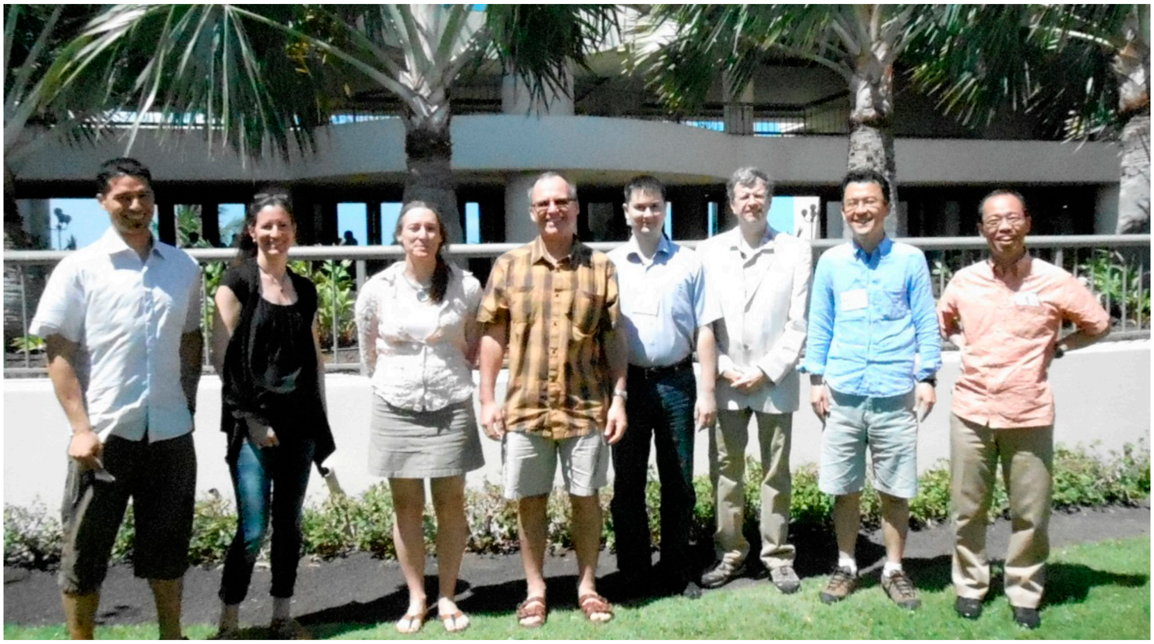
OSM Workshop on "*Bridging the divide between models and decision-making: The role of uncertainty in the uptake of forecasts by decision makers*"

by Edward J. Gregr



Convenors and invited speakers (left to right): Kai M.A. Chan (Canada), Lee Failing (invited speaker, Compass Resource Management Ltd., Canada), Georgina A. Gibson (invited speaker, International Arctic Research Center, University of Alaska Fairbanks), Edward J. Gregr (Canada), Vladimir Kulik (Russia), Hal Batchelder (PICES Secretariat), Motomitsu Takahashi (Japan), Shin-ichi Ito (Japan), Missing: Naesun Park (Korea), Ian Perry (Canada), Jameal Samhouri (USA).

The FUTURE science program recognizes the need to more directly address uncertainty in products such as ocean climate forecasts, and to improve how the knowledge produced by PICES is disseminated. In a series of presentations and discussions, our workshop (W2), held April 14, 2014, examined both the nature of uncertainty in model systems, and how uncertainties can be included in the decision making process. The workshop was well attended, with broad representation from PICES member countries. We identified a number of opportunities for the PICES community to improve how uncertainty is characterized, and to highlight several advantages that would emerge from tailoring model outputs, including uncertainties, for diverse audiences.

Understanding uncertainty

The first step in addressing uncertainty is to understand its source. Gregr and Chan (in review) consider three classes (Data, Scope, and Process) of uncertainty based on the assumptions necessary at various steps in the model design process. Assumptions about data relate to uncertainties about things such as sampling bias, representativeness, and the overall relevance of the data to the study under consideration. Decisions about model scope (*e.g*., specification of spatial, temporal, and compositional extents) are central to model design and contain uncertainties about model boundaries and resolution, among other things. Once model data and scope are defined, decisions and assumptions about process must be made, for example, which ecosystem components interact and the nature of these interactions, some of which are also uncertain.

For the purposes of communication and decision-making, Gregr and Chan added two additional classes of assumptions, Communication and Relevance (Table 1). Assumptions around communication obscure uncertainties related to things such as language and disciplinary epistemology. Perhaps most importantly, the relevance of ecosystem model results to decision-making is often assumed to be quite high by model developers. However, this is far from certain, and evidence suggests that it is often quite low (Failing, this workshop). This class of assumptions thus relates to uncertainties about indicator selection and the context relevance. In many cases, comprehensive treatments of model uncertainties are not necessarily desirable (or tractable). However, Gregr and Chan argue that a more explicit recognition and discussion of model assumptions is necessary for improving our understanding and communication of model results, and the associated uncertainties.

Table 1 Assumption classes and the associated types of uncertainty.

Assumption class	Uncertainty
Data	Observational
Scope	Design uncertainty
Structure	
Process	Parameter estimation Natural variation Inherent randomness
Communication	Ambiguity Under-specification Vagueness
Relevance	Context dependence Relativism

Representing uncertainty

Several presentations illustrated methods for examining model uncertainties. Invited speaker, Georgina Gibson (USA), discussed the role of assumptions in the development of lower trophic level (LTL) ecosystem models. Describing how the complexity of model structure and parameterization can increase quickly, she emphasized the associated need for assumptions to manage this. She demonstrated how to use sensitivity analysis to identify critical parameters, but noted that the large computational demands limit the extent to which it can be applied. Gibson and Spitz (2011) used a one-dimensional lower trophic level model to examine a suite of 135 biological and 8 environmental factors, and ranked these factors according to their influence on model outputs. Although the approach identified parameters deserving closer scrutiny, similar analysis has not been applied to 2- or 3-dimensional models because of the computational limitations, leaving important parameters untested.

Exploring the parameter uncertainties in such simulation models is typically handled using established Monte Carlo methods. However, knowing the range over which to sample parameters is critical to such efforts. Unfortunately, such ranges (which are necessary to parameterize theoretical, mechanistic models) are not always known, and thus represent important design assumptions. Similarly, initial or starting conditions for models may be unknown, which can have a significant effect on the trajectory of model predictions (Gibson and Spitz 2011).

Rowenna Gryba (Canada) examined assumptions about the relevance and utility of data, and how this influences the evaluation of habitat suitability in models of North Pacific Right whales. Standard cross-validation approaches to evaluating models of habitat suitability are sensitive to potential biases in the data. Analytical methods typically assume unbiased data, but analyses often contain implicit, potentially false assumptions about the relevance or suitability of such data, which may contain geographic or seasonal sampling biases. Gryba also considered conceptual assumptions implicit in such models, where, for example, it is often assumed that mammal sightings are correlated with high prey concentrations. She showed how this conceptual assumption is testable using independent data on prey distributions, thus providing insights into the uncertainty associated with this key habitat modeling assumption.

The challenge of coupling models was discussed by Shin-Ichi Ito (Japan), who presented the results of a fisheries production model for Pacific saury forced using sea surface temperature predictions from 12 different global climate models developed by the Intergovernmental Panel on Climate Change (IPCC). While a number of correlations were found, uncertainty in fish growth projections were dominated by uncertainties in the physical forcing. This emphasizes the need for appropriate scaling methods when moving from global to regional study areas. Ito suggested that to effectively couple models across scales, more attention needs to be paid to key processes at the interfaces. For example, zooplankton dynamics play a key role in saury abundance. Thus, it is critical to appropriately capture the relationships between physics and zooplankton, and between zooplankton and higher trophic levels (HTLs). Given that HTLs typically respond to multiple drivers operating at different scales (*e.g*., Palacios *et al*. 2013), a better understanding is needed about how HTLs respond to short-term forecasts.

The need to understand such processes and their interactions was nicely illustrated by Bill Peterson (USA), who showed how the correlation between the Pacific Decadal Oscillation (PDO) and Chinook salmon ocean survival, which had shown a robust negative correlation for 15 years, suddenly failed dramatically in 2011. The causal relationship appears mediated by copepods, which provide an index of the lipid richness at the base of the food chain. This 'lipid rich copepod index' is, in turn, correlated with Chinook survival. However, the decoupling of the relationship highlights new uncertainties about the scale and process of the presumed mechanism. Once again, this emphasizes the need to understand the process, though even so, surprises should be expected. For HTL models in particular, the need to transition from correlative to mechanistic model frameworks is increasingly relevant (Palacios *et al*. 2013).

Decision making and communication

Lee Failing (Canada), our second invited speaker, provided an important perspective on the role of research and uncertainty in decision making. Failing noted that while many frameworks exist to support integrated management, the process of actually making decisions and managing the risks arising from uncertainty are rarely emphasized. Rather, the decision-making components are often presented as *post-hoc* interactions with the principal science represented in prominent detail (*e.g.*, Figure 1). Treating decision-making as an afterthought introduces many implicit and likely false assumptions about the role of science in the decision-making process. Such perspectives are grounded in the information deficit model of science communication, an approach that is increasingly understood to be false (see http://en.wikipedia.org/wiki/Information_deficit_model). Only a small portion of science as currently practiced is typically salient to decision makers. To improve the relevance of science to policy and decision making, Failing emphasized the transformative power that comes from "making the decision" the goal of the scientific effort and analysis. This leads to immediate identification of what is important, and informs where science could best contribute to the process. The salience of such contributions would be greatest if they helped inform the trade-offs faced by decision-makers and their stakeholders.

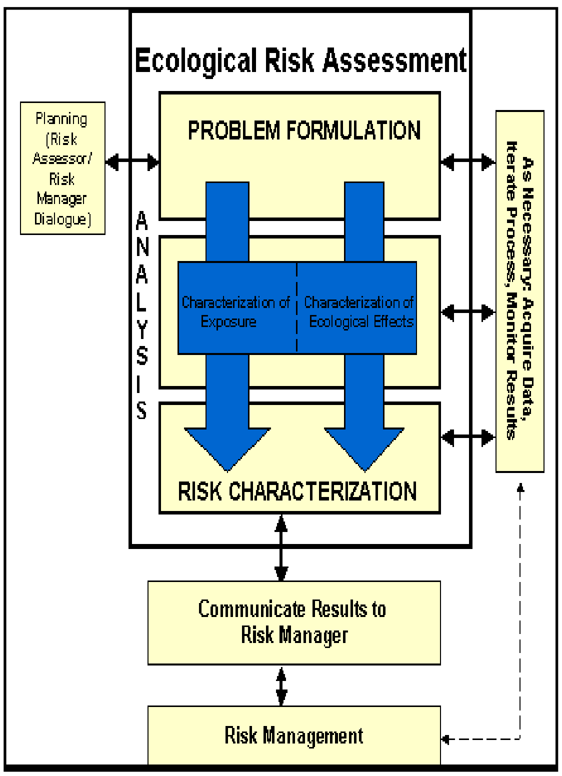


Fig. 1 Example risk assessment framework emphasizing (red oval, added) the implied post-hoc role for the decision making process.

This leads to the question of science communication, and Kai Chan (Canada) argued that this is as much a question of targeting as it is of understanding the science and the inherent uncertainties. Through various examples, Chan emphasized the need to focus on the complete decision scenario to identify what really matters and, equally important, what is at risk. From the perspective of the FUTURE program, this means identifying relevant metrics and understanding the distribution of inputs and outputs. It also means being explicit about unquantified assumptions to help understand the associated risk. And perhaps most importantly, it means recognizing that there is no single audience or stakeholder, but rather a diversity of interests for whom different metrics and presentation methods may be required. Targeting – identifying what matters, and how it is best measured, for each decision scenario – will be key to effectively communicating FUTURE products beyond the PICES scientific community.

Challenges and opportunities

In addition to the presentations, we devoted considerable time to discussion, including a joint session with the participants of workshop W3 on "*Climate change and ecosystem-based management of living marine resources: appraising and advancing key modeling tools*". The joint session acknowledged that the fundamental challenge for the modeling community is to identify what resonates with decision makers. Given the diversity of management and policy decisions that are regularly made, this emphasizes the need to develop communication strategies that can adapt effectively to diverse audiences. Decision makers would like to reduce risk and reduce surprises. This would presumably simplify the trade-offs inherent in policy and management decisions.

The role of reliable ecosystem forecasts in reducing risk and producing fewer surprises is recognized, although the risk of such forecasts being wrong and surprising decision makers will need to be carefully managed. Integrating data from regional Ocean Observing Systems, focusing on short-term forecasts, and predicting the responses of HTLs are essential components of such ecosystem forecast systems. The increasing risks faced by decision makers due to climate uncertainty provide an opportunity to advocate for ocean climate forecast services at regional scales, emphasizing that their utility for managing risk is as high as traditional short-term weather forecasts.

Uncertainties related to closure terms (*i.e.*, the parameters required to represent aspects not included in the model), model structure, and the downscaling of global models will continue to present challenges to the development of such short-term forecasts. Ensemble modeling is increasingly providing an opportunity to address the cumulative uncertainty in highly complex models, allowing the assessment of robustness (Knutti and Sedláček 2013). To demonstrate their relevance, a key performance challenge for such short-term forecasts is to achieve not only statistical accuracy, but to reasonably predict the phase (*i.e.*, timing) of climatic events. This will be best approached through regional models, which have already met with some success, such as the prediction of hypoxia events (Siedlecki *et al.* 2014). Accurate predictions of phase changes is critical (although emphatically not sufficient) for forecasting the HTL indicators important for many stakeholder groups.

Other opportunities are emerging due to the consequences of a changing ocean. As ecosystem boundaries shift, baselines on which stock assessment data are based will begin to expose the assumption of spatial stationarity. This provides an opportunity for fisheries scientists to reconsider how the science underpinning management decisions is conducted, and perhaps refocus it more directly on the decision and the risks to stocks in a more unpredictable ocean. This is particularly salient in light of recent research suggesting ocean conditions play a much stronger role in recruitment than previously believed (Szuwalski *et al*. 2014), re-enforcing the need for reliable ocean forecast systems.

The take-home message for FUTURE from the workshop is that broader uptake of our knowledge products will require clearly articulating the decision context to which they contribute. The extent to which we can explicitly inform the risks in the choices facing managers and policy makers will influence the uptake of our science into decision making. Casting our uncertainties as risks, and targeting these results at the appropriate audiences, will further increase our contribution to evidence-based decision making. Finally, by considering how we can contribute to decisions that will be made in the future, the ocean science community has an opportunity to move from a reactive, crisis-management role to proactive leadership where best available science provides timely, salient, and sound advice to support ocean management decisions.

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Acknowledgments

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