equitable use, Native consultation	Understand human impacts
	Interconnectedness among air, land, sea	Multiple, external influences	Recognize climate/ocean conditions			Incorporate climate into analyses

Ecological indicators

For the Bering Sea, the indicators listed in Fig. 4 (Boldt, 2005) have been used to examine correlations among climate, oceanography, and fisheries and are comparable with the indicators reported by Overland *et al.* (2004).

With reference to the subset of goals and objectives in the Alaskan *Ecosystem Considerations* appendix, the following indicators have been suggested and are listed in relation to the potential indicators discussed in the PICES North Pacific Ecosystem Status report (PICES, 2004) for the Bering Sea and the Gulf of Alaska (Table 2).

Indicators in the Alaskan *Ecosystem Considerations* appendix have been organized to assess impacts to predator–prey relationships, diversity, and ecosystem energy flows (Appendices 4 and 5). However, indicators could also be arranged to relate to NPFMC Groundfish fishery management plans (FMP) goals (Table 3).

Further development of aggregate indicators that can provide information on ecosystem changes in relation to climate shifts and changes in community species composition would be helpful to reduce the number of indicators presented in the Alaskan *Ecosystem Considerations* appendix. We will now discuss the use of a subset of ecosystem indicators within three domains: climate and oceanography, ecology, and management and conservation.

Climate and oceanographic domain

Climate

As described in Overland *et al.* (1999), three dominant modes of climate variability occur during the winter in the eastern Bering Sea, the Arctic Oscillation (AO), the Pacific Decadal Oscillation (PDO), and El Niño Southern Oscillation (ENSO) events. They have an influence on both the spatial distribution and intensity of the winter storms in relation to the position and strength of the Aleutian Low (AL). These climate modes have been used to identify different periods and patterns during the winters for over 30 years in the eastern Bering Sea (Overland *et al.*, 1999): 1967–1976 (negative PDO, mixed AO, and positive AL), 1977–1988 (positive PDO, negative AO and AL), and 1989–1998 (mixed PDO, positive AO, and negative AL), and major ecosystem shifts in the northern Bering Sea (Grebmeier *et al.*, 2006). Some of the links between climate change and ecosystem processes in the Bering Sea have been illustrated by Overland and Stabeno (2004) showing changes in the surface air temperature (SAT) in relation to sea ice concentration and other ocean processes, some of which ultimately affect the recruitment of Bering Sea winter spawning flatfish (Wilderbuer *et al.*, 2002). The effects of climate change in relation to pelagic ecosystem processes, including phytoplankton blooms, zooplankton abundance and the survival of larval/juvenile fish, and their recruitment, has been studied in the southeastern Bering Sea (Hunt *et al.*, 2002).

It is important to recognize the difference between regime shift and phase transition when we try to link climate and ecological processes. According to Ciannelli *et al.* (2005) regime shifts can be seen as the changes of a forcing variable of a system, such as climate, and its effect on the entire ecosystem. Phase transitions are related to the mechanistic properties of a system and how it responds to both exogenous (*e.g.*, climate/environmental forcing) and endogenous forcing (*e.g.*, density-dependence processes). Therefore, regime shifts can be regarded as a set of homogeneous controlling variables, whereas phase transitions can been seen as a set of homogeneous observational variables of the system attributes such as diversity patterns at the community level and recruitment processes at the population level (Ciannelli *et al.*, 2005).

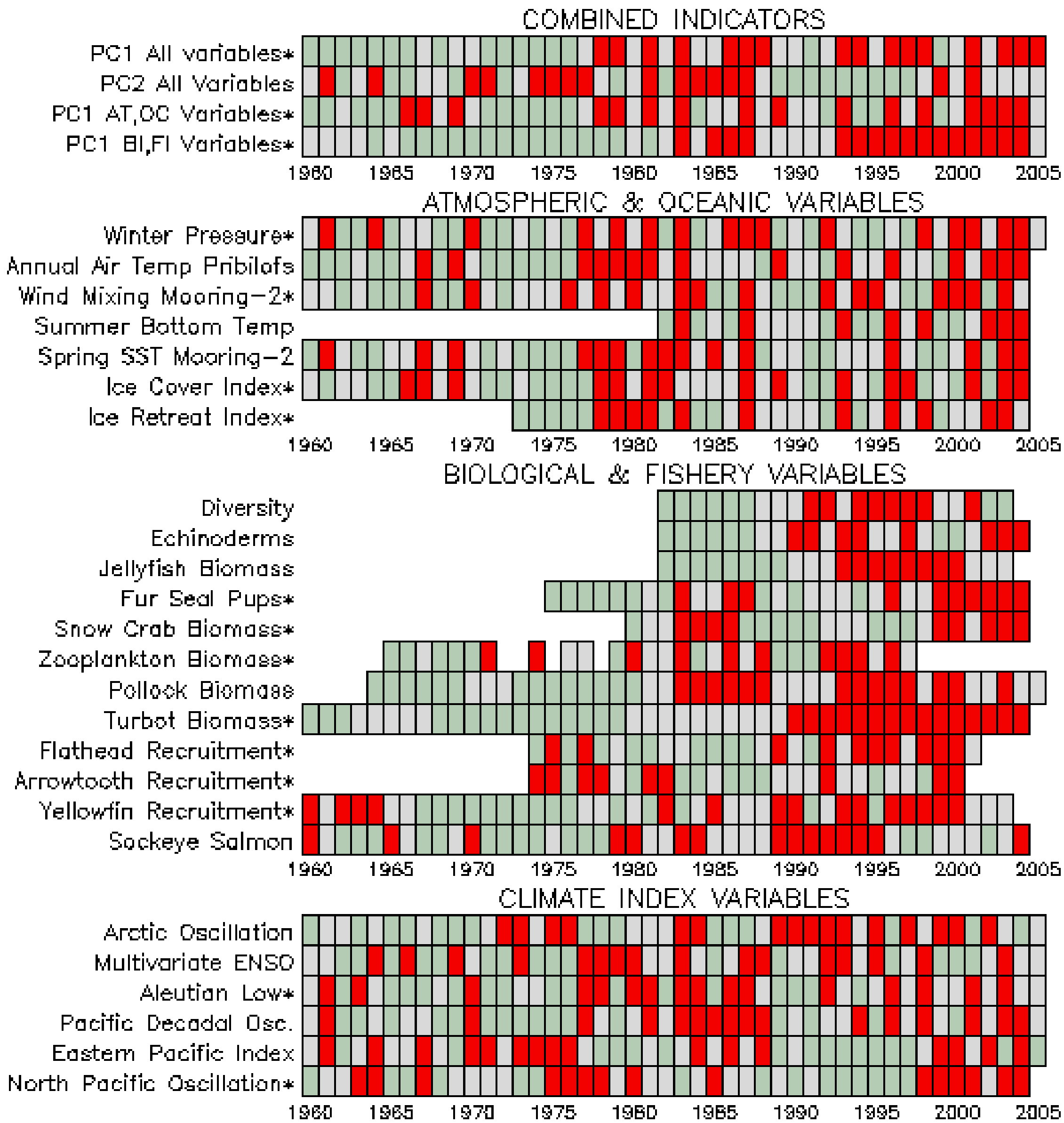

Fig. 4 Bering Sea indicators combining climate, oceanography, fisheries. Red colors indicate the large changes in recent years (largest one third of values in record). The middle third is shown in grey and the lowest third is shown in green. The combined indicators are the result of a mathematical analysis (principle component analysis) which resolves the trends in all the time series into two major components. To demonstrate covariability over time, the values in the same series have been inverted, as noted by the asterisk (from the Bering Climate web page at: http://www.beringclimate.noaa.gov, Rodionov, 2004; Boldt, 2005).

Table 2 Comparison of ecosystem indicators for the goals and objectives reported in the Alaskan *Ecosystem Considerations for 2006* appendix (2005) and PICES North Pacific Ecosystem Status report (2004).

Goals	Objectives	Indicators: *Ecosystem Considerations* appendix	Indicators: PICES North Pacific Ecosystem Status report
Maintain predator-prey relationships	Maintain pelagic forage availability	• Population trends in forage biomass (quantitative – walleye pollock biomass, Atka mackerel, non-target species such as squid and herring)	• Biomass index, catch biomass, plankton (phytoplankton, zooplankton), • Changes in CPUE of non-target species
	Reduce spatial and temporal concentration of fishery impact on forage fish	• Degree of spatial/temporal concentration on forage species (qualitative – species as above)	• Geographic areas in relation to changes in biomass (basin, coastal domain, middle domain, outer domain), • Forage fishes biomass changes in CPUE*
	Reduce removals of top predators	• Trophic level of catch; sensitive bycatch levels (quantitative: sharks, birds; qualitative: pinnipeds), • Population status (whales, pinnipeds, seabirds) relative to MBAL	• Marine birds and mammals, pinnipeds, cetaceans
	Reduce introduction of non-native species	• Total catch	
Maintain energy flow and balance	Reduce human included energy redirection	• Trends in discard (quantitative) and offal production, • Scavenger population trends relative to discard and offal production (qualitative), • Bottom gear effort (qualitative measure of unobserved gear mortality on bottom organisms)	
	Reduce system impacts due to energy removal	• Trends in retained catch (quantitative)	• Catch and abundance trends
Maintain diversity	Maintain species diversity	• Population size relative to MSST or ESA listing thresholds, linked removals (qualitative), • Bycatch of sensitive (low population turnover rate) species that lack population estimates (quantitative: sharks, birds, structural habitat biota)	• Species diversity measures
	Maintain functional (trophic, structural habitat) diversity	• Guild diversity or size diversity changes linked to fishing removals (qualitative), • Bottom gear effort (measure of benthic guild disturbance), • Structural habitat biota bycatch	• Shifts in demersal fish and benthic invertebrates
	Maintain genetic diversity	• Degree of fishing on spawning aggregations or larger fish (qualitative), • Older-age-group abundance of target groundfish stocks	• Groundfish recruitment

* CPUE = catch per unit effort; MBAL = minimum biological acceptable level; MSST = minimum stock size thresholds; ESA = Endangered Species Act

Table 3 Comparison of Alaska groundfish fishery management plan (FMP) goals to indicators in the *Ecosystem Considerations for 2006* appendix.

Groundfish FMP Goals	*Ecosystem Considerations* Indices
Prevent overfishing	Status of stocks, annual surplus productivity
Promote sustainable fisheries and communities	Fishing overcapacity programs
Preserve food web	Many indices of pelagic forage availability, spatial/temporal conc. of fishery impact on forage fish, removals of top predators, introduction of non-native species
Manage incidental catch and reduce bycatch and waste	Prohibited species, discards, bycatch
Avoid impacts to seabirds and marine mammals productivity, and chronology trends	Seabird and mammal incidental take, population abundance
Reduce and avoid impacts to habitat	EFH research, effects of fishing gear on habitat research
Promote equitable and efficient use of fishery resources	Fishing overcapacity programs, groundfish fleet composition
Increase Alaska native consultation	Alaska Native Traditional Environmental Knowledge of climate regimes
Improve data quality, monitoring and enforcement	

EFH = Essential Fish Habitat

Time lags between climate, ecological processes and fisheries

There is a need to understand the complex mechanisms underlying the connections between climate variability and the ecological response to this exogenous forcing in relation to fisheries management. In the present fisheries management framework there are no specific considerations of the importance of time-lags and delayed responses or of the type of actions to be taken to respond to climate/fishery related processes (King and McFarlane, 2006). However, their framework approach to incorporate climate regime shifts into management strategies and policy is a single-species approach and is far from the essence of an EAF and EAM that require moving from a single-species to a multi-species framework.

In order to implement a framework that includes climate-driven changes in the ecosystem as regime shifts or phase transitions, we need to further understand the links between climate processes, physical oceanographic processes and primary productivity. There is the need to develop adequate methods for the detection of regime shifts (Rodionov and Overland, 2005) to allow a better definition of the type of climate/physical oceanographic indicators we can use to explain the variability we observed at the population, community and ecosystem level at different temporal and spatial scales. We need to look in more detail at the importance of time lags when considering potential causal direct/indirect links between climate and ecological processes (Belgrano *et al.*, 1999).

Climatic, atmospheric, and oceanic variables need to be first linked to the variations in phytoplankton, primary production (*e.g.*, Chl *a*, SeaWiFS data) and nutrients (*e.g.*, BASIS survey 2000–2004; BS FOCI; SEBSCC nutrients), since we need to understand the links between climate forcing and changes in the primary production required (PPR), Pauly and Christensen (1995) for recruitment processes, predator-prey relationships, and diversity. We need to consider the importance of spatial autocorrelation (Legendre, 1993) and adequate multivariate analysis approaches (Borcard *et al.*, 1992) to define the ecological variation explained by exogenous and endogenous processes.

The Alaskan ecosystem protection goals, such as the maintenance of predator–prey relationships and biological and genetic diversity, are closely related to exogenous forcing and further research is necessary to capture the complexity of these relationships to refine the existing “ecological indicators” used to describe variability patterns.

Ecological domain

We will consider a subset of ecological processes that are part of a broader ecological domain that are related to these goals:

- Maintain predator–prey relationships;
- Maintain energy flow and balance;
- Maintain diversity, including genetic diversity.

Ecology

The analysis of food webs has been used to describe communities as complex adaptive systems as well as to look at the links between food-web complexity and ecosystem stability. Food webs can provide a working framework for linking observed/predicted patterns to specific management issues.

For the maintenance of predator-prey relationships we have to realize that aquatic food webs are strongly size-based (Sheldon *et al.*, 1972). Therefore, individual body size provides a link between individual organisms making up a community and predator-prey interactions. As pointed out by earlier studies individual body mass can be described by scaling laws (West and Brown, 2005) and linked to the biological properties of a system to provide estimates of ecosystem properties such as production (Kerr, 1974; Boudreau and Dickie, 1992; Kerr and Dickie, 2001; Jennings and Blanchard, 2004).

There is the need to link the structure of size-based food webs to predator-prey body-size ratios, trophic transfer efficiency, and abundance-body-size relationships. These properties have been recognized since the earlier work by Sheldon and Kerr (1972) and more recently by others (Link, 2002a,b; Nicholson and Jennings, 2004) to be important ecosystem descriptors used for assessing the effect of both climate change and fishing pressure on marine ecosystems, but they have not yet been used to link patterns to policy. A key issue is to understand the relationships between structure and diversity in food webs (Jennings *et al.*, 2002; Cohen *et al.*, 2003) that includes the recent development in scaling theory and macroecology (Belgrano *et al.*, 2002; Li, 2002; Jennings and Mackinson, 2003) applied to marine systems.

In this context the use of a size-based food web approach framework will allow us to better understand the abundance-body-size relationship for communities that share a common energy source (Cyr, 2000; Ware, 2000; Brown and Gillooly, 2003; Cohen *et al.*, 2003). In this respect, the following indicators can be used examine the links between predator–prey relationships in relation to specific management issues:

- body size,
- Predator–Prey Mass Ratio (PPMR),
- Trophic Efficiency (TE),
- Trophic Level (TL).

The investigation of complexity and stability issues in food webs dates back to the early work by May (1972, 1973) when he developed a framework to relate the number of species, S, the connectance in the food web, C, and the number of links, L, (*e.g.*, species interactions). More recently these food web properties have been extended into network analysis and theory (Williams and Martinez, 2000; Dunne *et al.*, 2002, 2004; Krause *et al.*, 2003; Morris *et al.*, 2005). However, further work is necessary on the use of statistical inference in food web models (Solow and Beet, 1998; Neubert *et al.*, 2000; Solow, 2005). Complexity–stability implications are related to both food web dynamics and biodiversity process and have been recently reviewed by Dunne *et al.* (2005), Kondoh (2005), and Naeem (2006). This particular aspect is related to the third Alaska ecosystem protection goal “*Maintain diversity including genetic diversity*.”

In particular we can refer to the re-analysis of the Benguela food web dynamics by Yodzis (1998, 2000) where he used an energetic and allometric modeling approach to show that the interaction between hake and fur seals is linked to many other species in the food web. As Kondoh (2005) points out it is important to understand the relationship between connectance, C, and population persistence in the presence of adaptive foragers in relation to the adaptive food web hypothesis (Kondoh, 2003a,b), "*where the effect of changing species richness on population stability depends on the fraction of adaptive foragers and their adaptation rate (Kondoh, 2005).*"

In the context of species diversity and biodiversity measurements related to fisheries (Hoff, 2006) we often see the use of a richness index, evenness index, and the Shannon-Weaver, or Shannon-Wiener index of diversity based on Simpson's (1949) indices. This measurement is the alpha (α) diversity that measures the diversity in species at individual sites. Since we are interested in the variation in species composition among locations in a geographic area (*e.g.*, Bering Sea, GOA) we need to use the beta (β) diversity. As pointed out by Legendre *et al.* (2005), "*If the variation in community composition is random, and accompanied by biotic processes (e.g., reproduction) that generate spatial autocorrelation, a gradient in species composition may appear and beta diversity can be interpreted in terms of rate of change, or turnover, in species composition along that gradient.*"

In this respect, the following indicators can be used to link species diversity and trophic, structural habitat diversity to specific management issues:

- species body-size,
- beta (β) diversity,
- species richness,
- species rank,
- habitat conservation.

However, as pointed out by Bascompte *et al.* (2006), there is a need to understand further how communities shape co-evolutionary interactions and how these networks are related to biodiversity maintenance. In this respect it is important to maintain genetic diversity and to develop management tools aimed at preserving natural genetic variation in fish populations and maintaining genetic diversity (Conover and Munch, 2002):

- Size-dependent mortality.

With reference to the second Alaska marine protection goal, *Maintain energy flow and balance*, in a recent review by Morris *et al.* (2005), Zorach and Ulanowicz (2003) and Krause *et al.* (2003), some of the current metrics used to understand the interrelationships between food webs and the properties of ecosystems have been discussed in the context of food web complexity. The following indicators may be tested in the context of food web stability and energy flow, and balance:

- Trophic Efficiency (TE),
- Trophic Level (TL),
- Interactive Connectance (IC),
- Total System Throughput (TST),
- Average Mutual Information (AMI).

Fisheries

When we turn to fisheries, the kind of ecological indicators used in relation to an ecosystem-based fishery management approach (EAF) are overwhelming (*e.g.*, CPUE, spawning biomass, recruitment, production biomass, consumption biomass, fishing mortality, *etc.*). Cury *et al.* (2005a,b) used a subset of indicators in relation to trophodynamics derived from model output as well as from observed patterns emerging from field data. With reference to the three goals from the Alaskan *Ecosystem Considerations* appendix: (1) Maintain predator–prey relationships, (2) Maintain energy flow and balance, and (3) Maintain diversity including genetic diversity, some ecological indicators have been used to integrate similar goals. For example:

- Trophic Level of the Catch (TLC),
- Trophic Level (TL),
- Mixed Trophic Impact (TI),
- Fishing-in Balance (FIB) index,
- recruitment indices,
- total biomass,
- forage biomass indices,
- fishery bycatch,
- Primary Production Required (PPR).

However, we need to provide ecological indicators that can account for ecosystem-level patterns and match them with the criteria for implementing an EAF.

Management and conservation domain

To have an ecologically sound approach to managing uses of marine resources, we need to clarify and understand that there are links between the rates of ecological change, climate change and human disturbance (Jackson *et al.*, 2001).

Recalling the overall objectives of EAF (Pikitch *et al.*, 2004):

1. *"avoid degradation of ecosystems, as measured by indicators of environmental quality and system status*
2. *minimize the risk of irreversible change to natural assemblages of species and ecosystem processes*
3. *obtain and maintain long-term socioeconomic benefits without compromising the ecosystem*
4. *generate knowledge of ecosystem processes sufficient, robust and precautionary fishery management measures that favor the ecosystem should be opted."*

Development of aggregate indicators of sustainable use limits is important. As an example, Fowler and Hobbs (2002) used empirical information to estimate the Ecologically Allowable Take (EAT) for the Bering Sea and Georges Bank, (northwestern Atlantic) to address questions regarding total biomass that can sustainably be consumed by humans as predators in such systems. Validating the information used to derive such indicators and ensuring that they are based on contemporary, well-estimated parameters is ongoing. Aggregate indicators can also be derived from whole-ecosystem approaches, such as those obtained from ECOPATH/ECOSIM models.

A systemic management approach is proposed (Fowler 1999, 2003) to understand ecosystem dynamics and the emergence of ecosystem patterns to management issues. Systemic Management (SM) can be defined as a macroecological approach that is based on emergent patterns (probability distributions) that are directly relevant to specific management questions. Macroecology (Brown, 1995) is a statistical approach used to investigate processes related to invariant–variant patterns of structured class-size, body mass, species abundances, composition and interactions across different spatial and temporal scales (Belgrano and Brown, 2002; Jonsson *et al.*, 2006; Naeem, 2006). Therefore, a SM approach could also be used to address questions related to the spatial and temporal distribution of fisheries harvest, as well as to the establishment of marine reserves and closed seasons (Fowler and Crawford, 2004), which are part of EAF and EAM. An example of other management questions that have been addressed systemically include how to allocate catches over space, time, and alternative resources species (Fowler, 1999; Fowler and Crawford, 2004).

As pointed out by Baskett *et al.* (2005), in the context of Marine Protected Areas, we need to consider the importance of evolutionary changes induced by fishing (*e.g.*, changing size-dependent mortality) in relation to the harvested species. Management and conservation actions need to be taken in consideration of the knowledge that the interactions between species are embedded in multispecies food webs with different degrees of complexity that cannot be ignored (Yodzis, 2000). We need to maintain the natural variability in populations and species diversity by reducing the selective pressure exerted by commercial fisheries on prey stock by taking into account predation patterns observed in large predators (*e.g.*, marine mammals). Therefore, we need to define what is sustainable in terms of selectivity by body size to address genetic effects of commercial harvesting, as pointed out by Birkeland and Dayton (2005) and Etnier and Fowler (2005), and to better describe the trophic position of the harvested species in relation to the patterns of predation rates (Melian and Bascompte, 2004; Bascompte *et al.*, 2005), as well as by accounting for natural mortality, M, that in current fisheries models is often attributed a constant value (Yodzis, 2001).

If we now return to the subset of ecological indicators to be used in implementing an EAF and EAM we need to consider the temporal and spatial scales at which ecosystems operate (Naeem, 2006), and match those with the scale at which policy and management decisions and actions operate. We also need to address the issue of complexity (Taylor, 2005) in EBM and to consider ecosystems as complex adaptive systems (Lansing, 2003), where the emergence of patterns is often the result of local interactions operating at different spatial and temporal scales. In a fisheries co-management context, for example, the application of game theory combining economic and biological parameters showed interesting results in addressing problems related to a fishery cooperative system (Trisak, 2005).

Outlook

Given the urgency of moving toward sustainable fisheries, we need to consider the use of ecological and socio-economic indicators as part of a framework for an EAF and EAM of marine resources and promote the health of the oceans (Cury *et al.*, 2005a,b; Livingston *et al.*, 2005) by addressing long-term objectives.

Models

We often turn to models to address both theoretical and applied questions. Fisheries management has used, to date, single-species models focused on target species (Hilborn and Walters, 1991; Quinn and Deriso, 2000) and embedded in stock assessment estimates using virtual population analysis tools (Yodzis, 2001). The maximum sustainable yield (MSY) fishing rate concept, criticized by Larkin (1977) and Walters *et al.* (2005), was shown to be inappropriate for use in the context of ecosystem-based fishery management. Despite efforts to move toward a multi-species approach (Walters *et al.*, 1997) single-species management approaches are the current management practice (Hoffman and Powell, 1998). Single-species approaches typically used in stock assessment need to take into consideration allometric relations involving individual body-size (Yodzis, 1998). Also, the intrinsic growth rate, r, should be used in a stochastic framework that takes into account both endogenous and exogenous forcing, if we need ecological/fisheries oriented indicators from stock assessment studies.

Multi-species modeling uses a bioenergetic approach (Christensen and Pauly, 1992) and simulations using the (ECOPATH/ECOSIM) modules have been used successfully for addressing fishery-induced ecosystem changes in the Gulf of Thailand, but less successfully to address, for example, the decline of Steller sea lions in relation to fisheries management in the Bering Sea (Trites, 1999). The ECOPATH model approach has also been tested in the context of fishing effects on food web dynamics in the eastern and western Bering Sea ecosystems (Aydin *et al.*, 2002). Other applications of multi-species ecosystem models have been developed for the eastern Bering Sea using a multi-species virtual population analysis (MVPA) as described by Livingston and Jurado-Molina (2000) and for the Bering Sea groundfish fisheries (Jurado-Molina and Livingston, 2002).

As part of the process to move toward a multi-species approach to EAF, we need to describe and evaluate the many ecological indicators so far proposed in the context of fisheries management. Ecological indicators have been evaluated from model output (Fulton *et al.*, 2005), and by statistical approaches (Link *et al.*, 2002; Mueter and Megrey, 2005). However, we may need to consider the spatial variation of community composition data and apply statistical methods that include space as a variable (Legendre, 1993). We need models that combine the effects of different mortality factors as shown, for example, in the case study for collapse of the Barents Sea capelin (Hjermann *et al.*, 2004) and we need to consider the non-linearity present in the dynamics of large-scale marine ecosystems (Hsieh *et al.*, 2005).

Ecological indicators

Future work will take the multiple ecological indicators for each of the three ecosystem protection objectives outlined for the Bering Sea ecosystem and develop aggregate indicators. In the PICES report (2004), information gaps are listed for three major areas or domains: climate, ocean productivity, and living marine resources; suggesting the need to link climate and oceanographic process to nutrients dynamics, phytoplankton and zooplankton variability, and food web dynamics. We need to develop ecological indicators that can be used for EAF and EAM at different spatial scales across geographical areas and integrate this information with GIS data. We need to maintain and expand the current monitoring programs and combine the information with oceanographic data derived from satellites (Polovina and Howell, 2005). Toward this end there are initiatives to develop a theoretical framework to provide environmental vulnerability indicators (EVI) which provide a way to quantify environmental vulnerability, conservation status and resilience across different spatial and temporal scales (Villa and McLeod, 2002).

There is a need to understand the complexity and the mechanisms underlying the ecological processes that are at the core for improving our ability to translate this type of information into tools that can be used to sustain ecosystem services (Carpenter and Folke, 2006), but as pointed out by Steele (2006), "*At present, the science is unable to measure and relate the fundamental concepts of diversity, productivity and resilience for management decisions*." Although this might be true for ecosystem-level measures of these attributes, certainly these attributes are considered in decision-making at lower organizational levels (*e.g.*, species) by fishery managers. Thus, the implementation of system-level management measures is not likely in the short-term. In the meantime, definition of more specific, operational objectives in regions will allow the measurement of more refined, sub-system level indicators to measure performance.

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Appendix 4 Descriptions and sources of Bering Sea/Aleutian Islands time series presented in Table 2 of Appendix C: *Ecosystem Considerations for 2006*.

BERING SEA, ALEUTIAN ISLANDS

Class	Attribute	Index	Series	Description	Source
Climate	Physical Environ.	Ice index	1954-2004	A combination of 6 highly correlated ice variables	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	SAT	1916-2004	Surface winter air temperature	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	PDO	1901-2004	Pacific Decadal Oscillation	http://jisao.washington.edu/pdo/PDO.latest
Climate	Physical Environ.	MaySST	1970-2004	May sea surface temperature	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	AOI	1951-2004	Arctic Oscillation Index	http://www.beringclimate.noaa.gov/index.html
Climate	Physical Environ.	Summer BT	1982-2003	Summer bottom temperature	http://www.beringclimate.noaa.gov/index.html
Pelagic forage	Predator-prey	Herring	1978-2004	Togiak herring age-4 recruits	West, this report
Pelagic forage	Predator-prey	A.Mackerel	1977-2002	Atka mackerel log-transformed recruit per spawning biomass	NPFMC 2004a
Pelagic forage	Predator-prey	Pollock	1964-2002	Walleye pollock log-transformed recruit per spawning biomass	NPFMC 2004a
Pelagic forage	Predator-prey	Forage fish	1997-2002	Forage fish bycatch	Gaichas, this report
Pelagic forage	Predator-prey	Squid	1997-2002	Squid bycatch	Gaichas, this report
Top predators	Predator-prey	BS Trophic level	1954-2003	Bering Sea trophic level of the catch	Livingston, this report
Top predators	Predator-prey	AI Trophic level	1962-2003	Aleutian Island trophic level of the catch	Livingston, this report
Top predators	Predator-prey	Sharks	1997-2002	Shark bycatch	Gaichas, this report
Top predators	Predator-prey	Pinnipeds	1989-2004	Non-pup Steller sea lion counts	Sinclair and Testa, this report
Top predators	Predator-prey	GT	1973-2003	Greenland turbot log-transformed recruit per spawning biomass	NPFMC 2004a
Top predators	Predator-prey	ATF	1976-2000	Arrowtooth flounder log-transformed recruit per spawning biomass	NPFMC 2004a
Intro non-natives	Predator-prey	log(CPUE)	1982-2003	Total catch per unit effort of fish and invertebrates in bottom trawl surveys	Mueter, this report
Energy redirection	Energy flow	Cod	1977-2003	Pacific cod log-transformed recruit per spawning biomass	NPFMC 2004a
Energy redirection	Energy flow	BLKI	1975-2002	Black-legged kittiwake productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Energy redirection	Energy flow	RLKI	1975-2002	Red-legged kittiwake productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Energy redirection	Energy flow	BS H+L	1990-2001	Bering Sea Hook and line (longline) effort (number of hooks)	Coon, this report
Energy redirection	Energy flow	AI H+L	1990-2001	Aleutian Islands Hook and line (longline) effort (number of hooks)	Coon, this report
Energy redirection	Energy flow	BS Bottom Trawl	1990-2003	Bering Sea bottom trawl duration (24 hour days)	Coon, this report
Energy redirection	Energy flow	AI Bottom Trawl	1990-2003	Aleutian Island bottom trawl duration (24 hour days)	Coon, this report
Energy redirection	Energy flow	BS Pelagic Trawl	1995-2003	Bering Sea pelagic trawl duration (24 hour days)	Coon, this report
Energy removal	Energy flow	BS catch	1954-2003	Total catch Bering Sea	NPFMC 2004a
Energy removal	Energy flow	AI catch	1962-2003	Total catch Aleutian Islands	NPFMC 2004a
Species diversity	Diversity	HAPC	1997-2002	HAPC non-target catch Bering Sea/Aleutian Islands	Gaichas, this report
Species diversity	Diversity	BS Diversity	1982-2003	Bering Sea groundfish diversity (Shannon-Wiener index)	Mueter, this report
Species diversity	Diversity	BS Richness	1982-2003	Bering Sea groundfish richness (avg. # species per survey haul)	Mueter, this report
Other	Other	COMU	1976-2002	Common murre productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Other	Other	TBMU	1976-2002	Thick-billed murre productivity (fledglings per egg) at St. Paul Island	D.E. Dragoo, USFWS, pers. comm.
Other	Other	BB Salmon	1956-2003	Total catch of Bristol Bay salmon	Eggers and Fair, this report
Other	Other	Jellyfish	1982-2003	Jellyfish biomass in survey catches	Lauth, this report
Other	Other	AK plaice	1975-1999	Alaska plaice log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	Crab biomass	1980-2002	Total crab biomass	Otto and Turnock, this report
Other	Other	YFS	1964-1998	Yellowfin sole log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	POP	1960-1993	Pacific Ocean perch log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	Northerns	1977-1993	Northern rockfish log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	Rock sole	1975-1997	Rock sole log-transformed recruit per spawning biomass	NPFMC 2004a
Other	Other	FHS	1977-2000	Flathead sole log-transformed recruit per spawning biomass	NPFMC 2004a

Anomalies for each of 34 time series were calculated by subtracting the mean and dividing by the standard error, based on the time series reported below. Most data were taken from the Ecosystem Indicators section, and the author is noted with the year of the *Ecosystem Considerations* appendix.

Appendix 5 Standardized anomalies time series in the Bering Sea/Aleutian Islands from 1970 to the present, using a similar method as Link *et al.* (2002) and DFO (2003) used for ecosystems on the east coasts of the U.S. and Canada. (See next page for symbol explanation.)

Class	Indicator	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	Normalized time series
Top predators	BS Trophic level	o	o	+	+	+	+	+	+	o	o	+	+	+	+	o	o	o	o	o	o	+	o	o	o	o	+	+	o	o	+	+	+	+	+		1954-2003
Climate	Ice index	o	+	+	o	+	+	+	o	-	--	o	-	-	o	o	o	o	-	o	-	o	+	+	-	o	+	--	o	+	o	+	--	+	-	-	1954-2004
Top predators	AI Trophic level	-	-	o	+	o	o	o	o	o	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	o	o	o	o	o	o	o	o	o	o		1962-2003
Energy removal	AI catch	-	--	-	--	-	-	-	-	-	-	o	o	o	o	+	o	o	-	-	++	o	o	+	++	+	++	++	+	+	o	o	o	o	o		1962-2003
Other	BB Salmon	+	-	-	-	-	o	-	-	o	+	++	o	o	+	+	+	o	o	o	+	+	+	+	+	+	++	+	-	-	+	o	o	-	o		1956-2003
Climate	SAT	o	--	--	o	-	--	--	o	+	++	+	+	+	o	o	+	o	+	-	+	o	-	o	o	o	-	++	o	o	o	-	++	-	+	+	1916-2004
Climate	PDO	+	-	--	o	-	-	-	+	o	-	o	+	o	+	+	+	+	++	+	-	o	--	o	o	+	-	o	o	+	o	-	o	o	++	o	1901-2004
Climate	MaySST	+	-	-	o	+	-	-	+	++	++	+	++	-	+	-	-	-	o	o	o	o	o	-	+	o	-	+	o	-	-	o	o	o	+	+	1970-2004
Energy removal	BS catch	o	++	++	+	+	o	-	--	-	-	-	-	--	-	-	o	o	o	+	o	o	+	+	o	+	o	o	o	o	-	-	o	+	+		1954-2003
Climate	AOI	-	o	o	+	o	+	+	--	-	-	o	o	o	o	o	-	-	-	o	++	+	+	+	++	o	+	-	o	o	+	+	-	+	o	-	1951-2004
Pelagic forage	Herring									o	-	-	+++	+++	+	o	o	-	o	o	-	-	+	o	o	o	o	o	o	-	-	o	o	-	-	o	1978-2004
Pelagic forage	A.Mackerel								++	o	o	o	-	-	-	o	o	+	o	++	o	-	o	o	-	-	o	--	-	+	++	+	-	o			1977-2002
Intro non-natives	log(CPUE)													-	o	-	--	-	o	o	o	o	o	o	+	++	+	o	o	o	o	o	o	o	++		1982-2003
Species diversity	BS Diversity													-	-	-	-	-	-	-	-	o	+	+	o	+	+	+	+	++	o	o	+	-	-		1982-2003
Other	Jellyfish													-	-	-	-	-	-	-	-	-	o	o	o	+	o	+	+	+	+	+++	o	o	o		1982-2003
Other	AK plaice						++	++	+	+	+	+	o	-	-	o	-	-	o	-	o	-	o	-	o	-	o	o	-	o	o	o	+				1975-1999
Energy redirection	Cod								+++	++	++	o	+	+	o	o	-	-	-	-	o	-	o	o	-	-	o	o	o	o	+	o	o	o	o		1977-2003
Pelagic forage	Pollock	-	o	o	o	+	+	+	+	++	+	+	o	+	-	o	-	--	--	-	o	o	o	+	-	-	-	o	-	-	o	o	-	-	-		1964-2002
Species diversity	BS Richness													+	+	o	--	-	--	-	-	o	+	o	+	o	-	o	o	+	o	o	+	-	++		1982-2003
Other	Crab biomass											+	o	o	-	-	-	-	o	o	+	++	++	o	o	o	o	o	o	o	-	-	-	-			1980-2002
Energy redirection	BLKI						+	+	+	o	+					-	o	o	o	+	-	o		o	o	-		-	o	+	-	+	-	++			1975-2002
Other	TBMU							++	o	+						--	o	o	o	o	o	o		o				o	-	--	o	o	o	+			1976-2002
Energy redirection	RLKI						o	++	+	-	o					-	o	o		+		o		o	o	o	-		o	+	o	+	-	+			1975-2002
Other	YFS	+	+	++	++	++	+	+	o	o	o	o	o	-	o	-	-	-	-	-	-	-	o	-	-	-	o	-	-	-	-						1964-1998
Other	POP	o	o	o	o	o	o	+	+	+	+	+	++	+	+	++	+	+	o	o	o	-	-	-	-	-											1960-1993
Other	Northerns								+	o	o	o	-	-	-	++	o	-	-	+	+	-	-	-	o	+											1977-1993
Top predators	GT				+	+	+	o	++	+	o	o	-	-	o	+	+	o	-	-	o	+	-	-	-	-	-	-	-	-	-	o	+	+	+		1973-2003
Top predators	ATF							+	o	o	+	++	o	o	++	+	+	++	+	o	-	o	-	-	-	-	o	-	-	o	-	-					1976-2000
Other	Rock sole						+	o	o	o	o	+	+	+	+	+	+	+	+	o	o	o	o	-	-	-	--	-	--	--							1975-1997
Other	FHS								+	++	+	++	++	+	+	+	+	o	o	o	-	o	o	-	-	-	-	-	-	-	-	-	-				1977-2000
Climate	Summer BT													-	+	o	o	-	+	o	+	o	o	-	+	-	-	+	o	+		-	o	+	++		1982-2003
Other	COMU									+							+	-	+	+	o	o		o				o	-		-	o	+	+			1976-2002
Energy redirection	BS H+L																					-	o	+	o	+	+	+	+	-	-	-	--				1990-2001
Energy redirection	AI H+L																					++	o	+	+	o	o	+	-	-	-	-	-				1990-2001
Energy redirection	BS Bottom Trawl																					--	+	+	o	+	o	+	+	o	-	o	-	-	-		1990-2003
Energy redirection	AI Bottom Trawl																					+++	o	o	o	o	o	+	-	o	-	-	-	-	o		1990-2003
Energy redirection	BS Pelagic Trawl																										o	++	o	+	-	-	o	o	o		1995-2003
Pelagic forage	Forage fish																												-	-	o	+	+	-			1997-2002
Top predators	Sharks																												-	o	o	o	++	o			1997-2002
Top predators	Pinnipeds																				o	+	+	+		o		o		-		-		-		-	1989-2004
Pelagic forage	Squid																												+	o	-	-	+	+			1997-2002
Species diversity	HAPC																												+	o	-	o	+	o			1997-2002

Legend

X>2.6	+++
2.6>X>1.6	++
1.6>X>0.5	+
0.5>X>-0.5	o
-0.5>X>-1.6	-
-1.6>X>-2.6	--
X<-2.6	---

Symbols and shading represent seven divisions of anomalies; blank cells indicate no data. Time series were arranged on the y-axis so that variables with similar responses were grouped together. The time series presented were chosen because of their importance to ecosystem processes in the Bering Sea/Aleutian Islands, however, there are some variables that will be added when those time-series become available. See Appendix C: *Ecosystem Considerations* for 2006 for a description of the time series included in this table.

Legend

AI	Aleutian Islands	GT	Greenland turbot
AK	Alaska	HAPC	habitat area of particular concern
AOI	Arctic Oscillation Index	H+L	Hook and line
ATF	Arrowtooth flounder	PDO	Pacific Oscillation Index
BB	Bristol Bay	POP	Pacific Ocean perch
BLKI	Black-legged kittiwake	RLKI	Red-legged kittiwake
BS	Bering Sea	SAT	surface air temperature
COMU	Common murre	SST	sea surface temperature
CPUE	catch per unit effort	TBMU	Thick-billed murre
FHS	Flathead sole	YSF	Yellowfin sole

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Ecological indicators: Software development

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Upgrade to the sequential regime shift detection method

The sequential regime shift detection method, described in Rodionov (2004), was based on the assumption that observations in the series are independent of each other. Many ecological indicators, however, exhibit serial correlation (also referred to as red noise). Due to the presence of red noise, these time series are characterized by long intervals when the observations remain above or below the overall mean value. These intervals can be easily misinterpreted as genuine regimes with different statistics, as illustrated in Fig. 5.

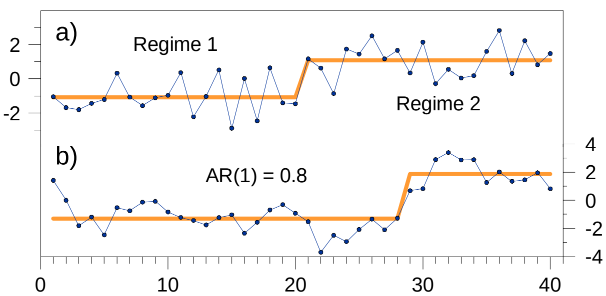


Fig. 5 Realizations of a) white noise process with a shift in the mean at t =21 from –1 to 1, and b) red noise process with AR1 = 0.8. The shift at t = 29 in the latter case would be statistically significant at the $3 \cdot 10^{-9}$ level, if the data points were independent.

There are two approaches to deal with the serial correlation. The first approach is to reduce the degrees of freedom used to determine the significance level of the shifts in proportion to the magnitude of the serial correlation. The second approach is to use a prewhitening procedure, which removes red noise from a time series prior to applying a regime shift detection method. Both approaches require an estimation of lag-1 autoregressive coefficient (AR1). A known problem is that regime shifts in a time series often lead to overestimates of the magnitude of the AR1 coefficient. A possible solution to this problem is to break the time series into subsamples, so that the majority of them do not contain change points, and then use the median value of all AR1 estimates.

It is well known, however, that conventional estimators, such as the ordinary least squares (OLS) or maximum likelihood techniques, yield biased estimates for AR1, particularly for small samples. Rodionov (2006) discusses two bias correction procedures of the OLS estimator for short time series. The first procedure is called MPK after Marriott, Pope and Kendall, who proposed a formula for the expected value of the OLS estimator of AR1. The second procedure, called IP4 (Inverse Proportionality with 4 corrections), is based on the assumption that the first approximation of the bias is approximately inversely proportional to the subsample size and is always negative. Both procedures are included in the new version of the sequential regime shift detection method (Fig. 6). The software can be downloaded from http://www.beringclimate.noaa.gov/regimes.

Extensive Monte Carlo experiments have demonstrated that the MPK and IP4 bias correction techniques produce similar AR1 estimates for subsample sizes greater than 10. For smaller subsample sizes, however, IP4 substantially outperforms MPK in terms of both the magnitude of the bias and variability of the estimates.

To illustrate the effect of prewhitening the regime shift detection, the method was applied to the annual series of the Pacific Decadal Oscillation (PDO) index, 1900–2005. Figure 7 illustrates changes in AR1 estimates depending on the bias correction technique and subsample size. The MPK and IP4 estimates are practically the same for subsample size $m > 11$. The estimates remain relatively stable at about 0.45, as m increases to 27. For greater *m*, AR1 estimates jump to a higher level of about 0.60. This behavior of AR1 is typical for the time series that represent a mixture of red noise with shifts in the mean. It shows that a characteristic time scale of the PDO regimes is about 25–30 years.

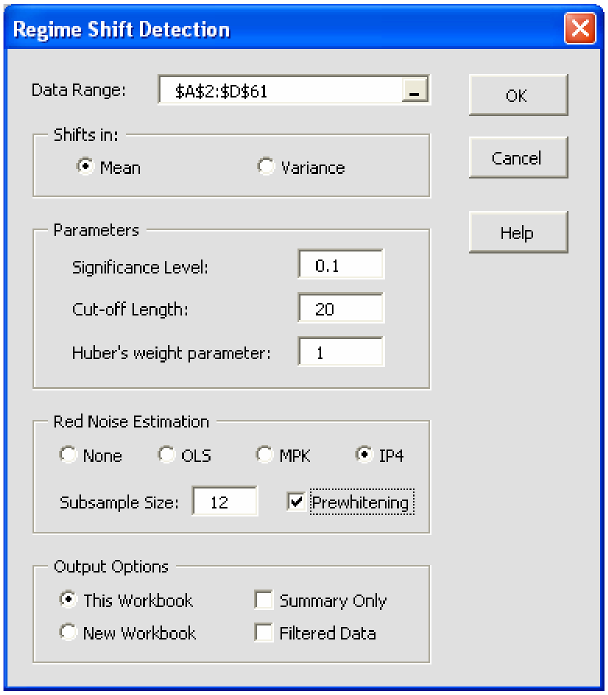


Fig. 6 Entry form of the regime shift detection method.

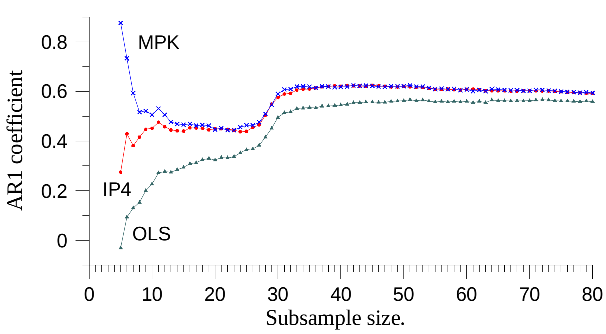


Fig. 7 Ordinary least squares **(**OLS) estimates of AR1 in the annual PDO index with no bias correction and using the Marriot, Pope, Kendall (MPK) and Inverse Proportionality with 4 corrections (IP4) techniques.

After prewhitening, statistically significant (at $p < 0.01$) regime shifts in the PDO are still detected in 1948 and 1976, although their magnitudes are smaller than those in the observed time series (Fig. 8). The red noise component (Fig. 8c), which accounts for about 25% of the total variance in PDO, enhances the shifts. The overall conclusion is that the PDO appears to be more than just a manifestation of red noise, as was suggested in some recent publications (Rudnick and Davis, 2003; Hsieh *et al.*, 2005).

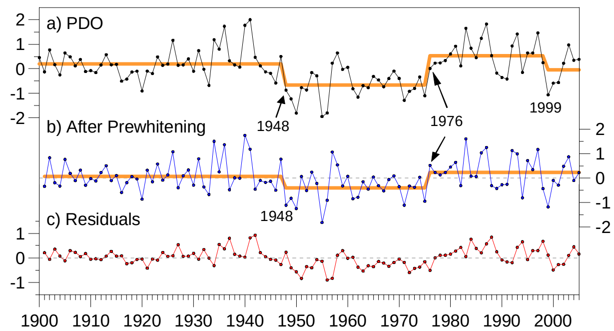


Fig. 8 a) Annual PDO index, 1900-2005, with a stepwise trend, b) the same time series after prewhitening, and c) difference between the time series in a and b.

Vitus: Knowledge management system for the Bering Sea

An increasingly large number of ecological indicators call for methods to deal with information overload. One large group of methods tries to resolve this problem by reducing the dimensionality of the system. This group includes principal component analysis, singular value decomposition, multidimensional scaling and other methods. These methods proved to be useful in analysis of large sets of indicators (*e.g.*, Hare and Mantua, 2000), although there is often a problem in interpreting the results. Another important drawback of those methods is that they do not preserve information about the relationships between the indicators.

An alternative approach to information overload is to use a tool that can help manage information in such a way that only the information relevant to the problem or question at hand is provided to the user at any given point of the analysis. With this in mind, a prototype of a knowledge management system for the Bering Sea ("Vitus") has been developed. The system itself is far from completion, that is, its data and knowledge bases are not filled, but about 80% of its functionality is in place. It is written in VB.NET with the use of several off-the-shelf Microsoft products: Word, Excel, Access, and Visio.

The major components of Vitus are: Data Explorer, Rule Explorer, Inference Engine, Graphical Interface, Search and Reporting Facilities. In many respects, Vitus is similar to an expert or decision support system, but unlike those commercial expert systems that I am familiar with, both the knowledge presentation and inference process are more transparent to the user and designed to be used in environmental research.

The Data Explorer (Fig. 9) organizes information about indicators based on geographical hierarchy. The user can easily create his/her own geographical domain with the necessary level of details. The data for each variable are kept in a separate Excel file and the descriptive information in a Word file. The user can see a list of rules, for which a selected variable participates in the IF or THEN clauses (Fig. 10). With a click of the mouse, the variable can be inserted into the project, which is visualized as an influence diagram (Fig. 11).

The domain knowledge is presented in the form of IF-THEN rules and is controlled via the Rule Explorer (Fig. 12). The number of variables in the IF part of a rule is unlimited. For example, a rule may look like:

IF ENSO event = warm,
AND Aleutian low circulation type = W1,
THEN SAT at St. Paul = above normal; CF = 10.

Here, CF is the confidence factor for the rule (more about it is below). It is important to note that the data and code for each rule are placed in a separate Excel file. Therefore, although the IF-THEN form is default, the user can write his/her own code to express the relationship between the IF and THEN variables. For example, the user can program the Ricker stock-recruitment formula, or use linear regression instead of a simple IF-THEN relationship. Another advantage of this rule information storage is that the user can easily experiment with each rule separately and develop a better feeling of confidence in it.

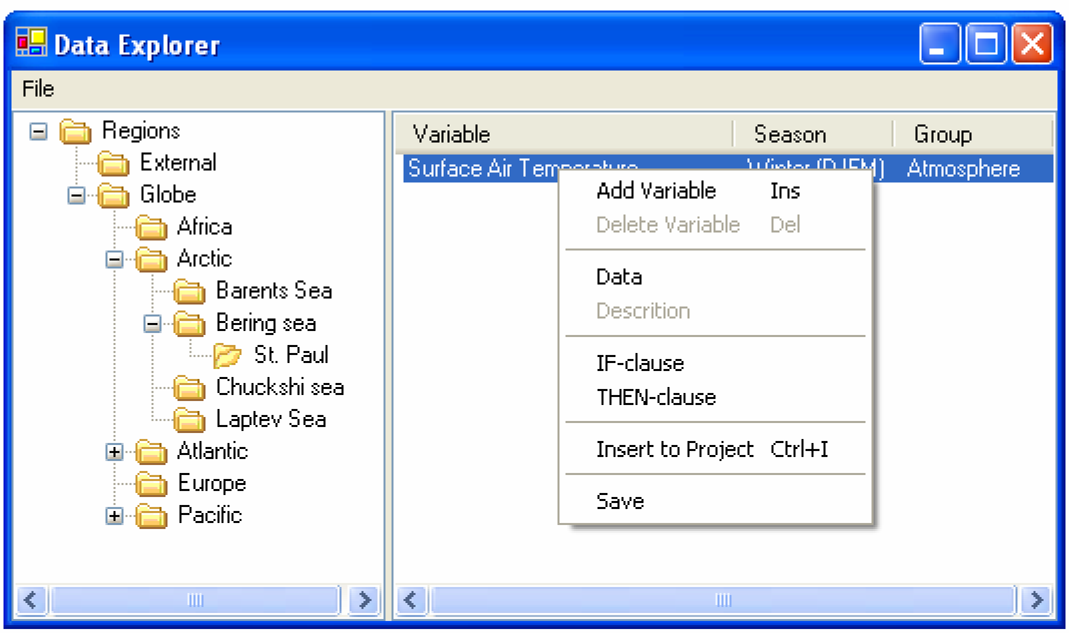


Fig. 9 Data Explorer interface.

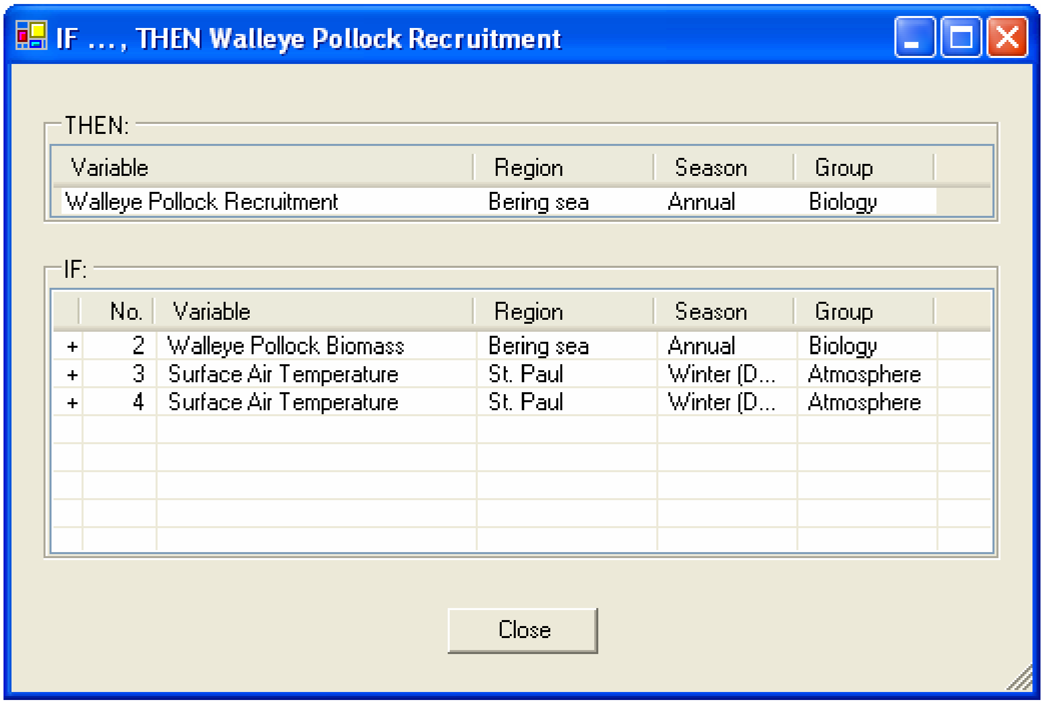


Fig. 10 A list of rules that describe factors affecting walleye pollock recruitment.

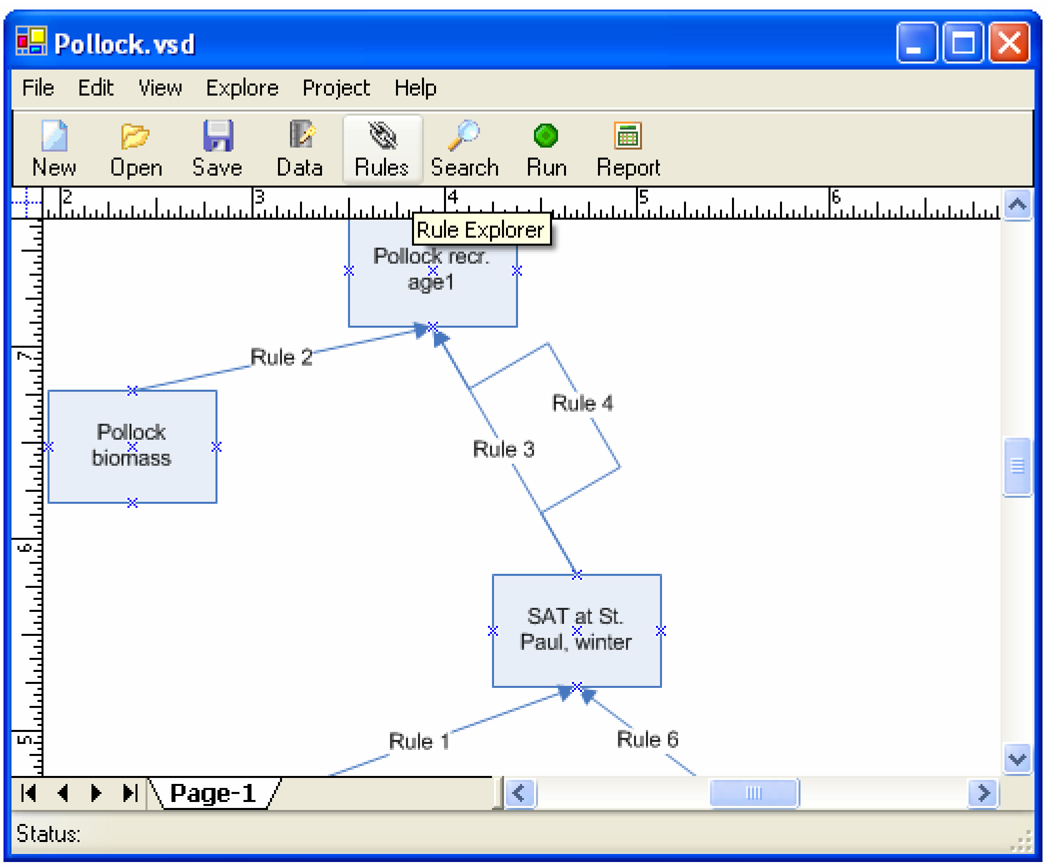


Fig. 11 Part of the influence diagram for walleye pollock recruitment.

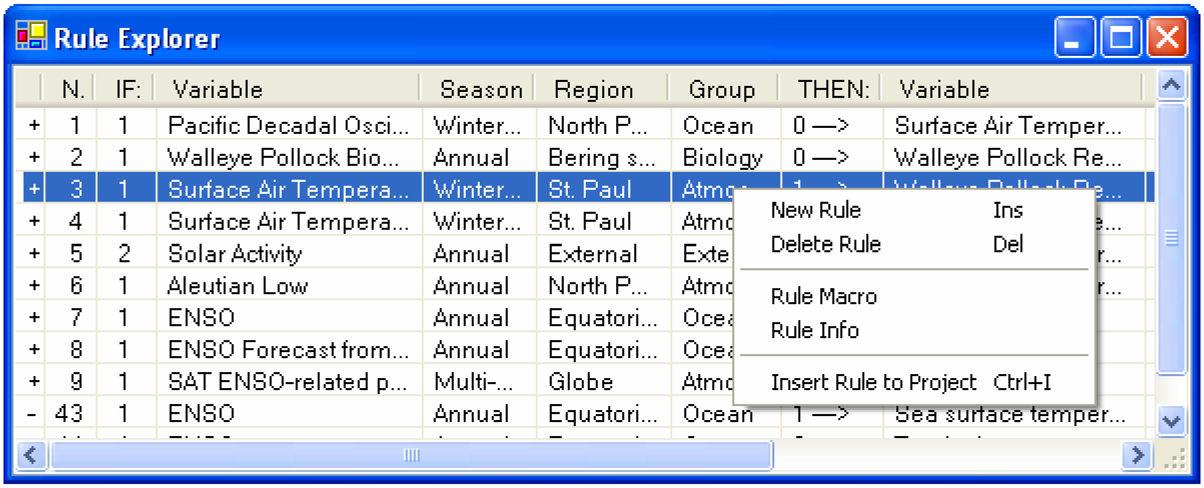


Fig. 12 The Rule Explorer.

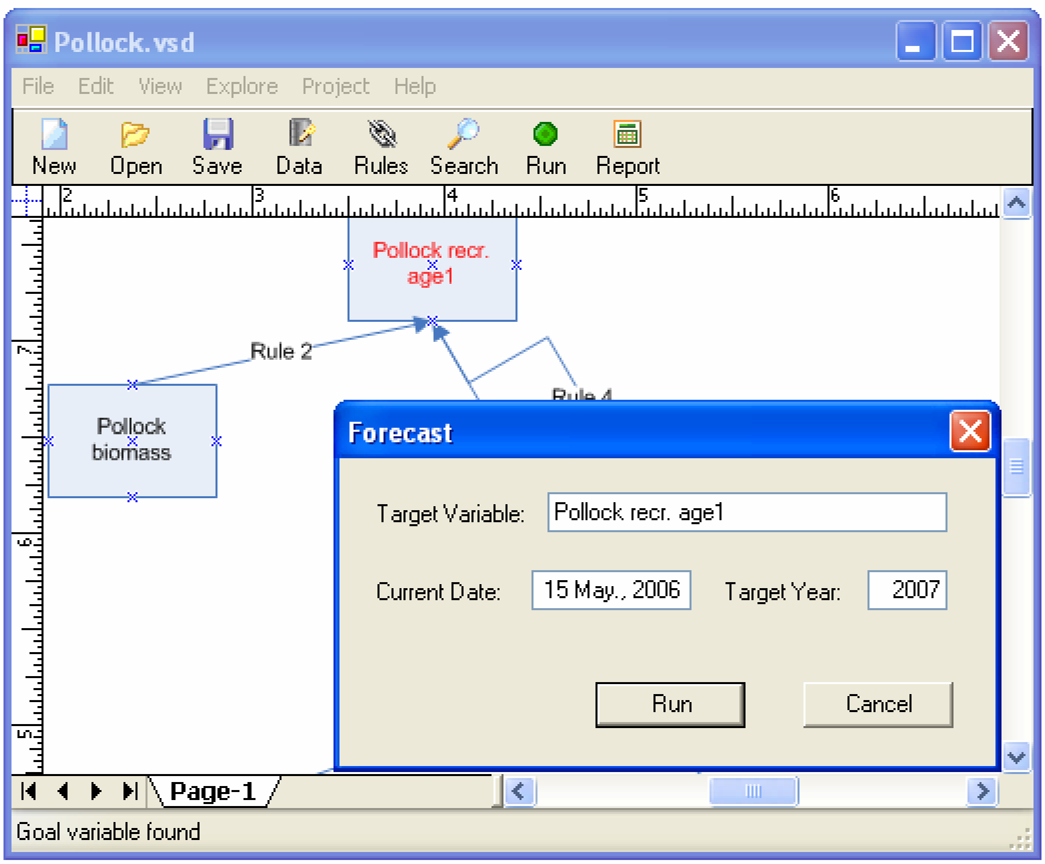


Fig. 13 Running the project in the forecast mode.

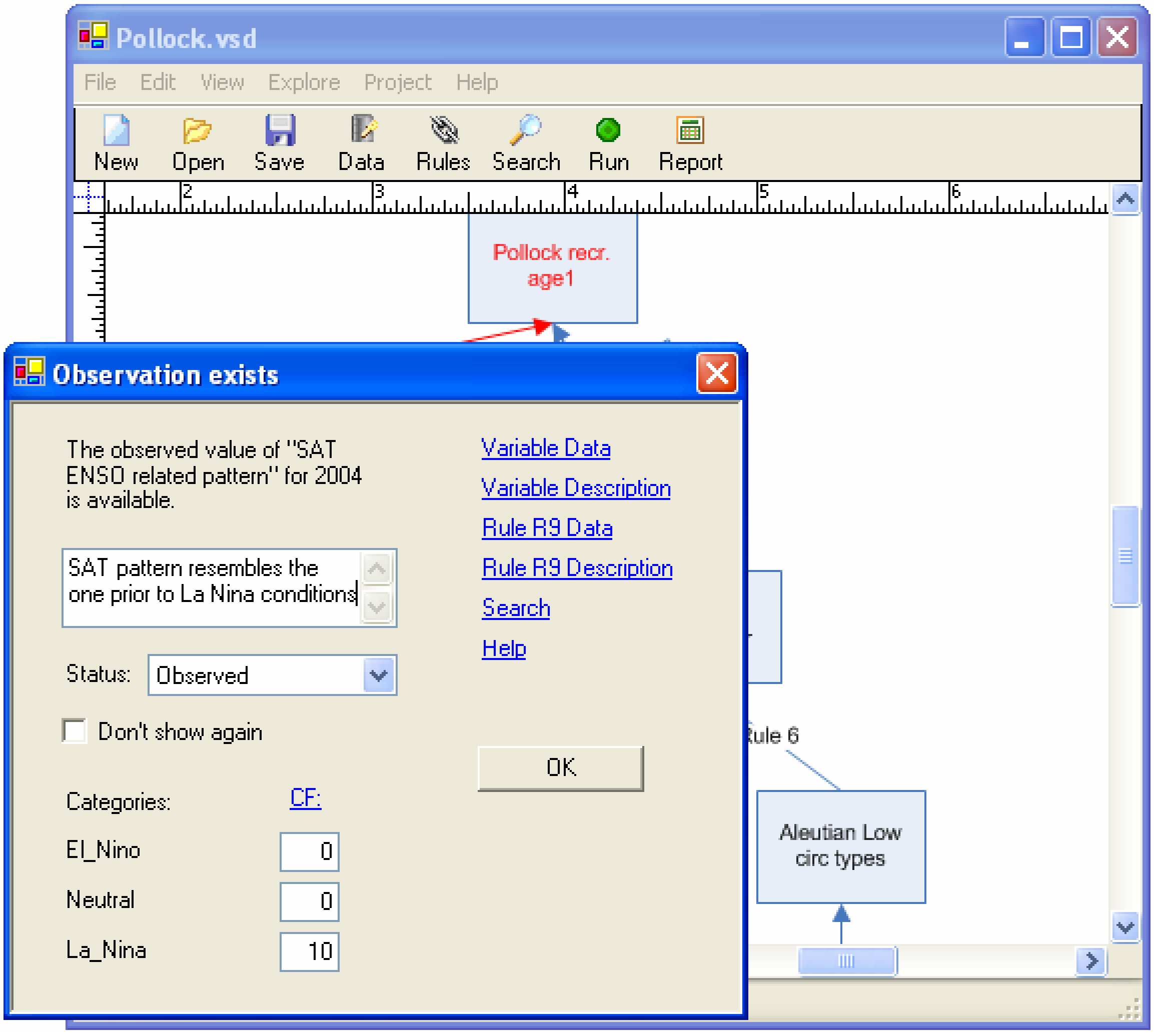


Fig. 14 The system asks questions about the variables in the terminal nodes.

When the influence diagram is prepared, the user may run the project in the forecast or hindcast mode to infer the value of the target variable in a given year (Fig.13). During this process, the system asks for the information about the variables in the terminal nodes of the diagram (Fig. 14). To facilitate the answer to those questions, the user is provided with the access to the data and descriptive information about the variable and related rule. The user can also search for any other pertinent information (Fig. 15).

Previous experience of working with climatic expert systems (Rodionov and Martin, 1996; 1999) showed that, in assigning confidence factors to the rules, it is important to maintain the relative importance of each rule in the system. In other words, it is not the numbers themselves, but the consistency in procedure of their assignment, that should be of major concern to the user. Therefore, although the CF is equivalent to the subjective probability, whenever possible, it is recommended to estimate its value based on the formula:

$$CF = (P(C \mid e) - P(\neg C \mid e)) * 100\%,$$

which is the difference between the probability of category **C** of the variable given the evidence **e** and probability of any other category of the variable given the same evidence **e**, expressed in percent. When CF = 0, it means that observing e will not change our prior confidence (if any) in C.

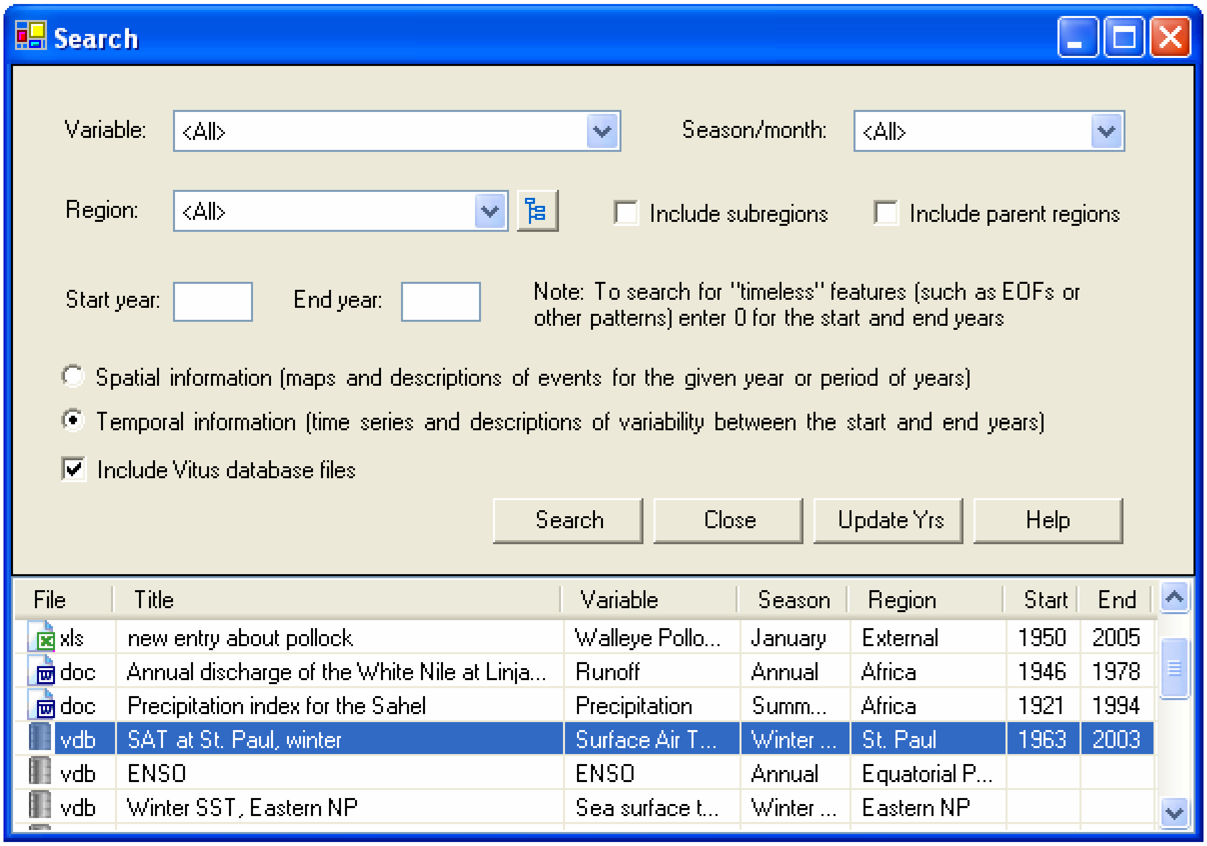


Fig. 15 Search for the relevant information.

The value of CF = 100 means that we can be 100% confident in C, given the evidence e. The confidence factors, calculated using the above formula, should be adjusted for the number of observations. The formula for adjustment (A) used here is as follows:

$$A = 100 - \log(N)/2 * 100,$$

where N is the sample size.

As an example, Table 4 shows the contingency table for the Pacific/North American (PNA) teleconnection index and North-South winds at St. Paul. The CF for an anomalously strong northerly wind in the case of positive PNA will be

$$CF\,(Wind+ \mid PNA+) = (17/24 - 7/24) * 100\% = 42,$$

and after adjustment

$$CF_{adj}\,(Wind+ \mid PNA+) = 42 - 100 - \log(24)/2 * 100 = 42 - 31 = 11.$$

The value of CF_{adj} (Wind– | PNA–) is calculated similarly, so that the rule for these two variables will be as follows:

IF PNA index = positive (negative),
THEN NS wind anomaly = positive (negative); CF = 11 (9).

Table 4 Contingency table for the Pacific/North American (PNA) teleconnection index and North-South winds at St. Paul (Pribilof Islands). Both variables are broken into two categories of above and below normal values. Data: 1949–2005.

NS wind anomaly	**PNA +**	**PNA –**	**Total**
Wind +	17	11	28
Wind –	7	22	29
Total	24	33	57

The evidence from different sources is combined using the following formula:

$CF_{comb} = CF_{old} + CF_{new} - (CF_{old} * CF_{new})/100.$

In addition to the CF algebra, a Bayesian inference technique may be added later. When all the evidence is collected, a forecast for the target variable is issued either in the form of odds (*e.g.*, strong *versus* weak year class of walleye pollock) or probabilities. The user can also open the Custom Property window (Fig. 16) and check the information about individual variables and rules, or open the report that traces the logic behind the forecast (Fig. 17).

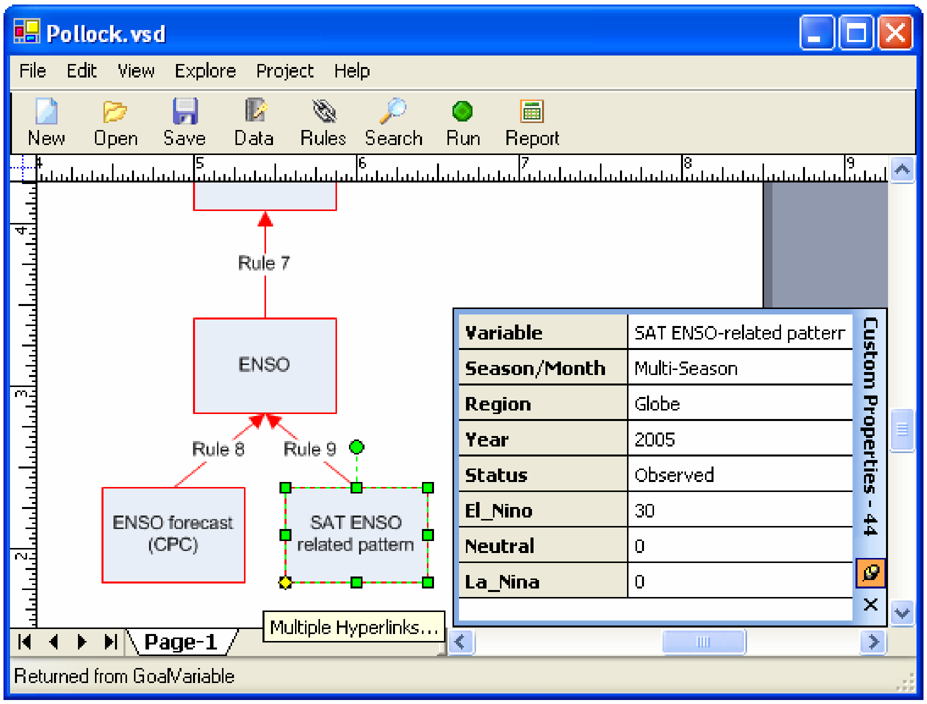
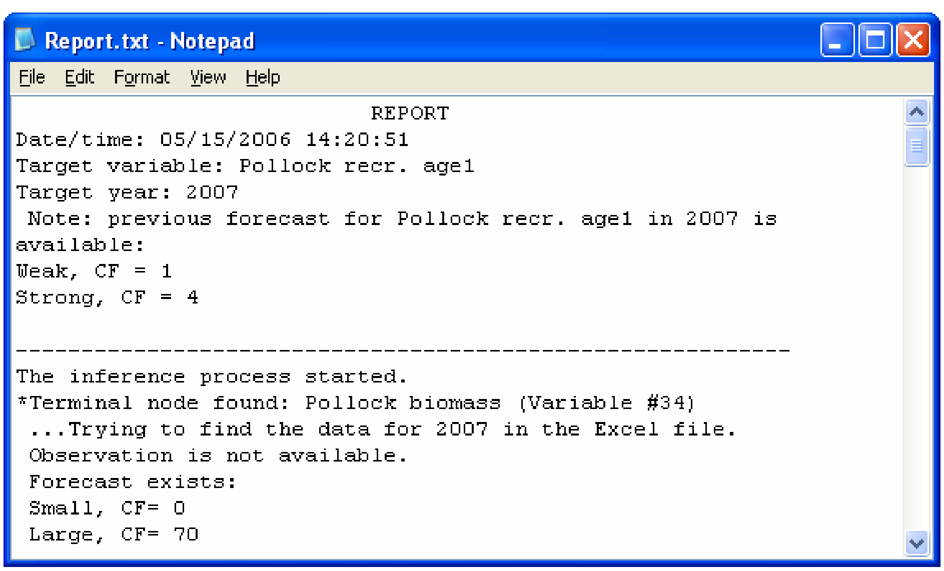


Fig. 16 Displaying information about the variables and rules in the property window.



Report.txt - Notepad

File Edit Format View Help

```
                              REPORT
Date/time: 05/15/2006 14:20:51
Target variable: Pollock recr. age1
Target year: 2007
 Note: previous forecast for Pollock recr. age1 in 2007 is
available:
Weak, CF = 1
Strong, CF = 4

------------------------------------------------------------
The inference process started.
*Terminal node found: Pollock biomass (Variable #34)
 ...Trying to find the data for 2007 in the Excel file.
 Observation is not available.
 Forecast exists:
 Small, CF= 0
 Large, CF= 70
```

Fig. 17 An example of the report that traces the inference procedure.

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ECOSYSTEM REPORTS

Structure and purpose of the Alaskan *Ecosystem Considerations* appendix

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As fishery management organizations move toward ecosystem-oriented management, there is a need to more clearly define the ecosystem management goals of the organization and the tools available to managers to attain those goals. Parallel to this must be an expansion of the scientific advice provided to management beyond traditional single-species stock assessment advice. Although there have been advances in multi-species and ecosystem modeling approaches, these approaches have not yet been embraced completely by the fishery management community. In some cases, this situation arises from the difficulties in validating these models and in other cases, because of the lack of sufficient data and knowledge of the critical processes to develop an appropriate model. Progress can be made, however, in providing ecosystem advice to managers while waiting for these approaches to mature. GLOBEC and GLOBEC-like research efforts are going on throughout the world, with increasing emphasis on habitat research, trophic interactions, and long-term monitoring of non-commercial species to provide useful information on ecosystem status and trends. Some of this ecological information can be used to gauge the success of various management schemes that have been put in place to meet ecosystem management goals.

The *Ecosystem Considerations* appendix is a compilation and synthesis of ecosystem status and trend information for the eastern Bering Sea, Aleutian Islands, and Gulf of Alaska shelf/slope ecosystems. The most recent version of this report and associated data can be found on the web at: http://access.afsc.noaa.gov/reem/EcoWeb/index.cfm. It includes information on climate forcing and fishing, along with information on individual ecosystem components from nutrients to marine mammals and aggregate indicators of changes in ecosystem production and composition. The status and trend information is organized taxonomically by region. The assessment section of the appendix links the status and trend information to objectives for an ecosystem approach to management. As multi-species and ecosystem models are validated, they will be used to assess the possible future ecosystem status under varying scenarios of climate and human interactions. Details of the genesis of the report and the framework for the indicator report are included in Livingston *et al.* (2005).

Reference

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PICES report on *Marine Ecosystems of the North Pacific*: Towards ecosystem reporting for the North Pacific basin

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In 2004, the North Pacific Marine Science Organization (PICES) published its first report on the marine ecosystems of the North Pacific, which had been in preparation since 2002 (PICES, 2004). The objectives of the report were to:

1. describe the present state of marine ecosystems of the North Pacific Ocean (Status), in the context of their recent (past 5 years) and longer variability;
2. summarise assessments of conditions in the various marine ecosystems and regions of the North Pacific into a broad basin-wide synthesis;
3. identify critical factors causing changes in these ecosystems; and
4. identify key questions and critical data gaps inhibiting understanding of these marine ecosystems.

An important point to note is that the report was not explicitly designed to provide advice for ecosystem-based management, and no explicit management objectives were identified in the report. The report was built around individual chapters on specific themes and geographic regions:

- Large-scale ocean and climate indices,
- Yellow and East China seas,
- Japan/East Sea,
- Okhotsk Sea,
- Oyashio/Kuroshio,
- Western Subarctic Gyre,
- Bering Sea,
- Gulf of Alaska,
- California Current,
- Gulf of California, and
- North Pacific Transition Zone.

It also included chapters on individual species of particular importance and for which international management agencies were responsible, such as Pacific halibut, tuna, and Pacific salmon. Each regional chapter addressed the same topics:

- background (setting),
- climate,
- hydrography,
- nutrients,
- plankton,
- phytoplankton (chlorophyll),
- zooplankton,
- fish/invertebrates,
- seabirds,
- marine mammals,
- issues,
- critical factors causing change.

The first chapter of the report used a thematic approach cutting across all regions. For example, it addressed large-scale atmospheric and ocean forcing of these ecosystems and, in particular, looked across all regions at subarctic coastal systems, central oceanic gyres, and temperate coastal and oceanic systems. In addition, the synthesis examined (briefly) the human pressures on the North Pacific, aquaculture, and other pan-Pacific issues.

The emphasis in each chapter was on the "most recent" data and information, *i.e.*, conditions over the past 5 years (if available), put into the context of the existing time series. The readership was assumed to be interested marine scientists, and possibly the interested public and non-governmental organizations. More work could be done for future releases to better identify and clarify the audience, which would make a more targeted product. For example, if the goal of future reports is to advise citizens and governments of Pacific Rim countries on the state of the ocean, then better development of synthetic indicators would be required.

In producing each chapter, information was drawn from existing ocean status reports (*e.g.*, Canada) and ecosystem summaries (*e.g.*, California Current, Bering Sea) whenever possible. Where such reports were not available, regional workshops were convened with local experts to present and synthesize recent information. This was the approach used for the Japan/East Sea (workshop held at Seoul National University, August 2002), the Okhotsk Sea (workshop held at TINRO Center, June 2003), and the Yellow and East China Seas (workshop held during the PICES Twelfth Annual Meeting in Seoul, Korea, October 2003). For some regions, individual "countries" were invited to convene local experts to develop the various chapter sections. This was the approach taken for the Eastern Subarctic Gyre (Alaska), the Oyashio/Kuroshio region and the Western Subarctic Gyre (Japan), and the Gulf of California (Mexico). For each of the species-specific chapters (tuna, Pacific halibut, and salmon) fishery organizations were responsible for their content.

Significant data gaps

This first report on North Pacific marine ecosystems was intended as a pilot project. As such, it was not expected to cover all topics in equal detail. Indeed, it is not possible to cover all topics in equal detail as such data do not exist for many topics. Regional coverage of some chapter components was uneven, in particular for chemical oceanography (especially nutrients), and benthos. It is not clear whether the absence of these issues in the report represents an actual lack of data or lack of awareness of data. Another notable omission was regional data on harmful algal blooms. An active Section of the PICES Marine Environmental Quality (MEQ) Committee is examining harmful algal blooms in the North Pacific; their participation in the next report would serve to greatly increase the information on this important topic. Future efforts to produce the PICES marine ecosystem report might make good progress at filling these data gaps by convening workshops of disciplinary experts from around the North Pacific to address specific topics, *e.g.*, nutrient data.

The report also contained several themes that were only weakly developed in the various chapters. These include:

- contaminants,
- inter-tidal / sub-tidal ecosystems,
- "human dimensions" (*e.g.*, fishing effort, *etc.*),
- large, basin-scale physical oceanography/ocean circulation (in particular with Argo data),
- development and presentation of common and synthetic "ecosystem indicators".

All chapters have some level of abundance and/or biomass measures for fish. Several chapters have some level of abundance and/or biomass information for highest and lowest trophic levels. However, only a few chapters (*e.g.*, the eastern Bering Sea and Gulf of Alaska) include synthetic information, such as information on species diversity and recruitment.

Eastern Bering Sea chapter highlights

The report highlights the following recent general conditions in the eastern Bering Sea:

- Oceanographic and ecosystem dynamics are dominated by sea ice, and sea ice has been diminishing in recent years;
- There have been shifts in abundance of fish and invertebrates over past 20 years; groundfish populations appear to have stabilized, whereas some crab stocks remain at low levels;
- There are concerns about declines of western Steller sea lion and northern fur seal and North Pacific Right whale populations;
- Significant issues include sea ice and climate warming, unusual phyto- and zooplankton blooms, interactions of fishing with bottom habitats, marine mammal population declines and their unusual distributions.

Key messages

Key messages from the synthesis of these regional and species chapters include:

Climate

A new atmospheric pattern altered storm tracks across the North Pacific after 1998. This new climate pattern was associated with a change from warm to cool conditions from northern Vancouver Island to the Baja California Peninsula, and warming in the central Pacific, but had little effect in the northern Gulf of Alaska and Bering Sea which stayed warm or in the Okhotsk Sea which stayed cool. This pattern, named the Victoria Pattern, has subsequently changed again.

Ocean productivity

Blooms of various species of harmful phytoplankton are increasing around the North Pacific. Some species are detrimental to fish and shellfish mariculture operations, and some species have harmful effects on marine mammals as the toxins are passed up the food web. An unusual bloom of coccolithophorid phytoplankton occurred in the Bering Sea during equally unusual ocean conditions in the summer of 1997, which created milky-coloured water visible from space. Jellyfish blooms have appeared and disappeared in Asian waters and Bering Sea without satisfactory explanations. Large changes in the mix of subarctic and temperate zooplankton species have occurred in the eastern North Pacific.

Living marine resources

There have been significant successes in maintaining productive fish stocks through a combination of active and conservative management. Total Pacific salmon catches were at historical high levels through the 1990s, supported by large releases of chum and pink salmon from hatcheries on both sides of the Pacific, and wild sockeye salmon. Walleye pollock abundance in the eastern Bering Sea has been relatively stable while elsewhere in the North Pacific, its abundance has been declining. The total biomass of Pacific halibut has remained high in the Gulf of Alaska throughout the 1990s as a result of several years of good recruitment.

Some species/stocks, however, have not fared so well. Rockfishes in the California Current System, walleye pollock in the Okhotsk Sea, and hairtail in the Yellow Sea are heavily or overexploited. Many individual salmon populations, especially of coho and chinook, declined dramatically during the 1990s in the southern part of their North American range, but there have been encouraging signs of recovery since 1999. Small pelagic fishes, which naturally undergo very large changes in abundance, have also undergone fluctuations in recent times. Pacific sardine abundances were very high in the late 1980s throughout the entire North Pacific, except in California, but declined abruptly in the early 1990s and have generally remained low since then. This synchrony suggests an important role of a large-scale force such as climate in determining abundance. In the California Current System, sardines remained low in the 1980s but began recovering in the late 1990s. The western populations of Steller sea lions are currently at very low abundances. Despite new conservation measures (and increased research), large-scale recovery has not yet occurred. Mass mortalities of marine mammals (pinnipeds) have occurred over the past decade in the Gulf of California and off the State of California, due to unusual harmful algal blooms. Intensive mariculture is increasing dramatically around the North Pacific rim and is well-established in the southwestern North Pacific.

Future plans for the marine ecosystem report

PICES convened a workshop at its 2005 Annual Meeting (PICES XIV) to review the successes and shortcomings of the first (pilot) report and to decide how future reports should look. Discussion focused on several key topics or questions:

- What should the report contain?
- Who is the intended audience?
- How often should it be "published"?
- What form should it take?
- Who would be responsible for preparing it?

Those attending emphasized the need for timely information and suggested that the product, audience, and format might be best addressed in future iterations if a staggered or nested approach was used, whereby some (easy to obtain) information would be readily available on an annual basis, while some of the more synthetic information and analyses would be available less frequently. The group also discussed the need to make some products specifically for policy makers from the PICES member countries. The group settled on the following approach (Table 5), whereby some of the time series were made available to users on an annual basis via the worldwide web. Syntheses and interpretations (similar to the first North Pacific Ecosystem Status report) would be published on the web and in hardcopy less frequently (say every 3 to 5 years) and longer range outlooks for policy makers might be published once every 5 to 10 years or more frequently if there were emerging issues that warranted concern or special attention.

Table 5 Proposed system of future PICES North Pacific Ecosystem Status report products, audience, and which group within PICES should be responsible for their preparation.

Product	Audience	Period	Form	Who
time series	• scientists, • public	annual	web	?
syntheses/interpretations of ecosystem status	• scientists, • public, • policy makers	3–5 years	web and hardcopy	Working Group
outlooks	• policy makers	5–10 years	brochure	Study Group

Main conclusions

- The PICES North Pacific Ecosystem Status report (2004) was a highly successful pilot project, and it will evolve with the next iteration. Discussions have begun to define its audience more clearly, *e.g.*, decision makers and general public, or ocean management specialists and scientists, and to consider best formats to present the varying types of information contained in the first report;
- The process to define significant data gaps has also begun. What are the gaps and what is the best way to fill them? Should PICES conduct its own analyses and develop indicators? Which indicators would it use? Should it connect with PICES/NPRB Indicators workshop conclusions?
- PICES workshops continue to address the significant information and understanding that can be gained by using large-scale, basin-wide comparisons. To do these comparisons of large marine ecosystems (LMEs) we must consider developing indices based on selected species/functional species groups or key features which are shared or common across LMEs.

In developing ecosystem indicators, in particular for the eastern Bering Sea and coastal Gulf of Alaska, the experience of the PICES report on *Marine ecosystems of the North Pacific* demonstrates the value of a comparative approach in which (at least) key indicators and key species are compared across a geographic area wider than just the target region.

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INDICATOR USAGE IN OTHER REGIONS AND SUGGESTIONS FOR THE NORTH PACIFIC/BERING SEA

SCOR/IOC Working Group 119 on Quantitative ecosystem indicators for fisheries management

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Working Group 119 on Quantitative ecosystem indicators for fisheries management was established in 2001, with 32 members from 19 countries. The working group, co-chaired by Drs. Philippe Cury and Villy Christensen, was designed to support the scientific aspects of using indicators for an ecosystem approach to fisheries, to review existing knowledge in the field, to demonstrate the utility and perspectives for new indicators reflecting the exploitation and state of marine ecosystems, as well as to consider frameworks for their implementation.

The Working Group met first in October 2001, in Reykjavik, Iceland, to plan and report on progress; and then in December 2002, in Cape Town, South Africa, to organize its efforts with a series of task forces working in parallel on:

- environmental indicators including habitat changes,
- species-based indicators,
- size-based indicators,
- trophodynamic indicators,
- integrated indicators,
- selection criteria,
- data sets and reviews, and
- frameworks for implementing indicators.

As part of their work, the task forces reviewed the current status of using indicators for ecosystem approaches to fisheries, as well as seeking to develop new theory, applying it, and evaluating the performance of indicators. The major results of these endeavours formed the core of the presentations at an international symposium held at the UNESCO headquarters in Paris, in April 2004. The symposium received wide interest with more than 200 abstracts submitted for presentation, and 160 of these presented.

The symposium was organized with two major themes. Theme 1 discussed how indicators synthesize the structure and functioning of ecosystems in time and space, and, in turn, how fisheries influence them. It considered how the indicators have been, or should be, applied to different types of ecosystems or fisheries exploitation, and covered the following topics:

- Environmental indicators that quantify climate change or environmental variability and their ecosystem effects (*e.g.*, regime shifts) as well as the quantification of habitat modification induced by fisheries;
- Ecological indicators that characterize the functioning and the dynamics of marine-exploited ecosystems on the basis of species composition, size distribution, and trophodynamics;
- Fisheries indicators that quantify the impact of fishing on exploited and unexploited components of ecosystems. The session presentations outlined a vast array of well-defined indicators for fisheries management, described their properties, evaluated how they can be used at an ecosystem level to describe the impact of fisheries, and also evaluated the relative contribution of environmental and fisheries impacts. Given the number of available, applied indicators, it is also clear that emphasis must be given to methodologies for selecting indicators and evaluating how capable they are of detecting trends in a noisy environment.

Theme 2 addressed the evaluation, implementation, communication, and use of indicators. Quantitative indicators of ecosystem status have many uses, and ecosystems have many properties that are critical to conservation and management. As a consequence, a large number of indicators have already become available within a relatively short time. Evaluating indicators relative to management objectives needs to be achieved by defining appropriate criteria. Several contributions presented methodologies for evaluating and comparing various indicators, as well as methods for elaborating and constructing data sets for evaluation of indicators.

To implement an operational ecosystem approach to fisheries, selected indicators have to be assembled into frameworks within which they can be aggregated and combined. Institutional frameworks may include indicators of the exploitation and state of ecosystems, and indicators relating to social and economic aspects. Contributions showed how such frameworks can facilitate indicator development and implementation. Studies of trade-offs between frameworks that tend to make incremental improvements to conventional methods *versus* the more difficult design and implementation of completely new approaches for aggregating indicators were also debated. Communicating the relevance of indicators among stakeholders is an important aspect of their usefulness, and means for achieving this were addressed. Contributions reviewed how indicators can be communicated efficiently in practical situations. These reviews include aspects of decision-making, and of how ecosystem indicators are currently, or may be, used.

Recognizing that communication is an important aspect of scientific work, the symposium was organized with only plenary sessions for oral presentations, and with ample time set aside for poster sessions. Approximately three-quarters of the 160 symposium presentations were displayed as posters, indicating the important role posters play in international symposia.

Some of the findings from the symposium are listed below:

- Defining, selecting, evaluating, and implementing indicators is an achievable task given present knowledge, available data, and existing frameworks;
- Environmental and low trophic-level indicators (*e.g.*, for plankton) capture environmental change and bottom-up effects in a spatially explicit manner. However, the global effect of environmental change on higher trophic levels in the foodweb is not well captured by most indicators (*e.g.*, regime shifts);
- Top predators or high-trophic-level indicators (*e.g.*, birds and marine mammals) summarize changes in the fish communities which are most often (but not always) related to exploitation. Top-down effects, such as trophic cascades, that occur in several ecosystems can be quantified using trophodynamic indicators;
- Several trophodynamic indicators are needed to measure the strength of the interactions between the different living components, and of structural ecosystem change resulting from exploitation. Those indicators are sometimes sensitive to the choice of trophic level made for certain species;
- Size-based indicators have received considerable scientific attention and are perceived as promising for characterizing fish community dynamics in a context of overexploitation;
- An ecosystem approach to fisheries (EAF) requires integration of the spatial dynamics of the various components (including fishers). It also requires quantification of the interactions between different components of the ecosystem. Spatial indicators are currently developed in many ecosystems and are key to understanding the interaction between the different components of the ecosystem and human activities;
- No single indicator (or single ecosystem model) describes all aspects of ecosystem dynamics; we need a suite of indicators (covering different data, groups, and processes), because indicator performance may differ (with ecosystem, history of exploitation, and other pressures, *e.g.*, pollution);
- Aggregated indicators can provide a quick evaluation of the state of marine ecosystems; they should be used simultaneously with a suite of indicators to understand the mechanisms and processes that are acting;
- Ecosystem-based indicators are conservative in the sense that they only show if the ecosystem is strongly affected, so trends and rapid changes must be acknowledged in, and evaluated by, management, even if reference points are lacking;

- Interpretation of indicators requires scientific expertise because of potential, often subtle, error and bias in their analysis;
- Considering both target reference points (TRP) and limit reference points (LRP) in the same framework or model represents a promising way to reconcile constraints and objectives when exploiting natural resources. This may be a promising way also to reconcile the principles of conservation and exploitation;
- Several indicators are better used for surveillance than for prediction. Regime shifts, a feature often associated with the North Pacific Ocean, illustrates a situation where surveillance indicators may be useful;
- In an EAF, the objective is not to find the best indicator, but rather a relevant suite of indicators with known properties; developing methodologies for selecting indicators forms an integral part of the process. Guidelines for how to test indicators and develop frameworks for their application are essential;
- Analysis of single-species *versus* ecosystem harvest strategies shows that we need to provide explicit protection for those species whose value derives, in part, from support of other species as well as from harvesting. Harvesting all species at their single-species maximum sustainable yield may lead to ecosystem erosion;
- Reinforce (or start) the process of implementing ecosystem-based indicators (TRP and LRP) and a framework for fisheries worldwide. Pragmatic approaches need to be taken to move towards an EAF. This may be viewed as a stepwise process that needs to integrate scientific results (data, models, and indicators) and management expertise in a spatially explicit manner;
- A strong feedback between scientific expertise and management is necessary to ameliorate indicators and their practical use. The conclusion of the symposium as expressed through a closing panel discussion is clear: with regard to ecosystem indicators, the science that is needed to make an ecosystem approach to fisheries operational is in place.

The proceedings from the Paris symposium is published as a special issue of the *ICES Journal of Marine Science* **62**(4), and it was published within a year of the symposium, thanks not the least to the dedicated effort of the guest editor, Professor Niels Daan.

Eastern Canada – Ecosystem approach to fisheries in DFO Maritimes Region

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Prompted by proclamation of Canada's Ocean Act in 1997, the Department of Fisheries and Oceans (DFO) initiated a pilot project on the Eastern Scotian Shelf as a "laboratory" to test implementation approaches for integrated management (IM). Since its inception, the Eastern Scotian Shelf Integrated Management (ESSIM) project has explored both governance frameworks (Rutherford *et al.*, 2005) and the development of conceptual and operational ecosystem objectives. ESSIM evolved before national policy and guidelines were available; now ESSIM is retracing some of its steps to be compliant with these. In addition, since 2004, collaboration with the U.S. National Marine Fisheries Service (NMFS) is leading to another IM experiment in the Gulf of Maine area (GOMA).

The boundaries of the ESSIM area illustrate some of the pragmatic decisions being made. While the desire is for ESSIM to encompass the inshore zone, given the governance complexities in this area, efforts have so far been restricted to the offshore. In addition, with the dialogue on an ecosystem approach to fisheries (EAF) in the Gulf of Maine, there has been recent discussion on the possibility of moving the current western boundary farther south. While it might be a better reflection of administrative jurisdiction, it would not be as optimal as the current one for reflecting shelf-wide ecosystem differences (DFO, 2004a).

The ESSIM planning hierarchy (overarching ecosystem objectives, conceptual and operational objectives, and ocean sector operational objectives) is not dissimilar from that used elsewhere (*e.g.*, Australia). The overarching ecosystem objectives were developed in 2001 as national policy. The planning area conceptual objectives, released in draft form in fall 2005, were based upon conservation issues, impacted ecosystem components, and threats identified with the input of stakeholders (O'Boyle *et al.*, 2005; O'Boyle and Jamieson, 2006). These will be updated once ecologically and biologically significant species and areas, and depleted species and areas have been identified (DFO, 2004b). Thus far, a formal risk analysis is not part of the process to determine priority issues and objectives, which is seen as a requirement.

A science working group had developed a work plan to associate indicators and reference points/directions with the ESSIM draft objectives but this has been put on hold until the latter are updated. At the same time, another science group had been collaborating with NMFS on the monitoring requirements of an EAF in the Gulf of Maine, relying on earlier ESSIM work. An opportunity was thus afforded to compare and contrast progress to date in ESSIM and GOMA, engage and educate DFO staff on EAF, and develop a generic set of operational objectives that could be discussed with the fisheries sector (DFO, 2005). These generic objectives highlight not only the need to keep fishing mortality at a moderate level, but also to control incidental mortality and impacts on the benthic habitat. The latter is an issue across a number of ocean industries and has been the focus of a three-phase program led by DFO science to classify the benthic communities of the Scotian Shelf and to manage human impacts. The draft suite of operational objectives has received the support of the fishing industry, and regional fisheries management plans are being evaluated to see how they comply with these objectives. A number of the objectives have been completed for Georges Bank (groundfish, herring, scallop, lobster and crab), which highlight the need to address discarding and benthic impacts of fishing in these plans.

In addition to the identification of management performance indicators, over 60 contextual indicators, although not associated directly with management actions, have been useful in furthering understanding of ecosystem processes and detecting regimes shifts. The latter are related to overall system productivity and thus influence the population-specific performance indicator reference points. In 2003, the first Ecosystem Status Report for the Eastern Scotian Shelf (DFO, 2003) described a shift in this ecosystem from predominantly groundfish in the 1970s–80s to predominantly pelagics and invertebrates in the 1990–2000s. Three hypotheses were suggested to explain this shift: (1) top-down control, (2) increased stratification, and (3) cooling – although it was not possible to determine which of these was most plausible. An ecosystem status report is being considered for GOMA, which would take into consideration the ecosystem objectives that are being discussed for this ecosystem.

The linkage between regime shifts and reference points is illustrated by changes in the performance indicator reference points of the 4TVW haddock fishery (DFO, 2002) which are associated with bottom water temperature fluctuations. The suite of operational objectives and contextual objectives at the planning area level could form the basis of future reports of ecosystem health.

Lessons for the PICES/NPRB Indicators workshop

- There is a need to develop a common understanding of the high-level ecosystem objectives for the Bering Sea amongst the various institutions with responsibilities and interests in the area;
- There is a need to develop a suite of contextual objectives that report on ecosystem processes and which could be used to inform the performance indicator reference points;
- It will be useful to keep the PICES North Pacific Ecosystem Status report rather general in its approach but to consider ecosystem objectives in its structure to increase its utility in a management context;
- Rather than striving for a small subset of indicators, as understanding is limited, the suite of indicators should be maintained, perhaps emphasising which indicators are most pertinent to monitoring ecosystem change.

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Most ecological indicators are invoked in a broader, more holistic ecosystem-based fisheries management (EBFM) context. Although there are several indicator taxonomies or frameworks, there are some common approaches and properties to consider when selecting which ones to use. Our empirical and simple modeling results generally concur with model results from elsewhere in the world. Most ecological indicators in an EBFM context typically include some metrics associated with:

- size,
- production,
- diversity,
- “canary” species,
- energy flow – trophodynamics,
- habitat,
- physio-chemical regime.

Socio-economic and management performance/ response indicators also merit consideration. Many of the data needed to develop these indicators are extant; producing the indicators often requires a new perspective on data mining. Once a set of indicators has been identified and culled, there are three main ways that we and others tend to present them: traffic lights, surfaces or polar coordinates, and multivariate components.

Linking indicators to decision criteria remains a key challenge. We have studied two main approaches to this end. First, we explored multivariate approaches to identify reference directions, surfaces, poles, quadrats, *etc.* (*i.e.*, regions) that provide a strategic, bounding (of what is scientifically possible) of potential ecosystem states. This approach is helping us to define aggregate or systemic regions of desirability (or non-desirability). The second approach seeks to develop ecosystem or aggregate reference points that are more tactical (*i.e.*, binding) in nature, analogous to many of the traditional fishery or toxicological reference points. Additional research is needed to establish relationships between these indicators and their major drivers, particularly fishing pressure in an EBFM context.

The use of indicators has been varied in our region, much like in the rest of the world. Currently indicators are used primarily to elucidate ecosystem status, effectively serving as a heuristic tool to reveal key ecosystem processes and patterns. The emphasis on status is common, needed, and should not be overlooked; we can now feasibly assess the status of marine ecosystems, in an integrated and holistic manner in ways that previously were never done. Even providing this material as contextual background for EBFM is useful from many perspectives. Although still in development, we are exploring the strategic use of indicators to set feasibility bounds on various ecosystem configurations. Like elsewhere in the world, the tactical use of indicators remains a longer-term prospect, but there have been some instances when ecological indicators have been used in this manner to affect change in how we manage living marine resources.

We note, positively, that status indicators exist, management indicators exist, and ecosystem reference points/regions exist. But we are cautious to note that ecological indicators do not equate to reference points, and reference points do not equal control rules; *i.e.*, one needs to be judicious in the use of indicators. Given this concern, we are optimistic that ecological indicators can be quite useful for further development of EBFM approaches. Finally, continuing to develop indicators for EBFM use also highlights the continued commitment necessary for the underlying monitoring and modeling efforts that provide information requisite to producing these indicators.

STATUS OF THE BERING SEA

Ecosystem Considerations for 2006 in fishery management – Upper trophic level and aggregate indicators for the status of the southeastern Bering Sea

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Ecosystem Considerations for 2006 is an appendix of the Stock Assessment and Fishery Evaluations (SAFE) report, produced annually by the Alaska Fishery Science Center (AFSC) for the North Pacific Fishery Management Council (NPFMC). The appendix includes three sections: (1) an ecosystem assessment, (2) updated status and trend indices, and (3) ecosystem-based management indices and information for the Bering Sea (BS), Aleutian Islands (AI) and the Gulf of Alaska (GOA) ecosystems.

The purpose of the first section, Ecosystem Assessment, is to summarize historical climate and fishing effects from an ecosystem perspective and to provide an assessment of the possible future effects of climate and fishing on ecosystem structure and function. The purpose of the second section, Ecosystem Status Indicators, is to supply new information and updates on the status and trends of ecosystem components to stock assessment scientists, fishery managers, and the public. The goals are to give stronger links between ecosystem research and fishery management, and to spur new understanding of the connections between ecosystem components by bringing together many diverse research efforts into one document. The purpose of the third section, Ecosystem-based Management Indices and Information, is to provide either early signals of direct human effects on ecosystem components that might warrant management intervention, or to provide evidence of the efficacy of previous management actions.

Previous ecosystem analyses for the draft groundfish Fishery Management Plan environmental impact statements categorized effects into three main classes: predator–prey, energy flow and removal, and diversity. The Ecosystem Assessment section of the *Ecosystem Considerations* appendix adapts these as the three main objectives for ecosystem protection. Livingston *et al.* (2005) outline several topics within each of these objectives (Table 6). Several indices were chosen from the second and third sections of the appendix to address these objectives and topics. Trends in upper trophic level species/groups and aggregate indicators for the Bering Sea were reviewed.

No significant adverse impacts of fishing on the ecosystem relating to predator–prey interactions, energy flow/removal, or diversity were noted. There are gaps in understanding the system-level impacts of fishing and spatial/temporal effects of fishing on community structure and prey availability. Fishing mortalities from a multispecies bycatch model can be used to drive multispecies and ecosystem predator–prey simulations to evaluate the predator–prey implications of these fishing strategies. Predictions from multispecies models will be incorporated into the ecosystem assessment in future drafts when bycatch data can be updated and when some methodological problems are solved. Validation of models, research and models focused on understanding spatial processes, and improvements in monitoring systems would further our current understanding. Until more accurate predictions of climate status and effects can be made, a range of possible climate scenarios and plausible effects on recruitment should be entertained.

Reference

Livingston, P.A., Aydin, K., Boldt, J., Ianelli, J. and Jurado-Molina, J. 2005. A framework for ecosystem impacts assessment using an indicator approach. *ICES J. Mar. Sci.* **62**: 592–597.

Table 6 Significance thresholds for fishery induced effects on ecosystem attributes.

Issue	Effect	Significance Threshold	Indicator
Predator–prey relationships	Pelagic forage availability	Fishery induced changes outside the natural level of abundance or variability for a prey species relative to predator demands	• Population trends in pelagic forage biomass (quantitative - pollock, Atka mackerel, catch/bycatch trends of forage species, squid and herring)
	Spatial and temporal concentration of fishery impact on forage	Fishery concentration levels high enough to impair the long term viability of ecologically important, non-resource species such as marine mammals and birds	• Degree of spatial/temporal concentration of fishery on pollock, Atka mackerel, herring, squid and forage species (qualitative)
	Removal of top predators	Catch levels high enough to cause the biomass of one or more top level predator species to fall below minimum biologically acceptable limits	• Trophic level of the catch, • Sensitive top predator bycatch levels (quantitative: sharks, birds; qualitative: pinnipeds), • Population status of top predator species (whales, pinnipeds, seabirds) relative to minimum biologically acceptable limits
	Introduction of non-native species	Fishery vessel ballast water and hull fouling organism exchange levels high enough to cause viable introduction of one or more non-native species, invasive species	• Total catch levels
Energy flow and balance	Energy re-direction	Long-term changes in system biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery discarding and offal production practices	• Trends in discard and offal production levels (quantitative for discards), • Scavenger population trends relative to discard and offal production levels (qualitative), • Bottom gear effort (qualitative measure of unobserved gear mortality particularly on bottom organisms)
	Energy removal	Long-term changes in system-level biomass, respiration, production or energy cycling that are outside the range of natural variability due to fishery removals of energy	• Trends in total retained catch levels (quantitative)
Diversity	Species diversity	Catch removals high enough to cause the biomass of one or more species (target, nontarget) to fall below or to be kept from recovering from levels below minimum biologically acceptable limits	• Population levels of target, nontarget species relative to MSST or ESA listing thresholds, linked to fishing removals (qualitative), • Bycatch amounts of sensitive (low potential population turnover rates) species that lack population estimates (quantitative: sharks, birds, HAPC biota), • Number of ESA listed marine species, • Area closures

Table 6 Continued

Issue	Effect	Significance Threshold	Indicator
Diversity	Functional (trophic, structural habitat) diversity	Catch removals high enough to cause a change in functional diversity outside the range of natural variability observed for the system	• Guild diversity or size diversity changes linked to fishing removals (qualitative), • Bottom gear effort (measure of benthic guild disturbance) • HAPC biota bycatch
	Genetic diversity	Catch removals high enough to cause a loss or change in one or more genetic components of a stock that would cause the stock biomass to fall below minimum biologically acceptable limits	• Degree of fishing on spawning aggregations or larger fish (qualitative), • Older age group abundances of target groundfish stocks

MSST = minimum stock size thresholds; ESA = Endangered Species Act; HAPC = habitat of particular concern

PERSPECTIVES ON INDICATORS

Perspective on ecological indicators

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The North Pacific Research Board issued a call for indicator science, and we are reminded that this will have to be solid science, because when it is used to make management decisions, the issues will be contentious. This is to say that the science needs to be solid enough to stand up in court.

The presentations these past days have painted a bewildering picture of the state of indicator science for the Bering Sea, because the Stock Assessment and Fishery Evaluation (SAFE) document reports 100+ indicators without a clear enough representation of which indicate what, how they are used, or how they could be used.

In fact, this list of 100+ indicators includes several different kinds of quantities, which complicates the message that they convey. What we have at the moment should be sorted so that we can categorize them in a way that clarifies what each is, what it does, and why we think it is worth measuring and reporting. This sidesteps, at least for the moment, the prescriptive definition of "what is an indicator" and instead, asks for a descriptive taxonomy of "what are the kinds of things that are in the present list of indictors in the SAFE document."

This way, rather than ask for a cosmic definition of a "good indicator," we can consider for each distinct kind of thing we are calling an indicator, what would constitute a good one within that class. This might serve as a basis for ranking priorities both for investment and for emphasis in communication. What might be grounds for dropping an indicator from the *Ecosystem Considerations* appendix of the SAFE report? What might be grounds for stopping monitoring one of those indicators?

The indicators reported in the SAFE report, as a set, are just time series of variables that have been measured. There seem to be three main kinds of measures:

1. direct measures of system state,
2. summaries of measures of system state,
3. surrogate measures of system state.

Examples of direct measures of system state might be chlorophyll, or ice, possibly measured at a defined set of locations, possibly reported as a spatial average. We think that these are informative in their own right.

Examples of summaries of measures of system state might be PDO or trophic level biomass ratios. Note that the summaries do not relieve the need for the underlying measurement. Mathematically, PDO is a linear combination of sea surface temperatures over a spatial field. We may believe scientifically that this is a very revealing way to describe climate state. But we still need to measure sea surface temperatures in order to calculate PDO. Fortunately there are lots of other reasons for measuring sea surface temperature, and it is now routinely done by means of remote sensors, so the marginal cost of obtaining a measurement of PDO is very small.

Surrogate measures are proxies for things that are too expensive to measure directly on a routine basis, but hopefully the proxy is well enough correlated with the object of our actual interest. For example, sea bird reproduction may correlate well with zooplankton production within a known radius of their rookery, and may be simpler to monitor than the zooplankton production itself.

The index of biotic integrity, used extensively in surveys for freshwater systems, is another example of a surrogate measure. The procedure for development and validation of this index is well documented. A set of reference sites ranging from degraded to pristine, within a defined habitat type and geographic region, are selected and sampled; easily identifiable biota are counted across that gradient; statistical operations identify a surrogate index, based on easy sampling of recognizable biota, that is correlated with the degree of degradation of the site. Once this calibration has been done, the index based on easy sampling can replace the possibly more difficult direct measurement of environmental stress at new sites that were not involved in the calibration. Different habitat types and geographic regions, of course, harbor different biota regardless, so for each habitat type and geographic region a distinct index of biotic integrity must be developed and calibrated.

What must we ask about these measures that we are calling indicators? The first question, as with any environmental measure is how well it is measured. There is often a serious amount of measurement error in the technology of measurement itself. Sampling error often is even more serious since, as a practical matter, the measurements may be made at a very limited number of times and places, yet the result may be taken to represent a field that is known to be very heterogeneous and which is known to exhibit large temporal variation.

When developing a surrogate index, another important issue arises. The surrogate is not credible as an index without documentation of the degree of correspondence with ground truth. A proposed index for which a ground truth is unmeasured or unmeasurable is not subject to validation. A surrogate for which a ground truth is not operationally defined as a measurable should be a non-starter. Note that ecosystem health is a metaphor, not a measurable.

The possible reasons for reporting an indicator are fourfold. The indicator may serve to quantify:

- utility,
- attainment,
- normalcy,
- forecast.

An example of an indicator that directly represents a measure of utility would be fisheries yield. Our interest in this is self-explanatory. The importance of an indicator with this motivation depends on the value of the utility that it measures.

An indicator of attainment is a measure of a quantity for which a management reference point has already been agreed upon. In one sense the importance of an indicator with this motivation is a social construct – it is as important as the agreement that is behind it. But if the agreement rested on a belief about ecological consequences (such as the amount of escapement necessary for maintenance of higher trophic levels, as in the international Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) agreement for managing fisheries in the Antarctic), the stability of the agreement may change with changes in scientific knowledge about the connection to consequences.

The interest in indicators of "normalcy" is based on the expectation that the system is unlikely to confront us with unwelcome surprises as long as the system is operating within known historic bounds. Thus the indicators of normalcy may be measures of state or rate or correlation for properties that we believe to be significant to system function, and for which we have a long enough historic record to have convincingly identified normal bounds.

The reasons for interest in a reliable forecast will depend on the quantity that is being predicted. It may be a description of system state, where the interest in the prediction is scientific. The quantity predicted may be of interest because it directly constitutes utility in its own right, as in forecasts of fishery yield, or the quantity being predicted may have broad ramifications, such as predictions of regime change or ecosystem upheaval.

Note that the claim for any of these reasons for interest in an indicator may merit a second look. If the claim is utility, is there wide acceptance that this is a measure of value? If the claim is attainment, is there an actual governing policy, and are the reasons for that policy sound? If the claim is normalcy, what are the defining boundaries for the normal envelope, and what is the empirical evidence for these boundaries? If the claim is forecast, what is the statistical confidence in the forecast, and what is the empirical basis underlying the calculation of confidence?

The preceding taxonomy of indicators suggests a descriptive definition of ecosystem indicators. An ecosystem indicator is something we can measure that in turn serves as a measure, an estimate, or a prediction of something we care about. In every case there is room to ask hard questions about how well we measure, how accurately we estimate, how reliably we predict, and why we care. It would be helpful if the 100+ indicators in the SAFE report were catalogued in this way, with an examination of the hard questions, and documentation of the available answers.

It may emerge that some of the hard questions cannot be answered very well for some subset of the indicators. In particular, it is imaginable that documentation for performance for some of the surrogates and predictors may be thin. If so, it is important to recognize that interest in these is speculative, so each must be treated as a scientific hypothesis which carries a scientific responsibility to test the hypothesis. Therefore, for any indicator which does not convincingly pass the first layer of hard questions, there should be a second layer of hard questions about how the hypothesis is being tested, what is the design of that test, and how ongoing measurements, monitoring both the indicator and the ground truth, will eventually resolve the hypothesis.

Comments on the SAFE *Ecosystem Considerations* appendix and the PICES North Pacific Ecosystem Status report, and review of Day 1

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My comments arise from reading the SAFE *Ecosystem Considerations* appendix and the PICES North Pacific Ecosystem Status report, all the background papers, listening to the first day's presentations, and to the discussions that took place between the presentations. These are placed within the context of my experience in several other domestic (Canada) and international (ICES, EU, FAO, *etc.*) fora. My comments are structured as follows. First, I looked at the overall messages from the reports. Then I tried to assess what was missing, present but vague, or present but requiring greater discussion. Finally, I provide my own ideas of useful ways ahead.

My first observation is that you are in pretty good shape. A considerable amount of effort has been spent on objectives where there is an appreciation of the need for specificity, noting that objectives are converging from many sources. There is recognition of the need for socio-economic objectives and their differences from ecological objectives, on matching indicators to objectives, acknowledging two modes of use, and especially, there is no indication that the region is in desperation mode.

Both of the major ecosystem reports are very good, but I note that their different audiences are matched by their different content. Both reports have enough detail to allow users with preconceptions to guide the selection of the content. My suggestion for improvement is to avoid including details in the report that a reader/user of the report will not want. You should aim for a guidebook rather than an encyclopaedia and try to motivate and guide readers. Finally, make the big messages clearer.

Features that were either missing or under-represented in the papers and talks include the following:

- The DPSIR (Driver, Pressure, State, Impact, Response) structure has proven useful for organizing dialogue and in reducing numbers of indicators, and for matching indicators to their use in the overall processes.
- There was an overall absence of a risk management framework in the papers. The Fulton presentation has demonstrated one way for making progress on this topic. There is a need to focus more on displaying uncertainty. Of the suites of indicators, spatial content was missing everywhere, and I noted that size-based indicators are under-represented relative to their performance elsewhere (especially ICES).
- There does not appear to be a formal indicator selection process.

Several facets of the indicator issue were present but vague.

- There was no discussion of how to test the performance of indicators during the selection process.
  - NOT the same for indictors used in AUDIT function and indicators used in CONTROL function
  - AUDIT – Targets primary, limits secondary
  - CONTROL – Limits primary, Targets secondary
  - METHODS EXIST FOR TESTNG BOTH

- Where do we get the reference points?
  - Differentiate Indicator (say, SSB) from Reference Points (Bmsy, B35%, *etc.*)
  - Reversibility of impact? Responsiveness to management at all?

- The “classic” three-stage model (discussed below) should have ONE (NOT two) biological (or socio-economic) fixed points and the rest is making uncertainty explicit.

There are several areas that could use more critical thinking. These include when and how to use absolute-scale indicators *versus* relative-scale indicators. The experience with IUCN decline criterion for marine species is a case in point. Should there be different reference points for different regimes? Perhaps for the population size, NO, but for the uses of populations, YES, especially if likelihood of prompt detection of regime change is low. If the “traffic light” style of presentation is preferred, then the biological calibration of the cut-points is a crucial research topic, as are strategies for dealing with redundancies among indicators, and weighting of indicators when providing support for decisions. There is a need to understand what to do with tough decisions and multiple indicators that might reflect opposing trends. An example of this is the EU experience using just B and F (biomass and fishing mortality). I note that U.S. legislation on over-fishing and over-fished will not transfer readily to ecosystem metrics.

I was stimulated to ask what other field of science works with indicators in a similar context? My experience in psychometric research has some similarities. The fundamental underlying processes are critically important but they are NOT accessible to direct measurement. Therefore, indirect indices have proliferated and they are flexible, and are easily adopted. In psychometrics, “normal” is not a fixed point on ANY scale, but is a general “neighbourhood” in the centriod of the multi-dimensional space of the indicators. Usage focuses not on how close an individual subject is to exact centre of the neighbour, but rather on whether an individual subject is deviant in some particular direction and if so, by how much and what might be done about it. In psychometrics, a lot hinges on decisions based on the indicators and the ability to abuse and/or misinterpret indices is relatively easy. Hence the field has developed quite explicit and detailed guidelines for their use.

An important step is the selection process when indicators are being used in their Control function. A process which I find particularly attractive is derived from signal detection theory and its application to Human Factors Research. It has a 70-year history with its first flowering during WWII. It requires reconstructions of historical time series of indicator values. Once this has been developed, the next step is to reconstruct what a history of good decisions would have been. If it is not possible to do this retrospectively, how can we support any decision-making into the future, based on these indicators. Four outcomes are possible in evaluating an indicator:

1. HIT (something should have been done and the indicator said DO IT),
2. TRUE NEGATIVE (no management response was needed and the indicator said *status quo* OK),
3. MISS (something should have been done but the indicator did not say action was needed),
4. FALSE ALARM (nothing needed to be done but the indicator called for management intervention).

The results of this exercise can be represented in a 2×2 table. A perfect indicator has no Misses or False Alarms. The approach explicitly acknowledges that the costs associated with Misses and False Alarms are not the same. The approach allows users to choose a decision point on an indicator (“reference point”) that minimizes the overall error rate or, controls the ratio of Misses and False Alarms that reflect their relative costs (*e.g.*, medical situations). In this way, it becomes easy to compare the performance of indicators.

Considering the Audit function in psychometrics, the diagnostics have a history of over a century of use. Many mistakes (and advocacy abuses) have occurred but many lessons were learned. The uses are numerous, from career aptitude testing, to assessing legal competency for actions, and diagnosing personality disorders. Their application has involved extensive validation testing and codification of professional standards.

The general approach is to have a large battery of “questions” (= “suites of indicators”) – Binet, MMPI, Rorschach, *etc*., then test a large populace with the battery of questions. In addition to a large number of subjects chosen at random from the general population, there is a special role for test sets, which involve individuals that are known with confidence to have specific disorders. The diagnostic tools are developed by determining a combination of weighted questions that group subjects known to share a specific pathology as distinct, while leaving most of the populace in a central cloud. To my knowledge, this approach has not been tried in ecology.

In the classic 3-stage mode (Fig. 18) for using indicators and reference points to guide decision-making, there is one fixed reference point. This is determined by some government responsibility – law or policy. The objective is typically to prevent any "serious or irreversible harm" (language of the Precautionary Approach from Agenda 21 of Rio). The best biological estimate of that property is determined (*e.g.*, in ICES it is Blim – damaged productivity). The next issue is estimate the current status relative to that point with some measure of uncertainty, so a buffer is needed (*e.g.*, Bpa). This is the point where the probability that true stock biomass may be at the limit exceeds 0.05. This framework allows the current value of an indicator to guide risk-averse management, and makes the whole system precautionary.

The issue of predictability requires us to consider various temporal scales of interest. It is also instructive to consider whether "scenario explorations" associated with climate change and with marine ecosystem dynamics have important differences. Climate change has no expectation of accuracy on timescales greater than 30 days or less than 30 years. Ecosystem dynamics, on the other hand, at lead times of 3 to 7 (10?) years provide some of the core decision support for management. The climate change decisions are long-term strategic, but the ecosystem dynamics decisions are medium-term and tactical.

In considering what to predict, it seems that one should not try to capture inter-annual flutter. It will be more important to know how the probability of an extreme event (good or bad) varies with natural or anthropogenic forcers, rather than try to predict minor deviations up or down from long-term average conditions Multi-factor non-parametric probability density estimation methods do show inflections in plot of P (extreme event) as f (specified forcers). The predictions should be easy to use and to interpret but they do require decisions about what is "extreme."

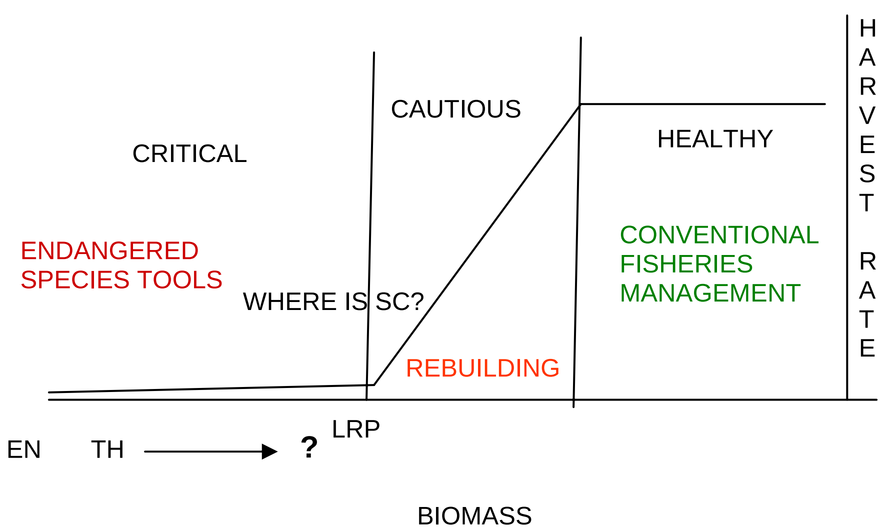

Fig. 18 The classic 3-stage model.

Ecosystem indicators have also been a priority for OSPAR (the Oslo–Paris Commission) to use in fulfilling their mandate for protection of environmental quality of the North East Atlantic. ICES was requested to advise on the suitability of different sorts of ecosystem indicators, and the Working Group on Ecosystem Effects of Fishing was asked to undertake the evaluation. Over a series of several meetings in the late 1990s and early 2000s, they developed screening criteria for ecosystem indicators, reviewed literature on marine ecosystem indicators, and tested both their criteria and a number of classes of indicators with some extensive data sets from the ICES area. Starting with a suite of more than 60 types of indicators, the ICES Working Group on Ecosystems (WGECO) found that the best alternatives included:

For the biodiversity/fish community

- slope of size-spectrum;
- mean length of fishes from a standardized survey;
- % of fish greater than some system-specific size in a standardized survey;
- bycatch rate of "particularly sensitive" species in observer data, where "particularly sensitive" is determined by rough estimates of "q" for the gear and an estimate of sustainable Z from life history parameters and
- survey-based abundance estimates;
- K-dominance (ABC) curves;
- frequency distribution of L_{max} in a standardized survey;
- species richness.

For trophodynamic processes/status

- No model-based indicators were found to perform well, and size-based indicators are better, even though they are surrogates for the processes.

For spatial integrity

- No suitable indicators were found.

Group discussion

James Overland: I have a hard time imagining applying the psychometric analogue to marine ecosystems. Where might we find a significant population of marine ecosystems? Do we need to compute a pdf of ecosystem responses?

Jake Rice: No one has tried to do this…it works in psychometrics.

Jason Link: The leads like a commercial for the comparative ecosystem session at the 2007 ICES Annual Science Conference that will try to pull all of the high latitude ecosystem comparisons together (Convenors: Ian Perry, Bernard Megrey, Jason Link).

Andrea Belgrano: How do they deal with the multi-dimensional issues that are so critical to the study of ecosystems, in psychometrics?

Rice: They would argue that human personality is a dimensionally complex problem.

Overland: I think that it relates to overfishing; our problem is shifted to looking at the shift in the system dynamics or response to climate, *etc.* which may eventually have a management implication but does not have one right now. Is there a different way that we should be thinking about things?

Rice: Indicators are used widely in environmental health reporting, *e.g.*, coastal pollution. There they ask, "What is the optimal way to use a community that has this common trait compared to one that does not?"

Francis Wiese: I like the idea of retrospective studies of indicators.

Rice: For regimes, you do not want to base decision making on insensitive indicators. The indicator needs to have a history.

DISCUSSION GROUP RESULTS

During the second day of the workshop, participants were divided into smaller groups to facilitate discussion. During the morning session, participants were randomly assigned to one of four discussion groups, and each group was asked to consider the same topic: objectives and indicators. There were no strict guidelines, allowing the discussion to be free to explore whatever issues that it deemed appropriate. During the afternoon, four aspects of the ecosystem indicators issue were discussed in three groups: (1) Matching objectives with indicators; (2) Methodologies to monitor ecosystem-wide structural change; (3) Communicating results. Participation in these groups was by personal preference. The following are short summaries of the discussions in each of these groups.

Convenors and discussion group leaders (clockwise from far left): Glen Jamieson, George Hunt Jr., Sarah Kruse, Gordon Kruse, Patricia Livingston, James Overland, Nathan Mantua, Franz Mueter, Ian Perry, Anne Hollowed, and Robert O'Boyle.

Objectives and use of indicators in the Bering Sea/North Pacific

GROUP 1: Robert O'Boyle (facilitator), Skip McKinnell (rapporteur), Franz Mueter, Sergei Rodionov, James Overland, Ian Perry, David Fluharty, Andrea Belgrano, Kerim Aydin, Jeffrey Napp, and Carl Schoch

To stimulate the discussion, the facilitator outlined issues that he thought might be useful to pursue. These were related to high level objectives, and to Bering Sea fishery objectives, both conceptual and operational. The latter of these includes indicators and reference points. He also highlighted the use of "contextual" indicators that could be used to monitor ecosystem state. The following is a summary of the discussion.

Issues

A number of overarching issues were identified by the group. The first was that, while the workshop terms of reference focused on an ecosystem approach to fisheries, there is a need to put this in the context of other human activities (*e.g.*, oil and gas exploration) through an overall ecosystem approach to management. This will require harmonization of the high-level objectives to ensure that all sectors are striving toward the same ends.

While there were fisheries management issues noted by the group (*e.g.*, abundance of Steller sea lions and crabs), in comparison with other jurisdictions (*e.g.*, Northwest Atlantic), fisheries management appears to be effective in regulating the effects of fishing. However, managers do not want surprises that might arise from productivity changes in the ecosystem. In a sense, the impact of the ecosystem on fisheries is the prime issue, not the other way around. Two ecosystem-level changes were mentioned – regime shifts involving ecosystem oscillation between "warm" and "cool" states and changes due to the regional effects of global climate change. Managers would like to know as much as possible about future ecosystem changes for planning. For instance, if the ecosystem was shifting from a primarily demersal-dominated to pelagic-dominated ecosystem, managers could initiate a review of pelagic fisheries management plans.

The state of the Bering Sea was felt to be quite different from that of the North Atlantic, where harvesting impacts on ecosystems have been, and continue to be, a concern. From this perspective, there is more utility in developing a suite of indicators that monitor broader ecosystem change than focusing on improvements to the current suite of fisheries performance indicators.

Objectives and indicators

The group considered that it would be useful to include a non-fisheries management objective in the determination of ecosystem state and the following objective was suggested:

"Determine the current state of the Bering Sea ecosystem to inform management decisions"

To achieve this objective, a suite of "contextual" indicators and reference points/directions would be needed to inform managers about the current state of the ecosystem and its probable future states. The contextual indicators typically require no immediate management action but they provide a context for the performance of indicators used in fisheries management.

The group considered this could be done through first developing conceptual model(s) of the Bering Sea ecosystem to summarize current understanding and hypotheses about the driving processes. Then, a suite of indicators would be chosen based upon this model(s) and would be used as an "ecosystem watch" by resource managers. It was considered essential to have an associated guidebook for PICES and NPFMC that would describe the background on the selection of the suite of indicators, describe the formulation of each indicator, and outline how the suite of them should be interpreted.

Regarding reporting, the group thought that formally separating the contextual and performance indicators in the *Ecosystem Considerations* appendix would facilitate demonstrating how each is used in management.

The group discussed how to improve the operational objectives, particularly focusing on the linkage between the contextual and performance indicators. This could be done by considering the influence of contextual indicators on the reference points/directions of particular operational objectives. Management decisions would then take this linkage into consideration.

The group ended by emphasizing the need for models that would be used in developing scenarios for managers which would describe potential ecosystem changes and modifications to management. A probabilistic-based, risk assessment approach will be a key element of this approach.

GROUP 2: Anne Hollowed (facilitator), Nicholas Bond, Clarence Pautzke, Bernard Megrey, Sarah Kruse, Gordon Kruse, Glen Jamieson, and Lisa Eisner

The group discussion began with a review of the objectives for monitoring ecosystem indicators. The group recommended adding an objective and modifying one objective:

- "*Assess ocean conditions and anthropogenic activities in an annual report on anomalies and their potential ecosystem impacts.*"
- Modify the statement on "*avoid seabird and marine mammal impacts*" to "*protect sensitive species*".

The first objective would link outcomes to indicators of the state of ocean conditions. The modification to the seabird and marine mammal objective would allow consideration of corals, and other species as well as assessment of status of sensitive species for reasons other than fishing impacts.

Objectives

The group identified the need to assess the overall goals and objectives for ecosystem management within national fisheries management authorities. In the United States, this would involve vetting the recommendations through the regional fisheries management councils. The group also pointed out that scientists are responsible for identifying unacceptable ecosystem properties. The group noted that, while defining "acceptable use" of the ecosystem is a social issue, the process would benefit from a description of the range of acceptable effects on the ecosystem. The group acknowledged that this step will be challenging for natural scientists because it will necessitate an examination of the accuracy of ecosystem forecasts. The accuracy of predictions will allow scientists to judge whether they are ready for use in defining acceptable levels of ecosystem impact. If ecosystem forecasts are reliable, social scientists would be able to present a better description of the expected societal outcomes. The group noted that defining acceptable social characteristics is difficult as well.

Recommendations for new research or monitoring

New funds are needed to collect and interpret ecosystem indicators. Funds should be used to focus on specific unfunded needs/activities and to take advantage of existing platforms of opportunity whenever possible. There is a compelling need to establish new process-oriented research focused on the processes influencing the frequency and intensity of species interactions. Standard census-type surveys are not designed to collect this type of information. One technique for establishing new process-oriented sampling would be to select locations for intense monitoring at meso-scales, both temporal (weeks) and spatial (kilometers). The sites could be visited frequently to capture the seasonal time scale of change. Moorings could be deployed to capture the very fine temporal scale of change in oceanography. Site selection should focus on one or more of the following criteria:

- regions of aggregation for several key species;
- habitats that are utilized by a large number of key species;
- regions that directly influence the fitness consequences for species utilizing the habitat (*e.g.*, nursery grounds);
- unique habitats that protect rare species that are directly tied to a specific habitat type.

Selection of locations could be based on outcomes of three dimensional bio-physical models coupled with ground-truthing by observation. The group noted that one key area might be the southern Bering Sea shelf where flow into the eastern Bering Sea is an important variable to monitor (see below).

Selection of regions based on the fitness consequences of ecosystem change could consider the location of fronts or spawning and nursery grounds. These features can control the degree of spatial overlap of predators, prey and the concentration of prey (fronts) or the dispersal of reproductive products across the Bering Sea (spawning and nursery grounds).
The following areas were recommended, based on their unique characteristics and their role in the production of living marine resources in the Bering Sea: Pribilof seal colonies, cod alley, and submarine canyons as regions of cross-shelf exchange.

The group noted the following to place-based regional research:
Advantages:
- Is cost effective;
- Solves the untenable problem of needing to sample everything everywhere.

Issue:
- Modeling is needed to translate observations at pulse points to an overall status of the ecosystem.

Review of indicators for objectives

Limit ecosystem impacts

We dismissed this topic because we felt that it was comparatively easy to select indicators of ecosystem impacts on fish, seabirds and marine mammals given existing monitoring programs for these species groups. Before managers decide to limit impacts they must first identify what are acceptable levels of impact. This is a difficult and complex scientific issue. We did note that our ability to assess the abundance of plankton and infauna and benthic epifauna is currently limited.

Indicators of food webs

The group felt that there should be some acknowledgement of the difficulty of managing food webs. It might be more appropriate to establish limits to ecosystem stress and then request input from society on the goals for management within the acceptable limits. For example, one might be able to establish a goal to avoid an ecosystem shift from a gadid-dominated system to one dominated by elasmobranchs.

Maintain trophic structure

The group noted that the approach of using trophic-level ratios and identification of appropriate reference points for this might be difficult to interpret. These indicators would be improved if efforts focused on data quality and monitoring of functional groups. The group also recommended a focus on:
- indicators of seasonal shifts,
- benthic infauna,
- cephalopods,
- benthic habitat-forming epifauna,
- habitat mapping,
- zooplankton abundance,
- pelagic fish species.

There is a need for more detailed information on species interactions.

The group discussed several analytical techniques for evaluating ecosystem properties. Among these, they noted that network analyses could be used to identify regions where a disproportionate ratio of energy concentrates at one of the key nodes. The group also recommended that analysts should conduct sensitivity analyses on food webs to inform of overfishing definitions.

Spatial management

Several recommendations for this element were discussed above. The group identified the following steps:

- Identify bio-regions;
- Review existing management areas to assess whether they match bio-regions;
- Use multi-beam and other technologies to assess habitat types (sand, mud, *etc.*);
- Determine corridors used by migratory species and evaluate migration pathways relative to the long-term norms;
- Determine the locations of spawning grounds.

Uncertainty

The use of ecosystem indicators in management is an effort to assess natural and anthropogenic impacts on ecosystems. Thus, the state of science is uncertain and thus, the advice to managers should include a clear description of the uncertainty associated with the indicators. The group recommended the following considerations when evaluating uncertainty:

- Develop scenarios to assess the implications of climate variability;
- Develop techniques to assess structural changes.

Key research issues lie in the identification of mechanisms linking growth, productivity, and vulnerability to survey species composition.

Governance

There is a need to distinguish between human and non-human impacts:

- Acknowledge that thresholds to human impacts can be controlled. Acknowledge that non-human changes require adaptation of control rules given the state of nature;
- Metrics exist, *e.g.*, average age of the fishers within a fleet, economic status, and education level. However, issues associated with a definition of acceptable societal attributes are almost as difficult as defining what is an acceptable ecosystem;
- Decision criteria must be defensible.

GROUP 3: Nathan Mantua (facilitator), Jake Rice, Suam Kim, Francis Wiese, Jason Link, Diana Evans, and Jennifer Boldt

Are there unique characteristics of the Bering Sea that would lead to a certain path or is it more appropriate to talk about general indicators for many ecosystems? There are indices that can be used for all ecosystems, but there are also ecosystem-specific indices. For example, North Atlantic fishing pressure outweighs climate signals whereas, in the Bering Sea, climate is more important than fishing. In the North Pacific, changes in carrying capacity are so large that strategic, long-term views and planning must consider the unstable nature of carrying capacity. There is a need, therefore, to have leading environmental indicators for the Bering Sea. Objectives must consider a temporal scale. If the concern is focused only on next year's fishery, climate indices may not be necessary, but if the concern is the status of the fishery over the longer term, then climate rises in importance.

The Bering Sea is unique because a large fishery has built up around a particular ecosystem state, which may present challenges for ecosystem indicators and objectives. There must be a framework to organize indicators and objectives, and indicators need to have clear functions. The Ecosystem Assessment (first section of the *Ecosystem Considerations* appendix) contains a framework that organizes indicators under three main objectives (maintain predator–prey relationships, diversity, and energy flow and balance), each with several sub-objectives. There are indices in the second and third sections of the *Ecosystem Considerations* appendix that are used to address these objectives. There are also indices in these two sections of the report that are not necessarily used to address these objectives.

It was suggested that indicators should be considered within a risk assessment framework. For example, the probability of various levels of stock productivity could be plotted as a function of the Pacific Decadal Oscillation (PDO), perhaps with a third axis that includes some measure of fishing (likelihood of an indicator as a function of environmental indicators). Despite the lack of an explanatory mechanism to support this correlation, it still may be useful to have a risk-based framework that encompasses what is known. The main concern is about an increasing risk of an undesirable change. When it occurs, it is necessary to understand whether the source was anthropogenic or whether the environment changed such that the likelihood of a good year-class decreased. A framework of this nature would help to identify key drivers for the processes of interest and allow us to choose a few appropriate indices. The framework could also provide NPFMC with advice such as "there is a 30 to 40% chance that there will be poor recruitment for the next 3 to 4 years." Knowledge of an ecosystem may not be sufficient to provide an accurate forecast, but information about the risk of these events may be valuable in meeting conservation goals.

With regard to thresholds, there is a need to focus on inflection points in the relationship between probability of a process (like production) and, for example, climate indicators. Predictions, in risk framework, can be used in developing and assessing future scenarios. Managers cannot influence environmental variables, but their strategy could look at the probability of productivity being high or low. Models can then incorporate a parameter to identify the current state. The less a system is understood, the more cautious we must be in perturbing it.

Concerning assessments of vulnerability, it will be important to build into the management process a means to avoid undesirable ecosystem states.

Process studies are important to improve management decisions, but how empirical and process studies can be linked to management is a difficult subject.

Recommendations

1. Driving ecosystem processes need to be identified and appropriate indicators selected.
2. Take an inventory of the status of indicators (*e.g.*, size, production, diversity, "canary" species, energy flow trophodynamics, habitat, physio-chemical regime) and map them to objectives.
3. Link selected indicators to see how they interact (correlative, mechanistic, *etc.*). Identify drivers *versus* responses and create relational type models.
4. Once relationships are established, identify key thresholds and appropriate levels.
5. Develop scenarios for risk assessment that assess the risks and benefits of different actions, given uncertainty.

What do you do when you are in a poor-productivity regime? How does it translate into a real suggestion to management? The advice for the first year might not result in a management action, but brings the subject to their attention and may provide a way of identifying important monitoring that needs to be done. This can also help provide an advanced "heads-up" to management and the public, if presented to the Council before there is a problem; it gives people a chance to get caught up on research, and have a dialogue.

GROUP 4: George Hunt (facilitator), Patricia Livingston (rapporteur), Villy Christensen, Elizabeth Fulton, James Ianelli, Vladimir Radchenko, and Akihiko Yatsu

Objectives

What do you want to indicate?

The group initially focused its discussion on objectives by talking about the state of the North Pacific and how its health might be measured. It soon became evident that there needed to be a clear, quantifiable definition of "ecosystem health". Only then could indicators of this ecosystem quality be identified. Likewise, the objective of maintaining the structure and function of marine ecosystems was described as difficult to quantitatively defend because the natural degree of variation in ecosystem properties is so poorly known that the significance of observed change is hard to interpret. The difficulties in defining "acceptable state" were also discussed. In some cases, it was recognized that it might be easier to define what states might need to be avoided, as opposed to defining an optimum or acceptable ecosystem state. Thus, it would be desirable to avoid reducing the abundance of a species, significantly reducing a species' range, or causing unacceptable levels of eutrophication such that the risk of its extinction is increased substantially. In some cases, there are strategic processes in place that alter management for habitat and protected species such as Essential Fish Habitat (EFH) protection measures and Endangered Species Act (ESA) consultations.

The group agreed that it is difficult to have a scientific definition of what is acceptable and/or what is not because the issue of acceptability is one of human values. For example, the Bering Sea was once home to an ecosystem that had many great whales, many Pacific ocean perch (*Sebastes alutus*) and few walleye pollock (*Theragra chalcogramma*). An unanswered question is whether the current state, with fewer great whales and Pacific ocean perch and many walleye pollock, is due to natural or human effects. If the current state (which some will consider desirable) is due to top-down effects of fishing on the Bering Sea ecosystem, then perhaps it would return to the old system if these top-down controls were reduced. The return of a large biomass of whales will likely change the Bering Sea. It is entirely possible that the two potential objectives, restoring great whales and maintaining the existing ecosystem, are incompatible. Tradeoffs between diametrically opposed goals might need to be made.

Short-term *versus* long-term objectives

How to use the indicator

The group discussed the differences between strategic and tactical indicators. Tactical indicators are for measuring immediate, short-term management responses, such as estimated stock biomass. Tactical objectives from other regions include those that support age structure of key species. For example, indicators measuring rockfish abundance and catch in space and time could be used to guide management decisions. Strategic indicators might be those that are context setting, such as changes in the productivity or biomass of lower trophic-level organisms, or trends in the Steller sea lion population or salmon bycatch. Management action does not follow immediately upon changes in these, but information on their trajectories might provide context for future management actions.

Strategic indicators of future ecosystem response ("sentinels of climate change") depend on the past being a good predictor of the future. If climate variability, at a variety of temporal scales, causes the rules by which ecosystems function to change, then the use of these longer-term predictors becomes problematic. A possible avenue of approach is to identify and understand the responses of key processes to climate variability. Indicators based on these processes could potentially have greater predictive power than those just based on species distributions or abundances. If species are to be useful as sentinels of change, *e.g.*, northern fur seals and winter-spawning flatfish, then there is a need to calibrate their responses to changes in ecosystem function.

Some measures of ecosystem-level effects of fishing could include changes in the trophic levels of the catch, size structure changes, piscivore-to-planktivore ratios, habitat changes or changes in productivity. Some objectives might be related to optimizing yield, in which case the 2 million metric ton yield cap in the eastern Bering Sea is an important threshold. It was recognized that there are tradeoffs in achieving multispecies maximum sustainable yield (MSY) because single species MSY cannot be achieved simultaneously due to predator–prey interactions between managed species. Species value might be one of the criteria used to determine which species catches should be optimized. The group considered economic–ecosystem indicators as a topic of potential interest. Would it be useful to learn about the mean profit level of the total catch? A shift from more to less valuable species could indicate ecosystem change.

Overall, there is a general lack of science-based advice about limits and thresholds at higher organizational levels. Thus, it is important to focus on development of objectives and measures relating to higher level changes, such as food web changes, ecosystem-level productivity, or multispecies MSY considerations. Ultimately, it should be management objectives and explicit societal goals that drive the indicators and determine how they are to be used.

Spatial scale

The group discussed the appropriate spatial scale for the system to be monitored. The broad classifications used to define large marine ecosystems were seen to be too coarse for some of the purposes under consideration in the southeastern Bering Sea, but there was recognition that a reef by reef scale is too fine. There was thus considerable interest in identifying practical eco-regions or bio-regions at intermediate spatial scales. For example, Australian bioregions have been defined based on multivariate biological/ physical/geological properties. The Australian objective is to maintain spatial diversity, and the policy has been to close off 15% of the habitat in each bioregion. It was recognized that stakeholders may need to be involved in these decisions.

Overview

There was some agreement that existing structures/processes are in place to protect species. The outstanding scientific issues include the need to focus on indicators that identify food web changes, ecosystem productivity, and multi-species MSY *versus* single species. Strategic indicators of future response to climate shifts will require a better understanding of ecosystem processes and how these are affected by climate variability. Food web constraints limit achieving certain societal goals for an ecosystem. Considering stakeholder input, tradeoffs will need to be made in designing objectives that meet human needs without impacting ecosystem function.

Matching objectives with indicators

Ian Perry (facilitator), Jake Rice, Glen Jamison, Francis Weise, Anne Hollowed (rapporteur), Suam Kim, and Akihiko Yatsu

Objectives

The group began by reviewing the high-level objectives for ecosystem-based management in the eastern Bering Sea (and North Pacific) as defined by several management agencies for these regions, and summarized by Belgrano *et al.* (this report):

- Protect ecosystem structure, functioning, and key processes (including diversity and habitats);
- Account for food web interactions;
- Manage regionally;
- Incorporate precaution into decisions;
- Integrate broad societal goals; and
- Acknowledge multiple, external influences, including climate.

The group noted that most of the objectives were not true objectives (many are "directions" to improve management), and that all could be folded under objectives 1 and 5 as overarching (but very general) objectives. The group decided that to spend time discussing these high-level goals was not useful for the following reasons:

- These objectives will be established by governmental agencies with broader input than the members of this group;
- Most governmental institutions have already established high-level objectives; and
- The goals are so broad and general that scientists cannot offer meaningful scientific advice on them.

It was also noted that objective 5 in its current form is inappropriate for the activity of this workshop because integration of societal goals is not necessarily important to conservation. For example, it was pointed out that governments (generally) cannot be sued for failing to maintain high levels of walleye pollock, however, they can be sued for failing to prevent the pollock stock from falling into an overfished state. A key point for the group was that the integration of societal goals comes once the boundaries of conservation have been identified – it is the role of scientists to determine and articulate these conservation boundaries. Identifying conservation objectives is the core of science and, although not "easy", methods are being developed to achieve this task. Socio-economic objectives need to be better defined, and by a larger constituency than scientists; once this has been done then scientists can identify ecological means to move towards these socio-economic objectives. Therefore, a 3-step procedure was envisaged:

1. scientific identification of conservation limits;
2. articulation of socio-economic objectives; and then
3. scientific identification of means to move towards socio-economic goals.

The North Pacific Fishery Management Council (NPFMC) should play a central role in identifying socio-economic objectives for the ecosystems discussed here.

Legislative language typically sets objectives to "avoid a certain state". With ecosystems, however, this type of language should be broadened to include terminology such as "maintain the ability for ecosystems to recover from perturbation". Such an objective could then be dissected into the knowledge, *e.g.*, biodiversity and a natural mix of species and age groups that maintain resilience, and the actions required to achieve this objective.

Indicators

The group discussed the difference between contextual and management indicators. Contextual (or "audit") indicators provide background context, and may index conditions over which humans have no direct control. Management (or "control") indicators report on conditions over which humans have some direct control; they could be used to monitor the results of management actions. Several issues were noted for indicators:

- Most tend to index current conditions rather than predict a future state;
- There are unresolved issues of how well indicators might perform between different "regimes", or whether they may exist at all, *e.g.*, whether sea ice will be an important indicator in a future (warm) Bering Sea.

The existence of vague objectives makes identification of effective indicators particularly difficult, if not impossible. It would be useful for stakeholders to clearly define their goals to evaluate how conservation and stake holder goals match, and to enable scientists to define management actions to increase the likelihood of achieving these goals. However, in the Bering Sea where fishing mortality is tightly controlled, the ability for managers to engineer an ecosystem to achieve a societal goal may be limited due to uncertainties of ecosystem productivity.

Characteristics of good indicators include (*e.g.*, Rice and Rochet, 2005):

- Forecast: Indicators should be able to consistently predict a particular phenomenon.
- Sensitivity analysis: Given an objective and a list of potential indicators and the processes that may impede or accelerate progress towards achieving the objective, evaluate which indicators are most sensitive to threats.
- Is it measurable? What is the cost of collection?
- What is the ease with which you can communicate the criterion?
- Can you link the indicator to a management action?
- The indicators must be able to withstand scrutiny when it is used for decision making, particularly when the decision may result in reduced access to resources.

The group noted that there are a few cases in which an ecosystem indicator has been used by management to limit fisheries activities, *e.g.*,

- Kittiwake fledging success has been used to control sand eel fisheries in the North Sea.
- Harvest control rules for Pacific sardine fisheries are conditional on temperature at Scripps Pier. However, the temperature has never dropped to a level at which reductions in fishing mortality have been implemented.

Lessons could be learned by examining societal responses to the use of such indicators in a management context.

DPSIR approach

The Driver-Pressure-State-Impact-Response (DPSIR) framework has become increasingly useful for determining ultimate drivers, indicators, and responses of environmental systems to stressors. The ICES community has been exploring this framework in an assessment of the key pressures of human activities on marine ecosystems (*e.g.*, Table 7). A schematic flowchart of how such a DPSIR approach might be integrated into issues of indicators and objectives has been developed (Fig. 19). At present, scientists in the Bering Sea–North Pacific regions have good sets of indicators for Pressures and State, but poor indicators for their Impacts. In addition, the Response to these Drivers, Pressures and Impacts need to depend on the desired (and stated) objectives for the ecosystem.

Risk assessment

There are often multiple pathways leading from objectives to indicators; risk assessment is a formal tool which can help to choose among these various pathways (*i.e.*, given the knowledge available and uncertainties, which pathway might be expected to achieve the desired result). The group recognized that it may not be practical at present to do risk assessments on whole ecosystems. At present, a more practical question is to ask, "Will activity *A* do harm to specific key parts of the ecosystem?"

The group noted that there are techniques for assessing the risk of specific management decisions. Regional fisheries management councils should evaluate what level of risk is acceptable. To do this, scientists must provide an evaluation of the risk to ecosystem function by a particular activity. This requires assessment of the cumulative effects of past and present activities. While this can be done qualitatively, developing a probabilistic representation of this surface is likely to be difficult. Too broad a surface may give clients and fisheries managers a sense of security that the system is more resilient (less responsive) to management actions than may be true.

Table 7 The relationship between activities in the North Sea and the mechanisms through which they exert pressure on the marine ecosystem. From ICES Working Group Report 2006, WGECO, Table 4.4.3.1.

	Activity	Aquaculture	Climate change	Dredging	Oil & Gas	Renewable energy	Aggregate extraction	Fisheries	Recreation	Military	Research	Shipping	Land-based discharges & emissions
Pressure													
Physical	Substratum loss			■	■	■	■	■			■		
	Smothering	■		■	■	■	■	■			■		■
	Change in suspended sediment	■		■	■	■	■	■	■		■		■
	Change in water flow rate	■	■		■	■	■	■			■		■
	Change in temperature		■		?							?Ballast	■
	Change in turbidity	■	■	■	■	■	■	■	■		■		■
	Change in sound field		?	■	■	■	■	■	■	■	■	■	
	Change in light regime	■	■	■	■	■	■	■			■		■
	Visual presence	■			■	■		■	■		■		
	Abrasion/ physical disturbance	■		■	■	■	■	■			■		
Chemical	Synthetic compound contamination	■		■	■		?			?		■	■
	Heavy metal contamination			■	■		■	■		■	■	■	■
	Hydrocarbon contamination			■	■		■	■	■	■	■	■	■
	Radionuclide contamination			■	■		■	■		■	■		■
	Changes in nutrient levels	■	■	■	■		■	■	■		■		■
	Changes in salinity		■									■	■
	Changes in oxygenation	■	■	■	■	■	■	■	■		■		■
Biological	Introduction of microbial pathogens/ parasites	■	■					■	■	■	■	■	■
	Introduction of non-native species & GMOs	■	■		■			■	■	■	■	■	
	Selective extraction of species	■						■	■		■		

Shading indicates an existing mechanism for a particular activity, while ‘?’ indicates a potential mechanism.

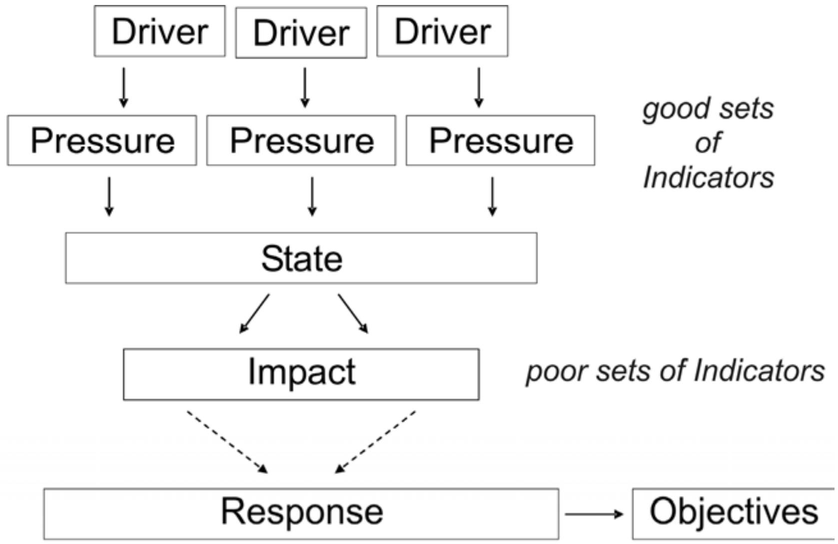

Fig. 19 Schematic that matches indicators to objectives using a DPSIR approach.

Recommendations

1. The integration of societal goals should occur once the boundaries of conservation have been identified – it is the role of scientists to determine and articulate these conservation boundaries. A 3-step procedure is recommended to develop objectives for ecosystem-based management of particular systems:
   - scientific identification of conservation limits;
   - articulation of socio-economic objectives (not exclusively by scientists); and then
   - scientific identification of means to move towards socio-economic goals.

   Regional fisheries management councils, such as NPFMC, should play a central role in identifying socio-economic objectives for the ecosystems considered in this workshop.

2. Selection of indicators is a signal detection exercise. Scientists in the PICES region should develop formal evaluation criteria and perform the evaluation (see Rice and Rochet, 2005). Scientific standards must be high but this should not deter forecasting as failures in prediction are often informative.

3. Consider the Driver-Pressure-State-Impact-Response (DPSIR) framework as a tool to evaluate human and climate drivers of changes in marine ecosystems, how these might be adequately indexed (*e.g.*, considering "contextual" and "control" indicators), and how they relate to management actions and decisions.

4. Risk assessment techniques must be developed and included in evaluating appropriate response pathways from indicators to action and in how they relate to objectives.

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Methodologies to monitor ecosystem-wide structural change

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Recognizing that the protection of ecosystem structure and functioning (including diversity and habitat) is an integral part of ecosystem-based fisheries management (EBFM), methodologies to monitor structural changes are a key component of any approach to EBFM. We defined structural changes as:

- changes in relative species composition of any faunal assemblage (based on abundances of individual species, functional groups, or trophic groups);
- changes in species richness, evenness, and/or diversity of faunal assemblages;
- changes in size composition (within or across species);
- changes in habitat type and/or quantity;
- changes in spatial distribution of individual species or species groups.

Methodologies for monitoring structural changes require (1) suitable indicators that can be measured at different points in time, typically on an annual basis, and (2) graphical or statistical methods to examine whether the resulting time series display patterns that may indicate a structural change.

The group's assessment of some of the most promising and useful indicators included indicators from four broad classes.

1. Abundance or biomass of "key" taxa. Commercial fish species and many seabirds and marine mammals are already being monitored closely and status and trend information is published annually. There are, however, clear gaps in our ability to monitor lower trophic-level species that could serve as early indicators of changes in bottom-up forcing and prey availability such as phytoplankton abundance (Chl *a*) and productivity, zooplankton abundance and productivity, abundance of lower trophic level benthos, and abundance of forage fish.

2. Trophodynamic indicators include simple ratios such as pelagic *versus* benthic biomass that were felt to be most useful, easy to interpret, and readily obtained from existing data. Other existing indicators such as the trophic level of the catch and the "Fishing in Balance (FiB)" indicator are currently being computed on an annual basis, but lack clearly defined reference points. Other promising indicators that could be monitored include the community condition factor, the trophic level of the community (based on survey data) relative to the trophic level of the catch, and diet-based indicators of the relative abundance of forage fishes.

3. Size-based indicators have proven useful in many systems and include the mean length (or weight) in the community, slope and intercept of length (or weight) spectra, and the proportion of "large" fish in the community.

4. Diversity indicators were not considered to be particularly useful without further examination of the diversity–productivity relationship. However, the related methodology of constructing abundance/biomass curves was felt to offer a more promising approach as an indicator of "stressed" communities.

The above indicators are largely measures of states rather than rates. Rate indicators are likely to be more sensitive to changes, but are more difficult to measure. Most of the indicators are univariate or aggregate measures derived from survey data. Many other indicators could be derived from multivariate analyses of existing time series or from ecosystem models. However, such indicators are often more difficult to interpret and may be more suitable as a research tool rather than a routine monitoring tool.

To detect structural changes in any indicator time series requires methods to distinguish "normal" fluctuations of a stationary time series from "anomalies" such as one-time events, long-term trends, and gradual or abrupt changes in the mean or variance of a series. Statistical methods for detecting specific deviations from stationarity are available and need to be applied to existing indictor series.

Communicating results

Sarah Kruse (facilitator, rapporteur**),** Diana Evans, David Fluharty, Gordon Kruse, Patricia Livingston, and Skip McKinnell

Who is the intended audience and who will use the information?

The intended audience currently includes stakeholders, scientists and managers. Is there a need to expand this list? The first PICES report was published only in English. This means there is little or no public communication with organizations in Asian member countries. Should this situation be changed and if so, by whom?

For the reports to be more directly linked to management in Alaska, they need to include recommendations. Should the report consider trends and drivers in different regions of the North Pacific? What can be learned from trends in other regions – synthesis or comparison? What is the best way to prioritize information and put forward key information to NPFMC? Perhaps what is required is an attractive executive summary that is broadly distributed to the general public.

How do we communicate with the public (*i.e.*, products and tools)?

Is TV the only medium? Although the executive summary is intended for NPFMC, it may translate more easily into an interview, news article, or report. It may be possible to use current communications groups (*e.g.*, Alaska Sea Grant) to translate the summary into a newsworthy report. Other considerations include the expansion of the NMFS website or finding other places where an ecosystem management section might be interesting (*e.g.*, teachers and high school students).

The *Ecosystem Considerations* appendix includes an Ecosystem Assessment section (the take-home message) but it is not clear how to communicate this. Could the bulk of the existing report be reduced by including the details on the website? The hard copy version is currently not working.

It might be useful to consider having two versions of *Ecosystem Considerations*: a full version for stock assessment and a shorter one for NPFMC.

The annual *Marine Science in Alaska* Symposium is very useful as a way to work with and communicate with others. There might be an opportunity to have a routine PICES oral presentation as a part of the symposium.

How do we create a user guide to indicators?

There are two issues – the need to define indicators generically and then to define specific indicators. Describe the resonance of the indicator to get a sense of its value. Resonant indicators reflect properties of systems other than their own internal variation.

How do we learn from and work with others?

Cooperating with organizations that share common interests may be important to understand their experience in communicating indicators. It may also be important to understand what trends are shared commonly among the regions. The group recommended a symposium be convened for countries and groups working with ecosystem approaches to management which could be both domestic and international.

What is the process of utilizing the document or information?

Reporting frequency was discussed, as was the need to reach a stage where NPFMC uses the report and its information. One suggestion was to maintain the information on the web, updating as new data become available, similar to a living ecosystem status report. Could there be a checklist that each stock assessment must address? The actively updated reports could provide information such as "what is the risk that a regime shift is coming?" It will be important to understand what proportion of variability (be it biomass or recruitment) comes from regime shift and from inter-annual variability. This will provide guidance on which temporal scales to focus attention.

WORKSHOP OBJECTIVES AND OUTCOMES

Develop a set of operational objectives for the southeastern Bering Sea ecosystem

In 2004, the U.S. National Marine Fisheries Service (NMFS) completed a comprehensive assessment of the overarching conservation and management policies and objectives of the Alaska groundfish fishery management plans. As a consequence of that review, the North Pacific Fishery Management Council (NPFMC) adopted a high-level policy statement with broad objectives for the fishery, including 45 specific objectives classified under nine priority issues. Four of the nine issues address social and economic concerns, whereas the remaining five address conservation of species, communities and ecosystems. Conservation objectives, indicators, and reference points are well-defined for commercially exploited groundfish and invertebrates, as well as some other taxa, such as marine mammals and seabirds that are listed under the U.S. Endangered Species Act.

The annual NMFS *Ecosystem Considerations* appendix includes hundreds of ecosystem and management indicators. Some of these are composite indicators that monitor ecosystem-level objectives related to maintaining predator–prey relationships, diversity, and energy flow and balance. The report establishes linkages between many indicators and the conservation objectives adopted by NPFMC. Although specific limit reference points are not yet formally defined for ecosystems/communities, these indicators are used to evaluate sources and amounts of change in Alaska marine ecosystems that might warrant further research or possible change in management. When indicators suggest a potential conservation problem, the *modus operandi* of NPFMC is to develop a problem statement and to consider a detailed analysis of the situation, along with management alternatives and their ecological, social, and economic impacts. Then, NPFMC selects an alternative in which specific conservation limits and management actions are adopted. This process involves high levels of stakeholder input, along with review, comment, and recommendations by a Scientific and Statistical Committee. One of several examples of recent actions taken to address ecosystem conservation issues includes closure of 95% of the Aleutian Islands management area to bottom trawling to protect deep-sea corals based, on observed coral bycatch, distribution of fishing activity, habitat mapping, and recent discovery of 25 species of corals endemic to the area.

The objectives adopted by NPFMC and the Ecosystem Status Indicators and Ecosystem Assessment in the *Ecosystem Considerations* appendix formed the initial basis for reviewing Bering Sea objectives and indicators for the Indicators project. Two open meetings were arranged to solicit feedback from the scientific and stakeholder communities on the completeness of this set of objectives and indicators. These meetings attracted participants with interests in developing ecosystem-based approaches to management of the southeastern Bering Sea and Gulf of Alaska. The first meeting occurred on January 25, 2006, in Anchorage, in association with the annual *Marine Science in Alaska* Symposium, and the second was held on February 8, 2006, in Seattle, during a meeting of the North Pacific Fishery Management Council. These meetings were preparatory to the PICES/NPRB Indicators workshop that was convened on June 1–3, 2006, in Seattle.

Operational objectives can be categorized under two broad dimensions: (1) conservation of species and habitat; and (2) socio-economics of marine ecosystems. A logical sequence is to develop socio-economic operational objectives and indicators after the boundaries of conservation have been identified by scientists. Scientists can then determine the means to move, within ecological limits, toward these socio-economic objectives.

Although much progress has been made in defining conservation objectives for the Bering Sea, as already mentioned, there is a continuing need for greater specificity by developing operational objectives in an open public process with a high level of stakeholder involvement. For instance, among the 45 specific objectives developed by NPFMC, many are not sufficiently specific to allow a determination about whether they have been met.

The use of ecosystem-scale indicators could be a way to identify conservation issues before they reach crisis points so that management does not need to routinely operate in a reactive mode. However, the science of ecosystem-based management has not yet developed sufficiently to allow the setting of scientifically defensible conservation limits at the fish community and ecosystem levels. Best available science should be used to assess the ecosystem benefits to be derived from various management alternatives. Indeed, some research in these areas is currently underway. Also, research is needed on the application to the Bering Sea of ecosystem-level indicators that have proven useful in other jurisdictions, such as aggregate biomass, biomass groupings and biomass–ratio indicators. Useful biomass groupings are:

- gelatinous zooplankton,
- cephalopods,
- planktivores,
- scavengers,
- demersal fishes,
- habitat-forming epifauna,
- piscivores,
- top predators.

Biomass-ratio indicators might include piscivore/planktivore, pelagic/demersal, and infauna/epifauna ratios.

Socio-economic objectives and indictors were explicitly omitted from this project owing to the scope of supported work, not because they are unimportant. Whereas the *Ecosystem Considerations* appendix links indicators to NPFMC conservation objectives, there is a pressing need to develop operational objectives and associated indicators for the socio-economic dimension. This might be best achieved by conducting a series of workshops involving economists, social scientists, and stakeholders, not unlike the workshop we have conducted with respect to ecosystem objectives and indicators. It is recommended that the results of these workshops should be used to transform the existing NMFS *Economic Status* report into an annual *Socio-economic Considerations* report that relates social and economic status indicators to socio-economic objectives much in the same way that the *Ecosystem Considerations* report links indicators to conservation objectives. In the United States, NPFMC should play a central role in shepherding the development of these socio-economic objectives and indicators for the southeastern Bering Sea and Gulf of Alaska ecosystems.

Evaluate the two ecosystem status reports

Two ecosystem status reports were discussed during the Indicators workshop. *Ecosystem Considerations for 2006* is an appendix to the annual *Stock Assessment and Fishery Evaluation* (SAFE) report published by NPFMC. *Marine Ecosystems of the North Pacific* is a compendium of overviews of regional marine ecosystems that was published for the first time, in 2004, by PICES. *Ecosystem Considerations* demonstrates that considerable progress has been made to link a large suite of ecosystem status and management indicators to the broad objectives identified by NPFMC for managing groundfish fisheries in the Gulf of Alaska, Aleutian Islands and eastern Bering Sea. *Marine Ecosystems of the North Pacific* provides a very useful region by region comparison of ecosystems in the entire North Pacific.

Describing complexity is a challenge. It is difficult, even for experts who understand the meaning of individual indicators and their interconnections, to identify the major patterns of ecosystem change in the hundreds of indicators contained in these two reports. The most recent versions of *Ecosystem Considerations* partly address this issue by including an executive summary that shows recent important and/or interesting trends from a subset of indicators.

Identify steps to validate indicator performance, improve the monitoring network, and integrate into predictive models

It was noted that although the *Ecosystem Considerations* appendix contains an assessment section where a subset of important indicators is presented, this subset has not been subjected to an objective evaluation and selection process. Different methodologies for indicator evaluation and selection were presented at the Indicators workshop. The Rice–Rochet framework was recommended as a more structured process to evaluate and screen indicators. This framework identifies eight steps for selecting a suite of indicators for fisheries management. Steps that have not yet been done with *Ecosystem Considerations* are to score the indicators in the report against screening criteria and to use those scores and user input to select the suite of indicators on which to report.

The Driver-Pressure-State-Impact-Response (DPSIR) framework was also thought to be useful in exploring the key pressures of human activities and climate on marine ecosystems and might be used to organize indicators by pressure points or threats. Composite indicators can be derived from existing data, but there are many ecosystem components that could serve as "pulse points" but they are not well-monitored. A number of gaps in the monitoring network were identified at the Indicators workshop.

Predictive models of future change were not a central focus of the Indicators workshop. However, it was recognized that the use of risk assessment and scenario approaches, such as those employed in Australia, were worthwhile avenues for making progress. It appears that a number of modeling approaches are being advanced and improved upon in Alaska. In addition, future climate scenarios are being developed to drive some of the models.

Investigate methodologies that monitor system-wide structural changes within the marine ecosystem

The workshop was successful in establishing two benchmarks for the use of indicators in the Bering Sea.

The first benchmark is that the use of indicators has utility as a communication technique between fisheries managers and supporting scientists. While scientists will point to the overall complexity of the ecosystem, and managers would like defensible environmental information to take actions that have potential economic consequences, semi-quantitative indicators provide, at present, a known and tested technique for reaching a common understanding in fisheries throughout the world.

The second benchmark is that there are now management objectives in place for the Bering Sea, based on the work of NPFMC and the Alaska Fisheries Science Center (AFSC). There is a concern in the literature that indicators should be matched to specific objectives. This concern was a major consideration in planning the workshop. It was clear from the presentations and discussions that the Bering Sea is in good shape with regard to management objectives. For example, the management objective "to preserve the food web" could have an operational objective "to maintain the mean trophic level between 3.3 and 3.7" which is the trophic-level range of the catch in recent years after banning new fisheries on forage species. Other examples of management objectives in the eastern Bering Sea are to:

- prevent overfishing,
- manage bycatch,
- avoid seabird and marine mammal impacts,
- reduce impacts on habitat,

each with appropriate operational objectives and indicators.

The situation for the Bering Sea was commented on by scientists from Australia, the Canadian and U.S. east coasts, and by the Co-chairman of the SCOR/IOC Working Group 119 on Quantitative ecosystem indicators for fisheries management, Dr. Villy Christensen, as well as by Bering Sea specialists. They emphasized that unlike many other large marine ecosystems, management of the Bering Sea is not in "desperation mode", as the Bering Sea is not generally overfished. Factors they saw as missing or under-represented included:

- a risk management framework,
- a formal process of indicator selection;
- a lack of reference points to determine when the value of an indicator should initiate action.

In further discussion, however, it was noted that because the Bering Sea is not in desperation mode, the present method of adaptive management, where the system is monitored for change and issues are dealt with as they arise, was a better approach for the Bering Sea than setting formal reference points for a large number of indicators.

The review team concluded that, unlike many other regions that deal primarily with the consequences of overfishing, the Bering Sea needs both management objectives and ecosystem status objectives. Because the Bering Sea lies between the North Pacific and the Arctic, its ecosystem and commercial fisheries are subject to climate variability and climate change, as has been seen in both historical records and in climate projections. Thus, it is important to develop and include indicators that link climate to ecosystem changes.

While the workshop was successful in reviewing objectives and management indicators, it leaves for the future the task of selecting an appropriate set of ecological indicators. Any synthesis of information should discuss both the interpretation of what is meant by ecosystem status and the methodology for reducing the number of potential indicators. It was suggested that selection criteria should be: relevant, integrative, sensitive, correct, defensible, vetted and economical.

The methodologies used to develop indicators cannot be separated from the process of how the information will be used. So their communication to managers must be sufficiently convincing to allow them to take and defend their actions.

Recommendations

Ecosystem Objectives and Indicators

1. Ecosystem-level and community-level conservation thresholds are relatively new ideas in marine conservation. Since they will require new kinds of indicators, research is needed for their development and application to the Bering Sea.
2. New research is needed to understand how to synthesize the large set of Bering Sea data records into a reasonable number of ecosystem status indicators.
3. A formal process of evaluating and selecting ecosystem indicators is a general requirement. The Alaska Fisheries Science Center should consider developing and applying such a process to the indicators in its *Ecosystem Considerations* appendix.
4. Enhancements to the ocean/ecosystem monitoring network are needed to fill data gaps at ecological pulse points (plankton, benthic infauna and epifauna, seasonal species interactions and movements, small pelagics, and cephalopods) to improve predictive models and the development of ecosystem indicators.
5. More collaboration between modelers at the Alaska Fisheries Science Center and the Pacific Marine Environmental Laboratory, and elsewhere is encouraged to link various climate/ecosystem and conservation/assessment models, and to use these models to evaluate management strategies.

Socio-economics

While the workshop did not address socio-economic operational objectives for the Bering Sea and North Pacific, linkages between the well-being of people and healthy marine ecosystems require a level of attention comparable to those for ecosystem conservation objectives:

6. Socio-economic objectives related with the marine environment should be developed for the region, along with their indicators and reference points.
7. The North Pacific Fishery Management Council should play a central role in shepherding the development of these socio-economic objectives and indicators for the southeastern Bering Sea and Gulf of Alaska ecosystems;
8. There is a need to conduct scientific and policy analyses of pathways to achieve socio-economic objectives while remaining within ecosystem-level conservation limits.

Communication

9. Plans should be developed at an early stage on how the information from indicators can best be communicated to scientists, policy and decision makers, and the general public. The plans should include publishing concise, attractive executive summaries of major ecosystem status reports that will describe important trends and patterns in marine ecosystems for non-scientists.
10. To reach policy makers and the public in Asian countries, future iterations of the Synthesis chapter in the PICES North Pacific Ecosystem Status report should be published in multiple languages.
11. The development by the National Marine Fisheries Service of an *Ecosystem Considerations* website greatly increased access to time series of ecosystem indicators for the Alaska region, and should be maintained and enhanced.
12. An overview of the status of the Bering Sea ecosystem(s) should be presented at the annual *Marine Science in Alaska* Symposium to foster broader communication among the diversity of regional scientists, managers and the public.

Specific recommendations from individuals/groups can be found under Discussion Group Results in this report.