

Modeling Flathead Lake:

Using 35 years of data to investigate climate change, nutrient loading, and trophic interactions



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ELCOM



Estuary, Lake and Coastal Ocean
Model:

Hydrothermal-physical
dynamics

CAEDYM

Computational Aquatic Ecosystem
Dynamics Model:

Nutrient, Food Web & Trophic Dynamics

In short...

Physical Parameters

- Depth
- Bathymetry
- Landscape Hydrology

Meteorology

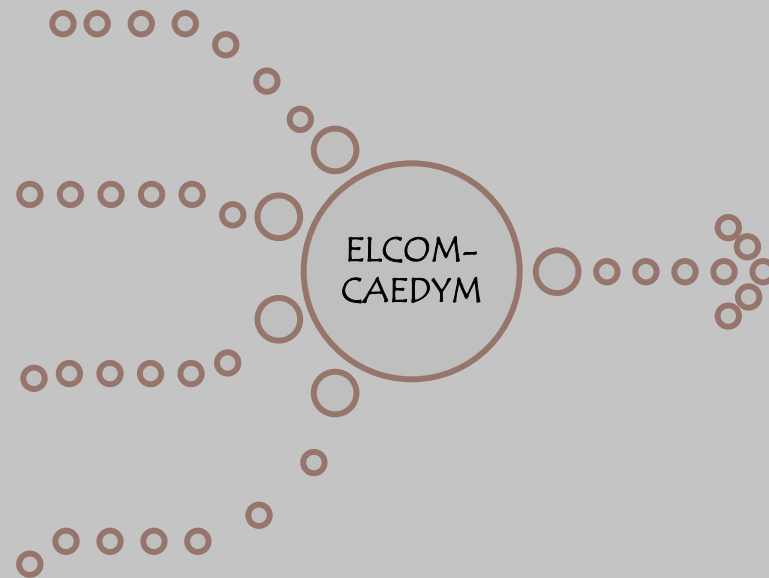
- Temperature
- Solar Radiation
- Wind Speed and Direction

Biology & Chemistry

- Nutrients
- Phytoplankton
- Zooplankton
- Fish

Ecology

- Trophic Interactions
- Behavior



A picture of Flathead Lake

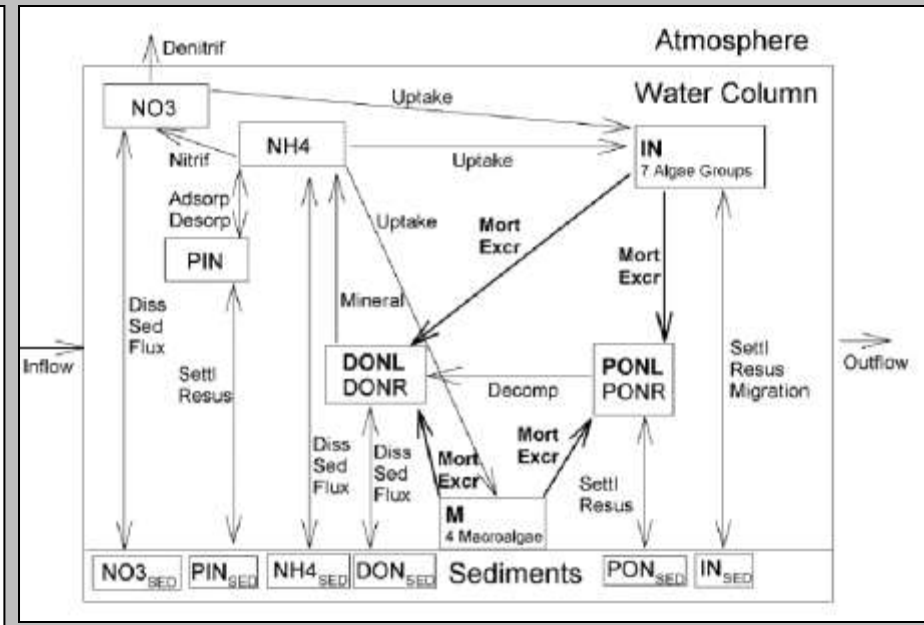
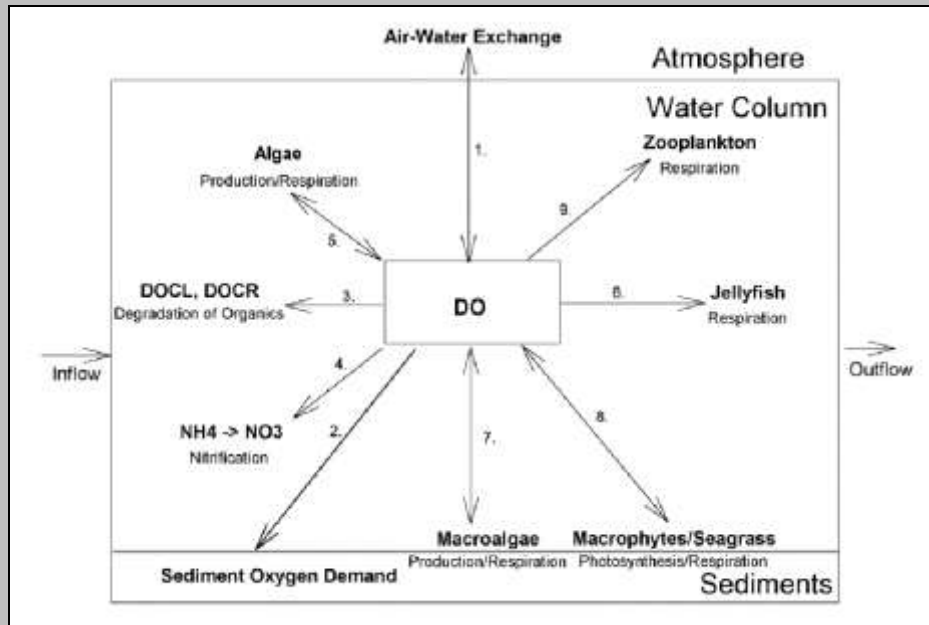
In long...

Velocities are mixed my mass such

$$U'_{ml} = \frac{\rho_{ml}U_{ml}dz_{ml} + \rho_l U_l dz_l}{\rho_{ml}dz_{ml} + \rho_l dz_l} \quad (6.15)$$

For partial mixing only the cell being mixed and the cell at the bottom of the mixed layer are modified.

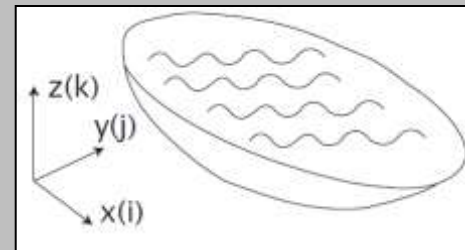
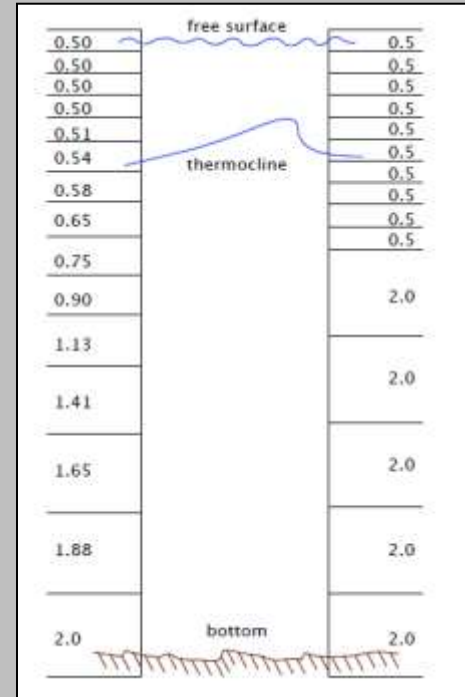
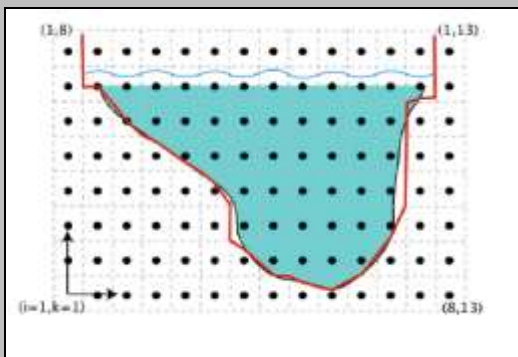
$$C_k = \begin{cases} C_{ml} & k = k_l + 2 : k_{ml-top} \\ (1 - \eta_f)C_{ml} + \eta_f \frac{C_{ml}dz_k + C_l dz_l}{dz_k + dz_l} & k = k_l + 1 \\ (1 - \eta_f)C_l + \eta_f \frac{C_{ml}dz_{k+1} + C_l dz_l}{dz_{k+1} + dz_l} & k = k_l \end{cases} \quad (6.16)$$



Estuary, Lake, and Coastal Ocean Model

ELCOM

- ∞ 3 dimensional hydrodynamic model
- ∞ Models internal currents, mixing, and movement of energy and matter
- ∞ Inputs:
 - Bathymetry and morphology
 - River discharge and loading
 - meteorological data
- ∞ In other words: Perfect for studying Climate Change





Select a Site

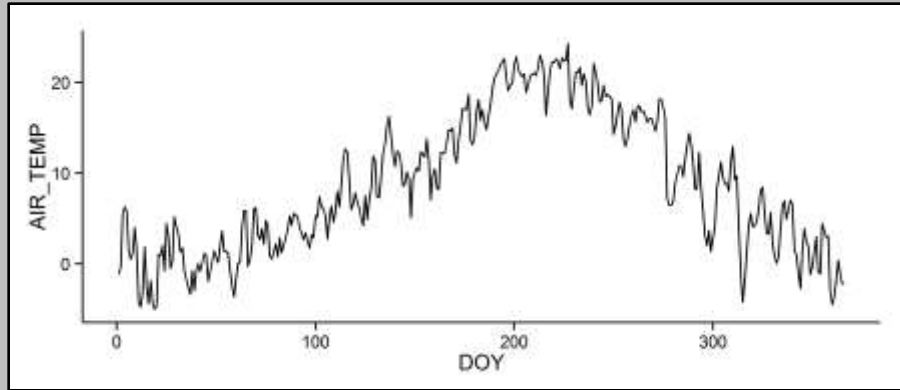


Location	Time	Air Temp	Water Temp	Rel Hum	Bar Pr	Wind Spd/Dir	Precip
FLBS Hill	11:15a	44.4 F		93.9 %	29.9 in Hg	2.8 mph E	0.19 in
West Shore	11:15a	42.9 F		95.2 %	29.9 in Hg	1.2 mph SE	0.09 in
YB Point	11:15a	46.3 F	45.9 F			8.4 mph ENE	
East Shore	11:15a	40.9 F		93.9 %	29.9 in Hg	2.2 mph N	0.35 in
Narrows	11:00a	46.0 F	47.9 F		29.9 in Hg	6.9 mph ENE	
Somers							
North Shore	5:00a	53.7 F	52.7 F		29.8 in Hg	14.2 mph ENE	

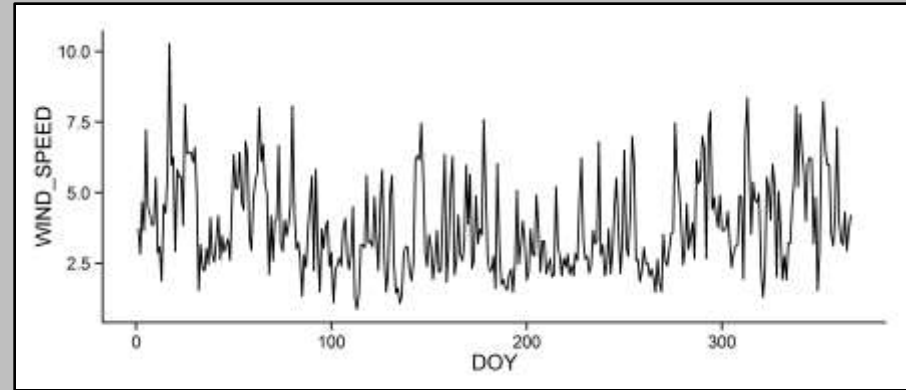


Meteorological Variables 2012

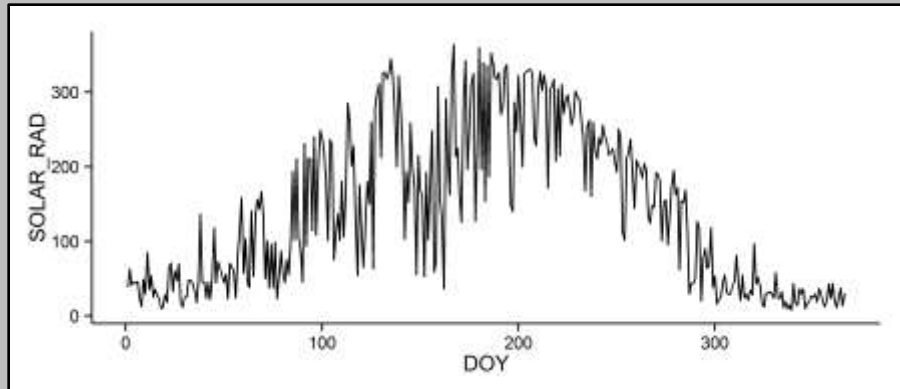
Air Temperature



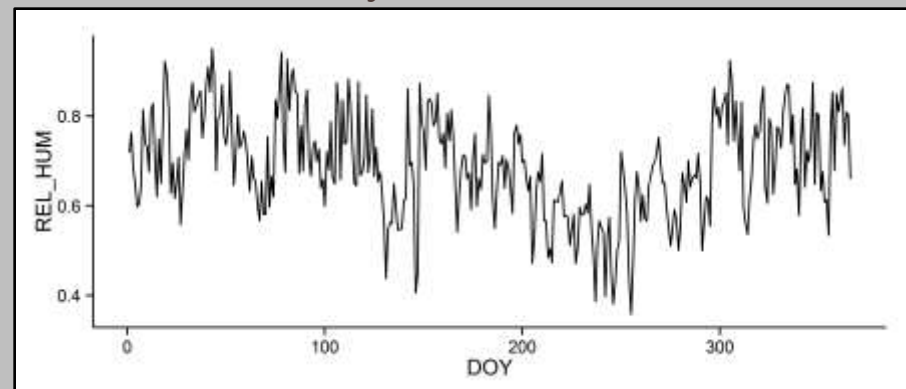
Wind Speed



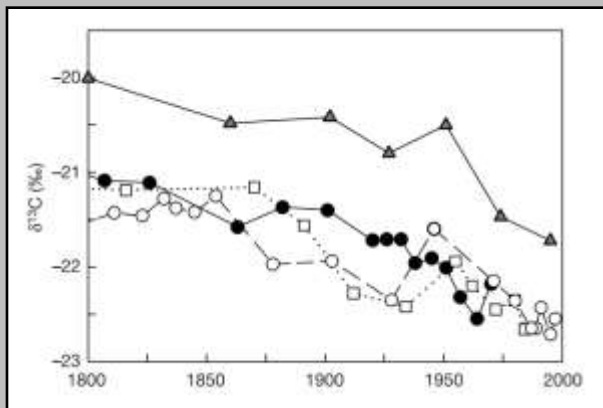
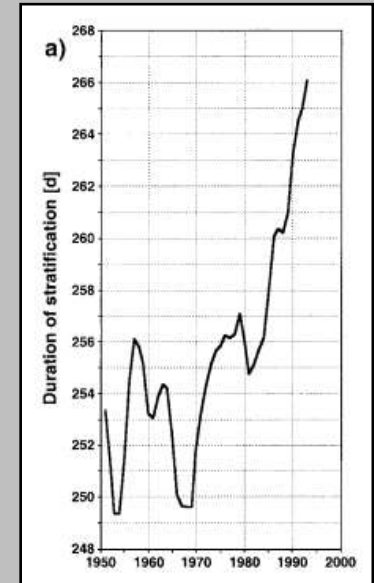
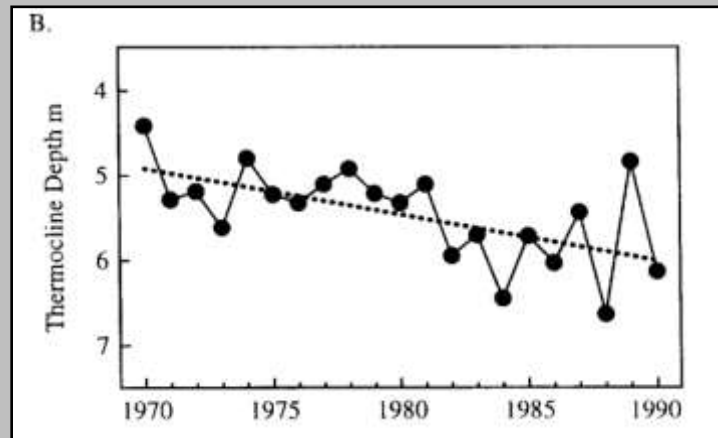
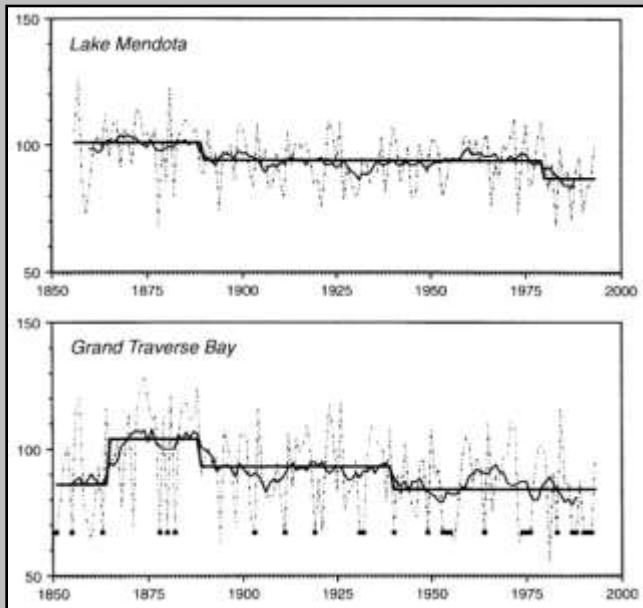
Solar Radiation



Relative Humidity

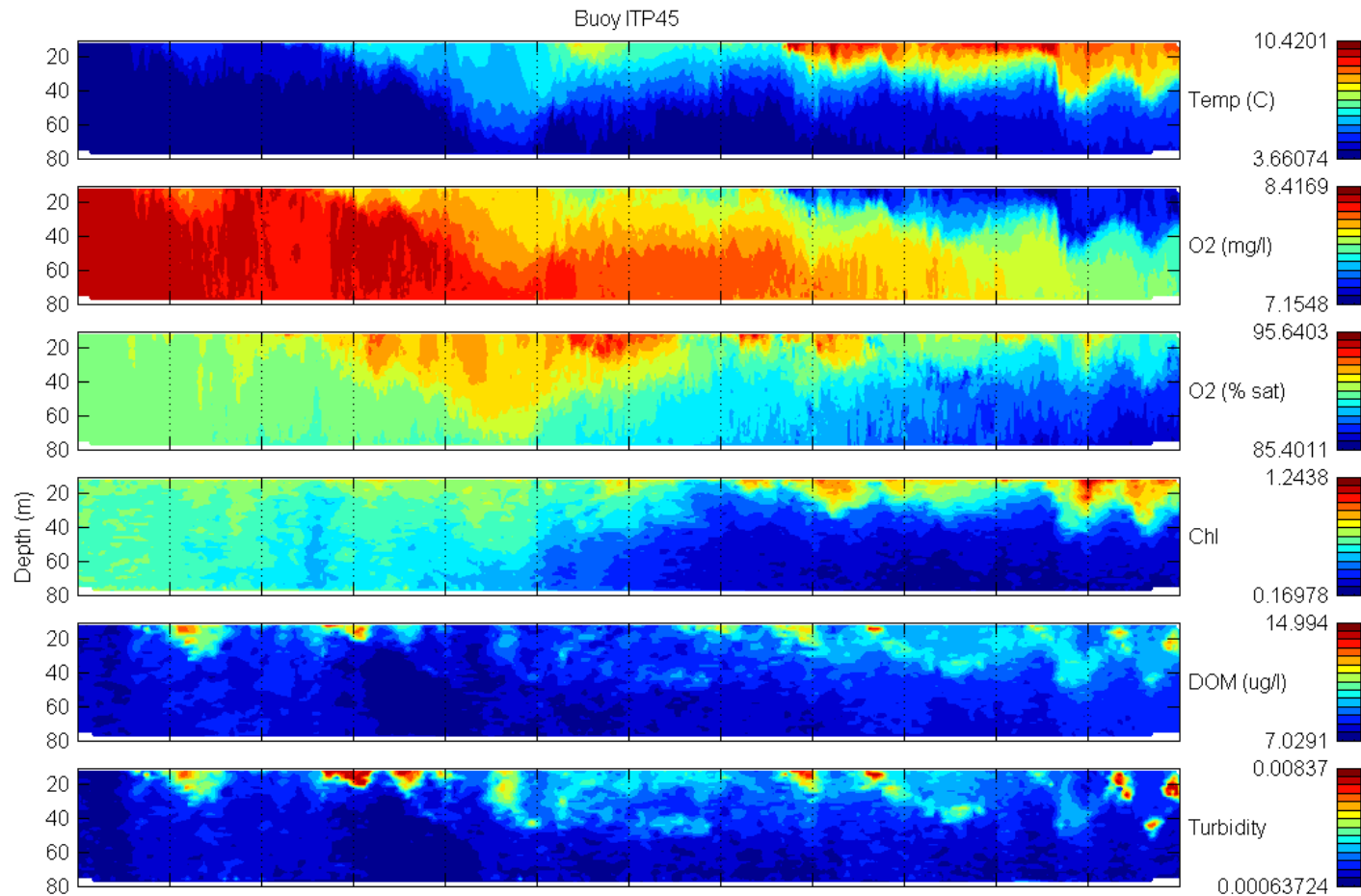


Climate change and large lakes

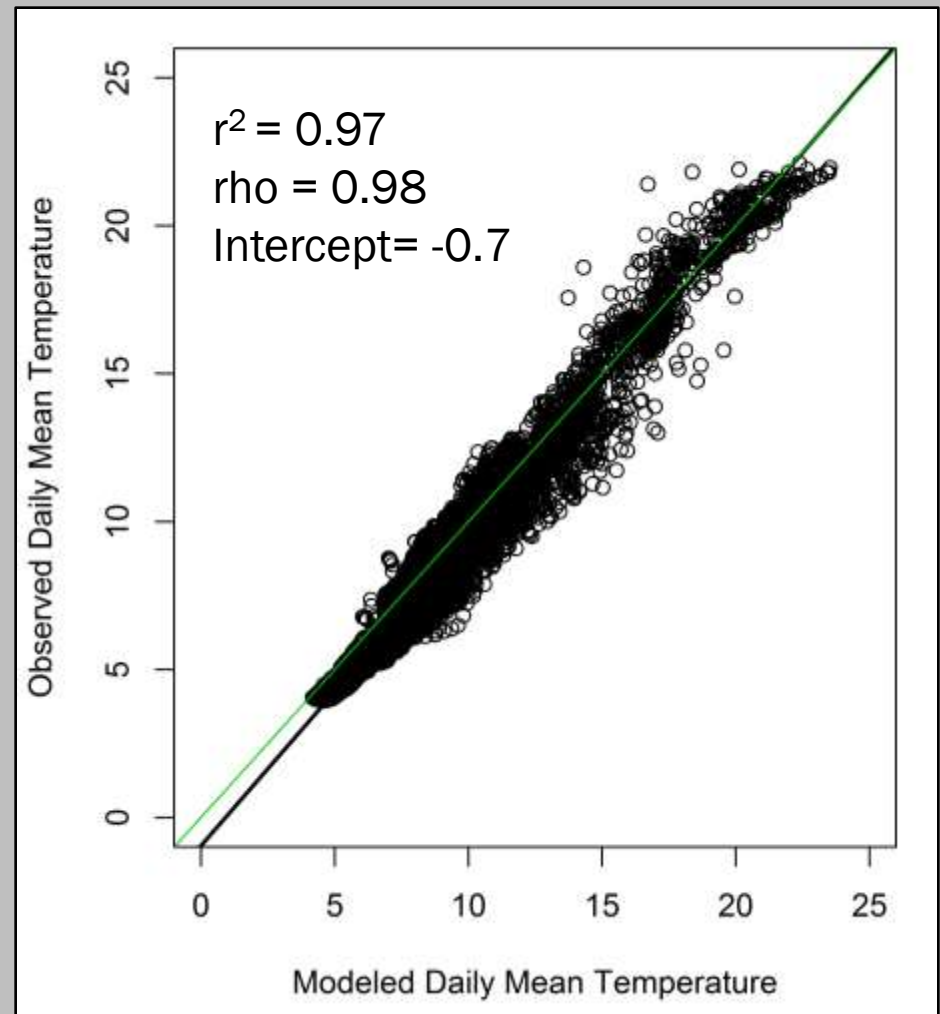
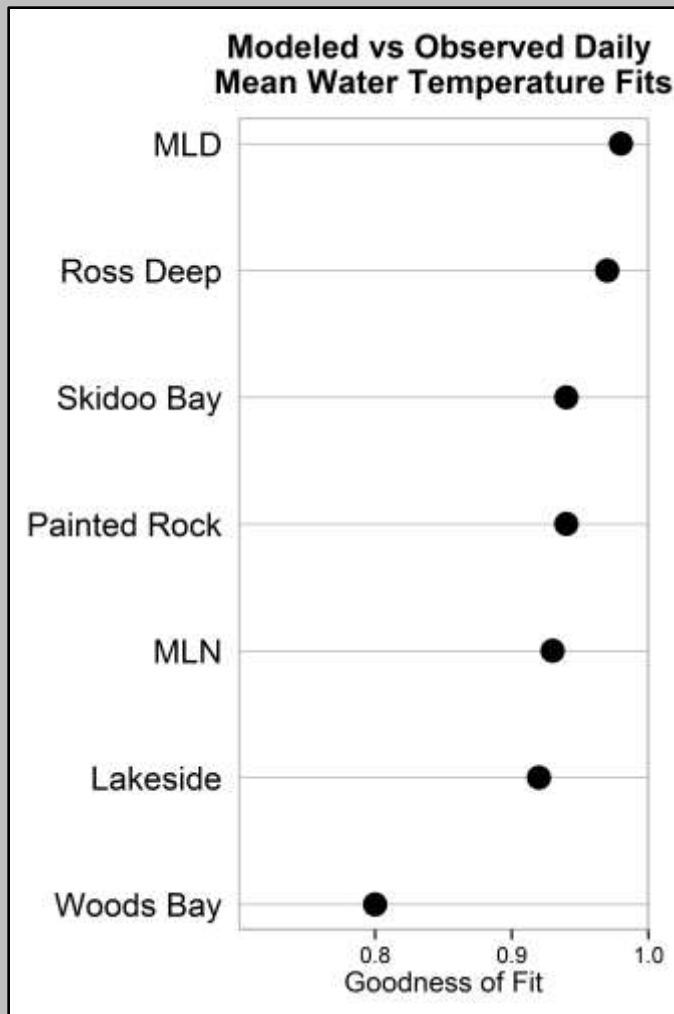


Magnuson et al, 1997; O'Reilly et al, 2003;
Livingstone 2003

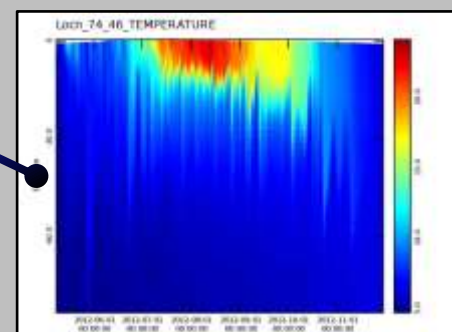
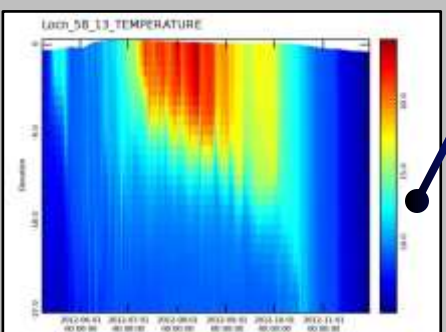
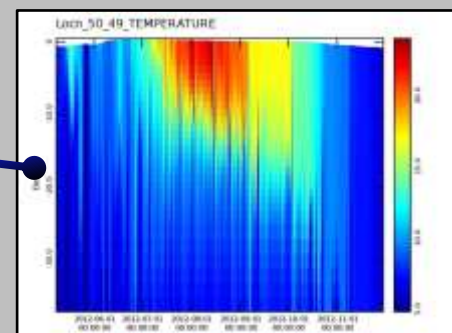
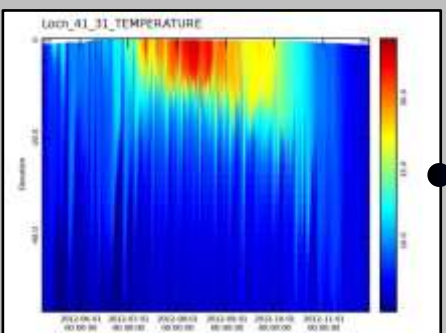
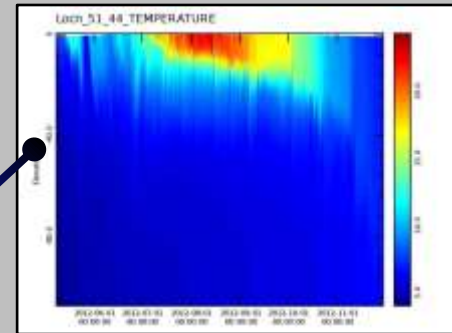
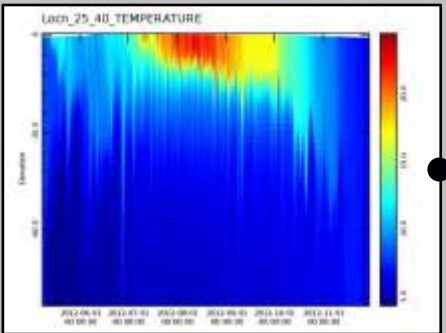
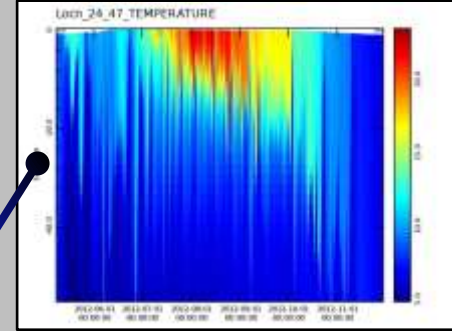
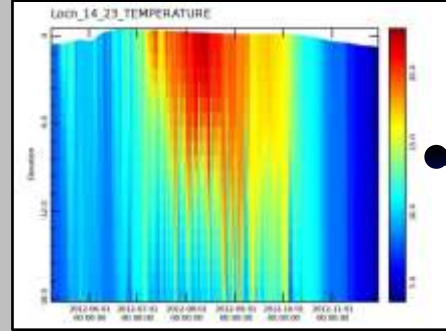
Buoy data proved invaluable!



How does ELCOM do?



Water Temperature throughout Flathead Lake



Climate Projections

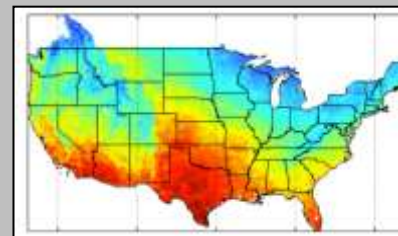
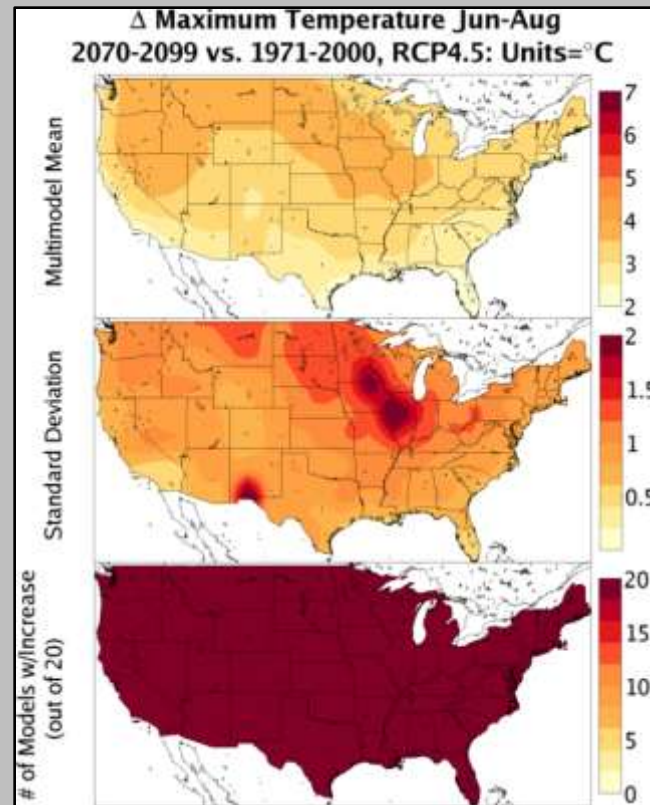
Multivariate Adaptive
Constructed Analogs (MACA)
Statistical Downscaling Method

2 Future Projection scenarios

RCP 4.5 (optimistic)
&
RCP 8.5 (dire)

All meteorological variables
necessary for ELCOM

Used mean value of 20 climate
projection models from Coupled
Model Inter-Comparison Project
(CMIP5) to project 2012 forward
through 2100



Climate Projections

Riverscape Analysis Project's (RAP) Extraction toolkit projected phenology of the Flathead and Swan Rivers for 2020, 2040 & 2080

The Riverscape Analysis Project

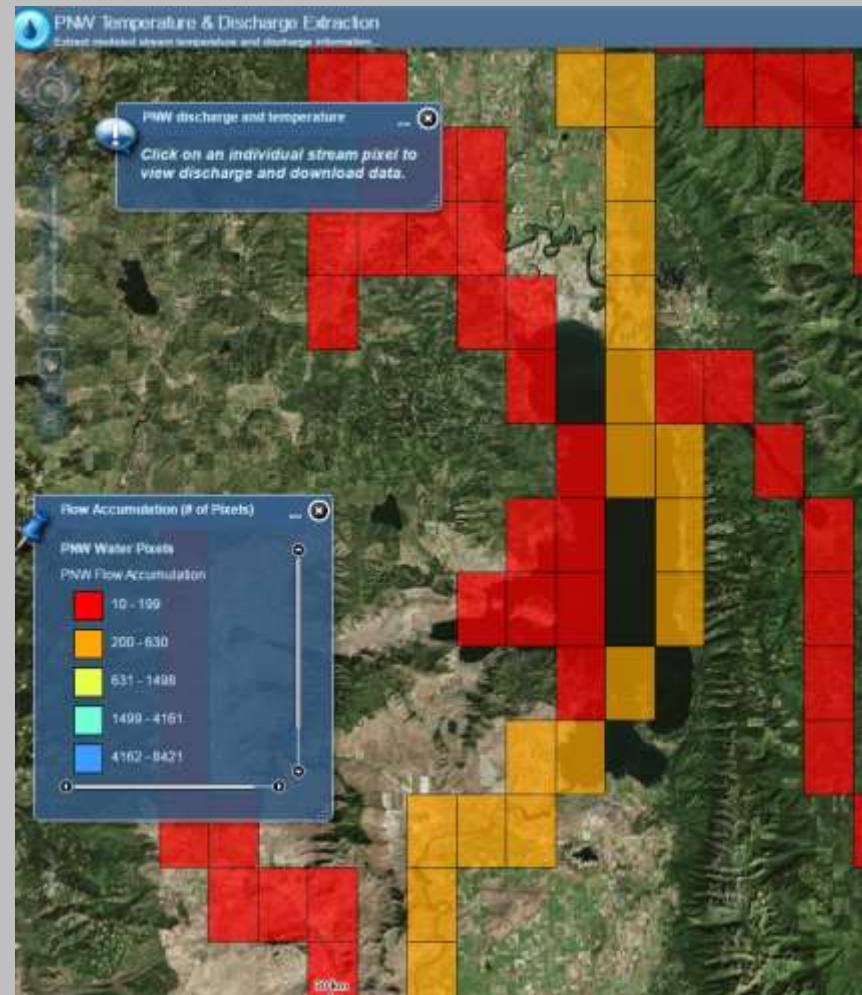
HOME | SALMON HABITAT | VULNERABILITY ASSESSMENT | LANDSCAPE GENETICS | MONITORING | RESOURCES | CONTACT

Tools

RAP includes a variety of interactive software database tools to view, query, and extract data. Two interactive viewers (Watershed Viewer and Query) allow users to view or query individual metrics and rankings for individual watersheds. In addition, specific dynamic tools within RAP have been developed to facilitate watershed, subwatershed, area of interest, climate, and field data extraction. Video tutorials have been developed for some tools.

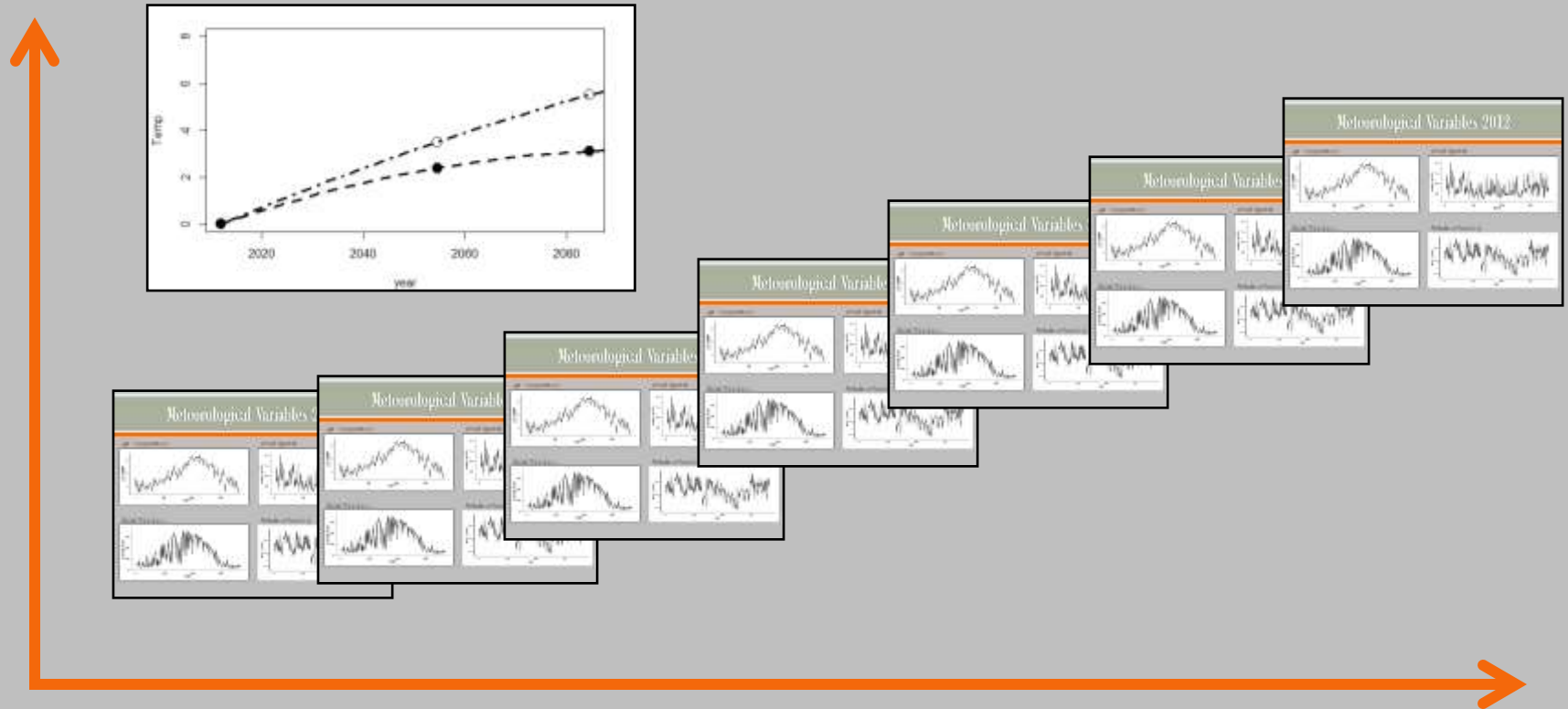
Physical Metrics	Map Tool	Tutorial	Output
	Watershed Viewer This tool allows users to view overall ranking and corresponding physical landscape metrics for individual watersheds.		Map/Viewer
	Watershed Query This tool allows users to interactively query 1,074 watersheds and summarize corresponding physical landscape metrics as well as relative rankings. A list of all non-habitat RAP watersheds can be found here - RAP Watershed List .		Map/Viewer
	New Metric Extraction Tool (Extract Subwatershed or your own user defined Area of Interest (AOI)) This tool allows users to interactively create a subwatershed or draw your own AOI and summarize corresponding physical landscape metrics. This tool is for all areas within the RAP study area except for areas south of San Francisco, CA.		Shapefile

- Salmon Habitat**
Extract RAP climate and habitat data.
- Climate Change Vulnerability Assessment (CCVA)**
Tools and resources for assessing salmonid climate change vulnerability.
- Landscape Genetics**
Tools and resources for analyzing the influence of physical habitat factors on genetic diversity and connectivity.
- Glizee Science**
Help conserve salmon and build a database while fishing.
- Genetic & Demographic Monitoring**
Tools and resources for monitoring abundance and genetic diversity.



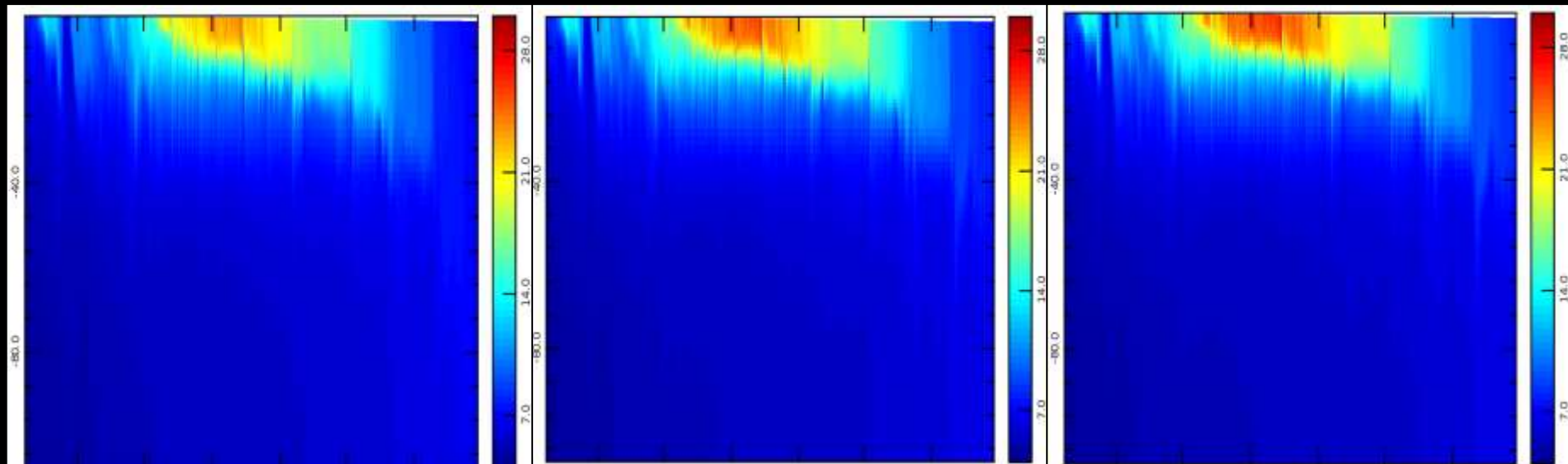
Projecting future climate using 2012 intra-annual variation

Projected relative change in Climatic change

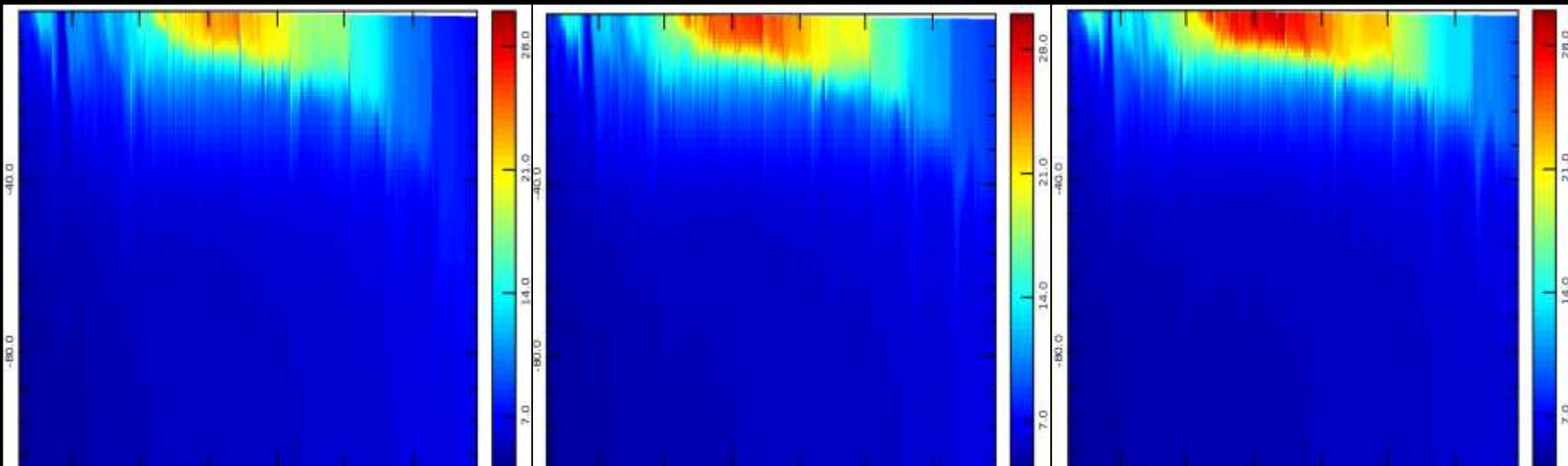


Time 2012 through 2096

RCP 4.5



RCP 8.5

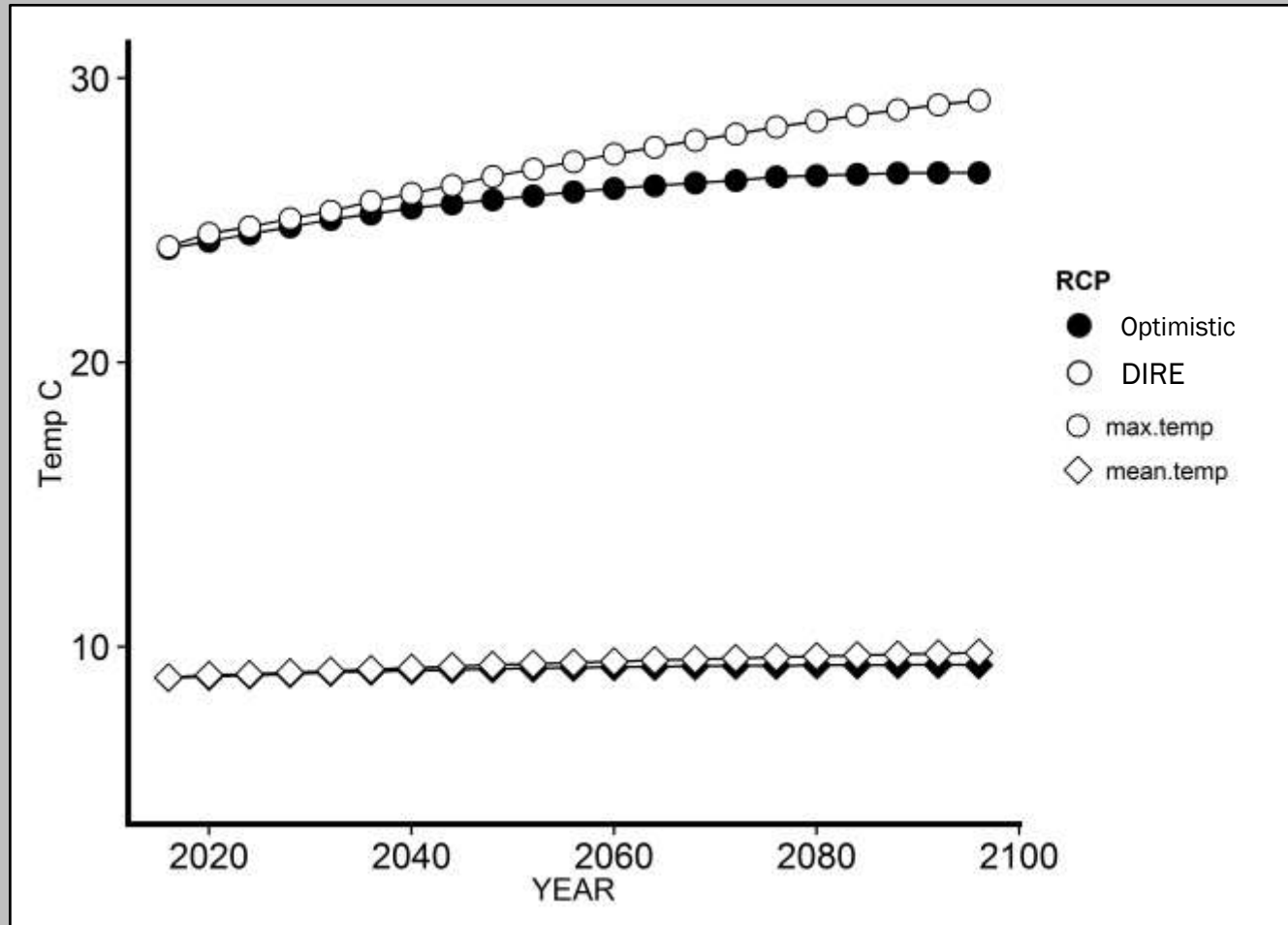


2020

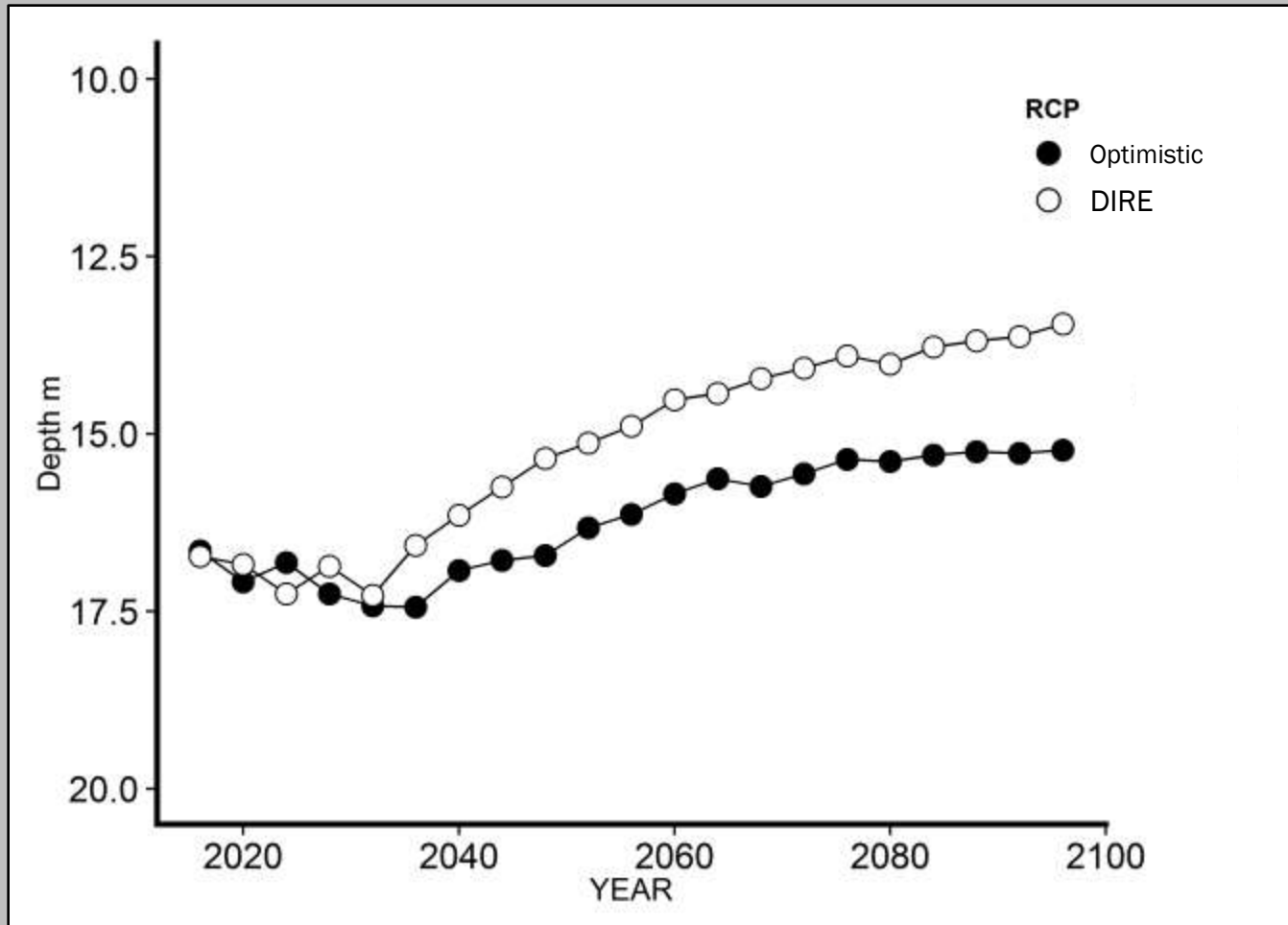
2056

2092

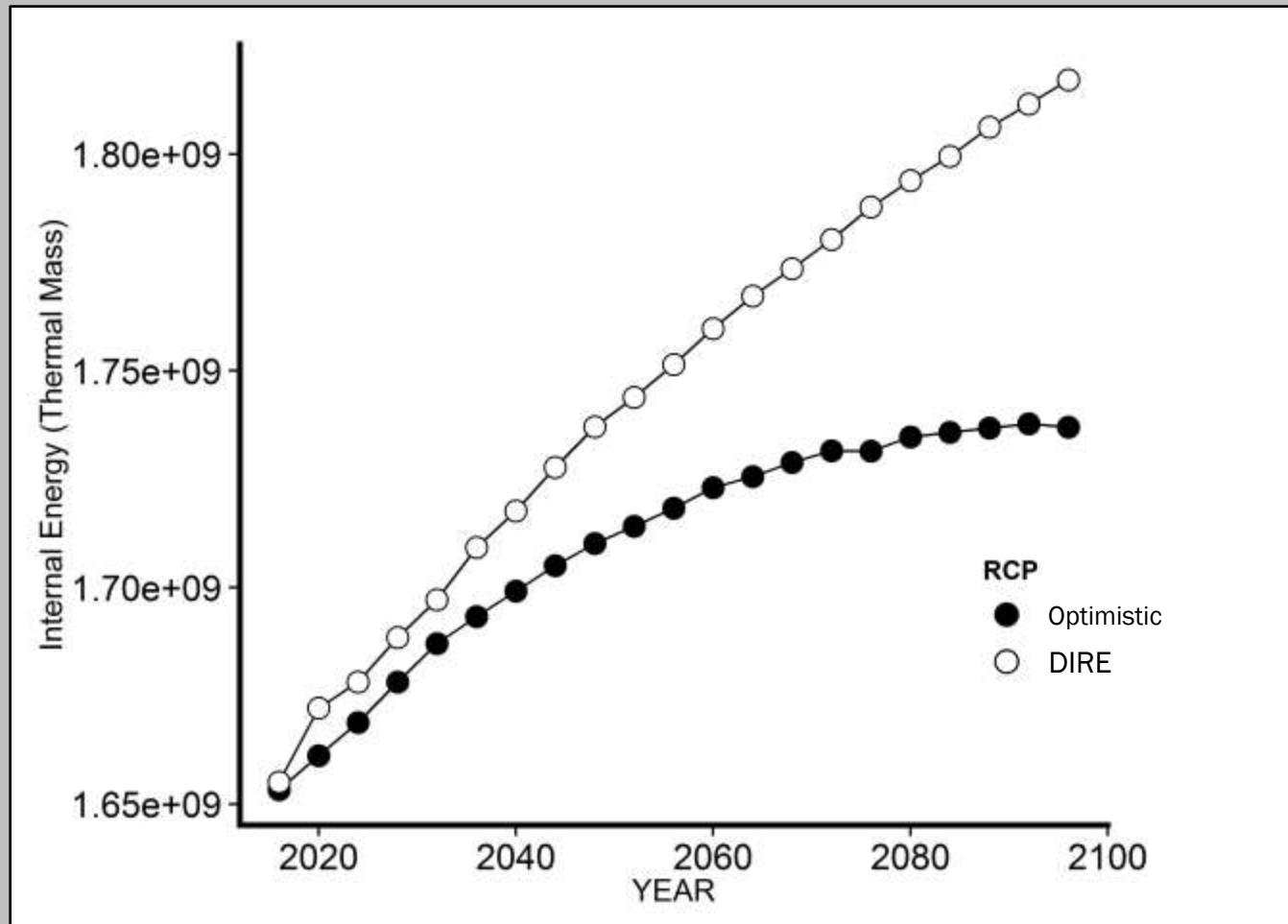
Water Temperature



Thermocline

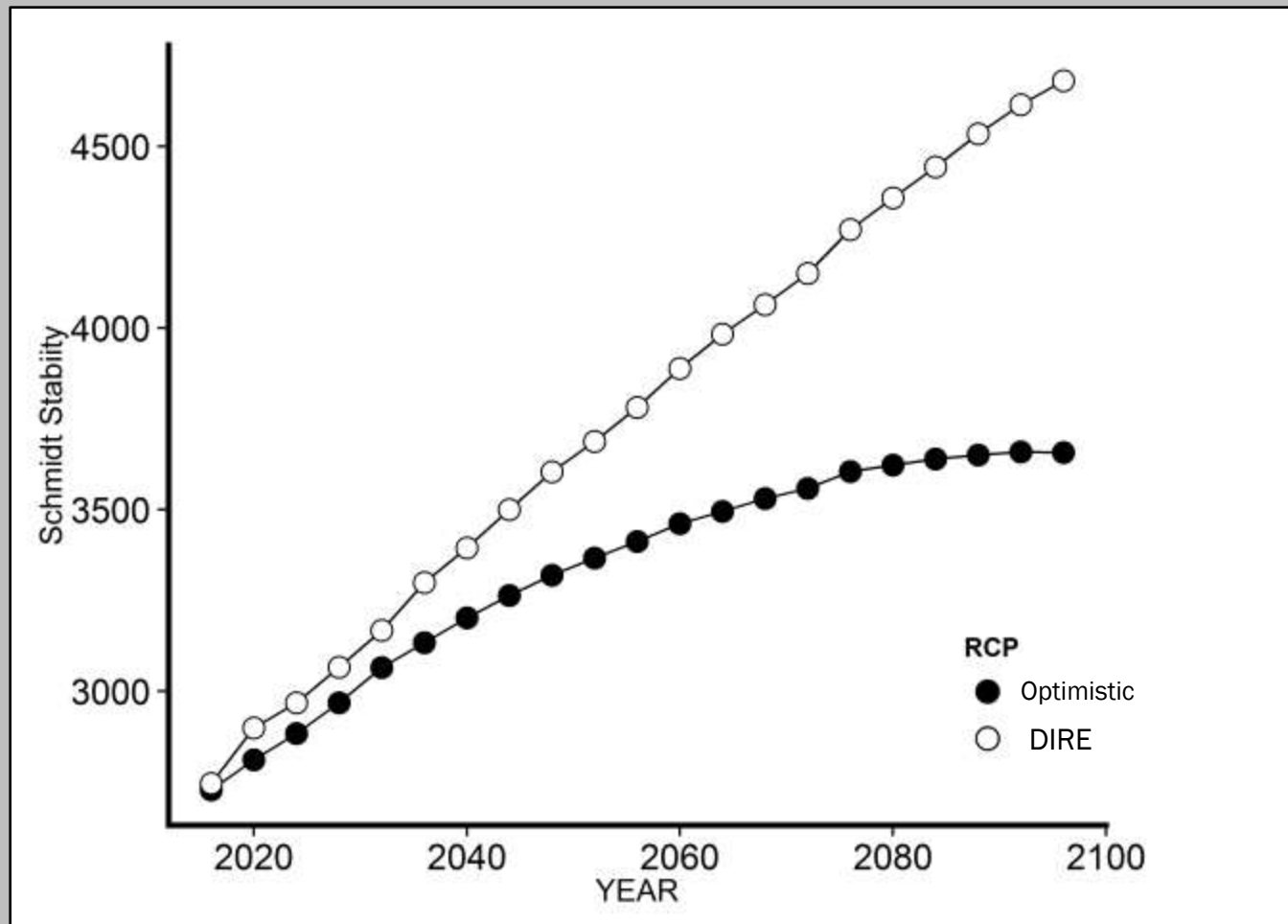


Internal Energy – Heat Budget

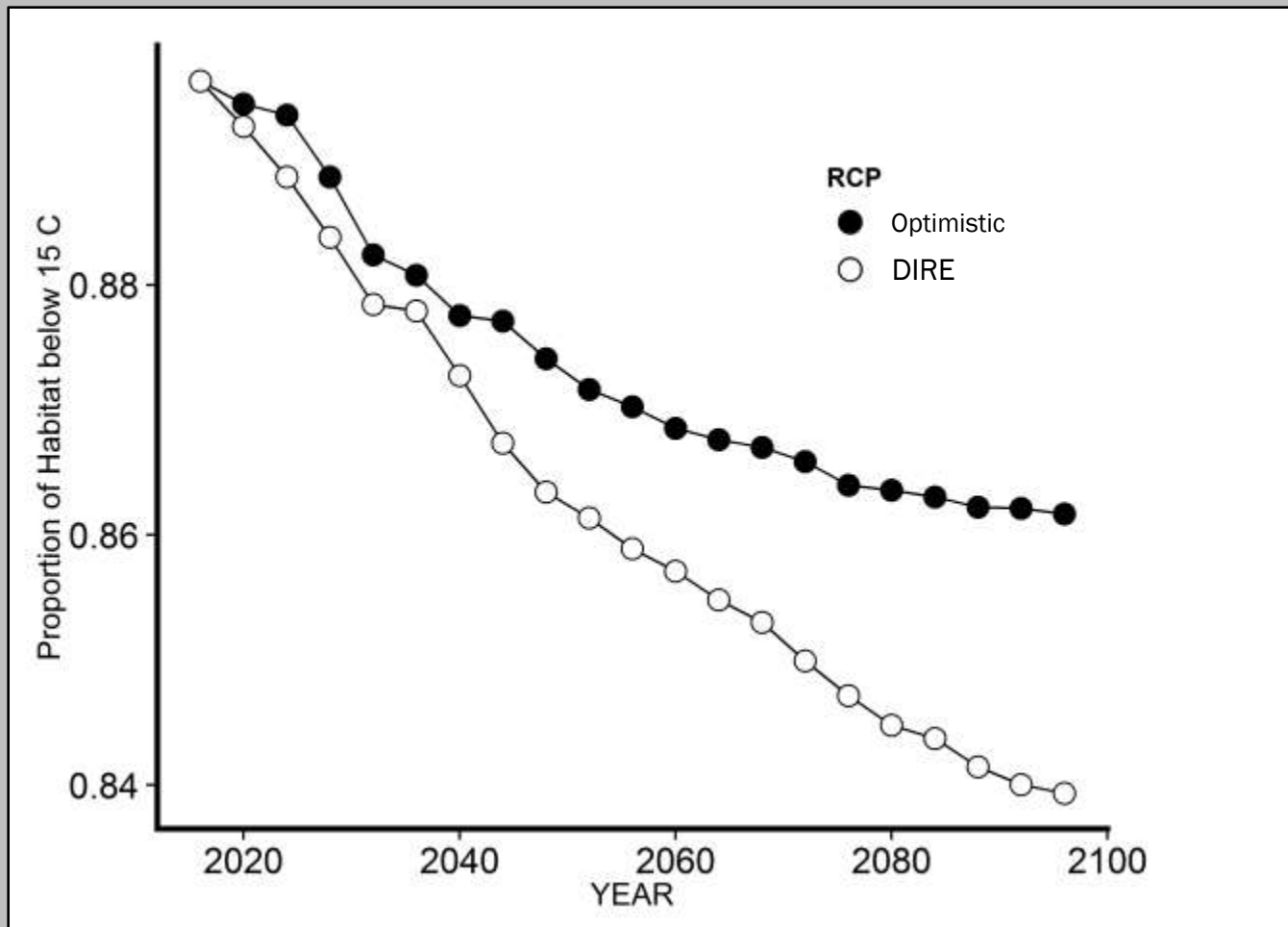


Schmidt Stability

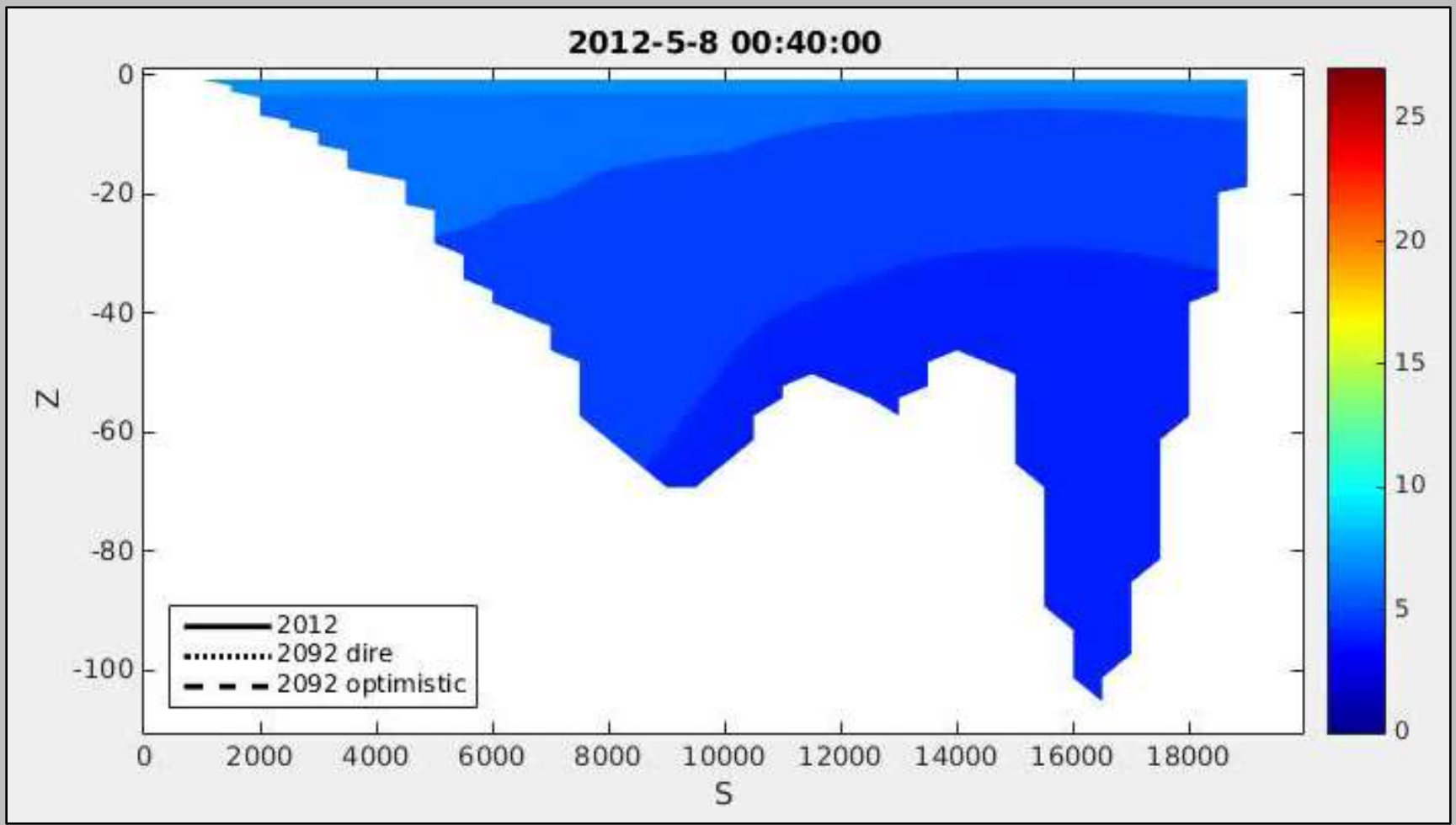
Resistance to mixing



Thermal Habitat Changes



Loss of thermal habitat for Mysis and Lake Trout



Climate Change Conclusions

- ∞ Significant increase in epilimnion temperatures but no overall increase in mean temperature of the lake (weighted or unweighted)
- ∞ Significant decrease of thermocline depth
- ∞ Increase in Schmidt Stability and Thermal Mass
 - Longer period of stratification (Nutrients)
- ∞ Decreased habitat for Lake Trout and Mysis, however relative to total habitat available only about 5%
- ∞ Thermal Refugia for riverine species immigrating from high elevation stream systems??

NO₃

Science Man.

$$\frac{dNO_3}{dt} = -f_{NO_3}^{DEN}(T, DO, NO_3) + f_{NH_4}^{NIT}(T, DO, NH_4) + f_{NO_3}^{DSF}(T, DO, pH) + f_{NO_3}^{BUP}(A, M, NH_4)$$

[Click here to view nitrogen schematic](#)

Bacteria



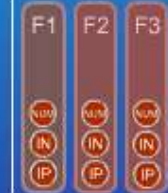
Phytoplankton



Zooplankton



Fish



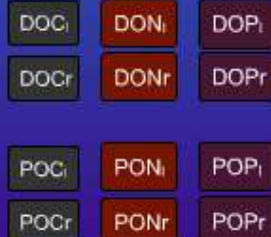
Pathogens



Derived

- CMR
- NPP
- NZP
- PPB
- ZPB
- TN
- TP
- TA

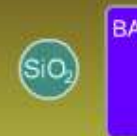
Detritus



Inorganic Pool



Metals



Long Term Data

1998

NORTHEASTERN NATURALIST

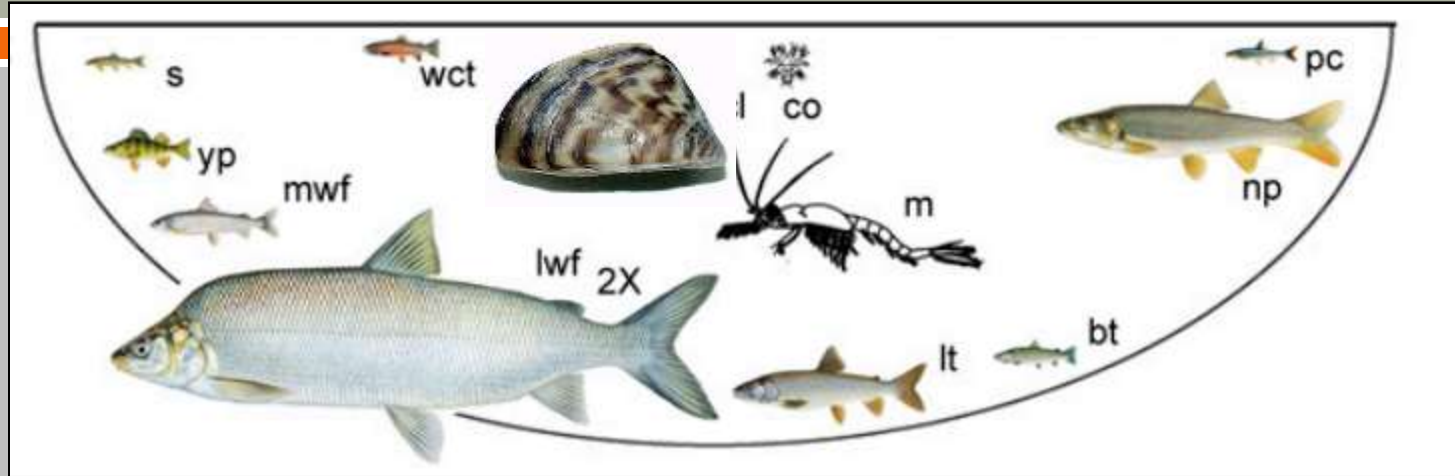
5(2): 127-136

THE IMPORTANCE OF LONG-TERM DATA IN ADDRESSING REGIONAL ENVIRONMENTAL ISSUES

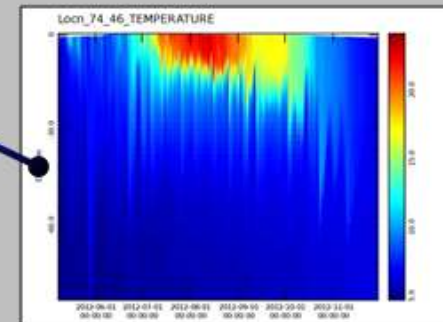
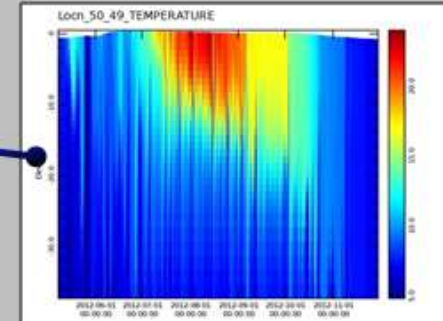
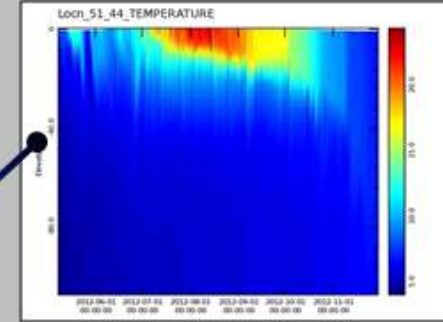
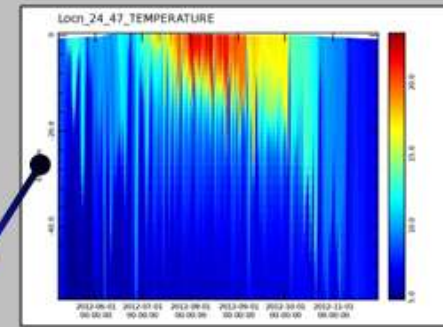
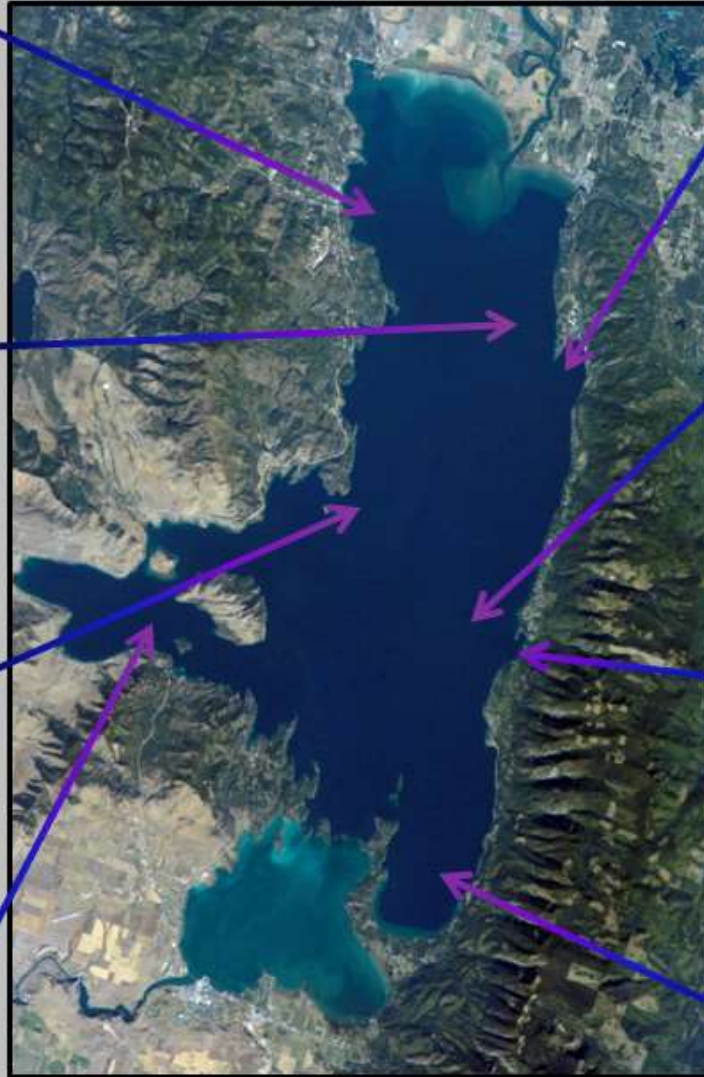
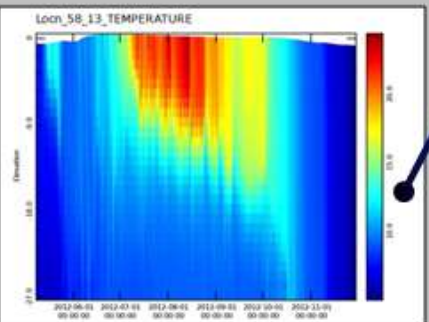
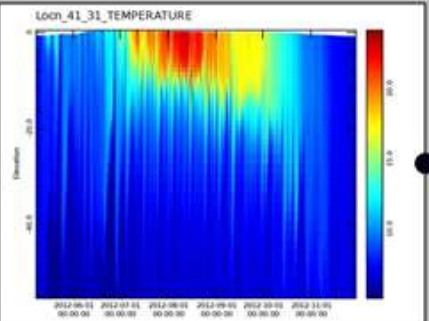
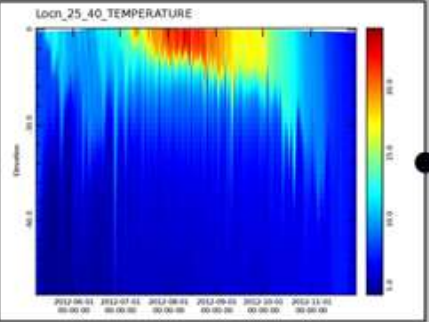
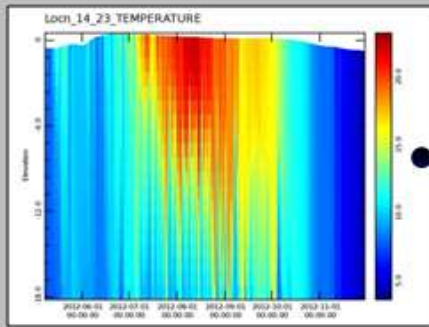
GENE E. LIKENS * AND KATHLEEN FALLON LAMBERT **

ABSTRACT - Long-term data have been used to evaluate complex, environmental problems, such as the anthropogenic acidification of regional landscapes by acid rain, and to quantify changes in ecosystem function associated with large-scale land use, such as forest harvesting and development. In this paper, we discuss the importance of long-term monitoring in addressing regional environmental issues by examining two examples of anthropogenic stress—acid rain and forest harvesting. We also suggest that a watershed-ecosystem approach is useful for understanding, and for managing, the potential synergistic effects of chemical and vegetational changes in forest ecosystems in the northeastern U.S.





Trophic Interactions

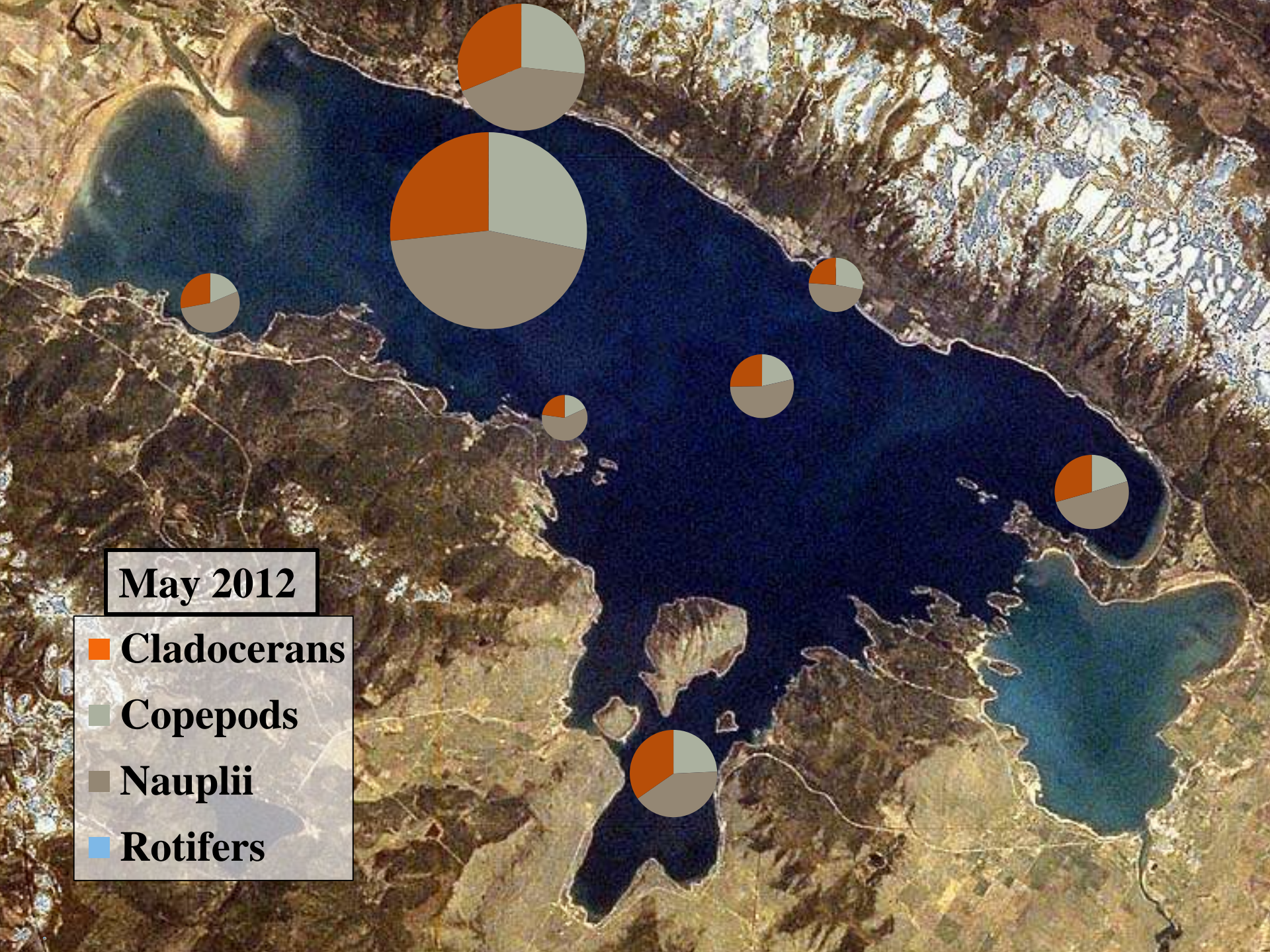


Water Temperature throughout Flathead Lake

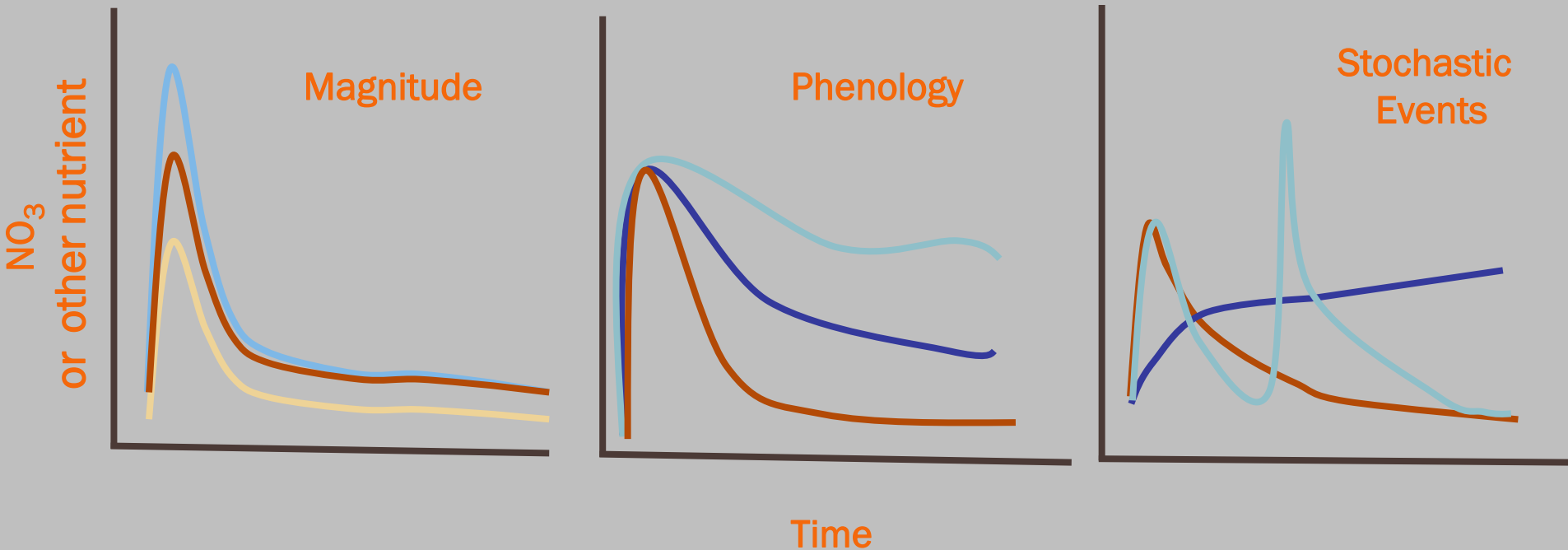
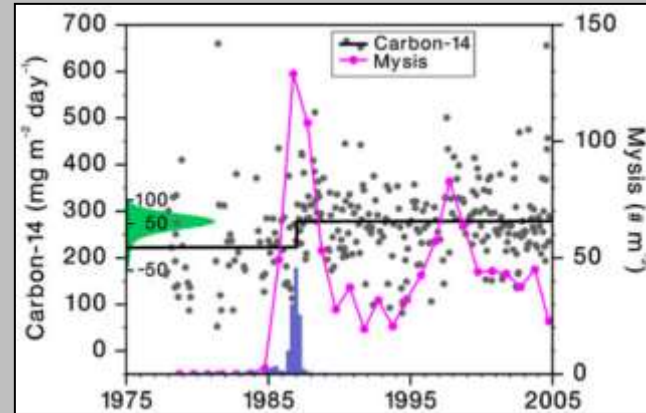
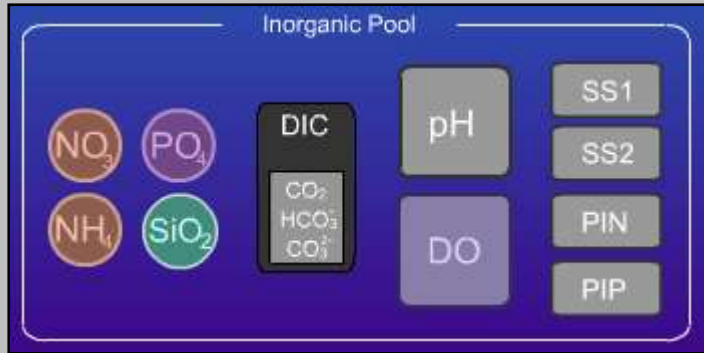


May 2012

-  **Cladocerans**
-  **Copepods**
-  **Nauplii**
-  **Rotifers**



Nutrient Loading



Summary

Models allow us to conduct impossible experiments:

- ∞ Examine implications of invasions or community manipulations without potential damage to systems
- ∞ Determine what effect changes in nutrient loading will have on water quality
 - Magnitude
 - Hydrology
 - Stochastic/ catastrophic events
- ∞ Assess how 100 years of warming and drying climate will effect the thermal and physical dynamics of Flathead Lake

Something to keep in mind



Essentially, all models are wrong, but some are useful.

(George E. P. Box)