Integration of Ecological Indicators for the North Pacific with emphasis on the Bering Sea: A Workshop Approach
(short title: Bering Indicators Workshop)

Project Summary
Ecosystem indicators are part of a larger process of considering policy-level goals regarding an ecosystem, detailed objectives, and performance criteria. Indicators are empirical measures used to establish these criteria. Indicators are useful in reducing the complexity of an ecosystem, but depend on careful selection based on representativeness, concreteness, and sensitivity. The Bering Sea is advanced in application of ecosystem-based concepts to manage marine resources. An "Ecosystem Considerations" Appendix is prepared for the North Pacific Fishery Management Council. Similarly, PICES has produced a North Pacific Ecosystem Status Report. These Reports can be improved through consensus on operational objectives and appropriate indicators. We propose four activities for a Workshop to be held in April 2006:

- Involve the Bering Sea and international communities in developing of a set of operational objectives for the southeast Bering Sea ecosystem.
- Evaluate the two Status Reports with a goal of integrating results and streamlining the presentation.
- Investigate methodologies that monitor system-wide structural changes within the marine ecosystem.
- Identify steps in validating indicator performance, improving the monitoring network, and integration into predictive models.

Pre-activities include working papers for the first three tasks, followed by an after-Workshop report. PICES has a successful history of providing workshop/consensus science reports. The Co-Convenors for the workshop would be Glen Jamieson (Canada), Gordon Kruse, Patricia Livingston and James Overland (U.S.A.). Because stakeholders and information providers are part of the process, we envision a step forward in ecosystem management for the Bering Sea, and a precedent for the North Pacific.

1. **Responsiveness to NPRB Identified Project Need 1***: Integrated Ecosystems Research Program Planning - #2. Evaluate the Utility of Ecosystem Indicators*

Society has major economic and social interests in wise management of the Bering Sea and North Pacific ecosystems. Modern marine ecosystem approaches to management require collaboration among the authorities and interests of international, federal and state organizations, native peoples, industry, and resource users, community and NGO interest groups, academia and the public. The NPRB mission statement articulates this point*, a science program that provides better understanding of the North Pacific, Bering Sea, and Arctic Ocean ecosystems and enables effective management and sustainable benefits*. A further NPRB research goal is *prioritization of pressing fishery management and ecosystem information needs.*

Indicators are not normally considered an end in themselves, but fit within a hierarchical framework (Sainsbury and Sissenwine, 2004). Our process begins with review of *conceptual goals* for the ecosystem, *i.e*., broad statements of intent or major management issues such as sustainability of human use and conservation of species and habitat. *Conceptual goals* are made more concrete by *operational objectives* that have a direct and practical interpretation. *Operational objectives* are then tracked based on the degree of divergence of a measurable *indicator* from a target or *reference point*. The process continues with a *planned response* and *review process* which acknowledges the learning process and the large uncertainties in understanding of the ecosystem.

An indicator is an empirical measure such as biomass of a particular species, a temperature at a particular location, or a composite of several individual indicators. A *conceptual goal* regarding the state of an ecosystem, such as "maintain predator/prey relationships", could have an *operational objective* such as "maintain forage fish biomass above 50,000 t." Change in an *indicator* (forage fish biomass) relative to the *reference level* (50,000 t threshold) is taken as evidence of whether an objective is met. Indicators are useful in reducing the complexity of an ecosystem, but depend on careful selection based on their representativeness, concreteness, and sensitivity. When chosen wisely they are considered to be representative of critical aspects for the functioning of an ecosystem. Their strength is that they are objective measures, which when compared to reference levels, are considered to be evidence that a certain objective has been met, or a certain ecosystem status has been maintained. Such comparisons are a method to reduce subjectivity in statements about the ecosystem.

A 2004 report to Congress, www.nmfs.noaa.gov/sfa/reports.html, lists only two overfished stocks in the Bering Sea (snow crab and Pribilof Islands blue king crab), 28 stocks not overfished, and 30 stocks unknown but not subject to overfishing based on abundance estimates for the entire complex. This is a remarkable positive statement compared to the general status of the world's fisheries. It creates a major responsibility for those with interest in the Bering Sea, but also an opportunity. The emphasis for management and research can be on understanding and managing the ecosystem, rather than correcting for previous overfishing.

At present, there is developing experience with implementing ecosystem approach to management which depend on indicators. It has been used for over a decade by the Environmental Protection Agency for fresh water watersheds. In 2001, the Scientific Committee on Ocean Research (SCOR) established a Working Group on *Quantitative Ecosystem Indicators for Fisheries Management*, which held an international symposium in April 2004. The North Pacific Marine Science Organization (PICES) established a Working Group on *Ecosystem-based management science and its applications for the North Pacific* at their October 2004 meeting. O'Boyle *et al*. (2004) showed how indicators for ecosystem-based management can be used for the Scotian Shelf, and Link *et al*. (2002) has discussed indicators for Georges Bank.

Ecosystem indicators and ecosystem management concepts have already been applied to the Bering Sea as evidenced by the "Ecosystems Considerations" Appendix in the Stock Assessment and Fishery Evaluation (SAFE) Report for the North Pacific Fisheries Management Council (NPFMC), www.fakr.noaa.gov/npfmc/SAFE/SAFE.htm. In 1999, this Appendix began to include ecosystem indicators and ecosystem-based management performance measures. Some of these indicators are also available on a website developed with support from the NPRB: www.beringclimate.noaa.gov, which discusses the derivation and significance of each indicator; analysis software is available including a program that provides a measure of the strength of shifts within a time series. Table 1 taken from the most recent "Ecosystems Considerations" Appendix lists 34 biotic, abiotic and human indicators for the Bering Sea/Aleutian Islands.

The framework of ecosystem management for the Bering Sea as developed in the "Ecosystems Considerations" Appendix can be improved through 1) identification of more explicit operational objectives (a task requiring stakeholder involvement), 2) integration of results (*i.e*., further consideration of composite ecosystem indicators), and 3) streamlining presentation for clarity.

Similarly, PICES has produced a North Pacific Ecosystem Status Report (NPESR) on all the major marine ecosystems around the North Pacific. The reporting of ecosystem status and progress in implementing ecosystem approaches to management throughout the North Pacific could be further developed through agreement on a common set of objectives and discussion of appropriate ecosystem-specific indicators. Ideally, these objectives would match at some level, the objectives agreed upon for Alaska.

Bering Sea/Aleutian Islands

	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	Normalized time series
BS Trophic level of catch	.	.	+	+	+	+	+	+	.	.	+	+	+	+	.	.	.	.	.	.	+	.	.	.	.	+	+	.	.	+	+	+	+	+		1954-2003
Ice Cover Index	.	+	+	.	+	+	+	.	-	--	.	-	-	.	.	.	.	-	.	-	.	+	+	-	.	+	--	.	+	.	+	--	+	-	-	1954-2004
AI Trophic level of catch	-	-	.	+	.	.	.	.	.	+	+	+	+	+	+	+	+	+	+	+	+	+	+	.	.	.	.	.	.	.	.	.	.	.		1962-2003
Surface Winter Air Temp.	.	--	--	.	-	--	--	.	+	++	+	+	+	.	.	+	.	+	-	+	.	-	.	.	.	-	++	.	.	.	-	++	-	+	+	1916-2004
Total salmon catch	+	-	-	-	-	-	-	-	.	+	+	+	.	++	++	+	.	.	.	+	++	+	++	+++	++	+++	++	.	-	+	+	.	.	.		1900-2003
PDO	+	-	--	.	-	-	-	+	.	-	.	+	.	+	+	+	+	++	+	-	.	--	.	.	+	-	.	.	+	.	-	.	.	++	.	1901-2004
Herring recruits									.	-	-	+++	+++	+	.	.	-	.	.	-	-	+	.	.	.	.	.	.	-	-	.	.	-	-	.	1978-2004
May SST	+	-	-	.	+	-	-	+	++	++	+	++	-	+	-	-	-	.	.	.	.	.	-	+	.	-	+	.	-	-	.	.	.	+	+	1970-2004
COMU Productivity							.		+							+	-	+	+	.	.		.				.	-		-	.	+	+			1976-2002
AOI	-	.	.	+	.	+	+	--	-	-	.	.	.	.	.	-	-	-	.	++	+	+	+	++	.	+	-	.	.	+	+	-	+	.	-	1951-2004
Atka (R/S)								++	+	.	.	-	-	-	.	.	+	+	++	+	-	.	.	-	-	.	--	-	+	+	-					1977-2000
Total CPUE													-	.	-	--	-	.	.	.	.	.	.	+	++	+	.	.	.	.	.	.	.	++		1982-2003
BS Diversity													-	-	-	-	-	-	-	-	.	+	+	.	+	+	+	+	++	.	.	+	-	-		1982-2003
Jellyfish biomass													-	-	-	-	-	-	-	-	-	.	.	.	+	.	+	+	+	+	+++	.	.	.		1982-2003
AK Plaice (R/S)						++	++	+	.	.	.	.	--	--	.	-	-	.	-	.	-	+	.	+	-	.	.	.	.	.						1975-1999
Cod (R/S)								+++	++	++	+	.	+	-	.	.	-	-	-	.	.	-	.	-	-	-	.	.	.	.	.	-	.			1977-2002
Pollock (R/S)	-	-	.	.	+	+	+	+	++	+	+	.	+	-	.	-	--	--	-	.	.	.	+	-	-	.	.	-	-	.	.	-	-			1964-2002
BS Richness													+	+	.	--	-	--	-	-	.	+	.	+	.	-	.	.	+	.	.	+	-	++		1982-2003
Total crab biomass											+	.	.	-	-	-	-	.	.	+	++	++	.	.	.	.	.	.	.	-	-	-	-			1980-2002
BLKI Productivity						+	+	+	.	+					-	.	.	.	+	-	.		.	.	-	-	-	.	+	-	+	-	++			1975-2002
TBMU Productivity							++	.	+						--	.	.	.	.	.	.		.				.	-	--	.	.	.	+			1976-2002
RLKI Productivity						.	++	+	-	.					-	.	.	-	+	-	.	-	.	.	.	-	-	.	+	.	+	-	+			1975-2002
YFS (R/S)	+	+	++	++	++	+	+	.	.	.	.	.	-	.	-	-	-	-	-	-	-	.	-	-	-	-	-	-	-							1964-1998
POP (R/S)	.	.	.	.	.	.	+	+	+	+	+	++	+	+	+	+	+	.	.	.	-	-	-	-												1960-1993
Northerns (R/S)								+	.	.	.	-	-	.	++	.	-	.	+	+	-	-	-	+												1977-1993
GT (R/S)				+	+	+	+	++	+	+	.	-	--	-	.	+	.	.	-	.	+	-	-	-	-	.	-	-	-	.						1973-1999
ATF (R/S)							+	.	.	+	++	.	.	+	+	+	++	+	.	.	.	-	-	--	-	-	-	-	-							1976-1998
Rock sole (R/S)						+	.	.	.	.	+	+	+	+	+	+	+	+	.	.	.	.	-	-	-	--	-	--								1975-1997
FHS (R/S)								+	+	+	++	++	+	+	+	+	.	.	.	.	.	.	-	-	-	-	-	-	-	-	-					1977-2000
Summer Bottom Temp.													-	+	.	.	-	+	.	+	.	.	-	+	-	-	+	.	+	--	-	.	+	++		1982-2003
Hook and Line Effort																								-	-	-	-	.	.	.	+	++	+			1993-2002
AI Bottom Trawl Duration																					++	.	+	+	.	.	+	-	-	-	-	-				1990-2001
BS Bottom Trawl Duration																					-	.	+	.	+	+	+	+	-	-	-	--				1990-2001
BS Pelagic Trawl Duration																										.	++	.	+	-	-	.	.	.		1995-2003

Legend

+++	X>2.6
++	2.6>X>1.6
+	1.6>X>0.5
.	0.5>X>-0.5
-	-0.5>X>-1.6
--	-1.6>X>-2.7
	no data

Table 1 taken from the Appendix shows anomalies of 34 biotic, abiotic and human time series for the Bering Sea with different periods of record.

The Bering Sea is an ideal region for further application of the ecosystem approach to management and the use of indicators, building on present strengths and incorporating new concepts. Progress can be based on ideas developed at the 2004 symposium on "Quantitative Ecosystem Indicators for Fisheries Management" with respect to integration of lists of indicators relative to operational objectives. A purpose of indicators is to reduce subjectivity in ecosystem approach to management. Too many indicators create confusion and provide less clear guidance, while too few indicators cannot support decisions because they do not capture the complexity of ecosystems and/or objectives. Nine screening criteria for indicators have been proposed by the international community (ICES 2001, 2004): concreteness, clarity, scientific basis, availability, cost, measurability, sensitivity, specificity and responsiveness. A workshop format is an ideal venue for capturing a diverse set of concepts for future applications in the Bering Sea and North Pacific. The NPRB through its Science and Advisory Panels responded to this situation by requesting a specific Project Need to host a workshop for evaluation of the utility of ecosystem indicators.

The North Pacific Marine Science Organization (PICES) proposes to develop and host a workshop on Bering Sea ecological indicators for early April 2006 in conjunction with the NPFMC meeting in Anchorage, Alaska. This work will be carried out by four workshop Co-Convenors: Glen Jamieson (Canada), Gordon Kruse, Patricia Livingston and James Overland (U.S.A.) and PICES staff (Alexander Bychkov and Stewart (Skip) McKinnell). The next section details the issues to be addressed before and during the Workshop, and section 3 discusses the details of the Workshop.

2. Soundness of Design and Conceptual Approach

We propose four activities for a NPRB Ecosystems Indicators Workshop to be held in early April 2006, in conjunction with the NPFMC meeting in Anchorage. The Workshop would define operational objectives for an ecosystem approach to management in the Bering Sea (as a North Pacific case study) and advance the usefulness of indicators for the Bering Sea by further integration of available information:

- Involve the Bering Sea and international communities in development of a set of operational objectives for the southeast Bering Sea ecosystem. Contacts have been made with the international community, Alaska Department of Fish and Game, the Central Bering Sea Fisherman's Association, the Division of Subsistence-ADFG, the Alaska Fisheries Science Center, and the PICES scientific community. Other groups of scientists, managers and stakeholders will be encouraged to respond. A set of indicators can then be rationalized against a set of multiple objectives. Results from this process, once outlined, would be available to other PICES regions in the North Pacific.
- Evaluate the framework for ecosystem impacts assessment and use of indicators in the "Ecosystem Considerations" Appendix for the Bering Sea and the PICES Ecosystem Status Report, with a goal of suggesting methods for integration of the results and streamlining the presentation of the material. The international community of scientists involved with indicators and ecosystem approach to management can be invited to the Workshop to help address these issues from Canada and an international SCOR Working Group, for example, R. O'Boyle, J. Rice, and P. Cury.
- Investigate whole-system methodologies for indicators that preserve information about the relationships among classes of indices, *i.e.*, that monitor structural changes within the marine ecosystem. This higher level of aggregation should provide greater stability in estimates of a state or trend, and can be used in coordination with other presentation methods.
- Identify next steps in validating indicator performance, improving the monitoring network to provide key missing indicators, and integration into predictive models.

Pre-activities for the workshop will consist of development of working papers on the first three areas (and software for Task 3) for formal evaluation by the participants before and during the workshop, followed after the Workshop by a report in the PICES Scientific Report Series with recommendations for implementation. A scientific article in an international peer-reviewed journal based on our experience is also planned. PICES has a successful history of providing consensus science reports based on workshops as proposed here, and has just initiated a Working Group on to address similar issues for North Pacific countries. The next four sub-sections expand on the four activities.

A) Task 1: Involve the Bering Sea and international communities in development of a set of operational objectives

Gordon Kruse will lead this effort to develop a set of operational objectives for the Bering Sea based on expanded community involvement. A working paper will be prepared before the workshop in which tentative operational objectives are more fully developed for critical evaluation and modification by workshop participants. Gordon serves on the Scientific and Statistical Committee of the North Pacific Fishery Management Council and is familiar with research activities of NMFS-AFSC, ADFG and other marine research organizations. We have made contact with the groups listed below. Others will be contacted as the plan for the Workshop develops.

The Alaska Department of Fish and Game manages sockeye salmon and the largest herring fishery in Alaska at Togiak in northern Bristol Bay. Sockeye salmon returns have recently decreased and herring prices have declined, so the value of fisheries is heavily dependent on the ability of ADFG to manage the harvest. The timing of herring runs also has implications for migrations of other species, such as marine mammals and birds. Gordon is currently wrapping up a NPRB-funded study that is developing better forecast models of herring spawning timing for direct use by ADFG fishery managers and industry participants to set fishery openings that optimize roe product quality for the highly competitive world herring markets. ADFG also manages the largest crab fisheries in the United States. Causes for wide fluctuations in crab stocks remain largely unknown, but fluctuations appear to be largely environmentally driven. Wayne Donaldson and Lowell Fair are principal ADFG contacts.

The Central Bering Sea Fishermen's Association (CBSFA) represents St. Paul Island, the largest Aleut community in the world. St. Paul is located near the center of several major Bering Sea fisheries, including crab, cod, pollock, and halibut. Changes in marine resources have had a major impact on this community in recent years. Not only has there been greatly reduced availability of fur seal, but also the Pribilof Islands king crab fisheries were closed in 1990 – 1994 and 1999 – 2003 owing to low crab abundance. They are represented by Heather McCarty.

The Division of Subsistence of ADFG provides comprehensive information on the customary and traditional use of wild resources in Alaska. They furnish this information to meet resource management goals. They assist in developing regulations, facilitating collaborative agreements, assessing environmental impacts and describing the unique role of wild resources in the lives, communities and culture of Alaskans. Mary Pete is the Director and our collaborator.

The National Marine Mammal Laboratory of the Alaska Fisheries Science Center is responsible for providing advice on the status of northern fur seals and Steller sea lions to the NPFMC, Indigenous Peoples Council and the Office of Protected Species. The Endangered Species Act requires that marine mammals be monitored and their population trends assessed. Without this information, commercial fisheries and subsistence harvest could be restricted. Susan Moore and Elizabeth Sinclair are most interested in tracking changes in the Bering ecosystem as it affects mammal population shifts.

B) Task 2: Review the current framework proposed for the ecosystem assessment contained in the "Ecosystems Considerations" Appendix and the PICES North Pacific Ecosystem Status Report

In 2003, an integrating section in the "Ecosystems Considerations" Appendix called an "Ecosystem Assessment" was outlined (http://www.afsc.noaa.gov/refm/docs/2003/APPENDIX%20C%20Ecosystem%20Considerations%20Chapter.pdf), which provides analysis of key indicators in an ecosystem impacts framework, which had been previously developed in Programmatic Supplemental Environmental Impact Statement (EIS) for Alaska Groundfish Fisheries (NMFS, 2004). To illustrate the types of considerations that will be evaluated under Task 2, Table 2 lists three conceptual ecosystem goals that were outlined in the EIS. This framework is organized to assess impacts under the overarching goals of: maintaining trophic relationships, maintaining ecosystem energy flow and balance, and maintaining different types of diversity (species, functional, genetic). This framework has identified more specific objectives underneath these broader, conceptual goals and a subset of indicators that could be used (Livingston *et al*. in press).

The framework of ecosystem management for the Bering Sea as developed in the "Ecosystems Considerations" Appendix can be improved through

1) identification of more explicit operational objectives (a task requiring stakeholder involvement);
2) integration of results (*i.e*., further consideration of composite ecosystem indicators); and
3) streamlining presentation for clarity.

The "Ecosystem Considerations" Appendix of the NPFMC SAFE Report will be reviewed and compared with conceptual level guidelines (NOAA for Regional Marine Ecosystem Approaches to Management, consistency with the NOAA Strategic Plan, and international plans) and efforts to develop performance indicators with regard to ecosystem approaches to management, particularly FAO, SCOR, and ICES. *Indicators* will be reviewed based on the operational objectives developed from Task 1. The issues of integration of indicators into ecologically relevant classes and presentation methods will be examined. The structure of the PICES North Pacific Ecosystem Status Report will also be examined with regard to these guidelines and approaches.

C) Task 3: Assessment of aggregate indicators

New methods should be investigated for application to the Bering Sea and North Pacific. There are three levels of possible aggregation of indicators: single time series, composite indicators and a whole system analysis. Many single and composite indicators are already part of the "Ecosystem Consideration" Appendix. Examples are calculation of total biomass from the biomass of individual species, the trophic level of the catch, fish community size spectrum, and species richness and diversity. Review of these existing indicators will be accomplished in Task 2. In Task 3 we will develop tests for assessing abrupt alterations in the ecosystem, seen as climate shifts and changes in community composition, based on preserving information about the relationships among a large set of indicators. This effort will be lead by James Overland.

In recent years, a new line of research has emerged in statistical quality control and econometric modeling. Given that in the real world new data arrive steadily, it is more natural to check whether incoming data are consistent with previously established relationships, *i.e*., the internal structure and stability of the historical data set across variables and indicators.

Table 2. Goals, objectives, significance thresholds and indicators for fishery-induced effects on ecosystem characteristics (MBAL - minimum acceptable biological limits; MSST - minimum stock size threshold).

Goal	Objective	Significance threshold	Indicators
Maintain predator-prey relationships	Maintain pelagic forage availability	Changes outside natural level of abundance or variability for a prey species relative to predator demands	Population trends in forage biomass (quantitative – walleye pollock biomass, Atka mackerel, non-target species such as squid and herring)
	Reduce spatial and temporal concentration of fishery impact on forage fish	Concentration high enough to impair long-term viability of non-resource species such as marine mammals and birds	Degree of spatial/temporal concentration on forage species (qualitative – species as above)
	Reduce removals of top predators	Catches high enough to cause biomass of a top predator to fall below MBAL	Trophic level of catch Sensitive bycatch levels (quantitative: sharks, birds; qualitative: pinnipeds) Population status (whales, pinnipeds, seabirds) relative to MBAL
	Reduce introduction of non-native species	Exchange of ballast water and hull fouling organisms high enough to cause viable introduction	Total catch
Maintain energy flow and balance	Reduce human-induced energy re-direction	Long-term changes in system biomass, respiration, production or energy cycling caused by discarding and offal production practices that are outside the range of natural variability	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	Long-term changes in system biomass, respiration, production or energy cycling caused by fishery removals that are outside the range of natural variability	Trends in retained catch (quantitative)
Maintain diversity	Maintain species diversity	Catches high enough to cause biomass of one or more species to fall below, or to recover from, MBAL	Population size relative to MSST or ESA listing thresholds, linked to removals (qualitative) Bycatch of sensitive (low population turnover rate) species that lack population estimates (quantitative: sharks, birds, structural habitat biota) Number of ESA listed marine species Amount of area closed to fishing
	Maintain functional (trophic, structural habitat) diversity	Catches high enough to cause a change 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) Structural habitat biota bycatch
	Maintain genetic diversity	Catches 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 MBAL	Degree of fishing on spawning aggregations or larger fish (qualitative) Older-age-group abundance of target groundfish stocks

As an example of Task 3 activities, this paragraph outlines one method in some detail. Consider a standard multiple linear regression model:

$$\boldsymbol{Y}_t = \boldsymbol{X}_t \boldsymbol{\beta}_t + \boldsymbol{\varepsilon}_t \quad (t = 1, \ldots, n, n+1, \ldots),$$

where at time t, $\boldsymbol{Y}_t$ is the observation vector of m target variables, $\boldsymbol{X}_t$ is the vector of $k + 1$ predictors, and $\boldsymbol{\beta}_t$ is the $m\times(k + 1)$ matrix of regression coefficients. The data from $t = 1, \ldots, n$ is referred to as the history period, where the regression coefficients are assumed to be constant, i.e., $\boldsymbol{\beta}_t \equiv \boldsymbol{\beta}_0$, $t = 1, \ldots, n$. New data are monitored from time $n + 1$ onwards to test whether structural change occurs in this monitoring period, *i.e.*, whether $\boldsymbol{\beta}_t = \boldsymbol{\beta}_0$ $(t > n)$ against the alternative that the coefficient matrix $\boldsymbol{\beta}_t$ changes. A second group of tests are based on monitoring the residuals $\boldsymbol{\varepsilon}_t$. We are particularly interested in investigating the ecological constraints that follow from the mathematical properties of $\boldsymbol{\beta}_t$. We propose an index that monitors structural changes for the entire system. This structural discontinuity index (SDI) is defined as a sum of the residuals proportional to the multiple correlation coefficients ($\boldsymbol{R}$) between the individual target variable and its predictors:

$$SDI_t = \frac{1}{m}\sum_{i=1}^{m} \varepsilon_{ti} R_i .$$

We will employ a running window technique with an adjustable window size, as in Rodionov (2004) to evaluate the temporal structure of the regression coefficients and monitor the SDI. The basic idea is that during a given regime all the components of the ecosystem are adjusted to each other, so that the SDI fluctuates around a constant value. When a shift occurs, the links between these components break, and the degree of the system disruption as expressed by the SDI, reaches a maximum.

A major obstacle to ecosystem approach to management is the role of uncertainty in recommendations for adjustment to changes in the climate/ecosystem state. The proposed methods, in part through understanding the stability of the $\boldsymbol{\beta}_t$ matrix, are designed to improve the reliability of ecosystem indicators developed from simultaneous quantitative analysis of ecosystem data sets. A software package with two modules (a fluctuation test and SDI) will be developed using VBA for Excel and made available to the Workshop.

In addition to uncertainty, a second issue is reconciliation of conflicting information. An approach to be investigated is called Bayesian Belief Network. A belief network is constructed to update conditional probabilities associated with different components of the system. The divergence between prior and posterior probability distributions is used as indication of inconsistency between statistical model structure and parameter values. An iteration scheme forces prior and posterior distributions to become equal. This helps to resolve inconsistencies between different sources of information.

D) **Task 4:** Prepare a workshop report identifying recommendations and next steps

This activity would be lead by the Workshop conveners plus Skip McKinnell of the PICES Secretariat. Preparation includes contributions which balance Bering scientists and external scientists with a broader perspective on synthesizing the workshop results. A scientific article in an international peer-reviewed journal based on our experience is also planned.

3. Project Management, Workshop Details, and Project Costs

The 3-day Bering Indicator Workshop of intermediate scope (40 participants) is envisioned. The goal of the workshop is to provide a report on the merits and recommendation for use of various classes of ecosystem indicators, through the application of selection criteria and their correspondence to operational objectives developed before and during the workshop. Participants would be international and regional experts on resource management, climate, fisheries and ecosystems. Key suggestions and evaluations would be provided by invited scientists with considerable expertise in the application of indicators as represented by members of the SCOR Working Group 119. The Co-Convenors for the Bering Indicators Workshop would be Glen Jamieson (Canada), Gordon Kruse, Patricia Livingston and James Overland (U.S.A.).

Three working papers will be developed before the meeting: (1) on operational objectives for the Bering Sea, (2) on the ecosystem assessment contained in the "Ecosystem Considerations" Appendix and PICES Ecosystem Status Report, and (3) on application of aggregate methods to the Bering Sea. The workshop format would consist of first day presentation of the working papers and formal comments, followed by discussion and consideration of alternate viewpoints. The second day would be contributed presentations and discussion on the current status of the Bering Sea ecosystem and alternative indicator methods. The third day would develop a summary of recommendations from the first and second day for discussion and approval. Next steps would be outlined, particularly with reference to evaluating performance, and resource managers would comment on the utility of the workshop from their perspective.

The three working papers are lead by Bering scientists (Kruse, Livingston, Overland) while the synthesis post-Workshop report and an article in a peer-reviewed journal involves these authors and includes those with a more distant perspective (Jamieson, McKinnell, Perry). While the PICES Secretariat (Alexander Bychkov**)** has responsibility for the implementation of the workshop and completion of the report, the scientific content is the responsibility of the conveners.

Outreach is the heart of our proposal. There is community involvement before, during and after the workshop. A project website that contains working papers, workshop information, abstracts of presentations and the post-workshop report will be created on the PICES server (http://www.pices.int). PICES will work with the NPRB and its education contractors to provide summary information for the public.

<u>Timetable and Deliverables</u>

July 2005	Begin contacts to develop working papers (Gordon Kruse for operational objectives for the Bering Sea; Patricia Livingston for evaluation of the current framework for the ecosystem assessment contained in of the "Ecosystem Considerations" Appendix and PICES NPESR; and James Overland for assessment_aggregated indicators)
August 2005	Development of the project website
February 2006	Completion of three working papers; provision of software
April 2006	Workshop in Anchorage
August 2006	Review findings with stakeholders
September 2006	Completion of PICES Report on Workshop recommendations
October 2006	Presentation and discussion of results at the PICES Fifteenth Annual Meeting
January 2007	Presentation of results at Alaska Science week; completion of a manuscript for journal publication.

PICES has considerable experience conducting workshops and providing results, including reports in the PICES Scientific Report Series, special journal issues of collected scientific articles, or consensus advice on particular topics. An abbreviated list of such activities since 2000 is provided as Table 3.

Table 3 Selected symposia and workshops organized/co-organized by PICES in 2000-2005

PICES Annual Meetings (with 10-12 Topic Session and 5-7 workshops), every October; Special issues are produced from some sessions/workshops, *e.g.* a special issue of *Progress in Oceanography* on "*Variability in the Bering Sea ecosystem*", 2002, Vol. 55 (1-2): 1-261, which is based on selected papers presented at the Topic Session on "A decade of variability in the physical and biological components of the Bering Sea ecosystem: 1991-2001".

Beyond El Niño – Conference on "Pacific climate variability and marine ecosystem impacts", March 23-26, 2000, La Jolla, U.S.A. (co-sponsored by IATTC, IPHC, ISC, NPAFC and SCOR); Selected papers are published as a special issue of *Progress in Oceanography*, 2001, Vol. 49 (1-4): 1-639.

Symposium on "North Pacific CO_2 data synthesis", October 18-21, 2000, Tsukuba, Japan (co-sponsored by several Japanese organizations: JST, MIRC/JHA, NIES/GCER).

Workshop on "Impact of climate variability on observation and prediction of ecosystem and biodiversity changes in the North Pacific", March 7-9, 2001, Honolulu, U.S.A. (co-sponsored by CoML and IPRC); Proceedings are published as *PICES Scientific Report*, 2001, No. 18, 210 pp.

Symposium on "North Pacific transitional areas", April 23-25, 2002, La Paz, Mexico (co-sponsored by CIBNOR and CICIMAR); Selected papers are published as a special issue of *Journal of Oceanography*, 2003, Vol. 59 (4): 387-535.

Symposium on "Recent progress in studies of physical processes and their impact to the Japan/East Sea ecosystem", August 22-24, 2002, Seoul, Korea (co-sponsored by CREAMS); Selected papers are published as a special issue of *Progress in Oceanography*, 2004, Vol 61 (2-4): 103-348.

PICES/GLOBEC/ICES Zooplankton Production Symposium on "The role of zooplankton in global ecosystem dynamics: Comparative studies from the World Oceans", May 20-23, 2003, Gijon, Spain; Selected papers are published as a special issue of *ICES Journal of Marine Science*, 2004, Vol. 61 (4): 441-737.

Third PICES Workshop on "Okhotsk Sea and adjacent areas", June 4-6, 2003, Vladivostok, Russia (co-sponsored by CoML and TINRO-Center); Proceedings are published as *PICES Scientific Report*, 2004, No. 26, 275 pp.

Two meetings of PICES Study Group on "Fisheries and ecosystem responses to recent regime shifts" to deal with the U.S. request for scientific advice on the implications of the 1998 regime shift for North Pacific fisheries, February 9-10, 2004, Victoria, Canada, and June 14-16, Seattle, U.S.A.; Results will be published in the *PICES Scientific Report Series* and as a glossy brochure.

Symposium on "Quantitative ecosystem indicators for fisheries management", March 31-April 3, 2004, Paris, France (co-sponsored by IOC, SCOR, PICES, ICES, FAO, GLOBEC, NOAA/NMFS, e); Selected papers will be published as a special issue of *ICES Journal of Marine Science*, in early 2005.

GLOBEC/PICES Symposium on "Climate variability and sub-Arctic marine ecosystem", May 16-20, 2005, Victoria, Canada (co-sponsored by DFO, ICES, NPRB, NOAA/NMFS, NSF); Selected papers will be published as a special issue of *ICES Journal of Marine Science*, in 2006.

4. Summary - Rationale for refinement of ecological indicators for the Bering Sea

A challenge is to investigate and monitor aspects of the North Pacific ecosystem so that we have a greater understanding of the causes for increases or decreases in major marine populations. Through feedback from long-lived species by top-down predation and bottom-up climatic control, recruitment may be altered for fish and invertebrates.

In recent decades, certain species of the Bering Sea ecosystem show changes in abundance or distribution, which in many cases correlate with physical variability, most notably the shift from cold to warm conditions after the mid-1970s and the warm springs of the late 1990s and early 2000s (Overland and Stabeno, 2004). The winter of 2003 was the first known year that the Bering Sea middle shelf did not completely mix to the bottom for a significant portion of winter. Recent increases in the number of extreme events, such as the coccolithophorid bloom, have the potential to alter recruitment patterns of commercial and subsistence marine populations. If such events continue, their impact may be such that warmer bottom temperatures would allow expansion of the range of temperate epibenthic-feeding fish into subarctic and arctic habitats and create severe competitive pressure on benthic-foraging marine mammal populations of the central Bering Sea. Changes would also include expansion of economically important species. The next decade is a critical time for possible reorganization of the Bering Sea. A continued upward trend of the Arctic Oscillation climate pattern and/or more general Arctic warming will preferentially impact boreal seas. Recent early retreats of sea ice in the Bering Sea are particularly disturbing; this impacts top predators, the timing and productivity of zooplankton as prey for fish communities, and a shift from cold to warm species based on temperature regulation.

Our proposed Workshop builds on current strengths and incorporates new concepts and ideas. It provides the framework for making the best use of existing information sources, to address the likely potential changes in the Bering Sea over the next decade. Investigation of this methodology for the Bering Sea will have a wider application to the North Pacific and other regions.

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