The Arctic LTER Project: Mid-term Site Review
24-26 June 2019
NSF 1637459

• Monday 24 June
  – Morning: Overview, science presentations
  – Afternoon: Field trips
  – Evening: Posters
• Tuesday 25 June
  – Morning I: Management, Information Management, Education, & Outreach
  – Morning II: Meet students, RAs, & postdocs, Meet TFS management
  – Afternoon: Field trips
  – Evening: Review team executive session, writing
• Wednesday 26 June
  – Morning I: Review team executive session, writing
  – Morning II: Review team feedback, discussion
• Thursday 27 June - Depart
Why an Arctic LTER?

- One of the world’s major biomes, unique and valuable in its own right
- Model systems for advancing general understanding of ecosystem function
- Plays an crucial role in the global environmental system
- Warming fast, more-frequent disturbances like wildfire, thermo-erosion
- Potential release of C from permafrost significant to atmospheric CO₂
- Harbinger of response to global warming for ecosystems further south

- Warming at >2X global average
- More frequent wildfire
- More thermokarst slumping
- Higher fertility indicated by “greening” tundra
What is the Arctic LTER?

Ecological research began in 1975
ARC LTER was established in 1987.
*The overall aim: develop a predictive understanding of the arctic landscape including tundra, streams, lakes, and their interactions.*
Focus evolves as understanding grows and as new opportunities are recognized.

THE ARCTIC LTER SITE IS PART OF THE US LTER NETWORK

Maintain continuity of core data from long-term experiments and monitoring

5 LTER Network core research areas:

1. **Primary Production**: periodic harvests, eddy covariance, chamber-based CO₂ & O₂ measurements, water column incubations, fertilization
2. **Population Studies**: population dynamics and community structure through time and with fertilization, warming, and grazer/predator exclosures (point frames, harvests, eDNA, tag & recapture, RFID tags)
3. **Movement of Organic Matter**: movement of DOM down hillslopes, streams, and lakes, seasonal fish migration, photoactivation of DOM
4. **Movement of Inorganic Matter**: movement of nutrients down hillslopes, streams, and lakes
5. **Disturbance Patterns**: response to climate change, wildfire, thermal erosion of permafrost
Evolving goals of the Arctic LTER


• ARC-LTER IV (2004-2010): Understanding changes in the arctic system at catchment and landscape scales through knowledge of linkages and interactions among ecosystems.

• ARC-LTER V (2011-2017): Understanding changes in the arctic system at catchment and landscape scales as the product of: (i) Direct effects of climate change on terrestrial and aquatic ecosystems, and (ii) indirect effects of climate change on ecosystems through a changing disturbance regime.

• ARC-LTER VI (2017-2023): The role of biogeochemical and community openness in governing arctic ecosystem response to climate change and disturbance.

ARC LTER has a strong record of publication in books and journals indexed by Web of Science

ARC LTER publications have had very high impact and are now cited >10 times per day, every day, in books and journals indexed by Web of Science.

<table>
<thead>
<tr>
<th>H index</th>
<th>Since 1975</th>
<th>Since 1989</th>
<th>Since 1999</th>
<th>Since 2010</th>
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<tbody>
<tr>
<td></td>
<td>113</td>
<td>108</td>
<td>92</td>
<td>42</td>
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**Conceptual Framework:**
Openness and Connectivity

**Openness** is a property of a landscape element. **Connectivity** is a landscape property.

**Biogeochemical openness:** Does the biogeochemistry of a landscape element rely on internally recycled nutrients and organic matter produced locally by photosynthesis (closed) or on external sources of nutrients and organic matter (open)?

**Community openness:** Does the structure and function of the community depend only on interactions among organisms within the same landscape element (closed) or on interactions with organisms in surrounding landscape elements (open)?

**Biogeochemical and community connectivity:** Do biogeochemical or community changes at one location propagate across the landscape (connected) or are such changes isolated to one location (unconnected)?

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**Core Question for the Arctic LTER VI**

How do **openness** and **connectivity** govern the response of arctic ecosystems to disturbances like:

1. climate change and deeper thaw (press) and
2. changes in the magnitude and frequency of wildfire and thermokarst activity (pulse)?

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

Openness index = throughput/cycling

<table>
<thead>
<tr>
<th>Less Open System</th>
<th>More Open System</th>
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<tbody>
<tr>
<td>“Self-reliant”, depends on internally recycled nutrients &amp; locally produced organic matter</td>
<td>Strongly depend on outside sources of nutrients &amp; organic matter</td>
</tr>
<tr>
<td>Not sensitive to disturbances that deplete external nutrient supply (in the short term)</td>
<td>Sensitive to disturbances that deplete external nutrient supply</td>
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<tr>
<td>Absorb increases in external nutrient supply &amp; only slowly re-release nutrient after increase in nutrient supply abates</td>
<td>Sensitive to increases in external nutrient supply but rapidly re-release nutrient after increase in nutrient supply abates</td>
</tr>
<tr>
<td>Recover slowly from disturbances that deplete internal nutrient stocks</td>
<td>Recover rapidly from disturbances that deplete internal nutrient stocks</td>
</tr>
<tr>
<td>Openness index = small</td>
<td>Openness index = large</td>
</tr>
<tr>
<td>Poorly connected to other systems</td>
<td>Strongly connected to other systems</td>
</tr>
</tbody>
</table>

**Residence time of C and N in tundra, lakes, and streams**

\[
\text{Residence time (years)} = \frac{\text{Stock (g/m}^2\text{)}}{\text{Input (g/m}^2\text{/yr)}}
\]

- **Carbon**
  - Long residence time = less open
  - Short residence time = more open

- **Nitrogen**
  - Long residence time = less open
  - Short residence time = more open

- **Residence time (years)**
  - Terrestrial
  - Lake
  - Stream

- **Carbon**
  - Terrestrial: 30 years
  - Lake: 10 years
  - Stream: 1 year

- **Nitrogen**
  - Terrestrial: 3,000 years
  - Lake: 10 years
  - Stream: < 1 year
Biogeochemical Connectivity

Within-patch nutrient cycling

Less-open ecosystems on hillslope are poorly connected and therefore delay and attenuate signals moving down slope (e.g., nutrient pulse).

Downstream nutrient spiraling

More-open ecosystems in streams are well connected and therefore propagate signals moving downstream (e.g., nutrient pulse).

Asymmetric connectivity

Accumulation over large catchment area enhances connectivity of more-open aquatic ecosystems to less-open terrestrial ecosystems.

Lagged and attenuated change in N throughput resulting from the nearly closed N cycles and poor connectivity of terrestrial tundra ecosystems along a hillslope transect (results from the General Ecosystem Model: GEM).

Rastetter et al 2004
Community Openness & Connectivity
Evolving concept applied to subcomponents of community

Less Open System
Population and community interactions internal to landscape element

.: Isolated from disturbances to the community elsewhere in the landscape

Slow recovery from species/functional losses unless disturbance also opens the system

Poorly connected to adjacent systems

More Open System
Strong population and community interactions with surrounding landscape

.: Sensitive to disturbances to the community in surrounding landscape

Species/functional losses compensated by interactions with surrounding landscape & recovery facilitated by recruitment from surrounding landscape

Strongly connected to adjacent systems

Genetically distinct populations of arctic char indicating lack of connectivity among populations in different catchments
The concepts of “Openness” and “Connectivity” provide a common conceptual framework from which to compare and contrast very different tundra ecosystems (terrestrial tundra, streams, and lakes).

These concepts also provide a means to assess tundra response to disturbance in relation to responses of other ecosystems around the world.

Project Organization

Arctic LTER research includes three major components:

1. Long-term monitoring and surveys of natural variation and change of terrestrial and aquatic ecosystems in space and time.
2. Long-term experimental manipulations of terrestrial and aquatic ecosystems.
3. Synthesis of results and predictive modeling at ecosystem and watershed scales.
Major Arctic LTER study sites & place names

- Eddy covariance towers
- Thermokarst

Geologic surface ages from 14k years to 350k years (5m-year surface further north).
All major vegetation types for the Low Arctic present within research area.

- Terrestrial ecosystems tend to be N limited.
- Wet sedge are often P limited or N-P co-limited.
- Streams are usually P limited.
- Lakes can be N-limited, P-limited, or N-P co-limited.

How does it work?

Four research groups:
- Terrestrial - Laura Gough
- Land-Water Interactions – George Kling
- Streams – Breck Bowden
- Lakes – Phaedra Budy

Each group participates in all three components of ARC-LTER research (monitoring, experimental manipulations, synthesis)

It is our policy to encourage other researchers to make use of our long-term experiments and monitoring sites.

These collaborating studies extend what we are able to do with LTER resources and greatly enhance LTER science.
Next: Research of the Arctic LTER

• Terrestrial ----Laura Gough
• Land-Water---George Kling
• Streams---Breck Bowden
• Lakes---Phaedra Budy/Anne Giblin
• Synthesis---Ed Rastetter