Geographic Variation in Fish Growth and Population Responses to Regime Shifts in the North Pacific:

A Comparison of Herring and Saury Using NEMURO.FISH, a Coupled Fish Bioenergetics and NPZ Model

Authors

Kenneth A. Rose, Louisiana State University, Baton Rouge

Bernard .A. Megrey, Alaska Fisheries Science Center, Seattle, Washington

Shin-ichi. Ito, Tohoku National Fisheries Research Institute, Miyagi

Francisco. E. Werner, University of North Carolina, Chapel Hill

Douglas E. Hay, Pacific Biological Station, Nanaimo, British Columbia

Maki Aita-Noguchi, Frontier Research Center for Global Change, Yokohama

Yasuhiro Yamanaka, Graduate School of Environmental Earth Science, Hokkaido

Michio. J. Kishi, Graduate School of Fisheries Sciences, Hokkaido

Jake Schweigert, Pacific Biological Station, Nanaimo, British Columbia

Matthew Birch Foster, Alaska Department of Fish and Game, Kodiak

Dan Ware, Nanaimo, British Columbia

David Eslinger, NOAA Coastal Services Centre, Charleston, South Carolina

Robert Klumb, Great Plains Fish and Wildlife Management Assistance Office, Pierre, South Dakota

S. Lan Smith, Frontier Research System for Global Change, Yokohama

Acknowledgments

We gratefully thank the following for funding of the workshops:

North Pacific Marine Science Organization (PICES)
Heiwa-Nakajiima Foundation
City of Nemuro
Japan International Science and Technology Exchange Center
Japan Fisheries Agency
Asia-Pacific Network (APN)
GLOBEC

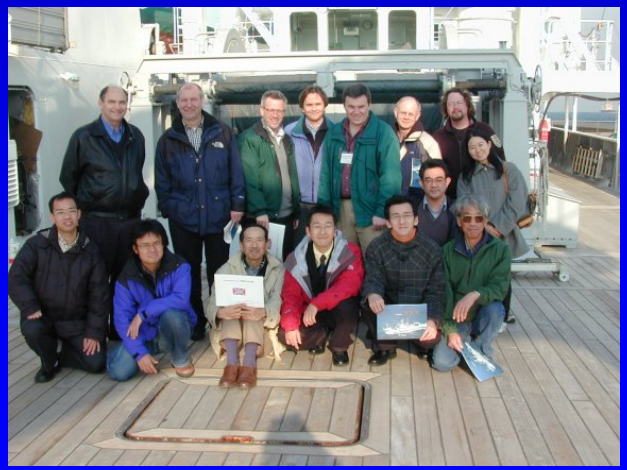
CCCC Model Task Team Recommendations

- Since comparison of 12 regional ecosystems is at the core of the CCCC, a prototype LTL model should be adopted to examine climate impacts
- The prototype model should have a generalized structure that can correctly represent the characteristics of each system
- Structural and formulation differences should be minimized
- Prototype model will facilitate development of comparison protocols

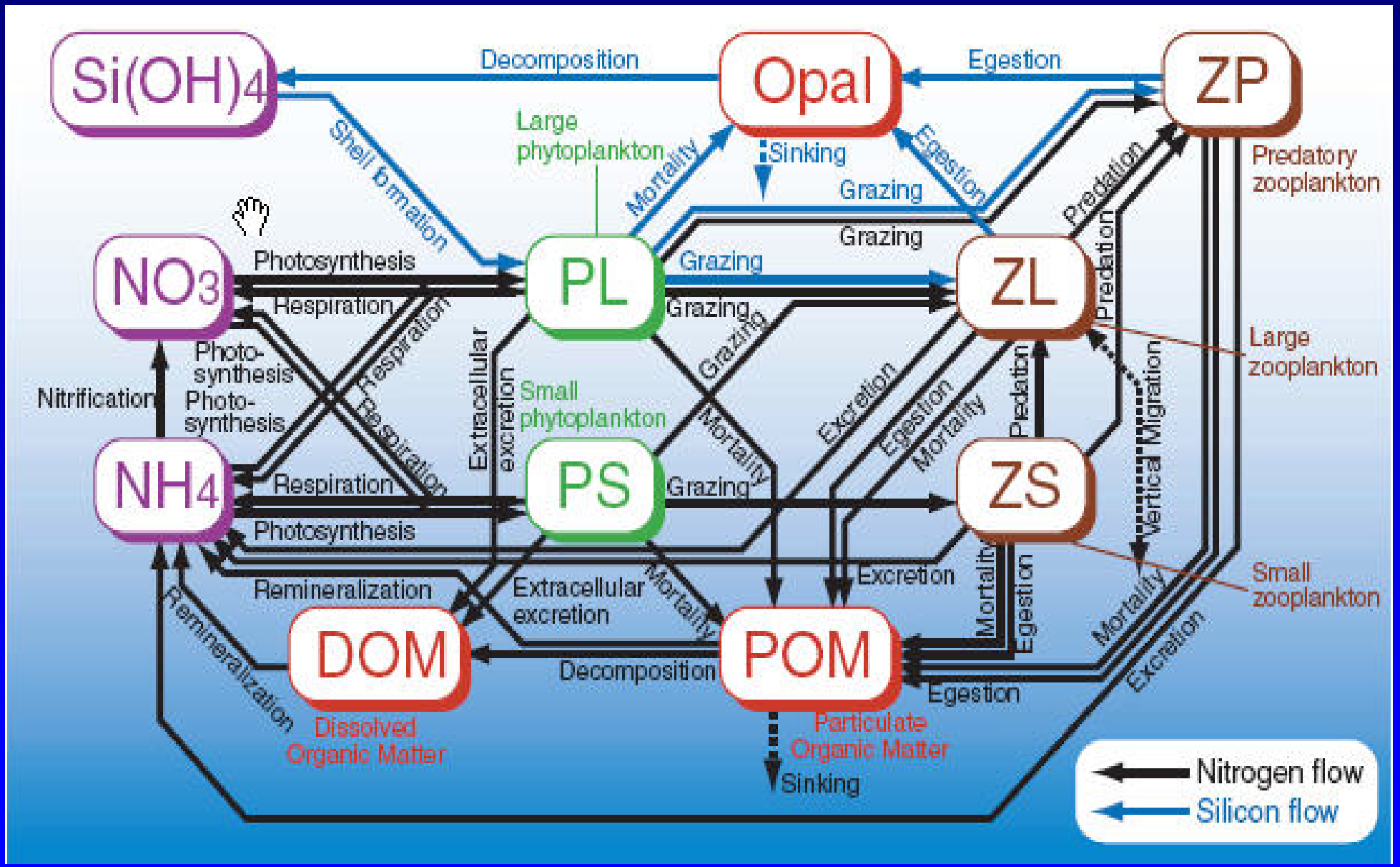
NEMURO

North Pacific Ecosystem Model for Understanding Regional Oceanography

10 workshops over 7 years



NEMURO


Si(OH)4
Opal
ZP
Decomposition
Egestion
Shell formation
Large phytoplankton
Mortality
Sinking
Egestion
Grazing
Predation
Predatory zooplankton
Grazing
NO3
PL
ZL
Photosynthesis
Respiration
Grazing
Grazing
Predation
Large zooplankton
Photo-synthesis
Nitrification
Photo-synthesis
Respiration
Respiration
Extracellular excretion
Small phytoplankton
Grazing
Mortality
Excretion
Egestion
Mortality
Predation
Vertical Migration
NH4
PS
ZS
Respiration
Grazing
Photosynthesis
Excretion
Remineralization
Extracellular excretion
Mortality
Mortality
Egestion
Small zooplankton
Remineralization
DOM
POM
Decomposition
Mortality
Egestion
Excretion
Dissolved Organic Matter
Particulate Organic Matter
Sinking
Nitrogen flow
Silicon flow

NEMURO Applications

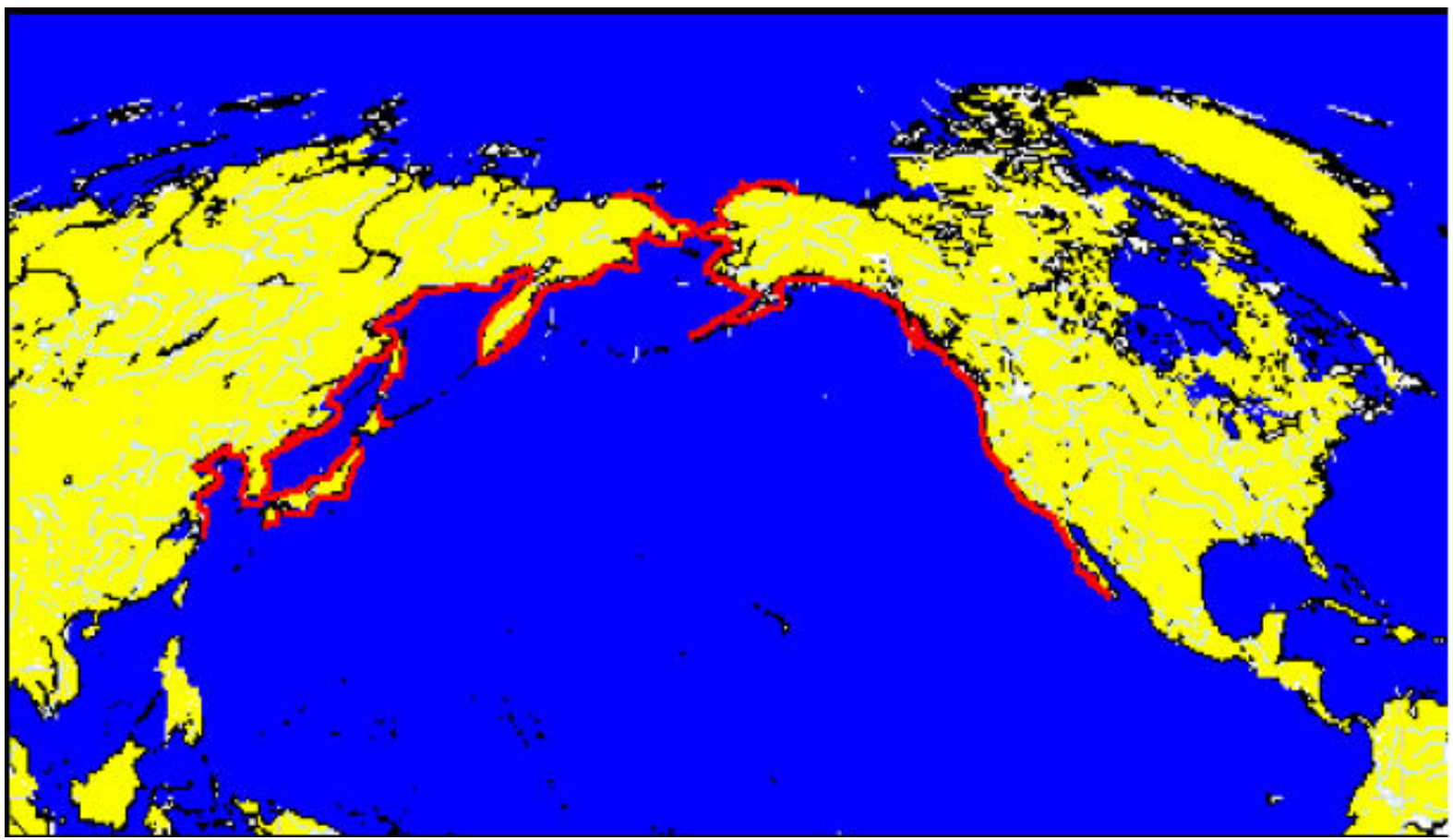
- Examples
  - Station Knot – Fujii et al. (2002)
  - Station A-7 – Yamanaka et al. (2004)
  - Particle flux – Kishi et al. (2004)
  - Vertical migration – Yoshie et al. (2003)
  - Data assimilation – Kuroda and Kishi (2004)
  - 3-D implementation - Aita-Noguchi et al. (in review)

- Dedicated issue of Ecological Modelling (Kishi, Megrey, Werner, and Ito, editors)

Today

- Expansion to NEMURO.FISH (For Including Saury and Herring)
- Three examples:
  - WCVI herring (coupled)
  - Eight herring populations (uncoupled)
  - Herring versus saury (uncoupled)
- We show a few examples to illustrate– more analyses and explanations of the results can be found in the papers

Herring



Herring Bioenergetics

$$\frac{dW}{dt} = \left[C - (R + S + F + E) - H\right] \cdot \frac{CAL_z}{CAL_f} \cdot W$$

Zoop from NEMURO

$$C_j = \frac{C_{MAX} \cdot \frac{PD_j \cdot v_{ij}}{K_{ij}}}{1 + \sum_{k=1}^{n} \frac{PD_k \cdot v_{ik}}{K_{ik}}}$$

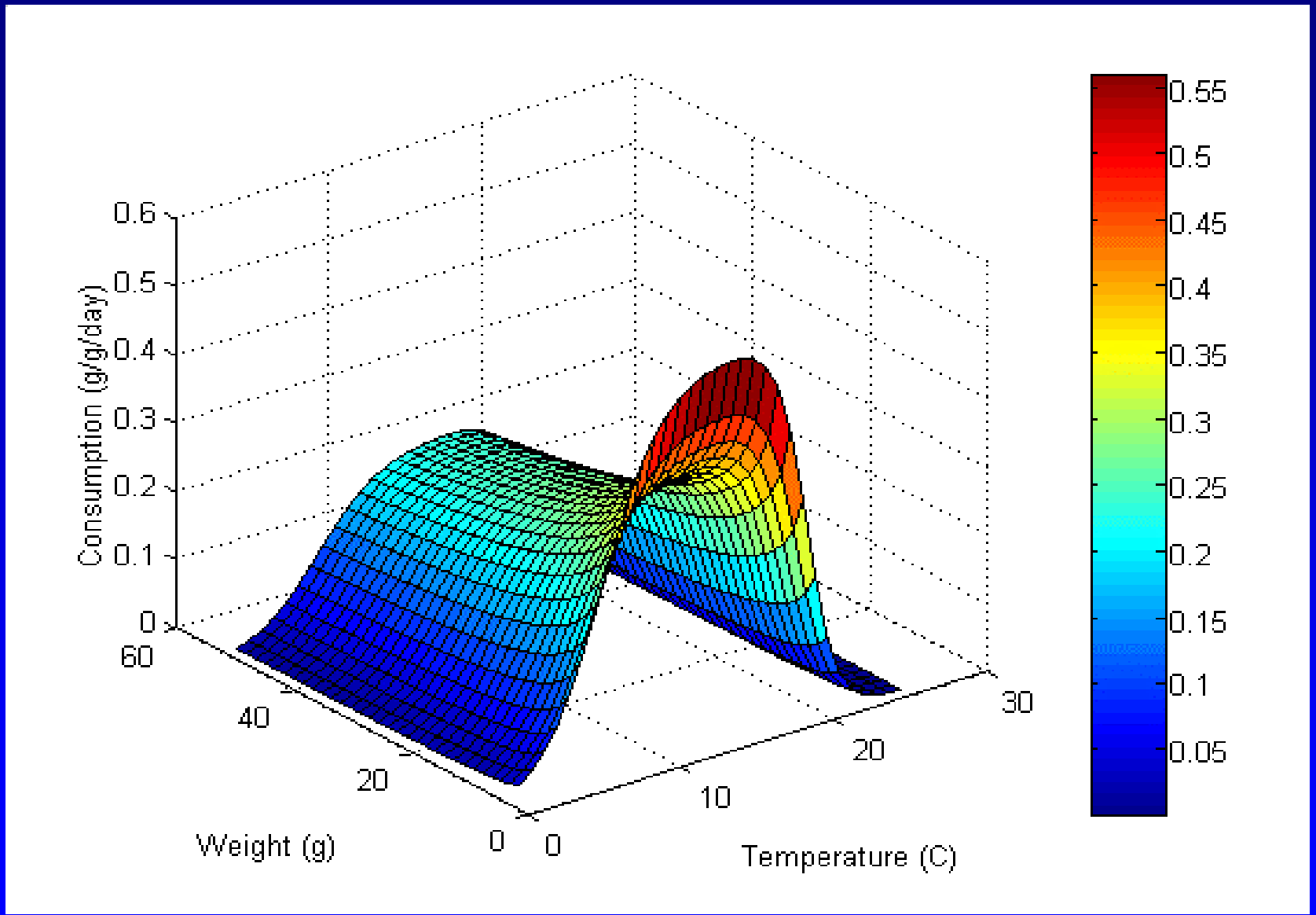
If coupled, mortality rate to NEMURO

W = weight (g ww)
C = consumption (1/day)
R = respiration
S = SDA
F = egestion
E = excretion
H = reproduction

Depend on W and temperature

PD = prey density (1=ZS; 2=ZL; 3=ZP)
V = vulnerability
K = feeding efficiency

Maximum Consumption



Closing the Life Cycle

- Mortality: Natural (0.44/y) and fishing (0.25/y)
- Spawn: March 15
- Maturation: 95% at age-3; 100% age-4 and older
- YOY (#/m^3): enter on June 20 at 0.2 g ww

YOY Recruitment

$$YOY_t = SSB \bullet 10^{-3} \bullet e^{(3.24 + 0.032 \cdot SSB_t + 0.44 \cdot NPPI_t - 0.26 \cdot AIR_t - 0.36 \cdot SST_t)}$$

SSB - spawning stock biomass (g wet weight/m^3)

NPPI - North Pacific Pressure Index

AIR - Air temperature

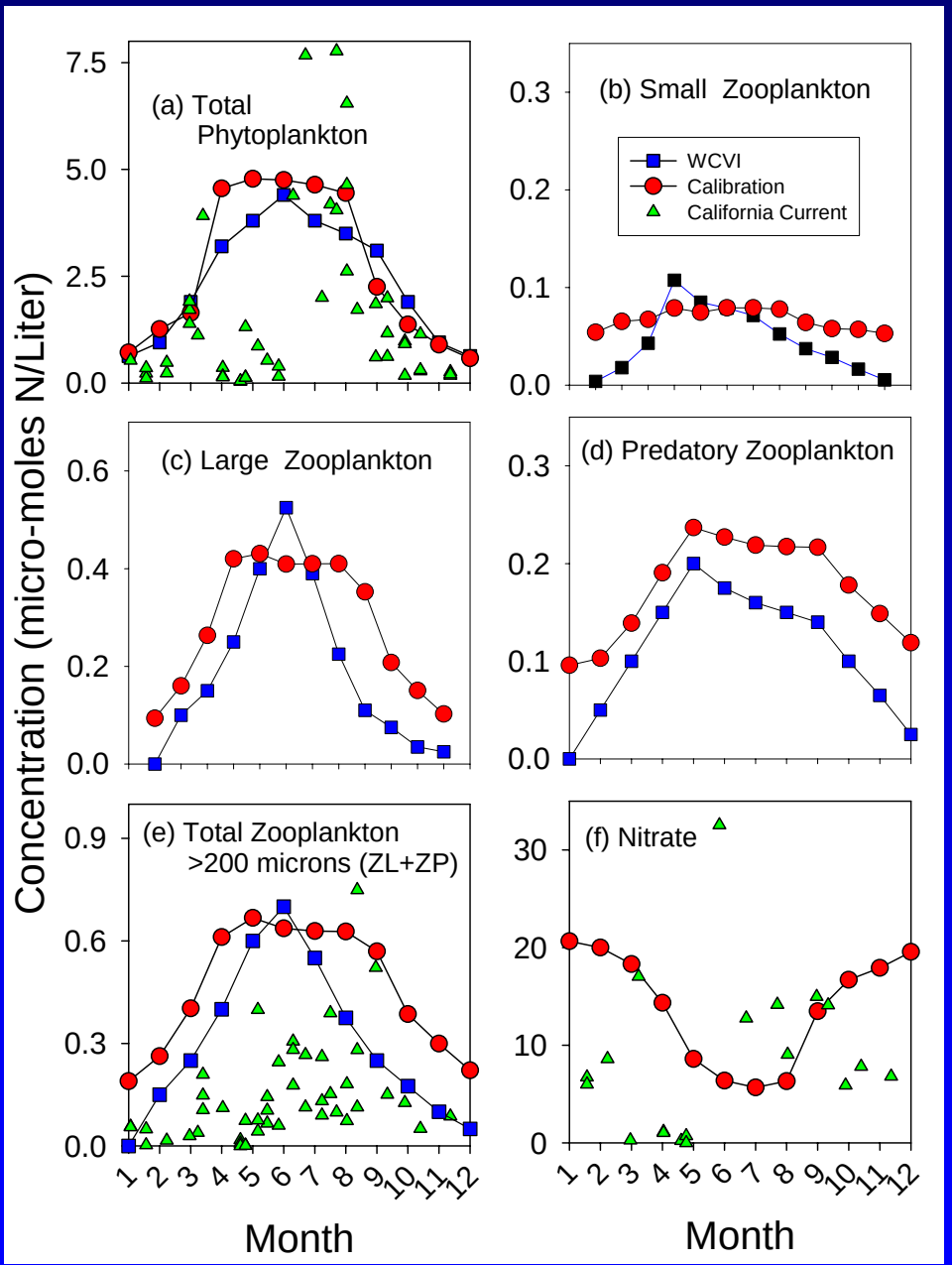
SST - Sea surface temperature

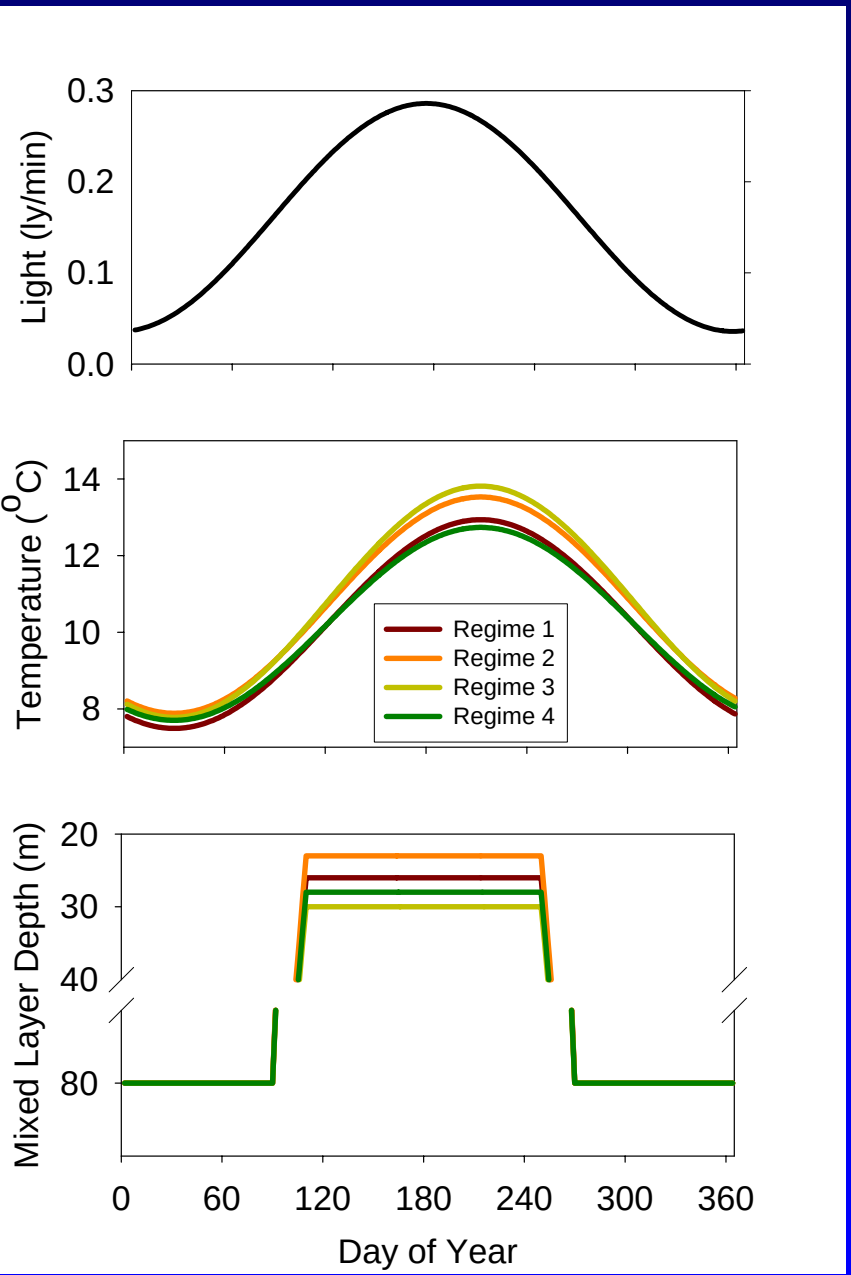
Williams and Quinn (2000) Fish Oceanogr 9: 300-315

Example 1: WCVI herring

- Calibrated NEMURO to field data on phytoplankton and zooplankton for WVCI (regime 3 – 1990's)
- ***Coupled***: herring consumption removes zooplankton
- Used historical environmental indices for recruitment (Williams and Quinn, 2000)
- Simulated conditions for four regime periods
  - 1962-1976 1977-1988 1989-1997 1998-2002

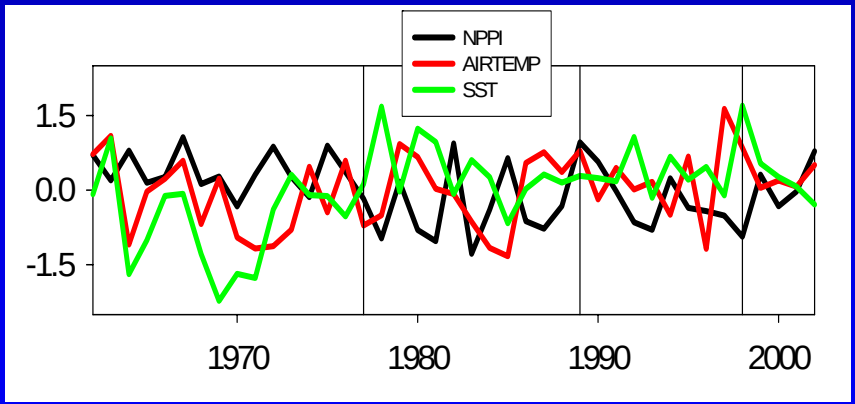
Rose et al. (in press) TAFS; Megrey et al. (in review) EM; Rose et al. (in review) EM

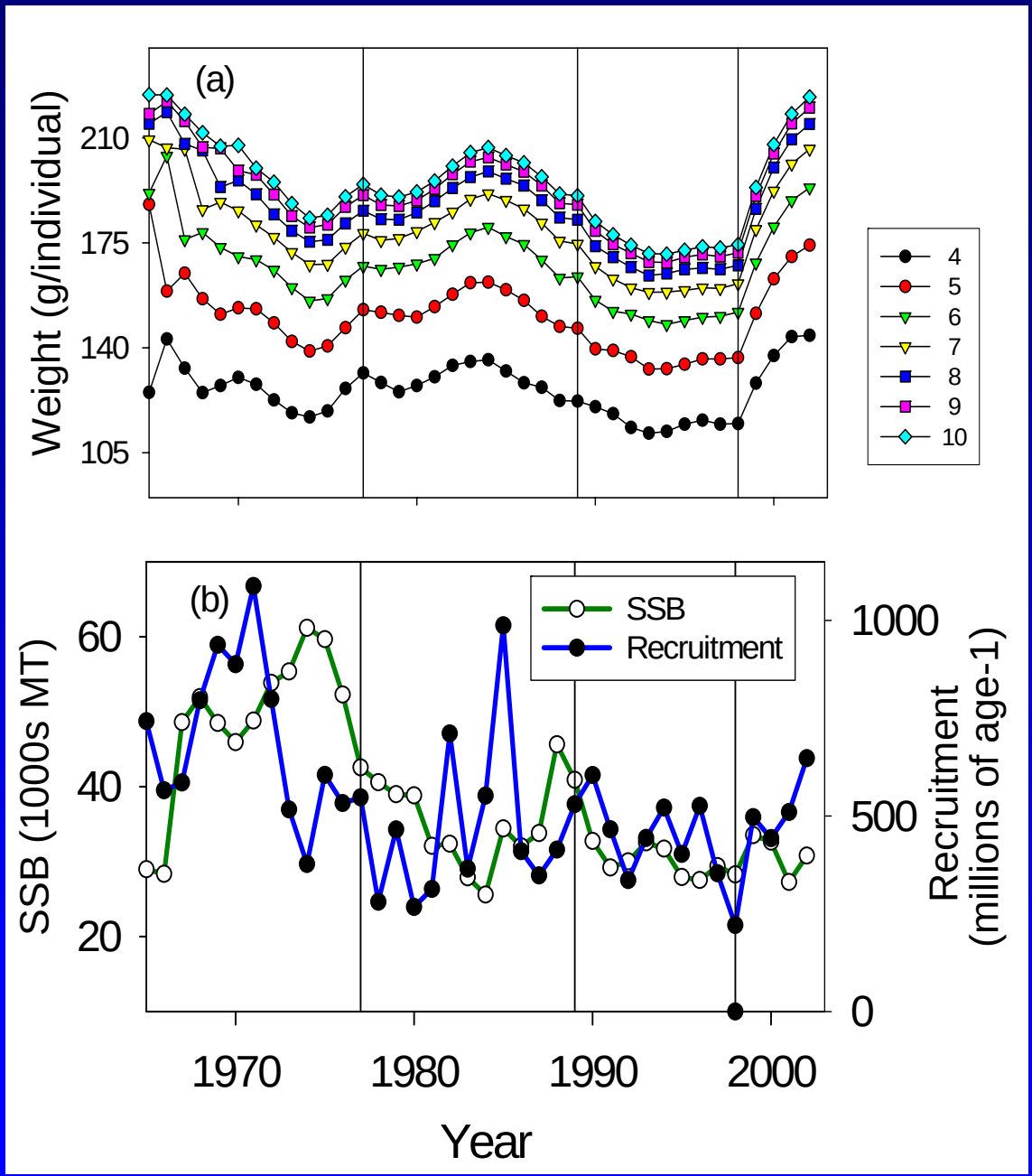

Concentration (micro-moles N/Liter)
(a) Total Phytoplankton
(b) Small Zooplankton
WCVI
Calibration
California Current
(c) Large Zooplankton
(d) Predatory Zooplankton
(e) Total Zooplankton >200 microns (ZL+ZP)
(f) Nitrate
Month
Month

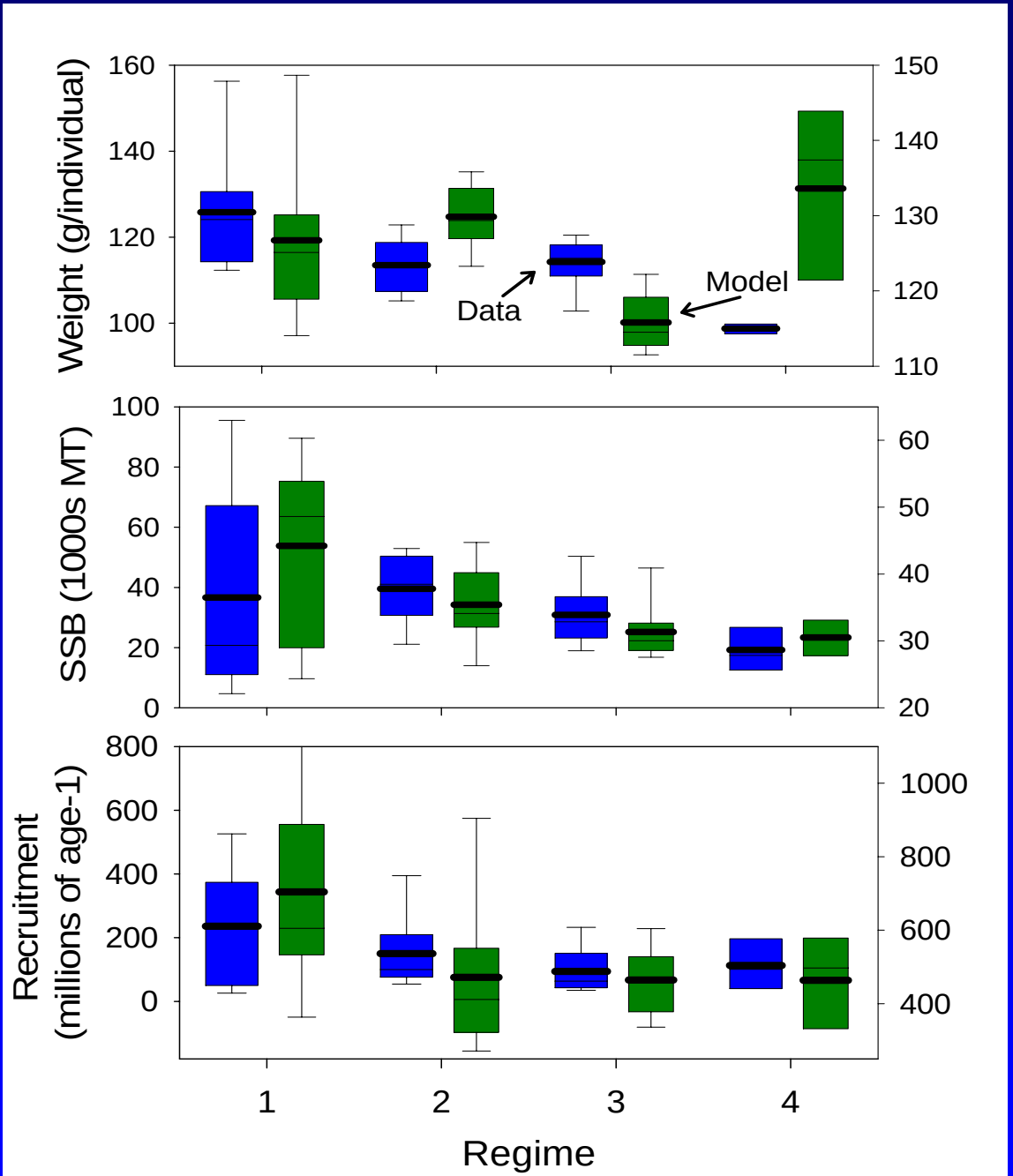

Light (ly/min)
Temperature (°C)
Regime 1
Regime 2
Regime 3
Regime 4
Mixed Layer Depth (m)
Day of Year

Calibrated Nemuro

+







Note: This is a rare case in this talk of real data

Example 2: Eight Herring Populations

- Used predictions of temperature and zooplankton from NEMURO imbedded in a 3-D circulation model
  - Aita-Noguchi, Yamanaka, and Kishi (in review) Ecological Modelling
  - See poster
- ***Uncoupled***: used stored output from NEMURO as input to herring growth model
- Regime shifts cascading up food web?

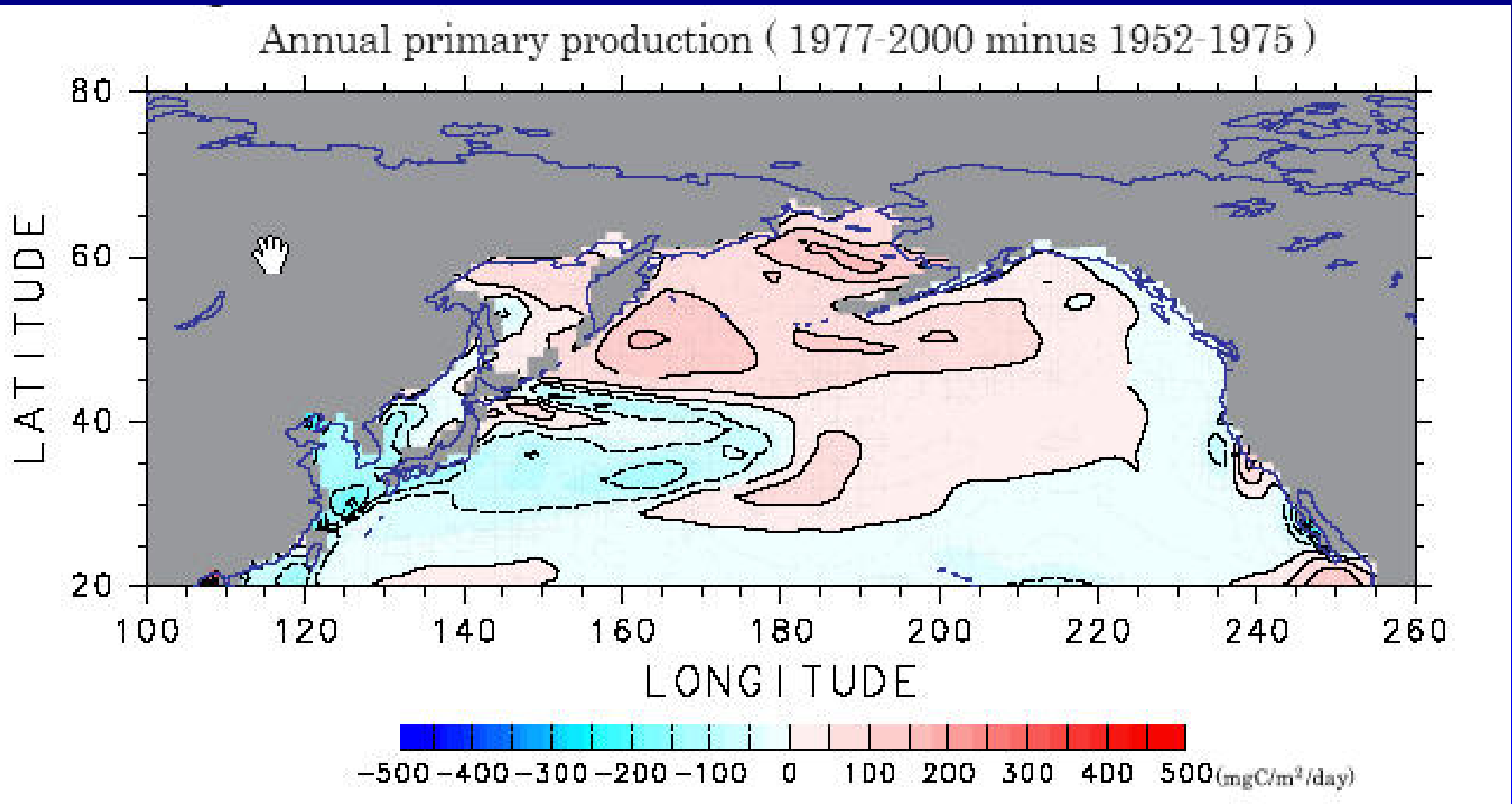
Three of the populations reported in Rose et al. (in review) EM

NEMURO-3D Implementation

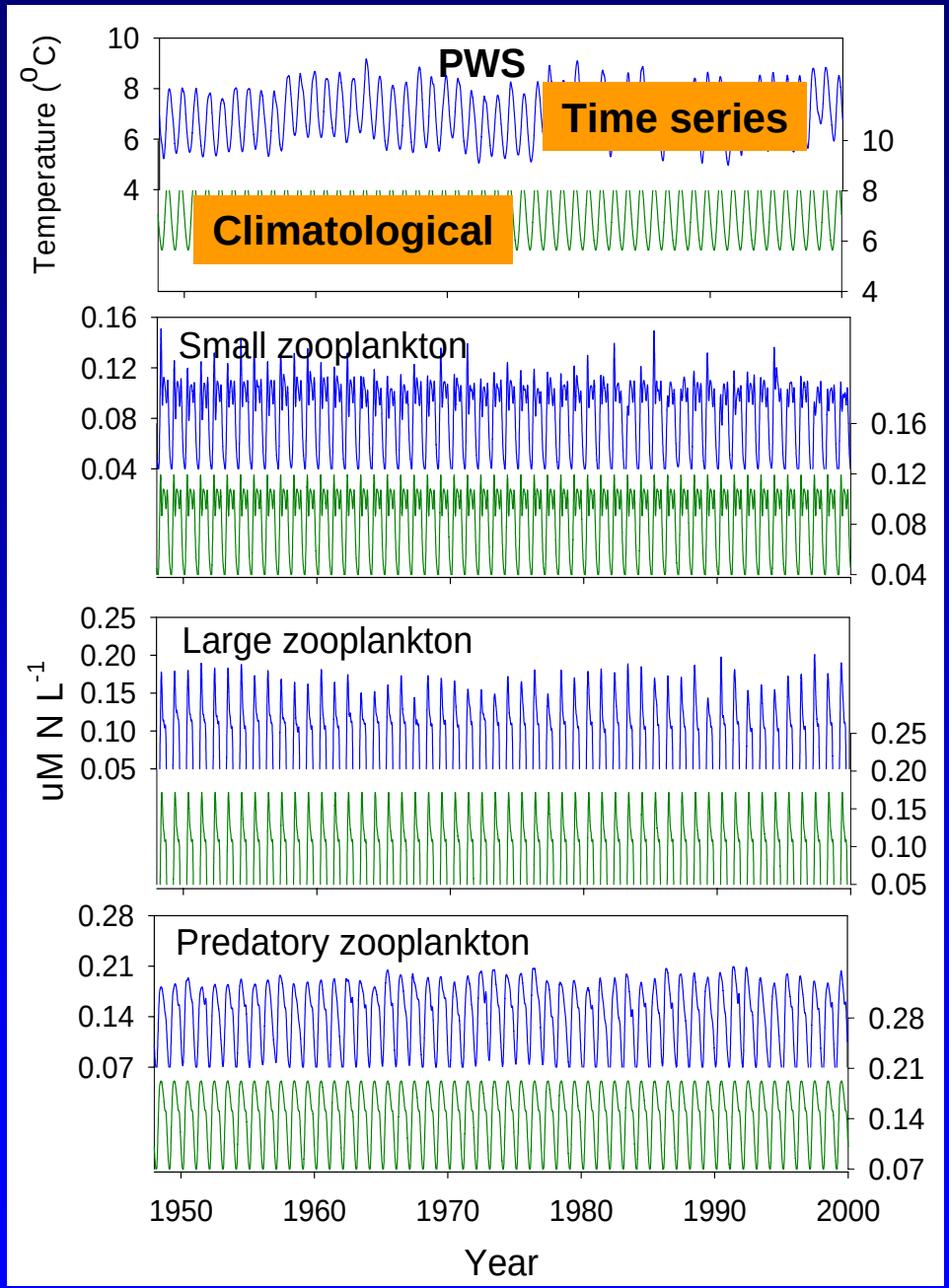
Aita-Noguchi et al. (in review)

- Physical model: CCSR Ocean Component Model 3.4
- Horizontal: 1 degree by 1degree (360x180)
- Vertical: 54 levels from the surface to 5000 m
- Real boundary conditions (daily surface forcing)

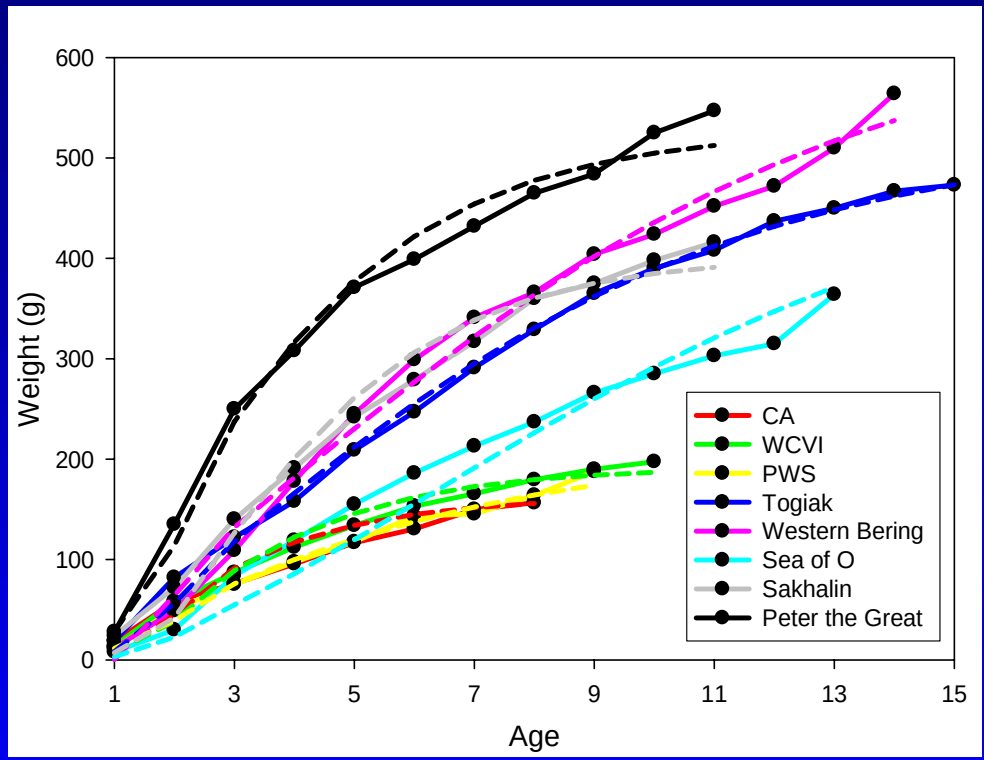
Aita-Noguchi, Yamanaka, and Kishi. in review. Interdecadal variation of the lower trophic ecosystem in the northern Pacific between 1948 and 2002, in a 3-D implementation of the NEMURO model.



Extracted temperature and zooplankton (ZS, ZL, ZP)
Averaged for top 100 m

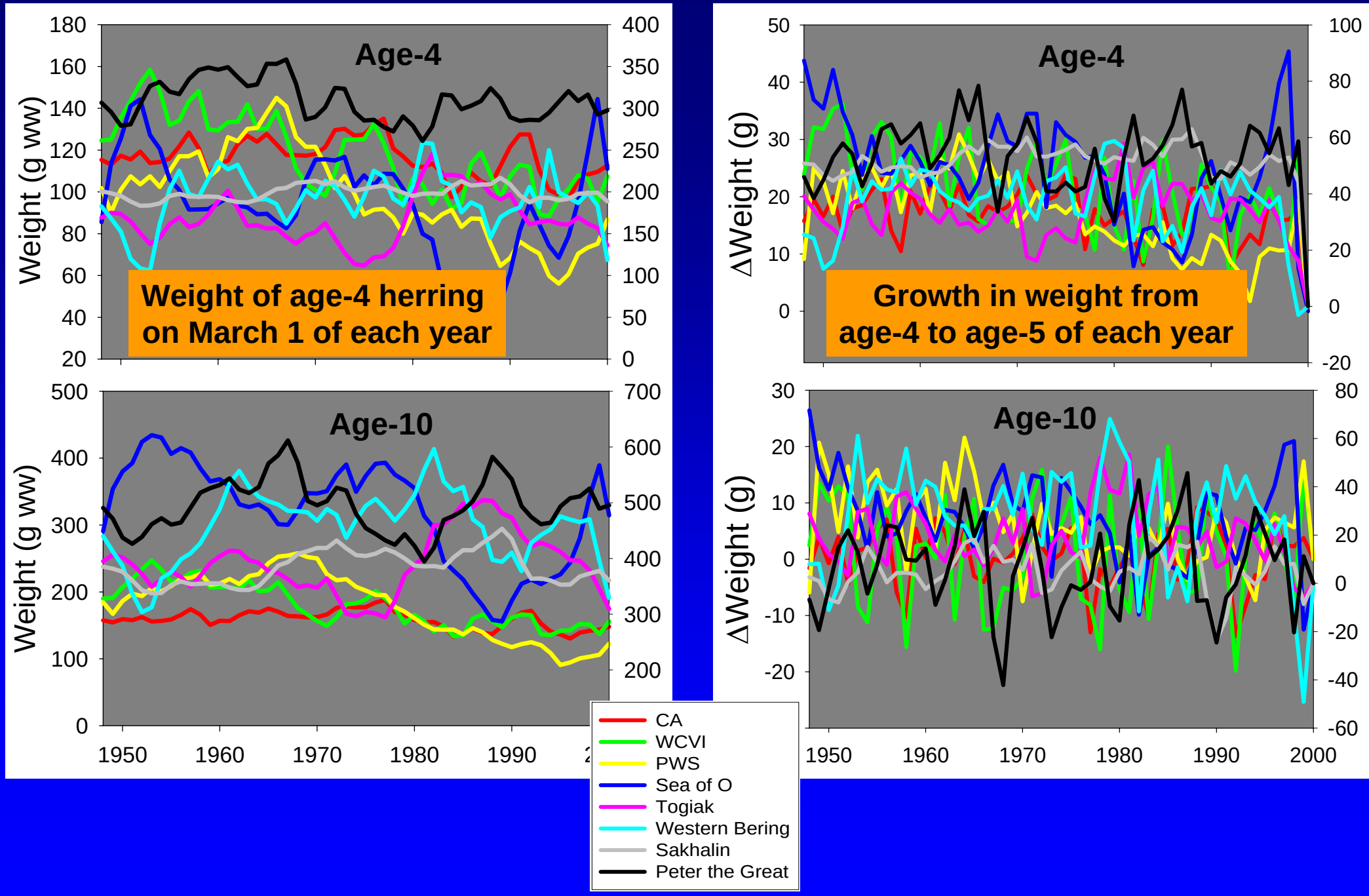


Calibration with PEST using Climatological Steady-state weights-at-age

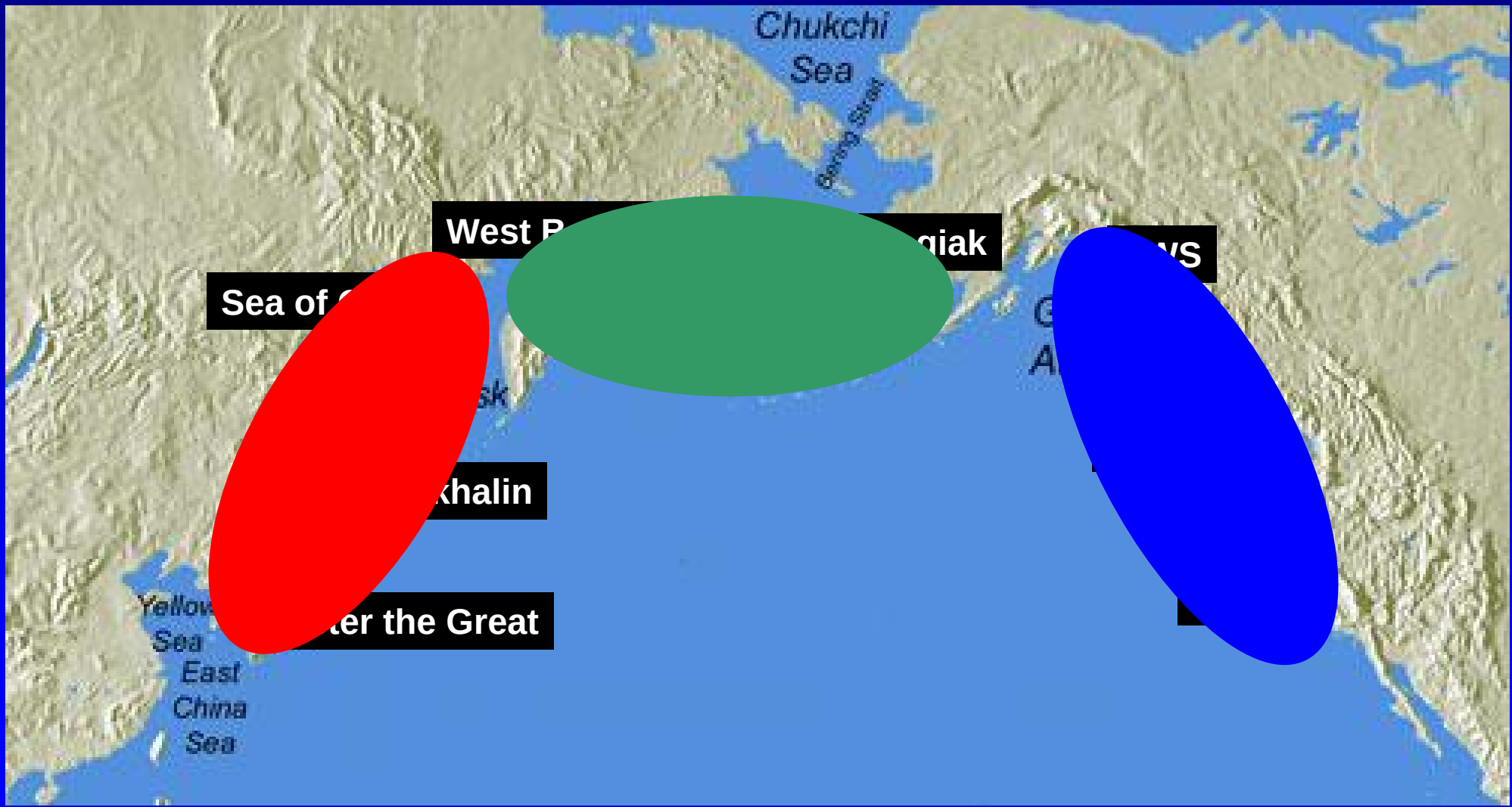


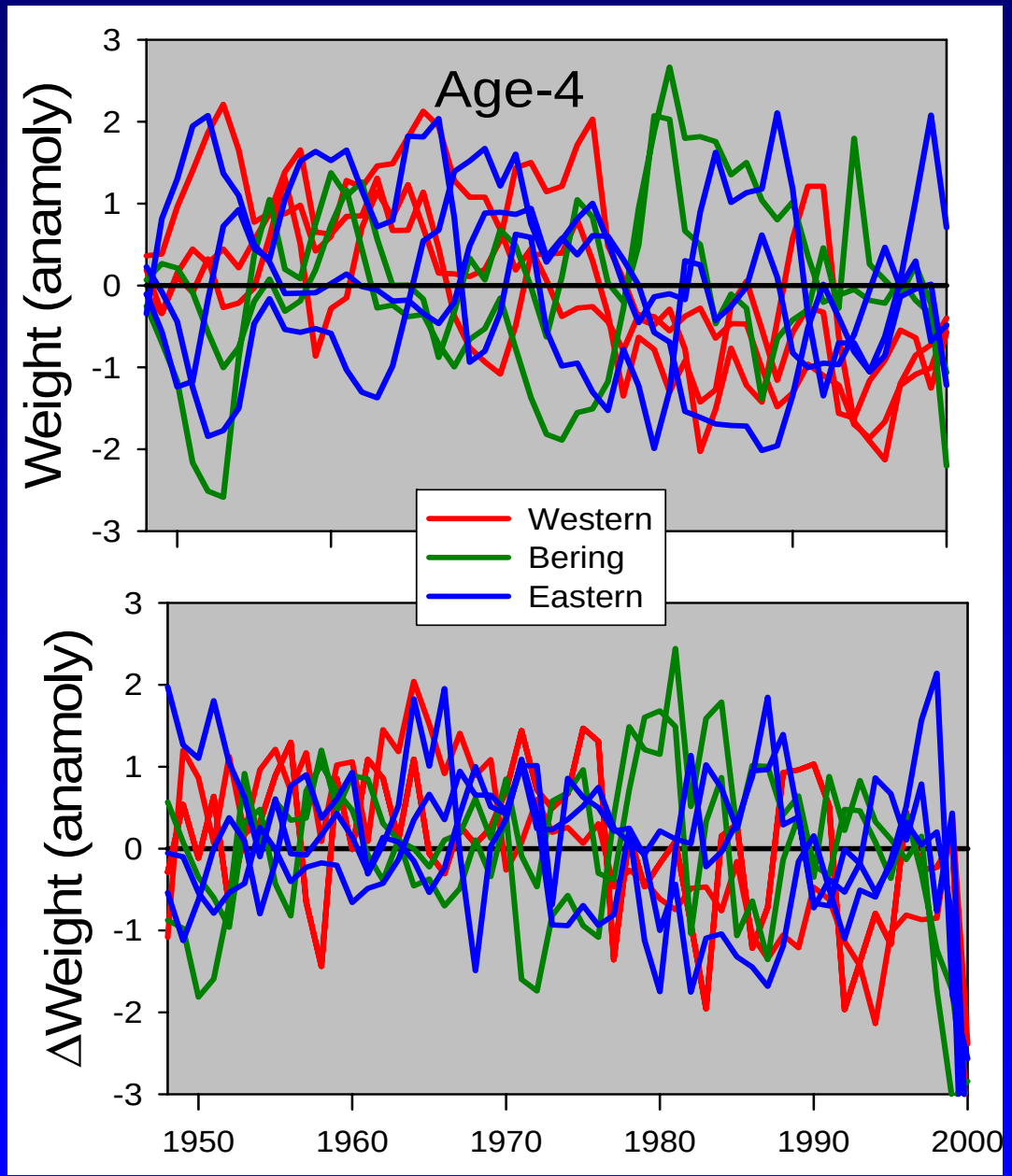
Weights-at-age from:

- Naumenko (2002) Report 20
- ADFG stock assessments
- Schweigert et al. (2004)
- Lassuy (1980)

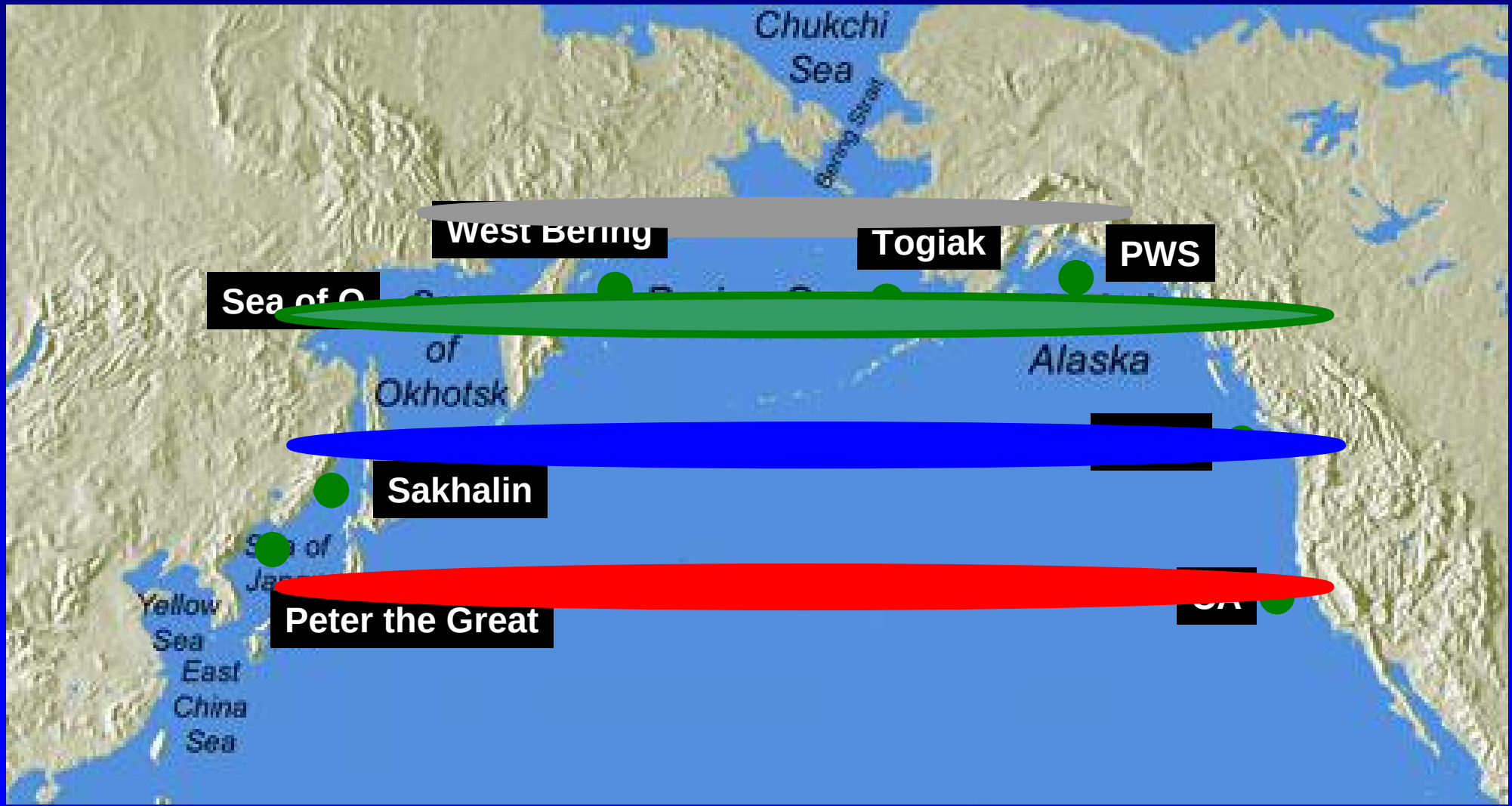

Age-4
Weight (g ww)
Weight of age-4 herring
on March 1 of each year
Age-4
ΔWeight (g)
Growth in weight from
age-4 to age-5 of each year
Age-10
Weight (g ww)
Age-10
ΔWeight (g)
1950
1960
1970
1980
1990
2000
CA
WCVI
PWS
Sea of O
Togiak
Western Bering
Sakhalin
Peter the Great

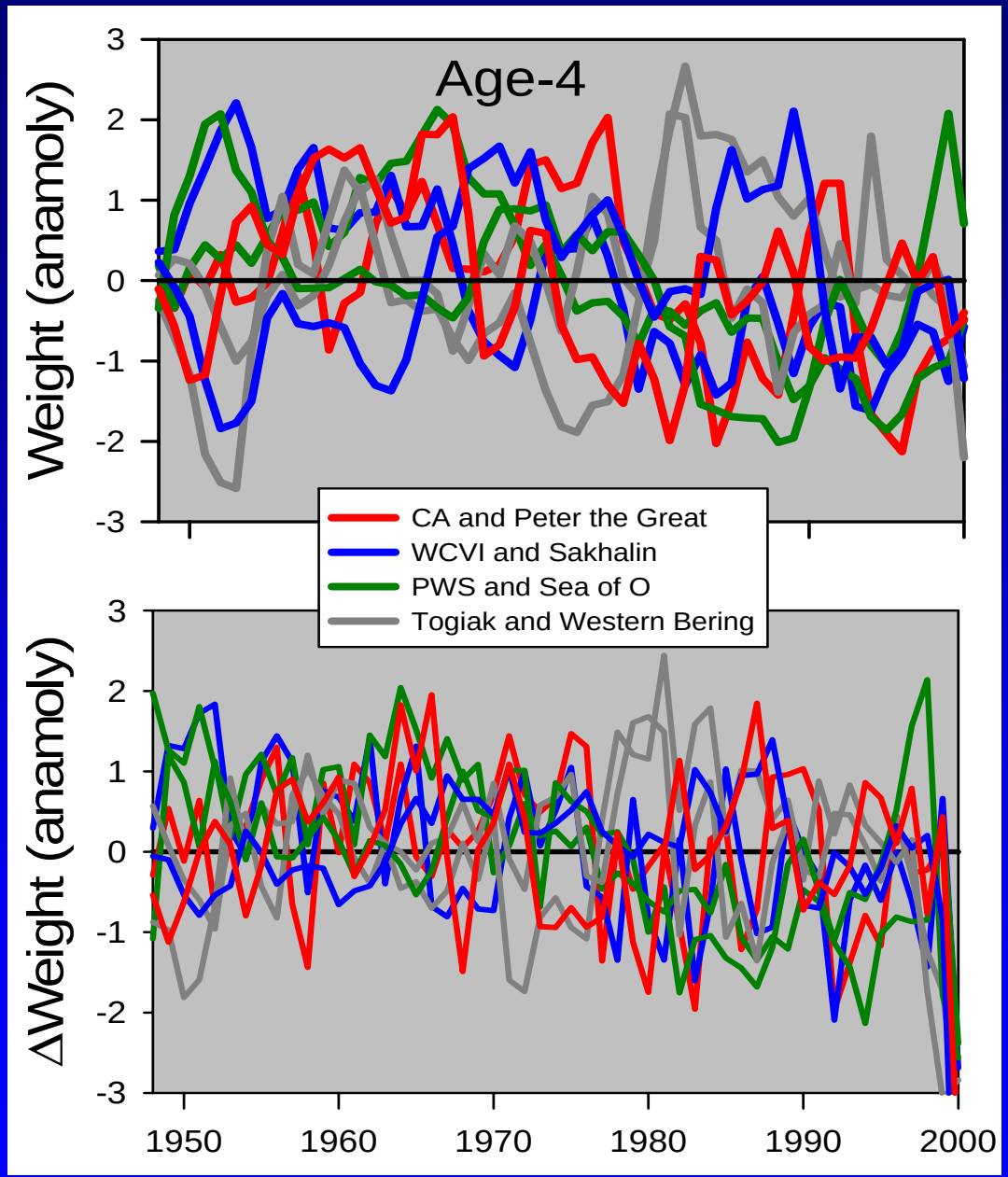
Looking for Patterns?




Age-4
Weight (anamoly)
3
2
1
0
-1
-2
-3
Western
Bering
Eastern
ΔWeight (anamoly)
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000

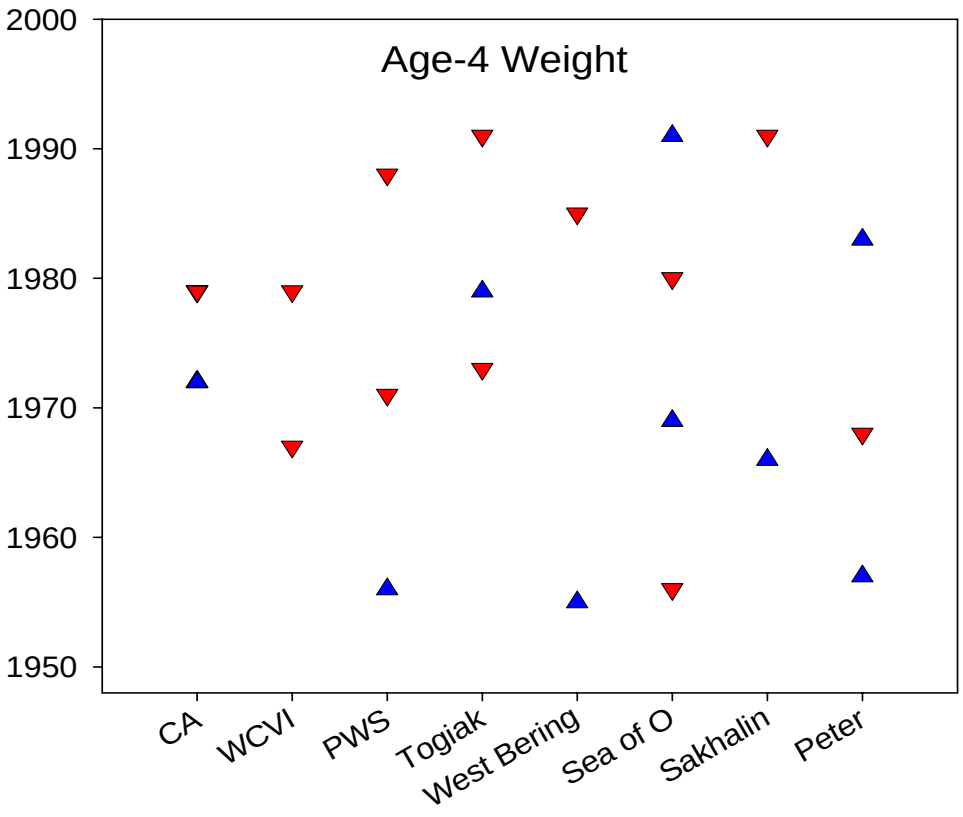
Still Looking for Patterns?

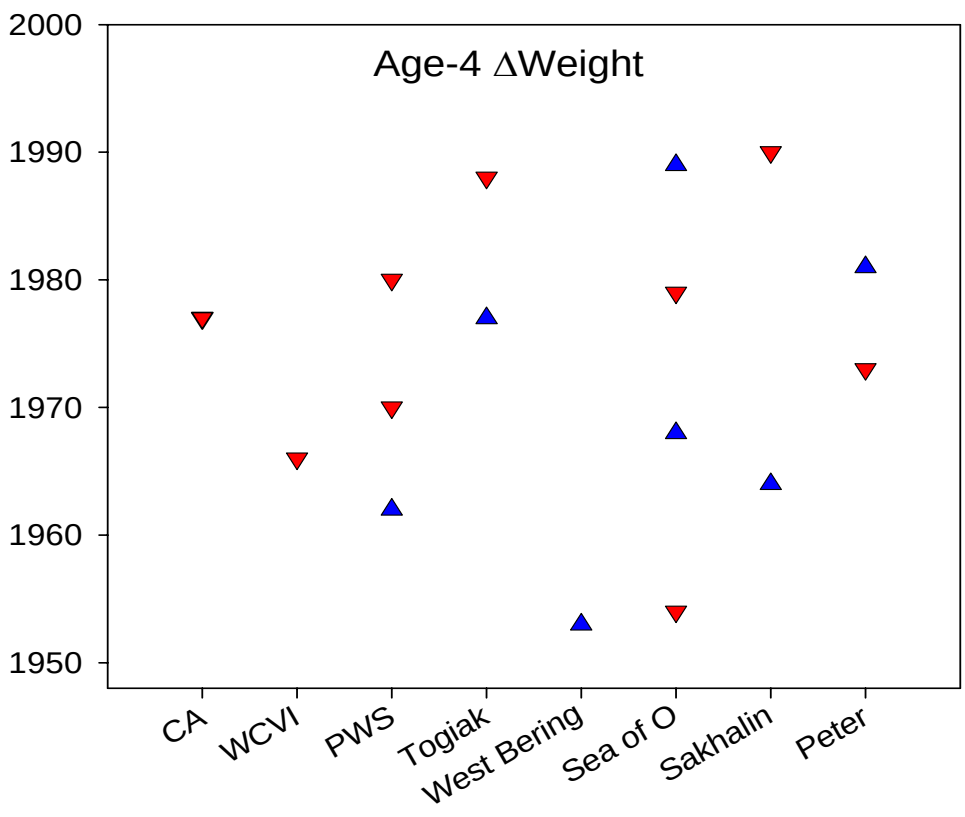



Age-4
Weight (anamoly)
ΔWeight (anamoly)
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000
CA and Peter the Great
WCVI and Sakhalin
PWS and Sea of O
Togiak and Western Bering

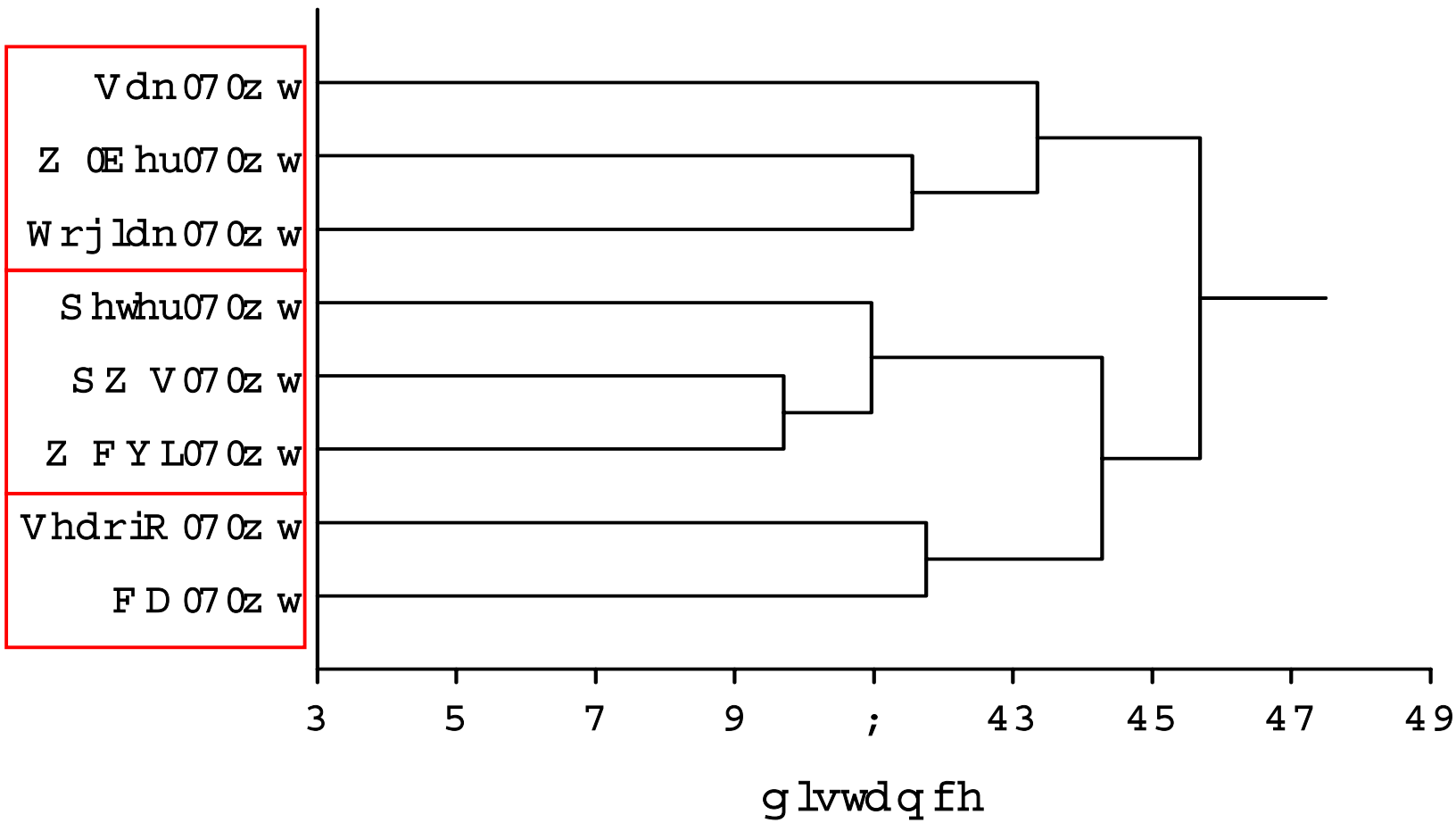
Regime Detector - STARS

(Rodionov and Overland, 2005)



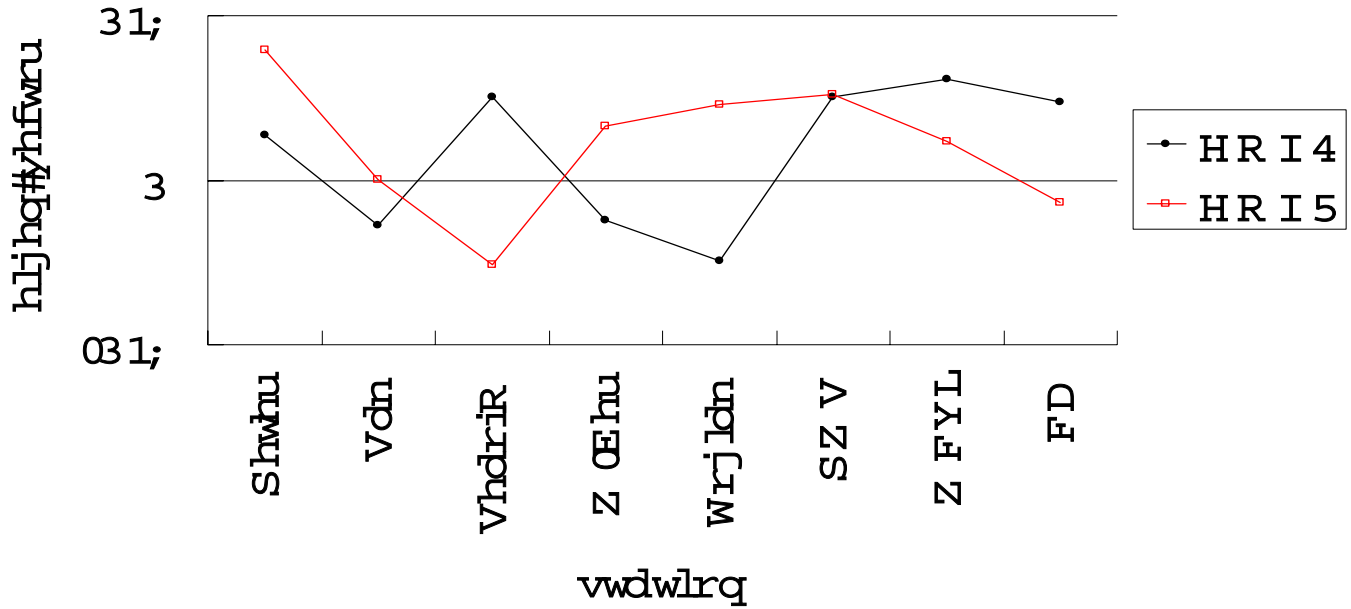


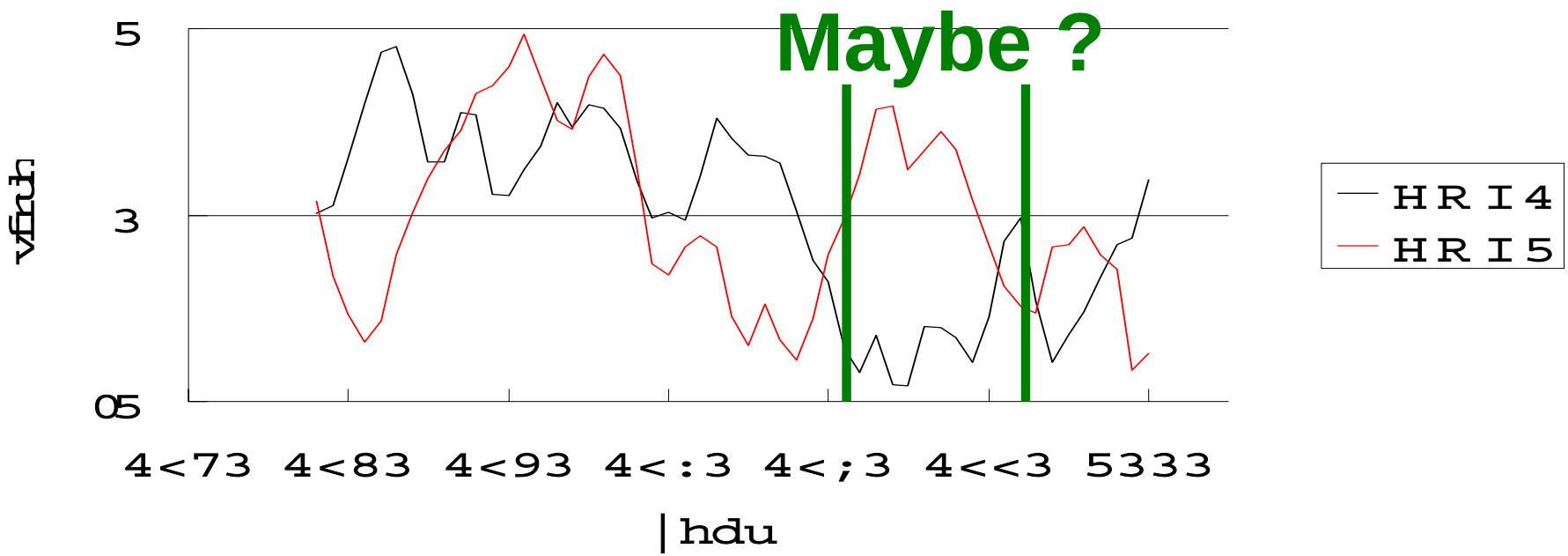
Desperately looking for patterns – Clustering



Use complete connection method
with standardized Euclidian distance

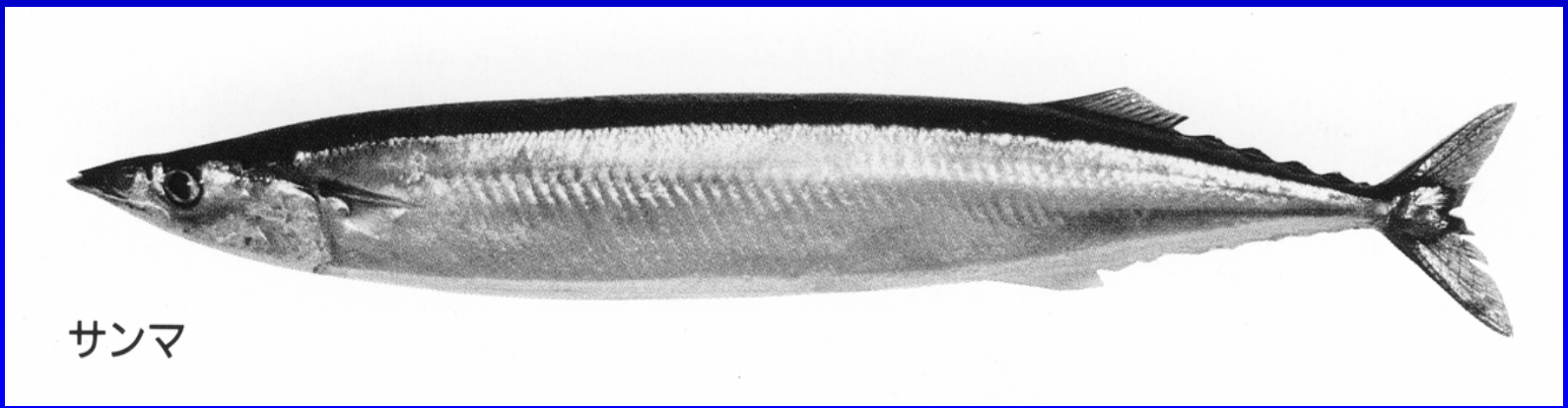
Eigenvector
for wet weight
EOF1 38.1%
EOF2 19.4%



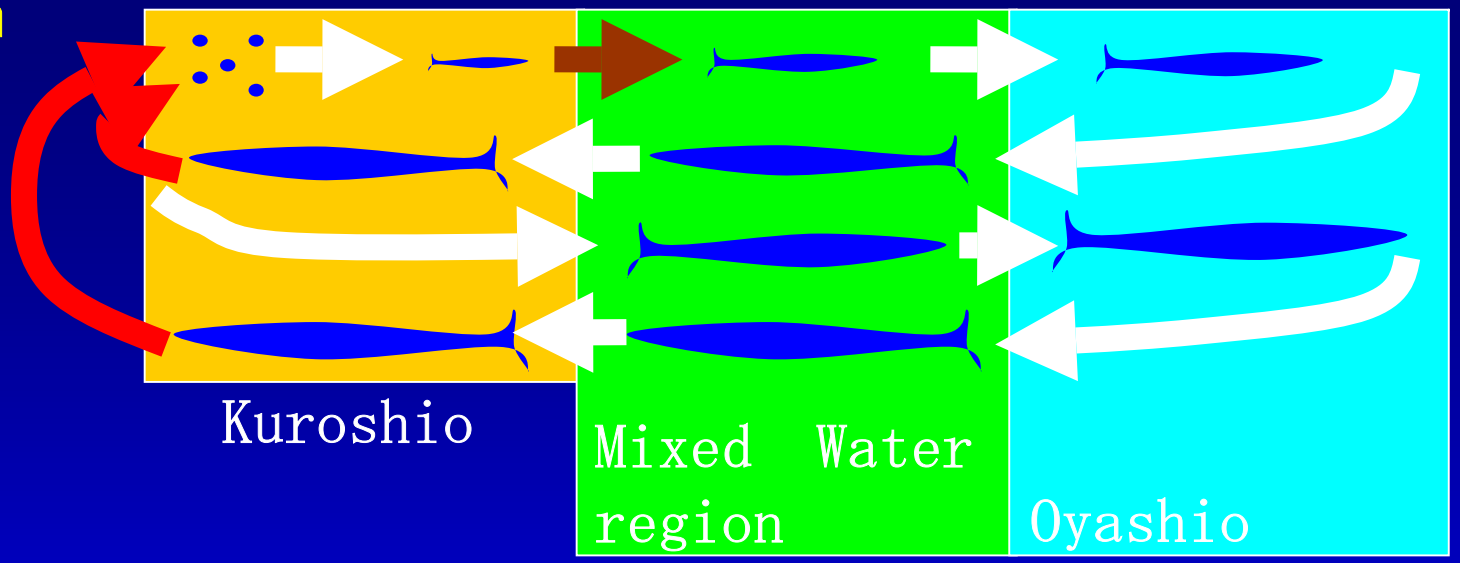


Example 3: Herring and Saury

- Parallel bioenergetics model developed for saury (Ito et al. 2004. Fish. Ocenogr.)



3-box version



Stage	region
larvae	Kuroshio
juvenile & young	mixed region
small	Oyashio
adult	mixed region
adult matured	Kuroshio
adult	mixed region
adult	Oyashio
adult	mixed region
adult matured	Kuroshio

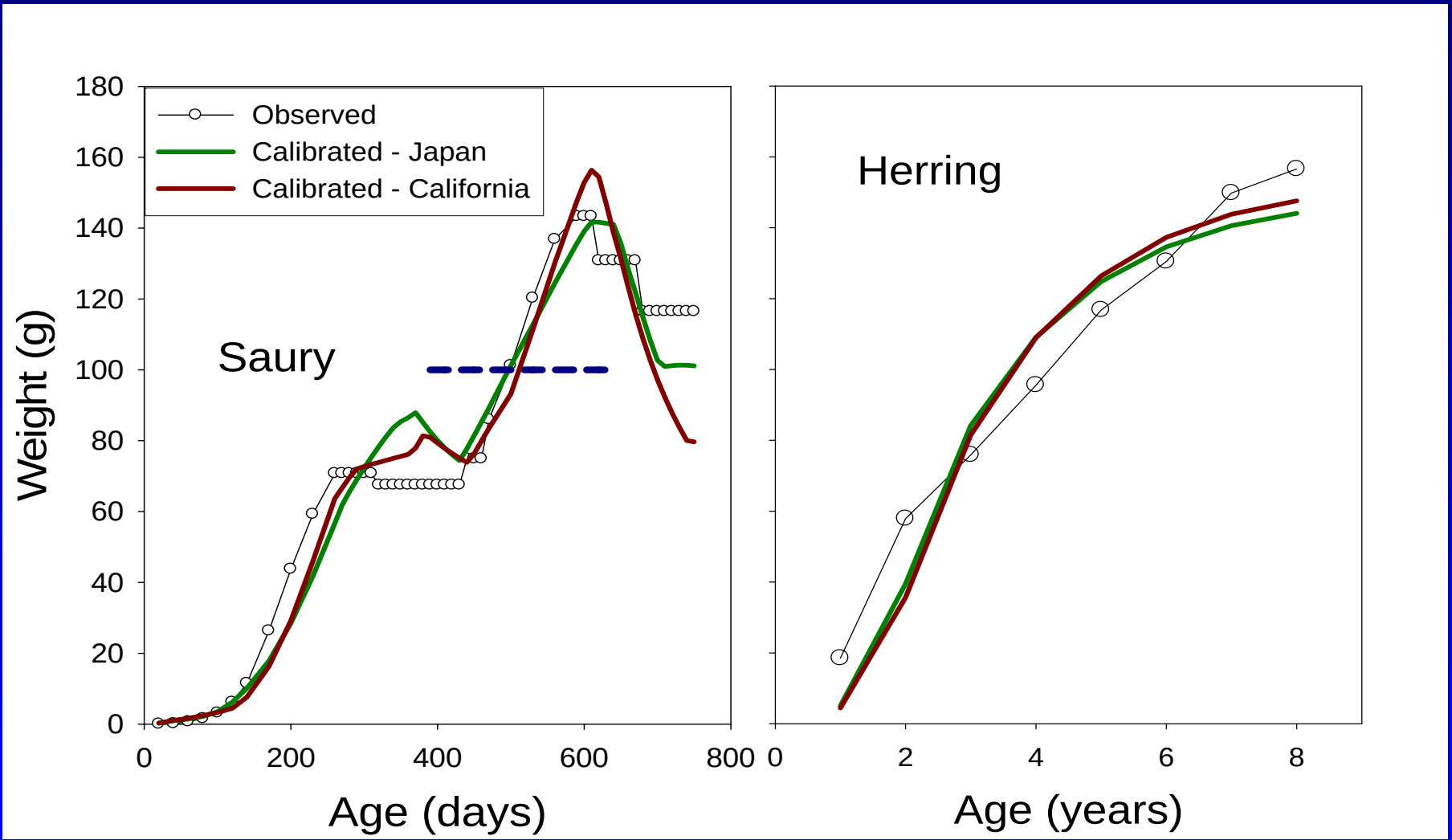
Ito et al. (2004)
Also see Poster

Extracted temperature and zooplankton (ZS, ZL, ZP)
Averaged for top 50 m

Example 3: Methods

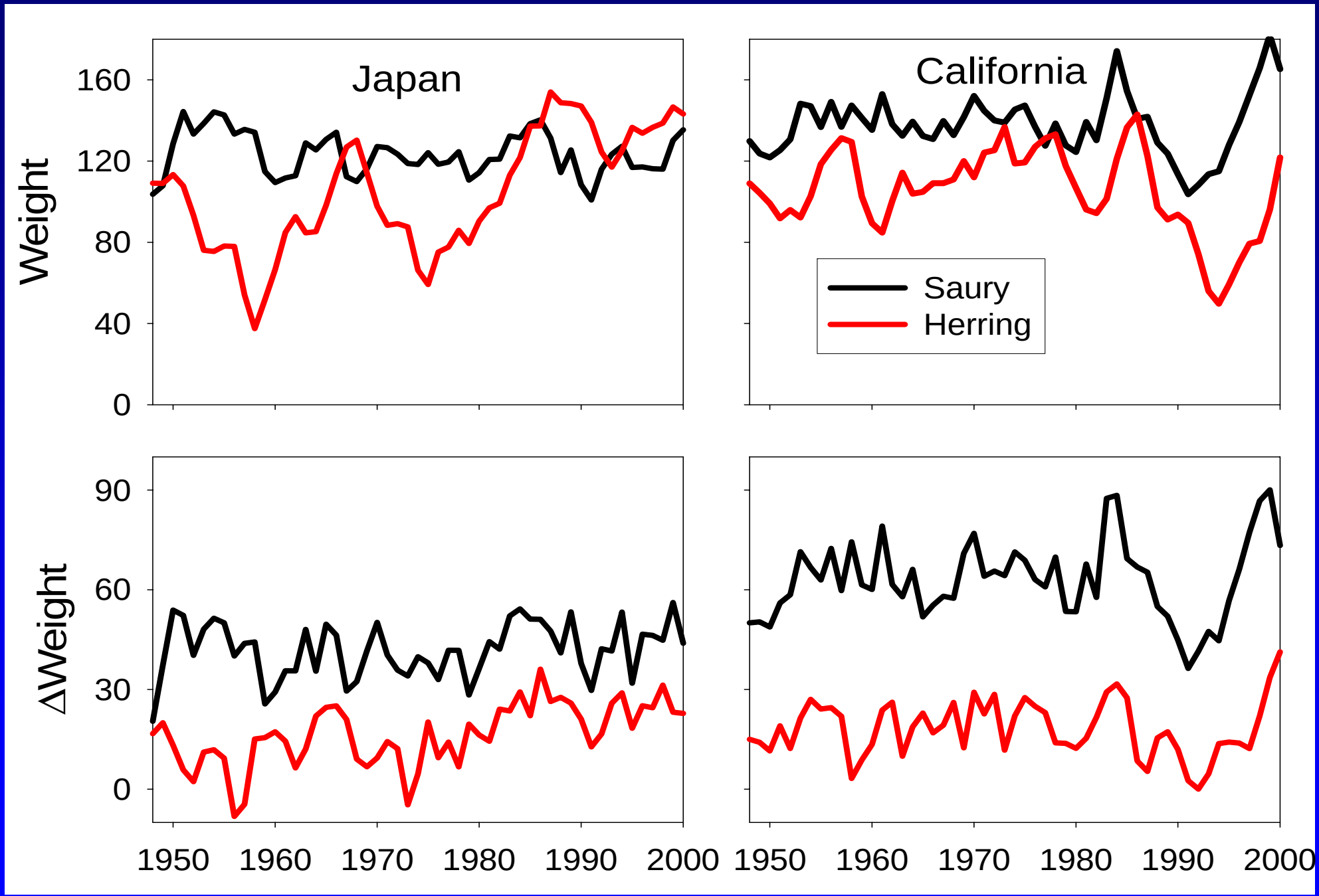
- Extracted NEMURO-3D output for the 3 Japan and the 3 California boxes
- Herring in northernmost box for summer growth, even though they do not live there in nature (the benefits of a virtual world)
- Calibrated the same way using climatological (averaged conditions repeated every year) and weights-at-age

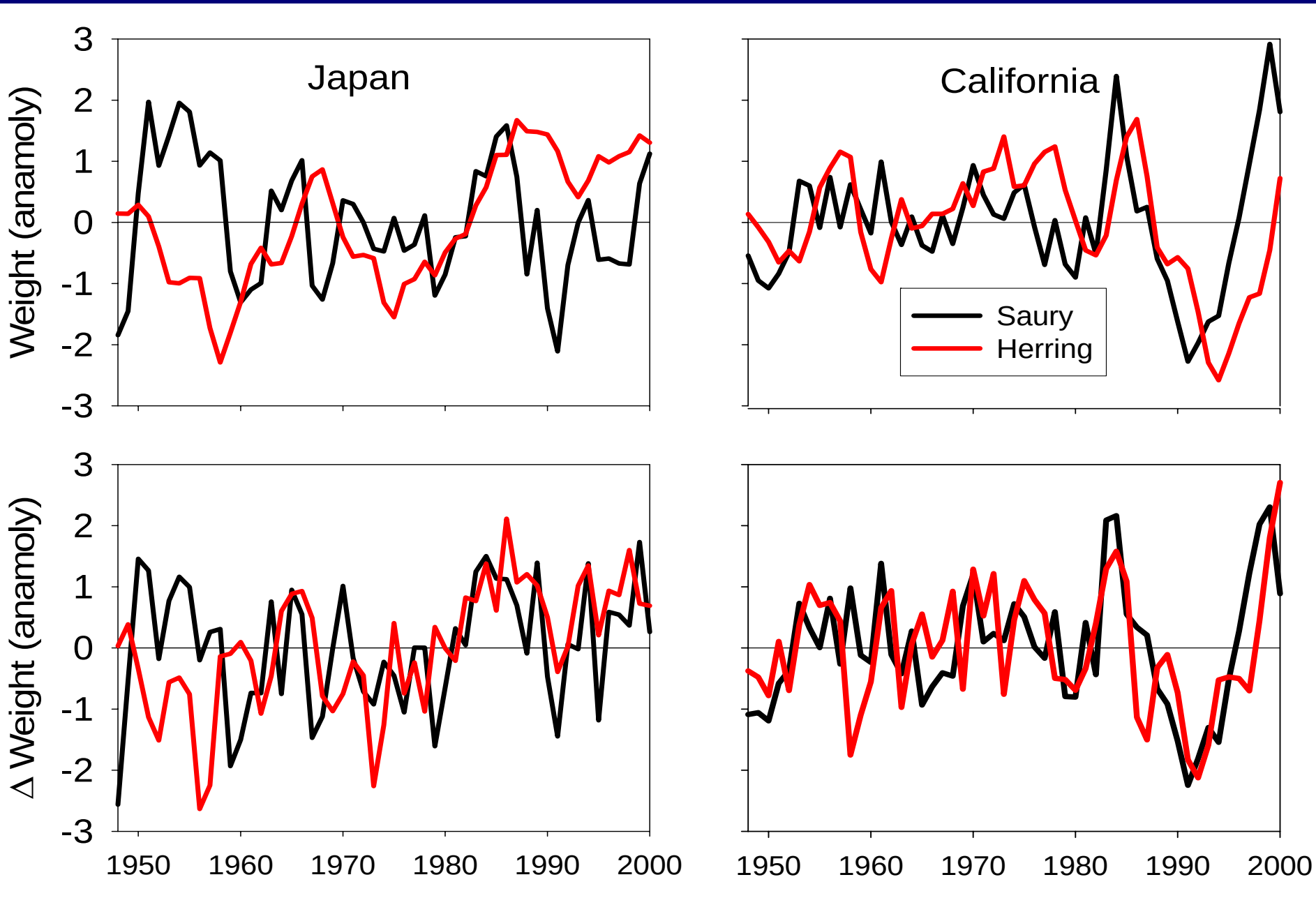
Example 3: Calibration

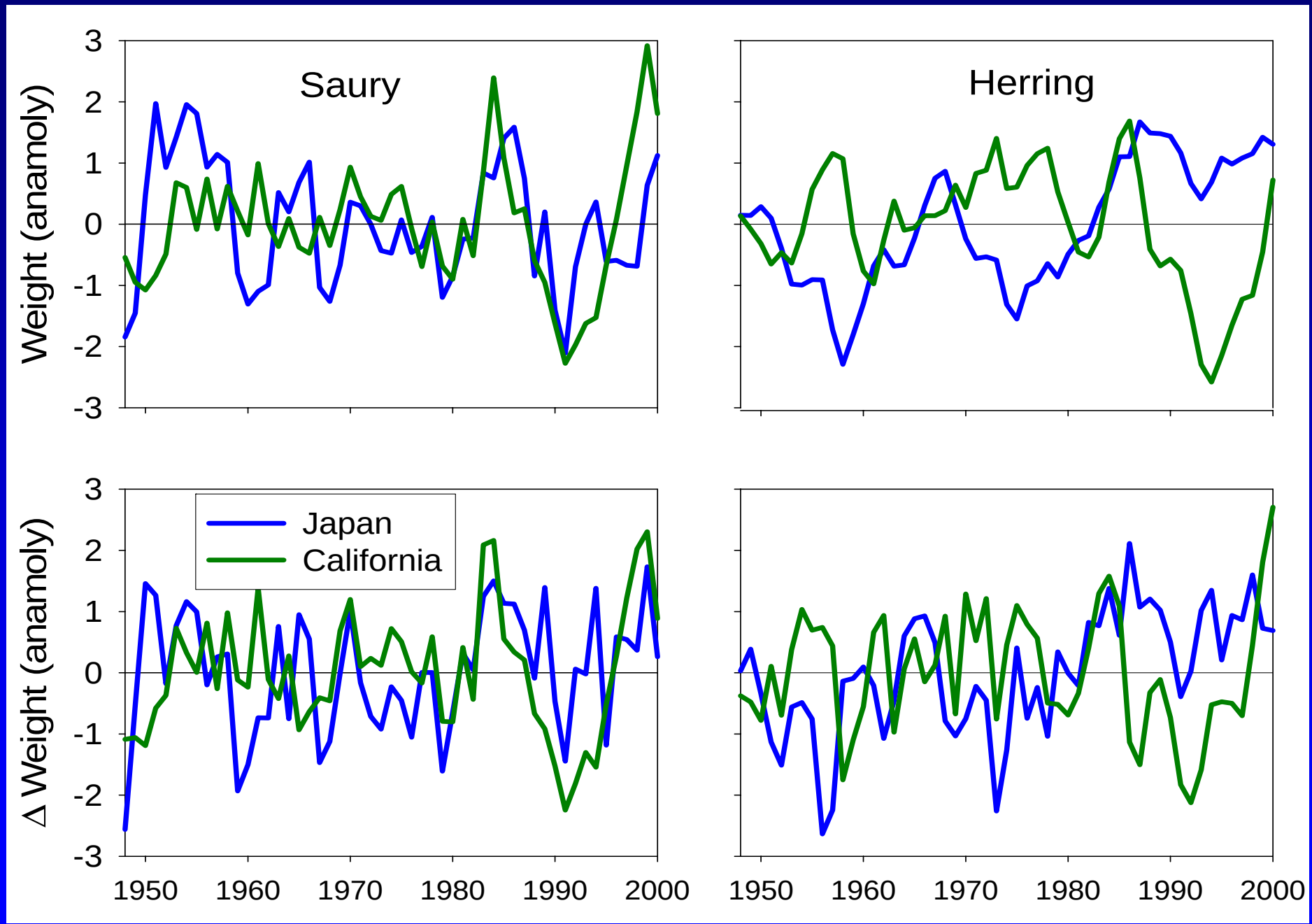


Time Series Simulatios

- Simulated the time series versions of temperature and zooplankton densities
- Herring: age-4 weight on March 1 and growth from age-4 to age-5
- Saury: September weight in second year of life and growth from January to September


Japan
California
Weight
ΔWeight
160
120
80
40
0
90
60
30
0
Saury
Herring
1950
1960
1970
1980
1990
2000


Japan
California
Weight (anamoly)
Δ Weight (anamoly)
Saury
Herring
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000


Saury
Herring
Weight (anamoly)
Δ Weight (anamoly)
Japan
California
3
2
1
0
-1
-2
-3
1950
1960
1970
1980
1990
2000

Future

- Understand these results
  - Look at temperature and zooplankton time series
  - PCA and clustering applied to eight herring locations
  - force saury in northernmost box
  - effects of serial correlation in weight
- Analyze Bering Sea using same coupled approach as WCVI (extension to Example 1)
  - If we can find seasonal zooplankton data

Future

- Coupled models like NEMURO.FISH are useful, especially when their predictions differ from known patterns and data – thus we will continue

- Investigate additional climate change scenarios and perhaps global warming scenarios?

- Next major step - individual-based, full life cycle, anchovy-sardine model on a 2-D spatial grid of Nemuro's – NEMURO.SAN (Sardine and ANchovy)

Future

- In my opinion, we have almost fully exercised the point version of NEMURO.FISH

- Slowly but steadily approaching a 3-D full-physics, NPZ, coupled with an individual-based, full life cycle, multi-species fish model

  maybe NEMURO.ULTIMATE?

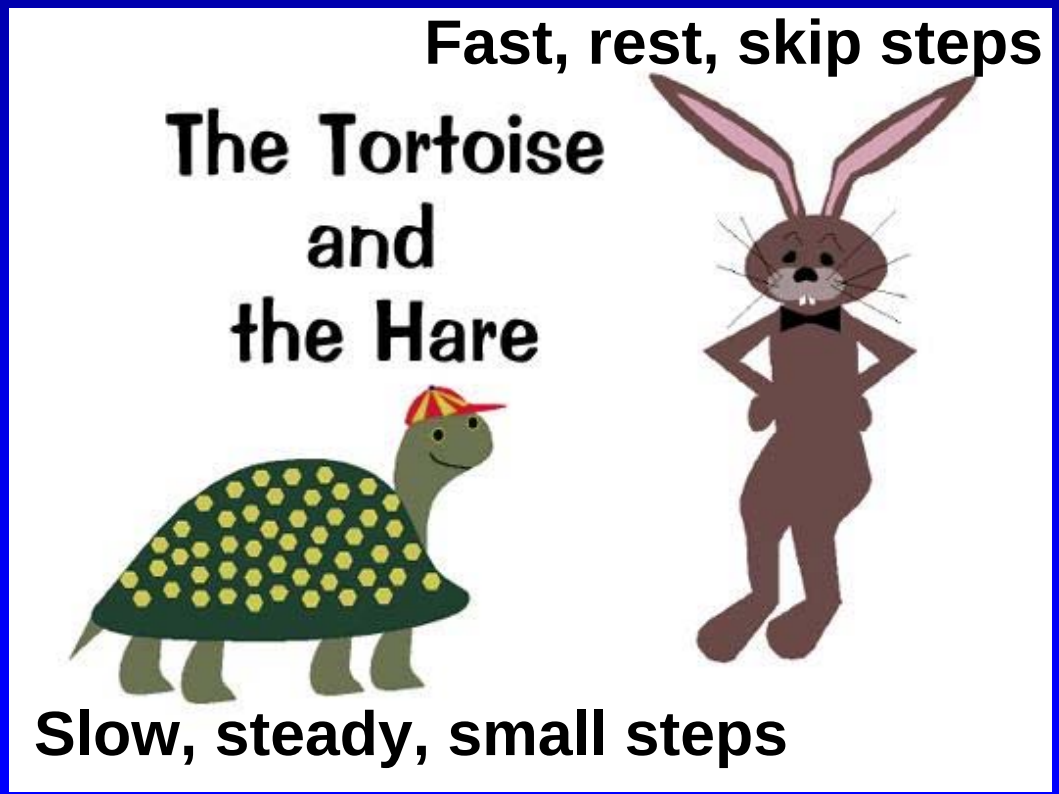
- Not ready to move from simulation experiments to forecasting

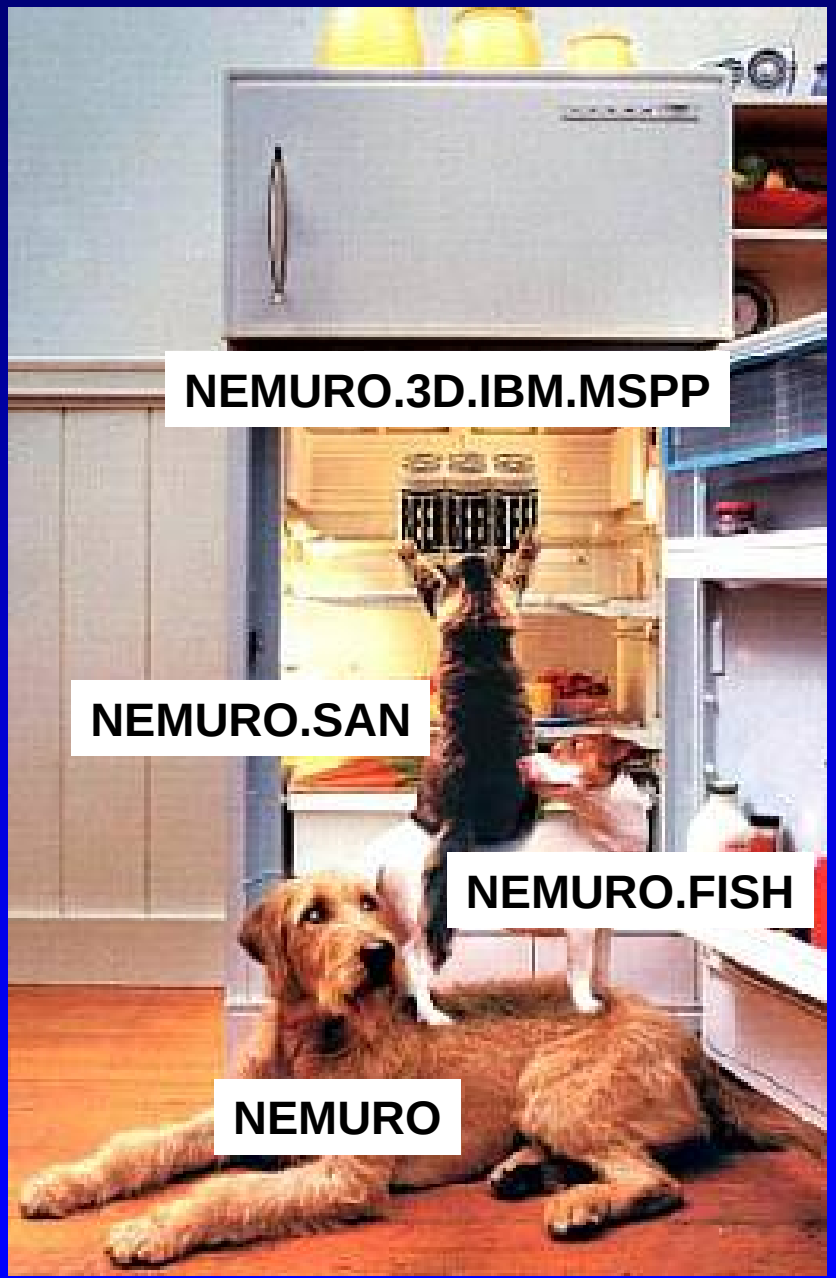
"Predictions are difficult, especially about the future."

Yogi Berra, Baseball player

FINISH LINE

Full 3-D mutli-species coupled model





Post Script

Honoring the late Professor Michitaka Uda, the Japanese Society of Fisheries Oceanography established the Uda Prize. In 2006, the Uda prize was awarded to Michio J. Kishi (in part) for his activities with the MODEL Task Team and the development and application of the NEMURO and NEMURO.FISH models.