Climate Change and Invasive Mussel Effects on the Lake Michigan food web: Some Examples Using the Atlantis Ecosystem Model Framework

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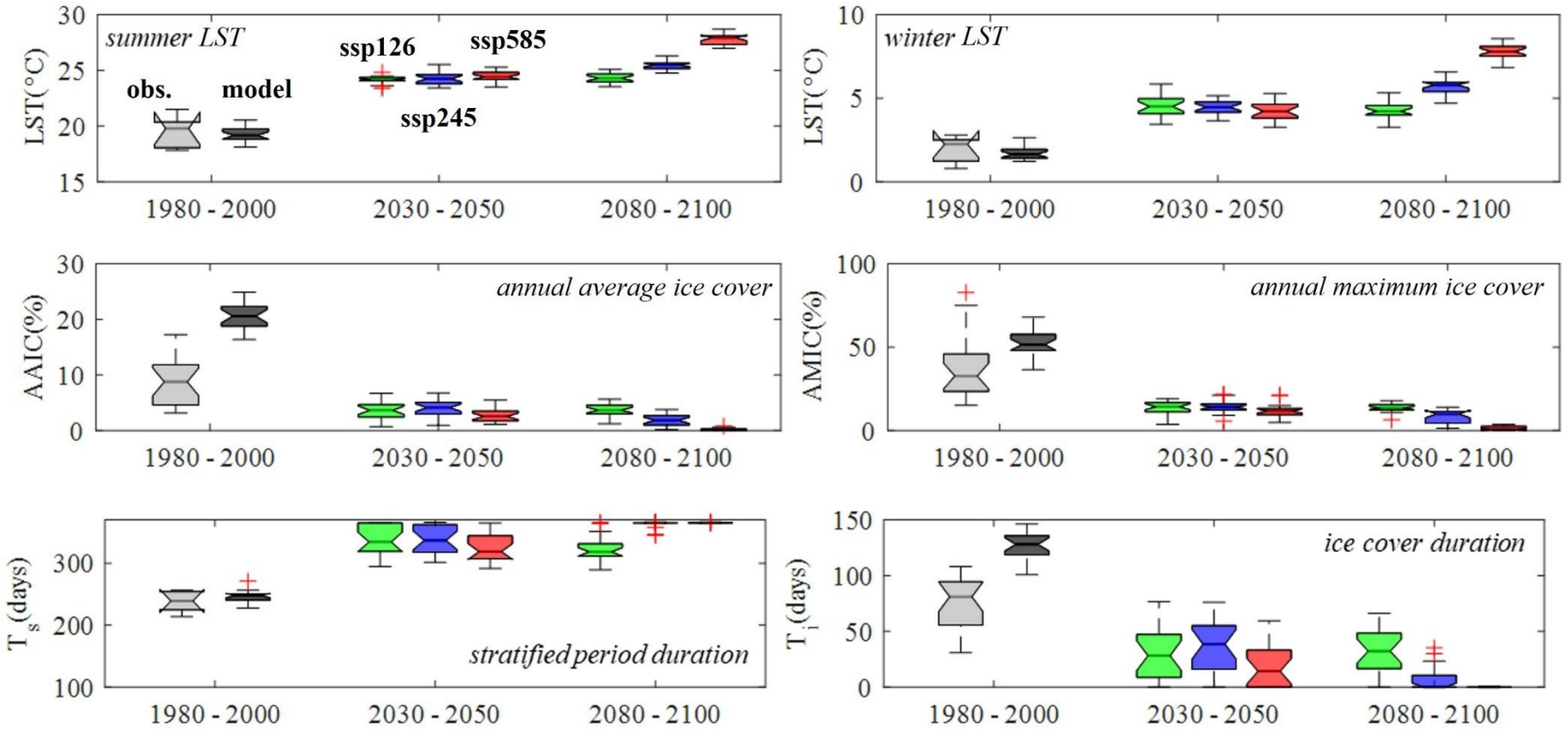
Objectives

- Potential effects of climate change on LM ecosystem
- Describe ecosystem model – Atlantis
- Run scenarios of mussels and mixing
- Some preliminary runs of climate effects on mixing, mussels and food web
- Future work

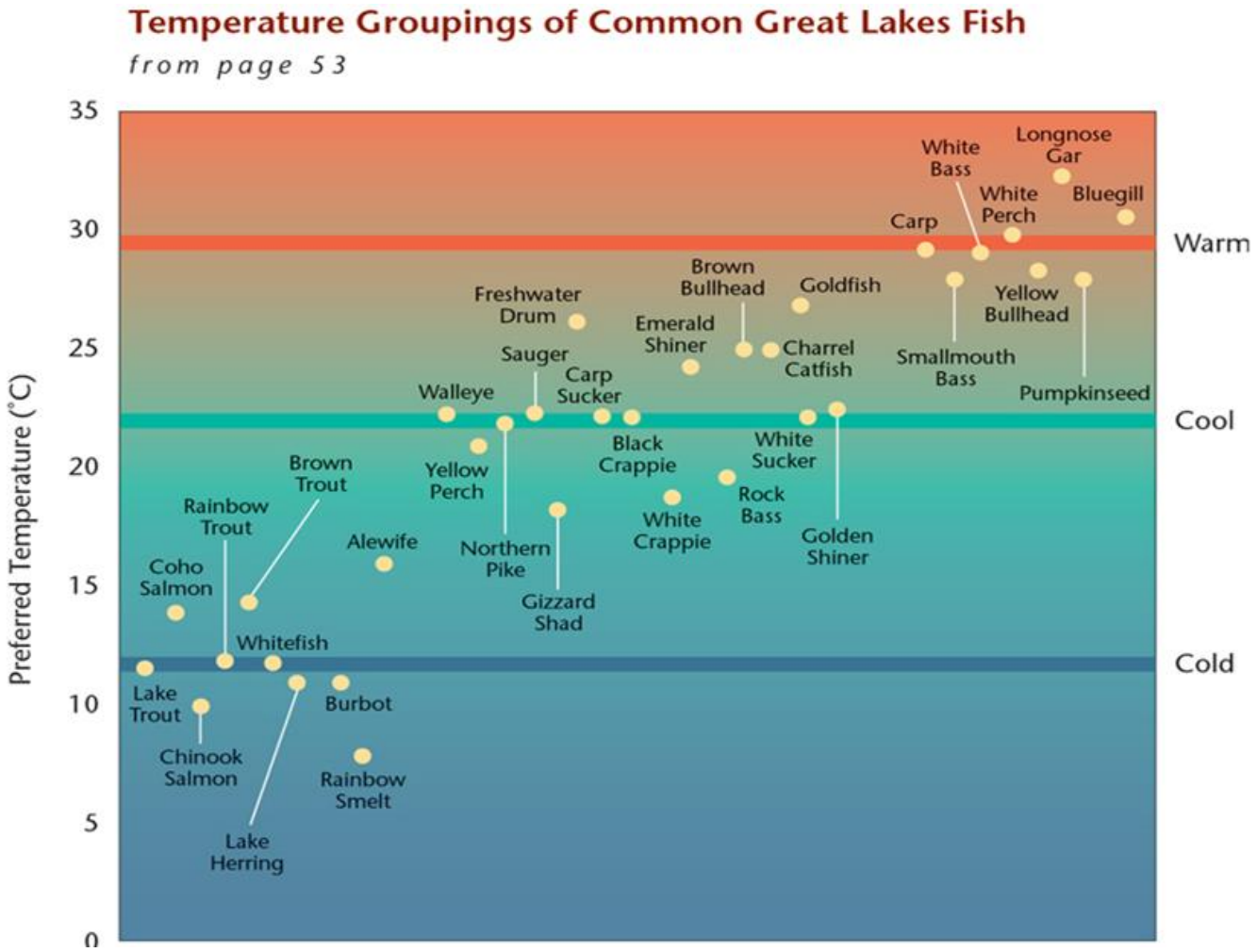
LM Climate Change Projections



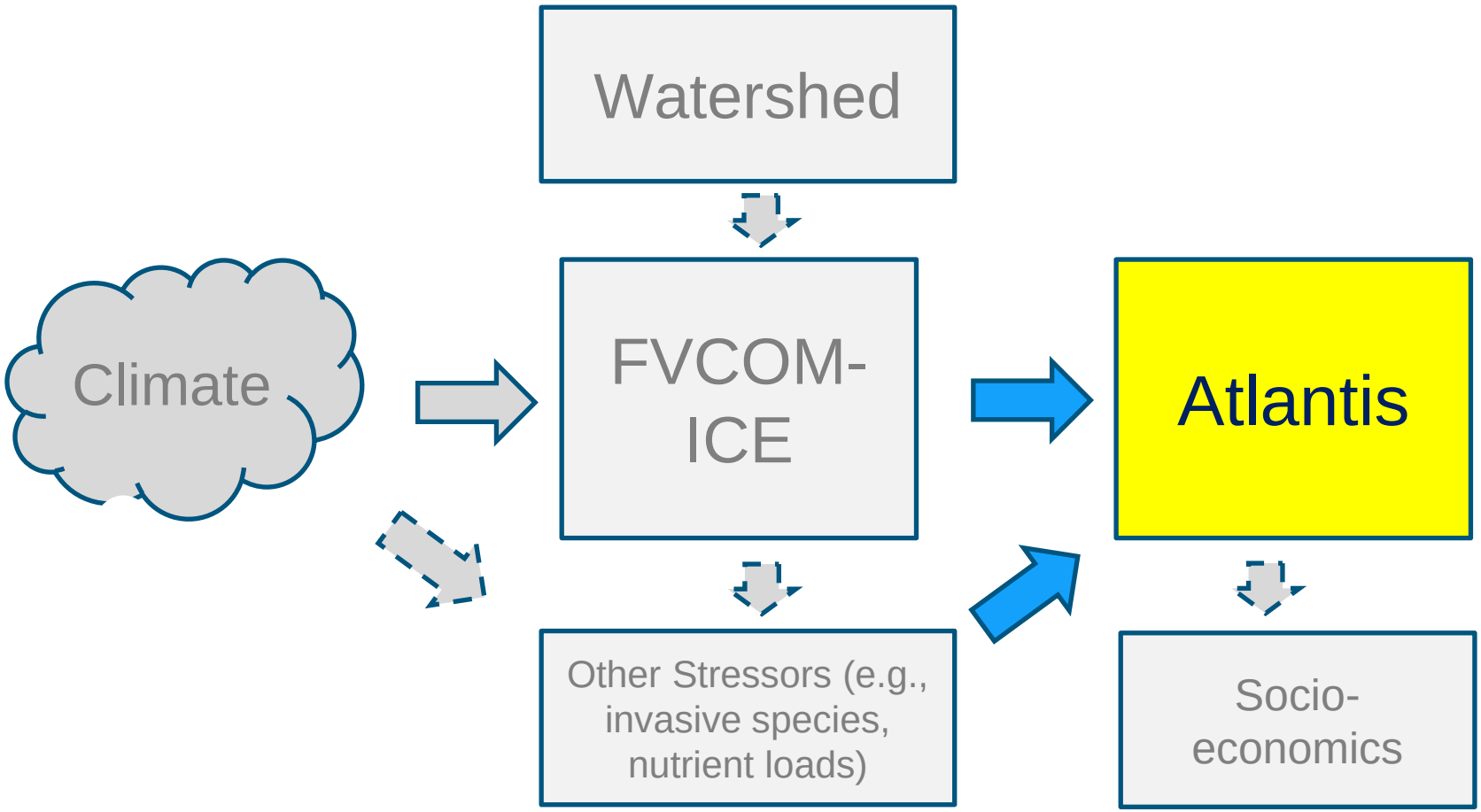
Potential Climate Change Effects

- Lower water levels
- Shorter Winters - longer ice-free periods
- Higher summer surface temperature
- Longer lake stratification period
- Higher risk of hypoxia events

Fish thermal preferences suggest climate winners, losers



Great Lakes Earth System Model (GLESM)



Atlantis Ecosystem Model- What is it?

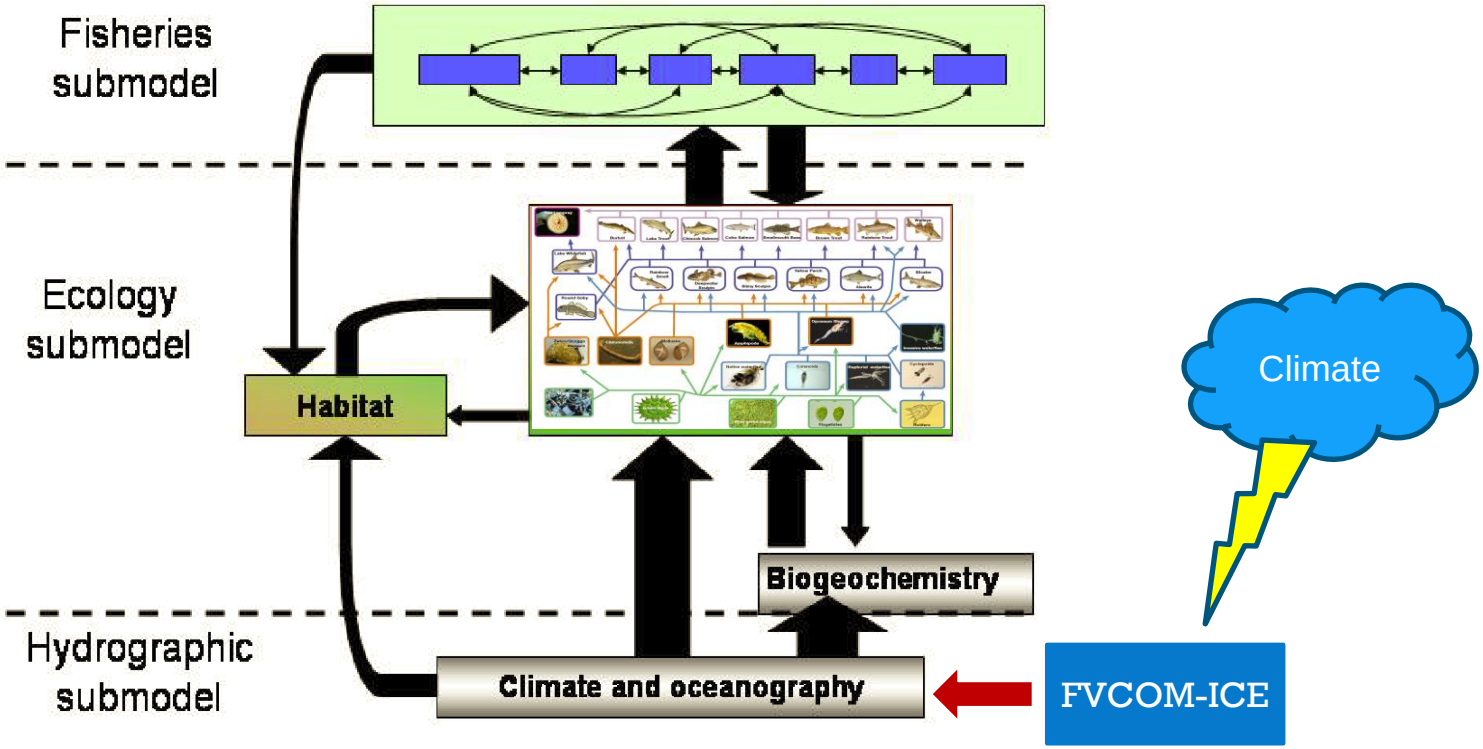
- Deterministic, dynamic, 3-dimensional, end-to-end model integrating physics, geochemistry, biology, fisheries management and assessment, and economics
- Modular by design
- Framework developed by Dr. Beth Fulton at the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO)
- Over 30 models developed worldwide

Applications

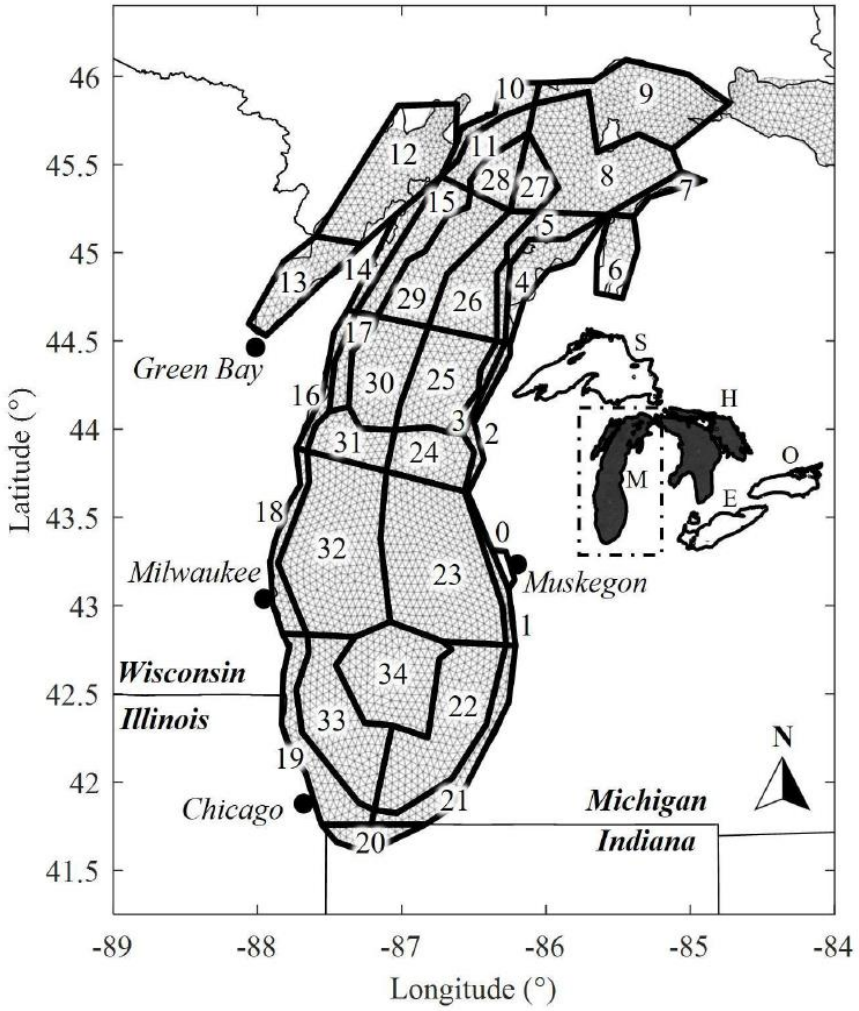
- Best used for scenario-based evaluations of competing forcing factors and simulating what-if scenarios
- Ecosystem-based applications include:
  - Fisheries assessment and management
  - Assessment of ecosystem indicators
  - Evaluation of marine protected areas
  - Effects of anthropogenic stressors

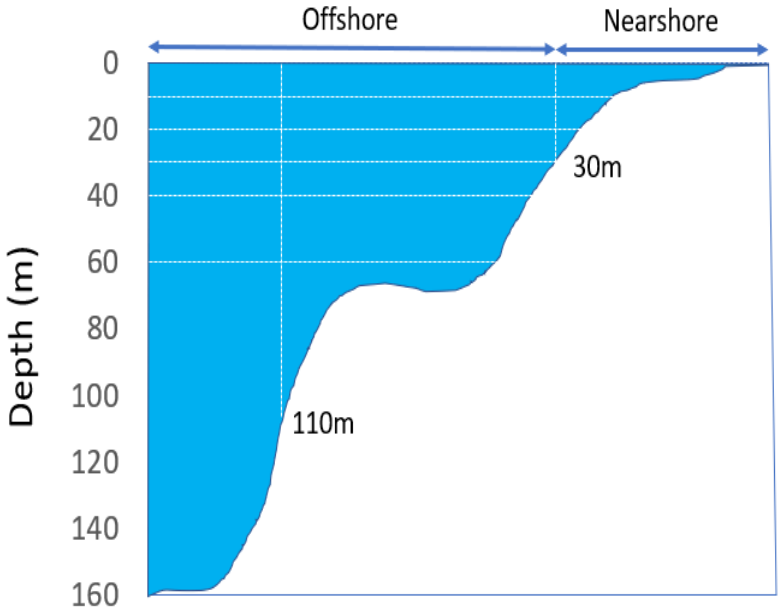
    Climate change
    Invasive species
    Fishing pressure
    Ocean acidification
    Eutrophication
    Oil spills

Atlantis Ecosystem Sub-Models for Lake Michigan

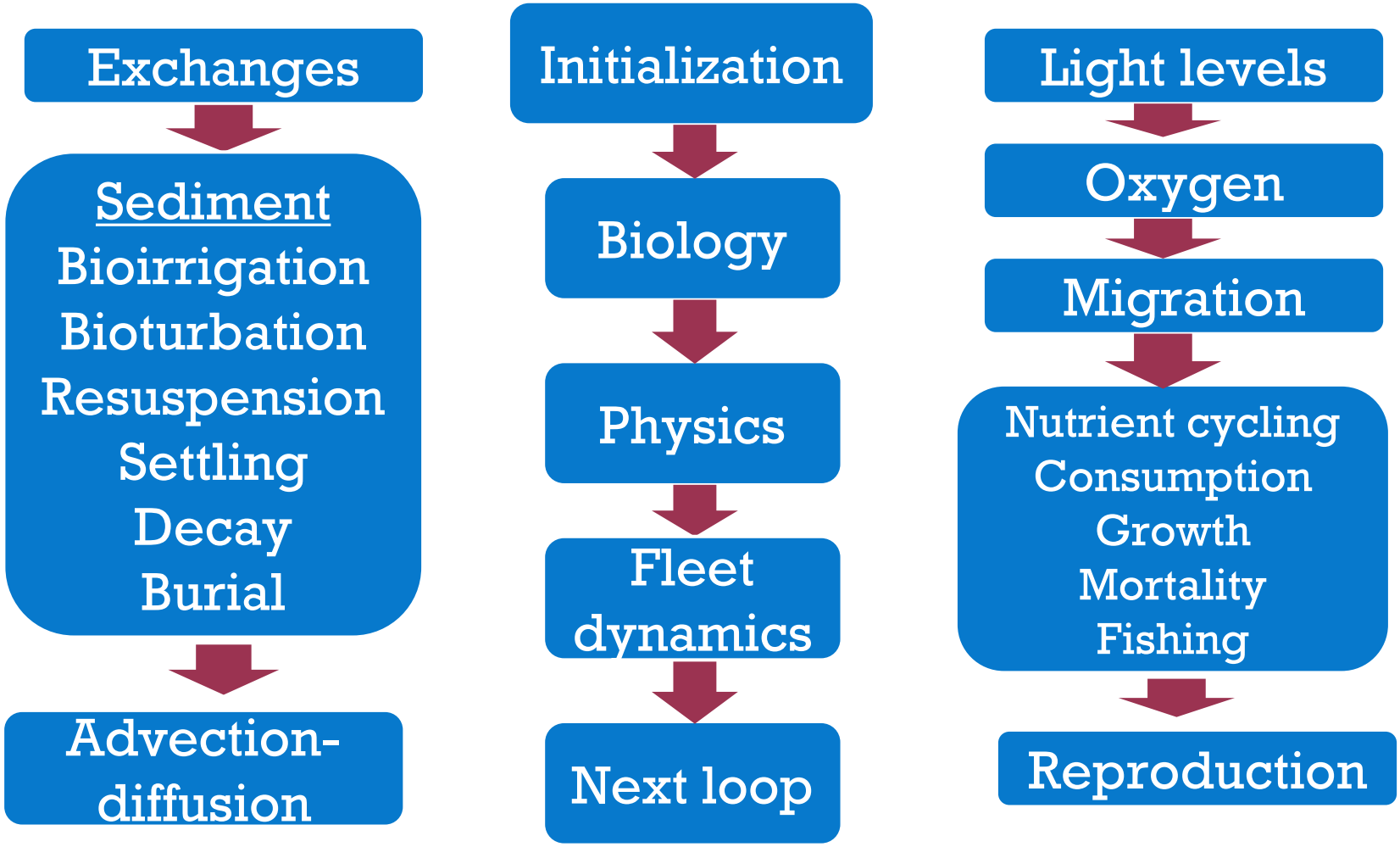


Horizontal and Vertical Resolution

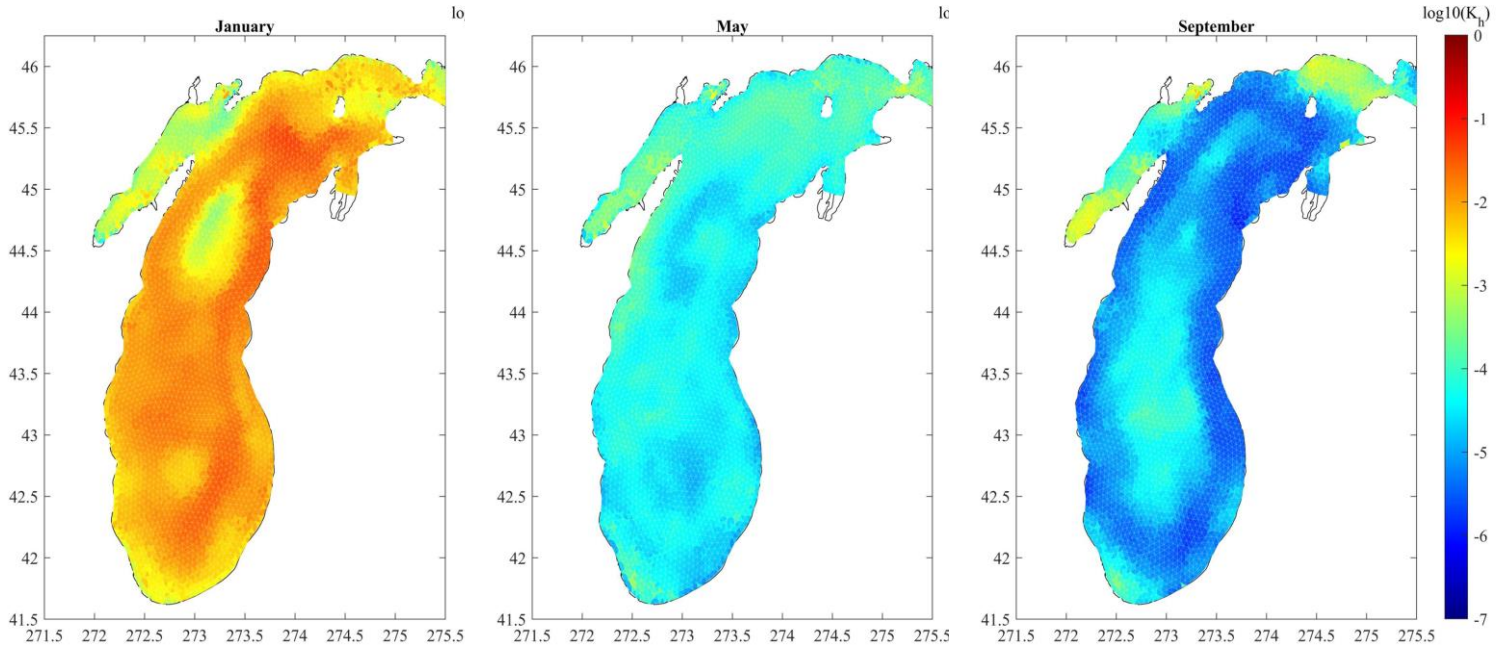




Lake Michigan Atlantis Flow Diagram



LM Vertical Mixing Seasonality

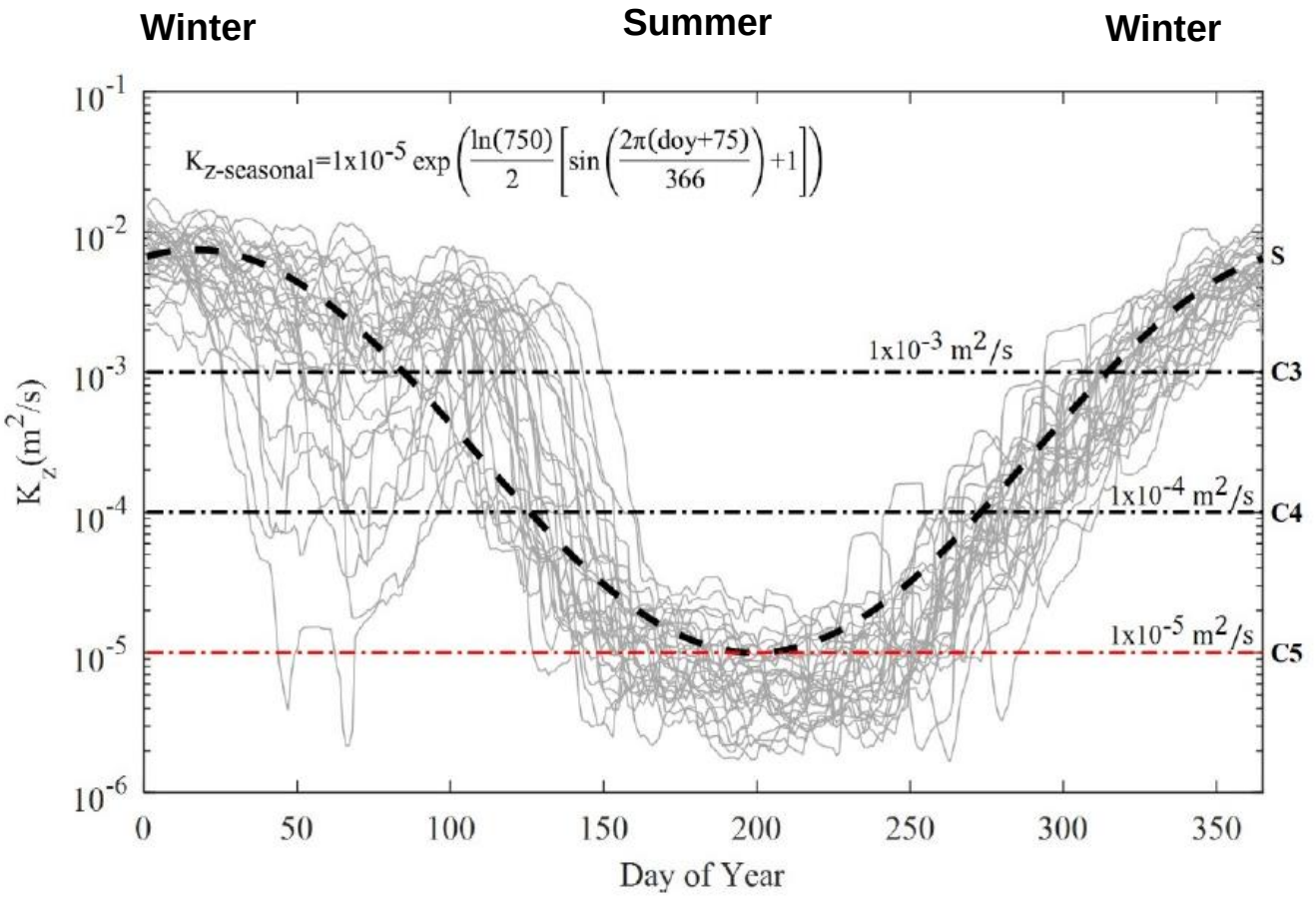


Need to account for highly variable seasonal mixing conditions

Vertical mixing

- Vertical mixing (turbulent mixing) not well integrated in Atlantis
- Important given the predicted increase in stratification and reduced water column mixing
- How important is vertical mixing for the Lake Michigan food web?
- First step towards adapting GLESM for climate change

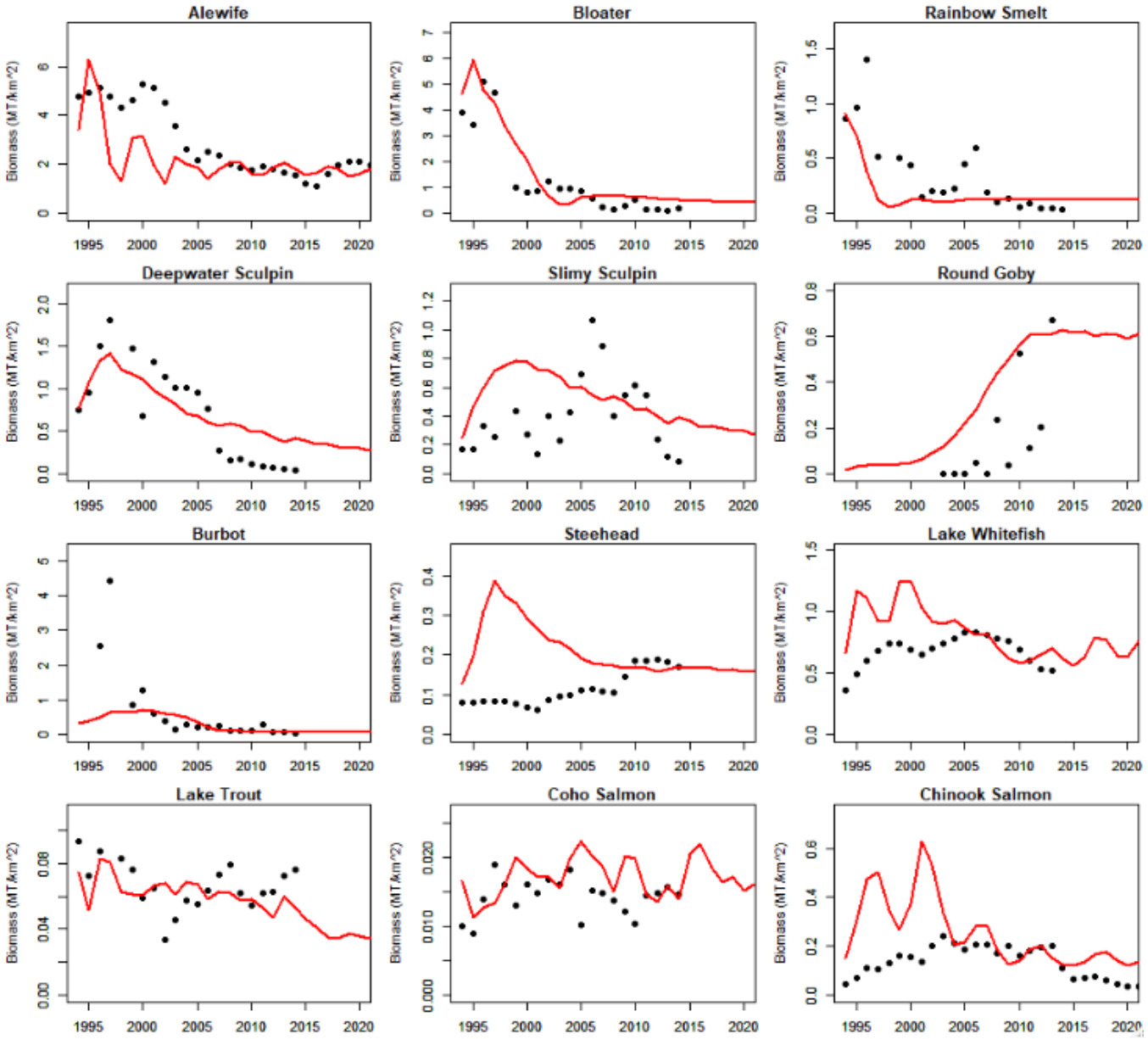
Seasonal Average Mixing (Sinusoidal Vertical Turbulent Diffusivity)



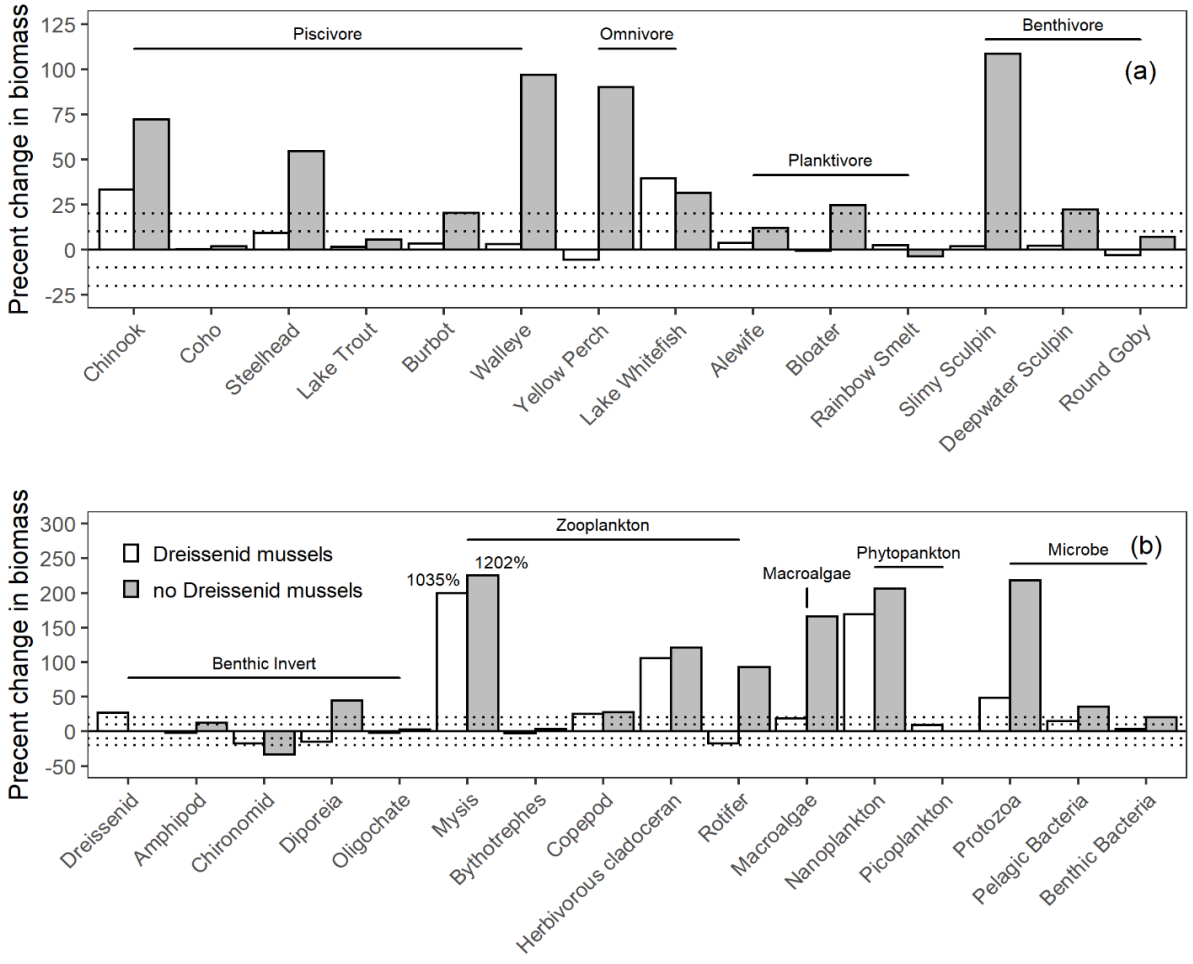
Cannon DJ, Troy C, Bootsma H, Liao Q, MacLellan-Hurd RA (2021). Characterizing the seasonal variability of hypolimnetic mixing in a large, deep lake. J Geophys Res: Oceans 126:e2021JC017533

Cannon D, Fujisaki-Manome A, Wang J, Kessler J, Chu P (2023) Modeling changes in ice dynamics and subsurface thermal structure in Lake Michigan-Huron between 1979–2021. Ocean Dynamics 73:201–218. https:// doi. org/ 10. 1007/ s10236- 023- 01544-0

Model Data Comparisons



Mussels, Mixing Effects on LM Food Web

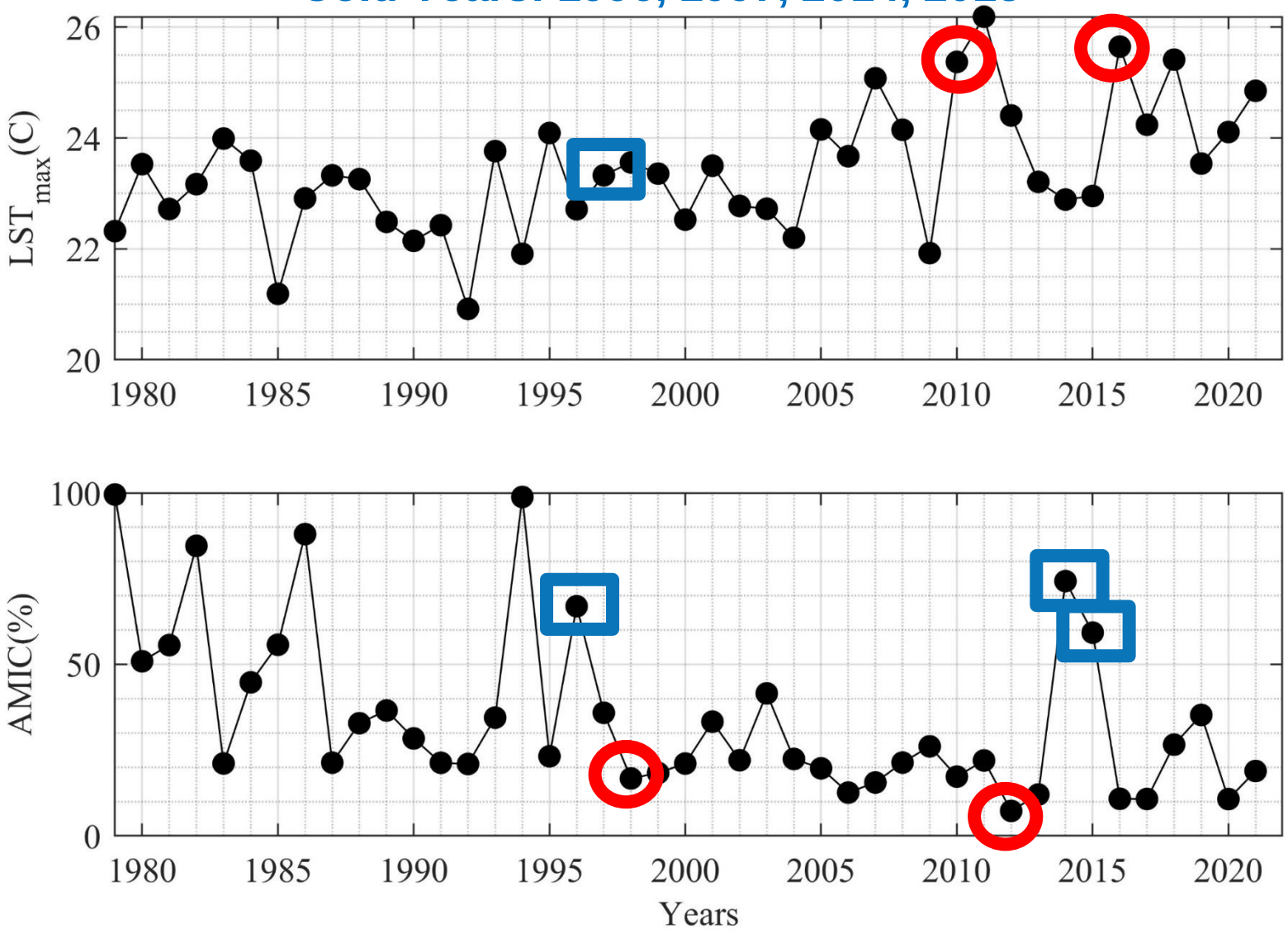


Zhang et al. 2023. Effects of Vertical Mixing on the Lake Michigan Food Web: An Application of a Linked End-to-End Earth System Model Framework, Ocean Dynamics https://doi.org/10.1007/s10236-023-01564-w

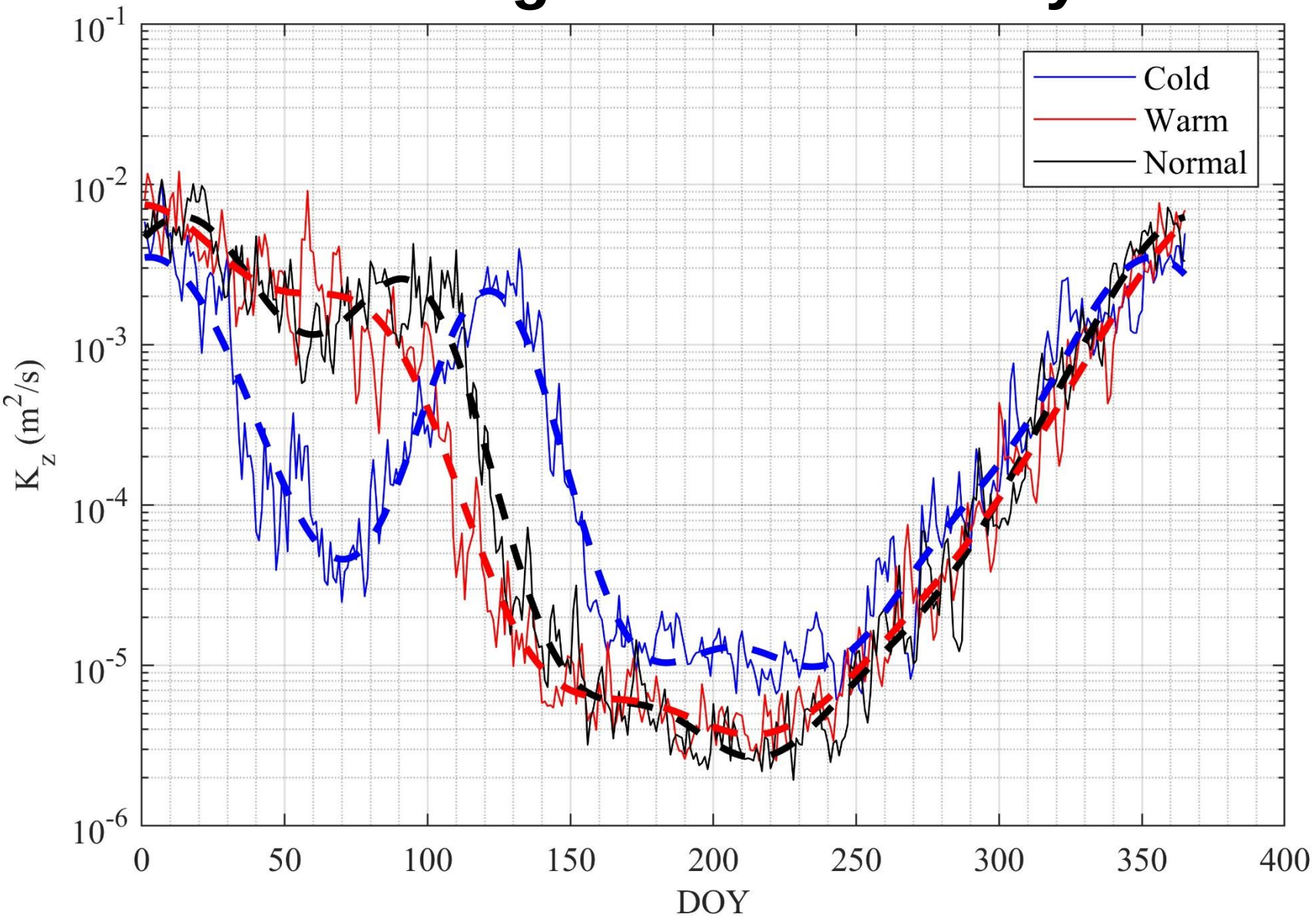
Now Look at Climate Effects

Warm Years: 1998, 2010, 2012, 2016

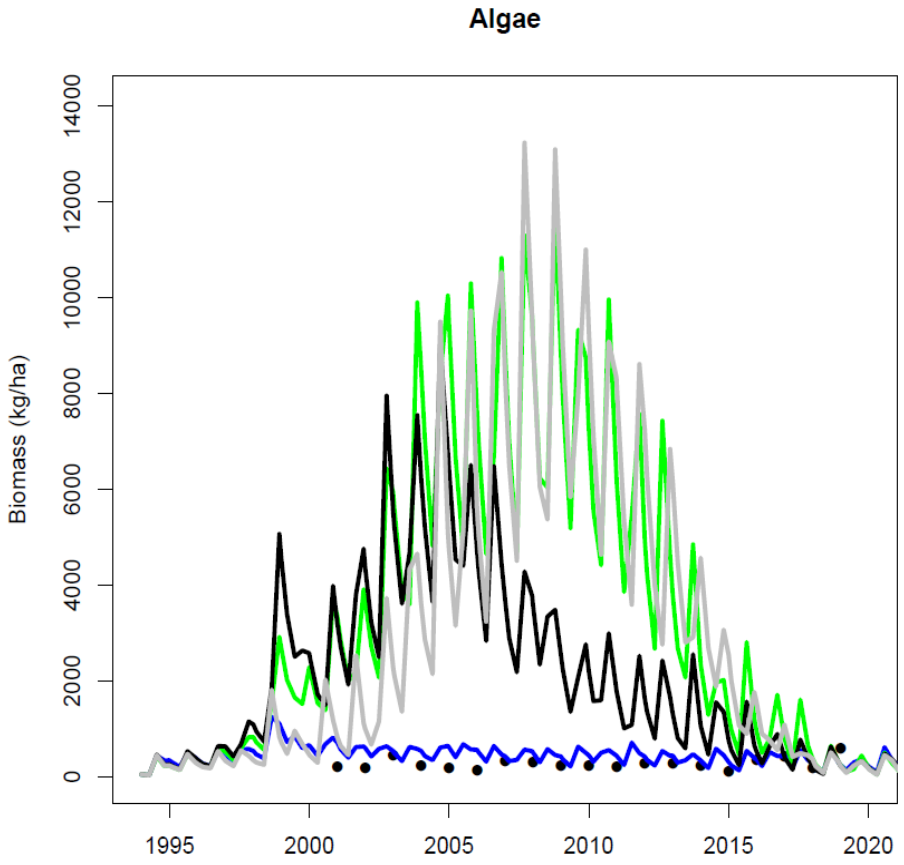
Cold Years: 1996, 1997, 2014, 2015

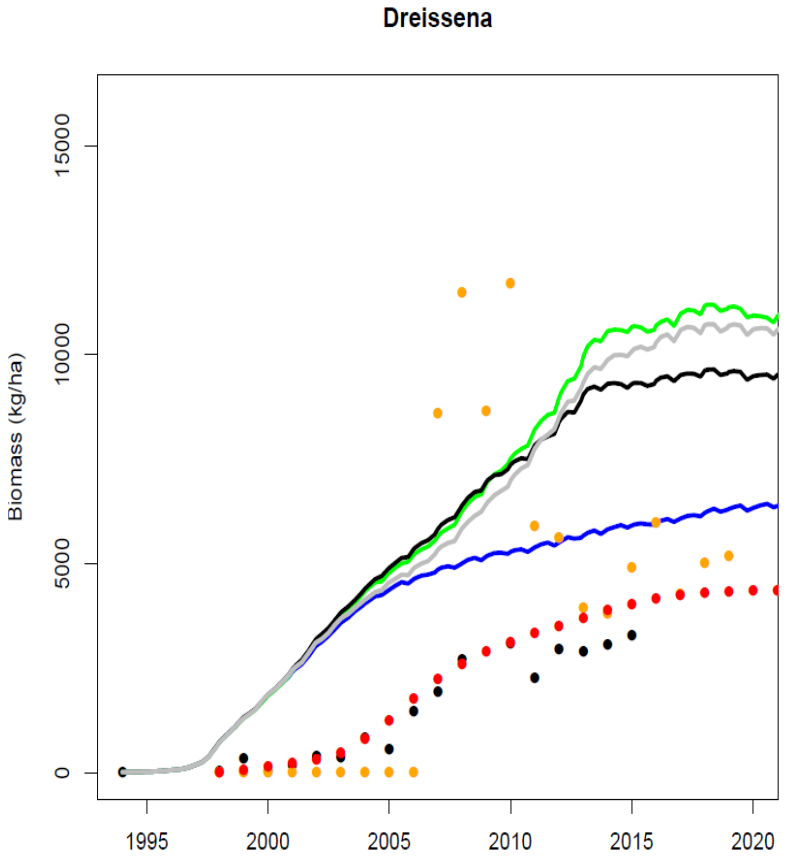


Vertical Turbulent Diffusivity (mixing) varies among cold and warm years



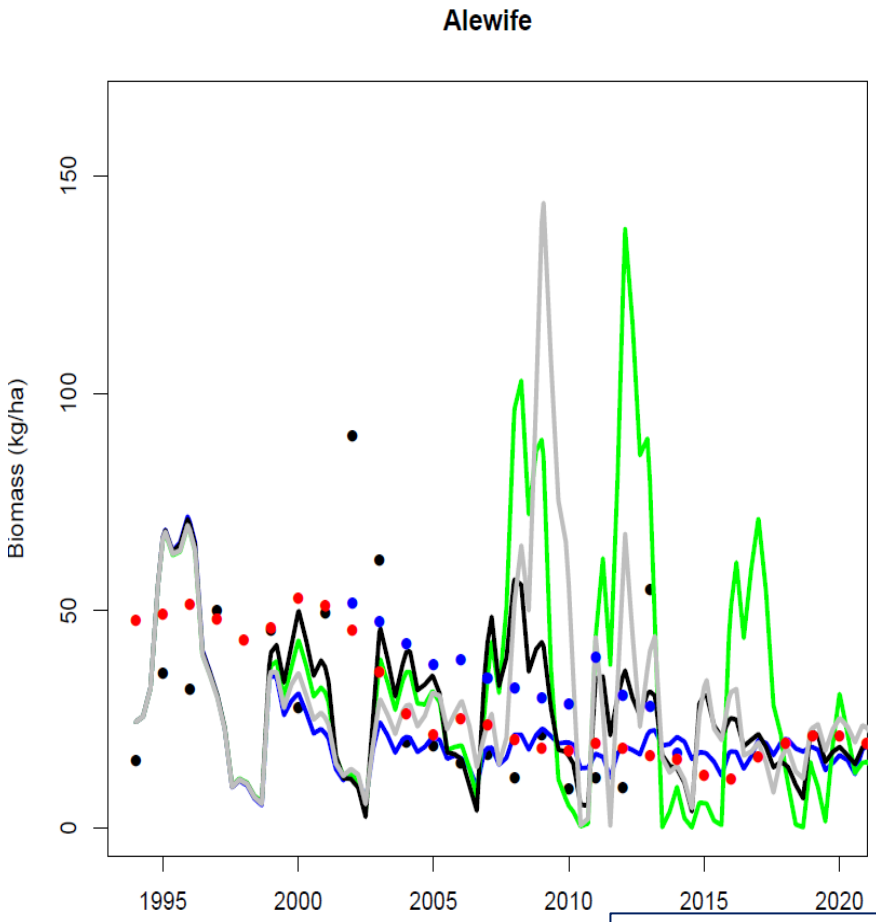
Model Calibration 1995-2020

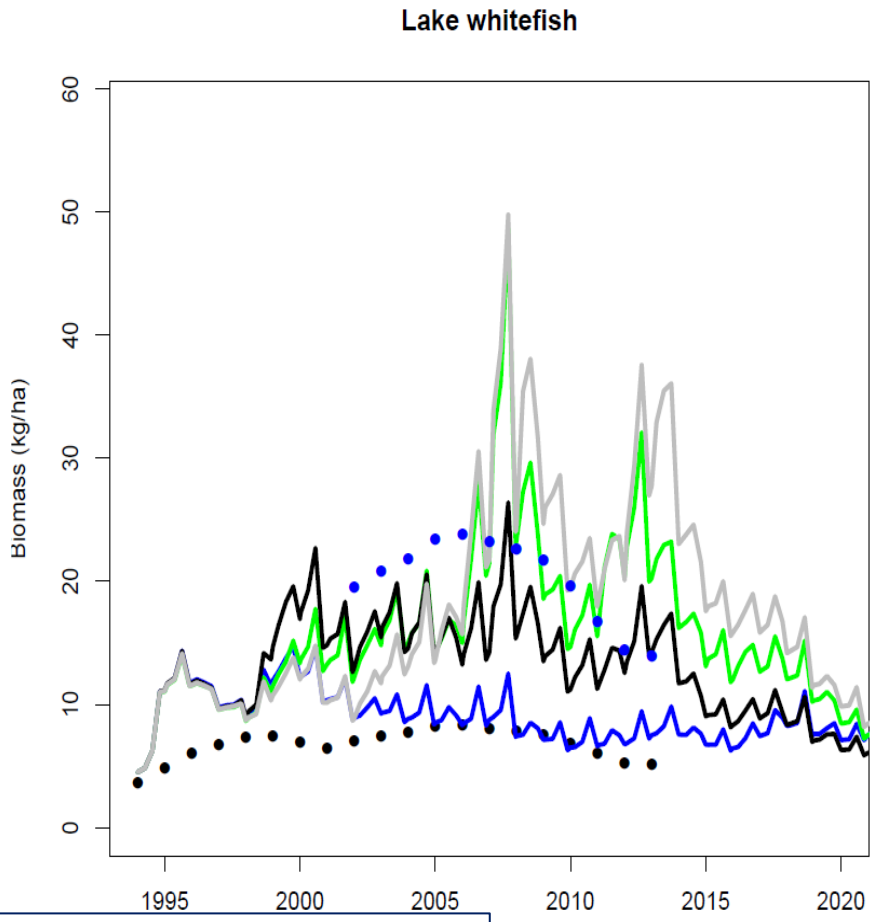




Green – normal years
Blue – seasonal average (SVTD)
Black – cold years
Grey – warm years

Model Calibration 1995-2020





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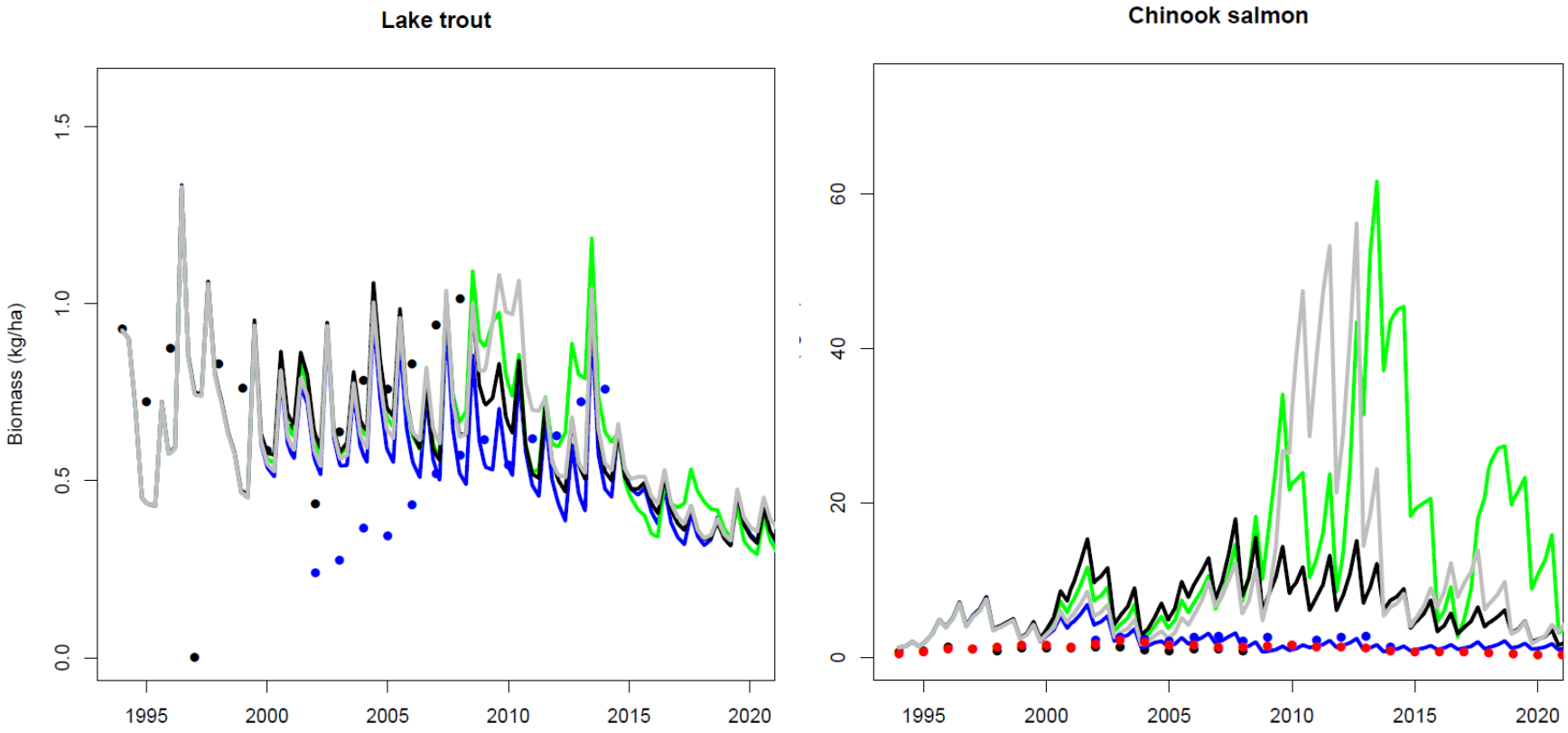

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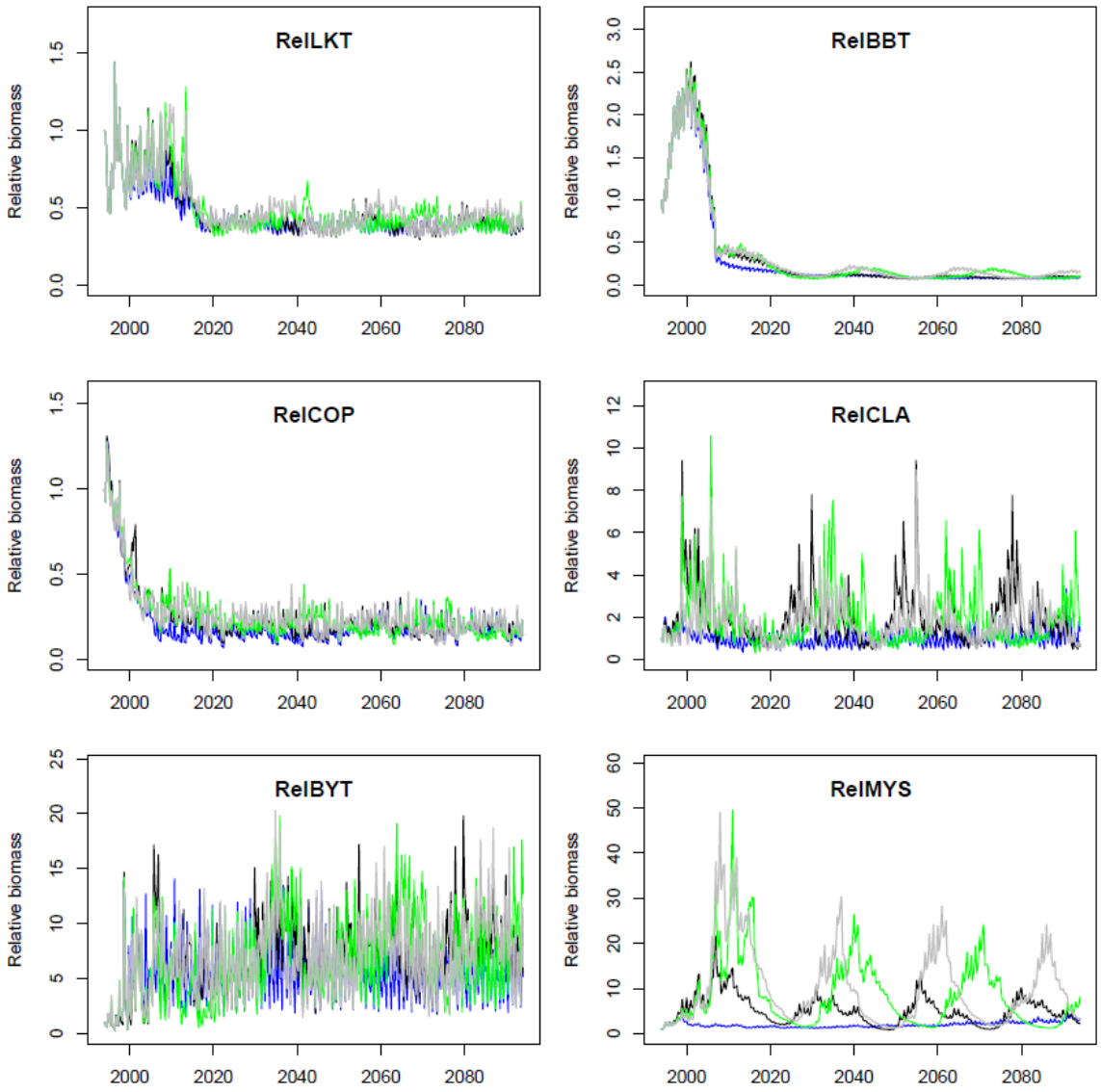
Grey – warm years

Model Simulation 80 years

Green – normal years
Blue – seasonal avg (SVTD)
Black – cold years
Grey – warm years



Discussion and Summary

1. Why poor model calibration under warm/cold mixing?
2. Mussels and mixing processes (warming in spring, cooling in fall) have significant effects on food web.
3. Projecting climate change for decadal time scales and broad spatial scales of a great lake is too coarse for fisheries managers – they operate on seasonal to annual cycles and mostly nearshore within state/provincial boundaries.

Future Efforts

1. Recalibrate model to observations under seasonal mixing scenarios, and include ice effects on food web and fish reproduction

2. Downscale CMIP6 global GCMs into the Great Lakes to drive various future climate scenarios

3. Add selected nearshore and warmwater fishes (bass, centrarchids, cyprinids, suckers) to model.

4. Model finer space and time scales

Questions? Thoughts?