The Arctic LTER Project: Synthesis Activities

Within-site Synthesis: Long term trends and consequences of warming
Although air temperature at Toolik Lake has not warmed significantly in the last 40 years, there are other indicators of significant warming (Hobbie et al. 2017).

- **Permafrost warming at 20 m depth**
  - Updated from Romainovskiy et al. (2011)

- **Toolik Lake alkalinity has doubled**
  - Updated from Kling et al. (2014)

- **Thaw depth increasing**
  - Updated from Hobbie et al. 2017

- **Tundra is “Greening”**
  - Data from Guay and Goetz

- **But we see no significant trends in aboveground vascular biomass in control plots**
  - Data from Shaver
How soon should warming be detected in tundra?

Ten replicate simulations using the MEL model with the same 0.05 °C/yr warming trend but random variation in annual temperature around that trend.

Trend not likely to emerge as significant for 50-100 years even with model’s zero measurement error.

Critical question for ectotherms: will there be enough food to support increased demand in a warmer climate?

- consumption demand by fish predicted to increase 28-34 % in a warmer lake
- a warmer climate might be able to support some increased fish demand

Log(Biomass_{ik}) = α + β_1 + s(Day of Year_{i}) + Temperature_{j} + α_k + ε_{ik}

Klobucar et al. 2018
Within-site Synthesis: Fertilization experiments in terrestrial, stream, and lake ecosystems

Warming should stimulate microbial activity and thaw organic matter currently frozen in permafrost resulting in an increase in nutrient availability across the arctic landscape.

Increased fertility favors woody deciduous species.

<table>
<thead>
<tr>
<th>Year of harvest</th>
<th>Control</th>
<th>Fertilized</th>
</tr>
</thead>
</table>

However, gains in aboveground biomass are offset by decreases in belowground biomass when bryophytes & lichens are included.
Kuparuk River Fertilizer Experiment

Fertilizer increased productivity and opened community to invasion by a new species

Deep lakes with fish

Shallow lakes with no fish

Budy et al in prep.
Synthesizing results of nutrient additions across terrestrial, stream, and lake ecosystems

Moist Acidic Tussock Tundra

Kuparuk River

Lake N2

Food web C & N flux maps

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Fertilized</th>
<th>fertilized : Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>C</td>
</tr>
<tr>
<td>Dry Heath</td>
<td>33.13</td>
<td>34.86</td>
<td>0.93</td>
</tr>
<tr>
<td>Tussock</td>
<td>0.51</td>
<td>0.53</td>
<td>0.51</td>
</tr>
<tr>
<td>Shrub</td>
<td>0.49</td>
<td>0.52</td>
<td>0.49</td>
</tr>
<tr>
<td>Streams</td>
<td>1.73</td>
<td>1.60</td>
<td>1.73</td>
</tr>
</tbody>
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Analysis by John Moore
A simple model of coupled C and N in an ecosystem to examine effects of openness

**STOCKS**
- $B_{C}$: autotrophic C
- $D_{C}$: detrital & heterotrophic C
- $B_{N}$: autotrophic N
- $D_{N}$: detrital & heterotrophic N
- N: inorganic N

**PROCESSES**
- $P$: photosynthesis
- $R$: autotrophic respiration
- $L_{SC}$: C in litterfall
- $R_{h}$: heterotrophic respiration
- $U$: autotrophic N uptake
- $L_{TN}$: N in litterfall
- $N_{min}$: gross N mineralization
- $U_{Nm}$: N uptake by heterotrophs
- $N_{in}$: inorganic N inputs
- $N_{out}$: inorganic N losses

**Processes and Stocks:**

- $B_{C}=100$
- $B_{N}=2$
- $D_{C}=1000$
- $D_{N}=50$

**Openness Index**
- $N_{in}/U = 0.01$ (Terrestrial-like)
- $N_{in}/U = 0.1$
- $N_{in}/U = 1$ (Stream-like)

**Response to 2X N inputs and then recovery**

**Terrestrial response to fertilization**
- $N_{in}/U_{N}=0.01$

**Stream response to fertilization**
- $N_{in}/U_{N}=1$

Steady state with 2X N inputs is the same for all three ecosystems, but the less open system (slowest throughput) takes longer to get there.
The more open system responds and recovers fastest.
Response to a 99% removal of autotrophic biomass

(\sim 3.7\% loss of ecosystem N)

Less open \rightarrow More open

\[ N_{in}/U_N = 0.01 \quad N_{in}/U_N = 0.1 \quad N_{in}/U_N = 1 \]

Recovery from fire

Autotrophic recovery nearly the same in all three ecosystems, fueled predominantly by redistribution of N from detritus to autotrophic biomass.

Heterotroph/detrital recovery strongest in most open ecosystem.

Synthesis: North Slope and Pan-Arctic Analyses
Shrub expansion in the Arctic
Net result of climate warming and herbivory

Small expansion of evergreen shrubs: moderate positive climate effect and weak negative herbivory effect

Strong expansion of unpalatable deciduous shrubs: strong positive climate effect and weak negative herbivory effect

Moderate expansion of palatable deciduous shrubs: strong positive climate effect and strong negative herbivory effect

Optimum tussock tiller growth shifted northward: Indication of climate warming?

Δ Thaw degree-day sum (garden – source)

McGraw et al. 2015
There is a remarkable convergence of structure and function among diverse vegetation canopies around the Arctic. NEE predictable from just three variables.

\[
N_{EE} = R_x + (R_0 L_T e^{-\beta T}) - \frac{P_{max}}{k} \ln \left( \frac{P_{max} + E_0 I}{P_{max} + E_0 I e^{-\kappa L_T}} \right)
\]

- \(N_{EE}\): net ecosystem CO₂ exchange (µmol CO₂ m⁻² s⁻¹)
- \(R_x = 0.729\)
- \(R_0 = 1.233\)
- \(L_T\): LAI (m² m⁻²)
- \(\beta = 0.046\)
- \(T\): air temperature (°C)
- \(P_{max} = 15.184\)
- \(k = 0.5\)
- \(E_0 = 0.041\)

CCaN: Coupled Carbon And Nitrogen model

CCaN [Model] NDVI Trends

Rocha et al. in prep
The Multiple Element Limitation (MEL) Model

MEL model projections of C in vegetation, soil organic matter, and total ecosystem for IPCC SRES B1 and A2 climate scenarios

Jiang et al 2016
Synthesis: LTER-network analyses
Responses on aboveground NPP to changes in resources and climate

Smith et al. 2015

Plant adaptation to local temperatures evident in longitudinal trend in leaf respiration around the globe

Atkin et al. 2015
Rastetter et al. (submitted)

13 authors from 4 LTER sites (ARC, CCE, CWT, & FCE)

One of five LTER network papers submitted to Ecosphere as a special issue organized by Peter Groffman

Multiple Element Limitation (MEL) model simulated C metabolism across LTER sites
Multiple Element Limitation (MEL) model simulated N stocks 2X CO₂, +10% Ppt, & +3.5°C