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PICES

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Report of the PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish

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PICES

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Contents

Executive Summary

In 2008, the North Pacific Marine Science Organization (PICES) and the International Council for the Exploration of the Sea (ICES) approved the formation of an interdisciplinary Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS). This Working Group was designed to enagage the PICES and ICES scientific communities in an effort to discuss and assess our current understanding of the implications of climate change on marine fish and fisheries. The group was quite active, and the products of WG-FCCIFS include one major scientific symposium, a symposium volume and several peer reviewed journal articles. WG-FCCIFS's primary accomplishments and research findings are described in this report. The group promoted research on climate change impacts on marine ecosystems by scientists in PICES and ICES member countries through coordinated communication, exchange of methodology, and organization of meetings to discuss and publish results. In collaboration with relevant expert groups in PICES and ICES, WG-FCCIFS developed frameworks and methodologies for projecting the impacts of climate change on marine ecosystems, with particular emphasis on shifts in the distribution, abundance and production of commercial fish and shellfish. WG-FCCIFS members met to review the results of designated case studies to test methods. Given the limitations of our forecasts, they also explored techniques for estimating and communicating uncertainty in forecasts and strategies for research and management under climate change scenarios. As the 3-year term for WG-FCCIFS approached, it was clear that PICES and ICES were well positioned to serve as world leaders in advancing science on assessments of climate change impacts on marine ecosystems. This recognition led to the formaton of the ICES Strategic Initiative on Climate Change Effects on Marine Ecosystems (SICCME), referred to as the Section on *Climate Change Effects on Marine Ecosystems* (S-CCME) within PICES.

Introduction

In the fall of 2008, the North Pacific Marine Science Organization (PICES) and the International Council for the Exploration of the Sea (ICES) approved the formation of a PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS). The rationale for establishing the joint group was to promote and coordinate research on the potential impacts of climate change on marine fish and shellfish around the world. In ICES, the group initially reported to the Oceanography Committee and ICES Climate Change Steering Group (SGCC) and later, after ICES restructuring in 2009, changed to the Steering Group on Human Interactions on Ecosystems (SSGHIE), under the Science Committee (SCICOM). In PICES, WG-FCCIFS reported to the Fishery Science Committee (FIS) and Physical Oceanography and Climate Committee (POC), and the activities of the group were designed to advance the Organization's new integrative science program on **F**orecasting and **U**nderstanding **T**rends, **U**ncertainty, and **R**esponses of North Pacific Marine **E**cosystems (FUTURE).

Drs. Anne B. Hollowed (PICES/USA), Manuel Barange (ICES/United Kingdom), Suam Kim (PICES/Korea), and Harald Loeng (ICES/Norway) were appointed as co-chairmen of WG-FCCIFS. The full membership of the group is listed in Appendix 1.

This report synthesizes the activities of the group to highlight the key findings. As this is a PICES publication, some additional information from a PICES perspective has been added in the Introduction. The ICES counterpart to the report can be found at http://www.ices.dk/publications/library/Pages/default.aspx#k=wgfccifs. In some cases documents have been re-printed here to provide a permanent record of decisions or key actions.

Background

Prior to the establishment of WG-FCCIFS, ICES and PICES scientists had conducted several studies on climate change effects on fish and fisheries, including: (a) guidance on methods for selection of IPCC scenarios for use in projections; (b) techniques for downscaling IPCC scenarios to local regions, (c) development of coupled ecosystem models for use in evaluating climate-induced shifts in environmental conditions, (d) synthesis of relationships between climate forcing and marine fish and shellfish distribution and production, and (e) stock assessment techniques for evaluating management strategies to mitigate the impacts of change. A challenge facing ICES and PICES was the need to integrate all of this research to provide stakeholders with quantitative estimates of the potential impact of climate change on marine life throughout the world. To meet this challenge, an interdisciplinary research team of experts was assembled to focus attention on the development of common and standardized frameworks for forecasting climate change impacts on marine life, with particular emphasis on commercially important fish and shellfish. The formation of the joint group enabled the research communities of both organizations to develop the capability to provide (1) quantitative contributions to the fifth set of Intergovernmental Panel on Climate Change (IPCC) Assessment Reports and (2) guidance for management under climate change scenarios.

Within PICES, the idea for such an expert group dated back to 2006–2007 when the following workshops were held:

- workshop on "*Linking climate to trends in productivity of key commercial species in the sub-arctic Pacific*" in October 2006 in conjunction with the 2006 PICES Annual Meeting in Yokohama, Japan;

- Phase 1 workshop on "*Forecasting climate impacts on future production of commercially exploited fish and shellfish*", co-sponsored by the North Pacific Research Board (NPRB) in July 2007, in Seattle, USA;
- Phase 2 PICES/NPRB workshop on "*Forecasting climate impacts on future production of commercially exploited fish and shellfish*" in October 2007, in conjunction with the PICES Annual Meeting in Victoria, Canada.

The goal of this workshop series was to develop a coordinated international effort to provide quantitative estimates of the impacts of climate change on major fish populations. Discussions revealed that there were several international programs which had goals similar to the PICES forecasting effort. The proceedings of the two 2007 workshops were combined and published in 2008 (PICES Scientific Report No. 34).

Similarly, ICES commissioned several study groups, working groups, workshops and strategic initiatives on the topic of climate change effects on fish and fisheries, including:

- workshop on "*Cod and future climate change*" (WKCFCC) in June 2008, in Copenhagen, Denmark;
- ICES/GLOBEC Working Group on Cod and Climate Change (WGCCC);
- ICES/PICES/GLOBEC–SPACC workshop on "*Changes in distribution and abundance of clupeiform small pelagic fish in relation to climate variability and global change*" (WKSPCLIM) in November 2008, in Kiel, Germany;
- ICES Strategic Initiative on Climate Change (Reid and Valdés, 2011).

It was at the 2007 Annual Meeting in Victoria that a proposal was put forth to the FIS Committee of PICES to form a working group initially named "*Implications of Climate Variability and Climate Change on Trends in Commercially Important Fish and Shellfish*". FIS strongly supported this proposal, and felt the effort would be consistent with the activities envisioned under PICES' second integrative science program, FUTURE, and PICES-sponsored work in this area would provide a good start to this line of research that would likely become an ongoing effort in FUTURE. The proposal was deferred by PICES Science Board to the following year (2008) to more fully consider the interactions and synergies of the new group with POC's Working Group on *Evaluations of Climate Change Projections* (WG 20). The Working Group was renamed to *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS/PICES WG 25) upon its establishment in 2008.

WG-FCCIFS objectives and activities

WG-FCCIFS was tasked with providing guidance on the potential impacts of climate change on marine ecosystems and the response of commercial fish and shellfish resources to these changes. Members of ICES and PICES recognized that both organizations had a long history of research on the links between climate variability and change on fish and fisheries. They also recognized that a partnership between ICES and PICES scientists would better address the global scale of climate change impacts on marine ecosystems. Through the formation of WG-FCCIFS, ICES and PICES sought to ensure that their research communities produced peer-reviewed publications that quantitatively inform climate–marine resource interactions to be considered for future IPCC reports, and to provide insights on the effect on marine resource population responses to climate change.

The Terms of Reference for WG-FCCIFS were to:

1. Promote research on climate change impacts on marine ecosystems by scientists in ICES and PICES member nations through coordinated communication, exchange of methodology, and organization of meetings to discuss and publish results;
2. In collaboration with relevant expert groups in PICES and ICES, develop frameworks and methodologies for forecasting the impacts of climate change on marine ecosystems, with particular emphasis on the distribution, abundance and production of commercial fish and shellfish;
3. Review the results of designated case studies to test methods;
4. Explore techniques for estimating and communicating uncertainty in forecasts;

5. Explore strategies for research and management under climate change scenarios, given the limitations of our forecasts;
6. Plan for a science symposium in early 2010 to present, discuss and publish forecasts of climate change impacts on the world's marine ecosystems, with particular emphasis on commercial fish and shellfish resources;
7. Produce publications that are relevant to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change;
8. Publish report(s) summarizing work.

WG-FCCIFS was extremely productive during its 3-year term, organizing a major symposium, holding several inter-sessional and annual business meetings, and convening inter-sessional workshops and theme/topic sessions during ICES Annual Science Conferences (ASC) and PICES Annual Meetings. A chronological list of these activities led by, or related to, the group is given below.

June 2009
Inter-sessional WG-FCCIFS meeting, Victoria, British Columbia, Canada

September 2009
WG-FCCIFS meeting and ICES/PICES Theme Session on "*Climate impacts on marine fish: Discovering centennial patterns and disentangling current processes*", ICES Annual Science Conference, Berlin, Germany

October/November 2009
WG-FCCIFS meeting and POC/FUTURE Topic Session on "*Outlooks and forecasts of marine ecosystems from an earth system science perspective: Challenges and opportunities*", PICES-2009, Jeju, Korea

April 2010
PICES/ICES/FAO Symposium "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses, and evaluating management strategies*", **Publication: Special volume *ICES Journal of Marine Science* 68(6)**, and inter-sessional WG-FCCIFS meeting, Sendai, Japan

September 2010
WG-FCCIFS meeting and ICES/PICES Theme Session on "*Responses to climate variability: Comparison of Northern Hemisphere marine ecosystems*", ICES Annual Science Conference, Nantes, France

October 2010
WG-FCCIFS meeting and PICES/ICES Topic Session on "*Impact of climate variability on marine ecosystems: understanding functional responses to facilitate forecasting*", PICES-2010, Portland, USA

April 2011
Presentation of a Science Plan for the Section (Strategic Initiative) on *Climate Change Effects on Marine Ecosystems* at the PICES inter-sessional Science Board meeting, Honolulu, USA

May 2011
ICES/PICES Workshop on "*Reaction of Northern Hemisphere eosystems to climate events: A comparison*" (WKNORCLIM), Hamburg, Germany

ICES/PICES Workshop on "*Biological consequences of a decrease in sea ice in Arctic and Sub-Arctic seas*" (WKBCASAS), **Publication: Hollowed *et al.*, 2013, *Fisheries Oceanography* 22(5)**, and inter-sessional WG-FCCIFS meeting in conjunction with the ESSAS Open Science Meeting, Seattle, USA

June 2011
Workshop on "*Basin-wide impact of Atlantic Multidecadal Oscillation*" (WKAMO), **Publication: Edwards *et al.*, 2013, *PLoS ONE* 8; Alheit *et al.*; *Journal of Marine Systems*, in press,** in Woods Hole, USA.

September 2011
WG-FCCIFS meeting, ICES Theme Session on “*Biophysical modeling tools and their potential use in marine spatial management: A strategic dialogu*e”, and ICES/PICES Theme Session on “*Atmospheric forcing of the Northern Hemisphere ocean gyres, and subsequent impact on adjacent marine ecosystems*”, ICES Annual Science Conference, Gdańsk, Poland

October 2011
WG-FCCIFS meeting and PICES/ICES Topic Session on “*Mechanisms of physical-biological coupling forcing biological “hotspots”*” and PICES/ICES Topic Session on “*Linking migratory fish behavior to end-to-end models*”, PICES-2011, Khabarovsk, Russia

A major milestone for the group was the organizing of a joint PICES/ICES/FAO Symposium on “*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses, and evaluating management strategies*” (April 2010, Sendai, Japan), and a summaries of all sessions and workshops convened at the symposium constitute the main body of this report. A resulting publication of a special issue from the symposium in the *ICES Journal of Marine Science* (2011, Vol. 68(6)) provided a set of peer-reviewed papers assessing current knowledge of the effects of climate change on fish and fisheries suitable for consideration by the IPCC’s Fifth Assessment Report.

The remainder of the report consists of Appendices 1 to 6 which list WG-FCCIFS membership (1), brief reports of inter-sessional and annual meetings (2), summaries from PICES/ICES sessions and workshops (3), proposal for a new expert group (4), relevant background reports from PICES Annual Meetings (5), PICES Press news articles related to WG-FCCIFS activities (6), and completes with references.

Future directions in the formation of S-CCME

Following the success of the Sendai symposium, WG-FCCIFS members met in the fall of 2010 at the ICES Annual Science Conference in Nantes, France and at the PICES Annual Meeting in Portland, USA, to discuss on-going activities and the need to develop a long-term strategic initiative on climate change effects on marine ecosystems. PICES and ICES recognized that great strides in new sciences had emerged from collaborative work between two organizations and the importance of preparing a Science Plan that would outline a structure for continued collaboration focused on climate change. A proposal for new expert group, generated from the merging of an ICES Strategic Initiative on Climate Change with WG-FCCIFS was presented at the PICES inter-sessional Science Board meeting (April 2011, Honolulu, USA). Adjustments to the proposed expert group Terms of Reference to integrate the program into PICES’ FUTURE plans and activities were made, and at WG-FCCIFS’ inter-sessional meeting (Seattle, USA) one month later, members discussed the Implementation Plan. At the 2011 fall meetings of ICES (Gdańsk, Poland) and PICES (Khabarovsk, Russia), a joint ICES/PICES initiative termed Strategic Initiative on Climate Change Effects on Marine Ecosystems (SICCME) in ICES, termed Section on *Climate Change Effects on Marine Ecosystems* in PICES (S-CCME), was established.

Report of the PICES/ICES/FAO Symposium on "*Climate Change Effects on Fish and Fisheries: Forecasting Impacts, Assessing Ecosystem Responses, and Evaluating Management Strategies*"

WG-FCCIFS convened an international symposium to provide a venue for the exchange of scientific information and the discussion of the issues and challenges related to predicting the future impacts of climate change on the world's marine ecosystems. Working Group members played a key role in organizing and convening the PICES/ICES/FAO Symposium on "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses, and evaluating management strategies*" in Sendai, Japan, on April 26–30, 2010. A total of 35 papers from the symposium were published as a special issue in the *ICES Journal of Marine Science* in 2011 (Hollowed *et al*., 2011). A synthesis of the outcomes of this symposium was published in the *ICES Journal of Marine Science* (Hollowed *et al*., 2013).

The symposium and the subsequent publications advanced understanding within the scientific community of the potential effects of climate change on fish and fisheries. The symposium also provided the background information needed to address four of the WG-FCCIFS Terms of Reference:

- Identify frameworks and methodologies for forecasting the impacts of climate change on the growth, distribution and abundance of marine life with particular emphasis on commercial fish and shellfish;
- Assess the results of designated case studies to test methods;
- Establish techniques for estimating and communicating uncertainty in forecasts;
- Evaluate strategies for research and management under climate change scenarios, given the limitations of our forecasts.

Key findings from the symposium were distributed using three approaches:

1. Meeting summaries were published in PICES Press: http://pices.int/publications/pices_press/volume18/v18_n2/PICES_Press18_FULL.pdf. This vehicle provided immediate outreach to scientists in the PICES and ICES communities.
2. Theme Session and Workshop co-convenors prepared more detailed summaries of key findings from their sessions that were published as an ICES CM report: http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGHIE/2010/WGFCCIFS10.pdf (see also this report).
3. Selected papers were published in a special issue of the *ICES Journal of Marine Science* with sufficient time for them to be considered by review panels responsible for the next Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and other review bodies (*e.g.*, the Millennium Report of the United Nations Development Program).

The response to this symposium exceeded the expectations of the convenors, with more than 350 abstracts submitted by scientists from over 40 countries. A total of 208 oral presentations and 105 posters were presented. Scientists from around the world debated the issues stemming from climate change impacts on marine ecosystems during the 3½-day symposium. The symposium provided a venue for the international research community to work together in an interdisciplinary setting to assess and evaluate the impacts of climate change on fish and fisheries.

The symposium was arranged around ten theme sessions, with six workshops preceding the meeting. These sessions and workshops encompassed a broad range of topics that provided a global perspective on climate change and the future of the world's fish and fisheries. Day 1 started with presentations by four plenary speakers: Drs. Kevin Trenberth (USA), Akihiko Yatsu (Japan), Ussif Rashid Sumaila (Canada) and Edward Allison (Malaysia).

The theme sessions for Day 1 included:

- **Session P1-D1**: Forecasting impacts: from climate to fish (co-chaired by Kenneth Drinkwater, Harald Loeng, Franz Mueter, Carl O'Brien, Graham Philling and Yashuhiro Yamanaka),
- **Session P2:** Forecasting impacts: from fish to markets (co-chaired by Manuel Barange, Jacquelynne King, Ian Perry and Adi Kellermann),
- **Session A2:** Species-specific responses: changes in growth, reproductive success, mortality, spatial distribution and adaptation (co-chaired by Richard Beamish, Myron A. Peck and Motomitsu Takahashi).

The themes for Day 2 included:

- **Session A1:** Downscaling variables from global models (co-chaired by Michael Foreman and Jason Holt),
- **Session A2:** Continuation: Species-specific responses: changes in growth, reproductive success, mortality, spatial distribution and adaptation (co-chaired by Richard Beamish, Myron A. Peck and Motomitsu Takahashi),
- **Session B1:** Assessing ecosystem responses: impacts on community structure, biodiversity, energy flow and carrying capacity (co-chaired by Thomas Okey and Akihiko Yatsu).

The themes for Day 3 focused the following topics:

- **Session B2:** Comparing responses of climate variability among nearshore, shelf and oceanic regions (co-chaired by Jürgen Alheit, Jae Bong Lee, and Vladimir Radchenko),
- **Session C1:** Impacts on fisheries and coastal communities (co-chaired by Edward Allison, Keith Brander, and Suam Kim),
- **Session C2:** Evaluating human responses, management strategies and economic implications (co-chaired by Tarub Bahri, Kevern Cochrane and Jake Rice),
- **Session D2:** Contemporary and next generation climate and oceanographic models, technical advances and new approaches (co-chaired by Jonathan Hare and Shin-ichi Ito).

The final ½-day session (**Session P3**, Day 4) was held in plenary. This session focused on sustainable strategies in a warming climate and it was co-chaired by Drs. Anne Hollowed and Michael Schirripa. Dr. Steve Murawski provided a summary of first impressions from the meeting.

The key outcomes from the symposium are:

- Long-term ocean monitoring programs are needed to track and understand ecosystem and climate change as they occur.
- Networks of shelf-seas ecosystem models have already been developed within several of the world's Large Marine Ecoystems (LMEs). These models provide a basis for examining structural uncertainty within shelf sea ecosystem models.
- Three sources of uncertainty in Global Ocean Models (GOMs) are under investigation: (1) parameter uncertainty, (2) structural uncertainty, (3) scenario uncertainty. Parameter uncertainty is being addressed to some degree with sensitivity tests, structural uncertainly is being explored via comparison of different coupled physical–biological models, and scenario uncertainty deals with greenhouse gas emissions and economics could be addressed *via* using ensemble model sets.
- There are eight approaches to predicting the effects of climate change on fish and fisheries: (1) global or basin-scale static models, (2) global-scale dynamic models, (3) dynamic downscaling, (4) statistical downscaling, (5) deductive approach, (6) comparative approaches, (7) statistical/time series approach, and (8) field and laboratory studies. Each has strengths and weaknesses.

- Fisheries oceanography and laboratory studies are critical to integrating biological and oceanographic models, evaluating species environmental tolerances and adaptation, and to tracking species responses to long-term ecosystem and climate change as it occurs.
- Models that couple marine social and economic responses are needed to evaluate management strategies. However, few examples exist.
- Issues of food security and marine conservation may require new approaches to satisfy the growing demand for marine resources.
- Two-way communication is needed with scientists and stakeholders to develop meaningful scenarios on human responses to the impact of ecosystem and climate change.

WG-FCCIFS tasked the convenors to summarize the outcomes of their respective sessions. These reports are organized by Theme (A–D) or Plenary (P1–P3) sessions. In an effort to focus the reports to address key tasks within the Working Group's Terms of Reference, WG-FCCIFS requested that each session summary address the following set of questions:

- What advances on frameworks and methodologies for forecasting climate change were presented/ discussed?
- What results were presented from designated case studies (to test methods)?
- What techniques were presented for estimating and communicating uncertainty in forecasts?
- What strategies were evaluated regarding research and management under climate change scenarios?

Several authors provided summaries of climate change impacts on ocean ecosystems and tools for modeling these changes (Brander, 2010; Ito *et al*., 2010; Overland *et al*., 2010; Stock and Dunne, 2010). This report supplements those efforts by providing a global perspective on the problem.

Much of the following text, including reports from workshops that preceded the meeting, was previously published in the ICES CM report http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGHIE/2010/WGFCCIFS10.pdf. In this report, a number of references have been updated.

Session P1-D1: Forecasting impacts: From climate to fish

Co-Convenors
Ken Drinkwater (Institute of Marine Research, Norway)
Harald Loeng (Institute of Marine Research, Norway)
Yasuhiro Yamanaka (Hokkaido University, Japan)
Franz Mueter (School of Fisheries and Ocean Sciences, University of Alaska Fairbanks, USA)
Carl O'Brien (Centre for Environment, Fisheries and Aquaculture Science, UK)
Graham Pilling (Centre for Environment, Fisheries and Aquaculture Science, UK)

Introduction

This session focused on the impacts of future climate change on the physical oceanography, biogeochemistry, and food webs of the world oceans, with an emphasis on changes in fish and shellfish populations. Methods for projecting climate change impacts on marine ecosystems at both regional and global scales were presented, as well as methods for estimating and communicating the associated levels of uncertainty. Presentations addressed downscaling from global models to produce regional future climate and physical oceanographic scenarios, scenarios of climate-induced changes in nutrient dynamics and other biogeochemical processes, and changes in ecosystem structure from phytoplankton and zooplankton through to fish populations, including changes in production and distribution and their influence upon biodiversity.

The session consisted of 20 oral presentations and 19 posters, including invited presentations by Kevin Trenberth and Randall Peterman. Dr. Trenberth provided an overview of the Earth's climate system and presented unequivocal evidence that humans are warming the world's atmosphere and oceans. He emphasized the importance of changes in the extremes rather than in mean climate states. Dr. Peterman discussed the major sources of uncertainty when forecasting climate effects, highlighting the importance of structural model uncertainty, which can only be addressed by considering multiple alternative models. He emphasized that inadequate communication among scientists, decision makers, and stakeholders can be a potentially important and poorly understood source of uncertainty.

Session P1-D1: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

A variety of frameworks and methodologies were employed to forecast potential effects of climate warming on fish and shellfish populations at regional to global scales. The majority of papers generated quantitative forecasts of future productivity or distribution of selected species based on the output of one or more global circulation models (GCMs). Approaches based on GCMs were divided into (a) global-scale static models, (b) global-scale dynamic models, (c) dynamic downscaling techniques, and (d) statistical downscaling techniques. Other approaches did not produce quantitative forecasts but aimed at predicting the likely direction of future changes under global warming based on understanding the mechanisms that relate productivity of a key species to climate variability (e). The comparative technique (f) was similarly employed to better understand the mechanisms that favor different species during warm and cold periods. Statistical time series analyses (g) were used to better understand past variability in climate and biological populations as an aid in understanding future variability, but forecasting future responses based on past patterns of variability is fraught with difficulties. Finally, presentations on field and laboratory studies (h) highlighted the importance of such studies to help estimate vital rates for fishes, which are needed to elucidate and quantify important mechanisms and to support modeling efforts.

Frameworks (a): Global- or basin-scale static models

Jang and Yoo employed a basin-scale approach for the Pacific Ocean to predict possible consequences of global warming on patterns of production (Jang *et al.*, 2011). Gridded GCM model output was used to directly estimate changes in mixed-layer depth (MLD) and stratification and to predict changes in primary production based on changes in the entrainment of nutrients. The authors employed a multi-model approach to compare predicted changes in MLD and primary production across 11 global models from the IPCC AR4 suite of models. Spatial patterns of change differed substantially among models but some regions showed a consistent response.

Models to predict changes in phytoplankton production have previously been used on a global scale (Sarmiento *et al*., 2004; Steinacher *et al*., 2009), but the formal comparison and classification of responses across multiple models employed by Jang *et al*. (2011 represented a new approach to address model uncertainty. Static models have been used similarly to estimate fish production at global scales, for example, on the basis of size-based models of production (Jennings *et al*., 2008), which served as a starting point for the dynamic size-based approach of Blanchard *et al*. (*Blanchard et al.*, 2012) described below (b).

Frameworks (b): Global-scale dynamic models

A dynamic model to estimate fish production on a global scale was presented by Cheung *et al*., who extended the bioclimate envelope model of Cheung *et al*. (2009) to include the effects of ocean chemistry on the physiology of fish species based on the theory of oxygen limitation of growth (*Cheung et al*., 2011). Blanchard *et al*. presented a dynamic size-based model that was used on a near-global scale to estimate changes in production by size class in coastal large marine ecosystems (LMEs) from around the world. Their model is a component of the QUEST fish project, which dynamically links a shelf ecosystem model adapted to each LME to a global circulation model (see Barange *et al*. (session P3); *Barange et al.*, 2011[1]; and Allen, Holmes *et al*., and Holt *et al*. (session A1)). The QUEST-Fish project links a lower trophic level shelf ecosystem model to a size-based model of fish production that has good theoretical and empirical support (Jennings and Brander, 2010) and this dynamic version of the size-based approach represents an important advance. Details on the QUEST modeling approach through lower trophic levels were presented in session A1. This effort also includes a 'Global Scale Impacts' project that was used to assess the vulnerability of nations to climate change (Scutt-Phillips *et al*. (session P1-D1)). A similar size-based model with potential applicability on a global scale has also been developed by Maury (2010).

Other basin-scale and global-scale models that aim to predict the effects of climate change on primary producers and higher trophic levels are at various stages of development (see, for example, Blackford *et al*., 2010), typically consisting of biogeochemical models based on plankton functional types (Allen *et al*., 2010). Outputs from these models are directly relevant to understanding biological consequences of climate change but require further validation and research before reliable predictions can be made.

Evaluation

The global approaches described in Frameworks (a) and (b) above are appealing because they offer a consistent method applied across multiple ecosystems that allows for an evaluation of global-scale impacts. Mapping projected changes across marine ecosystems provides an effective tool for directly communicating the global nature of these challenges. Moreover, identifying regions where changes are projected to be particularly pronounced can highlight areas that need more detailed studies.

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[1] Citation in italics following the presenter's name indicates a paper that was published arising from the symposium (see the list of publications after the session and workshop summaries).

An important limitation of the global modeling approach is the current inability of global circulation models to capture the spatial dynamics in coastal and shelf areas, such as tides, upwelling and freshwater influences. Therefore, results that are directly derived from GCM output without downscaling to regional seas are most useful in open ocean regions. This is particularly problematic when such models are extended to fish production because most of the world's fish production occurs along the ocean margins. An important advance in this regard is the linking of multiple versions of a regional model (ERSEM – European Regional Seas Ecosystem Model) to global circulation models as implemented in QUEST-Fish.

Conclusion

Models of fish production on a global scale need to be based on well supported theory and may need further evaluation. For example, extensions of the bioclimate approach to include eco-physiological effects hold promise, but have not been tested against available data.

Frameworks (c): Dynamic downscaling

This approach links GCM models dynamically to regional coupled biophysical models which may extend from climate to fish and beyond (end-to-end models, Steele *et al*., 2007). For predicting the response of upper trophic levels, we distinguish models that focus on individual species from multi-species approaches.

Single-species focus

Several scientists presented results from models that coupled climate models to regional bio-physical models of lower trophic dynamics to single species population models. Ito *et al*. extended the lower trophic level NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanograhy) model to include a bioenergetics model for Pacific saury (NEMURO.FISH, *Ito et al.*, 2013), while Hufnagel *et al.* provided an example of an individual-based model (IBM) linked to a regional circulation model (*Hufnagel and Peck*, 2011). Similar IBMs have been constructed for fish and shellfish species in both the Pacific (*e.g*., Rose, 2008) and in the Atlantic (Kristiansen *et al*., 2009).

Multi-species focus

Similarly to the above single-species models, regional biophysical models have been linked to multiple fish populations using a bioenergetics approach that may include age and size structure and that may, in turn, be linked to the dynamics of fishing fleets and socio-economic models. Aydin *et al*. (presented by Ortiz) are developing such a model (FEAST – Forage and Euphausiid Abundance in Space and Time) for the data-rich eastern Bering Sea. Fulton (session B1; *Fulton*, 2011), and others have developed end-to-end models based on a much coarser representation of the underlying physics, but including the behaviour of fishing fleets and other socio-economic considerations. Regional biophysical models may also be linked to multi-species IBMs. For example, Shin and Cury (2001, 2004) developed the Object-oriented Simulator of Marine ecOSystems Exploitation (OSMOSE) that modeled multi-species interactions using IBMs on a coarse physical domain. Rose *et al*. presented preliminary model runs only of a similar model during the symposium. The size-based model by Blanchard *et al*. (see Frameworks (b) above) reflects another example of this approach but uses size-based dynamics rather than the dynamics of individual species, which may span several orders of magnitude in size.

Evaluation

Dynamic downscaling approaches generally focus on a specific region and one or more species of interest, which may be selected for their ecological as well as their commercial importance. Among all of the modeling approaches, these regional and species-specific schemes incorporate the greatest degree of realism at the upper trophic levels, taking advantage of species-specific parameters estimated from field and laboratory studies.

Among the modeling approaches considered during the symposium, the dynamic downscaling method may be the most directly relevant for providing advice to fisheries managers, given that they are stock-specific and that the model region typically corresponds to an existing management area. These models were particularly useful when fishing is included as a driver, allowing the use of the models in management strategy evaluations. IBM models do not model fish dynamics in terms of total abundance or biomass and generally do not include fishing as a source of mortality; therefore, some these models may not be directly useful for providing management advice. However, IBMs can be very useful as hypothesis-testing tools (Neuheimer *et al*., 2010).

Important limitations arise from the limited number of species and the regional scale of these models. The selection of one or a few key species necessarily ignores interactions with other species that are not included in the model. Hence evaluating possible responses of the selected fish populations to climate change can be problematic if the species composition changes as a consequence of warming. For example, one or more of the selected species may become a minor component of the fish community in the future and community dynamics may become dominated by other, formerly less abundant species. A second limitation arises from the regional nature of the models, which requires that the modeled species complete their life cycle within the model region. This assumption may no longer be valid if shifts in distribution occur as a result of future warming.

A number of end-to-end models are currently being used or developed to explore the consequences of both bottom-up and top-down processes, including fishing and other human activities, on marine ecosystems (*e.g.*, Fulton, 2010; Ito *et al*., 2010).

A major challenge in modeling the responses of fish populations to future climate change will be the appropriate treatment of the adaptive capacity of fishes. Many marine fish populations are adapted to their local environment (Conover and Munch, 2002) but their ability to adapt to a changing environment through genetic or phenotypic adaptations has been documented (Pörtner, 2002), but to our knowledge has not been incorporated in modeling the future dynamics of fish populations.

Frameworks (d): Statistical downscaling

The statistical downscaling approach uses a mechanistically-based understanding of climate effects on recruitment, growth, mortality, or spatial distribution to develop functional relationships between key environmental drivers and biological responses. Future trajectories for these key drivers are obtained from GCM output and are used together with the identified functional relationships to project the future dynamics of the fish population of interest under various climate change scenarios.

Depending on the goals of the study, future projections may be based on a population dynamics model that includes climate effects on recruitment or on a habitat model that includes climate effects on habitat suitability. The former approach was used to project future recruitment and abundance of walleye pollock in the Bering Sea (Mueter *et al*.; *Mueter et al*., 2011), Bond *et al*., and Ianelli (session P3; *Ianelli et al*., 2011), rock sole in the Bering Sea (Wilderbuer *et al*., presented by Bond; *Wilderbuer et al*., 2013) and Pacific mackerel in Korean waters (Kang *et al*.). The same process was used by Hare *et al*. (*Hare et al*., 2010) to forecast changes in the gray snapper population along the east coast of the United States. Other case studies used habitat models to project future distributions of gray snapper off the eastern U.S. (*Hare et al*., 2012), seaweed around Japan (Komatsu *et al*.), corals around Japan (Yara *et al*.) and tuna in the South Pacific (Hobday *et al*.; *Hobday et al*., 2011). The approach of Hare *et al*. provided a general relationship for estimating northern range boundaries based on known temperature limits.

Evaluation

Statistical downscaling provides a useful approach to forecasting the expected response of individual species to future climate variability. We consider this an interim process that can provide immediate management advice when used in combination with Management Strategy Evaluations (MSEs, *e.g.*, Mueter *et al.* and Ianelli (session P3)). This technique is likely to be merged with and superseded by dynamic downscaling approaches that are being developed from first principles to provide projections for individual species or multiple species of interest. A blending of these approaches may be required in cases where the population models used for dynamic downscaling cannot be fully parameterized and may, for example, require predictions of survival rates at poorly understood life stages based on empirical relationships.

The key to statistical downscaling is the reliability of the functional relationship between climate variables (*e.g.*, temperature) and the modeled biological responses. Moreover, the relationship between ecosystem indicators and biological responses is assumed to be stationary to provide reliable forecasts under environmental conditions that may not have been observed in the past. The possibility that the functional relationships governing biological dynamics may fundamentally change introduces an additional source of uncertainty that has generally not been considered.

Quantifying this uncertainty will be a challenge as existing time series are typically too short to fully evaluate stationarity or to estimate the probability of phase shifts in important functional relationships. Process oriented field programs often provide the foundation for the functional relationships used in these models. Given some understanding of the underlying mechanisms, statistical downscaling is likely to provide reasonable forecasts of the direction of change in a population, if not the magnitude.

Statistical downscaling approaches typically occur on a scale that is directly applicable to management by focusing on a single commercial stock. Projections are therefore amenable to MSEs. The challenge is to appropriately quantify and communicate uncertainty, as discussed below.

Because it typically focuses on a single species and on tractable statistical relationships between climate forcing and a specific biological response, this approach may offer the best opportunity for exploring adaptive responses of fish to changing climate conditions. However, this requires a better understanding of the adaptive capacity of fishes in response to changes in temperature, pH, O_2 levels, and other stressors.

Frameworks (e): Deductive approach

The deductive approach relies on process studies to identify the mechanisms (including climate impacts on prey availability and predation) that affect survival or growth of fish and shellfish. Results from process studies are typically compared along a gradient of environmental conditions, *e.g.*, by comparing responses between warm and cold years. If a good mechanistic understanding can be gained from such studies, this understanding can be used to predict directional changes in the population of interest under continued warming, *e.g.*, Hunt *et al.* (*Hunt et al.*, 2011) for eastern Bering Sea pollock; Frusher *et al.* (*Frusher et al.*, 2010) for Tasmanian rock lobster; Ono *et al.* (session B1) for the response of zooplankton to changes in bloom timing in the Oyashio region).

Evaluation

In the context of predicting effects of climate changes, a better mechanistic understanding of the response of fish and shellfish to different environmental conditions is crucial to informing and validating models and to providing credibility to empirical relationships that are used for statistical downscaling. The BEST/BSIERP effort in the eastern Bering Sea offers an excellent case study that illustrates the strength of integrating detailed process studies with an end-to-end modeling effort (Aydin *et al.*) and with a statistical downscaling approach (Mueter *et al.*, Bond *et al.*).

As with the other approaches, predicting future responses based on a mechanistic understanding requires that the same mechanisms continue to operate in the future. Although functional relationships based on a mechanistic understanding are more likely to continue operating in the future than simple empirical relationships without such understanding, there is no reason to believe that the same mechanisms will continue to govern multi-species interactions when temperatures increase beyond their historical range.

Frameworks (f): Comparative approaches

Fréon *et al*. (presented by Checkley) reviewed comparative analyses of the response of small pelagic fishes to climate variability across a number of coastal upwelling systems. One of the goals of such studies is to identify common patterns across systems that help identify the mechanisms that determine fluctuations in the productivity and abundance of different species or functional groups. Understanding these patterns will improve our ability to forecast such fluctuations. The value of comparative analyses for understanding the linkages between biological responses and climate changes is increasingly recognized and has led to a number of international efforts to compare ecosystems within and between ocean basins (*e.g*., PICES' Climate Change and Carrying Capacity (CCCC), ICES' and GLOBEC's Cod and Climate Change (CCC), Small Pelagics and Climate Change (SPACC), and Northeast Pacific (NEP) programs; IMBER's Ecosystem Comparisons of Subarctic Seas (ESSAS); the U.S. partnership between NOAA and NSF Comparative Assessment of Marine Ecosystem Organization (CAMEO) program, and many others).

Evaluation

To date, comparative studies have been largely descriptive and have identified general patterns of variability by retrospectively comparing trends in selected species or species groups across different ecosystems. Using these studies to provide better forecasts of future variability remains a challenge. Comparisons across large marine ecosystems require international cooperation and a commitment by numerous institutions to maintain relevant data series and contribute datasets for comparative analyses. It is particularly challenging to standardize data series across systems and maintain consistent data series.

Frameworks (g): Statistical/time series approach to identify basin-scale patterns of variability

Several papers discussed statistical time series approaches to identify major patterns of climate and biological variability over time (*e.g*., *Overland et al*., 2011; Mendelssohn, 2011; Yasuda *et al*., 2009; and Hsu *et al*.). These studies aim to link climate variability to biological variability on a regional to basin-wide scale. In principle, these statistical relationships can then be applied to climate projections to predict future biological responses.

Evaluation

Statistical time series approaches have largely been used as a tool for the analysis of historical patterns of variability and it is not clear if they can be successfully used in forecasting long-term ecological trends. Overland *et al*. (presented by Bond; *Overland et al*., 2011) emphasized that forecasting biological responses is complicated by the large variety of possible responses that have been documented in biological systems (phase shifts, directional trends, lagged effects, non-linearities, hysteresis, *etc*.). Hence it is far from clear if statistical relationships can provide reliable forecasts without an adequate understanding of mechanisms and projections outside the range of historical conditions will always be problematic.

Frameworks (h): Field and lab studies

The review by Peck *et al*. and a number of case studies in other sessions highlighted the importance of field and laboratory studies that estimate vital rates of fishes. Such studies are crucial to informing existing models, to quantifying changes in vital rates relative to changes in temperature and other variables, and to determine the adaptive capacity of fishes.

Session P1-D1: *What results were presented from methodologies applied in designated case studies (to test methods)?*

The focus of many papers in this session was on cutting-edge modeling approaches and methodologies to forecast the effects of climate change. Many of these approaches have only been developed in recent years and only preliminary results were reported in many cases. We briefly summarize some of the key findings:

- Jang and Yoo found that output from most of the GCMs, coupled with a simple production model, imply increased stratification and therefore decreased production in the Kuroshio extension area, while production may be expected to increase in the western subpolar region of the North Pacific. These results agree with predictions by Merryfield and Kwon (2007). Projections for high latitude regions were inconsistent across GCMs, similar to the recent results of Steinacher *et al*. (2009).
- Preliminary results from an analysis of growth potential in the NW Atlantic (Cheung *et al*.) and implied changes in distribution suggest northward shifts in distribution across numerous species with range expansions into more northern waters and possible local extinctions at the southern extent of their ranges. This has implications for the estimated catch potential. While a simple bioclimate envelope model predicts increases in production in high latitude regions, accounting for effects of O_2 limitation and changes in pH suggests a loss in maximum catch potential for many of the same regions.
- The local disappearance of a number of seaweed species (*Sargassum* spp.) and replacement of these species by subtropical species in southern Japan was reported by Komatsu *et al*. Modeling the changes in distribution for a selected species (*S. horneri*) based on its inferred temperature range and projected changes in average temperature (A2 model of CCSR/NIES/FRCGC (MIROC)) suggests a substantial range contraction under predicted warming. This is expected to have negative consequences for a number of fish species that use seaweed as nursery areas for larvae and juveniles.
- A northward expansion of gray snapper (*Lutjanus griseus*) in the western boundary current off the U.S. east coast was predicted by Hare *et al*. based on the fact that juveniles are carried poleward by the prevailing currents, combined with strong evidence that juvenile overwinter survival in estuaries limits the northern range of the species. The authors developed a general relationship between minimum predicted winter temperature and latitude that can be used to predict range extensions for similar species.
- Large projected changes in temperatures around Australia due to intensification of the East Australian Current is expected to reduce the productivity of rock lobster in the region due to decreases in recruitment and settlement success (Frusher *et al*.). In contrast, a temperature threshold for successful development of larval urchins (*Centrostephanus rodgersii*) and decreased predation by lobsters suggests that urchins will benefit from increasing temperatures, implying an increased risk of further “urchin barrens”.
- Walleye pollock (*Theragra chalcogramma*) in the eastern Bering Sea were previously believed to benefit from warmer temperatures. Recent field studies comparing spring bloom dynamics during warm and cold years suggest that the large zooplankton which are critical prey for juvenile pollock during late summer were replaced by small zooplankton during a series of warm years, resulting in the failure of several walleye pollock year classes (Hunt *et al*.). Therefore, projected warming trends in the Bering Sea under most climate scenarios (Bond *et al*.) imply a substantial reduction in average recruitment and decreased abundances of walleye pollock under a variety of harvest scenarios (Mueter *et al*.).
- Ito *et al*. based on a coupled physical-bioenergetics model of Pacific saury off Japan predict a decrease in the size of Pacific saury due to decreased prey abundances but an increase in egg production. However, using an ensemble modeling approach suggests considerable uncertainty in the response of Pacific saury due to the complex interplay between changes in temperature, distribution, and prey availability. Similar levels of uncertainty are to be expected in many other studies that relied on output from a single climate model.
- A biological ensemble modeling approach was also employed by Gårdmark *et al*. (presented by Lindegren; *Lindegren et al*., 2011) to show that fishing had a stronger impact on future cod trajectories in the Baltic Sea than climate change and that reducing fishing pressure is expected to rebuild cod stocks under most scenarios.
- Preliminary estimates of fish production from 20 large marine ecosystems based on size-based models linked to regional circulation models (ERSEM) driven by a global circulation model suggest large variability among these systems in their response to future climate warming with no clear geographical patterns (Blanchard *et al*.).

Session P1-D1: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

Most of the forecasts presented in this session were based on output from one or more global circulation models. Inferences about biological responses to climate change based on GCM output must deal with structural uncertainty in the GCM models, as well as uncertainty in modeling the biological responses. Jang and Yoo illustrated that even quantities computed directly from GCM output (*e.g*., mixed layer depth) can vary widely among models if they are based on parameters that are poorly estimated by GCMs.

A variety of methods were proposed, or were used in specific case studies, to (1) quantify uncertainty in important parameters needed for projections, (2) quantify uncertainty in the projected responses and future population trajectories, and (3) communicate uncertainties to managers and the public:

- Hierarchical models (Peterman), using a fully Bayesian or empirical Bayes approach, are a powerful tool for quantifying uncertainty in the estimated responses of fish populations to climate change across multiple stocks, regions, or other “replicate” units (see, *e.g*., Mueter *et al*., 2002). Because of the computational demands, such hierarchical models are only beginning to be applied to coupled bio-physical models (*e.g*., Fiechter *et al*., 2009).
- Ensemble modeling is commonly used to characterize uncertainty in climate projections across multiple models (Wang *et al*. (session A1); *Wang et al*., 2010; Hollowed *et al*., 2009; Moss *et al*., 2010) and has recently also been used in coupled models to examine uncertainty in both climate trajectories and in the biological responses. Examples from this session include (a) Ito *et al*., who used an ensemble of climate models with a single species bio-energetic model for Pacific saury, (b) Bond *et al*. and Mueter *et al*., who used an ensemble of climate models to drive a stock projection model under various climate and fishing scenarios, and (c) Gårdmark *et al*. who used multiple biological models (single, multispecies, food web) that incorporated statistical uncertainty and were driven by two alternative climate models (with and without climate change), as well as alternative fishing scenarios. Biological models in these ensemble approaches may be driven by dynamically (Ito *et al*.) or statistically downscaled climate scenarios (Gårdmark *et al*., Bond *et al*.). We are not aware of any modeling efforts that use an ensemble of climate models together with an ensemble of biological models. The ensemble modeling approach typically uses simulations to account for various sources of uncertainty, including structural uncertainty. One of the unresolved issues in ensemble modeling is the appropriate selection of and/or weighting of alternative models when combining results across models. Results from multiple model runs may be presented separately for each model or combined across models (see ‘communicating uncertainty’ below).
- An alternative to using multiple climate models and ensembles of possible trajectories to separately drive one or more biological models is to combine the forecasts of important parameters from alternative climate models into a single trajectory with an estimate of uncertainty in each future year (Hollowed *et al*., 2009). Beltrán *et al*. provided an example of using a hierarchical Bayesian model to combine SST projections from multiple climate models (*Beltrán et al*., 2012).
- Whether or not the impacts of multiple models are investigated, a simulation (Monte Carlo) approach can generally be used when making projections to account for known uncertainty in climate (random draws from a suite of likely climate trajectories and/or scenarios), population dynamics (random draws of important population parameters from multiple univariate or, better, a single multivariate distribution), and environment-biology relationships (random draws of parameter values for estimated or assumed functional relationships from a suitable probability distribution or from historical values). For case studies, see Mueter *et al*. (session P1-D1), Brodziak *et al*. (this session), Ianelli (session P3), and Planque *et al*. (session A2; *Planque et al*., 2011). A simulation approach is also utilized in the context of Management Strategy Evaluations, which allows the robustness of management strategies to be tested in the face of that system uncertainty, but at the expense of considerable time and processing power.
- Sensitivity analyses on important parameters are the primary means for identifying particularly influential parameters. If models are particularly sensitive to a given parameter, uncertainty about the true parameter value is an important source of uncertainty. Sensitivity analyses are typically used to prioritize field and laboratory studies, but can be used to quantify uncertainty in projections by repeatedly running models across different values of the important parameters to bracket possible responses. However, this requires

some knowledge of the likely distribution of parameter values and can be challenging with complex models that have multiple important parameters, which may require a large number of model runs. Gibson *et al*. (session D2) provides an example of exploring the effects of parameter uncertainty in an NPZD model on estimates of phytoplankton biomass in the eastern Bering Sea.

- The most basic approach to characterizing, if not quantifying, uncertainty about potential future responses to climate change consists of presenting results and implications from the analysis of different models and to compare and contrast the resulting patterns across models. For example, Jang and Yoo (this session) compare estimates of changes in mixed layer depth and implied changes in primary production across a large number of global circulation models to identify robust spatial patterns in these changes that are seen across a large number of models.
- The majority of presentations in this session did not explicitly include uncertainty in the presentation of results, but several authors stressed the need for considering alternative biological processes or relationships when predicting the effects of warming (Frusher *et al*.; Peck *et al*.).

With respect to communicating uncertainty to managers and the public, several approaches were recommended or used in specific case studies.

- Peterman recommended the use of more easily understood concepts when communicating uncertainty to user groups. For example, cognitive psychologists have found that most people relate more readily to cumulative probability distributions (rather than probability density functions) and to frequencies (*e.g.*, “2 out of 10”) rather than probabilities (0.2).
- For ensemble approaches or for other multi-model approaches, results from each model can be displayed to graphically illustrate the variability in the responses (*e.g*., Gårdmark *et al.*; Hare *et al*.; Jang and Yoo; see Figure 1).

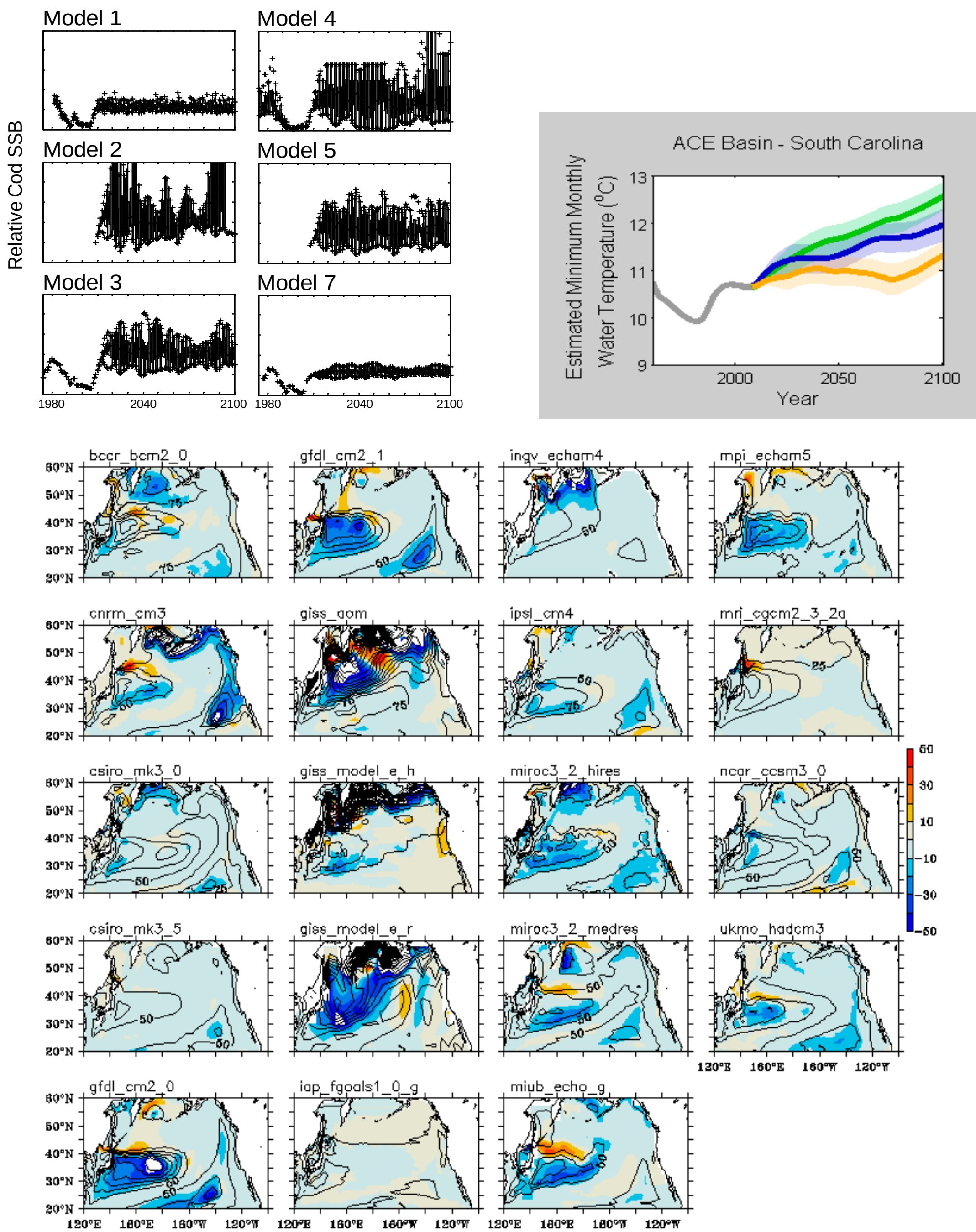

Fig. 1 Examples of model predictions for (top left) future trajectories of cod biomass from different population dynamics models (Gårdmark *et al.*), (top right) changes in minimum winter temperatures under different climate scenarios (Hare *et al.*), and (bottom) changes in mixed layer depth from 19 global circulation models (Jang and Yoo).

- Results from multiple models can be combined into a single figure to illustrate the uncertainty in model predictions. For example "simulation envelopes" illustrate the full range of results (Gårdmark *et al.*) or specified upper and lower percentiles (Mueter *et al.*) (Fig. 2). It is important to note that these envelopes do not represent statistical confidence intervals and may not illustrate the full range of uncertainty if they are based on a subjective choice of climate models and/or biological models. However, they illustrate the possible range of responses that may be expected, conditional on the models included in the analysis.

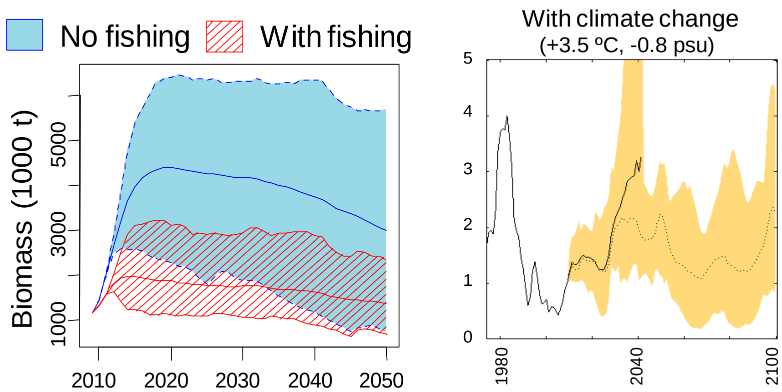

Fig. 2 Examples of predictions of (left) biomass trajectories based on multiple climate and fishing scenarios (Mueter *et al*. with 80% simulation envelope) or (right) based on multiple biological models (full range of ensemble predictions, Gårdmark *et al*.).

- Where possible, it is preferable to use a combination of the previous two approaches that shows the variability in individual predictions to illustrate the variety of possible responses, as well as an envelope across all predictions to illustrate the range of responses. Illustrating individual responses can be important to clearly communicate the common observation that the expected response may vary greatly in space or over time (*e.g*., Fig. 1, Fig. 3).

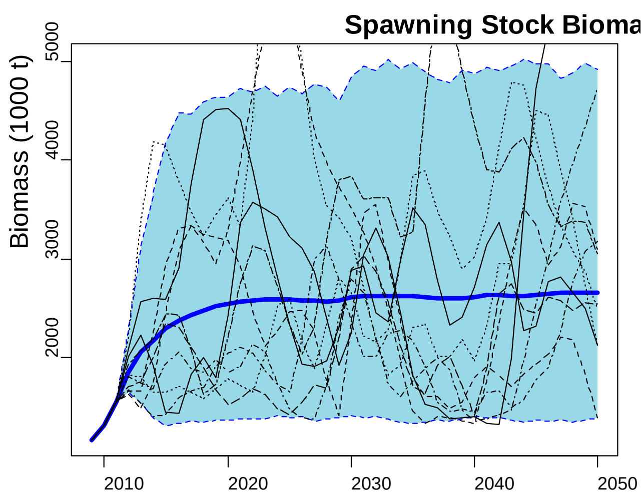

Fig. 3 Example showing simulation envelope along with individual trajectories based on a given model, model parameters, and inputs (based on Mueter *et al*.).

- The output from spatially explicit global models is typically displayed in the form of maps showing point estimates for a single variable one model at a time (*e.g.*, Jang and Yoo, Fig. 1) without indicating the level of uncertainty even when it is known. It will be important to use appropriate methodologies for formally assessing and illustration uncertainty in spatial surfaces. A commonly used approach is to show the magnitude of change in a variable of interest for only those locations (*e.g*., grid cells) where the change has been determined to be significant based on appropriate statistical tests or other criteria.
- A novel approach to addressing uncertainty across multiple models was illustrated by Jang and Yoo who used a hierarchical cluster analysis to identify models that show a similar spatial response and then averaged responses across similar models to obtain more robust spatial patterns of change. However, these patterns are not associated with any measure of uncertainty.

Session P1-D1: *What strategies were evaluated regarding research and management under climate change scenarios?*

While this session did not directly focus on strategies for research or management, several such strategies were evaluated or employed in the context of making forecasts of future population trajectories of commercial fish or shellfish species.

- Many of the case studies examined in this session clearly illustrate the need for bringing together different fields of science (*e.g*., climatology, oceanography, biology, economics and social science) when examining and responding to climate change impacts. This requires the development of a common language and a cohesive response to the problem. A good example that illustrates the interdisciplinary approach to address research challenges is the BEST/BSIERP program in the Bering Sea (Aydin *et al*., presented by Ortiz), which links multi-disciplinary field and laboratory studies with a vertically integrated modeling approach that includes modelers with expertise in climate science, plankton biology, fish population dynamics, economics, the social sciences, and other fields.
- A'mar *et al*. (A'mar *et al*., 2009) introduced a technique for incorporating climate impacts in management strategy evaluations (MSEs). Several examples of this type of climate driven MSE were presented in Sendai. Management strategies ranging from no fishing to fishing under status-quo control rules were evaluated by Gårdmark *et al*., Mueter *et al*. and Ianelli (session P3) to evaluate the performance of status-quo management for individual stocks under climate change scenarios. The results from such MSEs, which simulate future population dynamics based on robust climate–recruitment relationships, critically depend on the functional form and uncertainty in these relationships to obtain plausible results. This requires, at a minimum, a good mechanistic understanding of the dynamics of the population of interest.

Session P1-D1 Conclusions and recommendations

- Scientists are increasingly being asked to provide forecasts of the biological impacts of anticipated climate changes. Therefore, it is critical to develop approaches that produce credible forecasts and appropriately deal with uncertainty. The IPCC AR4 experience has highlighted the importance of acknowledging and examining the uncertainty in our knowledge of how ecosystems operate and in communicating this uncertainty to stakeholders. As the marine science community moves forward in providing relevant input to the next IPCC Assessment Report, this session offered some lessons for improving the quality of the science that will be instrumental in providing relevant advice to policy makers. Specifically, we offer the following recommendations:
- Whenever possible, inferences about potential biological impacts based on downscaled global circulation models should be based on multiple future scenarios and multiple climate models. For example, a variety of climate models should be used to drive regional models in the dynamic downscaling approach. Bayesian model averaging can also be used to carry uncertainty forward for dynamic downscaling case studies. Both approaches characterize the range of variability in responses across models and for assessing how robust the results are to the underlying assumptions about climate change.
- Forecasts of climate change impacts will be needed at both the regional and global scale. However, we note that global-scale comparisons based on GCM output or earth system models linked to GCMs are unlikely to provide reliable predictions of changes in coastal marine ecosystems where the majority of fish production occurs. Therefore, regional models linked to GCMs are critical in coastal regions. However, regional ecosystems are not closed systems and the responses in a given ecosystem are not independent of changes in adjacent systems. The dynamic downscaling approach accounts for connectivity across regions by providing appropriate boundary conditions, but the biological system is typically assumed to be closed within the study region. This can be particularly problematic in highly advective systems. Hence we encourage the development of methods to account for the dynamics of stocks that extend beyond the region being modeled, for example by linking regional models among adjacent ecosystems.
- We encourage the consideration of a range of existing models of different complexity to forecast the response of a given fish or shellfish species to climate change. Model diversity is important for covering the likely range of possible responses. Biological ensemble modeling offers a straightforward approach to

deal with a disparate set of models, but requires agreement on a common set of output parameters for comparisons.

- For any model-based forecast, a careful evaluation of the degree of complexity that is needed to estimate quantities of interest should be undertaken. There is a clear trade-off between model complexity and the ability to fully deal with uncertainty. In order to meaningfully assess uncertainty, repeated model runs using different inputs and parameter values are required. While this is feasible for single-species models and simple ecosystem models, it may be computationally too demanding for more complex models (Stock *et al*., 2011).
- The range of uncertainty across scenarios, models, and model runs must be acknowledged when forecasting biological responses from climate models. Uncertainty should generally be illustrated when presenting results, including an indication of the range of possible outcomes and some illustration of the variability among individual trajectories (*e.g*., Figure 3). To the extent possible, ICES and PICES should consider developing a consistent approach for presenting results to policy makers and informing the next IPCC report.
- When downscaling from global circulation models some standardization in the choice of emissions scenarios would be desirable, while the choice of climate models is specific to the problem and to the region of interest. Downscaling approaches in this session typically considered three alternative scenarios to cover the range of expected emissions scenarios, most commonly A2 (high range), A1B (middle), and B1 (low) or “commit” (status quo emissions). While the “commit” scenario may be useful for comparisons with current conditions, it provides an unlikely lower bound for projections, hence we suggest using A2, A1B, and B1 to capture a likely range of emissions scenarios. The choice of which models to consider is partly guided by the performance of different models with respect to the variable of interest as well as the region of interest. Some guidance on the selection of appropriate models was provided by Wang *et al*. (session A1).
- When using models to forecast impacts of climate change on fish and shellfish it is important to assess the utility of a given model with respect to providing useful and relevant advice to fisheries managers. For example, several case studies in this and other sessions used Individual Based Models to illustrate potential consequences of climate change. At this stage, IBMs are more appropriately used as research tools for hypothesis testing than for providing relevant management advice. To maximize the utility of end-to-end models or coupled biophysical models that include fishing as a source of mortality they should be used in combination with management strategy evaluations.
- The development of models for forecasting requires a careful evaluation of the ability of these models to hindcast historical data, as well as up-to-date observations for verification and as boundary conditions for projections. Therefore maintaining consistent data series is a high priority, as is making these data more widely available to facilitate model development and verification by teams of dispersed researchers from multiple disciplines.
- The use of empirical relationships without some understanding of the underlying mechanisms should be avoided, particularly for predictions on decadal scales or longer.
- We recommend a prioritization of specific field and laboratory studies needed to support modeling the impacts of climate changes on fish. This may best be accomplished by regional workshops to identify species for which critical information on important vital rates is missing or incomplete.
- Finally, we need to consider the capacity of fishes to adapt to a changing climate when making long-term predictions (discussed further under session A2).

Session P2: Forecasting impacts: From fish to markets

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Introduction

Direct impacts of climate change on marine populations will alter the provision of food from oceans to markets. At the same time, the on-going process of economic globalization will modify or exacerbate the vulnerability of fish production systems to climate change at global, regional and local level. Policy and management agencies will require scientific advice on the potential impacts that climate change (and its associated economic developments) will have on the availability of fish populations to fisheries, markets and consumers. This session focused on: (1) forecasting changes in marine population dynamics as they relate to fisheries (*e.g*., impacts on catchability or maximum sustainable yield), to processing and market demands (*e.g*., changes in size-at-age), to market forces (*e.g*., changes in price and trade) and to food security (*e.g*., collective vulnerability analysis); (2) quantifying the uncertainty of these forecasts in risk assessment frameworks useful to resource managers; and (3) exploring the interactivity between the ecosystem and market dynamics.

Session P2: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

Climate–fish–people models are beginning to be constructed, but are still in their early stages. Simpler (statistical) models which identify present fishing habitats and use these to project future fishing locations with future climate conditions are more common. These latter models were used as the bases for most of the presentations in this session. These types of models often use simple parameters such as sea surface temperature; future developments need to use at least O_2 and temperatures at depth. These types of models also have many uncertainties, including how information moves among participants, and human behaviour generally. An example of the former is the extent to which knowledge (of where and when to fish, *etc*.) gained from past experience can be applied to future conditions (*e.g*., Haynie and Pfeiffer; Haynie and Pfeiffer, 2012). An example of the latter is the presentation by Sumaila *et al*. (presented by Lam) for climate change impacts in West Africa (*Sumaila et al*., 2011) – this is an already highly disturbed (from fishing) system. If this system is not able to respond adequately to current intensive fishing, how can it be expected to respond to the “new” concerns of climate change?

Session P2: *What results were presented from designated case studies (to test methods)?*

The importance of institutions was noted in several studies. Fishing enterprises were often described as being very “flexible” and likely to be able to adapt to future climate change quite easily. Issues of concern are the adequacy of information flows and the value of past knowledge applied to future conditions. Regulatory “institutions” and arrangements were described as potentially adaptable (*e.g*., the presentation by Ishimura *et al*. (*Ishimura et al*., 2013), although “free-riders” (countries that gain from remaining outside of an international agreement for the sharing of migratory fish populations) can be a problem. Ways to mitigate these issues, such as side payments, can be developed to overcome these problems.

Session P2: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

The presentation by Badjeck and Mendo (*Badjeck et al*., 2010) on the use of scenarios to engage experts and to elicit their local knowledge, and to incorporate uncertainty, shows how important such scenario approaches will become in the future. Their study found that perceptions of what the major drivers of change will be in the future were different from their perceptions of past drivers of change.

Session P2: *What strategies were evaluated regarding research and management under climate change scenarios?*

Further research on governance issues involved in climate change impacts on migratory stocks and issues of multi-species responses to climate change and how fishing enterprises may respond are needed.

Session A1: Downscaling variables from global climate models

Co-Convenors
Michael Foreman (Institute of Ocean Sciences, DFO, Canada)
Jason Holt (Proudman Oceanographic Laboratory, UK)

Introduction

Analyses and summaries recently presented in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) indicate that many of the dramatic changes observed in the circulation and physical characteristics of the oceans over the past century will continue in the future. One of the major limitations of the global climate models used to estimate these future projections is their relatively coarse resolution. Statistical or dynamical downscaling is often needed to provide sufficient spatial detail in the variables of interest. Presentations in this session generally fell into one of three categories: (1) downscaling of global climate model variables relevant to marine ecosystems; (2) downscaling techniques and/or their application to particular regions or variables; and (3) analyses of global climate models projections or results from higher-resolution regional ocean, or coupled atmosphere-ocean, models that were forced by, and take their boundary conditions from, global climate models.

Session A1: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

Several key methodological advances were presented in this session. Wang *et al*. discussed multiple selection criteria for narrowing the number of global climate models (GCMs) to be used for statistically downscaling future projections. The technique was illustrated in the Bering Sea where she and colleagues examined GCM accuracy in capturing sea ice extent and seasonal variability over recent decades. This double screening quickly narrowed the number of credible GCMs from 23 to 6, and provided an ensemble projection of more quickly disappearing ice than was predicted by all 23 models, a feature that has been borne out in recent years. Several examples of dynamical downscaling were also presented (Kurogi *et al*.; *Kurogi et al.*, 2013) in the waters off eastern Japan, Holt *et al*. (*Holt et al*., 2010) and Holmes *et al*. for various continental shelves around the world, Curchitser *et al*. for the Northeast Pacific, Kuroda *et al*. for the Northwest Pacific and waters around Japan, Foreman *et al*. for the British Columbia shelf; Hermann *et al*. for the Bering Sea), and in each case the need for better resolution of physical processes relevant to their particular regional marine ecosystems was made. In two instances (Kurogi *et al*. and Curchitser *et al*.) there was two-way communication between the nested regional climate model (RCM) and the more coarsely resolved GCM or basin scale model, with Curchitser *et al*. showing that the “upscaling” feedback associated with a more accurate representation of upwelling in the California Current system had significant effects well outside the downscaled region. However, in this case the ocean models were also coupled to an atmospheric model so some of these far-field feedbacks may have arisen through atmospheric teleconnections. A natural extension of this would be to include a high resolution downscaled atmospheric model. Allen (invited) also discussed the development of generic software that would allow easy coupling between lower trophic level planktonic ecosystem/biogeochemistry models and higher trophic level models.

Holt *et al*. presented the Global Coastal Ocean Modeling System (GCOMS) as a means of easily porting the POLCOMS (Proudman Oceanographic Laboratory Coastal Ocean Modelling System) model that was originally developed for the NW European shelf to other continental shelf regions of the world (specifically those with important fisheries). Hermann *et al*. presented multi-variate EOF analyses of combined physical and biological variables as a means of better understanding linkages.

Allen proposed that ecosystems models should move beyond a “chemical factory” approach to include intra-cellular processes and cell-cell interactions explicitly, hence better capturing plankton physiology.

Session A1: *What results were presented from designated case studies (to test methods)?*

Virtually all presentations included case studies to illustrate their methodology. Wang *et al*. mainly focused on Arctic seas like the Bering, Chukchi, Barents, and Okhotsk, but also illustrated her approach with a GCM accuracy assessment of the Pacific Decadal Oscillation in the North Pacific. Kurogi *et al*. examined the effects of slightly different scalings of wind stress on variations in the path of the Kuroshio Current near Japan while Holmes *et al*. presented ROC (Receiver Operator Characteristic; a binary discriminator test to assess success in decision making based on variable thresholds) and wavelet (a spatial scale dependent skill assessment) based evaluation schemes. These were used for assessing the skill of chlorophyll simulations in the QUEST-Fish model through comparison with SeaWiFs data. Through a set of GCOMS simulations, Holt *et al*. demonstrated that apart from SST, there were no simple correlations between primary productivity and other basic oceanic or atmospheric variables, thereby justifying the need for dynamical, as opposed to statistical, downscaling in continental shelf regions. Kilmatov’s (co-authored with Dmitrieva) theoretical analysis suggested that the warming of ocean waters could weaken density gradients and weaken the jet-like nature of the Kuroshio Current. Hermann *et al*. evaluated 1995–2005 model temperatures and salinities against analogous values from the M2 mooring on the Bering shelf, and Foreman *et al*. assessed the accuracy of GCM and RCM winds against observations from buoys off the British Columbia coast. Yu *et al*. examined the importance of directly including tides in global model simulations (as opposed to parameterizing their effects) while Ustinova examined potential limitations on statistical downscaling in the Western Pacific and its marginal seas, largely due to a decline in the Russian terrestrial observational network. Finally, Temnykh *et al*. presented results on phytoplankton studies in the Black Sea, and the potential impact of climatic changes to the prevailing winds.

Session A1: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

Allen devoted a substantial portion of his presentation to ways of estimating model uncertainties, suggesting an approach analogous to that developed by Hawkins and Sutton (2009) for global mean temperature that could be appropriate to marine ecosystem applications. He decomposed uncertainty into three contributions: parameter uncertainty, structural uncertainty, and scenario uncertainty. The first one can be addressed by a series of sensitivity tests that alter parameter values through a reasonable range. The second refers the specific nature of the model, particularly the biogeochemical component. It could be explored, for example, by coupling biological models with differing complexity to the same physical model and examining the range and accuracy of the results. In the context of climate projections, the third refers to uncertainties in greenhouse gas emissions and can only be addressed by computing ensembles that cover a range of plausible states.

Session A1: *What strategies were evaluated regarding research and management under climate change scenarios?*

Management strategies were not discussed in this session. However, each of the preceding three topics had components that are relevant to research strategies. Though not a primary focus of discussion, important issues are model complexity and resolution. Underlying both is an ongoing need to enhance computing resources so that both higher resolution and larger ensemble runs are feasible.

Session A2: Species-specific responses: Changes in growth, reproductive success, mortality, spatial distribution, and adaptation

Co-Convenors
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Myron A. Peck (Center for Marine and Climate Research, University of Hamburg, Germany)
Motomitsu Takahashi (Seikai National Fisheries Research Institute, FRA, Japan)

Introduction

This theme session focused on climate-driven community-, species- and/or population-level changes in commercially and ecologically important marine fish and invertebrates. Presentations documented climate-driven changes in vital rates (*e.g.*, changes in growth, reproductive success and mortality) as well as expansions, contractions and/or shifts in the distribution of fish stocks resulting from changes in suitable habitats (habitats allowing life cycle closure and successful recruitment). The session also attempted to attract presentations on the capacity for individual species (or populations) to adapt to changes in important abiotic and biotic factors either through changes in the phenology of important life history events (*e.g.*, migration, spawning) and/or physiological changes (*e.g.*, temperature tolerance or thermal reaction norms of key traits such as growth).

Session A2 Summary

This theme session provided a forum for 68 presentations, 28 oral presentations (2 invited) and 40 posters focusing on the response of key fish and fisheries species worldwide to climate change. Presentations documented historical, often long-term fluctuations in abundance and distribution, discussed processes underlying current changes, and/or projected future impacts in light of adaptive capacity using a variety of approaches. The research utilized a variety of methodological approaches. Most studies included topics such as observed and/or projected changes in the distribution and/or productivity. A rough estimate indicated that 17 separate species were examined while another 8 presentations were inter-specific/community-level investigations. One study examined sources of variability in models designed to project changes in the distribution of marine species. The session was well attended but discussion was limited since the full amount of time was often utilized by speakers.

Presentations could be separated into a number of general categories including (1) correlative studies employing time series analysis, (2) mechanistic/physiological studies of the impacts of climate-driven abiotic and biotic factors on key life stages of key species, (3) community-level analyses exploring climate driven changes in species assemblages, particularly spatial distributions, (4) process-oriented research identifying climate impacts on critical life stages, and (5) various types of modeling studies, and (6) methodological examples. The latter category summarized a wide-array of different approaches. The presentations are briefly summarized using those five categories.

1. Correlative studies

Time series of changes in productivity and/or distribution were presented for a wide range of species-types (small pelagics, large pelagics, demersals, anadromous/catadromous) within a large geographic region of the world's marine habitats (essentially a global coverage when the 30+ posters were also considered including deep pelagic environments to shallow coastal areas) (Fig. 4). For some species in some areas, relatively long time series (30+ years) exist from either catch or survey data (Fig. 5). The importance of these time series to understanding potential climate impacts cannot be over-emphasized. For a retrospective understanding climate-driven changes, particularly to disentangle the effects of climate from exploitation, longer time series (100s of years) reveal an increasing trend with decadal variation patterns. Examples of long time series include yellowtail (*Seriola quniqueradiata*) in the Japan Sea[2] from 1894 to 2000 and a 100-yr time series of changes in commercial landings of different species. Distributional changes in large pelagic species such as blue marlin (*Makaira nigricans*), yellowfin tuna (*Thunnus albacares*), bluefin tuna (*Thunnus thynnus*) were explored in relation to projected changes in SST derived from modeling activities. Demersal species examined included gadiforms such as saffron cod (*Eleginus gracilis*), Atlantic cod (*Gadus morhua*) and flatfish species such as Pacific halibut (*Hippoglossus stenolepis*; Valero *et al.*). In session A2, very few studies discussed climate-driven changes in coastal species. An exception was research on black rockfish (*Sebastes inermis*) within seagrass beds throughout Japanese waters and two presentations on salmonids such as Hokkaido chum salmon (*Oncorhyncus keta*) and Fraser River sockeye salmon (*Oncorhynchus nerka*) (Martins *et al.*; *Martins et al.,* 2011), and Seo *et al.*; *Seo et al.*, 2011). Naturally, salmonid presentations were made and thoroughly discussed in workshop W4.

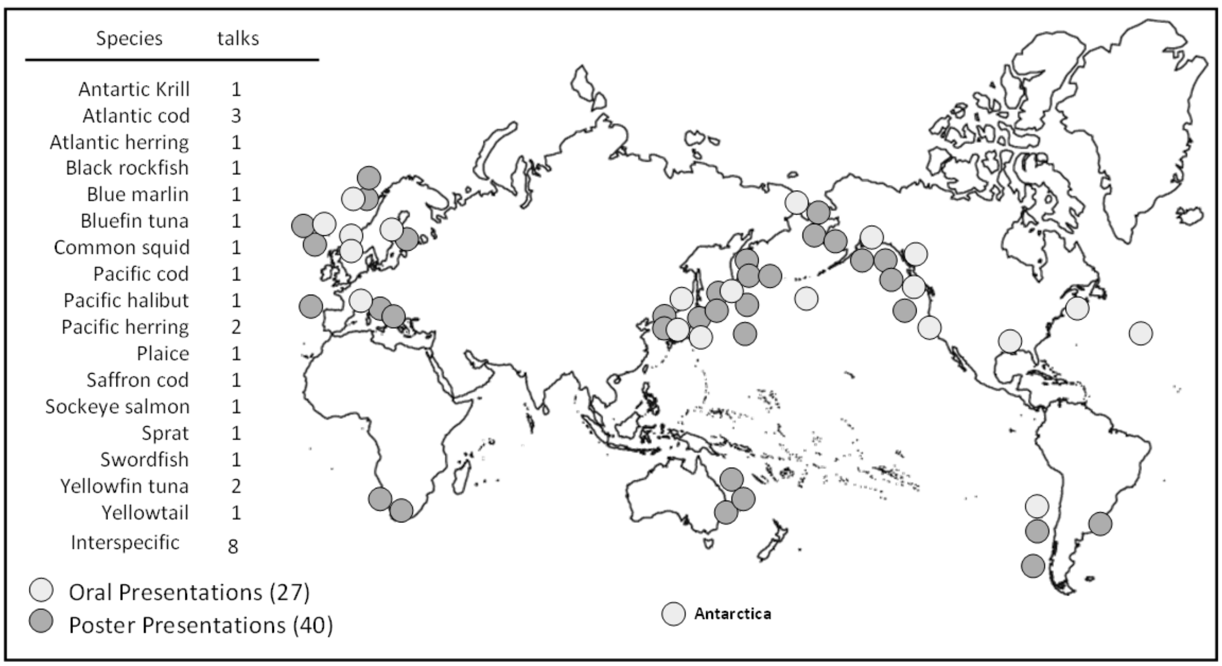

Fig. 4 Overview of species list and geographical areas covered by oral and poster presentations in session A2.

[2] Geographical names, as described by the authors in their presentations, are retained in their original form in the session and workshop summaries.

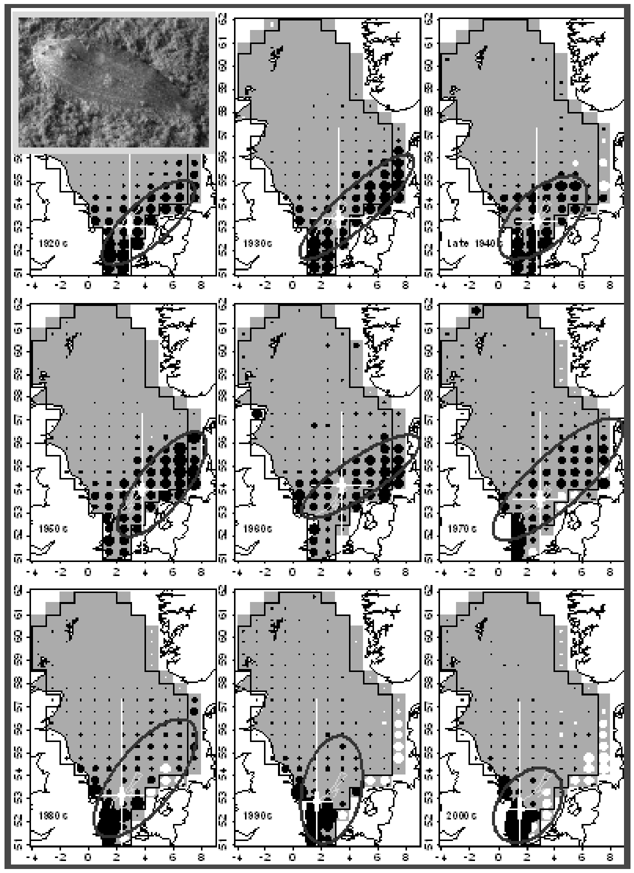

Fig. 5 Sole (*Solea solea*) catch per unit effort in the North Sea in each of nine time periods between 1920s and 2000s (from Pinnegar *et al*., session A2; *Engelhard et al*., 2011). In the 1920s, the species had a very inshore distribution in southwest in 1930s–1960s and then shifted/expanded more offshore and more northeastward (especially the German Bight) while in the 1980s–2000s the species contracted away from the northeast and was, once again, more inshore but more limited to southwest.

Traditionally, small pelagic species are excellent bio-indicators of climate change on regional and basin scales. Within this theme session, presentations examined a variety of different small pelagic species including common squid (*Todarodes pacificus*) in Japanese waters, sprat (*Sprattus sprattus*) and herring (*Clupea harengus*) in the Baltic Sea (Voss *et al*.; *Voss et al.*, 2011) and Casini *et al*. (presented by Bartolino; *Casini et al*., 2010) and some interesting comparative analyses of responses of species of anchovy and sardine in the eastern and western Pacific (Takasuka *et al*.). Efforts to estimate the environmental factors that impact the distribution of various species were presented. This included work on Pacific hake (*Merluccius productus*) (Haltuch *et al*.) that employed statistical approaches to assess historical distributions using environmental covariates. The ability to make robust projections of future distribution (*e.g*., using short-term ocean forecasts) would greatly improve survey designs as well as spatial management of stocks.

2. Mechanistic/physiological impacts

Quantitative evidence linking physiological responses to ecosystem change in various climate scenarios is scarce. Patterns identified in long-term field data or via macrophysiology and meta-analyses using various statistical tools are not sufficient to understand climate effects because the fundamental, underlying physical mechanisms are lacking. One of the keynote speakers (Pörtner; *Pörtner*, 2010) discussed the physiological underpinnings that define tolerable marine habitats in fish and invertebrates. Cellular-level changes in metabolic scope via changes in oxygen and capacity-limited thermal tolerance are shown in Figure 6. This presentation also highlighted changes in ocean pH and the need to examine interactive effects of multiple stressors on vital rates. A second presentation (Kjesbu *et al.*) focused on the reproductive biology of cod (*Gadus morhua*) and potential impacts of changes in water temperature on maturation in small versus large cod, their spawning windows and the potential match–mismatch dynamics (consequences) for early larvae assuming consistent phenology of zooplankton production. Another presentation (Kawaguchi *et al*.) discussed first results of laboratory studies exploring the effects of increased pCO_2 on early life stages of Antarctic krill, a species that normally experiences high, sub-surface levels of pCO_2 as they perform ontogenetic vertical migration. Naturally, a number of presentations included information on climate-driven changes in growth physiology of key life stages of species such as plaice (*Pleuronectes platessa*) in the North Sea (Rijnsdorp *et al*. (presented by van Hal; *Englehard et al*., 2011). A variety of poster presentations examined thermal physiology of specific species from the effects of acclimation to different temperatures on growth in coral reef fish (Donelson *et al*.; *Donelson et al.*, 2011) and swimming performance in 24 species of fish in coastal Japanese waters (Itoh *et al*.) to behavioural responses to increases in water temperature (Miura *et al.*).

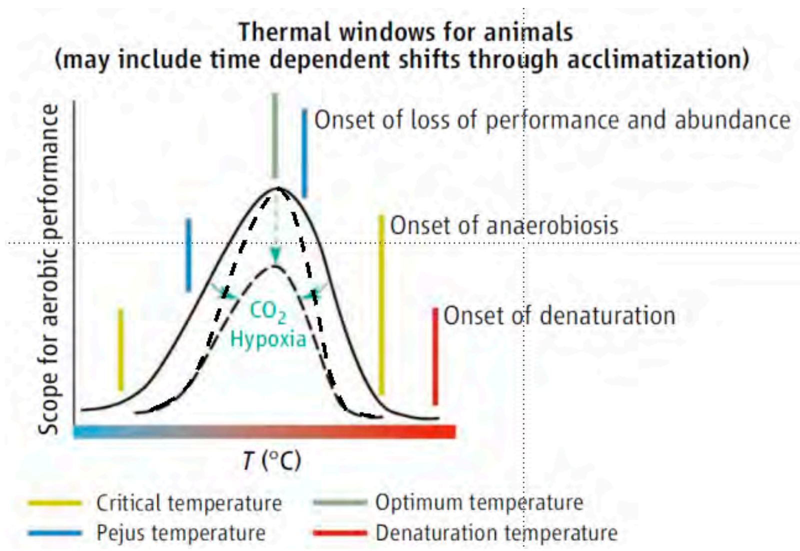

Fig. 6 Oxygen and capacity limited thermal tolerance (from Pörtner and Farrell, 2008) as presented by Pörtner. The synergistic effects of multiple factors reduce the scope for aerobic performance and limit the tolerable range in temperatures. Capacity limits occur at low temperatures while oxygen (aerobic) limits occur at high temperatures as indicated by the onset of anaerobiosis.

One aspect of this session that was not adequately covered by presentations (or by many ongoing studies attempting to project climate impacts) was the adaptive capacity of species to environmental change. A laboratory study examining the effects of ocean acidification (CO_2 1000 ppm, pH 7.8) on Pacific oysters (*Crassostrea gigas*) indicated clear differences in the responses among three genetically distinct populations (Kurihara *et al.*). One presentation (Martins *et al*.; *Martins et al.*, 2011) revealed site-specific/sub-stock differences in thermal tolerance for adult Fraser River sockeye salmon (*Oncorhynchus nerka*) returning to spawning grounds. However, adaptive capacity of sub-stocks was not discussed. Clearly, reviews of the adaptive capacity (heritability estimates and genetic correlations of traits) exist for various fish and shellfish species, particularly salmonids such as O. *mykiss* and *Salmo salar* (*e.g.*, Carlson and Seamons, 2008; Waples and Hendry, 2008) due in part to intensive hatchery production efforts. Future (high priority) research needs include additional studies examining adaptive capacity.

3. Community-level analyses

Disentangling the effects of fishing and climate was a topic specifically addressed within a few presentations dealing with species assemblages. In one case, estimates of stock sizes of Lusitanian and Boreal species were examined during contrasting periods of fishing pressure and mean temperature in the North Sea (Hofstede and

Rijinsdorp; *Hofstede and Rijnsdorp*, 2011). An extremely thorough analysis was presented of the distributional changes along the east coast of the United States between the mid-Atlantic Bight and Georges Bank from onshore to offshore (to greater depths) among 36 fish stocks and 6 invertebrate species (Nye *et al*.; Nye *et al*., 2009, Fig. 7). That presentation mirrors the findings in other shelf areas such as the North Sea and in many other Large Marine Ecosystems (LMEs) presented in other sessions at this conference. In the case of the mid-Atlantic Bight, changes in distribution appear decoupled from fishing effects (*Hare et al*., 2010).

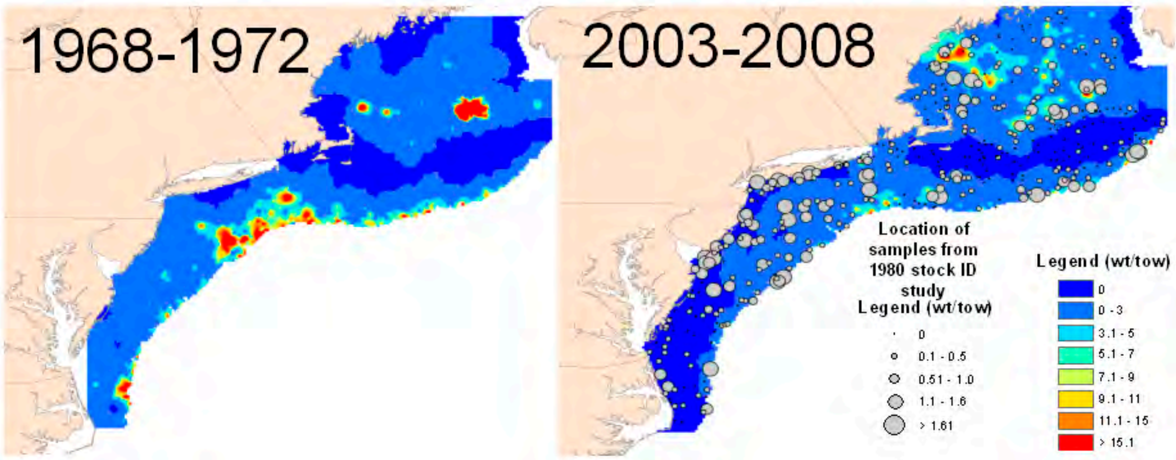

Fig. 7 Changes in the distribution of silver hake along the Atlantic coast of the USA between 1968–1972 and 2003–2008 along with the stock ID. From Nye *et al*. (2009), presented by Nye.

4. Process-oriented research

There exists an impressive amount of process knowledge regarding historical recruitment dynamics in some well-studied fish stocks. Temporal changes in recruitment dynamics of four herring grounds within the California Current and Gulf of Alaska were compared with regard to differences in the importance of trophodynamics (top-down and bottom-up) processes (Pinnegar *et al*., see Figure 9). The importance of trophodynamic control with regard to recruitment dynamics was also highlighted in the Baltic Sea in bioeconomic scenarios of sprat recruitment depending upon strengths of the Baltic cod stock (Casini *et al*., presented by Bartolino). One study highlighted density-dependent changes in growth, maturity and distribution in Pacific halibut (Valero *et al*.). The interactive roles of hydrographic and trophodynamic (prey and predator) processes were described in a few presentations (Tian *et al*., Abecassis *et al*., Schweigert *et al*., Fig. 8). Some "basic" research was presented within posters dealing with environmental factors and their influence on behaviour.

5. Modeling studies

Although modeling was the direct topic of other sessions, some presentations in session A2 included modeling activities. A bio-envelop modeling approach examined changes in endemic species in the Mediterranean Sea (Ben Rais Lasram *et al*.; *Ben Rais Lasram et al*., 2010). This topic was re-visited by one of the keynote speakers, Pinnegar *et al*. (Fig. 9) discussing community-level changes in the North Sea and globally (Fig. 5). That presentation summarized the recent modeling exercise examining >200 marine fish species by Cheung *et al*. (2009). A number of studies also attempted to "disentangle" the effects of climate and fishing on specific stocks. This included one presentation exploring the influence of fishing-induced juvenescence using a Leslie matrix approach Hidalgo *et al.* (*Hidalgo et al.,* 2012). Another study evaluated the bio-economic consequences of climate-driven changes and interactions among species in the Baltic Sea based upon stage-specific process knowledge on the impacts of temperature on survival and recruitment potential (Voss *et al*.). An evaluation of the impacts of strong (90%) reductions in the population of European eel on genetic estimates of effective population size was provided along with scenarios of reproductive dynamics in the Sargasso Sea required to obtain the genetic patterns observed in nursery areas around European waters (Pujolar *et al*.). Another talk showed model-based temporal changes in eight herring stocks due to changes in zooplankton dynamics predicted from the coupled NEMURO-FISH model between 1948–2002 (Megrey *et al.*).

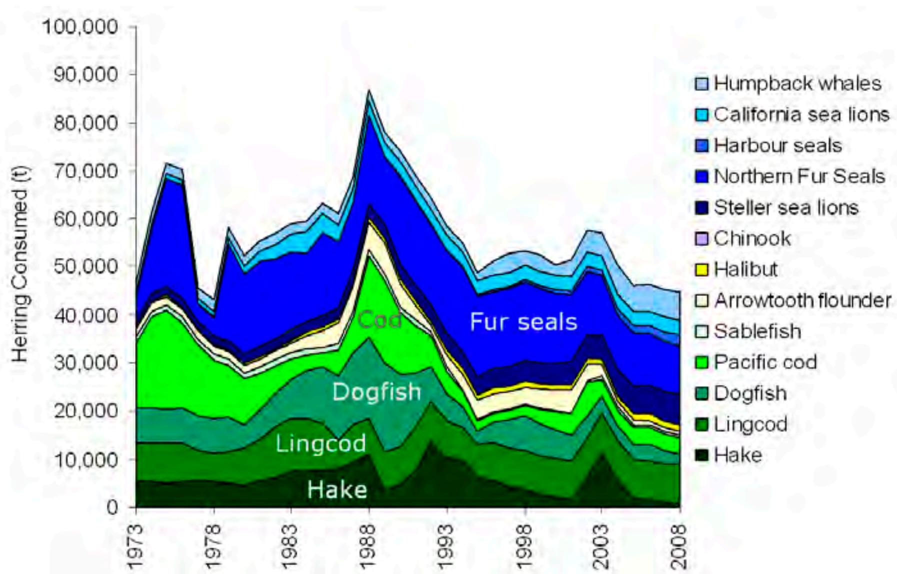

Fig. 8 Estimates of the biomass of Pacific herring consumed by 13 different piscivorous fish and marine mammals presented by Schweigert *et al*. (Schweigert *et al*., 2010). The figure illustrates the intense, temporally variable predation pressure experienced by that species and is used as an example of the importance of examining multiple processes in light of climate driven changes in systems and impacts on key species.

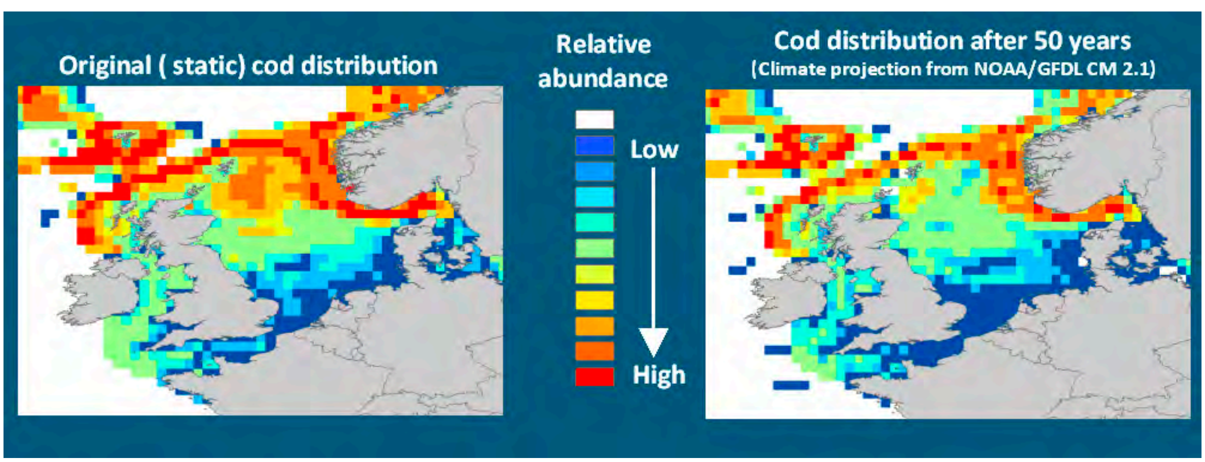

Fig. 9 Estimates of the current distribution (left) and projected, 50-year future distribution of Atlantic cod (*Gadus morhua*) in the North Sea and greater European shelf based upon bioclimate modeling. This work was based on Cheung *et al*. (2009) and presented by Pinnegar *et al*.

6. Methodological-based studies

A number of poster presentations discussed advances in methodologies that are particularly useful in identifying climate responses in fish. Examples include morphological and chemical analyses of otoliths (Chang and Geffen; Wilson *et al*.) as tools to investigate historical changes in growth and/or distribution (*Geffen et al*., 2011). A variety of different biochemical techniques were utilized, including DNA fingerprinting as part of an assessment of historical changes in 12 regional stocks of Chinook salmon (*Oncorhynchus tshawytscha*) (Tucker *et al.*). Lipid and fatty acid analyses were used as part of a study examining seasonal energy partitioning in an Arctic stichaeid species (Murzina *et al.*; *Murzina et al.*, 2012). In terms of analyses of the physical environment, a few presentations examined variability in hydrographic properties such as mesoscale features (*e.g*., as eddies or fronts (Attwood *et al.*, Rodríguez-Sánchez *et al.*)) or water currents (Kim and Kim) and sub-surface thermal structure (Twata *et al*., Takano *et al.*). Variability in these hydrographic features was then correlated with changes in the distribution, abundance or transport dynamics of key species.

Session A2: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

The summary presented above discusses a number of advances on frameworks and methodologies. One highlight from this "retrospective" session was the renewed investigations into physiological concepts that challenge current researchers to seek mechanistic explanations and perform measurements to gain cause-and-effect understanding of how climate change impacts the distribution and productivity of fisheries resources. A renewed emphasis on physiology is based, in part, on efforts to project climate change impacts on key species (or groups of species) using first principles.

Session A2: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

One presentation examined the sources of error including the initial collection of data (from sampling bias due to design attributes of field surveys) to underlying assumptions and the parameterization of models providing projections (Planque *et al.*; *Planque et al.* 2011). A schematic was used to highlight the various sources of uncertainty (Fig. 10) A total of 1137 articles were reviewed and 75 published studies were evaluated which developed models that are (or could be) used in a predictive fashion. Of these studies, < 25% explicitly treated uncertainty within observations, most elements of their conceptual model and their choice of numerical model. Most (≥70%) included uncertainty in the environment and numerical model parameter estimates while none (0%) attempted to assess the role of adaptation.

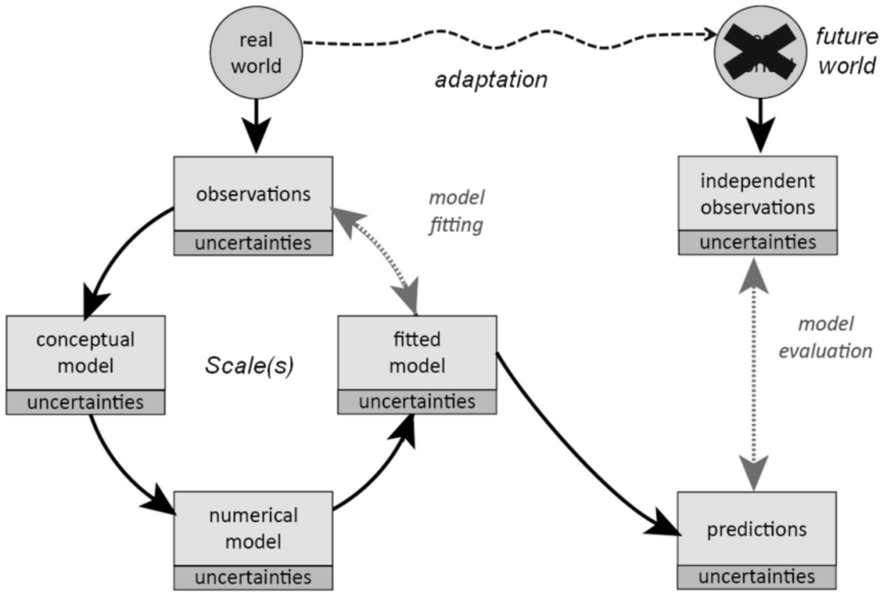

Fig. 10 Various sources of uncertainty within models used to project climate impacts on marine species as presented by Planque *et al*. (also see *Planque et al*., 2011).

Session A2: *What strategies were evaluated regarding research and management under climate change scenarios?*

The vast majority of presentations in session A2 focused on retrospective analysis but many also contained projections (*e.g*., what if scenarios based upon changes in water temperature predicted by GCMs). Management was not a focus of the session.

Session A2 Recommendations

There are at least three, quite broad recommendations for advancing research that attempts to project climate impact on fish and fisheries. Although these recommendations are based upon session A2 presentations, they likely echo research themes stressed in other sessions. Specific recommendations include the following.

1. The need for physiological measurements and conceptual framework

Physiological measurements of key life stages of all target marine fish species and laboratory experiments should examine the effects of multiple factors on growth bioenergetics (rates of energy losses and gains). For example, there is an urgent need to explore interactive effects (temperature × salinity × O_2) on survival and growth performance in a variety of fish and invertebrates and to gain more data on growth physiology (*e.g*., bioenergetics) of all life stages. This will not only help in the short term for statistical downscaling, but also in the long-term to build physiologically-based models that can make use of dynamically downscaled forcing data.

2. Continued research using relatively long time series data

Time series measurements must be continued and knowledge gained on the key climate-driven processes explaining trends. The continued development of longer time series (hundreds of years) from novel sources must be a high priority. Examples would include proxies for the abundance of species such as preserved scales within sediments. This will be particularly important to gauge the magnitude of natural variability (abundance, distribution) of marine fish and shellfish resources in light of their relatively recent responses to multiple anthropogenic stressors (climate, eutrophication, pollution, *etc*.).

3. Using process studies to disentangle multiple anthropogenic and natural drivers

Continued emphasis should be placed on identifying (and/or comparing) the drivers of recruitment variability between and within species. Analyses within a species (among stocks) can reveal broad, climate-related patterns in productivity (*e.g.*, Dutil and Brander, 2003) that would otherwise be elusive. Furthermore, continued process-oriented investigations are necessary to reveal how various abiotic (temperature, pH) and biotic (trophodynamics) factors interact with fishing pressure to make populations most susceptible to climate-driven changes. In terms of understanding recruitment drivers, "non-stationarity" was repeatedly discussed as an important point to consider in understanding historical and current recruitment drivers. Such information should help identify how various factors contribute to changes in the productivity and distribution of marine fish observed in the last two to three decades (*e.g*., Rose, 2005; Rijnsdorp *et al*., 2009) and to make more robust projections of future changes.

Session B1: Assessing ecosystem responses: Impacts on community structure, biodiversity, energy flow and carrying capacity

Co-Convenors
Thomas A. Okey (University of Victoria/West Coast Aquatic/Pew Fellow in Marine Conservation, Canada)
Akihiko Yatsu (Seikai National Fisheries Research Institute, FRA, Japan)

Introduction

This session called for retrospective analyses of changes in freshwater, coastal, and offshore ecosystems and communities, experimental studies on species interactions under climate-change-related conditions, and conceptual and numerical modeling of ecosystems relevant to climate change with an eye toward the development of forecasting approaches. Convening of this session was viewed as needed because (1) future changes in physical forcing in the oceans (*e.g*., temperature, pH, dissolved oxygen) will exceed historically observed values, (2) biological responses or adaptations to these changes are highly uncertain, particularly over a long time period, and (3) changes in geographic ranges, vertical distributions, phenologies, population structures, and productivities will differ among individual species thereby altering the connectivities and functions of ecosystem components, including predator–prey relationships and competition, species assembly, community structure, biodiversity, energy flow, and carrying capacity. These changes are expected to affect available food for humans, other ecosystem services, and ecosystem and earth system functioning.

This session received the greatest number of submissions of the symposium (56) due to its scope relating to ecosystem responses. Twenty-seven oral presentations, including two invited keynote addresses, were selected from this pool for this 9.5 hour-long session. Fifteen poster presentations were also selected and presented under this session theme. Eight of the 27 oral presentations contributed advancements of frameworks or methodologies for assessing ecosystem responses; almost all contributions included results from case studies; five of the presentations presented techniques for estimating and communicating uncertainty in forecasts; and only one or very few suggested any strategies for research and management under climate change scenarios.

Session B1: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

Eight contributions in this session presented advances to frameworks and methodologies for assessing ecosystem responses. Although these advances represent only a small subset of approaches available globally, they provide real progress toward forecasting capabilities.

- As the first keynote address, Polovina *et al*. examined “Possible trends in North Pacific ecosystems over the 21st century based on output from a coupled climate, biogeochemical, and phytoplankton model in which they examined changes in “dynamic biomes” using NOAA’s GFDL model, which includes tracers of phytoplankton with allometric zooplankton (*Polovina et al.*, 2011).
- Sumata *et al.* presented “Effects of climate forcing on the North Pacific Ocean ecosystem simulated using an eddy permitting marine ecosystem model” in which iron limitation was included in the NEMURO model, and this provided reasonably good reproduction of chlorophyll spatial distributions (*Sumata et al*., 2010).

- Hirata *et al*. showed their work on the "Global distribution of phytoplankton functional types estimated from satellite ocean colour" in which a new operational technique was developed to estimate PFT (phytoplankton functional types) from satellite ocean colour (chlorophyll data).
- Fulton, for the session's second keynote address, presented applications of end-to-end ecosystem models (*e.g*., Atlantis models) to multiple marine ecosystems around the world (*Fulton*, 2011).
- Howell *et al*. introduced work on "Modeling the central North Pacific ecosystem response to predicted climate variations and fishery management scenarios" in which Ecopath with Ecosim simulations were forced with the output of the GFDL Earth System Model and fishing projections for 21st century (*Howell et al*., 2012). This was a one-way model in which phytoplankton primary productivity affects higher trophic levels, but for which there is no effect of predation on phytoplankton.
- Cheung *et al.* (presented by Okey) reviewed work on "Projecting future changes in pelagic nekton communities along the west coast of North America" for which they downscaled and applied his global bioclimatic envelope model for estimation of future distributions of Northeastern Pacific fishes according to biological traits and preferred habitat, driven by the GFDL Earth System Model and calibrated using existing trawl data from Northeast Pacific pelagic salmon trawl surveys (*Cheung et al*., 2011).
- Munday *et al.* discussed the effects of ocean acidification on reef fish populations in which they conducted a variety of field experiments to evaluate acidification effects (Munday *et al.*, 2010).
- Graham *et al*. used a refined approach to estimating "Extinction vulnerability of coral reef fishes in response to climate change and fisheries exploitation" in which they plotted a suite of reef fishes based on climate vulnerability and extinction risk, as well as climate vulnerability versus fishing vulnerability.

Session B1: *What results were presented from designated case studies (to test methods)?*

As mentioned previously, almost all of the 27 oral contributions included results from case studies, but discussion of results in the text below are limited to the eight that contributed advancements in frameworks or methodologies. Results presented from the rest of the presentations are shown in Table 1.

- Polovina *et al*. found that the subtropical biome (poorest production area) in the Pacific Ocean is expanding, and that examination of boundary areas between these and more productive areas provided important insights into how Pacific ecosystems are changing.
- Sumata *et al*. provided reasonably good reproduction of spatial distribution of chlorophyll with their advanced methods.
- Hirata *et al*. found that the production of large phytoplankton may have decreased (and small phytoplankton may have increased) over the period 1998–2007.
- Fulton summarized that maximum sustainable yield (MSY) is projected to decrease considerably in a multi-species context. She also concluded that there will be a skewed response, *i.e*., small pelagic fishes, squids and jellies do well, while benthos, demersal fishes and top predators will be reduced.
- Howell *et al*. forecasted that the biomass of Hawaiian commercial target species (*e.g*., tunas, billfishes) will decrease, while the biomass of currently incidental species (*e.g*., snake mackerel, mahi mahi, *etc*.) will increase. The GFDL model scenarios indicated an ~18% drop in phytoplankton in HLFG (Hawaii Longline Fishing Grounds) during the 21st century, thus resulting in projected species declines due to bottom-up forcing. The simulations indicated that climate effects could be compounded by top-down fishing pressure, and *vice versa*. This results in lower projected target species biomass and lower ratios of target to incidental species.
- Cheung *et al*. showed a downscaled global model for forecasting poleward shifts in Northeastern Pacific fish populations with implications for species invasions and re-assembly as estimated by species richness.
- Munday *et al*. found that mortality of a pomacentrid fish increased after exposure to 750 ppm CO_2, which was identified as a critical threshold, due to altered smell ability and behavior.
- Graham *et al*. produced results indicating that both climate change and fishing affect fish communities by removing the most vulnerable species on the extremes such that a generalist subset of species would be somewhat resistant to both.

Table 1 Results from case studies presented from work that did not include conspicuous advancements of frameworks or methodologies for assessing ecosystem responses.

Authors	Title	Results from designated case studies
Napp *et al*.	The response of eastern Bering Sea zooplankton communities to climate fluctuations: Community structure, biodiversity, and energy flow to higher trophic levels	Zooplankton community (and pollock recruitment) changed concurrent with changes in sea ice and temperature; diversity increased from warm to cold period; *Calanus* and euphausiids favored in cold period; pteropods, larvacea, *Eucalanus* more abundant in warm period.
Hsieh *et al*. (Hseih *et al*., 2011)	Larval fish assemblages in the waters around Taiwan, western North Pacific: A comparison between, during and after the northeasterly monsoon	The distribution patterns of larval fish assemblages were likely influenced by hydrographic conditions due to alternate intrusions of the China Coastal Current and Kuroshio Branch Current and availability of food.
Aseeva and Figurkin	Changes of bottom ichthyocenosis structure on the shelf of west Kamchatka under changing environments in the last two decades	There were changes and shifts in species composition and distribution of mass fish species in the last 2 decades, possibly due to water temperature changes and their possible influence on the bottom communities.
Asch and Checkley, Jr.	Climate change leads to earlier seasonal occurrence of larval fishes in the southern California Current	Approximately 40% of species are spawning earlier and 20% later; species that use offshore habitats and spawn in spring and summer tend to display earlier phenology; species with earlier phenology track SST, but not upwelling and zooplankton. This could lead to mismatches.
Sydeman *et al*. (Black *et al*., 2010)	Ocean climate change and phenology: Effects on trophic synchrony and consequences to fish and seabirds in the northern-central California Current	Murres are coming earlier, upwelling is intensifying and happening later, and these are related. Spatial mismatch is likely for birds and krill.
Nishihara and Terada(Nishihara and Terada,2010)	A preliminary study of the effects of a wave exposure gradient on the species richness of marine macrophytes along the eastern rim of the East China Sea	Maximum species richness declines with wave exposure; increased storminess in the East China Sea Region may increase algal diversity in 50% of the regions.
Jung *et al*.	Climate-driven shifts in marine fish communities indicated by commercial catch statistics from Korean coastal waters	Coincidence with the regime shifts and correlation analysis alone do not say so much about processes and mechanisms in climate-related studies.
Saito *et al*.	Understanding and forecasting of fish species alternation in the Kuroshio-Oyashio ecosystem: The SUPRFISH programme	Fish species alternation has implications in social and economical science.
Stephen	Decline in mackerel fishery along west coast of India and its relation to the diminishing density of an abundant upwelling copepod: A multi-decadal study	Mackerel have declined, possibly due to a lower abundance of copepods.
Ahirrao	Effect of climate change on fish and fisheries of Marathwada region of Maharashtra state (India)	Global generalities were discussed.
Simpson *et al*. (Simpson *et al*., 2011)	Long-term climate-driven changes in UK marine fish communities	Water temperature increases and range shifts; there is increased species richness, and other community and phenological changes; there are winners and losers.
Hofstede *et al*. (Hofstede *et al*., 2010)	Global warming changes the species richness of marine fish in the eastern North Atlantic Ocean	Regional warming, with change in species richness related to biogeography – no relation to fisheries.
Reygondeau *et al*. (Reygondeau *et al*., 2011)	Changes in the environmental factors controlling the global biogeography of tuna and billfish communities	Top predators match the provinces of Longhurst; global climate change affects the spatial change of the environmental structure of the ecoregion, the spatial shift of communities, the reorganisation of species composition and inter-specific relationships.

Authors	Title	Results from designated case studies
Stock and Dunne (Stock and Dunne, 2010)	Modeling global patterns in the transfer of energy between primary producers and mesozooplankton in a global circulation model	Mesozooplankton production is generally ~1–20% of primary production; Z-ratio trends from 1–3% in center of sub-tropical gyres to 10–20% in highly productive ecosystems. This trend implies that the mesozooplankton response to a change in primary production is "amplified".
Rykaczewski and Dunne (Rykaczewski and Dunne, 2010)	Comparison of the ecosystem response to climate change in the mid-latitude North Pacific and California Current ecosystems	Upwelling, nitrate, primary and secondary production in the California Current will increase in the 21st century according to a GCM model, while oxygen and pH will decrease. The mechanism from climate to fishes would change.
Wilson *et al*.	Ecology of small neritic fishes in the western Gulf of Alaska: Top-down mechanisms can moderate bottom-up forcing	An increase in abundance of small krill resulted in an increase in predator per capita consumption of krill (observation).
Won *et al*. (Won *et al*., 2011)	Comparison of benthic community structure in natural habitats of abalone Haliotis discus hannai affected by different current systems	Abalone habitat was compared in two places.

Session B1: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

- Fulton and Howell *et al*. presented somewhat large ranges of uncertainty in projected changes for the various functional groups in the ecosystem modeling examples they presented (*Fulton*, 2011; *Howell et al*., 2012). Howell *et al*. presented ranges of uncertainty in his results associated with different assumptions.
- Saito *et al*. indicated inconsistency in the northern limit migration range between their model and observations.
- Stock and Dunne provided a statement of large unexplained variation from mesozooplankton patchiness (Stock and Dunne, 2010). Historical ocean-ice simulations are underway and may improve model fidelity.

Session B1: *What strategies were evaluated regarding research and management under climate change scenarios?*

- Howell *et al*. recommended a decrease in fishing effort in HLFG to preserve the Target/Incidental ratio and decrease biomass reduction of target species.
- Graham *et al*. recommended that conservation be focused on the least vulnerable species that provide the most functional support and integrity.
- Saito *et al*. recommended reducing the fleet and fishing pressure.

Session B2: Comparing responses to climate variability among nearshore, shelf and oceanic regions

Co-Convenors
Jürgen Alheit (Leibniz Institute for Baltic Sea Research, Germany)
Jae Bong Lee (National Fisheries Research and Development Institute, Korea)
Vladimir Radchenko (Sakhalin Research Institute of Fisheries and Oceanography, Russia)

Introduction

The goal of this session was to (1) discuss the interactions, ramifications, and potential connections between climate variability and marine ecosystems and (2) demonstrate the impact of climate variability with a view of future climate change. A total of 15 oral presentations were given. The session suffered from the absence of several key speakers. Four replacement talks selected on short notice from the posters were included. Most presentations were about retrospective studies and did not deal with forecasting and uncertainty aspects. This might have been due to the theme of the session which, first, was on climate variability (not climate change) and which, second, required a comparison of responses of different ecosystems. Including forecasting and uncertainty aspects under such a situation added to the complexity.

Session B2 Summary of invited talks

The first invited speaker (Svein Sundby) was unable to attend. The second invited speaker, Nicholas Dulvy, focused on climate impact on Caribbean coral reefs and North Sea fishes. He demonstrated that Caribbean coral reef cover is at an all time low and that the associated collapse in architectural complexity has led to severe habitat loss for coral reef fishes and recent declines in fish abundance. Warming of the North Sea has affected fish distribution and has led to range extensions of southern species and range contractions of northern species within the North Sea. Also, coherent depth changes in 27 North Sea fish species were observed which are highly consistent with climate variability and change.

Questions

For the reasons mentioned above, most presentations did not deal with the four key questions. Consequently, this section does not contribute a great deal.

Session B2: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

Lee and Megrey (presented by Megrey) talked about the use of visual tools to reduce the dimensionality of high dimensional data sets.

Okey *et al*. (presented by Samhouri) used Ecopath with Ecosim models to project the impacts of climate change on various indicators of ecosystem structure and function in different North Pacific ecosystems up to 2060 (*Okey et al*., 2012).

Alheit discussed the utility of using forecasts of climate oscillations for short-term forecast of fish population dynamics.

Session B2: ***What results were presented from designated case studies (to test methods)?***

Lucey and Nye showed that temporal and spatial changes in species assemblages within the Northeast U.S. Large Marine Ecosystem occur due to a combination of fishing effects and climate. Whereas fishing affected relative biomass and was more important at the beginning of the time series in the early 1960s, climatic factors have gained importance as fishing pressure has decreased and has been responsible for spatial shifts.

Rodríguez-Sánchez *et al*. noted that climatic regime shifts have caused changing population sizes and geographical variations in the position of the centre of distribution and bulk of sardine and anchovy biomass in the California Current system. This explains the alternation of sardine/anchovy dynamics and temporal disappearance of both species from the northern California Current.

Poloczanska *et al*. presented preliminary results from their construction of a marine impacts database with respect to key questions concerning vulnerability of marine systems to climate change.

Sugimoto and Niki examined a highly relevant long-term time series of sergestid shrimp catches starting at 1900. They showed that shrimp dynamics seem to be synchronous to anchovy dynamics and are impacted by the meandering of the Kuroshio path.

Regime shifts observed in different ecosystems were compared by Niiranen *et al*. with the aim to quantify marine regime shifts on a global scale and noted that changes in ecosystem state (regime shifts) affect the success of different management options. Understanding the general mechanisms and feed-back loops behind regime shifts detected across different ecosystems will increase predictability of future shifts and facilitate their mitigation.

Eisner *et al*. demonstrated that zooplankton community composition and diet analysis and energy density of eastern Bering Sea forage fish are related to climate variations (2002–2009). A warming climate may decrease the abundance of large zooplankton and so be detrimental for forage fish.

Peterson *et al*. (Zonal gradients in copepod community structure in shelf, slope and oceanic waters off Oregon, USA) found that composition of copepod fauna is determined by strength of upwelling (only on the shelf) and, particularly, by PDO phase (Keister *et al.*, 2011). During cool PDO phases, boreal coastal copepods are transported from the Gulf of Alaska into the Oregon region. During warm PDO phases, subtropical copepods are transported from offshore into the Oregon region.

Ñiquen (co-authored with Peña) determined that the neritic Peruvian anchovy (*Engraulis ringens*) and the mesopelagic oceanic lanternfish (*Vinciguerria lucetia*) react in opposite ways to the same climate signal. Warm conditions enhance the lanternfish, whereas cold conditions favour the anchovy.

Rogachev showed that the Oyashio and the Bering Sea are warming much faster than the global ocean, partly due to advection of warm submesoscale filaments from deeper waters invading the coastal realm. This will severely restrict the area of distribution and migration routes of chum salmon (*Oncorhynchus keta*).

Kidokoro *et al*. noted that the Japanese common squid (*Todarodes pacificus*) population in the Kuroshio current decreased around 1970 and recovered again in the late 1980s, in synchrony with SST, whereas the squid population in the Sea of Japan decreased around the mid-1970s, but also increased in the late 1980s (Kidokoro *et al*., 2010).

Rothschild stated the necessity of studying the coupling and decoupling among fish stock dynamics, fishing and ocean environment to better understand environmental effects and also potential, or lack of potential, for rebuilding stocks.

Lee and Megrey (presented by Megrey) used self-organizing maps (SOMs) and k-means clustering to provide a highly visual tool to easily identify patterns in the timing of high or low productivity years across both species and ecosystems by reducing the dimensionality of high dimension data sets. Results suggest that productivity in the compared Atlantic and Pacific areas were synchronous within basins but alternating between basins indicating common, probably climatically induced, external factors.

Alheit showed that population size of small pelagic fish species in waters surrounding Europe has swung in association with the dynamics of oscillating climate indices, in particular the North Atlantic Oscillation (NAO) and the Atlantic Multidecadal Oscillation (AMO) indices. However, forecasting the dynamics of both oscillations is impossible at present. Consequently, forecasting dynamics of small pelagic fish populations for the next 5–10 years based on NAO or AMO, as desired by fisheries managers, does not seem very feasible.

Using Ecopath and Ecosim models, Okey *et al*. (presented by Samhouri) studied the impacts of climate change on various indicators of ecosystem structure and function in different North Pacific ecosystems up to 2060. They found that climate change impacts are not identical in different ecosystems and across species, but produce winners and losers, and species interactions play an important role in impacts. Consequently, viewing climate change impacts in isolation might be misleading.

Session B2: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

No contributions.

Session B2: *What strategies were evaluated regarding research and management under climate change scenarios?*

Niiranen *et al*. noted that changes in ecosystem state (regime shifts) affect the success of different management options. Understanding the general mechanisms and feed-back loops behind regime shifts detected across different ecosystems will increase predictability of future shifts and facilitate their mitigation.

Lee and Megrey used comparative analysis and macro-ecological approaches.

Session B2 Recommendations

Whereas many contributions of the symposium focused on forecasting dynamics of fish populations for the next several decades, relatively few presentations covered climate forecasts for the next 3, 5 or 10 years, the time-frame fisheries and ecosystem managers are most interested in. According to the presentation by Alheit, it is impossible to make these kinds of forecasts, at least for the North Atlantic.

Session C1: Impacts on fisheries and coastal communities

Co-Convenors
Edward Allison (Policy, Economics and Social Science, Worldfish Center, Malaysia)
Keith Brander (Technical University of Denmark, National Institute of Aquatic Resources, Denmark)
Suam Kim (Pukyong National University, Korea)

Introduction

Climate variability and change have had an impact on fisheries and coastal communities throughout history, due to environmentally driven fish stock fluctuations, changes in species distribution, extreme events and changes in sea-level. The survival of coastal communities depended on being able to cope with such changes, by altering their fishing practices or switching to alternative livelihoods. In many cases communities did not survive or suffered economic hardship and emigration. Although some adaptability can be expected in response to recent anthropogenic climate change, the new situation is different in a number of ways. The expected rate of change is rapid and in one direction; most fisheries are now already under pressure from overfishing, habitat degradation and other sea and coastal uses and new pressures arise from ocean acidification. This session focused on forecasts of expected impacts of climate change on the coastal fish stocks and the communities that depend on them as well as strategies for survival under a changing climate.

Session C-1 consisted of 13 oral presentations and 11 poster presentations. Keith Brander (National Institute of Aquatic Resources, Technical University of Denmark, Denmark) and Suam Kim (Pukyong National University, Korea) had served as co-convenors for developing the session theme, selecting oral/poster presentations, and identifying invited speakers as well as early career scientists to be invited. Due to the absence of Dr. Brander at the Symposium, Edward Allison (The WorldFish Center, Penang, Malaysia) served as session co-chair with Dr. Kim for the session operation.

Session C1: *What advances on frameworks and methodologies for forecasting climate change were presented/discussed?*

It is clear that the IPCC's vulnerability analysis framework, articulated in the IPCC Third Assessment Report (2001), has become the dominant framework to analyse the vulnerability of fishery systems to climate change, and to link social and ecological components of such systems. The framework accommodates the climate signal in the form of an "exposure" variable or composite indicator, and the potential for ecological, social and economic impact in the form of a sensitivity indicator. Potential economic and social responses to projected change are captured in a measure of adaptive capacity. While a few studies using this framework have emerged in fisheries in the last two years, and several on-going studies drawing on its ideas were presented in this session, many of the integrated systems and social studies remain at the conceptual or awareness-raising phase, and are not as well advanced empirically as the impressive body of work on the biophysical models and impacts relating to climate variability and change. In session C-1, two invited speakers, Ian Perry (*Perry et al.*, 2010) and Tarub Bahri (presenting on behalf of Kevern Cochrane *et al.* (Cochrane *et al.*, 2009), introduced the concept of coupled natural and social systems in fisheries in their papers on "Adapting marine social-ecological systems to a world of change: Lessons from the GLOBEC experience" and "Evolution in an instant: Adaptation and resilience to climate change in fisheries", respectively. Both presentations agreed that climate change is likely to be a powerful driver of change in fish stocks and communities.

Dr. Perry reviewed the components of coupled marine social–ecological systems, and identified major drivers of change with scale differences in natural and social systems. Some examples on how environmental changes and the impacts of globalization in the past link to the marine social–ecological system were demonstrated. Due to the increased uncertainty in the future, however, the expected future climate changes might go beyond the ranges of past variability. He emphasized that policy goals should be focused on sustaining healthy marine social–ecological systems that maintain desirable ecosystem services and the ability to support human livelihoods. To establish the management and policy measures for adapting marine social–ecological systems to global change, holding trans-disciplinary workshops among relevant stakeholders in social science, industry, natural science, and management focus groups is necessary. In order to achieve policy goals, he also suggested we develop and promote capabilities for observing, assessing, and adapting marine social–ecological systems to changes through strengthening of (1) observing systems, (2) coupled modeling, (3) indicators, (4) regional assessments, and (5) increased application of marine management tools such as Ecosystem-based Management, stock rebuilding strategies, and marine protected areas.

Dr. Bahri divided her presentation into three parts: (1) some examples on climate change impacts in fisheries, (2) key features of the Ecosystem Approach to Fisheries (EAF), and (3) an assessment of how EAF could address climate change. Climate change will add to vulnerabilities and hamper the sector's ability to cope and contribute to social and economic development. Resilience requires, above all, diversity (genetic and species), low stress from other factors, and healthy and productive populations. Effective EAF (in ecological and human dimensions) should lead to resilient social–ecological systems because the EAF is a mechanism to attain sustainable development in fisheries/aquaculture – stressing holistic, integrated and participatory processes. Its basic objectives are maintaining ecosystem integrity/ecological well-being, improving human well-being and equity, and promoting/enabling good governance using a precautionary approach, available knowledge, and adaptive management. Some ways in which adaptation and mitigation options could be applied within an EAF context were suggested.

Session C1: *What results were presented from designated case studies (to test methods)?*

Other oral presentations were mostly examples in fishery and marine ecosystem changes resulting from interannual environmental variability and some case studies in socio-ecological approaches to understand potential adaptive responses to these changes, from various geographical areas in the North Pacific, North Atlantic, and Indian Ocean: Saha (postlarval fishing in Bangladesh), Papaioannou *et al*. (GIS in the Baltic Sea; *Papaioannou et al.*, 2012), M.A. Lee *et al*. (satellite observation on coldwater intrusion – Taiwan Strait; *Chang et al.*, 2013), Geffen *et al*. (presented by Chang on fossil otoliths of Atlantic cod in Norway), Krupnova *et al*. (macro-algae in Primorye, northwestern Pacific, Russia), Fauzi *et al*. (uncertainty issues in small-scale fisheries in Indonesia), J.H. Lee *et al*. (climate and ecological regime shift in Korean waters), Guzman *et al*. (sardines as climate proxy in Philippines), and Nguyen and Than (presented by Than on climate change impacts and adaptive capacity in Vietnam,). Andonegi *et al*. introduced the potential use of the Gadget model to predict stock response to climate change. Due to the cancellation of the presentation by Coetzee *et al*., Lluch-Cota *et al*. (vulnerability and adaptation strategy in Baja California, Mexico) was a replacement.

Papaioannou *et al*. examined past incidents in environmental changes in the Baltic Sea, and simulated the future state of the marine environment and fish distributions. The landings, revenues, fishing areas of small-scale coastal fisheries were changed by environmental variability such as a strong inflow event and regime shift. Due to the lack of information, however, their economic projection on the cod fishery in 2050 did not provide a concrete conclusion on how the landings and revenues may change. The spatial pattern of fishing vessels, movement of vessels, and mitigation measures of climate change impact on fisheries should be considered in policy and management formulation. S. Kim *et al*. forecasted seawater temperature using the MPI model under climate change scenario SRES A1B, and anticipated the delay of peak fishing season from autumn to winter in the northwestern Pacific as ocean warming continues in the 21st century. Also, the suitable spawning areas that were based on the optimal temperature range for larval survival will be expanded to the middle of the Japan/East Sea by 2050.

Several presentations demonstrated ecosystem responses to environmental variability. M.-A. Lee *et al*. revealed that episodic intrusion of cold water into the southern Taiwan Strait damaged marine life forms and cage aquaculture in Taiwan. Krupnova *et al*. also examined historic data on ocean environments and bottom macro-algae on the coast of Primorye (Japan/East Sea), and found a strong positive correlation between periods (in days) with optimum temperature range (8~15°C) in autumn and the number of *Laminaria japonica* in the next spring. J.H. Lee *et al*. described the climate and ecological regime shifts in Korean waters, which showed shifts of fish species and ecosystem structures in 1976/1977, 1988/1989, and 1998/1999 in accordance with environmental variability in ocean surface waters. In Philippines waters, the changes in sardine populations, which are very sensitive to climate change, were investigated. There was an apparent asynchrony in seasonal sardine abundance in two bays, and Guzman *et al*. hypothesized this may be due to upwelling-driven and river-driven variability, respectively.

By examining the chemical composition in cod otoliths that were collected from archaeological sites in northern Norway, Geffen *et al*. could reconstruct the temperature regime experienced by fish. Also, information on habitat environments, age and size, seasonality in life history, and stock separation for Atlantic cod that lived several hundred years ago could be achieved by otolith analysis.

Session C1: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

None of the presentations explicitly treated the techniques for estimating and communicating uncertainty in forecasts. However, Fauzi *et al*. showed that fishing-dependent coastal communities on the north coast of Java (Indonesia) were challenged by uncertainties arising from climate variability and related socio-economic forces. Fluctuations in fish catch have profound impacts on the livelihood of small-scale fishermen, leading to poverty and disruption of human well-being. Therefore, coastal communities in Java have developed some adaptation strategies to cope with uncertainties, including fishing and non-fishing strategies. This study shows that traditional fishers have ample knowledge and strategies to cope with negative impacts of climate change: temporal and seasonal migration, income diversification, developing work sharing, investing in social capital, and exploring non-fisheries resources.

Session C1: *What strategies were evaluated regarding research and management under climate change scenarios?*

Saha showed that the indiscriminate fishing of prawn post-larvae in Bangladesh had serious impacts on biodiversity in coastal ecosystems. Because climate change (*i.e*., salinity increase, temperature increase, habitat destruction, and storm surges) is closely related to fishing activity in this region, the impacts of climate change should be considered in fishery management. He argued that community-based governance could allow for fishing activity without jeopardizing the marine ecosystem. Government’s climate change adaptation policy would include the monitoring and supervision system, spatial and seasonal ban of fishing, providing alternative livelihoods, and plantation of mangrove trees to avoid negative consequences of climate change.

Than (and co-author Nguyen) stated that the coastal communities in Vietnam were rarely considered in studies of climate variability and responses to climate change. Despite the domination of centralized policies, many fisheries communities have established and exercised their own organizations and regulations to successfully manage coastal resources and cope with changes in the climate and political environment. For example, the local community in Giao Xuan involved in aquaculture indicated a detailed list of activities in five resource areas (*i.e*., natural, physical, financial, social, and human resources) that were needed to build adaptive capacity to climate change. Especially, they believed that local knowledge was useful for climate change adaptation and mitigation.

Lluch-Cota *et al*. informed that the fisheries on the west coast of Baja California, Mexico, can be regarded as a relatively well-managed ecosystem in terms of sustainability. This area has shown high ecological productivity and persistence of key species. Furthermore, other social and economic systems such as transparent decision making processes and high level of negotiation capacity assist in maintaining successful fisheries. Coupled ecological and climate models, however, indicated that this ecosystem could be vulnerable to climate change in the future. A menu of adaptation strategies organized as specific actions was proposed from catch to the market (productive chain).

Session C1 Recommendations

- To understand impacts of climate change on fisheries and coastal communities, it was suggested to have time series of environmental information, as well as biological collections such as otolith and scale deposition.
- The potential use of a Gadget model was recommended to predict stock responses to climate change. Modeling practice may give us a clue to reduce uncertainty in forecasts.
- As shown in Southeast Asian examples, examining adaptive strategies of fishing communities which have survived for a long period under changing environment may assist with future adaptation planning.
- To target and implement adaptation and mitigation actions, vulnerabilities at household level need to be identified, livelihoods for income generation need to be diversified and environmentally friendly (*e.g*., low carbon) livelihood and development opportunities need to be selected.
- Awareness of the "co-benefits" to both adaptation and mitigation that arise from biodiversity conservation and protection and restoration of mangroves and other coastal vegetation needs to be increased.
- Coastal resources governance needs to be strengthened, to develop community-based disaster risk management needs to be developed, and climate change issues need to be integrated into local and national socio-economic development planning.

These recommendations, with minor modification, can be applied to any fishery communities around the world.

Session C2: Evaluating human responses, management strategies and economic implications

Co-Convenors
Tarub Bahri (Fishery Resources Division, FAO)
Kevern Cochrane (Fishery Resources Division, FAO)
Jake Rice (Ecosystem Science Directorate, DFO, Canada)

This session focused on how society, at a range of scales from community to population, might adapt to the changes expected in the oceans, and in the goods and services on which they depend so that optimal benefits may be obtained and balance is attained between provision of food security and conservation of marine biodiversity. There were 13 presentations and 7 posters.

Two presentations gave an overview on the implications of climate change for food security, at global scale (Garcia *et al*. (presented by Rice); *Rice and Garcia*, 2011) and, at regional scale (Bell (invited); *Bell et al*., 2013). Human population growth appears to be a stronger driver than climate change when it comes to food security. In this context, in historically overfished areas restoration of sustainable fisheries production is a priority. However, it seems likely that production from capture fisheries will have to be augmented by aquaculture production to address food security needs at regional and global scales. The impacts of climate change in terms of species diversity and of livelihoods of fishers were also described at local scale (Omitoyin *et al*.), recalling that climate change gives urgency to solve problems, as human nutritional requirements and community vulnerability are at stake.

Three presentations illustrated the importance of taking into account local/traditional knowledge for the analysis of the impacts of climate change and thinking of possible solutions to adapt to it. Silvano *et al*. and Huntington *et al.*, presenting work on Brazil and Alaska, documented that local/traditional knowledge of fishermen can be a source of long-term information on temporal occurrence and abundance of fish species, and that work to collect such information on climate change can also raise awareness among the fishermen themselves. Pecl *et al*., presenting work done in Australia, showed that modern informatics technology can be used to collect this information.

Four presentations showed how communities/fisheries have developed strategies to adapt (Shimizu *et al*. in Japan, Muhammad *et al*. in Indonesia, and Omitoyin *et al*. in Nigeria), for example, with a combination of economic strategies for regional industries and control of prices that were used by the salmon industry in Japan to adapt to changing resource productivity. The importance of and how gender issues may be important in adaptation strategies was also addressed (Takahashi in Japan). The adaptability of some fisheries was assessed (Tobin and Sutton, Australia) and an experience of a multidisciplinarity approach for adaptation was described (Holliday, Australia). Holbrook *et al*. (presented by Pecl) discussed an Australian networks used to share positive experiences on adaptation research and knowledge.

Three presentations described management or planning options that were adopted to address issues related to climate change (Orencio and Fujii in the Philippines,) or confronted different possible options, analyzing pros and cons (McCay (invited)). It was recalled that diversity of fisheries is likely to be an asset for adaptation (in comparison with highly specialized fisheries). Two studies presented focussed on the adaptiveability of management to climate change. One concluded that positive benefits would be gained if catch rules could take into consideration environmental proxies (Hurtado-Ferro *et al*. on anchovy and sardine in Japan), whereas the other (Arias-Schreiber *et al*.) documented the opportunities for more sustainable harvest of large-scale anchovy fisheries in Peru when management reacted quickly with both changes in adapted catch controls and spatial fisheries measures in reaction to changes in environmental conditions. Decision making or planning would be improved for aquaculture as well if impacts of climate change were taken into consideration to select suitable sites (Radiarta *et al*. on scallops in Japan). A pair of talks on ecosystem planning in the Philippines (Pido *et al*., and Orencio and Fujii) to rationalise and harmonize different uses of the coast, rehabilitate and protect coastal habitats, and manage and develop the fisheries sector highlighted how important it is to use the knowledge of both communities and experts in the academic sector. An important theme in many talks was underlined by McCay that, despite rhetoric, people have not been treated as truly part of marine ecosystems in much research and policy.

Bastardie *et al*. analysed the mitigation potential of the fisheries sector through a modeling exercise of different scenarios of energy efficiency gained by targeting less valuable stocks closer to the ports and presented the tradeoffs in terms of stock dynamics and concentration of fishing pressure on certain areas.

Session D2: Contemporary and next generation climate and oceanographic models, technical advances and new approaches

Co-Convenors
Jonathan Hare (National Marine Fisheries Service, USA)
Shin-ichi Ito (Tohoku National Fisheries Research Institute, FRA, Japan)

Introduction

The projection of marine ecosystem response to future climate scenarios is needed to assess and implement marine ecosystem management. The marine ecosystem is part of the earth system and prediction of ecosystem responses requires integrated knowledge from physical, chemical, and biological perspectives as well as from marine, terrestrial and atmospheric perspectives. The earth system is complex with nonlinear feedbacks (including biological to physical), regime shifts, and, in some cases, thresholds beyond which change is irreversible. Therefore, the uncertainties of climate and oceanographic models cause uncertainties in the projection of marine ecosystem response not only directly but also through complex feedback mechanisms. To reduce the uncertainties of the marine ecosystem projection, we must understand the mechanisms controlling climate systems and the linkages to marine ecosystems. Specific species responses to future ecosystem conditions are required by natural resource managers, and these require specific information (*e.g.*, environments in coastal area during the short spawning period) as well as information regarding change of the ecosystem as a whole (*e.g.*, total primary production, food-web dynamics). These issues are not part of climate modeling, but mechanistic links between the biological, physical, and chemical systems must be identified and incorporated into coupled population-ecosystem-climate models. Technical advances and new approaches are essential to achieve the goal of producing better projections of marine ecosystem response to future climate scenarios. This session focused on climate and oceanographic models, including modeling of climate and ecosystem interaction, and technical advances and new approaches to project marine ecosystem response to future climate variability and change.

Session D2 Summary

Session D2 included the current state and future directions for a number of elements of the climate–ocean–fisheries–socio-economics modeling system. Two invited talks, 11 contributed talks and 7 posters were presented. Tremendous strides in climate modeling (coupled atmosphere–ocean general circulation models – AOGCMs) and ocean modeling (ocean general circulation models – OGCMs) have been made in the past two decades. Both AOGCMs and OGCMs have been extending to fisheries through the development of Earth System Models (ESMs) and Nutrient–Phytoplankton–Zooplankton Models (NPZs) and through the investigation of direct effects. In recent years, the climate modeling and ocean modeling communities have been blending and further integration will be very important for the development of ecosystem-based approaches to fisheries management.

A general outline of the IPCC AR5 (Intergovernmental Panel on Climate Change - Fifth Assessment Report) modeling plan was made by Kawamiya in an invited lecture. While the centennial time-scale will be addressed with medium resolutions GCMs (~200 km scale), the decadal time-scale and extreme-events (*e.g.*, typhoons, flooding) will be addressed with high-resolution GCMs (~50–100 km scale). New emission scenarios will also be developed. Examples of these various activities were provided by Kawamiya and by

Sakamoto *et al*. for the MIROC4 (high resolution) and MIROC5 (medium resolution) models. The plan for assessing decadal skill was described and involves developing a data assimilation and then initializing the model with a portion of the data assimilation. The resulting prediction is then compared to the next 10 years of the data assimilation. This procedure is repeated stepping through the hindcast. Initial results with MIROC4 indicate increased skill in PDO predictability and better representation of El Niño variability. The dynamics of the Kuroshio current are also better represented. Tatebe *et al*. examined in more detail the role of data assimilation in improving decadal forecasts. Working with the MIROC model used in AR4, the use of data assimilation improved representation of interannual to decadal modulation of the high frequency eddy activity in the Kuroshio–Oyashio confluence zone. These examples from the North Pacific suggest that the community of AR5 high resolution models will represent a significant improvement above the AR4 class models for use in marine ecosystem projection on both decadal and centennial time scales.

Significant developments were also reported in ocean modeling. Nonaka *et al*. presented results regarding Kuroshio variability (*Nonaka et al*., 2012). The Kuroshio path affects sea surface temperature anomalies and mixed-layer depth in the region. There may be predictability in the path related to Rossby wave propagation from east to west across the Pacific. Increased predictability may contribute to understanding variation in sardine survival and recruitment. Miyazawa *et al*. discussed the development of an operational model forecasting system for the Kuroshio and the concomitant development of a regional hindcast. Data assimilation with satellite observed data (sea surface temperature and height) and *in situ* hydrographic data was evaluated, and the *in situ* data greatly improved the assimilated fields. These results provide strong support for the continuation of *in situ* data collection to support data assimilation for interannual-to-decadal predictions in support of fisheries assessments and marine ecosystem projections.

Curchitser *et al*. presented exciting results from a two-way coupled AOGCM–OGCM. The need for OGCMs that are coupled to larger-scale AOGCMs has long been recognized and there are now many examples of such one-way nested models. There are also well known biases in AOGCMs that are thought to be caused by insufficient resolution of the regional ocean. Curchitser *et al*. described a fully two-way model linking a regional Northeast Pacific Ocean model with an AOGCM. The inclusion of regional-scale dynamics in the AOGCM resulted in an improvement in model biases including improved spatial fields of precipitation and temperature. The areas in the AOGCM impacted by inclusion of the regional model extended far beyond the regional domain showing the influence of regional dynamics on the global climate. From climate to regional, the coupling provides an excellent tool for examining the effects of climate change and climate variability on regional fisheries issues. A number of issues related with the two-way nested models were discussed including re-gridding between models, blending of model grids, and time-step coupling. The presentation clearly shows the value of coupling OGCMs and AOGCMs and lays the framework for similar efforts across the world oceans.

An important focus of the session was Earth Systems Models (ESMs) that are linked to AOGCMs. These models include nutrients, phytoplankton, and zooplankton and are clearly staged to serve an important role in assessing the effects of climate change on fisheries and marine ecosystems in the coming decade. An excellent overview was given by Gnanadesikan (invited; *Gnanadesikan et al.*, 2011). This talk addressed the potential role of ESMs in forecasting fishery impacts through bottom-up effects. The importance of planktonic size structure, salinity, phenology, and boundary areas was illustrated – factors that have been given much less attention than temperature and habitat/gyre volume. The need to better bridge between phytoplankton (P) and zooplankton (Z) was also stressed as this is the conduit for energy moving to higher trophic levels. Kawamiya also discussed ESM developments associated with MIROC. Kishi *et al*. presented the results of an NPZ model (NEMURO: **N**orth Pacific **E**cosystem **M**odel for **U**nderstanding **R**egional **O**ceanography) linked to an AOGCM model and provided examples of potential climate change effects on fish (*Kishi et al*., 2011). This and similar work show the value of coupling regionally developed NPZ models with AOGCMs. Hashioka *et al*. also used a version of the NEMURO model with a projected environment from an AOGCM and found a relatively large effect of climate change on the timing of the spring bloom, with less effect on the magnitude of the bloom. Based on the group of contributions working with ESMs, there is a clear need for the ESM community to conduct comparisons among models, to work more closely with regional ocean models that more explicitly treat the P to Z link, and for researchers to move toward an ensemble-based approach regarding ESM models – similar to the approach promoted by the AOGCM community.

A large focus of the session was biogeochemical and NPZ models that are linked to OGCMs. Komatsu *et al*. presented developments of the NEMURO framework: coupling the NPZ to an eddy-resolving OGCM and using data assimilation. The model captured large-scale patterns in macronutrients, phytoplankton, and zooplankton and results indicate the importance of capturing eddy variability in coupled OGCM–NPZ models. Gibson *et al*. presented work linking a NPZ model to an ice–biology model and a benthic model. This work indicates the importance of capturing sea ice and benthic processes in coupled OGCM–NPZ models in the Arctic and sub-Arctic seas (*Gibson et al*., 2013). A number of posters presented developments with the NEMURO model. Watanabe *et al*. found that a 1-D NEMURO model coupled with an OGCM yielded realistic vertical and seasonal distributions of nutrients, phytoplankton, and zooplankton. Yoshie *et al*., also using NEMURO, showed the capability to reproduce the distribution and variability of nutrients and plankton across a range of time and space scales in the western North Pacific (*Ito et al.*, 2010a). Using a different biogeochemical–NPZ model, Wang *et al*. demonstrated the potential influence of climate change on phytoplankton in the South China Sea. The boundaries between traditional NPZ and ESM models continue to blur and the lessons learned from the regional NPZs are moving into ESMs, which will further improve the ability of ESMs to project changes in the biogeochemical and lower trophic levels in the ocean. The major future step is the more explicit addition of fisheries in these models. Okunishi *et al*. provided one example of linking ocean models to fish. They coupled physical, biochemical–plankton and fish models in an individual-based modeling framework and their results provide support for the hypothesis of density-dependent habitat selection. Kishi *et al*. also provided examples linking ocean models to fish. There are numerous approaches to linking ocean models to fish and fisheries including production-based approaches, more detailed food web approaches, and habitat-centric approaches. Following the example of the two-way coupled OGCM and AOGCM (Curchitser *et al*.), a similar coupling of ESM and NPZ/ecosystem models can be envisioned.

Despite the improvements in modeling, continued observational and process-oriented studies are needed. The past 20 years have focused on regional oceanography (*e.g*., GLOBEC: Global Ocean Ecosystem Dynamics). Most of these programs revealed that boundary forcing is an important aspect of regional dynamics, which started many efforts to link basin-scale and global models. Future efforts similar to the QUEST-Fish (Quantifying and Understanding the Earth System) approach and full ESMs will need improved understanding of regional and basin-scale dynamics. Peterson *et al*. showed that patterns in zooplankton in the northwest U.S. are related to larger-scale PDO variability – stressing the point that understanding basin- and global-scale processes are needed to forecast regional changes in marine ecosystems. Kishi *et al*. and other talks in the session described links between basin-scale processes and fish abundance and distributions. To link among the regional, basin, and global scales, Werner *et al.* presented an overview of the BASIN (Basin-scale Analysis, Synthesis, and INtegration) program. The aim of BASIN is to understand and simulate the impact of climate variability and change on key species of plankton and fish, as well as community structure as a whole, of the North Atlantic and to examine the consequences for the cycling of carbon and nutrients in the ocean, and thereby contribute to ocean management. PICES has a similar program in the North Pacific: FUTURE (**F**orecasting and **U**nderstanding **T**rends, **U**ncertainty and **R**esponses of North Pacific Marine **E**cosystems). The goal of FUTURE is to understand how marine ecosystems in the North Pacific respond to climate change and human activities, to forecast ecosystem status based on a contemporary understanding of how nature functions, and to communicate new insights to its members, governments, stakeholders and the public. These programs and others are necessary to parameterize the models, to test and develop process oriented understanding, and to continue the observations needed to support hindcasts and forecasts. These efforts will also support the development of Observing System Simulation Experiments (OSSEs) with the goal of providing a quantitative assessment of the impact of observing systems on earth system science, data assimilation, and numerical prediction.

Another issue that was covered in the session was the development of broadly available visualization tools. The connectivity tool presented by Condie *et al*. allows particle tracks to be explored in terms of sources and sinks. The tool has a web-interface, making the application very broad. This one tool can serve as an example for various visualization approaches that make model results available to a much broader community. The last issue covered in the session was an ethno-oceanographic framework presented by Gasalla *et al*. Fishers' oceanological knowledge was surveyed by questionaries to them and the results were used to identify ocean changes. This kind of approach seems important to communicate fishery and science in future.

Session D2: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

- General Circulation Models
- Ocean Circulation Models
- Earth System Models
- Nutrient-Phytoplankton-Zooplankton Models
- Living Marine Resource Models
- Need for Basin-scale Observations-Modeling-Process studies
- General visualization tools

Session D2: *What results were presented from designated case studies (to test methods)?*

- AOGCMs – MIROC4 and 5 – high-resolution decadal forecasts,
- OGCMs – Kuroshio studies – improvement in capturing circulation; in-situ data assimilation makes significant contributions,
- ESMs – GFDL, MIROC – tremendous improvement; focus on temperature and primary productivity too narrow; need to add salinity, dissolved oxygen, carbon cycle, iron from a fisheries perspective; ESMs address the issue of bottom-up control of fisheries,
- NPZs – NEMURO – many different improvements (eddy variability, vertical and seasonal distributions, sea-ice/benthic coupling, coupling to fish),
- LMRs – various approaches to coupling modeling to LMRs; food web specific, general primary productivity, and habitat selectivity/Lagrangian approaches,
- Two-way coupling between AOGCMs and OGCMs.

Session D2: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

- Not explicitly covered (but was covered in other sessions);
- Uncertainty caused by initial condition: data assimilation approaches may be able to reduce uncertainty of the prediction which is based on the initial conditions.

Session D2: *What strategies were evaluated regarding research and management under climate change scenarios?*

- A combination of AOGCM–OGCM and ESM–NPZ/vision fully coupled AOGCM–OGCM–ESM–NPZ models;
- The importance of model tools around which the community can work (*e.g.*, NEMURO);
- The need for continued observation/modeling/process studies at the basin scale;
- Continued observation which provides a "tool" for assessing stationarity through time; this will be an important issue and continued observation can inform us when a system has "changed";

- The need to use models for OSSEs (Observing System Simulation Experiments) to improve observing networks;
- Visualization that is model/approach independent;
- The importance of data assimilation is producing hindcasts and initializing decadal AOGCMs;
- The continuation of building the ensemble approach from AOGCMs to OGCMs/ESMs/NPZs;
- The use QUEST-Fish as an example from climate-to-markets;
- A general tension between standardizing model output or providing translators to work with specific formats;
- High resolution ESMs take a long time to run: ½ day for 1 year – 100 years = 50 days; still unrealistic to run multiple scenarios and ensembles.

Session D2 Recommendations

- Continue to support blending of AOGCM/OGCM/ESM/NPZ;
- More models should be developed as community models (NEMURO);
- Continue observations and evaluation of observing systems;
- Research efforts to link regional studies to basin- and global-scale issues;
- Model diversity should be kept to allocate multi-view analysis (if we tend to focus on realistic model with high resolution, it will reduce capability of ensemble projection);
- Research efforts to enable projections of unprecedented phenomena.

Session P3: Sustainable strategies in a warming climate

Co-Convenors
Anne B. Hollowed (Alaska Fisheries Science Center, NMFS, NOAA, USA)
Michael J. Schirripa (Southeast Fisheries Science Center, NMFS, NOAA, USA)

Introduction

Many nations have adopted a goal of building sustainable fisheries. Traditionally, this goal has been pursued through the adoption of precautionary harvest policies that are based on the expected productivity of the stock in a relatively constant environmental state. These harvest policies seldom explicitly consider how possible future climate change may modify critical aspects of the productivity of the stock. At the single species level, climate change could significantly influence the carrying capacity, the reproductive potential as well as the spatial distribution of the stock. At the multispecies level, climate change may change the abundance of competitors and predators of species targeted for fishing. Societal changes in the consumption of fish and policies regarding marine ranching and aquaculture may also change the economic factors governing fisheries. This session emphasized novel approaches to build sustainable management strategies under a changing climate.

Session P3 consisted of 9 oral presentations and 1 poster. Drs. Éva Plagányi (*Plagányi et al.*, 2011) and Chang Ik Zhang (*Zhang et al.*, 2011) were the invited speakers for this session. Presentations in this session focused on examples of management strategies that could be applied to sustain fisheries under a changing climate and techniques for assessing and forecasting the performance of harvest policies under changing climate. A key outcome of this session was the need for two-way communication between scientists and stakeholders to develop meaningful scenarios on human responses to the impact of ecosystem and climate change.

Session P3: *What advances on frameworks and methodologies for forecasting climate change impacts were presented/discussed?*

Zhang and Lee proposed a new assessment framework to evaluate how strategies for marine resource management would perform under different scenarios regarding bottom-up responses to changing climate conditions. This approach maps how climate change induced changes in bottom-up forcing would flow through the food web using NEMURO, and Ecopath with Ecosim. The innovation of their approach was to assess the performance of management strategies using an Integrated Fisheries Risk Analysis Method for Ecosystems (IFRAME) framework. The IFRAME approach provides a system for assessing ecosystem conditions relative to the ecosystem standards and objectives. This coupled model projection approach extends Management Strategy Evaluation (MSE) type evaluations to provide an Integrated Ecosystem Assessment.

Plagányi *et al*. presented a framework for two-way communication between scientists and stakeholders to develop strategic approaches to complement tactical fisheries assessment measures under a changing climate. They reviewed the effectiveness of single-species assessment methods, management strategy evaluation approaches and multi-species assessment models as tools for evaluating the likely impacts of climate change.

Session P3: *What results were presented from designated case studies (to test methods)?*

Presentations by Hollowed *et al*. and Ianelli (*Ianelli et al*., 2011) provided insight on the need for stakeholder input in the selection of scenarios for use in single species MSEs with climate change scenarios. These two presentations demonstrated a process for selecting management scenarios and a method for communicating the tradeoffs to stakeholders and managers.

Nielsen *et al*. (*Nielsen et al*., 2012) presented a case study on the implications of climate change on salmon in the Arctic. They highlighted the need to consider the implications of climate change at different life stages (particularly the freshwater phase).

Pecl *et al*. made a strong case for using the comparative approach to identify the commonalities in responses of hotspot regions to climate change. The concept of a hotspot network holds great promise for enhancing shared experiences and learning on sensible adaptation pathways for other global regions.

Session P3: *What techniques were presented for estimating and communicating uncertainty in forecasts?*

Ianelli (single species) and Zhang (and co-author Lee)(ecosystem) presented frameworks for communicating the implications of management strategies to stakeholders in a readily understandable manner. As expected, capturing the uncertainty in stock projections is much easier than capturing the uncertainty in coupled models. The IFRAME coupled model system proposed by Zhang is one way to generate multiple climate scenarios for use in describing uncertainty in ecosystem assessments.

Session P3: *What strategies were evaluated regarding research and management under climate change scenarios?*

As noted above, the focus of this session was on strategic planning for fisheries management under a changing climate. The presentations by Hollowed *et al*., Plagányi *et al*. and Zhang and Lee all showed the importance of including socio-economic factors when developing scenarios for the future of fish and fisheries. Zhang and Lee presented a method to evaluate the performance of management strategies within an ecosystem context. Schirripa *et al*. presented plans for the development of an Integrated Ecosystem Assessment for the southeastern region of the United States. Kaeriyama *et al*. (Kaeriyama *et al*., 2012) illustrated the need for more holistic models that extend MSE assessment frameworks to include economic performance measures (*Kaeriyama et al*., 2012). Barange *et al.* presented the QUEST-Fish framework which utilizes a multi-disciplinary approach to assessing risks and vulnerabilities to climate change (*Barange et al*., 2011). A common theme for most speakers in this session was the need to extend our forecasts to include assessments of the status of marine ecosystems, food security, and the human condition under a changing climate. Another common theme was the need to seek stakeholder input when developing scenarios for long-term strategies for fisheries management.

Workshop W1: Reducing global and national vulnerability to climate change in the fisheries sector: Policy perspectives post-Copenhagen

Co-Convenors
Cassandra de Young (Food and Agriculture Organization)
Eddie Allison (Worldfish Center, Malaysia, on behalf of the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA))
Tarub Bahri (Food and Agriculture Organization)
Marie-Caroline Badjeck (Worldfish Center, Malaysia, on behalf of the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA))

Introduction

A ½-day workshop was convened by Dr. Cassandra de Young (Food and Agriculture Organization and Dr. Eddie Allison (WorldFish Center) on behalf of the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA; see Figure 11 for membership of PaCFA) and was attended by 22 people. The general goals of the workshop were to: (1) discuss the responses of individual PaCFA agencies and other institutions attending the UN Framework Convention on Climate Change (UNFCCC) meeting in Copenhagen in December 2009 (COP15), (2) identify the critical gaps in the science underpinning climate impacts on fish production systems and marine and coastal ecosystems and on potential adaptation responses and mitigation options, and (3) develop the basis of a strategy to ensure that the next IPCC report and national adaptation and mitigation plans will take full account of emerging ocean and fishery science related to climate change.

Fig. 11 Global Partnership on Climate, Fisheries and Aquaculture (PaCFA) is a voluntary global level initiative among 20 international organizations and sector bodies. In 2009 these organizations recognized their common concern for climate change interactions with global waters and living resources and their social and economic consequences and decided to have a coordinated response from the fisheries and aquaculture sector to climate change during COP15. See www.climatefish.org.

The workshop started with a review of the workshop objectives and an introduction to the PaCFA by Dr. Marie-Caroline Badjeck from the WorldFish Center. This was followed by presentations from Drs. Tarub Bahri (FAO), Edward Allison (WorldFish Center) and Sung Bung Kim (OECD) who outlined their respective experience in 2009 in terms of developing research and policy messages in the runup to the COP15 and their current post-Copenhagen activities and plans for continued engagement in the UNFCCC process.

Following the presentations, the participants divided into two groups on (1) Impacts and exposure and (2) Adaptation and mitigation, with the guidelines of identifying the major policy issues to be addressed and the science needed to address them. The key messages that were highlighted during the plenary discussions are summarized below.

W1 Summary of the discussion: Critical gaps

It was agreed that climate change adds to other issues such as overfishing and ecosystem impacts that are already affecting many of the fisheries systems around the world. The group agreed that the focus should be on sustaining and restoring productive ecosystems, which are key long-standing objectives that would need to be addressed through an ecosystem approach, as agreed in the 2002 World Summit on Sustainable Development. Climate change should not be an excuse for dropping the focus on existing fishing problems such as the need to reduce effort or seek alternative livelihoods. The importance of social science analysis of adaptations required in management systems was further highlighted, as well as the need for determining whether existing plans to manage and use resources will be derailed by climate change. In this respect, the diversification of livelihoods, both at household and at community level, was mentioned as one relevant option that would strengthen robustness to change, including to climate change.

In regard to mitigation issues, reducing fishing capacity has a side benefit on reducing emissions. However, a balance is needed between emissions benefits and effects on livelihoods. Carbon emissions cycles were also discussed and it was noted that some fish production systems may be relatively efficient with respect to other food production systems (for instance, livestock), yet there still is a need for a carbon life cycle analysis for fisheries products and for the development of low-carbon or even carbon-neutral aquaculture systems.

Lack of information and data was thoroughly discussed and scale issues were raised while addressing gaps in the knowledge currently available on exposure to, and impacts of, climate change. It was underlined that there is a fair knowledge and modeling capacity to represent and/or forecast the trends in environmental variables, but the link to fish stocks productivity is largely missing. There is a research need to downscale global information and models to regional and local ones, in particular regarding the link between physical and biological systems (*e.g.*, identifying the impacts of climate change on the distribution of Pacific micronekton that are the food of tuna).

Moreover, there is still a need to pull together local knowledge on the array of climate change impacts (intensity and frequency of storms, changes in salinity, sea level rise, effects on habitats and productivity, effects on the ability of fishermen to fish, biodiversity and invasive species, *etc*.) so that these can inform local adaptation strategies which may be more suitable as a result of having been based on local observation.

An important gap underlined by the group was the lack of socio-economic information related to climate change impacts on societies and economies. Participants raised the question about the socio-economic indicators that should be used to monitor the impacts of climate change and underlined the need to understand, identify and use indicators that reflect the country/local adaptive capacity. The discussion also addressed the level of aggregation of the information, in particular the fact that global analyses do not pick up local issues that may appear to be contradictory. An example was given of the United States which seems to be one of the less vulnerable countries at a global scale, but with highly vulnerable local situations, *e.g.*, North American indigenous groups whose vulnerability is higher because of their stronger reliance on fisheries.

The need for household level knowledge on impacts of climate change was highlighted. More science is currently needed to understand the exposure to, and impact of, climate change. In particular, the lack of long-term observation mechanisms providing data and information to run socio-economic models was underlined. Investments should be made accordingly and interaction should be sought with national statistic departments, in particular regarding the inclusion of fisheries and aquaculture-related information in household living standard (HLS) surveys. This would allow for the measurement of impacts of climate change and success of adaptation measures. The WorldFish Centre has been encouraging the inclusion of fisheries-related information in HLS measurement surveys in Uganda and Malawi, but this is required more broadly, particularly in countries with substantive artisanal marine fisheries. Bottom-up analyses, rather than top-down, are currently needed to scale up the knowledge from local to regional scale and to be able to incorporate traditional knowledge that is too often disregarded.

This lack of information is linked to the lack of political power of local fisherfolk and the fact that the most vulnerable do not have a strong voice in policy terms (*i.e*., social justice), thus underlining the need for clear messages for policy makers and economic leaders. A positive example of Vietnam was given where a study was carried out on the measurable benefit and cost for mitigation/adaptation of fishing communities that convinced policy makers to act. However, while reviews were carried out on climate change justice issues across other sectors, those for fisheries are lacking. This is contrary to the fact that fishing-dependent communities are generally highly vulnerable, and fisheries often serve the role of a livelihood option of last resort.

At the same time, it was recalled that the need for improved science should not be used as an excuse for not acting and that our growing understanding of the underlying uncertainty should be used as a powerful instrument to advocate for a precautionary approach rather than just as a basis for increasing research requirements which, unfortunately, often leads to a reason for not acting. It was agreed that fisheries scientists should improve the way they convey uncertainty and the related risks and take advantage of the fact that politicians are risk averse and are more likely to take precautionary measures if they understand those uncertainties. A discussion was held on how researchers/scientists should present uncertainty when communicating with policy makers and, in particular, on the need to highlight the risks of socio-economic losses if no action is taken. In this respect, the mismatch between social and natural research, both in vocabulary and in methods and approaches, was underlined and the need for collaborative research was recalled.

The participants highlighted that scientists should not only better communicate their findings to policy makers, but also to consumers and other constituencies within the sector across the value chain. Certification low-carbon production systems can all be entry points for adaptation and mitigation but further engagement with the private sector and consumers and innovative partnerships are needed.

The need for sectoral integration was discussed, underlining the inter-dependence of the different sectors and the need for a better understanding of the links between aquaculture and capture fisheries, both small scale and industrial sectors, in terms of adaptation and mitigation strategies. If climate change affects the ability of capture fisheries to provide food for aquaculture products, the effects on aquaculture need to be assessed. Contradictions and tradeoffs related to food security and climate change were also underlined, in particular the case of fish culture in rice farms that was encouraged to meet food security but which appears to be an important source of methane emissions. Finally, the disconnect of fisheries policies and biodiversity policies in the face of climate change was commented on, as for example, the increasing risk of released farmed fish into the natural watershed because of increased storm events and the consequences on biodiversity. Generally speaking, the policy frameworks on biodiversity and on food security and fisheries are on two different tracks and will need to come together in the global climate change discussions.

W1 Recommendations

- In responding to climate change, do not lose the focus on existing problems in fisheries (harmful ecological impacts, overcapacity, need for livelihood diversification…);
- A carbon life cycle analysis should be carried out for the fisheries sector for emissions accounting purposes and to inform both consumers and national planners on the options for low-carbon futures for different livestock and fisheries/aquaculture production systems;
- Global climate impact models should be scaled down to regional and local levels, in particular to link impacts of climate change and fish productivity at these higher resolutions;
- Socio-economic data and information should be collected to improve information on the impacts of climate change at fleet, community and household level;
- Issues related to climate change should be addressed through an ecosystem approach to fisheries so that they are considered alongside other forcing factors;
- Scientists should improve the way they convey uncertainty while interacting with policy makers and stakeholders to evaluate risks of different policy options;
- Sectoral integration should be sought, in particular to find common ground between food security, biodiversity and fisheries in the global discussions on climate change.

Workshop W2: Potential impacts of ocean acidification on marine ecosystems and fisheries

Co-Convenors
Kenneth L. Denman (Canadian Centre for Climate Modelling and Analysis; DFO, Canada)
Yukihiro Nojiri (National Institute for Environmental Studies, Japan)
Hans Pörtner (Alfred-Wegener Institute, Germany)

The oceans are becoming acidic as carbon dioxide from fossil fuel emissions enters surface ocean waters from the atmosphere. Talks and posters presented at the workshop reported on manipulation experiments and observations on the effects of elevated carbon dioxide on organisms at all trophic levels of fisheries foodwebs, and modeling approaches to predict the impact of continuing increases in atmospheric carbon dioxide.

The first talk (Denman *et al*.) presented observational evidence of open ocean increases in pCO_2 and decreases in pH, followed by model projections of global mean and spatial patterns of the decrease in pH until the end of this century. Several talks and posters reported on studies of organisms with calcium carbonate skeletal structures subjected to various experimental exposures to low pH (high pCO_2) waters in controlled laboratory or field situations. Several other talks and posters reported on physiological and behavioural responses of animals to elevated CO_2 conditions. One poster evaluated the adequacy of several ecosystem models to simulate adaptation over long time scales to changes in CO_2 (and other related variables) associated with climate change.

Nakamura *et al*. reported on a depression of metabolism and growth in coral larvae with elevated CO_2 levels. Similarly, Lartey-Antwi (co-authored with Anderson) found decreased growth rates in flat-tree oysters. Suwa (co-authored with Shirayama) presented data obtained with a system precisely mimicking constant and fluctuating CO_2 levels, where the fluctuating levels showed less impact on the growth and skeletal structures of echinoderm larvae than CO_2 levels set permanently high. Kurihara provided an overview on different levels of CO_2 sensitivities according to taxon and in early life stages. Ishimatsu *et al*., Munday *et al*. and Dissanayake *et al*. reported on changes in various processes indicating tolerance limits, decreased aerobic scope and behavioural changes in shrimp and young fish in response to elevated CO_2 levels, with species-specific differences even among closely related fish species. Salau talked about a model of reduced carrying capacity for pteropods as pH decreases, and the feedback effects on pink salmon: as a result even and odd year differences in salmon stock size will increase over time with management implications for repeating strong and weak returns in alternating years. Rumrill *et al*. presented long-term observations of an estuary showing decreasing pH effects on oysters in the outer saline estuary and increasing pH probably resulting from changes in precipitation and freshwater runoff. Takami *et al*. demonstrated how elevated CO_2 levels slow and disturb development in abalone and Sugie *et al*. found enhanced drawdown in Si:N by Bering Sea phytoplankton as pH fell and iron was limited. B.K. Kim (co-authored with H.W. Kim) used brine shrimp as a model for identifying changes in the expression of individual genes during exposure to low pH. Finally, Le Quesne and Pinnegar (presented by Pinnegar) analyzed various ecosystem models emphasizing that parameterizations of various physiological processes would be needed to support the evaluation of responses to changing pH.

W2 Summary of noteworthy findings

- Overall, investigators are observing different sensitivity levels among investigated organisms, some closely related, ranging from calcification and growth to development, behaviours and ecosystem level responses. The consideration and introduction of environmental variability changes the pattern and level of response. In light of the complexity and diversity of responses observed, it is thus too early to draw general conclusions regarding the responses of ecosystems to elevated CO_2.
- The inclusion of preindustrial levels (around 280 ppm CO_2) in experimental protocols as well as the precise control of diel CO_2 cycling was considered highly valuable in studying the impact of ocean acidification. In fact, one study reported improvement in calcified structures in echinoderm larvae under pre-industrial compared to present day levels of ambient CO_2. Investigations of mechanisms under high pCO_2 need be complemented by testing the role of such responses under expectable pCO_2 according to ocean acidification scenarios.
- In terms of behavioral and physiological responses to elevated CO_2, these studies of organisms that are not necessarily calcifiers are less mature, but are exciting because so little is known from the past.

W2 Recommendations and key questions

- Pre-industrial control runs should be done more often, since organisms have already adapted from that point.
- Experiments often include current day pCO_2 (~380 ppm) and an elevated level, often ~1000 ppm. If emissions are controlled to try to achieve < 3°C global warming, then intermediate levels of, say 450, 550, and 700 ppm pCO_2 require consideration. Both these recommendations require precise pCO_2 (pH) control.
- Long-period culture experiments/multi-generation studies are both required to try to obtain information on long-term adaptive capacity and evolutionary change, but are usually restricted to species with generation times of less than 1 year. Comparisons of species from various climate regimes and CO_2 environments may help to circumvent these constraints in long-lived species.
- In experimental studies diel, seasonal and inter-annual variability of CO_2 levels should be simulated if relevant for the respective ecosystem. Such experiments would be needed to identify slow trends embedded in highly variable environments.
- Population genetic and functional genomic analyses need to be applied more widely.
- Models need to be examined as to whether they formulate physiological and behavioural processes that are dependent on changing environmental drivers such as pCO_2 or temperature.
- Some aquaculture species respond differently than their "wild" counterparts. Have they already become adapted to higher pCO_2, *e.g.*, by being cultured in water supply from depths below the mixed layer that already have elevated pCO_2 relative to the depths at which the wild populations live?
- Can we learn from species already experiencing higher pCO_2 naturally? For example, some species of copepods and euphausiids already migrate several hundreds of metres vertically on diel and seasonal timescales (diapause) where at depth they are exposed to pCO_2 levels of 500 to 1000 ppm.
- Importantly, experimental protocols must include behavioural and physiological dependencies on multiple variables that we expect to change with the climate: pCO_2, dissolved oxygen, temperature, micro-nutrients (Fe), *etc*. (*e.g.*, Pörtner and Farrell, 2008).
- Sensitivities need to be systematically identified across taxa and in between species comparisons.
- Through a combined experimental and modeling approach, can we start to evaluate possible changes in whole ecosystem structure resulting from the possible disappearance and replacement of key species?

Workshop W3: Coupled climate-to-fish-to-fishers models for understanding mechanisms underlying low frequency fluctuations in small pelagic fish and projecting its future

Co-Convenors
Salvador E. Lluch-Cota (Fisheries Ecology Program, Centro de Investigaciones Biológicas-del Noroeste, Mexico)
Enrique N. Curchister (Institute of Marine and Coastal Sciences, Rutgers University, USA)
Shin-ichi Ito (Tohoku National Fisheries Research Institute FRA, Japan)

Low-frequency variability of abundance of small pelagic fish is one of the most emblematic and best documented cases of population fluctuations not wholly explained by fishing effort. Over the last 25 years, diverse observations have led to several hypotheses. However, because of limited-duration time series, testing hypotheses has proven extremely difficult with available statistical and empirical tools. As a result, the mechanistic basis for how physical, biogeochemical, and biological factors interact to produce the various patterns of synchronous variability across widely separated systems remains unknown. Identification of these mechanisms is necessary for exploring projections and building scenarios of the amplitude and timing of stock fluctuations and their responses to human interactions (fisheries) and climate change. The workshop was intended to compare state-of-the-art modeling tools and discuss what expertise is necessary to tackle this important scientific and environmental problem.

The workshop, attended by about 50 scientists, started with an opening address by the convenors. Six oral presentations were given. Ryan Rykaczewski used bioenergetic models to compare anchovy and sardine growth potential in the California Current region. He found that anchovy growth is dependent on the community structure of nearshore eutrophic waters, and that sardine growth is possible under offshore oligotrophic conditions. He also discussed the importance of accurate representation of plankton size structure for mechanistic models of sardine and anchovy populations. Wolfgang Fennel introduced a NPZDF (nutrient, phytoplankton, zooplankton, detritus and fish production) model with two-way coupling between prey and predators; hence, mass balance between NPZD and fish or prey fish and predator fish are conserved. The model was applied to the Baltic Sea where the fish dynamics is dominated by two prey species (sprat and herring) and one predator (cod). To demonstrate performance of the model, the effects of eutrophication and fishery scenarios were addressed. Three 3-D NPZDF models were presented by Triantafyllou *et al*., Ito *et al*., and Hedström *et al*. who discussed applications of super Individual-Based Models (IBMs) for three different regions of the globe. Triantafyllou *et al*. developed a super IBM for the European anchovy in which particles representing fish have information of fish population, adding to those of age, position, length, and weight of the fish. This Lagrangian model is coupled to a biophysical model based on the Princeton Ocean Model (POM) and the European Regional Seas Model (ERSEM). Moreover, the ERSEM was assimilated to satellite-derived phytoplankton density.

Ito *et al*. introduced a super-IBM of the Japanese sardine and clearly showed the significance of the density dependence effect on fish distribution and growth. They also demonstrated the importance of predators on migration of prey fish.

Hedström *et al*. used a community biophysical model; the Regional Ocean Modeling System (ROMS) for the physical circulation model and NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) for the NPZD model. They intend to include a fishery effect in their model and extend it to an end-to-end model. They noted difficulties of such a state-of-art NPZDF model, including spatially locating eggs after spawning and scaling the predator–prey interactions among fish species. In the final talk, Rose addressed issues that arise with developing complicated models in general, and new issues specific to the development of end-to-end models.

An open discussion was held in the afternoon session. Based on the presentation by Rose, participants discussed end-to-end models and how they deal with different issues, particularly zooplankton dynamics and linkages with upper and lower trophic levels. Several attendees expressed concern over the uncertainty and increasing error derived from coupling different models, especially when outcomes from one model are used as input for a chain of other models. Also, strong concern was expressed on how to evaluate performance or validate the models because of the multiscale nature of these models. No single data set seems to be sufficient. After recognizing the valuable review by Plagányi (2007), the group discussed the need to quantitatively compare performance of models for different processes and promote the use of the best modeling approach option for each question. In this sense, keeping modeling approaches diverse was considered a better strategy than agreeing to a single model. Assemblages of models, as done by the climate community, do not seem to be a feasible approach for end-to-end models. However, the group believed it would be useful for small pelagic fish and climate change research to compile and/or develop different models for at least some of the major small pelagic fishing regions, specifically the Benguela, California, Humboldt, and Kuroshio/Oyashio currents.

Workshop W4: Salmon workshop on climate change

Co-Convenors
James R. Irvine (Pacific Biological Station, DFO, Canada)
Masa-aki Fukuwaka (Hokkaido National Fisheries Research Institute, FRA, Japan)
Suam Kim (Pukyong National University, Korea)
Vladimir Radchenko (Sakhalin Research Institute of Fisheries and Oceanography (SakhNIRO), Russia)
Loh-Lee Low (Alaska Fisheries Science Center, Seattle, USA)
Shigehiko Urawa (North Pacific Anadromous Fish Commission)

Introduction

The North Pacific region is home to multiple species of salmonid fishes, including anadromous Pacific salmon that regularly migrate from freshwater to the sea and back. Salmon provide economic benefits in the form of subsistence, commercial, and recreational fisheries, and contribute to the cultural enrichment of the regions where they occur. Their ecological role is complex as they facilitate energy transfer directly and indirectly at multiple trophic levels in many ecosystems. Their ability to occupy habitats in fresh, salt, and brackish water has led to a remarkable diversity of life histories, but climate change threatens to alter their distribution and abundance.

Salmon are found most frequently in cooler regions of the Pacific Ocean. In recent years, commercial catches have been among the highest on record, with no indication of declines. Yet coho, Chinook, and some sockeye salmon populations are declining in many areas.

This 1-day workshop examined scenarios for the future of Pacific salmon, based on climate projections from coupled ocean/climate or other models or from statistical projections of expected climate changes.

Following welcoming remarks from Dr. Vladimir Fedorenko, Executive Director of the North Pacific Anadromous Fish Commission (NPAFC), 9 oral presentations and 5 oral poster presentations were given, followed by 2 discussion sessions. Presentations were diverse and informative. The majority (12/14) dealt with Pacific salmon (9 marine, 2 fresh water, 1 database) while 2 presentations dealt with Atlantic salmon.

The first presentation, by Irvine and Fukuwaka, set the stage for much of the rest of the day, providing an overview of abundance trends for Pacific salmon at the scale of the North Pacific, Asia, and North America. All nations' commercial catch data indicate that marine production of Pacific salmon is at all time high levels, dominated by chum and pink salmon, albeit with significant contributions from hatcheries. High levels of synchrony among regions for catches of chum and pink salmon were found by Fukuwaka *et al*., although the response of salmon abundance to various climate indices varied among regions. Kaeriyama *et al*. (presented by Seo) showed that increased temperatures have resulted in faster growth and survival for Hokkaido age-1 chum salmon. Interestingly, this may lead to population density-dependent effects that will ultimately reduce the growth and extend the maturation schedule for chum salmon in the Bering Sea. Farley *et al*. reported results from their research in the eastern Bering Sea that fortuitously covered 4 consecutive warm years (2002–2005) followed by 4 cool years (2006–2009). Warm years tended to benefit age-0 walleye pollock resulting in higher growth potential for salmon. Farley *et al*. also reported preliminary results from Russian work carried out in February/March 2009, evaluating sockeye salmon lipid levels.

Mundy and Evenson concluded the timing of spawning migrations of high latitude chinook will become more highly variable as climate warms. Wainwright and Weitkamp used an ecosystem approach to evaluate climate effects on Oregon coho salmon. They determined that climate change will likely have a strong negative effect on coho, although there remains great uncertainty in biological responses. Reed *et al*. applied an evolutionary model to predict how well some Fraser River sockeye salmon might respond to predicted changes in river temperature resulting from global warming. They concluded the persistence of some salmon populations will depend on their ability to adapt quickly, which will be determined by the existence of sufficient genetic variation. Peterman *et al*. presented the development of a Salmon Monitoring Advisor web site designed to help in the design of salmon monitoring programs. Wasserman described the successful experience of the Skagit Climate Science Consortium which is integrating scientific analyses at the watershed level in order to manage salmon populations in the face of climate change.

Piou and Prévost and Prusov *et al*. described their findings on populations of Atlantic salmon in the Scorff River (France) and the White Sea (northwest Russia), respectively. Piou and Prévost's models projected climate change-related life history effects, concluding that marine conditions and freshwater flow regimes are of utmost importance in determining stock abundance. Prusov *et al*. described changes in Atlantic salmon growth and age compositions during recent years of increasing temperatures but concluded that changes in management practices have thus far had the greatest impact on the status of northern populations of Atlantic salmon. Miyakoshi *et al*. documented changes in coastal temperatures around Hokkaido and described plans to adjust the release timing of young chum salmon to take advantage of these changes in an attempt to increase salmon survivals. Ishida and colleagues' archeological work showed that the distribution of chum salmon in Japan during an earlier warmer period was more northerly than it is today, and predicted similar northerly shifts in salmon distribution with climate change. Ruggerone *et al*. (presented by Neilson) demonstrated that chinook salmon growth was related to their previous growth history and pink salmon abundance while coho salmon growth was strongly linked with pollock abundance, which was linked to temperature.

Following presentation of papers and posters, separate discussion sessions considered the broad topics of forecasting impacts and long-term research needs. Participants had been previously provided with a link to the recent NPAFC document (http://www.npafc.org/new/pub_special.html) describing a proposed long-term research and monitoring plan.

The following questions were considered.

Forecasting impacts

a. Do we expect the North Pacific to remain at the current high levels of salmon production?
b. How will climate change affect salmon differently in various regions?
c. Will sustained warming have an opposite effect on productivities of northern and southern salmon populations?
d. Are the southern and northern limits to the range of salmon shifting northward?

Assessing ecosystem responses

a. Is the North Pacific ecosystem changing to favor pink and chum salmon?
b. What mechanisms are most likely responsible for changes to salmon distribution, production, and relative species composition?

Although it was not possible to thoroughly debate all the above questions in the limited time available, there appeared to be consensus on some issues:

- The North Pacific is currently producing large amounts of salmon but rates of increase seen during the last 20 years will not continue.
- Climate change is already affecting salmon differently in the northern and southern regions. There will be additional northward shifts in the southern boundary of salmon distribution. There was no consensus on whether the northern boundary would shift further north into the Arctic.

- Marine production of pink and chum salmon is increasing, but there was no consensus on how much of this might be due to ecosystem changes *versus* enhancement.
- A proper understanding of climate change effects on salmon requires consideration of each life history stage. Phases to focus on include: freshwater residence, early marine (first couple of months) and the first winter at sea.
- Important areas of future research include improving our understanding of effects of interactions between hatchery and wild salmon in their early marine environment, and linkages between coastal oceanography and young salmon growth and survival.
- Integrated research programs including experts from multiple disciplines and countries are most likely to improve our knowledge base.

Workshop W5: Networking across global marine "hotspots"

Co-Convenors
Gretta Pecl (Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Australia)
Alistair Hobday (CSIRO, Marine and Atmospheric Research, Australia)
Stewart Frusher (Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Australia)
Warwick Sauer (Rhodes University, South Africa)

Background

Regional global warming "hotspots", typified by above average ocean temperature increases, provide the potential for early warning and evidence of the response by natural resources to climate change. In theory, regions at the "front-line" of climate change should also be leading the field in terms of assessing impacts and evaluating adaptation options. Networking and synthesising outcomes from across hotspots can facilitate accelerated learning and also indicate sensible pathways for maximising adaptation and minimising impacts for other global regions.

This workshop was designed to highlight (1) where global marine hotspots occur now, and where they are projected to occur in the future, (2) summarise the information currently emerging on biological climate change impacts in these areas, and (3) to discuss the potential for developing a global network of scientists, policy makers and managers working in marine hotspots.

W5 Outcomes

Twenty-four regional hotspots were identified and experts were contacted to present at the workshop. All contacted scientists responded positively to the concept and 12 were able to participate. Presentations covered a range of temperate, sub-temperate, polar and tropical systems as well as developed and developing countries.

There was discussion on the merits of using sea surface temperature (SST) to define hotspots and on other potential metrics. While it was noted that there are other metrics, the focus for the use of SST was on defining regions that were rapidly changing and thus provide the first opportunities to inform society of climate change impacts and adaptation options. It was noted that temperature *per se* may not be the driver as it could be a proxy for wind regime changes and/or current shifts.

It was noted that for the network to be manageable there needed to be a limit in the number of regions. The 24 regions identified by the analysis of SST covered:

- Tropical, temperate, sub temperate, polar,
- Developed and developing countries,
- Range of adaptive capacities,
- Variety of ecosystem types,
- Range of anthropogenic pressures and disturbances.

There was broad agreement that while SST is only one driver, it was a major driver of distribution, abundance, phenology and life history. Temperature was also the most common identified metric in the presentations at both the workshop and the broader symposium. Although the need for a manageable number of regions was supported, it was agreed that the network would welcome participation by other areas that are experiencing significant biological change (*e.g*., upwellings, coldspots, *etc*.).

W5: *What results were presented from designated case studies (to test methods)?*

Common themes that were apparent in the presentations include:

- Most hotspots had temperature records "validating" selection as a hotspot. However, in many cases temperature was (partly?) a proxy for current shifts and wind regime changes;
- Many range shifts were already being observed including movements to deeper waters;
- Changes were occurring in fisheries distribution and associated changes in fleet structure and operations;
- Many areas showed significant deoxygenation;
- There is an increased frequency of harmful algal blooms;
- There are shifts in species diversity of phyto/zooplantkon communities (mainly large to small individuals) and increased diversity and species richness of fish species;
- Large changes were occurring in distribution and abundance of some species, subsequently acting as "invasives", creating negative ecosystem impacts;
- Regions with naturally high variability appeared to be equally vulnerable to change and were not pre-adapted;
- There are management implications for harvesting of "shifting biomass", especially across jurisdictional boundaries;
- Synergistic effects such as increased frequency of extreme events and temperature may not enable biomass to rebuild after reduction in fishing effort.

The value of a "Hotspots Network" was summarized as:

- Providing a mechanism for scientists, managers and policy makers to communicate and see how science was being translated into policy and practical adaptive management measures in those regions of the world where impacts were occurring.
- Networking across these regions would facilitate comparative studies through:
  - Promotion of consistency in data collection, analysis, reporting;
  - Potential for greater certainty in projection models through first opportunities for validation.
- Comparisons between regions would provide greater certainty in the understanding of impacts for stakeholders (i.e., other stakeholders are experiencing similar issues);
- It would provide for shared learning and capacity building about adaptation science (successes and failures).
- As the hotspots regions are at the forefront of climate change, the network would provide valuable insights into the impacts, model validation and the success or failures of adaptation planning for the broader global community.

The path forward

- A Consensus statement would be produced to be signed by participants. Participants would be encouraged to obtain, in principal, support from their respective research/management institutions as further support for the Network.
- Each of the regional hotspots contacted was asked to provide a summary of:
  - Physical changes documented in last few decades;
  - Observed (or predicted) biological/ecological/fisheries impacts, including changes in distribution, abundance and phenology at each of the trophic levels and any observed ecosystem changes;
  - Details of climate change programs or major research initiatives;
  - Indications of ecological, cultural, or economic importance.

This information will be summarised and developed into a manuscript. Seed funding would be sought to develop a website for communication of the Network and for hosting an initial workshop to determine a strategic and operational plan for the Network. The plan would identify resource implications and potential funding opportunities.

- Funds would be sought to run targeted workshops on identified areas of need such as monitoring methodologies, inter-disciplinary approaches for linking science to practical management, *etc*.
- Funds would be sought to establish demonstration projects. Examples of such projects could include:
  - Identification of key monitoring sites for global comparisons;
  - Establishment of a project to evaluate tools and approaches for implementation of adaptation options that identify and balance the tradeoffs in ecological, social and economic indices using some of these regions as case studies.

Vision for the Network

- A global network of scientists, managers and policy makers where shared information is synthesised, contrasted and compared across locations providing the best possible learning opportunity to address climate challenges;
- A mechanism for capitalising, as efficiently and effectively as possible, on emerging information in a rapidly changing world;
- A framework for facilitating accelerated learning and indication of sensible adaptation pathways for other global regions;
- Implementation of local/regional adaptation needs through a global partnership of shared expertise and capacity building.

Workshop W6: Examining the linkages between physics and fish: How do zooplankton and krill data sets improve our understanding of the impacts of climate change on fisheries?

Co-Convenors
William Peterson (Hatfield Marine Science Center, NMFS, NOAA, USA)
Kazuaki Tadokoro (Tohoku National Fisheries Research Institute, FRA, Japan)

Introduction

The goal of this workshop was to provide an opportunity for those keenly interested in "how data on zooplankton and krill can be used to better understand and forecast the impacts of climate change on fisheries" to discuss the topic in an informal workshop atmosphere.

W6 Summary

The meeting convenors solicited papers that demonstrated explicitly how information on species of copepods and euphausiids might contribute to a better understanding of the linkages between physics and fish. Although the convenors worked hard to invite people to submit abstracts, only 8 were submitted, thus reducing the workshop to a ½-day. More than 50 people attended the workshop. The high level of attendance was evidence that there is a great deal of interest in learning more about mechanistic linkages between physics through the zooplankton to fish.

W6: *What results were presented from designated case studies (to test methods)?*

Most of the discussion focused on a discussion of case studies. These case studies were previously described in the PICES Press (Vol. 18, No. 2, 2010) and are summarized here for this report.

William Peterson opened the meeting with an overview of mechanisms linking physical forcing and zooplankton distribution and abundance to fishes in the North Pacific.

Ryan Rykaczewski gave a Pacific basin-scale perspective on how the Kuroshio and California Current might be linked. He examined basin-wide variability in the depth of the nutricline across the mid-latitude North Pacific using a global, earth system model and found that variability in the depth of wintertime convection in the western North Pacific stimulates anomalies in the vertical distribution of nitrate and that these anomalies propagate from west to east with the North Pacific Current with a transit time on the scale of decades.

William Peterson *et al*. discussed two hypotheses: (1) lipids and cold water copepod species, and (2) source water which feeds the northern California Current to see how these are linked with salmon survival.

Jay Peterson (and co-author W.T. Peterson) showed that there have been chronic changes in the upwelling ecosystem off Newport, Oregon over the last 40 years. First, there has been an increase in the number of copepod species routinely found along the coast (0.11 species per year); second, there has been an intensification of oxygen-depleted bottom waters on the shelf; third, there has been a deepening in the depth from which water upwells.

Shaw *et al*. discussed relationships between timing and strength of upwelling and euphausiid spawning. They showed that *Euphausia pacifica* spawning is strongly associated with the timing of the onset of upwelling but not with upwelling strength. *Thysanoessa spinifera*, on the other hand, spawn prior to and during upwelling and seem to be more strongly affected by water temperature. Future changes in the timing of the spring transition are likely to affect *E. pacifica* spawning behavior. They predicted that a warmer ocean will likely lead to a decrease in *T. spinifera* abundance and spawning. Both scenarios will affect the availability of euphausiids as a food source for higher trophic level predators.

Takahashi *et al*. discussed some of their work carried out during a short visit at the Peterson lab (Hatfield Marine Science Center, NWFSC, NOAA) in Newport. They looked at otoliths of late-larval and juvenile northern anchovy and Pacific sardine collected off Oregon in the summer of 2005, an unusual year in which upwelling began very late, in mid-July. The results suggested that the fish responded quickly to the intensification of upwelling after mid-July, due to the development of a bloom of phytoplankton and a surge in production of cold water copepod species. Increased secondary productivity led quickly to enhanced larval growth rate of northern anchovy.

Tadokoro (and co-author Okazaki) noted that a great deal of work has been done on the large *Neocalanus* copepod species in the Oyashio–Kuroshio region, with relatively little research being done on the small copepods species upon which larval and juvenile sardines feed. More work is needed on both food habits of juvenile planktivorous fishes as well as on the zooplankton upon which they feed.

Kuriyama *et al*. reported on long-term variation in the copepod community in relation to the climatic change in the Kuroshio waters off southern Japan from 1971 to 2009. They revealed that copepod abundances were high in the early 1970s and after the 1990s, and low in the 1980s. *Paraclanus parvus*, as one of the important prey of the Japanese sardine, was abundant through the study period.

The final talk was by Kobari *et al*. who demonstrated decadal changes in seasonal timing and population age-structure of *Eucalanus* in the Oyasiho from a time series that originated in the 1970s. They showed that a decline in copepod abundance originated at the early life stages, and was associated with a shift in atmospheric and oceanographic conditions. Possible biological mechanisms to account for the decline were reduced egg production, lower survival for the portion of the annual cohort with late birth date, and overwintering of the survivors at younger stages.

W6 Recommendations

The workshop participants recommended the following:

- Zooplankton time series that are based on either size of copepod taxa, or on species abundance, have far greater value than time series of "total biomass" or "volume" of the catch.
- Future workshops on the same topic would be welcomed.

More specialized workshops should be convened whereby zooplankton ecologists with long time series could work with fisheries scientists from the same region to try harder to relate inter-annual variations in zooplankton abundance and species composition with variations in some key aspects of pelagic fishes life history – either recruitment or growth.

Peer-reviewed publications related to the Symposium presentations

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Frusher, S.D., Pecl, G.T. and Gardner, C. 2010. The east coast Tasmanian rock lobster fishery: vulnerability to climate change impacts and adaptation response options. 2010 International Climate Change Adaptation Conference, June 29–July 1, 2010, Gold Coast, Queensland, Australia.

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WG-FCCIFS Summary Relative to its Terms of Reference

As noted in the introduction, the Terms of Reference for WG-FCCIFS were to:

1. Promote research on climate change impacts on marine ecosystems by scientists in ICES and PICES member nations through coordinated communication, exchange of methodology, and organization of meetings to discuss and publish results.
2. In collaboration with relevant expert groups in PICES and ICES, develop frameworks and methodologies for forecasting the impacts of climate change on marine ecosystems, with particular emphasis on the distribution, abundance and production of commercial fish and shellfish;
3. Review the results of designated case studies to test methods;
   Explore techniques for estimating and communicating uncertainty in forecasts;
4. Explore strategies for research and management under climate change scenarios, given the limitations of our forecasts;
5. Plan for a science symposium in early 2010 to present, discuss and publish forecasts of climate change impacts on the world's marine ecosystems, with particular emphasis on commercial fish and shellfish resources.
6. Produce publications that are relevant to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change;
7. Publish report(s) summarizing work.

The actions of WG-FCCIFS achieved all of these activities. Review of the literature cited in this report serves as a testament of the success of the group's ability to foster interest in climate change and its potential impacts on fish and shellfish throughout the Northern Hemisphere. We anticipate that the papers generated through the efforts of the Working Group will be useful to writers preparing the IPCC's Fifth Assessment Report. The formation of the Section (Strategic Initiative) on *Climate Change Effects on Marine Ecosystems* will allow PICES and ICES to remain leaders in fostering and supporting the science needed to understand, assess and project the implications of climate change on marine ecosystems.

Appendix 1

WG-FCCIFS membership

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Appendix 2

WG-FCCIFS inter-sessional and annual meeting reports

2009 Inter-sessional WG-FCCIFS meeting, Victoria, Canada

The first meeting of the joint PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS) was held in conjunction with the GLOBEC Open Science Meeting in Victoria, Canada, on June 21, 2009.

The main objective of this meeting, as one of the Working Group's Terms of Reference, was to agree to the structure of a science symposium on "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses, and evaluating management strategies*" organised under the auspices of the WG-FCCIFS. Members of the Working Group discussed plans for the symposium that would take place in Sendai, Japan, in April 2010.

Also discussed was the relationship between WG-FCCIFS and other ICES expert groups including: the Steering Group on Climate Change, and Working Group on Cod and Climate Change, Working Group on Integrated Assessments of the Baltic Sea and Working Group on Life Cycle and Ecology of Small Pelagic Fish.

The Working Group's links with PICES' Fishery Science Committee (FIS) and Physical Oceanography and Climate Committee (POC) were reviewed as well as the Group's relationship with expert groups, including Working Group (WG 20) on *Evaluating Climate Change Projections*, and PICES' second integrative science program, FUTURE (**F**orecasting and **U**nderstanding **T**rends, **U**ncertainty and **R**esponses of North Pacific Marine **E**cosystems) that is expected to be formally inaugurated at the 2009 PICES Annual Meeting in Jeju, Korea. FUTURE will be made up of three Advisory Panels that will provide guidance to all expert groups to achieve the aims of FUTURE: AICE (Anthropogenic Influences on Coastal Ecosystems), COVE (Climate, Ocean Variability and Ecosystems), and SOFE (Status, Outlooks, Forecasts and Engagement). WG-FCCIFS will have the strongest links with SOFE and COVE.

Synergies with other organizations were also discussed.

Dr. Kenneth Drinkwater provided an overview of the Ecosystem Studies of Subarctic Seas (ESSAS) project. ESSAS has elected to become a project under the Integrated Marine Biogeochemistry and Ecosystem Research project (IMBER). ESSAS encourages comparative studies of ecosystems within the sub-arctic seas. It provides funding for comparative ecosystem studies what will be relevant to WG-FCCFIS.

Dr. Shin-ichi Ito discussed a proposal that was submitted to SCOR (Scientific Committee on Oceanic Research) titled "Coupled climate-to-fish-to-fishers models for understanding mechanisms underlying low frequency fluctuations in small pelagic fish". This project is likely to contribute case studies that will be relevant to the WG-FCCIFS effort.

Dr. Manuel Barange reported on recent developments within the Food and Agriculture Organization of the UN (FAO), World Bank and United Nations Environment Program (UNEP), among other regional/global stewardship organizations. These organizations are particularly interested in models and decision support tools that provide information on the socio-economic implications of, and adaptations to, climate change on fish and fisheries.

WG-FCCIFS reviewed its Terms of Reference and determined that several items could not be undertaken until after the 2010 symposium in Sendai. The symposium was expected to provide a forum for discussing frameworks and methodologies for forecasting impacts of climate change on the growth, distribution and abundance of marine life. The Group agreed to initiate some writing assignments during the summer of 2009 (mainly collation of existing methodologies relevant to the objectives of the Working Group). WG-FCCIFS members decided to meet again the day after the Sendai symposium to summarize the results presented and to develop a timetable for the delivery of the Working Group products to ICES and PICES.

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2009 WG-FCCIFS meeting, ICES ASC, Berlin, Germany

The ICES/PICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS) met in Berlin, Germany, on September 20, 2009. The main objective of this meeting was to review workshop proposals for the symposium organised under the auspices of the Working Group in April 2010, in Sendai, Japan. The group discussed the possibility of developing a second symposium volume that would include synthesis papers developed by the theme session co-chairs. The group finalized and submitted their proposal for a 1½-day Working Group meeting immediately after the Symposium.

Drs. Anne Hollowed and Harald Loeng gave presentations to the ICES Science Committee Steering Group on Human Interactions and the Environment (SGHIE) on Monday, September 21 and Wednesday, September 23. Dr. Loeng also represented the WG-FCCIFS at the Steering Group on Ecosystem Function (SGEF) on September 21.

The WG-FCCIFS discussed the ICES practice of annually revising the terms of reference of each working group. As the TORs were negotiated between PICES and ICES, it was decided not to recommend any revisions and to keep the existing Terms of Reference.

One of the TORs for the WG-FCCIFS was a review of the relationship of the planned work for the group relative to other activities of ICES and PICES. The relationship between WG-FCCIFS and other ICES expert groups was discussed (mainly SGCC, WGCCC, WGIAB and WGLESP). There was an introductory discussion about the need to raise the awareness and profile of climate change research in ICES.

Dr. Alheit reported that the ICES Study Group on Climate Change (SGCC) planned to submit their report to SCICOM in May.

Drs. Hollowed and Jon Hare discussed activities currently underway in the U.S. Dr. Hollowed reported that she has been discussing the development of an overview paper that would address the strengths and weakness of different forecasting approaches that would be co-authored by the WG-FCCIFS co-chairs. Dr. Hare mentioned that several scientists met to discuss how IPCC projection models could be utilized for fisheries issues at Princeton University, in June 2009 (proceedings published in Stock *et al*., 2011).

Dr. Skip McKinnell reported on a meeting he had with Dr. Philippe Cury, EUR-OCEANS, concerning cooperation with EUR-OCEANS in scenario development and their co-sponsorship for the Sendai symposium. Dr. Christian Möellmann volunteered to contact Dr. Cury to explore this further.

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2009 WG-FCCIFS meeting, PICES-2009, Jeju, Korea

A WG-FCCIFS meeting was held on October 29 to discuss research activities and to review plans for the international symposium on "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses, and evaluating management strategies*" to be held in Sendai, Japan. The Working Group proposed two Theme Sessions for PICES co-sponsorship at the 2010 ICES Annual Science Conference in Nantes, France: "*Development and use of ocean observing and forecasting systems in coastal and marine management*" and "*Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting*". The latter was also proposed as a Topic Session for the 2010 PICES Annual Meeting in Portland, USA. All proposals were subsequently supported by Science Board.

During the PICES Annual Meeting, the WG-FCCIFS Co-Chairs, Drs. Anne Hollowed (PICES/USA), Suam Kim (PICES/Korea), and Manuel Barange (ICES/UK), attended the kickoff meetings of the new Advisory Panels, AICE (Anthropogenic Influences on Coastal Ecosystems), COVE (Climate, Oceanographic Variability and Ecosystems) and SOFE (Status, Outlooks, Forecasts and Engagement) of PICES' second integrative science program, FUTURE (**F**orecasting and **U**nderstanding **T**rends, **U**ncertainty and **R**esponses of North Pacific Marine **E**cosystems) to answer questions regarding the activities of the Working Group.

List of participants

Members

Jürgen Alheit (ICES, Germany)
Manuel Barange (ICES, UK)
Michael Foreman (PICES, Canada)
Anne B. Hollowed (PICES, USA)
Shin-ichi Ito (PICES, Japan)
Xianshi Jin (PICES, China)
Sukyung Kang (PICES, Korea)
Suam Kim (PICES, Korea)
Franz Meuter (PICES, USA)
Yashiro Yamanaka (PICES, Japan)
Akihiko Yatsu (PICES, Japan)
Yury Zuenko (PICES, Russia)

Obervers

Alexander Bychkov (PICES)
Ik Kyu Chung (Korea)
Laura Richards (Canada)
Steven Rumrill (USA)
Thomas Therriault (Canada)
Yasunori Sakurai (Japan)

2010 Inter-sessional WG-FCCIFS meeting, Sendai, Japan

The joint PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS) met in Sendai, Japan, on April 29–30, 2010. Twenty scientists from 9 countries attended the meeting. The main objective of this meeting was to review the outcomes of the PICES/ICES/FAO Symposium on "*Climate change effects on fish and fisheries*" and to discuss plans for future collaborative research in 2010–2012.

The meeting opened with a review of ICES and PICES working groups that were related to climate change. The role of PICES working groups was summarized by Dr. Alexander Bychkov (Executive Secretary), followed by a summary of the role of ICES working groups by Dr. Manual Barange (SCICOM Chairman), by phone). Both PICES and ICES see climate change research as an integrative cross-cutting activity. Following the ICES and PICES overviews, Dr. Barange discussed QUEST-Fish, an ongoing project linking climate to fish to markets and the newly funded EURO-BASIN project. BASIN (Basin-scale Analysis, Synthesis and INtegration) is an international effort to understand and simulate the impact of climate variability and change on key species of plankton and fish, as well as community structure as a whole, of the North Atlantic.

Dr. Jürgen Alheit led a discussion that identified potential PICES and ICES topic/theme sessions for upcoming Annual Meetings. There were a number of recommendations – some specific and some more general. Continued co-hosting of sessions between ICES and PICES was discussed for a number of the potential sessions.

WG-FCCIFS Co-Chair, Dr. Anne Hollowed, provided an update of several NOAA activities, including COMPASS (Communicaton Partnership for Science and the Sea) and NOAA's new Climate Services. Dr. Shin-ichi Ito updated the Working Group on ESSAS (Ecosystem Studies of Subarctic Seas project) research actives, and Dr. Jon Hare discussed a workshop held at NOAA's Geophysical Fluid Dynamics Laboratory during the summer of 2009.

Following these general issues, WG-FCCIFS reviewed the symposium workshops and suggested that a summary of the symposium be written and submitted for publication. Some specific journals were identified, including the new *Nature Climate* magazine, *Fisheries Oceanography* and *Progress in Oceanography*.

The final issue discussed was a timetable for a follow-up symposium. Calendars of upcoming meetings were reviewed. Specifically, the 3rd Symposium on "*The ocean in a high CO_2 world*" was noted as an important meeting for WG-FCCIFS to be aware of (http://oceanacidification.wordpress.com/2010/07/16/third-symposium-on-the-ocean-in-a-high-co2-world/). An offer was made by the Korean government to host the next Symposium on "*Effects of climate change on the world's oceans*" in conjunction with the Ocean Expo 2012 in Yeosu, Korea. This will be discussed further at the next Working Group meeting during the 2010 ICES Annual Science Conference in Nantes, France.

The Working Group requested an endorsement by ICES and PICES to organize:

- A 5-day ICES/PICES Workshop on "*Reaction of Northern Hemisphere ecosystems to the climate events in the late 1980s: A comparison*" (May 2011, Hamburg, Germany) to be convened by Jürgen Alheit (Germany), R. Diekmann (Germany) and TBD (PICES). PICES is requested to nominate a co-convenor for this workshop.
- A 1-day workshop on climate change effects on fish and fisheries in conjunction with the ESSAS Open Science Meeting (May 2011, Seattle, USA).
- ICES/PICES Theme Session on "*Atmospheric forcing of the Northern Hemisphere ocean gyres, and the subsequent impact on the adjacent marine climate and ecosystems*" for the ICES ASC (September 2011, Gdańsk, Poland) to be convened by E. Di Lorenzo (PICES/USA) and I. Yasuda (PICES/Japan) H. Hatun (ICES/Faroe Islands) and Jürgen Alheit (ICES/Germany).
- PICES to co-sponsor an ICES Symposium on "*Forage fish interactions and ecosystem approach to fisheries management*" (September 10–14, 2012, Nantes, France). ICES has already agreed to sponsor it, therefore, this request is for action by PICES.

- A 1½-day theme session at the Symposium on "*Effects of climate change on the world's oceans*" to be held in conjunction with Ocean Expo 2012 (May 2012, Yeosu, Korea); it was also requested that funds for invited speakers be included as part of the overall financial contribution to the symposium.

The Working Group may request funds from ICES for a second volume of papers to be published in the *ICES Journal of Marine Science* in September, 2011. This resolution will be resolved during the ICES ASC.

The WG-FCCIFS meeting closed with a warm thank you to the Local Host Organizations – Fisheries Research Agency of Japan (FRA) and Tohoku National Fisheries Research Institute (TNFRI) FRA, and the individuals – Drs. Yukimasa Ishida, Manpei Shuzuki, Hiroyasu Adachi, Katsumi Yokouchi, and Shin-ichi Ito for putting on a wonderful Symposium. The venue was excellent, the city of Sendai was beautiful, the support for the scientific program was wonderful, and the social events were very enjoyable. WG-FCCIFS also thanked the Symposium convenors for putting together an excellent scientific program: Drs. Anne Hollowed (Alaska Fisheries Science Center, NMFS/NOAA, USA), Manuel Barange (Plymouth Marine Laboratory, United Kingdom), Shin-ichi Ito (Tohoku National Fisheries Research Institute, FRA, Japan), Suam Kim (Pukyong National University, Republic of Korea), Harald Loeng (Institute of Marine Research, Norway).

List of participants

Name	**Affiliation**
Jürgen Alheit	Leibniz Institute for Baltic Sea Research, Germany
Alexander Bychkov	PICES Secretariat
Michael Foreman	Fisheries and Oceans Canada, Institute of Ocean Sciences, Canada
Stewart Frusher	University of Tasmania, Australia
Jonathan Hare	Narragansett Laboratory, National Marine Fisheries Service, NOAA, USA
Anne Hollowed	Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, USA
Jason Holt	Proudman Oceanographic Laboratory, United Kingdom
Shin-ichi Ito	Tohoku National Fisheries Research Institute, FRA, Japan
Sukyung Kang	National Fisheries Research and Development Institute, Korea
Adolf Kellerman	Science Programme, ICES, Denmark
Suam Kim	Pukyong National University, Korea
Skip McKinnell	PICES Secretariat, Canada
Franz Mueter	University of Alaska Fairbanks, USA
Thomas Okey	Ecosystem Sciences, Westcoast Aquatic and University of Victoria, Canada
Myron Peck	Center for Marine and Climate Research, University of Hamburg, Germany
Graham Pilling	Centre for Environment, Fisheries and Aquaculture Science, United Kingdom
Jake Rice	Fisheries and Oceans Canada, Ecosystem Science Directorate, Canada
John Stein	Northwest Fisheries Science Center, National Marine Fisheries Service, NOAA, USA
Motomitsu Takahashi	Seikai National Fisheries Research Institute, Japan
Yury Zuenko	Pacific Research Institute of Fisheries and Oceanography (TINRO-Center), Russia

2010 WG-FCCIFS meeting, ICES ASC, Nantes, France

The WG-FCCIFS met on September 23, 2010 in Nantes, France, to review their Terms of Reference. Drs. Skip McKinnell (PICES Deputy Executive Secretary), Sinjae Yoo (PICES Science Board Chairman) and Luis Valdés (Head, Section for Ocean Science, IOC) also attended. The following issues were considered.

- Status of Working Group report:
  The Symposium on "*Climate change effects on fish and fisheries*" summary report was delivered to ICES in September 2010.
- Status of Symposium volume in the *ICES Journal of Marine Science*:
  The group discussed category 2 requests for additional pages if necessary.
- Discussion of synthesis paper for *Nature Climate*:
  The group agreed that this synthesis would be an excellent activity. Dr. Anne Hollowed will coordinate the synthesis with help of other symposium convenors and session co-chairs.
- Inter-sessional activities:
  - WG-FCCIFS proposes a workshop in conjunction with the ESSAS Open Science Meeting in May 2011, in Seattle, USA, to be convened by Drs. Harald Loeng (ICES/Norway) and Anne Hollowed (PICES/USA).
  - WG-FCCIFS proposes an ICES/PICES Workshop on "*Reaction of Northern Hemisphere ecosystems to the climate events in the late 1980s: A comparison*" to be convened by Dr. Jürgen Alheit (Germany), Christian Möllmann (Germany) and suggested PICES scientists on May 2–6, 2011 in Hamburg, Germany;
  - WG-FCCIFS requests PICES to co-sponsor an ICES Symposium on "*Forage fish interactions and ecosystem approach to fisheries management*" to be held from September 10–14, 2012 in Nantes, France.
- Theme session proposals for ICES 2011 ASC:
  - ICES/PICES Theme Session on "*Atmospheric forcing of the Northern Hemisphere ocean gyres, and the subsequent impact on the adjacent marine climate and ecosystems*" to be convened by Dr. Emanuele Di Lorenzo (PICES/USA) Ichiro Yasuda (PICES/Japan) Hjálmar Hátún (ICES/Faroe Islands) and Jürgen Alheit (ICES/Germany).
- Status of the WG-FCCIFS proposal for a 1½-day theme session at the Symposium on "*Effects of climate change on the world's oceans*" in conjunction with Ocean Expo 2012 (May 2012, Yeosu, Korea).
- A proposal for an International Research Program for the South Pacific that will be discussed at the upcoming Conference on the Environment and Resources in the South Pacific.
- Opportunities for coordination with other ICES expert groups, strategic initiatives and other groups.
- Discussion of opportunities to enhance WG-FCCIFS contributions to IPCC AR5 reports.
- Proposals for a global effort to compare the performance of model forecasts of the effects of climate on fish and fisheries. WG-FCCIFS members recognize the need to develop a strategic plan for international fishery forecasts under climate change.

Several WG-FCCIFS members attended the first PICES/ICES strategic planning meeting to develop a framework for scientific cooperation in Northern Hemisphere marine science on September 21, 2010, in Nantes, France. The group discussed operational guidelines needed to allow smooth coordination between ICES and PICES. The current operations of WG-FCCIFS adhere to most of the timelines for approval by ICES and PICES. The one area where additional discussion is needed is the timeline for proposals for theme/topic sessions at upcoming annual science conferences/meetings of ICES and PICES. Since ICES precedes the PICES meeting, the joint sessions would be approved by ICES before PICES has a chance to discuss the proposal.

Future directions for WG-FCCIFS

In recognition of the long-term research interest in climate change impacts on marine ecosystems, ICES plans to develop further a Strategic Science Initiative on Climate Change (SSICC). During the WG-FCCIFS meetings at the ICES ASCs and PICES Annual Meetings, participants discussed the possibility of merging WG-FCCIFS activities with the initial plans for a SSICC. This would require consideration and approval by PICES and ICES. Working Group members will work with ICES SSICC members and others to develop a document to be tabled at the end of April 2011 (at the PICES inter-sessional Science Board meeting) and early May (at the ICES SCICOM meeting), with a plan of action describing the objectives, approaches and activities to be conducted under an ICES/PICES SSICC (*e.g.*, theme sessions, workshops, working groups, symposia). This document may already have indications of funding needs, which both organizations will have to discuss at their meetings in the fall of 2011. The document may also indicate additional partners (not necessarily sponsors), to ensure the activity plays its full leadership role in setting the climate change research agenda in the marine environment. The Working Group agreed to work on the SSICC document and to support the merging of WG-FCCIFS with the ICES SSICC to create a more permanent long-term research effort.

2010 WG-FCCIFS meeting, PICES-2010, Portland, USA

WG-FCCIFS met on October 24, 2010, in Portland, USA, to review their Terms of Reference. The group discussed the topics (summarized in the report above from the ICES ASC in Nantes, France). Dr. Ian Perry presented a request for PICES to support an international Workshop on "*Climate and oceanic fisheries, and development of climate tools for fisheries*" which will be held by the Cook Islands Meterological Service, Rarotonga, Cook Islands, on October 3–5, 2011. WG-FCCIFS supported the idea of PICES involvement and supported the proposal. Working Group members also discussed opportunities for coordination with other ICES expert groups, strategic initiatives and other groups (see also the report above from the ICES ASC).

The Co-Chairmen of WG-FCCIFS, Drs. Anne Hollowed (PICES/USA), Suam Kim (PICES/Korea) and Harald Loeng (ICES/Norway) also attended the FUTURE Advisory Panel meetings of AICE (Anthropogenic Influences on Coastal Ecosystems), COVE (Climate, Ocean Variability and Ecosystems) and SOFE (Status, Outlooks, Forecasts and Engagement) to any answer questions regarding the activities of the Working Group.

The Working Group will have their next meeting in May 2011 in conjunction with the ESSAS Open Science Meeting in Seattle, USA.

Deliverables

- Publish the results of the PICES/ICES/FAO Symposium on "*Climate change effects on fish and fisheries*" held April 26–29, 2010, in Sendai, Japan, in the July 2011 issue of the *ICES Journal of Marine Science*. Some Working Group members will serve as guest editors for this publication.
- Symposium co-chairs and interested Working Group members will develop a synthesis paper that will describe the issues and challenges facing the scientific community as they embark on an effort to assess climate change effects on fish and fisheries.
- WG-FCCIFS proposes to convene a 1-day workshop on "*Biological consequences of decrease in sea ice in Arctic and Sub-Arctic Seas*" in conjunction with the ESSAS Open Science Meeting in May 2011, in Seattle, USA. ICES has already agreed to sponsor it, therefore, PICES endorsement is requested.
- WG-FCCIFS proposes to convene an ICES/PICES Workshop on "*Reaction of Northern Hemisphere ecosystems to the climate events in the late 1980s: A comparison*" to be convened by Dr. Jürgen Alheit (Germany), Christian Möllmann (Germany) and suggested PICES scientists on May 2–6, 2011 in Hamburg, Germany. ICES has already agreed to sponsor it, therefore, PICES endorsement is requested.
- WG-FCCIFS requests that PICES co-sponsor an ICES inter-sessional meeting on "*Forage fish interactions and ecosystem approach to fisheries management*", to be held in Nantes, France, from September 10–14, 2012. ICES has already agreed to sponsor it, therefore, this request is for action by PICES only.
- Working Group members will convene a 1½-day theme session at the Symposium on "*Effects of climate change on the world's oceans*" in conjunction with Ocean Expo 2012 (May 2012, Yeosu, Korea). ICES has already agreed to sponsor it, therefore, this request is for action by PICES only. WG-FCCIFS also requests that ICES and PICES clarify that funds for invited speakers be included as part of the overall financial contribution to the symposium.
- WG-FCCIFS will report to ICES (*via* SSGHIE) by September 1, 2011.

Funding requests

- WG-FCCIFS may request funds from ICES for additional papers to be published in the *ICES Journal of Marine Science* in September, 2011.
- Travel support for 2 PICES scientists to attend an ICES/PICES Theme Session on "*Atmospheric forcing of the Northern Hemisphere ocean gyres, and the subsequent impact on the adjacent marine climate and ecosystems*" at ICES ASC (in September 2011, Gdańsk, Poland).
- Travel support for 2 PICES scientists to attend inter-sessional workshops.
- WG-FCCIFS may request an endorsement by ICES and PICES of the addition of 1–2 new Working Group members who would represent an emerging new South Pacific marine science organization.

List of participants

Members

Jürgen Alheit (ICES, Germany)
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Anne Hollowed (PICES, USA)
Suam Kim (PICES, Korea)
Jacquelynne King (PICES, Canada)
Harald Loeng (PICES, Norway)
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Observers

Teresa A'Mar (USA)
Robin Brown (USA)
Jonathan Hare (USA)
Jin-Yeong Kim (Korea)
Vladimir Kulik (Russia)
Phillip Mundy (USA)
Thomas Okey (Canada)
Ian Perry (Canada)
John Stein (USA)
Mikhail Stepanenko (Russia)
Motomitsu Takahashi (Japan)
Sinjae Yoo (PICES Science Board Chairman)

2011 Inter-sessional WG-FCCIFS meeting, Seattle, USA

WG-FCCIFS met in Seattle, Washington, USA, on May 22, 2011, after the ICES/PICES Workshop on "*Biological consequences of decreases in sea ice in Arctic and Sub-Arctic seas*" (see Appendix 3) to plan future topic/theme sessions for the ICES ASC and PICES Annual Meeting, and to discuss the Science Plan for the ICES/PICES Strategic Initiative on Climate Change Effects on Marine Ecosystems (SICCME) and tasking for development of the SICCME Implementation Plan (see Appendix 4).

List of participants

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2011 WG-FCCIFS meetings, ICES ASC, Gdańsk, Poland, and PICES-2011, Khabarovsk, Russia

WG-FCCIFS held its meetings during the ICES Annual Science Conference in Gdańsk, Poland (on September 19) and the PICES Annual Meeting in Khabarovsk, Russia (on October 14). The SICCME Science Plan and Implementation plans were presented to leadership within both organizations and both organizations approved the formation of a Strategic Initiative/Section on Climate Change Effects on Marine Ecosystems (SICCME). The group used the time to plan for future theme and topic sessions to be held in conjunction with the 2nd Symposium on "*Climate change effects on the world's oceans*" in Yeosu, Korea, in May 2012, and for the next ICES Annual Science Conference and PICES Annual Meeting.

Appendix 3

Session/workshop summaries related to WG-FCCIFS activities

ICES Annual Science Conference
September 21–25, 2009
Berlin, Germany

ICES/PICES Theme Session E
Climate impacts on marine fish: Discovering centennial patterns and disentangling current processes

Convenors: Myron A. Peck (Germany), Brian MacKenzie (Denmark), Skip McKinnell (PICES) and Corinna Schrum (Norway)

Climate change will impact fisheries resources and challenge both fishers and managers to develop sustainable exploitation strategies and disentangling the effects of climate variability from those due to fishing pressure is problematic. Unfortunately, the bulk of information on the impacts of climate variability on fish populations is often merely descriptive and stems from the last century (from periods of intense exploitation).

The goal of the session was to provide a venue for the presentation and discussion of both long-term (historical) and current (process-based) research on the impacts of climate variability and change on marine fish species. A second goal was to foster the links that have been established between PICES and ICES in terms of research targeting climate impacts on marine fisheries. The session attracted the largest number of submissions at this year's ICES ASC. In total 28 oral presentations and five posters were delivered. Presentations covered a wide range of topics that, for convenience in this session report, could be separated into different categories (Fig. A3.1). Presentations focused on: 1) examining correlations between the vital rates of single species and environmental variability, 2) evaluating the impacts of climate variability and change on multiple populations/community analyses, 3) constructing and analyzing long-term/historical data sets, and 4) process studies utilizing biophysical modeling and other methods. Naturally, most presentations could be included within multiple categories (categories were not mutually exclusive).

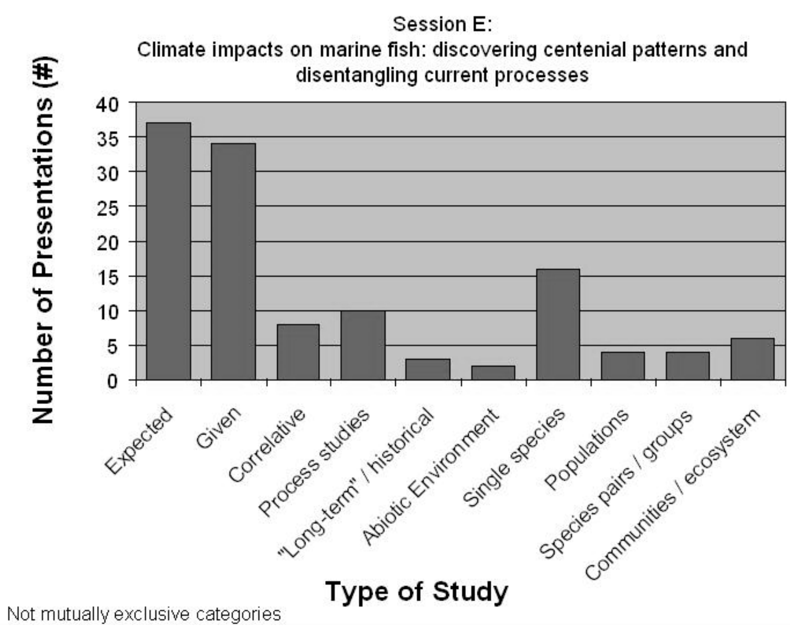

Fig. A3.1 Overview of presentations (oral and poster) within session E including various study categories. Note, most studies can appear in more than one category.

1) Single species/stocks

The most common theme of presentations centered on correlative studies of various time series data emphasizing a single population and/or stock and its variation due to environmental factors. One presentation (E:27) attempted to test the hypothesis that cohort survival and year class success of striped bass (*Morone saxatilis)* were associated with periods of strong river discharge due to changes in the dynamics of an estuarine turbidity maximum zone (TMZ) in the upper Chesapeake Bay estuary. This and other correlative studies speculated on the causal mechanisms and processes underlying trends in time series data including changes in vital rates (rates of survival, growth, reproduction) and/or distribution. Time series data were often statistically evaluated with respect to various environmental factors and/or climate indices such as the Gulf Stream index (GSI), the North Atlantic Oscillation (NAO), the Atlantic Multi-decadal Oscillation (AMO) or the Siberian High. These included studies on redfish (*Sebastes mentella*) in the Irminger Sea (E:15), haddock (*Melanogrammus aeglefinnus*) on the Scotian Shelf (E:31), Pacific cod (*Gadus macrocephalus*) in the Yellow Sea (E:28), two studies on European sardine (*Sardina pilchardus*) on the Iberian Atlantic coast (E:20 and E:30) and saithe (*Pollachius virens*) in the Faroe Islands (E:23). Some of these studies included relatively long time series data, including work on spawning stock biomass of Northeast Artic cod (*Gadus morhua*) (1946–2002) (E:05, see Fig. A3.2), the condition of saithe (1962–2007) and Pacific cod (1969–2006), size-at-age of haddock (1970–2008) and egg production rates by Baltic cod (1957–1996) presented in E:06. One poster presentation examined the response of yellowtail (*Seriola quinqueradiata*) in Japanese waters to sea water temperature over the last century (E:34). Most studies evaluated stocks using data collected after 1970, concentrating on time series that included years associated with a regime shift (*e.g.*, late 1980s in the North Sea).

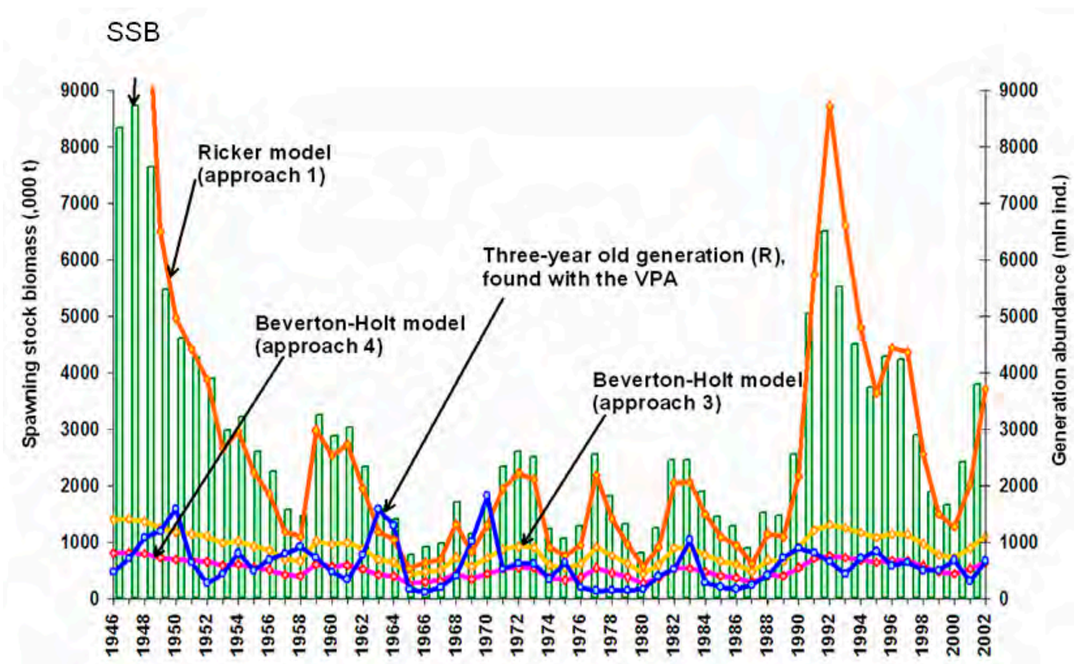

Fig. A3.2 Example of single species time series data presented in Session E: Spawning stock biomass of Northeast Arctic cod. Environmental factors were included (*e.g.*, four-year mean weighted temperature anamolies at the Kola section) and the stock separated into three productivity regimes to help generate robust recruitment predictions (for details, see Kotenev *et al*., 2009).

Trends in some time series of abiotic factors were related to the ecophysiology of specific life stages (*e.g.*, eggs and larvae of Pacific and Baltic cod; E:28 and E:04, respectively). A particularly interesting example of this was a presentation calculating the impacts of increased hypoxia (low dissolved oxygen concentrations) on various life stages of Baltic cod including: egg survival (6% decrease per decade), larval vertical migration

(–5%/decade), juvenile settlement (area decreases of 900 km^2 per decade), feeding of adults based upon gastric evacuation rate (decrease about 5% per decade) and adult age-dependent egg survival probability (larger/older females produce larger more buoyant eggs). The latter calculation indicated an increase in the female age from 4 to 8 years based on the probability for 50% egg survival. Utilizing ecophysiology to understand climate impacts was a theme discussed within two posters (E:37 and E:38).

2) Multiple populations/community analyses

A few studies evaluated climate-driven changes in demographic features of different populations or vital rates of conspecifics inhabiting different ecosystems. This included work on various spawning stocks of Atlantic herring (*Clupea harengus*) (E:17) as well as Atlantic cod (*Gadus morhua*) larvae on Georges Bank, around Iceland, in Lofoten and the North Sea (E:03). A third example evaluated environmental impacts impacting juvenile salmon emerging from 60 different Norwegian rivers (E:27) identifying common trends and river-specific patterns due to differences in land-use/anthropogenic activities. In the Baltic Sea, spatial differences in the rate of change in water temperature (depth-specific) were assessed with regard to potential impacts on key fish species based upon ecophysiological thresholds (tolerances to abiotic factors) of early life stages of sprat (*Sprattus sprattus*) and Baltic cod. Other presentations examined the impacts of climate variability (5 to 20 years) on changes in species-pairs such as potentially competing flatfish species in the North Sea (E:02) and the community composition of fishes within various systems. The community-level analyses included work in the Barents Sea (E:21) and North Sea (E:11) with an emphasis on demersal fishes and their habitat characteristics (including potential prey species).

One presentation reconstructed the fisheries landings in the North Sea since the 1890s (see Fig. A3.3) and asked the question: Can one describe time series in changes in fish stocks using only catch data – or does one also need to include climate as an explanatory variable? This modeling effort with ECOSIM had 46 functional groups, including seabirds, seals, sharks, cephalopods with time series built from a variety of sources. Five fishing gears were used in the model (seal hunting, trawlers, drifters, *etc*. The presentation provided a clear example of process-oriented research attempting to disentangle the effects of exploitation (fishing) and climate.

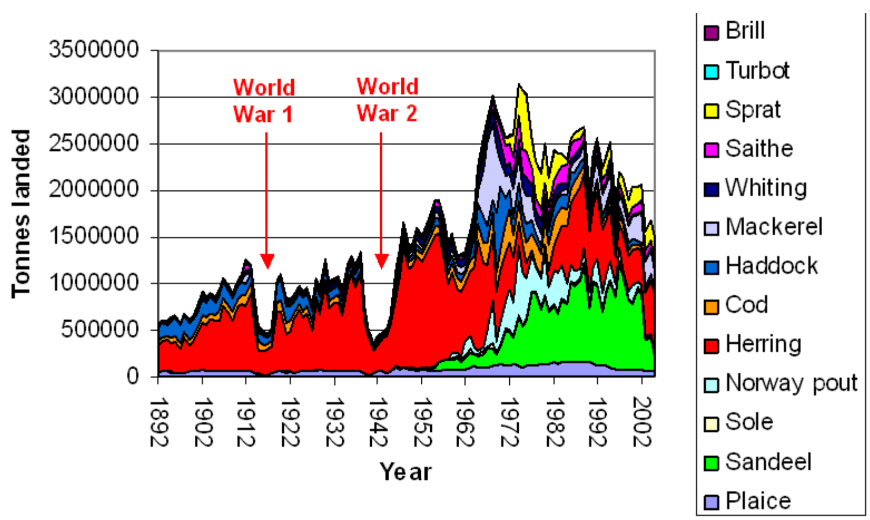

Fig. A3.3 Time series of landings for various fish species in the North Sea (Pinnegar *et al*., E:24). This analysis was part of a modelling exercise (ECOSIM) attempting to disentangle the impacts of fishing and climate on the North Sea fish assemblage.

A world-wide view of climate impacts on fisheries was provided by Sherman *et al*. (E:01) who summarized data series on fisheries catches in 64 large marine ecosystems that, together, account for > 80% of fisheries production. Based upon analyses of temperature time series from 1982 to 2006, these systems were classified as having either slow (n = 23), moderate (20), fast (12) or "super fast" (6) warming (Fig. A3.4). The share of world-wide fish production within large marine ecosystems has declined in the last 25 years.

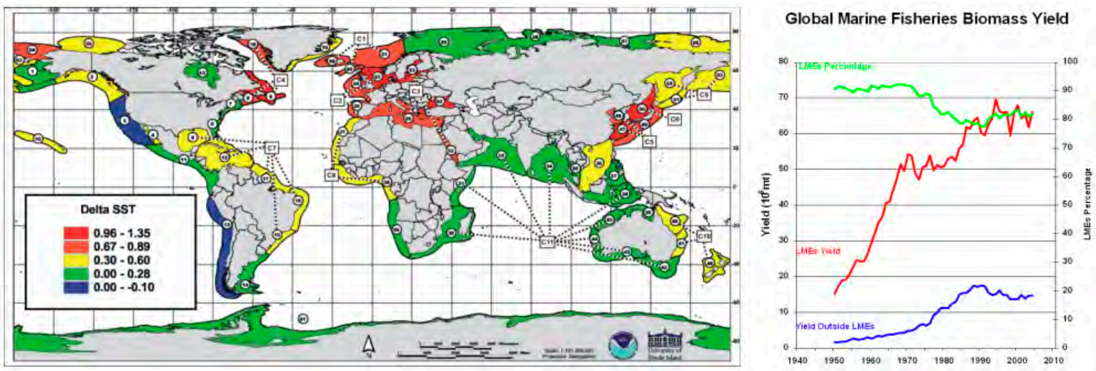

Fig. A3.4 Map of 64 large marine ecosystems (LMEs) with color code indicating relatively slow (blue) to rapid (red) trends in warming from 1982 to 2006. The right panel indicates fisheries yields within and outside of LMEs *versus* time since the 1950s. The share of world-wide catches coming from LMEs is indicated (green line) (from Sherman *et al*., 2009).

3) Long-term historical studies

The longest time series (1520s to 1960s) was provided by Caballero-Alfonso *et al*. (E:10) describing changes in bluefin tuna (*Thunnus thynnus*) caught using almadrabas traps, a traditional fishing method that has been employed since ~900 BC (Fig. A3.5). Catches in various regions were analyzed with respect to a number of environmental factors including precipitation, solar irradiance, SST, air temperature, sunspot number, volcanic dust and the concentration of green house gasses. Almost all climatic patterns were significantly correlated with catches, but green house gasses were the most important single factor along with temperature.

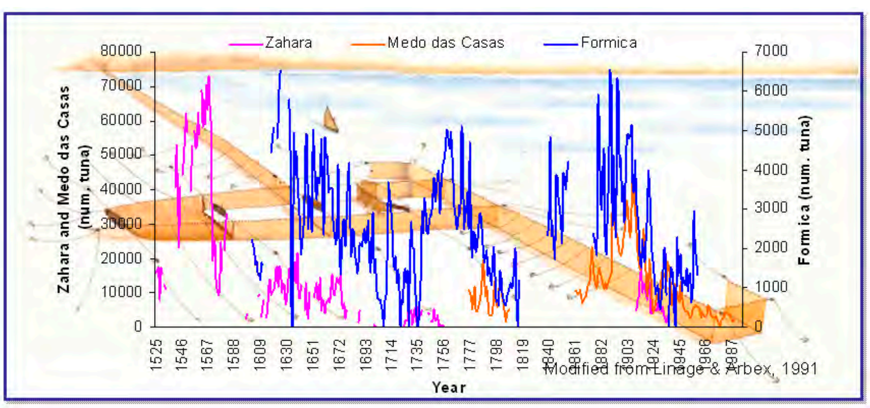

Fig. A3.5 Catches of bluefin tuna from almadrabas traps from thee sites in the western Mediterranean (from Caballero-Alfonso *et al*., 2009).

A second presentation (E:12) reconstructed rates of fishing mortality and environmental stressors (*e.g.*, jellyfish outbreaks) impacting Atlantic herring within Danish (Limfjord) waters during the 1800s. The message from that presentation was that overfishing makes ecosystems more vulnerable to trophic reorganization which can result in fish populations that are more vulnerable to future collapses. A third presentation (E:01), presenting North Sea time series data from the 1890s onwards was discussed in a previous section.

4) Biophysical processes

Key processes impacting early life stages of marine fish were examined within a number of presentations. Both match-mismatch (prey field dynamics) and transport (member-vagrant) dynamics were examined. For example, transport mechanisms were also the main theme in a presentation summarizing trends in transport (*via* upwelling filaments) and changes in the larval clupeids assemblage in the Canary Islands (E:16). A second presentation employed hydrodynamic modeling to explore seasonal and inter-annual transport dynamics of European anchovy (*Engraulis encrasicolus*) in the Bay of Biscay (E:08). The latter study explored climate-driven changes in transport patterns by statistically interpreting drift routes via dispersion kernel analyses.

The impacts of climate-driven changes in prey fields (*e.g*., match-mismatch dynamics) were assessed using coupled 3-D Biophysical modeling of early life stages of Atlantic cod, European anchovy and Atlantic herring in European waters. Climate-driven changes in key abiotic/physical factors such as wind fields, solar irradiance and associated hydrographic impacts (current fields and water temperatures) were examined using scenario modeling. In one study, a mechanistic (physiologically-based), individual-based model that included foraging and growth subroutines was employed to calculate historical (1970 to 2005) changes in prey requirements of larval herring in the North Sea and the potential for climate-driven "bottom-up" regulation of survival during the larval overwintering period (E:09). In a second example, climate-driven changes in prey fields were included in simulations by coupling an NPZD (nutrient phytoplankton, zooplankton and detritus) model and generating prey fields for an individual-based model constructed for larval Atlantic cod (E:18). The NPZD-IBM was used to generate maps of potential larval survival (Fig. A3.6). A main message from that presentation was that a number of environmental factors can interact to influence model estimates of survival and that caution must be taken when only analyzing temperature impacts.

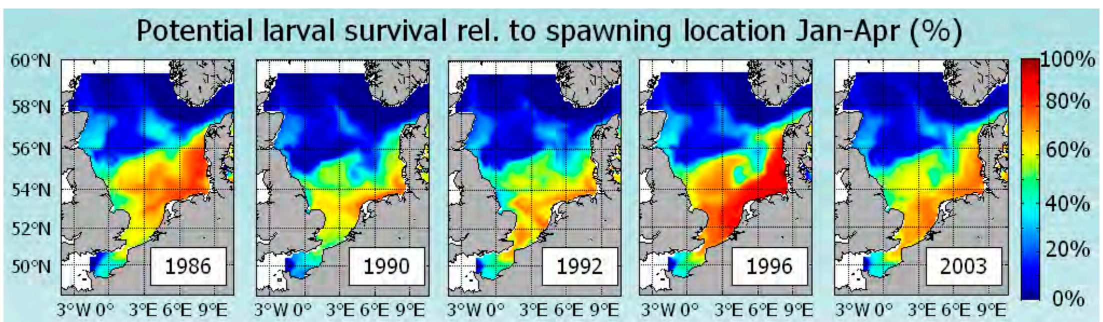

Fig. A3.6 IBM-based estimates of potential survival of Atlantic cod larvae in different years in the North Sea. Among these years, 1996 was the coldest (negative NAO) year (from Daewel *et al*., E:18).

The impacts of spatiotemporal variability in environmental factors on early life stages were also examined using a dynamic energy budget (DEB) approach which identified areas based upon unsuitable combinations of temperature and food to support energy allocation into reproduction by adult anchovy in the Bay of Biscay (E:22). Finally, North Sea and Bay of Biscay hydrodynamic model outputs were analyzed with respect to their spatiotemporal variance attributes using empirical orthogonal function (EOF) analysis and correspondence of those hydrodynamic factors to one another and in time using multi-factorial analysis (MFA). The variance of key factors was then discussed in relation to the timing of key life history events of fish species inhabiting both shelf sea areas.

Finally, a presentation by Curchitser (E:26) described ongoing efforts to construct end-to-end models to explore climate impacts in the North Pacific Ocean. That modeling effort includes: 1) multi-scale ocean and atmospheric physics, 2) community-based lower trophic level biology and 3) spatially-explicit, full life cycle, individual-based higher trophic level biology including a fishing fleet. A multi-species fish model can simulate 5–6 species using an individual-based approach, species can compete for food resources and eat each other. One species can represent a fishing fleet. The model will explicitly model growth, mortality, reproduction and movement. The presentation also highlighted issues concerning downscaling from global climate models to regional hydrodynamic impacts. The presentation highlighted future advances that will be necessary (*e.g.*, incorporation of deterministic and probabilistic elements) and the need for observations to be made at the same "big picture" scale as is being used in complex model development.

5) Final discussion

The session ended with a half hour discussion period. To stimulate discussion, the conveners posed four questions to the audience:

1. Have we learned all we can from time series and correlation analyses?
2. How much process understanding is "enough"?
   a. When do you know you have "enough" knowledge for a question of interest?
   b. Has uncertainty been adequately addressed?
3. Are climate impact studies on single-species level sufficient for Ecosystem-Based Management?
4. What messages do we wish ICES to put out to the "scientific community" in its "White Paper" on climate change impacts on marine ecosystems?

Given that it was the last session on the last day, the audience became vigorously engaged in the discussion, although not always on the questions posed. Main comments from the discussion included:

- Time series and correlative analyses are an essential first step in the development of process understanding. The importance of long-term data sets (and the need to continue their collection) was stressed. Continued data mining and compilation of long-term data sets are essential activities and more value may be obtained from them by subjecting multiple time series data sets to meta-analysis using, for example, the traffic light approach. Time series are essential for assessing model results.
- There is a need to understand the effects of ocean acidification on fish, in addition to the calcareous organisms. A convener noted that the lack of presentations on ocean acidification in the session may be because ocean acidification is a CO_2 pollution problem, not a climate change problem.
- Communication of ICES results within peer-reviewed, high impact literature may be a more rapid route to engaging the public and should be utilized along with the publication of an ICES cooperative research report focusing on climate impacts.
- The vast majority of studies discuss negative impacts of climate change. However, some benefits can also be expected (in particular areas and/or for specific species) and these should not be overlooked.
- An upcoming symposium in Sendai (April 2010) sponsored by ICES, PICES and FAO was advertised as a venue for research on climate impacts on fish and fisheries. Associated workshops to that conference will address ocean acidification, policy, and other topics.
- The need for better laboratory data on physiological tolerances of various life stages of fish species was indicated including basic data on interaction effects (*e.g.*, dissolved oxygen and temperature vs. growth and survival of larval fish).
- Community-level analyses often reveal important responses to environmental variability/climate trends that single-species analyses do not.

<u>List of papers</u>

Oral presentations

Kenneth Sherman, Igor Belkin, Kevin D. Friedland, Jay O'Reilly, and Kimberly Hyde
Accelerated warming and emergent trends in fisheries biomass yields of the world's large marine ecosystems

R. Van Hal, F. Stuke, I. Tulp, and A. D. Rijnsdorp
Climate induced changes in the growth rate of flatfish species in the North Sea by means of food competition

T. Kristiansen, K. Drinkwater, and J. Zavala-Garay
Analyzing warm and cold climate phases to understand differences in survival and connectivity of larval cod: possible implications for climate change

Rudi Voss, Christoph Petereit, and Hans-Harald Hinrichsen
The spatial dimension of climate-driven temperature change in the Baltic Sea

B. N. Kotenev, V. P. Serebryakov, M. V. Bondarenko, and A. D. Morozov
Climatic impact on Northeast Arctic cod year-class strength: relevance of the Ricker and Beverton-Holt models for determination "recruitment-stock" dependence

Hinrichsen, Huwer, Makarchouk, Neuenfeldt, Petereit, Schaber, and Voss
Climate driven long-term evolution of oxygen concentration in the Baltic Sea: potential consequences for the Baltic cod stock

E. M. Karasiova, G. Kraus, and R. Voss
Long-term fluctuations of Baltic cod egg production in relation to major inflow events

Martin Huret, Pierre Petitgas, and Fabien Léger
Sensitivity of anchovy larval dispersal to climate variability in the Bay of Biscay

Marc Hufnagl, Myron A. Peck, Mark Dickey-Collas, Richard D. M. Nash, and Thomas Pohlmann
Climate-driven changes in the recruitment of North Sea herring: Bottom-up control on the survival of early life stages identified using a biophysical individual-based model

Ángela M. Caballero-Alfonso, A. Trujillo-Santana, U. Ganzedo-López, A. Santana del Pino, and J. J. Castro-Hernández
Do climate patterns explain by themselves the oscillations observed for the Bluefin tuna (*Thunnus thynnus*) at the Western Mediterranea 'almadrabas' traps catches since 1500s to 1960s?

A. F. Sell, A.F., S. Ehrich, V. Stelzenmüller, and G. Wegner
Regional effects of climate change on North Sea bottom fish assemblages

Brian R. MacKenzie and Bo Poulsen
Fishing and jellyfish eradicate fish 180 years ago

Jaime Otero, Arne J. Jensen, Jan Henning L'Abée-Lund, Nils Chr. Stenseth, Geir O. Storvik, and Leif Asbjørn Vøllestad
Factors affecting year-to-year and within river variability of one-sea winter Atlantic salmon in Norwegian rivers

S. P. Melnikov, A. L. Karsakov, V. I. Popov, V. L.Tretyak, and I. S. Tretyakov
The impact of variations in oceanographic conditions on distribution, aggregation structure and fishery pattern of redfish (*Sebastes mentella* Travin) in the pelagial of the Irminger Sea and adjacent waters

Marta Moyano, Jose María Rodríguez, and Santiago Hernández-León
Clupeoid fish in the Canaries-African coastal transition zone: transport dynamics and links to climate

Thomas Brunel and Mark Dickey-Collas
Can we estimate the effects of temperature change on herring growth? A macroecological analysis of temperature and density-dependence on North Atlantic herring growth

Ute Daewel, Corinna Schrum, and Myron Peck
Impact of environmental change on North Sea Atlantic cod (*Gadus morhua*): Scenario modeling in the North Sea

Mark R. Payne, Hjálmar Hátún, Asbjørn Christensen, and Jan Arge Jacobsen
Recruitment in a changing environment: the role of oceanographic processes in blue whiting population dynamics

G. J. Pierce, M. B. Santos, J. M. Cabanas, I. Riveiro, and C. Porteiro
Are there climatic signals in fishery data for sardine (*Sardina pilchardus*) along the Iberian Atlantic coast?

M. Fossheim, E. Johannesen, R. Primicerio, and M. Aschan
Spatial variation and structural change of the Barents Sea fish community

Caroline Struski, Pierre Petitgas, and Martin Huret
Long-term hindcast and climate change forecast of habitat suitability using a bioenergetics model: anchovy in the Bay of Biscay and the North Sea

Eydna í Homrum, Petur Steingrund, Lise H. Ofstad, and Hjálmar Hátún
Is the growth of Faroe Saithe density dependent or climate dependent?

John K. Pinnegar, Steven Mackinson, and Georg H. Engelhard
Back to the Future: 115 years of climate and fisheries in the North Sea

Pierre Petitgas, Martin Huret, Fabien Léger, Myron Peck, and Adriaan Rijnsdorp
Summarising with Multiple Factor Analysis (MFA) the seasonal and inter-annual variability in the long-term hindcasts of lower trophic ecosystem models: applications in the North Sea and Bay of Biscay

Enrique Curchitser, Kenneth Rose, Kate Hedstrom, Jerome Fiechter, Shin-ichi Ito, Salvador Lluch-Cota, and Bernard Megrey
Development of a climate-to-fish-to-fishers model: progress, issues, and some solutions

Ginger L. Jahn and Elizabeth W. North
Do striped bass (*Morone saxatilis*) spawn in response to high river flow events?

H. Kim, H. J. Hwang, D. H. Kim, M. H. Sohn, J. B. Kim, K. H. Choi, and I. Yeon
Effect of Siberian High on the catch fluctuation of pacific cod, *Gadus macrocephalus*, in the Yellow Sea

Sean P. Powers, F. Joel Fodrie, Nicole Shaffer, Matthew W. Johnson, and Robert L. Shipp
Changes in growth rates of reef fish in the Gulf of Mexico: Evidence for climate change or overharvesting?

M. F. Borges
Fish production regime shifts in the West Iberia upwelling system and their relation to climate patterns: a review

Anna B. Neuheimer and Christopher T. Taggart
Climate and fishing: Disentangling factors affecting growth in Scotian shelf haddock (*Melanogrammus aeglefinus*)

Posters

A. V. Dolgov, O. V. Smirnov, K. V. Drevetnyak, and O. Yu. Chetyrkina
New data on composition and structure of the Kara Sea ichthyofauna

Vladimir Laptikhovsky and Alexander Arkhipkin
Environmental changes caused recent increase in abundance of rock cod, *Patagonotothen ramsayi* in the Southwest Atlantic

Yongjun Tian, Hideo Sakaji, Ken Watanabe, and Masahiro Kuno
Response of yellowtail *Seriola quinqueradiata* in the Japanese waters to sea water temperature over the last century and potential effect of global warming

Harald Loeng and Øystein Skagseth
The rise and fall of the blue whiting stock

D. L. Lajus, Ya.I. Alekseeva, Z. V. Dmitrieva, A. V. Kraikovsky, and J. A. Lajus
Climate effect on populations of Atlantic salmon *Salmo salar* in the Barents and White Sea basins (17–20th cc.)

Maja Walter, Muriel-Marie Kroll, and Myron A. Peck
Larval fish growth physiology and climate impacts: species-specific differences in thermal tolerance

Myron A. Peck, Mark R. Payne, Ute Daewel, Marc Hufnagl, Irina Alekseeva, and Corinna Schrum
Climate-driven changes in suitable habitats for North Sea fish: Physiological constraints on the survival of early life stages

PICES Eighteenth Annual Meeting (PICES-2009)
October 23–November 1, 2009
Jeju, Korea

POC/FUTURE Topic Session (S9)
Outlooks and forecasts of marine ecosystems from an earth system science perspective: Challenges and opportunities

Co-sponsored by IMBER

Co-Convenors: Harold P. Batchelder (USA), Michael Foreman (Canada), Anne B. Hollowed (USA) and Hiroaki Saito (Japan)

Background

The prediction of responses of marine ecosystems to future climate scenarios is an important objective of PICES' new science program, FUTURE (**F**orecasting and **U**nderstanding **T**rends, **U**ncertainty and **R**esponses of North Pacific Marine **E**cosystems). However, the marine ecosystem is part of the earth system and its prediction needs integrated knowledge from physical, chemical, and biological perspectives. Earth system science is an interdisciplinary approach that integrates anthropology, atmospheric science, biology, oceanography, geophysics and policy to provide predictions of ecosystem response to climate change. The earth system is complex with non-linear feedbacks, threshold responses, and, in some cases, irreversible change. Understanding the mechanisms controlling these system properties is critical to accurately forecasting future states of nature in a changing climate. Moreover, conducting large-scale experiments on the earth system is impossible. Therefore, regional marine ecosystem models should include the earth system science links that are essential for producing better predictions of marine ecosystem response to future climate scenarios. This session focused on multidisciplinary coupled models and theoretical, observational and experimental studies designed to provide outlooks and/or forecasts of marine ecosystems. Outlooks and forecasts differ in that outlooks are qualitative with (often) unbounded uncertainties, while forecasts are often quantitative, but must have bounded certainties. Presentations that focus on both long-term and short-term predictions, and that link two or more disciplines (such as physical oceanography, climate, ecosystem dynamics, marine resource management, or socio-economic systems), were welcome, especially presentations that explore what additional information or data are needed to provide outlooks andforecasts, and especially to transition from providing outlooks to providing forecasts.

Summary of presentations

The session consisted of 17 oral presentations distributed over two days from scientists in 5 countries. This was the first session at a PICES Annual Meeting that was formally considered a FUTURE topic session. The intent of the session was to focus on multi-disciplinary models and observational studies designed to provide outlooks and forecasts—two types of forward-looking predictions. Topics varied from relatively small-scale investigations of coastal lagoons to global-scale data synthesis, and included socioeconomic impacts of climate change and other anthropogenic forcing at local (Chesapeake Bay) to global scales. Four presentations were invited (Okunishi, Murtugudde, Barange, Dalton).

Several presentations described the results of coupled biophysical models. In an invited talk, Takeshi Okunishi described the results of simulation models of small pelagic fish in the western North Pacific and found that the agreement between observations and models was best when predation by skipjack tuna was included in the dynamics of the small pelagics. Fei Chai and colleagues were able to link physical, lower trophic level ecosystem and IBM models of anchovy off Peru to provide 9-month forecasts arising from NCEP-predicted atmospheric conditions that had some skill at capturing larger-scale responses of anchovy to large forcing (El Niño, La Niña). Enrique Curchitser described some progress and challenges encountered in expanding lower trophic level biophysical modeling frameworks to not only fish, but fishing fleet behaviors. Keiji Kiyomatsu described the use of OFES ocean hindcasts of SST and velocities to estimate transport, growth and survival of Japanese sardine into the Kuroshio extension region.

Several presentations discussed reanalysis or new analyses of historical data sets. Yury Zuenko examined climate and ocean conditions in relation to productivity and transfer of production to higher trophic levels in the Japan/East Sea. V.S. Labay documented the evolution of benthic species in small Sakhalin coastal lagoons, and found bio-invasions from the sea. When lagoon openings became seasonal or restricted, this led to changed benthos structure, and to a prevalence of species having warmer affinities.

Masahiko Fujii and colleagues used projected temperatures from the MIROC IPCC climate scenario (global warming) model of the 21st century to examine temperature related bleaching of coral reef systems near Japan. Though the northward extent of coral habitat was projected to extend northward by about 200 km, bleaching events were forecast to occur nearly every year during the decade beginning 2060 compared to no events in the decade beginning in 2000.

Hiroaki Saito reported on the importance of composition and ballasting of particles for the vertical export of organic matter from the euphotic zone. Compositional changes can strongly influence the sinking rate and rate of remineralization, complicating simple vertical export models.

In an invited talk, Raghu Murtugudde described an end-to-end Earth system model of the Chesapeake Bay (East Coast of USA) system. The model is used to provide nowcasts and forecasts at daily to decadal time scales. Oxygen conditions, harmful algal blooms and sea nettle blooms are skillfully predicted at short time scales (few days) and with quantified levels of uncertainty. In another invited talk, Manuel Barange described the QUEST-Fish project which is using global climate models to estimate primary production through trophic relationships and assumptions of fish production. The model framework also considers other anthropogenic stressors, including economic policies and variable geographic and temporal exploitation. The focus is on shelf-sea systems, and on the consequences of the stressors on market based fish commodities.

Anne Hollowed described a framework for downscaling Bering Sea climate indices applied to the walleye pollock and flatfish, with designs for constructing a management strategy evaluation (MSE) for some key species. Akihiko Yatsu described the results of a CCCC-CFAME Task Team exploration of the possible climate and global warming effects from IPCC scenarios on several key species (chum salmon, walleye pollock, sardine, anchovy, saury, squid) in the Kuroshio-Oyashio region. Information on the species biology (lifespan, prey types) and expected changes from IPCC scenarios were used to construct outlooks for several of these species.

In an invited talk, Michael Dalton described a population-environment-technology (PET) model applied to 9 regions worldwide. PET is multisector, multiregional and includes five production sectors and four types of consumer goods (energy, food, transport, other). The value of such models is that by being based on market information, it allows the model to span spatial scales.

Harold (Hal) Batchelder described approaches to, and results of, quantitative skill assessments of earlier and later implementations of ROMS physical models to the California Current and northern Gulf of Alaska regions. The results showed sensitivity of the stratification to the controlling influence (temperature in the south; salinity in the north) in the earlier model, and greater robustness/fidelity of the later model to observed temperature and salinity. Highly skillful physical models are useful as the basis for ecosystem models; models lacking physical skill should not be the basis for coupled ecosystem models. Jie Shi used a Princeton Ocean Model and coupled ecosystem and kelp models to examine the production of kelp and its control by nutrient fluxes from outer Sungo Bay, China. The model suggests that reduced kelp density at the mouth of the bay would increase yield significantly in the whole bay, since greater nutrient fluxes would be supplied to the inner region.

The recently released version of the World Ocean Atlas 2009 and World Ocean Database 2009 were described by Hernan Garcia. WOA-2009 and WOD-2009 are the largest quality controlled collections of ocean profile data available online. Steve Bograd documented strong correlations between retrospective analysis of climate records, growth chronologies of rockfish and seabird egg laying and fledging data. Good years for rockfish and seabirds were associated with strong high pressure systems, strong upwelling and cooler SSTs. Correlations of the biological metrics were seasonally highest with winter (JFM) conditions, indicating the importance of wintertime ocean conditions for ecosystem productivity.

Overall, this rather diverse collection of talks was well attended, and presented a number of different approaches that might be used for creating outlooks and forecasts within the Advisory Panel on *Status, Outlooks, Forecasts and Engagement* (SOFE-AP). It was an auspicious beginning to FUTURE topic sessions.

List of papers

Oral presentations

Takeshi Okunishi, Shin-ichi Ito, Atsushi Kawabata, Hiroshi Kubota, Taketo Hashioka, Hiroshi Sumata and Yasuhiro Yamanaka (Invited)
A multi-trophic level ecosystem model for understanding mechanisms of small pelagic fish species alternation

Fei Chai, Francisco Chavez, Yi Chao, Lei Shi, Hongchun Zhang and Richard Barber
Using remote sensing and modeling in operational forecasting of fisheries

Keiji Kiyomatsu, Takuji Waseda and Yasumasa Miyazawa
Reconstruction of high-resolution historical February SST in the northwestern Pacific and its application to larval dispersion

Yury I. Zuenko
How trends, shifts, and interdecadal fluctuations in climate reconstruct the ecosystem of the Japan/East Sea

Raghu Murtugudde (Invited)
Marine ecosystem forecasting with an Earth System Prediction model

V.S. Labay
Evolution of a benthos of coastal lagoons of Sakhalin Island: Causes and consequences

Yumiko Yara, Masahiko Fujii, Yasuhiro Yamanaka, Naosuke Okada, Hiroya Yamano and Kazuhiro Oshima
Projected effects of global warming on coral reefs in seas close to Japan

Hiroaki Saito
Modeling of organic matter dynamics in the mesopelagic zone: A perspective on modeling and ecosystem studies

Enrique N. Curchitser, Kenneth A. Rose, Kate Hedstrom, Jerome Fiechter, Shin-ichi Ito, Salvador Lluch-Cota and Bernard A. Megrey
Development of a climate-to-fish-to-fishers model: Progress, issues, and some solutions

Manuel Barange, Icarus Allen, Eddie Allison, Marie-Caroline Badjeck, Julia Blanchard, James Harle, Robert Holmes, Jason Holt, Simon Jennings, Gorka Merino, Christian Mullon and Emma Tompkins (Invited)
Predicting the impacts and socio-economic consequences of climate change on global marine ecosystems and fisheries: The QUEST_Fish framework

Anne B. Hollowed, Nicholas A. Bond, James E. Overland and Thomas Wilderbuer
Future conditions in the Bering Sea: Applications to walleye pollock and flatfish

Akihiko Yatsu, Sanae Chiba, Yasuhiro Yamanaka, Shin-ichi Ito, Yugo Shimizu, Masahide Kaeriyama and Yoshiro Watanabe
Future of Kuroshio/Oyashio ecosystems: An outcome of the CFAME Task Team and WG20

Michael Dalton (Invited)
Climate change and marine ecosystems: Demographic and economic implications under IPCC scenarios

Harold P. Batchelder, Enrique N. Curchitser and Kate Hedstrom
Modeling physical processes in the Northeast Pacific: model-data comparisons for assessing when model skill is sufficient as a basis for ecosystem simulation

Jie Shi, Hao Wei and Liang Zhao
Numerical study of the aquaculture carrying capacity in a typical raft culture bay of China

Hernan Garcia, Sydney Levitus, Tim Boyer, Ricardo Locarnini, John Antonov, Daphne Johnson, Olga Baranova, Alexey Mishonov, Dan Seidov, Igor Smolyar, Melisa Zweng and Evgeney Yarosh
The World Ocean Database and Atlas 2009

Steven J. Bograd, Bryan A. Black, William J. Sydeman, Isaac Schroeder and Peter Lawson
Wintertime ocean conditions synchronize rockfish growth and seabird reproduction in the California Current

Posters

Licheng Feng, Baochao Liu, Yi Cai, Zhanggui Wang, Jiping Chao and Jianping Li
Numerical simulation of the Changjiang estuary ecosystem

ICES Annual Science Conference
September 20–24, 2010
Nantes, France

ICES/PICES Theme Session S
Responses to climate variability: Comparison of Northern Hemisphere marine ecosystems

Convenors: Jürgen Alheit (ICES/Germany), Harald Loeng (ICESNorway), Anne Hollowed, (PICES/USA), and Suam Kim (PICES/Korea)

The climate of northern regions is changing and marine ecosystems are heavily affected by climate variability. Relevant questions related to external forcing functions that link global and regional climate processes to the physical oceanography are *inter alia*:

- How does the climate vary and what changes do we see in the physical conditions?
- How does variability of the physical aspects of the marine systems affect ecosystem structure and processes?
- How can we integrate across spatial and temporal scales to permit forecasting how changes in climate may affect the productivity and sustainability of the marine ecosystems?

Climate impact studies have been made within single ecosystems or between different systems of the same region. However, comparisons between ecosystems of different regions or even of different ocean basins are rare. Such comparisons are vital in order to better understand responses of ecosystems to climate forcing, particularly with a view to large-scale climate forcing and teleconnection patterns.

The number of participants at the joint ICES/PICES Theme Session changed between 70 to 120, reflecting the large interest in the theme. The total number of oral presentations was 18. Two 15-minute periods of extra discussion were included in the session to allow for comparing results from different papers. Ten presentations focussed on the Atlantic, 5 on the Pacific and 3 were direct comparisons of both oceans. The success of this theme session demonstrates the value of this kind of joint ICES/PICES initiatives.

Atlantic

The previously reported seesaw relationship of air and sea temperatures between the Labrador Sea and the Norwegian/Barents Sea regions from the 1950s to the mid-1990s was confirmed by Drinkwater *et al*. (S:03). However, temperatures on both sides of the Atlantic are now in phase since the mid-1990s, due to a spatial shift of atmospheric pressure patterns and a weakening of the NAO, clearly indicated by strong warming and reduced ice cover in both regions with concomitant ecosystem consequences.

Getzlaff *et al*. (S:01) studied the impact of the four winter climate regimes in SLP over the North Atlantic, which had been identified by Hurrell and Deser (2009) from cluster analysis, on the Baltic Sea for the period from 1948–2008. The different atmospheric regimes determine the circulation patterns in the Baltic Sea through their impacts on direction and strength of prevailing winds and thus influence ecosystem structure and processes.

Sherman *et al*. (S:15) showed that reactions of Large Marine Ecosystems bordering the North Atlantic rim were different between the eastern and western side. The higher warming rates in the NE Atlantic seem to influence particularly higher trophic levels, whereas nutrient over enrichment in relation to harmful algal blooms and hypoxic conditions are more important in the NW Atlantic.

Johannesen *et al*. (S:10) compared the impact of climate variation and fishing on the Eastern Scotian shelf and the Barents Sea with a particular view to cod stock dynamics. In the early 1990s, climatically induced warm water penetration has led to a strong increase of the cod stock in the Barents Sea, whereas demersal fish collapsed through high fishing pressure and cold water in the Eastern Scotian shelf, leading to a trophic cascade favouring forage fish and affecting lower trophic levels. The Gulf of Maine experienced a pronounced shift in salinity, primary and secondary production which led to significant changes in herring and tuna condition (Golet *et al*., S:20).

Alheit and Wagner (S:12) showed that the Atlantic Multidecadal Oscillation (AMO) has driven multidecadal dynamics of many NE Atlantic small pelagic fish populations of herring, sardine and anchovy since at least early last century through lasting warm and cold periods, as demonstrated by examples from Moroccan waters in the south to Norwegian waters in the North.

After about 40 years of absence, anchovies and sardines have re-invaded the North Sea and adjacent waters such as the Irish and Baltic seas and established there again spawning populations (Alheit *et al*., S:14). Whereas sardine arrived in larger quantities around 1990, very likely in response to warmer winter temperatures associated with the pronounced increase of the NAO index, anchovy followed only in the mid-1990s. Anchovy was probably driven into the North Sea because of warmer summer temperatures due to the sudden increase of the AMO or the northeast shift of the NAO pressure centers or the contraction of the North Atlantic sub-polar gyre or a combination of them.

Based on a long-term time series which was started at 1919, Johannessen (S:19) showed that gadoid fish suffered repeated abrupt and persistent recruitment collapses which seem to have been caused by gradually increasing nutrient loads. These resulted in abrupt changes in the plankton community with negative consequences for 0-group gadoids. Global warming might increase these abrupt changes and enhance recruitment collapse.

Otero *et al*. (S:13) demonstrated that contemporary ocean warming and freshwater conditions contribute to delay the completion of maturation of Atlantic salmon, among possible reasons being changed composition of marine zooplankton communities and increased precipitation and number of springtime flooding events.

Pacific

According to Bulatov and Klyashthorin (S:02), long-term trends in climate indices such as PDO, ALPI, NPI, Arctic temperature anomalies and Total Solar Irradiance exhibited synchronous dynamics over the last 100 years with 60–65 years cycles and with peaks in the decades of the 1940s and 2000s and a low around the 1960s/1970s. Over the last 30 years, walleye pollock biomass has shown very similar dynamics. Based on these relationships, walleye pollock biomass is projected to decline up to 2020–30.

The adjacent eastern Bering Sea (EBS) and the Gulf of Alska (GoA) ecosystems are inhabited by similar species communities and affected by similar anthropogenic and large scale forcing. Hunsicker *et al*. (S:06) evaluated, how environmental and demographic factors influence the variability in spatial overlap of arrow tooth flounder and pollock, for a better understanding of their predation interactions.

Hollowed *et al*. (S:20) compared the impact of climate driven shifts in ocean conditions on forage fish (young walleye pollock and capelin) in the GoA and the EBS. Hydrography and bathymetry are important for the distribution of these forage fish and frontal systems and predator avoidance plays a major role.

Interannual variability in Northern California Current food web structure was studied by Ruzicka *et al*. (S:08) using different models, whereby the relative importance of alternate energy pathways at intermediate trophic levels (small pelagic fish, euphausiids, jellyfish) for the efficiency of the system and the productivity of the top trophic groups was particularly considered. Euphausiids seem to more important in the energy transfer to top trophic level production than small pelgic fishes.

Tian and Kidokoro (S:05) showed that there was no regime shift in the Tsushima Warm Current region in the Japan Sea in the mid-1970s, as reported for the central and eastern North Pacific. Instead, abrupt changes were observed in the early 1970s with cold-water fish species such as sardines and walleye pollock increasing and warmwater species such as anchovy and horse mackerel decreasing.

Comparison Atlantic – Pacific

Bi *et al*. (S:07) compared the influence of climate variability by AMO and PDO on zooplankton communities from the east and the west coast of the USA and demonstrated that the decadal-scale PDO affected west coast communities, but the multi-decadal AMO did not cause consistent responses in east coast zooplankton over the period of observation from 1978–2008.

Durant *et al*. (S:09) studied the ecological consequences of fisheries effects on population properties, such as intrinsic growth rate, in relation to fishing intensity and climate, using data from Barents Sea cod, European hake (three stocks) and Bering Sea pollock. The different stocks exhibited different reactions, whereby three stocks showed evidence of a truncated age structure, which was caused by fishing pressure, influencing population persistence.

<u>List of papers</u>

Oral presentations

Andreas Lehmann, K. Getzlaff, H.-H. Hinrichsen, and F. Köster
CAVIAR: Climate Variabilityof the Baltic Sea area

O.A. Bulatov and L.B. Klyashtorin
Walleye pollock biomass dynamics in the Bering Sea: possibility of long-term forecasting

Ken Drinkwater, Eugene Colbourne, Harald Loeng, Svein Sundby, and Trond Kristiansen
Comparison of the atmospheric forcing and oceanographic responses between the Labrador Sea and the Norwegian and Barents Seas

Bernard A. Megrey, Jason S. Link, Thomas J. Miller, Tim Essington, R. Ian Perry, Alida Bundy, and Ken F. Drinkwater
Using production models as a tool to examine factors that influence productivity of marine systems: A comparative analysis among 10 northern hemisphere ecosystems

Yongjun Tian and Hideaki Kidokoro
Long-term variability in the fish populations in the Japan Sea with special reference to the impact of the mid–1970s regime shift

Mary E. Hunsicker, Lorenzo Ciannelli, Kevin M. Bailey, and Stephani Zador
Processes driving differences in major food web linkages of the Gulf of Alaska and eastern Bering Sea ecosystems: a conceptual view

Hongsheng Bi, Bill Peterson, Cheryl Morgan, Jon Hare, and Joseph Kane
Comparative analysis of zooplankton communities in the east and west coast of United States–biological response to large scale driving forcing?

James J. Ruzicka, Robert L. Emmett, Jeannette E. Zamon, Cheryl A. Morgan, Andrew C. Thomas, John H. Steele, and Richard D. Brodeur
Inter-annual variability in the Northern California Current food web structure: inferred changes in energy flow pathways and system response to alternate forcing scenarios

Joël M. Durant, Manuel Hidalgo, and Lorenzo Ciannelli
How does exploitation of prey fish affect population growth rate in changing seas?

Edda Johannesen, Mette Skern-Mauritzen, Randi Ingvaldsen, Jan Erik Stiansen, and Emma Orlova
Eastern Scotian Shelf and Barents Sea intercomparison: climate fluctuations, human impact and system resilience

Carola Wagner Rita Adrian, Jürgen Alheit, Thorsten Blenckner, Stephanie E. Hampton, Franz, Hölker, Douglas J. Beare, and Daniel E. Schindler
Regime shifts in marine and lake ecosystems: Teleconnection patterns

Jürgen Alheit and Carola Wagner
Impact of Atlantic Multidecadal Oscillation (AMO) on NE Atlantic ecosystems

Jaime Otero, Arne J. Jensen, Jan Henning L'Abée-Lund, Nils Chr. Stenseth, Geir O. Storvik, and Leif Asbjørn Vøllestad
Contemporary ocean warming and freshwater conditions contribute to delay the completion of maturation in Atlantic salmon throughout the Norwegian range of distribution

Jürgen Alheit, C. Wagner, T. Pohlmann, M. Casini, A. Sell, and R. Vorberg
Climate variability drives anchovies and sardines into North and Baltic Seas

Kenneth Sherman, I. Belkin, K.D. Friedland, J. O'Reilly, and K. Hyde
Changing states of North Atlantic Large Marine Ecosystems

Michaël Gras, Olivier Goetz, Jehane Lepoittevin, and Jean-Paul Robin
English Channel cuttlefish (*Sepia officinalis*) stock structure in the reproduction period

Walter J. Golet, Jason Stockwell, Graham Sherwood, Andrew Pershing, Jeffrey Runge, and Molly Lutcavage
Bottoms up: Potential effects of environmental forcing on apex predators in the Gulf of Maine

Tore Johannessen
Repeated observations of abrupt and persistent recruitment collapses in gadoids – a potential scenario in relation to climate change?

Anne B. Hollowed, S. Barbeaux, N. Cokelet, S. Kotwicki, P. Ressler, and C. Wilson
Comparison of the effects of climate variations on pelagic ocean habitats and their potential role in structuring the forage fish distributions in the Bering Sea and Gulf of Alaska

Posters

F. Litvinov, N. Timoshenko, and Pavel Chernyshkov
Oscillations of abundance in North Atlantic fishes in 1977–2010 compared to synchronous changes of commercially important species in other parts of the World Ocean due to global climatic variability

Sangdeok Chung and Suam Kim
Relationship between climate/environmental factors and Pacific cod (*Gadus macrocephalus*) catch in the southwestern Japan/East Sea

Ana Moreira, Paulo Fonseca, Cristina Silva, Miguel Santos, Aida Campos, and Maria de Fátima Borges
Are there evidences of environmental-driven fluctuations in landings from the Portuguese trawl crustacean fishery?

Silje Ramsvatn, Torstein Pedersen, and Einar M. Nilssen
Comparing trophic structure and diversity in northern ecosystems using stable isotope data

Dhanya Pushpadas, Ute Daewel, Corinna Schrum, and Sturla Winger Svendsen
Comparing long term changes in primary and secondary production in the North and Baltic Sea: A modelling study

Jaime Otero Arne J. Jensen, Jan Henning L'Abée-Lund, Nils Chr. Stenseth, Geir O. Storvik, and Leif, Asbjørn Vøllestad
Environmental effects on ocean entry of Atlantic salmon (*Salmo salar*) smolt across its range of distribution

Anke Weber
Monitoring and Evaluation of Spatially Managed Areas (MESMA)

2010 PICES Annual Meeting
October 22–31, 2010
Portland, USA

FIS/POC/BIO Topic Session (S8)
Impact of climate variability on marine ecosystems:
Understanding functional responses to facilitate forecasting

Co-sponsored by: *ICES*

Co-Convenors: *Jürgen Alheit (ICES/Germany), Suam Kim (PICES/Korea), Harald Loeng (ICES/Norway), James Overland (PICES/USA) and Yasunori Sakurai (Japan)*

Background

Understanding the role of natural variability, occurring over a variety of temporal and spatial scales, is essential for effective management of marine ecosystems in the wake of predicted global change. Evidence suggests that climate variability can trigger regime shifts in marine ecosystems. Regime shifts are characterized by a reorganization of marine communities, species dominance, and tropho-dynamic relationships. Often, synchronous shifts occur in aquatic ecosystems that are separated by thousands of kilometers. This finding suggests that atmospheric teleconnections are mediating regional system changes. We postulate that comparative studies of ecosystems that have experienced regime shifts will provide insights into the expected responses of marine organisms to climate change. Papers were invited that went beyond simple pattern matching. The primary focus was on understanding shifts in the pelagic realm, including phytoplankton, zooplankton, small pelagic fishes, gadids, and squids, with preference given to research that provides evidence of the functional responses and relationships that underlie regime shifts, and to statistical or modeling studies that successfully simulate observed shifts.

Summary of presentations

This session was held on Tuesday, October 26, 2010 and consisted of 20 oral presentations (including 4 invited talks) plus 15 posters. The session was jointly organized by PICES and ICES, as a part of 2010 WG-FCCIFS activities. The first invited paper, by Hans O. Pörtner, described that the whole organism responses to warming or cooling link to ecosystem response, and that climate warming emphasizes the need for a common understanding of thermal limitation by physiologists and ecologists nowadays. He introduced the concept of oxygen and capacity limited thermal tolerance (OCLT) in relation to climate change. His recent works showed that a mismatch in oxygen supply *versus* demand causes a limitation in aerobic scope and finally transition to anaerobic metabolism, paralleled by the development of molecular stress events. In fact, functional characters in polar species may reflect adaptation to excess oxygen availability rather than limitation.

The second invited paper by Kazuaki Tadokoro showed geographical comparison of the decadal-scale variations in marine ecosystems in the North Pacific Ocean. A decreasing trend in nutrients was observed in the surface layer of the Gulf of Alaska, Oyashio waters, Kuroshio-Oyashio Transition waters, Kuroshio, western subtropical waters, and East China Sea, and Chl-*a* concentration and zooplankton biomass also represented a significant decreasing trend in the waters, which suggest that global warming decreases the productivity of the lower ecosystems simultaneously among the regions.

The third invited speaker, Shin-ichi Ito, talked about multi-trophic level ecosystem modeling for understanding the mechanism of small pelagic fish species alternation associated with climate regime shifts. Various modelings and statistical techniques were used for coupling physical, biochemical-plankton (NEMURO: North Pacific Ecosystem Model for Understanding Regional Oceanography) and Japanese sardine (*Sardinops melanostictus*). His model reasonably reproduced weight decrease of sardine during the higher stock period.

Moreover, the model reproduced expansion of the habitat area and decrease of prey plankton during the period. The fourth invited paper by Franz J. Mueter showed long-term forecasts of walleye pollock dynamics in the eastern Bering Sea based on estimated responses of recruitment and growth to climate variability. Recent advances in our understanding of the role of climate variability in regulating lower trophic levels in the eastern Bering Sea support a dome-shaped relationship between the recruitment of walleye pollock and surface temperatures during late summer. He also speculated that future recruitment may not be reduced as much as the temperature relationship alone would suggest because of (1) reduced cannibalism on larval and early juvenile stages and (2) larger size-at-age of older juveniles and adults, which is likely to increase reproductive output.

The remaining talks covered a wide range of topics and geographical regions. Most oral presentations showed regional examples on ecosystem responses in relation to climate variability, and geographical coverage was well balanced: 4 from the Atlantic Ocean, and 15 from the Pacific Ocean (6 focused on the eastern Pacific, 6 on the western Pacific, and 3 on the Bering Sea). In the Poster Session, one presentation co-authored by C.J. Jang and S. Yoo, which received the Best Poster award for a POC-sponsored topic session (see list at the end of the Session Summaries report), demonstrated variability of mixed layer depth (MLD) and its relation with chlorophyll (CHL) concentration in the North Pacific Ocean on seasonal to year-to-year timescales. The variability of MLD is well correlated with CHL variability in some regions in the North Pacific Ocean, including the Kuroshio Extension (KE) region. The good correspondence between MLD and CHL suggests that increased MLD helps to entrain deep nutrients into the upper ocean and thus to maintain high CHL in the KE.

The Best Poster award was shared between Sarah Ann Thompson for "*Comparing pathways of functional response of top predators to seasonality of upwelling in the California Current*", and Chan Joo Jang for "*Variability of mixed layer depth and its relation with chlorophyll concentration in the North Pacific Ocean*".

List of papers

Oral presentations

Hans O. Pörtner (Invited)
Oxygen and capacity limited thermal tolerance (OCLT): Linking climate to ecosystem change

Julie E. Keister, Emanuele Di Lorenzo, Sanae Chiba, Vincent Combes, Cheryl A. Morgan and William T. Peterson
Climate-related changes in ocean transport control zooplankton biogeography around the North Pacific basin

Yury Zuenko, Ludmila Chernoivanova, Alexander Vdovin and Elena I. Ustinova
Saffron cod fluctuations in the Japan Sea: An evidence of match/mismatch hypothesis

William R. Crawford and James R. Irvine
Climate variability and ecosystem response in Pacific Canadian coastal waters

Kazuaki Tadokoro, Yuji Okazaki, Tsuneo Ono and Hiroya Sugisaki (Invited)
Geographical comparison of the decadal-scale variations in marine ecosystems in the North Pacific Ocean

Ken Drinkwater, Glen Harrison, Erica Head, Padmini Dalpadado, Jim Carscadden and George Lilly
Comparison of the ecosystem responses to climate forcing and fishing between the Labrador Sea and the Norwegian/Barents seas

Jürgen Alheit, Michele Casini, Wulff Greve, Thomas Pohlmann, Anne Sell, Ralf Vorberg and Carola Wagner
Climate variability drives anchovies and sardines into North and Baltic Seas

Joachim P. Gröger, Gordon H. Kruse and Norbert Rohlf
Climate cycles and population dynamics of North Sea herring

Anne B. Hollowed, Steven Barbeaux, Ned Cokelet, Stan Kotwicki, Patrick Ressler and Christopher Wilson
Effects of climate change on pelagic ocean habitats and their potential role in structuring Bering Sea and Gulf of Alaska ecosystems

Shin-ichi Ito, Takeshi Okunishi, Atsushi Kawabata, Hiroshi Kubota, Akinori Takasuka, Taketo Hashioka, Hiroshi Sumata and Yasuhiro Yamanaka (Invited)
Multi-trophic level ecosystem modeling for understanding the mechanism of small pelagic fish species alternation associated with climate regime shifts

Richard D. Brodeur, James J. Ruzicka and John H. Steele
Investigating alternate trophic pathways through gelatinous zooplankton, krill, and planktivorous fishes in an upwelling ecosystem using end-to-end models

William J. Sydeman, Jarrod A. Santora, Sarah Ann Thompson, Kyra L. Mills, John C. Field, Brian K. Wells, Baldo Marinovic and Bryan A. Black
Numerical responses of krill predators to variation in krill abundance and spatial organization

Seokjin Yoon, Hiroya Abe and Michio J. Kishi
Variance estimation of the growth and food sources of the Manila clam by global warming in a subarctic lagoon, Japan

Harald Loeng
Impacts of climate change on the Arctic Ocean and adjacent seas

Franz J. Mueter (Invited)
Long-term forecasts of walleye pollock dynamics in the eastern Bering Sea based on estimated responses of recruitment and growth to climate variability

Oleg Bulatov
Climate fluctuations and walleye pollock biomass dynamics

Bryan A. Black, Isaac D. Schroeder, William J. Sydeman, Steven J. Bograd and Brian K. Wells
Winter and summer upwelling modes and their biological relevance in the California Current Ecosystem

Masahide Kaeriyama, Hideaki Kudo, Hideki Kaeriyama and Katherine W. Myers
Spacio-temporal changes in the feeding pattern of Pacific salmon, *Oncorhynchus* spp., in the North Pacific Ocean ecosystems during 1958–2009

Melissa A. Haltuch and André E. Punt
On the promises and pitfalls of including decadal-scale climate forcing of recruitment in demersal fish stock assessment

Yongjun Tian, Hideaki Kidokoro and Tsuneo Goto
Long-term changes in the condition factor of small pelagic fishes in the Japan Sea and the impact of the late 1980s regime shift

Poster presentations

Vanessa R. von Biela, Christian E. Zimmerman, Thomas E. Helser, Bryan Black and David C. Douglas
Terrestrial and marine correlates to black rockfish (*Sebastes melanops*) growth in the California and Alaska Coastal Currents

Michael A. Litzow, Franz J. Mueter and Dan Urban
Can rising variance predict sudden shifts in populations and ecosystems? A test using Alaskan crustacean data

Elena A. Shtraikhert, Sergey P. Zakharkov and Tatyana N. Gordeychuk
Inter-annual variability of the spring chlorophyll *a* concentration maximum in the Peter-the-Great Bay (Sea of Japan) in 1998-2010

Se-Jong Ju, Chang-Rae Lee and Ah-Ra Ko
Latitudinal variation of lipid contents and compositions in copepods, *Euchaeta* and *Pleuromamma* spp., from the Northwest Pacific Ocean: Its implication in feeding ecology

James J. Ruzicka, Thomas C. Wainwright, Richard D. Brodeur, Jeannette Zamon, Elizabeth Daly, Cheryl A. Morgan and Robert L. Emmett
Interannual variability in the Northern California Current food web structure: Inferring trophic pressures upon juvenile salmon

Suam Kim, Sangwook Yeh, Chung-Il Lee, Sukyung Kang, Hyunwoo Kang, Jin-Hee Yoon, Jung Jin Kim and Sinjae Yoo
Forecasting practice on the common squid (*Todarodes pacificus*) population responding to climate/oceanographic changes

Sarah Ann Thompson, William J. Sydeman, Jarrod A. Santora, Robert M. Suryan, Bryan A. Black, William T. Peterson and John Calambokidis
Comparing pathways of functional response of top predators to seasonality of upwelling in the California Current

Jun Shoji, Syun-ichi Toshito, Ken-ichiro Mizuno and Yasuhiro Kamimura
Possible effects of global warming on fish early life stages: Shift in spawning season and latitudinal distribution can alter growth of juvenile fishes through the changes in daytime length

Chan Joo Jang and Sinjae Yoo
Variability of mixed layer depth and its relation with chlorophyll concentration in the North Pacific Ocean

Ken-ichiro Mizuno, Yasuhiro Kamimura and Jun Shoji
Effect of temperature on growth of black rockfish *Sebastes cheni* juveniles in seagrass and macroalgae beds

Hee Dong Jeong, Sang-Woo Kim, Yong Kyu Choi, Jeong Min Shim and Kee Young Kwon
A striking difference of coastal SST related to climate change in the eastern coast of Korea

Jackie R. King, Vera N. Agostini, Chris J. Harvey, Gordon A. McFarlane, Michael G. Foreman, James E. Overland, Nicholas A. Bond and Kerim Y. Aydin
Climate forcing and the California Current ecosystem

Ann E. Edwards and Shannon Fitzgerald
Predicting resilience to ecosystem change in a far-ranging, pelagic, generalist forager

Oleg N. Katugin, Konstantin A. Karyakin and Alexander A. Nikitin
Contrasting distribution patterns of the common squid (*Todarodes pacificus*) in Peter the Great Bay (Japan/East Sea) in 2008 and 2009

Mikhail A. Zuev and Oleg N. Katugin
Distribution patterns of the gonatid squids (Gonatidae, Oegopsina) in the northern Sea of Okhotsk in 1990-2008

2011 inter-sessional workshop
May 2–6, 2011
Hamburg, Germany

Workshop on "*Reaction of Northern Hemisphere ecosystems to climate events: A comparison*"

Co-Convenors: Jürgen Alheit (ICES/Germany), Christian Möllmann (ICES/Germany), Sukgeun Jung (PICES/Korea) and Yoshiro Watanabe (PICES/Japan)

Regime shifts have been observed, especially during the late 1980s, in several Northern Hemisphere marine ecosystems in the Atlantic and the Pacific such as the Baltic Sea, the North Sea, the Mediterranean Sea, Gulf of Alaska/Northern California Current, the Oyashio-Kuroshio System and the Japan/East Sea which all have important small pelagic resources. A respective multi-authored manuscript has been drafted by an earlier joint ICES/PICES workshop describing the associated climatic teleconnection patterns between these ecosystems which are widely separated from each other. The present workshop will extend this descriptive exercise in a quantitative way. Long-term time series of physical, chemical and biological variables from these regional ecosystems will be compared and analyzed by a team of experts from PICES and ICES countries using multivariate statistics. These studies will yield further insight into how ecosystems change state, as, for example, the rates and magnitudes of change are not the same for the different systems reflecting regional specific differences in the forcing factors. In any one geographical ecosystem the expression of changes resulting from climatic forcing may take on different patterns reflecting the detailed mechanisms and local processes that are influential within the constraints of the larger scale forcing. However, there is growing evidence that although climate forcing appears to be a significant trigger for many regime shifts, those ecosystems subject to high levels of human activity such as fishing pressures appear to be at greater risk to this phenomena).

This workshop conducted a meta-analysis of changes in ecosystem structure and function over several Northern Hemisphere ecosystems in relation to climate and other anthropogenic drivers[3]. The goals of the workshop were to:

a) Assemble multivariate data sets of long-term time series of physical, chemical and biological variables from regional ecosystems;
b) Identify trends and abrupt changes (*i.e.*, regime shifts) in the regional data sets using multivariate statistical and discontinuity analyses;
c) Identify the region-specific importance of climate events relative to anthropogenic forcing factors such as eutrophication and exploitation;
d) Conduct a meta-analysis of ecosystem trends and their potential drivers over all Northern Hemisphere ecosystems.

<u>List of presentations</u>

Christian Möllmann
Introduction to workshop and first results of a North Atlantic Meta-Analysis of ecosystem changes

Rabea Diekmann
Introduction into planned statistical analyses

Joachim Gröger
Detection of regime and other shifts in marine time series – the new shiftogram approach

Jürgen Alheit
Climatic teleconnections NW Pacific – NE Atlantic

[3] See http://www.pices.int/members/working_groups/Disbanded_working_groups/WG-FCCIFS/2011-ICES-PICES-Wsh-Germany-WG25.pdf for a report on the outcome of the workshop. Individual papers were published from the workshop, and presented at PICES-2011.

Yongjun Tian
Data presentation Japan/East Sea, including a brief description of the area

Yury Zuenko
Data presentation Japan/East Sea, including a brief description of the area

Sukgeun Jung
Data presentation Japan/East Sea, including a brief description of the area

Motomitsu Takahashi
Data presentation Kuroshio/Oyashio region, including a brief description of the area

Skip McKinnell
Data presentation, salmon

List of participants

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2011 inter-sessional workshop
May 22, 2011
Seattle, USA

Workshop on "*Biological consequences of a decrease in sea ice in Arctic and Sub-Arctic seas*"

(held in conjunction with the ESSAS Open Science Meeting, Seattle, USA)

Co-Convenors: Anne Hollowed (PICES/USA) and Harald Loeng (ICES/Norway)
Publication: Hollowed *et al.* 2013, *Fisheries Oceanography* 22(5)

Invited Speakers: Trond Kristiansen (Norway) Hyunju Seo (Korea)

This workshop reviewed life history information and habitat associations to assess the risk of immigration and settlement of new biological populations in the Arctic and surrounding shelf seas in response to the retreat of sea ice. Criteria necessary to establish residency of new species in the Arctic Ocean and surrounding areas were developed and compared to expected conditions based on climate scenarios. Ways for cooperation in information sharing between groups charged with managing the Arctic were explored, and the results of the workshop will be reported to both PICES and ICES scientists working on these issues.

List of papers

Trond Kristiansen (Invited)
Analyzing warm and cold climate phases to understand differences in survival of larval fish: Possible implications of climate variability

Hyunju Seo, Hideaki Kudo and Masahide Kaeriyama (Invited)
The effect of global warming and density-dependence on Hokkaido chum salmon from the 1940s to the early-2000s

Nicholas A. Bond, Paul D. Spencer and Anne B. Hollowed
Impacts of climate change on the habitat of Bering Sea arrowtooth flounder

Anne B. Hollowed, Steven Barbeaux, Edward Farley, Edward D. Cokelet, Stan Kotwicki, Patrick Ressler, Cliff Spital and Christopher Wilson
Forecasting climate change impacts on forage fish distributions in the Bering Sea

Michael Klages, Eduard Bauerfeind, Antje Boetius, Melanie Bergmann, Christiane Hasemann, Eva-Maria Nöthig, Ingo Schewe and Thomas Soltwedel
Rapid shifts of the marine ecosystem at HAUSGARTEN deep-sea observatory (Fram Strait; 79°N, 04°E) observed over the past decade

Daria Martynova and Nikolay Usov
A life with and without ice in the White Sea: Who will stay tuned?

2011 inter-sessional workshop
June 6–10, 2011
Woods Hole, USA

Workshop on "*Basin-wide impact of Atlantic Multidecadal Oscillation*"

Co-Convenors: Jürgen Alheit (Germany), Ken Drinkwater (Norway) and Janet Nye (USA)
Publication: Edwards *et al.*, 2013, *PLoS ONE* 8; Alheit *et al.*; *Journal of Marine Systems*, in press

Over the last 20 years, changes in abundance and distribution of plankton and fish populations have been recorded in ecosystems on both sides of the North Atlantic. Similar historical observations were also made from about 1930 to 1960 and around the 1880s. These long-term fluctuations cannot be explained well by dynamics of decadal oscillations such as the NAO. The Atlantic Multidecadal Oscillation (AMO) seems to be associated with these long-term dynamics of plankton and fishes. However, the physical basis of the AMO and how it relates to temperature and currents in the North Atlantic is poorly understood. We expect that the study of impacts of multidecadal climate variability would contribute to understand and predict impacts of climate change on marine ecosystems and fish stocks.

The objective of the workshop was to assemble all relevant information on physical and biological processes related to AMO dynamics and to investigate whether AMO dynamics can be predicted. The results of the workshop will allow us to better understand climate impacts on multi-decadal fluctuations in marine communities.

List of plenary presentations

Janet Nye, Ken Drinkwater, Jürgen Alheit
Overview of ecosystem effects of the AMO and discussion

Mike Alexander
Overview of AMO physical properties and discussion

Hali Kilbourne
A palaeontological perspective on AMO

Mingfang Ting
Anthropogenic and natural forcing of AMO

Sirpa Häkkinen
Physical aspects of AMO

Janet Nye
Relation between AMO and subpolar gyre and with position of the Gulf Stream

Ken Drinkwater
Response to AMO forcing: contrasts between warm and cold periods

Svein Sundby
Ecological response to forcing of different frequencies

Bob Wood, Ed Martino
Impact of AMO on estuarine and coastal ecosystems

Youg-Oh Kwon
Decadal variability and western boundary current systems in the North Pacific and Atlantic

Andrew Kenny, Joachim Gröger
Applications of AMO for fisheries and ecosystem management

Break out group discussions

Dicussion leader: **Mike Alexander**
Mechanistic hypotheses responsible for AMO

Discussion leader: **Jürgen Alheit**
Ecological effects

Discussion leader: **Mingfang Ting**
Anthropogenic vs natural forcing of AMO and its relationship to global climate change

Discussion leaders: **Sirpa Häkkinen, Ken Drinkwater**
Physical aspects

Discussion leader: **Janet Nye**
Relationship of AMO with local oceanographic features

Discussion leader: **Ken Drinkwater**
Contrasts between warm and cold periods

Discussion leader: **Svein Sundby**
Ecological response to forcing of different frequencies

Discussion leaders: **Bob Wood, Ed Martino**
Impact of AMO on estuarine ecosystems and fisheries. Can AMO be useful to nearshore/coastal environments?

Discussion leader: **Young-Oh Kwon**
Decadal variability and westeren boundary currents in N Pacific and Atlantic

Discussion leaders: **Joachim Gröger, Andrew Kenny**
Applications

2011 ICES Annual Science Conference
September 19–23, 2011
Gdańsk, Poland

Theme Session L
Biophysical modelling tools and their potential use in marine spatial management: A strategic dialogue

Convenors: Myron A. Peck (Germany), Pierre Petitgas (France) and Vanessa Stelzenmüller (Germany)

Mapping the location of key habitats and understanding spatial and temporal changes in those habitats are prerequisites for effective management of marine fish and shellfish resources and to promote an ecosystem approach to marine spatial management. Recent advancements in biophysical modelling (from individual-based particle tracking of early life stages of single species to end-to-end ecosystem models) now allow researchers to move beyond mere static representations of key habitats for marine fish and shellfish species (*e.g.*, maps of nursery grounds) and allow dynamic representations that include estimates of the spatial and temporal variability in key habitats. These recent advances in spatial modelling have not yet been utilized by fishery management owing to a number of reasons including the ten- to 100-fold mismatch in spatial scales between model estimates (1 to 10s of kms) and marine management (100s to 1000s kms).

This theme session attempts to bridge the gap between potential spatial modelling outputs and management requirements by providing examples of model-derived estimates of the dynamics of essential habitats (*e.g.*, seasonal and interannual variability in suitability and connectivity) and scenario tests (*e.g.*, projected future changes). Presentations on this research should attempt to identify realistic ways in which model outputs can be utilized by management (including sensitivity analyses of results). Furthermore, the session offers a platform for managers to engage researchers on how best to use these tools in light of the reformed common fishery policy, the marine strategy framework directive (MSFD) or implementation of marine spatial planning. The goal of the session is to open a dialogue between managers and researchers to ascertain how to most effectively utilize advancements in modelled physics and biology within ecosystem-based fishery management.

Summary

The increasing human footprint on marine environments has resulted in complex conflicts between different human activities due to their overlapping requirements for space and their various impacts on coastal and offshore waters world-wide (Halpern *et al*., 2008b). To resolve these conflicts, system-specific management options are required which satisfy current and future needs of multiple sectors and that integrate multiple objectives, including those concerned with marine conservation. Ecosystem-based management (EBM) represents such an integrated and holistic approach and there is consensus that implementing place-based or spatial management such as marine spatial planning (MSP) will facilitate the implementation of EBM (Lackey, 1998). Thus, the spatially-explicit assessment of the risk of spatial management options for ecosystem components is crucial for a sustainable development of marine resources. This, in turn, requires a sound knowledge base on the spatial-temporal dynamics of species distributions, ecosystem functions, and driving processes.

The coupling of biological and physical models in the 1980s has significantly enhanced our understanding of the dynamics of marine species and the ecosystems in which they live (Werner *et al*., 2001). There are a myriad of different biophysical modelling approaches, some of which have now progressed to the point where their estimates can be useful for the spatial management of marine systems. A case in point is 3-d biophysical individual-based models (IBMs). IBMs are increasingly employed to explore population connectivity (Pineda *et al*., 2007) and/or the processes affecting rates of survival and growth of early life stages of marine fishes and invertebrates (Peck and Hufnagl, 2011). A “best practices” guide was recently published for early life stage

IBMs (North *et al*., 2009) and the usefulness of IBMs for marine fisheries management has been reviewed (Hinrichsen *et al*., 2011).

In parallel to the development of IBMs, spatially-explicit food web (Christensen and Walters, 2004; Christiansen *et al*., 2005) and fishing fleet models (*e.g*., Venables *et al*., 2009; van Putten *et al*., 2011) have been coupled (*e.g*., Brand *et al*., 2007; Fulton *et al*., 2010). These more complex "end-to-end" models (*e.g*., Atlantis) specifically include management evaluation frameworks for scenario testing (Fulton *et al*., 2010). There is building consensus that this new generation of integrated modelling will be valuable to marine resources managers and that continued development is needed (Rose *et al*., 2010; Plagányi *et al*., 2011). One appealing aspect of these coupled models is that they integrate across various parts of the ecosystem and have the potential act as a risk assessment tool for different management measures (Fulton, 2011).

Given the recent advances and ongoing developments in biophysical models, this session was proposed to create a dialogue between modellers and managers. Session participants were contacted a few months prior to the ICES ASC and provided with a common set of questions (recommended topics) in the hope of providing a "red thread" through a variety of different modelling approaches. The questions were:

1) What are management's objectives and how can models help obtain those objectives? (*e.g*., in light of current policies in EU, USA or CA) How can spatially-explicit models modify current management objectives in your area?

2) What important information can modelling reveal regarding the spatial and temporal dynamics of your system (*e.g*., seasonal and inter-annual variability in suitability and connectivity, essential habitats, productivity, *etc*.)?

3) How sensitive (reliable) are these spatial model estimates? (Have sensitivity analyses been performed, how much confidence do you have in the estimates?)

4) What types of scenarios have been (or can be) performed that might be helpful to spatial management issues? (*e.g*., projected future changes, closed areas, *etc*.) Also, how can (has) uncertainty be (been) taken into account to evaluate management scenarios?

5) What gaps in knowledge remain and what methodological advances are needed?

The relatively small, focused session was separated into four sub-sessions: 1) predictive habitat mapping, 2) biophysical characterization of key habitats and/or processes, 3) Coupled modelling: from habitats to species life history, and 4) integrative bio-economic modelling and spatial management of systems. Within these subsessions there were 2, 4, 4 and 2, oral presentations, respectively. A time slot at the end of the session was devoted to summary discussion. In the following, we briefly summarize the presentations made in each subsession and highlight key discussion points.

Subsession 1) Predictive habitat mapping

Predictive habitat modelling is being increasingly embraced as an accurate and cost-effective tool to fill gaps in knowledge on spatial patterns and to help reveal environmental drivers causing observed distributions in different marine systems (Pittman *et al*., 2007; Leathwick *et al*., 2008). Thus, spatial habitat mapping provides two sources of information needed for making effective spatial management decisions in marine habitats: where and why.

Two presentations provided good examples of how models have been utilized to describe key characteristics of suitable habitats for target species including the spawning areas of cuttlefish in the English Channel (L:07; Fig. A3.7) and macrophyte habitats supporting two fish species in the Finnish archipelago of the northern Baltic Sea (L:04). Both presentation highlighted how a combination of techniques (*e.g*., examining connectivity between habitats) and variables (positive catches of the target species) could be combined using generalized additive modelling (GAM) and Maximum Entropy Modelling (MaxEnt, see Phillips *et al*., 2006). In the cuttlefish example, utilization of hierarchical (or nested) models provided estimates at the regional (Channel) and local (small bay) scales. In the Baltic example, ensemble-averaged projections (maps) of macrophyte habitats for two fish species using key environmental factors (depth, wave exposure, Secchi's depth). Different, future scenarios of eutrophication (Secchi's depth) were examined using reference levels for eutrophication of the Baltic Sea Action Plan.

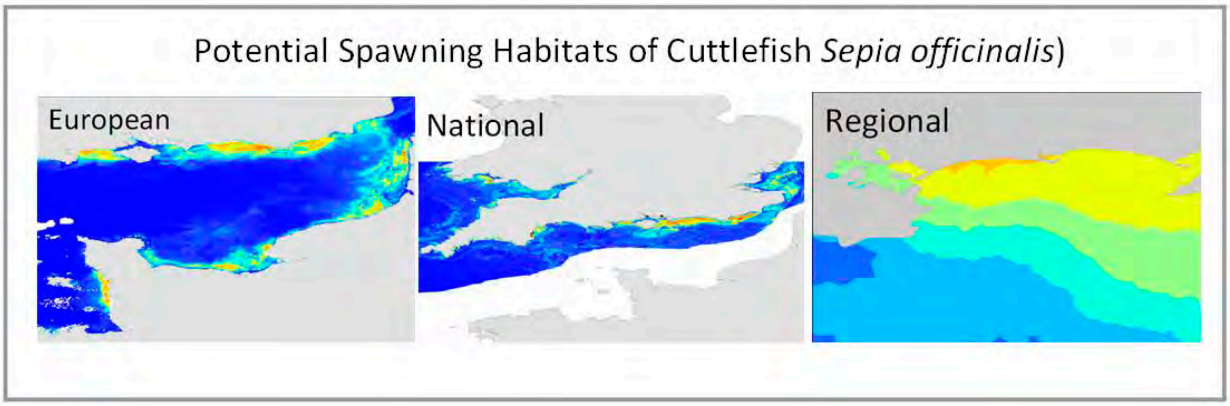


Fig. A3.7 Example of nested (hierarchical) model-based probabilities of spawning habitats (blue = low, red = high) for cuttlefish in the Channel (from Bloor *et al*., L:07).

Subsession 2) Biophysical characterization of key habitats and/or processes

As mentioned in an earlier section, biophysical models have become popular tools to use in examining how characteristics of habitats can affect the distribution, growth and survival of early life stages of marine fishes (North *et al*., 2009). The ability of these models to provide management-relevant information has been reviewed (Hinrichsen *et al*., 2011).

The four presentations in this subsession illustrated how biophysical models have been utilized to explore how key physical features will impact on important processes within and between habitats (such as transport of early life stages and habitat connectivitiy). Three talks examine the effect of wind on physical structures (currents, degree of hypoxia) in a shallow estuary (L:03) and/or probabilities for retention or dispersion routes of the larvae of herring (L:11) and cod (L:02; Fig. A3.8) in spawning and/or nursery habitats in western Baltic Sea. Practical applications of model outputs include the correction of survey estimates of larval fish abundance due to differences in retention and the identification of changes in transport routes and nursery areas due to inter-annual variability in physical forcing (see Figure A3.7). A summary of 145 biophysical, individual-based models constructed for marine fish larvae (L:12) suggested a need for sensitivity analyses of model parameters, highlighted a general lack of biological and physiological data on modelled organisms, and recommended future research that would increase confidence in biophysical IBM estimates of larval losses due to advection, starvation and predation.

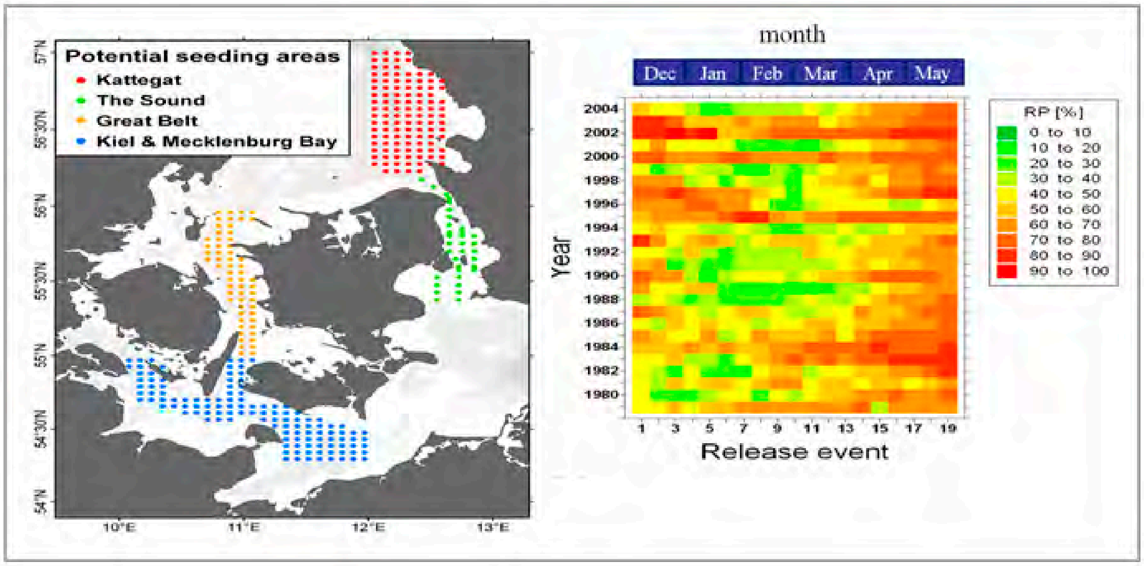


Fig. A3.8 Release areas for cod eggs and yolksac larvae in different regions of the western Baltic (left) and example of modelled estimates of reproductive potential (RP) taking into account the effects of salinity on egg buoyancy (from Hinrichsen *et al.*, 2011).

Subsession 3) Coupled-modelling: from habitats to species life history

Spatially-explicit biogeochemical and lower trophic level models are beginning to supply information relevant for management needs such as the potential impacts of effluents from fish farms (Wild-Allen *et al.*, 2010) and/or the spatial extent of areas of low dissolved oxygen due to eutrophication (Lenhart *et al.*, 2010). Some of these models have been used in concert with fish growth/population models to explore the factors causing changes in the productivity of upper trophic levels in marine systems (Sinena *et al.*, 2008; Fennel, 2010).

The four talks in the session provided different examples of how model-derived estimates of hydrodynamics and lower trophic level productivity (phyto- and zooplankton) can be useful to spatial management either when used alone (L:10) or when linked to upper trophic level (fish) models (L:05, L:06, L:09). For example, hind-, now- and forecasts from operational oceanographic and biogeochemical models (L:10) have been utilized in the marine spatial planning of windfarms and mariculture locations in the German exclusive economic zone (EEZ). When biophysical, lower trophic level and upper trophic level (fish) models are coupled, models can provide dynamic estimates of changes in the distribution, growth and population size of commercially important species. Examples were provided for models developed for Baltic Sea sprat, cod and herring (L:06), anchovy in the Aegean Sea anchovy (L:05) and Pacific skipjack tuna (L:09). Most of these models utilized the super-individual approach and explored different management scenarios such as the location and timing of seasonal closures for anchovy. In the Pacific, a lower trophic level model (SEAPODYM) was linked to a spatial population dynamics model for the target species (skipjack tuna) that included two-way coupling between the fishing effort and spatial tuna population dynamics (Fig. A3.9). That model system has provided spatial estimates of mortality and productivity for management of different EEZs in the western Pacific.

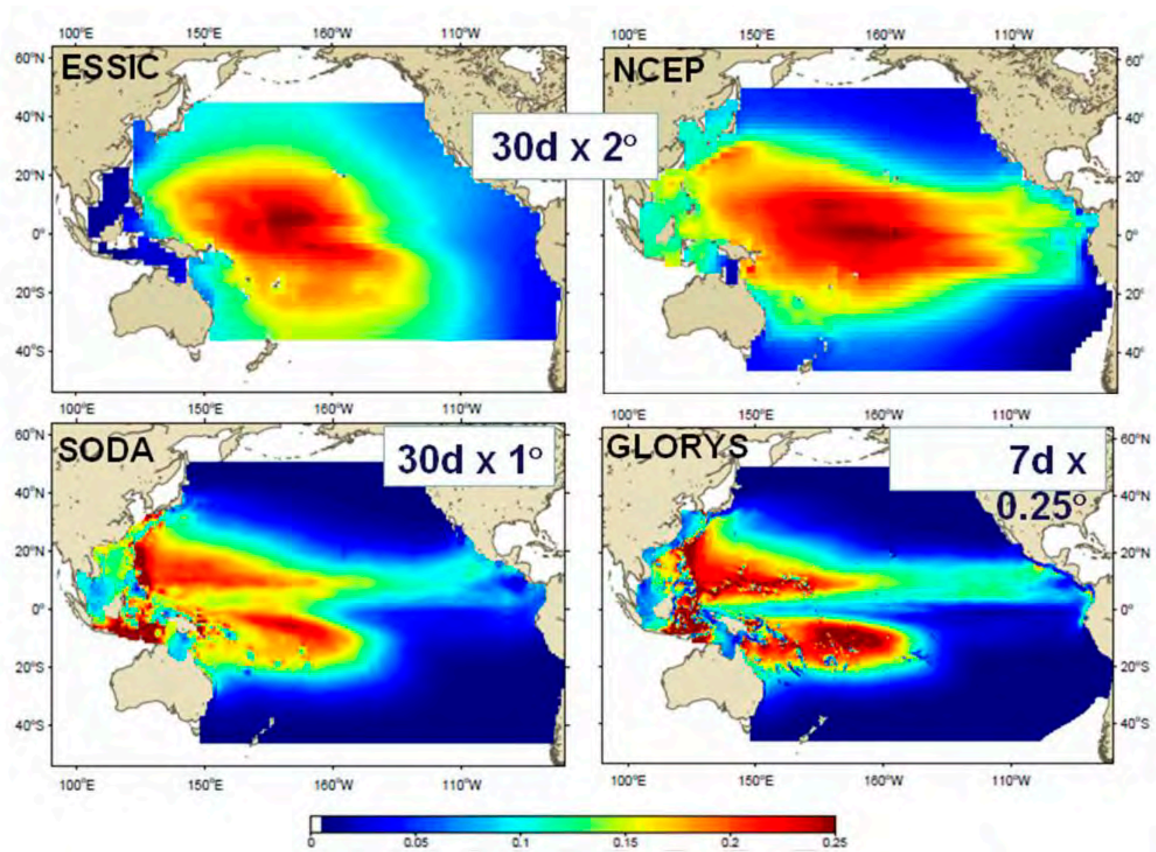


Fig. A3.9 Skipjack tuna distribution (mmt) in the North Pacific based upon coupling modelling (hydrodynamic model + biogeochemical and lower trophic level model + "SEAPODYM" that includes modules for tuna prey and tuna population dynamics). Shown above are coupled model results using environmental forcing data from four different sources (panels) that include differences in spatial (2.0 to 0.25°) and temporal (30 to 7 d) resolutions (from Lehodey and Senina, 2011; updated Lehodey *et al*., submitted to *Deep-Sea Research*).

Subsession 4) Integrated bioeconomic modelling and spatial management of systems

Coupled, end-to-end models are being actively developed for many marine systems throughout the world (Rose *et al*., 2010). These models are designed to evaluate the consequences of management strategies to marine resources, the fishing industry, and potentially other economic sectors (Fulton *et al*., 2011).

The final two talks provided examples of how coupled models have merged environmental, ecological, and economic analyses to provide information useful in management strategy evaluation (MSE). One example was an end-to-end model system developed for the northern prawn fishery in a small Australian bay (Fig. A3.10). In that region, eight models have been stitched together as a "proof of concept" that models representing all aspects of the environment, population dynamics/foodweb interactions, and fishing dynamics can be useful in exploring the most effective harvest strategies to meet management objectives. The second presentation discussed the COEXIST project (http://www.coexistproject.eu/) focusing on the shrimp (Crangon) fishery in the German EEZ. A key result of this coupled biological-economic model was a conflict analysis in which mapping of overlapping activities suggested that 40% of the historical fishing revenues came from areas allocated for current and future windfarm development. Again, the modelling approach can utilize various biological and economic scenarios to explore the best spatial management options.

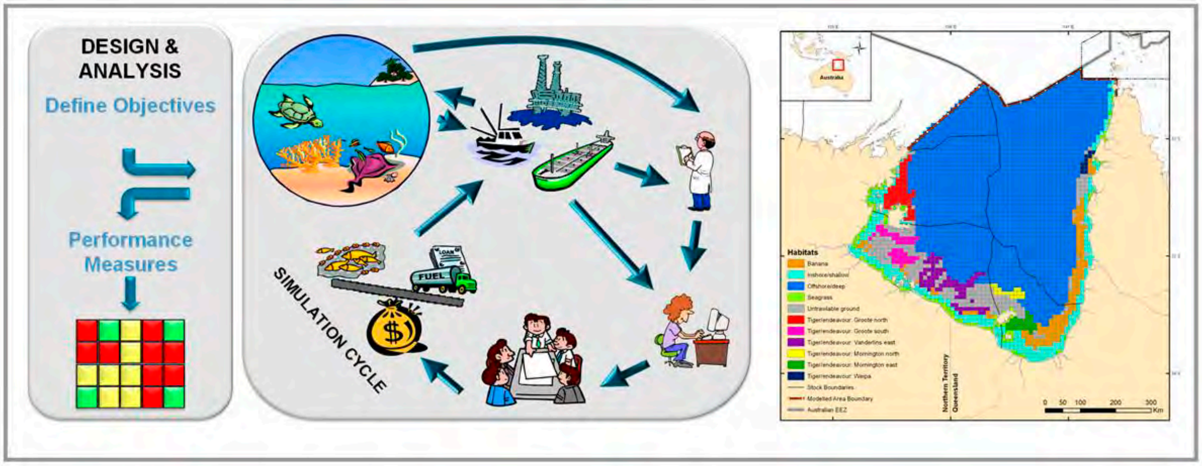


Fig. A3.10 Example of a spatially-explicit, end-to-end model simulating the ecological and socio-economic costs and tradeoffs of management actions within Australia's northern prawn fisheries. The model domain is the Gulf of Carpentaria (right). The model loop (left and center) includes a management evaluation framework (from Morello *et al*., L:01).

Final discusion/take home messages

Based upon presentations and discussions, there was consensus that biophysical models can provide important estimates that will aid in the effective spatial management of marine systems. There are a growing number of examples from around the world where coupled biological-physical models are providing information important to management. One common theme addressed in many presentations was the need to adequately describe and quantify model uncertainty and confidence. Skill assessment and sensitivity analyses are recurrent themes in the biophysical modelling literature (*e.g*., see Stow *et al*., 2009; Peck and Hufnagl, 2011). It is important to note that uncertainty originates from different sources (see Planque *et al*., 2011). This session underscored the importance of: 1) quantifying sensitivity of model estimates to changes in both biological parameters (behaviour, growth physiology) and aspects of physical models such as their spatial and temporal resolution, 2) developing consensus on techniques to use to assess the sensitivity of coupled models, 3) utilizing-model ensembles to display uncertainty in future projections. With regard to the latter point, it is important to recognize that future ecosystem states may not be adequately described by historical patterns, particularly when populations and/or ecosystems display hysteresis (*e.g*., Fauchald, 2010).

A second topic that emerged from the final discussion was the importance of continuing to develop end-to-end models. Models such as Atlantis (Fulton, 2011) are being adapted for use in many European regional seas based upon goals of EU FP7 projects (*e.g*., VECTORS, http://www.marine-vectors.eu/) and national funding initiatives. These complex, coupled models are the only tools that allow one to simulate the response of complex systems to changes in both biological (trophodynamic, physical forcing), economic (fishing fleet dynamics) and policy/governance drivers. The recognition that multiple drivers are acting to change marine resources across the globe (Halpern *et al*., 2008) fuels the development and application of end-to-end models within marine systems.

List of papers

L:01 Rodrigo H. Bustamante, Cathy M. Dichmont, Nick Ellis, Shane P. Griffiths, Wayne A. Rochester, and Aijun R. Deng
Biophysical assessments and adaptive spatial management for tropical trawling

L:02 H.-H. Hinrichsen, K. Hüssy, and B. Huwer
The impact of hydrodynamics and hydrography on western Baltic cod early life stage survival

L:03 Meng Xia
The response of a Gulf estuary plume and hypoxia to wind forcing

L:04 Ulf Bergström, Göran Sundblad, Anna-Leena Downie, Martin Snickars, and Mats Lindegarth
Evaluating management scenarios using predictive habitat modelling – effects of eutrophication mitigation in the Baltic Sea

L:05 D.V Politikos, G. Triantafyllou, K. Tsiaras, M. Giannoulaki, A. Machias, C. Maravelias, and S. Somarakis
The application of a biophysical model to the north Aegean anchovy fishery: its implication for spatial management

L:06 Wolfgang Fennel and Hagen Radtke
Modelling nutrient to fish model – an Eulerian approach

L:07 Isobel Bloor, Charlotte Marshall, Emma Jackson, Jean-Paul Robin, and Martin Attrill
Sepia officinalis: spawning habitat modelling in the English Channel and its potential for fisheries management

L:08 T. Schulze, V. Stelzenmüller, A. Sell, J. Berkenhagen, and K. Schulte
Spatial management scenarios for the brown shrimp fisheries in the German Bight: Possible influences of product prices, TAC for plaice and sole, and Nature 2000 management plans

L:09 Patrick Lehodey and Inna Senina
Near real time prediction and spatial management of Pacific skipjack tuna

L:10 Frank Janssen, Tian Tian, Zhenwen Wan, and Karen Edwards
The potential use of operational biochemical models in marine spatial management

L:11 Robert Bauer, Daniel Stepputtis, and Ulf Gräwe
Retention of western Baltic herring larvae within the main spawning area

L:12 Myron A. Peck and Marc Hufnagl
Can biophysical individual-based models reliably tell us why most larvae die in the sea?

ICES/PICES Theme Session Q
Atmospheric forcing of the Northern Hemisphere ocean gyres, and subsequent impact on adjacent marine ecosystems

Convenors: Jürgen Alheit (ICES/Germany), Hjálmar Hátún (ICES/Faroe Islands), Emanuele Di Lorenzo (PICES/USA) and Ichiro Yasuda (PICES/Japan)

It has recently become apparent that the dynamics of the North Pacific and Atlantic subpolar and subtropical gyres have considerable impacts on adjacent marine ecosystems. As this theme has been neglected so far in the ICES community, it seemed appropriate to organize this joint ICES/PICES Theme Session to make the ICES community aware of this promising theme. The session consisted of nine oral presentations, of which seven were given by PICES scientists and, unfortunately, only two by ICES scientists. This probably reflects the weak relation of ICES with the physical oceanography community in ICES countries.

Q:04. In his presentation on “Climatically induced impact of gyre dynamics on coastal ecosystems: a comparison of different oceans“, J. Alheit pointed out that changes in the strength and extent of gyres in the Atlantic and Pacific cause changes in offshore, shelf, and coastal ecosystems. Changes in the dynamics of the Atlantic Sub polar Gyre, related to the North Atlantic Oscillation (NAO) and Atlantic Multi-decadal Oscillation (AMO), cause reactions in the fauna of a large number of North Atlantic ecosystems affecting plankton, fish, and whales. Changes in ocean circulation associated with the Pacific Decadal Oscillation (PDO) affect zooplankton and fish in the California Current. Dynamics of the Kuroshio and Oyashio Currents affect population size of Japanese sardine. Alternations of anchovies and sardines in the Humboldt Current seem to be driven by the approach and retreat of oceanic offshore waters, probably associated with gyre dynamics.

Q:05. H. Hátún *et al*. presented a paper on the “The North Atlantic Subpolar Gyre and blue whiting stock dynamics”. The subpolar gyre can influence stock size and shifts in migration patterns of blue whiting directly by regulating environmental conditions that influence behaviour and migration routes and indirectly via trophodynamics. Since the late 1970s, large shifts in climate and spatial distribution of blue whiting have been observed. Temporal variability in east-west spatial shifts of the blue whiting resembles the dynamics of the gyre index. The pronounced mid-1990s decline of the subpolar gyre from a strong to a weak state impacted the blue whiting stock and its food sources. During periods of a weak gyre, catches in the western distribution area, in Icelandic and Faroe waters, are relatively large.

Q:08. In their presentation on “Exploring mechanisms for coherent variations between ocean gyres of the Northern Hemisphere”, E. Di Lorenzo and N. Schneider explored a possible mechanism underlying coherent changes in the North Pacific and North Atlantic Gyre. Decadal modulations of the North Pacific gyre-circulation are captured by the North Pacific Gyre Oscillation (NPGO; Di Lorenzo *et al*., 2008). The NPGO is the oceanic response to atmospheric variability of the North Pacific Oscillation (NPO) (Chhack *et al*., 2009) – a pattern of sea level pressure variability that captures changes in the strength of the mean atmospheric circulation over the North Pacific. The low frequency variability of the NPO that drives the decadal variations of the NPGO is linked to decadal variability in the central tropical Pacific associated with the central Pacific warming pattern (CPW) (Di Lorenzo *et al*., 2010). This link from the CPW to the NPO is established through the excitation of large-scale atmospheric Rossby waves or teleconnections to the extra-tropics that project onto the NPO (Furtado *et al*., 2011). Recent studies show that the extra-tropical teleconnection of the CPW can affect also the Arctic Oscillation (AO) (Hegyi and Deng, 2011). To the extent that some of the AO variability has a surface expression into the North Atlantic Oscillation (NAO) pattern, which is known to drive changes in the North Atlantic gyre-scale circulation (Curry and McCartney, 2001), the CPW atmospheric teleconnections provide a possible mechanism to force coherent changes of the North Pacific and North Atlantic gyres. This mechanism needs further investigation and is now considered mostly as a working hypothesis. Figure A3.11 summarizes this hypothesis.

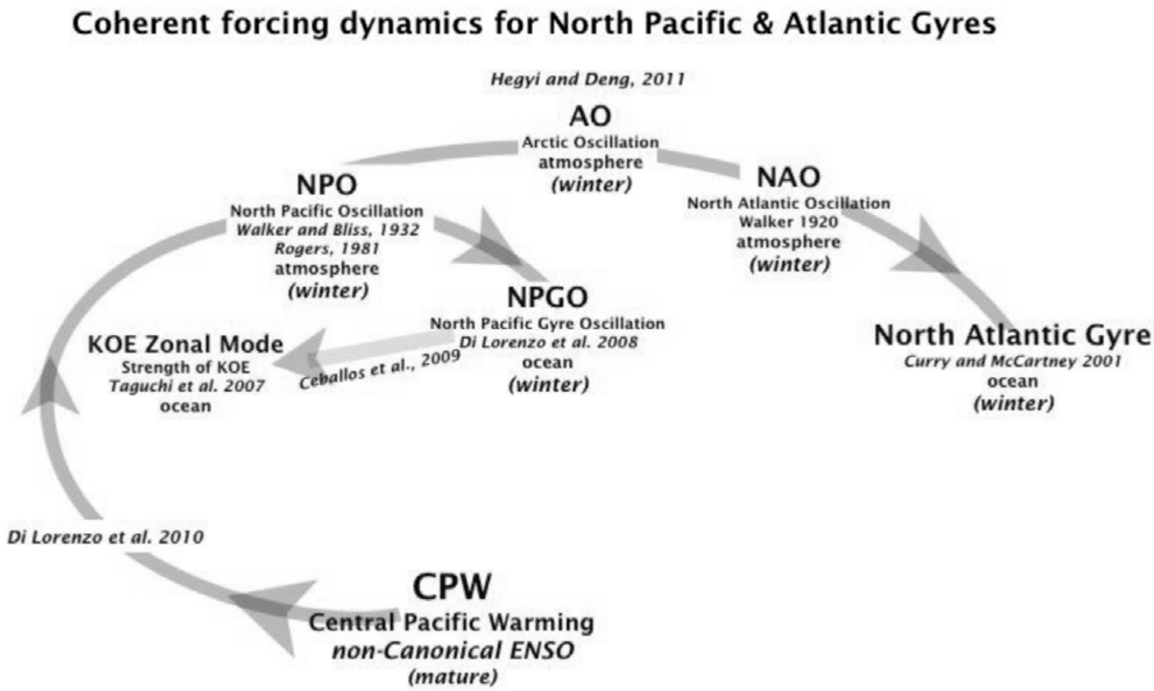


Fig. A3.11 Schematic of the hypothesized climate connections governing climate variability in the northern hemisphere (from Di Lorenzo and Schneider, Q:08).

Q:10. S. McKinnell talked about “A PICES-ICES Climate Mode”. Overland *et al*. (2010) noted that “Climate variables such as temperatures and winds can have strong large scale covariability within individual ocean basins, but between-basin teleconnections [...] are usually much weaker and a highly intermittent function of the conditions prevailing at the time within the adjoining basins.” The Pacific Decadal Oscillation (PDO) has a large-scale pattern of inverse correlation in SST across the Pacific. The Atlantic Multidecadal Oscillation (AMO) has a large-scale pattern of, for the most part, common sign in the Atlantic. Only along the coast of the Carolinas and Florida is there a hint of inverse correlation in the North Atlantic. Both results are based on EOF analysis of SST and both are dominated by lower frequency variability. When combined into a single analysis, the Northern Hemisphere oceans exhibit a correlation pattern which suggests that the PDO and the AMO are part of a hemispheric mode. Its temporal pattern is dominated by a shift in sign in the spring of 1998 that had a strong global effect rather than the weak between-basin teleconnection described above.

Q:07. W. Peterson *et al*. reported on the impact of basin-scale gyres in the North Pacific on the coast of Oregon, USA, (“The Pacific Decadal Oscillation and gyre-ecosystem linkages in the northern California Current (NCC): source waters which feed on the NCC determine food web structure”). This project has identified important relationships among basin-scale physical processes, local physical processes, community structure and abundance of copepods, and survival and growth of commercially important salmon species. Evidence suggests that major biological changes in the local ecosystem are forced by changes in alongshore advection which is related to the Pacific Decadal Oscillation. When the Pacific Decadal Oscillation (PDO) is in a negative phase, cold subarctic waters from the Gulf of Alaska feed into the NCC and transport large, lipid-rich copepods into the NCC. When the PDO is positive, warm, subtropical waters from offshore and south of Oregon feed the NCC transporting small, oceanic, lipid-poor copepods to the coastal upwelling zone. So, the basin-scale changes in wind that drive the PDO result in changes in transport that, in turn, control foodchain structure. These changes in food chain structure correlate with (and predict) salmon return to the Columbia River.

R. Rykaczewski presented his work relating to changes in the nutrient supply to the Northeast Pacific in response to anthropogenic forcing (Changes in source water properties of the California Current in response to future basin-scale climate processes"). Through analysis of global atmosphere-ocean general circulation models, he suggested that future increases in stratification associated with global warming will reduce the ventilation of subsurface water masses in the central North Pacific. When these deep water layers are upwelled in the California Current, they carry increased nutrient concentrations due to the greater period of time over which these deep waters have accumulated organic matter.

Q:02. I. Yasuda *et al.* contributed to the understanding of the dynamics of the Japanese sardine with their presentation on "Oceanic and atmospheric forcing of recruitment of Japanese sardine (*Sardinops melanostictus*)". They concluded that recruitment variability of the sardine is mainly governed by the Kuroshio Current velocity and winter cooling which is related to the East Asian Winter Monsoon. A slow Kuroshio Current and cold temperature are related to deep MLD and enhanced food production for larvae. In contrast, a stronger Kuroshio Current and warmer temperature are related to a shallow MLD and low food production, a situation which has led to the collapse of the Japanese sardine stock in the late 1980s.

Q:03. S. Jung *et al.* studied the influence of climate-driven oceanographic changes on Korean fisheries ("Climate-driven shifts in fish communities in Korean waters detected by application of multivariate analysis and Bayesian markov switching models"). By applying canonical correspondence analysis to a number of abiotic and biotic variables, including volume transport of the Tsushima Warm Current (TWC), an offspring of the subtropical gyre system. A regime shift was observed in the Japan/East Sea in the late 1980s, but a relation between the volume transport of the TWC, the dynamics of main fish populations or the regime shift in the late 1980s could not be detected.

List of papers

Q:02 Ichiro Yasuda, Haruka Nishikawa, Sachihiko Itoh, and Kosei Komatsu
Oceanic and atmospheric forcing for the recruitment of Japanese sardine (*Sardinops melanstictus*)

Q:03 Sukgeun Jung, Il Su Choi, and Suam Kim
Climate-driven shifts in fish communities in Korean waters detected by application of multivariate analyses and Bayesian Markov switching models

Q:04 Jürgen Alheit
Climatically induced impact of gyre dynamics on coastal ecosystems: a comparison of different oceans

Q:05 Hjálmar Hátún
Atmospheric forcing of the North Atlantic Subpolar gyre

Q:06 Anne Hollowed, Megan Stachura, Nate Mantua, and Ray Hilborn
Regime shift effects on fish and fisheries in the Northeast Pacific

Q:07 William T. Peterson, Hongsheng Bi, Cheryl A. Morgan, Jennifer Fisher, Jay Peterson, and Ryan Rykaczewski
The Pacific Decadal Oscillation and gyre–ecosystem linkages in the northern California Current (NCC): source waters which feed the NCC determine foodweb structure

Q:08 Emanuele Di Lorenzo and Niklas Schneider
Exploring mechanisms for coherent variations between ocean gyres of the Northern Hemisphere

Q:09 Catherine L. Johnson
Influence of circulation variability on Scotian Shelf (Northwest Atlantic) zooplankton communities

Q:10 Skip McKinnell
A PICES–ICES climate mode

2011 PICES Annual Meeting
October 14–23, 2011
Khabarovsk, Russia

BIO/POC Topic Session (S2)
Mechanisms of physical-biological coupling forcing biological "hotspots"

Co-sponsored by: *ICES*

Co-Convenors: *Jürgen Alheit (ICES/Germany), Elliott Hazen (PICES/USA), Oleg Katugin (PICES/Russia), Robert Suryan (PICES/USA), Yutaka Watanuki (PICES/Japan) and Ichiro Yasuda (PICES/Japan)*

Background

This session examined the physical and oceanographic factors that correspond to ecological or economic "hotspots" in the North Pacific and North Atlantic and their marginal seas. "Hotspots" can broadly be defined as areas encompassing high species diversity, high abundance of individuals, especially of important indicator species, or areas of high economic value. Interdisciplinary contributions on physical-biological coupling and resulting seasonal or year-round "hotspots" in primary to tertiary productivity were invited. This included data on physics, phyto- and zooplankton, forage fish, and upper trophic level predators (*e.g.*, fish, seabirds, mammals, humans).

Summary of presentations

Session 2 at PICES 2011 had a total of 14 talks and with no fewer than 40 attendees in the audience. Some talks focused on the physical oceanography at known marine hotspots (4 papers), while others considered seabirds (4), fish (3), and marine mammal (3) hotspots, multispecies hotspots, and also overlaps between hotspots and human impacts. A common theme was the issue of scale underlying identification or formation of hotspots, from those formed by ocean currents spanning 5000 km^2 to tidally driven hotspots in the wakes of headlands at the scale of 100 km^2. Scale differences highlight a range in biophysical factors affecting hotspot formation and persistence.

We discussed interest in assembling a special journal issue stemming from the theme session and at least half of the presenters were prepared to contribute a paper to a special issue. Our impression was that by reaching out to the broader community there will be sufficient interest for a full volume. Further interest and potential journals will be considered during the coming months. The audience felt that by focusing on mechanisms of hotspot formation in addition to other questions noted below, this volume would be sufficiently distinguished from the 2006 *Deep-Sea Research II* volume stemming from a 2004 PICES hotspot session. From the discussion session, we identified which questions about hotspots were most important to answer as a focus of the theme issue and came up with the following:

1) How do the two broad classes of hotspots differ, specifically what are the mechanisms of hotspot formation for both 1) aggregative and 2) bottom-up forced hotspots? How do the mechanisms allow the hotspot to persist or re-occur predictably?
2) How do we prioritize hotspots, *e.g.* does a certain percentage of the population have to visit a hotspot for it to be a hotspot, or are hotspots that support high biodiversity and strong ecological interactions the most important hotspots?
3) How might species interactions affect the use of hotspots by certain species?
4) What hotspots are at greatest risk? Which hotspots have greatest threat from human uses (*e.g.* fisheries, shipping lanes). For persistent or predictable hotspots, how persistent are they over decadal or multi-decadal time scales, *e.g.* which hotspots are likely to change under broad scale forcing such as regime shifts or climate change?

List of papers

Oral presentations

Sei-Ichi Saitoh, Robinson M. Mugo, Mukti Zainuddin and Fumihiro Takahashi (Invited)
Potential fishing zones as "hotspots" of skipjack tuna (*Katsuwonus pelamis*) and albacore (*Thunnus alalunga*) in the western North Pacific

Shin-ichi Ito, Yugo Shimizu, Shigeho Kakehi, Taku Wagawa, Masatoshi Satoh, Daisuke Ambe, Takeshi Okunishi and Kazuyuki Uehara
A quasi-steady warm water jet and an ecological hotspot in the western North Pacific

David G. Foley
Constructing oceanographic data sets and delivery systems to meet the needs of biologgers

Robert Suryan, Kathy Kuletz, Martin Renner, Patrick Ressler, Shannon Fitzgerald, Kiyoaki Ozaki, Fumio Sato, Tomohiro Deguchi and Elizabeth Labunski (Invited)
Mechanisms affecting seabird-prey associations over submarine canyons in the northwestern Bering Sea

Igor M. Belkin (Invited)
Satellite oceanography of fronts as biological hotspots

Robinson M. Mugo, Sei-Ichi Saitoh, Fumihiro Takahashi, Akira Nihira and Tadaaki Kuroyama
When, where and why skipjack tuna, red flying squid and pacific saury potential fishing zones are likely to overlap in the western North Pacific: A proof of concept

Takashi Yamamoto, Akinori Takahashi, Nariko Oka, Takahiro Iida, Nobuhiro Katsumata, Katsufumi Sato and Philip N. Trathan
Foraging areas of streaked shearwaters in relation to seasonal changes in the marine environment of the Northwestern Pacific

Jürgen Alheit (Invited)
Climate variability impact on North Sea ecosystem

Elliott L. Hazen, Scott A. Shaffer, Michelle A. Kappes, Ryan R. Rykaczewski, David G. Foley, Steven J. Bograd and Daniel P. Costa
Oceanographic habitat segregation among postbreeding Hawaiian albatrosses and potential changes from 2001-2100

Mary-Anne Lea, Jeremy T. Sterling, Nicholas A. Bond, Sharon Melin, Rolf Ream and Tom Gelatt
Habitat use of Alaskan northern fur seal pups in the western North Pacific Ocean

Kaoru Hattori, Takeomi Isono and Orio Yamamura
Wintering aggregations of Steller sea lions in Ishikari-Bay, Sea of Japan

Haruka Nishikawa, Ichiro Yasuda, Sachihiko Itoh, Yoshikazu Sasai and Hideharu Sasaki
Impacts of climatic regime shift on Japanese sardine stock collapse

Konstantin Rogachev
Satellite and direct observations of circulations features associated with bowhead feeding hotspots in the Sea of Okhotsk

Poster presentations

Tomoko Harada, Kentaro Kazama, Tomohiro Deguchi, Hajime Suzuki and Yutaka Watanuki
Foraging behavior of subtropical black-footed albatross *Phoebastria nigripes* and the marine environment around Bonin Islands

Igor M. Belkin and S. Kalei Shotwell
Propagation of SST anomalies along the North Pacific

POC/FIS Topic Session (S8)
Linking migratory fish behavior to end-to-end models

Co-sponsored by: *ICES*

Co-Convenors: Enrique Curchitser (PICES/USA), Geir Huse (ICES/Norway), Shin-ichi Ito (PICES/Japan), Michio Kishi (PICES/Japan) and Skip McKinnell (PICES)

Background

In order to understand ecosystem response to climate impacts, End-to-End modeling (E2E) approaches are essential. One of the most difficult parts for E2E is the modeling of fish behavior migration. Fish behavior can be very complex; it is a consequence of genetics, physical, chemical and biological environments and their interaction. Learned behavior may also be a factor. Recently, new technology has been introduced to tagging equipment, and as a consequence data availability is vastly improved. Additionally, new technologies are used to investigate fish movements in laboratory settings. This new information is expected to improve our understanding of fish migration mechanism and contribute to the development of fish migration models. Furthermore, the development of high-resolution ecosystem models coupled to circulation models makes it possible to simulate fish migration in the context of realistic environmental fields. The purpose of this session was to understand the current state of development in modeling fish behavior and discuss future potential collaborations to improve fish migration models.

Summary of presentations

Dr. Shin-ichi Ito and Dr. McKinnell chaired the session and introduced the history of this difficult topic. Invited speaker, Prof. Kenneth Rose of Louisiana State University, described why there is a growing increase in migration modelling. He noted that traditional modelling methods are perceived as unsuccessful, how many management issues involve space, how climate change is expected to affect distributions and behaviours, that data collection is becoming very spatially-detailed, how computing power continues to increase, and that significant advances in hydrodynamics and upper trophic level modeling have been made recently. He described an approach that is being used with doctoral candidate Kate Shepard to validate fish behaviour. Movement algorithms (kinesis, neighbourhood search, event-based) were evaluated. They concluded that the results were encouraging, that the three methods successfully trained with the Genetic Algorithm produced realistic movement, and that total egg production was fairly constant across methods and grids. Jerome Fieschter, the second invited speaker, described the performance of their end-to-end model efforts directed at sardine and anchovy. He is using a 3-D ROMS for ocean circulation, NEMUROMS for NPZ, a multi-species IBM for fish, and a fishing fleet dynamics model. To date, they have solved many numerical and bookkeeping issues, implemented different behavioral cues for movement, and next is to add more realistic biology. They found that balancing food/dietary factors when compared with balancing SST gave different results. In future, they intend to increase biological realism, and investigate the causes of low-frequency cycles. Yu-Heng Tseng described a modelling study of Japanese anchovy in the East China Sea. Little is known about the oceanic migration of the adults but spawning is known to occur in Taiwan Strait. The ability of the adults to reach southern spawning grounds may depend on Changjiang River discharge. He described that when coastal discharge from the Chiangjiang is included in the model, its variability is expected to affect migration routes (and availability) of anchovy to local fishermen. Skip McKinnell speculated on how the factors responsible for contemporary fish behaviour may have been determined by selective forces affecting the species centuries ago. Migration timing in sockeye salmon is relatively invariant compared to other behavioural traits. At the southern extreme of their range in North America, they have much earlier run timing than is expected from their spawning dates. Arriving at the “normal” time for their relatively late spawning date appears to have been selected against in earlier times. Kjell Utne and Geir Huse discussed how they are using individual-based models (IBM), genetic optimization algorithms, and observational data in their migration models of herring, blue whiting and mackerel in the northern North Atlantic Ocean. It is embedded within the NORWECOM coupled model system to provide access to daily physical and prey fields. The additional complexity is increasing the demand for computational resources. Shin-ichi Ito and his colleagues ended the session with an interesting presentation showing how they had evaluated both Euler-type and an IBM of saury migration. Euler-type models are computationally efficient because they simply move biomass from place to place on a fixed grid, but there is no information about the migration pathways of individuals that is possible with IBMs. Scaling IBMs to represent biomass has huge computational costs. The Euler-type model was able to capture the general features of saury feeding migration, egg production, and body size, but was unable to capture the westward spawning migration and required a somewhat artificial mixture of body sizes. The convenors were encouraged by the better-than-expected turnout of attendees to the topic session, so a repeat session is planned for PICES-2012 in Hiroshima.

List of papers

Oral presentations

Kenneth A. Rose, Katherine Shepard, Haosheng Huang, Sean Creekmore, Paul Venturelli, Jerome Fiechter, Enrique N. Curchitser, Kate Hedstrom, Matthew Campbell and Dubravko Justic (Invited)
Modeling movement of fish over spatial and temporal scales: If fish were dumber and people were smarter

Jerome Fiechter, Kenneth A. Rose, Enrique N. Curchitser, Kate Hedstrom, Miguel Bernal and Alan Haynie (Invited)
Behavioral cues for small coastal pelagic species in the California Current: Results from a fully-coupled end-to-end ecosystem model

Shin-ichi Ito and Takeshi Okunishi
Comparison of migration algorithms for Japanese sardine (*Sardinops melanostictus*) in the western North Pacific

Chen-Yi Tu, Yu-Heng Tseng, Tai-Sheng Chiu, Mao-Lin Shen and Chih-Hao Hsieh
Using coupled fish behavior-hydrodynamic model to investigate spawning migration of Japanese anchovy, *Engraulis japonicus*, from Taiwan to the East China Sea

Skip McKinnell
Evolution's challenge to modeling sockeye salmon spawning migration

Kjell Rong Utne and Geir Huse
Towards end-to-end modeling with a special focus on planktivorous fish

Shin-ichi Ito, Masatoshi Sato, Takeshi Terui, Michio J. Kishi, Daisuke Ambe, Takahiko Kameda, Satoshi Suyama, Masayasu Nakagami and Yasuhiro Ueno
Euler-type and Individual Based modeling approaches for fish migration: An example of Pacific saury

Appendix 4

Proposal for a Section on Climate Change Effects on Marine Ecosystems (S-CCME)

(joint expert group with ICES Strategic Initiative on *Climate Change Effects on Marine Ecosystems*)

Parent Committees: BIO, FIS and POC
Duration: lifetime of FUTURE

S-CCME Goals (approved at PICES-2011)

- Define, coordinate and integrate the research activities needed to understand, assess and project climate change impacts on marine ecosystems;
- Plan strategies for sustaining the delivery of ecosystem goods and services, and when possible predictions should include quantifying estimations of uncertainty;
- Define and quantify the vulnerability and sustainability of marine ecosystems to climate change, including the cumulative impacts and synergetic effects of climate and marine resource use;
- Build global ocean prediction frameworks, through international collaborations and research, building on ICES and PICES monitoring programs.

Core Elements of S-CCME Implementation Plan Phases (3 years in duration)

- Synthesis of existing knowledge;
- Advancement of new science and methodology;
- Communication of research findings.

Phase 1: 2012–2014

- **Synthesis of existing knowledge:**
  - Complete synthesis papers from the 2010 Sendai Symposium and 2012 Yeosu Symposium;
  - Interpret the vulnerabilities of marine ecosystems to changing climate.
- **Advancement of new science and methodology:**
  - Identify techniques for predicting climate change impacts in systems impacted by decadal variability;
  - Define the vulnerability of commercial species to climate change and identify which species would be most likely to experience shifts in spatial distributions;
  - Engage the global earth system modelling community in modelling climate change effects on marine ecosystems and identify opportunities for collaborations;
  - Build response scenarios for how the human community will respond to climate change.
- **Communication and integration of science through international symposiums:**
  - Publish results in peer reviewed literature;
  - Serve as symposium/session co-convenors;
  - Assist in preparing and convening the PICES/ICES/IOC Symposium on "*Effects of climate change on the world's oceans*" (May 2012, Yeosu, Korea).

Phase 2: 2015–2017

- Continue to advance new science focused on climate change effects on marine ecosystems through theme/topic sessions and workshops;
- Update and improve forecasts with IPCC AR5 scenarios;
- Convene an international symposium in 2016;
- Develop regional synthesis reports;
- Initiate inter-sessional training for projecting climate change impacts on marine ecosystems;
- Continue collaboration with global climate change research community.

Phase 3: 2018–2020

- Continue to advance new science focused on climate change effects on marine ecosystems through theme/topic sessions and workshops;
- Update and improve predictions with IPCC AR6 scenarios;
- Develop regional synthesis reports;
- Convene an international symposium in 2018.

Science Plan for ICES/PICES Strategic Initiative (Section) on Climate Change Effects on Marine Ecosystems

Vision

ICES and PICES will become the leading international organizations providing science and advice related to the effects of climate change and variability on marine resources and ecosystems.

ICES and PICES will develop the scientific basis for evaluating the vulnerability, status and sustainability of marine systems under changing climate conditions. Collaborative research within ICES and PICES will facilitate the development, maintenance and evolution of a network of regional interdisciplinary research teams that will share research approaches on a global scale to foster laboratory, field and modeling activities that will provide data at the spatial and temporal scales needed to monitor, assess and project climate change impacts on marine ecosystems.

Background

Recent reviews have provided compelling evidence that global warming is occurring and greenhouse gasses are very likely contributing to this trend (Arctic Climate Impacts Assessment, ACIA 2005; 4th report of the Intergovernmental Panel on Climate Change, IPCC AR4 Report 2007). Since then, the marine science community has endeavoured to address the paucity of information regarding impacts on marine ecosystems and to provide new science in time for consideration by the future IPCC review panels.

New studies show that climate change will impact marine ecosystem productivity, habitat quality and quantity (Arrigo *et al.*, 2008; Cheung *et al.*, 2009; Durner *et al.*, 2009; Nye *et al.*, 2009; Philippart *et al.*, 2011). These changes will affect biodiversity, and the phenology, spatial distribution, interactions, and vital rates of marine biota resulting in changes in the quantity, quality and availability of marine resources for human use (Mueter and Litzow, 2008; Sundby and Nakken, 2008; A'mar *et al*., 2009; Hunt *et al*., 2011). The ripple effect of these changes will be felt around the world (Barange *et al.*, 2011). The timeline for projections (20–100 years) requires the development of mechanistic scenarios of future bio-physical couplings as well as scenarios for expected changes in anthropogenic trends in marine resource use including fishing technology, markets, demand, and consumption in light of trends in marine policy (Allison *et al.*, 2009; Kim, 2010; Merino *et al.*, 2010; Fulton, 2011; Stock *et al.*, 2011). Interdisciplinary research teams will be required to develop science-based advice to decision makers (Plagányi *et al*., 2011; Rice and Garcia, 2011).

Although the IPCC reports provide concise assessments of the evidence for and projections of the impacts of climate change on the planet, there remains a need for coordinated research to understand climate change effects on specific regions of the globe. Research coordination is especially needed to understand climate change effects on regional marine ecosystems. The North Pacific Marine Science Organization (PICES) and the International Commission for Exploration of the Sea (ICES) have emerged as the leading organizations responsible for scientific advice on marine issues in the Northern Hemisphere.

In the early 2000s, ICES and PICES independently initiated efforts to develop frameworks for assessing and projecting climate change impacts on marine resources and the ecosystems that support those resources. In 2007, ICES formed the Steering Group on Climate Change [SGCC] to overview the research, services and operational issues related to Climate Change supported by ICES expert groups, to assess the quality and adequacy of the assessment process, and to manage the start-up transit of ICES toward the establishment of a program in Climate Change. The life time of the group was 3 years, ending in December 2010. The group was renamed as the Strategic Initiative on Climate Change [SICC] in 2009 (Res 2009/2/SSGEF01). The final report of that group ("Report of the Science Strategic Initiative on Climate Change", SCICOM May 2010 Doc 15) described international collaborative efforts (listed later under ICES/PICES joint activities) and the following activities:

- The coordination and production of a multi-authored, peer-reviewed ICES CRR report on Climate Change in the North Atlantic;
- The drafting of an ICES position paper on Climate Change in the North Atlantic;
- The steering and promotion of theme sessions and workshops on climate change topics during the recent ICES ASC.

During the same period PICES initiated a series of workshops and topic sessions at Annual Meetings focused on forecasting the implications of climate change on marine ecosystems including:

- 2004 POC Topic Session: The impacts of climate change on the carbon cycle of the North Pacific;
- 2004 CCCC Topic Session: The impacts of large-scale climate change on North Pacific marine ecosystems;
- 2005 CCCC/MODEL Topic Session: Modeling climate and fishing impacts on fish recruitment;
- 2006 CCCC Symposium: Climate variability and ecosystem impacts in the North Pacific;
- 2006 FIS Workshop: Linking climate to trends in productivity of key commercial species in the subarctic Pacific;
- 2006 POC Workshop: Evaluation of climate change projections;
- 2007 POC/CCCC/MONITOR Topic Session: Operational forecasts of oceans and ecosystems;
- 2007 BIO/FIS/POC Topic Session: Phenology and climate change in the North Pacific: Implications of variability in the zooplankton production to fish, seabirds, marine mammals and fisheries (humans);
- 2007 POC/CCCC Workshop: Climate scenarios for ecosystem modeling;
- 2007 CCCC/CFAME Workshop: Climate forcing and marine ecosystems;
- 2008 CCCC/POC Topic Session: Marine system forecast models: Moving forward to the FUTURE;
- 2008 CCCC/POC/FIS Workshop: Climate scenarios for ecosystem modeling (II);
- 2009 POC/BIO Topic Session: Anthropogenic perturbations of the carbon cycle and their impacts in the North Pacific;
- 2009 POC/FUTURE Topic Session: Outlooks and forecasts of marine ecosystems from an earth system science perspective: Challenges and opportunities;
- 2009 POC Workshop: Exploring the predictability and mechanisms of Pacific low frequency variability beyond inter-annual time scales.

ICES and PICES collaboratively sponsored joint scientific workshops, theme/topic sessions and symposia focused on forecasting the implications of climate change on marine ecosystems including:

- 2008 PICES/ICES/IOC Symposium: Effects of climate change on the world's oceans (Gijón, Spain);
- 2009 ICES/PICES Theme Session: Climate impacts on marine fish: Discovering centennial patterns and disentangling current processes (ICES ASC, Berlin, Germany);
- 2010 PICES/ICES/FAO Symposium: Climate change effects on fish and fisheries (Sendai, Japan);
- 2010 ICES/PICES Theme Session: Responses to climate variability: Comparison of Northern Hemisphere marine ecosystems (ICES ASC, Nantes, France);
- 2010 PICES/ICES Topic Session: Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting (PICES-2010, Portland, USA);

- 2011 ICES/PICES Workshop: Reaction of Northern Hemisphere ecosystems to climate events: A comparison (Hamburg, Germany);
- 2011 ICES/PICES Workshop: Biological consequences of a decrease in sea ice in Arctic and Sub-Arctic Seas (Seattle, USA);
- 2011 ICES/PICES Theme Session: Atmospheric forcing of Northern Hemisphere ocean gyres and their subsequent impact on adjacent marine climate and ecosystems (ICES ASC, Gdańsk, Poland);
- 2011 PICES/ICES Topic Session: Mechanisms of physical-biological coupling forcing biological "hotspots" (PICES-2011, Khaborovsk, Russia);
- 2011 PICES/ICES Topic Session: Linking migratory fish behaviour to end-to-end models (PICES-2011, Khaborovsk, Russia);
- 2011–2012 Organization, planning and implementation of the 2012 PICES/ICES/IOC Symposium: Effects of climate change on the world's oceans (Yeosu, Korea).

These meetings revealed that the scale and complexity of climate change issues required a more formal partnership between the ICES and PICES organizations. Soon after the PICES/ICES/IOC symposium in 2008, the governing bodies of both PICES and ICES formally recognized the benefits of collaboration with respect to climate change research and approved the formation of the first joint ICES/PICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS). That group was jointly chaired by two members from each organization and was responsible for organizing the PICES/ICES/FAO symposium in Sendai and a forthcoming special volume of the *ICES Journal of Marine Science*.

The life time of the ICES SICC ended in December 2010, and WG-FCCIFS's term will end December 2011. Both PICES and ICES recognize that great strides in new science have emerged from collaborative work between their two organizations. Therefore, they requested the formation of a science plan that outlines a structure for continued collaborations focused on climate change. The terminology for longer-term research efforts differs between the two organizations. Within ICES, our plan would be consistent with a Strategic Initiative. Within PICES, our plan would be to create a Section on *Climate Change Effects on Marine Ecosystems*. To avoid confusion with the previous ICES SICC, we will refer to this proposal as the ICES/PICES Strategic Initiative on Climate Change Effects on Marine Ecosystems (SICCME). The remainder of this document provides a roadmap for long-term continuation of a collaborative research on climate change through the formation of an ICES/PICES SICCME.

Goals

Never in the history of PICES or ICES has there been a more serious need for cooperation on a marine science issue of global significance. ICES and PICES must *respond to the need for credible, objective and innovative science advice on the impacts of climate change on marine ecosystems.* This advice will foster management and policies that will preserve these resources and habitats for the benefit of future generations. To achieve this overarching goal, the following actions should be addressed.

i. Define the research activities needed to understand, assess and project climate change impacts on marine ecosystems with sufficient spatial and temporal resolution to plan strategies for sustaining the delivery of ecosystem goods and services and the preservation of biodiversity. When possible predictions should include quantifying estimations of uncertainty.
ii. Define and quantify the vulnerability of marine ecosystems to climate change, including the cumulative impacts and synergetic effects of climate and marine resource use.
iii. Build global ocean prediction frameworks, through international collaborations and research, building on ICES and PICES monitoring programs.

As the leading Northern Hemisphere international organizations, ICES and PICES will direct the SICCME to draw on the network of marine scientific expertise to make a valuable contribution to advancing science towards resolving these challenges.

Objectives

The success of this strategic initiative rests on:

i. Advancing the scientific capacity on the three main challenges identified above by engaging the PICES and ICES scientific community in focused workshops, theme/topic sessions and symposia that target key uncertainties and technical barriers that impact the predictive skill of ocean models used to project the impacts of climate change.
ii. Effectively communicating this capacity to clients, member countries, stakeholders and the broader scientific community.
iii. Facilitating an international effort to design data collection networks at the spatial and temporal scales needed to monitor, assess and project climate change impacts on marine ecosystems.
iv. Facilitating international collaboration to design and implement comparative analysis of marine ecosystem responses to climate change through modeling and coordinated process studies.

Key questions

The overarching goal of the initiative will be to answer the following linked questions:

i. How will the physical, chemical and biological components of regional marine ecosystems of the Northern Hemisphere change under future climate scenarios?
ii. How will marine biodiversity change (and thus biodiversity conservation objectives) as a result of pressures on the physiology, behavior and ecology of individuals, populations and ecosystems within the PICES and ICES regions?
iii. How will the demand for, and delivery of, ecosystem services change in response to anthropogenic and climate change driven changes to ecosystems?
iv. How will societies that depend on ecosystems services respond to climate-driven changes in ecosystem services, and which responses are consistent with an ecosystem approach to management?
v. What are the most significant key sources of uncertainty in projections of climate-ecosystem projections? Is it possible to design monitoring, process-oriented or laboratory studies to reduce this uncertainty?
vi. What research is needed to understand the interactive nature of climate and resource exploitation on marine ecosystem functioning?

Relation of the initiative to ICES and PICES strategic plans

The Science Plan for an ICES/PICES SICCME is responsive to both PICES and ICES Missions. In the case of PICES, a strategic plan for climate change research would respond to all aspects of the new FUTURE research plan by evaluating current and future assessments for the *Status, Outlooks, Forecasts and Engagement* (SOFE) Advisory Panel (AP). Members of the SICCME would conduct research that would advance our understanding of climate change impacts on marine ecosystems which is consistent with the mandate for the *Climate, Oceanographic Variability and Ecosystems* (COVE) AP. With respect to the *Anthropogenic Influences on Coastal Ecosystems* (AICE) AP, the SICCME would draw from, and contribute to, new science. Members of the SICCME would utilize information on expected trends in anthropogenic forcing on coastal ecosystems to develop scenarios for use in projecting the implications of climate change on marine ecosystems. Likewise, the output from projection models could be used by others to address issues such as placement of marine protected areas and marine spatial planning. Modelers attempting to project the future food production from sea ranching and aquaculture could utilize products from the SICCME. Thus, the SICCME research would sit at the intersection of all three of the FUTURE Advisory Panels (Fig. A4.1). The SICCME would also be directly responsible to the standing committees of PICES through its focus on climate change impacts on physical oceanography (POC), fish and shellfish (FIS), marine ecosystems (BIO), and in a more limited regional aspect on marine environmental quality (MEQ). Clearly, the SICCME serves as a cross-cutting research effort that aligns the different aspects of the PICES community around a highly visible research issue that is of crucial importance to decision makers and the public.

This SICCME Science Plan is also responsive to the ICES overarching goal "*To advance the scientific capacity to give advice on human activities affecting, and affected by, marine ecosystems*". Members of the SICCME will oversee the development and testing of projection models. No single modeling approach has emerged as the best for forecasting. Therefore, we will follow the example of the IPCC and encourage the formation of model ensembles that apply different approaches to project the future status of marine ecosystems under different management strategies. As such, the SICCME will integrate climate change research and fishery science within the wider ecosystem context to provide advice on the Principles of Sustainable Development under a changing climate. The talents and creativity of all scientists within the ICES community will be needed to develop current and future projections of the implications of climate change on marine resources and to develop strategies to respond to these changes. The ICES/PICES SICCME is particularly responsive to the SICOM Steering Groups on: Ecosystem Function (SSGEF), Human Interactions on the Ecosystem (SSGHIE), and the Sustainable Use of the Ecosystem (SSGSUE). The SICCME will draw from and contribute to the ICES PICES Initiative to Review Recent Advances in Stock Assessment Models Worldwide (SISAM).

The proposed SICCME will work closely with emerging expert groups that are tasked with providing research products to address focused tactical or strategic issues related to climate change. Members of the SICCME will include scientists who are experts in climate change related research, therefore, it is likely that some members of the SICCME will also serve as members of expert groups proposed to address a specific issue relevant to climate change research. This type of cross-cutting research is encouraged because it provides an opportunity for members of the SICCME to share the larger vision for climate change related research in a more focused setting. Joint membership will allow the SICCME to stay abreast of current science, methods and techniques related to climate change. The recent relationship between WG-FCCIFS and PICES Working Group on *Evaluations of Climate Change Projections* (WG 20) serves as an excellent example of how this cross-cutting activity would occur. The WG-FCCIFS was established to improve our understanding of and our capability to forecast the implications of climate change on marine fish and shellfish populations. WG 20 was established to review techniques for downscaling IPCC-class models for use in predicting impacts on ocean ecosystems. The two groups worked closely together to produce two papers for the Sendai symposium volume that applied an interdisciplinary approach to forecasting (*e.g.*, King *et al.*, 2011; Mueter *et al.*, 2011). We expect that similar partnerships and collaborations will emerge on issues related to impacts on coastal communities and other human dimensions. If approved, ICES and PICES will task the SICCME to establish a longer term and ongoing research activities related to improving our understanding of, and our ability to predict, climate change impacts on marine ecosystems. We will continue to work closely with ICES and PICES expert groups to ensure a smooth exchange of information between groups.

The SICCME proposes an ambitious new research effort that will focus on an issue that is of global significance. The world needs our advice, and we stand ready to devote our time and energy to provide answers to the pressing societal questions of future food security, sustainable management strategies under a changing climate. To provide these answers ICES and PICES must improve their understanding of the mechanisms linking climate and physics to marine ecosystem vulnerability, status, trends and function. Improving understanding must include sustained monitoring and targeted field studies to assess model skill and validate key parameters and functional relationships. This will require strong partnerships with national and international research organizations. The SICCME will assist ICES and PICES and their member countries by communicating and integrating PICES and ICES research into national and international research organizations that could contribute to a coordinated global research effort on climate change. Potential research partner organizations include: the Food and Agriculture Organization (FAO), the Intergovernmental Ocean Commission (IOC), the Integrated Marine Biogeochemstry and Ecosystem Research program (IMBER), the Scientific Committee on Oceanic Research (SCOR), and the World Bank. In the near term, the SICCME activities will help to identify opportunities to coordinate field and modeling research to maximize the opportunity for regional comparisons and testing responses of living marine resources to climate change. Scientific collaborations will be facilitated through expert group meetings, workshops, and topic/theme sessions at annual meetings or symposia. Members of the SICCME will strive to identify and respond to funding opportunities to leverage funding to maximize the utility of the research.

Structural issues

The SICCME will be jointly managed by ICES SCICOM and PICES Science Board (Fig. A4.1). The Co-Chairs of the SICCME will make annual reports to the ICES Steering Groups, SSGEF and SSGHIE, and the PICES standing committees, FIS, POC and BIO. The SICCME will also report to PICES FUTURE's Advisory Panels, SOFE, COVE and AICE. The initiative will facilitate new interest and thinking, at all ecosystem levels from physics to fish and fish to markets. It is not intended to set up new structures, rather it will work within the structural framework of ICES and PICES to engage and inspire the scientific community to direct their intellect to improving our ability to predict climate change impacts, to communicate these impacts to decision makers and to assess the performance of management strategies under a changing climate.

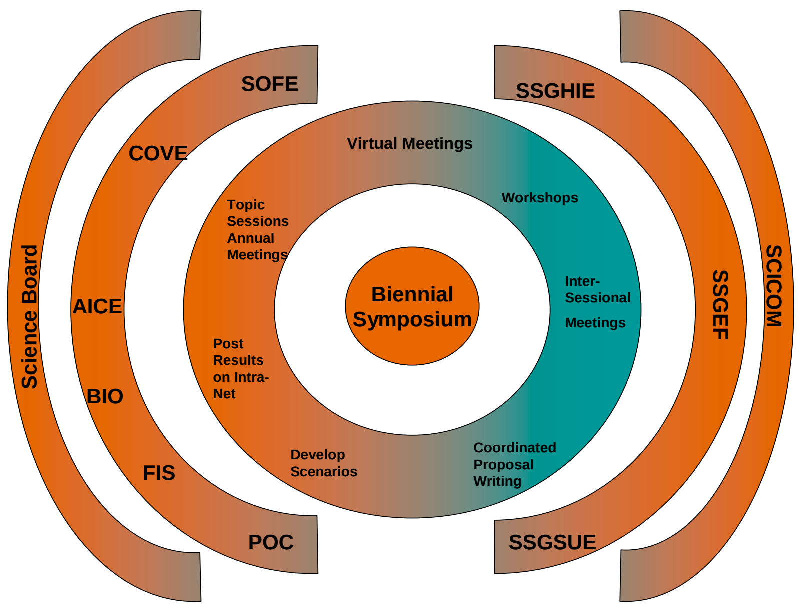


Fig. A4.1 A conceptual model of the Strategic Initiative on Climate Change and Marine Ecosystems showing concentric circles that represent how members of the initiative will conduct their research and report to ICES and PICES.

The SICCME will identify approaches and operational practices that will facilitate and encourage development of integrated scenarios of climate impacts on marine systems by engaging scientists from diverse backgrounds, including: climatology, oceanography, ecology, fisheries, technology, social-science, and markets. Members of the SICCME will include representatives with expertise in each of these areas. The SICCME will strive to co-convene a major international symposium that will showcase the accomplishments of ICES and PICES scientists working on climate change related activities on a biennial basis (Fig. A4.1). Selected papers from the symposium will be published in scientific journals such as the *ICES Journal of Marine Science*. This will have the dual impact of providing a venue for scientists from other regions to share results and ideas and of raising the visibility of the ICES Journal. By scheduling the symposium on a regular basis, scientists will be able to plan collaborative research to take advantage of the opportunity to meet. Ideally, the venue for the symposium will rotate between locations on the Atlantic and locations on the Pacific. This will maximize the opportunity for participation by young scientists who might otherwise be unable to attend. The biennial time-step for symposia is responsive to the IPCC reporting schedule. The IPCC publishes reports on approximately a 5-year time-step. We expect that the new science published in symposium volumes will be cited by the IPCC, and that the new scenarios provided by the IPCC will be used by members of the SICCME to force regional ocean circulation models. The proposed biennial time-step for the ICES/PICES SICCME symposia ensures this complementary relationship is preserved.

In the intervening period between symposiums, members of the SICCME will conduct semi-annual virtual meetings that utilize the internet meeting software. If a sufficient number of members plan to attend an inter-sessional meeting, an in-person meeting of the SICCME may be scheduled as well. During virtual or in-person meetings, members will plan inter-sessional workshops, and topic/theme sessions for the PICES Annual Meetings and ICES Annual Science Conferences. Inter-sessional workshops and topic/theme sessions will provide venues to plan, discuss, and coordinate international collaborative research that will advance our understanding of climate change effects on marine ecosystems.

Members of the SICCME will be drawn from PICES and ICES. The travel costs associated with sending large numbers of scientists to two meetings each autumn can be high. Therefore, the SICCME will strive to rotate their sponsored theme/topic sessions between the the PICES Annual Meetings and ICES Annual Science Conferences. This would not limit co-sponsorship of a theme/topic session during an "off-cycle" year.

It is expected that selected members of the SICCME will report to the PICES and ICES scientific steering bodies annually by summarizing the activities of the expert group and submitting proposals for topic/theme, inter-sessional or biennial symposiums.

Sound science necessitates collaborative integrative research on a global scale. The framework shown above will facilitate opportunities for this type of work and will lead to regular publications of results in the peer-reviewed literature.

As scientists develop scenarios and models to project the implications of climate change they will inevitably identify key sources of uncertainty. Left unaddressed this uncertainty will propagate through the projections. We anticipate that the activities of the SICCME will raise awareness of the need for long-term spatially resolved ocean monitoring data and focused field and laboratory studies to address these issues. These recommendations will be communicated to PICES Technical Committee on Data Exchange (TCODE) and other interested steering groups within ICES and PICES.

There is a long list of potential clients who would be interested in the SICCME products. The SICCME will develop a strategy to ensure that new findings are communicated to the governing bodies of ICES and PICES to keep the organizations updated on findings, initiatives and opportunities. The SICCME will work with the FUTURE SOFE AP to develop a strategy to ensure that national and international science organizations are aware of opportunities for global collaboration.

All indications at present suggest that there will be an increasing demand for marine resources as the population continues to grow through 2050. Understanding the limits of marine ecosystem extraction will necessitate simulations of climate impacts on marine systems and scenarios for resource extraction. Successful implementation of this initiative will position PICES and ICES to be the leading organizations to respond to this demand. Following the IPCC model, we anticipate that once the projection models have been fully reviewed, and properly tested, the scenarios for ecosystem change under different climate scenarios will be made available through PICES and ICES websites.

Benefits

The proposed ICES/PICES SICCME will have the following anticipated benefits:

- Increased understanding of physical, chemical and biological linkages and ecosystem responses to anthropogenic and climate forcing;
- Coordinated monitoring and descriptions of the current state of ecosystems;
- Projections of future states of Northern Hemisphere marine ecosystems and their associated uncertainty;
- More robust quantitative and qualitative forecasts, with specified uncertainty, of ecosystem responses to climate change and increasing human influence;
- IPCC-like reports on responses of Northern Hemisphere marine ecosystems to climate change;
- Quantification of the benefits and risks associated with different management strategies;
- Increased marine science capabilities in ICES and PICES member countries.

These benefits were also listed in the PICES FUTURE Science Plan. While the FUTURE program established the vision and the plan for climate change research, the SICCME provides the foundation of working scientists that will ensure that work is completed and delivered in a manner consistent with the goals and objectives of SICOM and PICES Science Board. The pace of discovery, innovation and progress will be accelerated through adoption of this initiative that will facilitate rapid exchange of information between ICES and PICES scientists. The formation of the ICES/PICES SICCME will expand opportunities for use of the comparative approach by extending our partners to other regions in the Northern Hemisphere.

Timeline

- Second Quarter 2011: Submit proposal (the present document);
- May and April 2011: Present proposal to ICES and PICES governing bodies;
- May 2011: First planning meeting in conjunction with the ESSAS Open Science Meeting;
- Summer 2011: Develop draft Implementation Plan;
- September 2011: Second planning meeting in conjunction with the ICES ASC;
- October 2011: Third planning meeting in conjunction with the PICES Annual Meeting;
- Fourth Quarter 2011: Finalize the membership;
- Last Quarter 2011: Start-up;
- May 2012: Co-convene a Theme Session on “*Climate change effects on living marine resources: From physics to fish, marine mammals, and seabirds, to fishermen and fishery-dependent communities*” at the PICES/ICES/IOC Symposium on “*Effects of climate change on the world’s oceans*” (Yeosu, Korea);
- September 2012: Finalize Implementation Plan.

Implementation Plan for the ICES/PICES Strategic Initiative (Section) on Climate Change Effects on Marine Ecosystems

Vision

ICES and PICES will become the leading international organizations providing science and advice related to the effects of climate change and variability on marine resources and ecosystems.

ICES and PICES will develop the scientific basis for evaluating the vulnerability, status and sustainability of marine systems under changing climate conditions. Collaborative research within ICES and PICES will facilitate the development, maintenance and evolution of a network of regional interdisciplinary research teams that will share research approaches on a global scale to foster laboratory, field and modeling activities that will provide data and understanding at the spatial and temporal scales needed to monitor, assess and project climate change impacts on marine ecosystems.

Background

In the spring of 2011, ICES and PICES agreed in principle to move forward on the Science Plan for an ICES/PICES Strategic Initiative on Climate Change Effects on Marine Ecosystems (SICCME). As stated in the Science Plan the goal of SICCME will be to:

i. Define the research activities needed to understand, assess and project climate change impacts on marine ecosystems with sufficient spatial and temporal resolution to plan strategies for sustaining the delivery of ecosystem goods and services and the preservation of biodiversity. When possible predictions should include quantifying estimations of uncertainty.
ii. Define and quantify the vulnerability of marine ecosystems to climate change, including the cumulative impacts and synergetic effects of climate and marine resource use.
iii. Build global ocean prediction frameworks, through international collaborations and research, building on ICES and PICES monitoring programs.

In support of this effort, ICES and PICES requested the co-chairs to work in conjunction with members of ICES and PICES to develop an implementation plan for this initiative. The Science Plan outlines the goals and objectives of the initiative and the framework for how members of SICCME will work with other science advisory bodies within ICES and PICES. This Implementation Plan focuses on the specific research activities that members of the SICCME will conduct and will provide a timeline for completion of research products. Since the SICCME is designed to provide a roadmap for a long-term effort within ICES and PICES, this implementation plan should be considered a guide for future research that is responsive to the changes and new science that will emerge over time.

Phased implementation

The SICCME Science Plan envisioned that successful implementation of the initiative would position ICES and PICES to be the leading international groups to provide scientific information on the implications of climate change on marine ecosystems in the Northern Hemisphere. The key deliverables for ICES and PICES are the development of sufficient knowledge and understanding to successfully predict the future implications of climate change on marine ecosystems and the ability to use this information to develop strategies for managing living marine resources under a changing climate. The SICCME Implementation Plan is designed to facilitate and accelerate the acquisition of new knowledge and to insure that new knowledge is communicated and published on a schedule that would allow it to be useful to, and considered by, international scientific organizations responsible for providing advice on climate change such as the Intergovernmental Panel on Climate Change (IPCC) and the United Nations. To be responsive to the international bodies likely to use our research products, the implementation of the SICCME should occur in phases. These phases address the relationship between the SICCME and the IPCC (Fig. A4.2). While the specific activities may change overtime, three elements of the SICCME implementation plan are always present: synthesis of existing knowledge, advancement of new science and methodology, and communication of research findings.

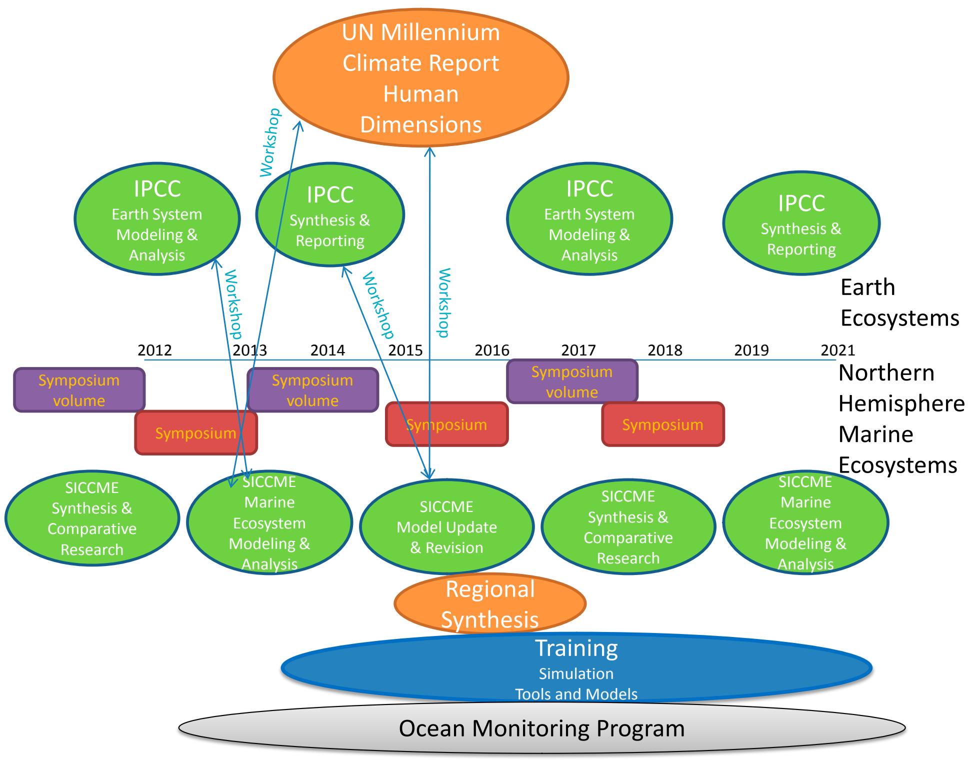


Fig. A4.2 Schematic timeline for SICCME research activities and interactions with Earth System research organizations.

Phase 1, 2012-2014

During this period members of the IPCC are conducting their assessments. The SICCME will focus their work on the synthesis of existing information acquired during the 2010 international symposium in Sendai, Japan, testing of modeling techniques based on IPCC Assessment Report 4, and the facilitation of new interdisciplinary research within ICES and PICES. The key activities of the SICCME that will occur during this period are as follows:

1. **Synthesis of existing knowledge**. Members of the SICCME plan to write a synthesis paper that will provide an overview of the implications of climate change on marine ecosystems. The paper will draw heavily from the results of the recent climate change symposium held in Sendai, Japan, in April 2010 and on the position paper developed by the ICES Steering Group on Climate Change. This synthesis will provide a valuable reference for consideration by IPCC writing teams which also are responsible for providing concise interpretations of the vulnerabilities of marine ecosystems to changing climate.

2. **Advanced science and methodology**. The results from the Sendai symposium revealed that no single analytical approach was superior to others when considering tools to predict future climate change impacts on marine ecosystems. Each approach had inherent strengths and weaknesses. In Phase 1, research will focus on four critical issues:
   a. Identifying techniques for predicting climate change impacts in systems impacted by decadal variability;
   b. Defining the vulnerability of commercial species to climate change and identifying which species would be most likely to experience shifts in spatial distributions;
   c. Engaging the global earth system modeling community in modeling climate change effects on marine ecosystems and identifying opportunities for collaborations;
   d. Building response scenarios for how the human community will respond to climate changes.

3. **Communication and integration of science through international symposiums**. In Phase 1, scientists will continue to refine methods and scenarios for use in predicting the status of marine ecosystems under changing climate conditions. Therefore, the primary vehicle for communication of results will continue to be the development of papers that will be published in the peer-reviewed literature including journals such as the *ICES Journal of Marine Science*. Members of the SICCME will identify and facilitate new research partners by serving as symposium/session co-convenors including the upcoming Symposium on "*Effects of climate change on the world's oceans*" in Yeosu, Korea, in 2012. These activities will raise global awareness of ICES and PICES as key organizations responsible for advancement of new science on climate change related issues in the marine environment.

Advancing science and methodology (2 above) will be the major activity of the SICCME in Phase 1. The SICCME will address this issue through an ambitious suite of international collaborations and integrated research.

The SICCME will address the issue of forecasting climate change in systems impacted by decadal variability (2a above) through a series of theme/topic sessions at ICES Annual Science Conferences and PICES Annual Meetings. During Phase 1, the SICCME will propose the following theme/topic sessions and inter-sessional workshops:

- Theme Session on "*Climate change effects on living marine resources: From physics to fish, marine mammals, and seabirds, to fishermen and fishery-dependent communities*" for the PICES/ICES/IOC Symposium on "*Effects of climate change on the world's oceans*" in May 2012, in Yeosu, Korea;
- Theme Session on "*Basin-wide impact of Atlantic Multidecadal Oscillation (AMO)*" for the ICES ASC in Bergen, Norway in 2012. This theme session will build on the outcomes of the AMO workshop held in June 2011 in Woods Hole, USA;
- Topic session on "*Comparison of impact of multi-decadal climate variability in N. Pacific and N. Atlantic ecosystems and corresponding teleconnection patterns*" for the 2012 PICES Annual Meeting in Hiroshima, Japan;
- The SICCME will work with the newly formed PICES Working Group on *North Pacific Climate Variability and Change* (WG 27) to foster integration and synthesis of ideas between SICCME and WG 27 scientists. The SICCME anticipates that PICES and ICES will work together to promote an inter-sessional workshop on comparison of impact of multi-decadal climate variability in the North Pacific and North Atlantic. It is possible that this workshop will be proposed to be held in conjunction with the Symposium on "*Effects of climate change on the world's oceans*" in May 2012 in Yeosu, Korea.

These workshops and theme sessions will address the first part of Key Question v in the SICCME Science Plan: v) *What are the most significant key sources of uncertainty in projections of climate-ecosystem projections?* The outcome of the proposed SCCIME activities will be particularly relevant to the ICES Steering Group on Ecosystem Function (SSGEF), and the Steering Group on Human Interactions on the Ecosystem (SSGHIE), PICES FUTURE Advisory Panel on *Climate, Ocean Variability and Ecosystems* (COVE), and PICES FIS, POC and BIO standing committees.

The SICCME will address issues of criteria for successful colonization and vulnerability assessment under climate change (2b above) through a combination of science sessions during ICES Annual Science Conferences and PICES Annual Meetings, and through planned inter-sessional symposiums. In 2012, the SICCME will contribute to the following theme sessions and workshops on this subject:

- Collaborate with ESSAS on Theme Session on "*Climate change effects on spatial distributions and interactions of Arctic and Sub-Arctic fish and their implications for future fisheries*" (ICES ASC, September, Bergen, Norway);
- ICES and EU project Forage Fish Interactions (FACTS) symposium on "*Forage fish interactions: creating tools for ecosystem based management of marine resources*" (November, Nantes, France).

We expect that issues of fish vulnerability and susceptibility to climate change will be discussed during these meetings. This effort will address SICCME Goal ii (see above) and Key Question ii in the SICCME Science Plan: ii) *How will marine biodiversity change (and thus biodiversity conservation objectives) as a result of pressures on the physiology, behaviour, and ecology of individuals, populations and ecosystems in the PICES and ICES regions?* It is expected that the outcomes of SICCME activities will be particularly relevant to the ICES SSGEF, the SSGHIE and the Steering Group on Sustainable Use of the Ecosystem (SSGSUE), PICES FUTURE Advisory Panels COVE, and *Status, Outlooks, Forecasts and Engagement* (SOFE), and PICES FIS, POC and BIO standing committees.

The SICCME will provide a forum to address the gap in science and methodology (2c) by convening an inter-sessional workshop with the Earth System modeling community in 2013. This timing is selected to avoid key production periods associated with the activities of Working Group 1 of the IPCC. This workshop would bring together representatives of each of the major earth system modeling centers and members of the climate change research community within ICES and PICES. The goal of this meeting will be to foster communication of what capabilities and analytical constraints each group has and to design efficient ways to exchange or integrate information. We expect that members of the newly formed ICES/PICES modeling working group will participate as well as members of the new PICES Working Group on *North Pacific Climate Variability and Change* (WG 27). This effort will address Key Question i in the SICCME Science Plan: i) *How will the physical, chemical and biological components of regional marine ecosystems in the Northern Hemisphere change under future climate scenarios?* The outcome of this workshop will be particularly relevant to ICES SSGEF and SSGHIE, PICES FUTURE Advisory Panels COVE and SOFE, and PICES FIS, POC and BIO standing committees.

SICCME will address gaps in knowledge of the human dimension (2d) by holding an inter-sessional workshop in 2013/2014 comprised of key experts on trends in human populations, marine resource economics, natural resource management, seafood markets (needed to forecast future shifts in demand for seafood), aquaculture, marine ranching, and commercial fishing with members of the ICES and PICES climate change research community. The goal of this meeting will be to develop regional scenarios for future use of marine resources. These regional scenarios will be used to address time trends in marine resource extraction to develop strategic advice on the trade-offs of different management approaches. We anticipate that members of the ICES SSGHIE and the potential PICES human dimensions expert group will be interested in participating in this workshop. This effort will address Key Questions iii, and iv in the SICCME Science Plan: iii) *How will the demand for, and delivery of, ecosystem services change in response to anthropogenic and climate driven changes to ecosystems?* iv) *How will societies that depend on ecosystem services respond to climate-driven changes in ecosystem services, and which responses are consistent with an ecosystem approach to management?* This effort will also help ICES and PICES to engage stakeholders and the broader scientific community in our effort to predict the implications of future climate change on marine ecosystems in the Northern Hemisphere. It is expected that the outcome of this SICCME activity will be particularly relevant to the ICES SSGHIE and SSGSUE, PICES FUTURE Advisory Panels COVE, SOFE, and *Anthropogenic Influences on Coastal Ecosystems* (AICE), and PICES FIS, POC and BIO standing committees.

Phase 2, 2015–2017

During Phase 2, members of SICCME will explore the implications of the IPCC's 5th Assessment Report (AR5). The primary activity of the SICCME will be to update and evaluate models to assess the implications of the revised climate change scenarios with respect to marine ecosystems. The SICCME will work to advance this effort in a manner similar to that recently completed by the ICES/PICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS) and PICES Working Group on *Evaluations of Climate Change Projections* (WG 20).

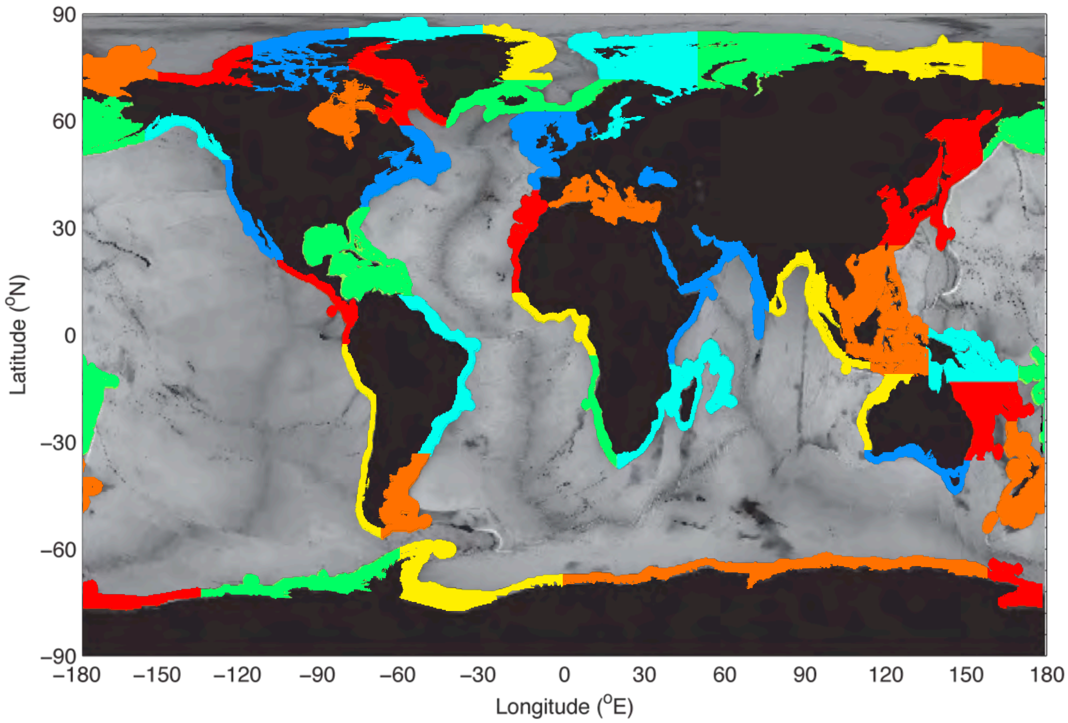


Fig. A4.3 Potential partitions for regional summaries based on the QUEST-fish program modeling effort.

1. **Synthesis of existing knowledge.** During Phase 2, the SICCME will work with ICES and PICES to develop a synthesis of the effects of climate change on regional marine ecosystems of the Northern Hemisphere. Planning for this report will be done in conjunction with PICES SOFE Advisory Panel and the ICES Publications Committee. The SICCME envisions that these regional syntheses will serve as a useful reference to scientists within and outside of ICES and PICES. These regional summaries will draw on the work performed in Phase 1 and on previous work completed by the PICES and ICES communities (*e.g.*, the ICES Steering Group on Climate Change position paper). As a starting point for discussion, the SICCME suggests that boundaries for regional synthesis reports should consider the Quantifying and Understanding the Earth System (QUEST) Fish program regional partitions (Fig. A4.3). Using these boundaries would have the distinct advantage of aligning impacts assessments with the location of existing modeling groups. We note that it may be useful to consider the Arctic ecosystem as a single system because of the connections between regions and the relative paucity of information. Furthermore, the regional partitions shown in Figure A4.3 roughly align with existing reporting regions for the PICES ecosystem status report. Publication of these regional summaries should be timed to allow their consideration by the IPCC in the formation of the AR6 report (for 2018). This effort will facilitate international collaboration and will provide a vehicle to communicate our current knowledge to stakeholders and the broader scientific community.

2. **Advanced science and methodology**. Phase 2 will be a busy period for scientists with the SICCME as they work with the information release from the IPCC AR5. As was the case with the release of the IPCC AR4 report, considerable effort will be required to interpret and integrate the results of the new IPCC scenarios into regional assessment models of marine ecosystems. The SICCME will encourage this work through collaborations with ICES and PICES standing committees. The research conducted in Phase 1 will guide these updates and collaborations. Further guidance will be provided by the conclusions and advice of the ICES/PICES ecological modeling working group. The SICCME will consider these results to inform the selection of different modeling approaches.

3. **Communication and integration of science through international symposiums.** Members of the SICCME will serve on the symposium steering committee and as co-convenors of scientific sessions for an international symposium on effects of climate change on fish and fisheries that will be held in Europe in 2014. The format for this symposium will be similar to that of the symposium held by the WG-FCCIFS in Sendai, Japan in 2011. One possible option would be to hold the meeting in conjunction with FAO to foster collaboration and integration of the research on the UN Millennium project.

Phase 3, 2018–2020

In Phase 3, the SICCME will conduct activities similar to those described in Phase 1. In addition, the SICCME will strive to share the knowledge gained through Phases 1 and 2 with all members within ICES and PICES by introducing a training program and will work to define a climate change impacts monitoring program to help build capacity within ICES and PICES and to support the scientists involved in providing strategic advice on climate change effects on marine ecosystems. Two types of courses will be considered:

Course 1. Fisheries oceanographers and fisheries management. This course will provide training in the use of statistical techniques for detecting biological responses to environmental change and attributing change to anthropogenic or natural causes. The course will review the strengths and weakness of different modeling approaches and will provide a guide for what type of simulation tool would be best suited for addressing a particular type of ecological impacts question or strategy evaluation. Students will be exposed to case studies where they will learn how to adapt simulation tools for applications for their region.

Course 2. Advanced ecosystem modeling and model development. This course will be designed for advanced ecosystem modelers. The background for participants will be a working knowledge of the Regional Ocean Modeling System, Automatic Differentiation Model Builder, and the R statistical package. Teachers will provide a series of lectures and presentations on the functional relationships used in different simulation modeling approaches. Downscaling techniques for coupling models developed at different temporal and spatial scales will be discussed. Students will work through case studies to learn how to modify existing models for use in their region.

The SICCME Science Plan envisions that ICES and PICES will "*Build global ocean prediction frameworks through collaborations and research, building on ICES and PICES monitoring programs*". In Phase 3, the SICCME will have sufficient information to design a climate monitoring program that addresses key sources of uncertainty in earth system models or regional marine ecosystem models. The SICCME will hold a workshop with the earth modeling and ocean modeling communities to identify what type of monitoring is needed to assess the temporal and spatial signature of climate change and to monitor responses of marine organisms to this change. This activity will be conducted in conjunction with the PICES Technical Committee on Monitoring (MONITOR) and related groups within ICES. This activity will address Key Question vi of the SICCME Science Plan: vi) *What research is needed to understand the interactive nature of climate and resource exploitation on marine ecosystem functioning?*

Conclusion

The goals and objectives of the SICCME are ambitious and will require that scientists within ICES and PICES engage in collaborative interdisciplinary research. The Implementation Plan illustrates how the SICCME will work within the ICES and PICES governance structures to accelerate advancements in our understanding of climate change effects on marine ecosystems. The plan outlines a suite of linked inter-sessional workshops, international symposiums, topic/theme sessions that will engage the collective knowledge and expertise of ICES and PICES scientists. By enlisting the minds and energy of scientists throughout the Northern Hemisphere, ICES and PICES will be able to deliver credible scientific advice regarding climate change effects on marine ecosystems in the near future.

Appendix 5

Meeting reports from past PICES Annual Meetings related to WG-FCCIFS activities

PICES Sixteenth Annual Meeting (PICES XVI)
October 26–November 5, 2007
Victoria, Canada

Extracted from:

2007 Report of the Fishery Science Committee

Workshops on "*Forecasting climate impacts on future production of commercially exploited fish and shellfish*" (FIS Agenda Item 5a)

Dr. Hollowed reported on two FIS workshops on "*Forecasting climate impacts on future production of commercially exploited fish and shellfish*", co-sponsored by PICES and NPRB. The first workshop was held July 19–20, 2007, in Seattle, USA, and the second follow-up workshop was convened on October 30, 2007, at PICES XVI. The proceedings of both workshops will be combined into one report to be published by PICES.

Proposals for new FIS subsidiary bodies (FIS Agenda Item 11)

…..The proposal to form a Working Group on *Implications of Climate Variability and Climate Change on Trends in Commercially Important Fish and Shellfish* (*FIS Endnote 6*) received strong support from the Committee. It was indicated that this effort is consistent with the activities envisioned under FUTURE and that PICES-sponsored work in this area would provide a good start to this line of research that is likely to become an ongoing effort in FUTURE. It was noted that the title of the Working Group could be shortened to reflect emphasis on commercially exploited species (so the title reported here is tentative). It was also suggested that a phased approach to initially implement forecasts for those species with the most complete information on climate linkages would be best. For other species with incomplete information, a scenario approach may be best until research confirms the nature of climate linkages for those species. Dr. Hollowed proposed that if the Working Group is approved, its first meeting should be held in conjunction with PICES XVII in Dalian.

FIS Endnote 6

Proposal for a Working Group on *Implications of Climate Variability and Climate Change on Trends in Commercially Important Fish and Shellfish*

An interdisciplinary Working Group to facilitate a coordinated international research effort to forecast climate change impacts on the distribution and production of major fisheries in the Northern Hemisphere is proposed. The objectives of the Working Group are to:

- review the activities of existing programs within each nation;
- examine the evidence for climate impacts on production of commercial fish species;
- develop medium-term to long-term forecasts of climate impacts on fish production; and
- assess the performance of management strategies to respond to these changes in production.

An interdisciplinary team of scientists representing the fields of climatology (global climate modeling), oceanography (physical and biological oceanography, and coupled biophysical models), fisheries oceanography, fish population dynamics, fisheries assessment, fisheries economics and ecosystem modeling will be assembled. This team would identify climate scenarios for use in forecasting and then develop tools for predicting climate impacts on commercial fish production. These tools will be used to develop quantitative forecasts of fish production around the Pacific Rim. The Working Group will provide a forum for discussion of four components needed to complete the forecasts in a timely and coordinated fashion including: (1) IPCC scenarios, (2) predictions of oceanographic impacts, (3) modeling approaches, and (4) scenarios for natural resource use and enhancement.

This Working Group builds on the work of the Climate Forcing and Marine Ecosystems Task Team (CFAME) and continues collaboration between FIS and POC via interactions with the Working Group 20 on *Evaluations of Climate Change Projections*. This effort is directly responsive to FUTURE and will encourage timely completion of early forecasts and associated management implications that can be used by FUTURE Task Teams to formulate cooperative research programs focused on improving forecasting skill through knowledge of processes influencing marine fish production. Expected benefits from this effort are as follows:

- International consensus could be reached on new directions for fisheries modeling and techniques for incorporation of ecosystem indicators and climate forcing in stock assessments.
- It is anticipated that the results of the coordinated research effort will be utilized by a broad spectrum of individuals outside of the research community. Stakeholders who rely on fish and shellfish resources will utilize the forecasts to anticipate changes that would influence their businesses and communities. Fisheries managers will utilize the forecasts to evaluate whether actions are needed to sustain fisheries in their regions. Conservation groups will be interested to better understand the regional and species-specific risks and challenges that climate change poses for species of interest.

The life span of the Working Group is 3 years and its milestones are:

- October 2008 – Convene an inter-sessional workshop to present forecasting results and to introduce techniques for evaluating management strategy evaluations;
- October 2009 – Report on implications of climate change and climate variability on commercial fish species (a contribution to the North Pacific Ecosystem Status Report);
- December 2009 – Finalize manuscript for publication in peer-reviewed literature.

Proposal proponents: Anne B. Hollowed and Michael Schirripa (USA) and Richard J. Beamish (Canada).

PICES Seventeenth Annual Meeting (PICES XVII)
October 24–November 2, 2008
Dalian, China

Extracted from:

2008 Report of the Fishery Science Committee

AGENDA ITEM 7
Status reports of FIS-sponsored groups

Dr. Hollowed provided a report of workshop W4 on "*Climate scenarios for ecosystem modeling*" sponsored by CCCC/POC/FIS. A written summary was provided and can be found in the Session Summaries chapter of the PICES 2008 Annual Report. The workshop discussion revolved around how to provide the climate scenarios for modeling of ecosystem effects. The proposal for a PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* was introduced. As this is a global issue, the proposed co-chairs would include both ICES and PICES members. The issues are well defined and several working group meetings are proposed; some would be virtual meetings. The proposal included a symposium to be held in early 2010 with the proceedings to be published in peer-reviewed literature by 2011. This time-critical deadline was chosen in light of the timetable for developing the 2013 IPCC report. In addition to a 2010 symposium, the proposal also included a request for a working group meeting at the GLOBEC Open Science Meeting (June 22–26, 2009, Victoria, Canada). It was noted that the proposed working group was already approved by ICES. FIS actions on the proposed new working group are reported under Agenda Item 10.

AGENDA ITEM 10
Proposals for new FIS Working Groups and Study Groups

FIS recommended approval of the PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS). It was approved last year by FIS, but the proposal was deferred by Science Board until 2008 in order to involve PICES Working Group on *Evaluations of Climate Change Projections*. FIS noted that this proposed Working Group is in line with FUTURE goals. A question was raised about the relationship between this Working Group and a possible task team of FUTURE. It was premature for a definitive answer, but the Working Group could possibly evolve into a task team. However, FIS urges that this work needs to proceed and cannot wait for FUTURE to be finalized. Dr. Hollowed recommended a meeting of the proposed Working Group to take place immediately prior to PICES-2009 in Korea.

Extracted from:

2008 Report of the Physical Oceanography and Climate Committee

AGENDA ITEM 5
Reports of existing subsidiary bodies and plans for new ones

Proposed new ICES/PICES (FIS/POC) Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish*

Dr. Foreman presented the background and Terms of Reference (see *POC Endnote 3*) for a proposed new ICES/PICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish*. It was resolved that POC would support the creation of this group.

POC Endnote 3

Proposal for a new PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS)

Proposed Parent Committees

ICES approved the formation of WG-FCCIFS as a permanent working group. FIS will serve as the parent committee for WG-FCCIFS with support from POC. The activities of WG-FCCIFS may be integrated into the PICES FUTURE program as a task team. WG-FCCIFS will report to the ICES Climate Change Steering Group, ICES Oceanography Committee, and the PICES FIS and POC Committees.

Suggested Co-Chairmen

Anne Hollowed (USA), Manuel Barange (United Kingdom), Suam Kim (Korea), Harald Loeng (Norway).

[Suggested Working Group members: James Overland – USA (ESSAS, PICES POC) , Shin-ichi Ito – Japan (ESSAS, PICES POC), Michael Foreman – Canada (PICES POC), Sang-Wook Yeh – Korea, Thomas Okey – Canada (PEW Trust), Richard Beamish – Canada (NPAFC, PICES FIS), Daniel Duplisea – Canada (ICES), Jason Holt – United Kingdom (QUESTFISH, ICES), Keith Brander – Denmark (ICES, IPCC ecosystem writing team), Jürgen Alheit – Germany (ICES, GLOBEC SPACC)]

Rationale

The work of the FCCIFS Working Group is essential to ensure that ICES and PICES will be able to provide guidance on the potential impacts of climate change on marine ecosystems and the response of commercial fish and shellfish resources to these changes.

The work done within ICES and PICES on climate change and fisheries has been diverse and has included: a) guidance on methods for selection of IPCC scenarios for use in projections; b) techniques for downscaling IPCC scenarios to local regions, c) development of coupled ecosystem models for use in evaluating climate-induced shifts in environmental conditions, d) literature documenting relationships between climate forcing and marine fish and shellfish distribution and production, and e) stock assessment techniques for evaluating management strategies to mitigate the impacts of change. A challenge facing ICES and PICES is the need to integrate all of this research to provide stakeholders with quantitative estimates of the potential impact of climate change on marine life throughout the world. This challenge calls for the establishment of an interdisciplinary research team composed of experts from around the world who will focus attention on the development of common and standardized frameworks for forecasting climate change impacts on marine life with particular emphasis on commercially important fish and shellfish. ICES and PICES should act now to ensure that our research communities develop the capibilities to provide quantitative contributions to the next IPCC reports and to provide guidance for management under climate change scenarios.

Several case studies will be identified by the Steering Group based on their potential for contributing to methodological development and the opportunity for comparison of marine species and community responses to climate forcing in different ecosystems. Members of the Working Group will be responsible for encouraging the development of regional interdisciplinary teams responsible for the production of forecasts. Members of the working group will provide guidance to the regional teams by providing a framework for the development of the forecasts and communication of new advances in analytical tools. The culmination of the Working Group’s effort will be presentation and discussion of results at an inter-sessional meeting and publication of results in a peer reviewed journal by 2011. The timing for the publication is critical because the future IPCC AR5 report is slated for release in 2013 and the IPCC only allows references to published papers.

Proposed Terms of Reference

We recommend that WG-FCCIFS be established to promote and coordinate research on the potential impacts of climate change on marine fish and shellfish around the world.
The working group will:

1. Promote research on climate change impacts on fish and shellfish by scientists in ICES and PICES member nations through coordinated communication, exchange of methodology, and organization of meetings to provide a venue for discussion and publication of results.
2. Develop frameworks and methodologies for forecasting the impacts of climate change on the growth, distribution and abundance of marine life with particular emphasis on commercial fish and shellfish;
3. Review the results of designated case studies to test methods;
4. Hold an inter-sessional symposium in early 2010 where scientists can present, discuss and publish forecasts of climate change impacts on the world's commercial fish and shellfish resources;
5. Establish techniques for estimating and communicating uncertainty in forecasts;
6. Evaluate strategies for research and management under climate change scenarios, given the limitations of our forecasts;
7. Produce publications that could be considered for the Fifth Assessment Report of the Intergovernmental Panel on Climate Change in 2013;
8. Publish a final report summarizing work.

The Working Group will utilize web technology to hold several virtual working group meetings. They will hold an inter-sessional Working Group meeting on June 21, 2009, one day prior to the GLOBEC Open Science meeting in Victoria, Canada. At that meeting members will review the results of designated case studies and discuss the symposium for 2010. The WG-FCCIFS will report by September 2009 for the attention of the ICES Climate Change Steering Group, ICES Oceanography Committee, and the PICES FIS and POC Committees. The WG-FCCIFS will provide the several case studies that will contribute to the PICES FUTURE program.

Working Group members will seek widened participation for this group, including contact with relevant academic and intergovernmental organizations such as fisheries managers, the North Pacific Anadromous Fish Commission, the Intergovernmental Oceanographic Commission, and FAO for the inter-symposium in 2010.

Extracted from:

2008 Summary of Scientific Sessions and Workshops at PICES XVII

CCCC/POC/FIS Workshop (W4)
Climate scenarios for ecosystem modeling (II)

Co-Convenors: Michael G. Foreman (Canada), Anne B. Hollowed (USA), Suam Kim (Korea) and Gordon McFarlane (Canada)

Background

Members of the *Climate Forcing and Marine Ecosystem* Task Team (CFAME), the Working Group on *Evaluations of Climate Change Projections* (WG 20), and the FIS Committee presented the results of their research on developing and applying the output of regional and global climate scenarios to ecosystem and fish stock forecasts. These groups have been developing conceptual and empirical models of the mechanisms that link climate variation to the dynamics of marine ecosystems and their commercially important species. Their work has focused on comparisons among a diversity of North Pacific ecosystems with differing dominant physical processes. WG 20 is developing higher resolution regional coupled atmosphere–ocean models forced by IPCC global or regional models to provide forecasts of regional parameters (such as SST, sea ice cover, and river discharge) that are relevant to ecosystem processes. This workshop provided an opportunity to discuss the results, present them to the PICES community, and describe their potential for the FUTURE Program.

List of papers

Oral presentations

Thomas A. Okey, Anne B. Hollowed, Michael J. Schirripa and Richard J. Beamish (Invited)
The 2035 modeling challenge for forecasting climate impacts on marine biota and fisheries: A collaboration emerging from an international workshop

James E. Overland, Muyin Wang and Nicholas A. Bond
Utility of climate models for regional ecosystem projections

Young Shil Kang and Sukgeun Jung
Regional differences in responses of meso-zooplankton to long-term oceanographic changes in Korean sea waters

Yasuhiro Yamanaka *et al.*
(WG 20 update): Recent results connecting climate change to fish resources using the high resolution model, COCO-NEMURO

Emanuele Di Lorenzo, N. Schneider, K.M. Cobb, K. Chhak, P.J.S. Franks, A.J. Miller, J.C. McWilliams, S.J. Bograd, W.J. Arango, H. Sydeman, E. Curchister, T.M. Powell and P. Rivere
(WG 20 update): North Pacific Decadal Variability in the FUTURE

James Christian
(WG 20 update): Canadian Earth System Model scenarios for the North Pacific

Qigeng Zhao, Qingquan Li, Jianglong Li and Fanghua Wu
A simulation of acidification in the Pacific Ocean

Enrique Curchitser, William Large, Jon Wolfe and Kate Hedstrom
(WG 20 update): Downscaling climate scenarios with a fully coupled global-to-regional model

Michael G. Foreman, William J. Merryfield, Badal Pal and Eric Salathé
An update of regional climate modeling along the British Columbia Shelf

Vadim Navrotsky
(WG20 update): On the role of ocean and land living matter in Global Climate Change

Anne B. Hollowed, Teresa A'mar, Richard J. Beamish, Nicholas A. Bond, James E. Overland, Michael Schirripa and Tom Wilderbuer
Fish population response to future climate drivers: A next step forward

Gordon H. Kruse, Jie Zheng and James E. Overland
A scenario approach to forecast potential impacts of climate change on red king crabs in the Eastern Bering Sea

Sukyung Kang, Jae Bong Lee, Anne B. Hollowed, Nicholas A. Bond and Suam Kim
Techniques for forecasting climate-induced variation in the distribution and abundance of mackerels in the northwestern Pacific

Michio J. Kishi, Yasunori Sakurai and Masahide Kaeriyama
What affects on the growth and stock of chum salmon, walleye pollack, and common squid in the Northern Pacific

Richard J. Beamish
A tail of two sockeyes

Richard J. Beamish
Evidence that the carrying capacity of local marine ecosystems can regulate the productivity of chinook salmon

Poster

Leonid Klyashtorin and Alexey Lyubushin
Cyclic climate changes and salmon production in the North Pacific

PICES Eighteenth Annual Meeting (PICES-2009)
October 23–November 1, 2009
Jeju, Korea

Extracted from:

2009 Report of the Fishery Science Committee

AGENDA ITEM 5
Reports of FIS-sponsored groups

Joint PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS)

Co-Chairman, Dr. Suam Kim, provided a summary of the activities of WG-FCCIFS. The Working Group had met previously at the GLOBEC Open Science Meeting in Victoria, Canada (June 2009), and at the ICES Annual Science Conference in Berlin, Germany (September 2009). The third meeting of this Working Group took place in Jeju, Korea, during PICES-2009 and another will occur for 1½ days immediately after the International Symposium on "*Climate change effects on fish and fisheries*" in Sendai, Japan, April 26–29, 2010. The Working Group plans to develop web meetings.

WG-FCCIFS finalized the organization of the Sendai symposium, including scientific sessions, invited speakers list, expected results of the conference, finances, and other logistical issues. The Working Group noted that many of their Terms of Reference cannot be achieved until after the symposium. It will provide a forum for discussing frameworks and methodologies for forecasting impacts of climate change on the growth, distribution and abundance of marine life. Dr. Kim noted that the proceedings of the Sendai symposium will be published as a special issue of the *ICES Journal of Marine Science*. However, he noted the Working Group's desire to produce a second publication, likely to be a synthesis of the Sendai workshops. FIS discussed and supported this proposal. Finally, WG-FCCIFS proposed a Topic Session for PICES-2010 on "*Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting*". (See POC Endnote 5, below.)

Extracted from:

2009 Report of the Physical Oceanography and Climate Committee

AGENDA ITEM 4
Reports of existing subsidiary bodies and plans for ones

PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS)

Dr. Shin-ichi Ito gave a brief report summarizing activities of WG-FCCIFS over the past year and an update on the status of the Group's upcoming Symposium on "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses, and evaluating management strategies*" in Sendai, Japan, April 26–29, 2010.

POC Endnote 5

(4.) a 1-day POC/FIS/BIO/FUTURE Topic Session on *"Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting"*
[sponsorship later changed to POC/FIS/BIO]

Understanding the role of natural variability, occurring over a variety of temporal and spatial scales is essential for effective management of marine ecosystems in the wake of predicted global change. Evidence suggests that climate variability can trigger regime shifts in marine ecosystems. Regime shifts are characterized by a reorganization of marine communities, species dominance, and tropho-dynamic relationships. Often, synchronous shifts occur in aquatic ecosystems that are separated by thousands of kilometers. This finding suggests that atmospheric teleconnections are mediating regional system changes. We postulate that comparative studies of ecosystems that have experienced regime shifts will provide insights into the expected responses of marine organisms to climate change. We seek papers that go beyond simple pattern matching. Contributions to this Theme Session should provide statistical evidence of the functional responses and relationships that underlie regime shifts and/or statistical or modeling studies that successfully simulate observed shifts. Studies that utilize these relationships to forecast of future climate change impacts are especially welcome. The primary focus of this session will be on understanding shifts in the pelagic realm including phytoplankton, zooplankton and pelagic species (for example, small pelagic fish, squids and gadids).

Co-Convenors: Suam Kim, Jurgen Alheit, Harald Loeng, James Overland, Yasunori Sakurai

Request funding for 2 invited speakers. (ICES will be asked to co-sponsor 1 speaker). Possible European candidates are Martin Edwards/Gregory Beaugrand, Svein Sundby

PICES Nineteenth Annual Meeting (PICES-2010)
October 22–31, 2010
Portland, USA

Extracted from:

2010 Report of the Fishery Science Committee

AGENDA ITEM 5
Status reports of FIS-sanctioned groups

Joint PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS)

Co-Chairman of ICES/PICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS), Dr. Suam Kim, provided a summary of the Working Group's activities. This Working Group was extremely active in 2010. Highlights included the International Symposium on "*Climate change effects on fish and fisheries: Forecasting impacts, evaluating ecosystem responses, and evaluating management strategies*" (Sendai, Japan, April 26–29, 2010). The symposium and a subsequent publication will advance understanding within the scientific community of the potential effects of climate change on fish and fisheries. Key findings from the meeting were summarized in PICES Press: (http://pices.int/publications/pices_press/volume18/v18_n2/PICES_Press18_FULL.pdf). Another major highlight included the 1-day FIS/POC/BIO Topic Session at PICES-2010 on "*Impact of climate variability on marine ecosystems: Understanding functional responses to facilitate forecasting*" (S8).

WG-FCCIFS requested several actions of the FIS Committee:

1. Funding for two PICES scientists from Asian countries to attend a workshop on "*Biological consequences of decrease in sea ice in Arctic and Sub-Arctic Seas*" at the 2nd ESSAS Open Science Meeting in Seattle (May 22–26, 2011). Convenors: Harald Loeng (ICES/Norway) and Anne Hollowed (PICES/USA).
2. Funding for two scientists to attend the ICES 2011 ASC Theme Session on "*Atmospheric forcing of the Northern Hemisphere ocean gyres, and the subsequent impact on the adjacent marine climate and ecosystems*" to be convened by Emanuele Di Lorenzo (PICES/USA), Ichiro Yasuda (PICES/Japan), Hjálmar Hátún (ICES/Faroe Islands) and Jürgen Alheit (ICES/Germany).
3. PICES' support and endorsement for a 1-day theme session during the International Symposium on "*Effects of climate change on the world's oceans*" in Yeosu, Korea (May 15–19, 2012).
4. PICES' support for an ICES Symposium on "*Forage fish interactions and ecosystem approach to fisheries management*" to be held in Nantes, France, from September 10–14, 2012.

WG-FCCIFS may consider an endorsement by ICES and PICES of the addition of 1–2 new working group members who would represent an emerging new South Pacific marine science organization.

It was proposed to merge ICES SSICC (term ends December 2010) and ICES/PICES WG-FCCIFS (term ends December 2011) to address a joint ICES/PICES Strategic Initiative on Climate Change Effects on Marine Ecosystems.

Extracted from:

2010 Report of the Physical Oceanography and Climate Committee

PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS)

Dr. Anne Hollowed, Co-Chair of WG-FCCIFS, gave a brief report summarizing activities of the Group over the past year, the highlight of which was the very successful symposium on "*Climate change effects on fish and fisheries*" organized in Sendai, Japan, April 26–29, 2010. There was some discussion on the future of this Working Group after its term ends in 2011 and how it might be linked to the new working group proposed by WG 20. ICES plans to create a Strategic Initiative on Climate Change (SSICC) as the next step to succeed WG-FCCIFS and was seeking to align its activities with PICES. POC Committee members agreed that the present ICES "Initiative" has a mandate that is too broad for a Working Group. Joint activities with PICES should be considered by POC after more concrete TORs are available. Travel support requests were made for a workshop on "*Biological consequences of a decrease in sea ice in Arctic and Sub-Arctic Seas*" at the ESSAS Open Science Meeting in Seattle, USA, on May 22, 2011; a session on "*Atmospheric forcing of Northern Hemisphere ocean gyres and their subsequent impact on the adjacent marine climate and ecosystems*" at the ICES Annual Science Meeting in Gdańsk, Poland, and a workshop on "*Reaction of Northern Hemisphere ecosystems to climate events: A comparison*" in Hamburg, Germany, in May 2011.

PICES Twentieth Annual Meeting (PICES-2011)
October 14–23, 2011
Khabarovsk, Russia

Extracted from:

2011 Report of the Biological Oceanography Committee

AGENDA ITEM 11
Report from joint PICES/ICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish*

A report summarizing the actions and requests related to PICES/ICES WG-FCCIFS was presented by Juergen Alheit. PICES (BIO) approval is being requested for continuation/renewal. BIO was concerned about being asked to endorse and approve this Working Group when the Committee had not previously reviewed the Implementation Plan or received other information such as the Terms of Reference, although detailed information had been presented to the FUTURE APs. BIO recommended that mechanisms for communication from the FUTURE APs to the parent Committees be improved. BIO recognized the importance of WG-FCCIFS for FUTURE and for PICES/ICES collaboration, but BIO had only a limited interest about participation on working group that focuses on fish and shellfish issues.

Extracted from:

2011 Report of the Fishery Science Committee

AGENDA ITEM 8
Reports of FIS-sanctioned Groups

Joint PICES/ICES WG on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS)

Co-Chair of WG-FCCIFS, Dr. Anne Hollowed, provided a summary of the activities of the joint Working Group in 2010–2011.

This Working Group was extremely active in 2011. WG-FCCIFS held four Working Group meetings, produced two reports, and held three inter-sessional workshops. WG-FCCIFS members co-convened 5 Topic/Theme Sessions at PICES Annual Meetings and ICES Annual Science Conferences.

The 3 workshops convened by WG-FCCIFS in 2011 were: *Reaction of Northern Hemisphere ecosystems to climate events: A comparison*, in Hamburg, Germany in May; *Biological consequences of a decrease in sea ice in Arctic and Sub-Arctic seas* in Seattle, USA in May, and *Basin-wide impact of Atlantic Multidecadal Oscillation*, Woods Hole, USA, in June.

In 2011, a major milestone was the ICES/PICES WG-FCCIFS publication of the special issue on "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses, and evaluation management strategies*" in the July issue of the *ICES Journal of Marine Science*, volume 68(6). The special issue provides a valuable assessment of current knowledge of the effects of climate change on fish and fisheries.

Members of the WG-FCCIFS met in October 2010 in Portland and in May 2011 in Seattle to discuss on-going activities of the group. During these meetings, the WG discussed the need to develop a long-term Strategic Initiative on Climate Change Effects on Marine Ecosystems (SICCME). The WG-FCCIFS term ends in

December 2011. PICES and ICES recognized that great strides in new sciences have emerged from collaborative work between two organizations and requested the development of a Science Plan that outlines a structure for continued collaboration focused on climate change. A Science Plan for SICCME was delivered to ICES and PICES in the spring of 2011. ICES agreed to the formation of SICCME, and PICES and ICES asked WG members to develop an Implementation Plan. These documents were provided to FIS members in advance of the meeting.

Planning of the upcoming PICES/ICES/IOC Symposium on "*Effects of climate change on the world's oceans*" (May 15–19, 2012, Yeosu, Korea) is proceeding as planned.

Dr. Hollowed described WG-FCCIFS's request to form a new PICES Section on *Climate Change Effects on Marine Ecosystems* (S-CCME). She described their desire for FIS co-sponsorship of this activity. In making this request, she noted that the current co-sponsorship by FIS has worked extremely well.

FIS congratulated Dr. Hollowed and her colleagues for the outstanding work of WG-FCCIFS. FIS strongly supports the proposal for FIS committee co-sponsorship of SICCME, given the strong direct ties of this work to FIS and the need to maintain past excellent levels of communication with FIS.

Extracted from:

2011 Report of the Physical Oceanography and Climate Committee

AGENDA ITEM 5

Reports of existing subsidiary bodies and plans for new ones

Dr. Michael Foreman, a member of WG-FCCIFS, gave a brief report summarizing activities of the Working Group in 2011, including those during 2011 ICES Annual Science Conference and 2011 PICES Annual Meeting. The Working Group had business meetings in May and September in 2011, and co-chaired and convened several sessions and workshops. The Group's term ends in December 2011, and its major TORs culminated in the publication of a special issue of *ICES Journal of Marine Science* based on 35 scientific papers from the 2010 PICES/ICES/FAO Symposium on "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses and evaluating management strategies*" held April 26–29, 2011, in Sendai, Japan. The volume will serve as a key reference for scientists developing international or national climate change impact assessments. The Working Group proposed establishing a new PICES/ICES Section on *Climate Change Effects on Marine Ecosystems* (S-CCME) as a successor. The draft plan was reviewed by the POC Committee at PICES-2010 before submitting the proposal for approval at PICES-2011. According to its plan for Phase 1 during 2012–2014, S-CCME will work with newly formed WG 27 to foster integration and synthesis of ideas between those two expert groups. It is also anticipated S-CCME will collaborate closely with a new Working Group on *Regional Climate Modeling* that POC proposed at PICES-2011 to address one of S-CCME's key questions, *How will the physical, chemical and biological components of regional marine ecosystems of the Northern Hemisphere change under future climate scenarios?* The POC Committee decided to support the S-CCME Science Plan. The Group requested support for a FIS/POC/S-CCME/WG27 Topic Session on "*Comparison of impact of multi-decadal climate variability in North Pacific and North Atlantic ecosystems and corresponding teleconnection patterns*" at PICES-2012. POC decided to support the request with high priority and submit the request at the Science Board Meeting.

Appendix 6

PICES Press articles related to WG-FCCIFS

PICES Fishery Science Committee Workshop in Gijón

by Thomas A. Okey, Anne B. Hollowed, and Michael J. Schirripa

A workshop entitled "*Linking Global Climate Model output to (a) trends in commercial species productivity and (b) changes in broader biological communities in the world's oceans*" was convened on May 18, 2008, at the ICES/PICES/IOC International Symposium on the "*Effects of climate change on the world's oceans*" in Gijón, Spain. The workshop had the ultimate goal of facilitating a coordinated international research effort to forecast climate change impacts on the distribution and production of the world's major fisheries, and on the biological communities in which these fisheries are embedded. It was attended by 33 people from 13 nations and there was consensus that this group could initiate a coordinated international collaboration to advance research in marine climate impacts. Originally proposed separate workshops entitled "*Linking climate to trends in productivity of key commercial species in the world's oceans*" and "*Screening approaches and linking Global Climate Model output with ecosystem and population models*" were combined by the convenors because they were complementary. In retrospect, blending the two "schools" was fortuitous as it placed us in a better-than-expected position to initiate an effective international collaboration.

The specific objectives were: (1) to review the activities of existing programs within each nation; (2) to examine evidence for climate impacts on production of commercial fish species and other marine life; (3) to discuss the feasibility of developing medium- to long-term forecasts of climate impacts; (4) to discuss possible responses of commercial fisheries, human communities, and governments to climate-driven changes in marine life; and (5) to identify common or standard approaches to forecasting climate change impacts on commercial species and marine communities and ecosystems.

Workshop participants discussed climate scenarios to use in forecasting and the tools required for predicting climate impacts on commercial fish production and broader marine ecosystems. The workshop provided a forum to examine four components needed to complete the forecasts in a timely and coordinated fashion. These included IPCC scenarios, predictions of oceanographic impacts, modeling approaches, and regional scenarios for natural resource use and enhancement. The ecosystem component of the workshop surveyed a wide variety of approaches, such as vulnerability assessments for informing location choices for ecosystem modeling efforts and management prioritization, trophodynamic fishery ecosystem modeling (*i.e.*, Ecopath with Ecosim), climate envelope modeling, statistical approaches, and three dimensional high-resolution biogeochemical ecosystem modeling (*i.e.*, CCCC-NEMURO).

The workshop began with an introduction by Anne Hollowed (U.S.A.) who proposed: (1) an overarching goal of producing quantitative estimates of climate change effects on the marine ecosystem – biology – in the next 5 years; (2) a review of all the related international efforts in a paper that would lay out a path for collaboration development; (3) initiation of a coordinated international effort—broader than one basin; and (4) production of a special journal issue for showcasing forecasting approaches that are available and are being developed. She discussed three broad approaches representing different levels of advancement in the science of climate impact forecasting, listed in increasing order of sophistication:

1. IPCC scenarios downscaled to local regions and ecosystem indicators used to project future fish production using detailed management strategy evaluations;
2. IPCC scenarios downscaled to local regions and coupled to bio-physical models with higher trophic level feedbacks;
3. Fully coupled bio-physical models that operate at time and space scales relevant to coastal domains.

The main program of the workshop started with a round table discussion of existing national or international projects developing forecasting initiatives, including Quest-FISH (Jason Holt), Fisheries and the Environment (FATE; Anne Hollowed), PICES FUTURE (Michael Foreman), North Pacific Research Board Bering Sea Integrated Ecosystem Research Program (NPRB BSIERP; Clarence Pautzke), Climate Impacts on Oceanic Top Predators (CLIOTOP; Alistair Hobday), Ecosystem Studies of Sub-Arctic Seas (ESSAS; Harald Loeng), Evidencias e Impacto do Cambio Climático en Galicia (CLIGAL; Antonio Bode), and initiatives by the Ministry of Fisheries New Zealand (Mary Livingston). The rest of the morning was devoted to eight presentations of projects that linked Global Climate Model (GCM) output to trends in commercial species productivity.

Nicholas Bond (U.S.A.) presented "*A method for using IPCC model simulations to project changes in marine ecosystems*", in which he compared ensembles of hindcasted atmosphere–ocean model output to observed measurements, and used a tiered statistical approach to select a subset of models that performed well in representing regional oceanographic projections. This work indicated that different models have different strengths, so a particular question should use a tailored subset of models.

Mary Livingston (New Zealand) presented "*Climate change, oceanic response and possible effects on fish stocks in New Zealand waters*", in which she described how climate change related ecological trends have been equivocal in New Zealand during the last 50 years due to its oceanographic and ecological uniqueness and complexity and the paucity of long time series. Some of New Zealand's marine life might be quite vulnerable to climate and oceanographic changes due to a variety of factors, and thus there are plans to integrate climate impact studies with marine fisheries research and management.

Jae Bong Lee (Republic of Korea) presented "*Forecasting climate change impacts on distribution and abundance of jack mackerel around Korean waters*", in which he illustrated how variations in ocean conditions and warming of ocean water around Korea has influenced the distributions of jack mackerel in terms of their seasonal visitation to Korean waters from the East China Sea, and suggested that continued warming by 2100 may have considerable effects on these stocks around Korea. Future sea surface temperature (SST), ocean drift and other oceanographic variables projected with GCMs will be incorporated into a stock projection model to forecast future production scenarios.

Sukyung Kang (Republic of Korea) presented "*Techniques for forecasting climate-induced variation in the distribution and abundance of mackerels in the northwestern Pacific*", in which she described an exploration of the positive relationship between mackerel production and warm ocean conditions, and progress in forecasting the impact of climate change on mackerel production by downscaling forecasts of atmospheric/ocean conditions from GCMs to drive stock projection models.

Adriaan Rijnsdorp (The Netherlands) presented "*Effects of climate change on sole and plaice: Timing of spawning, length of the growth period and rate of growth*", in which he reviewed how increased temperatures since 1989 in coastal nursery grounds in the southeastern North Sea has had a negative impact on plaice and a positive effect on sole thus causing a shifting species composition as their habitat quality changes. Implications of physiological trade-offs in this changing system will make forecasting challenging.

Z. Teresa A'mar (U.S.A.) presented "*The impact on management performance of including indicators of environmental variability in management strategies for the Gulf of Alaska walleye pollock fishery*", in which she provided her management strategy evaluation (MSE) of the Gulf of Alaska walleye pollock fishery, with multiple indices of climate forcing incorporated into her overall modelling framework. The best performing management strategies were ones that were more responsive to fluctuations in productivity due to environmental influences.

Michael Schirripa (U.S.A.) presented "*Simulation testing two methods of including environmental data into stock assessments*", in which he described the development of environmental indicators of fish stock recruitment and provided both modelling and a statistical examples of how such indicators could be used in stock assessments and forecasting. Sea surface height (SSH) was the best predictor of recruitment in this analysis, as low SSH occurs when the California Current and upwelling are both strong, and this is associated with high productivity.

Alan Haynie (U.S.A.) presented "*Climate change and changing fisher behavior in the Bering Sea pollock fishery*", in which he discussed how fishermen will respond to changes in fish abundance driven by climate change, and that this will, in turn, have an impact on the ecosystem. The fisheries we observe today result from current stock distributions, abundances, and prices—all of these will change with climate. Spatial and market regulations that consider the relationship between fishermen and the environment will be most effective.

The morning session concluded with a discussion of the presentations and the outlook for forecasting commercial fisheries.

Thomas Okey, Pew Fellow in Marine Conservation, introduced the afternoon session by providing a framework highlighting complementary modelling approaches that could be used to explore climate impacts on marine biota and ecosystems. He described conceptual and qualitative models that are useful for proactive decision-making as a segue to the more quantitative approaches to linking GCM output to changes in broader marine communities.

Jorge Sarmiento (U.S.A.) presented "*Modeling response of ocean biology to climate warming using an empirical approach*", in which he compared global warming simulations from six climate models and the physical changes projected for six ocean biomes. All six models indicated increases in primary production at high latitudes, but the models did not agree with direction of change at mid-latitudes.

Taketo Hashioka (Japan) presented "*Future ecosystem changes projected by a 3-D high-resolution ecosystem model*", in which he described efforts to develop a high-resolution ecosystem model by linking COCO (CCSR Ocean Component Models) to NEMURO and NEMURO–FISH models. Projections included a 30% decrease in the Kuroshio, 10–30% decreases in Chl-*a*, a shift from diatoms to small phytoplankton, a spring bloom 10 days earlier, changes in phytoplankton biomass (*i.e*., 20% increase in the subarctic region and 25% decrease in the subarctic-subtropical transition region), and a 2° shift in the distribution of sardines.

William W.L. Cheung (Canada) presented a "*Dynamic bio-climate envelope model to predict climate-induced changes in distribution of marine fishes and invertebrates*", in which he provided a global assessment of climate-induced range shifts of 1066 commercial species throughout the world's oceans from changing temperature, habitat characteristics, and other mediators of dispersal and range occupation.

Alistair J. Hobday (Australia) presented "*Informing location choices for ecosystem model development using a vulnerability index*" as an Australian example of a quantitative vulnerability assessment that is used to identify the ecosystems, habitats, biological components, and human values most vulnerable to projected climate change, so that climate impact modelling and monitoring can be prioritized and targeted efficiently. The CSIRO Mk 3.5 model projections to 2070 provided indicators of climate change while non-climate indicators were derived from other Australian data sets.

Simone Libralato (Italy) presented "*Towards the integration of biogeochemical and food web models for a comprehensive description of marine ecosystem dynamics*", in which he reviewed the progress and outlooks for achieving end-to-end modelling (*e.g*., from viruses to fishes, from nutrients to fisheries, including climatic changes) by linking biogeochemical models with trophodynamic models. He also summarized outcomes of the 2007 Trieste (Italy) workshop on "*Biogeochemical processes and fish dynamics in food web models for end-to-end conceptualisation of marine ecosystems: Theory and use of Ecopath with Ecosim*".

Steven Mackinson (UK) presented "*Which forcing factors fit? Using ecosystem models to investigate the relative influence of fishing and primary productivity on the dynamics of marine ecosystems*", in which he described dynamic fitting with Ecopath with Ecosim models to identify the main driving forces of fish stocks and marine ecosystems (*e.g*., fishing mortalities or proxies of primary production), to assess the relative importance of these factors across regions, and to evaluate whether similar groups in different ecosystems respond similarly?

Sheila Heymans (UK) presented "*The effects of climate change on the northern Benguela ecosystem*", in which she simulated the effect of global warming on the northern Benguela Current system by fitting a 1956 Ecopath with Ecosim model to 2000 conditions, and then simulating 50 years of SST rise. The ecological effects were evaluated by indices of ecosystem function and commercial gain.

The case studies presented during this workshop indicated the variety of approaches (and variations on similar approaches) for evaluating the impacts of climate change on marine life, biological communities, and ecosystem functions. Although the approaches appeared to be coordinated within communities of modellers, coordination was lacking at the global level. Most, if not all, of the presenters expressed the need to develop these approaches further, and there appeared to be consensus among participants that an international collaboration would be a good way to do this. A global coordination of teams and collaborators may prove to be a critical vehicle to use the increasingly refined physical and chemical projections from GCMs and regional models to evaluate impacts of climate change on the world's marine fisheries and ecosystems. The workshop described in this article may have been a key first step toward such a global collaboration.

Thomas Okey is a Pew Fellow in Marine Conservation with a focus on assessing the impacts of climate change on marine life and ecosystems in the contexts of fisheries and other anthropogenic stressors. He is the Scientist-in-Residence at Bamfield Marine Sciences Centre on Vancouver Island, Canada, and an Adjunct Professor in the School of Environmental Studies at the University of Victoria, Canada. He holds a B.S. in Biology and Environmental Studies from Saint Lawrence University in Canton, New York; a M.S. in Marine Science from Moss Landing Marine Laboratories; and a Ph.D. in Zoology from the University of British Columbia. He is the founder and Science Director of the Conservation Science Institute, which provides conservation science networking and communication.

Anne Hollowed is a Senior Scientist at the NOAA's Alaska Fisheries Science Center, in Seattle, U.S.A. She holds a M.S. in Oceanography from Old Dominion University, and a Ph.D. in Fisheries from the University of Washington. She is an Affiliate Associate Professor at the University of Washington and a Fellow of the Cooperative Institute for Arctic Research at the University of Alaska. Anne has served on panels for U.S. GLOBEC, PICES CCCC, the North Pacific Research Board, and Comparative Analysis of Marine Ecosystem Organization, and is a member of the Scientific and Statistical Committee of the North Pacific Fisheries Management Council.

Michael Schirripa has worked in fisheries science since 1985 for the U.S. Peace Corps, U.S. Forest Service, U.S. Fish & Wildlife, U.S. Parks, and NOAA Fisheries. He earned a B.S. from Michigan State University in fisheries and wildlife and M.S. and Ph.D. degrees in biology from Florida International University. Michael is a member of PICES Fishery Science Committee and is on the Steering Committee of NOAA's Fisheries and the Environment (FATE) Program. Michael recently moved from the NOAA's Northwest Fisheries Science Center in Newport, Oregon, to the NOAA's Southeast Fisheries Science Center in Miami, Florida.

2008 PICES Workshop on "*Climate Scenarios for Ecosystem Modeling (II)*"

by Michael Foreman, Anne Hollowed and Suam Kim

A key component of FUTURE (an acronym for Forecasting and Understanding Trends, Uncertainty and Responses of North Pacific Marine Ecosystems), the new over-arching science program within PICES, is understanding and communicating the impacts of climate change on North Pacific marine ecosystems. Whereas FUTURE's predecessor, the Climate Change and Carrying Capacity (CCCC) Program, focussed primarily on past climate change effects, this new program will have a stronger emphasis on future changes, and thus rely heavily on the global climate model projections described in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). Toward that end, the CFAME (*Climate Forcing and Marine Ecosystems*) Task Team of the CCCC Program has laid some of the groundwork for FUTURE by collaborating with the Working Group on *Evaluations of Climate Change Projections* (WG 20) in analysing downscaled atmospheric and physical oceanographic projected changes from a suite of global climate models to determine their impact on states of three North Pacific ecosystems: the California Current System, the Kuroshio/Oyashio System, and the Yellow and East China Seas System (see PICES Press, Vol. 16, No. 2, for the summary of their April 2008 workshop). A joint workshop of these two groups on "*Climate scenarios for ecosystem modeling (I)*" took place at the 2007 PICES Annual Meeting in Victoria, Canada, and a follow-up 1.5-day workshop, jointly organized by CFAME, WG 20, and a prospective new ICES/PICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish*, was held at the 2008 PICES Annual Meeting in Dalian, China. This article summarizes some highlights of this second workshop that was co-convened by Michael Foreman, Anne Hollowed, Suam Kim, and Gordon McFarlane.

The workshop opened with an invited presentation by Thomas Okey (Pew Fellow in Marine Conservation) on the challenge of forecasting changes to marine biota and fisheries in the year 2035. He summarized discussions from, and collaborations established at, a workshop preceding the conference on "*The Effects of climate change on the world's oceans*" held in Gijón, Spain, in May 2008, and outlined the motivation for the new ICES/PICES Working Group that is being led by Anne Hollowed. The next two speakers, James Overland and Young-Shil Kang gave updates of their work relevant to the CFAME terms of reference. In particular, Jim stressed that among the 22 global climate models that he and his colleagues Muyin Wang and Nicholas Bond investigated, no one model was uniformly best in capturing all the important oceanic features in the North Pacific. However, he did show a "wall of fame/shame" table rating model relative performance and indicated a group of approximately six models that gave generally acceptable results over a standard evaluation period, and that should be used in future ensemble estimates of climate change in the North Pacific.

Five out of the next six presentations were progress updates given by WG 20 members. Yasuhiro Yamanaka described recent results received with the COCO-NEMURO coupled biophysical climate model for the Kuroshio/Oyashio region. Emanuele Di Lorenzo gave a preview of his subsequent award-winning Science Board presentation describing his North Pacific Gyre Oscillation (NPGO) analysis of variability in North Pacific sea surface elevations and its links with ENSO signals. Jim Christian described the development of a carbon cycle component within the next generation of the Canadian Global Climate Model. Enrique Curchitser showed preliminary results of improved upwelling arising from embedding and fully coupling his 10-km regional ROMS model for the Northeast Pacific within the NCAR global climate model. Michael Foreman described wind downscaling results and new regional climate and ecosystem model initiatives in Canadian waters. Within these updates, Qigeng Zhao described his simulations of acidification in the Pacific.

The remaining presentations provided information on efforts to forecast the implications of climate change on fish and shellfish in the North Pacific. Anne Hollowed discussed a framework for making forecasts by using statistical methods to select credible IPCC models and extract their expected forcing. This forcing could then be incorporated into statistical age-structured models to project impacts on commercial fish populations. Gordon Kruse presented a qualitative method that could be used to forecast climate change impacts on red king crab stocks in the Eastern Bering Sea. Suam Kim talked about the response of Korean chub mackerel populations to climate forcing, showing that salinity is significantly correlated to year-class strength and suggesting that shifts in transport may play a key role in recruitment variability of this stock. Michio Kishi examined the role of climate variability on the growth of salmon, pollock and squid in the northwestern Pacific using a bio-energetic model. Preliminary results of this study suggest that chum salmon may not survive in waters off Hokkaido in 2100. Richard Beamish gave two talks on the impact of climate change on salmon stocks in British Columbia. His first talk showed that poor marine survivial of chinook salmon in the Strait of Georgia appears to be related to reduced growth resulting from a declining carrying capacity in the area, while his second talk compared two sockeye salmon runs that exhibited different population trends. As was the case in the first talk, the different trends appear to be related to the spatial distribution of food and the behaviour of juvenile salmon.

The final half-day of the workshop was devoted to discussions on the proposed new ICES/PICES Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WGFCCIFS). Manuel Barange, one of the ICES Co-Chairs for this group, provided an overview of ICES-community interest in this effort and noted that ICES had already approved the formation of WGFCCIFS and its terms of reference. Individuals from PICES member countries identified several research programs that would contribute to the activities of the working group.

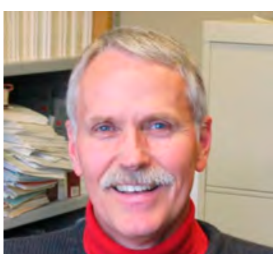
The participants discussed the rationale for start and end dates of 2035 and 2100, respectively, for the investigations. The former date was selected because it is the projected time when the climate change signal will begin to overwhelm the interannual and interdecadal signal in the North Pacific. The end date was selected because after it, forecasts will be heavily dependent on which particular IPCC emission scenario is chosen for predicting the rate of greenhouse gas build-up in the atmosphere. Mikhail Stepanenko noted that managers are most interested in forecasting future fish populations over short time horizons, and therefore, we should not ignore any efforts to also improve short-term projections. A clear linkage between short-term and long-term projections will be model validation activities. By examining the performance of projections in the short-term, analysts should be able to quantify expected inaccuracies associated with the long-term projections.

Different frameworks for delivering IPCC model output were discussed. It was agreed that the ideal framework would be one where oceanographers and climatologists from each member nation work with their biologists and modellers to develop relevant forecasts. However, it was noted that James Overland, Muyin Wang, and Nicholas Bond from the Pacific Marine Environmental Laboratory would be willing to assist various groups, when necessary and as time permits.

The participants had a lively discussion of the topic of communicating uncertainty. George Sugihara mentioned that forecasting is a complicated science and that there is a variety of analytical tools that have been developed for the business community which could be applied here. Jake Rice noted that the issue of communicating uncertainty requires that we identify the stakeholders who might be interested in our forecasts. It was noted that the advice of PICES and ICES on the future status of marine resources around the world could be used to address the following issues:

- global food security;
- implications on northward shifts in stocks on managing domestic fisheries, including shifts in the locations of fishes (*e.g.*, sardines, hake) and rights-based (communities and businesses) solutions;
- new fisheries in the north (especially for Canada, Russia and U.S.A.);
- assessing species and populations at risk (what are appropriate recovery targets for species in a changing world?).

Patricio Bernal (Intergovernmental Oceanographic Commission of UNESCO) indicated that his organization would be very interested in this new ICES/PICES effort. It was agreed that potential collaborations with IOC, FAO and other organizations would be investigated.



Dr. Michael Foreman (mike.foreman@dfo-mpo.gc.ca) is a physical oceanographer and numerical modeller for Fisheries and Oceans Canada at the Institute of Ocean Sciences in Sidney, British Columbia. His research interests include coastal circulation and river modelling, biological transport, tidal analysis, and climate change. Within PICES, he has been Chairman of the Physical Oceanography and Climate Committee since 2005, and Co-Chairman of Working Group 20 on Evaluations of Climate Change Projections *since 2006.*

Dr. Anne Hollowed (anne.hollowed@noaa.gov) is a Senior Scientist at the NOAA's Alaska Fisheries Science Center, in Seattle, U.S.A. She holds a M.S. in Oceanography from Old Dominion University, and a Ph.D. in Fisheries from the University of Washington. She is an Affiliate Associate Professor at the University of Washington and a Fellow of the Cooperative Institute for Arctic Research at the University of Alaska. Anne has served on panels for U.S. GLOBEC, PICES CCCC, the North Pacific Research Board, and Comparative Analysis of Marine Ecosystem Organization, and is a member of the Scientific and Statistical Committee of the North Pacific Fisheries Management Council.

Dr. Suam Kim (suamkim@pknu.ac.kr) received his B.Sc. (1976) and M.Sc. (1979) from the Seoul National University and his Ph.D. in Fisheries Oceanography from the University of Washington in 1987. Currently, he is a Professor of the Pukyong National University, Busan, Korea. His areas of interest include fisheries ecology, especially recruitment variability focusing on early life histories of fish in relation to oceanic/climate changes. Suam represented Korea on several international organizations/programs such as PICES, GLOBEC, CCAMLR, IGBP, NPAFC and SCAR. Currently, he serves as President of NPAFC.

2010 Symposium on "*Effects of Climate Change on Fish and Fisheries*"

by Anne B. Hollowed, Manuel Barange, Shin-ichi Ito, Suam Kim, and Harald Loeng

The North Pacific Marine Science Organization (PICES), International Council for the Exploration of the Sea (ICES) and Food and Agriculture Organization (FAO) held an international symposium on "*Climate change effects on fish and fisheries: Forecasting impacts, assessing ecosystem responses and evaluating management strategies*" from April 26–29, 2010, in Sendai, Japan, with co-authors of this article serving as symposium convenors. Unfortunately, Drs. Manuel Barange (UK) and Harald Loeng (Norway), as well as Dr. Kenneth Drinkwater (Norway; theme session convenor), were unable to attend the meeting because of the eruption of Mount Eyjafjallajökull in Iceland. Three more (out of 23) theme session convenors were unable to participate due to unexpected illnesses. Even though these were notable absences, the symposium was still considered a grand success.

The symposium was the culmination of the planning and preparation of PICES and ICES. In recognition that climate change impacts on marine ecosystems will not be limited to one region of the globe, these two organizations formed in 2009 the first joint Working Group on *Forecasting Climate Change Impacts on Fish and Shellfish* (WG-FCCIFS). One of the priority tasks for WG-FCCIFS was to convene a symposium to provide a venue for the exchange of scientific information and the discussion of the issues and challenges related to predicting the future impacts of climate change on the world's marine ecosystems. The symposium in Sendai was the product of this effort.

The symposium was designed to provide an opportunity for scientists and policymakers to discuss the potential impacts of climate change on marine ecosystems, and our use of the resources provided by these ecosystems. During the meeting, we considered strategies that society can take to be prepared for anticipated impacts on fish and fisheries. A key element was the desire to publish selected papers from the symposium, with sufficient time for them to be considered by review panels responsible for the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) and by other review bodies, such as the Millennium Report of the United Nations Development Program.

The response to this symposium exceeded our expectations, with more than 350 abstracts submitted by scientists from over 40 countries. After the final tally, 337 scientists from 37 countries were in attendance. A total of 208 oral presentations and 105 posters were presented.

During the symposium, the global significance of the issues was highlighted in many discussions and presentations. It was a great satisfaction for the convenors to see scientists from around the world debating the issues stemming from climate change impacts on marine ecosystems. Sound scientific advice on the expected impacts of climate change requires the international research community to work together in an interdisciplinary research setting to identify, forecast, and assess strategies to respond to the impacts of climate change on fish and fisheries. The symposium provided this type of interdisciplinary exchange of information.

President of the Fisheries Research Agency of Japan, Dr. Toshihiko Matsusato, preparing to register for the symposium.

The symposium was arranged around 10 theme sessions, with 6 workshops preceding the meeting (summary reports from 5 workshops are included elsewhere in this issue of PICES Press). These sessions and workshops encompassed a broad range of topics that provided a global perspective on climate change and the future of the world's fish and fisheries.

Day 1 started with presentations by four plenary speakers: Drs. Kevin Trenberth (National Center for Atmospheric Research, U.S.A.), Akihiko Yatsu (Seikai National Fisheries Research Institute, Japan), Eddie Allison (WorldFish Center, Malaysia) and Ussif Rashid Sumaila (University of British Columbia, Canada).

The themes for Day 1 included:

- *Forecasting impacts: From climate to fish* (co-chaired by Kenneth Drinkwater, Harald Loeng, Franz Mueter, Carl O'Brien, Graham Philling and Yashuhiro Yamanaka);
- *Forecasting impacts: From fish to markets* (co-chaired by Manuel Barange, Jacquelynne King, Ian Perry and Adolf Kellermann);
- *Species-specific responses: Changes in growth, reproductive success, mortality, spatial distribution and adaptation* (co-chaired by Richard Beamish, Myron Peck and Motomitsu Takahashi).

Symposium in session.

The themes for Day 2 were:

- *Downscaling variables from global models* (co-chaired by Michael Foreman and Jason Holt);
- *Assessing ecosystem responses: Impacts on community structure, biodiversity, energy flow and carrying capacity* (co-chaired by Thomas Okey and Akihiko Yatsu);
- *Species-specific responses: Changes in growth, reproductive success, mortality, spatial distribution and adaptation* (continued from the previous day);

The themes for Day 3 focused on:

- *Comparing responses of climate variability among nearshore, shelf and oceanic regions* (co-chaired by Jurgen Alheit, Jae Bong Lee and Vladimir Radchenko);
- *Impacts on fisheries and coastal communities* (co-chaired by Eddie Allison, Keith Brander and Suam Kim);
- *Evaluating human responses, management strategies and economic implications* (co-chaired by Tarub Bahri, Kevern Cochrane and Jake Rice);
- *Contemporary and next generation climate and oceanographic models, technical advances and new approaches* (co-chaired by Jonathan Hare and Shin-ichi Ito).

The final half-day session on "*Sustainable strategies in a warming climate*" (co-chaired by Anne Hollowed and Michael Schirripa) was held in plenary. Dr. Steve Murawski provided a summary of first impressions from the symposium. He identified many issues for participants to consider (Fig. 1).

It is impossible to summarize all of the exciting outcomes and research findings that were revealed during the symposium in a short article for the PICES Press. Thus, Table 1 includes the selection of key outcomes from the plenary and theme sessions that provide a glimpse of the broad scope of issues discussed during the meeting.

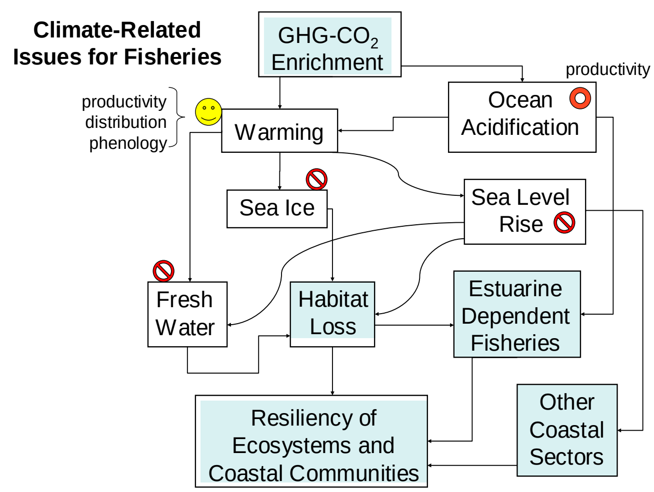


Fig. 1 Summary of climate-related issues for fisheries: smiling symbol indicates that substantial research is currently underway on this issue, open red circle indicates some research has been initiated on this subject, crossed red circles indicate that additional work is needed on this subject area (prepared by Dr. Steve Murawski).

Dr. Steve Murawski, Director of Scientific Programs and Chief Science Advisor for NOAA Fisheries, offering his impressions from the symposium.

	Table 1. Summary of key outcomes from the symposium
1	Long-term ocean monitoring programs are needed to track and understand ecosystem and climate change as they occur.
2	Networks of shelf-seas ecosystem models have already been developed within several of the world's LMEs. These models provide a basis for examining structural uncertainty within shelf sea ecosystem models (Fig. 2).
3	Three sources of uncertainty in Global Ocean Models (GOMs) are under investigation: (1) parameter uncertainty, (2) structural uncertainty, and (3) scenario uncertainty. Parameter uncertainty is being addressed to some degree with sensitivity tests; structural uncertainly is being explored via comparison of different coupled physical-biological models; and scenario uncertainty related to greenhouse gas emissions and economics can only be dealt with by using ensemble model sets.
4	There are five approaches to predicting the effects of climate change on fish and fisheries: (a) conceptual predictions, (b) inferences from laboratory studies, (c) statistical downscaling from GOM to the regional scale; (d) dynamic downscaling to regional ocean models; (e) whole earth system models. Each approach has strengths and weaknesses.
5	Fisheries oceanography and laboratory studies are critical to integrating biological and oceanographic models, evaluating species environmental tolerances and adaptation, and tracking species responses to long-term ecosystem and climate change as it occurs.
6	Models that couple marine social and economic responses are needed to evaluate management strategies; however, few examples exist (Fig. 3).
7	Issues of food security and marine conservation may require new approaches to satisfy the growing demand for marine resources.
8	Two-way communication is needed between scientists and stakeholders to develop meaningful scenarios on human responses to the impact of ecosystem and climate change.

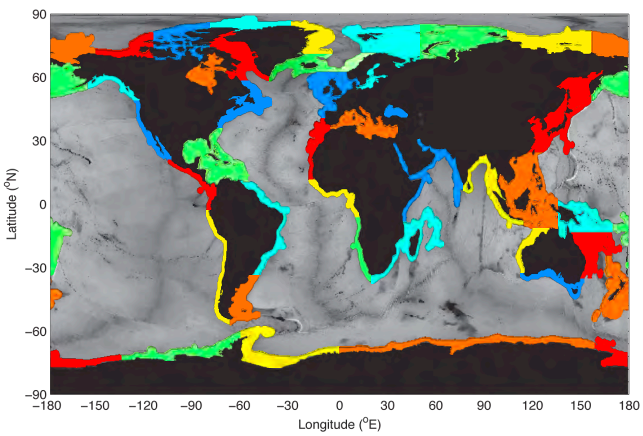


Fig. 2 The QUEST_FISH regional modeling domains (resolution 0.1 deg) defined by the 800 m contour plus 200 km of open ocean. The colors indicate that the models are regional and are only coupled through boundary conditions (Barange et al.; In: Ommer et al., Coping with climate change in marine socio-ecological systems. Blackwell FAR Series, in press).

The session on "*Forecasting impacts: From climate to fish*" consisted of 20 oral presentations and 19 posters, including invited talks by Drs. Kevin Trenberth, Akihiko Yatsu and Randall Peterman (Simon Fraser University, Canada). Dr. Trenberth provided an overview of the Earth's climate system and presented unequivocal evidence that humans are warming the world's atmosphere and oceans. He emphasized the importance of changes in the extremes rather than in mean climate states. Dr. Yatsu noted the need for interdisciplinary collaboration to incorporate the effects of climate forcing at different life stages when modeling impacts on marine fishes. Dr. Peterman discussed the major sources of uncertainty when forecasting climate effects, highlighting the importance of structural model uncertainty, which can only be addressed by considering multiple alternative models. He emphasized that inadequate communication among scientists, decision makers, and stakeholders can be a potentially important and poorly understood source of uncertainty. A key contribution of this session was the review of a variety of frameworks and methodologies employed for forecasting the effects of climate change on fish and fisheries. The majority of papers generated quantitative forecasts of future productivity or distribution of selected species based on the output of one or more global circulation models (GCMs). Based on GCMs, the approaches can be divided into global-scale static models, global-scale dynamic models, dynamic downscaling approaches, and statistical downscaling approaches. Other approaches did not produce quantitative forecasts but aimed at predicting the likely direction of future changes under global warming based on understanding the mechanisms that relate productivity of key species to climate variability. The comparative approach was similarly employed to better understand the mechanisms that favor different species during warm and cold periods. Statistical time series analyses were used to better assess past variability in climate and biological populations as an aid in understanding future variability, but forecasting future responses based on past patterns of variability is fraught with difficulties. Finally, some presentations highlighted the importance of field and laboratory studies to help estimate vital rates for fishes, which are needed to elucidate and quantify important mechanisms and to support modeling efforts.

The session on "*Forecasting impacts: From fish to markets*" consisted of 8 oral presentations, including invited talks by Drs. Eddie Allison and Rashid Sumaila. A key outcome of this session was the recognition that climate–fish–people models are beginning to be constructed, but are still in their early stages. Simpler (statistical) models which identify present fishing habitats and use of these to project fishing locations with future climate conditions are more common, and were included as the bases in most of the presentations in this session. This type of model often uses simple parameters such as SST. Future developments are needed to incorporate at least oxygen and temperatures at depth. Models of societal responses have many uncertainties, including how information is transferred within communities, and how human behavior responds to changing pressures.

The session on "*Downscaling variables from global models*" consisted of 13 oral presentations and 1 poster, including invited talks by Drs. J. Icarus Allen (Plymouth Marine Laboratory, UK) and Muyin Wang (Joint Institute for the Study of Atmosphere and Ocean, University of Washington, U.S.A.). This session focused on the techniques for estimating and communicating uncertainty in forecasts. Dr. Wang presented a framework for selecting scenarios for the Arctic and showed the importance of using models that address seasonal changes. Dr. Allen reviewed the different sources of uncertainty in climate models and outlined methods for estimating these uncertainties. He decomposed uncertainty into three categories: parameter uncertainty, structural uncertainty, and scenario uncertainty. The first one can be addressed by series of sensitivity tests that alter parameter values through a reasonable range. The second refers to the specific nature of the model, particularly the biogeochemical component, and could be explored, for example, by coupling biological models with differing complexity to the same physical model and examining the range and accuracy of the results. In the context of climate projections, the third refers to uncertainties in greenhouse gas emissions and can only be dealt with by computing ensembles that cover a range of plausible states.

The session on "*Species-specific responses: Changes in growth, reproductive success, mortality, spatial distribution and adaptation*" consisted of 28 oral presentations and 40 posters, including invited talks by Drs. Hans-Otto Pörtner (Alfred-Wegener-Institute, Germany) and John Pinnegar (Centre for Environment, Fisheries, and Aquaculture Science, UK). This session focused on the response of key fish species and fisheries worldwide to climate change. Presentations documented historical, often long-term fluctuations in abundance and distribution, discussed processes underlying current changes, and/or projected future impacts in light of adaptive capacity using a number of approaches. The research utilized a variety of methodological approaches. Most studies included topics such as observed and/or projected changes in distribution and/or productivity. A key outcome was the observation that quantitative evidence linking physiological responses to ecosystem change in various climate scenarios is scarce. Patterns identified in long-term field data or via macro-physiology and meta-analyses using various statistical tools are not sufficient to understand climate effects because the fundamental, underlying physical mechanisms are lacking. The session also revealed that additional research is needed to improve our understanding of the adaptive capacity of species to environmental change. Dr. Pörtner provided one example of the study type required. He reviewed the physiologically underpinnings that define tolerable marine habitats in fish and invertebrates, including expected cellular-level changes in metabolic scope via changes in oxygen and capacity-limited thermal tolerance. He also highlighted changes in ocean pH and the need to examine interactive effects of multiple stressors on vital rates.

The session on "*Assessing ecosystem responses: Impacts on community structure, biodiversity, energy flow and carrying capacity*" included 27 oral presentations and 15 posters. The invited speakers were Drs. Beth Fulton (CSIRO Marine and Atmospheric Research, Australia) and Jeffery Polovina (NOAA's Pacific Island Fisheries Science Center, U.S.A.). This session addressed the challenges involved in assessing the effects of climate change on marine ecosystems. A key outcome was the recognition that ecosystem models have been developed for many of the shelf-sea systems around the globe, and this network of models provides a foundation for examining shifts in the boundaries and structure of marine ecosystems.

The session on "*Comparing responses to climate variability among nearshore, shelf and oceanic regions*" included 15 oral presentations and 14 posters. The invited speakers were Drs. Nicholas Dulvy (Simon Fraser University, Canada) and Svein Sundby (Institute of Marine Research, Norway). Unfortunately, Dr. Sundby was unable to attend due to the eruption of the volcano in Iceland. Dr. Dulvy discussed climate impacts on Caribbean coral reefs and North Sea fishes. He demonstrated that Caribbean coral reef cover is at an all time low, and that the associated collapse in architectural complexity has led to severe habitat loss for coral reef fishes and resulted in declines in fish abundance. Warming of the North Sea has affected fish distribution and has led to range extensions of southern and range contractions of northern species. This session provided several case studies, showing the implications of climate change on near shore and oceanic regions.

The session on "*Impacts on fisheries and coastal communities*" consisted of 13 oral presentations and 11 posters. The invited speakers were Drs. Ian Perry (Pacific Biological Station, Canada) and Tarub Bahri (Food and Agriculture Organization). Dr. Perry reviewed the bio-physical, as well as human, drivers of changes in marine social-ecological systems and noted that we need to promote capabilities for observing, assessing, and adapting marine social-ecological systems to environmental changes to improve our ability to forecast the future impacts of climate change (Fig. 3).

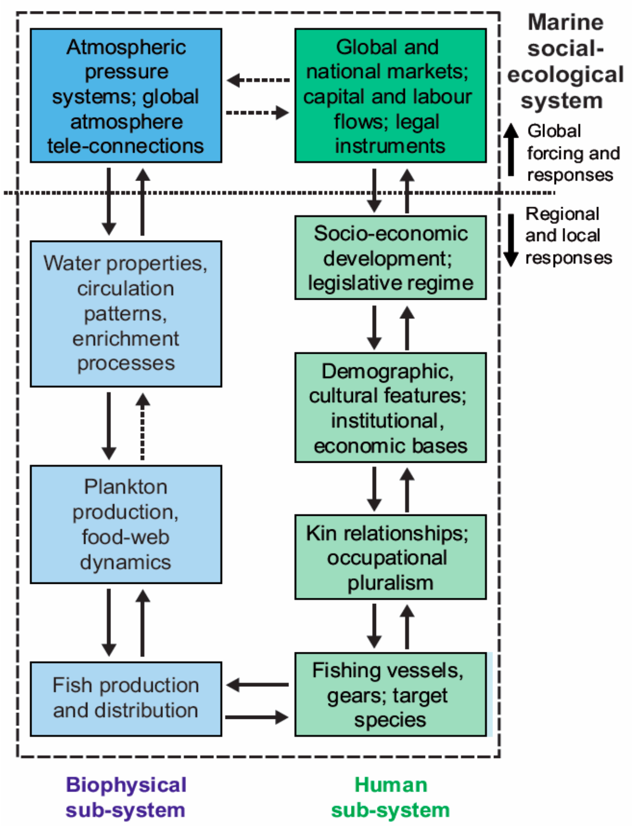


Fig. 3 Coupled marine social-ecological systems (Perry et al., 2010; In: Barange et al., Marine ecosystems and global change. OUP).

The session on "*Evaluating human responses, management strategies and economic implications*" included 13 oral presentations and 7 posters. The invited speakers were Drs. Johann Bell (Secretariat of the Pacific Community, New Caledonia) and Bonnie McCay (Rutgers University, U.S.A.). This session addressed a broad spectrum of studies that demonstrated how communities were influenced and adapted to change in the ecosystem. An important theme in many talks was underlined by Dr. McCay that despite rhetoric, people have not been treated as truly part of marine ecosystems in much research and policy.

The session on "*Contemporary and next generation climate and oceanographic models, technical advances and new approaches*" consisted of 13 oral presentations and 6 posters, including invited talks by Drs. Anand Gnanadesikan (NOAA's Geophysical Fluid Dynamics Laboratory, U.S.A.) and Michio Kawamiya (JAMSTEC's Frontier Research Center for Global Change, Japan). Dr. Kawamiya outlined the IPCC AR5 modeling plan and challenges to reduce uncertainty of future prediction, which arises from the initial condition, by applying data assimilation for the ocean part of the climate models. Dr. Gnanadesikan showed, as an example, a state-of-the-art earth system modeling which covers from climate to biochemical systems. This session provided an overview of the new modeling approaches currently under development and many of the presentations pointed out the difficulty of evaluation of complex state-of-the-art models. Continuing efforts to develop observational networks were emphasized.

The session on "*Sustainable strategies in a warming climate*" consisted of 9 oral presentations and 1 poster, including invited talks by Drs. Éva Plagányi (CSIRO Marine and Atmospheric Research, Australia) and Chang- Ik Zhang (Pukyong National University, Korea). This session focused on examples of management strategies that could be applied to sustain fisheries under a changing climate and techniques for assessing and forecasting the performance of harvest policies under changing climate. A key outcome was the need for two-way communication between scientists and stakeholders to develop meaningful scenarios on human responses to the impact of ecosystem and climate change.

The poster session, held over 2 evenings in the beautiful Sakura Hall, generated a lot of interest and resulted in many fruitful interactions.

Bottom left to right: Drs. Chang-Ik Zhang, Brian Rothschild and Takashige Sugimoto.

Early career scientists, (top left) Jörn Schmidt (Germany), (top right) Mega Laksmini Syamsuddin (Indonesia), (bottom left) Felipe Hurtado-Ferro (Columbia) accepting best poster award certificates from the symposium convenors; (bottom right) Dr. Yasuhiro Yamanaka accepting a certificate for Taketo Hashioka (Japan).

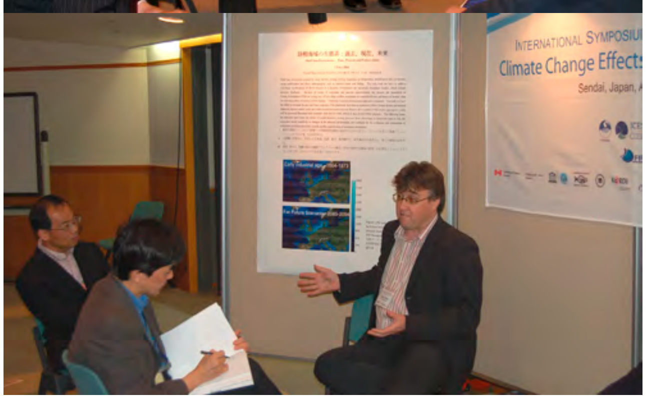
Posters, prepared by early career scientists, were evaluated during the symposium for excellence, and the recipients of these awards were:

- Jörn O. Schmidt (IFM-GEOMAR, Germany) for his paper on "*The rise and fall of snake pipefish* (Entelurus aequoreus L.) *off North Scotland*";
- Taketo Hashioka (JAMSTEC, Japan) for his paper on "*Potential impact of global warming on North Pacific spring blooms projected by an eddy-permitting 3-D ocean ecosystem model*";
- Mega Laksmini Syamsuddin (Hokkaido University, Japan/Indonesia) for her paper on "*Regional climate change impacts on bigeye tuna* (*Thunnus obesus*) *catch in the Indonesian Seas*";
- Felipe Hurtado-Ferro (University of Tokyo, Japan/ Columbia) for his paper titled "*Could management react to a changing climate? The case of the Japanese small pelagic fishes*".

During the symposium, a press interview booth was set up and selected experts had an opportunity to directly communicate their findings and thoughts at daily press conferences with the regional and national media (press and TV) on how climate change affects fish and fisheries. For the press conferences, an English/Japanese brochure was prepared which included summaries of the experts' presentations and selected figures. This brochure helped to encourage the communication with the public. An enlarged poster of the brochure pages was also displayed at the booth. The symposium was covered on two TV media outlets and by six newspapers.

On the day after the symposium, Drs. Anne Hollowed, Shin-ichi Ito and Akihiko Yatsu reported on the outcomes from the symposium at a public seminar held at the Sendai City Information and Industrial Plaza located next to the Sendai Station. A 4-page Japanese leaflet which contained a brief summary of the symposium was provided to the attendees. This leaflet was also distributed to policy-makers, members of Japan Fisheries Cooperatives and Japan Fisheries Industry Cooperatives.

The symposium was made possible by the hard work of the local organizers and professionals at the PICES and ICES Secretariats, by the hospitality of the people of Sendai, and by the generous financial support from our sponsors. In addition to primary international (PICES, ICES and FAO) and local (Fisheries Research Agency of Japan and Hokkaido



Drs. Akinori Takasuka (top), Michio Kawamiya (middle) and Icarus Allen (bottom) briefing reporters on science matters at a daily press conference conducted by Japanese media.

Grouped, left to right: Drs. Akihiko Yatsu, Anne Hollowed and Shin-ichi Ito describing the outcomes of the symposium to the audience at a public seminar, with moderator, Dr. Katsumi Yokouchi (far left), looking on.

University Global Center of Excellence Program) sponsors, the following agencies and organizations made financial contributions to the symposium:

- Fisheries and Oceans Canada (DFO)
- Integrated Climate System Analysis and Prediction, Germany (CLISAP)
- Intergovernmental Oceanographic Commission (IOC)
- International Pacific Halibut Commission (IPHC)
- Japan Society for the Promotion of Science (JSPS)
- Korea Ocean Research and Development Institute (KORDI)
- Australia National Climate Change Adaptation Research Facility (NCCARF)
- Japan National Institute of Environmental Studies (NIES)
- National Marine Fisheries Service of NOAA (NMFS)
- North Pacific Anadromous Fish Commission (NPAFC)
- North Pacific Research Board (NPRB)
- Pacific Salmon Foundation (PSF)
- Scientific Committee on Oceanic Research (SCOR)
- Sendai Tourism and Convention Bureau (STCB)
- World Bank (WB)

Without the funds these organizations provided, it would have been impossible to achieve the aim of convening a symposium of global scope. These funds allowed the support of 67 early career scientists and scientists from developing countries.

Immediately after the symposium, WG-FCCIFS members met to develop a report that will summarize the outcomes of the symposium. This report will be finalized over the summer and presented to ICES and PICES this fall. At this meeting, an agreement was reached to propose a Theme Session, tentatively titled "*Climate change effects on fisheries: Physics-fish-markets*", to be convened at the Second PICES/ICES/IOC Symposium on "*Effects of climate change on the world's oceans*". This symposium will be held from May 14–18, 2012, in Yeosu (Korea), as one of the official events related to the World Ocean Expo-2012. If accepted, we will strive to ensure that the PICES and ICES communities remain engaged in studies on the effects of climate change on fish and fisheries well into the future.

Dr. Anne Hollowed (Anne.Hollowed@noaa.gov) is a Senior Scientist with the U.S. National Marine Fisheries Service's Alaska Fisheries Science Center. She conducts research on the effects of climate and ecosystem change on fish and fisheries and leads the Status of Stocks and Multispecies Assessment (SSMA) program (http://www.afsc.noaa.gov/REFM/Stocks/default.php). Anne serves as Co-Chairman of the ICES/PICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish. She is also a lead author of Chapter 28, Polar Regions, of the Working Group II contribution to the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). Anne is an Affiliate Professor with the School of Fisheries and Aquatic Sciences at the University of Washington. She is a member of the NPFMC Scientific and Statistical Committee and the Fisheries and the Environment (FATE) Steering Committee.

Dr. Manuel Barange (m.barange@pml.ac.uk) is Director of Science at the Plymouth Marine Laboratory (UK), and Chairman of the Scientific Committee of the International Council for the Exploration of the Sea (ICES). His research interests are on the assessment of climate and anthropogenic impacts on marine ecosystems and their services, and on the interactions between natural and social sciences in fisheries, ecosystems and climate change. Manuel is the Principal Investigator of the QUEST_Fish research programme (http://web.pml.ac.uk/quest-fish/default.htm), and is particularly involved in the development of bioeconomic models of global fishmeal and fish oil, investigating the dual exposure of marine-based commodities to global environmental change and market developments. Until recently, he was Director of the International Project Office of the IOC-SCOR-IGBP core project GLOBEC (Global Ocean Ecosystem Dynamics). Manuel co-chairs the ICES/PICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish and is a founding member of the Global Partnership for Climate, Fisheries and Aquaculture (PaCFA).

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2010 Sendai Ocean Acidification Workshop

by Kenneth Denman, Yukihiro Nojiri and Hans-Otto Pörtner

The oceans are becoming acidified as carbon dioxide from fossil fuel emissions enters surface ocean waters from the atmosphere. Global surface pH has already decreased by more than 0.1 units, (IPCC WG1 AR4 Report, Chapter 5, 2007), and may decrease by another 0.4 units by the end of this century under the high CO_2 emission scenario. Some regions of the ocean may have a significant decrease in the $CaCO_3$ saturation state even with the same atmospheric CO_2 change. The key question that should be addressed in future studies on the effects of increasing PCO$_2$ in the ocean may be stated as: What will be the responses and adaptive capacities of individual species and whole ecosystems to a multi-decadal decrease in pH of 0.1–0.5 units (Fig. 1)?

A 1-day workshop on "*Potential impacts of ocean acidification on marine ecosystems and fisheries*", co-convened by the authors of this article, was held immediately prior (April 25, 2010) to the International Symposium on "*Climate change effects on fish and fisheries*" in Sendai, Japan. Talks and posters presented at the workshop reported on manipulation experiments and observations on the effects of elevated CO_2 on organisms at all trophic levels of fisheries foodwebs, and modelling approaches to predict the impact of continuing increases in atmospheric CO_2.

The first talk (Denman *et al.*) presented observational evidence of open ocean increases in PCO$_2$ and decreases in pH, followed by model projections of global mean and spatial patterns of the decrease in pH until the end of this century. Several talks and posters reported on studies of organisms with calcium carbonate skeletal structures subjected to various experimental exposures to low pH (high PCO$_2$) waters in controlled laboratory or field situations. Other talks and posters described physiological and behavioural responses of animals to elevated CO_2 conditions. One poster evaluated the adequacy of a number of ecosystem models to simulate adaptation over long time scales to changes in CO_2 (and other related variables) associated with climate change.

Nakamura *et al*. reported on a depression of metabolism and growth in coral larvae with elevated CO_2 levels. Similiary, Lartey-Antwi and Anderson found decreased growth rates of flat-tree oysters. Suwa and Shirayama presented data obtained with a system precisely mimicking constant and fluctuating CO_2 levels, where the fluctuating levels showed less impact on the growth and skeletal structures of echinoderm larvae than CO_2 levels set permanently high. Kurihara provided an overview on different levels of CO_2 sensitivities according to taxon and in early life stages. Ishimatsu *et al*., Munday *et al*. and Dissanayake *et al*. reported on changes in various processes indicating tolerance limits, decreased aerobic scope and behavioural changes in shrimp and young fish in response to elevated CO_2 levels, with species-specific differences even among closely related fish species. Salau introduced a model of reduced carrying capacity for pteropods as pH decreases, and the feedback effects on pink salmon: as a result, even and odd year differences in salmon stock size will increase over time with management implications for repeating strong and weak returns in alternating years. Rumrill *et al*. (poster) presented long term observations of an estuary showing decreasing pH and effects on oysters in the outer saline estuary and increasing pH probably resulting from changes in precipitation and freshwater runoff. Takami *et al*. demonstrated how elevated CO_2 levels

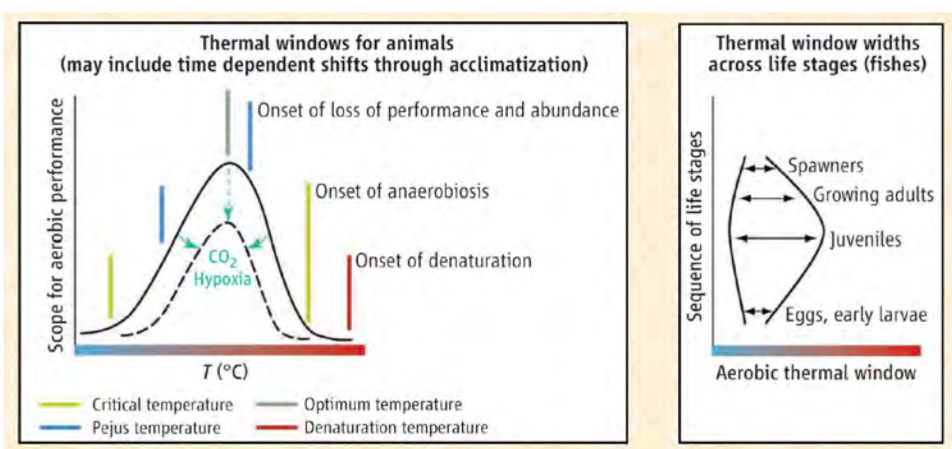

Fig. 1 Animal physiology and climate change showing (left panel) how the 'thermal window' for normal activity by marine animals may shrink with decreasing oxygen concentrations and increasing CO_2 concentrations, and (right panel) how the thermal window changes with life stage (from Pörtner and Farrell, 2008, Science, 322, 690–692).

slow and disturb development in abalone, and Sugie *et al*. (poster) found enhanced drawdown in Si/N by Bering Sea phytoplankton as pH fell and Fe was limited. Kim and Kim (poster) used brine shrimp as a model for identifying changes in the expression of individual genes during exposure to low pH. Finally, Le Quesne and Pinnegar (poster) analyzed several ecosystem models, emphasizing that parameterizations of various physiological processes would be needed to support the evaluation of responses to changing pH.

Noteworthy findings can be summarized as follows:

- Overall, investigators are observing different sensitivity levels among investigated organisms (some closely related), ranging from calcification and growth to development, behaviours and ecosystem level responses. The consideration and introduction of environmental variability changes the pattern and level of response. In light of the complexity and diversity of responses observed, it is thus too early to draw general conclusions regarding the responses of ecosystems to elevated CO_2.
- The inclusion of pre-industrial levels (around 280 ppm CO_2) in experimental protocols, as well as the precise control of diel CO_2 cycling, was considered highly valuable in studying the impact of ocean acidification. In fact, one study reported improvement in calcified structures in echinoderm larvae under pre-industrial compared with present-day levels of ambient CO_2. Investigations of mechanisms under high $P\text{CO}_2$ need be complemented by testing the role of such responses under expectable $P\text{CO}_2$ according to ocean acidification scenarios.
- Studies of behavioural and physiological responses to elevated CO_2 levels for organisms that are not necessarily calcifiers are less mature, but are exciting because so little is known.

Recommendations and Key Questions from the workshop include:

- Pre-industrial control runs should be done more often, since organisms have already adapted from that point.
- Experiments often include current day $P\text{CO}_2$ (~380 ppm) and an elevated CO_2 level of ~1000 ppm. If emissions are controlled to try to achieve <3°C global warming, then intermediate levels of, say, 450, 550, and 700 ppm, have to be considered. Both these recommendations require precise $P\text{CO}_2$ (pH) control.
- Long period culture experiments/multi-generation studies are both needed to try to obtain information on long term adaptive capacity and evolutionary change, but are usually restricted to species with generation times of less than 1 year. Comparisons of species from various climate regimes and CO_2 environments may help to circumvent these constraints in long-lived species.
- In experimental studies diel, seasonal and inter-annual variability of CO_2 levels should be simulated, if relevant for the respective ecosystem. Such experiments would be required to identify slow trends embedded in highly variable environments.
- Population genetic and functional genomic analyses need to be applied more widely.
- Models have to be examined as to whether they formulate physiological and behavioural processes that are dependent on changing environmental drivers such as $P\text{CO}_2$ or temperature.
- Some aquaculture species respond differently than their "wild" counterparts. Have they already become adapted to higher $P\text{CO}_2$, for example by being cultured in water supplied from depths below the mixed layer that already has elevated $P\text{CO}_2$ relative to the depths at which the wild populations live?
- Can we learn from species already experiencing higher $P\text{CO}_2$ naturally? For example some species of copepods and euphausiids migrate several hundreds of meters vertically on diel and seasonal timescales (diapause), where at depth they are exposed to $P\text{CO}_2$ levels of 500 to 1000 ppm.
- Very importantly, experimental protocols must include behavioural and physiological dependencies on multiple variables that we expect to change with the climate: $P\text{CO}_2$, dissolved oxygen, temperature, micro-nutrients (Fe), *etc*. [*e.g*., see Fig. 1 showing a shrinking "thermal window" (aerobic scope – difference between maximal and resting metabolic rates) with decreasing O_2 and increasing $P\text{CO}_2$ (and temperature?)].
- Sensitivities need to be systematically identified across taxa and in between species comparisons.
- Through a combined experimental and modeling approach, can we start to evaluate possible changes in whole ecosystem structure resulting from the possible disappearance and replacement of key species?



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2010 Sendai Coupled Climate-to-Fish-to-Fishers Models Workshop

by Salvador E. Lluch-Cota, Enrique N. Curchitser and Shin-ichi Ito

A 1-day workshop on "*Coupled climate-to-fish-to-fishers models for understanding mechanisms underlying low frequency fluctuations in small pelagic fish and projecting its future*", co-convened by the authors of this article, was held immediately prior (April 25, 2010) to the International Symposium on "*Climate change effects on fish and fisheries*" in Sendai, Japan. Low-frequency variability of abundance of small pelagic fish is one of the most emblematic and best-documented cases of population fluctuations not wholly explained by fishing effort. Over the last 25 years, diverse observations have led to several hypotheses. However, because of limited-duration time series, testing hypotheses has proven extremely difficult with available statistical and empirical tools. As a result, the mechanistic basis for how physical, biogeochemical, and biological factors interact to produce the various patterns of synchronous variability across widely separated systems remains unknown. Identification of these mechanisms is necessary for exploring projections and building scenarios of the amplitude and timing of stock fluctuations and their responses to human interactions (fisheries) and climate change. The workshop was intended to compare state-of-the-art modeling tools and discuss what expertise is necessary to tackle this important scientific and environmental problem.

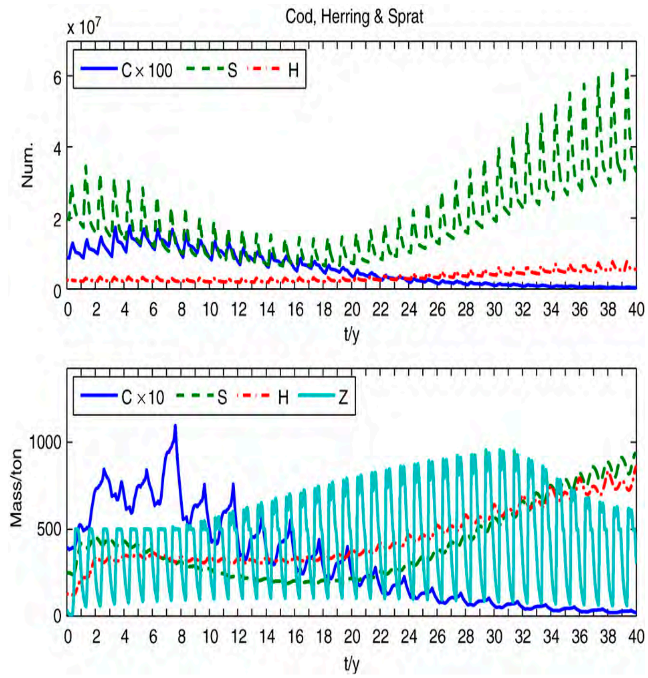

Fig. 1 The variation of total abundance of cod, sprat, and herring (upper, per km^3) and the variations of the total biomass of cod, sprat, herring, and zooplankton (lower, per km^3) derived from hindcast by Fennel's NPZDF model (W. Fennel, Journal of Marine Systems, 2010, 81, 184–195).

The workshop, attended by about 50 scientists, started with an opening address by the convenors. Six oral presentations were given. Ryan Rykaczewski used bioenergetic models to compare anchovy and sardine growth potential in the California Current region and suggested that anchovy growth is dependent on the community structure of near-shore eutrophic waters, and that sardine growth is possible under offshore oligotrophic conditions. Additionally, he discussed the importance of accurate representation of plankton size structure for mechanistic models of sardine and anchovy populations.

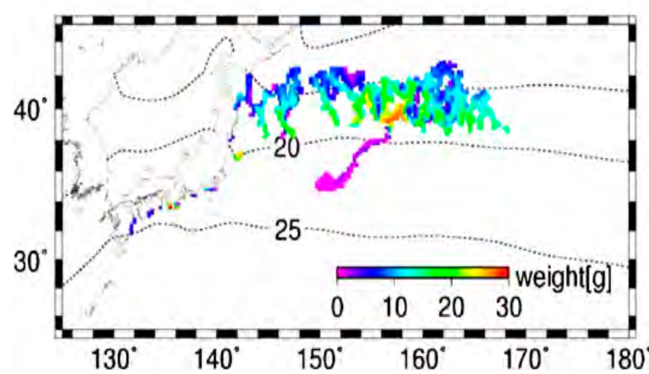

Fig. 2 Seasonally mean spatial weight distributions of Japanese sardine (0-year-old) in autumn simulated by a super-IBM model. The contours show climatological seasonal sea surface temperature from the World Ocean Atlas 2005 (Okunishi et al., Ecological Modelling, 2009, 220, 462–479).

Wolfgang Fennel introduced a NPZDF (nutrient, phytoplankton, zooplankton, detritus and fish production) model with two-way coupling between prey and predators, hence, mass balance between NPZD and fish or prey fish and predator fish are conserved. The model was applied to the Baltic Sea, where the fish dynamics is dominated by two prey (sprat and herring) and one predator (cod). To demonstrate performance of the model, the effects of eutrophication and fishery scenarios were addressed (Fig. 1).

Three 3-D NPZDF models were presented by George Triantafyllou, Shin-ichi Ito and Kate Hedström. Triantafyllou *et al.* introduced a super Individual-Based Model (IBM) of the European anchovy in which particles representing fish have information of fish population, adding to those of age, position, length, and weight of the fish. This Lagrangian model is coupled to a biophysical model based on the Princeton Ocean Model (POM) and the European Regional Seas Model (ERSEM). Moreover, the ERSEM was assimilated to satellite-derived phytoplankton density. Ito *et al.* introduced a super-IBM of the Japanese sardine (Fig. 2) and clearly showed the significance of the density-dependence effect on fish distribution and growth. They also demonstrated the importance of predators on migration of prey fish. Hedströme *et al*. used a community biophysical model; the Regional Ocean Modeling System (ROMS) for the physical circulation model and NEMURO (North Pacific Ecosystem Model for Understanding Regional Oceanography) for the NPZD model. They intend to include a fishery effect in their model and extend it to an end-to-end model. They noted difficulties of such a state-of-art NPZDF model, including spatially locating eggs after spawning and scaling the predator–prey interactions among fish species.

In the final talk, Kenneth Rose addressed issues that arise with developing complicated models in general, and new issues specific to the development of end-to-end models.

Open discussion was held in the afternoon session. Based on the presentation by Rose, participants discussed end-to-end models and how they deal with different issues, particularly zooplankton dynamics and linkages with upper and lower trophic levels. Several attendees expressed concern over the uncertainty and increasing error derived from coupling different models, especially when outcomes from one model are used as input for a chain of other models. Also, strong concern was expressed on how to evaluate performance or validate the models because of the multi-scale nature of these models. No single data set seems to be sufficient. After recognizing the valuable review by Plagányi (FAO Fish. Tech. Paper 477, 2007), the group discussed the need to quantitatively compare performance of models for different processes and promote the use of the best modeling approach option for each question. In this sense, keeping modeling approaches diverse was considered a better strategy than agreeing to a single model. Assemblages of models, as done by the climate community, does not seem to be a feasible approach for end-to-end models. However, the group believed it would be useful for small pelagic fish and climate change research to compile and/or develop different models for at least some of the major small pelagic fishing regions, specifically the Benguela, California, Humboldt, and Kuroshio/Oyashio Currents.



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2010 Sendai Salmon Workshop on Climate Change

by James Irvine

A 1-day workshop examining climate change impacts on salmon was organized by scientists working with the North Pacific Anadromous Fish Commission (NPAFC) and was held immediately prior (April 25, 2010) to the International Symposium on "*Climate change effects on fish and fisheries*" in Sendai, Japan. The NPAFC assembles and documents various types of biostatistical information, including catch and hatchery release statistics and recently published a *Long-term Research and Monitoring Plan* forecasting how salmon will respond to climate change (http://www.npafc.org/new/index.html).

The workshop consisted of 9 oral presentations (20 min), 5 posters (authors were also allowed to give a 10-min oral presentation), and 2 discussion sessions. Presentations were diverse and informative. The majority (12 of 14) focused on Pacific salmon (9 on marine aspects, 2 on fresh water aspects, and 1 on knowledge/database), while 2 papers dealt with Atlantic salmon.

Irvine and Fukuwaka gave an overview of abundance trends for Pacific salmon at the scale of the North Pacific, Asia, and North America. All nations commercial catch data indicate that marine production of Pacific salmon is at all time high levels (Fig. 1), dominated by chum and pink salmon, albeit with significant contributions from hatcheries. Focusing on chum and pink salmon, Fukuwaka *et al*. found high levels of synchrony among regions in catch, although the response to various climate indices varied. Hyunju Seo, who presented the paper by Kaeriyama *et al*., showed that rising temperatures have increased the growth and survival for Hokkaido age-1 chum salmon. However, this apparent benefit may ultimately lead to population density-dependent effects reducing the growth and extending the maturation schedule for chum salmon in the Bering Sea. Farley *et al*. reported results from the eastern Bering Sea that fortuitously covered four consecutive warm years (2002–2005) followed by four cool years (2006–2009). Warm years tended to benefit age-0 walleye pollock, resulting in generally higher growth potential for salmon. Mundy and Evenson concluded that the timing of spawning migrations of high latitude chinook will become more variable as warming continues. Wainwright and Weitkamp predicted that climate change effects on Oregon coho salmon will be largely negative, although great uncertainty in biological responses remains. Reed *et al*. applied an evolutionary model to forecast how some Fraser River sockeye salmon might respond to predicted changes in river temperature resulting from global warming. They concluded that the persistence of some salmon populations will depend on their ability to adapt quickly, which will be determined by the existence of sufficient genetic variation. Peterman *et al*. described the development of a new website intended to help in designing salmon monitoring programs. Wasserman documented the successful experience of the Skagit Climate Science Consortium that is integrating scientific analyses at the watershed level in order to manage salmon populations experiencing climate change. Piou and Prévost and Prusov *et al*. described their findings on Atlantic salmon in the Scorff River (France) and the White Sea (northwest Russia), respectively. Piou and Prévost's models project climate change-related life history effects, concluding that marine conditions and freshwater flow regimes are of utmost importance in determining stock abundance. Prusov *et al*. documented changes in Atlantic salmon growth and age

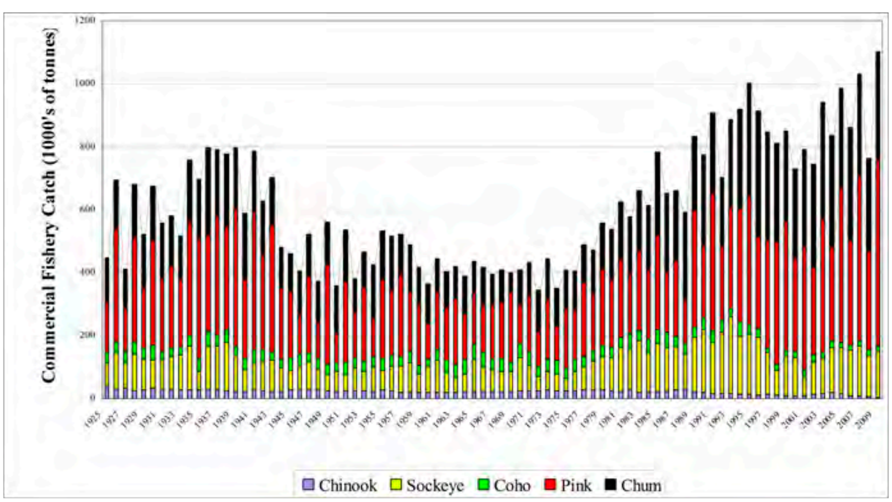

Fig. 1 All nations commercial Pacific salmon catch.

compositions during recent years of increasing temperatures but concluded that changes in management practices have thus far had the greatest impact on the status of northern populations of Atlantic salmon. Miyakoshi *et al.* documented changes in coastal temperatures around Hokkaido and described plans to adjust the release timing of young chum salmon to take advantage of these changes, and thereby increase salmon survivals. Ishida and colleagues' archeological work showed that the distribution of chum salmon in Japan during an earlier warmer period was more northerly than it is today, and predicted similar northerly shifts in salmon distribution with climate change. Jennifer Neilson, presenting the paper by Ruggerone *et al*., showed that chinook salmon growth was related to their previous growth history and pink salmon abundance, while coho salmon growth was strongly linked with pollock abundance, which was linked to temperature.

Following the oral presentations, separate discussion sessions considered the broad topics of forecasting impacts and long-term research needs. Although it was not possible to thoroughly debate all the above questions in the limited time available, there appeared to be consensus on some issues:

- The North Pacific currently produces large amounts of salmon, but rates of increase seen during the last 30 years will not continue.
- Climate change is already affecting salmon differently in northern and southern regions. There will be additional northward shifts in the southern boundary of salmon distribution. There was no consensus on whether or not the Arctic will become a more important area for salmon production.
- Marine production of pink and chum salmon is increasing, but there was no consensus how much of this might be due to ecosystem changes *vs.* enhancement.
- A proper understanding of climate effects on salmon requires consideration of each life history stage. Phases to focus on include: freshwater residence, early marine (first couple of months) and the first winter at sea.
- Important areas of future research include: improving our understanding of effects of interactions between hatchery and wild salmon in their early marine environment, and linkages between coastal oceanography and young salmon growth and survival.
- Integrated research programs with experts from multiple disciplines and countries are most likely to improve our knowledge base.

Acknowledgements: Many thanks to Drs. Masa-aki Fukuwaka (Japan), Suam Kim (Korea), Vladimir Radchenko (Russia), Loh-Lee Low (U.S.A.), and Shigehiko Urawa (NPAFC) for assistance in convening the workshop, with the author of this article, and preparing this report; Dr. Skip McKinnell (PICES Deputy Executive Secretary) for encouraging and promoting the workshop, and other participants for contributing their findings and ideas at the workshop.

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2010 Sendai Workshop on “*Networking across Global Marine Hotspots*”

by Gretta Pecl, Stewart Frusher, Warwick Sauer and Alistair Hobday

A 1-day workshop on “*Networking across global marine hotspots*” was held on April 25, 2010, immediately prior to the international symposium on “*Climate change effects on fish and fisheries*” in Sendai, Japan. The workshop was co-convened by the authors of this article and designed to (1) highlight where global marine ‘hotspots’ occur throughout our oceans, (2) summarize the information currently emerging on biological climate change impacts in these areas, and (3) discuss the potential for developing a global network of scientists, policy makers and managers working in marine hotspots. The workshop attracted considerable interest and was attended by approximately 50 scientists, including invitees from the identified hotspot regions.

The premise behind the workshop was that areas typified by above-average ocean temperature increases, or ocean ‘hotspots’, are the planet’s early warning system for understanding the impacts and adaptation options for marine climate change. Networking and synthesising outcomes from across hotspots can facilitate accelerated learning and also indicate sensible pathways for maximising adaptation and minimising impacts for other global regions. Research, development, management and communication can all be delivered faster, and with greater certainty, through a coordinated network across global hotspots. In these regions:

- Impacts associated with global warming will be observed earlier;
- Species or ecosystem models developed for prediction can be validated earlier than in other slower changing regions; and
- Adaptation options can be developed, implemented and tested first.

The workshop was introduced by Gretta Pecl who described our approach to defining hotspots, their location, and the rationale for the use of sea surface temperature (SST) to determine potential hotspots to include in a global network. Temperature is the most commonly used variable in marine species distribution studies, and as a metric of marine climate change. It is considered to be the major driver of distribution, abundance, phenology and life history. Temperature was also the most commonly identified metric in the presentations at both our workshop and at the main symposium in the days following the workshop. There was extensive discussion on the merits of using SST to define hotspots and on other potential metrics that are also important, such as productivity, acidification, upwelling and oxygen depletion zones. While it was noted that there are other metrics, the general consensus was that SST is a key factor affecting biological processes, and is also the most accessible global data for defining regions that were rapidly changing, and thus provides the first opportunity to inform society of climate change impacts and adaptation options. It was noted that temperature *per se* may not be the driver as it could be a proxy for wind regime changes and/or current shifts.

The intent behind the workshop was not to develop an exhaustive list of global hotspots, but rather to provide a platform to explore the idea of a network covering fast-changing areas across the globe. There was broad agreement that the network would welcome participation by other areas that are also experiencing significant biological change (*e.g.*, areas experiencing noteworthy changes in productivity) or large socio-economic impacts (such as developing countries highly dependent on fisheries).

Based on historical (last 50 years) and projected (next 50 years) rates of ocean warming, 24 regional hotspots were identified that were warming faster than 90% of the oceans. These hotspots covered tropical, temperate, sub-temperate and polar regions, developed and developing countries with a range of adaptive capacities, a variety of ecosystem types, and areas with varying degrees of anthropogenic pressures and disturbances.

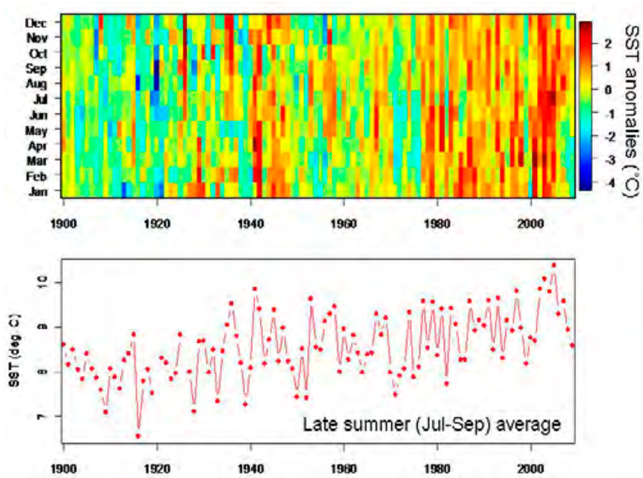

Fig. 1 Sea surface temperature (SST) anomalies in the eastern Bering Sea (from Franz Mueter’s workshop presentation).

Invited presentations covered the following hotspot regions: Southeastern Australia, Southern Africa/Benguela system, Galapagos archipelago, Mozambique Channel, eastern Bering Sea, British Columbia, North Sea, Japan Sea, East China Sea/Taiwan Strait, South China Sea, and coastal zone of Vietnam. Most speakers provided details on published or unpublished *in situ* temperature records demonstrating significant recent increase in temperatures, ‘validating’ the selection of regions as hotspots (*e.g.*, see Fig. 1 from Franz

Mueter's talk on the eastern Bering Sea). However, in many cases temperature either was, or was suspected to be, a proxy for current and/or wind regime changes. Common themes emerging from across these regions with high rates of temperature increase included areas of significant deoxygenation, increased frequency of harmful algal blooms, shifts in species diversity of phyto/zooplantkon communities (mainly from large to small individuals) and increased diversity and species richness of fish. Many presenters provided evidence of large-scale range shifts for a wide variety of species, including movements to deeper waters in some cases. In several regions, large changes in the distribution and abundance of range-shifting species resulted in these acting as 'invasives' creating negative ecosystem impacts (*e.g*., pipefishes in the North Sea and long-spined sea urchins in Tasmania). Interestingly, regions with naturally high climate variability were not less sensitive to climate change factors, instead appearing to be at least equally vulnerable to change and not necessarily 'pre-adapted'. For example, Kyushu in southern Japan and Galapagos archipelago both experience very large seasonal variations in temperature (11–28º and 18–30ºC, respectively), and yet have, in recent decades, undergone regime changes in the inshore areas. In several hotspots redistribution of fisheries effort and associated changes in fleet structure and operations has led to current or impending management implications for harvesting of 'shifting biomass', especially across jurisdictional boundaries.

Formal presentations were followed by a series of discussion topics. The first of these identified the value and practical functions that a global hotspot network could achieve. These were:

(1) Providing a mechanism for scientists, managers and policy makers to communicate and see how science was being translated into policy and practical adaptive management measures in those regions of the world where impacts were occurring;

Dr. Gretta Pecl (Gretta.Pecl@utas.edu.au) is a Fulbright Fellow and a Senior Research Fellow leading several projects within the Climate Change Impacts and Adaptation Theme at the Tasmanian Aquaculture and Fisheries Institute. Her current research activity spans a range of topics, including range extensions associated with climate change, evaluating adaptation options in socio-ecological systems, assessing population and fishery responses to climate change, and using citizen science approaches for ecological monitoring and engagement (http://www.REDMAP.org.au). She was Lead Author of the recent Australian Federal Department of Climate Change interdisciplinary report into the impacts and adaptation response options for the Tasmanian Rock Lobster Fishery (http://www.climatechange.gov.au/en/publications/coastline/east-coast-rock-lobster.aspx). Gretta is currently working in Alaska for her Fulbright Fellowship, a project developed specifically to facilitate collaboration and knowledge exchange between northern and southern hemisphere marine hotspot regions.

Dr. Stewart Frusher (Stewart.Frusher@utas.edu.au) is Associate Professor at the Tasmanian Aquaculture and Fisheries Institute at the University of Tasmania, where he leads the Climate Change Impacts and Adaptation for Marine Resources theme. He co-convenes the bio-physical node of Australia's Adaptation Network for Marine Biodiversity and Resources with Dr. Hobday. His interests are in providing the research to sustainably manage fisheries resources so that they continue to provide social and economic benefits to society. Stewart has extensive experience in crustacean resources and is becoming more involved in the development of interdisciplinary teams to address fisheries issues.

Dr. Warwick Sauer (W.Sauer@ru.ac.za) is Professor and Head of the Department of Ichthyology and Fisheries Science at Rhodes University in South Africa. His interests are in fisheries ecology and management, particularly in the translation of science into practical fisheries management. He serves on a number of management bodies, including the International Cephalopod Advisory Council, and has been involved in numerous regional research projects covering Sub Saharan Africa and the western Indian Ocean. He currently is a member of the Project Coordination Unit for the Agulhas and Somali Large Marine Ecosystem Project, and coordinates training and capacity building initiatives across the Agulhas region.

Dr. Alistair Hobday (Alistair.Hobday@csiro.au) is a Principal Research Scientist at CSIRO in Australia, and leads the Marine Climate Impacts and Adaptation research area (http://www.cmar.csiro.au/climateimpacts). His research has focused on the physical drivers and impacts of climate change on the distribution of marine species around Australia. As a result of his work on fisheries, aquaculture and biodiversity issues, Alistair has been asked to assist with development on national strategy to respond to climate risks. With Dr. Frusher, he co-convenes the bio-physical node of Australia's Adaptation Network for Marine Biodiversity and Resources. He also co-chairs of the international GLOBEC/IMBER program CLIOTOP (Climate Impacts on Top Ocean Predators).

(2) Facilitating comparative studies through:
   - promotion of consistency in data collection, analysis, and reporting, and
   - potential for greater certainty in projection models through first opportunities for validation;

(3) Providing (based on comparisons between regions) greater certainty in the understanding of impacts for stakeholders (*i.e.*, other stakeholders are experiencing similar issues);
(4) Allowing for shared learning and capacity building about adaptation science (successes and failures);
(5) Providing, as the hotspots regions are at the forefront of climate change, valuable insights into the impacts, model validation and the success or failures of adaptation planning for the broader global community.

The workshop participants agreed that a global network of researchers, managers and policy makers working in marine hotspot locations was an appropriate action for providing the science-to-policy framework that would guide climate change adaptation globally.

The final discussion session focused on a path forward and identified the following actions:

(1) A Consensus Statement would be produced to be signed by participants. Participants would be encouraged to obtain in principal support from their respective research/management institutions as further support for the network.
(2) A summary paper of the physical changes documented in last few decades in each region, including observed (or predicted) biological/ecological/fisheries impacts including changes in distribution, abundance and phenology at each of the trophic levels and any observed ecosystem changes and the flow on effects to cultural, social and economic impacts.
(3) A website would be developed for communication of the network and hosting an initial workshop to determine a strategic and operational plan for the network.
(4) Funds would be sought to run targeted workshops on identified areas of need, such as monitoring methodologies, inter-disciplinary approaches for linking science to practical management, *etc*.
(5) Funds would be sought to establish demonstration projects. Examples of such projects could include:
   - identification of key monitoring sites for global comparisons;
   - evaluation of tools/approaches for implementing adaptation options that identify and balance the trade offs in ecological, social and economic indices using some of hotspot regions as case studies.

The workshop was sponsored by Australia's National Climate Change Adaptation Research Facility's Marine Biodiversity and Resources Network (MBRN). The MBRN is an interdisciplinary network aimed at building adaptive capacity and adaptive response strategies for the effective management of Australia's marine biodiversity and natural marine resources under climate change.

NCCARF
National
Climate Change Adaptation
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Adaptation Research Network
MARINE BIODIVERSITY AND RESOURCES

2010 Sendai Zooplankton Workshop

by William Peterson and Kazuaki Tadokoro

The goal of a workshop, co-convened by the authors of this article immediately prior (April 25, 2010) to the International Symposium on "*Climate change effects on fish and fisheries*" in Sendai, Japan, was to provide an opportunity for those keenly interested in "*how data on zooplankton and krill can be used to better understand and forecast the impacts of climate change on fisheries*" to discuss the topic in an informal workshop atmosphere. Contributions were requested which demonstrated explicitly how information on copepods and euphausiids might lead to a better understanding of the linkages between physics and fish. We worked hard to invite people, but in the end we received only 8 abstracts, and thus decided to have a half-day workshop. When the happy day arrived, we did not know what to expect in terms of participation, and we were delighted and very pleased to find the room filled to its capacity, with more than 50 people in attendance. This is evidence of great interest in learning more about mechanistic linkages between physics through the zooplankton to fish.

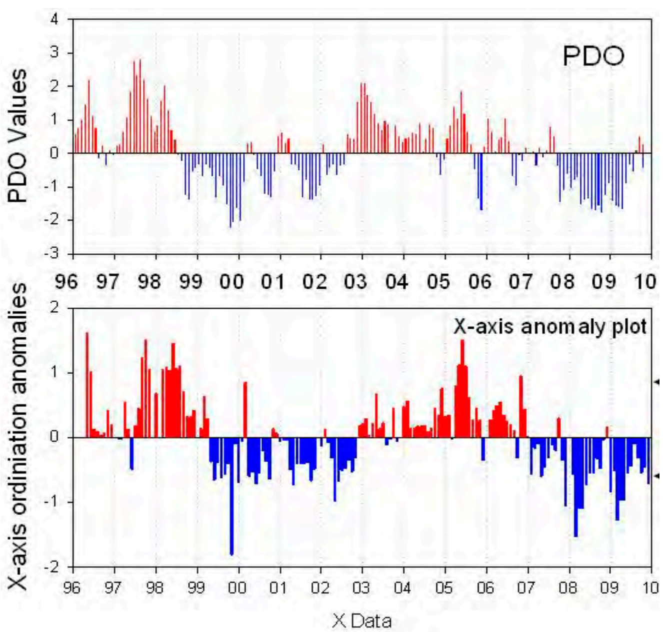

Fig. 1 PDO (upper panel) and monthly anomalies of the x-axis scores of a NMDS of copepod community structure (lower panel).

The meeting was opened by William (Bill) Peterson (NOAA Fisheries, U.S.A.), who presented an overview of some mechanisms that link physical forcing with zooplankton and fisheries response in the North Pacific. As one of the examples, he demonstrated a link between the Pacific Decadal Oscillation (PDO) and the copepod community structure (Fig. 1). The positive (negative) phase of the PDO results in the advection of warm (cold) water to the coast in the northern California Current. As a consequence, "warm" and "cold" water copepod species and communities dominate coastal waters; changes in community structure lag changes in the PDO by a few months.

Ryan Rykaczewski (Princeton Geophysical Fluid Dynamics Laboratory, U.S.A.) gave a Pacific basin-scale perspective on how the Kuroshio and California currents might be linked. He examined basin-wide variability in the depth of the nutricline across the mid-latitude North Pacific using a global, earth system model and found that variability in the depth of wintertime convection in the western North Pacific stimulates anomalies in the vertical distribution of nitrate, and that these anomalies propagate from west to east with the North Pacific Current, with a transit time on the scale of decades.

Bill Peterson discussed his two favorite hypotheses: (1) lipids and cold water copepod species, and (2) source water which feeds the northern California Current, and how these two are linked with salmon survival.

Jay Peterson (Hatfield Marine Science Center, U.S.A.) showed that there have been chronic changes in the upwelling ecosystem off Newport over the last 40 years. First, there has been an increase in the number of copepod species routinely found along the coast (0.11 species per year); second, an intensification of oxygen-depleted bottom waters on the shelf; and third, a deepening in the depth from which water upwells.

Tracy Shaw (Hatfield Marine Science Center) discussed relationships between timing and strength of upwelling and euphausiid spawning. She showed that *Euphausia pacifica* spawning is strongly associated with the timing of the onset of upwelling, but not with upwelling strength. *Thysanoessa spinifera*, on the other hand, spawn prior to and during upwelling and seem to be more strongly affected by water temperature. Future changes in the timing of the spring transition are likely to affect *E. pacifica* spawning behavior. A warmer ocean will likely lead to a decrease in *T. spinifera* abundance and spawning. Both scenarios will affect the availability of euphausiids as a food source for higher trophic level predators.

Motomitsu Takahashi (Nagasaki National Fisheries Research Institute, Japan), presented his work carried out during a short visit at the Peterson's laboratory. He looked at otoliths of late-larval and juvenile northern anchovy and Pacific sardine collected off Oregon in the summer of 2005, an unusual year in which upwelling began very late, in mid-July. The results suggested that the fish responded quickly to the intensification of upwelling after mid-July due

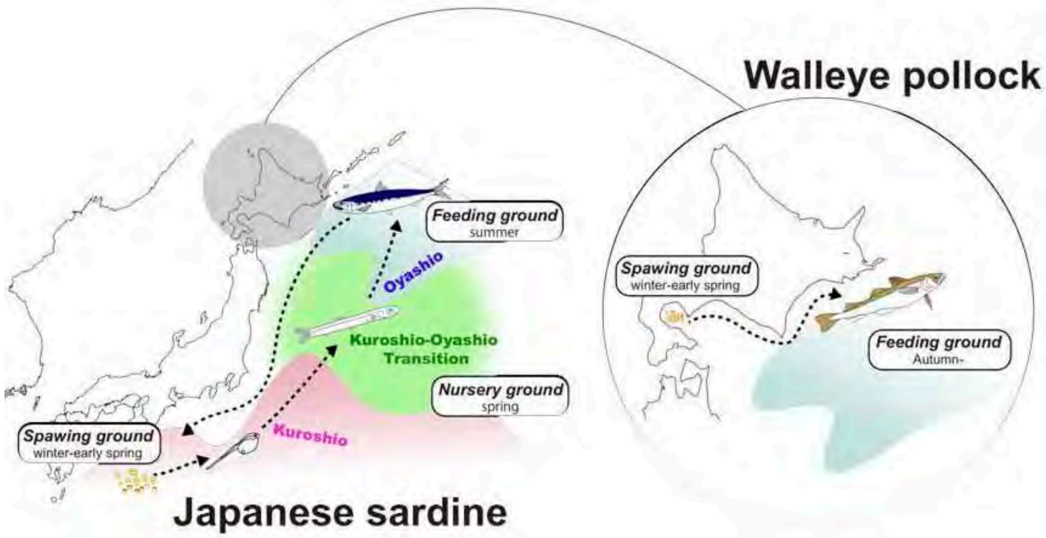

Fig. 2 Overview of the zooplankton from viewpoint of food for fish resources in the western North Pacific.

to the development of a bloom of phytoplankton and a surge in production of cold water copepod species. Increased secondary productivity led quickly to enhance the larval growth rate of northern anchovy.

Kazuaki Tadokoro (Tohoku National Fisheries Research Institute, Japan) provided an overview of the zooplankton from viewpoint of food for fish resources in the western North Pacific (Fig. 2). He reminded us that a great deal of work has been done on the large *Neocalanus* copepod species in the Oyashio-Kuroshio region, with relatively little work on the small copepods species upon which larval and juvenile sardines feed. More research is needed on both food habits of juvenile planktivorous fishes as well as on the zooplankton upon which they feed.

Dr. William (Bill) Peterson (bill.peterson@noaa.gov) is an oceanographer and Senior Scientist with the Northwest Fisheries Science Center, based in Newport, Oregon, at the Hatfield Marine Science Center. Bill is a Team Leader for the "Climate Change and Ocean Productivity" program. One of the core activities of this program is the biweekly oceanographic cruises carried out by his laboratory along the Newport Hydrographic Line, where hydrography, nutrients, chlorophyll, zooplankton and krill are measured. This ongoing activity was initiated in 1996. A key outcome of these monitoring cruises is that the data are now used to forecast successfully the returns of salmon to the Columbia River and coastal rivers of Washington. Bill has been active within PICES since his first meeting (1998), serving on the Executive Committee of the Climate Change and Carrying Capacity (CCCC) Program Implementation Panel, and as Chairman of the CCCC REX (Regional Experiment) Task Team. Now he is a member of the Biological Oceanography Committee and Co-Chairman of Working Group 23 on "Comparative Ecology of Krill in Coastal and Oceanic Waters around the Pacific Rim". Concerning the photo, the presence of the NOAA ship in the background (R/V Bell Shimada) is significant because the entire fleet of NOAA ships based in the Pacific Northwest will be adopting Newport as their new Fleet Headquarters in 2012.

Dr. Kazuaki Tadokoro (den@affrc.go.jp) is a biological oceanographer at the Tohoku National Fisheries Research Institute of the Fisheries Research Agency of Japan. He received his PhD from the University of Tokyo in 1997. Then he worked in the National Research Institute of Far Seas Fisheries, Hokkaido National Fisheries Research Institute, Ocean Research Institute of the University of Tokyo, JAMSTEC, and Hokkaido University. His research interests focus on the influence of the climate change on marine ecosystems of the North Pacific. Kazuaki is also collecting samples for and managing the Odate collection, known as a long-term zooplankton collection at the Tohoku National Fisheries Research Institute.

Mikiko Kuriyama (National Research Institute of Fisheries Science, Japan) reported on long-term variations in copepod community in relation to the climatic change in the Kuroshio waters off southern Japan from 1971 to 2009. She revealed that copepod abundances were high in the early 1970s and after the 1990s, and low in the 1980s. *Paracalanus parvus*, as one of the important prey for the Japanese sardine, was abundant through the study period.

The final talk by Toru Kobari (Kagoshima University, Japan) demonstrated decadal changes in seasonal timing and population age structure of *Eucalanus* in the Oyasiho from a time series initiated in the 1970s. He showed that a decline in copepod abundance originated at the early life stages, and was associated with a shift of atmospheric and oceanographic conditions. Possible biological mechanisms to account for the decline were reduced egg production, lower survival for the portion of the annual cohort with late birth date, and overwintering of the survivors at younger stages.

Each talk was discussed thoroughly, with many questions from the audience. The workshop ended with an open discussion which resulted in the following recommendations: (1) zooplankton time series that are based on either size of copepod taxa, or on species abundance have far greater value than time series of “total biomass” or “volume” of the catch; (2) future workshops on the same topic would be welcomed warmly; and (3) more specialized workshops should be convened whereby zooplankton ecologists with long time series would work with fisheries people from the same region to try harder to relate interannual variations in zooplankton abundance and species composition with variations in some key aspects of pelagic fishes life history – either recruitment or growth.

PICES and ICES on the River Elbe

by Stewart (Skip) McKinnell and Jürgen Alheit

Hamburg University might be considered by some as an unusual venue for a workshop focusing on North Pacific marine ecosystem variability, but its location highlights a continuing interest in conducting comparative studies of Northern Hemisphere oceans and climate. A search for the ultimate cause(s) of variable fish abundance demands an attention to the full range of spatial scales of the potential forces. The climate scale is large so ICES and PICES co-sponsored a workshop on "*Reaction of Northern Hemisphere ecosystems to climate events: A comparison*". It was convened during a cool but sunny week (May 2–6, 2011) by Jürgen Alheit and Christian Möllmann from ICES, and Sukgeun Jung and Yoshiro Watanabe from PICES. The focus of this workshop was an examination of time series from the northwestern North Pacific, within the context of an over-arching objective to conduct a meta-analysis of ecosystem trends and their potential drivers over the Northern Hemisphere. It followed an earlier workshop which had focused on northeastern Atlantic ecosystems.

Saskia Otto (Hamburg U. Ph.D. student) with Motomitsu Takahashi (Japan) and Sukgeun Jung (Korea) in analysis.

Yongjun Tian (Japan), Yury Zuenko (Russia), Sukgeun Jung (Korea), Motomitsu Takahashi (Japan), and Skip McKinnell (PICES) gave presentations about regional data sets from the Pacific during the first day and a half. In keeping with the workshop format, the serious work began by assembling multivariate data sets of long-term time series of physical, chemical and biological variables.

The normal challenges confronted the group as they strove to achieve a balance among the physical, chemical and biological variables. As the data originated in Japan, Republic of Korea and the Russian Federation, each with time series of variable durations, with missing years, different sampling methodologies and ecological emphasis, much of the first few days was spent trying to overcome these difficulties. Lack of balance will, for example, cause ecosystem shifts to be identified some time after they occurred when fishery statistics of long-lived animals have a significant influence on the results.

The analytical approach was to compare and contrast the results of several multivariate statistical methods with the intent to yield further insight into how ecosystems change state. For example, the rates and magnitudes of change may not be the same in the different systems, reflecting region-specific differences in the forcing factors and ecosystem responses to them. There was a general consensus among the methods and among various sub-divisions of the data that a change occurred in the climate and marine ecosystems in parts of the northwestern North Pacific between the winter of 1988/89 and that of 1992/93. The inability to specify one particular year was because different methods and data combinations produced slightly different results.

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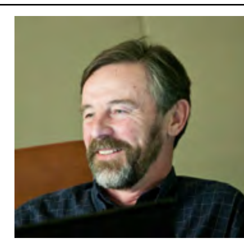

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Continued on inside back page

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