Arctic LTER Project

The Arctic LTER Project: Mid-term Site Review 18-19 June 2013

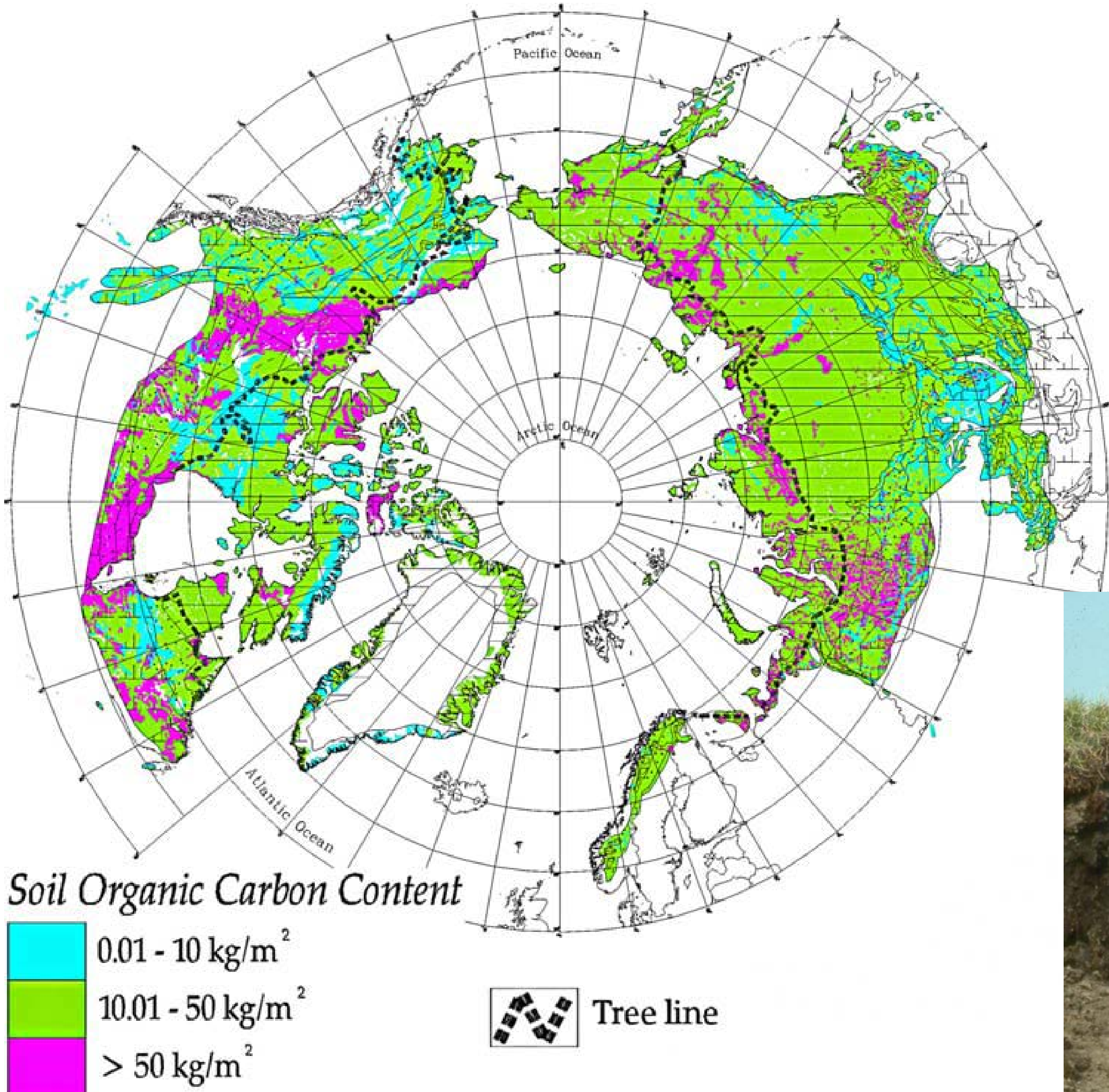
Welcome everyone

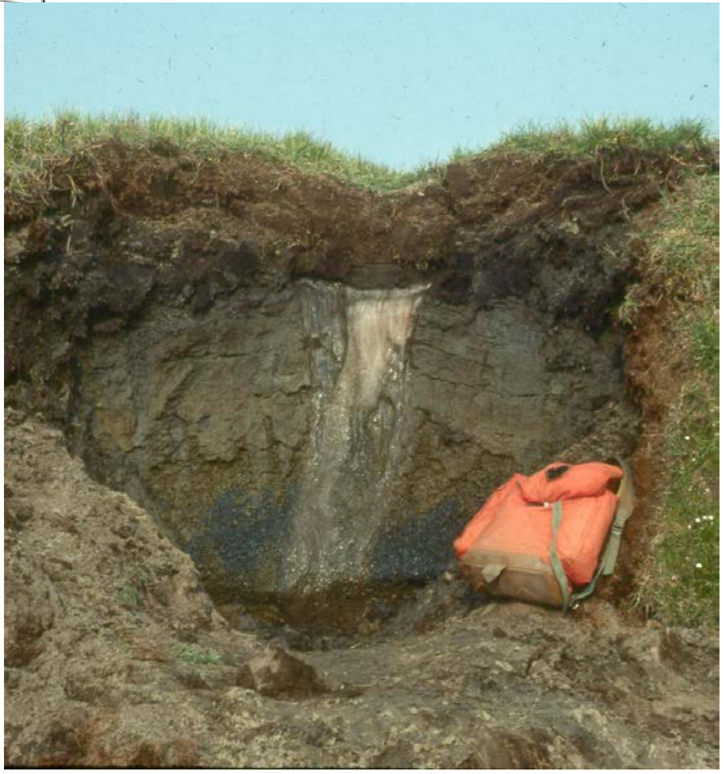
Arctic LTER Project

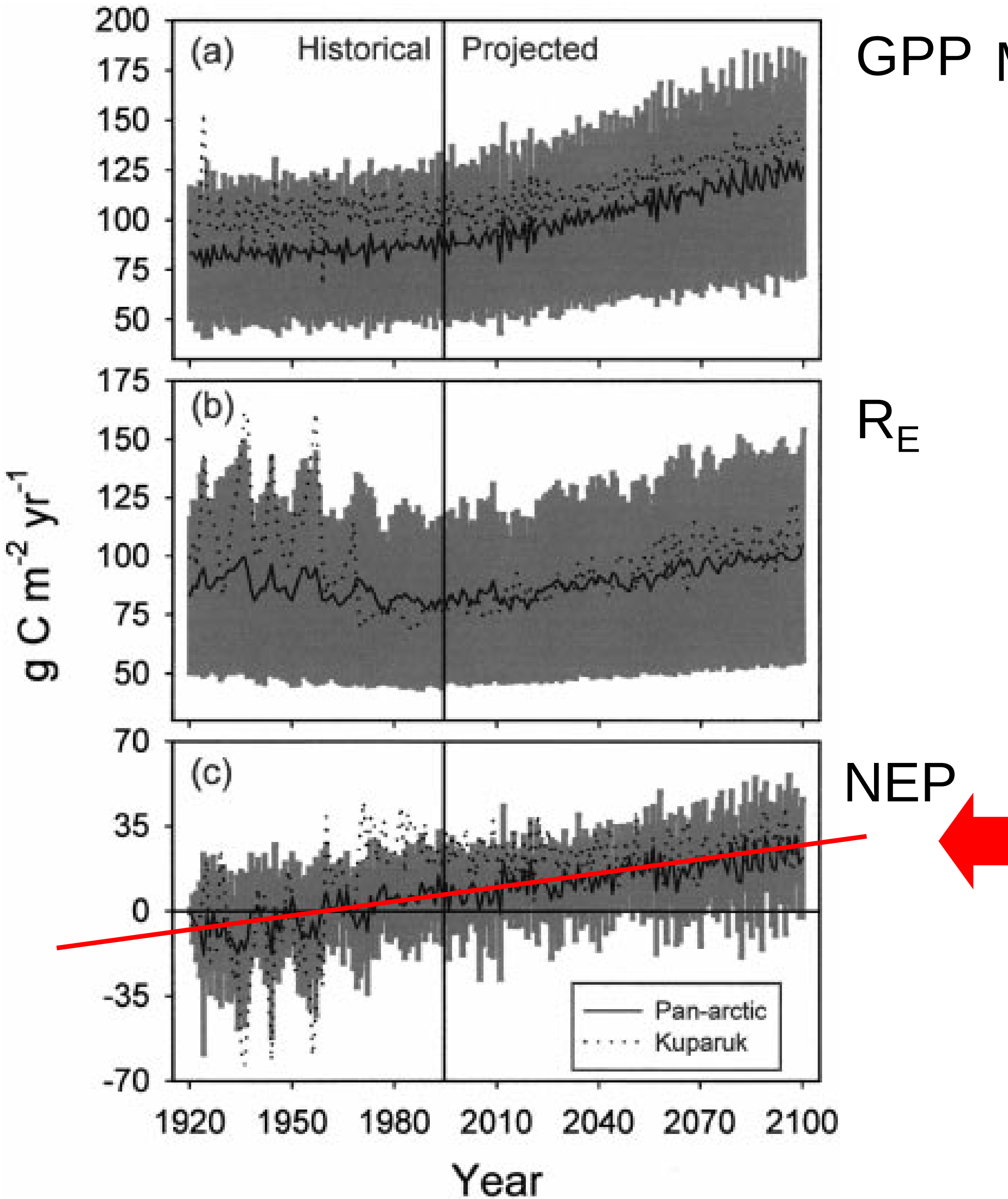
Research of the Arctic LTER: Synthesis

- How we do synthesis, imp of collaborating projects
- Within-site synthesis
  - Synthesis Book—58 coauthors
  - Lakes, Streams, Terrestrial, Land-water synthesis (previous presentations)
- Network and multisite synthesis
- Ecological theory: Moore and deRuiter Ecological Energetics
- Overall project: Fire in the Arctic Landscape
- PanArctic synthesis: Canopy-level controls on NEE
- Current within-site synthesis projects:
  - Trophic structure
  - C, N budgets

Soils underlain by permafrost contain almost 1700 Pg C, about 50 % of all soil C and >2x that held in the atmosphere







McGuire et al. 2000:

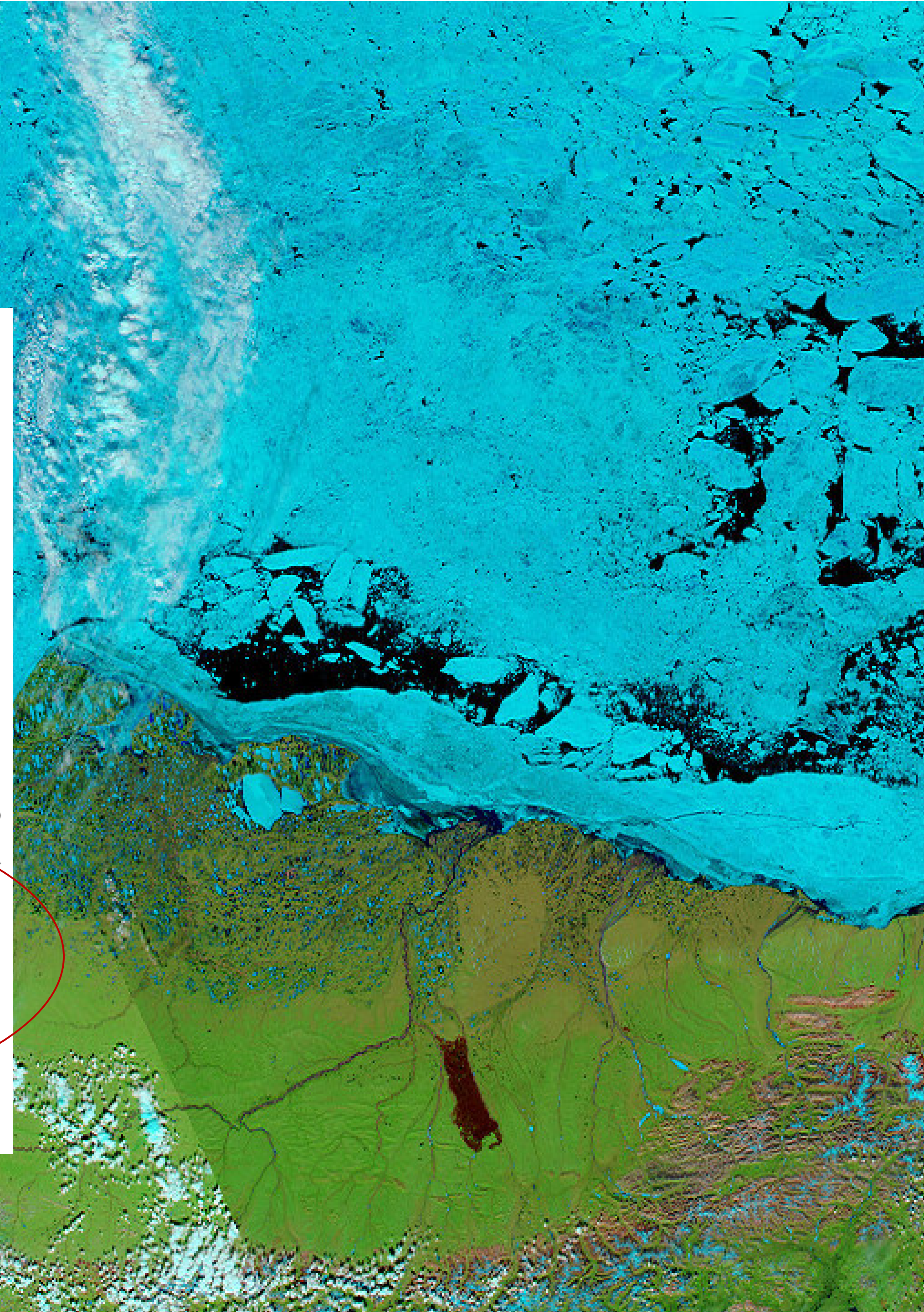
NEP of PanArctic tundra varies from -30 to +40 g C/m^2/y,

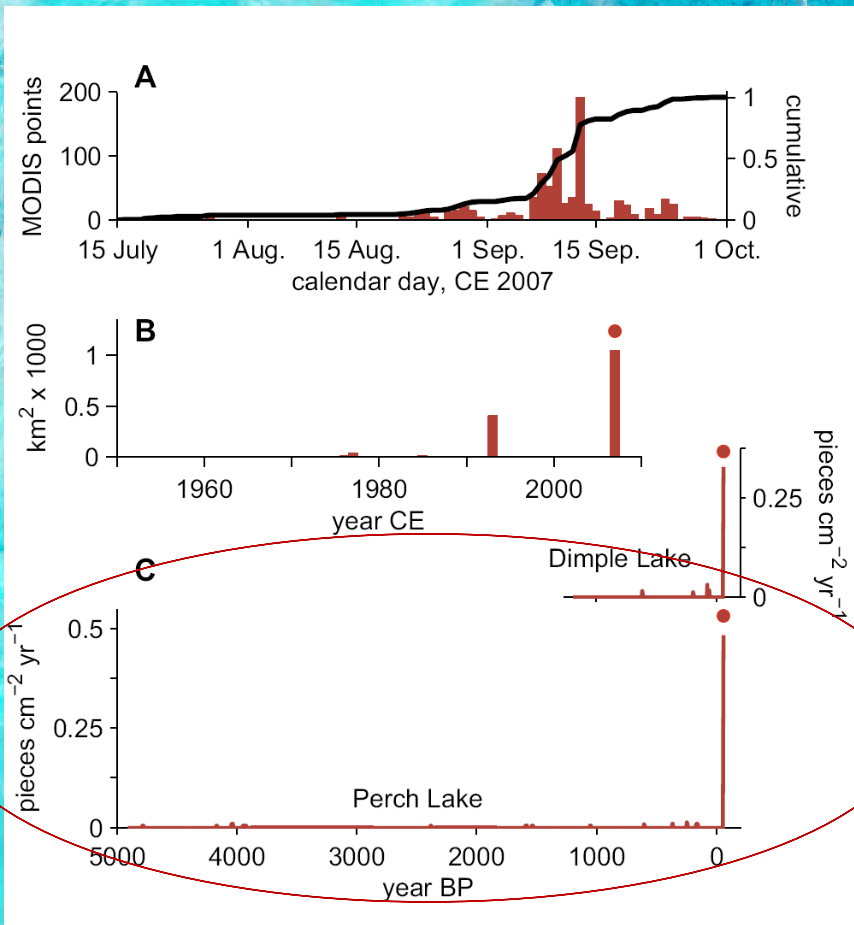
NEP of Kuparuk watershed is currently ~15-20 g C/m^2/y

Change in NEP due to climate change is <1.0 g C/m^2/y

Something new on the horizon

Anaktuvuk River Burn, MODIS, early June 2008

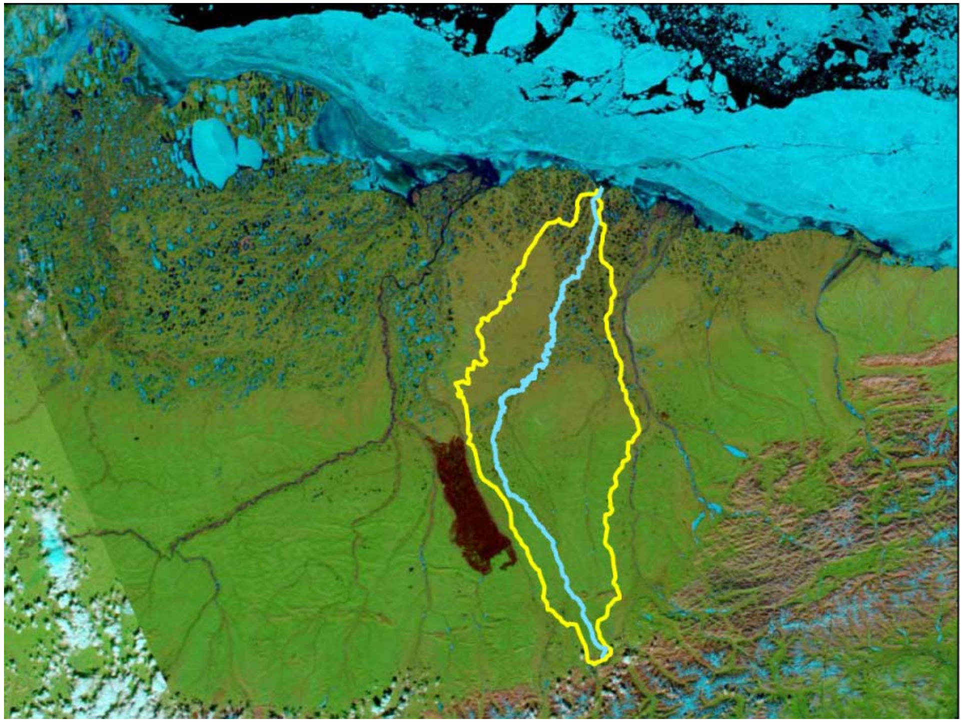




Hu et al. 2010: no fires in this area for past 5000 y

COMBUSTION LOSSES VS ANNUAL NEE OF KUPARUK BASIN:

C loss by combution was ~2.16 Tg over 1039 km2 (measured by Mack et al 2011)



Annual NEE of the Kuparuk R. catchment: 0.218 Tg net C LOSS (measured 1995-96 by Oechel et al. 2000) or 0.23 Tg net C GAIN (modeled 1980-2100 by McGuire et al. 2000) in 9200 km2.

OR: Fire released as much CO_2 to the atmosphere as annual NEE of 9-10 Kuparuk River watersheds in ~10-15% of the area of one watershed

PanArctic tundra biome C sink averaged 3 - 4 Tg C/y over the last 10 years of the 20th century (McGuire et al. 2009).

The US B-53 Nuclear Bomb

Explosive yield ~9 Megatons

1 Megaton = 4.2×10^{15} Joules

The Anaktuvuk River Burn

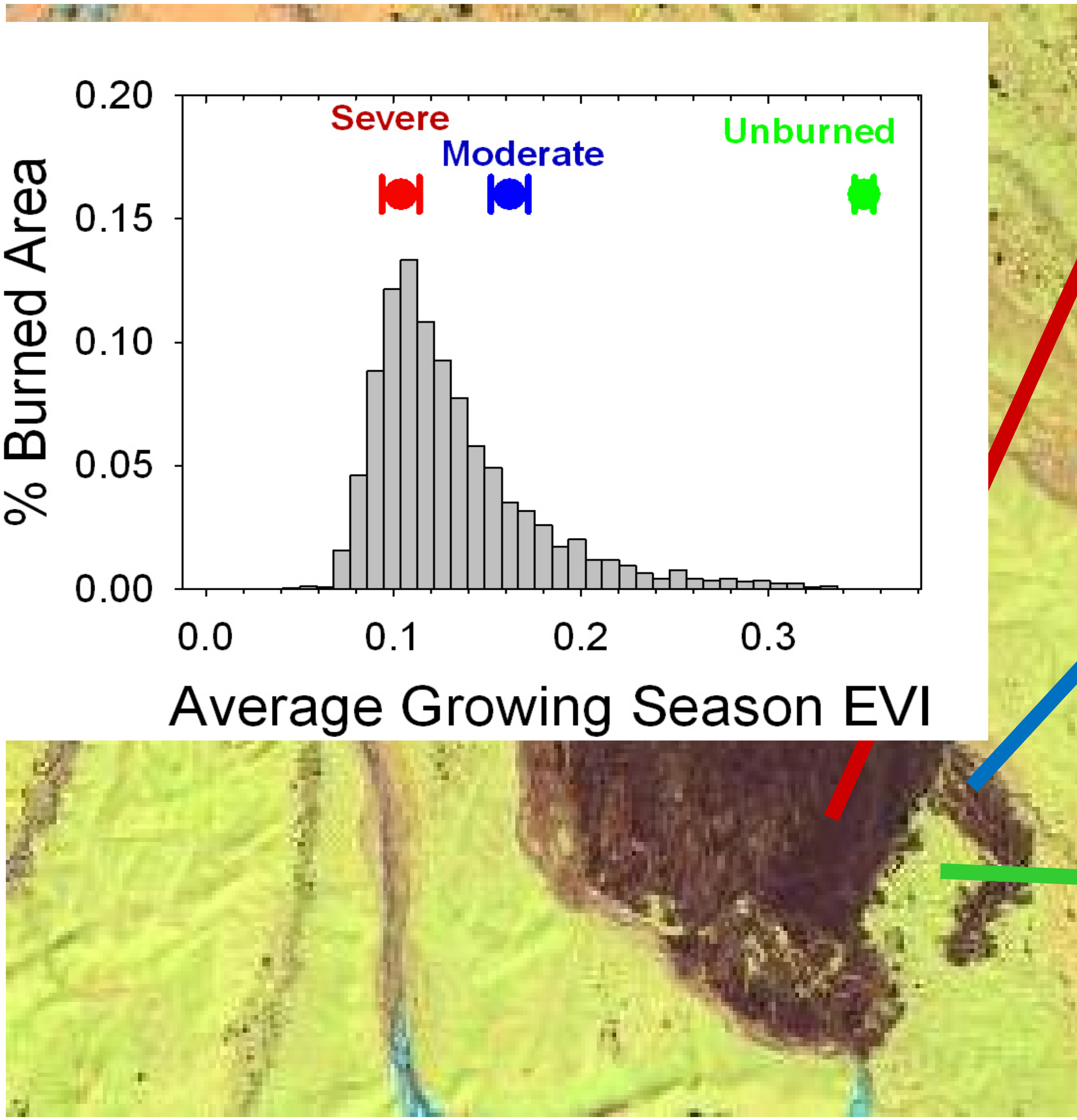
Energy released by combustion of organic matter

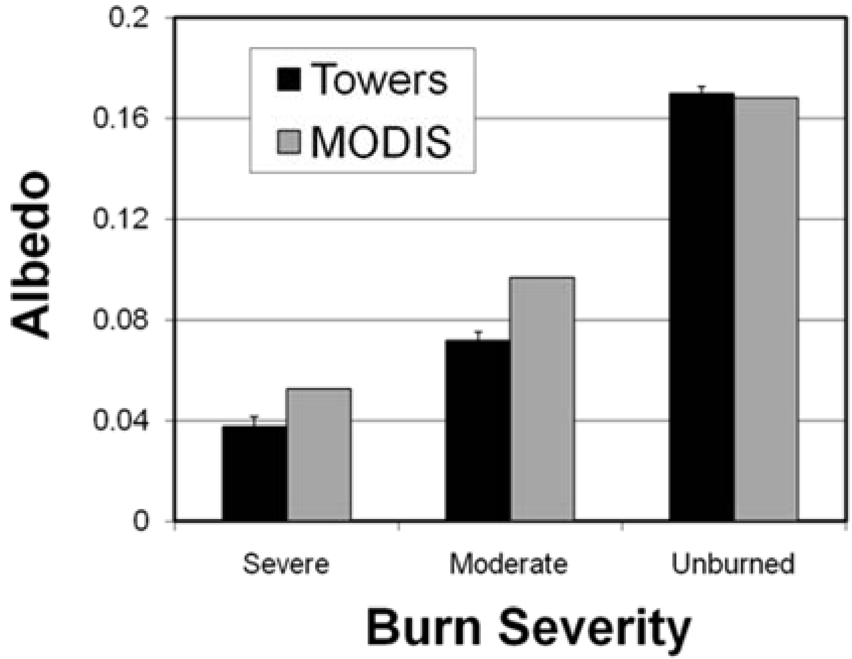
~93×10^{15} Joules, equivalent to

~22 Megatons TNT

Anaktuvuk River Fire

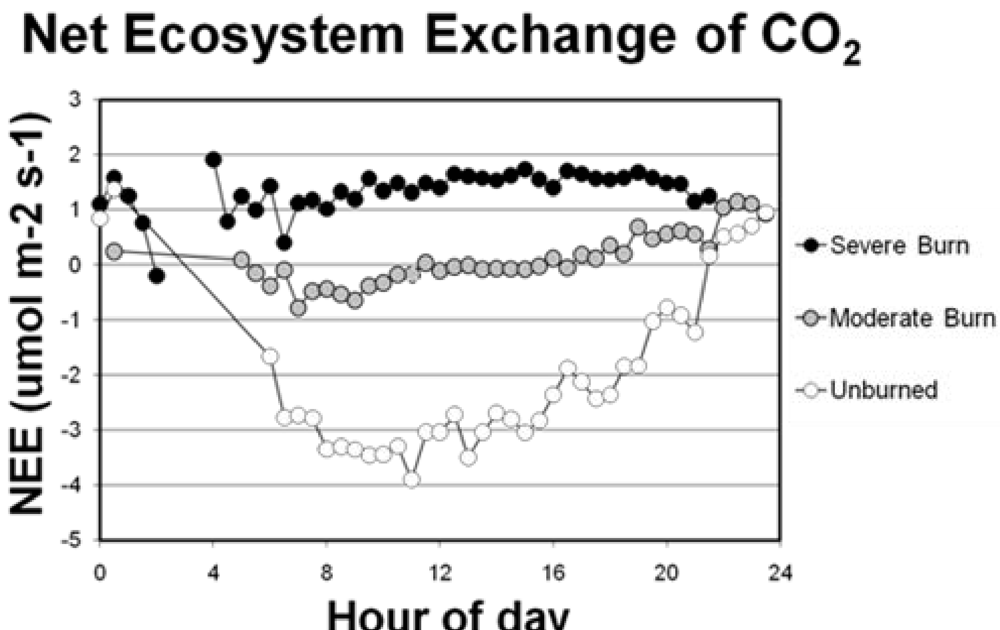
Area burned : 1039 km2
C released : ~2.16 Tg





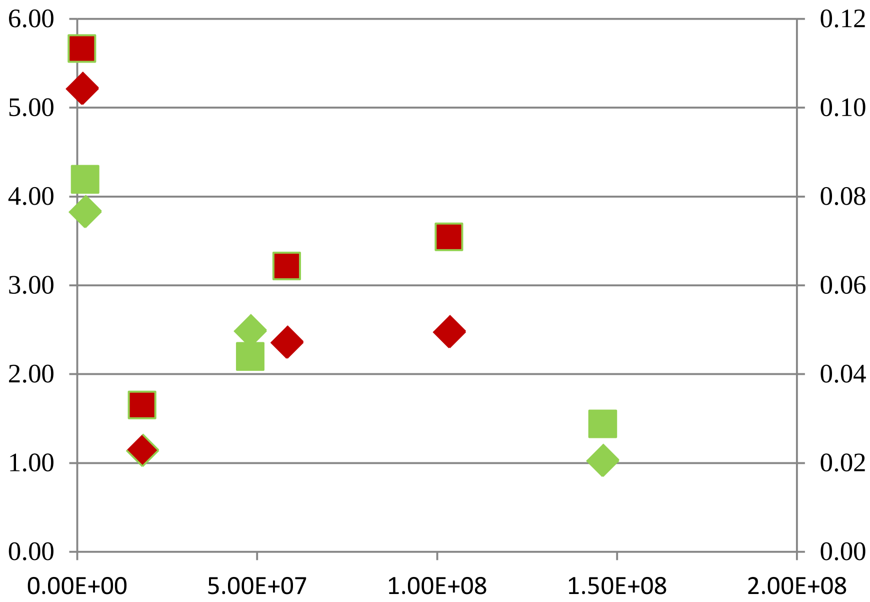
Albedo
0.2
0.16
0.12
0.08
0.04
0
Towers
MODIS
Severe
Moderate
Unburned
Burn Severity

Unburned Tundra, 4 July
Severe Burn, 31 May
Severe Burn, 4 July



Net Ecosystem Exchange of CO2
NEE (umol m-2 s-1)
3
2
1
0
-1
-2
-3
-4
-5
0
4
8
12
16
20
24
Hour of day
Severe Burn
Moderate Burn
Unburned

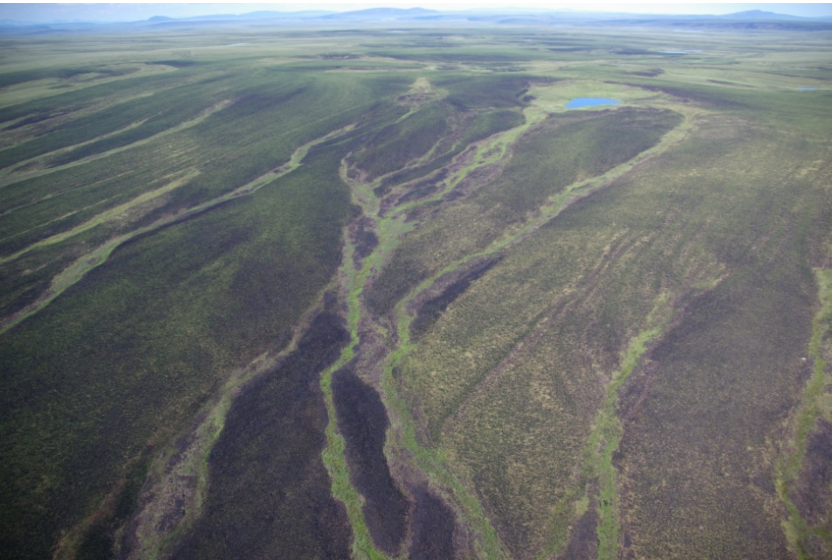
2008 Total C export, g/m2 (Diamonds)



2008 Total N export, g/m2 (Squares)

Watershed area, m2

Green=unburned, Red=burned



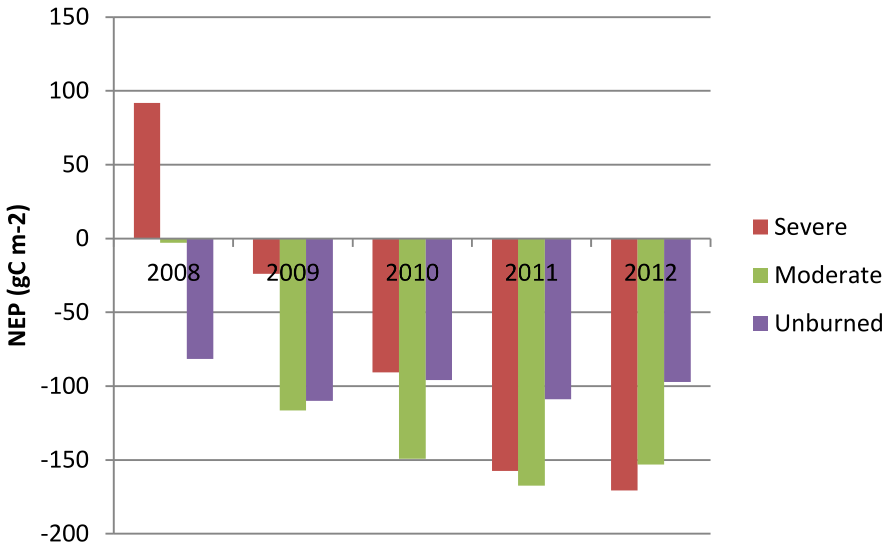
Data: G. Kling et al.

Summary of initial changes in C balance due to climate change and fire

	Yearly NEE	Change in NEE in 1 year due to:			
	(mean predicted)	Warming	Combustion	Recovery	Aquatic loss
Area:			2007	2008	2008
one m2	-15 gC	< -1 g C	2.02E+3 gC	80-140 g C	1-2 g C
AR Burn	-15.6E+09 gC	<-1.04E+09 g C	2.16E+12 gC	1.25E+11 g C	1-2E+09 gC
N Slope	-2.8E+12 gC	<-1.88E+11 g C			

- Although the area disturbed is relatively small, changes in response to disturbances (fire, thermokarst) are much greater and faster than direct responses to climate
- Changes in C cycling on disturbed sites are large enough that the regional response to climate change will be dominated by changes in disturbance regime, not direct impacts of climate change.

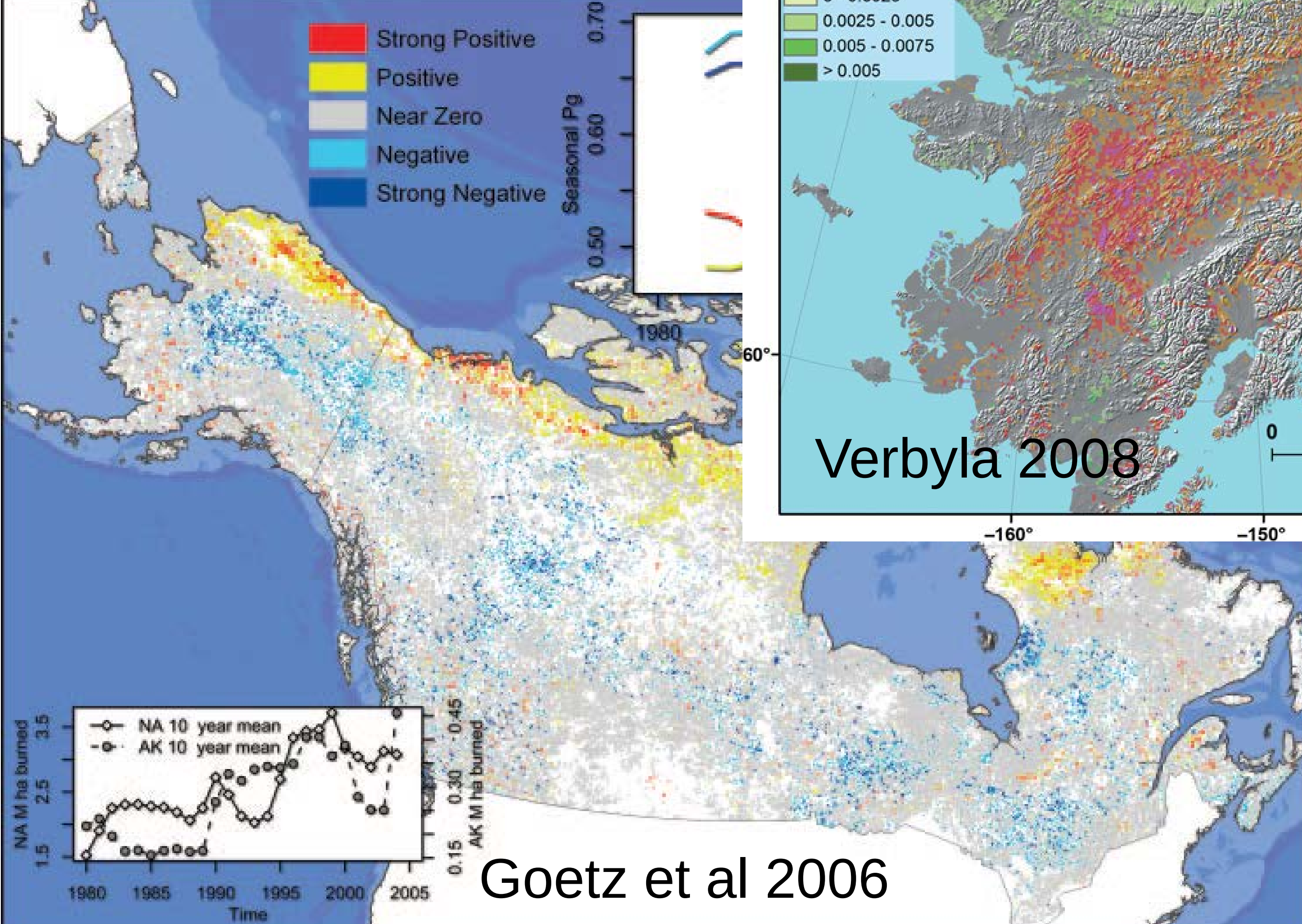
June-August NEE, 2008-2012



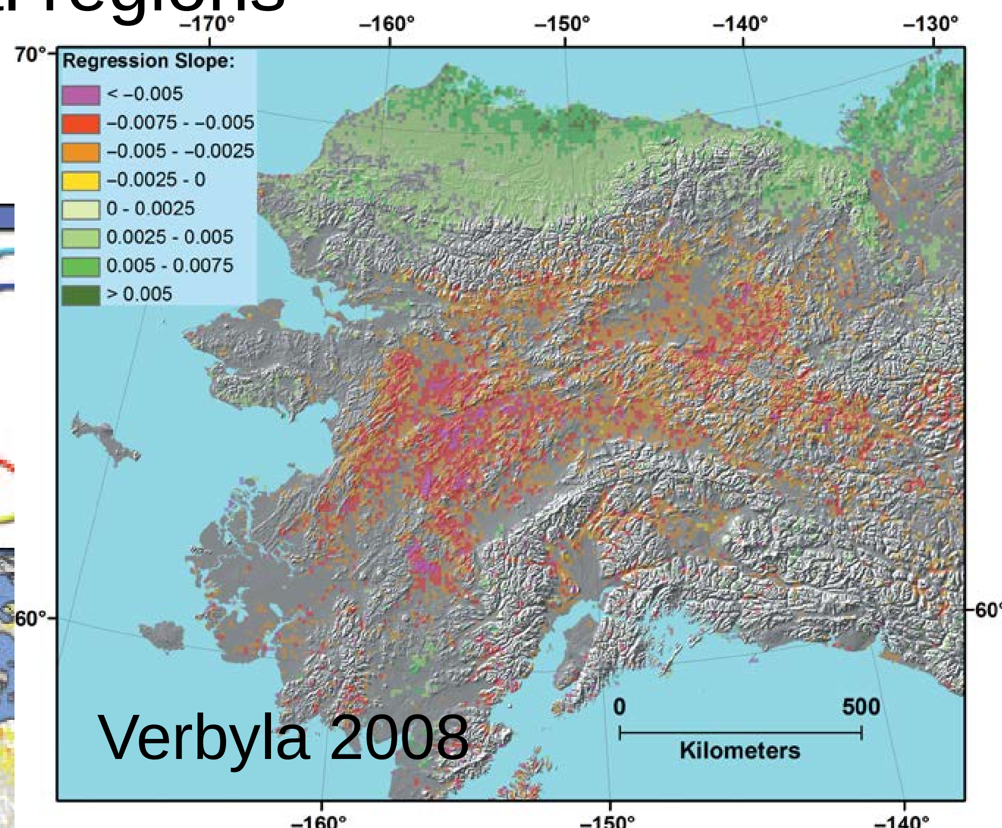


“The Valley of Thermokarsts”
active layer displacement

Panarctic Change: The Greening and the Browning of the Arctic and Boreal regions



Goetz et al 2006



Verbyla 2008

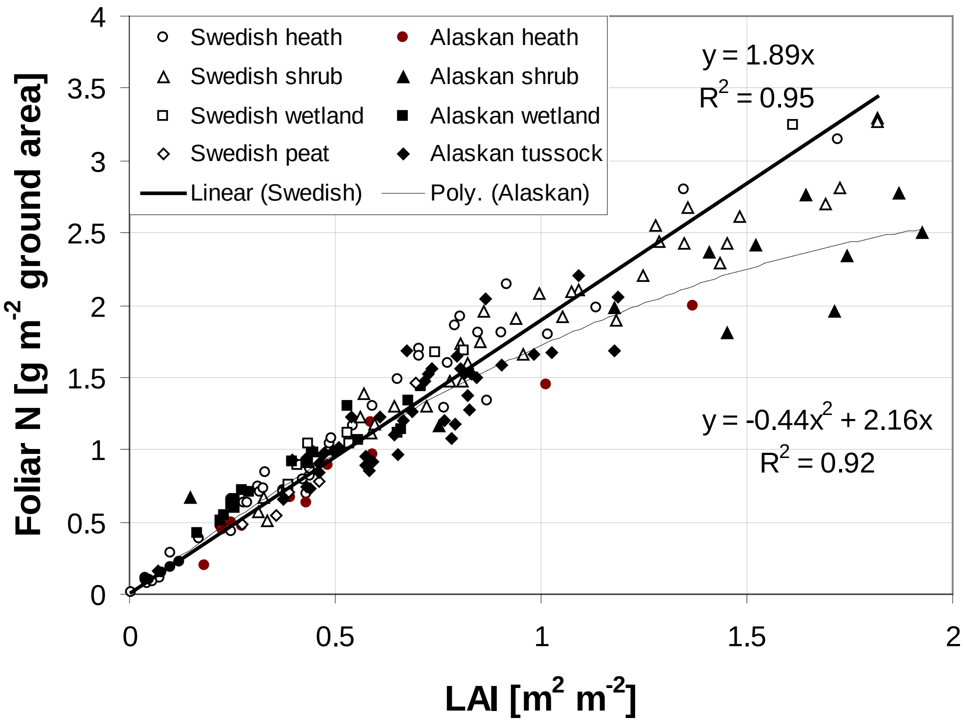
How can we evaluate these changes against a background of much greater variability in C stocks and turnover?

Productivity, for example, varies by 3 orders of magnitude among arctic ecosystems

Table 6.10. Soil organic matter, plant biomass, and net primary production (NPP) in the main Arctic ecosystem types. After Jonasson et al. (2001) based on data from Bliss and Matveyeva (1992) and Oechel and Billings (1992).

	Soil organic matter (g /m^2)	Vegetation biomass (g /m^2)	NPP (g /m^2/y)	Soil: Vegetation	Soil:NPP	Veg:NPP	% of total area
			High Arctic				
Polar desert	20	2	1	10	20	2.0	15
Semi-desert	1030	250	35	4.1	29	7.1	8
Wet sedge/mire	21000	750	140	28	150	5.4	2
			Low Arctic				
Semi-desert	9200	290	45	32	204	6.4	6
Low shrub	3800	770	375	4.9	10	2.1	23
Wet sedge/mire	38750	959	220	40	176	4.3	16
Tall shrub	400	2600	1000	0.2	0.4	2.6	3
Tussock/ sedge dwarf shrub	29000	3330	225	8.7	129	16	17

LAI-Canopy N relationship is constant across most vegetation types at Toolik Lake, Alaska, and Abisko, Sweden (van Wijk et al. 2005)



Observed LAI-N relationship optimizes GPP (Williams and Rastetter 1999)

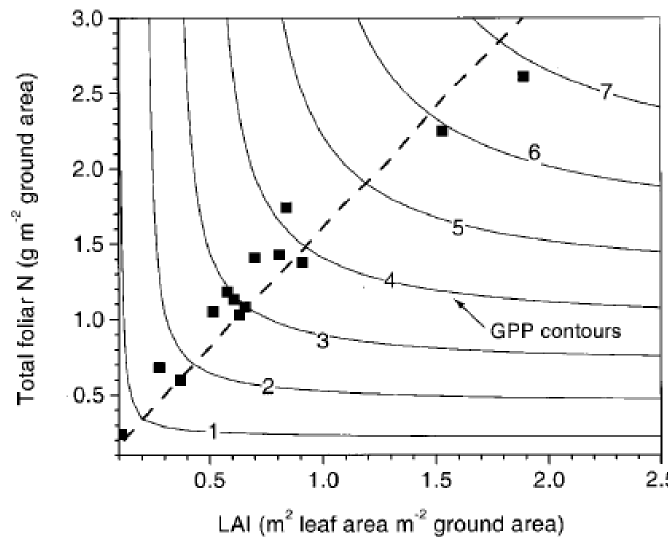
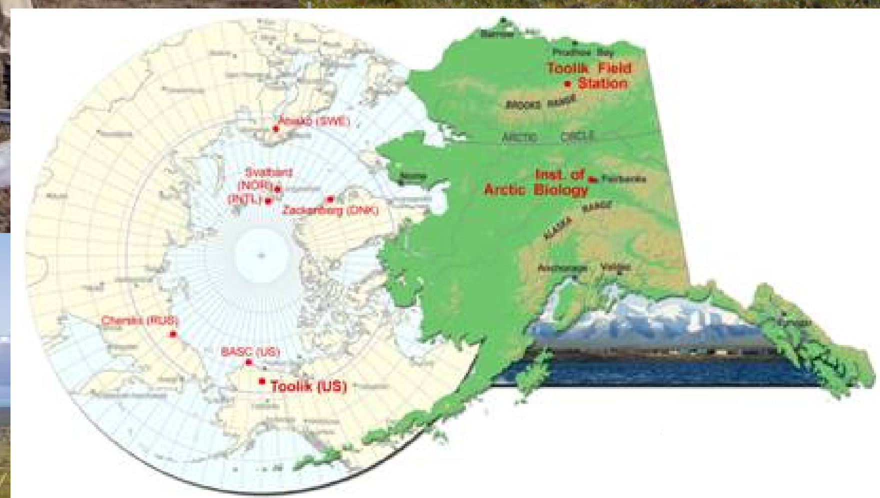


Fig. 6 The modelled response surface of GPP of vascular plants (contour lines, g C m^{-2} day^{-1}) to combined variations in LAI (L; m^2 leaf area m^{-2} ground area) and total foliar N (N; g N m^{-2} ground area). Also shown (symbols) are the LAI–N relationships for the sites along the transect, and the line that connects points on the surface where $\partial P/\partial L = 1.48\ \partial P/\partial N$, where P = GPP.






Barrow
Prudhoe Bay
Toolik Field Station
BROOKS RANGE
ARCTIC CIRCLE
Nome
Inst. of Arctic Biology
Fairbanks
ALASKA RANGE
Anchorage
Valdez
Abisko (SWE)
Svalbard (NOR)
Zackenberg (DNK)
Cherskii (RUS)
BASC (US)
Toolik (US)

The Model:

$$NEE = \left(\left(R_0 * e^{\beta T} * LAI\right) + R_x\right) - \left(\frac{P_{maxL}}{k} * \ln\left(\frac{P_{maxL} + E_0 * I}{P_{maxL} + E_0 * I * e^{-k*LAI}}\right)\right)$$

Where:

NEE is the measured or predicted net CO2-C flux (μmol C per m^2 ground per second)

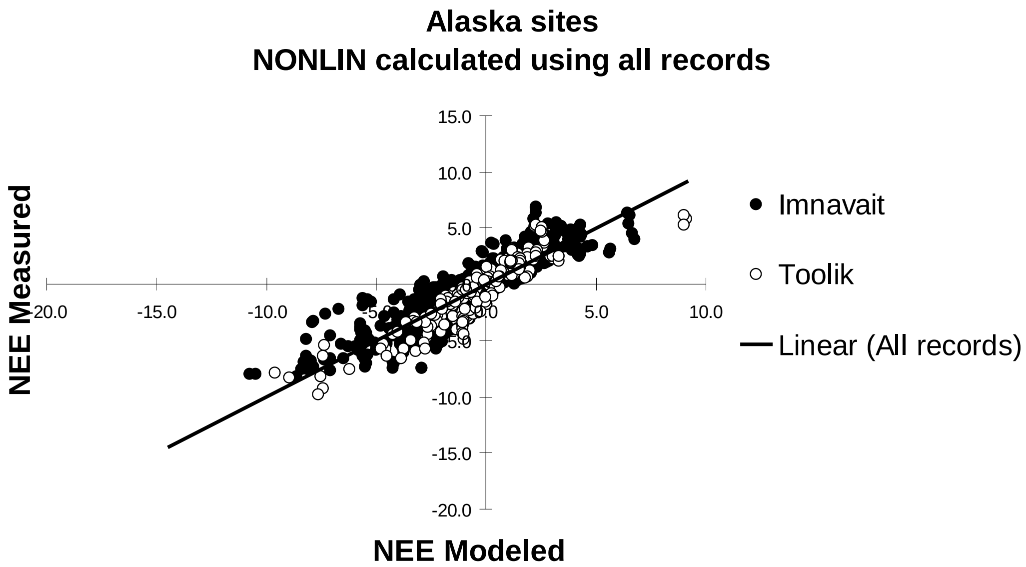
LAI is leaf area as calculated from the measured NDVI (m^2 leaf/m^2 ground)

I is the measured incident PAR(μmol photons per m^2 ground per second)

T is the air temperature during the measurement (°C)

R_o, R_x, b, P_{maxL}, k, and E_0 are parameters estimated by nonlinear regression

(Shaver et al. 2007)



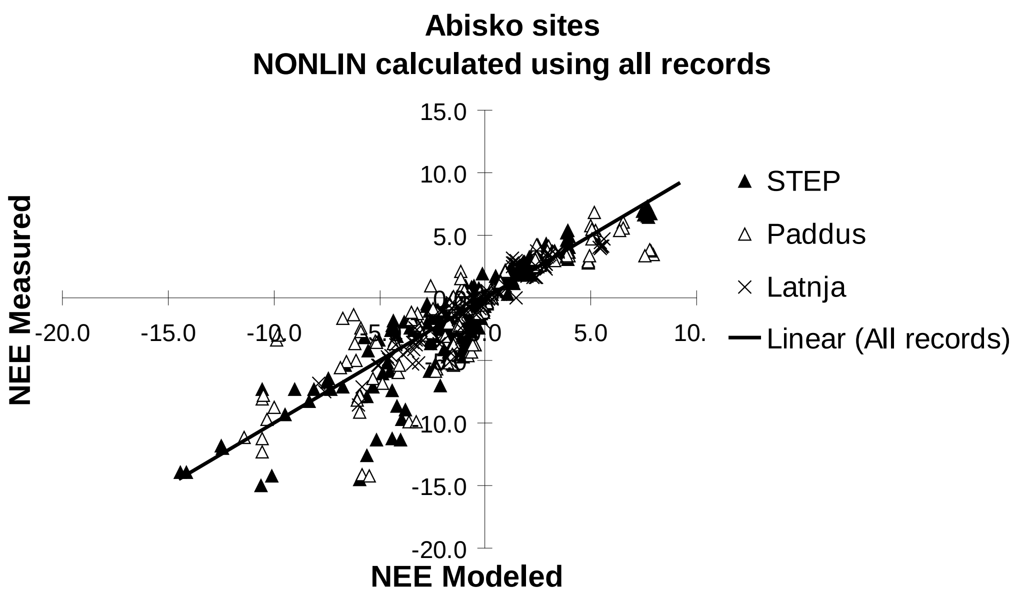
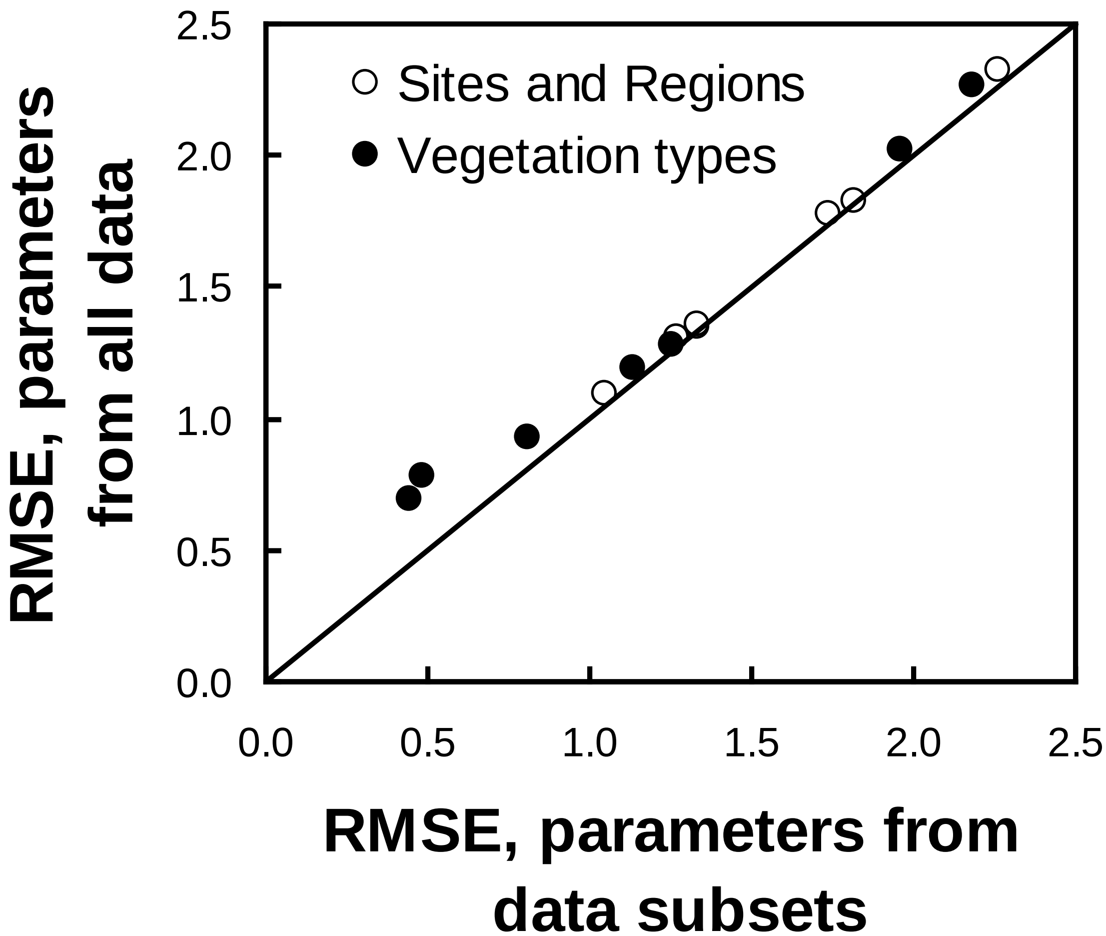


Figure 5. Measured versus modeled NEE, using all available data from 32 site/vegetation type combinations.

$r^2 = 0.799$
slope = 1.000
intercept = 0.000
RMSE = 1.53 µmol m^{-2} s^{-1}

Shaver et al. 2007



Model parameterized with data from any Low Arctic site or vegetation type predicts NEE accurately in other sites or vegetation

Figure 4. Root Mean Square Error (RMSE, μmol m^{-2} s^{-1}) for predictions of NEE in individual sites, regions, or vegetation types when the NEE_2 model parameters are developed by regression on the same data subsets (horizontal axis) or on the whole data set (vertical axis). Points above the 1:1 line indicate larger RMSE, and thus less accuracy, using the whole data set.

Shaver et al. 2007

Table 3. Statistics of fit (r^2) and accuracy (RMSE) for predictions of NEE based on regression parameters derived from the entire data set, for High Arctic data only, and for the Low Arctic data only. Numbers in bold represent cells where NEE is predicted for the same data set used for model parameterization. Numbers in plain font represent cells where parameters derived by regression using one data set are used to predict NEE in a different data set.

Data sets predicted by regression parameters

		r^2, predicted vs. observed			RMSE, predicted vs. observed		
Data used in regression	**n=**	**All Data**	**High Arctic**	**Low Arctic**	**All Data**	**High Arctic**	**Low Arctic**
All Data	4853	**0.759**	0.703	0.769	**1.512**	1.258	1.585
High Arctic	1179	0.622	**0.739**	0.627	2.192	**1.167**	2.431
Low Arctic	3674	0.759	0.698	**0.769**	1.513	1.271	**1.583**

So what?

- ~75% of the variation in net CO_2 flux (NEE) for a wide range of arctic ecosystems can be explained knowing only leaf area, air temperature, and light (PAR)
- Measurements made in one part of the Arctic can be used to predict CO2 fluxes in other parts of the Arctic
- Species/functional type composition doesn't seem to matter—composition changes dramatically and often abruptly along climatic gradients but NEE changes smoothly with leaf area
- Success of continuous model indicates high level of convergence in canopy structure and function among diverse tundras including diverse plant types
- Short term changes in NEE throughout the Arctic can be predicted with accuracy using a single parameterization of a single model

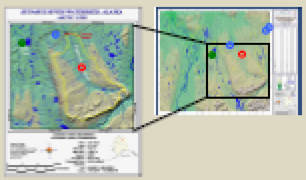
Food Webs Across Arctic Lake, Terrestrial, and Stream Ecosystems: *An ARC LTER Synthesis*

Colorado State University — John C. Moore, Kirstin Holfelder, Rodney Simpson
Marine Biological Laboratory — Gaius Shaver
NEON — Stephanie Parker
University of Alabama Tuscaloosa — Alex Huryn
University of Texas, Arlington — Laura Gough
Utah State University — Phaedra Budy

INTRODUCTION

The arctic biome is characterized by relatively low primary productivity because of the lack of sunlight, frozen soil and frozen water bodies through much of the year. Thus the amount of energy available to higher trophic levels is low compared with ecosystems at other latitudes. Species diversity is also lower in this region than at temperate and tropical latitudes, suggesting that food web structure may be simpler in the Arctic. In lakes, streams, and tundra, detritus provides much of the energy and nutrients required of consumer species in addition to primary producers. Omnivory occurs throughout these food webs as well.

We intend to use our results to test core ideas in ecology such as: are trophic cascades all wet? (Strong 1992), the Exploitation Ecosystem Hypothesis (Oksanen *et al.* 1981), the rates of C-flux of food web channels across systems (Moore and Hunt 1988, Rooney *et al.* 2006), and the relative importance of the green vs. brown channels across terrestrial and aquatic ecosystem (Moore *et al.* 2004, Hagen *et al.* 2012).



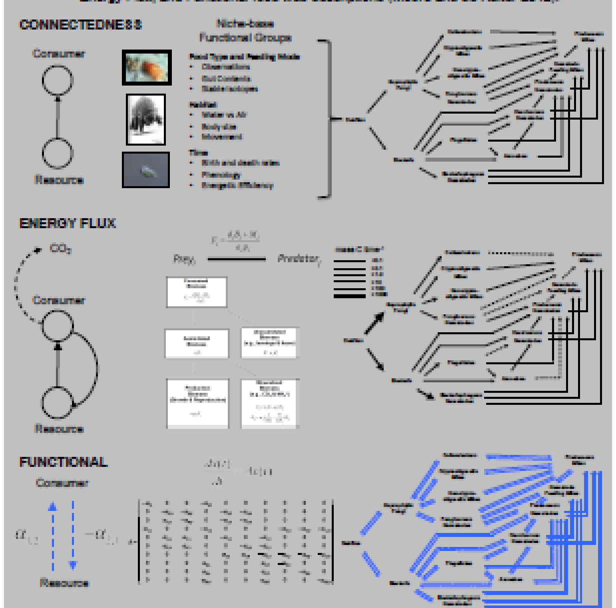
ARCTIC FOOD WEBS

- **Lakes** – A composite food web using data collected from three fish-containing lakes, e.g. Fog2, Fog1, E5.
- **Streams** - Upper Kuparuk food web.
- **Terrestrial** - Belowground food webs from Moist Acidic Tundra.

GOALS

- Characterize and compare food webs in representative Arctic lakes, streams, and tundra at the Arctic LTER sites to examine similarities and differences in trophic structure, energy flow, and dynamic properties across these ecosystems (Box 1).
- Compare the Arctic food webs to those from other ecosystems.

Box 1 – Schematic of the information and methodology used to construct the Connectedness, Energy Flux, and Functional food web descriptions (Moore and de Ruiter 2012).



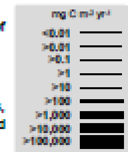
CONNECTEDNESS DESCRIPTIONS AND METRICS

Values of number of functional groups (S), number of resources ($S_{Resources}$), connectance (C), linkage density (SC), and maximum (FCL_{Max}) and mean (FCL_{Mean}) food chain length, and maximum interaction strength (I_{max}) are presented below (Below). A comparison of the Arctic food webs to the aquatic and terrestrial food web compiled by Briand (1983; Box 2).

System	S	$S_{Resources}$	C	SC	I_{max}	FCL_{max}	FCL_{mean}
Moist Acidic Tundra	20	2	0.289	5.78	0.416	9	5.23
Lake	13	4	0.615	8.00	0.354	5	3.59
Stream	21	9	0.324	6.80	0.383	5	3.01

ENERGY FLUX DESCRIPTIONS

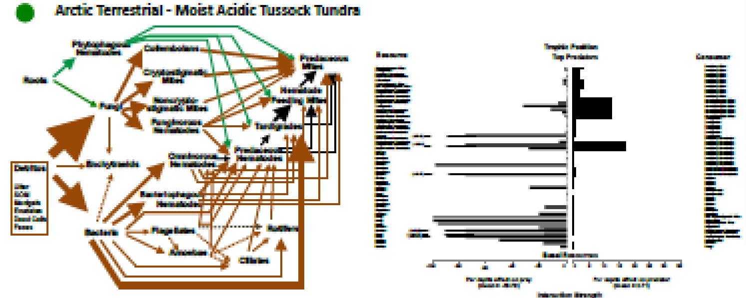
The thickness of the arrows of the energy flux description depict the flow of C (mg C m^{-2} yr^{-1}) estimated from the biomasses, birth and death rates and energetic efficiencies of the functional groups (Box 1). Green arrows indicate flows originating from primary producers, brown arrows indicate detritus flows, and black arrows indicated both.



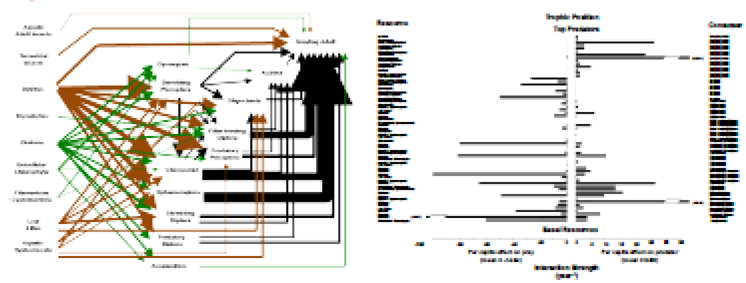
FUNCTIONAL DESCRIPTIONS

The interaction strengths (i.e., elements of the Jacobian matrix) define and characterize food web dynamics and stability. The pair-wise interaction strengths for each trophic interaction (off-diagonal elements) with the arctic food webs are arranged by increasing trophic position (below). The minimum multiplier '*s-min*' of the diagonal elements required for stability are presented in Box 2 (lower right). Asymmetric patterns of the pair-wise interaction strengths and low minimum s are indicative of stable systems.

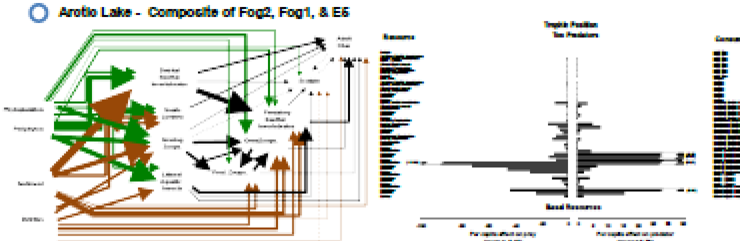
Arctic Terrestrial - Moist Acidic Tussock Tundra



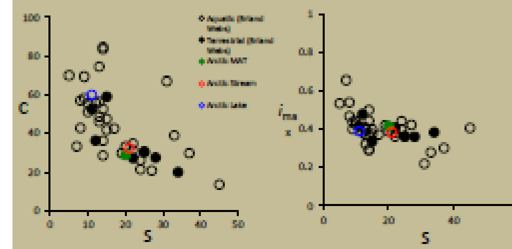
Arctic Stream – Upper Kuparuk



Arctic Lake - Composite of Fog2, Fog1, & E5

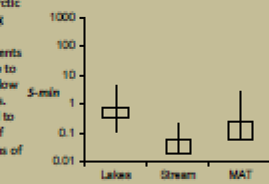


Box 2 - The relationship between (upper left) the connectance (C) and diversity (S), and (upper right) the maximum interaction strength (I_{max}) and diversity (S) using our arctic food webs and the aquatic and terrestrial food webs compiled by Briand (1983).



The decreases in C and I_{max} with increase S are consistent with the findings of Gardner and Ashby (1970) and May 1972 that increased complexity leads to instability and that the structures we observe reflect dynamic. The Arctic food webs follow this pattern.

We estimated the sensitivity of the Arctic food webs to disturbance by assessing the minimum multiplier '*s-min*' that would to be applied to diagonal elements of the Jacobian matrices for each web to ensure stability (adjacent). Values below 1 are indicative of stable architectures. These baseline estimates can be used to gauge changes in the dynamic state of the system through time or as a means of assessing treatments on the dynamic state of the system.



SUMMARY AND FUTURE PLANS

- We have compiled a set of metrics that will enable us to follow changes in the food web structure and dynamics of native and treated systems through time, and compare the Arctic systems to others.
- Our assessment of the Arctic food webs reveal that our systems share much in common with other terrestrial and aquatic food webs.
- Energy flux through the stream food web is large and uniform whereas fluxes are more concentrated at the base of the terrestrial and lake food webs.
- We will continue to refine estimates and descriptions, particularly at the base of the systems with greater attention given to plant species, detritus inputs, and microbial communities.
- Assess relationships between the structural and dynamic attributes emphasized here with using C dynamics with the N and P dynamics.

LITERATURE CITED

Briand, F. 1983. Environmental control of food web structure. Ecology 64:253-263.

Gardner, M.R. and W.R. Ashby. 1970. Connectance of large dynamic (cybernetic) systems: critical values for stability. Nature 228: 784.

Hagen, E.M., K.E. McCluney, K.A. Wyant, C.U. Soykan, A.C. Keller, K.C. Luttermoser, E.J. Holmes, J.C. Moore, J.L. Sabo. 2012. A meta-analysis of the effects of detritus on primary producers and consumers in marine, freshwater and terrestrial ecosystems. Oikos 121:1507-1515.

May, R.M. 1972. Will a large complex system be stable? Nature 238:413-414.

Moore, J.C., and H.W. Hunt. 1988. Resource compartmentation and the stability of real ecosystems. Nature 333:261-263.

Moore, J.C., and P.C. de Ruiter. 2012. Energetic Food Webs: An analysis of real and model ecosystems. Oxford University Press, Oxford, UK 333 pages.

Moore, J.C., E.L. Berlow, D.C. Coleman, P.C. de Ruiter, Q. Dong, A. Hastings, N. Collins -Johnson, K. S. McCann, K. Melville, P.J. Morin, K. Nadelhoffer, A.D. Rosemond, D.M. Post, J.L. Sabo, K.M. Scow, M.J. Vanni, and D. Wall. 2004. Detritus, Trophic Dynamics, and Biodiversity. Ecology Letters 7:584-600.

Oksanen, L., S. D. Fretwell, J. Arruda, and P. Niemel. 1981. Exploitative ecosystems in gradients of primary productivity. The American Naturalist 118:240-261.

Rooney, N., K. McCann, G. Gellner, and J.C. Moore. 2006. Structural asymmetry and the stability of diverse food webs. Nature 442:265-269.

Strong, D.R. 1992. Are trophic cascades all wet? the redundant differentiation in trophic architecture of high diversity ecosystems. Ecology 73:747-754.

This project is supported by a Math Science Partnership Grant from the National Science Foundation DUE 0831175. Any opinions, finding, and conclusions or recommendations are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Contact Information

Laura Gough – gough@uta.edu
John Moore – jcmoore@nrel.colostate.edu

ACKNOWLEDGEMENTS

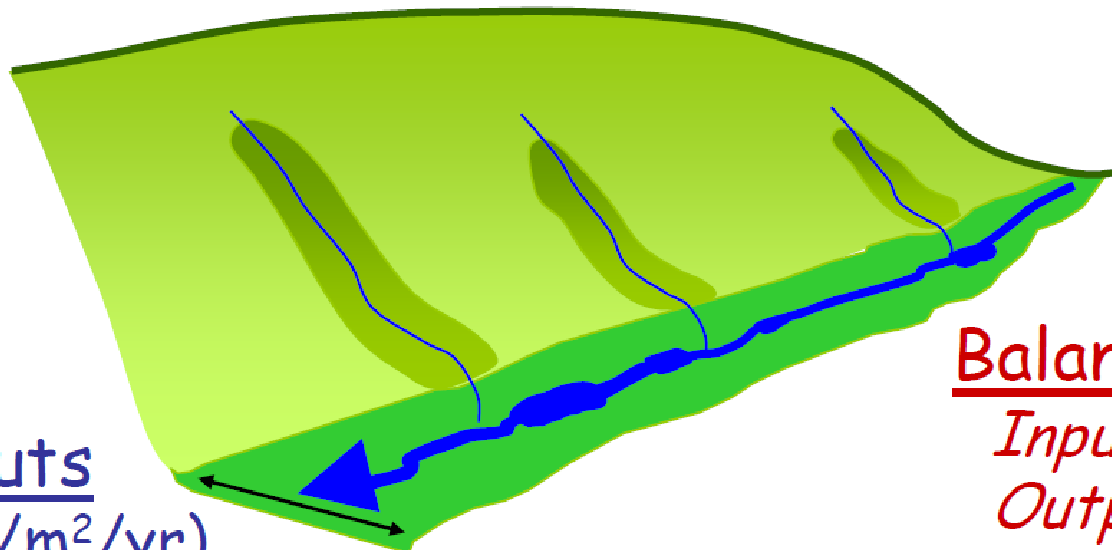
Funding for this project was provided by the National Science Foundation (OPP-0425806 and OPP-0909441 to John Moore; OPP-0425827 and OPP-0909507 to Laura Gough; DEB-0423385 and DEB-1026843 to Gus Shaver). Logistic support was provided by Toolik Field Station, University of Alaska, Fairbanks, and CH2M Hill Polar Services.

Imnavait Creek N Balance

Inputs (mg N/m²/yr)

Precipitation = 25
N-fixation = 106 (80-131)

TFS candy bar pieces = 1.3
DEET = 0.9



Outputs

(mg N/m²/yr)

Stream export = 63 (32-98)
Burial *(accumulation)* = 54
Denitrification = 1440 (0-1440)
(potential)

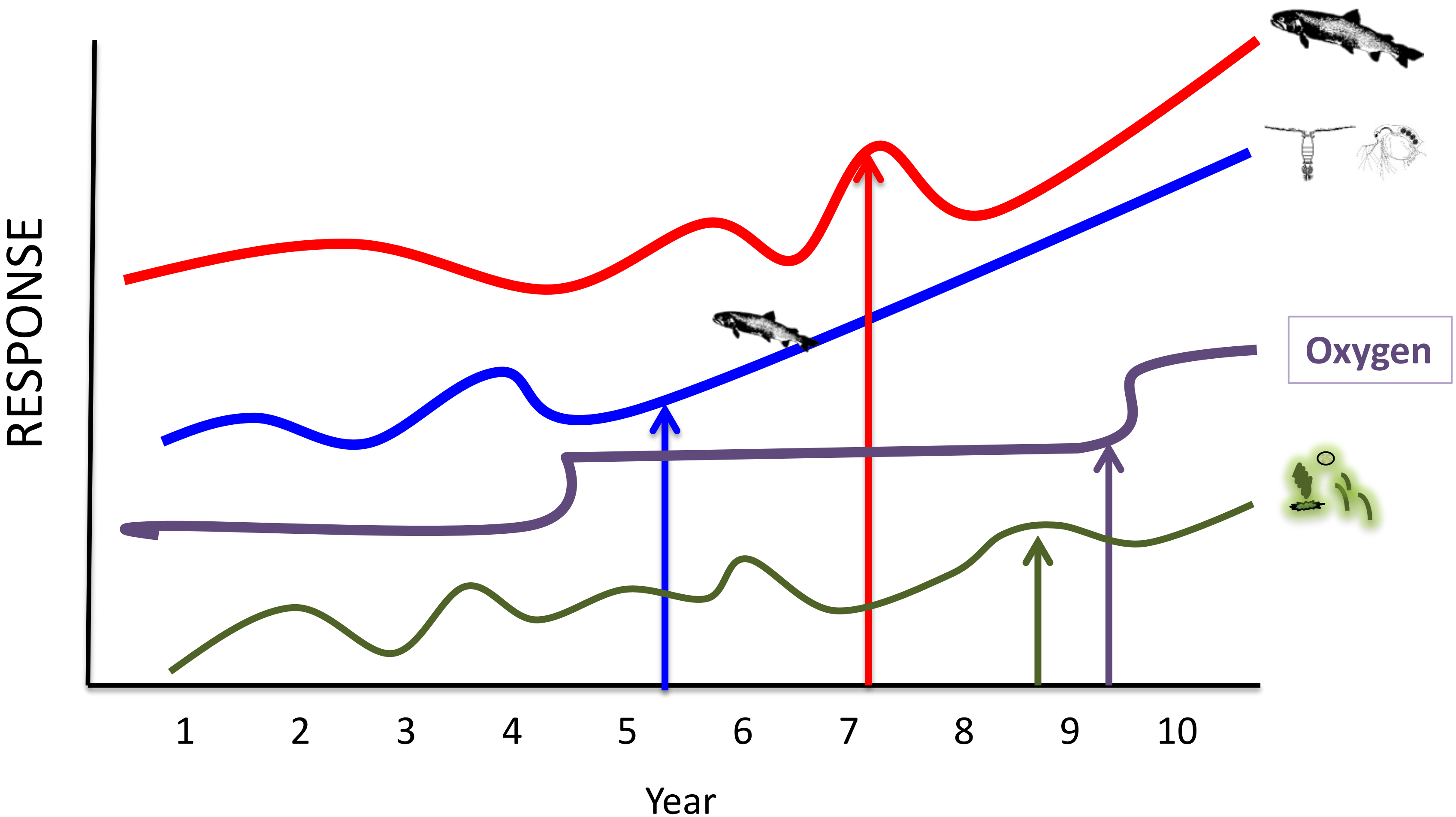
Balance

Inputs = 131
Outputs = 117

Difference = 14

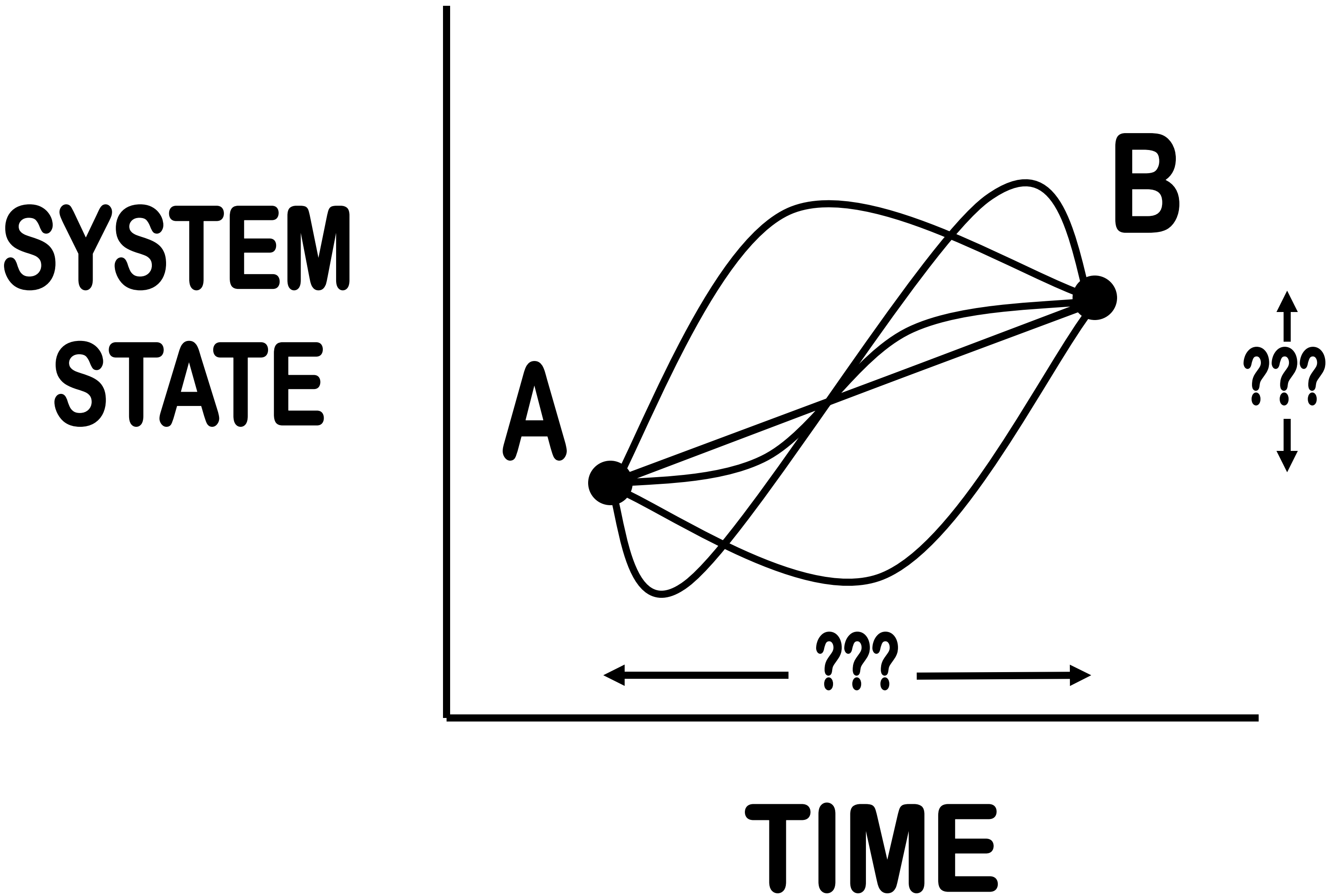
Plant N requirement
~ 4,000 mg N/m²/yr

Future: Linked trajectories of change??



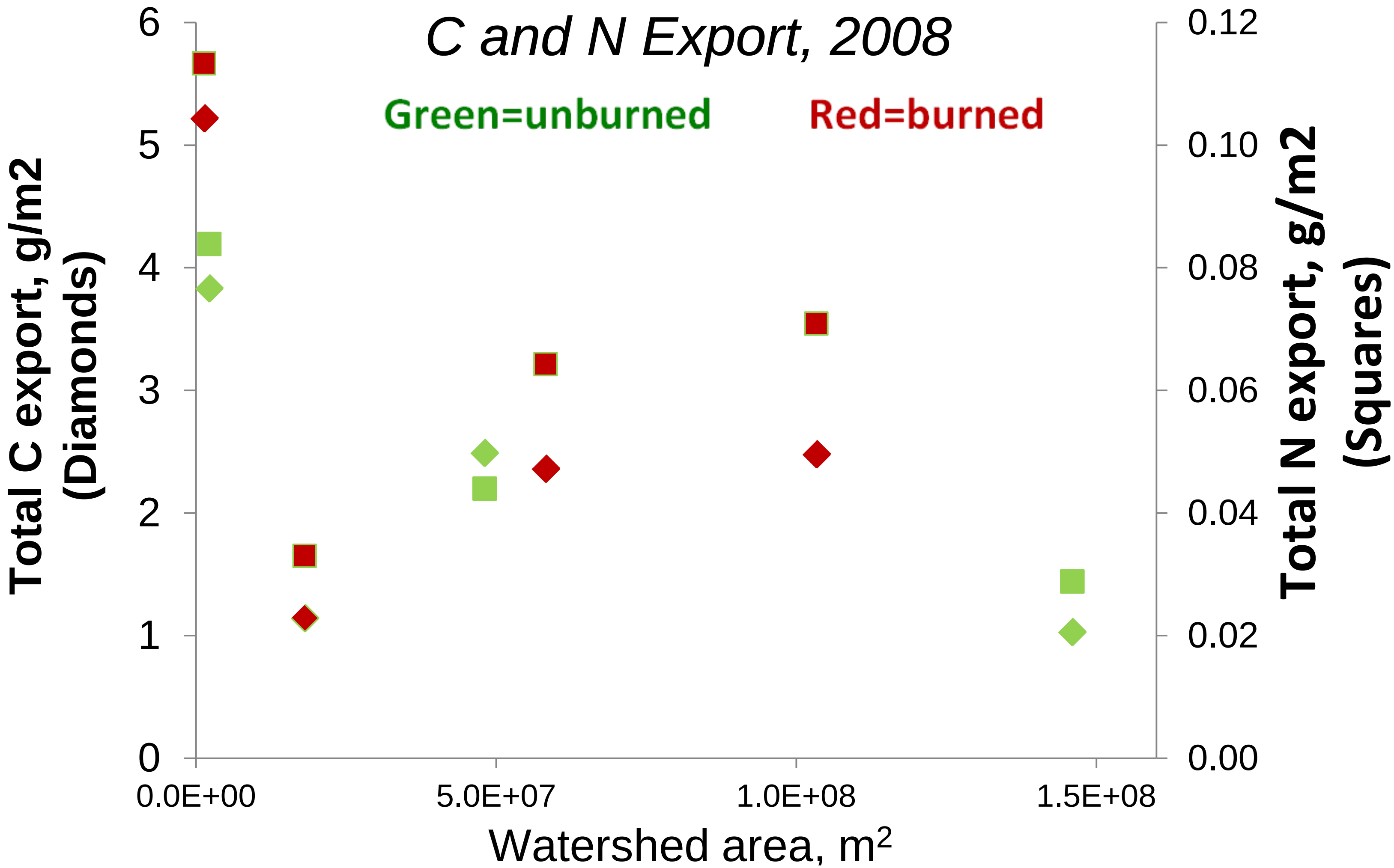
Threshold, tipping points, local stability ~ perturbation ??

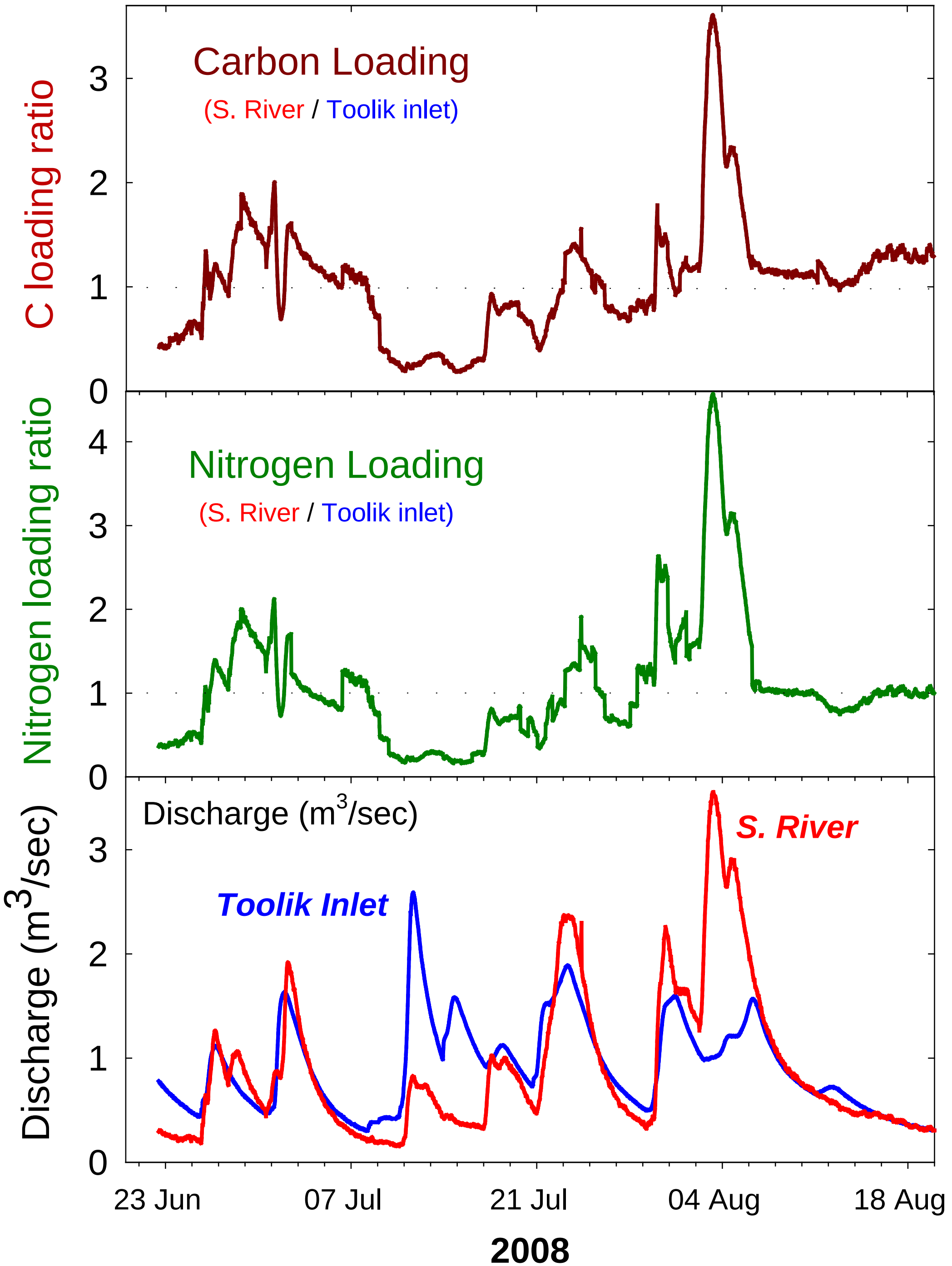
How do we get from Point A to Point B ?



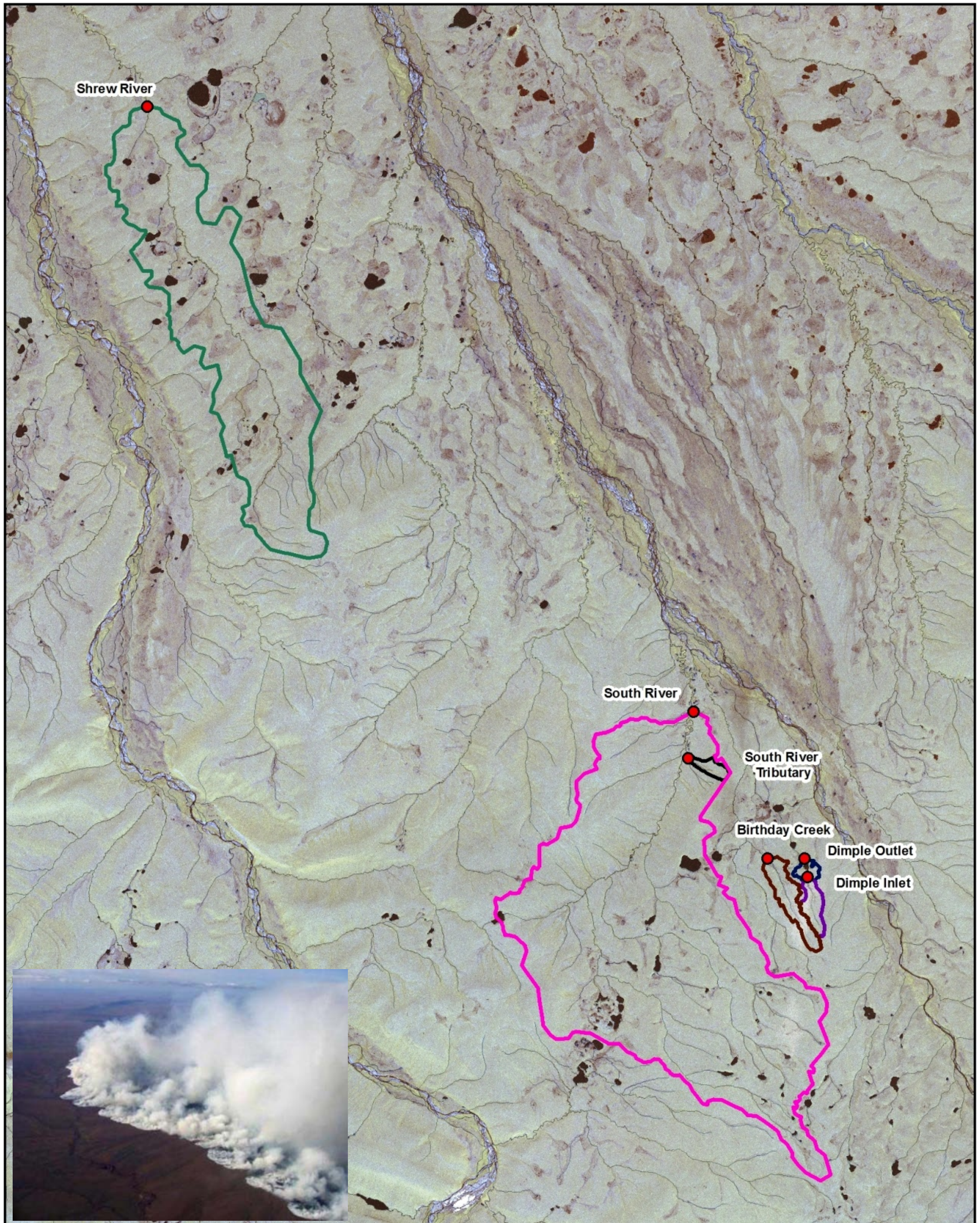
Links to overall project goals

- Large-area disturbance
- Are we meeting our proposal goals?   YES WE ARE


C and N Export, 2008
Green=unburned
Red=burned
Total C export, g/m2 (Diamonds)
Total N export, g/m2 (Squares)
6
5
4
3
2
1
0
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.0E+00
5.0E+07
1.0E+08
1.5E+08
Watershed area, m2



In larger streams, discharge drives loading, but when discharge is equal the burned site exports more carbon



Sampling Sites and Catchment areas

Small streams:

Dimple inlet = 1.4 km^2
Birthday Creek = 2.7 km^2
Dimple outlet = 0.6 km^2

Control:

Imnavait Creek = 2.2 km^2

Large rivers:

South River = 116 km^2
Shrew River = 58 km^2

Controls:

Toolik Inlet = 48 km^2
Kuparuk R. = 146 km^2

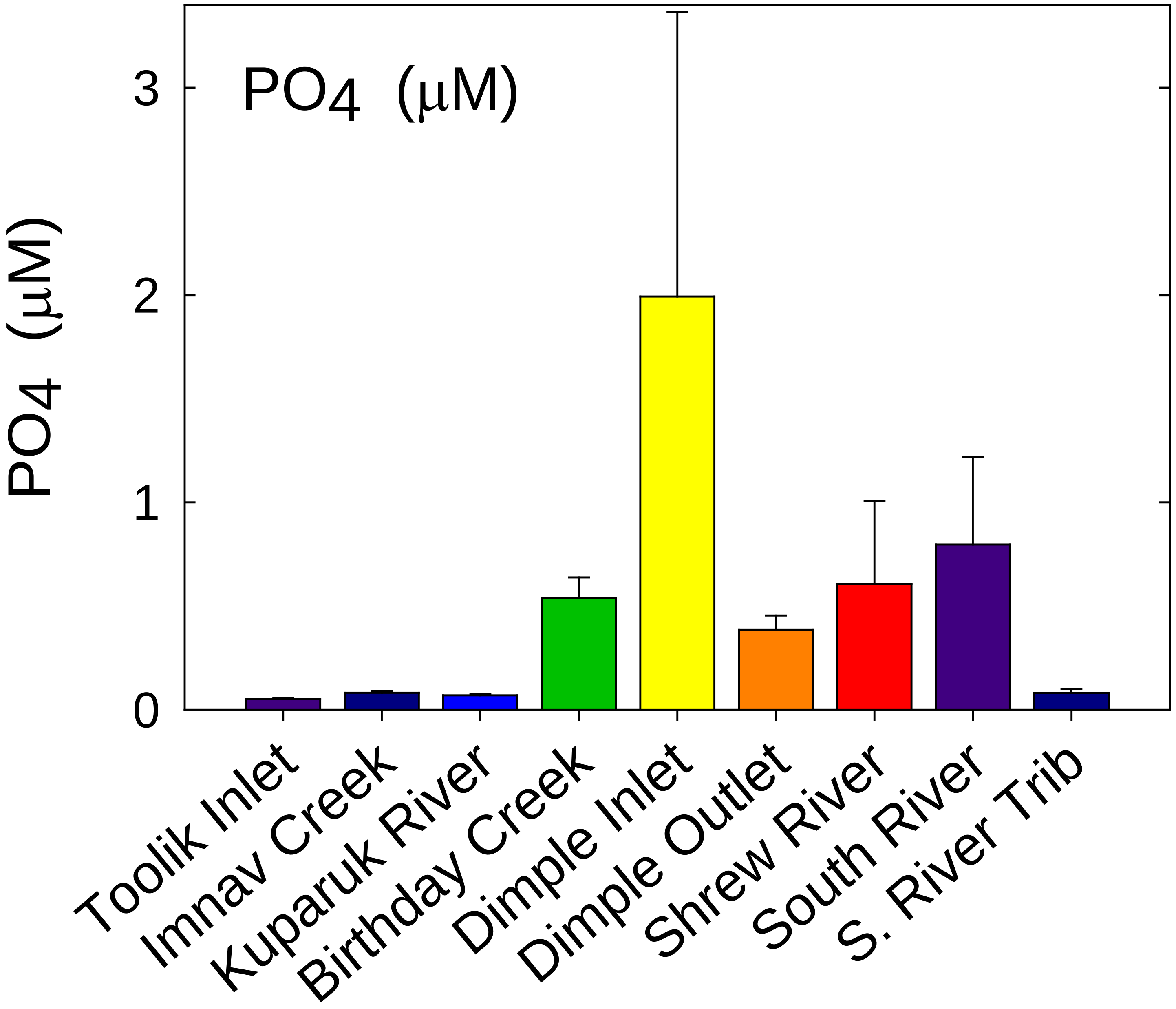
Dimple Lake area

variable burn intensity and area

South River basin - intensely burned areas

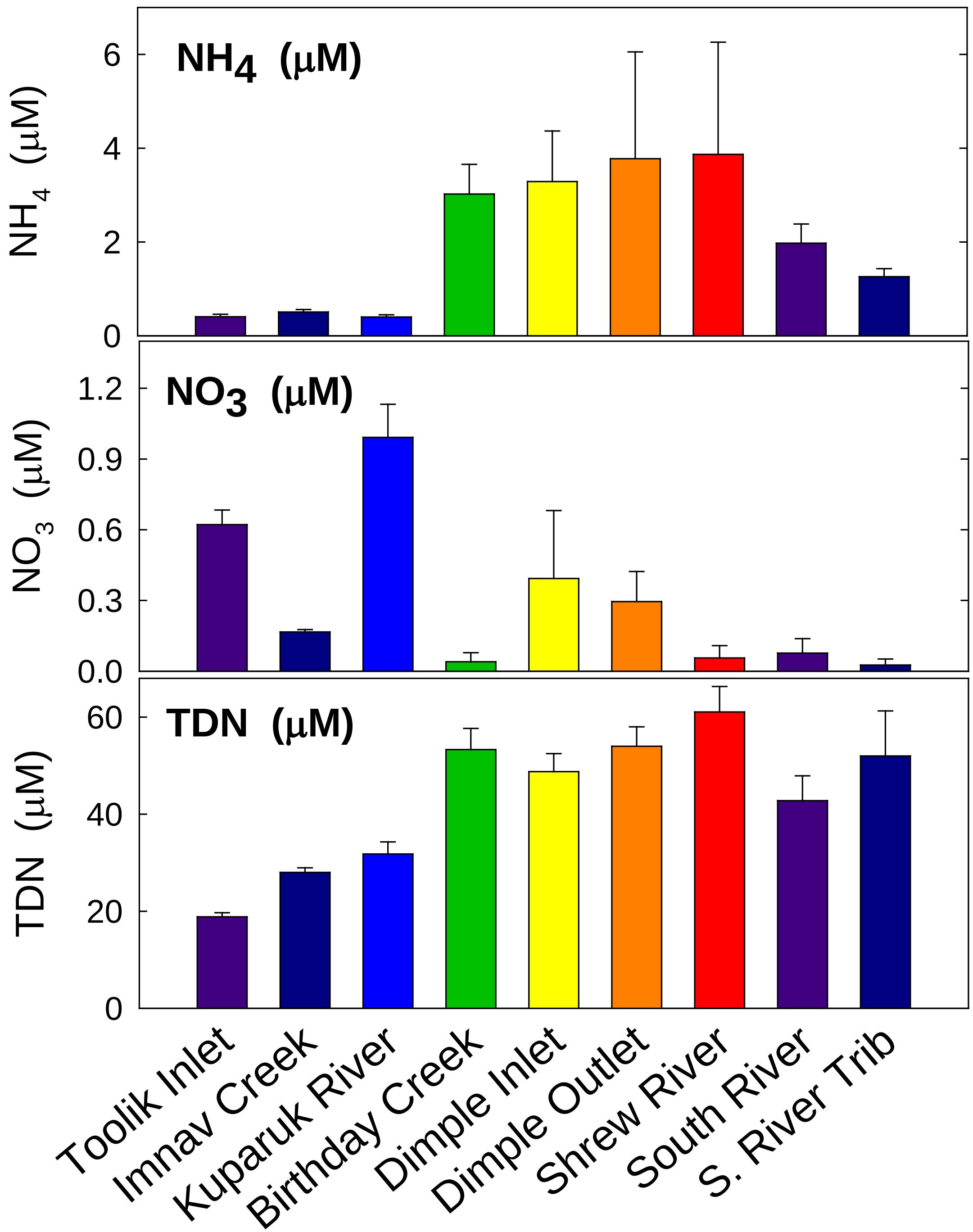
The Shrew River area
variable burn, less riparian damage

PO_4 concentrations



PO_4 is higher at the burn sites

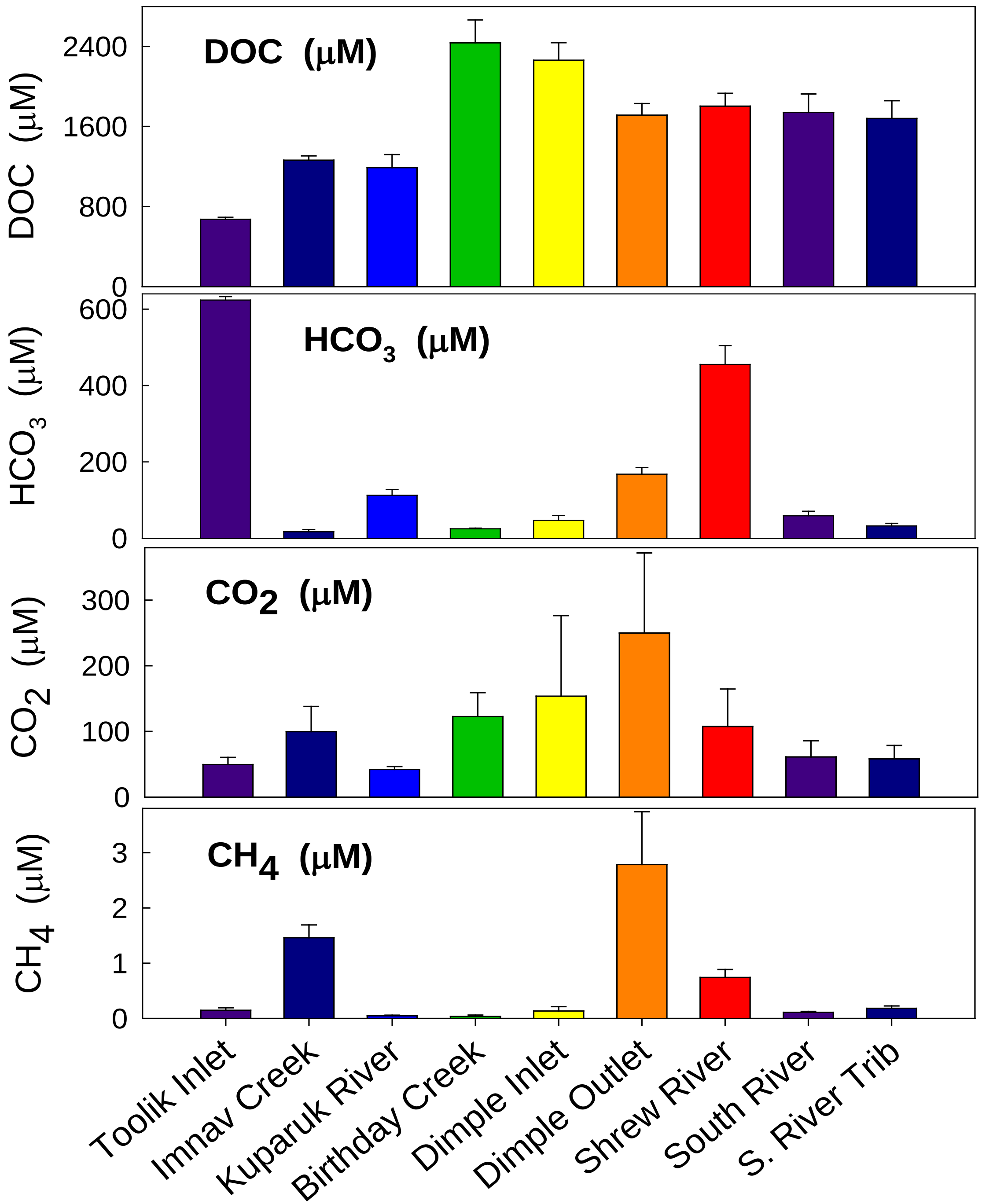
Nitrogen Concentrations



NH_4 and TDN concentrations are higher at the burn sites

NO_3 is generally lower at the burn sites

Carbon Concentrations

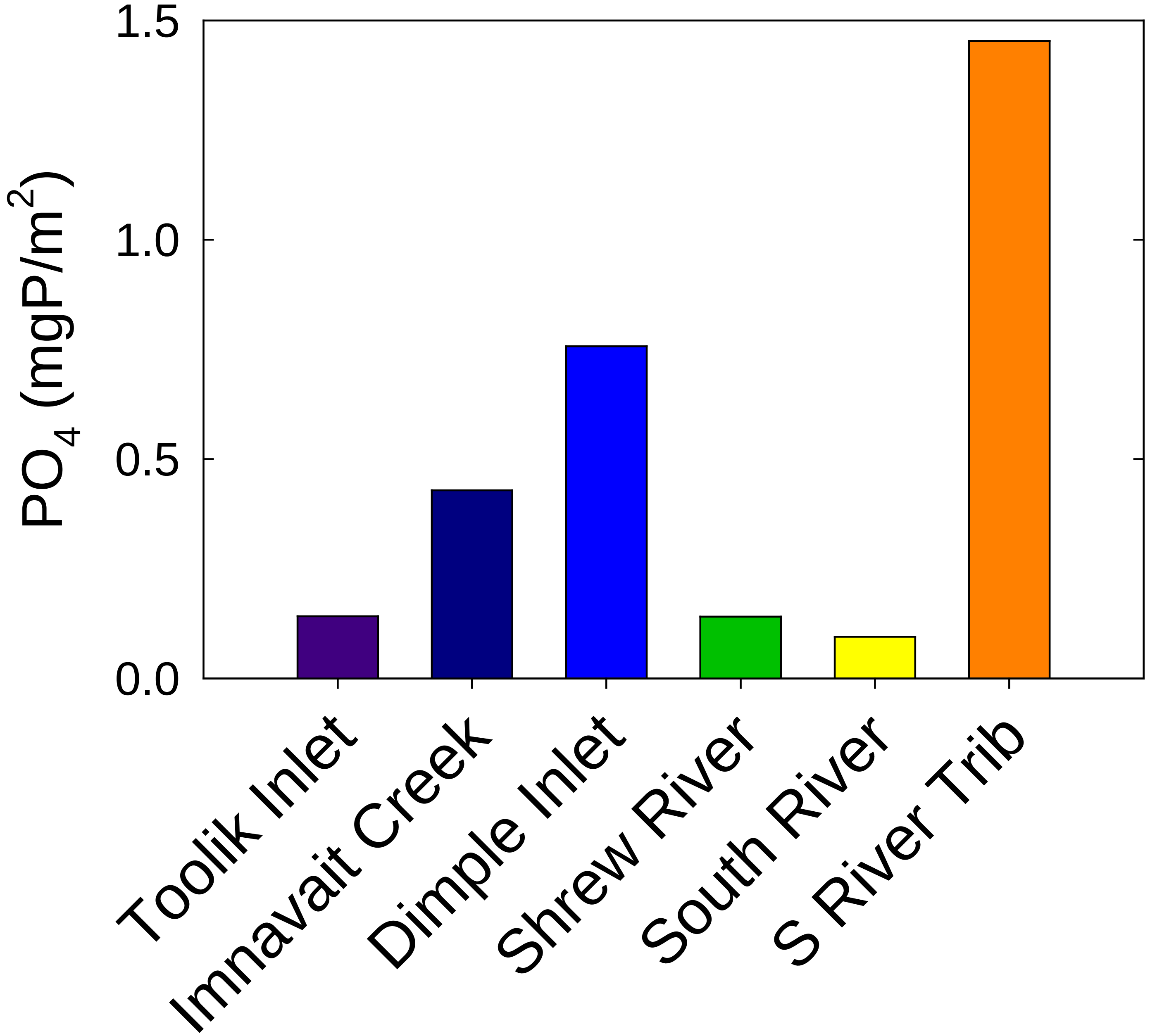


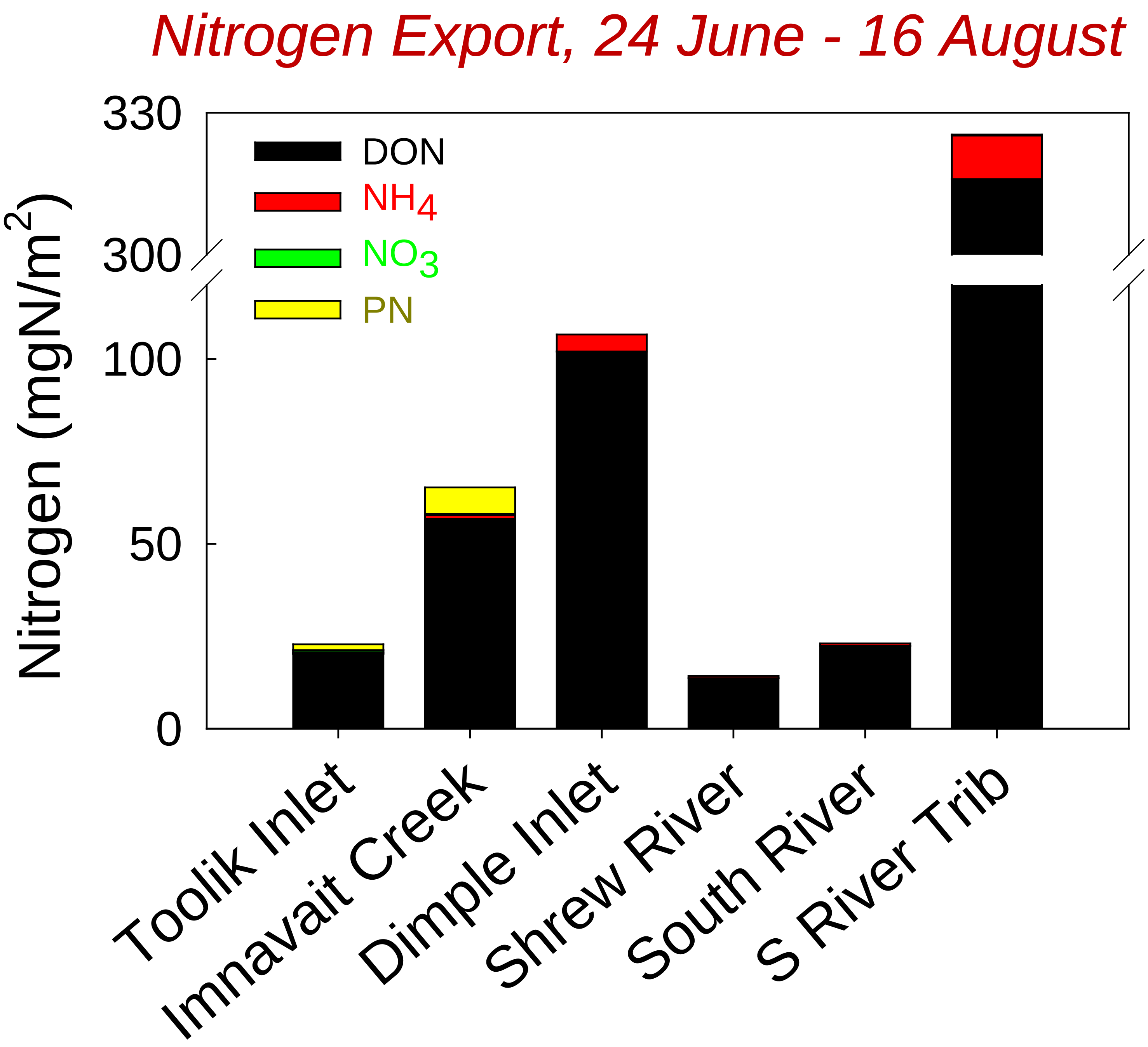
DOC is higher at the Burn sites.

CO_2 and CH_4 are related to stream size and lake influence

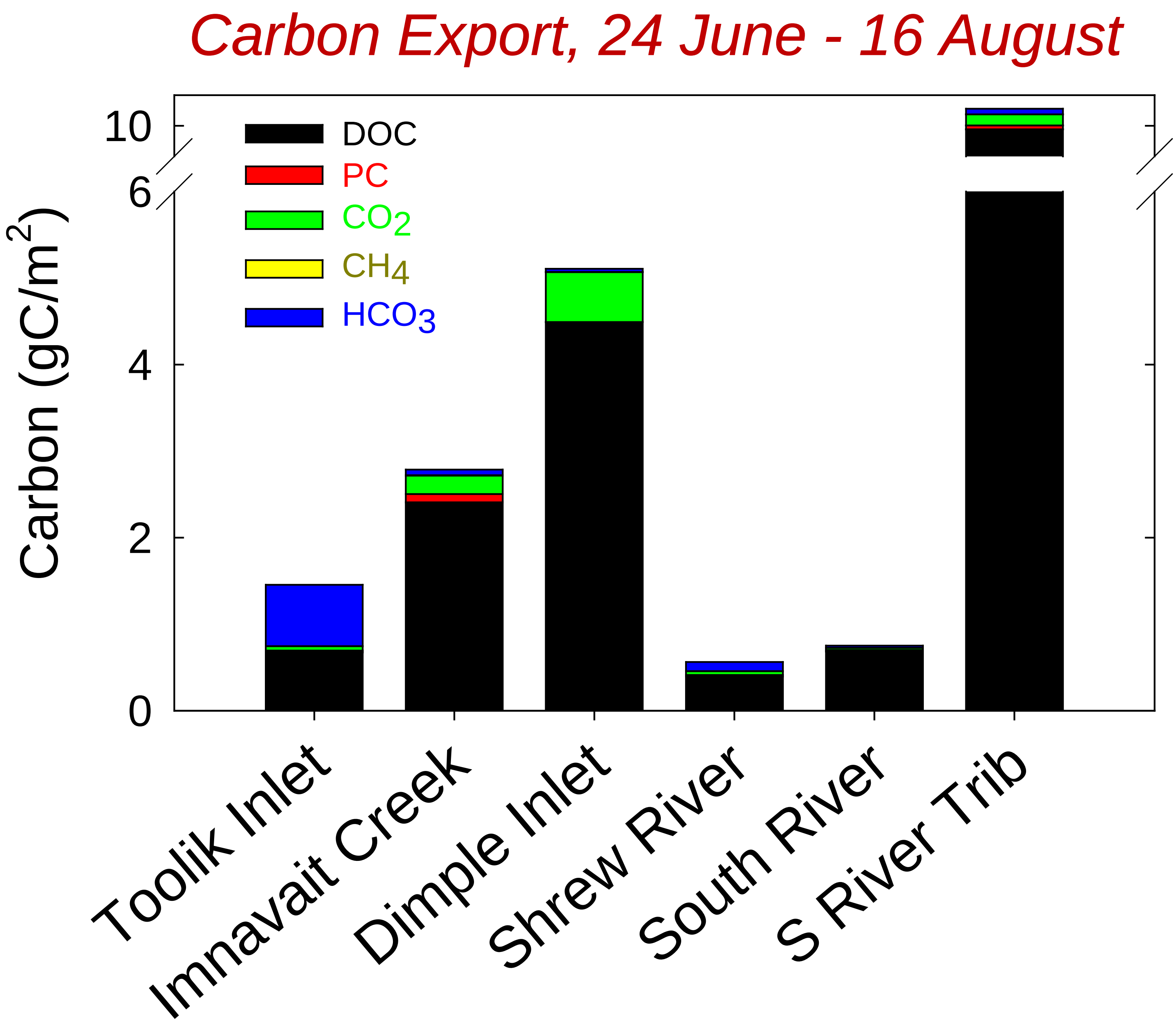
HCO_3 is related to bedrock

Phosphate Export, 24 June - 16 August

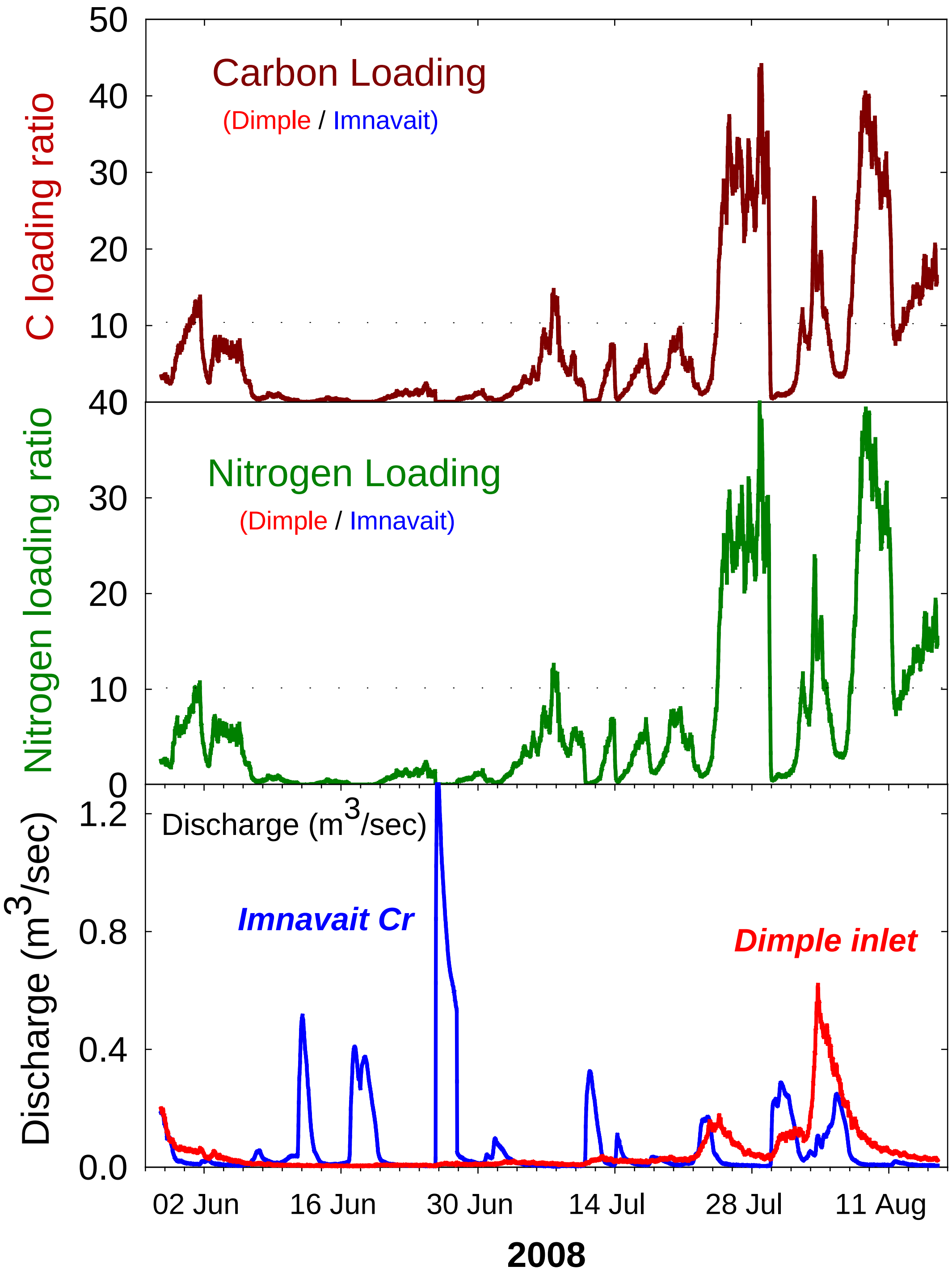




Nitrogen Export, 24 June - 16 August
Nitrogen (mgN/m2)
330
300
100
50
0
DON
NH4
NO3
PN
Toolik Inlet
Imnavait Creek
Dimple Inlet
Shrew River
South River
S River Trib

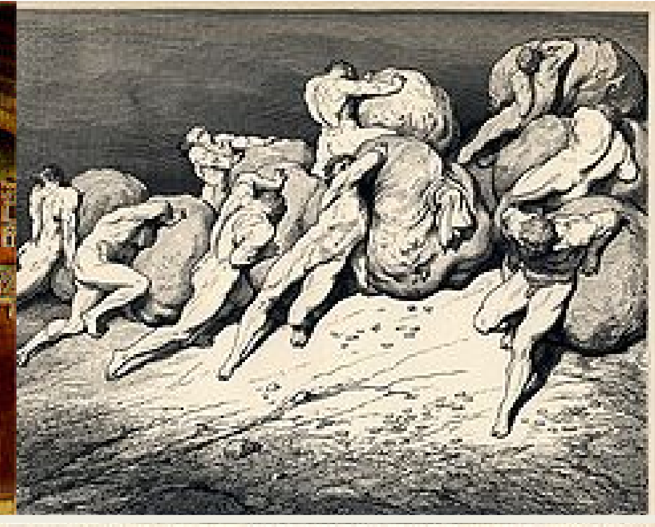


Carbon Export, 24 June - 16 August
Carbon (gC/m2)
0
2
4
6
10
DOC
PC
CO2
CH4
HCO3
Toolik Inlet
Imnavait Creek
Dimple Inlet
Shrew River
South River
S River Trib



In smaller streams, loading is highly variable and driven by discharge





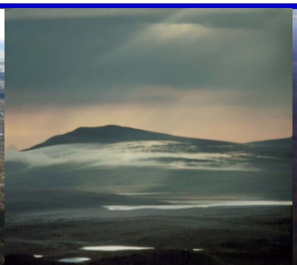
Fire, Flood, Landslide, and Plague

Land-water Interactions, or the *Divina Commedia Toolikia*

Data and Contributions from:

Angela Allen, Sarah Barbrow, Breck Bowden, Jeff Boyer, Jason Dobkowski, Amanda Field, Rob Geick, Cody Johnson, Doug Kane, Jen Kostrzewski, Meghan Miner, Elissa Schuet, Gus Shaver, Dan White, Lauren Yelen



Arctic LTER Project

The Arctic LTER Project: Mid-term Site Review 18-19 June 2013

Welcome everyone

Research of the Arctic LTER: Synthesis

- Synthesis
  - How we do synthesis, imp of collaborating projects
  - Project synthesis
    - Synthesis Book—58 coauthors
    - Lakes, Streams, Terrestrial, Land-water synthesis (previous presentations)
  - Ecological theory: Moore and deRuiter Ecological Energetics
  - Overall project; current examples

    Fire in the Arctic Landscape

    Trophic structure

    C, N budgets
  - PanArctic:
    - Canopy-level controls on NEE
  - Network and multisite synthesis

Summary of initial changes in C balance due to climate change and fire

	Yearly NEE	Change in NEE in 1 year due to:			
	(mean predicted)	Warming	Combustion	Recovery	Aquatic loss
Area:			2007	2008	2008
one m2	-15 gC	< -1 g C	2.02E+3 gC	80-140 g C	1-2 g C
AR Burn	-15.6E+09 gC	<-1.04E+09 g C	2.16E+12 gC	1.25E+11 g C	1-2E+09 gC
N Slope	-2.8E+12 gC	<-1.88E+11 g C			

Combustion losses/m2 were opposite in sign and ~100x annual NEE; combustion losses were >2000x expected gains due to warming alone; losses on AR Burn were >2/3 the yearly C gain of the entire N Slope (200x larger area) and >10x predicted gains due to warming only

In summer 2008, increased NEE (C loss) in recovering vegetation was 5-9 x predicted gains as annual NEE and >100x changes in NEE due to warming in equal area, and similar (but opposite in sign) to warming gains on entire N Slope

In summer 2008, aquatic losses in burned catchments were10% of unburned NEE and ~1-10x NEE gains due to warming