Examining the predictability limits of NPZ-fish dynamics in the Coastal Gulf of Alaska and the Bering Sea using a numerical model

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What we mean by “predictability”

• The ability to forecast some aspect of the environment with demonstrable skill
• Not known a priori what quantities are more predictable BUT:
  – Spatial and temporal averages are typically more predictable than point measurements
  – Trophic averages (combinations of species) ought to be more predictable than single species
Predicting ocean futures

- There are many possible ocean futures; wish to estimate the most likely outcome in a way which includes nonlinearity of the systems.

- Both physics and biology are highly nonlinear; hence the mean physics is not adequate to estimate the mean biology. Different temporal paths will have different endpoints!
Characterizing ocean futures

• Can look at the predictability of individual variables in coupled models, but gets complicated due to many variables. Can we look for fewer indices?

• One possible approach:
  – Use multivariate statistics to determine modes of variability produced by possible futures
  – Weight these modes using the probability distribution of the forcing

• Modes show the basic relationships among uncertainty of each variable
Bering Sea modes

- Ice has a strong effect on the structure of the ecosystem
- An ice-free Bering is fundamentally different from one with ice cover; expect these “modes” to emerge in the analysis
Procedure

- Run the NEMUROMS modes (NEMURO in ROMS) on a 1D grid
  - Choose coefficients appropriate to each region
- Force with a range of global warming scenarios
- Calculate annual means which eventually result from each scenario
- Calculate multivariate EOFs on normalized variables for
  - Coupled physical/biological modes
  - Trophic (P and Z categories only) modes
- Convolve results with probability of warming scenarios to get most likely outcomes and variance
NEMURO structure
ROMS structure for this experiment

- ROMS = Regional Ocean Modeling System
- NEMURO is embedded on the same grid
- LMD mixed layer physics
- Bulk flux algorithms for wind stress, heat flux
- Analytical wind, air temperature, shortwave inputs
  - Choose simple curves appropriate to Bering and CGOA
  - Increase air temperature according to various scenarios
EOFS for this analysis

• Typical oceanographic use of EOF is for capturing spatial structure of a single variable
• Here, use EOFs across variables to explain variance produced by temperature scenarios (each treated as an independent realization)
• Use depth/time average of each model variable over the last 12 months of the simulation as our independent variables for EOF calculation
How to normalize the variables for the EOFs?

- For biophysical modes, normalize raw values by standard deviation (hence all are unit normals).
- For trophic modes, use log transform then normalize by standard deviation. The log transform emphasizes fractional change of each category (needed since some are smaller than others).
Temperature scenarios

- Linear increase of air T with time (run for 7 years; “foreshortened” in time)
- Roe and Baker suggest *skewed probabilities* of different scenarios

![Graph showing probability of temperature increase at end of run](image)
Bering “no warming” scenario
get repeating pattern
Bering “no warming” scenario after 7 years
Bering "severe warming" scenario

note warming trend at surface
Bering "severe warming" scenario after 7 years spring bloom is advanced in time.
Bering biophysical modes

NO ICE LEFT!
Bering trophic modes

Predatory Zooplankton

Mesozooplankton

Microzooplankton

Diatoms

Nanophytoplankton
CGOA “no warming” scenario

get repeating pattern
CGOA “no warming” scenario after 7 years
CGOA
“severe warming” scenario
note warming trend at surface
CGOA “severe warming” scenario after 7 years

spring bloom only slightly advanced in time
CGOA trophic modes with predation removed
Compare CGOA models
predation included      predation removed

Predatory Zooplankton
Mesozooplankton
Microzooplankton
Diatoms
Nanophytoplankton
Compare coupled modes

Bering

CGOA
Compare trophic modes

Bering

Predatory Zooplankton
Mesozooplankton
Microzooplankton
Diatoms
Nanophytoplankton

CGOA

"pzooplankton_avg"
"mesozooplankton_avg"
"microzooplankton_avg"
"diatom_avg"
"nanophytoplankton_avg"
Preliminary Conclusions

- Coupled modes help to characterize the system
- In both cases, the dominant mode is strongly correlated with the forcing
- In the Bering, warming is associated with
  - more nanophytoplankton
  - less diatoms
- In the CGOA, warming is associated with
  - more nanophytoplankton
  - less diatoms, microzooplankton, mesozooplankton
- Who is the most variable (least predictable)?
  - Diatoms in the Bering
  - Nanophytoplankton in the CGOA
- Major sensitivity to presence of predators
Future work

• More comparison with data!
• Refine coefficient values
• Calculate expected values and variances
• Apply these techniques to 3D results in BEST/BSIERP
CGOA no pred “no warming” scenario
CGOA no pred “no warming” scenario
CGOA no pred "severe warming" scenario
CGOA no pred “severe warming” scenario
CGOA no pred coupled modes
CGOA no pred bio modes
Compare Bering and CGOA no pred coupled modes
Compare Bering and CGOA no pred bio modes