North Pacific Marine Science Organization

A New Science Program for PICES

FUTURE

Forecasting and **U**nderstanding **T**rends, **U**ncertainty and **R**esponses of North Pacific Marine **E**cosystems

Vision

To *understand* and *forecast* responses of North Pacific marine ecosystems to climate change and human activities at basin and regional scales, and to broadly *communicate* this scientific information to members, governments, resource managers, stakeholders and the public.

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FUTURE (**F**orecasting and **U**nderstanding **T**rends, **U**ncertainty and **R**esponses of North Pacific Marine **E**cosystems) is an integrative Science Program undertaken by the member nations and affiliates of PICES 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.

FUTURE will make advances by:

- Investigating the mechanisms underlying ecosystem response to natural and anthropogenic forcings;
- Improving forecasting capabilities and providing estimates of the uncertainty associated with these forecasts; and
- Developing more effective ways to convey knowledge and predictions.

FUTURE will build upon the Climate Change and Carrying Capacity (CCCC) Program that PICES initiated in cooperation with GLOBEC in the mid-1990s. The CCCC Program contributed significantly in stimulating and facilitating research on the links between climate variability, more than global warming, and marine ecosystem responses and dynamics with an emphasis on understanding how climate might alter the carrying capacity for a few species of fish. It then evolved into a program with much broader interests providing the first systematic, North Pacific-wide attempt to understand and document the physical and ecological processes that link large, low-frequency signals with population and ecosystem dynamics, which led to significant improvements in biophysical modeling and coupled climate–ocean modeling. Because of CCCC we know far more about the role of iron in oceanic systems, about direct and indirect effects of climate on marine organisms, populations and ecosystems, and about what processes are likely the most important—meaning we have improved understanding of the mechanisms. The CCCC Program emphasized climate change and impacts only, whereas FUTURE will place greater emphasis on societal concerns that arise from three potential threats to North Pacific ecosystems:

- Irreparable damage to non-renewable resources and the loss of resilience and productivity of natural environmental capital and services such as renewable resources and habitats;
- Loss of socioeconomic opportunities due to natural and anthropogenic change in marine ecosystems; and
- Increased challenges faced by managers and policy makers from unpredictable ecosystem responses to climate change and human activities.

These issues are driving a need to increase basic scientific understanding of ecosystem processes, to reduce predictive uncertainty of the ecological consequences of these threats, and to translate the information for use in decision making. FUTURE will build on improved understanding of marine ecosystem structure and function that has been gained during the past decade through diverse monitoring, observation, and retrospective studies and modeling activities conducted by PICES countries.

The success of FUTURE will require that our improved understanding of processes and mechanisms leads to an increased forecasting capability and to increased societal awareness of the status of the North Pacific ecosystems. The linkages between climate, ecosystems and societies will be explored to clarify both how human activities will alter the ecosystems of the North Pacific and how options for human use of these ecosystems will change.

Scientific Priorities

- The effects of climate and climate change on physical, geochemical and biological processes at geographical scales ranging from the North Pacific basin and its marginal seas to the coastal regions of interest to PICES member countries;
- Marine ecosystem responses on seasonal to decadal time scales and the consequences of these responses to ecosystem goods and services (*e.g.*, provisioning of foods, regulation of carbon and nutrient cycles, cultural and recreational benefits);
- Ecological interactions and connections between estuarine, coastal and offshore waters, the western and eastern Pacific, and the northern and equatorial Pacific;
- Direct and indirect effects of human activities, such as fishing, aquaculture, introduced species, habitat alteration, pollution, and greenhouse gas emissions and their consequences for member countries;
- Cumulative effects of multiple ecosystem stresses on biological diversity and ecosystem resilience and productivity with a better understanding of thresholds, buffers and amplifiers of change;
- Risk-based ecological assessments within a policy/management framework to communicate future states of nature, their implications, and uncertainties to decision-makers and the public.

Scientific Imperative

The Intergovernmental Panel on Climate Change (IPCC) concluded, in its fourth assessment report in 2007, that the evidence for global warming of the climate system is unequivocal:

- Globally averaged air and ocean temperatures are increasing, accompanied by widespread melting of snow and ice raising the globally averaged sea level. Average northern hemisphere air temperatures during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years.
- Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases.
- Anthropogenic warming could lead to some impacts that are abrupt, irreversible and severe, depending upon the rate and magnitude of the climate change.

It is against this backdrop of change that PICES is embarking on its next major Scientific Program. It is clear that increasing concentrations of greenhouse gases have launched the world onto a trajectory of change without a clear sense of the ultimate consequences. What is not so clear, and this must be a focus of FUTURE, is the manner and degree to which these global or hemispheric changes are manifested in the North Pacific Ocean and at a regional scale on land and in coastal seas. Both changing climate and increasing human activities are causing changes in North Pacific ecosystems. These changes are affecting ecosystem composition, structure and function in ways that are incompletely understood and possibly unprecedented. There is uncertainty of the magnitude and extent of the change that is occurring because large parts of the North Pacific Ocean and its marginal seas are not monitored or observed regularly. To improve our understanding we must increase observations of the North Pacific and study the mechanisms that underlie an ecosystem's response to the various pressures.

The North Pacific Ocean and its marginal seas are often characterized by strong contrasts among its sub-regions, cross-basin inverse correlations of sea surface temperature being foremost among these. The area of concern to PICES is so large that warming in one area is often accompanied by cooling in another. Understanding how these contrasts are likely to change, if at all, will be an important element of FUTURE. But global warming and its consequences are not the only issue. Natural and anthropogenic pressures are causing the oceans to acidify, while pollution, extirpations, invasive species, anoxia, habitat loss, and exploitation affect the coastal zones. Many species have not yet recovered from past or current over-exploitation, and there is ongoing damage to non-renewable resources. Plant and animal abundance and distribution, productivity of exploited and unexploited species, food-webs, biodiversity and general ecological resilience are all affected by these pressures.

While the trajectory of some of the major changes is now generally known, there is a great deal of uncertainty about their local magnitudes, their potential interactions and their impacts on North Pacific ecosystems. This uncertainty is caused by a lack of understanding of how the major drivers will individually, collectively and interactively affect ecosystem composition, structure and function and insufficient knowledge of the linkages between oceanic, coastal and terrestrial ecosystems. These major uncertainties hamper the ability of the scientific community to provide reliable estimates of the future status of ecosystems. FUTURE will improve these estimates and communicate them effectively so that science can better support policy. This view has led to the identification of an overarching question for FUTURE.

"What is the future of the North Pacific given current and expected pressures?"

Research Themes

FUTURE is organized around three research themes that are best characterized as key questions. Each of the key questions has a list of more specific questions that define an approach to address a research theme.

1. What determines an ecosystem's intrinsic resilience and vulnerability to natural and anthropogenic forcing?
    - 1.1. What are the important physical, chemical and biological processes that underlie the structure and function of ecosystems?
    - 1.2. How might changing physical, chemical and biological processes cause alterations to ecosystem structure and function?
    - 1.3. How do changes in ecosystem structure[1] affect the relationships between ecosystem components[2]?
    - 1.4. How might changes in ecosystem structure and function affect an ecosystem's resilience or vulnerability to natural and anthropogenic forcing?
    - 1.5. What thresholds, buffers and amplifiers are associated with maintaining ecosystem resilience?
    - 1.6. What do the answers to the above sub-questions imply about the ability to predict future states of ecosystems and how they might respond to natural and anthropogenic forcing?

2. How do ecosystems respond to natural and anthropogenic forcing, and how might they change in the future?
    - 2.1. How has the important physical, chemical and biological processes changed, how are they changing, and how might they change as a result of climate change and human activities?
    - 2.2. What factors might be mediating changes in the physical, chemical and biological processes?
    - 2.3. How does physical forcing, including climate variability and climate change, affect the processes underlying ecosystem structure and function?
    - 2.4. How do human uses of marine resources affect the processes underlying ecosystem structure and function?
    - 2.5. How are human uses of marine resources affected by changes in ecosystem structure and function?

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[1] Such as species composition, population structure and dynamics, *etc*.
[2] Such as species interactions, habitat usage, biological rates and biological diversity.

2.6. How can understanding of these ecosystem processes and relationships, as addressed in the preceding sub-questions, be used to forecast ecosystem response?
2.7. What are the consequences of projected climate changes for the ecosystems and their goods and services?

3. How do human activities affect coastal ecosystems and how are societies affected by changes in these ecosystems?
    3.1. What are the dominant anthropogenic pressures in coastal marine ecosystems and how are they changing?
    3.2. How are these anthropogenic pressures and climate forcings, including sea level rise, affecting nearshore and coastal ecosystems and their interactions with offshore and terrestrial systems?
    3.3. How do multiple anthropogenic stressors interact to alter the structure and function of the systems, and what are the cumulative effects?
    3.4. What will be the consequences of projected coastal ecosystem changes and what is the predictability and uncertainty of forecasted changes?
    3.5. How can we effectively use our understanding of coastal ecosystem processes and mechanisms to identify the nature and causes of ecosystem changes and to develop strategies for sustainable use?

Related to all three research themes is the goal of improving our capability to convey in a clear and effective way how societies will be affected by a changing North Pacific marine environment. The following question captures the goal of improved communication of the science from FUTURE.

"How can forecasts, uncertainty and consequences of ecosystem change be communicated effectively to society?"

Scientific Strategies

Scientific strategies for FUTURE will be fully developed in the FUTURE Implementation Plan. These strategies will include data compilation and retrospective studies, monitoring, mathematical modeling and process studies, all done with the FUTURE perspectives of understanding, forecasting and communicating.

Data compilation and retrospective studies will be used to identify the key physical, chemical and biological processes that are at highest risk from climate change and other anthropogenic stresses. Recommendations will be developed on future monitoring of the North Pacific so that ecosystem change of societal importance can be detected and understood. Monitoring will also provide the data needed for mathematical model development that will range from fine-scale models for coastal areas to whole ecosystem models of multiple trophic levels, including humans and top-predators. Improved understanding of mechanisms will be essential to understand how human uses of the ecosystem and climate change may interact, as well as to improve the capacity for forecasting ecosystem response and consequences of climate change for ecosystem goods and services.

As forecasting is a central element of FUTURE, it is important to note that specific forecasting strategies vary according to temporal and spatial scales. Seasonal forecasts of ecosystems rely on observations and seasonal forecasts of physical and chemical conditions which often depend on the output of operational mid-range weather forecasts. Regional forecasts will require accurate downscaling of global climate models/projections and, at times, linkage of oceanic models to hydrographic models of watersheds to capture the dynamics of coastal ecosystems influenced by large rivers. Only very recently have efforts been underway to downscale global climate projections for use at local scales. Due to their relatively coarse spatial resolution, existing climate models can be more readily used for basin-scale forecasts.

Forecasts of the state of marine ecosystems on decadal time scales require knowledge of the linkages and relationships within the present system, understanding of how these linkages might change with changing climate, and a good comprehension of future environmental conditions. Currently, efforts are being devoted to the latter. During the course of FUTURE, reasonable forecasts of the physical environment will be anticipated and used as they emerge. On multi-decadal time scales, the global warming signature may dominate internal climate variability and this will allow projections for marine ecosystems from global warming scenarios for the North Pacific. While forecasts of the future of North Pacific ecosystems will be a focus of FUTURE, nowcasts of the current state of ecosystems will provide an important context for predictions of future states.

Improving the understanding of mechanisms and increasing forecasting capability will require improved coordination of data accessibility and dissemination, evaluation and application of new technologies from molecular and genetic techniques to remote sensing. Finally, informational tools (*e.g.*, synthesis documents, websites and translations of the science for non-scientific audiences) that are specifically designed to work for each member country will be needed to effectively deliver the science from FUTURE to the public and governments of PICES member countries.

Anticipated Benefits

The scientific research, communication and outreach that occur during the 10-year life of FUTURE will increase understanding of the processes and mechanisms regulating ecosystems of the North Pacific and provide a sound scientific basis for developing scenarios of ecosystem response to climate change and other human-use influences. The anticipated benefits and products will include:

- Increased understanding of physical, chemical and biological linkages and ecosystem responses to anthropogenic and climate forcings;
- Coordinated monitoring and descriptions of the current state of ecosystems;
- Forecasts of future states of North Pacific marine ecosystems and their associated uncertainty;
- Better quantitative and qualitative forecasts, with specified uncertainty, of ecosystem responses to climate change and increasing human influence;
- IPCC-like reports on responses of North Pacific ecosystems to climate change;
- An improved scientific basis for managing coastal ecosystems to sustain ecosystem services and to mitigate various environmental problems;
- Quantification of the benefits and risks associated with different management strategies;
- Region-specific assessments of topical issues (*e.g.*, harmful algal blooms, eutrophication, native and alien species range changes, anoxia, and ocean acidification);
- Increased data sharing, access and dissemination with a focus on coordination and metadata.
- Increased marine science capabilities in PICES member countries;
- Increased participation in PICES of younger scientists and a greater role for social and economic scientists;
- Increased public awareness of the ecosystem changes in the North Pacific.

FUTURE will improve understanding of the North Pacific Ocean, including its climate, biological processes and human communities, and will enhance wise use of this information by governments and society at large.