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# Report of the Joint PICES/ICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish (WGFCCIFS)

29–30 April 2010

Sendai, Japan

ICES International Council for the Exploration of the Sea
CIEM Conseil International pour l'Exploration de la Mer

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## Contents

Executive summary ..... 1

1 Introduction and Terms of Reference ..... 3

2 Session P1-D1: Forecasting impacts: from climate to fish ..... 6

3 Session P2: Forecasting impacts: From fish to markets ..... 22

4 Session A1: Downscaling variables from global climate models ..... 23

5 Session A2: Species-specific responses: Changes in growth, reproductive success, mortality, spatial distribution, and adaptation ..... 26

6 Session B1: Assessing ecosystem responses: Impacts on community structure, biodiversity, energy flow and carrying capacity ..... 34

7 Session B2: Comparing responses to climate variability among nearshore, shelf and oceanic regions ..... 39

8 Session C1: Impacts on fisheries and coastal communities ..... 43

9 Session C2: Evaluating human responses, management strategies and economic implications ..... 47

10 Session D2: Contemporary and next generation climate and oceanographic models, technical advances and new approaches ..... 49

11 Session P3: Sustainable strategies in a warming climate ..... 55

12 Workshop W1: Reducing global and national vulnerability to climate change in the fisheries sector: policy perspectives post-Copenhagen ..... 57

13 Workshop W2: Potential impacts of ocean acidification on marine ecosystems and fisheries ..... 62

14 Workshop W3: 'Coupled climate-to-fish-to-fishers models for understanding mechanisms underlying low frequency fluctuations in small pelagic fish and projecting its future' ..... 64

15 Workshop W4: Salmon Workshop on Climate Change ..... 66

16 Workshop W5: Networking across global marine ‘hotspots’ ..... 70

17 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? ..... 73

Annex 1: WGFCCIFS – Working Group Meeting Report ..... 78

Annex 2: List of participants ..... 83

## Executive summary

In 2009 the North Pacific Marine Science Organization (PICES) and the International Council for the Exploration of the Sea (ICES) formed the first joint working group (the Working Group on Forecasting Climate Change Impacts on Fish and Fisheries, WGFCCIFS). The first task of WGFCCIFS 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. Working group members convened a symposium in Sendai, Japan on 26–30 April, 2010. Selected papers from the symposium will be published in the July 2011 issue of the ICES Journal of Marine Science. This report summarizes key outcomes of this symposium as relevant to the Terms of Reference for the Working Group.

The symposium and the subsequent publication will advance 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 the following WGFCCIFS 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. First, key outcomes and findings from the meeting were summarized in a volume of the PICES Press:(http://pices.int/publications/pices_press/volume18/v18_n2/PICES_Press18_FULL.pdf). This vehicle provided immediate outreach to scientists within ICES and PICES. Second, Theme Session and Workshop co-convenors prepared more detailed summaries of key findings from their session (this report). Third, selected papers will be 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. Over 60 papers were submitted for consideration by the ICES Journal of Marine Science and they are currently under review.

## Summary of key outcomes from the symposium

- 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 worlds Large Marine Ecosystems (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: (a) Global or basin-scale static models, (b) Global-scale dynamic models, (c) Dynamic downscaling, (d) Statistical downscaling, (e) Deductive approach, (f) Comparative approaches, (g) Statistical/time series approach, and (h) 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.

# 1 Introduction and Terms of Reference

In 2009, the North Pacific Marine Science Organization (PICES) and the International Council for the Exploration of the Sea (ICES) formed the first joint working group (the Working Group on Forecasting Climate Change Impacts on Fish and Fisheries, WGFCCIFS). The first task of WGFCCIFS 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. Working group members convened a symposium in Sendai, Japan on 26–30 April, 2010. Selected papers from the symposium will be published in the July 2011 issue of the ICES Journal of Marine Science. This report summarizes key outcomes of this symposium as relevant to the Terms of Reference for the Working Group.

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- 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;
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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. Over 60 papers were submitted for consideration by the ICES Journal of Marine Science and they are currently under review.

During the symposium the global significance of the issues was highlighted in many discussions and presentations. Scientists from around the world debated the issues stemming from climate change impacts on marine ecosystems during the 3 ½ day symposium. 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. This symposium provided this type of interdisciplinary exchange of information.

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 sponsors. In addition to primary international sponsors (PICES, ICES and the Food and Agriculture Organization, FAO) and local sponsors (the Fisheries research Agency of Japan and Hokkaido University Global Center of Excellence Program), 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)

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 (U.S.A.), Akihiko Yatsu (Japan), Ussif Rashid Sumaila (Canada) and Edward Allison (Malaysia). The themes for Day 1 included:

- Session P1-D1: Forecasting impacts: from climate to fish (co-chaired by Harald Loeng, Kenneth Drinkwater, Franz Mueter, Carl O’Brien, Graham Philling and Yashuhiro Yamanaka,)
- Session P2: Forecasting impacts: from fish to markets (co-chaired by Manuel Barange, Jacqueline 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 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 A1: Downscaling variables from global models (co-chaired by Michael Foreman and Jason Holt)

- 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 D1: 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 was held in plenary. This session focused on sustainable strategies in a warming climate and it was co-chaired by Michael Schirripa and Anne Hollowed. Dr. Steve Murawski provided a summary of first impressions from the meeting.

### Summary of key outcomes from the symposium

- 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 worlds 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: (a) Global or basin-scale static models, (b) Global-scale dynamic models, (c) Dynamic downscaling, (d) Statistical downscaling, (e) Deductive approach, (f) Comparative approaches, (g) Statistical/time series approach, and (h) 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.

This report summarizes the outcomes of the symposium. Reports are organized by Theme (A–D)or Plenary (P1–P3) sessions, and each report highlights outcomes relative to the four terms of reference for the working group ( frameworks and methods, case studies, documenting and communicating uncertainty, and strategies for research and management under a changing climate). Several authors have provided summaries of climate change impacts on ocean ecosystems and tools for modelling these changes (Brander 2010, Overland *et al*. 2010, Ito *et al*. 2010, Stock *et al*. In Press). This report supplements those efforts to by providing a global perspective on the problem.

# 2 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: Frameworks & methodologies for forecasting climate change impacts

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 (GCM). We divide approaches based on GCMs into (a) global-scale static models, (b) global-scale dynamic models, (c) dynamic downscaling approaches, and (d) 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 a key species to climate variability (e). The comparative approach (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 fraud 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 modelling efforts.

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

Jang and Yoo (hereafter, papers or posters presented during the symposium will be referenced by name, abstracts and selected presentations are available online at http://www.pices.int/publications/presentations/2010-Climate-Change/Day1-Plenary/Day1-Plenary.aspx) employed a basin-scale approach for the Pacific to predict possible consequences of global warming on patterns of production. 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 19 global models from the IPCC AR4 suite of models. Spatial patterns of change differed substantially among models but some regions showed a consistent response across models.

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 and Yoo represents a new approach to address model uncertainty. Static models have similarly been used 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*. 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*. 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. 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 (LME) 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), Allen *et al.*, 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 represent an important advance. Details on the QUEST modelling 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-Philips *et al*. 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 (a) and (b) 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 further, more detailed studies.

An important limitation of the global modelling 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) to global circulation models as implemented in QUEST fish.

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 model to include a bioenegetics model for Pacific saury (NEMURO.FISH), while Hufnagel *et al*. provided an example of an individual-based model (IBM) linked to a regional circulation model. Similar IBMs have been constructed for both 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) for the data-rich eastern Bering Sea and Fulton (session B1) 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 modelled 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*. discussed previously (see (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 modelling approaches, these regional and species-specific approaches 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 approaches considered here, the dynamic downscaling approach may be the most directly relevant modelling approach to provide advice to fisheries managers, given that they are stock-specific and that the model region typically corresponds to an existing management area. These models will be particularly useful if fishing is included as a driver, allowing the use of the models in management strategy evaluations. However, translating model output into management advice will be challenging for IBMs, which do not model dynamics in terms of total abundance or biomass and generally do not include fishing as a source of mortality, the usual currency 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 modelled 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 under development 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 modelling 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 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 modelling 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.*, Bond *et al.*, and Ianelli *et al.*, session P3), rock sole in the Bering Sea (Wilderbuer *et al.*) and Pacific mackerel in Korean waters (Kang *et al.*). The same approach was used by 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.*), seaweed around Japan (Komatsu *et al.*), corals around Japan (Yara *et al.*) and tuna in the South Pacific (Hobday *et al.*). 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 approach that can provide immediate management advice when used in combination with Management Strategy Evaluations (MSEs, e.g. Mueter *et al.*, and Ianelli *et al.*, session P3). This approach 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 modelled 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, O2 levels, and other stressors.

#### Frameworks (e) Deductive approach

The deductive approach relies on process studies to identify the mechanisms (including climate impacts on in 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*. for eastern Bering Sea pollock, Frusher *et al*. for Tasmanian rock lobster, Ono *et al*. 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 D. 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) program, GLOBEC's cod & climate, 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 & biological variability over time (e.g. Overland *et al*., Mendelssohn, Yasuda *et al*., 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 Assessment & recommendations

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) 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 & 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.

### Results from methodologies applied in designated case studies

The focus of many papers in this session was on cutting-edge modelling 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 (2006). 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 O2 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 westward boundary current off the US 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 large zooplankton, 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 modelling 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 modelling approach was also employed by Gårdmark *et al*. (presented by M. Lindegren) 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.*).

### Techniques 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 modelling the biological responses. Jong 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, presentation at 3rd GLOBEC Ocean Sciences Meeting).
- Ensemble modelling is commonly used to characterize uncertainty in climate projections across multiple models (Wang *et al*. Session A1, 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 modelling efforts that use an ensemble of climate models together with an ensemble of biological models. The ensemble modelling approach typically uses simulations to account for various sources of uncertainty, including structural uncertainty. One of the unresolved issues in ensemble modelling 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*. 2010). Beltran *et al*. (this session) provide an example of using a hierarchical Bayesian model to combine SST projections from multiple climate models.
- 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*. (this session), Brodziak *et al*. (this session), Ianelli *et al*. (P3), and Planque *et al*. (A2). 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 side-by-side to graphically illustrate the variability in the responses (e.g. Jang and Yoo, Gårdmark *et al*.., Hare *et al*., see Figure 1).

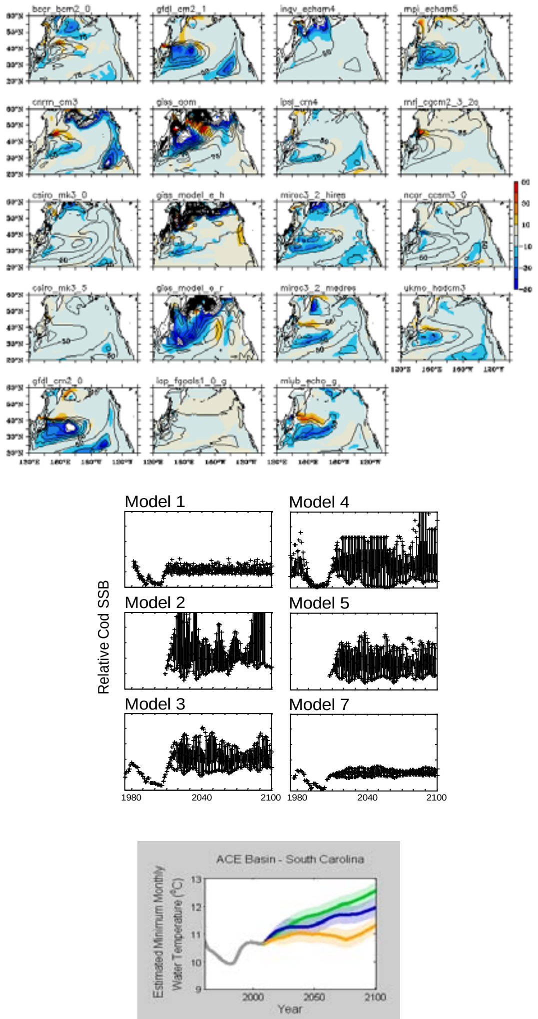


**Figure 1. Examples of model predictions for future trajectories of cod biomass from different population dynamics models (Gårdmark *et al.*), changes in mixed layer depth from 19 global circulation models (Jang and Yoo), and changes in mimumum winter temperatures under different climate scenarios (Hare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

- 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.*) (Figure 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.

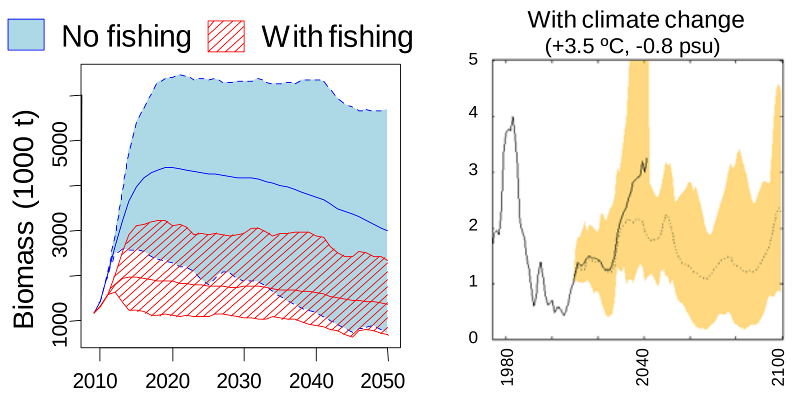


**Figure 2. Examples of predictions of biomass trajectories based on multiple climate and fishing scenarios (Mueter *et al.* with 80% simulation envelope) or based on multiple biological models (full range of ensemble predictions, Gårdmark *et al.*).**

- 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. Figure 1, Figure 3).

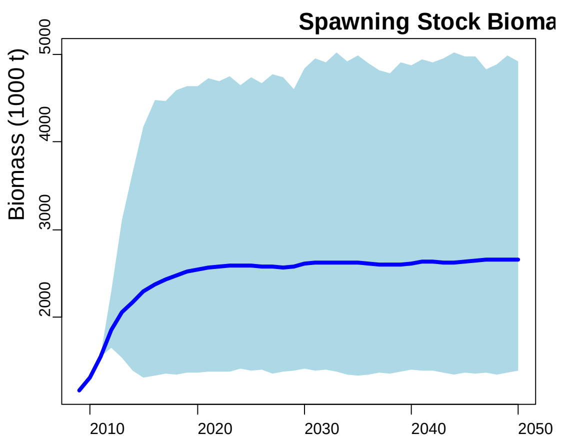


**Figure 3. Example showing simulation envelope along with individual trajectories based on a given model, model parameters, and inputs (based on Mueter *et al.*).**

- 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. Jong and Yoo, Figure 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.

### Strategies for 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*. (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. Different management strategies ranging from no fishing to fishing under status-quo control rules were evaluated by Gårdmark *et al*., Mueter *et al*. and Ianelli *et al*. (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*. 2010).
- 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 to 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 but are less useful in 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 adequately represent 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 modelling 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).

# 3 Session P2: Forecasting impacts: From fish to markets

Co-Convenors:

Manuel Barange (GLOBEC International Project Office)

Jacqueline King (Pacific Biological Station, DFO, Canada)

Co-Chairs:

Ian Perry (Pacific Biological Station, DFO, Canada)

Adi Kellermann (ICES, Denmark)

## 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 will focus 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: Advances in frameworks and methodologies

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 SST; future developments need to use at least O2 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. presentation by Haynie and Pfeiffer). An example of the latter is the presentation by Sumaila *et al*. for climate change impacts in West Africa – 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. Concerns related to 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*.), 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 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 techniques were presented for estimating and communicating uncertainty in forecasts

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.

## 4 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 that are 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 the following three categories: i) downscaling of global climate model variables relevant to marine ecosystems; ii) downscaling techniques and/or their application to particular regions or variables; and iii) 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: Advances on Frameworks and Methodologies

Several key methodological advances were presented in this session. Muyin Wang discussed multiple selection criteria for narrowing down 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 both sea ice extent and seasonal variability over recent decades. This double screening not only narrowed the number of credible GCMs from 23 to 6, but also provided an ensemble projection of more quickly disappearing ice than was predicted by all 23 models; a feature that has been born out in recent years. Several examples of dynamical downscaling were also presented (Kurogi in the waters off eastern Japan, Holt and Holmes for various continental shelves around the world, Curchitser for the Northeast Pacific, Kuroda for the Northwest Pacific and waters around Japan, Foreman for the British Columbia shelf, Hermann 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 and Curchitser), there was two-way communication between the nested regional climate model (RCM) and the more coarsely resolved GCM or basin scale model, with Curchitser 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 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 presented the Global Coastal Ocean Modeling System (GCOMS) as a means of easily porting the POLCOMS model that was originally developed for the NW European shelf to other continental shelf regions of the world (specifically those with important fisheries). Hermann 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: Case Studies to Test Methods

Virtually all presentations included case studies to illustrate their methodology. Wang 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 examined the effects of slightly different scalings of wind stress on variations in the path of the Kuroshio Current near Japan while Holmes 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 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 theoretical analysis suggested that the warming of ocean waters could weaken density gradients and weaken the jet-like nature of the Kuroshio Current. Hermann evaluated 1995–2005 model temperatures and salinities against analogous values from the M2 mooring on the Bering shelf, and Foreman assessed the accuracy GCM and RCM winds against observations from buoys off the British Columbia coast. Yu 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 presented results on phytoplankton studies in the Black Sea, and the potential impact of climatic changes to the prevailing winds.

### Session A1: Techniques 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 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: Evaluation of strategies 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.

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

**Conveners:**

**Richard Beamish (Pacific Biological Station, DFO, Canada)**

**Myron A. Peck (Center for Marine and Climate Research, University of Hamburg, Germany)**

**Motomitsu Takahashi (East China Sea Fisheries Research Division, 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 were documented 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).

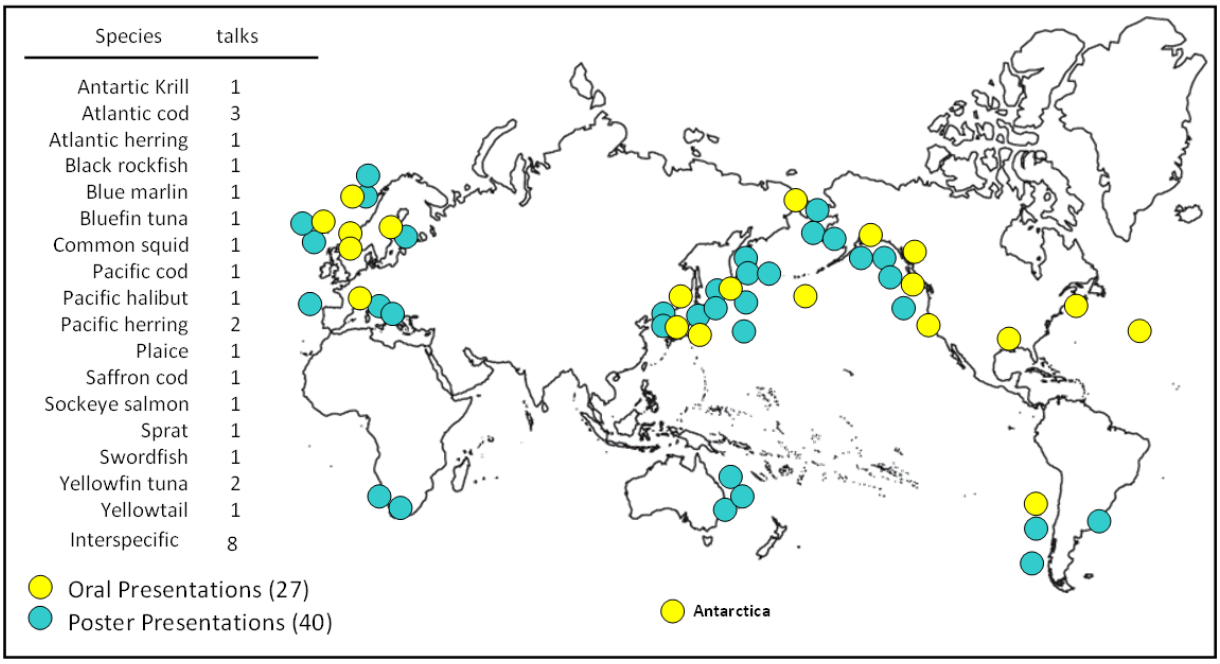


**Figure A2-1 Overview of species list and geographical areas covered by oral and poster presentations within session A2.**

## Session A2: Theme Session 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 i) correlative studies employing time series analysis, ii) mechanistic / physiological studies of the impacts of climate-driven abiotic and biotic factors on key life stages of key species, iii) community-level analyses exploring climate driven changes in species assemblages, particularly spatial distributions, iv) process-oriented research identifying climate impacts on critical life stages, and v) various types of modelling studies, and vi) methodological examples. The latter category summarized a wide-array of different approaches. The presentations are briefly summarized using those five categories.

**i) 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) (Figure A2-1). For some species in some areas, relatively long time series (30 + years) exist from either catch or survey data (Figure A2-2). 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 Examples of long time series include yellowtail (*Seriola quniqueradiata*) in the Japan Sea 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 (A2-6173). Within 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*) (A2-6028 & A2-6179). Naturally, salmonid presentations were made and thoroughly discussed in W4.

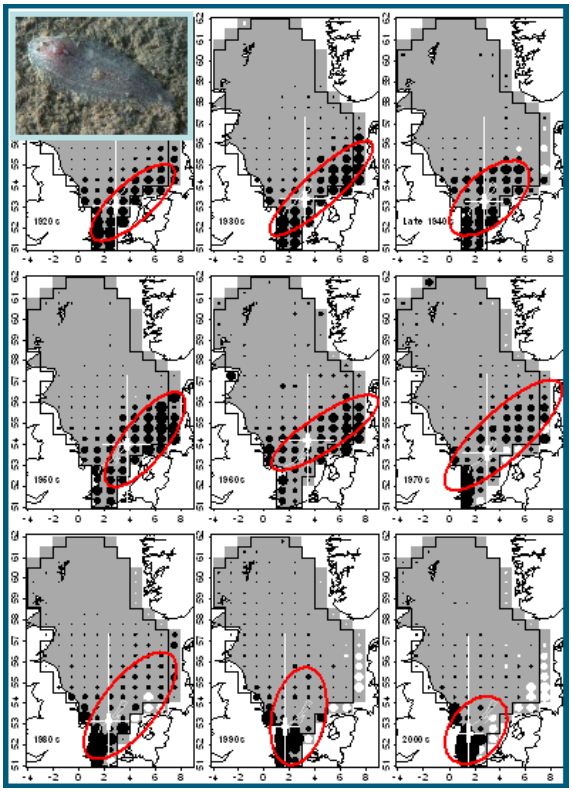

**Figure A2-2. Sole (*Solea solea*) catch per unit effort in the North Sea in each of nine time periods between 1920s and 2000s (from Pinnegar, A2-6362). In the 1920s, the species had a very inshore distribution in southwest in 1930s–1960s and then shifted / expanded more offshore and more northeastward (esp. 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 (A2-6202, A2-6345) and some interesting comparative analyses of responses of species of anchovy and sardine in the eastern and western Pacific (A2-6338). Efforts to estimate the environmental factors that impact the distribution of various species were presented. This included work on Pacific hake (*Merluccius productus*) (A2-6033) the 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.

ii) **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 (A2-6085) discussed the physiologically 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 (Figure A2-3). This presentation also highlighted changes in ocean pH and the need to examine interactive effects of multiple stressors on vital rates. A second presentation (A2-6099) 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 (A2-6153) 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 (A2-6258). 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 (A2-6092) and swimming performance in 24 species of fish in coastal Japanese waters (A2-6094) to behavioural responses to increases in water temperature (A2-6120).

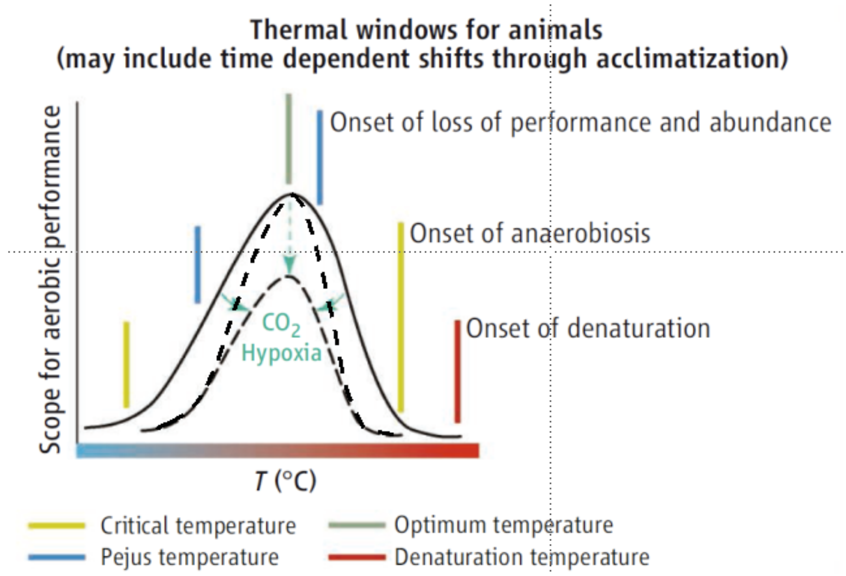


**Figure A2-3. Oxygen and capacity limited thermal tolerance from Pörtner and Farrell (2008 - Science 322, 690-692) as presented by Pörtner (A2 6085). The synergistic effects of multiple factors reduce the scope for aerobic performance and limit the tolerable range in temperatures. Capacity limits occur at low temperatures while oxygen (aerobic) limits occur at high temperatures as indicated by the onset of anearobiosis.**

The 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 (CO2 1000 ppm, pH 7.8) on Pacific oysters (*Crassostrea gigas*) indicated clear differences in the responses among three genetically distinct populations (A2-6319). One presentation (A2-6028) revealed site-specific / sub-stock differences in thermal tolerance for adult Fraser River sockeye salmon (*Oncorhynchus nerka*) returning to spawning grounds. (A2-6028). 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, parciularly 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.

iii) **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 Lusitanian and Boreal species was examined during contrasting periods of fishing pressure and mean temperature in the North Sea (A2-6080). 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 (A2-6196, Figure A2-4). That presentation mirrors the findings in other shelf areas such as the North Sea and in many other 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).

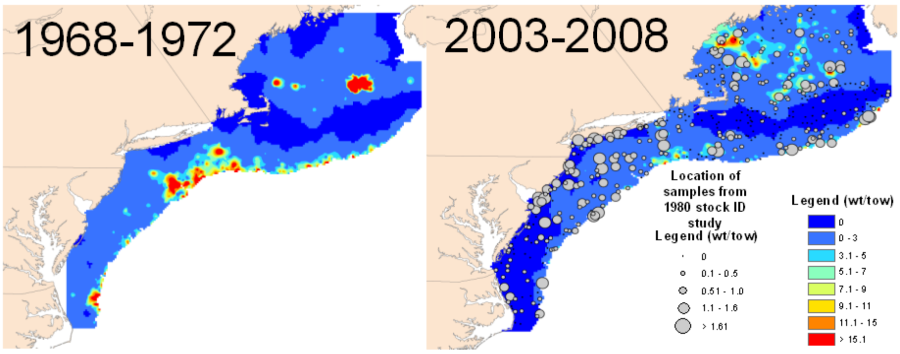


**Figure A2-4. Changes in the distribution of silver hake along the Atlantic coast of the USA between 1968-1972 and 2003-2008 along with the stock ID. This image was compiled from a presentation given by Nye *et al*. (A2-6196).**

iv) **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 (Figure A2-5). 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. One study highlighted density-dependent changes in growth, maturity and distribution in Pacific halibut. The interactive roles of hydrographic and trophodynamic (prey & predator) processes were described in a few presentations. Some “basic” research was presented within posters dealing with environmental factors and their influence on behaviour.

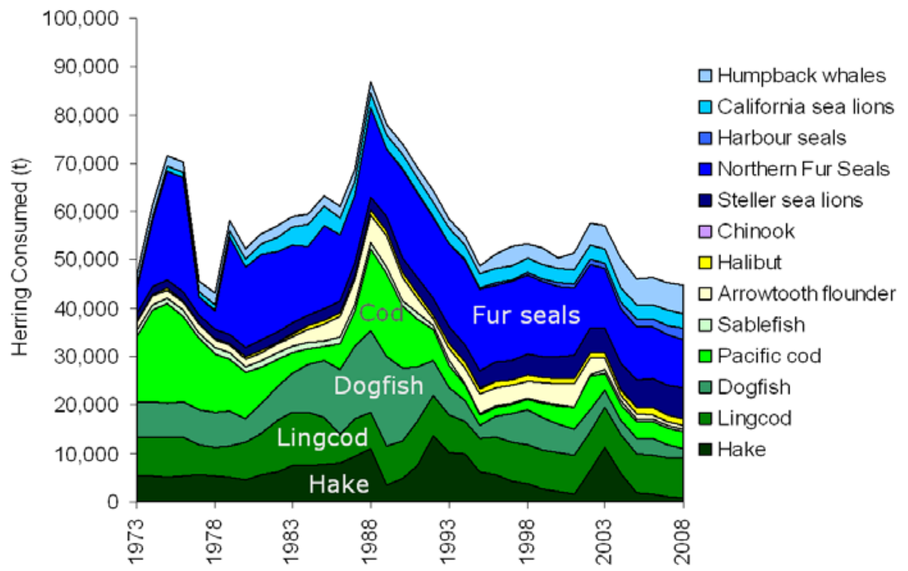


**Figure 4. Estimates of the biomass of Pacific herring consumed by 13 different piscivorous fish and marine mammals presented by Schweigert *et al.* (A2-6250). The figure illustrates the intense, temporally variable predation pressure experienced by that species and is used as an example of the importance of examining multiple processes in light of climate driven changes in systems and impacts on key species.**

v) **Modelling Studies**. Although modelling was the direct topic of other sessions, some presentations in A2 included modelling activities. A bio-envelop modelling approach examined changes in endemic species within the Mediterranean Sea (A2-6090). This topic was re-visited by one of the keynote speakers (A2-6362, Figure A2-6) discussing community-level changes in the North Sea and globally (Figure A2-2). That presentation summarized the recent modelling exercise examining >200 marine fish species by Cheung *et al*. (2009). A number of studies also attempted to "disentangle" the affects of climate and fishing on specific stocks. This included one presentation exploring the influence of fishing-induced juvenescence using a Leslie matrix approach (A2-6145). 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 (A2-6202). 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. Another talk provided a talk showing model-based temporal changes in eight herring stocks due to changes in zooplankton dynamics predicted from the coupled NEMURO-Fish model between 1948–2002 (A2-6224).

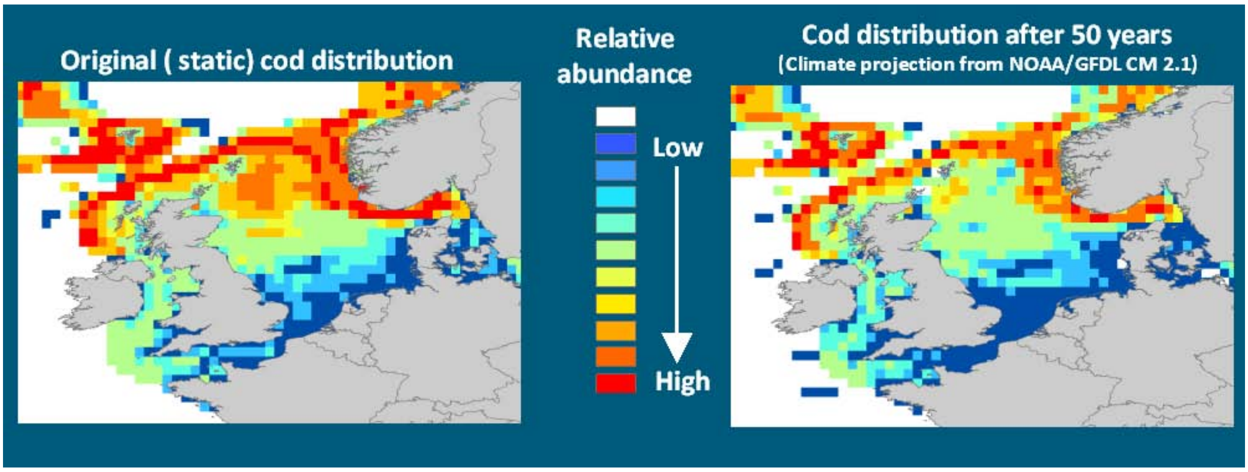


**Figure A2-5. Estimates of the current distribution (left) and projected, 50-year future distribution of Atlantic cod (*Gadus morhua*) in the North Sea and greater European shelf based upon bioclimate modeling. This work was based on Cheung *et al.* (2009) and presented by Pinnegar (A2-6362).**

vi) **Methodological-based studies**. A number of poster presentations discussed advances in methodologies that are particularly useful to identifying climate responses in fish. Examples include morphological and chemical analyses of otoliths (A2-6041, A2-6082) as tools to investigate historical changes in growth and/or distribution. 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*) (A2-6112). Lipid and fatty acid analyses were used as part of a study examining seasonal energy partitioning in an Arctic stichaeid species (A2-6139). 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 (A2-6060, A2-6161)) or water currents (A2-6187) and sub-surface thermal structure (A2-6142, A2-6255). 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 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.

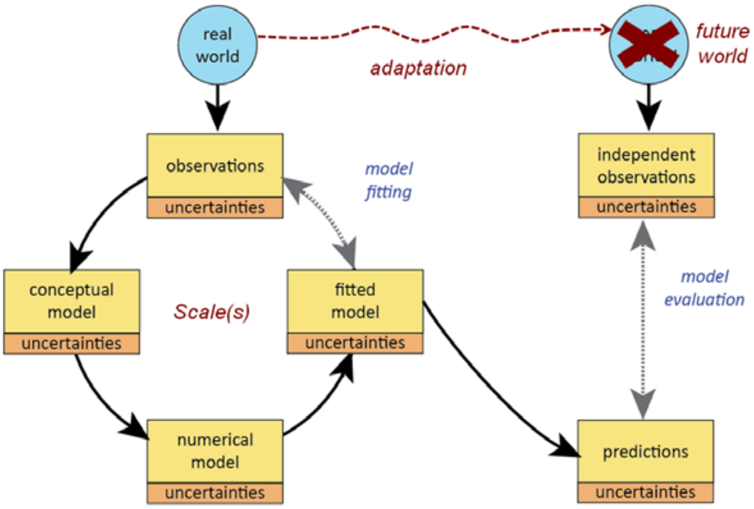


**Figure A2-6. Various sources of uncertainty within models used to project climate impacts on marine species as presented by Planque (A2-6019).**

## 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 (A2-6019).

A schematic was used to highlight the various sources of uncertainty (Figure A2-6). 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.

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

The vast majority of presentations in 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 present 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 A2 presentations, they likely echo research themes stressed in other sessions. Specific recommendations include:

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 x salinity x O2) 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 compare) 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 illusive. 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 repeated 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.

# 6 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 modelling 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: Advances in frameworks and methodologies

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** (on behalf of himself and 3 co-authors) presented "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.

**Sumata** (on behalf of himself and 9 co-authors) presented "Effects of climate forcing on the North Pacific Ocean ecosystem simulated using an eddypermitting marine ecosystem model" in which iron limitation was included in the NEMURO model, and this provided reasonably good reproduction of chlorophyll spatial distributions.

**Hirata** (on behalf of himself and 2 co-authors) presented 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 (chl 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.

**Howell** (on behalf of himself and 2 co-authors) presented 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 GDFL Earth System Model and fishing projections for 21st century.

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** (on behalf of himself and two colleagues) presented 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 GDFL Earth System Model and calibrated using existing trawl data from NE Pacific pelagic salmon trawl surveys.

**Munday** (on behalf of himself and three co-authors) presented work on the effects of ocean acidification on reef fish populations in which they conducted a variety of field experiments to evaluate acidification effects.

**Graham** (on behalf of himself and nine co-authors) presented 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: Results presented from designated case studies

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** and colleagues 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** and colleagues provided reasonably good reproduction of spatial distribution of chlorophyll with their advanced methods.

**Hirata** and colleagues found that the production of large phytoplankton may have decreased (and small phytoplankton may have increased) over the period 1998–2007.

**Fulton** summarized that 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** and colleagues forecasted that the biomass of Hawaiian commercial target specie (e.g. tunas, billfishes) will decrease, while the biomass of currently incidental species (e.g. snake mackerel, mahi mahi, etc) will increase. The GDFL model scenarios indicated an ~18% drop in phytoplankton in HLFG 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 visa versa. This results in lower projected target species biomass and lower ratios of target to incidental species.

**Cheung** and colleagues presented 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** and colleagues found that mortality of a pomacentrid fish increased after exposure to 750ppm CO2, which was identified as critical threshold, due to altered smell ability and behavior.

**Graham** and colleagues 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 |
|---|---|---|
| Jeffrey M. Napp and 6 others | The response of eastern Bering Sea zooplankton communities to climate fluctuations: Community structure, biodiversity, and energy flow to higher trophic levels (B1-6049) | Changes in zooplankton community (and pollock recruitment) 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. |
| Hung-Yen Hsieh and 5 others | Larval fish assemblages in the waters around Taiwan, western North Pacific: A comparison between, during and after the northeasterly monsoon (B1-6168) | The distribution patterns of larval fish assemblages were likely influenced by hydrographic conditions due to alternate intrusions of the CCC and KBC and availability of food |
| Nadezhda L. Aseeva and Alexander L. Figurkin | Changes of bottom ichthyocenosis structure on the shelf of west Kamchatka under changing environments in the last two decades (B1-6235) | Changes and shifts of 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 |
| Rebecca G. Asch and David M. Checkley, Jr. | Climate change leads to earlier seasonal occurrence of larval fishes in the southern California Current (B1-6216) | 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. |
| William J. Sydeman and 11 others | Ocean climate change and phenology: Effects on trophic synchrony and consequences to fish and seabirds in the northern-central California Current (B1-6220) | Murres are coming earlier, upwelling is intensifying and happening later, and these are related. Spatial mismatch likely for birds and krill. |
| Gregory N. Nishihara and Ryuta Terada | 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 (B1-6279) | Maximum species richness declines with wave exposure; Increased storminess in the East China Sea Region may increase algal diversity in 50% of the regions. |
| Sukgeun Jung and 4 others | Climate-driven shifts in marine fish communities indicated by commercial catch statistics from Korean coastal waters (B1-6253) | Coincidence with the regime shifts and correlation analysis alone do not say so much about processes and mechanisms in climate-related studies |
| Hiroaki Saito and 7 others | Understanding and forecasting of fish species alternation in the Kuroshio-Oyashio ecosystem: The SUPRFISH programme (B1-6101) | Fish species alternation. Implications of social and economical science. |
| Rosamma 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 (B1-6164) | Mackerel have declined, possibly due to a lower abundance of copepods |

| | | |
|---|---|---|
| Sunil D. Ahirrao | Effect of climate change on fish and fisheries of Marathwada region of Maharashtra state (India) (B1-6336) | Talked about global generalities |
| Stephen D. Simpson and 6 others | Long-term climate-driven changes in UK marine fish communities (B1-6056) | Water temperature increases, Range shifts; Increased species richness, other community changes; phenological changes, winners and losers |
| Remment ter Hofstede and 2 others | Global warming changes the species richness of marine fish in the eastern North Atlantic Ocean (B1-6078) | Regional warming; Change in species richness related to biogeography; No relation to fisheries |
| Gabriel Reygondeau and 3 others | Changes in the environmental factors controlling the global biogeography of tuna and billfish communities (B1-6305) | Top predators match the provinces of longhearst; Spatial change of the environmental structure of the ecoregion; Spatial shift of the communities; Reorganisation of species composition and inter-specific relationships |
| Charles A. Stock and John P. Dunne | Modeling global patterns in the transfer of energy between primary producers and mesozooplankton in a global circulation model (B1-6366) | 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 PP is "amplified". |
| Ryan R. Rykaczewski and John P. Dunne | Comparison of the ecosystem response to climate change in the mid-latitude North Pacific and California Current ecosystems (B1-6363) | Upwelling, Nitrate, primary and secondary production in CC will increase in 21st century according to a GCM model, while oxygen and pH will decrease. Mechanism from climate to fishes would change. |
| Matthew T. Wilson and 2 others | Ecology of small neritic fishes in the western Gulf of Alaska: Top-down mechanisms can moderate bottom-up forcing (B1-6081) | Increase in abundance of small krill resulted in increase of predator's per capita consumption of krill (observation) |
| Nam-Il Won and 4 others | Comparison of benthic community structure in natural habitats of abalone Haliotis discus hannai affected by different current systems (B1-6328) | Comparison of abalone habitat in two places |

## Session B1: Techniques presented for estimating and communicating uncertainty in forecasts

**Fulton** and **Howell** presented somewhat large ranges of uncertainty in projected changes for the various functional groups in the ecosystem modelling examples they presented. **Howell** presented ranges of uncertainty in his results associated with different assumptions.

**Saito** and colleagues indicated inconsistency in the northern limit migration range between their model and observations.

**Stock** (on behalf of himself and Dunne) provided a statement of large unexplained variation from mesozooplankton patchiness. Historical ocean-ice simulations are underway and may improve model fidelity.

## Session B1: Strategies evaluated for research and management under climate change scenarios

**Howell** and colleagues recommended decrease in fishing effort in HLFG to preserve Target/Incidental ratio and decrease biomass reduction of target species.

**Graham** produced the recommendation that conservation be focused on the least vulnerable species that provide the most functional support and integrity.

**Saito** and colleagues recommended reducing the fleet and fishing pressure.

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

Co-Convenors:

Jürgen Alheit (Lebiniz 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

A total was 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 not dealing with forecasting and uncertainty aspects. This might be 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 under such a situation forecasting and uncertainty aspects is adds to the complexity.

### Summary of invited talks

The first invited speaker (Svein Sundby) was unable to come. Nick Dulvy (Housing crisis: Climate change-induced habitat loss impacts on temperate and tropical fishes) 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 resulted in recent declines in fish abundance. Warming of the North Sea affected fish distribution and led to range extensions of southern 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 chapter does not contribute much. Sub-chapter 3.2 is a summary of all presentations.

## Session B2: What advances on Frameworks and Methodologies for forecasting are presented/discussed?

**Lee** and **Megrey**: Use of visual tools to reduce dimensionality of high dimensional data sets

**Okey** ***et al.***: Ecopath with Ecosim models were used to project the impacts of climate change on various indicators of ecosystem structure and function in different North Pacific ecosystems up to 2060.

**Alheit**: 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)?

This sub-chapter is a summary of all oral presentations.

**6198 – Lucey and Nye** (Shifting species assemblages in the North east US continental shelf Large Marine Ecosystem) Temporal and spatial change in species assemblages within Northeast US Large Marine Ecosystem occur due to a combination of fishing effects and climate. Whereas fishing affected relative biomass and was more important at beginning of time series in early 1960s, climatic factors gained importance as fishing pressure decreased and was responsible for spatial shifts.

**6163 – Rodríguez-Sánchez** ***et al.*** (Spatial dynamics of small pelagic fish in the California Current system on the regime time-scale. Parallel processes in other species-ecosystems) Climatic regime shifts have caused changing population sizes and geographical variations in the position of centre of distribution and bulk of biomass of sardines and anchovies in California Current system. This explains alternation of sardine/anchovy dynamics and temporal disappearence of both species from northern California Current.

**6278 – Poloczanska** ***et al.*** (Global meta-analysis of marine climate change impacts) Authors build a marine impacts database with respect to key questions concerning vulnerability of marine systems to climate change. Preliminary results were presented.

**6392 – Sugimoto and Niki** (Long-term variations in the catch of sergestid shrimps in Suruga Bay induced by variations in the Kuroshio path and climate regime shifts) A highly relevant long-term time series of sergestid shrimp catches starting at 1900 is presented. Shrimp dynamics seem to be synchronous to anchovy dynamics and are impacted by the meandering of the Kuroshio path.

**6188 – Niiranen** ***et al.*** (Are general mechanisms found behind regime shifts across marine ecosystems?) Regime shifts observed in different ecosystems were compared with the aim to quantify marine regime shifts on a global scale. Changes in ecosystem state (regime shifts) affect 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.

**6043 – Eisner** ***et al.*** (Spatial and interannual variability in oceanography, plankton and forage fish in the Bering Sea: Results from U.S. BASIS surveys for 2002–2008) 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 abundance of large zooplankton and be so detrimental for forage fish.

**0000 – Peterson** ***et al.*** (Zonal gradients in copepod community structure in shelf, slope and oceanic waters off Oregon, USA)Composition of copepod fauna is determined by strength of upwelling (only on shelf) and, particularly, by PDO phase. During cool PDO phases, boreal coastal copepods are transported from the Gulf of Alaska into Oregon region. During warm PDO phases, subtropical copepods are transported from offshore into Oregon region.

**6296 – Niquen and Pena** (Response of dominant species in coastal and oceanic regions of Peru) 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.

**6023 – Rogachev** (Coastal submesoscale circulation and thermal limits determine home migration of chum salmon) 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.

**6228 – Kidokoro *et al.*** (Changes in the stock size and life history traits of Japanese common squid *Todarodes pacificus* in relation to climate changes with special comparison between the Kuroshio-Oyashio region and the Sea of Japan) 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 Japan/East Sea decreased around the mid-1970s, but also increased in the late 1980s.

**6397 – Rothschild** (Coupling between multi-decadal transients in fish stock abundance and anthropogenic forcing) It is necessary to study 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.

**6225 – Lee and Megrey** (On the utility of self-organizing maps (SOM) and k-means clustering to characterize and compare low frequency spatial and temporal climate impacts on marine ecosystem productivity) SOMs and k-means clustering 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 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.

**6247 – Alheit** (The limits for forecasting fish population dynamics under changing climate scenarios: The example of small pelagic fishes) Population size of small pelagic fish species in waters surrounding Europe has been shown to swing 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.

**6261 – Okey *et al.*** (Potential impacts of climate change on North Pacific marine ecosystems) Using Ecopath and Ecosim models, the impacts of climate change on various indicators of ecosystem structure and function in different North Pacific ecosystems were studied up to 2060. Climate change impacts are not identical in different ecosystems and across species, but produce winners and losers. 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**: Changes in ecosystem state (regime shifts) affect 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**: Using 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. This issue should be discussed in the report.

# 8 Session C1: Impacts on fisheries and coastal communities

Co-Convenors:

Edward Allison (Policy, Economics and Social Science, Worldfish Center, Penang, Malaysia)

Keith Brander (Technical University of Denmark, National Institute of Aquatic Resources, Denmark)

Suam Kim (Pukyong University, Pusan, Republic of South 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.

C-1 Session was held on 28 April 28 2010. There were 13 oral presentations (25 min each for two invited talks, and 15 min for other talks) and 11 poster presentations. Keith Brander (National Institute of Aquatic Resources, Technical Univ. 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 Keith Brander at the Symposium, Edward Allison (The WorldFish Center, Penang, Malaysia) served as session co-chair with S. Kim for the session operation.

Four questions to be answered as Symposium outputs were:

## Session C1: What advances have we made in developing analytical frameworks and methodology?

It is clear that the IPCC's vulnerability analysis framework, articulated in the 3rd Assessment (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 C-1 session, two invited speakers, Ian Perry (PBS, Canada) and Tarub Bahri (FAO, presenting on behalf of Kevern Cochrane), 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 in 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, 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?

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: S. Saha (postlarval fishing - Bangladesh), E. Papaioannou (GIS in the Baltic Sea), M. Lee (satellite observation on coldwater intrusion – Taiwan Strait), M. Chang (presenting fossil otolith of Atlantic cod in Norway on behalf of A.J. Geffen),

T. Krupnova (macro-algae in Primorie, northwestern Pacific, Russia), A. Fauzi (uncertainty issues in small-scale fisheries in Indonesia), J.H. Lee (climate and ecological regime shift in Korean waters), A. Guzman (sardines as climate proxy in Philippines), and T.H. Nhung (climate change impacts and adaptive capacity and in Vietnam, presented by T.H. Than). E. Andonegi introduced the potential use of the Gadget model to predict stock response to climate change. Due to the cancellation of J.C. Coetzee, S. Lluch-Cota (vulnerability and adaptation strategy in Baja California, Mexico) replaced him.

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 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. Spatial pattern of fishing vessels, movement of vessels, mitigation measures of climate change impact on fisheries should be considered in policy and management formulation. S. Kim *et al*. (Poster presentation) forecasted seawater temperature using 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 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. T. Krupnova *et al*. also examined historic data on ocean environments and bottom macroalgae at 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 the climate change were investigated. There was an apparent asynchrony in seasonal sardine abundance in two bays, and A. 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, A.J. Geffen 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 forecast?

None of the presentations explicitly treated the techniques for estimating and communicating uncertainty in forecasts. However, A. Fauzi *et al*. showed that fishing-dependent coastal communities in 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: Strategies for research and management under climate change scenarios, given the limitations of our forecasts

S. 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.

T. H. Than *et al.* 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.

The fisheries in 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. Modelling practice may give us a clue to reduce uncertainty in forecast.

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, we need to identify vulnerabilities at household level, to diversify livelihoods for income generation and to select environmentally friendly (e.g. low carbon) livelihood and development opportunities.

We need to increase 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.

We need to strengthen coastal resources governance, to develop community based disaster risk management, and to integrate climate change issues into the local and national socio-economic development planning.

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

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

**Co-Convenors:**

**Tarub Bahri (FAO, Italy)**

**Kevern Cochrane (FAO, Italy)**

**Jake Rice (Fisheries and Oceans Canada, Ecosystem Science Directorate, 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 and J. Rice**) and, at regional scale (J. **Bell**). 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 fisherfolks were also described at local scale (poster by S. **Omitoyin**, Nigeria), 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. A.M. **Silvano+Huntington** presented work in 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 can also raise awareness among the fishermen themselves on climate change. G. **Pecl** presented work done in Australia show that modern informatics technology can be used to collect this information.

Four presentations showed how **communities/fisheries have developed strategies to adapt** (**I. Shimizu** in Japan, **S. Muhammad** in Indonesia, **S. Omitoyin** in Nigeria, poster), 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 (**S. Takahashi** in Japan). The adaptability of some fisheries was also assessed (**Tobin**, Australia) and an experience of multidisciplinarity approach for adaptation was described (**poster by Holliday**, Australia). Networks are proposed to share positive experiences on adaptation research and knowledge (poster by **G. Pecl**, Australia).

Three presentations described **management or planning options** that were adopted to address issues related to climate change (**P. Orencio** in the Philippines,) or confronted different possible options, analyzing pros and cons (**B. McCay**, USA). 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 and climate change. One concluded that positive benefits would be gained if catch rules could take into consideration environmental proxies (poster by **F. Hurtado-Ferro**, anchovy and sardine in Japan), whereas the other (**M. Arias-Schreiber**) documented the opportunities for more sustainable harvest of large scale anchovy fisheries in Peru when management reacted quickly with both changes inadapted catch controls and spatial fisheries measures in reaction to changes in when environmental conditions changed. Decision making or planning would be improved for aquaculture as well if impacts of climate change were taken into consideration to select suitable sites (poster by **I. Radiarta**, scallop in Japan). A pair of talks on ecosystem planning in the Philippines (**M. Pido and P. Orencio**) to rationalise and harmonize different uses of the coast, rehabilitate and protect coastal habitats and manage and develop fisheries sector, highlight 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 **B. McCay** that despite rhetoric, people have not been treated as truly part of marine ecosystems in much research and policy.

Finally, a poster analysed the mitigation potential of the fisheries sector through a modelling 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 (**F. Bastardie**, Denmark).

# 10 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 of 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 modelling, 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 will focus on climate and oceanographic models and technical advances and new approaches. Presentations that focus on modelling of climate and ecosystem interaction are also welcome.

## Summary

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 non-linear 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 of 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 modelling, 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 and technical advances and new approaches to project marine ecosystem response to future climate variability and change.

The session included the current state and future directions for a number of elements of the climate – ocean – fisheries – socio-economics modelling system. Two invited talks, 11 contributed talks and 7 posters were given the session. Tremendous strides in climate modelling (coupled atmosphere-ocean general circulation models - AOGCMs) and ocean modelling (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 modelling and ocean modelling 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) modelling 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 (~50–100km scale). New emission scenarios will also be developed. Examples of these various activities were provided by **Kawamiya and Sakamoto *et al.*** for the MIROC4 (high res) and MIROC5 (med res) 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 Nino variability. The dynamics of the Kuroshio current are also better represented. **Tatebe *et al.*** (poster) 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 both on decadal and centennial time scales.

Significant developments were also reported in ocean modeling. **Nonaka *et al.*** presented results regarding Kuroshio variability. 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 hieght) 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-ways model linking a regional northeast Pacific ocean model with a 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 effect of climate change and climate variability on regional fisheries issues. A number of issue related with the two-way nested 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**. 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: North Pacific Ecosystem Model for Understanding Regional Oceanography) linked to a AOGCM model and provided examples of potential climate change effects on fish. This and similar work show the value of coupling regionally developed NPZ models with AOGCMs. **Hashioka *et al.*** (poster) also used a version of the NEMURO model with a projected environment from a 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 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 OGCMs-NPZ models in the Arctic and sub-Arctic seas. A number of posters presented developments with the NEMURO model. **Wata-**

**nabe** ***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. Using a different biogeochemical-NPZ model, **Wang** ***et al.*** demonstrated the potential influence on 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 modelling, 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 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. 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 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 a example for various visualization approaches that make model results available to a much broader community. The last issue that was covered in the session was ethno-oceanographic framework presented by Gasalla. Fisher's oceanological knowledge was surveyed by questionaries to the fishermen and the knowledge was investigate 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 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, ESM 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 (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

- combination of AOGCM-OGCM & ESM-NPZ / vision fully coupled AOGCM-OGCM-ESM-NPZ
- importance of model tools around which the community can work (e.g. NEMURO)
- need for continued observation/modelling/process studies at the basin scale
- continued observation 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"
- need to use models for OSSE's to improve observing networks
- visualization that is model/approach independent
- importance of data assimilation is producing hindcasts and initializing decadal AOGCMs
- continue to build the ensemble approach from AOGCMs to OGCMs / ESMs / NPZs
- use Quest Fish as an example from climate-to-markets
- general tension between standardizing model output or providing translators to work with specific formats.
- high resolution ESM 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 from each theme session

- Continue to support blending of AOGCM / OGCM / ESM / NPZ
- More models should be developed as community models (NEMURO)
- Continued 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 effort to enable projections of unprecedented phenomena
- Others

# 11 Session P3: Sustainable strategies in a warming climate

**Co-Convenors:**

**Anne Hollowed (National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Alaska Fisheries Science Center, USA),**

**Michael Schirripa (National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Fisheries Science Center, U.S.A.)**

### 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 (CMAR, CSIRO, Australia) and Chang Ik Zhang (Marine Production Management, Pukyong National University, Republic of Korea) 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 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 foodweb 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 condition relative to the ecosystem standards and objectives. This coupled model projection approach extends MSE type evaluations to provide an Integrated Ecosystem Assessment.

Plagányi *et al*. presented framework for two-way communication between scientists and stakeholders to develop strategic approaches to compliment 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 and Ianelli 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 provided demonstrated a process for selecting management scenarios and a method for communicating the tradeoffs to stakeholders and managers.

Nielsen *et al*. presented a case study on the implications of climate change on salmon in the Arctic. She 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 *et al*. (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. As noted above the presentations by Hollowed *et al*., Plagányi *et al*. and Zhang and Lee all showed the importance of including socio-economic factors when developing of scenarios for the future of fish and fisheries. Zhang and Lee presented a method to evaluate the performance of manage strategies within an ecosystem context. Schirripa also presented the plans for the development of an Integrated Ecosystem Assessment for the southeastern region of the United States. Kaeriyama *et al*. illustrated the need for more holistic models that extend MSE assessment frameworks to include economic performance measures. The poster by Barange et al. presented the QUEST_Fish framework which utilizes a multi-disciplinary approach to assessing risks and vulnerabilites to climate change (Barange et al. In Press). 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 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.

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

**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 half-day workshop on "Reducing global and national vulnerability to climate change in the fisheries sector: Policy perspectives post-Copenhagen", convened by the Food and Agriculture Organization and the WorldFish Center, on behalf of the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA, see W1-Figure 1 for membership of PaCFA) was held at the International Symposium on "Climate Change Effects on Fish and Fisheries: Forecasting impacts, Assessing Ecosystem Responses, and Evaluating Management Strategies" on 25 April 2010 and attended by 22 persons. 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 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.

The workshop started by a review of the workshop objectives and an introduction to the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA) by Marie-Caroline Badjeck from the WorldFish Center. This was followed by presentations from 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 run up 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.

## 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.

As regards 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 (for example 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 the 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 of 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 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 household living standard 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 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 more 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 also 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 release of 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.

### 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 so as to have improved 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.

W1-Figure 1. 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

## Participants

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

**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 modelling 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 CO2 conditions. One poster evaluated the adequacy of several ecosystem models to simulate adaptation over long time scales to changes in CO2 (and other related variables) associated with climate change.

Nakamura *et al*. reported on a depression of metabolism and growth in coral larvae with elevated CO2 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 CO2 levels, where the fluctuating levels showed less impact on the growth and skeletal structures of echinoderm larvae than CO2 levels set permanently high. Kurihara provided an overview on different levels of CO2 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 CO2 levels, with species specific differences even among closely related fish species. Salau reported on 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*. (P) 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 run-off. Takami *et al*. demonstrated how elevated CO2 levels slow and disturb development in abalone and Sugie *et al*. (P) found enhanced drawdown in Si:N by Bering Sea phytoplankton as pH fell and Fe was limited. Kim and Kim (P) 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 (P) analyzed various ecosystem models emphasizing that parameterizations of various physiological processes would be needed to support the evaluation of responses to changing pH.

### 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 CO2.
- The inclusion of preindustrial levels (around 280 ppm CO2) in experimental protocols as well as the precise control of diel CO2 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 CO2. 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.
- 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 pCO2 (~380 ppm) and an elevated level often ~1000 ppm. If emissions are controlled to try to achieve < 3C 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 $pCO_2$, for example 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 meters vertically on diel and seasonal timescales (diapause), where at depth they are exposed to $pCO_2$ 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: $pCO_2$, dissolved oxygen, temperature, micro-nutrients (Fe), etc. [e.g. Pörtner and Farrell, 2008, Science, 322, 690–692].
- Sensitivities need to be systematically identified across taxa and in between species comparisons.
- Through a combined experimental and modelling approach, can we start to evaluate possible changes in whole ecosystem structure resulting from the possible disappearance and replacement of key species?

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

Convenors:

**Dr. Salvador E. Lluch-Cota (Fisheries Ecology Program at Centro de Investigaciones Biológicas-del Noroeste, Mexico)**

**Enrique N. Curchister (Institute of Marine and Coastal Sciences, Rutgers University, New Jersey, U.S.A.)**

**Shin-Ichi Ito (Fisheries Research Agency, 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 George

Triantafyllou, Shin-ichi Ito and Kate Hedström 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, Kenneth 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, 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.

# 15 Workshop W4: Salmon Workshop on Climate Change

**Convenors:**

**Dr. James R. Irvine (Chief)**
**Fisheries and Oceans Canada**
**Nanaimo, B.C. V9T 6N7 Canada**

**Dr. Masa-aki Fukuwaka**
**Hokkaido National Fisheries Research Institute**
**Hokkaido 085-0802, Japan**

**Dr. Suam Kim**
**Pukyong National University**
**Busan 608-737, Republic of Korea**

**Dr. Vladimir Radchenko**
**Sakhalin Research Institute of Fisheries & Oceanography (SakhNIRO)**
**Yuhzno-Sakhalinsk 693023, Russia**
**Dr. Loh-Lee Low**
**Alaska Fisheries Science Center**
**Seattle, WA 98115-0070, USA**

**Dr. Shigehiko Urawa**
**North Pacific Anadromous Fish Commission**
**Vancouver, B.C., V6C 3B2 Canada**

Following welcoming remarks from Vladimir Fedorenko, Executive Director of the North Pacific Anadromous Fish Commission, there were 9 oral presentations (20 min), 5 oral poster presentations (10 min), and 2 discussion sessions (see schedule appended at end of this summary).

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. Hyunju Seo, who presented the paper by Kaeriyama *et al*., 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 four consecutive warm years (2002–2005) followed by four 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 Feb/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 concluded 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*. described the development of a Salmon Monitoring Web site designed to help in the design of salmon monitoring programs. Wasserman described the successful experience of the Skagit Climate Science Consortium who are 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 fresh water flow regimes are of utmost importance in determining stock abundance. Prusov *et al*. documented 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. Jennifer Neilson, presenting the paper by Ruggerone *et al*., 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 describing a proposed long term research and monitoring plan (http://www.npafc.org/new/pub_special.html).

The following questions were considered:

1 ) 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?

2 ) 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 northern and southern regions. There will be additional northward shifts in the southern boundary of salmon distribution. There was no consensus whether the northern boundary would shift further north in to the Arctic.
- 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 including experts from multiple disciplines and countries are most likely to improve our knowledge base.

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# 16 Workshop W5: Networking across global marine 'hotspots'

**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 persons contacted to present at the workshop. All contacted scientists responded positively to the concept and 12 were able to participate in the workshop.

Presentations covered a range of temperate, sub-temperate, polar and tropical systems as well as developed and developing countries (Annex 1).

There was discussion on the merits of using 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 & developing countries
- Range of adaptive capacities
- Variety of ecosystem types
- Range of anthropogenic pressures & disturbances

There was broad agreement that while SST is only one driver, it was a major driver of distribution, abundance, phenology & 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).

### Session W5: What results were presented from designated case studies (to test methods)

Common themes that were apparent in the presentations include:

- Most hotspots did have 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 in fisheries distribution & associated changes in fleet structure & operations
- Many areas showed significant deoxygenation
- Increased frequency of harmfull algal blooms
- Shifts in species diversity of phyto/zooplantkon communities (mainly large to small individuals) and increased diversity and species richness of fish species.
- Large changes 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.
- 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 summarised as:

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.
2) 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
3) Comparisons between regions would provide greater certainty in the understanding of impacts for stakeholders (i.e. other stakeholders are experiencing similar issues).
4) It would provide for shared learning & capacity building about adaptation science (successes & failures).

5 ) 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.

## Session W5: 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, interdisciplinary 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 trade offs in ecological, social and economic indices using some of these regions as case studies.

### Vision for 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.

# 17 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, Newport Oregon, USA)

Kazuaki Tadokoro (Tohoku National Fisheries Research Institute, FRA, Shiogama, Japan)

**Workshop goals and results.** 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. 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. We worked hard to invite people to submit abstracts but in the end we received only 8 abstracts, thus we convened a half-day workshop. 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.

## Session 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 are were previously described in the PICES press and are summarized again 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.

Bill Peterson discussed his two favourite hypotheses: (1) lipids and cold water copepod species, and (2) source water which feed the northern California Current and how these are linked with salmon survival.

Jay Peterson 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 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. She 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.

Moto Takahashi discussed some of his work carried out during a short visit at the Peterson lab in Newport. 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 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.

Kazuaki Tadokoro from the Tohoku National Fisheries Research Institute in nearby Shiogama 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 work is needed on both food habits of juvenile planktivorous fishes as well as on the zooplankton upon which they feed.

Mikiko Kuriyama reported on long-term variation 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. *Paraclanus parvus*, as one of the important prey of the Japanese sardine, was abundant through the study period.

The final talk was by Toru Kobari demonstrated decadal decadal changes in seasonal timing and population age-structure of *Eucalanus* in the Oyasiho from a time series that originated in 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.

## W6 Recommendations

The workshop participants made the following recommendations:

- 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 zooplank-

ton abundance and species composition with variations in some key aspects of pelagic fishes life history –either recruitment or growth.

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## Annex 1: WGFCCIFS – Working Group Meeting Report

The ICES/PICES Working Group on Forecasting Climate Change Impacts on Fish and Shellfish (WGFCCIFS) met in Sendai, Japan on 29–30 April 2010. Twenty people participated from 9 countries (Annex 2). The main objective of this meeting was to review the outcomes of the Climate Change Effects of Fish and Fisheries Symposium and to discuss plans for future collaborative research in 2010–2012. The group proposed the following activities:

The meeting opened with a review of ICES and PICES Working Groups that are related to climate change. The role of PICES Working Groups was summarized by Alexander Bychkov and then the role of ICES Working Groups was summarized by Manual Barange (by phone). Both PICES and ICES see climate change research as an integrative cross cutting activity. Following the ICES and PICES overviews, Manual Barange discussed Quest-Fish, an ongoing project linking climate to fish to markets and the newly funded EU-BASIN project. BASIN 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.

Jürgen Alheit led a discussion that identified potential PICES and ICES Science 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. Anne Hollowed then provided an update of several NOAA activities including COMPASS and the new NOAA Climate Services. Shin-ichi Ito updated the group on ESSAS and Jon Hare updated the group on a workshop held at GFDL during the summer of 2009.

Following these general issues, the WG then began a review of the Symposium Workshops.

**Workshop 1** - Reducing global and national vulnerability to climate change in the fisheries sectors: Policy perspectives post Copenhagen - WG members felt that the workshop was a success. The goal of the workshop was to present the goals and strategies of the Global Partnership on Climate, Fisheries and Aquaculture (PaCFA) and to inform Symposium participants about discussions and decisions made during the the UN Framework Convention on Climate Change (UNFCC) COP15 meeting in Copenhagen, December 2009. Attendance was a little low, but the WG felt that inclusion of these high-level policy activities at the Symposium was important and should be continued in future meetings.

**Workshop 2** - Potential impacts of ocean acidification on marine ecosystems and fisheries - was represented by Kenneth Denman (Canadian Centre for Climate Modelling and Analysis, DFO, Canada) and Hans Pörtner (Alfred-Wegener Institute, Germany). There was a huge turn-out for this workshop indicating the interest and the importance of ocean acidification. The WG discussed whether future meetings should include specific ocean acidification theme sessions; the group was near consensus with the idea that these sessions would receive a lot of attention. However, there were mixed feelings regarding this idea since ocean acidification could be a climate impact included in any of the theme sessions at the current Symposium. Also, there is already a meeting dedicated to the ocean acidification issue (http://oceanacidification.wordpress.com/2010/07/16/third-symposium-on-the-ocean-in-a-high-co2-world/). Forming separate sessions might work against the integrative emphasis of the current symposium.

**Workshop 3** - Coupled climate-to-fish-to-fishers models for understanding mechanisms underlying low frequency fluctuations in small pelagic fish and projecting its future - was represented by Shin-ichi Ito (Tohoku National Fisheries Research Institute, FRA, Japan). This workshop was very successful. Over the last 25 years, diverse observations have been integrated into several hypotheses regarding the causes of low-frequency variability of small pelagic fish abundance. The workshop brought together experts from the around the world to present work and discuss new results in the context of existing hypotheses. The objectives were focused and the organizers expect several papers to be submitted to the Symposium proceedings based work and interactions developed during the workshop.

**Workshop 4** - Salmon workshop on climate change – was represented by James Irvine (Pacific Biological Station, DFO, Canada) and Suam Kim (Pukyong National University, Korea). The workshop continued discussions among North Pacific researchers as to the effects of climate change on salmon populations. Several overview talks were given and then several discussion panels were held. The discussion panels included: forecasting impacts, assessing ecosystem responses, and evaluating management strategies. The WG discussed the issue that many of the same climate-salmon interactions have been identified in the North Atlantic but very few North Atlantic researchers participated in the workshop. A recommendation of the WG is to suggest that PICES and ICES work harder to facilitate interactions between salmon biologists working in the two basins.

**Workshop 5** - Networking across global marine "hotspots" - was represented by Stewart Frusher (Tasmanian Aquaculture and Fisheries Institute, University of Tasmania, Australia). The workshop's goals were to (1) highlight where global marine 'hotspots' occur now, and where they are projected to occur in the future; (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 organizers envision a review paper coming out of the workshop that reports on these goals.

**Workshop 6** - 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? was represented by William Peterson (Hatfield Marine Science Center, NMFS/NOAA, USA). One of the main goals of this workshop was to ensure that climate effects on trophic interactions were included in the Symposium. This goal was achieved through the workshop and through many of the papers presented at in the theme sessions. It is clear that direct environmental effects and trophic interactions are both receiving attention in the research community.

Following review of the workshops, the Plenary Sessions on day 1 and 4 were reviewed. In general, the WG felt that the plenaries were excellent. The broadcast talk by Kevin Trenberth, who could not attend because of the Icelandic volcano, was very well done and provides an example how a global meeting could happen in the future with less travel. Owing to other travel problems, some of the plenaries on day 4 were re-arranged and Steve Murawski's summary was excellent.

Each theme session was then reviewed by the WG. This review focused on a set of specific questions and the detailed response of the theme session organizers to the questions will be presented in the Theme Session reports. The specified questions addressed were: 1) What advances on Frameworks and Methodologies were presented/discussed; 2) What results were presented from designated case studies (to test methods); 3) What techniques were presented for estimating and communicating uncertainty in forecasts; 4) What strategies were evaluated regarding research and management under climate change scenarios

### Recommendations from each theme session

What follows is a brief summary of discussions with an emphasis of issues that were outside of the specific questions.

Two theme sessions were focused on climate modelling and the link between climate modelling and fish and fisheries. Theme Session A1 - Downscaling variables from global models - was represented by Jason Holt. This session focused on issues related to down-scaling the current generation of GCM's for use in fish and ecosystem impact studies. Theme Session D2 - Contemporary and next generation climate and oceanographic models, technical advances and new approaches - was represented by Shin-ichi Ito and Jon Hare. This session focused on advances in the modelling that can be transitioned to advances in forecasting effects of climate change on fish and fisheries. These two sessions served an important role as they attracted climate scientists and models to the Symposium. Their ongoing participation in fisheries-climate research is critical and the WG discussed additional ways to include this science community in future symposiums.

Two theme sessions focused on environment – climate – fish links. These sessions had the most papers suggesting that much progress has been made in understanding and projecting climate effects on fish species. Theme Session P1-D1 - Forecasting impacts: From climate to fish – was represented by Franz Mueter. This session focused on linking climate projections to fish dynamics. This session was one of the largest. Theme Session A2 - Species-specific responses: Changes in growth, reproductive success, mortality, spatial distribution, and adaptation - was represented by Myron Peck. This session was the largest. Both of these sessions had a wide range of papers from simple correlative studies to intricate simulation studies. The WG discussed that understanding the relation between the environment and single species is gaining a lot of attention and techniques and approaches that use current climate model output are developing quickly.

Theme Sessions that covered climate impacts on ecosystems also had numerous presentations, though fewer than the climate-to-fish sessions discussed above. Theme Session B1 - Assessing ecosystem responses: Impacts on community structure, biodiversity, energy flow and carrying capacity - was represented by Thomas Okey. This session contained a number of excellent talks that addressed the broader climate effects on ecosystems and how in turn these could affect fish and fisheries. Theme Session B2 - Comparing responses to climate variability among nearshore, shelf and oceanic regions - was represented by Jürgen Alheit. This session focused on a comparative approach to understanding the effect of climate change of fish and ecosystems was highly successful. Over the next several years, the WG envisions that research covered by these two Theme Sessions will increase dramatically.

There were fewer papers presented at the Theme Sessions that addressed fish to markets. Theme Session P2 - Forecasting impacts: From fish to markets – was represented by Ian Perry and contained 8 talks. Theme Session C1 - Impacts on fisheries and coastal communities - was represented by Suam Kim and contained 13 scheduled talks.

Theme Session C2 - Evaluating human responses, management strategies and economic implications - was represented by Jake Rice and also contained 13 scheduled talks. The WG discussed the fact that this aspect of the Symposium really represented cutting-edge work; the linking of climate-to fish – to markets. The WG identified a major need to continue to bring in economists and social scientists into collaborative projects aimed at forecasting the effect of climate on fisheries and fishery communities and economies. QUEST Fish was discussed as an example and the development of future Theme Sessions and Symposiums around the economic and social impacts of climate effects on fisheries was encouraged.

Another issue was raised by the WG that was not represented at the Symposium – the adaptation of fish to changing climate. Most if not all of the studies presented at the Symposium assumed that the biology of fish was constant. Yet, there is every reason to expect some evolutionary response of fish to climate change. The WG discussed writing a perspective piece or more explicitly including this topic at a future Climate Change Effects on Fish and Fisheries.

The WG 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 Third Symposium on The Ocean in a High-CO2 World was noted as an important meeting for the WG to be aware of http://oceanacidification.wordpress.com/2010/07/16/third-symposium-on-the-ocean-in-a-high-co2-world/. The offer was made to host the next Climate Change Effects on Fish and Fisheries in conjunction with the Ocean-Expo 2012 in Yeosu, Korea. This will be discussed further at the next WG meeting in Nantes, France.

The WG meeting closed with a warm thank you to the Local Hosts Organizations - Fisheries Research Agency of Japan (FRA), and Tohoku National Fisheries Research Institute (TNFRI) FRA – and the individuals - 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. The WG also thanked the Symposium conveners for putting together an excellent scientific program: Anne Hollowed (Alaska Fisheries Science Center, NMFS/NOAA, U.S.A., 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). The Symposium was a huge success largely as a result of the hard work of the local hosts and symposium conveners.

## Draft Joint Resolution WGFCCIFS

1 ) Convene a 1 ½ day theme session in conjunction with the Effects of Climate Change on the World's Oceans meeting in conjunction with the 2012 Ocean Expo in Yeosu, Korea. We request an endorsement by ICES and PICES for this proposal by the WGFCCIFS. We also request that ICES and PICES clarify that funds for invited speakers will be included as part of the overall financial contribution to the symposium.

2 ) Request that PICES co-sponsor an ICES intersessional meeting on "Forage Fish Interactions and Ecosystem Approach to Fisheries Management", to be held in Nantes, France, from 10–14 September 2012 that will be convened by Myron Peck (U.S.A., ICES). ICES has already agreed to sponsor it, therefore, this resolution is for action by PICES only.

3 ) Convene a 1 day workshop on climate change effects on fish and fisheries in conjunction with the ESSAS open science meeting in Seattle, Washington, U.S.A in May 2010. We request an endorsement by ICES and PICES for this proposal by the WGFCCIFS.

The WGFCCIFS endorsed two proposals for joint PICES/ICES activities:

1 ) 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 2011 to be convened by E. DiLorenzo (U.S.A., PICES) and I. Yasuda (Japan, PICES) H. Hatun (Faroe Islands, ICES) and Jürgen Alheit (Germany, ICES). No action by ICES is needed as ICES does not provide travel support for participation in expert group activities.

2 ) ICES/PICES Workshop on "Reaction of Northern Hemisphere Ecosystems to the Climate Events in the Late 1980s: a Comparison" to be convened by Jürgen Alheit (Germany), R. Diekmann (Germany) and NN (PICES). No action by ICES is needed as ICES does not provide travel support for participation in expert group activities. We request that PICES nominates a co-convenor for this theme session.

The working group may request funds from ICES for a 2nd volume of papers to be published in the *ICES J. Mar. Sci.* in September, 2011. This resolution will be resolved during ICES ACS.

# Annex 2: List of participants

## WGFCCIFS meeting 29-30 April, Sendai, Japan

| First | Last | Institute | Location |
|---|---|---|---|
| Jürgen | Alheit | Leibniz Institute for Baltic Sea Research | Warnemuende, Germany |
| Alexander | Bychkov | PICES Secretariat | Sidney, British Columbia, Canada |
| Michael | Foreman | Fisheries and Oceans Canada, Institute of Ocean Sciences | Sidney, British Columbia, Canada |
| Stewart | Frusher | University of Tasmania | Hobart, Australia |
| Jonathan | Hare | Narragansett Laboratory, National Marine Fisheries Service, National Oceanic and Atmospheric Administration | Narragansett, RI, U.S.A. |
| Anne | Hollowed | Alaska Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration | Seattle, WA, U.S.A. |
| Jason | Holt | Proudman Oceanographic Laboratory | Liverpool, United Kingdom |
| Shin-ichi | Ito | Tohoku National Fisheries Research Institute, FRA | Shiogama, Miyagi, Japan |
| Sukyung | Kang | National Fisheries Research and Development Institute | Busan, Republic of Korea |
| Adolf | Kellerman | Science Programme, International Council for Exploration of the Sea (ICES) | Copenhagen, Denmark |
| Suam | Kim | Department of Marine Biology, Pukyong National University | Busan, Republic of Korea |
| Skip | McKinnell | PICES Secretariat | Sidney, British Columbia, Canada |
| Franz | Mueter | School of Fisheries and Ocean Sciences, University of Alaska Fairbanks | Juneau, Alaska, U.S.A. |
| Thomas | Okey | Ecosystem Sciences, Westcoast Aquatic and University of Victoria | Port Alberni, British Columbia, Canada |
| Myron | Peck | Center for Marine and Climate Research, University of Hamburg | Hamburg, Germany |
| Graham | Pilling | Centre for Environment, Fisheries and Aquaculture Science | Lowestoft, Suffolk, United Kingdom |
| Jake | Rice | Fisheries and oceans Canada, Ecosystem Science Directorate | Ottawa, Canada |
| John | Stein | Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration | Seattle, Washington, U.S.A. |
| Motomitsu | Takahashi | East China Sea Fisheries Research Division, Seikai National Fisheries Research Institute | Nagasaki, Japan |
| Yury | Zuenko | Japan Sea and North-West Pacific Oceanography, Pacific Research Institute of Fisheries and Oceanography (TINRO-Center) | Vladivostok, Russia |