Modeling Multi-trophic Level Marine Ecosystems using the NEMURO Family of Models: Climate Change Applications in the Boreal North Pacific and Scientific Potential for Ecosystem-based Management

Bernard A. Megrey, Michio J. Kishi, Shin-ichi Ito, Kenneth A. Rose, Francisco E. Werner and members of the MODEL Task Team and the NEMURO Mafia
Presentation Overview

• Introduce the members of the NEMURO family of models
• An example of use in climate impact investigations
• Describe extensions to applications to pelagic fishes and subtropical and tropical ecosystems of the North Pacific
• Potential for Ecosystem-based Management
The NEMURO Family of Models
NEMURO

North Pacific Ecosystem Model for Understanding Regional Oceanography

“A conceptual model representing the minimum trophic structure and biological relationships between and among all the marine ecosystem components thought to be essential to describe ecosystem dynamics in the North Pacific”

Source: Kishi et al. 2007. Ecological Modeling
Hardy’s (1924) North Sea Foodweb
NEMURO - A Compromise

Between mathematical tractability, sufficient biological simplicity/complexity and ecological realism

Make everything as simple as possible but not simpler
NEMURO

• Mathematically, NEMURO is an ecosystem model with detailed descriptions of important mechanistic and biological process (i.e. growth, photosynthesis, feeding, predation).
• 90 parameters
• Very different and a more complex approach compared to the ECOPATH bulk biomass approach
Parameter sets were assembled for three areas of the North Pacific Ocean.

Apply the same model structure (i.e. equations and parameters) and climate scenarios to three different ecosystems – any observed differences in dynamic response will be due to local characteristics and forcing.
NEMURO Dynamics

Simulated seasonal dynamics consistent with observations


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NEMURO.FISH
NEMURO
For Including Herring and Saury

- Explicitly include higher trophic level (fish) dynamics in the simulation of marine ecosystems

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Fish Biological Processes

- Growth (via bioenergetics model)
- Respiration
- Consumption/Grazing (ontogenetic shift in preferred prey; multi-species feeding functional response)
- Egestion; Excretion; Mortality
- All biological rates mediated by water temperature
- Environment-dependent Reproduction
- Multiple ontogenetic life stages description
- Population modeling via age/size structured fisheries population dynamics model-fisheries removals explicitly modeled.
Apply NEMURO.FISH to two areas of the North Pacific

- Pacific herring stock off West Coast Vancouver Island
- Pacific saury stock off Hokkaido Island
NEMURO described the WCVI observations well.
Pacific herring fish density and size-at-age described well

- Total Biomass (g ww/m²)
- Weight (g ww)
- Simulated Year
- Month

Predicted Size-at-age
Observed Size-at-age
NEMURO-3D

Basin scale predictions of the state of the LTL ecosystem
NEMURO embedded in a GCM grid of the North Pacific

Climate Change and Global Warming Applications

Apply the same model to the same species over a wide geographic area.
Apply the same model to Pacific herring, for three areas of the North Pacific, using the same 50 year climate forcing scenario.
Impact of Regime Shifts on Herring Growth

Responses were synchronous in time but different between regions:
- Bering Sea responded differently from WCVI and PWS;
- WCVI and PWS responded the same.

Extensions to NEMURO
NEMURO.SAN: A prototype ecosystem model to couple Sardine and ANchovy to the NEMURO lower trophic level model
NEMURO.SAN

• Biological extensions:
  – Two small pelagic species (sardine and anchovy)
  – Individual-based model for each species
  – Full life-cycle with environment-dependent S-R
  – Species-to-species competition for the same food resource
  – Dynamic predator on sardine and anchovy

• Spatially-explicit
  – Grid of cells
  – Fish move between cells using spatial habitat modeling

• NEMURO.FISH: bottom-up + top-down control due to the effects of climate on HTL species-to-species interactions.
NEMURO.SAN Applications
California Current

Victoria, British Columbia
NEMURO.SAN

Anchovy
Sardine
Predator

NEMURO
Separate version of NEMURO in each cell; Results for Year 20

- Small Zooplankton
- Large Zooplankton
- Predatory Zooplankton

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Anchovy #10

[Graph showing various parameters over age (days since recruitment).]

- Zooplankton
- Temperature
- Weight (g/fish)
- Maximum Consumption
- Respiration
- Egestion
- dW/dT (g fish/ind/d)

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Sardine #10060

Graph showing various biological metrics over time:

- Zooplankton
- Temperature
- Weight (g/fish)
- Age (days since recruitment)
- Maximum Consumption
- Respiration
- Egestion, excretion, SDA
- dW/dT (g fish/ind/d)
NEMURO that includes consideration of other biogeochemical dynamics
Extensions to include Calcium flows

Original NEMURO coupled with carbon cycles (Yamanaka et al., 2004)
NEMURO with Phosphorus

eNEMURO: An “extended” NEMURO configured for the subarctic and subtropical North Pacific
Extended NEMURO (eNEMURO)
introducing subtropical plankton and new temp. dep. (Yoshie et al., 2007)
tNEMURO: A “tropical” NEMURO configured for the Gulf of California with future links to Pacific sardine
## NEMURO-tNEMURO Comparison

<table>
<thead>
<tr>
<th>Subarctic NEMURO</th>
<th>Tropical tNEMURO</th>
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</thead>
<tbody>
<tr>
<td>Temperature:</td>
<td>Low</td>
</tr>
<tr>
<td>Nutrient &amp; Biomass:</td>
<td>High</td>
</tr>
<tr>
<td>Dominant plankton:</td>
<td>Large</td>
</tr>
<tr>
<td>Day Length:</td>
<td>Short</td>
</tr>
<tr>
<td>Light Intensity (clouds):</td>
<td>Low (lots)</td>
</tr>
<tr>
<td>Upwelling:</td>
<td>none</td>
</tr>
</tbody>
</table>
Marine Seas where the NEMURO Model has been Applied

- Bering Sea
- Sea of Okhotsk
- Hokkaido Island
- East China Sea
- Yellow Sea
- Aegean Sea
- Prince William Sound
- West Coast Vancouver Island
- California Current
- Gulf of California
- Station P
NEMURO+ROMS

• Hernan Arrango has successfully merged NEMURO with ROMS

https://www.myroms.org/forum/viewtopic.php?t=577
Summary

• NEMURO is
  – flexible and extensible
  – proven
  – widely used
  – Documented with freely available code
  – available in difference “flavors”
Potential Applications to Ecosystem-based Management

• Improve the conceptual understanding of the structure, function and interactions of the ecosystem under consideration.
  – May not be used explicitly in decision-making or scientific advice but could form the underlying context for any detailed management planning and decision-making (i.e. response to different production regimes)

• Examine both bottom-up (physical) and top-down (biological) ecosystem response and their interaction
  – Climate affects the ecosystem from the bottom of the food web through climate signals passed through the LTL up to the HTL (i.e. changes in SST, MLD, nutrient flux, LTL productivity), or
  – Top-down through climate influences on the UTL, the environment-dependent spawner recruit model that closes the life cycle, or species-to-species interactions
Potential Applications to Ecosystem-based Management

- Evaluate the effects of physical/environmental factors on the resources on which fisheries depend.
- Ability to include spatial, seasonal and temporal structure.
- Explicitly represent primary productivity, nutrient cycling, and environmental forcing.
  - Ability to evaluate the role of fishing vs. environment in structuring marine ecosystem dynamics.
- Potential to include fleet dynamics, technical interactions (e.g. multi-stock fisheries; by-catch),