Report of Working Group 28 on *Development of Ecosystem Indicators to Characterize Ecosystem Responses to Multiple Stressors*

WG 28 met from 9:00 to 18:00 h on October 12, 2013 in Nanaimo, Canada, under the chairmanship of Drs. Motomitsu Takahashi (Japan) and Ian Perry (Canada). The meeting objective was to review activities during the 2nd year (2012–2013) of WG 28, plan for activities during the 3rd year (2013–2014), and discuss the contents of the final report. Note that reports from previous WG 28 meetings and sponsored sessions are on the WG 28 web page at http://www.pices.int/members/working_groups/wg 28.aspx.

The participants at this meeting are listed in *WG 28 Endnote 1*. The agenda for this meeting is presented in *WG 28 Endnote 2*. The members of WG 28 are listed in *WG 28 Endnote 3*.

AGENDA ITEM 2
Review of activities during the 2nd year of WG 28

a) Review of Terms of Reference:

The terms of Reference for WG 28 (*WG 28 Endnote 4*) were reviewed and discussed. It was recognized they are very challenging and ambitious. WG 28 is making progress on addressing them, but may not be able to fully respond to all questions. Since this WG is connected to the FUTURE program, it was agreed that requesting an additional one or two years to the duration of WG 28's term is reasonable considering the complexities of the Terms of Reference and the contributions of WG 28 to this program.

WG 28 was requested by The FUTURE Advisory Panels to identify how it will link to the FUTURE. WG 28 will contribute directly to goals 1 and 3 of the FUTURE Science Plan and partially to goal 2:

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?

The responses of the Working Group to the additional questions posed by Science Board are:

- What is the progress with the expected contribution to FUTURE?
  - Good progress,
  - Habitat-stressor relationships and potential indicators have been identified,
  - Outline of the report has been developed,
  - About 6 months to get a draft together.
- What is the gap/obstacles in making progress?
  - Lack of full representation from all countries,
  - Data exchange,
  - Overuse of the same experts for similar surveys.
- What will be the necessary actions to overcome the gaps?
  - Members might need to be engaged by correspondence through written materials,
  - Bring to the Technical Committee on Data Exchange (TCODE),
  - Similar surveys – but there is no clearing house.
- What kind of coordination is needed with other expert groups?
  - Section on *Human Dimensions of Marine Systems*,
  - Advisory Panel on *Marine Birds and Mammals*,
  - Section on *Ecology of Harmful Algal Blooms in the North Pacific*,
  - WG 21 on *Non-indigenous Aquatic Species* (*e.g.*, Manila clams).
- How well do you communicate with Committees/FUTURE APs on FUTURE matters?
  - Currently report annually with the Committees and FUTURE APs and welcome the opportunity to have additional communication.

b) Report on participation and presentation by WG 28 in NOWPAP Workshop

Purpose of this workshop was to discuss Marine Protected Areas and biodiversity issues in the East Asian Seas region. Goals included developing common language around these topics, and developing marine ecosystem indicators. See PICES Press July 2013 article for a discussion of the meeting and of the WG 28 presentation by Dr. Kulik: http://www.pices.int/publications/pices_press/volume21/v21-n2/pp_28-29_NOWPAP-Wsh.pdf, and also the meeting report on WG28 web page: http://www.pices.int/members/working_groups/materials/WG-28-2013-Report-from-NOWPAP-MPA-Workshop.pdf

The HELCOM (Baltic Marine Environment Protection Commission – Helsinki Commission) presentation by Dr. Maria Laamanen is of interest to WG 28; see their website for their multi-layered core indicators report (www.HELCOM.fi). One conclusion is that the main interactions among pressures are not additive.

In discussion, it was suggested that Chapter 3 of the WG 28 report might include a summary of main indicator webpages and compare/contrast indicators among ecosystems. For example, which indicators are common in a majority of lists produced by various organisations, and which are 'unique' to specific locations? Many indicators are status indicators, but W G28 is looking for ecosystem response to multiple stressors; can we identify the dominant driver/stressor that is causing changes in an indicator from the observed ecosystem response? In addition, can WG 28 identify candidate early-warning indicators? See also websites for the health of the Salish Sea ecosystem (www2.epa.gov/salish-sea), Baltic Sea (www.HELCOM.fi), and www.oceantippingpoints.org.

Dr. Vladimir Kulik mentioned that another meeting on marine ecosystem indicators was held in early October in Russia. The interest here was to develop ecosystem indicators to assist decisions on Total Allowable Catches because often there is insufficient information to develop Virtual Population Analyses and other traditional stock assessments, but there is information on hydrological conditions and populations, *i.e.*, the use of ecosystem indicators to assist with fisheries management.

c) Report on participation and presentation by WG 28 to the 2013 Inter-sessional Science Board meeting, and at the ICES/PICES workshop on "Climate Change Effects on Marine Ecosystems" (SICCME)

These meetings took place in St. Petersburg, Russia, May 20–24, 2013; WG 28 was represented by Dr. Takahashi. For details on the workshop and presentation, please see the web site: http://www.pices.int/publications/presentations/2013-S-CCME-Wsh/2013-SCCME-wsh-agenda.aspx.
In discussion, it was noted that the vulnerability definitions adopted by the IPCC and expressed by Allison *et al*. (2009, *Fish and Fisheries* 10, 173–196), in which the vulnerability of a national economy (or any ecosystem) can be expressed as a function of exposure to pressures, sensitivity to those pressures, and the capacity to adapt to those pressures, may have some applicability to the work of WG 28, in particular at sub-national levels).

d) Report on additional WG 28 session proposals

At the FUTURE Open Science Meeting in Hawaii, April 14–18, 2014, WG 28 is supporting one scientific session and one workshop (*WG 28 Endnote 5*). The WG is also supporting a topic session at the 2014 PICES Annual Meeting in Yeosu, Korea (*WG 28 Endnote 6*).

e) WG 28-sponsored topic session at PICES-2013

WG 28 co-sponsored one topic session (S8) at this PICES Annual Meeting, titled "*Ecosystem indicators to characterise ecosystem responses to multiple stressors in North Pacific marine ecosystems*". Details of this session can be found in the Session Summaries section of the 2013 Annual Report at http://www.pices.int/publications/annual_reports/Ann_Rpt_13/2013-Session-Summaries.pdf.

f) Report on project MEcoPAM

The project "Sustainability of **M**arine **Eco**system **P**roduction under Multiple stressors and **A**doptive **M**anagement" (MEcoPAM) focuses on the impact of multi-stressors on the sustainability of marine ecosystem production in China. It is a project under IMBER.

The sustainability of marine ecosystem production is impacted by multi-stressors, such as physical processes, eutrophication, over-fishing and aquaculture. The objectives of the MEcoPAM project are to identify and characterize the interactions of marine biogeochemical cycles and marine ecosystems, and to understand the response of typical marine ecosystem production to multi-stressors, thereby improving our knowledge of the impact of multi-stressors on the sustainability of marine ecosystem production. The research areas include several unique sub-ecosystems in the Bohai Sea, Yellow Sea, and East China Sea (*e.g.*, the hypoxia zone off the Changjiang Estuary, and aquaculture sites in the Shandong Peninsula). The major scientific questions to be addressed are:

- What is the impact of multi-stressors on biogeochemical cycles in coastal ecosystems (*e.g.*, hydrodynamic control of biogenic element cycles, coupling mechanism of primary production with biogeochemical processes)?
- How does ecosystem functioning in the hypoxia zone of the East China Sea respond to multi-stressors (*e.g.*, the role of metabolism and redox processes on element cycles, impact of hypoxia on the function and structure of marine ecosystem, impact of open ocean and atmosphere)?
- What are the adaptive strategies of coastal aquaculture ecosystems to deal with multi-stressors (*e.g.*, the supporting role of main biogeochemical processes in food production and food web trophodynamics of major biological functional groups, adaptive strategies to fishery management)?

In addition to field observations of the physical, chemical and biological properties of ecosystems in East China Sea, Changjiang Estuary and the coastal area of the Shandong Peninsula, historical data analysis, numerical modelling and microcosm experiments will be undertaken.

The program is structured around five sub-projects: (1) Biogeochemical Dynamics of Marine Ecosystems; (2) Nutrient Cycles and Response to Multi-stressors; (3) Hydrodynamic Response to Multi-stressors and its Impact on the Supply of Nutrients; (4) Microbial Loop and Coupling with Biogeochemical Cycles; and (5) Feedback Mechanisms of Ecosystem Structure and Function to Climate Change and Human Activities.

The project is scheduled for completion in 2015. The project web site is at http://www.imber.info/index.php/Science/National-Network/CHINA/MEcoPAM-project-website.

AGENDA ITEM 3

Progress on Terms of Reference, and brief country reports of activities of interest to WG 28

Canada

Dr. Perry reported that an ecological risk assessment framework has been developed and a detailed case study application has been developed and reviewed – the report is in preparation. Indicators for the Salish Sea ecosystem (Strait of Georgia and Juan de Fuca Strait in Canada, and Puget Sound in the U.S.) have been updated and published (http://www2.epa.gov/salish-sea).

Japan

Dr. Takahashi stated that discussions have been ongoing with China regarding relevant work in the East China Sea. Work has also been ongoing to develop coupled pelagic-benthic biogeochemical models for the Mikawa Bay estuary (*e.g.*, see presentation on "*The pelagic and benthic coupled biogeochemical cycle model study for Mikawa Bay estuary*" in Session S8 by Dr. Kisaburo Nakata: S8-9005).

Korea

Dr. Jaebong Lee informed the WG that a primary ecosystem assessment framework is IFRAME; a current major goal is to identify reference points and conduct risk analyses. Korea has a new Fishery Act, but so far no methods for ecosystem-based management. IFRAME may be applicable to aquaculture as well to calculate total allowable aquaculture (TAA) and to assess the carrying capacity and risks of aquaculture to the ecosystem. This is a 3-year project. The project will start at the end of this year or early next year.

Russia

Dr. Kulik said that in Russia, damage to ecosystems is not part of the science program; therefore, there is difficulty in obtaining data. For example, estimates of the total biomass of targeted species can vary considerably because of the use of different base data (spring or fall surveys which target different life stages or species) and different geostatistical techniques (*e.g.*, GAMS, kriging, or other techniques). As a consequence, indicators show promise in providing alternative methods. Several indicators developed by IndiSeas have been explored, although there were issues with FAO designations of over- and moderately exploited species. General additive mixed models have been used to incorporate environmental indicators. Which values are included or excluded from indicators can affect indicator values/outputs. How data are selected or grouped also affects the results. In Russia, there is pressure from Industry on Science to lower the total allowable catch (TAC) because they have to catch 50% of TAC for the TAC to exist the next year. This could be viewed as precautionary since the TAC may not really reflect population status.

United States (Martone)

Dr. Rebecca Martone announced that significant efforts are being directed towards a Marine Monitoring Enterprise and a project on ocean tipping points: www.oceantippingpoints.org. This project is characterizing nonlinear responses in ecosystems, with the goal of developing early warning indicators and how these may be incorporated in oceans management. An example of an early warning indicator is the coefficient of variation, and how it may change as the system approaches a regime shift (*e.g.*, Lindegren *et al*., 2012, PLoS One 7(7), e38410). Case study locations for this project include Hawaii, and Haida Gwaii in Canada.

AGENDA ITEM 4
Report draft chapter outlines

Draft outlines for the chapters of the WG 28 final report were presented and discussed. These form the basis for focused work for the next year. The updated chapter outlines (revised from those developed last year in Hiroshima) are presented in *WG 28 Endnote 7*.

It is anticipated that about 50% of the report will consist of a literature review, 30% the application of existing methods to data and information from the PICES region, and 20% of new analyses. The goal now is to create drafts of each of the core chapters, for presentation and discussion at the FUTURE Open Science Meeting in April and subsequently (expecting that not all members of WG 28 will be able to attend this meeting). The objective of these first drafts is to take stock of what we have in hand, and to understand where the gaps remain. These gaps will then become the focus for directed efforts in the remaining two years of the WG.

In discussion of the revised outline for Chapter 2, one gap that was suggested was whether the report should include a summary from each PICES member country of relevant work, using a common template – this is something to consider. There was also discussion about how best to include the open ocean/high seas areas. Some of this may rely on existing assessments. It may also be useful to identify limitations of existing approaches, *e.g.*, the Halpern model for regional level applications; what is important to capture at small spatial scales. We need to be clear that we are not planning on a comprehensive and exhaustive review of all stressors everywhere in the North Pacific. Instead, we could identify what can apply to areas not covered in our report, and their limitations; we need to focus on areas for which we have expertise. A relevant recent publication was noted (Knights *et al*., 2013, *Ecological Applications* 23(4), 755–765) which conducted a network analysis on stressors.

In discussion of Chapter 3, it was noted there needs to be interaction between this chapter and the case studies, *i.e.*, perhaps including the trial of some of the indicators proposed in Chapter 3.

Chapter 4 should then take the recommendations from Chapters 2 and 3 to utilize and apply in case studies. It was also noted the terminology should be “indicators of ecosystem responses to multiple stressors” (not “indicators of multiple stressors”). It would be useful to include early warning indicators from the literature (*e.g.*, tipping points) where possible, although it was recognized this is a new and emerging field.

Reference points could also be included in Chapter 3: at least their importance should be discussed. They could be included in the Conclusions chapter under future work.

End of March 2014 was recommended as the due date for rough first drafts of Chapter 2 and 3, for circulation amongst WG members, to help prepare for the presentations at the FUTURE OSM, and to help identify remaining gaps which may need to be filled prior to completion of the report.

In broad discussion on the draft report outline, it was noted by Dr. Takafumi Yoshida (NOWPAP representative) that WG 28 appears to be focused on fisheries. Dr. Perry indicated that this WG does not have to be focused only on fisheries and, in fact, should include non-fisheries activities as well. It needs to be stated in the introduction that fisheries is just one example of an activity that may stress a marine ecosystem. Dr. Martone added that cumulative impacts work done to date elsewhere has included fishing, climate, land-based impacts (pollution and sedimentation); for some systems, land-based stressors are correlated with responses.

AGENDA ITEM 5
Interactions with other PICES groups

This item was largely covered by the discussions and responses of WG 28 to the questions posed by Science Board (see Agenda Item 2).

AGENDA ITEM 6
Plans for primary publications resulting from the WG 28 report

This item was deferred.

AGENDA ITEM 7
Other business

It was noted that the FUTURE OSM could be useful for informal discussions amongst WG members who are able to participate, as to the evolving chapter drafts. It was suggested that a good venue for a future meeting of the WG would be in China, as a way to engage Chinese representatives on the draft report.

The meeting adjourned at 18:00 h, with the next full meeting of the WG scheduled for the PICES 2014 Annual Meeting in Yeosu, Korea.

WG 28 Endnote 1

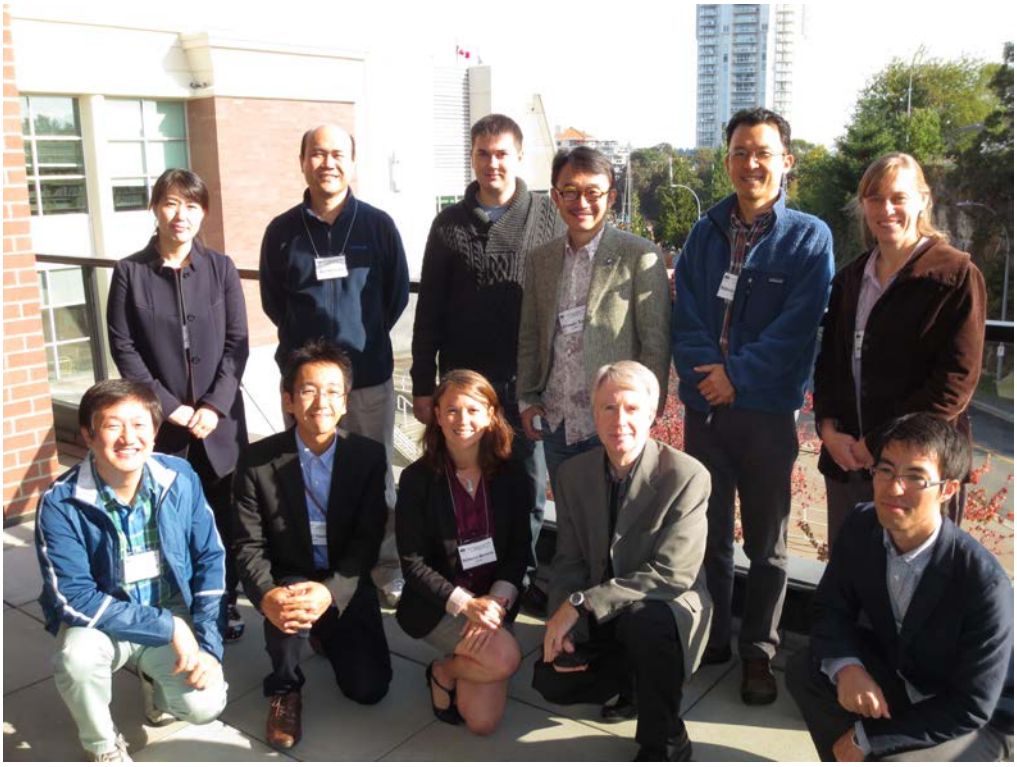
WG 28 participation list

Members

Jennifer L. Boldt (Canada)
Sachihiko Itoh (Japan)
Vladimir V. Kulik (Russia)
Jaebong Lee (Korea)
Rebecca Martone (USA)
Ian Perry (Canada, Co-Chair)
Motomitsu Takahashi (Japan, Co-Chair)
Naoki Yoshie (Japan)

Observers

Karin Baba (Japan)
Sunkil Lee (Korea)
Vadim Navrotsky (Russia)
Hiroaki Saito (Japan)
Jeong Hee Shim (Korea)
Sinjae Yoo (PICES)
Takafumi Yoshida (NOWPAP)



WG 28 meeting participants at PICES-2013 in Nanaimo, Canada. Left to right, back: Jeong Hee Shim, Sunkil Lee, Vladimir Kulik, Hiroaki Saito, Motomitsu Takahashi, Jennifer Boldt. Left to right, front: Jaebong Lee, Naoki Yoshie, Rebecca Martone, Ian Perry, Sachihiko Itoh.

WG 28 Endnote 2

WG 28 meeting agenda

1. Welcome, Introduction and sign-in (all) – including introductions of new Working Group members (co-chairs; see *WG 28 Endnote 3* for list of WG members)
2. Review of activities during the 2nd year of WG 28
   a) General review of Terms of Reference (see Appendix 3) plus discussion of expectations for the Working Group by PICES, and what we expect to be able to deliver (all)
   b) Report on participation and presentation by WG28 in NOWPAP Workshop (Kulik); [see PICES Press July 2013 article: http://www.pices.int/publications/pices_press/volume21/v21-n2/pp_28-29_NOWPAP-Wsh.pdf, also meeting report on WG28 web page: http://www.pices.int/members/working_groups/materials/WG-28-2013-Report-from-NOWPAP-MPA-Workshop.pdf.

c) Report on participation and presentation by WG28 to PICES Inter-sessional Science Board meeting, and at ICES/PICES workshop on Climate Change Effects on Marine Ecosystems (SICCME) (Takahashi)
d) Report on additional WG 28 session proposals, at 2014 PICES FUTURE Open Science Meeting (Perry), and submitted for 2014 PICES Annual Meeting (Martone/Samhouri)
e) Brief outline of WG 28-convened session at 2013 Annual Meeting later in the week (Session S8, titled "Ecosystem indicators to characterize ecosystem responses to multiple stressors in North Pacific marine ecosystems")
f) Report on the project MEcoPAM, which focuses on the impact of multi-stressors on the sustainability of marine ecosystem production in China (discussion led by Takahashi, with input from Chinese WG members)
g) Other related WG28 activities?

3. Review of progress on Terms of Reference
   General discussion of how far we have progressed in addressing our ToR – which have we covered, which have we still to do? To include brief reports from each country of activities of importance to WG 28.
4. Presentations on outlines for each of the draft report chapters, and plans for moving these ahead.
   Lead authors for the various chapters in our draft report outline are requested to present and lead a discussion of their proposed chapter outline, *i.e.*, contents, contributors and task assignments, timelines. Additional contributors (in particular among new WG members or those not able to participate in Hiroshima) are welcome:
   a) Chapter 2 "Frameworks linking pressures to impacts and changes in North Pacific marine ecosystems", and "Multiple pressures on North Pacific marine ecosystems" (discussion leads: Perry, Takahashi)
   b) Chapter 3 "Ecosystem indicators" and "Indicators for ecosystem responses to multiple pressures" [discussion leads: Boldt, Samhouri, Itoh, Yoshie, Chung, others (?)]
   c) Chapter 4 "Case study examples":

      Inland seas, *e.g.*, Salish Sea (Strait of Georgia; Puget Sound), Seto Inland Sea (discussion leads: Samhouri, Perry, Takahashi)

      High latitude seas, *e.g.*, possibly Sea of Okhotsk, Bering Sea (discussion leads: Kullik, Zador, Lukyanova)
   d) Re-look at proposed report chapter outline – are any topics missing (*e.g.*, reference points/tipping points – or could that be added to Chapter 3)?
   e) Conclusions and recommendations – can we begin to identify any of these now? (discussion leads: co-chairs)
5. Discussion of interactions with other PICES groups (co-chairs)
   a) Relationships between WG28 and other Working Groups and Committees
   b) Contributions to FUTURE
6. Discussion of plans for primary publications resulting from the WG 28 report (Samhouri)
7. Any other business

18:00 End

WG 28 Endnote 3

WG 28 members as of September 2013

Dr. Jennifer L. Boldt (Canada)
Dr. Ian Perry (Canada, WG 28 Co-Chairman)
Prof. Min Chao (China)
Dr. Baisong Chen (China)
Dr. Honghui Huang (China)
Dr. Chaolun Li (China)
Prof. Cuihua Wang (China)
Dr. Heng Zhang (China)
Dr. Shigeru Itakura (Japan)
Dr. Sachihiko Itoh (Japan)
Dr. Motomitsu Takahashi (Japan, WG 28 Co-Chairman)
Dr. Naoki Yoshie (Japan)
Prof. Ik Kyo Chung (Korea)
Dr. Jaebong Lee (Korea)
Prof. Chang-Ik Zhang (Korea)
Dr. Vladimir V. Kulik (Russia)
Dr. Olga N. Lukyanova (Russia)
Dr. Rebecca G. Martone (USA)
Dr. Jameal F. Samhouri (USA)
Dr. Stephani G. Zador (USA)

WG 28 Endnote 4

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?

WG 28 Endnote 5

WG 28-sponsored session at the FUTURE Open Science Meeting, Hawaii, April 2014

Identifying multiple pressures and system responses in North Pacific marine ecosystems

Co-convenors (alphabetically): Vladimir Kulik (Russia), Rebecca Martone (USA), Ian Perry (Canada), Jameal Samhouri (USA), Motomitsu Takahashi (Japan)

Coastal and offshore marine ecosystems of the North Pacific are impacted by increasing temperature, changing 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 FUTURE program is to identify and characterize these pressures in order to facilitate comparative studies of North Pacific ecosystem responses to multiple stressors and how these systems might change in the future. This session has two primary objectives: 1) to identify key stressors and pressures on North Pacific marine ecosystems, and to compare how these stressors/pressures may differ in importance in different systems and how they may be changing in time; and 2) to identify ecosystem responses to these multiple stressors and pressures, including gaining an understanding of 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. Papers using conceptual, model-based, observation-based, or experimental-based approaches are welcome, as well as papers which evaluate approaches to linking pressures to ecosystem changes, such as pathways of effects or driver-pressure-state-impact-response models. The overall goal of this session is to obtain an overview of the pressures being experienced by North Pacific marine ecosystems, how these pressures may be changing with time, variation in these pressures (both singly and in combination) among regions, and the combined effects of pressures, both now and in the future, on the marine ecosystems of the North Pacific.

WG 28-sponsored workshop at the FUTURE Open Science Meeting, Hawaii, April 2014

Bridging the divide between models and decision-making: The role of uncertainty in the uptake of forecasts by decision makers

Convenors: Harold Batchelder (USA), Kai Chan (Canada), Edward Gregr (Canada), Shin-ichi Ito (Japan), Vladimir Kulik (Russia), Naesun Park (Korea), Ian Perry (Canada), Jameal Samhouri (USA), Motomitsu Takahashi (Japan)

Uncertainty is a key theme of the FUTURE program. Scientific uncertainty extends beyond the outputs of oceanographic or ecosystem models and has significant consequences on human dimensions ranging from public and stakeholder perception to tactical and strategic decision making by managers and policy makers. The workshop will consider uncertainty along the entire path from data, through model design and implementation to communication and uptake of results by decision makers. Such end-to-end consideration of uncertainty is critical to improve the uptake of oceanographic model results by stakeholders and decision makers in all PICES member countries, particularly as the modeling community moves towards end-to-end models, and faces the challenges of managing multiple stressors. This workshop will thus bridge two central themes of the FUTURE Open Science Meeting: quantification and measurement of uncertainty in observations and projects, and communication and engagement in the development and dissemination of FUTURE products.

The workshop will be centered on two themes. The first of them concerns input data, model structure, and parameterization, and will focus on how sources of uncertainty can be articulated and presented on a technical level. This theme challenges the modeling community to explain the credibility of their results, articulate their assumptions, and generally expose sources of uncertainty. Models of any topic including stock assessment, ecosystem dynamics, and cumulative effects are welcome. The second theme will consider decision analysis and decision making, including psychological insights into how people perceive, understand, and incorporate complex information into decision-making. Discussions will focus on:

(1) how FUTURE can best articulate uncertainty assessments, and develop a communication strategy to broaden the engagement of the public, communities, decision makers and other stakeholders in the results emerging from FUTURE; and (2) how FUTURE products can link to coastal communities, with an emphasis on how and to what degree these products are relevant to the communities whose decisions they presume to affect. This includes the fundamental challenge of how to scale FUTURE scientific outputs with impacts on human dimensions, generally considered at more local extents. This theme in particular will consider approaches to communicate the value of FUTURE products beyond the natural science community. Potential topics of additional discussion include outreach to other disciplines (e.g., psychologists and anthropologists) with the intent of developing more insightful and applicable inter-disciplinary outputs and strategies for presenting FUTURE products to the broader, international stakeholder community. From this workshop, we plan a primary publication outlining how FUTURE products can be effectively communicated to the intended audiences.

WG 28 Endnote 6

Proposal for a 1-day Topic Session on
***"Tipping points: defining reference points for ecological indicators of multiple stressors in coastal and marine ecosystem"* at PICES-2014**

Co-sponsors: ICES, IMBER

Co-Convenors: Rebecca G. Martone (USA), Ian Perry (Canada), Jameal Samhouri (USA), Motomitsu Takahashi (Japan), Maciej Tomczak (Poland), Chang Ik Zhang (Korea)

Many coastal and marine ecosystems, ranging from reefs to estuaries to pelagic systems, are exposed to multiple stressors, which can lead to rapid changes with significant, long-term consequences that are often difficult to reverse. Changes in ocean climate, the abundance of key species, nutrients, and other factors drive these shifts, which affect ocean food webs, habitats, and ecosystem functions and people's livelihoods and well-being. Determining indicators of ecological changes due to multiple stressors and defining reference points for those indicators are key steps for managers to avoid ecological degradation and loss of keys goods and services. Setting ecological reference points in ecological systems presents a challenge to resource managers because (a) reference points are often difficult to determine due to the complexity of natural systems, including the presence of thresholds, tipping points, and non-linearities; (b) the paucity of theoretical modeling and empirical understanding needed to address these complexities, identify ecological thresholds and develop early warning indicators means that managers must make decisions based on high levels of uncertainty; and, (c) many institutional and governance structures do not allow managers the necessary flexibility to take up this information and react within relevant timeframes. This session will address these pressing challenges, and explore promising approaches to tackling them with the goal of catalyzing new research and management innovation. In particular, we invite presentations that (i) define the conceptual basis for reference points and management objectives surrounding reference points; (ii) use theoretical, modeling and observational approaches to identify potential reference points for indicators of changes in marine ecosystems; (iii) incorporate risk and sources of error (measurement, model, process) in such analyses; (iv) discuss how reference points may be used in helping to manage marine ecosystems, specifically in relation to the decision-making process related to evaluating and deciding on acceptable levels of risk. These discussions will be guided by the FUTURE science themes, with special attention to examining climate and anthropogenic drivers of ecological change, and identifying early warning indicators to enable forecasting to avoid crossing ecological thresholds. The outcomes will contribute to the work of PICES Working Group 28 on Development of ecosystem indicators to characterize ecosystem responses to multiple stressors.

WG 28 Endnote 7

Updated and revised (draft) outlines for each chapter of WG 28 final report

(revised from the version originally developed at the WG 28 meeting at PICES-2012 in Hiroshima)

General Outline

Chapter 1. Introduction (Co-Chairs: Takahashi/Perry)

- Background to the WG
- ToR/Objectives
- Brief overview of the issue of multiple activities/stressors on marine ecosystems
  - *e.g*., use of the phrase "activities/stressors (or "pressures") to indicate both natural and anthropogenic pressures, and that not all of these are always "bad" for the ecosystem. Define what is a "bad" ecosystem? – *e.g*., different objectives for ecosystem states, what is "bad" varies for fishers *vs* conservationists. Perhaps recommend the broader concept of retaining the natural resilience of ecosystems?
  - Include definitions for "stressors". Note the issue that information to construct indicators is often available at multiple but different time and space scales, *etc*.
  - Brief literature review of problems of multiple and cumulative stressors in marine systems – *e.g*., the norm, but difficult to assess more than 2–3 stressors at one time
    - presentation by Dr. Coté in Session S8 later in this PICES meeting provides an excellent overview and access to key literature.
    - include reference to climate change and fishing issues (*e.g*., age structures are truncated and this can create problems with resilience to climate change).
    - two general types of approaches:
      - mesocosm experiments,
      - whole ecosystem studies and statistical methods.
- Organization and guide to report contents

Chapter 2. Multiple stressors on North Pacific marine ecosystems (Perry, Takahashi, Samhouri, Zhang, Lee, Martone, others welcome!)

- Frameworks linking pressures to impacts and changes in North Pacific marine ecosystems (*e.g*., PICES Session S10 at 2012 Annual Meeting in Hiroshima)
  - brief review of potential frameworks that could be used to link activities and stressors to ecosystem responses,
  - assessment of their applicability to North Pacific marine ecosystems,
  - recommendations for applications.
  - *e.g*.,
    - Pathways of Effects
    - Driver-Pressure-States-Impact-Response models,
    - simulation and other analytical modeling approaches, *e.g*., Ecopath with Ecosim,
    - probabilistic (Bayesian) networks,
    - Integrated Ecosystem Analyses,
    - IFRAME, INVEST,
    - others?
- Multiple pressures on North Pacific marine ecosystems
  - identification of the spatial (and temporal, where possible) extent of important activities and stressors in North Pacific marine ecosystems,
  - identify habitats and general locations (if possible) where multiple stressors overlap,
  - identify trends in these activities/stressors if possible,
  - use existing literature as a starting point, but also build on own analyses.
- Sub-sections of this chapter for each PICES country, preferably using a common approach (???), plus a synthesis section. Or perhaps these might be included in the case studies?

Chapter 3 Ecosystem Indicators for multiple stressors (Boldt, Samhouri, Itoh, Yoshie, Chung, Martone, others?)

- A. Chapter Introduction
  - Identify need to include indicators of multiple stressors when evaluating the state of marine ecosystems.
  - Purposes of chapter:
    - review existing indicators,
    - review potential sources of data available from national and international programs,
    - indicator-selection criteria, and
    - approaches for evaluating indicators.
- B. Review of indicators in literature
  - General definition of indicators
  - General categories of indicators:
    - Human, biological (including trophodynamics), environmental, socio-economic-political,
    - State and trend,
    - Fulton (2003): strong, intermediate, and weak indicators.
  - Examples of indicators:
    - PICES Scientific Report No. 37:
      - Relative biomass, *e.g.*, top predators,
      - Biomass ratios, *e.g*., Piscivore:planktivore,
      - Habitat-forming taxa, *e.g*., proportional area covered by epifauna,
      - Community size spectra slopes,
      - Taxonomic diversity (richness),
      - Total fishery removals,
      - Maximum (or mean) length of species in catch,
      - Size-at-maturity,
      - Trophic level or trophic spectrum of the catch,
      - Biophysical characteristics, *e.g*., temperature, chlorophyll a.
    - IndiSeas1 (focused on effects of fishing):
      - Mean length,
      - Trophic level of landed catch,
      - Proportion under/ moderately exploited species,
      - Proportion predatory fish,
      - Mean life span,
      - 1/CV biomass,
      - Biomass of surveyed species,
      - 1/landings/biomass.
    - IndiSeas2 (in addition to IndiSeas1 indicators; expanded to include effects of environment and indicators of human dimensions)
    - Environmental indicators: SST, Chl-*a*, global and regional climate
    - Human dimensions indicators:
      - Effectiveness, efficiency and fairness of fisheries management and quality of governance,
      - Contribution of fisheries to food provision, economic and social well being,
      - Well being and resilience of fisher communities.
    - Biodiversity indicators:
      - Mean intrinsic vulnerability index of fish catch,
      - Trophic level of the community,
      - Mixed trophic index (TL $\geq$ 3.25),
      - Proportion of exploited species with declining biomass,
      - Relative abundance of flagship species,
      - Discards/landings.
- C. Indicator Selection Criteria
  - Rice and Rochet (2005) 8-step process for selecting a suite of ecosystem indicators:
    - Step 1 determine user needs,
    - Step 2 develop list of candidate indicators,
    - Step 3 determine screening criteria,
    - Step 4 score candidate indicators against screening criteria,

        - Step 5 summarise scoring results,
        - Step 6 decide how many indicators are needed,
        - Step 7 make final selection,
        - Step 8 report on chosen suite of indicators.
    - PICES 2011 FUTURE workshop criteria (each criterion should be weighted for relevance to end user identified):
        - available regularly and in a timely manner,
        - available as a time series,
        - statistical properties are understood and provided,
        - related to attribute either empirically or theoretically,
        - specific to attribute,
        - spatial and temporal scales of indicator appropriate to attribute,
        - responsive (sensitive to perturbation),
        - relevant to objective,
        - understandable by target audience,
        - provides a basis for comparison between ecosystems.
- D. Indicators of ecosystem responses to multiple stressors
    - Approaches:
        - Halpern *et al*. (2007, 2008, 2009), Teck *et al*. (2010) – cumulative impact scores,
        - Samhouri and Levin (2012).
        - IndiSeas2 exploring approaches to integrating/combining indicators (Shin *et al*., 2012):
            - scoring approach to aggregate all indicators into a single indicator,
            - multidimensional approach,
            - multi-criteria decision analysis.
        - Ban:
            - Data-based: Meta-analysis,
            - Expert-based elicitation,
            - Combined above, spatial: Regional mapping, GIS approaches,
            - Experimental,
            - Model-based.
        - Evaluation of indicators to identify vulnerable ecosystem components
            - despite pros and cons of each approach there is a need to use multiple approaches (expert elicitation, model-based simulation, and empirical analysis) to identify and evaluate critical multiple stressors of North Pacific marine ecosystems and indicators to assess their impacts.

Chapter 4. Case Studies
- Coastal systems (using Strait of Georgia, Canada, Puget Sound (US), Seto Inland Sea (Japan)
    - *e.g*., Perry *et al*. S8 presentation (but at the moment development of Indicators is lacking)
- Possibly: Sea of Okhotsk, Bering Sea (?Lukyanova, Kullik, Zador?)

Chapter 5. Conclusions and recommendations (drafted by Co-Chairs but developed by all WG 28 members)

Appendices
1. Terms of Reference
2. Membership
3. Reports of sessions held by WG 28

etc.