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

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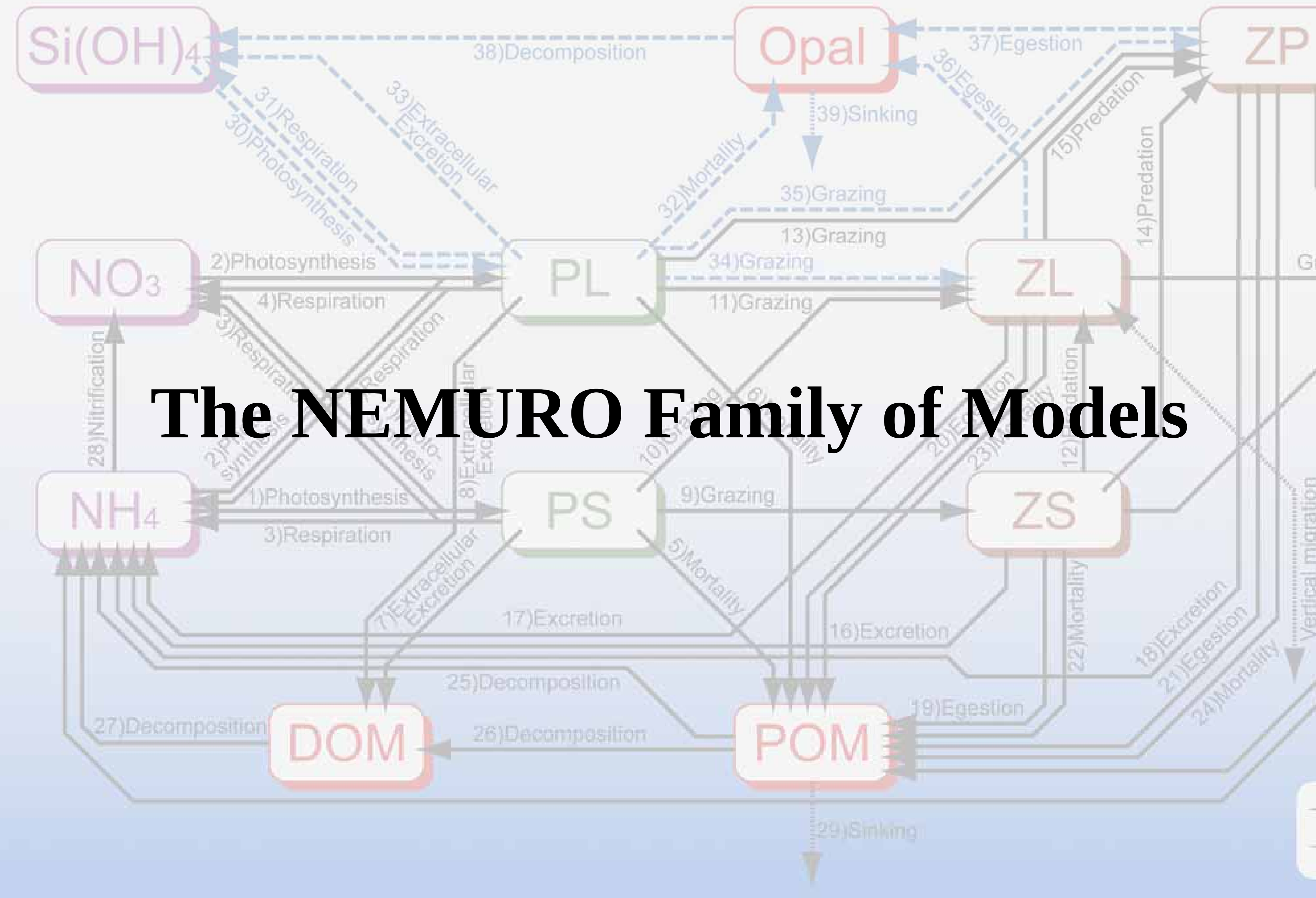
Presentation Overview

- 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



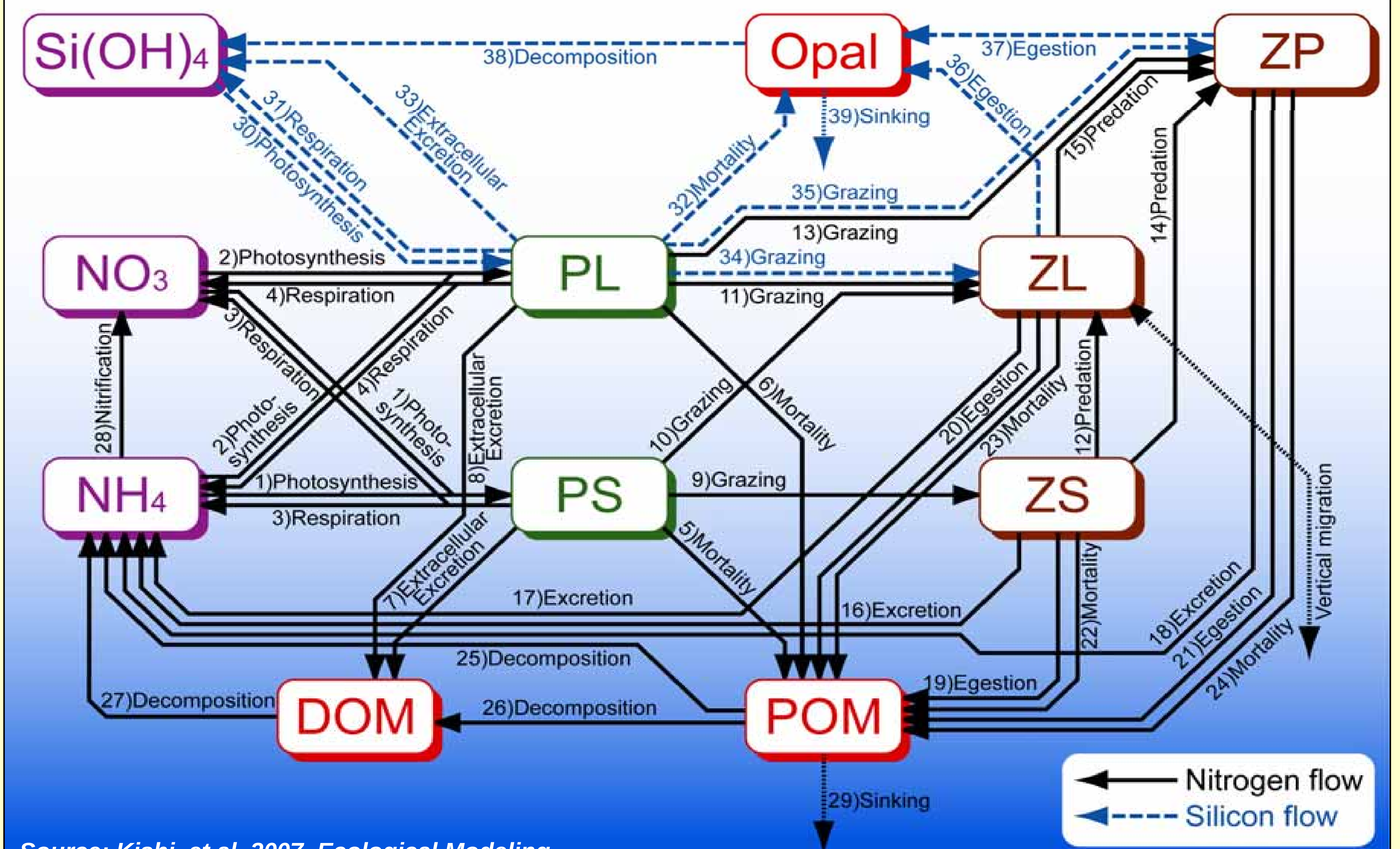
NEMURO

North Pacific **E**cosystem **M**odel for **U**nderstanding **R**egional **O**ceanography

"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"

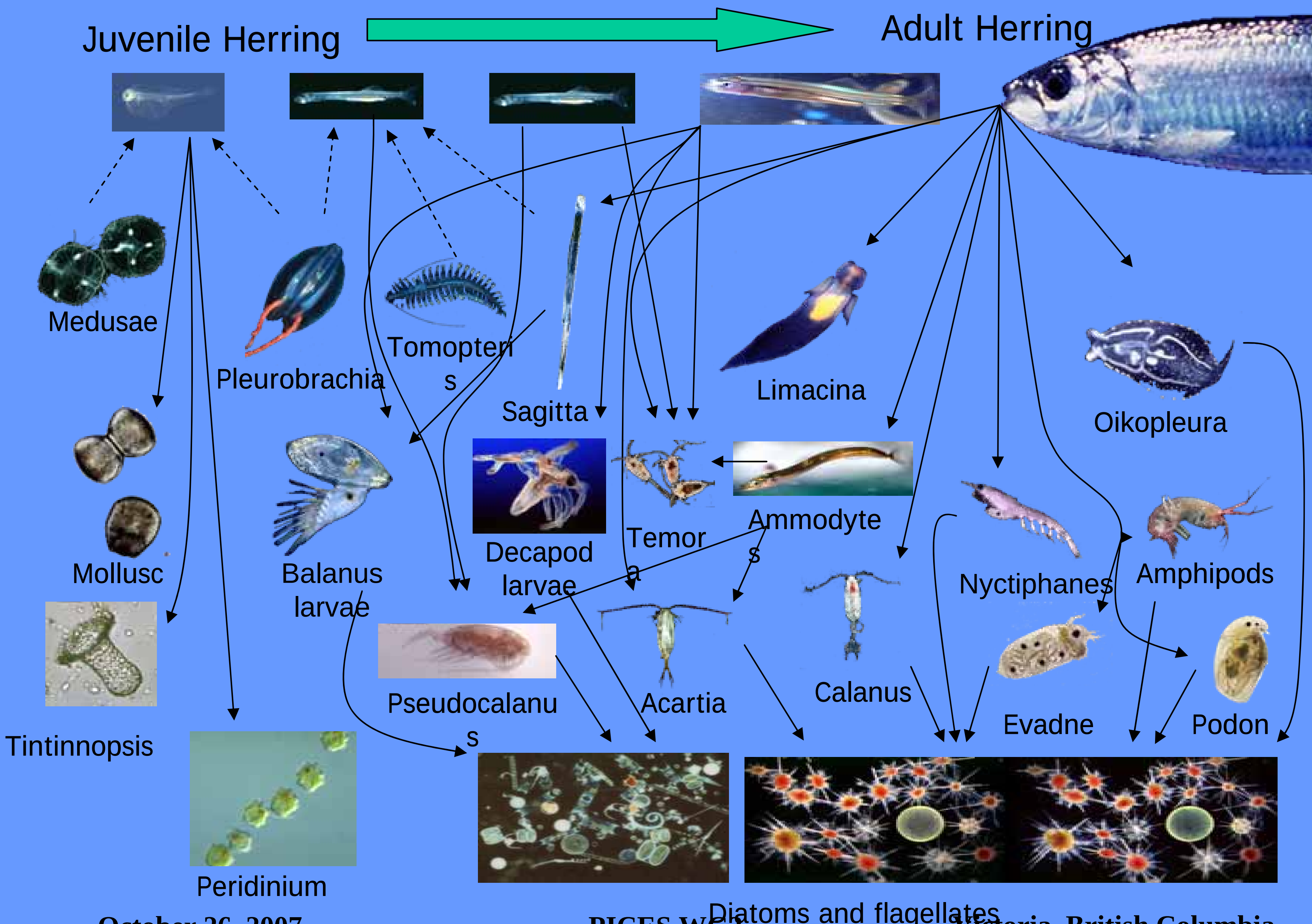
Source: Kishi et al. 2007. Ecological Modeling

NEMURO



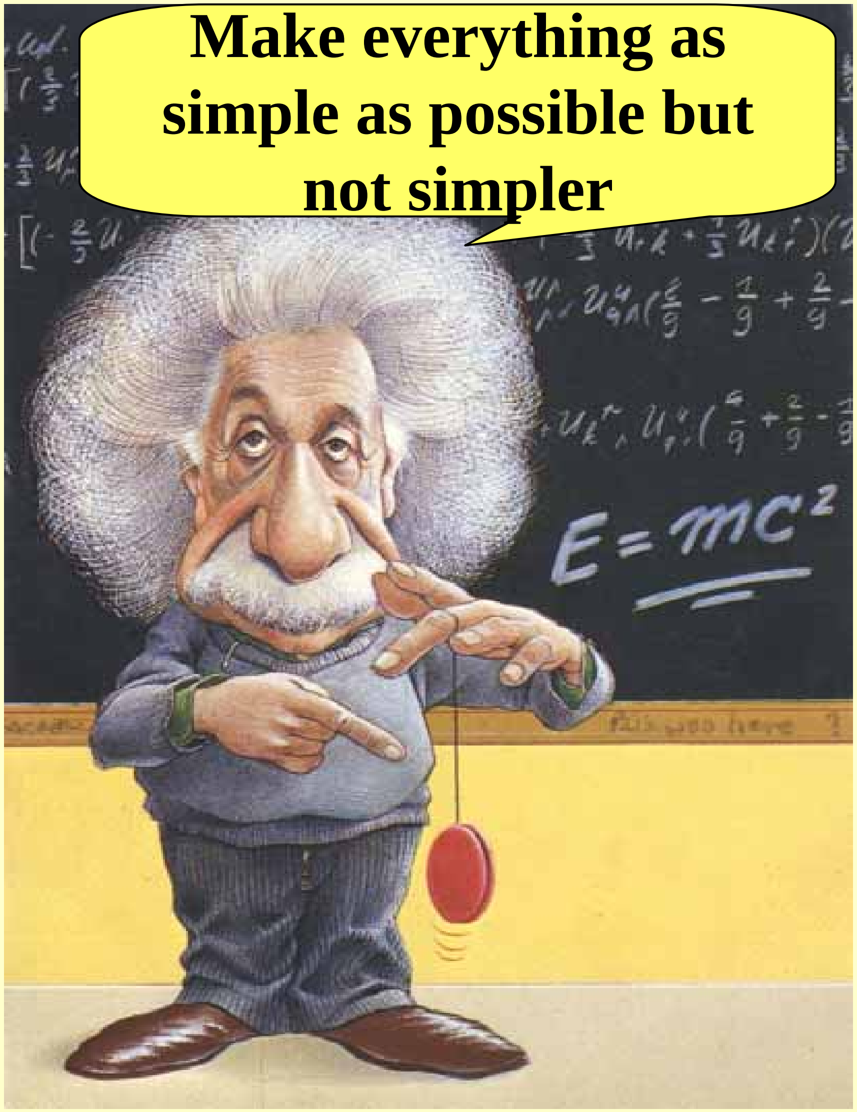
Source: Kishi et al. 2007. Ecological Modeling.

Hardy's (1924) North Sea Foodweb



NEMURO - A Compromise

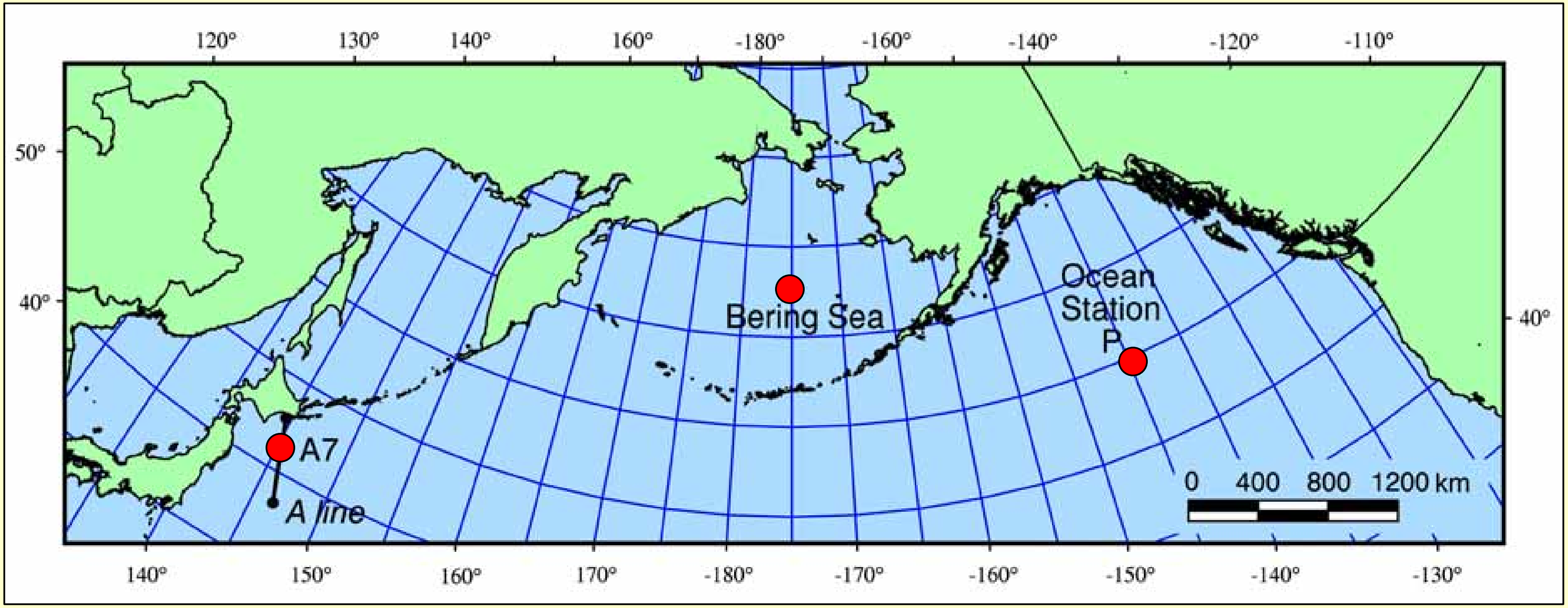
Between mathematical tractability, sufficient biological simplicity/complexity and ecological realism



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

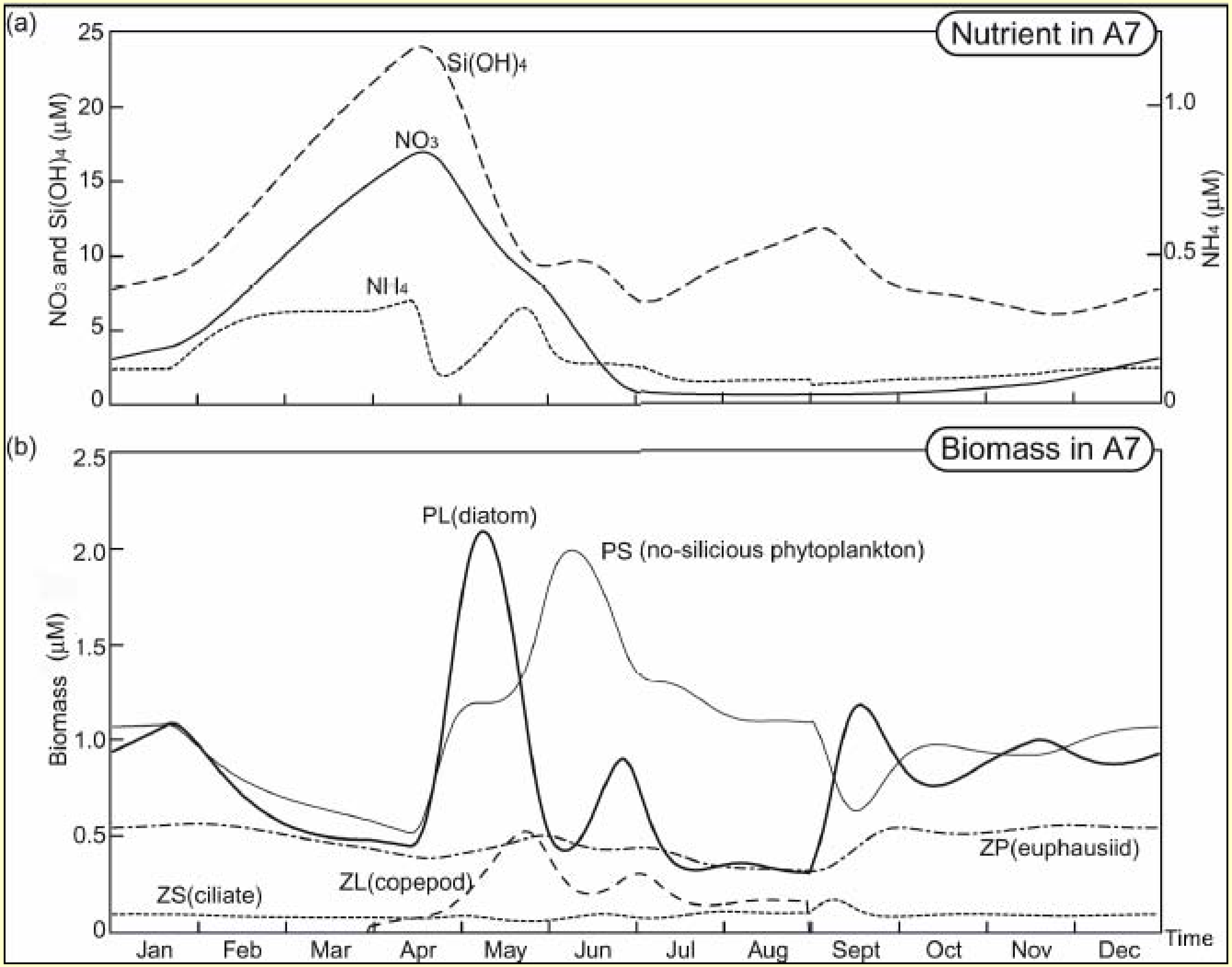
Parameter sets were assembled for three areas of the North Pacific Ocean



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

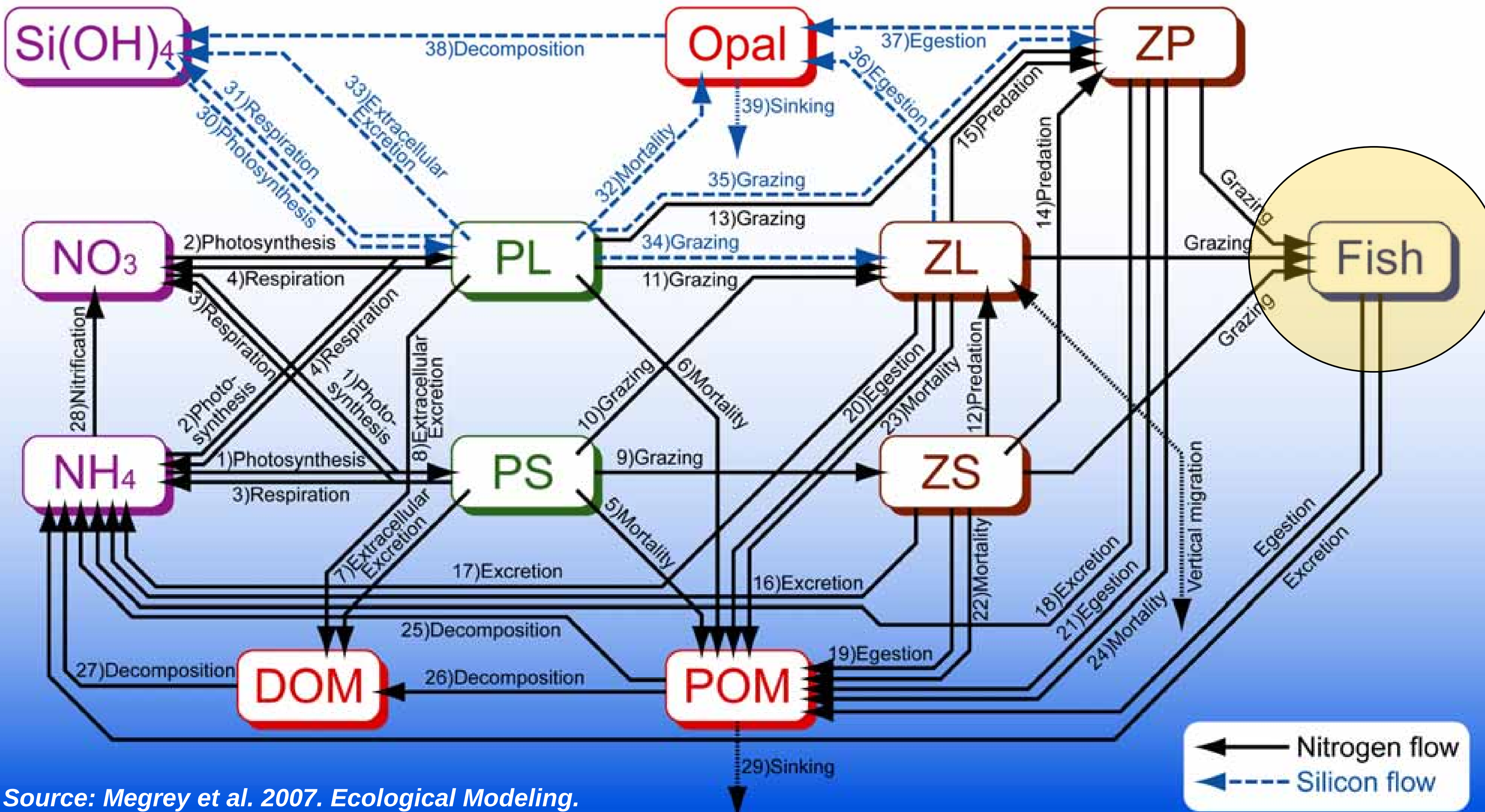


Source: Kishi et al (2007) Ecological Modeling

NEMURO.FISH
NEMURO
For **I**ncluding **H**erring and **S**aury

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

NEMURO.FISH

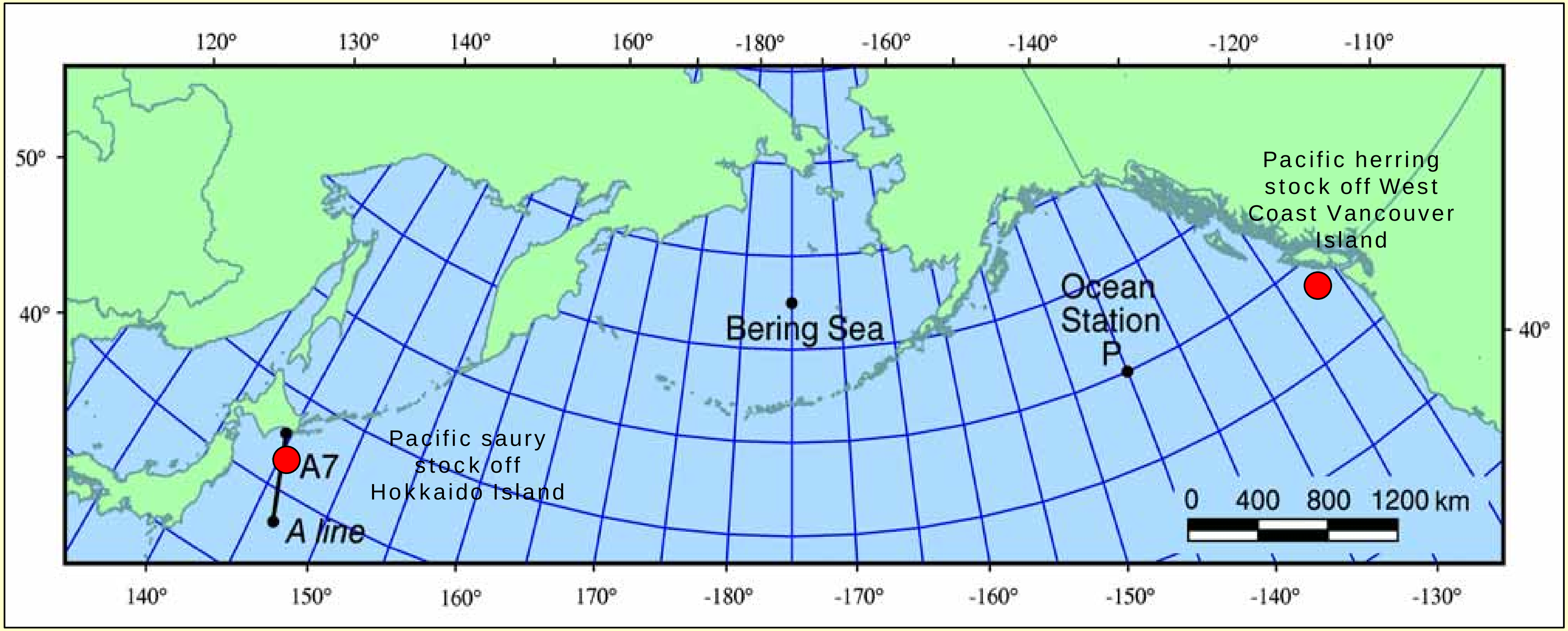


Source: Megrey et al. 2007. Ecological Modeling.

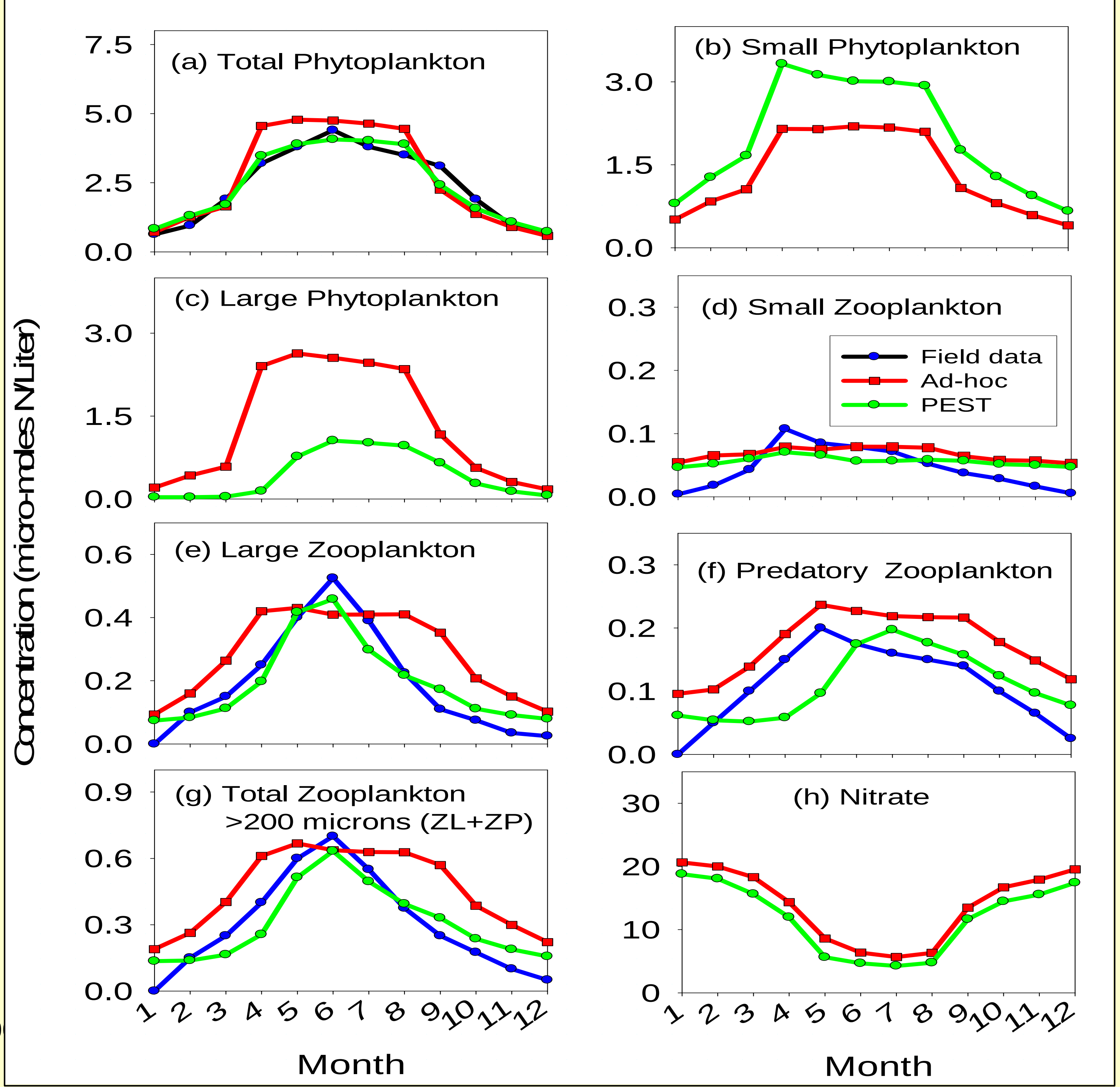
Fish Biological Processes

- 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.

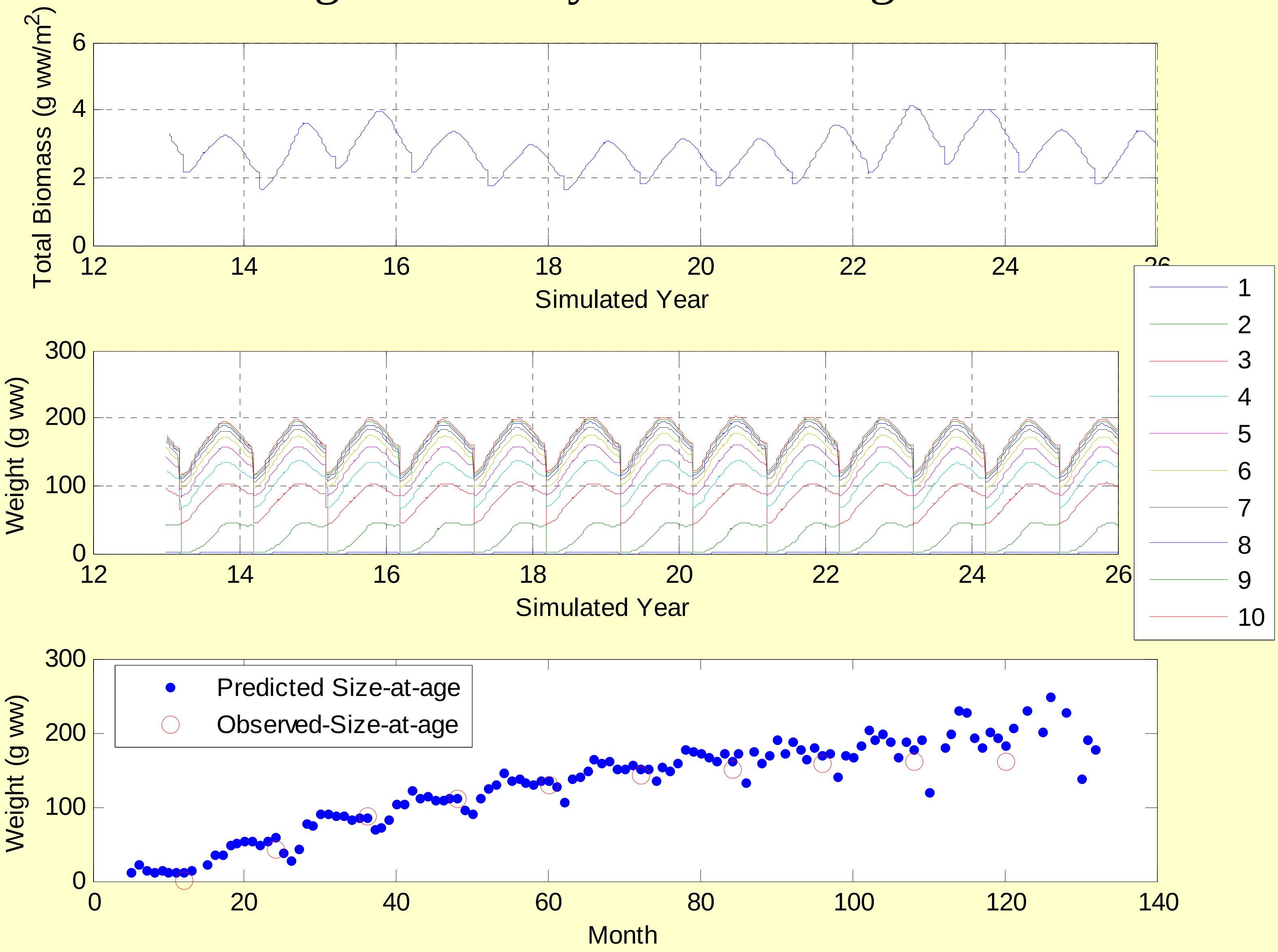
Apply NEMURO.FISH to two areas of the North Pacific



NEMURO described the WCVI observations well

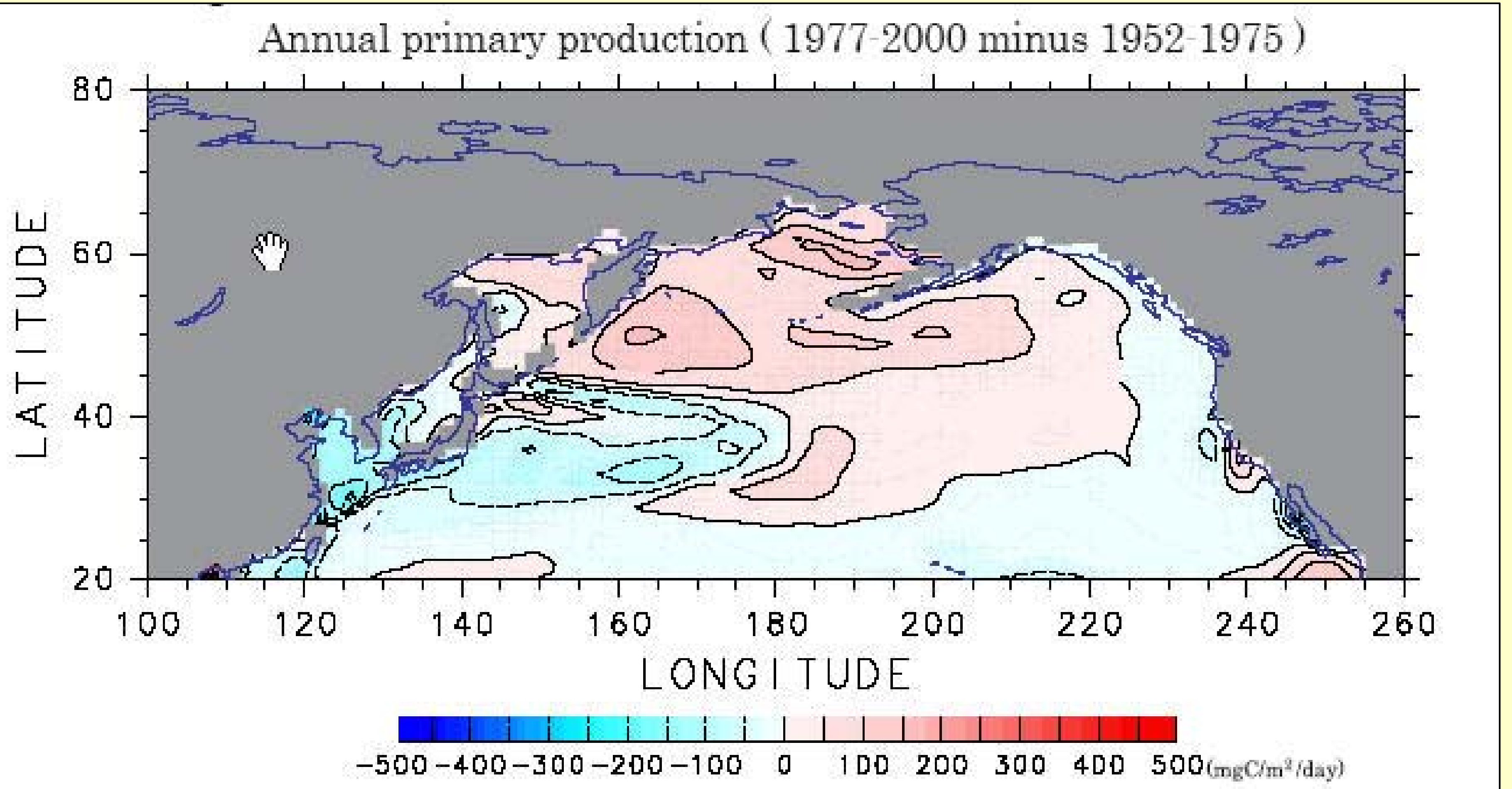


Pacific herring fish density and size-at-age described well

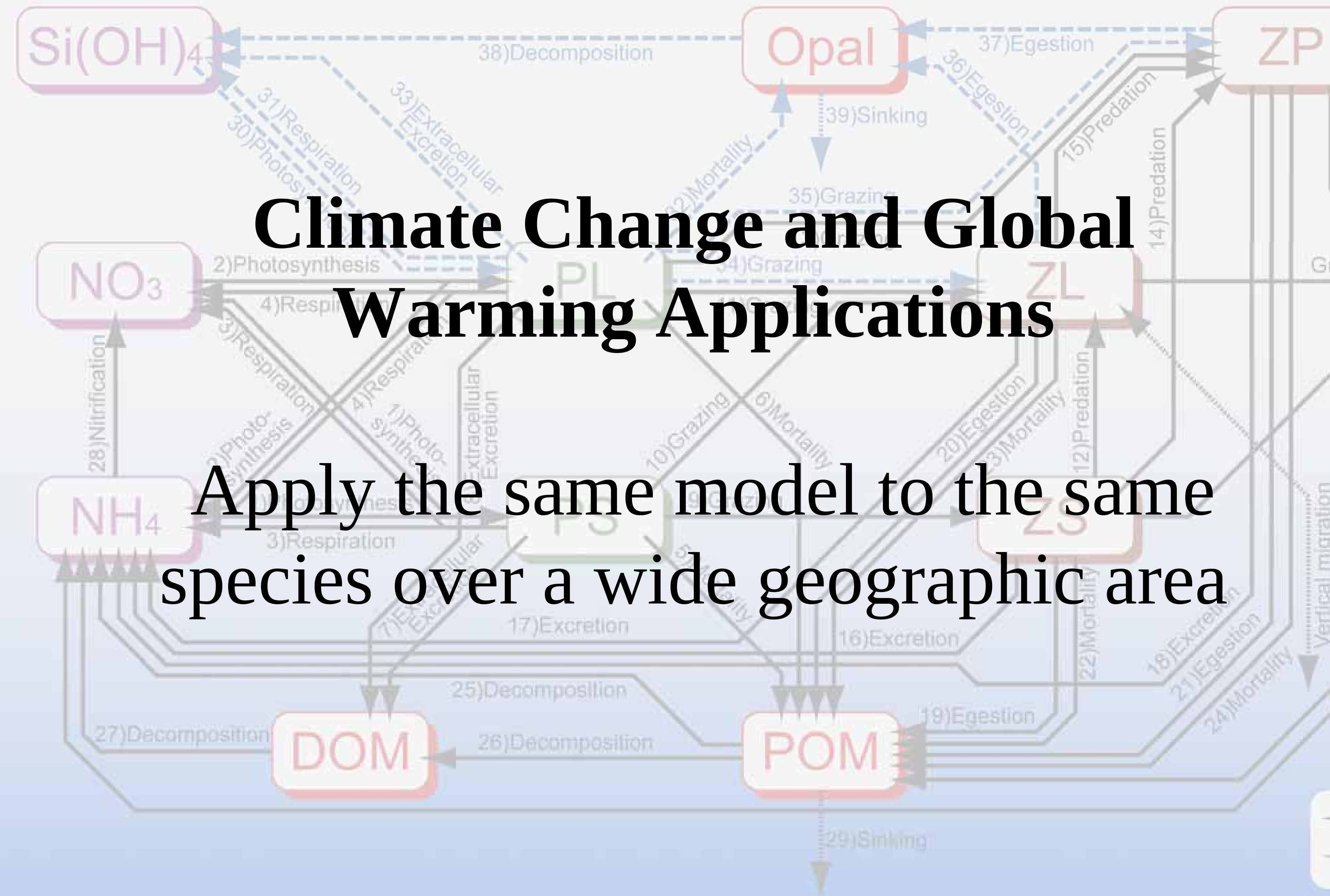


NEMURO-3D

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



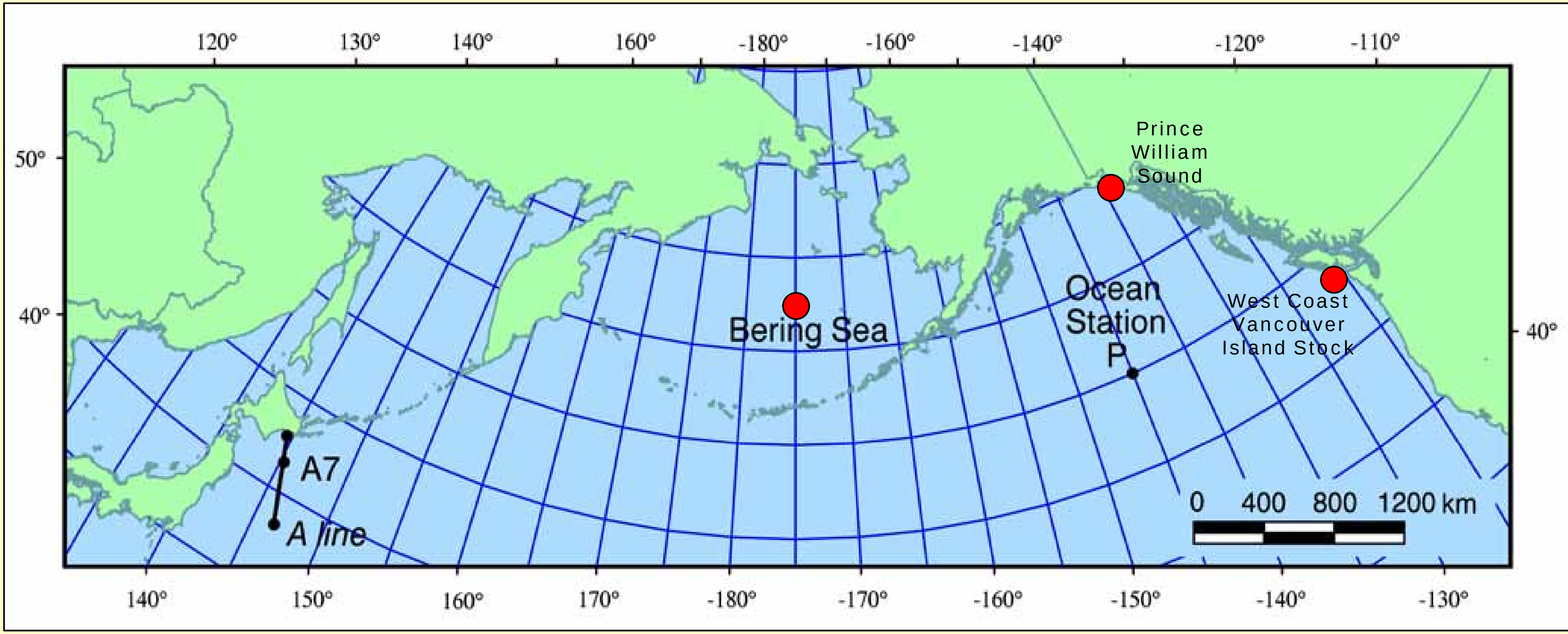
Source: Noguchi et al. 2007. Ecological Modeling.



Climate Change and Global Warming Applications

Apply the same model to the same species over a wide geographic area

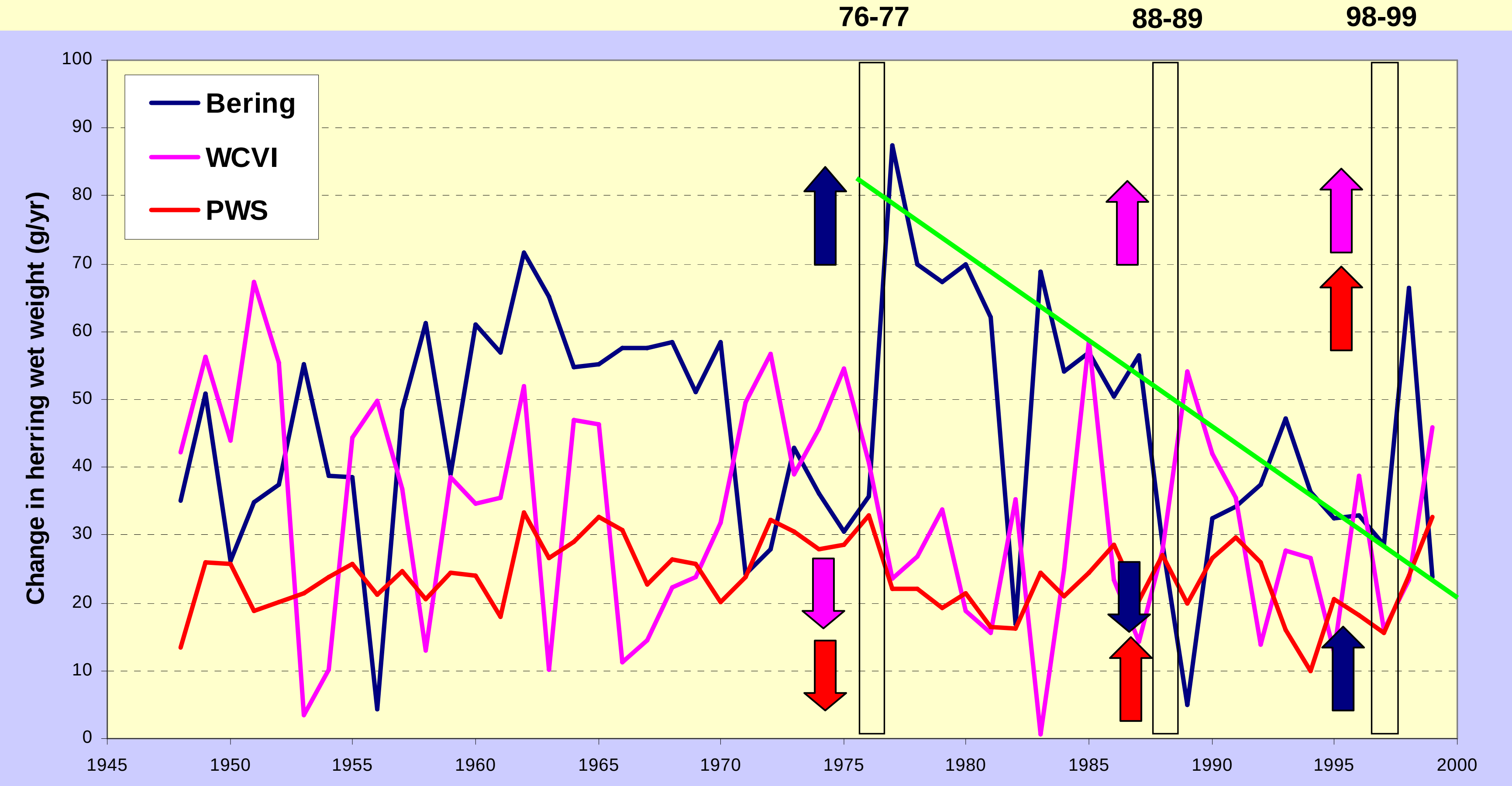
Apply the same model to Pacific herring, for three areas of the North Pacific, using the same 50 year climate forcing scenario



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



Source: Rose et al (2007) Ecological Modeling.

Source: Megrey et al (2007) Ecological Modeling.

Extensions to NEMURO

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

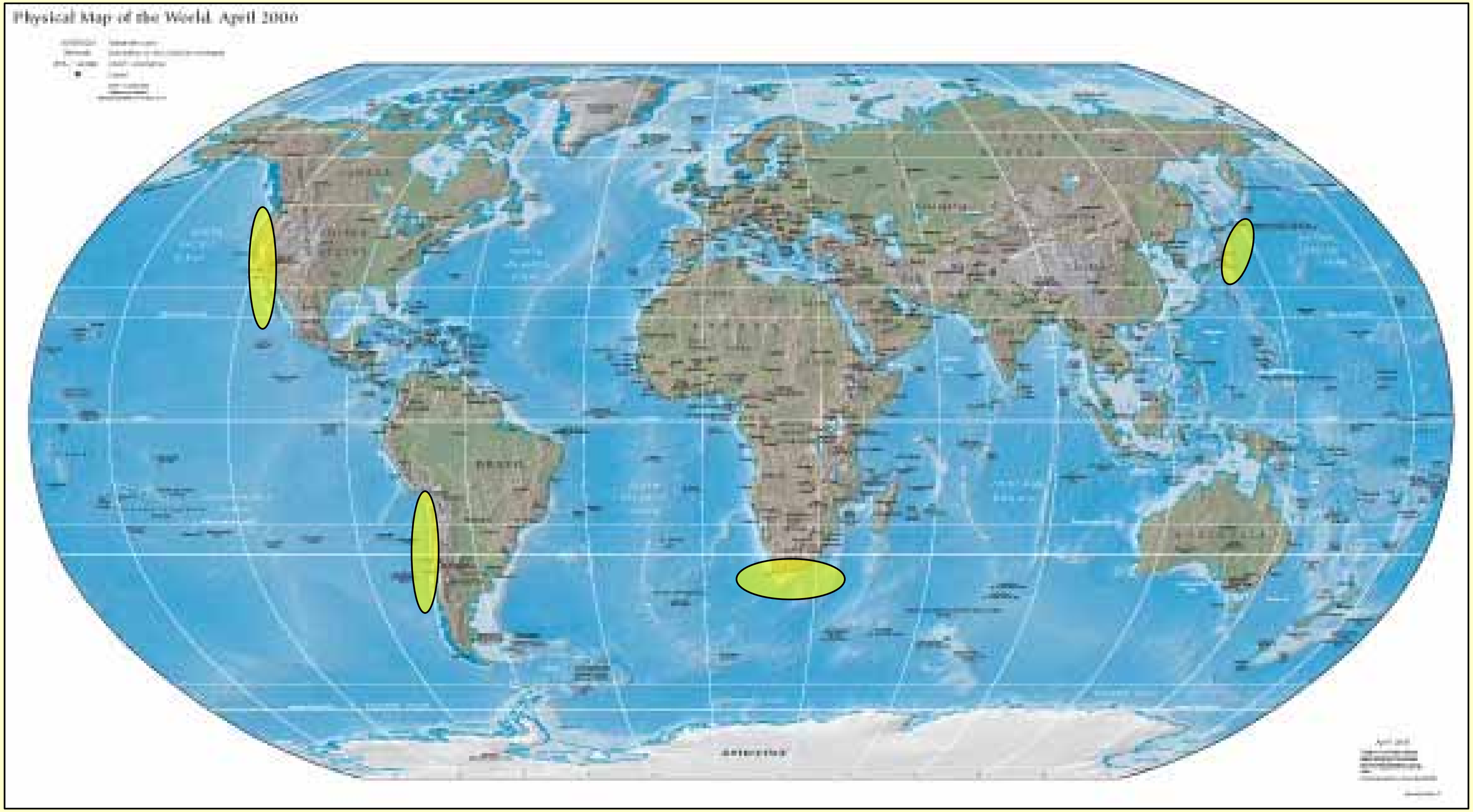
NEMURO.SAN

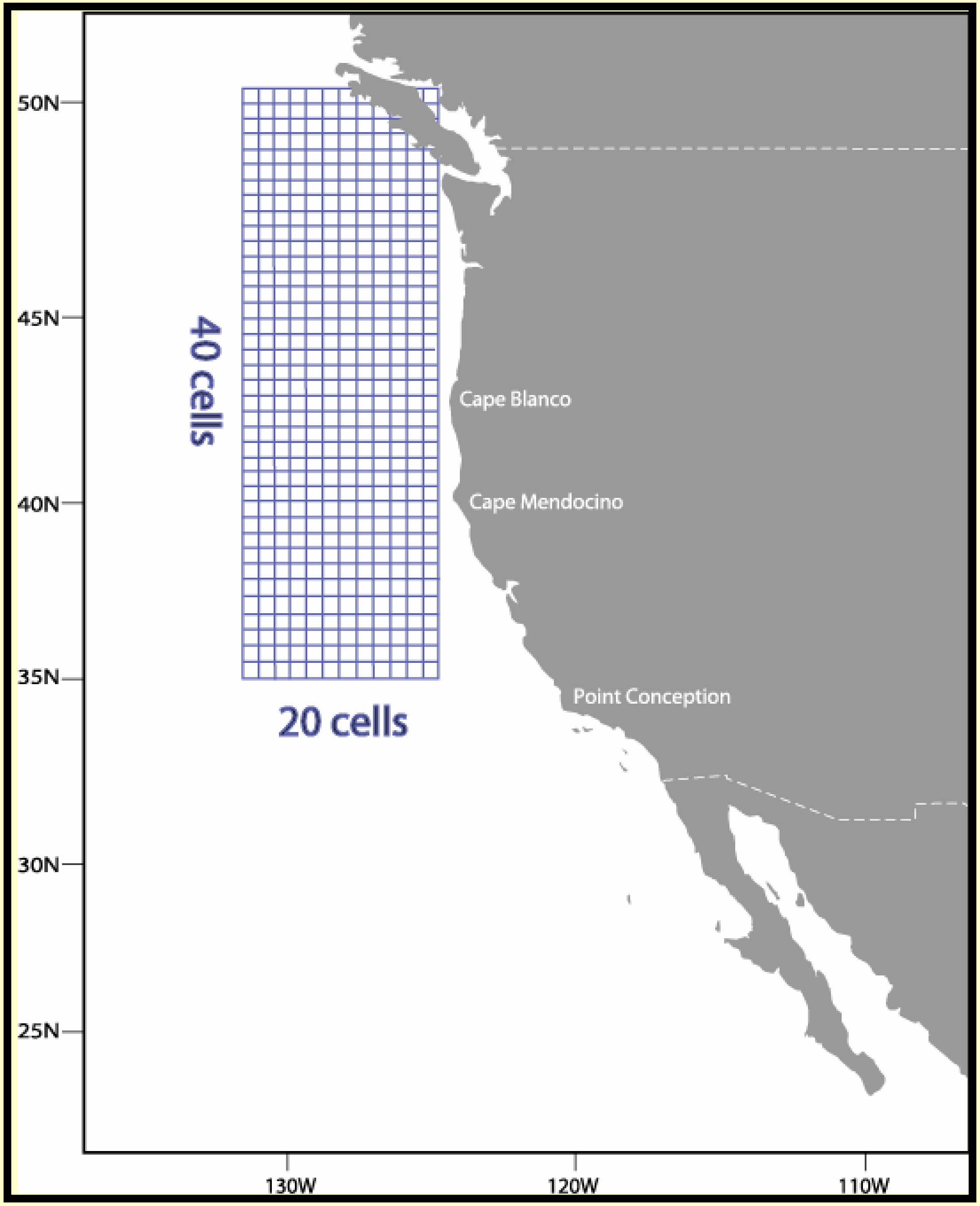
- Biological extensions:
  - Two small pelagic species (sardine and anchovy)
  - Individual-based model for each species
  - Full life-cycle with environment-dependent S-R
  - Species-to-species competition for the same food resource
  - Dynamic predator on sardine and anchovy

- 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

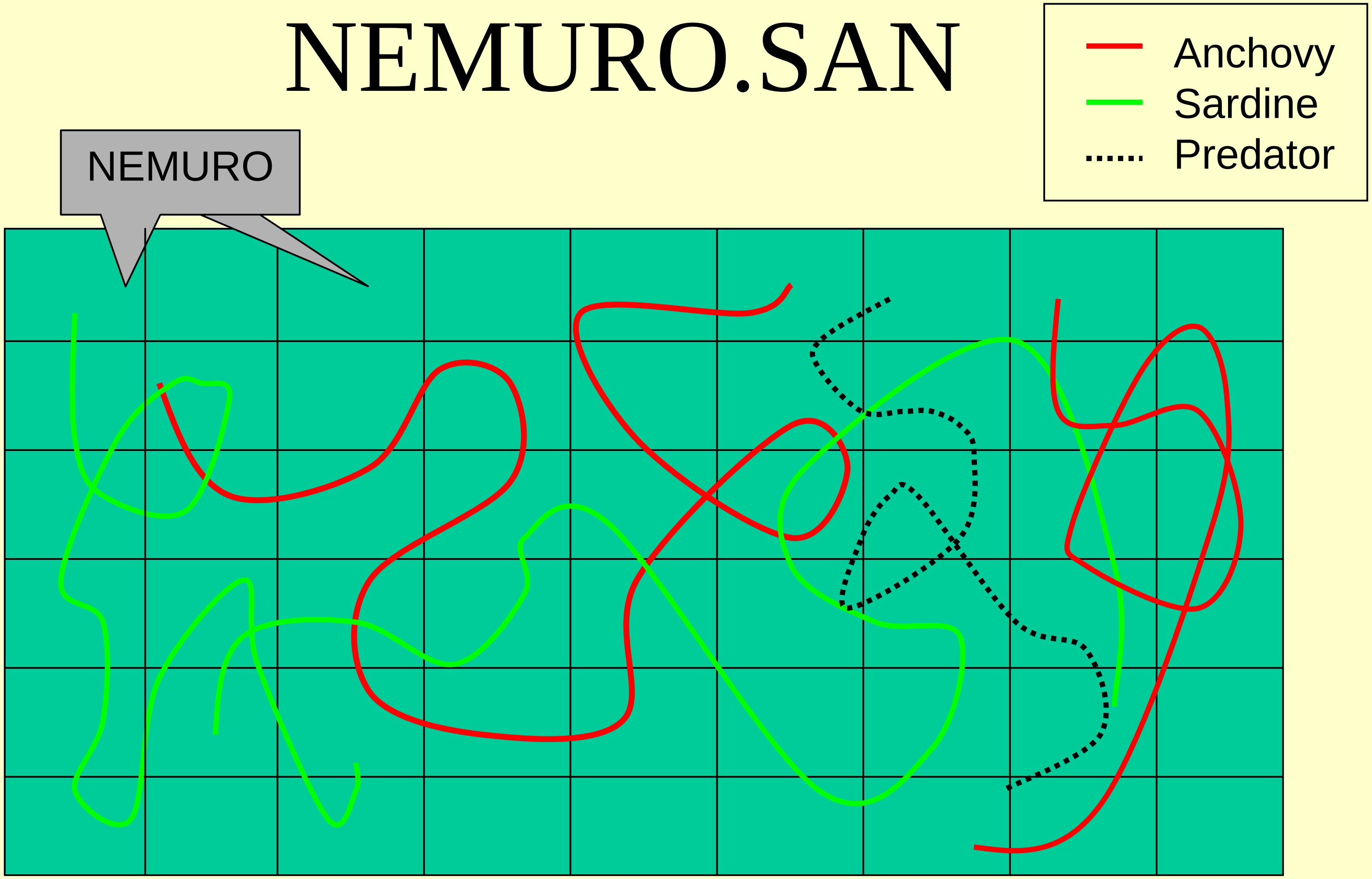




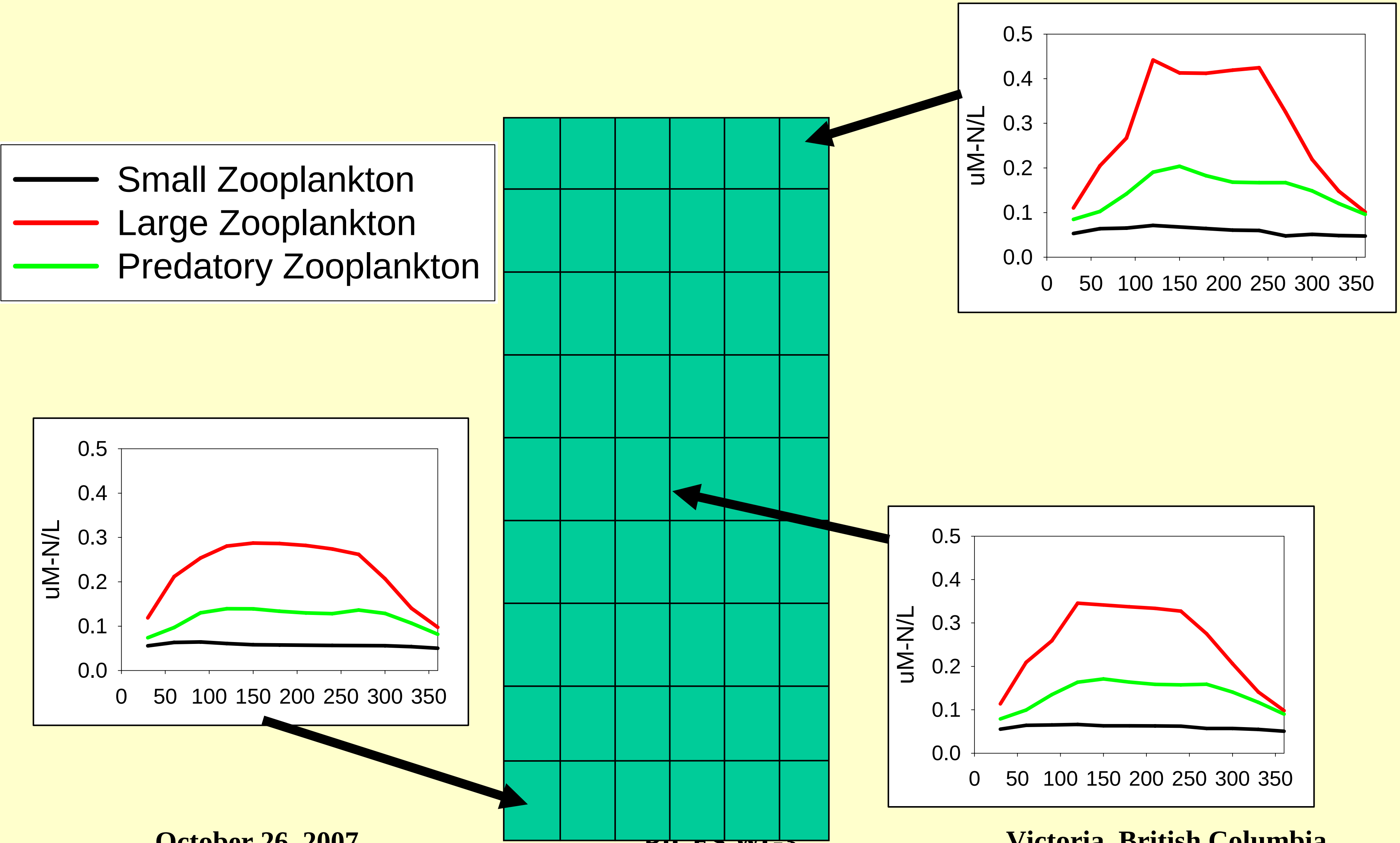
California Current

Victoria, British Columbia

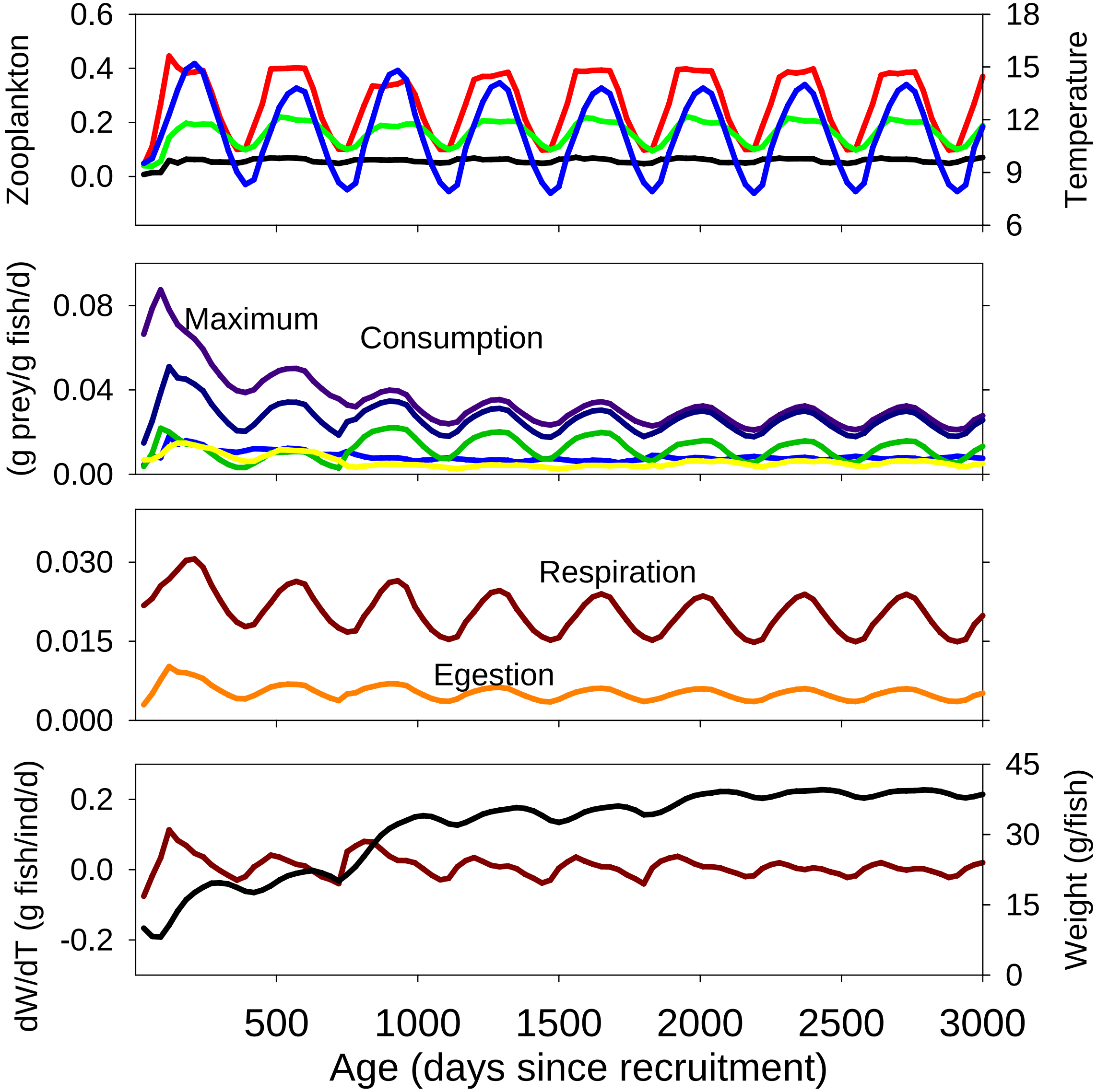
NEMURO.SAN



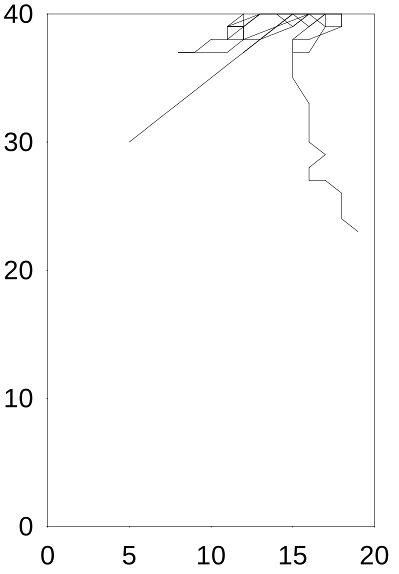
Separate version of NEMURO in each cell; Results for Year 20



Anchovy #10

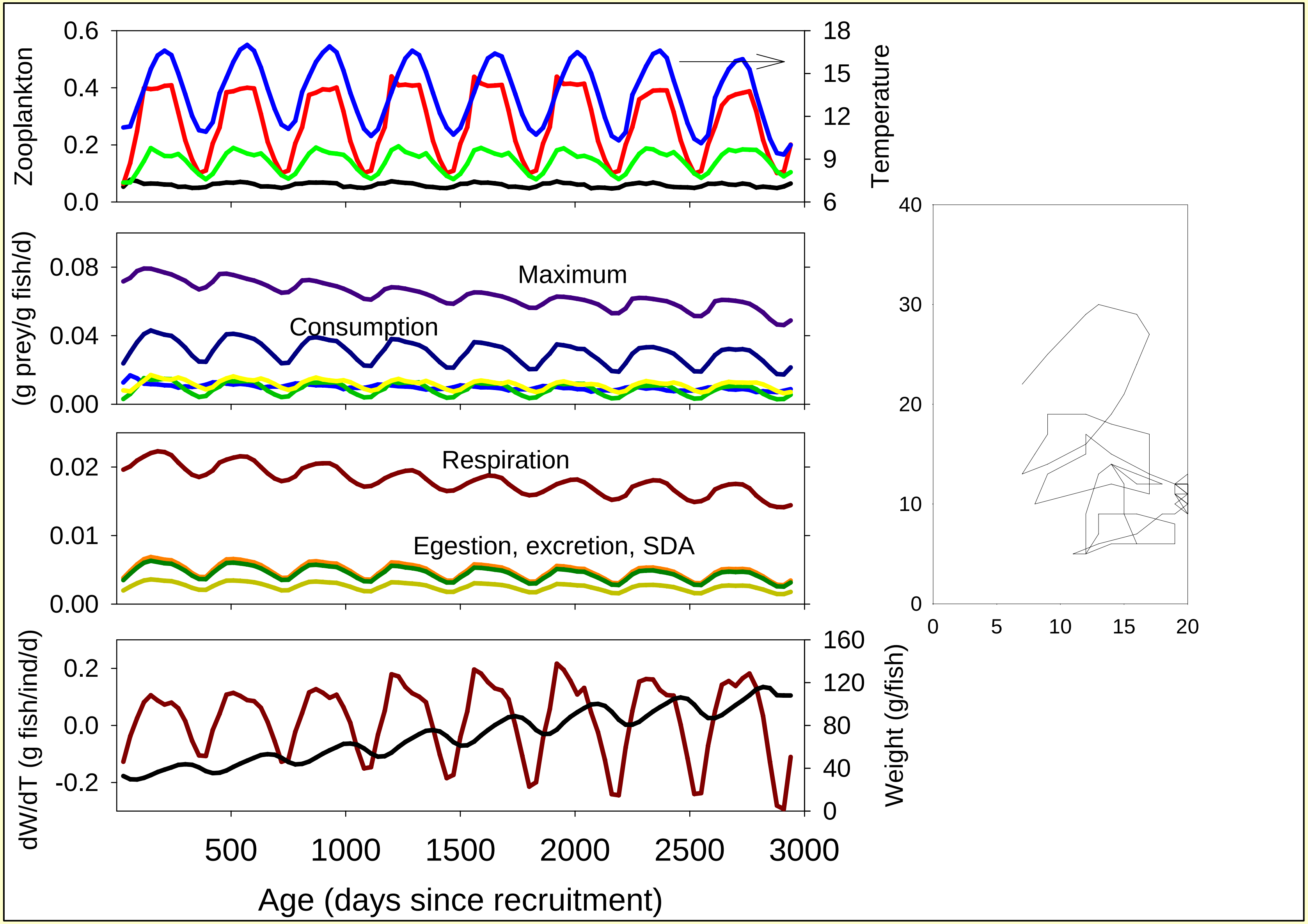


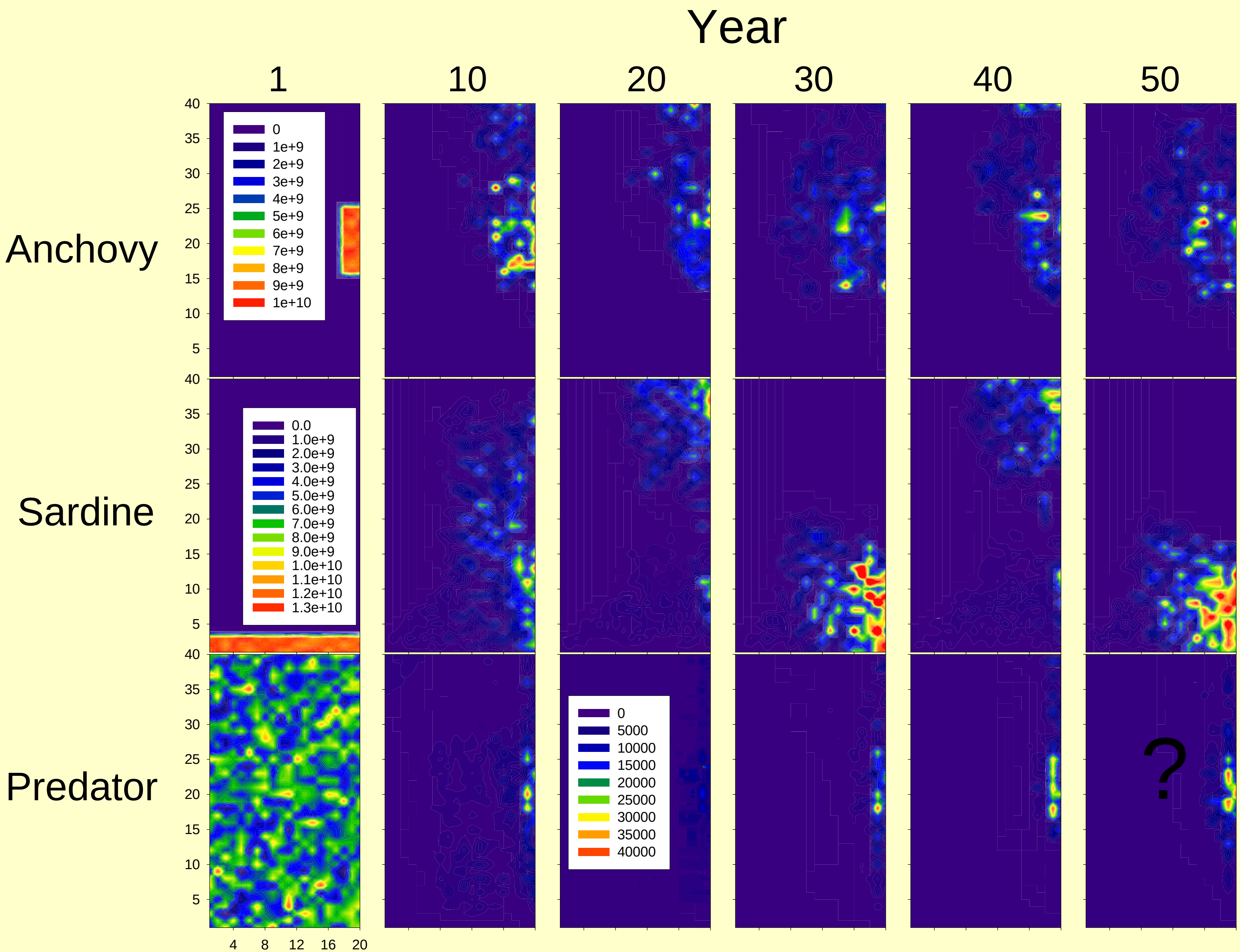
Zooplankton
Temperature
0.6
0.4
0.2
0.0
18
15
12
9
6
(g prey/g fish/d)
0.08
0.04
0.00
Maximum
Consumption
0.030
0.015
0.000
Respiration
Egestion
dW/dT (g fish/ind/d)
0.2
0.0
-0.2
45
30
15
0
Weight (g/fish)
500
1000
1500
2000
2500
3000
Age (days since recruitment)



40
30
20
10
0
0
5
10
15
20

Sardine #10060

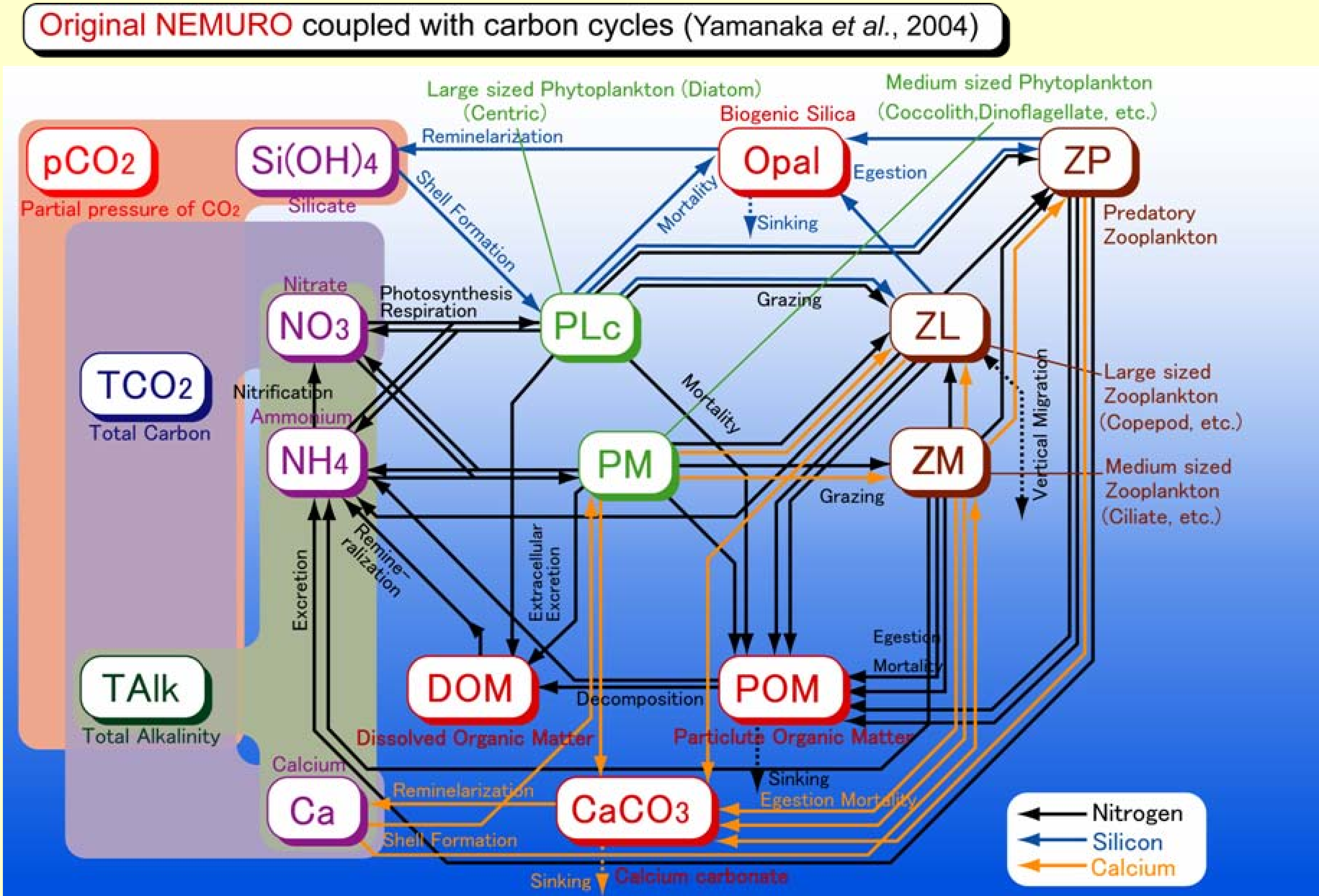




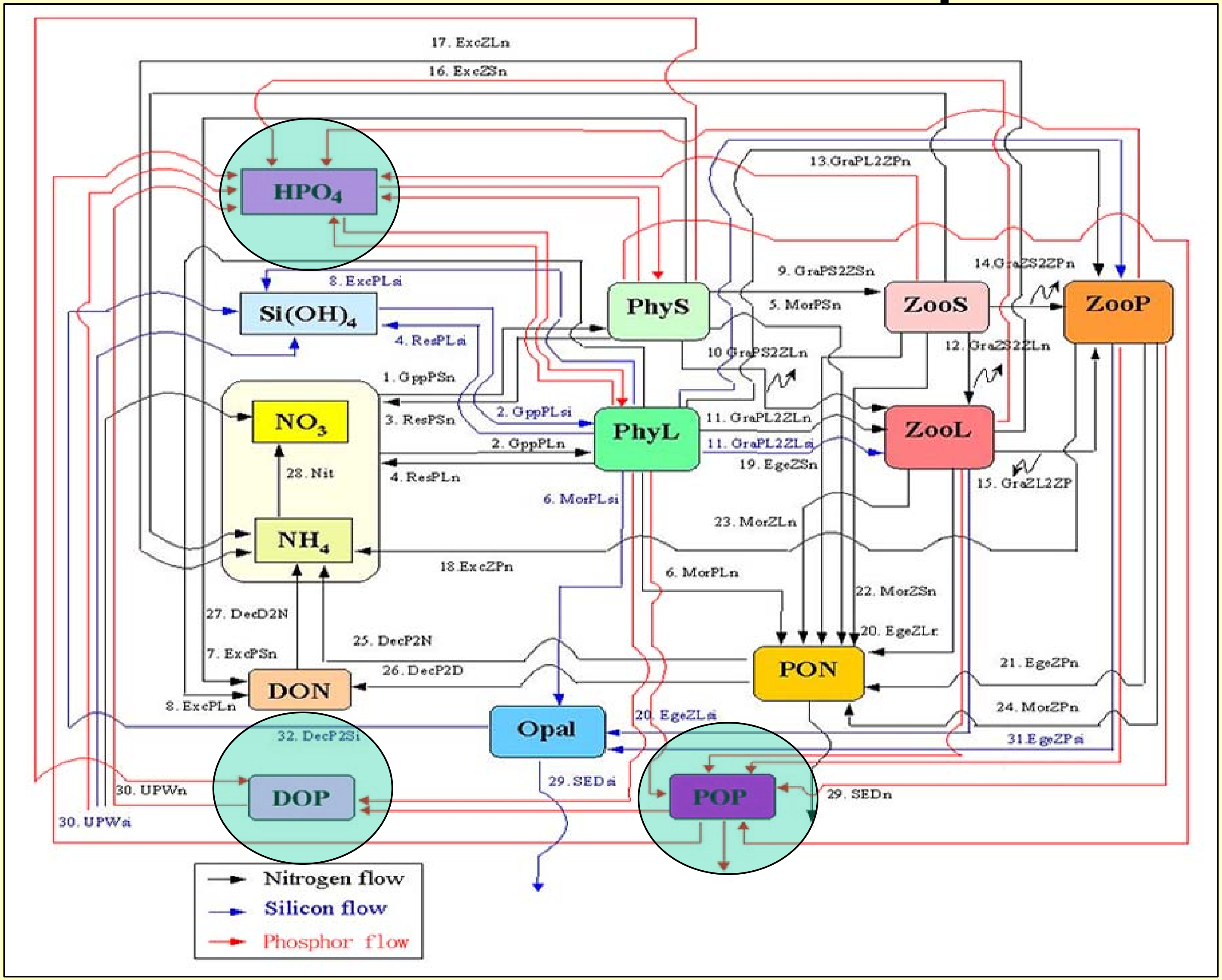
October 26, 2007 **PICES WG3** **Victoria, British Columbia**

NEMURO that includes consideration of other biogeochemical dynamics

Extensions to include Calcium flows



NEMURO with Phosphorus

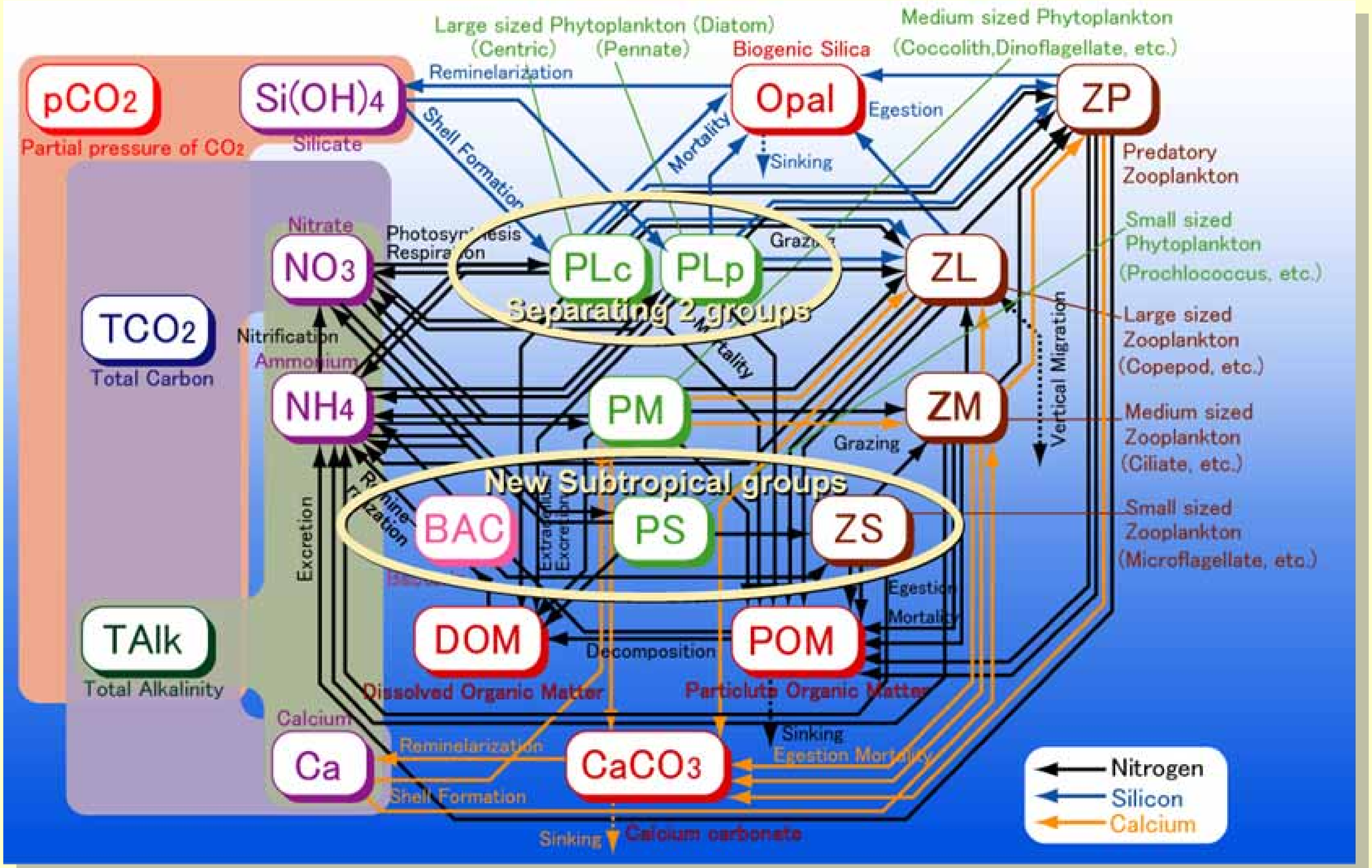


Source: Wang et al 2006, (in prep)

eNEMURO: An "extended" NEMURO configured for the subarctic and sub-tropical North Pacific

Extended NEMURO (eNEMURO)

introducing subtropical plankton and new temp. dep. (Yoshie *et al.*,2007)

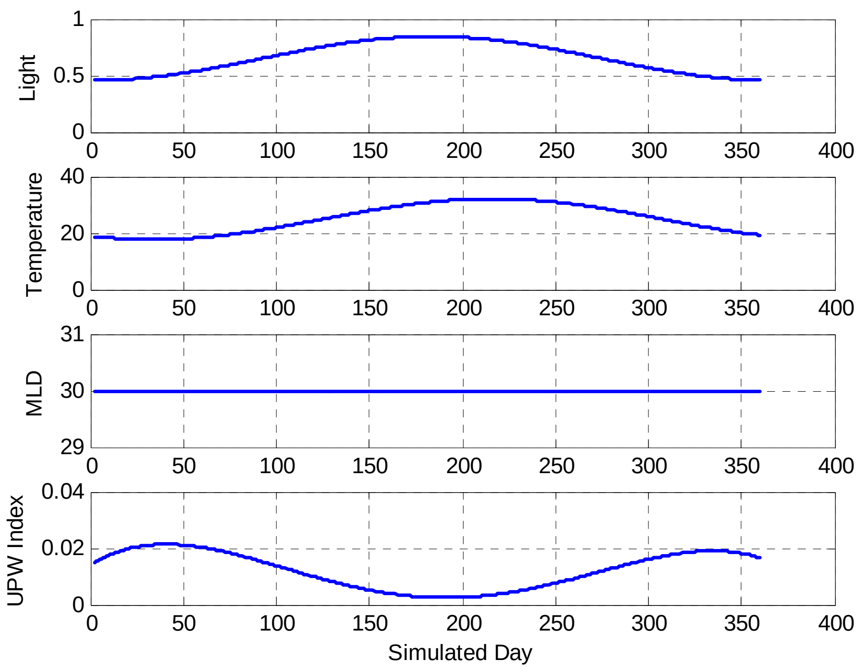


tNEMURO: A “tropical” NEMURO configured for the Gulf of California with future links to Pacific sardine

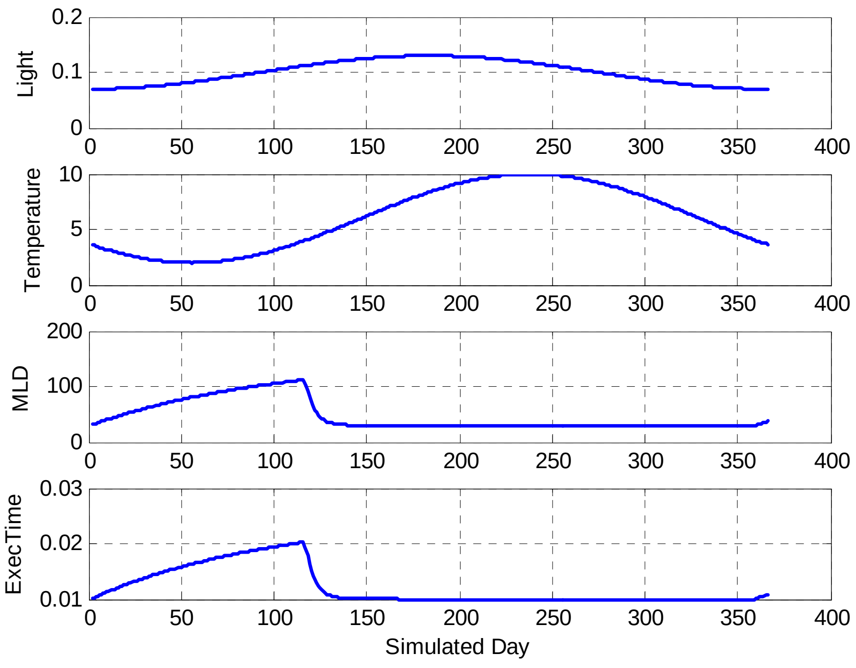
NEMURO-tNEMURO Comparison

	Subarctic NEMURO	Tropical tNEMURO
Temperature:	Low	High
Nutrient & Biomass:	High	Low
Dominant plankton:	Large	Small
Day Length:	Short	Long
Light Intensity (clouds):	Low (lots)	High (few)
Upwelling:	none	High

tNEMURO

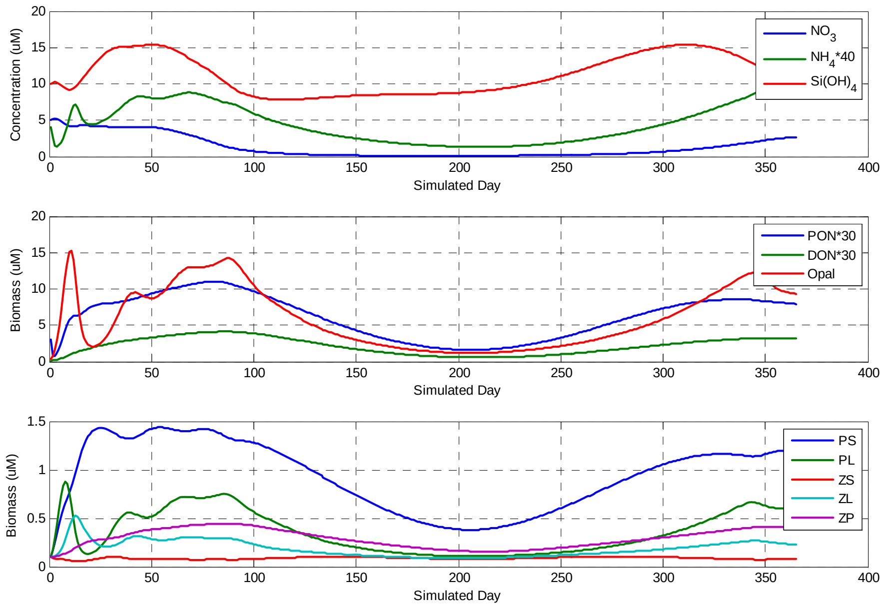


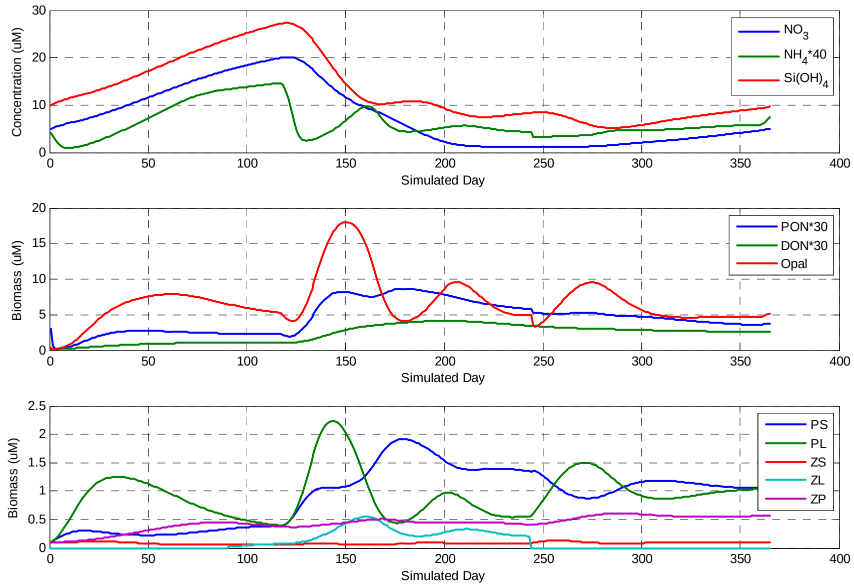
NEMURO



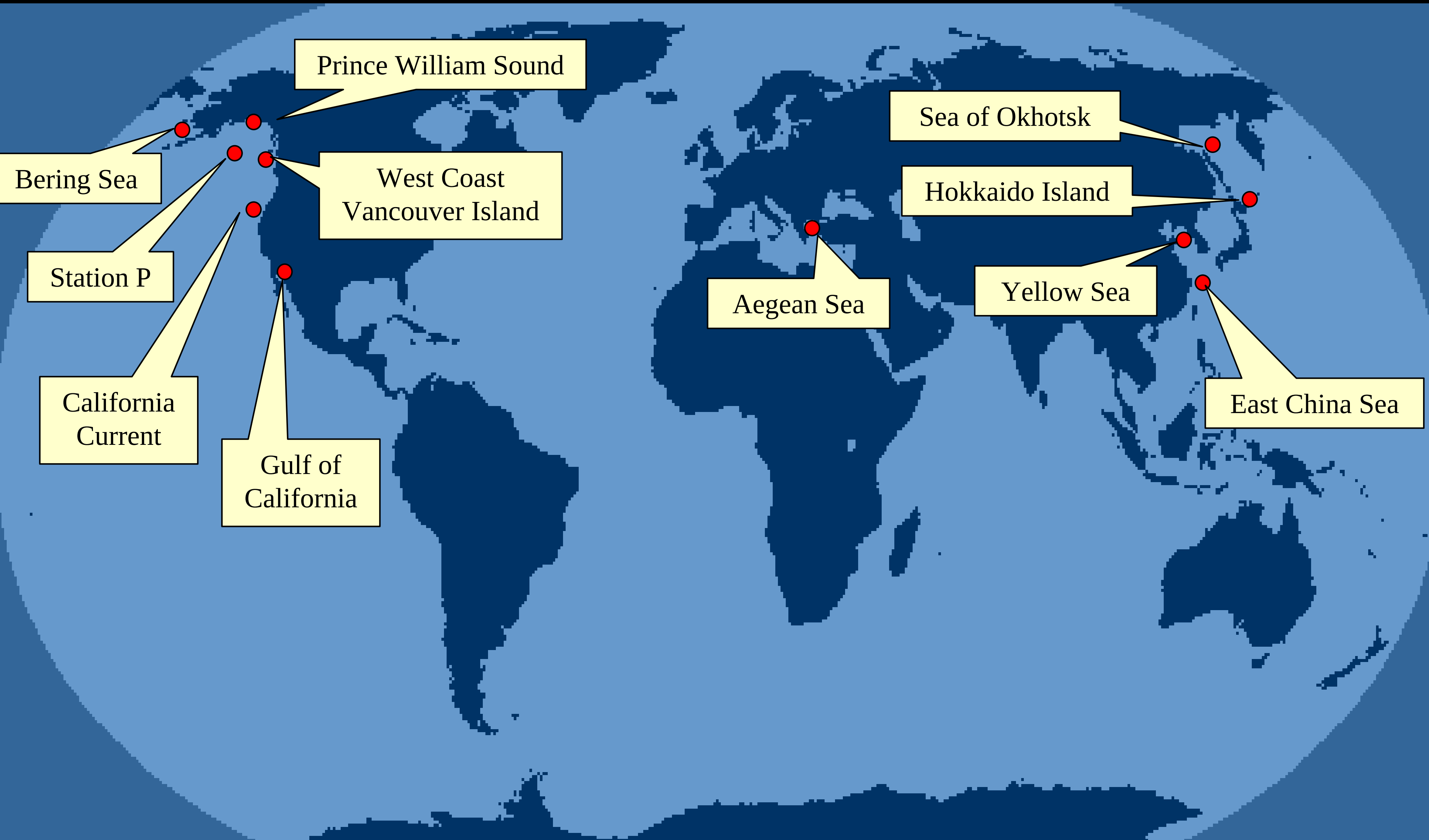
tNEMURO

NEMURO





Marine Seas where the NEMURO Model has been Applied



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),