Arctic LTER Project

# Arctic Lakes: Site Review 2019

**The Lakes Group**

**Phaedra Budy, Utah State University**

**February, 2018**

Arctic LTER Annual Meeting 2018

Arctic LTER Project

# The Lakes Team: Current PI's and Collaborators

*The Current Core*

- Phaedra Budy (PI)*
- Anne Giblin (PI)*
- George Kling (PI)
- Byron C. Crump (Co PI)
- Dan White (RA)
- Gary Thiede (Research Associate)
- Stephen Klobucar (former Ph.D.), collaborating Post doc)
- Will Daniels (former Ph.D., collaborating Post doc)
- Will Longo (former Ph.D., collaborating Post doc)

*Other Collaborators*

- Jereme Gaeta (USU), *Volunteer and Proposal Writing,* Fish
- Robert Al-Chokhachy (USGS NoRock), *Volunteer and Proposal Writing,* Fish
- Phoebe Zarnetzke (MSU)
- Matt Walsh (UoT Arlington – NSF $ Eager)
- Nick Barrett & Natasha Christman (Ph.D. Students) & Peter MacKinnon (Research Associate) – Lake Warming
- Dr. Kim Hageman (USU) & Yo-Ping Chin (UoDel), Airborn Bio-contaminents
- Soren Brothers – Limnologist (USU) – USU Seed Grant, *Proposal Writing*, Carbon

# *Mapping the* ARC-LTER Goal to Lakes Research

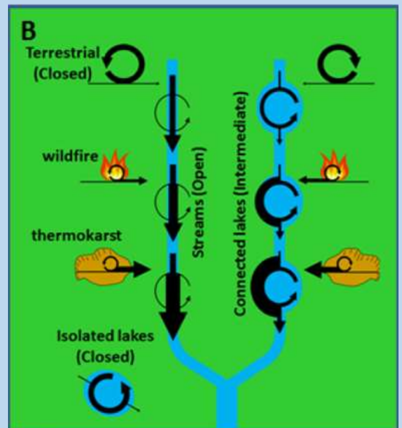
Determine how system openness and landscape connectivity interact to shape the response of arctic lake ecosystems to disturbance:

- Pulse – Fire, thermokarst failures
- Press – Climate change, permafrost thaw,
  - **local extinction or colonization events**

LAKES:

- More internally focused
- Lakes are intermediate in biogeochemical openness
- Lakes offer a continuum of community openness

- **ALSO On-going long-term monitoring of how lake ecosystems respond to environmental change**



Landscape of interconnected ecosystems with various degrees of openness to C, nutrients, organisms, and species.

# BACKGROUND: A landscape of lakes (50% freshwater)

- BACKGROUND:
  Ice-cover –
  9-10 months of year
  Low productivity
  Low species diversity

  Small changes?

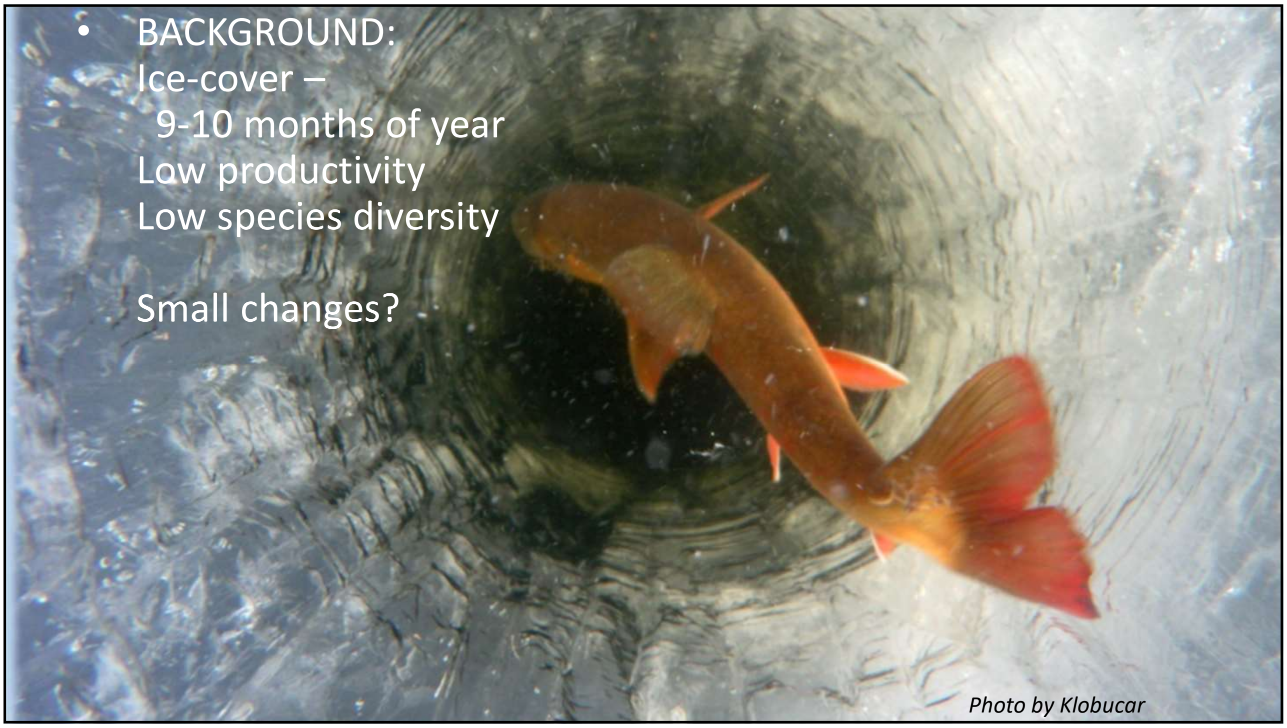
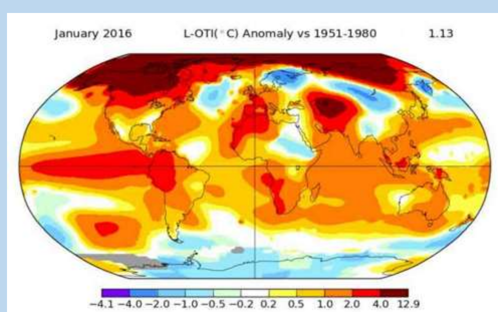


*Photo by Klobucar*

## BACKGROUND: Climate Change: Direct Effects

- BACKGROUND:
  Arctic Warming on Lakes
  - Warmer water temperature
  - Deeper epilimnions
  - Shifts in growing season
  - Longer period of ice-off period
    - Later ice on




Effects on biota?

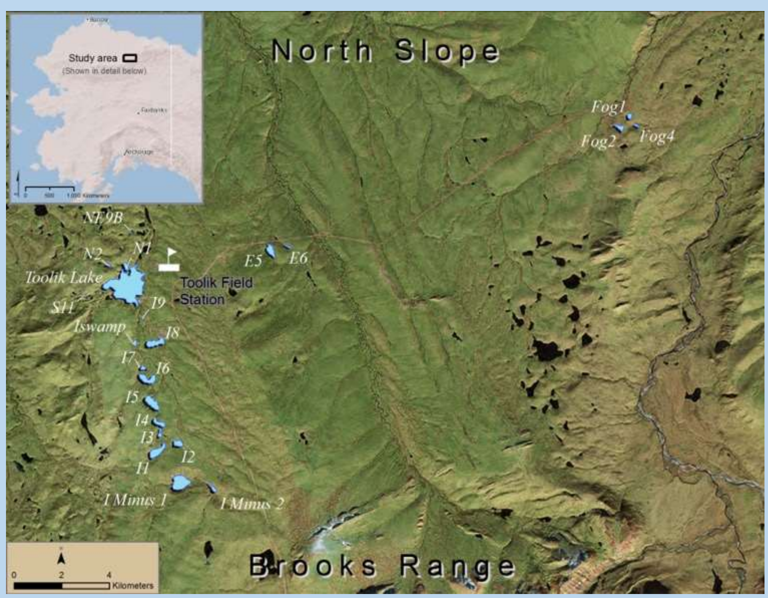
## LAKES *Ongoing*: Long Term Monitoring Activities

- Long-term sampling, process-level measurements, and modeling in:
  - Sentinel lakes including Toolik Lake, the Inlet Series lakes (I-lakes), and annually-selected others
  - Paired control (reference) and experimental lakes (in recovery, lake warming), sampled more or less frequently
  - Periodic and opportunistic sampling of lakes undergoing change due to disturbance (e.g., fire and thermokarst)
  - Lakes added to address New LTER Activities (e.g., new open vs. closed)

## LAKES *Ongoing*: Long Term Monitoring, 2018, e.g.,

**Lakes =32**
**Visits = 101 (1-17*)**
**Actual Samples = 681**
**Many measurements**

Toolik
I1-8, Iswamp
E1,5, 6
Fog1-5
LTER 345-347
N1-2
NE9B, NE12, NE 14
S6-7
Zev + Upper Zev
Lower Campsite



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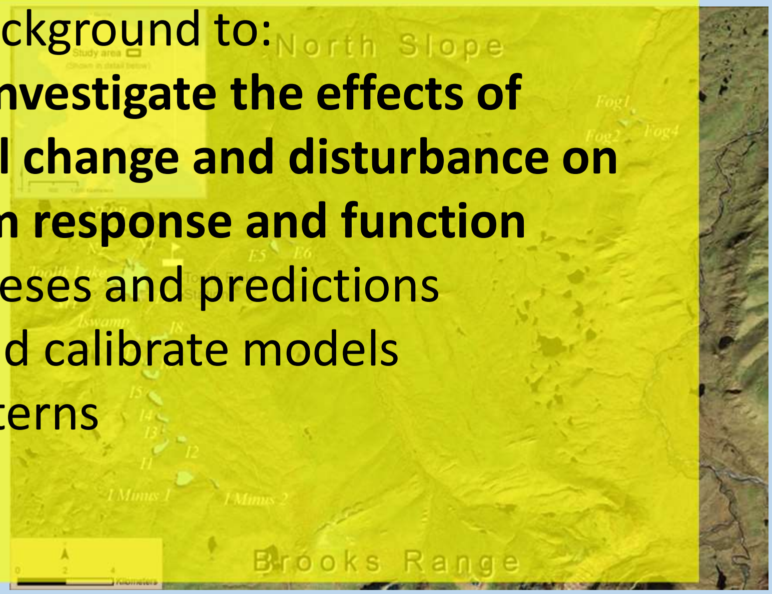
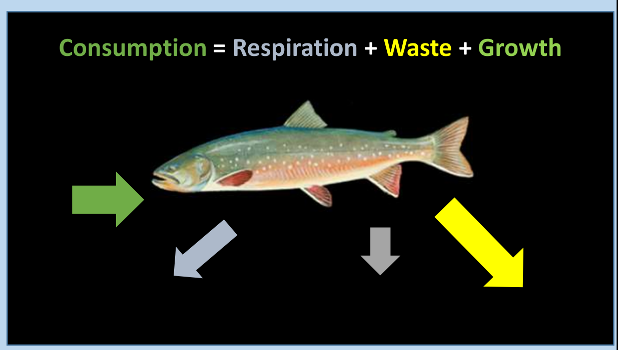


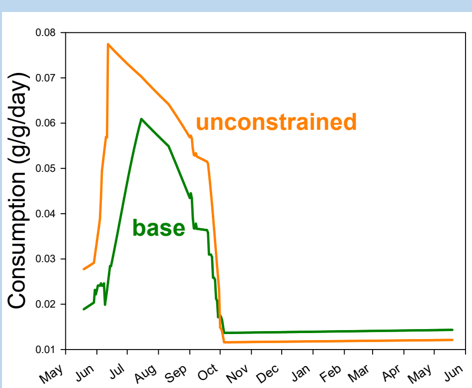

Provide the background to:

**Data used to investigate the effects of environmental change and disturbance on lake ecosystem response and function**

- Test hypotheses and predictions
- Populate and calibrate models
- Explore Patterns
- Etc.,

## LAKES *Ongoing*: Quantify fish vital rates, population dynamics, and community interactions in the face of climate change {disturbance}




- fish consumption is predicted to increase 28-34 % in a warmer, future lake

*Budy and Luecke 2014*

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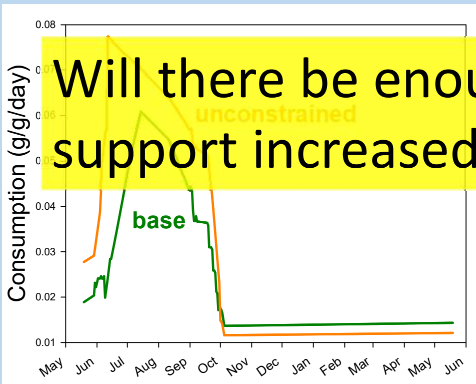
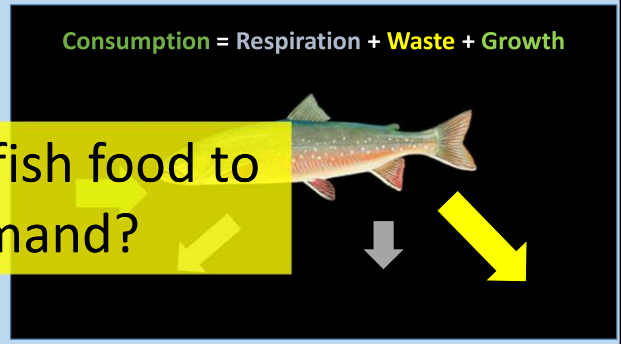


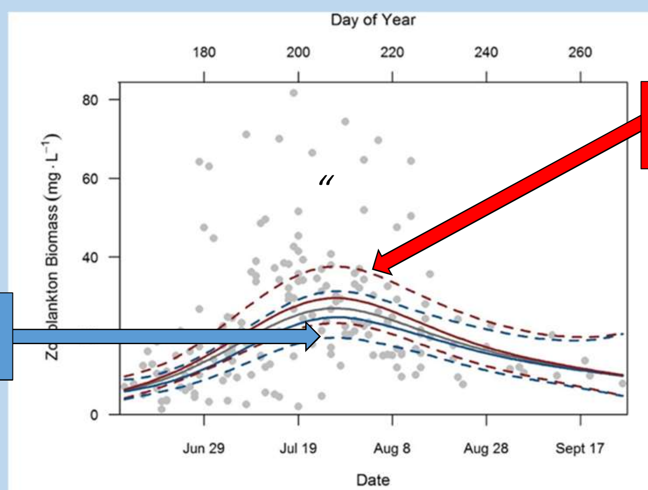




**Will there be enough fish food to support increased demand?**

- fish consumption demand is predicted to increase 28-34 % in a warmer lake

*Budy and Luecke 2014*

## LAKES *Ongoing*: Investigate study food web structure and trophic dynamics

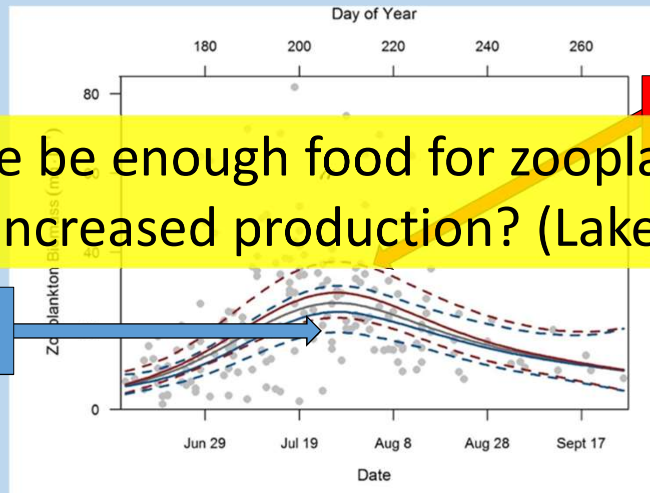



- a warmer climate *may* be able to support increased fish demand

$Biomass = \alpha + \beta_1 + s(Day\ of\ Year_i) + Temperature_j + a_k\ \varepsilon_{ik}$

*Klobucar et al. 2018*

## LAKES *Ongoing*: Investigate study food web structure and trophic dynamics




Warm year:

Will there be enough food for zooplankton to support increased production? (Lake Warming?)

Cold year:
20% decrease

climate *may* be able to support increased fish demand

*Biomass* = $\alpha + \beta_1 + s(\text{Day of Year}_i) + \text{Temperature}_j + a_k\, \varepsilon_{ik}$

*Klobucar et al. 2018*

## LAKES *Ongoing* : Monopolizing on intriguing events/observations/patterns as they inform our broader questions

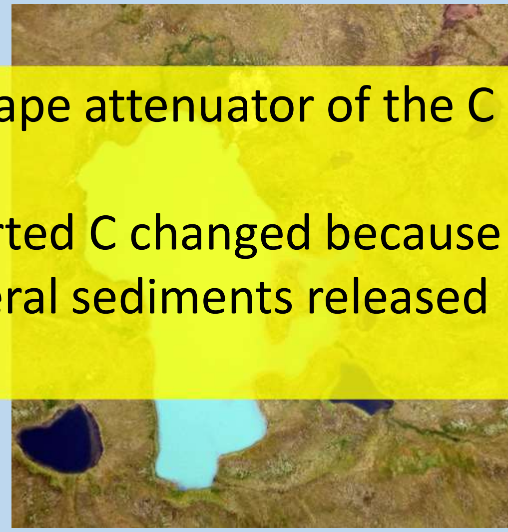
- Permafrost thaws
- Massive ice inclusion melts
- Soil collapses
- Sediment and nutrient export into lakes


https://www.youtube.com/watch?v=4fCAcoy0X0M

LAKES *Ongoing* : Monopolizing on intriguing events/observations/patterns as they inform our broader questions

**What is role and impact of thermokarst slumps?**

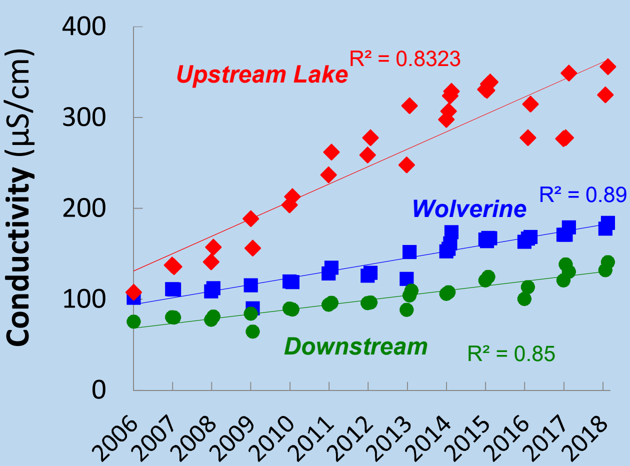
- Permafrost thaws
- Massive ice inclusion melts
- Soil collapses
- Sediment and nutrient export into lakes

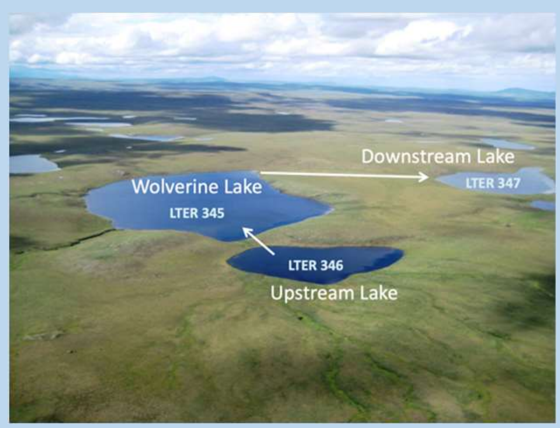


- Lake acted as a landscape attenuator of the C and N released.
- Character of the exported C changed because of interactions with mineral sediments released into the lake

## What is role and impact of thermokarst slumps (disturbance): are lakes becoming more open?

Wolverine Lake 2008-




Clear effect on the turbidity of Wolverine Lake, but the effect on conductivity is not clear

https://www.youtube.com/watch?v=4fCAcoy0X0M

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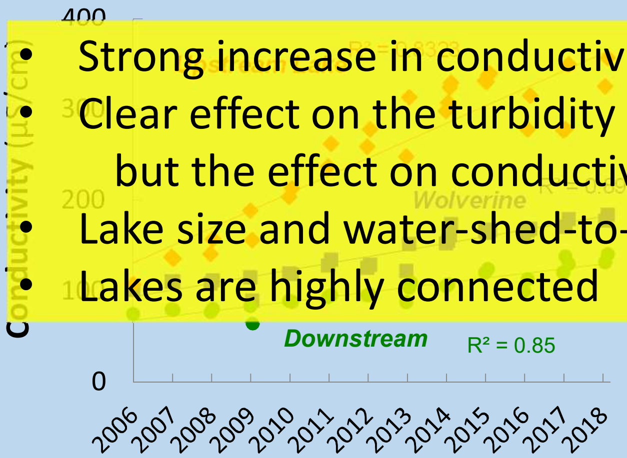
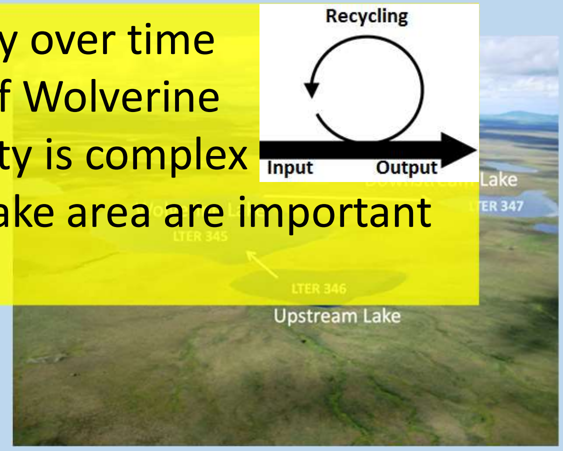



- Strong increase in conductivity over time
- Clear effect on the turbidity of Wolverine but the effect on conductivity is complex
- Lake size and water-shed-to-lake area are important
- Lakes are highly connected

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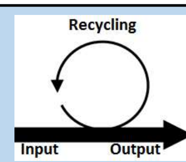


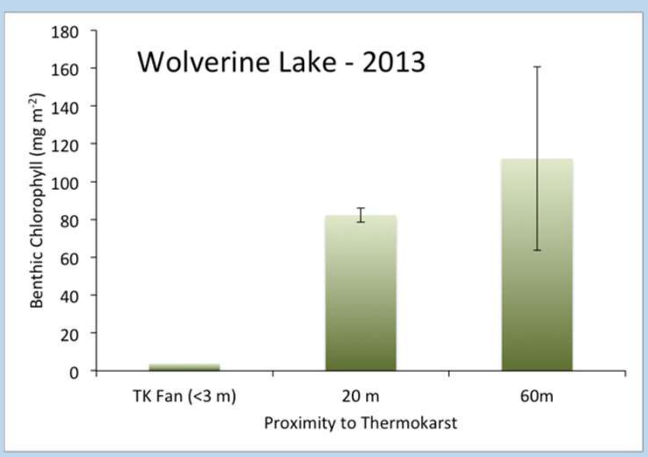


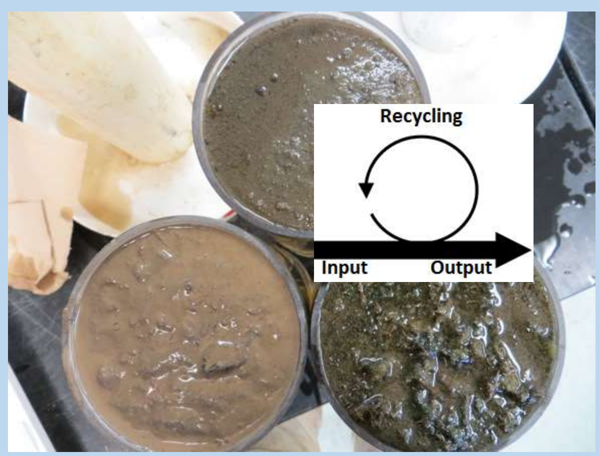

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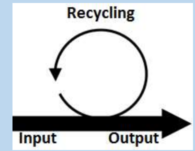
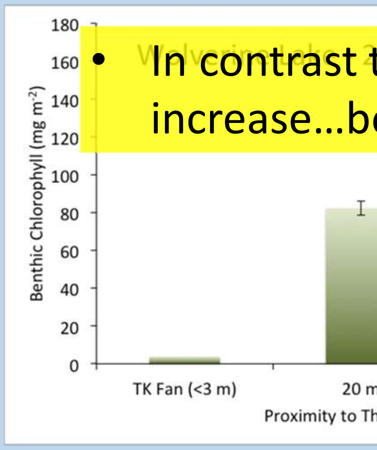
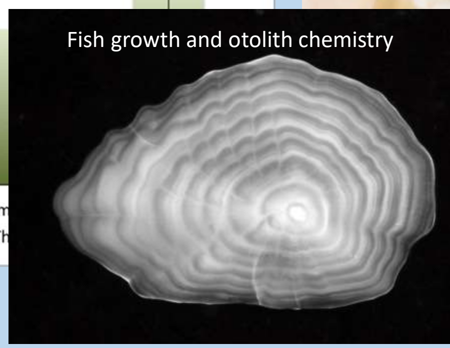



- In contrast to hypotheses that productivity will increase…benthic productivity is decreased



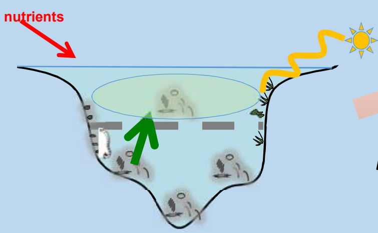




## LAKES *Ongoing* : Synthesize results of long-term lake manipulations. How do disturbances (deliver nutrients) change ecosystem states, processes, and linkages *in lakes?*

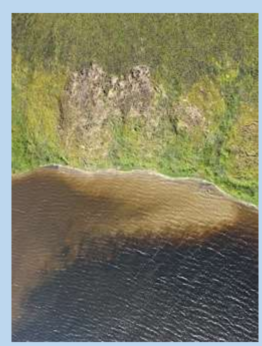
2 x natural loading, long time

***Change in nutrient loading***

***due to climate change driven disturbance***




***Lake process and function***



# LAKES *Ongoing*: Synthesize results of long-term lake fertilization

Biological
Chemical
Physical
?

| | |
|---|---|
| Deep Fertilized E5 | Deep Control Fog2 |
| Shallow Fertilized E6 | Shallow Control Fog4 |

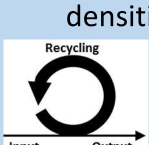
No fish

N&P – 2001 – 2012
2x natural loading
Phosphoric acid and ammonium nitrate
$^{15}N$ tracer - 2002-2005
"Recovery" period 2013-present
Monitoring a suite of indicators of response:
Production, biomass and diversity
Physiochemical response
Food web structure

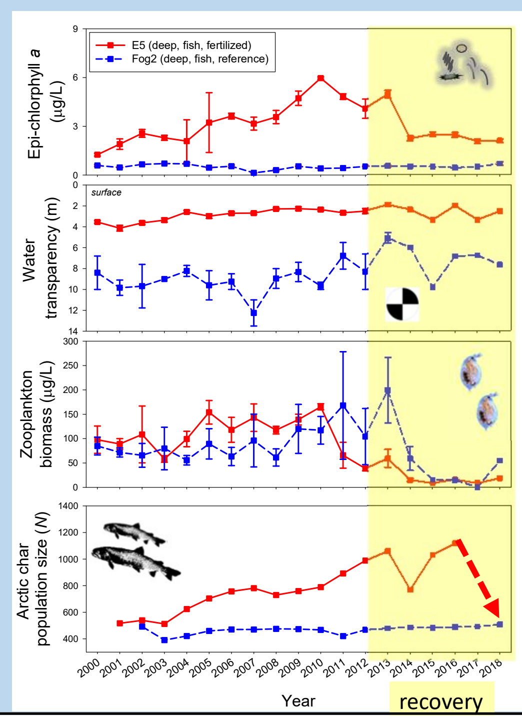
Experimental Design

# LAKES *Ongoing*: Synthesize results of long-term lake fertilization

- Chl *a* increased over 3 lagged phases
- Zooplankton did not increase until chl *a* had increased substantially, then stabilized
- Fish also increased over 3 lagged phases, reaching extremely high densities (all small adults)




*Budy et al, in review*



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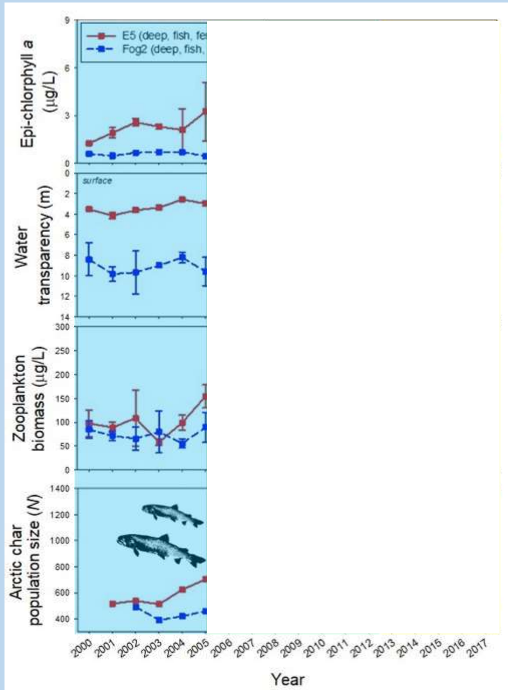


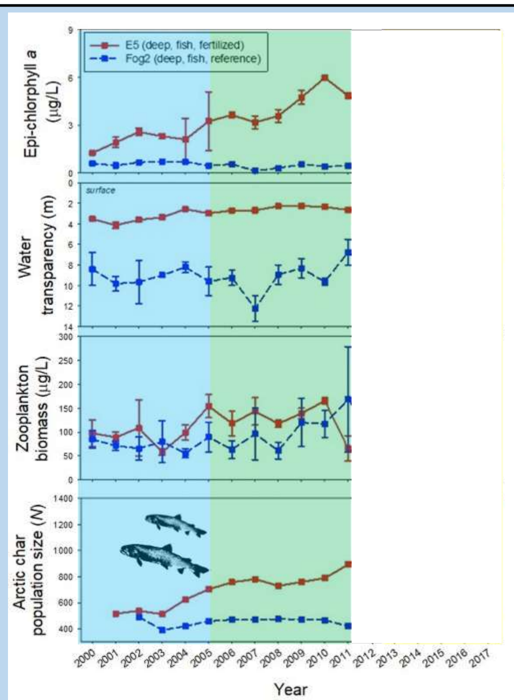

PHASE 1

- Fertilization rapid affect on primary production
- Secondary production beginning to respond

*Budy et al, in review*

LTER Long Term Data

# LAKES *Ongoing*: Synthesize results of long-term lake fertilization




PHASE 2

- Primary production really ramping up
- Secondary production has increased to a new, semi-stable state
- Fish are under steady increase

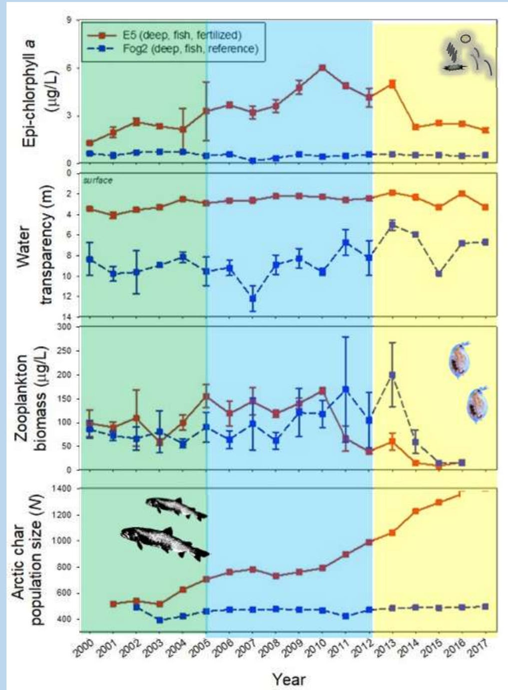
*Budy et al, in review*

LTER Long Term Data

# LAKES *Ongoing*: Synthesize results of long-term lake fertilization

- Threshold and lagged responses
- At some trophic levels - relatively rapid recovery once disturbance was removed
- ***Importance of a long-term LTER approach

LTER Long Term Data

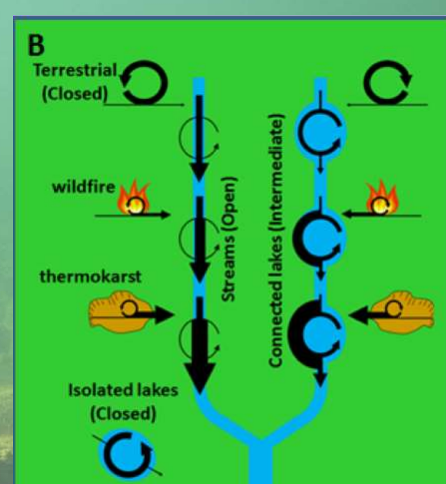



PHASE 3

- Chl *a* returns rapidly to pre levels once fertilization is terminated
- High densities of fish eat all the zoop; zoop collapse
- Fish begin rapid collapse

*Budy et al, in review*

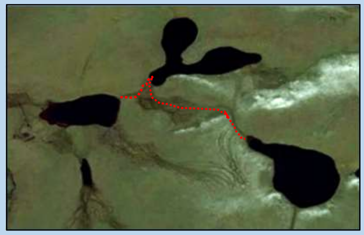
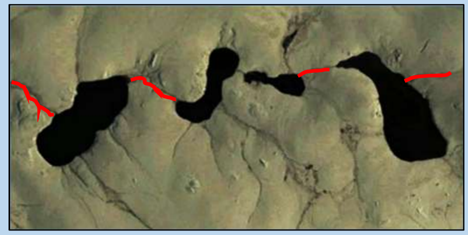
*NEW FOCUS*: Determine how system openness and landscape connectivity interact to shape the response of arctic lake ecosystems to disturbance:




Landscape of interconnected ecosystems with various degrees of openness to C, nutrients, organisms, and species.

# Lakes span continuum of connectivity/openness

Fog Lakes (and E's) | Wolverine Lakes | Inlet Lakes (I lakes)

Closed | "Leaky" | Open

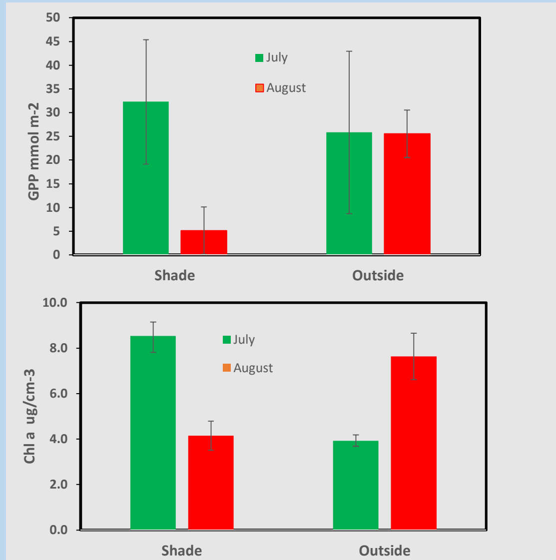
## *NEW*: How will benthic microalgae communities respond to changes in light availability caused by increase in delivery of DOC to lakes due to disturbance?
*Anne Giblin*

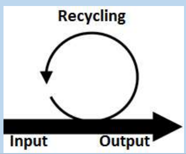
- Fog 2, Shade cloth, 1 m from the bottom, in two locations , 3m depth
- Remove shade cloth and retrieve cores from under the cloth and reference site
- Incubate cores at *in situ* temperatures at 5 light levels (including dark)
- Measure O2 uptake or production in the overlying water, chl *a*, GPP, etc.


## *NEW*: How will benthic microalgae communities respond to changes in light availability caused by increase in delivery of DOC to lakes due to disturbance?

*Anne Giblin*

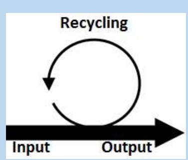
- 3 Weeks:
  - little change between shaded and unshaded sediments,
  - except Chl *a* in the shade plots increased
- 6 Weeks:
  - Chl *a* was much lower in the shaded plots
  - $GPP_{max}$ was greatly reduced, and respiration was also depressed
- Benthic microalgae appear to light limited
  - Sensitive to disturbance

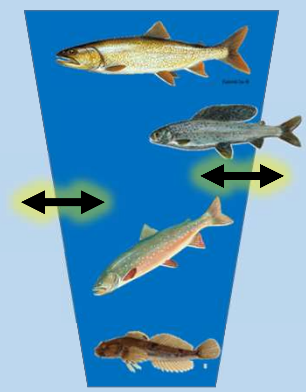


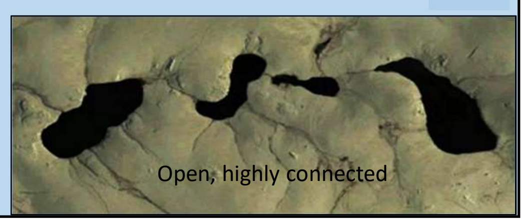

## *NEW*: Community Openness & Connectivity – Disturbance
## Open Lakes

- Highly connected via streams
- High diversity of fish species, abundance unknown
- Variable (sp.), large to moderately-sized top predator
- Little internal population regulation - buffered by immigration and emigration
  - species can move from unfavorable to favorable habitat
- More productive?



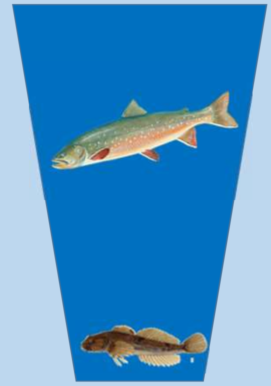



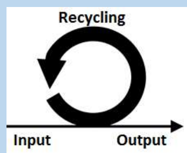
I lakes



# *NEW*: Community Openness – Closed Lakes

- Little to no connection via streams
- Low diversity & abundance (often 2 spp.)
- Common, 'small' top predator
- Strong internal population regulation, density dependence
- Less productive?

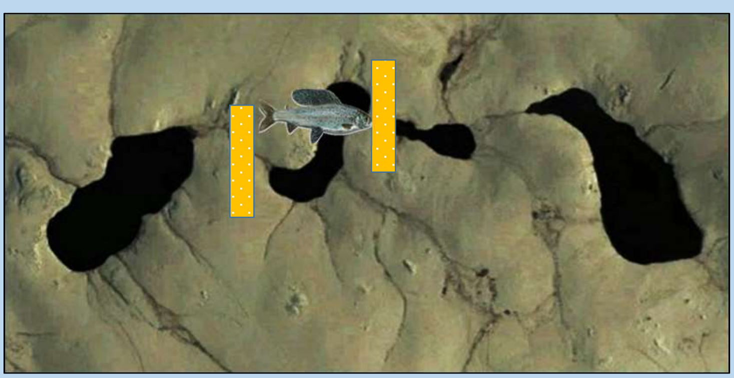




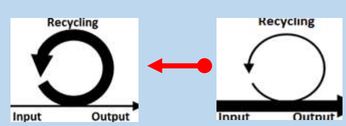


# *NEW*: Community Openness: Whole lake manipulation. Step 1.

- Hypothesis: Open lakes: = more resilient to disturbance
  - Whole lake community manipulation



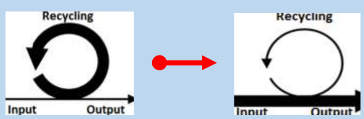
'Close' the lake
Monitor whole system response



# *NEW*: Community Openness: Whole lake manipulation. Step 2.

- Hypothesis: Closed lakes: = less resilient to disturbance
  - Whole lake community manipulation

'Open' the lake
Add highly mobile grayling
Monitor whole system response




# *NEW:* 2017-2019: Whole lake manipulation: Pre-Manipulation Data Collection

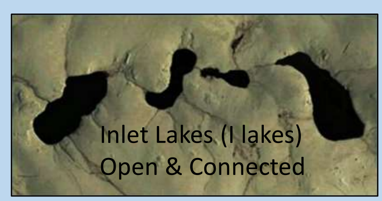
- I1 and I2 designated = Open Experimental & Reference
- Fog 2 and Fog 3 designated = Closed Experimental & Reference

- All lakes are LTER lakes*
  - Full limnological sampling, ~ 10 years

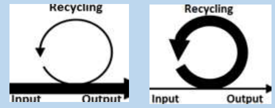
- Asymmetric: Fish and fish food, etc.
  - Fogs are part of Lake Warming project, lots known
  - I lakes had barely been sampled previously

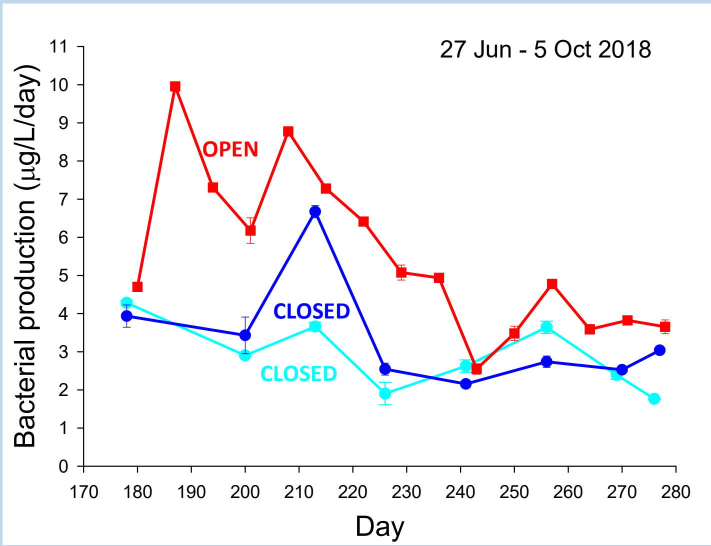
- NSF REU program
  - Collect baseline fish & lower trophic level (fish food) data, M/R

- New Comparative Analyses


# *NEW:* (2,3) Open (connected) versus Closed Lakes: BACTERIA, *Byron Crump et al.*



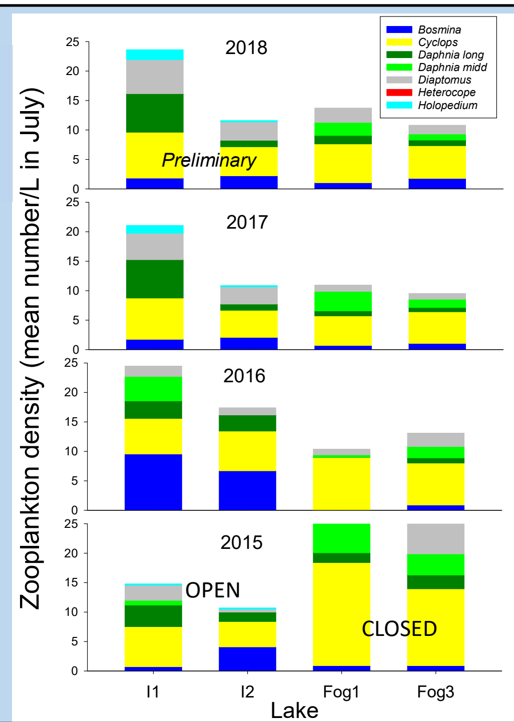




- Open lakes are more productive
- Upslope resources (nutrients, OM) support production
- DOC also affected by landscape age

- Mean ( $\pm$ 1 SE) at 3-m depth

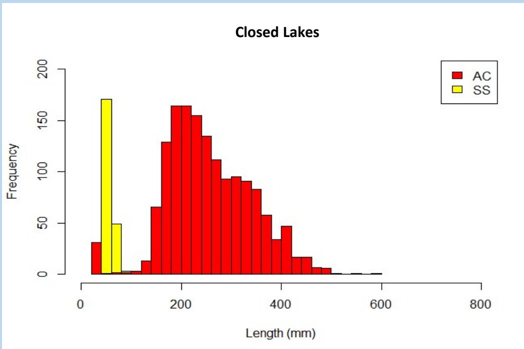
# *NEW:* 2017-2019: (2) Open (connected) versus Closed Lakes: ZOOPLANKTON

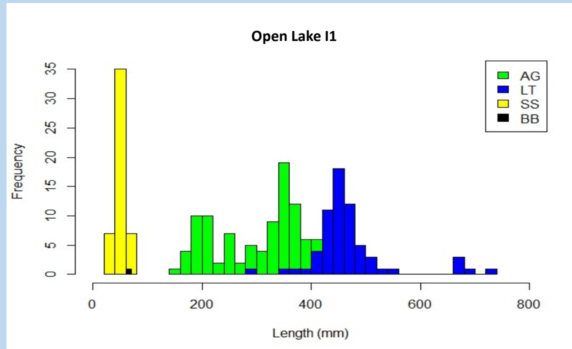
- Densities are similar
- Zooplankton diversity is much greater in Open lakes
- More Cladocerans (grazers, preferred by some fishes) in Open lakes




LTER Long Term Data

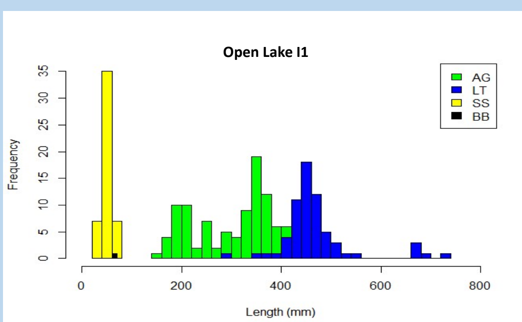
# *NEW:* 2017-2019: Open (connected) versus Closed Lakes: FISH

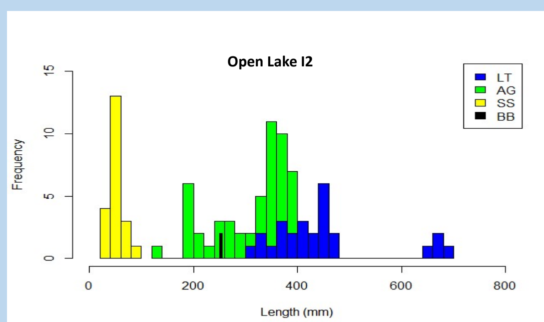



- Fish diversity is greater in Open lakes
- Fish size distribution is wider in Open lakes
- Max size is greater

# *NEW:* 2017-2019: Open (connected) versus Closed Lakes: FISH

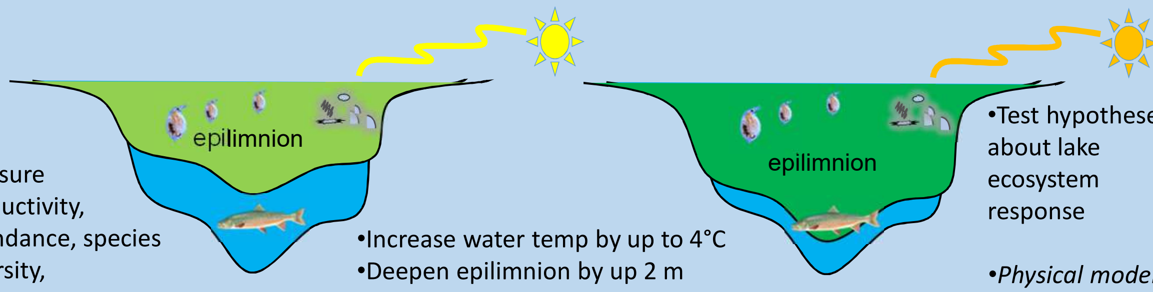



- I1 and I2 are a “good” pair for experiment

# *NEW*: Collaborative Research: Experimental Lake Warming (2016-2020)

- Budy, Null, Jin (USU), Giblin (MBL), and Crump (OSU)
  - *An exploration of the direct and indirect effects of climatic warming on arctic lake ecosystems.*




Measure productivity, abundance, species diversity, interactions

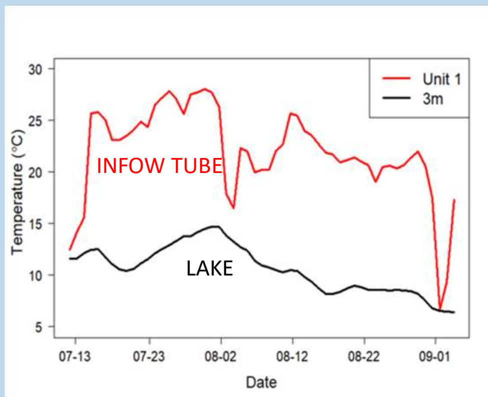
•Increase water temp by up to 4°C
•Deepen epilimnion by up 2 m
•Delay ice-on by up to 2 weeks to 30 days

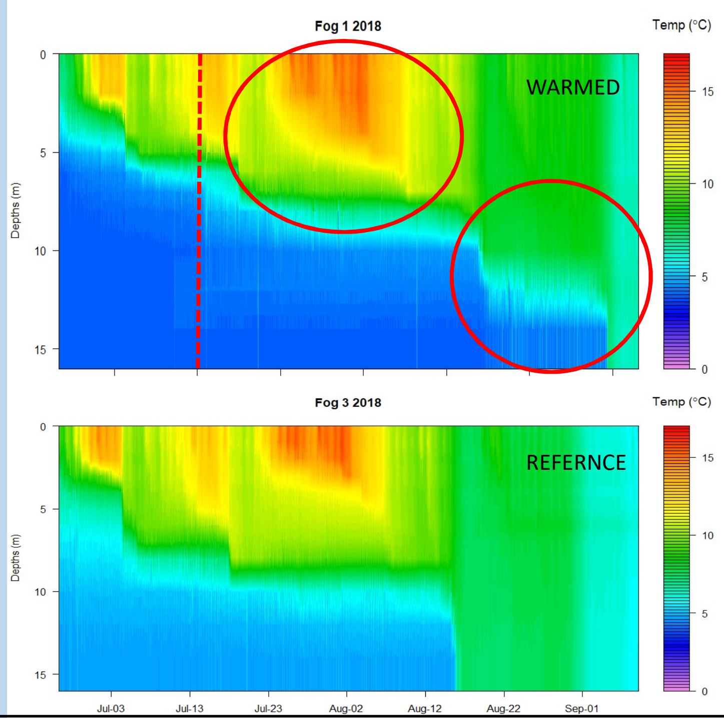
•Test hypotheses about lake ecosystem response

•*Physical modeling component*

# *NEW*: Collaborative Research: Experimental Lake Warming

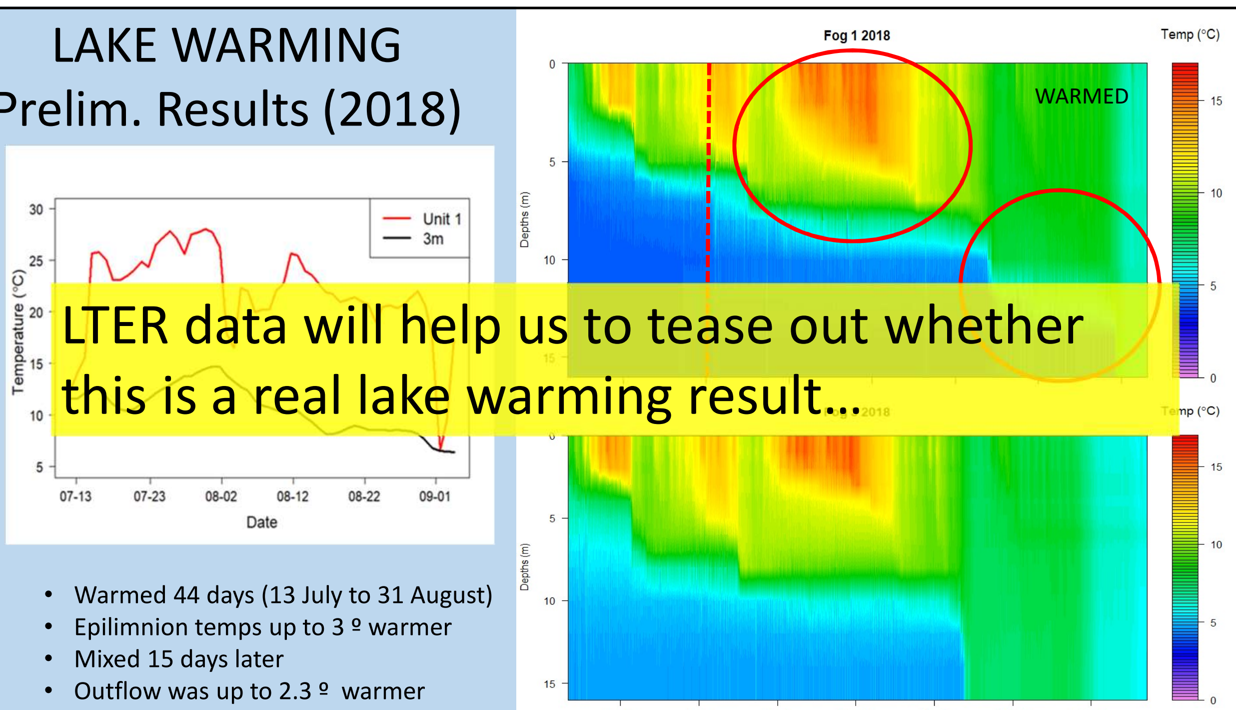
# LAKE WARMING
## Prelim. Results (2018)




- Warmed 44 days (13 July to 31 August)
- Epilimnion temps up to 3 º warmer
- Mixed 15 days later
- Outflow was up to 2.3 º warmer


# LAKE WARMING
## Prelim. Results (2018)

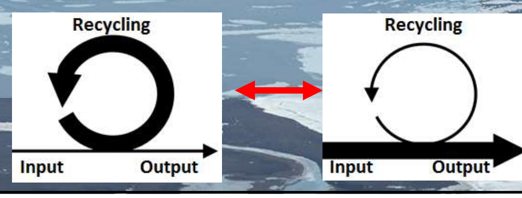



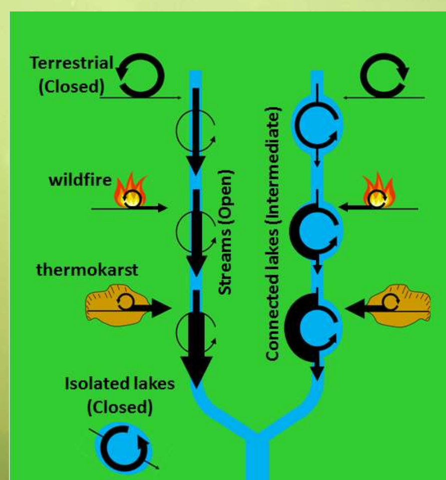


- Warmed 44 days (13 July to 31 August)
- Epilimnion temps up to 3 º warmer
- Mixed 15 days later
- Outflow was up to 2.3 º warmer

# Preliminary Conclusions

- Closed lakes are more sensitive to disturbance
  - Fertilization vs. Thermokarst slumps
- Open lakes are more biologically-diverse and productive, potentially more resilient to disturbance
  - Diverse fish community composed on many age classes
  - Terrestrial inputs = greater
  - *But* benthic productivity results suggest otherwise?
- Climate change (warming) may actually increase whole system productivity, to a point
  - Response likely to be different: closed vs open




**Arctic lakes fit well into a landscape of interconnected ecosystems and offer a continuum of openness and connectivity for C, nutrients, organisms, species, populations, communities, etc.**

Thank you and questions?