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 17 and 18, 2014 in Yeosu, Korea, under the chairmanship of Drs. Motomitsu Takahashi (Japan) and Ian Perry (Canada). The meeting objective was to review activities during the 3rd year (2013–2014) of WG 28, plan for activities during the 4th year (2014–2015), and discuss the contents of the final report. Note that reports from previous WG 28 meetings and sponsored sessions are available on the WG 28 web page.

Meeting participants and agenda are listed in *WG 28 Endnote 1*. The agenda for this meeting is presented in *WG 28 Endnote 2*.

AGENDA ITEM 2
Review of activities during the 3rd year of WG 28

a) Review of Terms of Reference:

The Terms of Reference for WG 28 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. It was also noted that there are expectations from PICES, FUTURE, and NOWPAP to provide a list of indicators as an output of the WG, and to recommend a set of indicators to the next version of the North Pacific Ecosystem Status Report.

b and c) Report on WG 28-sponsored sessions at the PICES FUTURE Open Science Meeting

WG 28 sponsored a Theme Session (S1) on "*Identifying multiple pressures and system responses in North Pacific marine ecosystems*" and co-sponsored a workshop (W2) on "*Bridging the divide between models and decision-making: The role of uncertainty in the uptake of forecasts by decision makers*" at the FUTURE Open Science Meeting held April 15–18, 2014, on Kohala Coast, Hawaii. See PICES Press Vol. 22, No. 2, 2014, http://www.pices.int/publications/pices_press/volume22/v22-n2/pp_09-10_S1_Perry.pdf and http://www.pices.int/publications/pices_press/volume22/v22-n2/article_pp_24-27_W2_Gregr.pdf.

d) Report on WG 28-sponsored session at PICES-2014

WG 28 co-sponsored a BIO/MEQ Topic Session (S3) on "*Tipping points: defining reference points for ecological indicators of multiple stressors in coastal and marine ecosystem*" at PICES-2014 with ICES and IMBER. Co-Convenors were Rebecca G. Martone (PICES/USA), Ian Perry (PICES/Canada), Jameal Samhouri (PICES/USA), Motomitsu Takahashi (PICES/Japan), Maciej Tomczak (ICES/Poland), Chang Ik Zhang (PICES/Korea). A summary of the Topic Session can be found in the Session Summaries of the 2014 Annual Report.

e) Other related WG 28 activities (including country reports)

Country reports were presented under Agenda Item 3.

AGENDA ITEM 3
Progress on Terms of Reference, and brief country reports of activities of interest to WG 28

Canada (Ian Perry)

Dr. Perry described work undertaken by the Puget Sound Science Panel to develop a process for identifying pressures on this ecosystem. This approach is systematic, expert-based, and includes an evaluation of the potential impact of stressors on endpoints. The process is described in Puget Sound Partnership Technical Report 2014-02 (Labiosa *et al.*).

China

No report.

Japan (Motomitsu Takahashi)

Dr. Takahashi described his work on understanding ecosystem responses to activities and stressors among inland (Seto Sea), shelf (Yellow Sea and East China Sea), and oceanic waters (Kuroshio/Oyashio) in the western North Pacific, using a comparative study based on expert elicitation. Presentation of his results were made in Topic Session S3.

Korea (Chang-Ik Zhang)

The ecosystem approach to fisheries management approach being developed in Korea uses the IFRAME approach (Zhang *et al*. 2011. *ICES J. Mar. Sci.*). It is not revolutionary, but rather is an evolutionary approach. It is capable of being applied with available information, is precautionary and environmentally sound, and is relatively simple and pragmatic to use. The second tier of this approach is underway to develop management objectives, indicators and reference points, and nested risk indices and management status indices. Examples of management objectives and indicators include: sustainability, habitat quality, socio-economy, and biodiversity.

Russia (Olga Lukyanova)

Dr. Lukyanova described work being conducted in Peter the Great Bay, which has the highest pressure from human activities of eastern Russian marine systems. Pressures being investigated include pollution, fisheries, *etc*. The approach used both expert elicitation and data driven methods. Dr. Kulik described issues with the exchange of data among institutes in Russia. In the past, they could only calculate the effects of stressors for individual regions within Russia. Recently, however, approval has been granted to share metadata among institutes.

United States (Jameal Samhouri)

Dr. Samhouri described activities (Integrated Ecosystem Assessments) by NOAA, and noted that a national meeting is being planned to consider issues of reference points, vulnerability, and stationarity over time. Regional studies are being conducted in Puget Sound and in the California Current System. In Alaska, an expert survey is ongoing to identify ecosystem indicators for the Gulf of Alaska, which would include the effects of climate change.

NOWPAP (Alexander Tkalin)

Dr. Tkalin described the Northwest Pacific Action Plan (NOWPAP). NOWPAP is interested in the outcomes of WG 28, as a potential user of the recommendations and materials provided. Dr. Tkalin noted that UNEP (United Nations Environment Programme) is also working on a toolbox of indicators, as is HELCOM (the Helsinki Commission) in the Baltic. NOWPAP is focused on 5 broad themes: biodiversity, eutrophication, pollution, marine litter, invasive species. Dr. Tkalin noted that fishing is not one of NOWPAP's foci.

AGENDA ITEMS 4 AND 5
Report draft chapter outlines

The working draft report's chapter outline is present in *WG 28 Endnote 3*.

Chapter 2 Multiple stressors on North Pacific marine ecosystems

Suggested items to include are:

- Comparing global GIS-based stressor maps with more detailed regional maps: do the global; maps represent the regional maps?
- The INVEST approach helps to structure and illustrate trade-offs. Note, however, that INVEST is more correctly a suite of tools rather than a framework *per se*. For WG 28, the more useful tools might be those relating to habitat risk assessment and sensitivity.

- Some frameworks require an Objective, *e.g.*, DPSIR. Therefore, Objectives need to be assigned in order for these frameworks to be applied, which is often done by a small group of indicator developers. It would be helpful to include a table which identifies those frameworks which require objectives, *etc.* (*i.e.*, which have specific requirements for data, objectives, *etc.*). Frameworks also need to be applied at the appropriate scales.

Chapter 3 Ecosystem Indicators for multiple stressors in the North Pacific

Dr. Boldt and colleagues were congratulated on their publication arising in part from work to prepare this chapter (Boldt, J., Martone, R., Samhouri, J., Perry, R.I., Itoh, S., Chung, I.K., Takahashi, M., Yoshie, N. 2014. Developing ecosystem indicators for responses to multiple stressors. *Oceanography* 27(4): 116–133).

The stacked bar chart figure in this publication is a great demonstration of the different processes (and indicators) across a number of areas. It will also be useful to compare the similarities and differences among these indicators sets. Some of the outcomes from preparing this paper included a recognition that one general list of indicators for multiple stressors is likely not currently possible (and maybe never). There are two obvious approaches: 1) ecosystem specific, for example in which a general set might be applied to many systems, and 2) a core set of general indicators supplemented by additional indicators specific to a particular system. The latter was considered as a 'toolbox' approach and was preferred by the WG. It was noted that the EU Marine Strategy Framework Directive included 11 descriptors with 57 indicators. Also noted was the general problem of a lack of objectives and how best to define "Good Environmental Status". The WG suggested it would be useful to include a list of potential indicators, matched against whether they were available to populate these indicators.

The approach taken in Japan is quite different. It uses a hierarchical medical chart analogy, and includes the smoothness of materials cycling (*e.g.*, see the presentation by Dr. Kisaburo Nakataat (BIO/FIS/MEQ/TCODE/FUTURE Topic Session (S8) on "*Ecosystem indicators to characterize ecosystem responses to multiple stressors in North Pacific marine ecosystems*" at PICES-2013 (Nanaimo, Canada). This approach also provides a framework for local people to conduct their own analyses.

Suggestions for additional information in Chapter 3 included:
- Western Pacific examples of programs/approaches to identifying indicators of multiple stressors and ecosystems assessments (*e.g.*, Itoh's list from Japan);
- A recommended list of indicators of responses to multiple stressors;
- Tables of data availability for indicators and pressures (mostly complete);
- Final summary with references to other chapters in the WG 28 report.

Much of Day 2 of the meeting involved extensive discussions on what indicators, and sets of indicators, should be recommended for application in PICES areas. It was agreed that the European Union Marine Strategy Framework Directive (EU-MSFD) indicators can serve as a reasonable starting point from which to build on or subtract from when applying to PICES areas. An important question to ask is whether any of these indicators might lead to mis-interpretation of results if multiple interacting stressors are present – *i.e.*, Are single indicators enough to capture status and trends in marine ecosystems, or might they lead to incorrect interpretations if multiple stressors are in fact present? The Crain *et al*. (2008) study might be useful as an initial guide to how various stressors may interact, additively or negatively. *WG 28 Endnote 4* presents the WG 28's initial assessment of indicators suggested by the EU-MSFD for application to the North Pacific.

The meeting adjourned at 15:00 h on 18 October 2014.

WG 28 Endnote 1

WG 28 participation list

Members

Jennifer L. Boldt (Canada)
Kazuhiko Mochida (Japan)
Sachihiko Itoh (Japan)
Vladimir V. Kulik (Russia)
Jaebong Lee (Korea)
Olga Lukyanova (Russia)
Rebecca Martone (USA)
Ian Perry (Canada, Co-Chair)
Jameal Samhouri (USA)
Motomitsu Takahashi (Japan, Co-Chair)
Naoki Yoshie (Japan)
Stephanie Zador (USA)
Chang-Ik Zhang (Korea)

Observers

Phil Levin (USA)
Alexander Tkalin (NOWPAP coordinator)
Sang Chul Yoon (NFRDI, Korea)
Xiaodong Zhong (NOWPAP Secretariat)

WG 28 meeting participants at PICES-2014 in Yeosu, Korea. Left to right: Sang Chul Yoon, Jaebong Lee, Naoki Yoshie, Xiaodong Zhong, Kazuhiko Mochida, Motomitsu Takahashi, Ian Perry, Jameal Samhouri, Chang-Ik Zhang, Vladimir Kulik, Jennifer Boldt, Sachihiko Itoh, Stephani Zador, Rebecca Martone.

WG 28 Endnote 2

WG 28 meeting agenda

1. Welcome, Introduction and sign-in (all)
2. Review of activities during the 3rd year of WG 28
   a) General review of Terms of Reference plus discussion of expectations for the Working Group by PICES, and what we expect to be able to deliver (all)
   b) Report on WG 28-sponsored Theme Session at the PICES FUTURE Open Science Meeting in Hawaii, April 2014 (Perry);
   c) Report on Workshop (W2) at the PICES FUTURE Open Science Meeting in Hawaii, April 2014
   d) Report on WG 28-sponsored Topic Session at PICES-2014 FUTURE Open Science Meeting (Martone/Samhouri)
   e) Other related WG 28 activities (including country reports)
3. Review of progress on Terms of Reference, and brief country reports of activities of interest to WG 28
   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 progress on each of the draft report chapters, and plans for moving these ahead (see Appendix 4 for draft report outline and lead authors, as discussed at our meeting in Nanaimo, 2013)
   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" - to include presentation/discussion of article accepted for publication in *Oceanography* [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)
5. Discussions of report outline, continued
   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). To include discussion of possible specific indicators to recommend to PICES for inclusion in the next North Pacific Ecosystems report.
6. Discussion of interactions with other PICES groups (co-chairs)
   a) Relationships between WG28 and other Working Groups and Committees
   b) Contributions to FUTURE
7. Discussion of plans for primary publications resulting from the WG28 report (Samhouri)
8. Any other business

18:00 End

NOTE: WG 28 has available a second day (Saturday, October 18, 2014, 0900–1800) for its business meeting if needed for work on the various chapters, etc. At present the agenda for day 2 is unscheduled.

WG 28 Endnote 3

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, 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.

WG 28 Endnote 4
Initial discussion list of potential indicators*

Indicator	Type	Could non-additive interactions between fishing and nutrients complicate interpretation of this indicator? (could be positive or negative reaction; could be antagonistic or synergistic)
1.1.1. Distributional range	State	yes
1.1.2. Distributional pattern within the latter	State	no
1.1.3. Area covered by the species (for sessile/benthic species)	State	yes
1.2.1. Population abundance and/or biomass	State	yes
1.3.1. Population demographic characteristics	State	no
1.3.2. Population genetic structure	State	no
1.4.1. Distributional range	State	no
1.4.2. Distributional pattern	State	no
1.5.1. Habitat area	State	no
1.5.2. Habitat volume, where relevant	State	no
1.6.1. Condition of the typical species and communities	State	yes
1.6.2. Relative abundance and/or biomass, as appropriate	State	yes
1.6.3. Physical, hydrological and chemical conditions	State	yes
1.7.1. Composition and relative proportions of ecosystem components (habitats, species)	State	yes
3.2.1. Spawning Stock Biomass (SSB)	State	yes
3.2.2. Biomass indices	State	yes
3.3.1. Proportion of fish larger than the mean size of first sexual maturation	State	yes
3.3.2. Mean maximum length across all species found in research vessel surveys	State	yes
3.3.3. 95% percentile of the fish length distribution observed in research vessel surveys	State	yes
3.3.4. Size at first sexual maturation	State	yes
4.1.1. Performance of key predator species using their production per unit biomass	State	yes
4.2.1. Large fish (by weight)	State	yes
4.3.1. Abundance trends of functionally important selected groups/species	State	?
5.1.1. Nutrients concentration in the water column	State	no
5.1.2. Nutrient ratios (silica, nitrogen and phosphorus)	State	no
6.1.1. Type, abundance, biomass and areal extent of relevant biogenic substrate	State	yes
6.1.2. Extent of the seabed significantly affected by human activities for the different substrate types	State	yes
6.2.1 Presence of particularly sensitive and/or tolerant species*	State	yes
6.2.2. Multi-metric indices assessing benthic community condition and functionality, such as	State	yes
6.2.3. Proportion of biomass or number of individuals in the macrobenthos above specified length/size	State	yes

6.2.4. Parameters describing the characteristics of the size spectrum of the benthic community	State	yes

*derived from the European Union's Marine Strategy Framework Directive, the type of indicator they represent, and WG 28's initial assessment of whether interactions among multiple stressors may lead to incorrect interpretations