Arctic LTER Project

Arctic Lakes: what have we learned about system response to direct and indirect effects of climate change?

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Arctic LTER Mid-Term Review
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Mapping ArcLTER Objectives to Streams Research

ArcLTER Shared Objectives

1. How does climate control ecosystem states, processes, and linkages?

2. How do disturbances change ecosystem states, processes, and linkages?

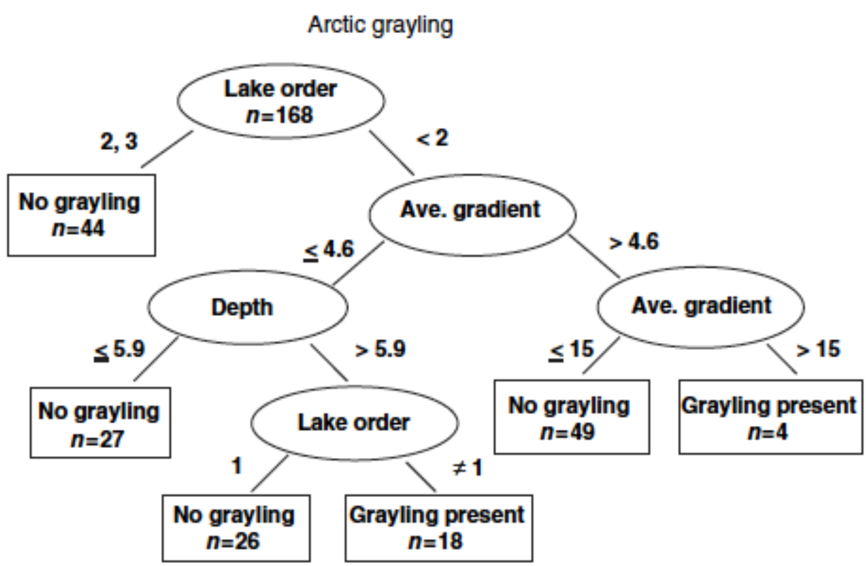
3. How do climate and disturbance <u>interact</u> to control biogeochemical cycles and biodiversity at catchment and landscape scales?

Frameworks for Lakes Research (This talk)

- Foundational Research Theme #1: Landscapes and Lake Communities
- Foundational and Current Research Theme #2: LTER lake monitoring (in a changing climate)
  - Limnological change
  - Fish Population Dynamics –
    - POSTER!
  - Fish Community Dynamics
    - Zarnetski Vignette and POSTER!
  - Temporal patterns in microbial diversity
    - Crump Vignette and POSTER!
  - Paleolimnology
    - Sheng POSTER!
- Foundational Research Theme #3: Lake fertilization – Pulse Experiments
- Current Research Theme #4: Lake fertilization – Press Experiments**
- Current Research Theme #5: Synthesis and integration across arctic food webs (lake food webs)
    - POSTER!

A landscape of kettle/moraine lakes: arose after several different Pleistocene glaciations

Foundational Research Theme #1: Landscape and Biological Communities



- *Landscape age determines lake chemistry, while lake size (p. of fish)structures and controls biological communities*

(Hershey et al. 2006)

Arctic lakes

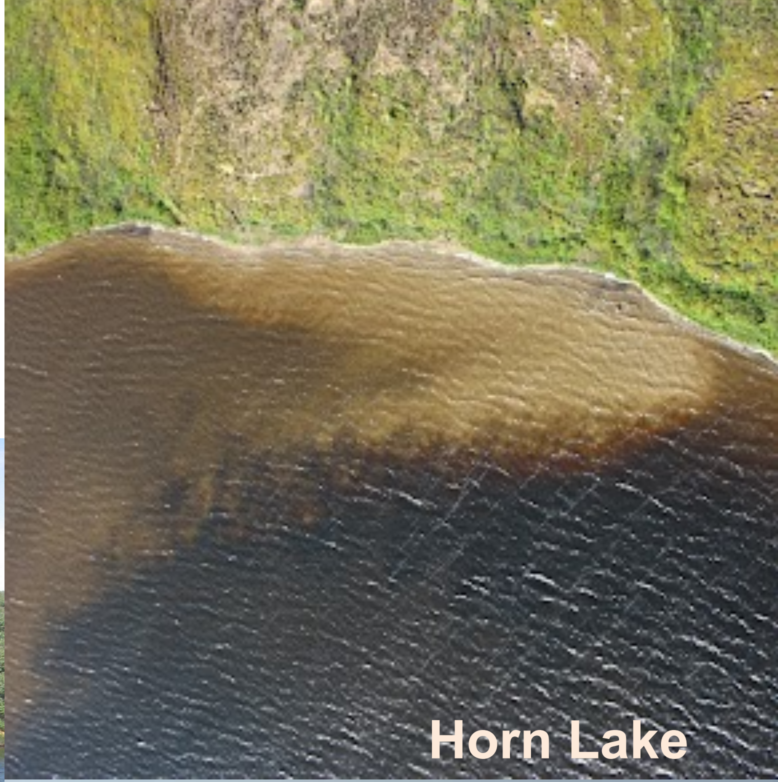
- Long period of ice cover
- Complete darkness
- 24-hour sunlight

- Nutrient poor
- Low biological productivity
- Low species diversity
  - Even less at higher trophic levels

- Impact the arctic region most severely
- 2.1 °C increase over last 30 years in Alaskan arctic
- Continued rise in winter & summer temperatures
- Warmer lakes? More ice-free days?
- *Fire, erosion, slumping, changing sea-level, etc.*

Global climate change

Environmental change: disturbance regime



Foundational and Current Research Focus Theme #2: LTER lake monitoring

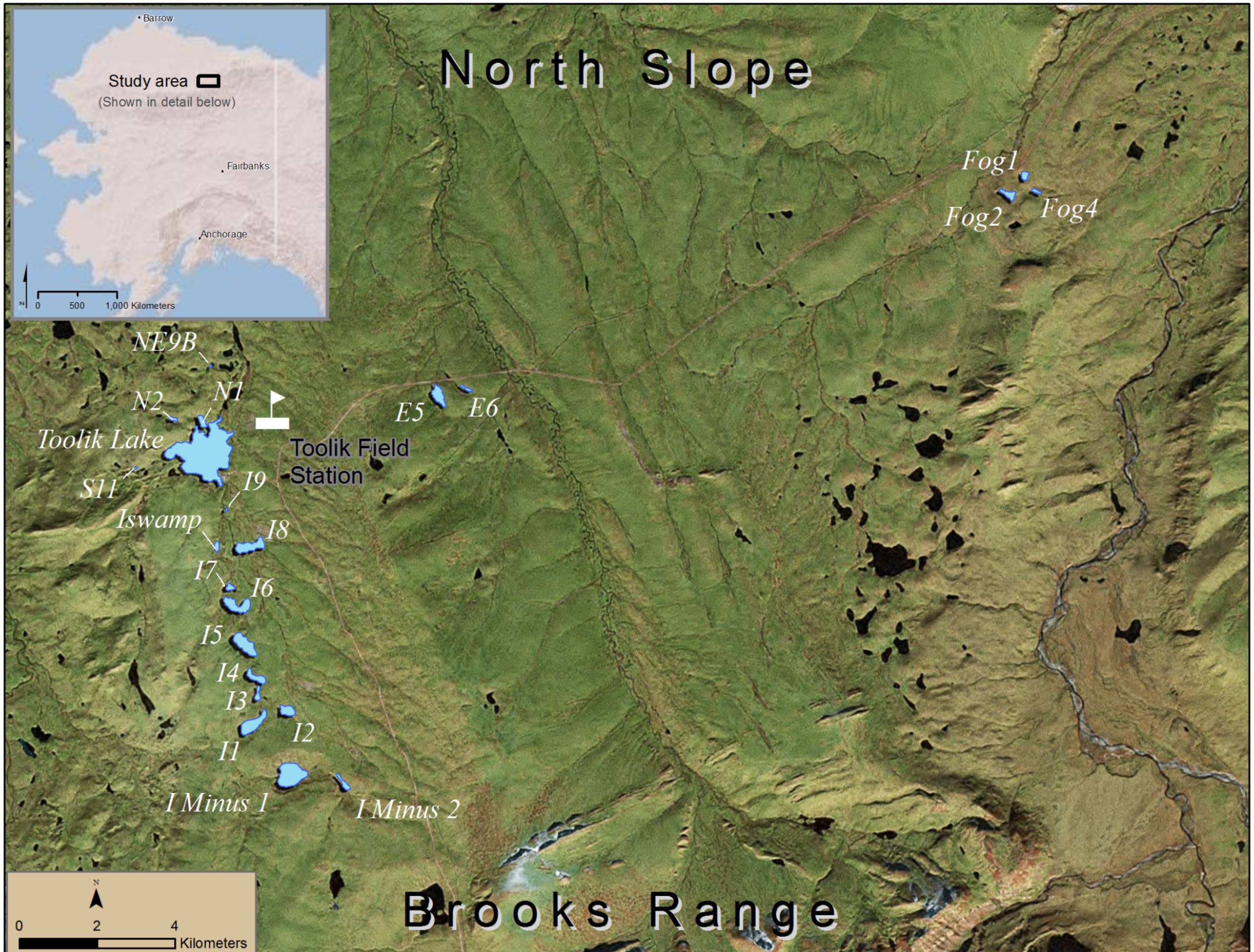
1. *How does climate control ecosystem (lake) states, processes, and linkages?*

2. *How do disturbances change ecosystem (lake) states, processes, and linkages?*

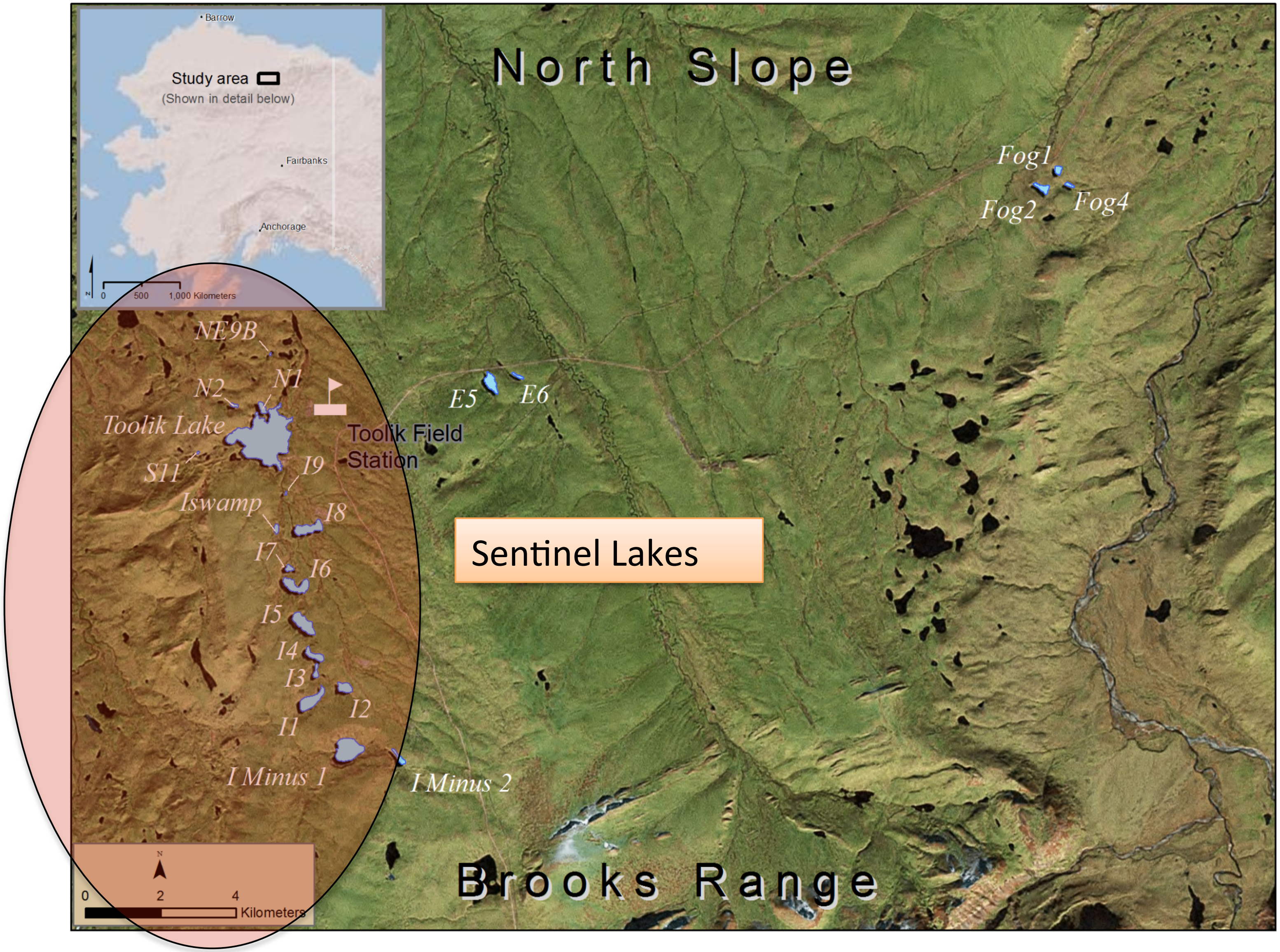
Requires both landscape and experimental approaches

- Landscape: continued long-term monitoring:
  - ~15 'sentinel' lakes surrounding Toolik
  - Full suite of biogeochemical and physical factors

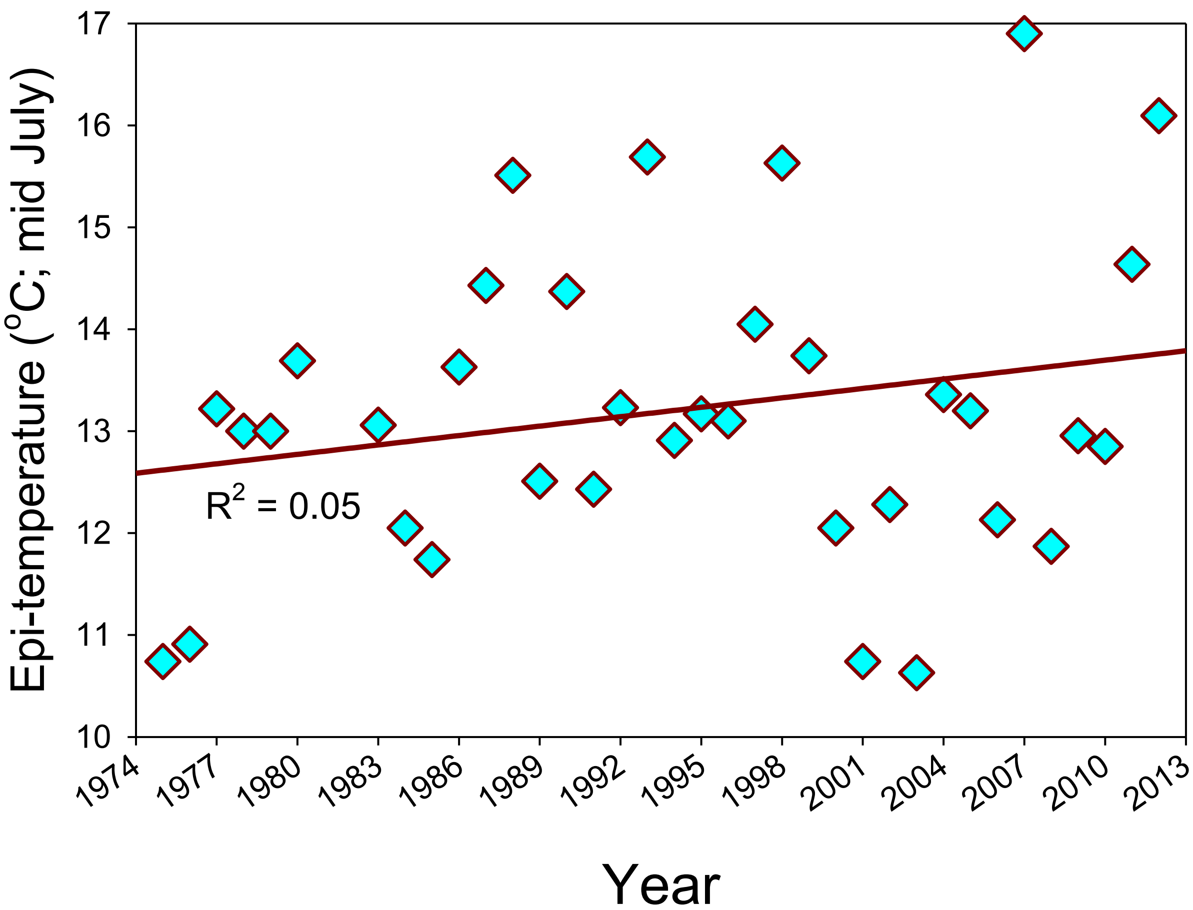
Sentinel and Experimental ARC LTER lakes



Sentinel and Experimental ARC LTER lakes



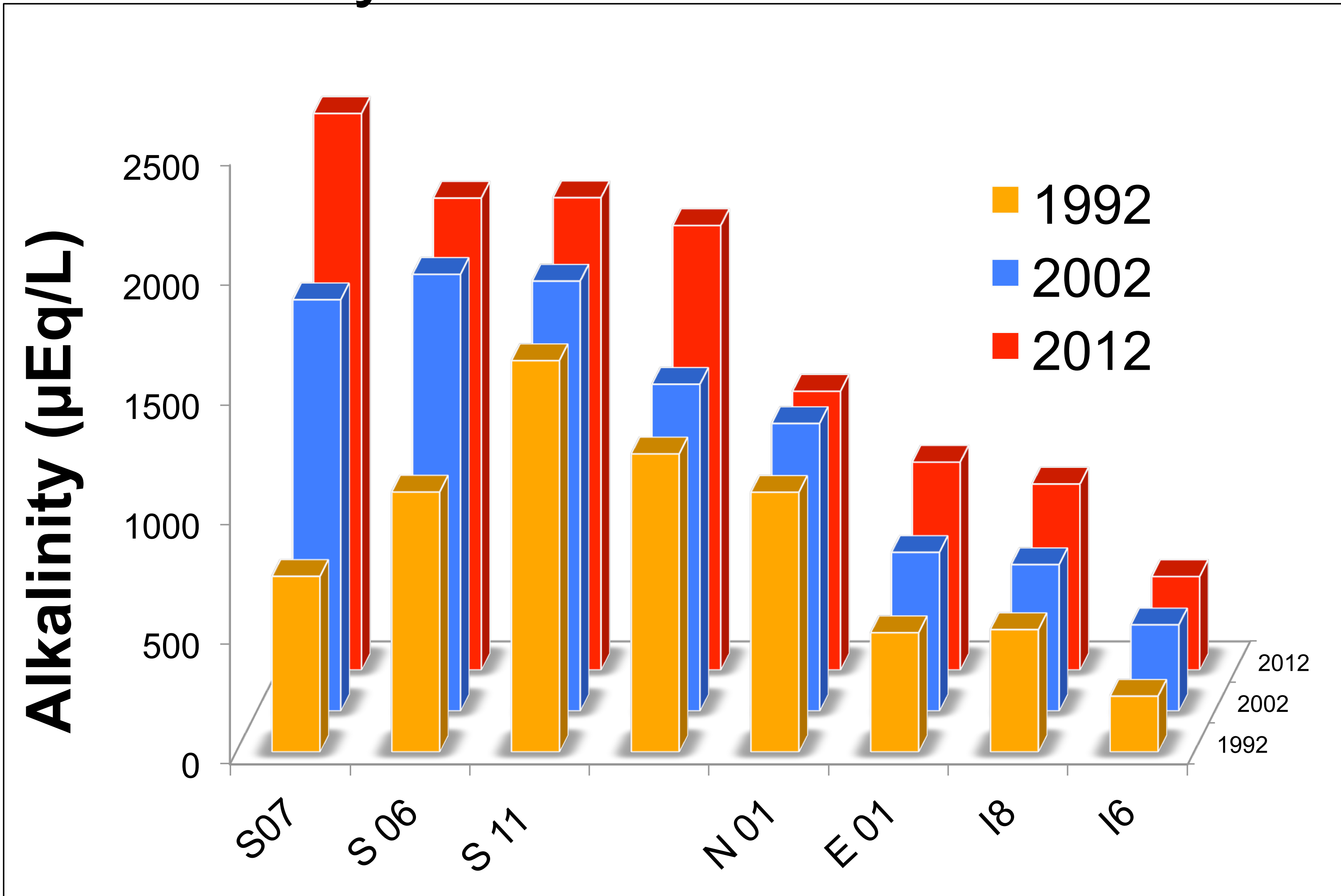
Toolik epilimnetic mean annual summer temperatures



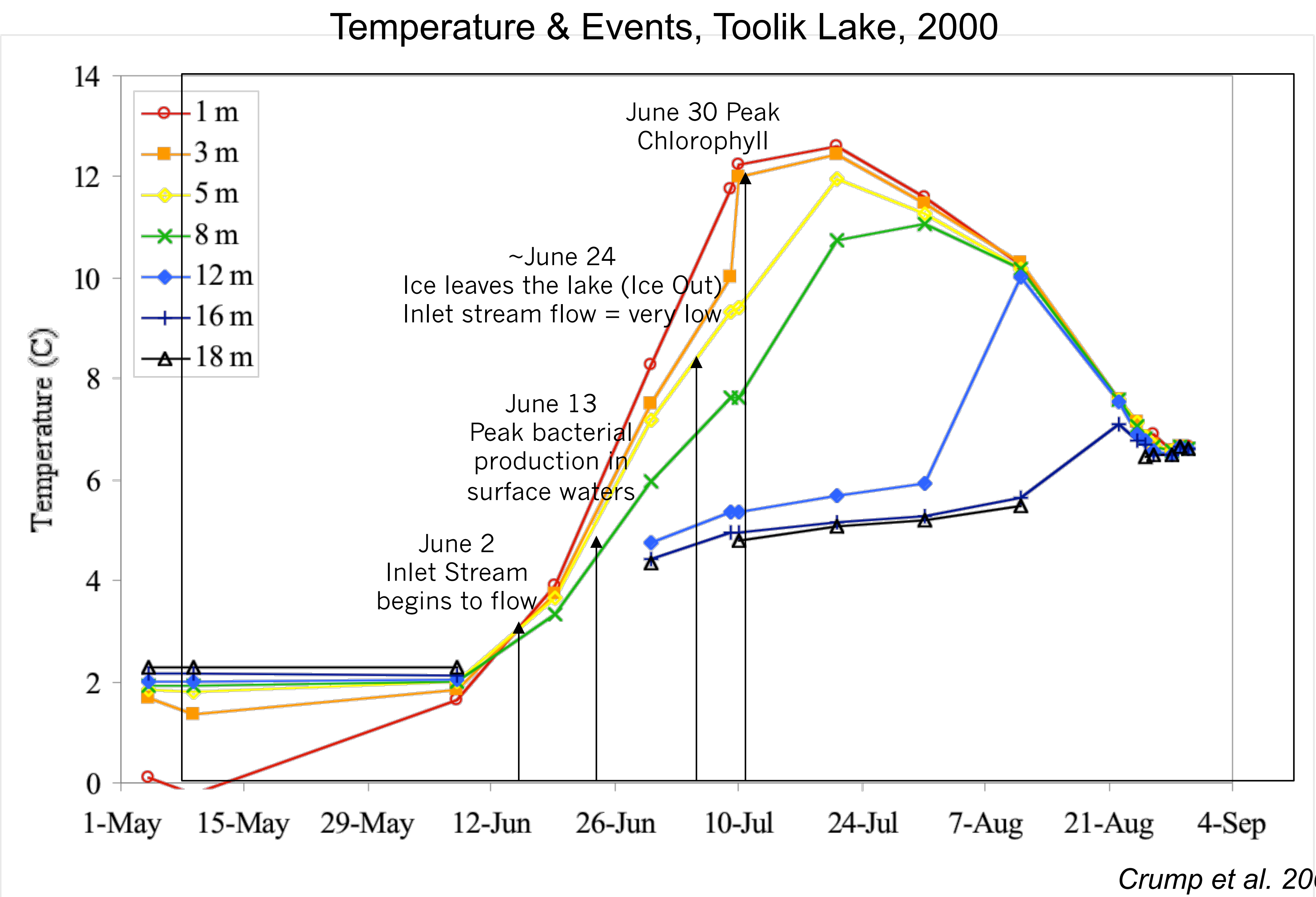
- Frequency of warm, dry summers increased (MacIntyre et al. 2006,2009)
- Increased stratification in warmer years = higher epilimnetic temps, greater zoop densities, and reduced fish growth (Johnson 2009)
- Synchrony

POSTERS! VIGNETTE

Alkalinity Trends in Sentinel Lakes



Seasonal and interannual patterns of microbial community composition



Crump et al. 2003

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Foundational Research Focus: Theme #3 “Pulse” Lake Fertilization Experiments

2. *How do disturbances change ecosystem states, processes, and linkages*

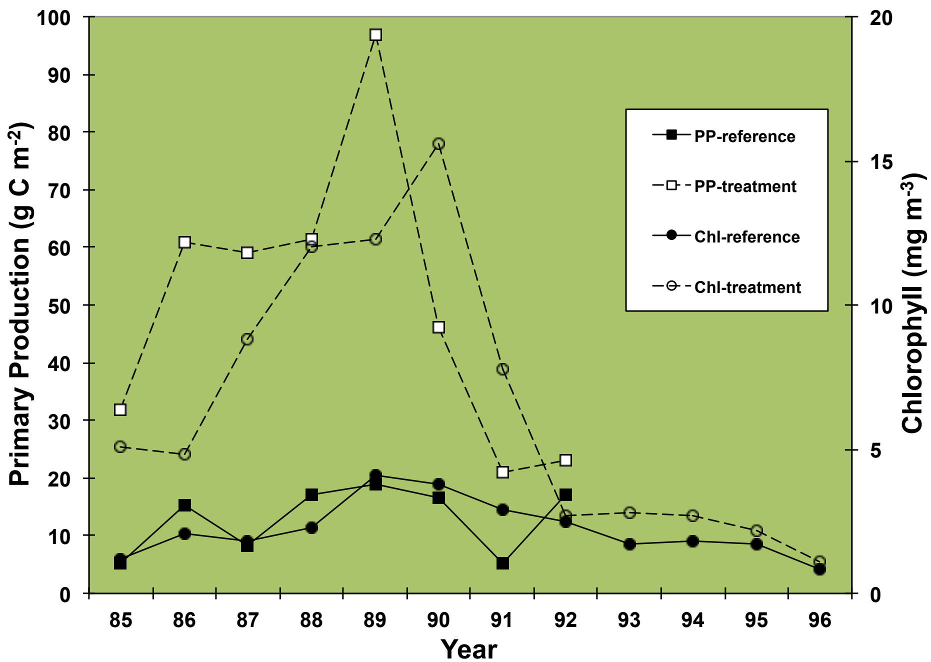
- Experimental:
  - whole-lake fertilization experiments
  - high-level “pulse”

Foundational Research Focus: Theme #3 "Pulse" Lake Fertilization

- Series of small lakes lakes (and limnocorrals)
  - E.g., Lake N2
  - Phosphoric acid & Ammonium nitrate
- Pulse
  - 5 X annual loading
  - 6 years
  - Recovery

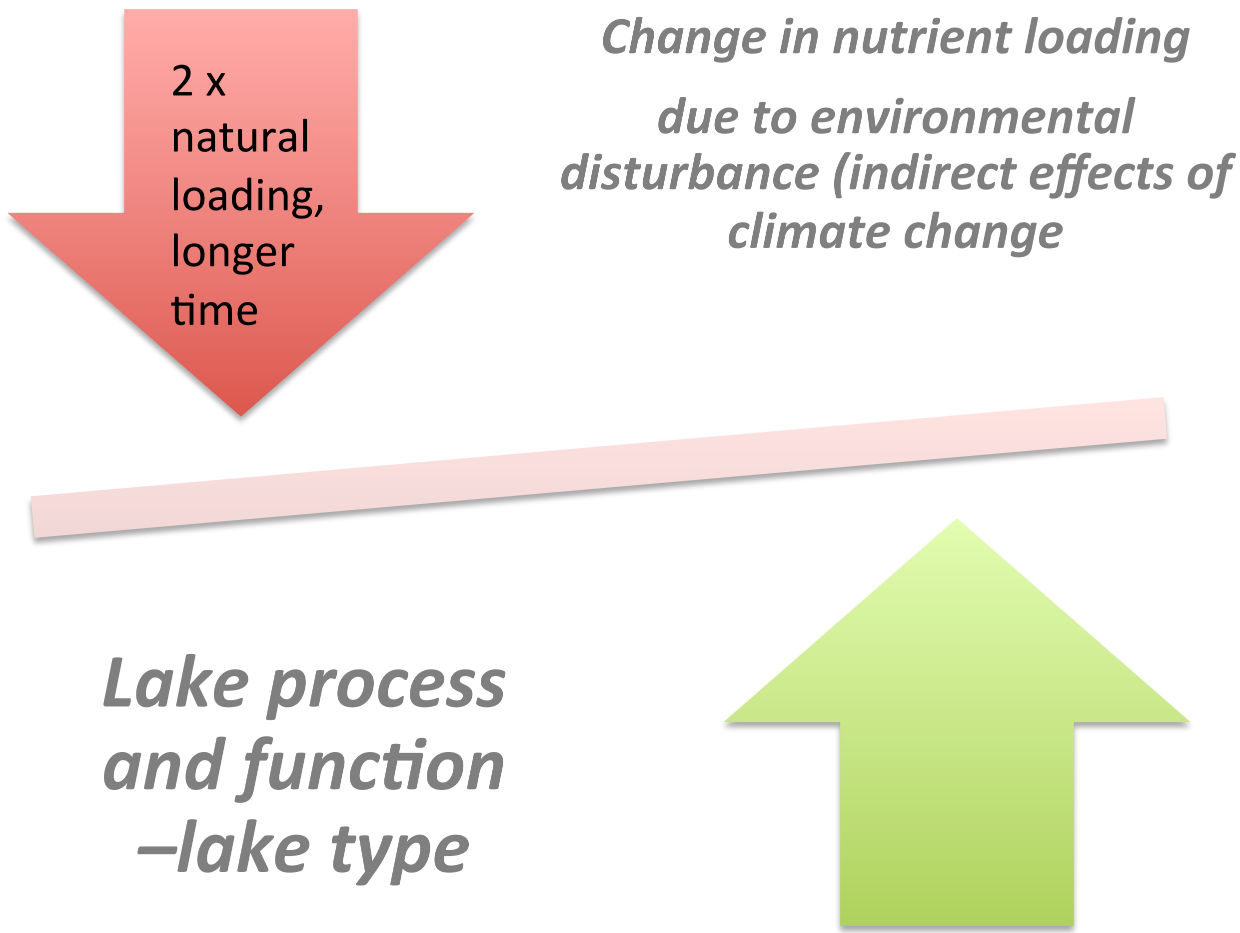
Hershey 1992, Rubelee and Bettez 1995, Kling 1994, Rubelee and Bettez 2001O'Brien et al. 2005, Lienesch et al. 2005

Foundational Research Focus: Theme #3 "Pulse" Lake Fertilization

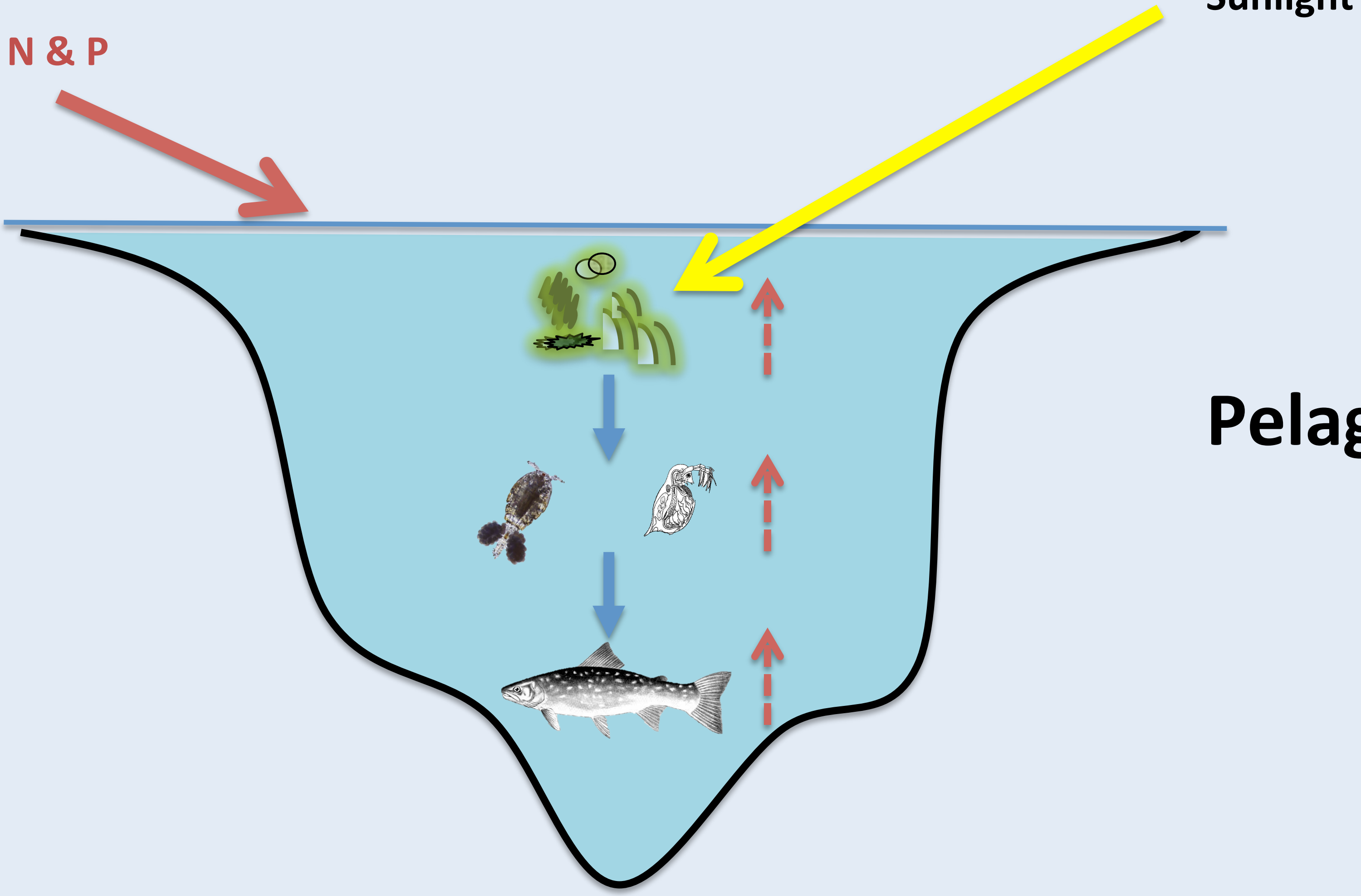


- Primary production
  - 3-10 x higher
  - ~ returned to pre-fert conditions 3 yrs. post
- O_2
  - Low in hypolimnion
  - Had not returned > 12 yrs. post
- Secondary production
  - Mixed response
  - Taxa dependent
- Fish response
  - N2, none – sculpin
    - (chironomids)
  - N1, lake trout = positive growth
    - (snails)

Current Research Focus: Theme #4 "Press" Lake Fertilization



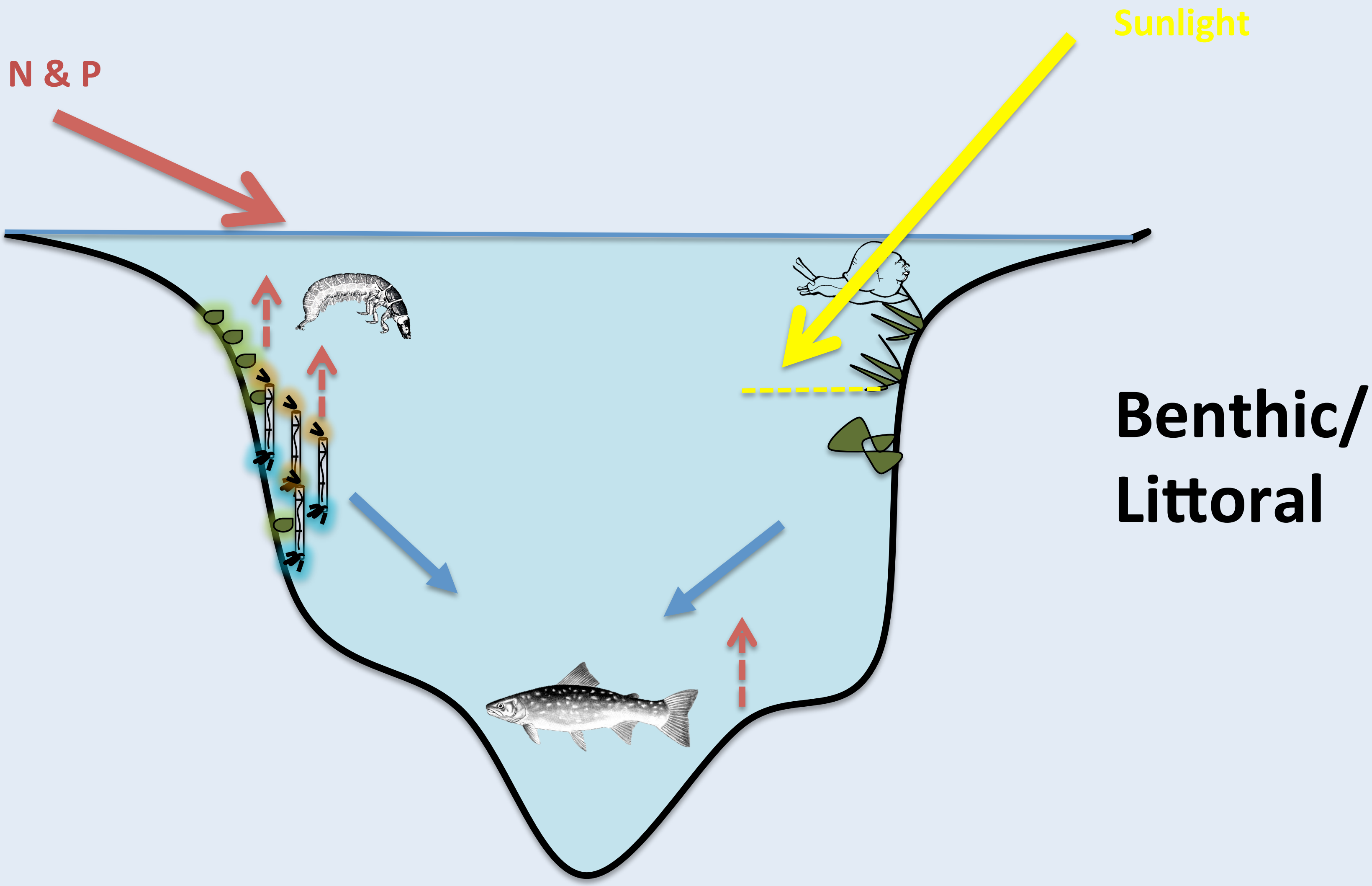
Energetic Pathways



Pelagic?

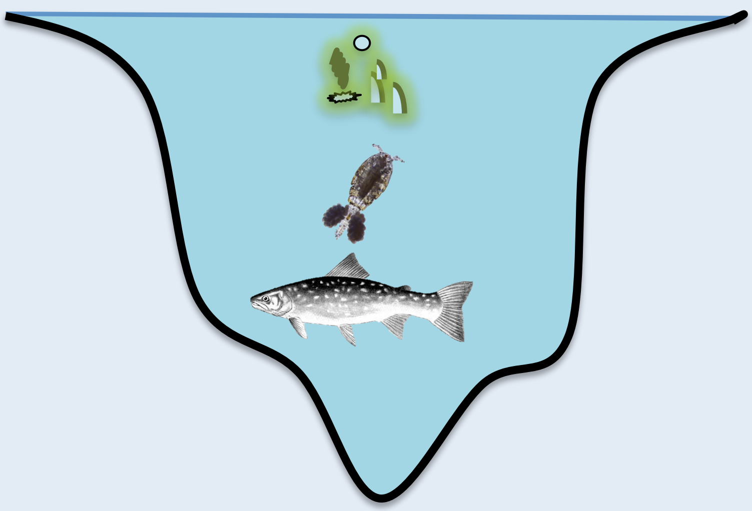
And associated physio/chemical change

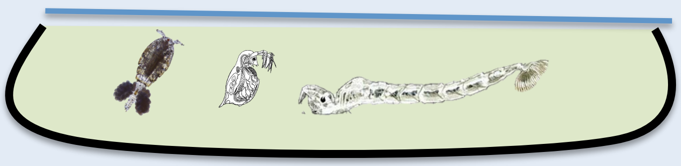
Energetic Pathways



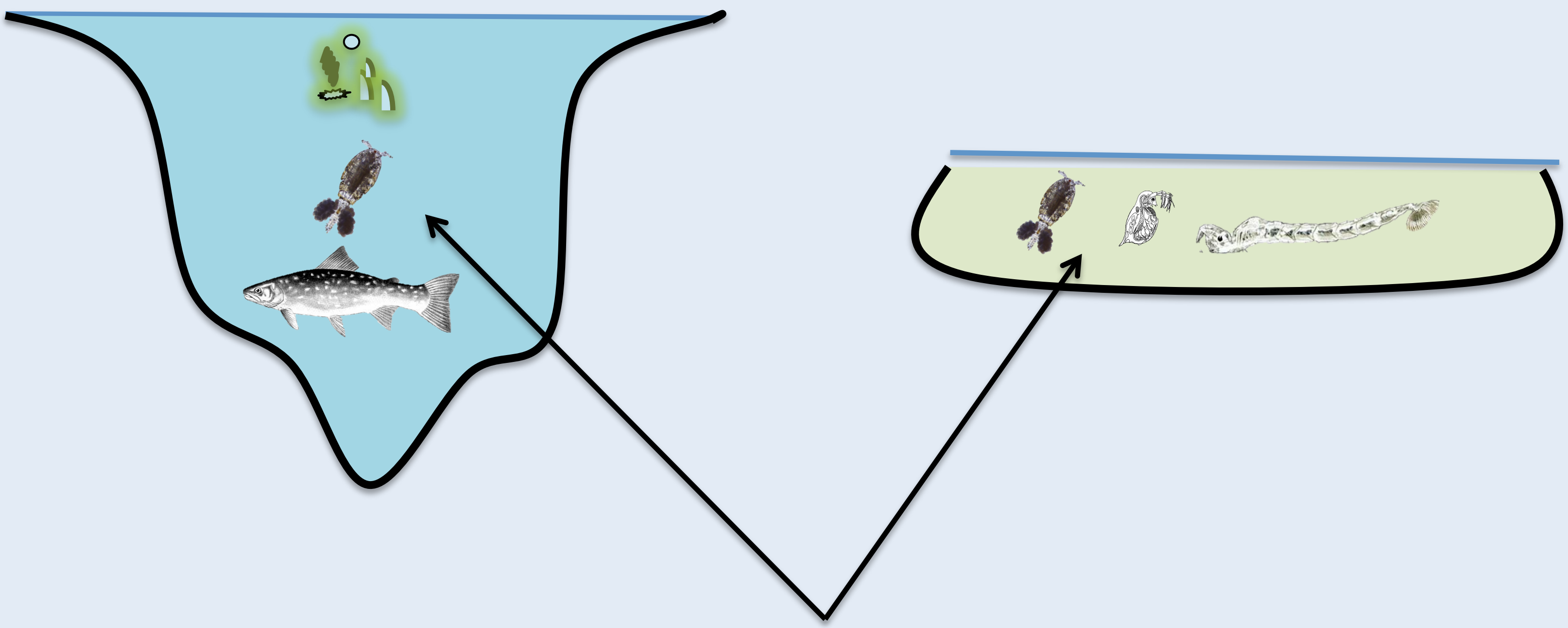
And associated physio/chemical change

Different pathways/responses: lake depth & presence-absence of fish?



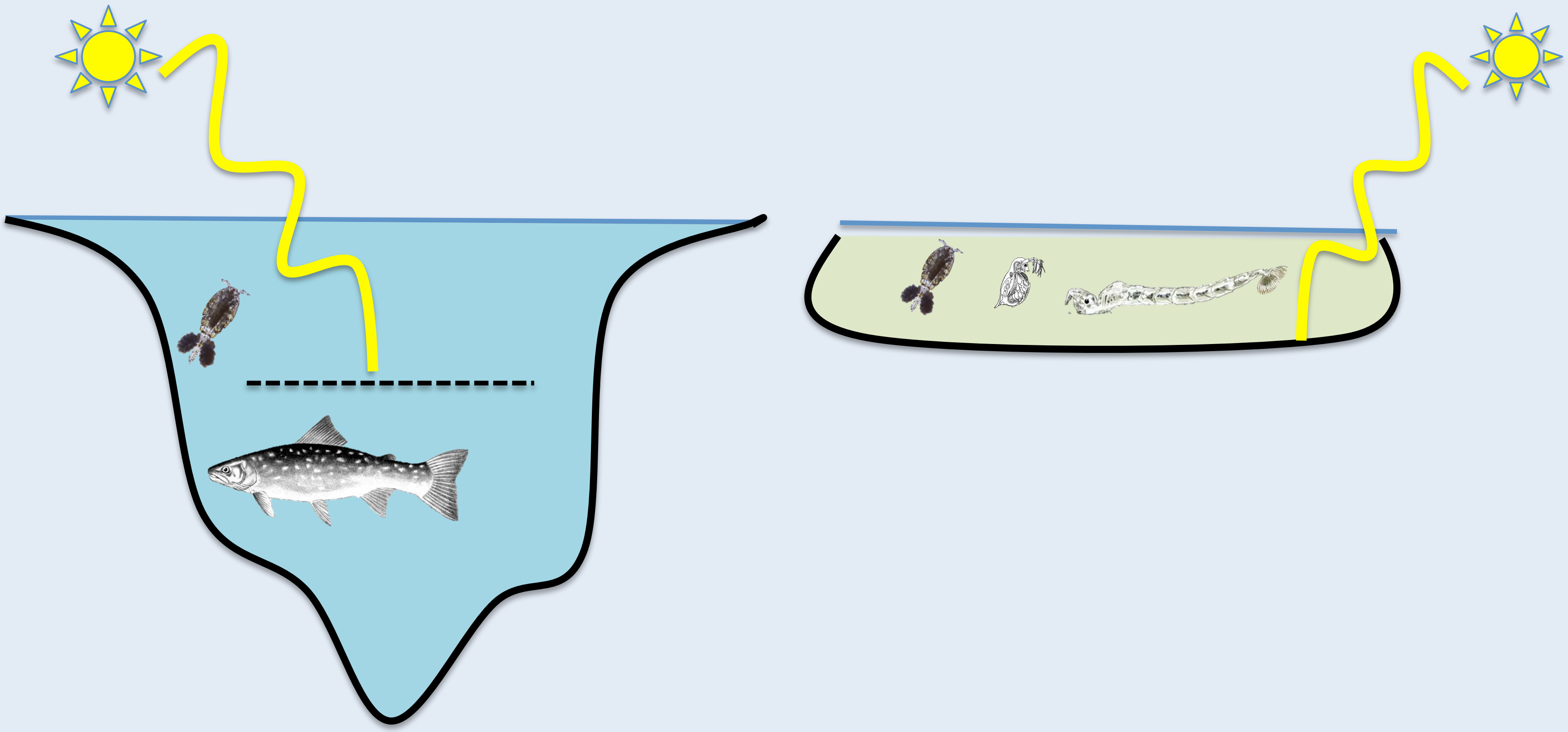


Different pathways/responses: presence-absence of fish?

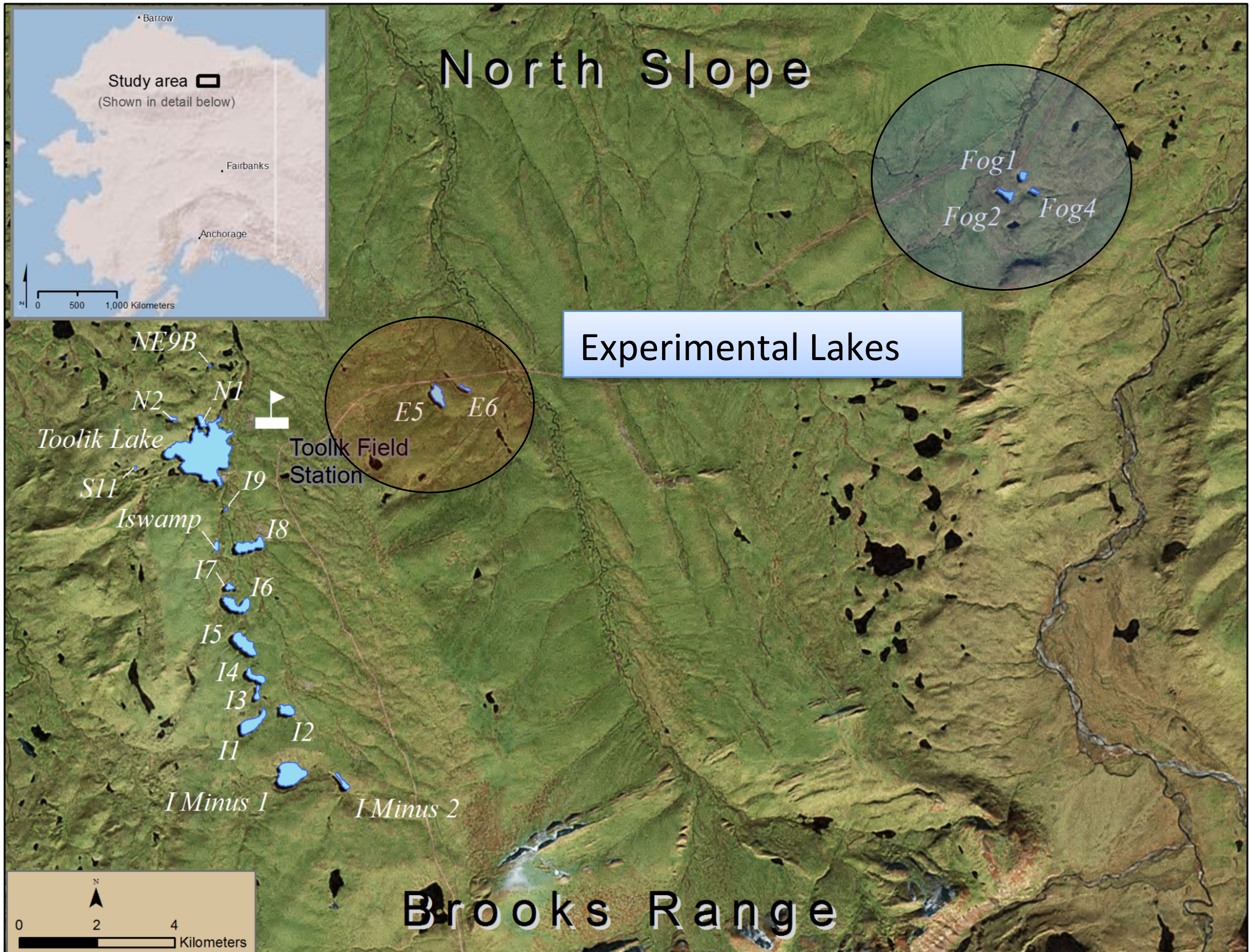


Zooplankton diversity and community structure

Different pathways/responses: lake depth & presence/absence of fish?



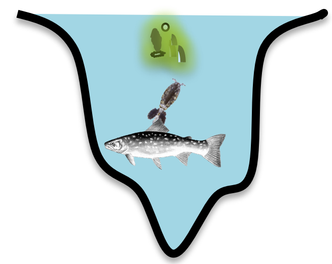
Sentinel and Experimental ARC LTER lakes



Experimental Design

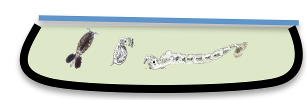
Deep
Fertilized
E5

Deep
Control
Fog2

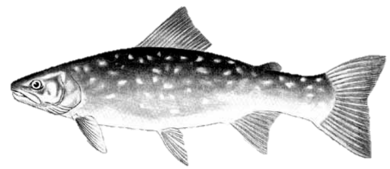


Shallow
Fertilized
E6

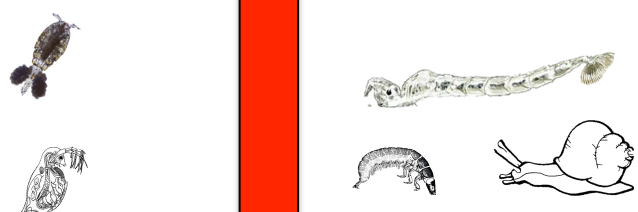
Shallow
Control
Fog4



Food Web & System Response



Fish



Secondary Productivity

Primary Productivity

Physio / Chemical

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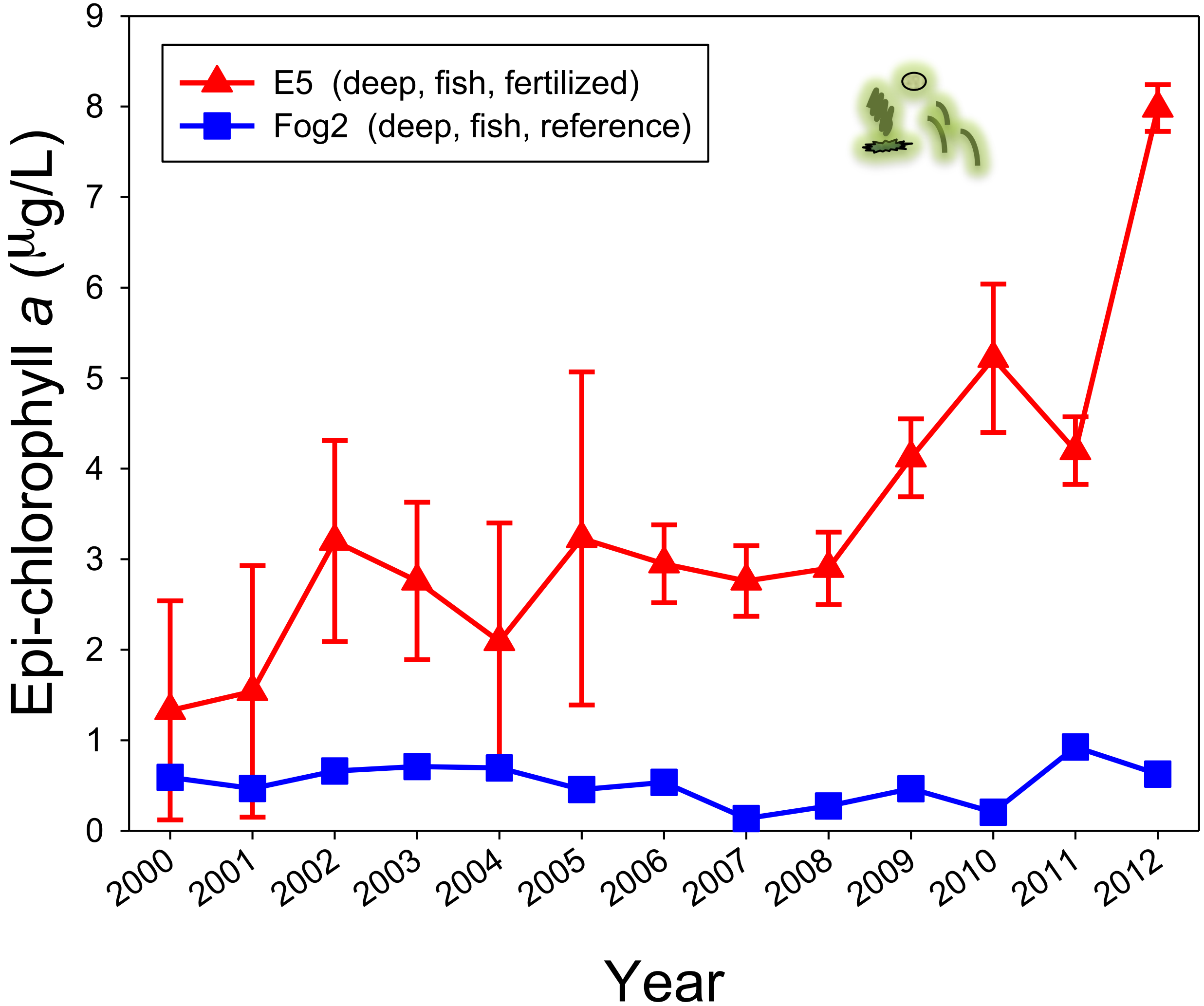
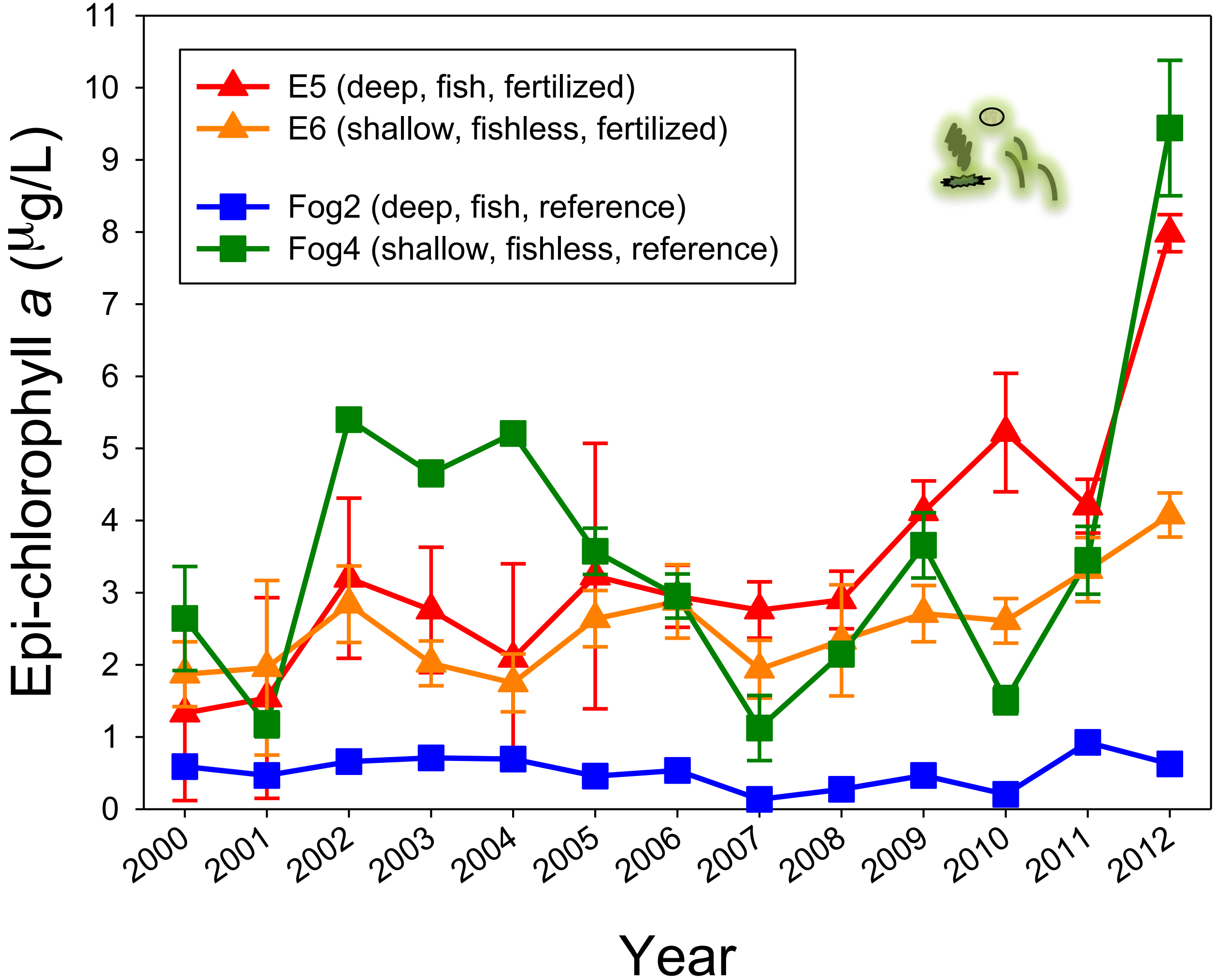
Primary Productivity: chl *a*

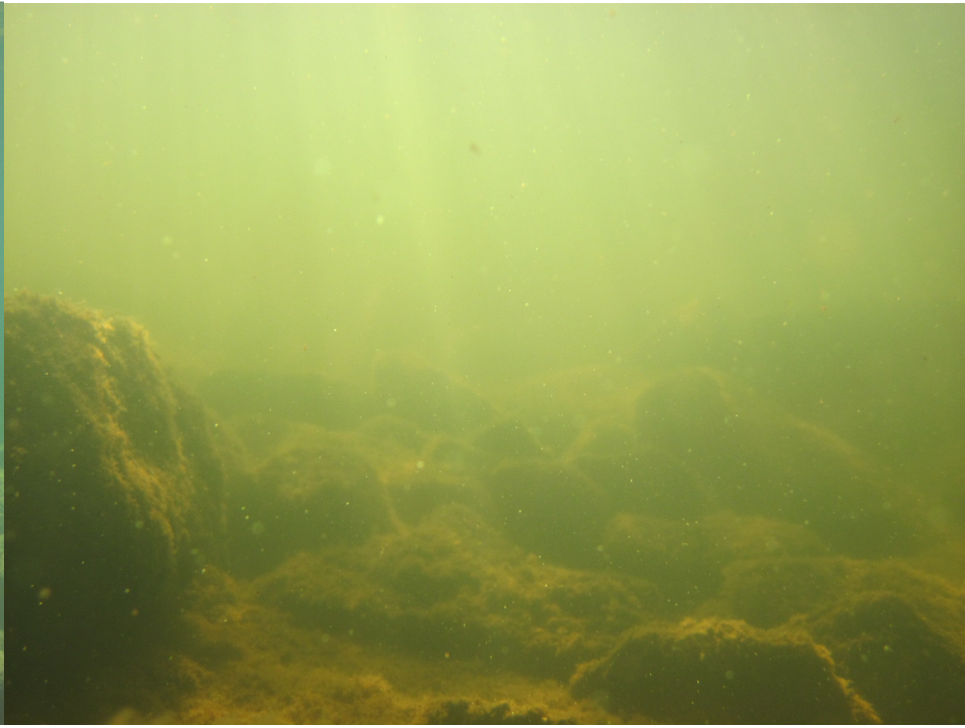


Primary Productivity: chl *a*

No consistent primary <u>fertilization</u> response in SHALLOW treatment lake.



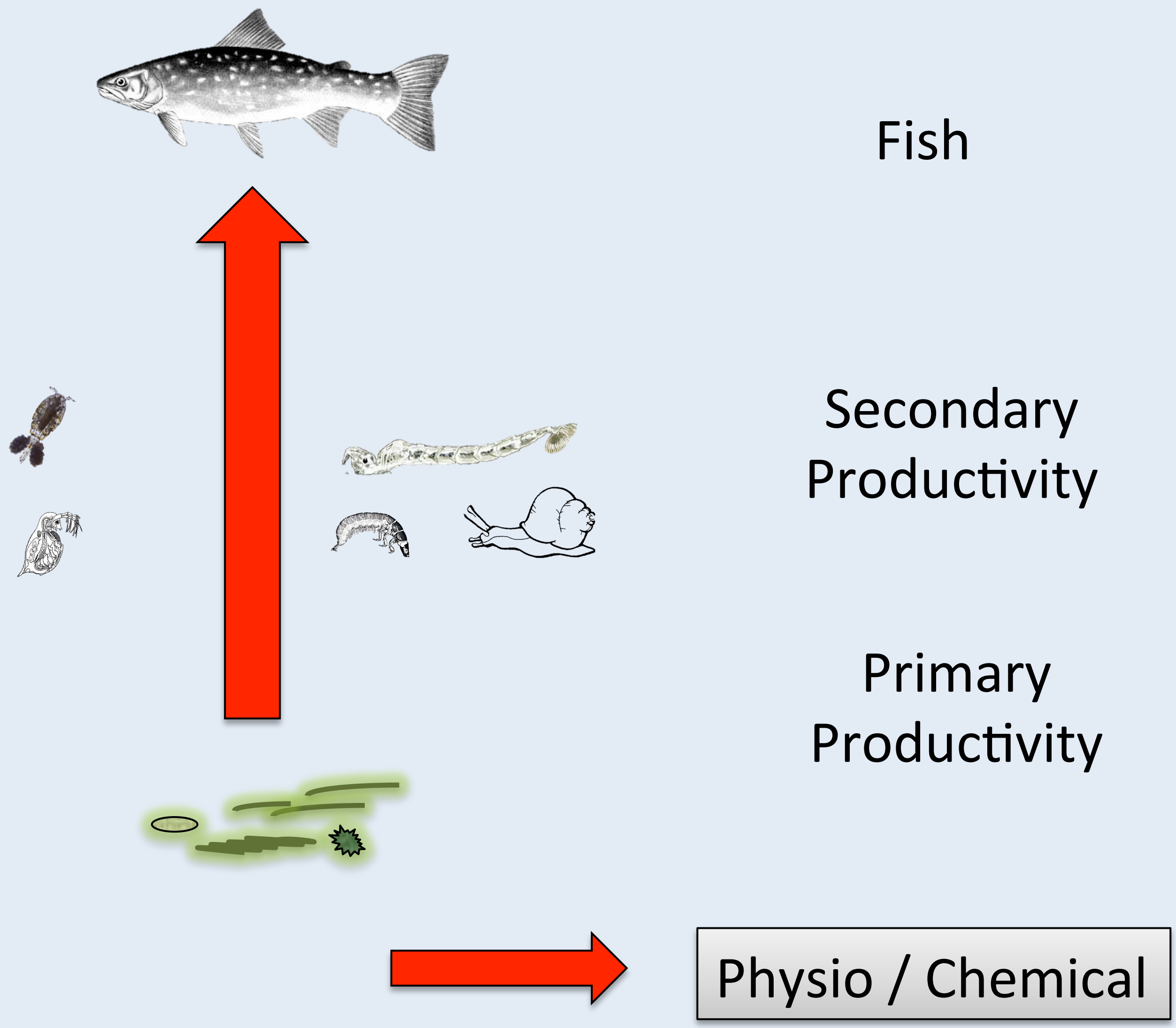
Water Transparency: 2010



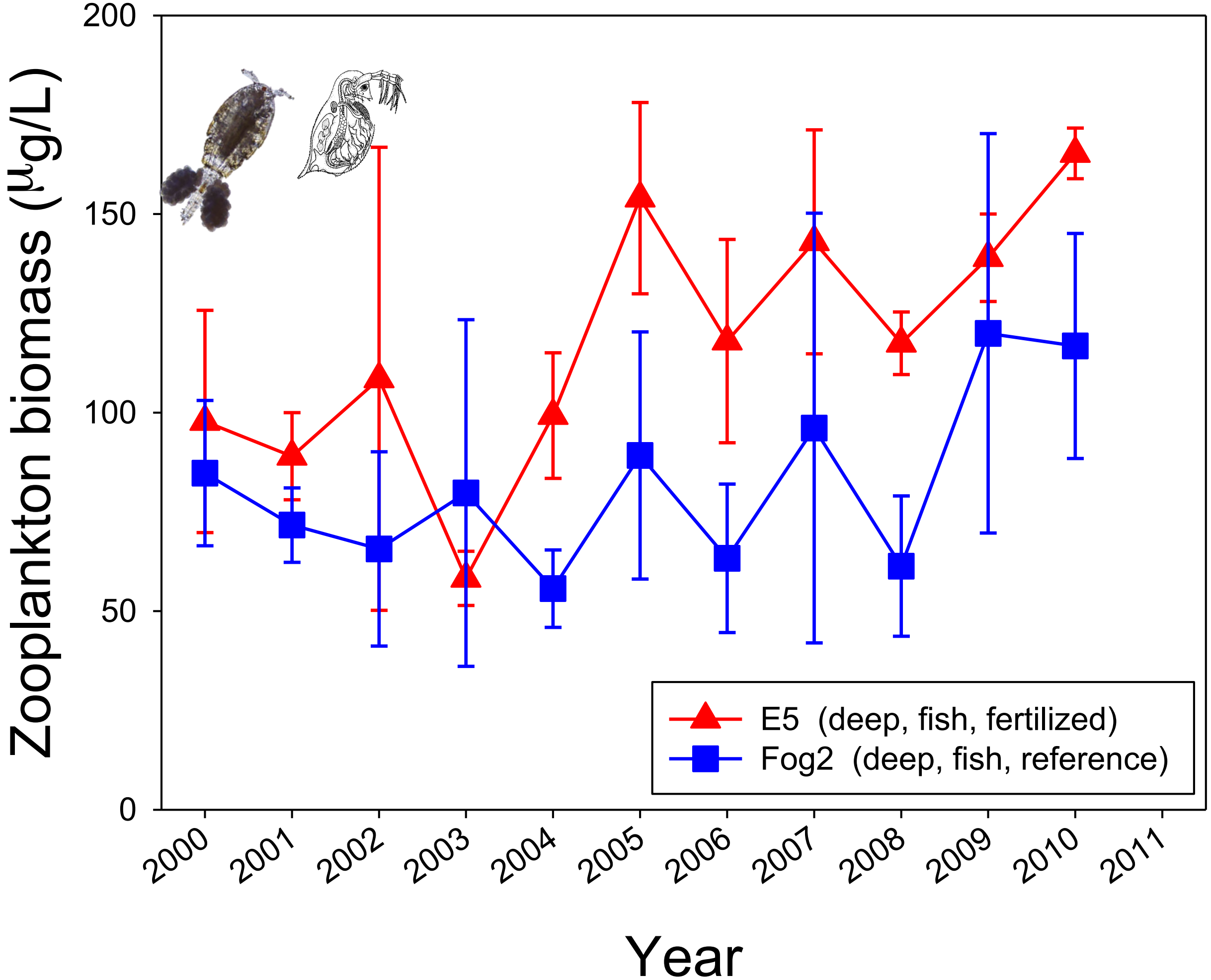
Lake Fog2 – REF
Chl *a* – 0.8 mg/m^3

Lake E5 - FERT
Chl *a* – 4 mg/m^3

Food Web & System Response



Secondary Productivity: Zooplankton



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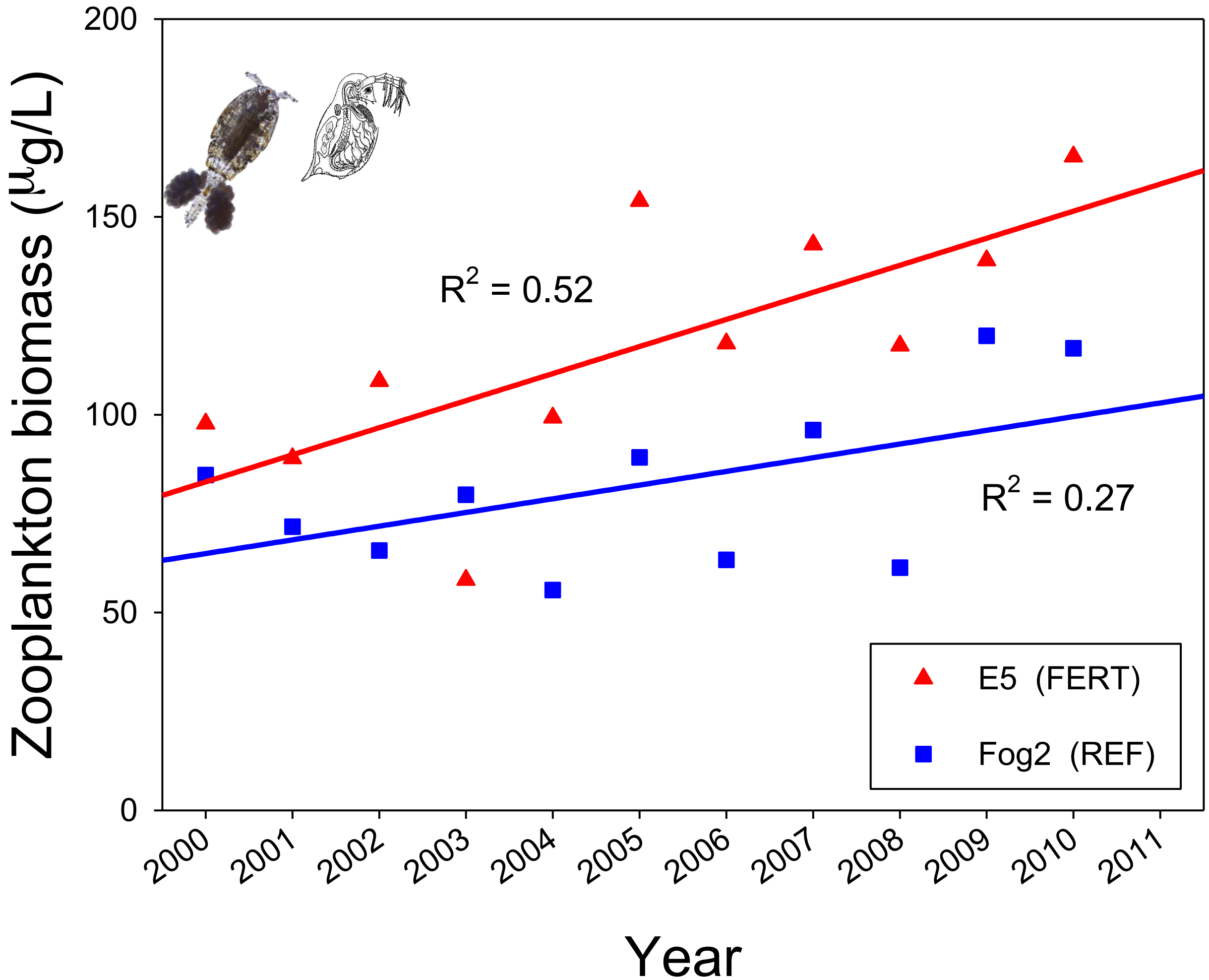
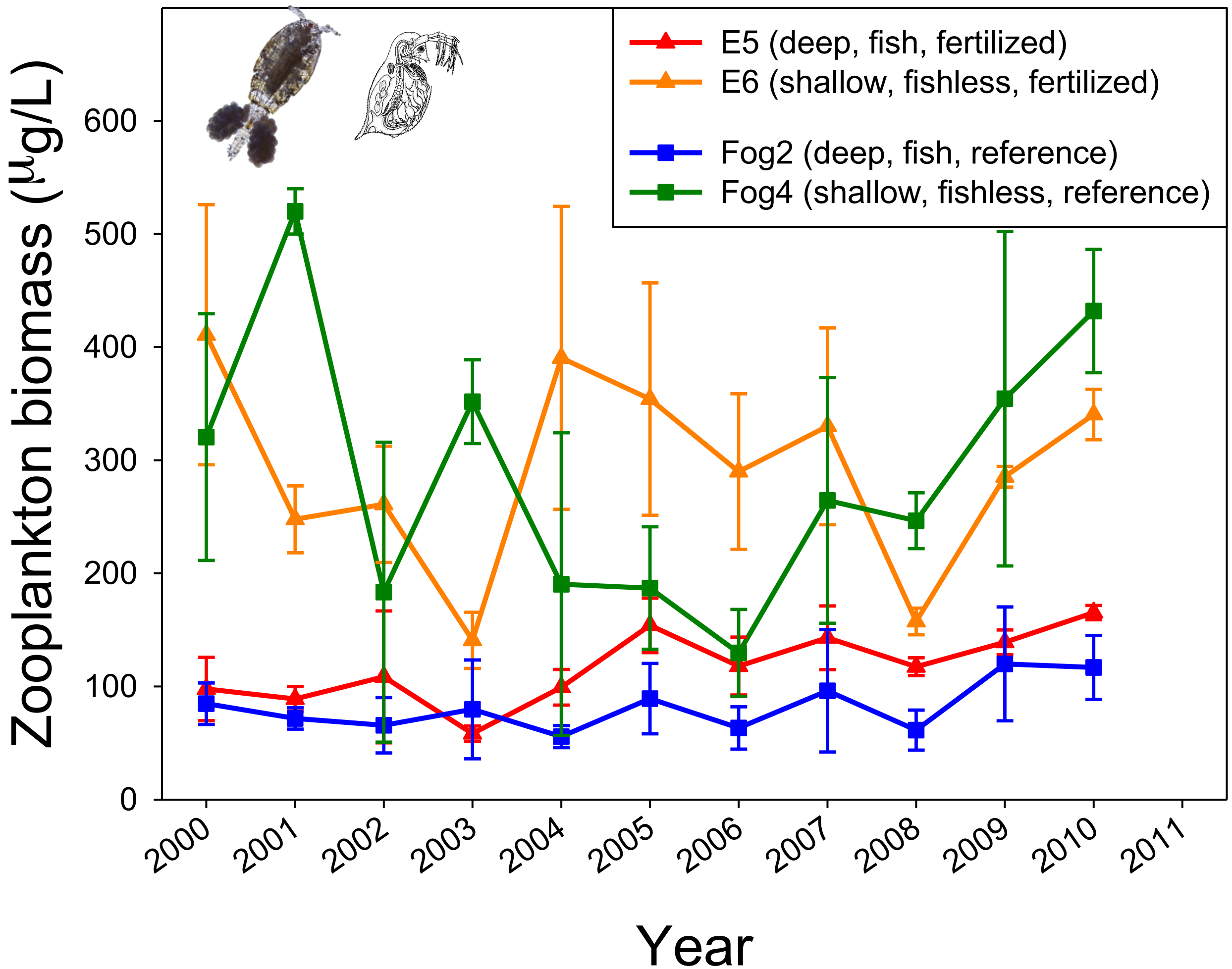
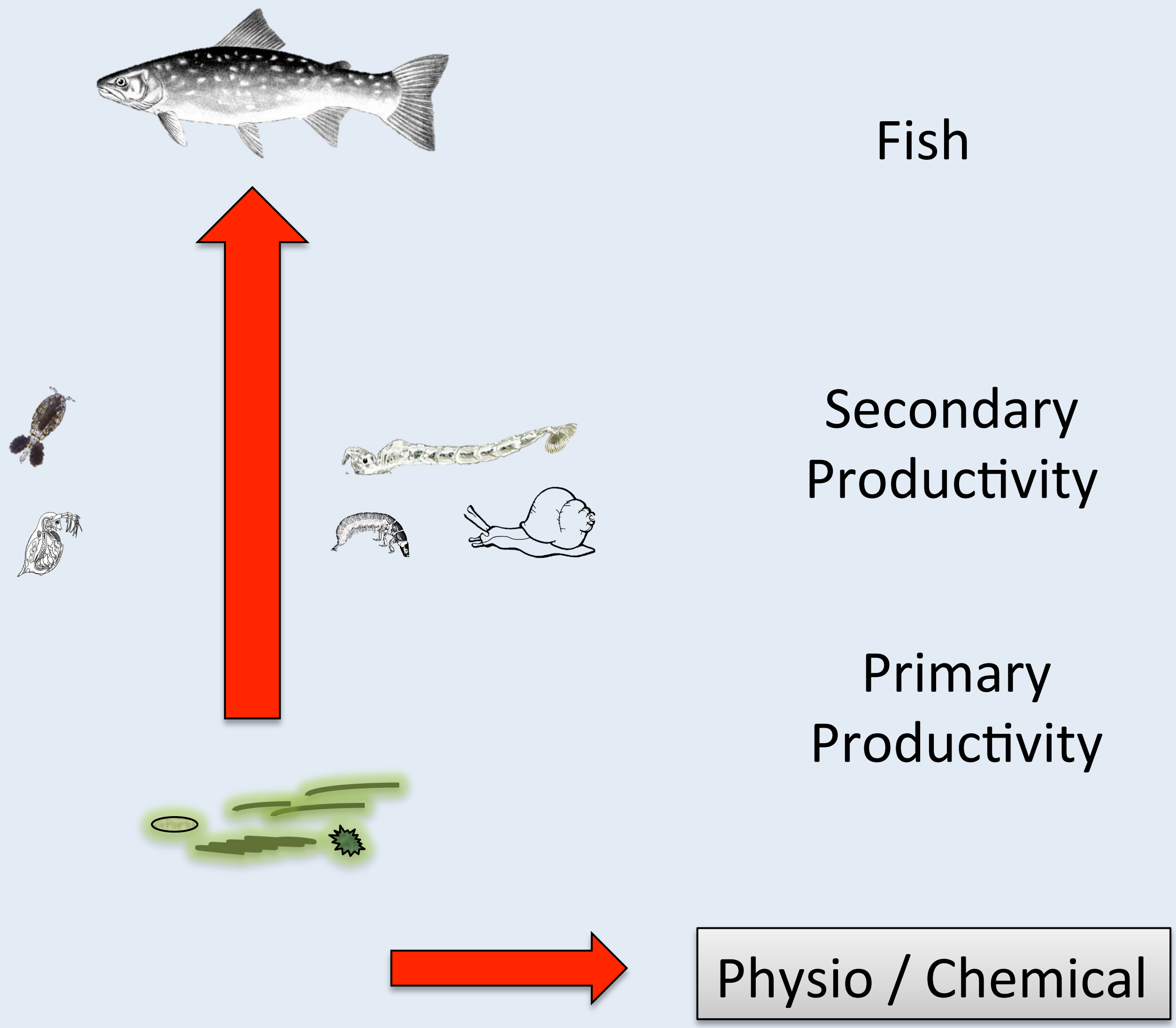


Secondary Productivity: Zooplankton

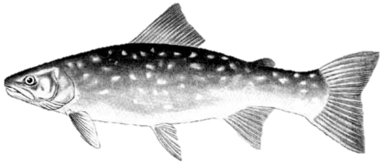
No consistent secondary fertilization response in SHALLOW treatment lake

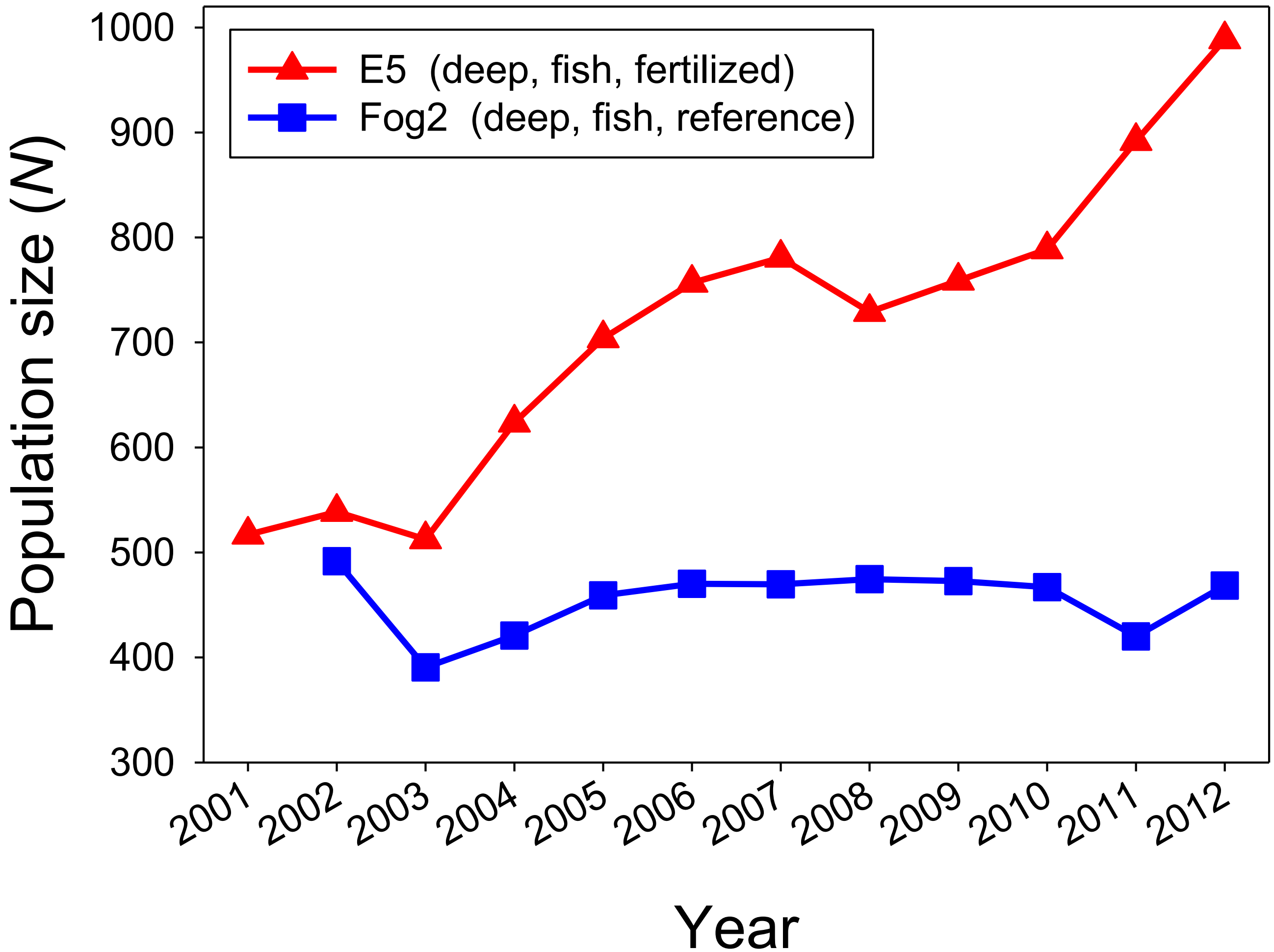


Food Web & System Response

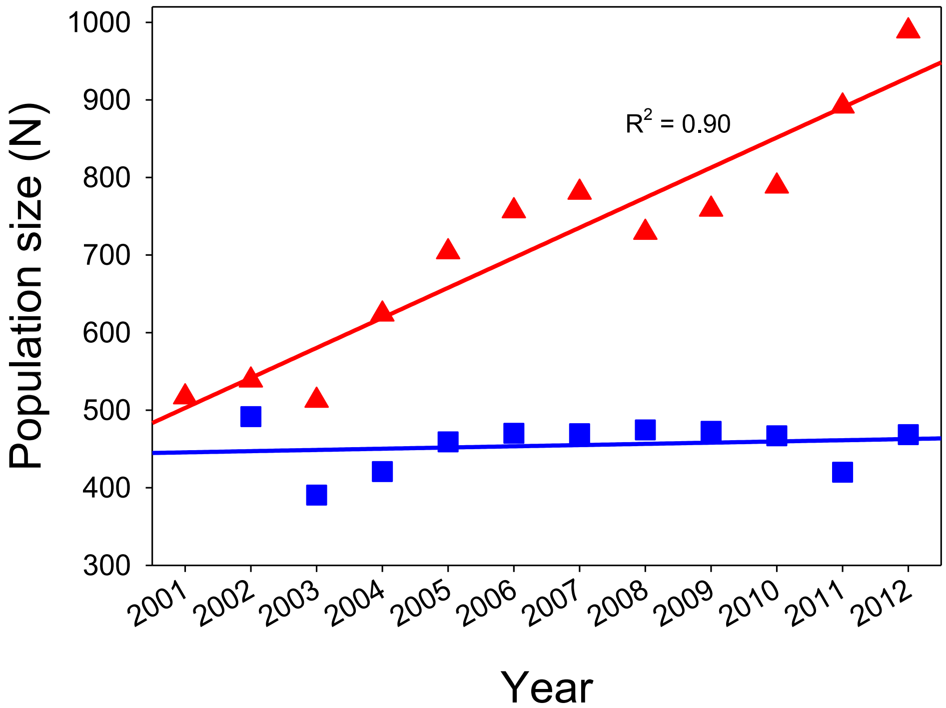


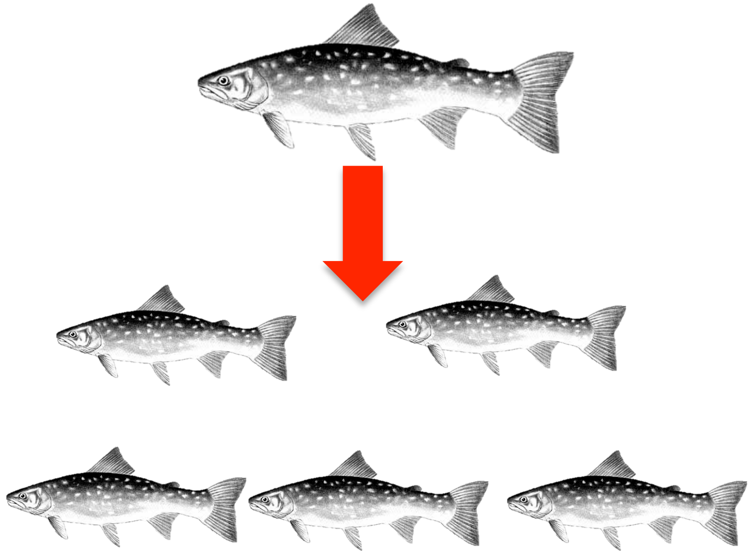
Tertiary Productivity: Fish





Tertiary Productivity: Fish



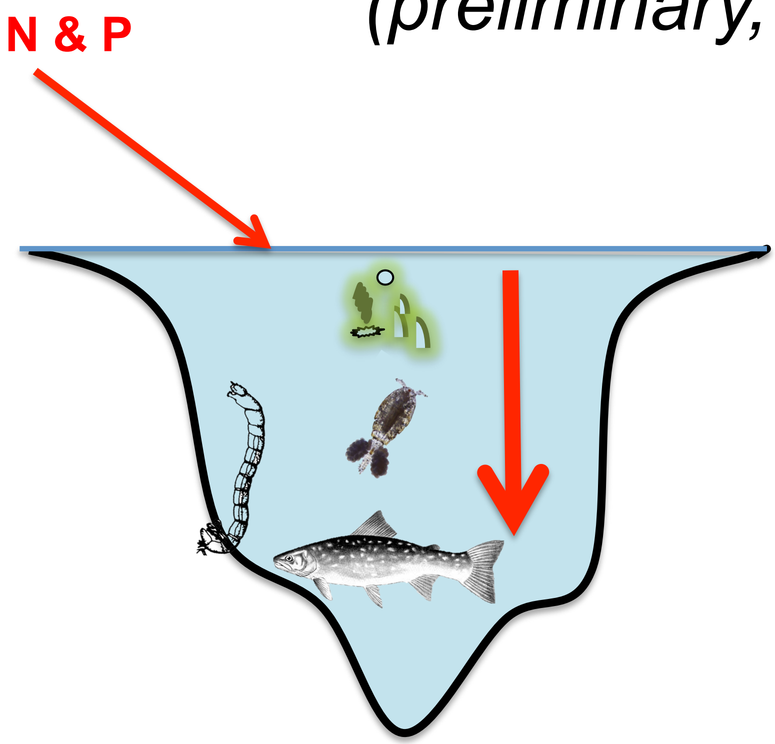


- *Population structure temporarily "stabilized" at high densities of small char*
- *Arctic char populations are regulated by strong intra-specific interactions that determine size structure (Budy and Leucke, in review)*

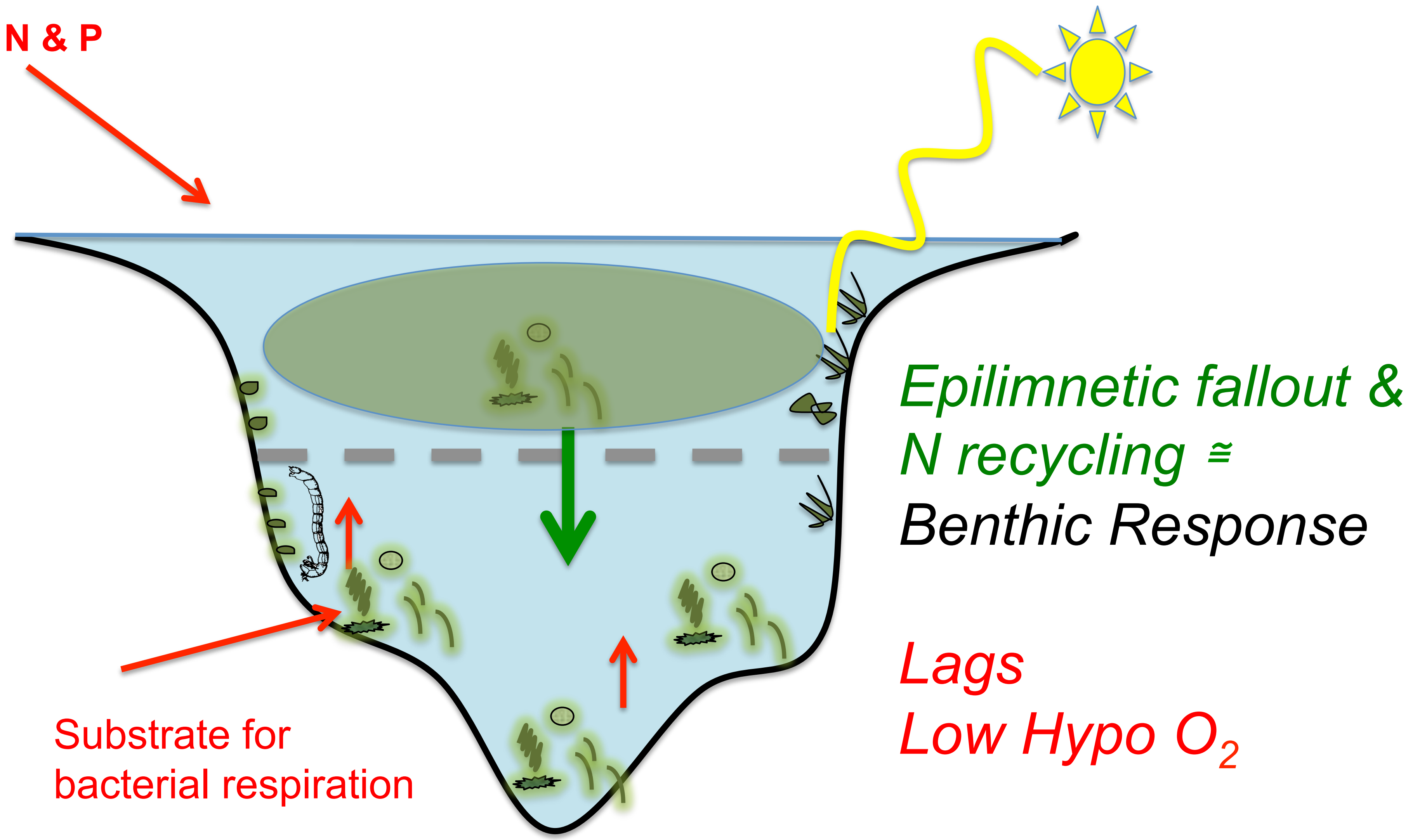
POSTER!

Deep Lakes with fish: System Response

(preliminary, synthesis just begun)

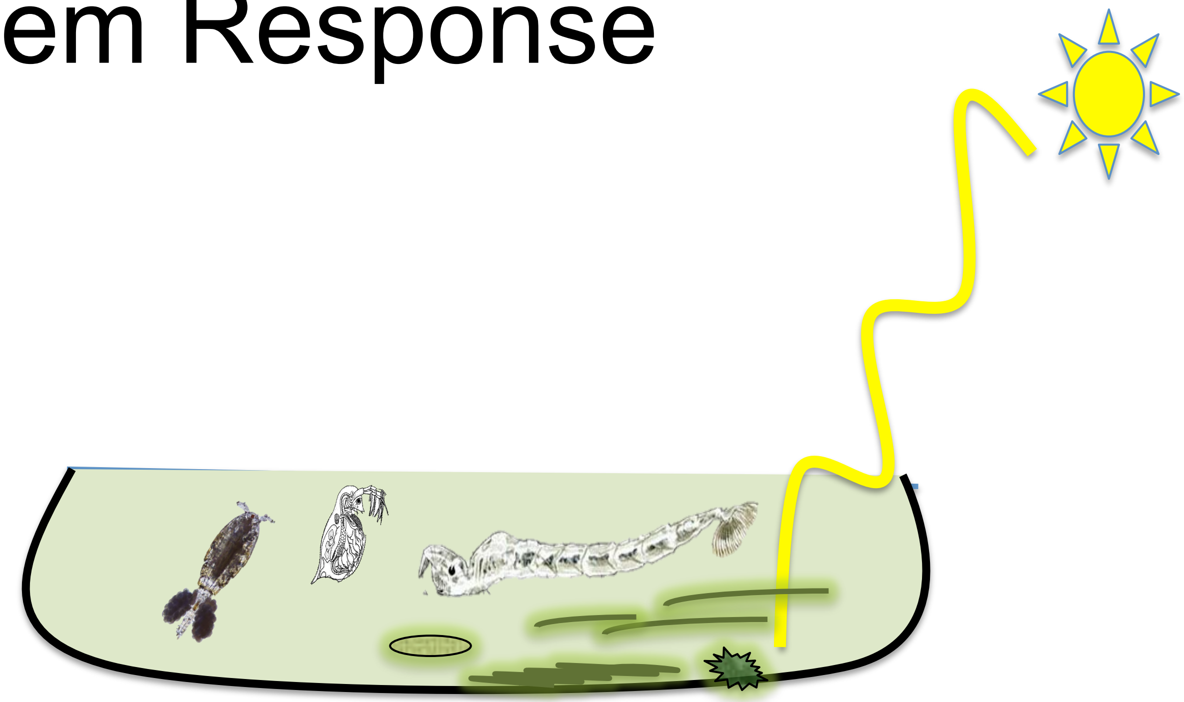


- *Clear and significant response to fertilization at all pelagic trophic levels*
- *Energy flows directly from phytoplankton to zooplankton and pelagic, benthic invertebrates to fish*


N & P
Epilimnetic fallout &
N recycling ≅
Benthic Response
Lags
Low Hypo O_2
Substrate for
bacterial respiration

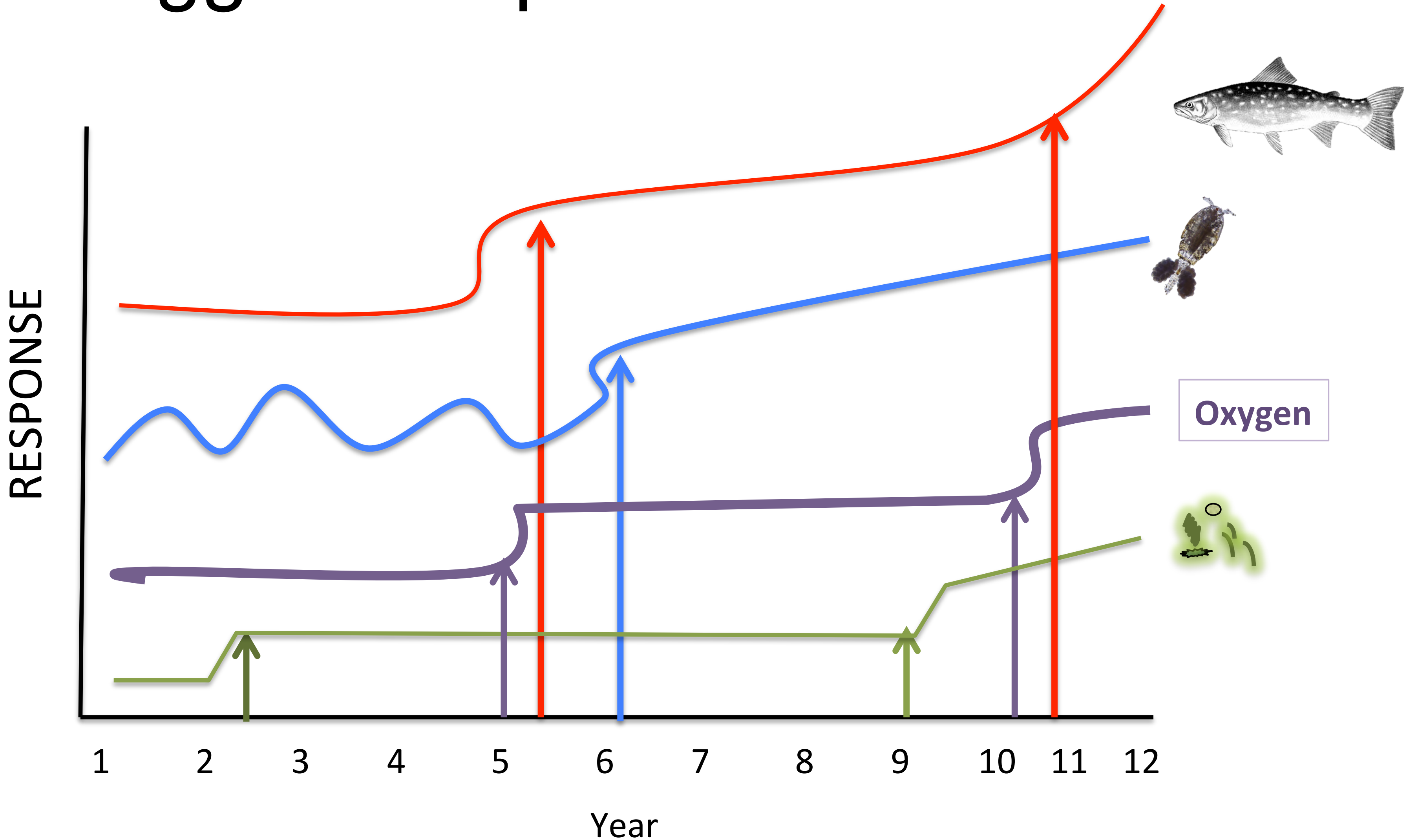
Shallow, fishless lakes: System Response

- *Much more sensitive to inter-annual variation*
- *Response is primarily benthic*
- *Effect of a thermokarst failure in reference lake may be as or more influential than low level fertilization*



POSTER!
VIGNETTE!

Lagged Responses & Thresholds



Conclusions: Current Research Foci

- *Foundational and Current Research: Theme #2 (LTER lake monitoring)*
  - Only a modest signal of increasing temperatures in lake ecosystems
    - However, increasingly frequent warm, dry summers = increased secondary productivity, predicted effects on fish population dynamics.
  - High degree of spatial and temporal synchrony among lakes, in response to temperature.
  - Microbial communities can respond rapidly to environmental change via “Species Sorting”
    - Predictable annual cycles of community composition may serve as indicators of ecosystem change
  - Arctic char populations are regulated by strong intra-specific interactions that determine size structure. Net growth is determined by the # of ice free days.

- *Current Research Theme #4: “Press” Lake Fertilization Experiments*
  - Response is lagged and occurs over different time steps depending on trophic level.
  - Clear and significant pelagic response to fertilization at all trophic levels, and energy flows directly from phytoplankton to zooplankton, to fish.
  - Ecosystem response indicates certain thresholds had to be met or exceeded to stimulate a consistent response at the next trophic level, total response required 10 years to be fully manifested.
  - Ecosystem response to fertilization varied among fishless, shallow lakes and deep lakes with fish.
    - Shallow, fishless lakes, fertilization stimulated increased benthic productivity.
    - Deep lakes with fish, fertilization had direct effects on the pelagic food web but also had indirect effects on the benthos in the form of phytoplankton fall out and nitrogen recycling.

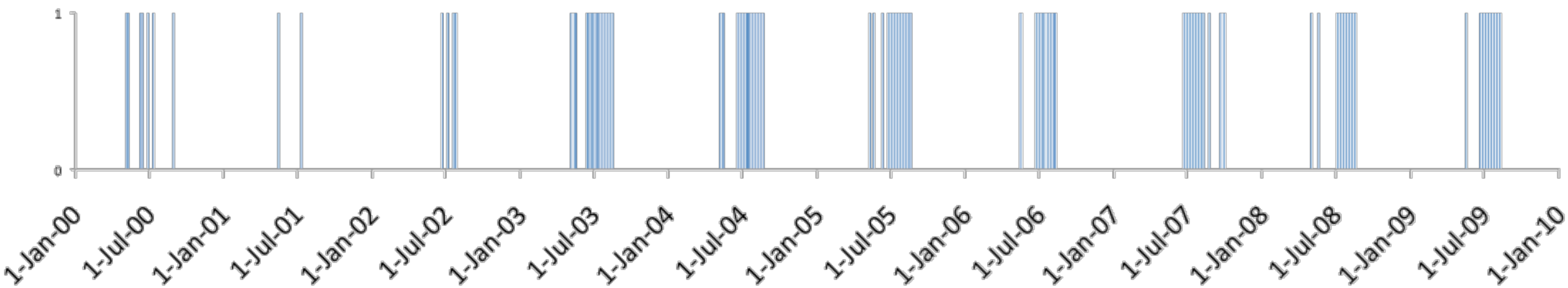
Future

- Continue Current Research Themes:
  - LTER lake monitoring
    - To be continued…
    - Synthesis of sentinel lake limnology time series
      - Signals of climate change, direct and indirect
      - Synchrony, spatial and temporal
  - “Press” Lake Fertilization Experiments
    - 2013 final year, recovery stage begins
      - Analysis of full fertilization response
  - New Theme: Experimental Lake Warming
    - Experimentally warm whole lakes
      - Late summer, warmer and deeper epilimnion, more ice free days
    - Measure response at all trophic levels
    - Run parallel small laboratory and pond experiments
    - Model effects at landscape scale, modeling
      - Bioenergetics, satellite imagery


Thank you!

Extra slides TO HAVE ON HAND

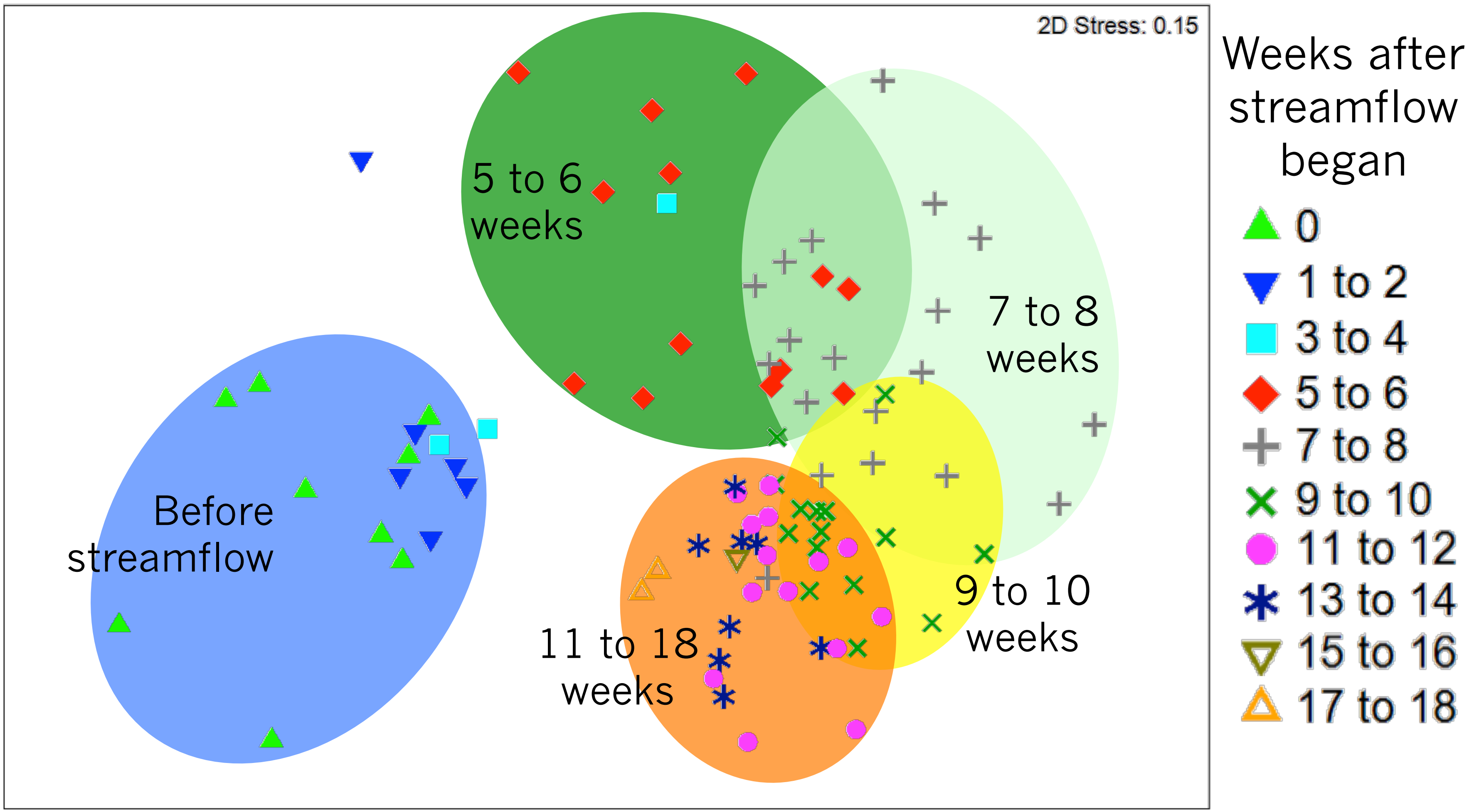
Arctic LTREB: 10 Years at Toolik Main



- Toolik Lake samples include:
  - Pre-thaw samples collected through the ice
  - Weekly samples during open water periods starting in 2003
  - Epilimnion, Hypolimnion, and primary inlet stream
- Sampling program extends to many other lakes, streams, and terrestrial environments
- Total archive = 3,901 (pre-2012)

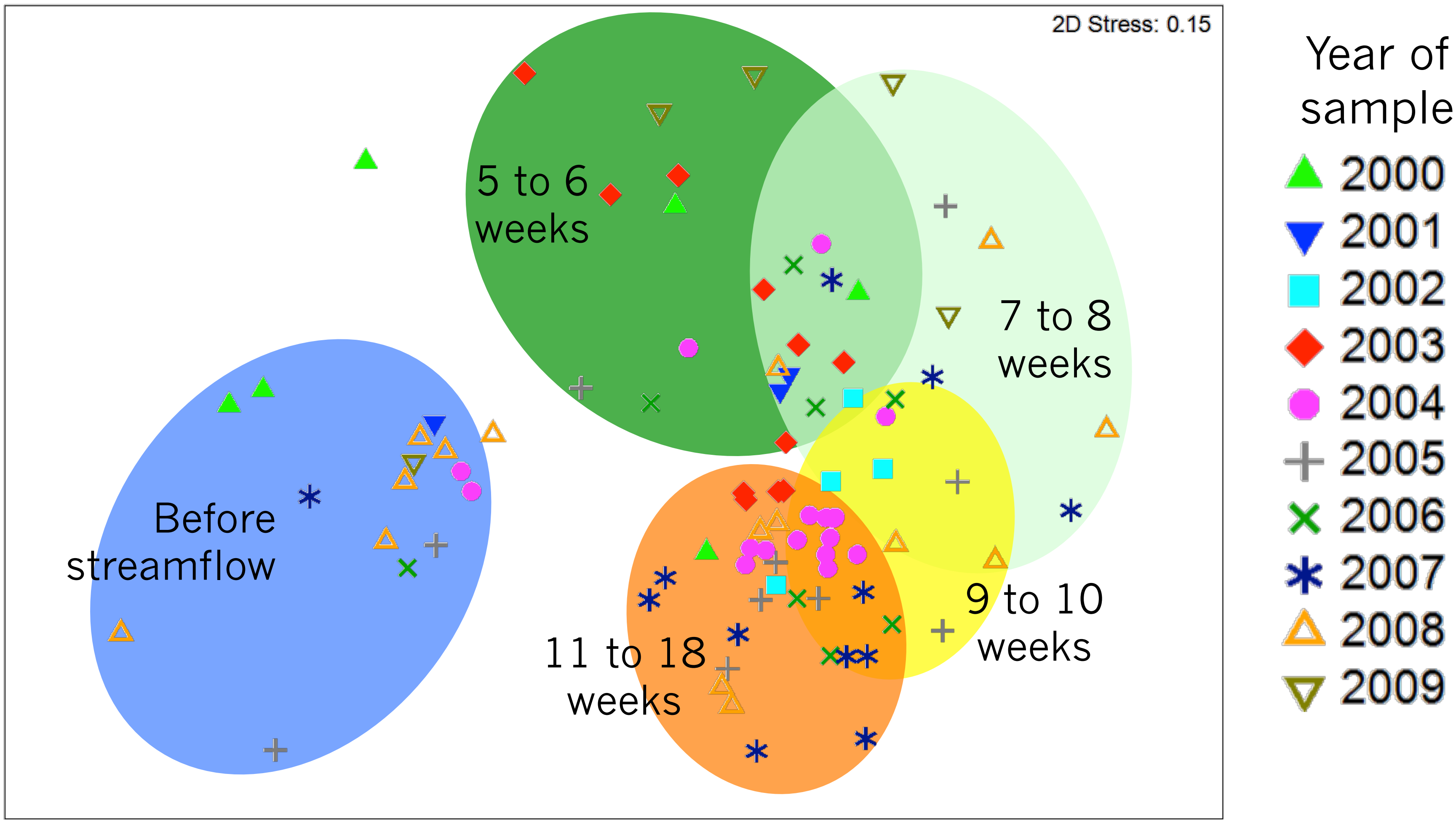
Seasonal bacteria in Toolik L. epilimnion

- 91 samples, 191,425 sequences (16S-V2)
- Rapid succession for 10 weeks following thaw
- Slow change during the rest of the year



Communities reassemble for 10 years

- High seasonal variability
- Low interannual variability



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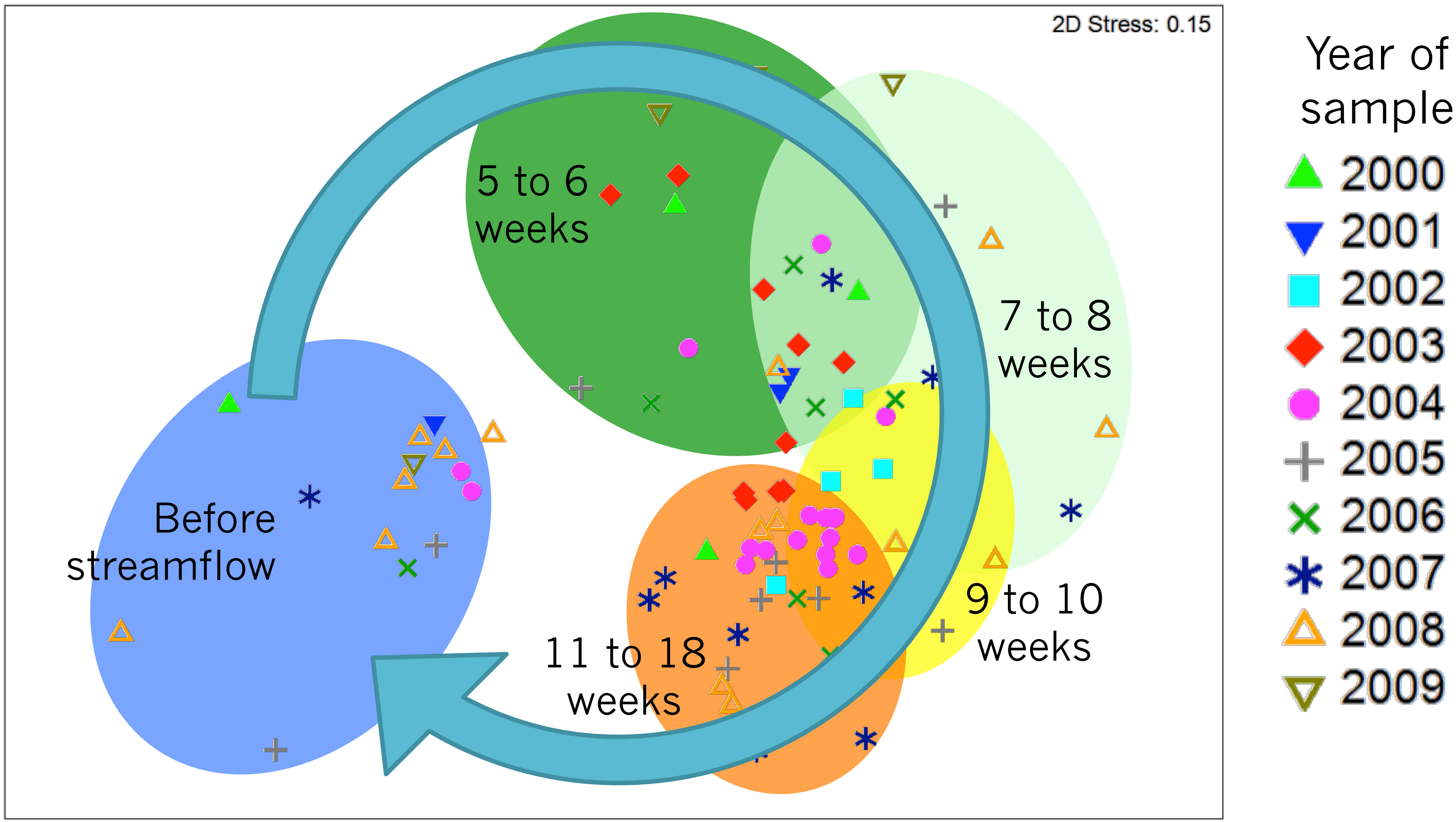
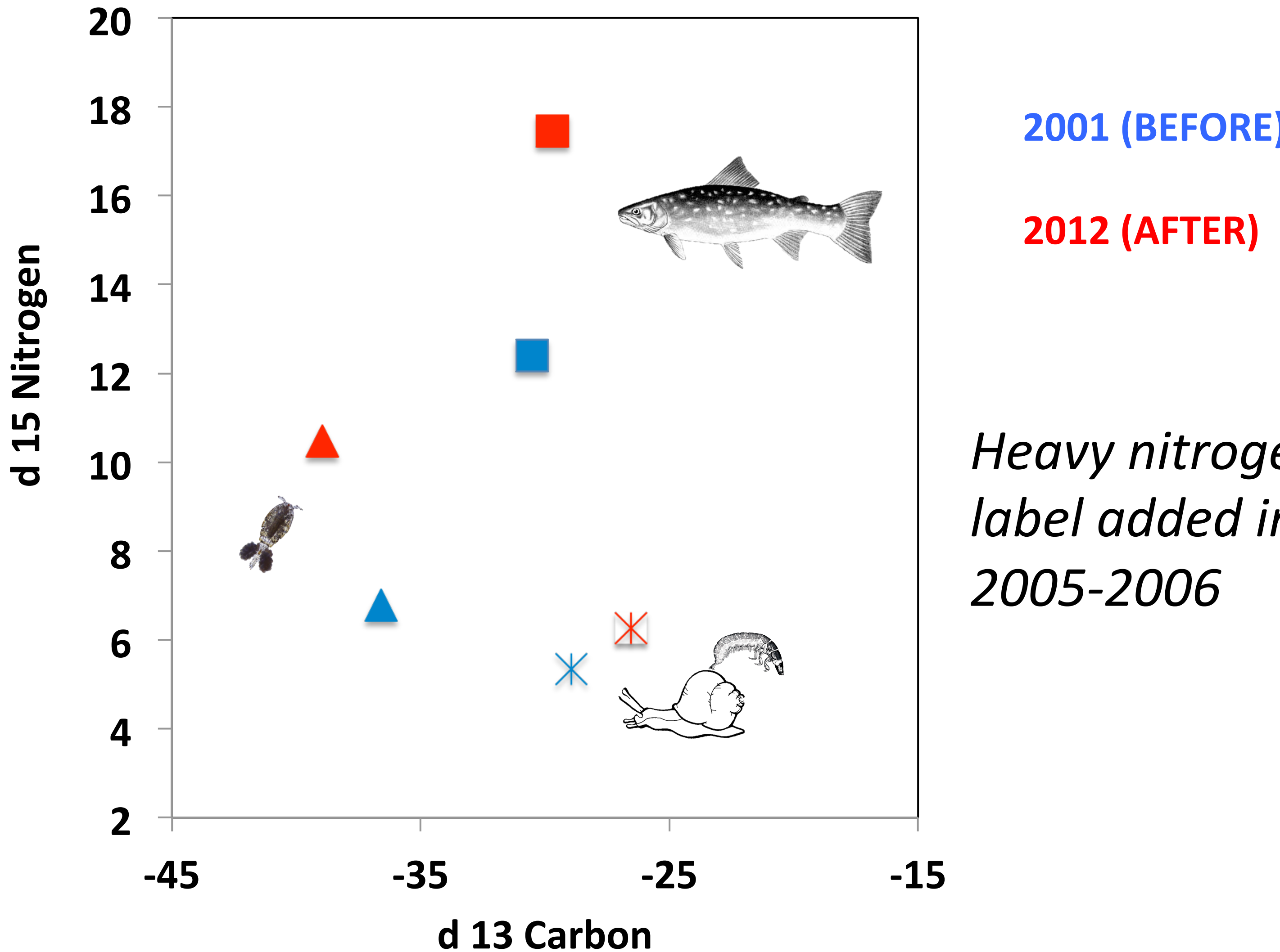


MICROBIAL Conclusions

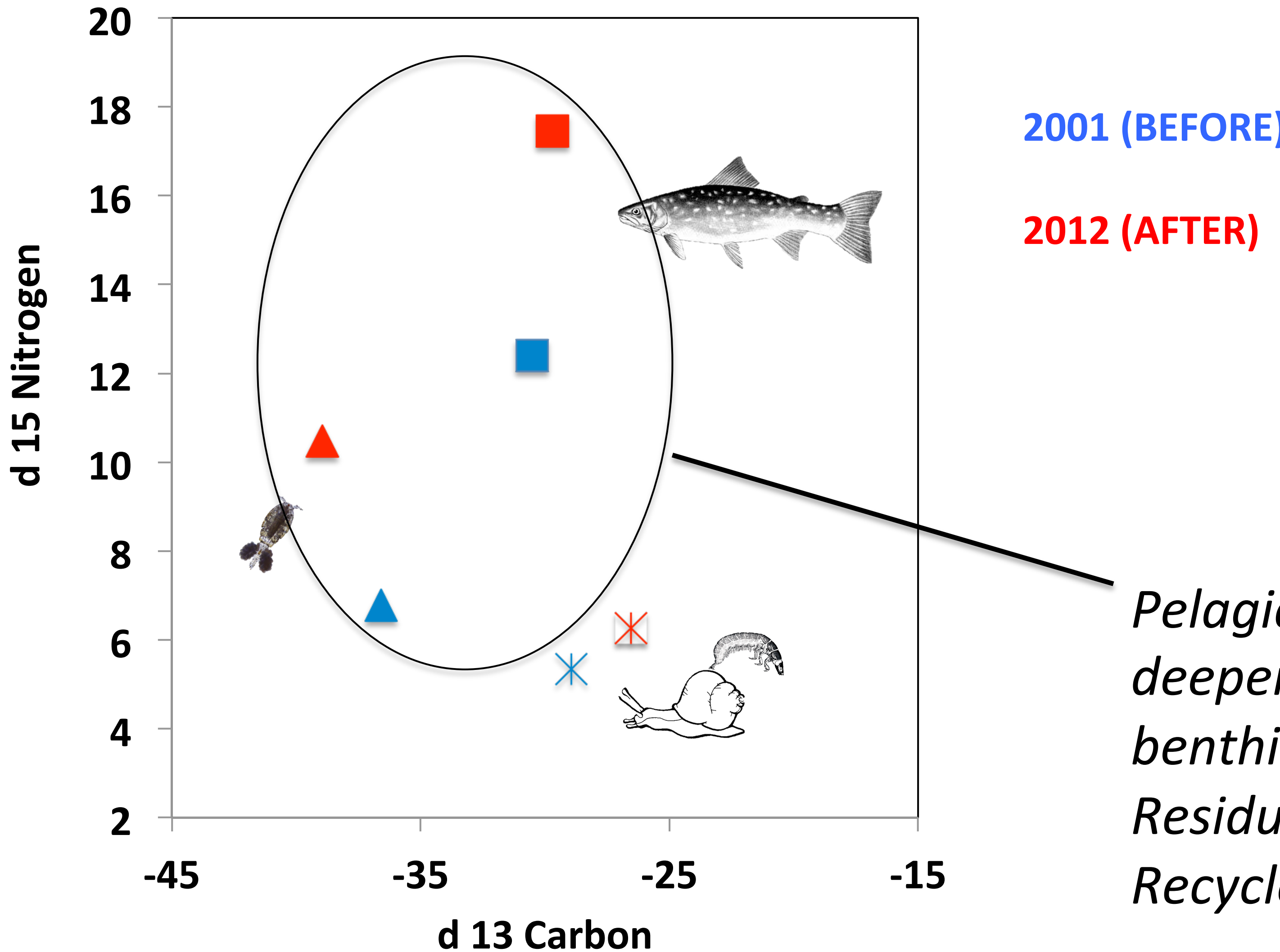
- Microbial communities can respond rapidly to environmental change via "Species Sorting"
- Landscape metacommunity is a reservoir of bacterial and archaeal diversity for down-slope environments
- Dispersal influences communities via:
  - mass effects (soilwater to streams)
  - inoculation followed by species sorting (lakes)
- Variability in community composition is greater seasonally than interannually
- Predictable annual cycles of community composition may serve as indicators of ecosystem change

Lag effects: nitrogen recycling?



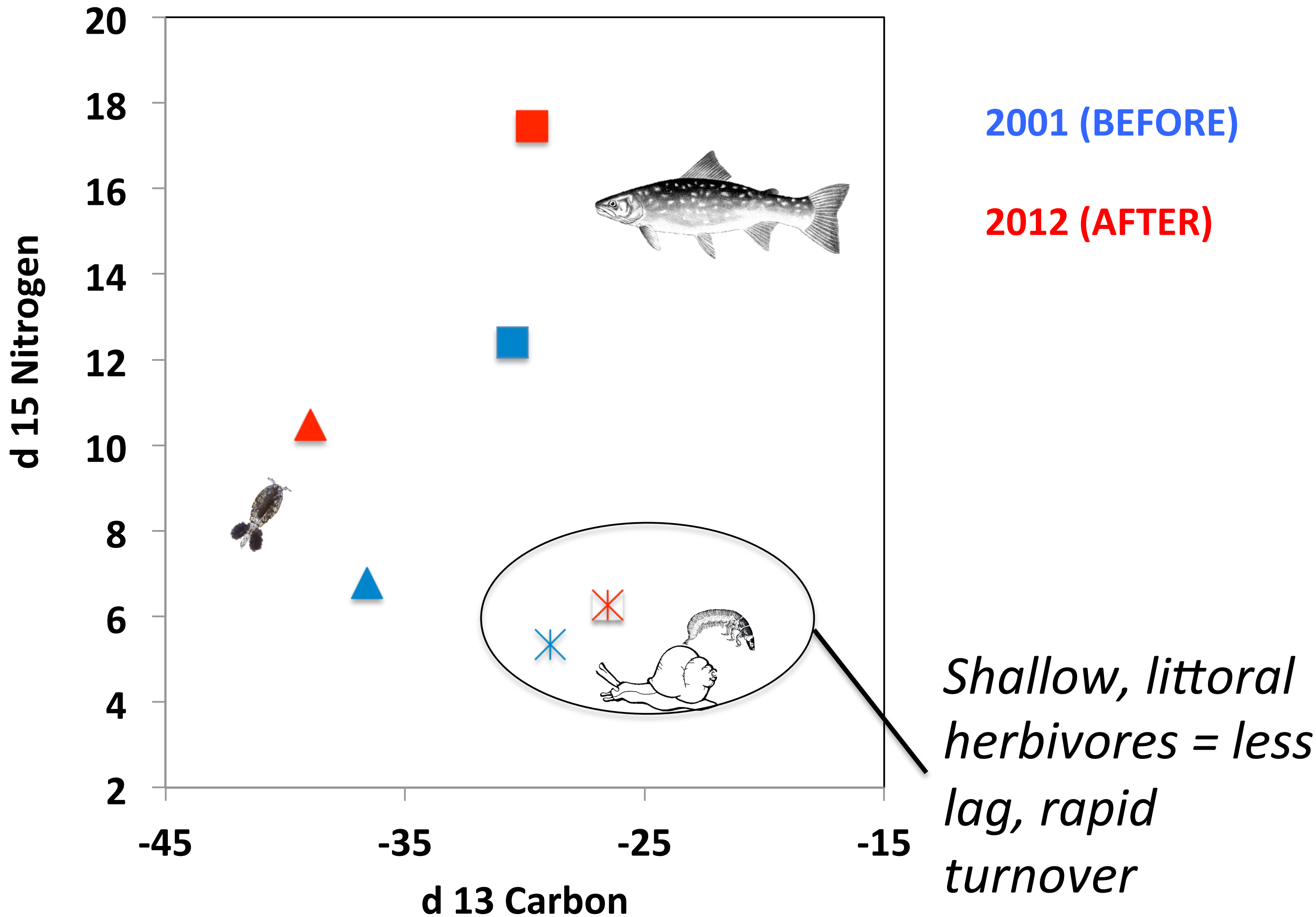
Heavy nitrogen label added in 2005-2006

Lag effects: nitrogen recycling?

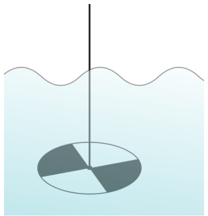


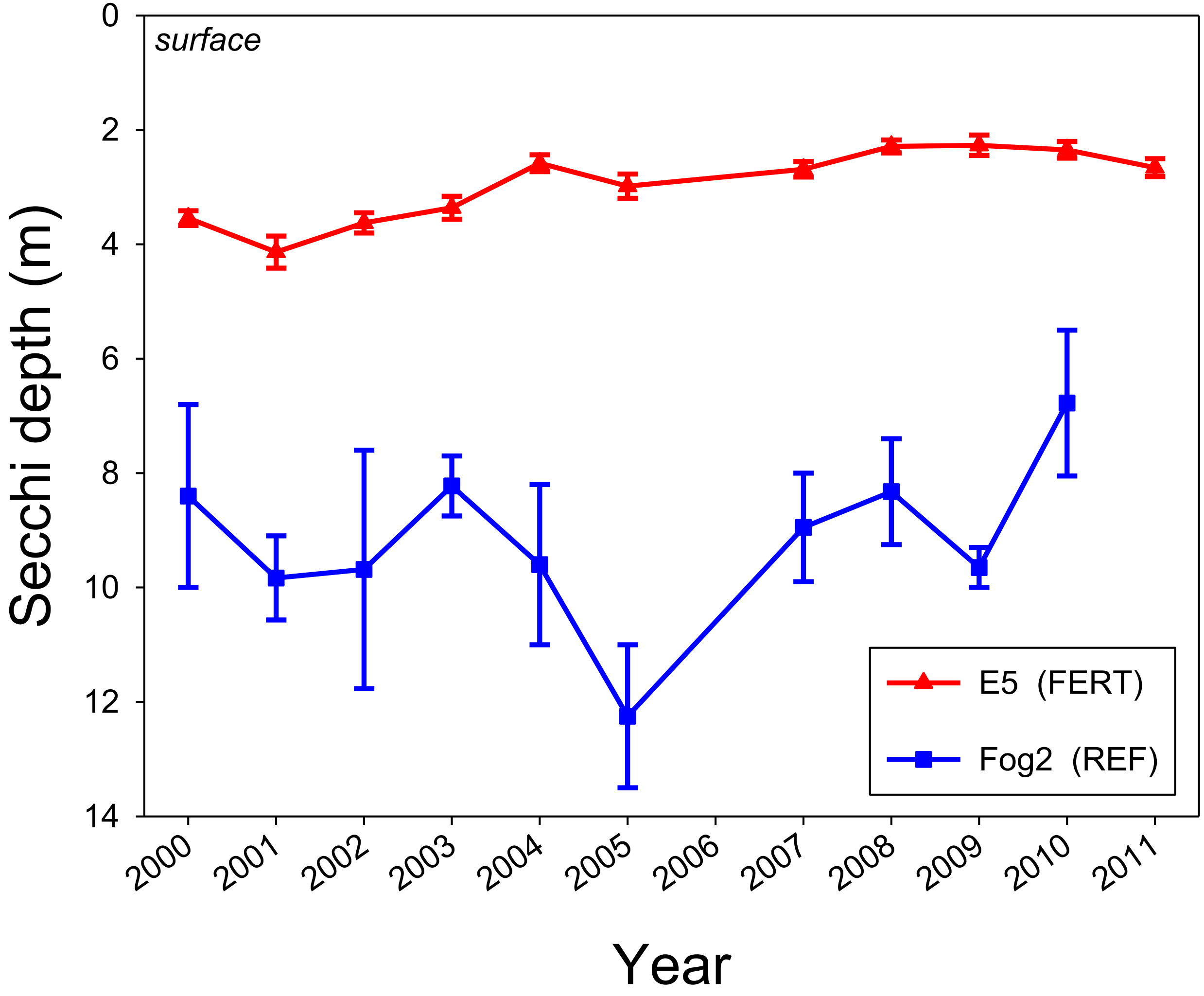
Pelagic, deeper & benthic - Residual 15N Recycled?

Lag effects: nitrogen recycling?



PPR: Water Transparency





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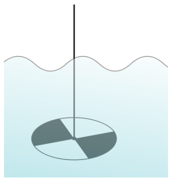
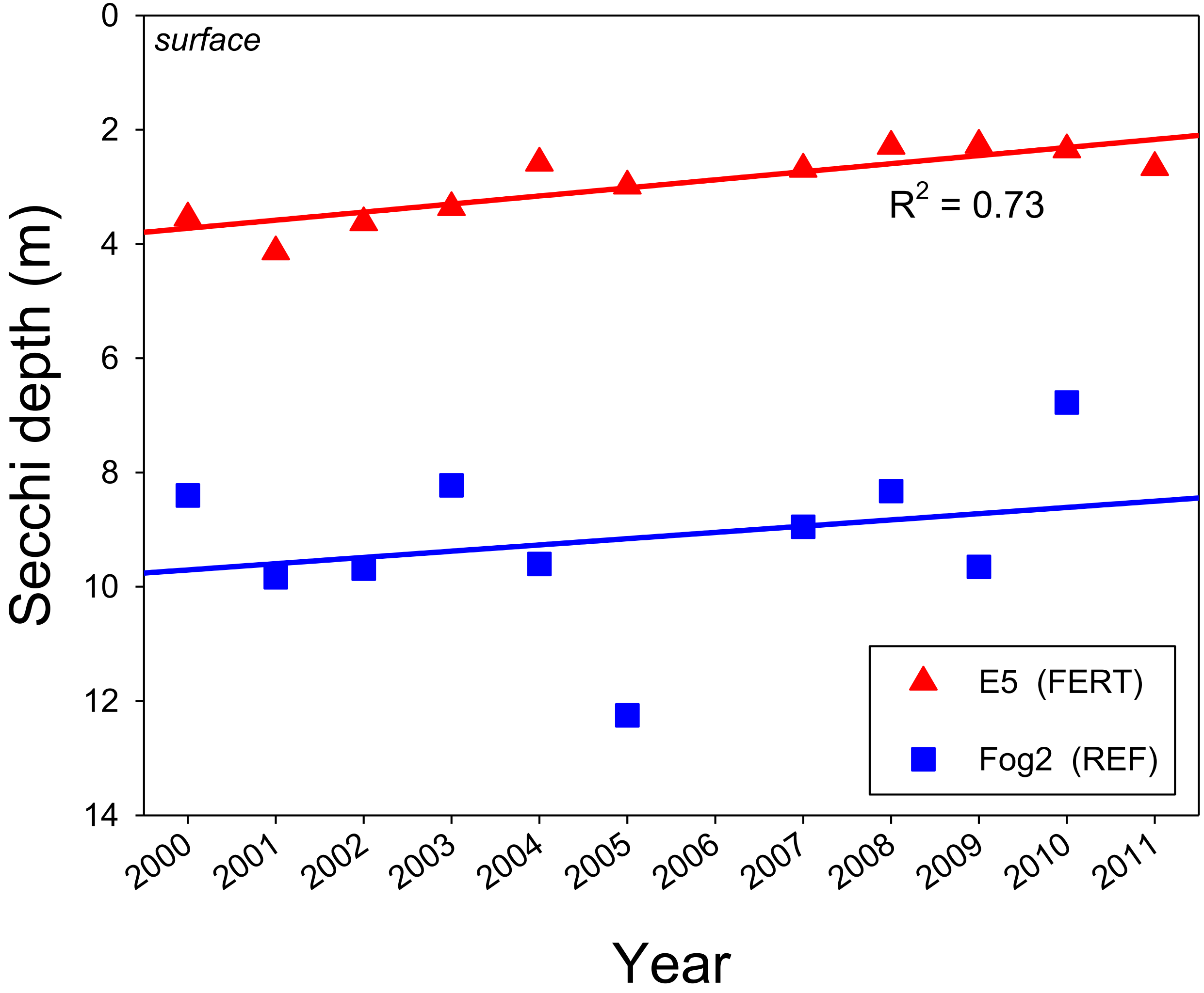
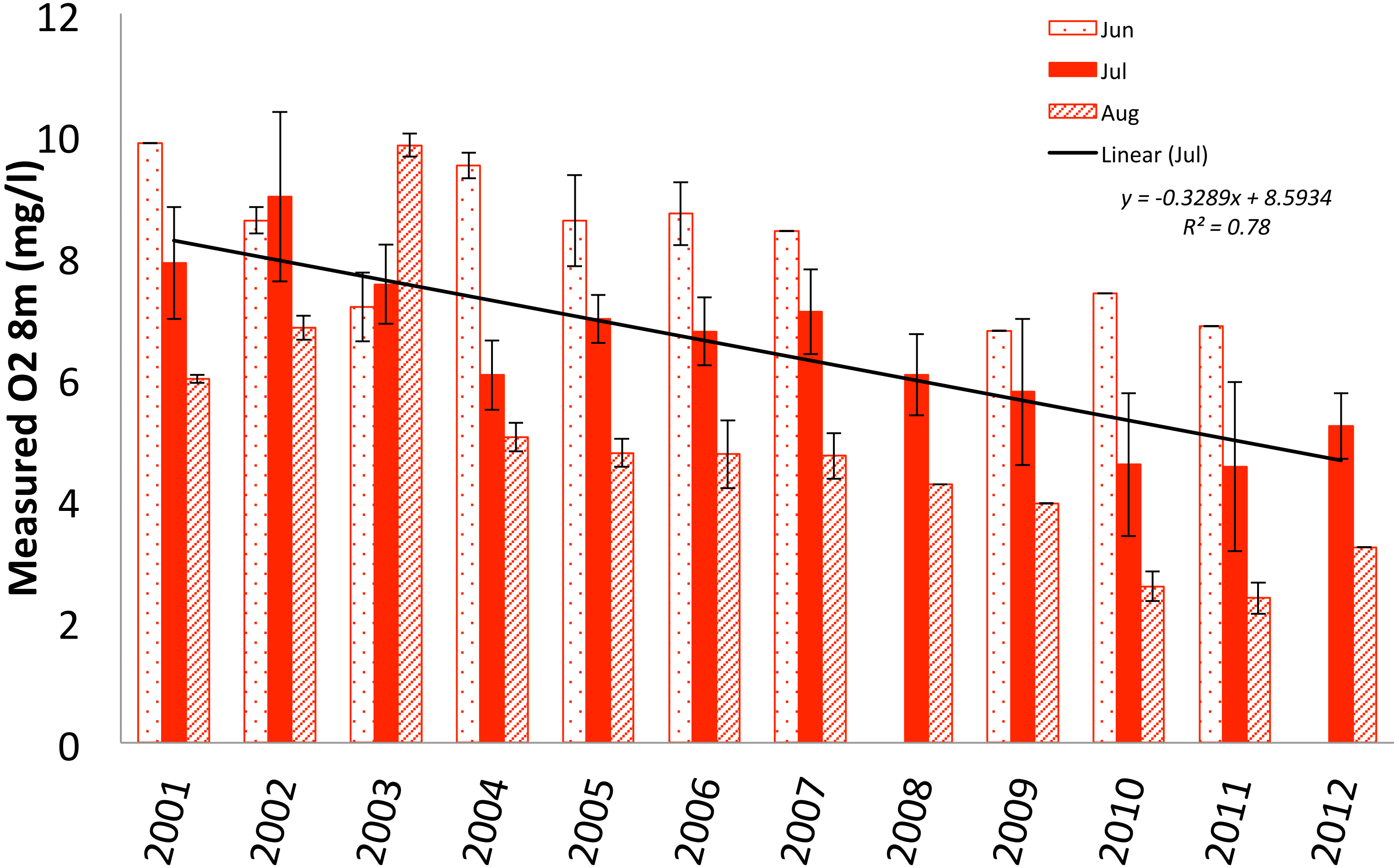
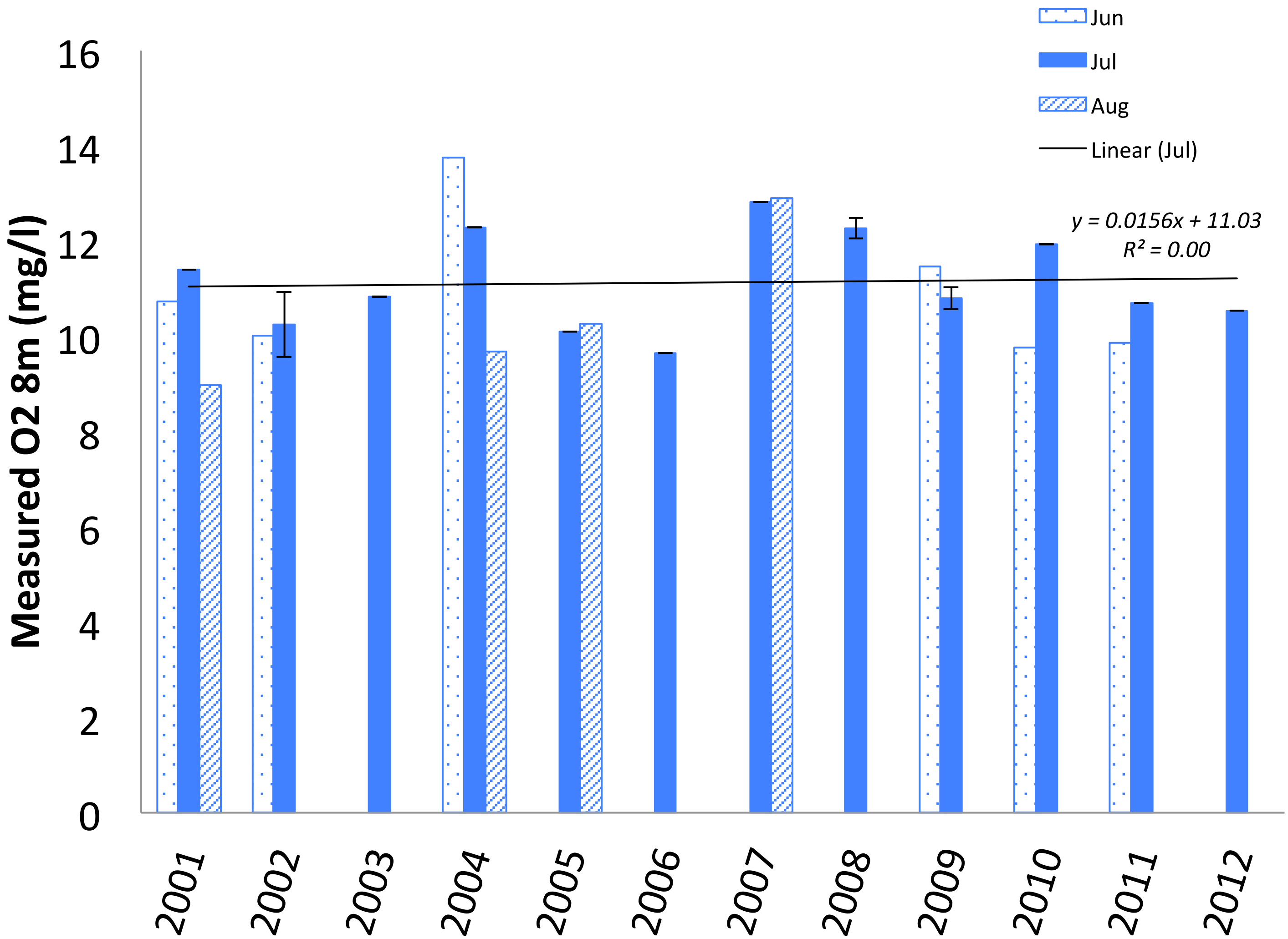




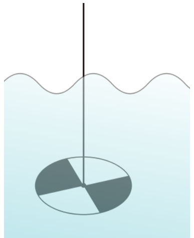
Physio/chemical changes:
Oxygen: Lake E5 (FERT)

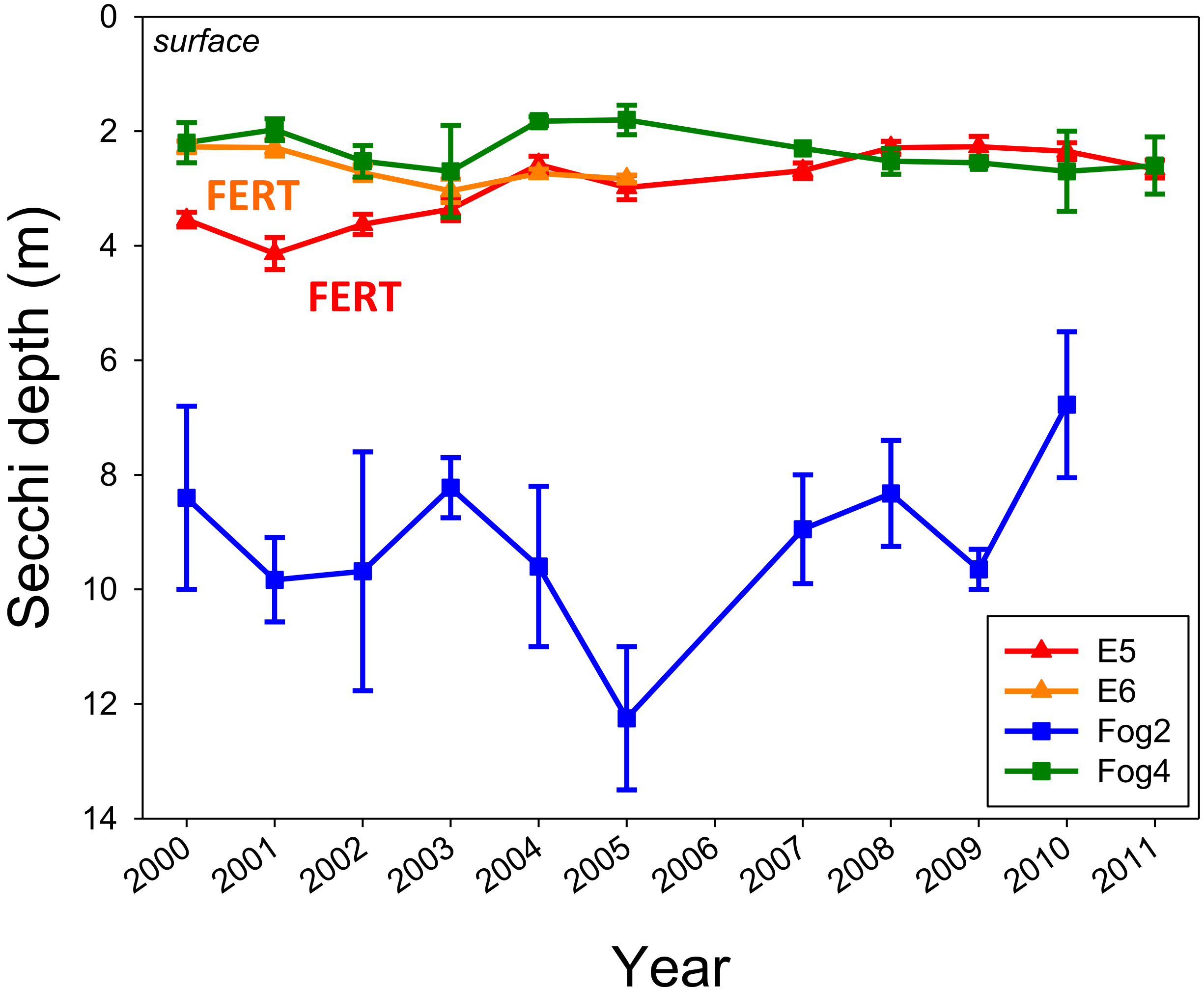


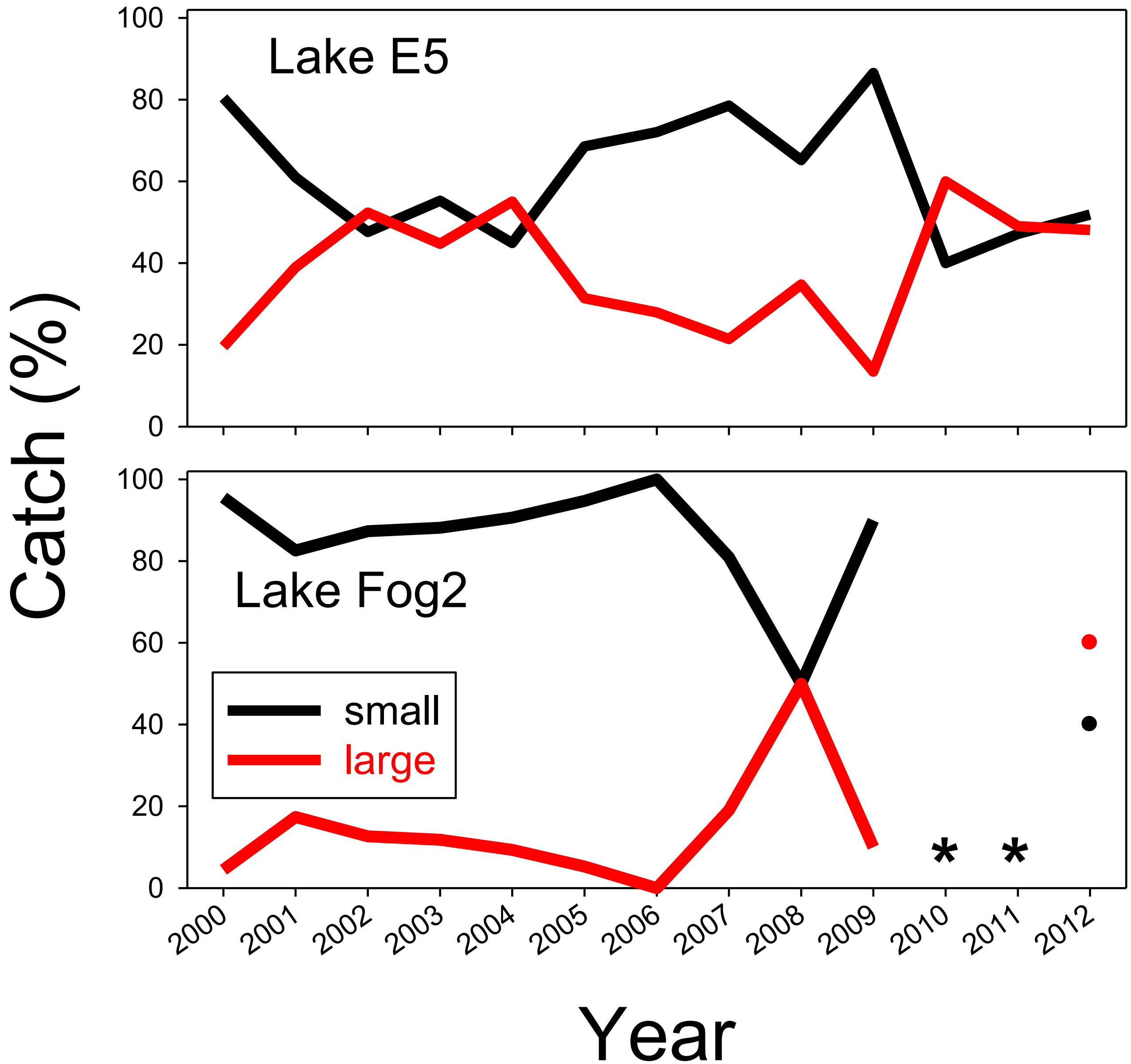
Physio/chemical changes: Oxygen: Lake Fog (REF)



PPR: Water Transparency



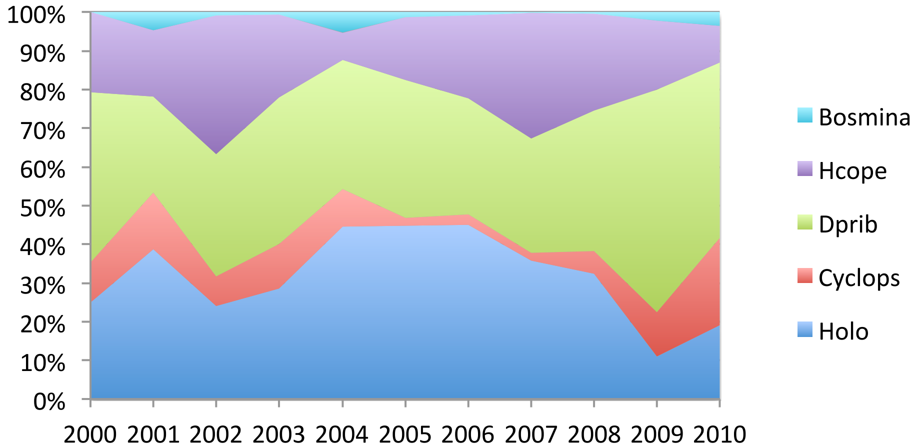




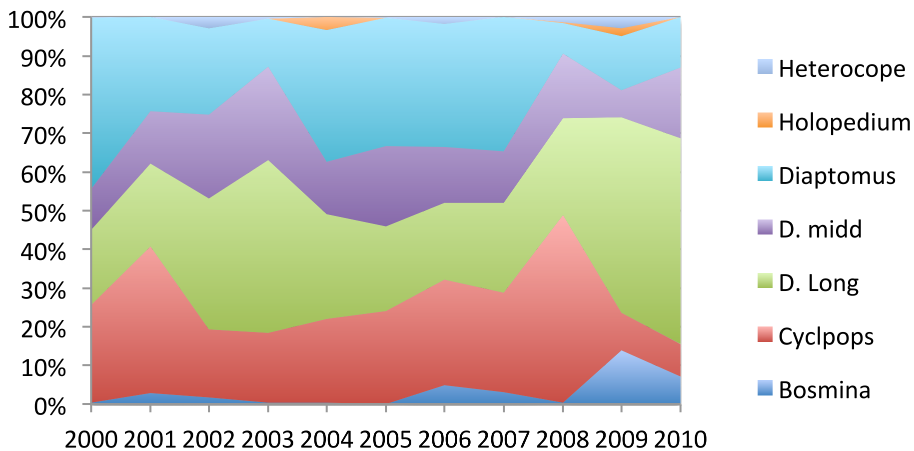
Lake E5
Lake Fog2
small
large
Catch (%)
Year
100
80
60
40
20
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
*
*

Zooplankton Biomass Composition

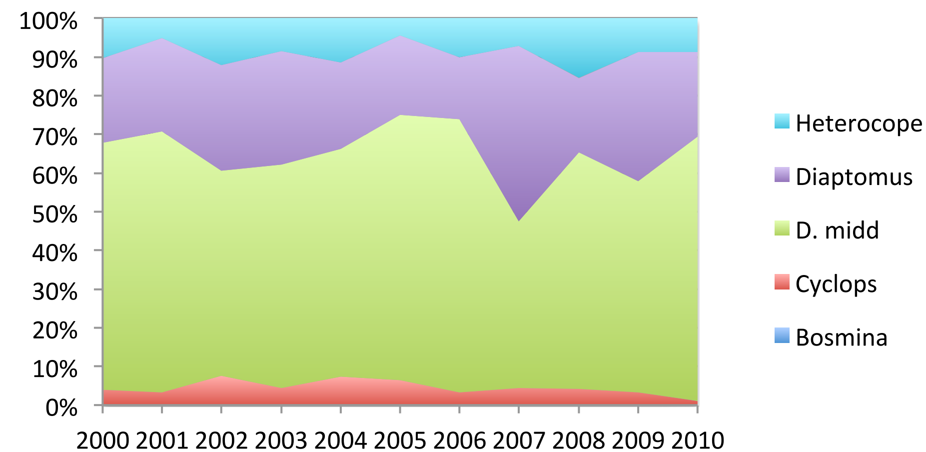
E5 (FERT)



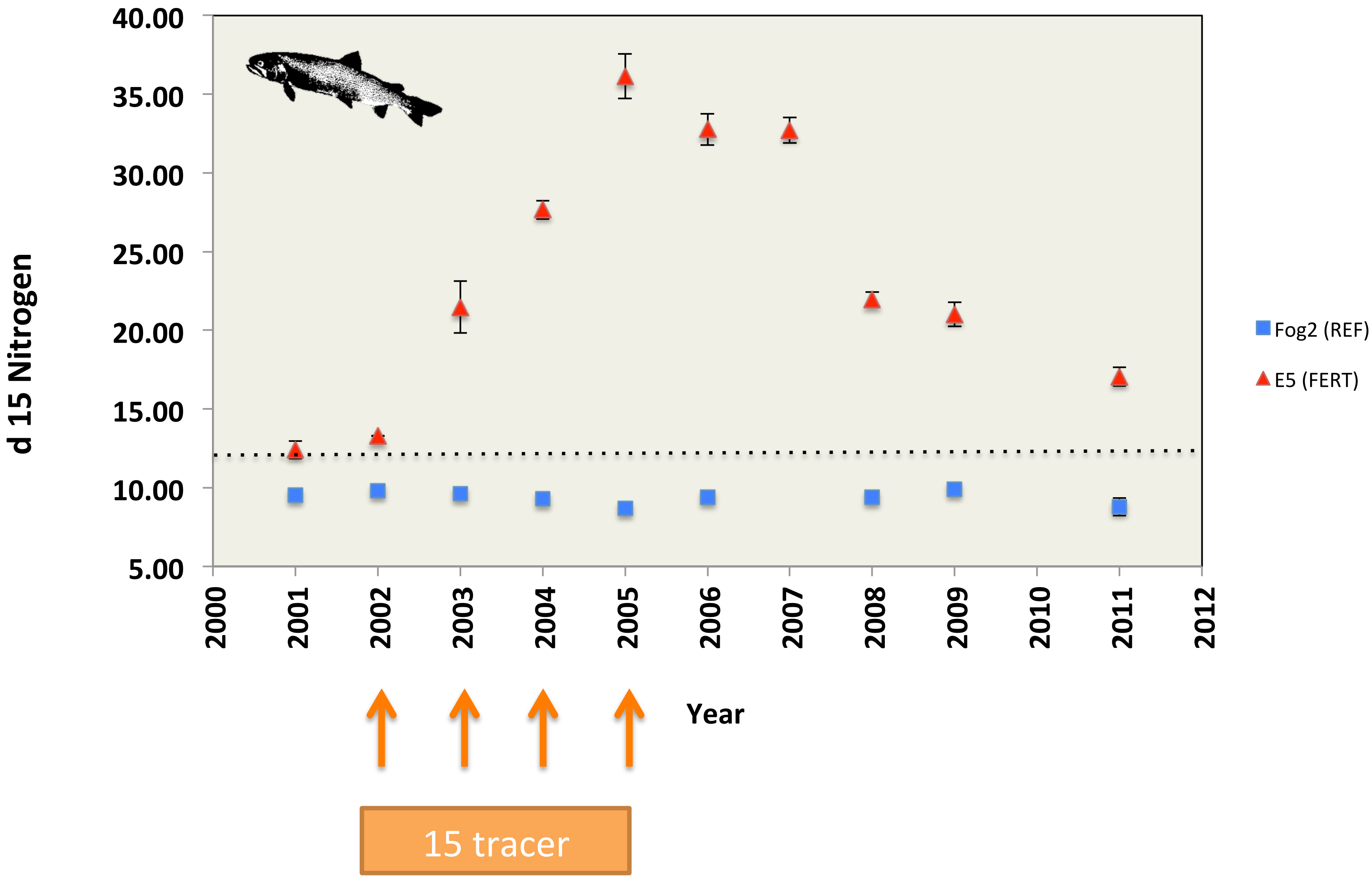
Fog2 (REF DEEP)



Fog4 (REF SHALLOW)



Tertiary: Nitrogen Enrichment



Sentinel lakes

In progress