

## **Indicators of Status and Change within North Pacific Marine Ecosystems: A FUTURE Workshop**

A 3 day workshop entitled “*Indicators of Status and Change within North Pacific Marine Ecosystems*” was held April 26-28, 2011 at the East-West Center (University of Hawaii), Honolulu, Hawaii, USA (see Appendix 1 for agenda). The co-convenors of the workshop were Sachihiko Itoh (Japan), Jacquelynne King (COVE-AP; Canada), and Thomas Therriault (AICE-AP; Canada) and the workshop was very well attended with over 45 participants; including 14 contributors (see Appendix 2 for abstracts). With the support of PICES, 4 invited speakers, Marta Coll M6nton (Institute of Marine Science, Spain), Jake Rice (Fisheries and Oceans Canada, Canada), Beth Fulton (Commonwealth Scientific and Industrial Research Organisation, Australia) and Sarah Gaichas (National Marine Fisheries Service, USA) provided provoking presentations on the three main workshop themes: (1) *Ecosystem-level Indicators and Assessments*, (2) *Ecosystem Resilience*, and (3) *Indicator Uncertainty*. This workshop was organized by the FUTURE Advisory Panels, and its main goal was to impart existing approaches and concepts to the PICES community in order to provide direction on elements of the FUTURE Science Plan.

### *Ecosystem-level Indicators and Assessments*

The selection and assessment of ecosystem-level indicators has been conducted by a number of collaborative programs and initiatives elsewhere, and Marta Coll M6nton provided a thorough background on the Indicator of the Seas Project (IndiSeas), which was launched in 2005 under the auspices of the EUR-OCEANS Scientific Programme as a follow-up to the SCOR/IOC Working Group 119 on “Quantitative Ecosystem Indicators”. The intent of this project was to evaluate the effects of fisheries on different marine ecosystems using a panel of ecological indicators, and to facilitate effective communication of potential ecological changes. Indicators were selected based on four criteria: (1) ecological significance (i.e. are the underlying processes essential to the understanding of the functioning and structure of marine and aquatic ecosystems?), (2) measurability: availability of data required for calculating these indicators, (3) sensitivity to fishing pressure, and (4) awareness of the general public. In the IndiSeas approach, local experts play a critical role, especially interpreting indicator outputs. Phil Levin (NMFS, USA) presented the outcome of an initiative for the Puget Sound ecosystem that involved both scientific experts and the general public. The Puget Sound initiative first identified goals for ecosystem ‘health’ and then developed a framework to select appropriate indicators. The framework identified ecosystem attributes for each goal, used specific criteria for indicator selection, and developed a portfolio of indicators based on a ranking/weighting of criteria. In the European Union (EU), the Marine Strategy Framework Directive has tasked Member States with developing Marine Strategies to achieve good environmental status by managing human pressures/drivers in order to protect and preserve the marine environment and prevent/reduce adverse inputs to the marine environment (Bego6na Santos, IEO, Spain). Eleven descriptors of good environmental status have been identified and ICES has been tasked to help select indicators to summarise information for management by 2012. A pilot study in Toyama

Bay, Japan, has been established to develop a new marine environmental assessment methodology which has two purposes: assessing the marine environment comprehensively and creating a suitable environment for marine life including the restoration of degraded environments (Takafumi Yoshida, NPEC, Japan). In 2010, the Alaska Fisheries Science Center undertook a new approach for its annual ecosystem assessment for the eastern Bering Sea (Stephani Zador, NMFS, USA). An interdisciplinary team of experts identified potential concerns for fishery management and endangered species issues and selected broad, community-level indicators of ecosystem-wide productivity, that were most informative for managers. These included the North Pacific Index, Eastern Bering Sea ice retreat, aggregate biomass indices for zooplankton, epifauna, benthic foragers, pelagic foragers, fish apex predators, fur seal pup production, thick-billed murre reproductive success, and bottom trawl disturbance. A number of parameters or ecosystem-components could serve as integrative indicators of ecosystem change and at the workshop two presentations were given on this topic. The first showed how natural stable isotope levels in higher trophic-level animals could provide integration across trophic levels of ecosystem changes (Thomas Kline, PWSSC, USA). Isotope records provide spatial and temporal variation due to climate change, recruitment, and growth rate. Similarly, another integrative indicator could be gelatinous zooplankton (Hiroaki Saito, FRA, Japan). In the Kuroshio Extension Region filter-feeding gelatinous zooplankton composition appears to be a potential indicator of zooplankton succession and nutrient depletion. Irrespective of how indicators are selected, their performance must be tested, especially for application to management (Jake Rice). Indicators need to represent the true properties that they are meant to measure; track progress in meeting objectives; respond to change; and inform decision-making. Performance testing of indicators can be undertaken with retrospective modeling and analysis; scenario modeling and analysis; management strategy evaluation or formal decision analysis. Isaac Kaplan (NMFS, USA) highlighted that whether indicators are used to detect status and change, or to make regional comparisons, the spatial scale of the underlying processes must be taken into account. Many ecosystem attribute-indicator relationships that are strong at a coast-wide scale break down at regional or local scales, and indicators must represent the processes at the appropriate spatial scale.

Workshop discussion highlighted that the PICES community would like to compare ecosystem indicators across North Pacific ecosystems (similar to the IndiSeas initiative), recognizing that identification of thresholds would be critical but potentially difficult to do. For ecosystem comparisons, it would be desirable to have both state and trend indicators provided but workshop participants noted that in many cases data limitations will restrict the development of similar indicators across all ecosystems. In addition, workshop participants debated the utility of ecosystem indicators that required the interpretation by local experts, as is the case for IndiSeas ecosystem indicators. If PICES focuses on communicating to external audiences, then ideal ecosystem indicators would be readily understood by a wide range of users, including non-experts. The ecosystem indicator work in Puget Sound provided a foundation for the workshop participants in identifying some common components used by a number of ecosystem indicator projects, and outline a framework for selecting ecosystem indicators. In general, researchers identify the overarching goal (e.g. measuring ecosystem health), and deconstruct that goal by selecting attributes of the ecosystem that reflect the objective and criteria that select

indicators of the attributes that are meaningful. If PICES undertakes long-term reporting on ecosystem indicators for FUTURE (e.g. status and trends report), then experience from the Alaska Fisheries Science Center (and elsewhere) suggests that using a report-card approach that presents indicator trend and status in a standardized format can be beneficial. A report-card with longstanding indicators also could be amended as hot (emerging) topics are identified.

### *Ecosystem Resilience*

The concept of ecosystem resilience features prominently in the FUTURE Science Plan and is specified in one of its' key research questions: "*What determines an ecosystem's intrinsic resilience and vulnerability to natural and anthropogenic forcing?*". Forecasting the response of ecosystem resiliency and vulnerability to stressors could involve ecosystem indicators that measure these attributes. However, there were no contributed papers to this theme of the workshop. Beth Fulton outlined some of the difficulties in measuring ecosystem resilience and vulnerability, namely that ecological resilience is difficult to assess and measure *a priori* and is often known only after the fact. Beth defined ecosystem resilience as the level of disturbance before the system changes to an alternate state. Resilience is a feature of the ecosystem controlled by internal system dynamics, such as predator-prey relationships, rather than a state of the ecosystem such as .... A state will have variability defined in space and time, and key to resilience are thresholds, past which a system may be perturbed into an alternate state. The difficulty will be in identifying ALL possible alternate states; however, it might be possible to identify threshold points based on observation or modeling. Methods of comparing current system states to threshold values include: (1) case studies of observed alternative system states (e.g. anchovy vs. sardines), (2) experiments, or active adaptive management, (3) exploration with ecosystem models, (4) mapping alternate ecosystem habitats, (5) mapping ecotones (i.e. edges of ecosystems) and species groupings at critical process spatial scales, and/or (6) measuring diversity as a surrogate for resilience. It is important to note that management can degrade an ecosystem's resilience, further complicating the issue.

Ecosystem resilience appears to be a very difficult topic to define and subsequently to develop specific research projects/programs to address. The workshop discussion centered on identifying differences between resilience and vulnerability, debating if PICES can outline researchable topics on resilience and vulnerability and if it is possible to measure and forecast either, with no consensus on these discussion topics reached by participants. If resilience is defined by a stable state, then to some degree there is a subjective determination of the 'tipping point' from that state. Society may determine desirable states, however, based solely on ecological function the ecosystem dynamics and properties determines the boundaries of each ecosystem state. These boundaries may be outside what society finds desirable. Vulnerability also is entwined with societal definitions, and human dimensions are part of the definition of sensitivity to change (e.g. what percentage of the workforce is dependent on fishing). Measuring resilience will require the identification of the underlying ecosystem processes that determine resilience.

An alternate may be to identify threshold values of alternate stable states and to identify their metrics. There are statistical time series techniques that provide measures of stability (i.e. resilience) that might be used here. However, these techniques require intensive amounts of data. Participants generally agreed that existing zooplankton time series data would be appropriate and that there may be 2-3 North Pacific ecosystems that have suitable zooplankton time series already available for such an analysis. FUTURE could focus in the next 1-3 years on these ecosystems to illustrate the use of resilience metrics and describing how resilience may change overtime either in a FUTURE-based Working Group or technical workshop. This focus might provide an analytical framework that FUTURE could apply to investigating means of forecasting resilience and communicating resilience metrics.

### *Indicator Uncertainty*

Measuring and reporting uncertainty in indicator values is relevant when there are threshold points or reference levels although thresholds are lacking for a number of indicators (Sarah Gaichas). Indicator uncertainty arises from field monitoring, statistical models, and mechanistic models (or combinations of all three). There are several types, or classes, of uncertainty: (1) natural variability (e.g. process noise), (2) observation error (e.g. sampling variability and bias), (3) model structural complexity (i.e. when parameterizations outstrip data available), (4) inadequate communication between scientists, scientists-managers, managers-stakeholders, etc (5) unclear management objectives, and (6) implementation or outcome uncertainty. Uncertainty must be included in indicator development and risk tolerance levels must be included in threshold development. Communication of indicator status and change requires clear communication with stakeholders that is relevant to their interests or objectives. Mark Dickey-Collas (IMARES, Netherlands) presented the EU Marine Strategy Framework Directive requirement for reference points and threshold levels to be identified for the eleven descriptors of good environmental status by 2012. For some descriptors, such as commercial fish, there already exists broad consensus on suitable reference levels. However, some reference levels, such as one for biodiversity, will be difficult to determine. Identification of reference levels in selected ecosystem indicators also is a challenge faced by the Korean National Investigation of Marine Ecosystems which is a national project to monitor and assess the status of coastal ecosystems in Korean waters (Sinjae Yoo, Kordi, Korea). Jay Peterson (OSU, USA) provided an example of communicating ecosystem indicator status to the general public, using a red, yellow, and green coded report card of ocean conditions that have been correlated to coho salmon survival in the northern California Current System. The visual representation is easy to follow, and supporting text conveys uncertainty in each indicator. This brings the discussion back to what level of information is needed for each end user, a question that will differ by user highlighting the need for increased involvement by SOFE within this context for FUTURE.

Workshop participants identified that elements of FUTURE require communication of uncertainty when conveying state, trend or forecasts of ecosystem indicators. Standard terms should be developed with oversight by SOFE as the communication method must

be tailored to the end user. PICES will need to draw on existing National or International programs that provide data for calculating ecosystem indicators and reference levels, and an obstacle will be the comparison of down-scaled metrics to up-scaled metrics. Information can be lost when indicators are derived from different spatial resolutions. Based on information presented, it appears that PICES' member countries will acquire advice that links to their existing management programs. This will require SOFE, as the communication arm of FUTURE, to identify the commonality between reference points or reference levels used by different member nations or end users. The intent would be to avoid confusion when communicating various requested reference points and thresholds as FUTURE moves forward.

### *Workshop Outcomes and Next Steps*

The third day of the workshop was devoted to discussion by the participants on issues surrounding (1) how to select ecosystem-level indicators of status and change; (2) the determination of ecosystem resilience or vulnerability; (3) methods to characterize uncertainty in indicators; and (4) whether common ecosystem indicators could be selected for regional comparisons by the PICES' community. The participants concluded that selecting common ecosystem indicators for regional comparisons would be premature and beyond the scope of the current workshop. Instead, Workshop participants recommended that all standing committees of PICES utilize the following common framework when identifying and calculating indicators for the common descriptors and attributes for North Pacific ecosystems:

1. identify the objective of selecting indicators
2. identify the end user
3. identify ecosystem attributes to be measured
4. apply the following criteria to select indicator for each attribute:
  - i. available regularly and in a timely manner applicable to the issue
  - ii. available as a time series
  - iii. statistical properties are understood and provided
  - iv. related to attribute either empirically or theoretically
  - v. specific to the attribute (i.e. how specific is the indicator to the processes being indexed?)
  - vi. spatial and temporal scales of indicator are appropriate to attribute
  - vii. responsive (sensitive to perturbation)
  - viii. relevant to objective
  - ix. understandable by target audience
  - x. provides a basis for comparison between ecosystemsEach criterion should be weighted for relevance to the end user identified.
5. identify indicator reference levels; otherwise report on the time series' statistics (e.g. current value relative to mean; trend; standard deviation)
6. test the performance of each indicator
7. identify a suitable method of communication that is based on end user and report indicator uncertainty

In addition to identifying a framework for selecting ecosystem indicators for use by PICES within FUTURE, workshop participants identified the need to create additional PICES Working Groups to start tackling the difficult topics of 1) ecosystem resilience, including metrics to measure and thresholds for comparisons; and 2) ecosystem vulnerability, especially the human dimension aspects of this topic.

Lastly, at the request of Governing Council, workshop participants reviewed and revised the Terms of Reference for a proposed PICES Working Group on multiple stressors.

### **Terms of Reference**

1. Identify and characterize the spatial (and temporal) extent of critical stressors in North Pacific ecosystems both coastal and offshore and identify locations where multiple stressors interact. Identify trends in these stressors if possible.
2. Review and identify categories of indicators needed to document status and trends of ecosystem change at the most appropriate spatial scale (e.g., coastal, regional, basin).
3. Using criteria agreed to at the 2011 PICES FUTURE Inter-sessional Workshop in Honolulu, determine the most appropriate weighting for indicators used for:
  - a. documenting status and trends
  - b. documenting extent of critical stressors
  - c. assessing ecosystem impacts/change
4. Review existing frameworks to link stressors to impacts/change, assessing their applicability to North Pacific ecosystems and identify the most appropriate for application to North Pacific ecosystems.
5. Determine if ecosystem indicators provide a mechanistic understanding of how ecosystems respond to multiple stressors and evaluate the potential to identify vulnerable ecosystem components.
6. For 1-2 case studies, identify and characterize how ecosystems respond to multiple stressors using indicators identified above. Are responses to stressors simply linear or are changes non-linear such that small additional stressors result in much larger ecosystem responses? Do different parts of the ecosystem respond differently (e.g., trophic level responses)? How do stressors interact?
7. Publish a final report summarizing results with special attention to FUTURE needs. This WG will focus primarily on delivery of FUTURE Questions 3 and 1 (outlined below).

### **Linkages to the FUTURE Science Plan**

1. What determines an ecosystem's intrinsic resilience and vulnerability to natural and anthropogenic forcing?
2. How do ecosystems respond to natural and anthropogenic forcing, and how might they change in the future?
3. How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?

## Appendix 1: Workshop Description and Agenda

### Workshop Description:

Ecosystems are affected by a number of natural stressors and, more recently, an increased number of anthropogenic ones. Ultimately, these stressors result in changes to ecosystem structure and function, which in turn can affect their overall productivity and the societies that depend on them. Metrics of ecosystem status are required to measure impacts of stressors and monitor change. Ecosystem indicators also could be used to identify systems that are resilient or vulnerable to stressors.

One of the themes of the PICES FUTURE Science Plan focuses on ecosystem resiliency and vulnerability to stressors and how these attributes might change in the in the future. In order to ensure scientists have the ability to detect ecosystem-level changes in a consistent and standardized way, common metrics must be developed. Further, in an attempt to understand the amount of inherent variability in marine ecosystems, these metrics also need to incorporate measures of uncertainty that can be conveyed to end users, including managers and policy makers.

The goals of this workshop will be to identify:

- 1) means of determining ecosystem resilience or vulnerability;
- 2) ecosystem-level indicators of status and change, including but not limited to fisheries-based indicators;
- 3) methods to characterize uncertainty in these indicators;
- 4) common ecosystem indicators to be used for regional comparisons by the PICES' community;

Please review the FUTURE Science Plan prior to this workshop ([http://www.pices.int/members/scientific\\_programs/FUTURE/FUTURE-main.aspx](http://www.pices.int/members/scientific_programs/FUTURE/FUTURE-main.aspx)). It outlines the key research questions (on pages 3-4) that underlie the objectives of this workshop.

### *Day 1: Ecosystem-level Indicators and Assessments*

9:00-9:20	Welcome and Outline of Workshop Objectives – J. King
<b>Convenor: Jacquelynne King</b>	
9:20-10:20	<i>Invited Speaker: Dr. Marta Coll <u>Mónton</u>, Institute of Marine Science, Barcelona, Spain</i> The IndiSeas experience to evaluate and communicate the ecological status of exploited marine ecosystems using data-based indicators, and additions from food-web modeling exercises
10:20-10:40	Philip <u>Levin</u> A framework for selection of ecosystem indicators for the California Current and Puget Sound Integrated Ecosystem Assessments
10:40-11:00	Coffee break
11:00-11:20	Thomas <u>Kline</u> Natural Stable Isotope Abundance as an Indicator of Status and Change within North Pacific Marine Ecosystems

11:20-11:40	Hiroaki <u>Saito</u> Temporal Succession of Ecosystem Structure in the Kuroshio Extension Region: Are Gelatinous Zooplankton Species Indicators of Ecosystem Status?
11:40-12:00	Bergona <u>Santos</u> Marine Ecosystem Indicators in Europe 1 – The Marine Strategy Framework Directive and ICES
12:00-13:30	Lunch
13:30-14:30	<i>Invited Speaker: Dr. Jake <u>Rice</u>, Fisheries and Oceans Canada, Ottawa</i> Performance Testing of Indicators: From Telling Stories to Informing Decisions
14:30-14:50	Takafumi <u>Yoshida</u> New Marine Environmental Assessment Method for Toyama Bay, Japan
14:50-15:10	Stephani Zador (presented by S. Gachias) A recent indicator-based assessment of the eastern Bering Sea
15:10-15:30	Coffee
<b>Convenor: Jacquelynne King</b>	
15:30-17:00	Discussion on Indicator Selection and Ecosystem Assessments

*Day 2 Ecosystem Resilience & Indicator Uncertainty*

<i>Ecosystem Resilience</i>	
<b>Convenor: Thomas Therriault</b>	
8:30-9:30	<i>Invited Speaker: Dr. Beth <u>Fulton</u>, CSIRO, Hobart, Australia</i> Resilience - do we know enough to say we're monitoring it?
9:30-10:30	Discussion on Ecosystem Resilience and FUTURE Science Workplan
10:30-11:00	Coffee
<i>Indicator Uncertainty</i>	
<b>Convenor: Sachihiko Itoh</b>	
11:00-12:00	<i>Invited Speaker: Dr. Sarah <u>Gaichas</u>, Alaska Fishery Science Center, Seattle, US</i> Uncertainty in ecosystem indicators: known knowns, known unknowns, and unknown unknowns
12:00-13:30	Lunch
13:30-13:50	Mark <u>Dickey-Collas</u> Marine Ecosystem Indicators in Europe 2 – Investigating reference levels to define good environmental status
13:50-14:10	Isaac <u>Kaplan</u> Performance Testing of Ecosystem Indicators at Multiple Spatial Scales for the California Current
14:10-14:30	Sinjae <u>Yoo</u> Ecosystem status assessment in Korea
14:30-14:50	Jay <u>Peterson</u> Indicators of Ocean Conditions in the Northern California Current



14:50-15:20	Coffee
<b>Convenor: Thomas Therriault</b>	
15:20-17:00	Discussion on Indicator Uncertainty and Measuring Reference Levels

*Day 3 Identifying Common Indicators in PICES regions*

<b>Convenor: Jacquelyne King</b>	
8:30-12:00	<p>Outline Indicator Selection Framework</p> <p>Identify Ecosystem Descriptors</p> <ul style="list-style-type: none"> <li>• unpack down to attributes</li> </ul> <p>Identify Criteria for Indicator Selection per attribute</p>
12:00-13:30	Lunch
<b>Convenor: Thomas Therriault</b>	
13:30-17:00	<ul style="list-style-type: none"> <li>• workshop recommendations <ul style="list-style-type: none"> <li>○ dealing with resilience and vulnerability (potential WG)</li> <li>○ application of indicator selection framework within PICES FUTURE</li> <li>○ potential research</li> </ul> </li> <li>• revise TOR of proposed Working Groups on <i>Ecosystem Responses to Multiple Stressors</i></li> </ul>

## Appendix 2: Abstracts of Workshop Oral Presentations

### Day 1

#### **The IndiSeas experience to evaluate and communicate the ecological status of exploited marine ecosystems using data-based indicators, and additions from food-web modeling exercises**

Marta **Coll-Monton**

Institute of Marine Science, Passeig Marítim de la Barceloneta, № 37-49, 08003, Barcelona, Spain. E-mail: mcoll@icm.csic.es

Synthetic and generic indicators are urgently needed to effectively monitor and soundly manage marine ecosystems while progressing towards an ecosystem-based approach to marine resources.

In 2005, the EUR-OCEANS IndiSeas Working Group was initiated to undertake a comparative study on EAF ecological indicators. Under this working group (<http://www.indiseas.org>, ICES Journal of Marine Science, 67(4)) a suite of community-to ecosystem-level data-based indicators was selected to represent a minimum list of indicators that are easy to calculate and agreed upon with respect to several criteria (ecological meaning, sensitivity to fishing, data availability, ecological objectives, and public awareness). Indicators were then calculated for several exploited marine ecosystems located worldwide using fishing data, monitoring results, and ecological databases. Comparative results were developed to provide insights on the relative current states and recent trends (1980-2005 and 1996-2005) of these ecosystems. The scope of this exercise was to evaluate the relative ecological status of different exploited ecosystems using simple and available indicators, including ecosystems that are normally excluded from studies that require more complex indicators only applicable to data-rich situations. The exercise also aimed at involving experts from each analyzed ecosystem.

Last November 2010, the second phase of IndiSeas, IndiSeas2, was launched. The main objective of IndiSeas2 is to refine the evaluation and communication of the ecological status of marine ecosystems subject to multiple drivers (climate, fishing) in a changing world in support of an EAF. Therefore, the working group aims to (i) update the ecological indicators of IndiSeas and expand the range of ecosystems included in the analysis, (ii) complement the initial list of indicators to explicitly include biodiversity and conservation-based, environmental and socioeconomic indicators, and (iii) further explore and test the indicators with development of new methods (integration, reference levels and modeling).

Complementary to data-based indicators, ecological modeling exercises can be used to develop and calculate ecological indicators. Ecological modeling can provide results to compare with data-based indicators, and can be used to hindcast past ecosystem states and project future ecosystem scenarios including multiple drivers and management goals.

In this communication, I will first provide an overview of IndiSeas objectives, methods and accomplishments. Then I will present the scientific plan and strategy of IndiSeas2, with an emphasis on the new biodiversity and conservation-based indicators.

Finally, I will highlight relevant results on ecosystem indicators using the widely used *Ecopath with Ecosim* food-web modeling approach ([www.ecopath.org](http://www.ecopath.org)), including broad indicators of ecosystem sustainability (such as the loss in production index and the associated probability of an ecosystem being sustainable fished).

### **A framework for selection of ecosystem indicators for the California Current and Puget Sound Integrated Ecosystem Assessments**

Phillip Levin, Jameal Samhour, Kelly Andrews and Greg Williams

NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Ave., Seattle, WA, 98112, USA. E-mail: [Phil.Levin@noaa.gov](mailto:Phil.Levin@noaa.gov)

A key challenge of Ecosystem-based Management (EBM) is the development of meaningful indicators that can provide useful information on ecosystem status and trends, and assess progress towards management goals. As part of the California Current Integrated Ecosystem Assessment, we developed a generalized framework for the methodical and transparent selection of ecosystem indicators. We applied the framework to the California Current LME and Puget Sound, the second largest estuary in the United States. Our approach integrates a variety of familiar approaches into one step-by-step approach that leads to consistent and reliable reporting on ecosystem condition. Importantly, the framework links indicators to policy goals, as well as a clearly defined indicator evaluation and scoring process, and results in a portfolio of useful and complementary indicators based on the needs of different users. Although indicator selection is often thought of as a scientific process, it is an intensely political process and often involves trade-offs between the scientific and social value of indicators. For both Puget Sound and the California Current LME, we will discuss ways in which our framework lays bare the politics of indicator selection, and we outline the means by which scientists and managers might operate along the trade-off between social and ecological value.

### **Natural Stable Isotope Abundance as an Indicator of Status and Change within North Pacific Marine Ecosystems**

Thomas Kline

Prince William Sound Science Center, Cordova, Alaska, USA. E-mail: [tkline@pwssc.org](mailto:tkline@pwssc.org)

Natural stable isotope abundance (NSIA) compliments more conventional biological ecosystem metrics such as body size, survival rate, and population as well as physical environmental parameters. In the north Pacific, NSIA has signaled change on geological, multi-decadal, and inter-annual time scales. NSIA variations are easily measured in higher trophic level consumers. NSIA variation is driven by primary producers and conserved in food chains so observations reflect processes driving upper trophic levels from the bottom up. Examples will be given that show relationships between NSIA and factors driving marine ecosystem change.

One basis for interpreting NSIA are maps showing spatial isotopic variation known as isoscapes. Isoscapes may follow zonal gradients. For example, very low C-13

values are associated with the organic carbon generated in iron-limited oceanic waters of the north Pacific whereas high C-13 values are associated with more productive coastal waters.

Physical processes operate to separate as well as to bring together disparate marine habitats. For example, mesoscale eddies facilitate exchange between oceanic and coastal waters while separating these water types at eddy fronts. The relative position of these eddies at the shelf edge during the spring drove local NSIA variability that was strongly correlated with salmon marine survival rate and recruitment.

NSIA can provide a history that is recorded in organismal hard structures such as otoliths, bones, scales, claws, vibrissae, and baleen. When organisms migrate across gradients within isoscapes the isotopic variation is recorded in these hard parts. An historical collection can be used as an indicator of change in migration pattern.

Ontogenetic, gender, and large-scale spatial NSIA variations have been measured in Pacific halibut, a long-lived, migratory, large, sexually dimorphic fish that is broadly distributed in the region. Because they have previously undergone long-term population change, there is the expectation of seeing long-term NSIA shifts with respect to one or more of these factors.

Fish recruitment may depend on species interaction shifts that can be detected using NSIA. For example, one can observe seasonal shifts in species interaction through differences in isotope value overlap. The degree of overlap may vary among years and drive recruitment. Species interactions may shift according to species-specific environmental sensitivity such as response to colder or warmer temperatures that favor one species over another.

### **Temporal Succession of Ecosystem Structure in the Kuroshio Extension Region: Are Gelatinous Zooplankton Species Indicators of Ecosystem Status?**

Hiroaki **Saito**<sup>1</sup>, Ken Furuya<sup>2</sup>, Kiyotaka Hidaka<sup>3</sup>, Mutsuo Ichinomiya<sup>4</sup>, Yuichiro Nishibe<sup>1</sup>, Yuta Nishibe<sup>2</sup> and Kazutaka Takahashi<sup>1</sup>

<sup>1</sup> Tohoku Natl. Fish. Res. Inst., Fisheries Research Agency, Shinhama-cho, Shiogama, Miyagi 985-0001, Japan

<sup>2</sup> Graduate School of Agricultural and Life Sciences, The University of Tokyo, Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan

<sup>3</sup> National Research Institute of Fisheries Science, Fisheries Research Agency, Fukuura, Kanazawa, Yokohama 236-8648, Japan. E-mail: hsaito@affrc.go.jp

The Kuroshio Extension (KEX) Region is the key area of pelagic fish recruitment such as sardine, anchovy, mackerel. The recruitment success of pelagic fish is largely influenced by the physical oceanographic condition in the KEX. The RPS (recruitment per spawner) index of Japanese sardine is positively correlated with the wintertime mixed layer depth and negatively correlated with SST in the KEX. Ecosystem model study indicated that the shallow mixed layer and high temperature induced the early initiation of spring bloom (February) which mismatch with the arrival of larval fish to the KEX (April-May). The prey plankton composition and its seasonal succession are, however, not well understood in the KEX. In the SUPRFISH (Studies on Prediction and Application of Fish Species Alternation) programme, we investigated horizontal and temporal change in the plankton composition. Phytoplankton assemblage succession from micro-nano-picophytoplankton mixed assemblage to picophytoplankton dominated assemblage was observed with consumption of nutrients. Copepods, the main prey for larval and juvenile fish, decreased with increase in the fraction of picophytoplankton. During the phytoplankton

succession, gelatinous zooplankton such as salps and doliolids increased. These results suggested that filter-feeding gelatinous zooplankton play an important role of phytoplankton succession in the KEX. It is also suggested that zooplankton assemblage succession from copepod to salp and then doliolids. We will discuss the potential use of zooplankton composition as an indicator of ecosystem status (phenology or degree of nutrient depletion) in the KEX.

## **Marine Ecosystem Indicators in Europe 1 – The Marine Strategy Framework Directive and ICES**

M Begoña **Santos**<sup>1</sup> and Graham J. Pierce<sup>2</sup>

<sup>1</sup> Instituto Español de Oceanografía, Centro Oceanográfico de Vigo, Apdo. 1552, 36200 Vigo, Spain E-mail: m.b.santos@vi.ieo.es

<sup>2</sup> University of Aberdeen, School of Biological Sciences, Tillydrone Avenue, Aberdeen AB24 2TZ, Scotland, UK E-mail: g.j.pierce@abdn.ac.uk

Indicators are “instruments that provide information”. Because ecological systems are so complex, indicators represent a logical solution to try to summarise large quantities of information about status and trends, and provide tools for managers/decision-makers to assess the health of ecosystems.

In Europe, ecosystem indicators have been taken forward into maritime policy, *e.g.* the adoption in June 2008 of the Marine Strategy Framework Directive (MSFD). The MSFD requires Member States to prepare national strategies to manage their seas so as to achieve or maintain Good Environmental Status (GES) by 2020. The Directive sets out eleven high level descriptors of GES and aims to enable sustainable use of marine goods and services by effectively managing human activities and pressures through an ecosystem-based approach. The Commission recently (September 2010) provided Member States with a detailed draft set of criteria and methodological standards to use as the basis for developing indicators and their associated targets of GES at national level.

ICES has several roles in addressing these scientific issues, including quality assurance in the choice and application of analytical methods that consolidate indicators; providing the narrative advice that correctly interprets the policy and management implications of these aggregate indicators, including dis-aggregation of such indicators to correctly reflect the information needed to guide management and policy responses.

### **Performance Testing of Indicators: From Telling Stories to Informing Decisions**

Jake **Rice**

Ecosystem Science Branch, Fisheries and Oceans Canada, Ottawa, ON, Canada. E-mail: Jake.Rice@dfo-mpo.g.ca

Indicators have many uses, including reporting on status and trends in ecosystem properties, and in triggering decision rules in management. One important lesson from the fisheries experience with full management strategy evaluations is that the properties that indicators need to be useful in reporting are less stringent than the properties needed to be reliable in guiding rule-based decision making. This talk will develop the implication of this lesson for broader classes of ecosystem indicators. Points to be addressed include:

- What is meant by rule-based decision-making, and why it matters even for ecosystem indicators;
  - What is meant by “performance” in these contexts, particularly with regard to different types of decision errors, risks of the different types of errors and tolerances for those risks;
  - Why performance testing is necessary for selecting indicators to support decision-making, and just “having a good ecological basis” may not be enough;
  - What frameworks are available for testing performance of indicators;
  - The role of modelling in performance testing;
- A practical way forward in an uncertain world that provides experts with limited resources

The overall intent of the talk is to first make the case that indicator selection should not resemble a beauty contest (which indicators look nicest and have some talent they can show off) and be like a rigorous job interview (which indicators actually can do the job best), and then illustrate that the latter standard is achievable if we focus more on how our indicators will be used, and less on how they can be produced

### **New Marine Environmental Assessment Method for Toyama Bay, Japan**

Takafumi Yoshida and Norihiko Tanaka

NOWPAP CEARAC (Special Monitoring and Coastal Environmental Assessment Regional Activity Centre), 5-5 Ushijimashin-machi, Toyama, 930-0856, Japan. E-mail: yoshida@npec.or.jp

Northwest Pacific Action Plan (NOWPAP), established in 1994, is an integral part of the UNEP Regional Sea Programme. The objective of NOWPAP is to address accelerating degradation of marine and coastal environment in the Northwest Pacific region through sustainable management and effective use of marine and coastal resources. The current situation of marine ecosystems in this region is explained in the NOWPAP “State of Marine Environment Report” (2007) and UNEP “Marine Biodiversity Assessment & Outlook Series” (2010), respectively. These reports indicate that there are many pressures which influence the marine ecosystems in this region adversely. For understanding and clarification of the problems, it is expected to conduct assessments regularly using common methods which can be used by all NOWPAP member states. From such point of view, NOWPAP CEARAC developed the common procedures for assessment of eutrophication status in 2009, and then started developing a new methodology for assessing the marine ecosystems comprehensively from various viewpoints.

Northwest Pacific Region Environmental Cooperation Center (NPEC), host organization of NOWPAP CEARAC, implements a pilot study in Toyama Bay, Japan, in order to examine a new marine environment assessment methodology. This methodology has two purposes: assessing the marine environment comprehensively and creating a suitable environment for marine life. Toyama Bay is one of important fishing grounds in Japan, and yellow tail, glass shrimp and firefly squid are typical commercial species caught in the bay. This pilot study has aspects of an impact assessment of influence from

land and an achievement assessment of the current coastal environmental situation against a desirable future status, which was designed based on the opinions of local people. So, various indicators related to “impact from land,” “marine environmental condition” and “marine life condition” were selected. The results of the pilot study show that it is necessary to further reduce nutrients inputs, to restore coastal habitats and to reduce the threat to ecosystems, such as invasive species and marine litter, for better conservation of the marine ecosystem of Toyama Bay.

Based on the results and experiences of the pilot study, NOWPAP CEARAC will develop a new marine ecosystem assessment method for the NOWPAP region. In the future, NOWPAP will be able to identify the marine environmental status and ecologically and biologically significant areas for conservation of the marine biodiversity by using this new assessment method.

### **A recent indicator-based assessment of the eastern Bering Sea**

Stephani Zador, Sarah Gaichas, and Kerim Aydin

Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA. E-mail: Stephani.Zador@noaa.gov

An Eastern Bering Sea Ecosystem Synthesis Team was assembled in 2010 to bring together a multidisciplinary group of experts to choose ecosystem indicators that could form as the basis of a new ecosystem assessment for the eastern Bering Sea (EBS). The goal of this assessment was to provide current and relevant scientific advice for fisheries managers. The team first met to develop a list of synthetic ecosystem indicators for the EBS. The suite of indicators was selected to represent key ecosystem components by choosing the best available indicators related to (1) atmosphere and upper-ocean physics, (2) lower trophic levels and primary production, (3) fish and shellfish distribution and abundance, (4) fish and shellfish production, (5) fisheries productivity, (6) seabirds, (7) pinnipeds, and (8) whales. During the second workshop, the team developed a new EBS assessment and report card. For this initial assessment, the team focused on a subset of 10 broad, community-level indicators to determine the current state and likely future trends of ecosystem productivity overall, including switches between major pathways (benthic/pelagic). The team also selected indicators thought to best guide managers on ensuring the needs of non-fishery apex predators and maintaining a sustainable species mix in the harvest, given the current state and likely future trends of overall productivity and the distribution/strength of pathways. In this talk we will give a brief rationale for each indicator's selection, describe the indicator, and its status, trends, and implications for fishery management. We will also review the assessment results as they were presented to the North Pacific Fishery Management Council as part of the annual catch specification process.

## Day 2

### Resilience - do we know enough to say we're monitoring it?

Elizabeth Fulton

CSIRO Marine and Atmospheric Research, GPO Box 1538, Hobart, Tasmania 7000, Australia. E-mail: Beth.Fulton@csiro.au

Change is at the heart of resilience, but many management and monitoring schemes are predicated on assessments that are often inventories against static reference points. In our effort to understand the state of the system are we successfully capturing an understanding of the processes or are we effectively "butterfly collecting"? Without understanding the processes leading to resilience we may not notice the hollowing out of the adaptive capacity of an ecosystem and may make management oriented decisions that are motivated with the best of intentions, but with unintended consequences. Are we at a point we can comfortably say we are measuring resilience?

### Uncertainty in ecosystem indicators: known knowns, known unknowns, and unknown unknowns

Sarah Gaichas

Resource Ecology and Fisheries Management Division, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, 7600 Sand Point Way NE, Building 4, Seattle, WA, 98115, USA. E-mail: Sarah.Gaichas@noaa.gov

Evaluating uncertainty in ecosystem indicators is critical for both indicator selection and for use within a management decision making framework. Ideally, we would select indicators that are either well-measured or robust to measurement error, and that represent the ecosystem attribute of management interest accurately under a wide range of conditions. When using these indicators in an ecosystem assessment, we would be able to estimate the uncertainty in the current and predicted future states of each indicator to determine the probability of achieving a target or exceeding a limit reference point. While these general concepts are straightforward, the variety of proposed ecosystem indicators combined with numerous sources of uncertainty complicate the picture. At least five classes of ecosystem indicators and at least six types of uncertainty have been identified. For example, Rice (2003) classifies ecosystem indicators as single ("indicator") species, biodiversity, ordination, aggregated, and emergent. Link *et al* (in review) divide uncertainty into the following categories: observation, process, model, communication, implementation, outcome, and unclear management objectives. Methods for estimating uncertainty in ecosystem indicators can be as simple as the expression of observation error (*e.g.* survey sampling standard deviation), or so potentially complex that standard approaches have yet to be developed. It is unclear, for example, how to estimate uncertainty for combined indices that involve several different survey data sources along with model outputs. In contrast, there has been considerable work on estimating uncertainty due to model parameterization and structure, and on performance testing of ecosystem indicators using models. Along with these developments, communication of complex information to stakeholders has advanced. While communicating scientific



uncertainty is necessary, it is difficult due to its complexity as well as the way humans tend to process information. Cognitive research suggests that simply reframing uncertain outcomes in terms of frequencies rather than decimal probabilities may improve communication and understanding. In this talk, I will present examples of uncertainty estimation and communication methods across a range of ecosystem indicators, and suggest directions for further research.

## **Marine Ecosystem Indicators in Europe 2 – Investigating reference levels to define good environmental status**

Mark **Dickey-Collas** and GerJan Piet

IMARES, P.O. Box 68, 1970 AB IJmuiden, The Netherlands. E-mail: mark.dickeycollas@wur.nl, GerJan.Piet@wur.nl

Europe's Marine Strategy Framework Directive (MSFD) has provided a suite of indicators by which it proposes to define good environmental status (GES). However despite choosing the relevant indicators, Europe is still challenged by the need to define reference levels for those indicators to determine if GES has been achieved. This presentation will show the challenges ahead and approaches being used within the EU to investigate and set reference levels for GES. Four worked examples will be considered based on four GES descriptors: commercial fish, biodiversity, sea floor integrity and food web. As a result of the common fisheries policy there is broad consensus about reference levels for the commercial fish stocks. Reference levels for biodiversity are notoriously difficult to determine but we will highlight one based on IUCN criteria. Determining indicators for sea floor integrity appears relatively straight forward but choosing reference levels is problematic. Finally, for the food web descriptor, a potential indicator was developed as part of the OSPAR EcoQO framework ([www.ospar.org](http://www.ospar.org)) and in collaboration with ICES called the Large Fish Indicator but this is region-specific (*i.e.* North Sea only) and based on a period when the system was considered to be sustainably exploited.

European states have an imposed deadline of July 2012 for considerations about the indicators. After this date there is a need by the European Commission to assess these indicators and reference levels and this may provide a role for both ICES collaborating with PICES.

## **Performance Testing of Ecosystem Indicators at Multiple Spatial Scales for the California Current**

Isaac C. **Kaplan** and Phillip S. Levin

NOAA Northwest Fisheries Science Center, 2725 Montlake Blvd. E., Seattle, WA, 98112, USA E-mail: Isaac.Kaplan@noaa.gov

A limited, comprehensible set of indicators is necessary to detect the response of marine ecosystems to climate and anthropogenic impacts, to draw lessons between regions, and to communicate the status of ecosystems to policy makers. Here we identify such a list of indicators for the California Current, using an Atlantis ecosystem simulation model and statistical techniques that estimate the strength of correlations between attributes of interest (*e.g.* biodiversity) and potential indicators. We examine attributes and indicators related to groundfish and a suite of broader ecosystem health metrics, foci of NOAA's California Current Integrated Ecosystem Assessment in 2010. The Atlantis model tracks attributes and indicators including those related to size composition and age structure, and considers ecosystem drivers including fishing and nutrient inputs. Most importantly it also allows us to test questions related to the spatial scaling of indicators and attributes.

Our results suggest that many attribute-indicator relationships that are strong at a coast-wide scale break down at local scales, and are not appropriate for extrapolating between spatial scales. More specifically, downscaling from indicators derived from coast-wide monitoring to local attributes (*e.g.* state or provincial waters) led to low and inconsistent correlations between attributes and indicators. For attributes related to groundfish, upscaling from local indicators to regional attributes commonly resulted in consistent significant relationships, particularly with indicators related to species groups that had strong, synchronous coast-wide trends. Attempts at upscaling to inform attributes related to ecosystem health were less successful. A subset of eight indicators, primarily related to fish and mammal populations, showed the potential for both downscaling and upscaling of monitoring. Our results highlight that whether indicators are used to detect status and change, or to make regional comparisons, the spatial scale of the underlying processes must be taken into account.

### **Ecosystem status assessment in Korea**

Sinjae **Yoo**

KORDI, Ansan, South Korea. E-mail: sjyoo@kordi.re.kr

National Investigation of Marine Ecosystems is a national project to monitor and assess the status of coastal ecosystems in Korean waters. The project began in 2006 and will continue indefinitely. The survey areas are divided into eight subdomains. The project will make seasonal measurements of more than 30 variables at one of the eight subdomains every year. One full cycle of monitoring to cover all the eight subdomains will survey more than 300 stations. In addition, special surveys are conducted at some protected areas. To synthesize and summarize the extensive datasets, an assessment

scheme is being developed. The scheme is divided into two categories: stressors and status. For the Yellow Sea, seven major stressors are identified for which metrics can be calculated from the datasets. These are eutrophication, changes in the nutrients balance, habitat disturbance, nonindigenous species, hazardous materials, disturbance in fresh water cycle, and sea warming. Status indicators include biomass, abundance and species diversity. In this talk, I will discuss major issues including determining reference values for assessment and comparison of geographical regions.

## **Indicators of Ocean Conditions in the Northern California Current**

William T. Peterson<sup>1</sup>, Jay O. **Peterson**<sup>2</sup>, Brian Burke<sup>3</sup> and Edmundo Casillas<sup>3</sup>

<sup>1</sup> NOAA Fisheries, Northwest Fisheries Science Center, 2030 SE Marine Science Dr., Newport, OR, 97365, USA

<sup>2</sup> Oregon State University, Hatfield Marine Science Center, 2030 SE Marine Science Dr., Newport, OR, 97365, USA E-mail: Jay.peterson@oregonstate.edu

<sup>3</sup> NOAA Fisheries, Northwest Fisheries Science Center, 2725 Montlake Blvd E., Seattle, WA, 98112, USA

A suite of ecosystem indicators is used to characterize the habitat quality of two salmon species, coho (*Oncorhynchus kisutch*) and Chinook (*O. tshawytscha*), over the shelf of the Northern California Current from 1998 to present. The indicators are derived from large-scale (ocean and atmosphere) processes as well as regional and local biological and physical variables, including the Pacific Decadal Oscillation (PDO) and Multivariate ENSO Index (MEI), the timing and magnitude of coastal upwelling, anomalies in surface and bottom temperature and salinity, zooplankton community composition and biomass, ichthyoplankton biomass, and catches of juvenile salmon.

These indices describe the status of ocean conditions, and in particular environmental and habitat requirements, for juvenile salmon during their first summer at sea. Based on this, forecasts of adult salmon returns to coastal rivers and streams are made 1 year in advance for coho and 2 years in advance for Chinook. By ranking the values within each indicator according to their relationship with salmon return data, and categorizing the ranks into good (green), average (yellow) and poor (red) conditions, we provide a qualitative “stop-light” assessment of the ocean conditions for each year. For quantitative predictions of salmon returns, we have used two approaches. The first approach simply uses the mean rank of all the indices regressed against annual return data, giving each index an equal amount of weight. The second approach uses Maximum Covariance Analysis and Partial Least Squares Regression as a method of weighting the various indicators. Taken together, the qualitative and quantitative data from this suite of indicators provides necessary predictions and other information relevant to management questions.

Further details on the indicators can be found at  
<http://www.nwfsc.noaa.gov/research/divisions/fed/oeip/a-ecinhome.cfm>