A seven-year effort of the PICES CCCC MODEL Task Team culminates in a dedicated issue of *Ecological Modelling*

By Bernard A. Megrey, Francisco E. Werner, Michio J. Kishi and Shin-ichi Ito

A seven-year effort of the PICES CCCC MODEL Task Team including planning, organizing, funding, and conducting 10 international workshops, will soon culminate in the publication of 19 peer-reviewed scientific papers on NEMURO (**N**orth Pacific **E**cosystem **M**odel for **U**nderstanding **R**egional **O**ceanography) and NEMURO.FISH (NEMURO **F**or **I**ncluding **S**aury and **H**erring) in a dedicated issue of *Ecological Modelling.* These contributions represent a rich set of case studies and in-depth modeling studies using the NEMURO family of models focused on the North Pacific that address: oceanic biogeochemistry, regional and seasonal variability of phytoplankton and zooplankton, reconstruction of 40-50 years of plankton dynamics, effects of climate on herring and saury growth and population dynamics, the feasibility of automatic calibration methods, the sensitivity of the model to parameter values, and projections of future states of the ecosystem under scenarios of climate change.

NEMURO is a nutrient-phytoplankton-zooplankton (NPZ) model of the lower trophic level of the marine ecosystem dynamically coupled to a fish bioenergetics model (NEMURO.FISH). It was originally developed for Pacific saury and Pacific herring to study climate change impacts on important commercial species in the North Pacific basin. The model was named after the City of Nemuro (Japan) that generously hosted the first model-buildup workshop in 2000. Under a separate project funded by PICES, Intra-American Institute (IAI), GLOBEC and the Asian Pacific Network (APN), NEMURO.FISH is now being extended to include species-to-species interactions via an implementation of sardine and anchovy populations (NEMURO.SAN) for regions that support important populations of small pelagic fish (California Current, Humboldt Current, Benguela Current, Oyashio/Kuroshio). NEMURO and NEMURO.FISH are among the few models that span and couple the processes from physics to populations of fish, include density-dependent ecosystem feedbacks, and potentially can be used to investigate the effects of climate change on populations of small pelagic fish.

Through the workshop process, the structure of NEMURO was developed in the course of discussions within a broad group of researchers from different fields including physics, biology and fisheries. Formulations and parameterizations were a result of a collective effort that engaged everyone equally. We believe that had smaller groups taken on similar tasks, it is likely that different formulations would have resulted, rather than the common single NEMURO and NEMURO.FISH formulations used in these papers. Similarly, once the formulations were agreed to, the implementation and application of the common model to different regions and different times was done with the benefit of the collective understanding gained through the joint "bottom-up" effort of the researchers involved. In other words, through the team effort, everyone's cross-disciplinary awareness of the different issues and limitations was increased. The resulting contributions, even at the level of the individual papers, provide a broader perspective and integration of the results than would otherwise have occurred by groups working in isolation. It is safe to say that the effort resulting in the papers in the special *Ecological Modelling* issue is greater than the sum of its parts, and even goes beyond the scientific content of the papers and how the scientists involved will approach new problems in the future.

To achieve a long-term goal of a true common ecosystem model, the community of researchers needs to come to agreement on unique expressions of key biological traits. A grand challenge is to define unique empirical equations for marine ecosystems. For example, scientists working in one region of the ocean will formulate the temperature dependence of target organisms using the data from that region, while scientists at other sites will likely derive a different formulation. The MODEL Task Team's effort in implementing NEMURO required the compilation of data from several locations in the North Pacific in order to set the model parameters. To make the data uniform and to be able to compare across sites, conversions needed to be applied. However, the factors themselves varied across sites and varied seasonally. The goal of constructing a "simple" ecosystem model for the North Pacific clearly showed that one of the most basic and important elements that can result from sustained international collaborations is the unification of observational methods, measurements and their interpretation. Such uniformity in approach will greatly help the definition of unique empirical equations for ecosystem modeling in general, and for their inclusion in a common NEMURO-like model.

Support from PICES and other agencies

Carrying out such ambitious objectives, among individuals coming from different countries and scientific cultures and backgrounds, was made difficult given that the work was conducted without the sustained support of a large well-funded international program. Fortunately, PICES provided a different approach. Working with PICES, the four Co-Chairmen of the MODEL Task Team (who rotated over a seven-year period) realized this difficulty and were able to secure funding from various sources [The Japan International Science and Technology Exchange Center (JISTEC, US$ 70,000), PICES (US$ 12,000), the City of Nemuro (US$ 40,000), Japan's Fisheries Research Agency

(FRA, US$ 60,000), the Heiwa-Nakajima Foundation of Japan (US$ 30,000), GLOBEC (US$ 6,000), the Asian Pacific Network (APN, US$ 45,000), and the Asian Pacific Network Capacity Building/Enhancement for Sustainable Development in Developing Countries Program (APN CAPaBLE, US$ 10,500)] to help fund the workshops that fostered model development.

PICES contributed significantly to the collaborative environment that was necessary to build our team by providing opportunities to meet at inter-sessional meetings and workshops, and by sponsoring special sessions at PICES Annual Meetings. This latter contribution helped keep the PICES community up-to-date on model developments as progress was reported, and basically kept the project on track. PICES generously provided funding to help support new emerging scientists. It is important to note the capacity building component of this effort whereby many students were afforded the opportunity to be trained through the workshop process, with the tangible result that several papers in the *Ecological Modelling* volume resulted from M.Sc. and Ph.D. theses (including those by M. Fujii, D. Mukai, T. Hashioka and N. Yoshie). It bears re-iterating that the success of these efforts would not have been possible without the encouragement, support, coordination and funding enabled by PICES' commitment to the project.

Now that NEMURO and NEMURO.FISH have been tested and scrutinized by an international community, we thank PICES and the other agencies mentioned above for their support, and we are pleased to publish the *Ecological Modelling* special issue which contains the latest papers describing the present status of NEMURO and/or NEMURO.FISH, as well as specific applications (the list of titles and authorship of papers appearing in the special issue can be found on the PICES MODEL Task Team web page at http://www.pices.int/members/task_teams/MODEL.aspx.

Personal aspects of an international collaboration

During the period of model development, numerous investigators freely contributed untold amounts of energy, disciplinary perspective, and intellect towards the creation, testing and application of these models. This often required working extra hours planning for a workshop, traveling long hours criss-crossing the international dateline, writing computer code in hotel rooms or while riding buses and trains, gathering in the lobby of a hotel after a late dinner to continue pursuing an interesting line of scientific thought, and then polishing these thoughts by working at home after the workshop. We are proud to report that the work was done in a truly international team setting of cooperation and in a highly collegial manner of open scientific sharing. The code for the NEMURO and NEMURO.FISH soon will be posted on the PICES website.

The inter-personal collaborative aspect of the group's endeavor was as important as its scientific contributions. One outcome has been the growth of deep personal friendships among the participants and, in many situations, opportunities to exchange visits to each others houses and for families to meet each other. The photographs at the end of this article were taken during one such meeting in Seattle.

Summary

NEMURO was developed as a common ecosystem model for the North Pacific. However, ecosystem models are different from general ocean circulation models. Circulation models are derived from first principles, together with constraints imposed by temperature, salinity and mass conservation equations. Ecosystem models rely much more on empirical relations and the judgment of the developers as to what to include and what to ignore. Hence, developing a generalized ecosystem model involves additional challenges.

NEMURO is only one milestone in a long process toward achieving a common ecosystem formulation for use in the North Pacific. The framework offered by the NEMURO model and its extensions provide the opportunity to examine the dynamics and variability of the North Pacific marine ecosystem. Although the complexity of the system demands significant idealizations and approximations, important contributions resulted in several areas ranging from methodological, such as techniques for coupling across trophic levels and better parameter estimation, to process studies that provided better understanding of the factors controlling marine ecosystems. The next steps should include increased resolution (not just computational, but in the processes included) with the aim of providing projections of future states. There will continue to be a need for additional hindcast studies, but these will always be data-limited to some extent. It is important that models be used to identify where additional data need to be collected so that maximum advantage is taken of available resources, and so that the data are collected optimally for integration with the models.

As we better quantify the observed variability in marine ecosystems and our predictive capacity increases, we will move closer to our goal of providing stewardship of our marine ecosystems. While our approaches so far are relatively simple, they represent important steps towards the integration of our understanding of climate variability and the responses of lower trophic levels and fish populations. As such, we have reason to be optimistic about models providing information needed to manage our oceanic resources. However, efforts of the magnitude required to take the next steps in the development of future marine ecosystem models cannot happen without sustained resources to train the next generation of scientists who will lead this charge.

Dedication

We acknowledge the important contributions to NEMURO and NEMURO.FISH made by our colleague, mentor and friend Dr. Daniel Ware who sadly passed away in 2005. Dan's many insights and encyclopedic knowledge into the workings of marine ecosystems and detailed knowledge about fish biology and population dynamics greatly enhanced NEMURO and NEMURO.FISH. All of the MODEL Task Team members who collaborated with Dan feel privileged to have worked with him. In recognition of Dan's contribution, we dedicated the special issue of *Ecological Modelling* to him.

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