Indicators for Status and Change within North Pacific Marine Ecosystems: A FUTURE Workshop

by Jacquelynne King and Thomas Therriault

A 3-day workshop on "*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, USA. The workshop was co-convened by Sachihiko Itoh (Japan), Jacquelynne King (COVE-AP; Canada), and Thomas Therriault (AICE-AP; Canada) and was very well attended, with over 50 participants, including 14 contributors. With the support of PICES, 4 invited speakers, Marta Coll Mónton (Institute of Marine Science, Spain), Jake Rice (Fisheries and Oceans Canada), Beth Fulton (Commonwealth Scientific and Industrial Research Organisation, Australia), and Sarah Gaichas (Alaska Fisheries Science Center, USA) gave provoking presentations on the three main workshop themes: (1) Ecosystem-level indicators and assessments, (2) Ecosystem resilience, and (3) Indicator uncertainty. The workshop was organized by the FUTURE Advisory Panels (AICE – *Anthropogenic Influences on Coastal Ecosystems*, COVE – *Climate, Oceanographic Variability and Ecosystems*, and SOFE – *Status, Outlooks, Forecasts, and Engagement)*, 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 Mónton 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.

Participants of the 2011 FUTURE workshop outside of the East-West Center, University of Hawaii, Honolulu, USA.

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 (Begoña Santos, Instituto Español de Oceanografía, 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: comprehensively assessing the marine environment and creating a suitable environment for marine life, including the restoration of degraded environments (Takafumi Yoshida, Northwest Pacific Region Environmental Cooperation Center, Japan).

In 2010, the Alaska Fisheries Science Center undertook a new approach for its annual ecosystem assessment for the eastern Bering Sea (Stephani Zador, Alaska Fisheries Science Center, 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 tropic-level animals could provide an integration across trophic levels of ecosystem changes (Thomas Kline, Prince William Sound Science Center, 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, Fisheries Research Agency, 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 (Northwest Fisheries Science Center, 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.

FUTURE workshop in session.

Ecosystem resilience

The concept of ecosystem resilience features prominently in the FUTURE Science Plan and is specified in one of the 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. She 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. 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 indentifying the 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.

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 and managers, managers and 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.

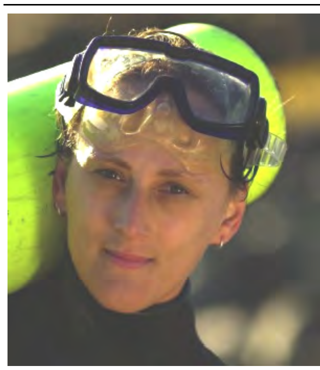
Mark Dickey-Collas (IMARES, The Netherlands) presented the EU Marine Strategy Framework Directive requirement for reference points and threshold levels to be identified for the eleven descriptors of good environmental status by 2012. For some descriptors, such as commercial fish, there already exists 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, Korea Ocean Research and Development Institute, Korea).

Jay Peterson (Oregon State University, 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 outcomes and next steps

The third day of the workshop was devoted to discussion 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 workshop. Instead, the workshop



Dr. Jacquelynne King (Jackie.King@dfo-mpo.gc.ca) is a Research Scientist with Fisheries and Oceans Canada at the Pacific Biological Station in Nanaimo, British Columbia, and an Adjunct Professor at the University of British Columbia. Jackie received her PhD in Limnology from the University of Toronto in 1997 and began her career in marine ecology as a Post Doctoral Fellow studying North Pacific regime shifts. Her current research includes climate change impacts on marine ecosystems and methods of incorporating climate variability into stock assessment advice. Jackie is also Program Head of the Canadian Pacific Shark Research Lab. Within PICES, she led the Study Group on Fisheries and Ecosystem Responses to Recent Regime Shifts (2003–2004), and was a member of the Climate Forcing and Marine Ecosystem Response Task Team (2004–2009) and Working Group 16 on Climate Change, Shifts in Fish Production, and Fisheries Management (1999–2005). Jackie is currently a member of the FUTURE Advisory Panel on Climate, Oceanographic Variability and Ecosystems (COVE), the Fishery Science Committee and the PICES/ICES Working Group on Climate Change Impacts on Fish and Shellfish.

Dr. Thomas Therriault (Thomas.Therriault@dfo-mpo.gc.ca) is a Research Scientist with Fisheries and Oceans Canada (DFO) at the Pacific Biological Station in Nanaimo, British Columbia. Tom is working on a number of aquatic invasive species research questions both within DFO and through the Canadian Aquatic Invasive Species Network (CAISN). He is the Principal Investigator for the Taxonomy Initiative of PICES Working Group 21 on Non-indigenous Aquatic Species (under the project on "Development of the prevention systems for harmful organisms' expansion in the Pacific Rim" supported by the Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan) that includes rapid assessment surveys (RAS) for non-indigenous species. Within PICES, Tom serves as Vice-Chairman of Science Board and leads the FUTURE Advisory Panel on Anthropogenic Influences on Coastal Ecosystems (AICE). He is a member of the Marine Environmental Quality (MEQ) Committee and the P/ICES Study Group on Developing a Framework for Scientific Cooperation in Northern Hemisphere Marine Science.

participants recommended that all PICES Standing Committees 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 the indicator for each attribute (each criterion should be weighted for relevance to the end user identified):
   - available regularly and in a timely manner applicable to the issue,
   - available as a time series,
   - statistical properties are understood and provided,
   - related to the attribute either empirically or theoretically,
   - specific to the attribute (*i.e*., how specific is the indicator to the processes being indexed?),
   - spatial and temporal scales of the indicator are appropriate to the attribute,
   - responsive (sensitive to perturbation),
   - relevant to the objective,
   - understandable by the target audience,
   - provides a basis for comparison between ecosystems;
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 pointed out the need to create additional 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. Overall, the convenors were extremely happy with the workshop and its accomplishments and feel that strong guidance has been provided to PICES FUTURE science.

The convenors would like to thank all of the participants for their contributions, and the PICES Secretariat for arranging the logistics and for hosting a reception on the first day for all of us to enjoy.

PICES Calendar

- PICES/MAFF–IOC/WESTPAC Workshop on "*Rapid assessment survey methodologies for detecting marine non-indigenous species*", July 19–21, 2011, Phuket, Thailand (http://www.pices.int/meetings/summer_schools/2011_training/RAS-Workshop-description.pdf);
- 7th International Conference on "*Marine bioinvasions*" (co-sponsored by PICES), August 23–25, 2011, Barcelona, Spain (www.icmb.info/);
- 5th SOLAS Summer School (co-sponsored by PICES), August 29–September 10, 2011, Cargèse, Corsica, France (http://solas-int.org/summerschool/welcome.html);
- Joint Theme Sessions at the 2011 ICES Annual Science Conference, September 19–23, 2011, Gdansk, Poland:
  - *Atmospheric forcing of Northern hemisphere ocean gyres and their subsequent impact on the adjacent marine climate and ecosystems*;
  - *Atlantic redfish and Pacific rockfish: Comparing biology, ecology, assessment and management strategies for Sebastes* spp.;
  - *Recruitment processes: Early life history dynamics – from eggs to juveniles*;
  - *Surplus production models: Quantitative tools to manage exploited fisheries and compare the productivity of marine ecosystems*;
- International Workshop on "*Development and application of Regional Climate Models*", October 11–12, 2011, Incheon, Korea (www.pices.int/meetings/descriptions.aspx#description8);
- PICES Annual Meeting, October 14–23, 2011, Khabarovsk, Russia (www.pices.int/pices2011.aspx);
- International NPAFC-led Workshop on "*Explanations for the high abundance of pink and chum salmon and future trends*" (co-sponsored by PICES), October 30–31, 2011, Nanaimo, Canada (http://www.npafc.org/new/events/workshops/2011Workshop1stAnnouncement.pdf);
- 2nd ICES/PICES Early Career Scientist Conference on "*Oceans of change*", April 24–27, 2012, Palma de Majorca, Spain (http://www.ices.dk/marineworld/oceans/index.asp);
- 2nd PICES/ICES/IOC Symposium on "*Effects of climate change on the world's oceans*" in conjunction with Ocean Expo-2012, May 14–18, 2012, Yeosu, Korea (http://www.pices.int/climatechange2012.aspx).