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

Andrea Belgrano[1], Jennifer L. Boldt[1,2], Patricia Livingston[2], and Jeffrey M. Napp[2]

[1] Joint Institute for the Study of the Atmosphere and Ocean (JISAO), University of Washington, Seattle, WA 98185, U.S.A. E-mail: belgrano@u.washington.edu
[2] NOAA/Alaska Fisheries Science Center, 7600 Sand Point Way NE, Bldg. 4, Seattle, WA 98115-6349, U.S.A.

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).

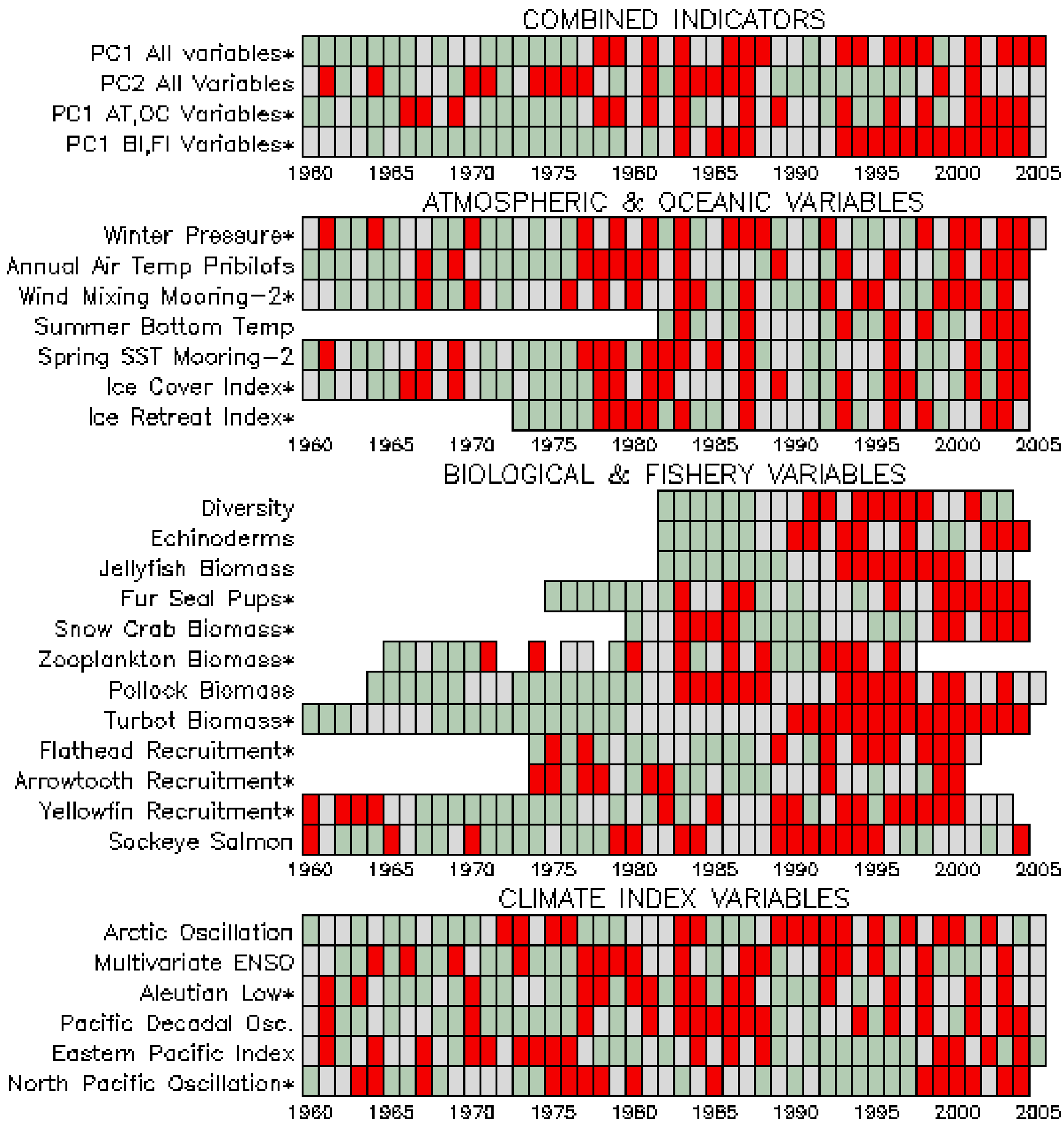

Fig. 4 Bering Sea indicators combining climate, oceanography, fisheries. Red colors indicate the large changes in recent years (largest one third of values in record). The middle third is shown in grey and the lowest third is shown in green. The combined indicators are the result of a mathematical analysis (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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