OSM Session on "*Identifying multiple pressures and system responses in North Pacific marine ecosystems*"

by Ian Perry

Marine ecosystems of the North Pacific, both coastal and offshore, are impacted by multiple pressures, such as increased temperature, change in iron supply, harmful algal bloom events, invasive species, hypoxia/eutrophication and ocean acidification. These multiple pressures can act synergistically to change ecosystem structure, function and dynamics in unexpected ways that differ from single pressure responses. It is also likely that pressures and responses will vary geographically. A key objective of the PICES FUTURE science program is the identification and characterization of these pressures to facilitate comparative studies of North Pacific ecosystem responses to multiple stressors and how these systems might change in the future. This session had two primary objectives: 1) identify key stressors and pressures on North Pacific marine ecosystems, including comparisons as to how these stressors/pressures may differ in importance in different systems and how they may be changing in time; and 2) identify ecosystem responses to these multiple stressors and pressures. Objective 2 includes understanding how natural and human perturbations may cascade through ecosystems, and whether there may be amplifiers or buffers which modify the effects of perturbations on marine systems. The overall goal of this session was to contribute to the work of PICES Working Group 28 on *Developing Ecosystem Indicators to Characterize Ecosystem Responses to Multiple Stressors* and to obtain an overview of the pressures being experienced by North Pacific marine ecosystems and their impacts on the marine ecosystems of the North Pacific.

In total, 15 papers were presented in session S1, plus one by Isabelle Rombouts in a plenary session (Fig. 1). All presentations demonstrated that multiple stressors are common, and that single stressors are rare (*e.g.*, Fig. 2). Literature analyses of multiple stressors usually list between 25 to 50 multiple stressors (Working Group 28 has been working with an integrated list of about 20 stressors for its comparative studies). Several presentations by Working Group 28 members (Takahashi *et al*., Martone *et al*., Kulik, Samhouri *et al*., Zador and Renner, Perry *et al*.) provided descriptions of multiple stressors in North Pacific marine ecosystems. The presentation by Perry *et al*. concluded that the scientific community is beginning to understand issues of sensitivity and exposure of habitats to multiple stressors (Fig. 3), but there is also consensus that a lot of questions remain. Early analyses from Working Group 28 suggest that there are more stressors, and greater impacts, in coastal than offshore areas. However, comparative studies also suggest there may be a shorter list of important stressors at regional scales. In analysis of scenarios of cumulative impacts along the coast of British Columbia, Canada, Clarke-Murray *et al*. found climate change impacts overwhelmed all other stressors.

Fig. 1 Plenary speaker, Dr. Isabelle Rombouts addressing the audience.

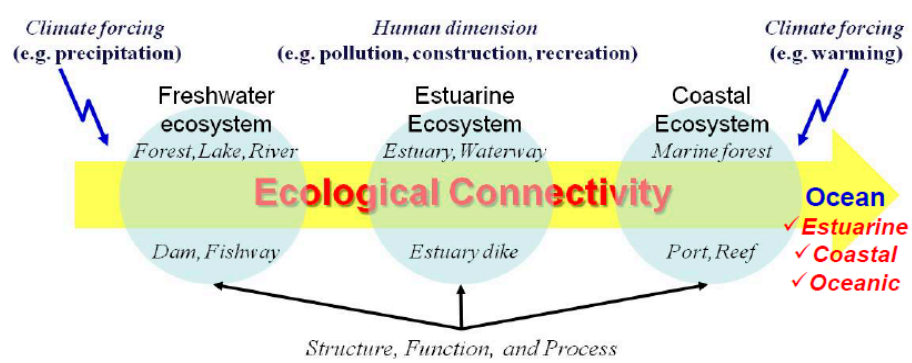

Fig. 2 Example of multiple and cumulative stressors along an ecological gradient from freshwater to marine systems. From Won et al.

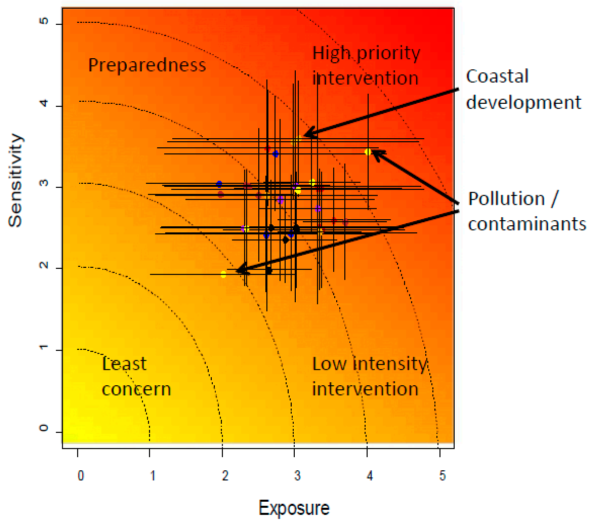

Fig. 3 Example of a risk plot (Exposure by Sensitivity) of multiple stressors (20 stressors by 22 habitats) for the Strait of Georgia, Canada. Color coding represents degrees of inferred relative risk. Horizontal and vertical bars represent uncertainties derived across multiple experts. From Perry et al.

Several presentations discussed options for developing ecosystem indicators to characterise ecosystem responses to multiple stressors. Boldt *et al*. outlined a number of requirements for such indicators. These include the need to define strategic goals and ecological or management objectives for these indicators, and the need for a suite of integrative indicators that would cover key components and gradients at the appropriate spatial scales. It was also recognised that mechanistic approaches can give insights into how pressures are likely to interact and how impacts may become observable. The synthesis of indicator status across multiple trophic levels may reveal broad-scale changes in the environment that may have important biological and management implications. For example, upper trophic level organisms such as seabirds and halibut may serve as integrative indicators that can provide near-real time cues of environmental state (Zador and Renner presentation).

Multiple stressors might interact in additive, synergistic, or antagonistic ways. An analysis of interaction type from 171 studies that manipulated 2 or more stressors found that 26% identified additive interactions, which are most commonly used in model studies of stressor interactions, but that 36% and 38% of the studies identified synergistic or antagonistic interactions, respectively (Crain *et al*. 2008, Ecology Letters). Examples presented during this session included the paper by Jung, who concluded that intensive fishing activities by Korean trawlers could have aggravated the potential resilience of the filefish stock, causing it to collapse when the climate changed; and the paper by Polovina and Woodworth-Jefcoats, who concluded that top-down responses in the Central North Pacific ecosystem means that fishing and potentially bottom-up climate impacts are likely to have stronger negative impacts on the larger fishes than on smaller fishes, causing the ecosystem size structure to shift towards smaller sizes. Their study, based on two ecosystem models, indicated that impacts from bottom-up stressors could range from moderate (–20%) to severe (–60%) depending on changes in phytoplankton. Del Raye and Weng identified a need for physiological models that use aerobic scope for activity to understand interactions between temperature and O_2 at discrete $p\mathrm{CO}_2$.

Based on the presentations and discussions, the session reached the following conclusions:

- Ecosystem responses to multiple stressors are non-uniform: a suite of indicators is best to capture a diversity of ecosystem responses.
- Because a diversity of ecosystem responses is expected, it is essential to clarify which types of ecosystem changes matter to a pre-specified group of people.
- Interactions between multiple stressors more often appear to be non-additive (synergistic or antagonistic); there is the need to understand how predicted ecosystem responses vary with different assumptions about interactions between stressors (noting, however, that there is no substitute for data).
- Climate and fishing provide good examples of how interactions between stressors can act non-additively in some cases and additively in others to change the dynamics of exploited fish populations.

Different approaches may be needed for situations with different degrees of complexity. For example, data-driven evaluations are obviously to be preferred for situations where data are available (in space, time, and types of variables). Expert opinion may be necessary when the focus is on broad spatial scales, although care should be taken to verify these opinions with data or other experts when possible.

Acknowledgements

I would like to thank the other S1 co-convenors, Vladimir Kulik, Rebecca Martone, Jameal Sambouri and Motomitsu Takahashi for their contributions in organizing and chairing this session.

Dr. Ian Perry (Ian.Perry@dfo-mpo.gc.ca) is a research scientist with Fisheries and Oceans Canada at the Pacific Biological Station in Nanaimo, British Columbia. His research includes the structure and function of marine ecosystems and the development of ecosystem approaches to management of these systems.