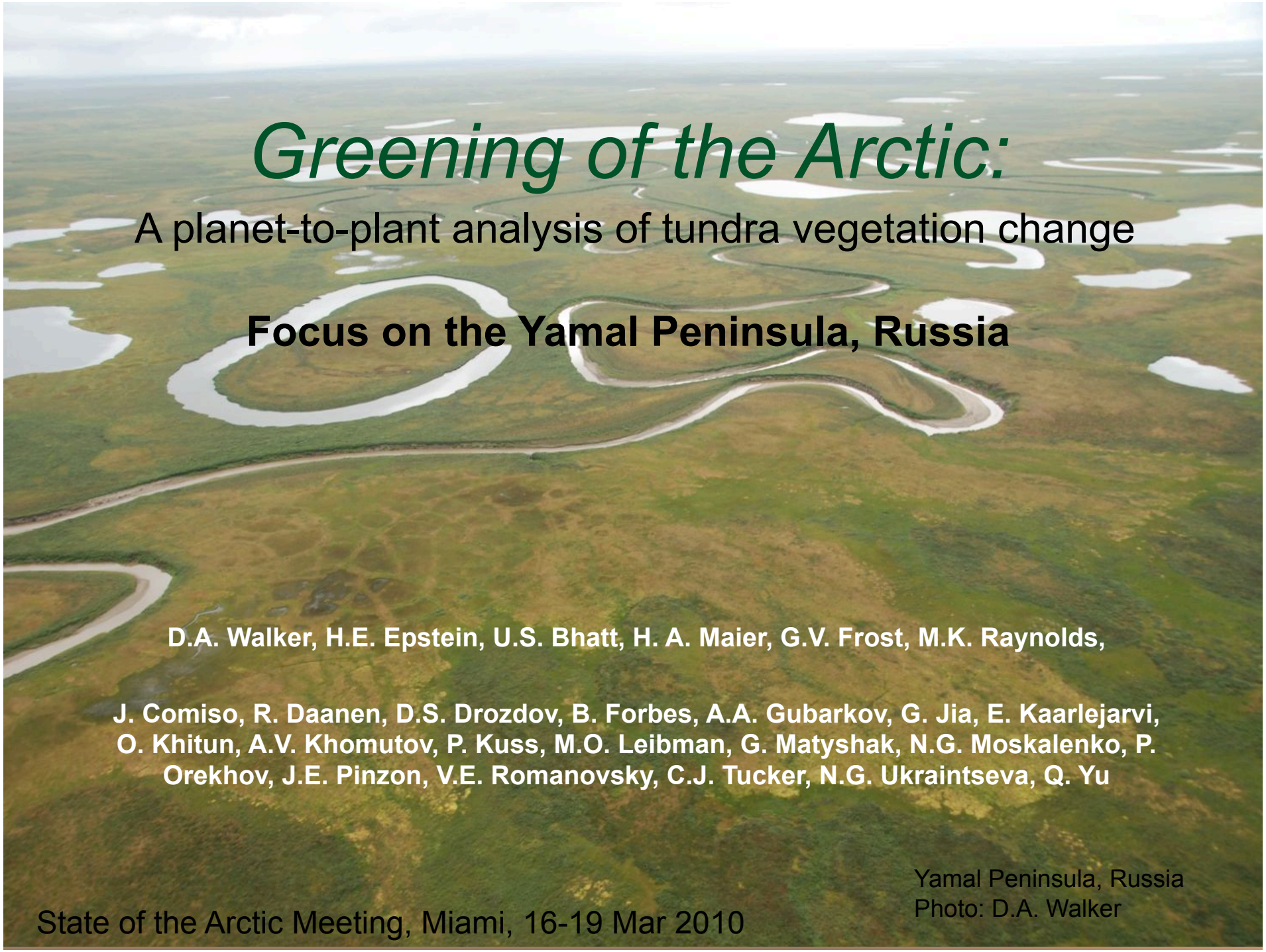


Greening of the Arctic:

A planet-to-plant analysis of tundra vegetation change

Focus on the Yamal Peninsula, Russia

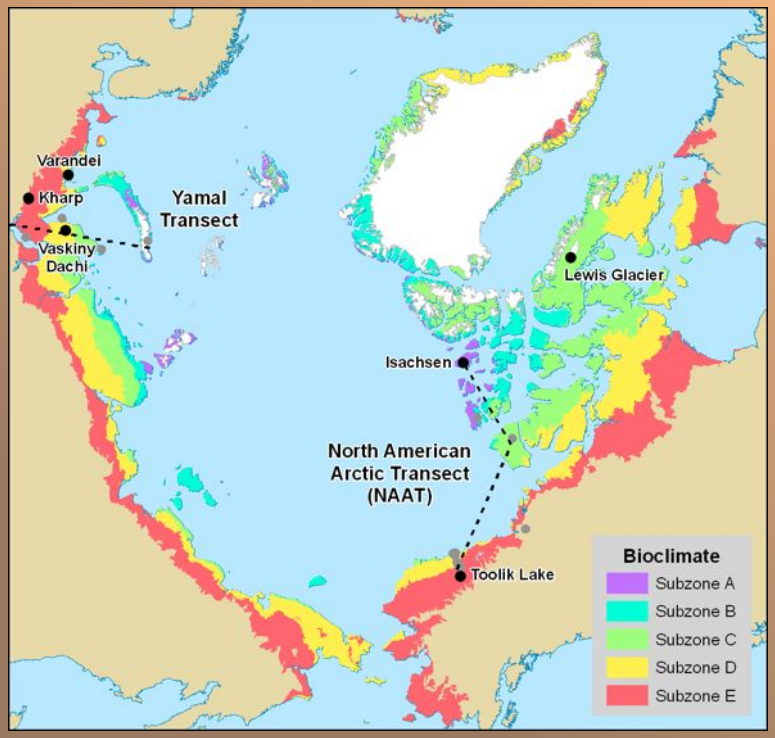
D.A. Walker, H.E. Epstein, U.S. Bhatt, H. A. Maier, G.V. Frost, M.K. Raynolds,

J. Comiso, R. Daanen, D.S. Drozdov, B. Forbes, A.A. Gubarkov, G. Jia, E. Kaarlejarvi, O. Khitun, A.V. Khomutov, P. Kuss, M.O. Leibman, G. Matyshak, N.G. Moskalenko, P. Orekhov, J.E. Pinzon, V.E. Romanovsky, C.J. Tucker, N.G. Ukraintseva, Q. Yu

Yamal Peninsula, Russia
Photo: D.A. Walker

State of the Arctic Meeting, Miami, 16-19 Mar 2010

Goal of GOA:
Examine trends of vegetation, climate, and greening (NDVI) along two transects through all 5 Arctic bioclimate subzones



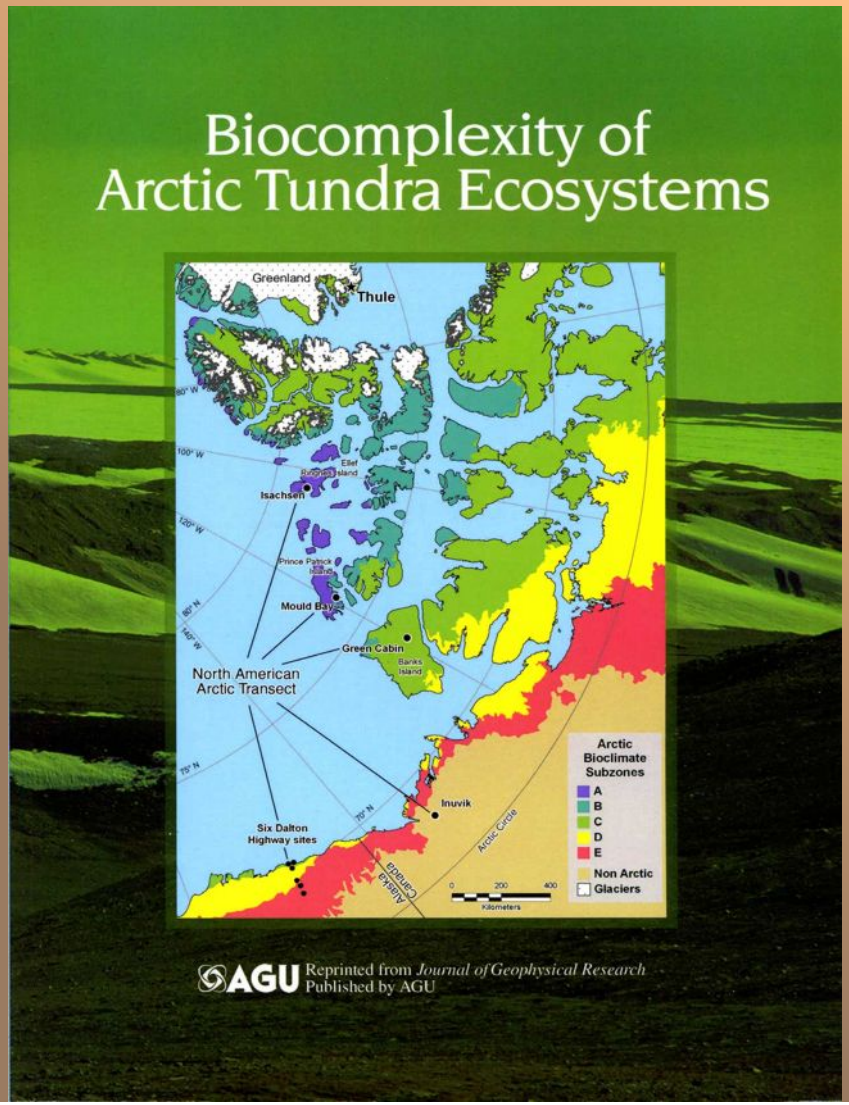
Bioclimate subzones as mapped by CAVM Team 2003

Sub-Zone	MJT	Shrubs
A	1-3 ˚C	none
B	3-5 ˚C	prostrate dwarf-shrubs
C	5-7 ˚C	hemi-prostrate dwarf shrubs
D	7-9 ˚C	erect dwarf-shrubs
E	9-12 ˚C	low-shrubs

Along the tundra bioclimate gradient:

- 10˚ C change in the MJT
- 10-fold change in zonal biomass
- 10-fold change in productivity
- 5 to 10-fold change in vascular-plant diversity

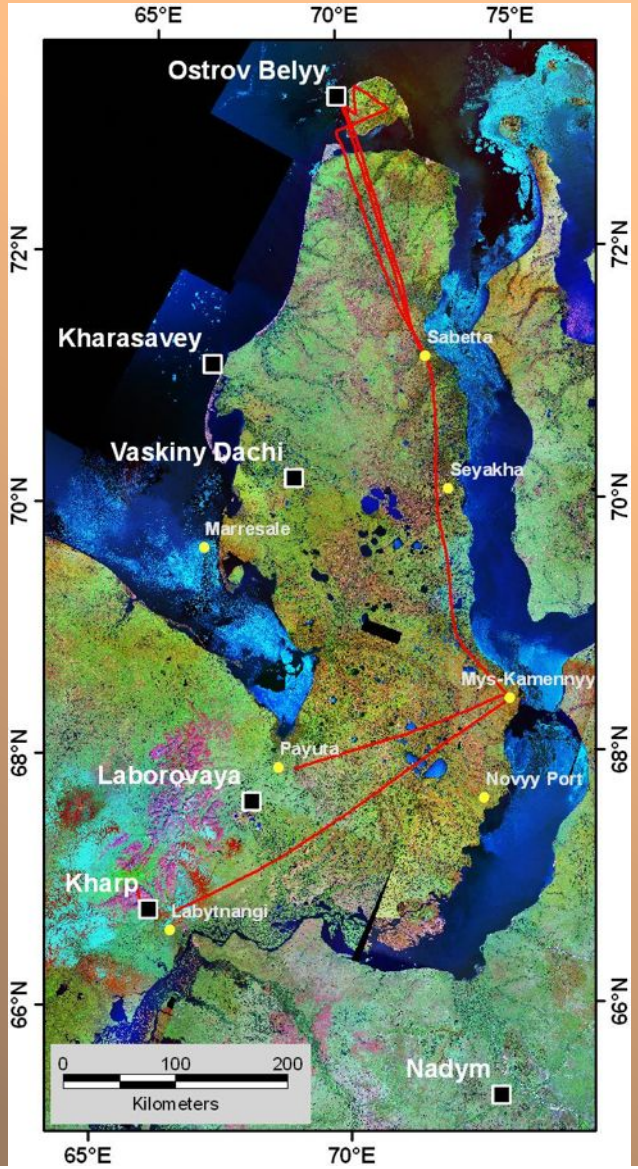
Results of the North American Arctic Transect were published in JGR special issue.



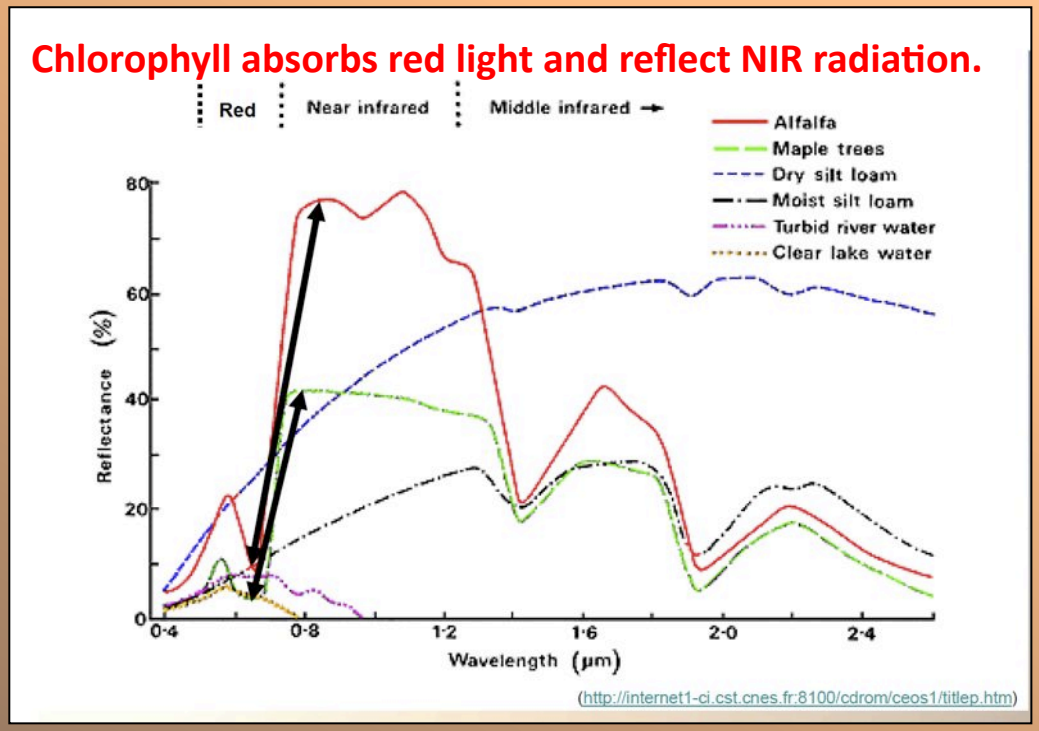
Walker et al. 2008. JGR

This talk focuses on the Yamal Transect

- Hierarchy NDVI analyses
  - AVHRR (12.5 km and 50 km)
  - AVHRR (1 km)
  - Landsat ETM+ (15 m)
  - Quickbird (60-cm resolution)
  - Hand-held measurements of NDVI along Yamal transect
- Ground observations along the Yamal transect
  - Vegetation analysis, relationship of NDVI to vegetation
- The roles of climate, substrate and disturbance along the Yamal transect.

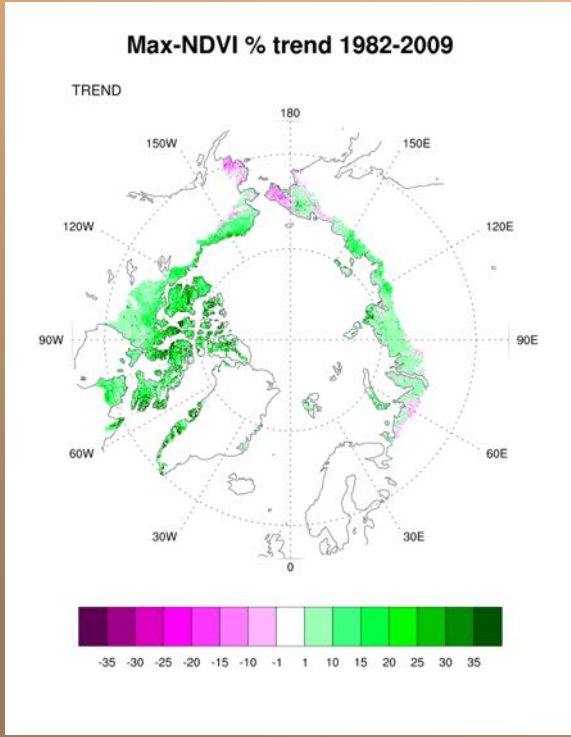


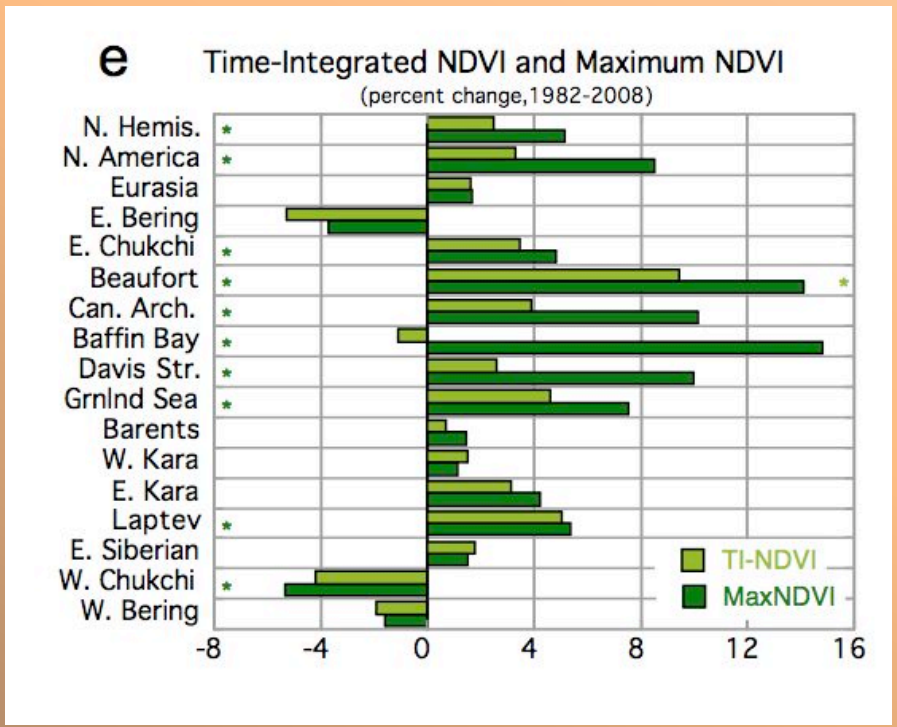
Much of project focuses on greenness patterns and change using the Normalized Difference Vegetation Index (NDVI)



- **NDVI = (NIR-R)/(NIR + R).** The difference between the reflectance in the NIR and R portions of the spectrum is a measure of the photosynthetic capacity of the surface. The difference is divided by the sum of the reflectances to adjust for variations in the index due to slope and shadows.

Circumpolar changes to early summer coastal sea ice, and summer land temperatures (1982-2008)Percentage MaxNDVI change

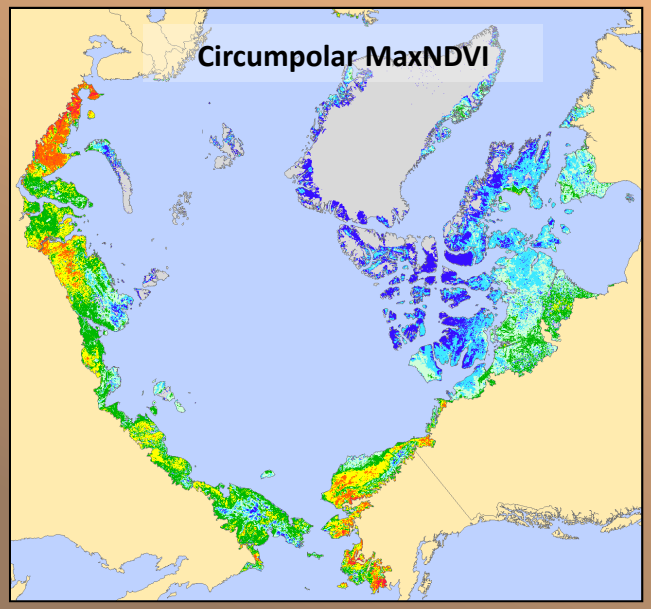




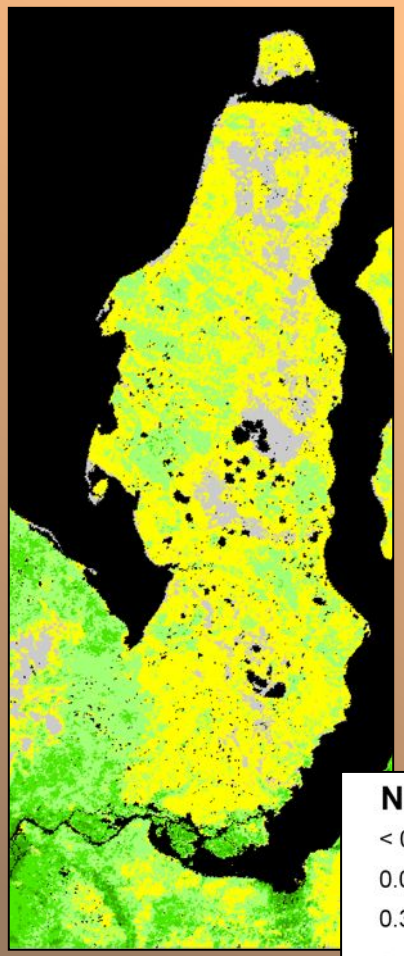
Bhatt et al. 2009 in revision, Earth Interactions.

- Arctic wide: +5%
- Much greater change in North America (+9%) than in Eurasia (+3%).
- Large increases in (10-15%) in the High Arctic (northern Canada and Greenland) and the Beaufort Sea area.
- Other analyses (not shown) revealed strong positive correlations between NDVI and land temperatures and strong negative correlations with the percentage of coastal sea ice.

Yamal 1-km AVHRR NDVI derived from CAVM data set



USGS data set used for the CAVM



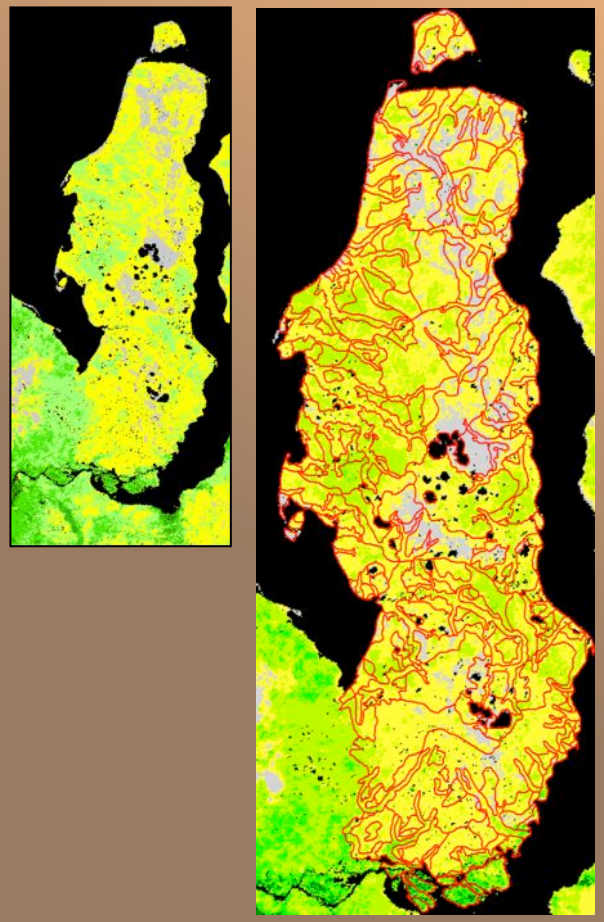
NDVI	Biomass (g/m2)
< 0.03	< 50
0.03-0.38	50-300
0.39-0.50	300-500
0.51-0.56	500-750
0.57-0.62	750-1000
>0.62	>1000

- NDVI shows surprisingly little trend with temperature along the bioclimate gradient, compared to the circumpolar Arctic.

M.K. Raynolds. 2010. Yamal LCLUC Workshop. Rovaniemi, FI

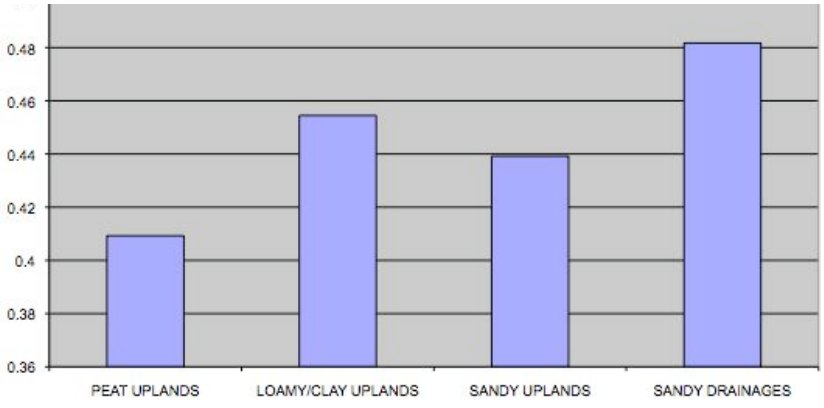
Analysis of NDVI with Landscape Units

NDVI with Landscape boundaries

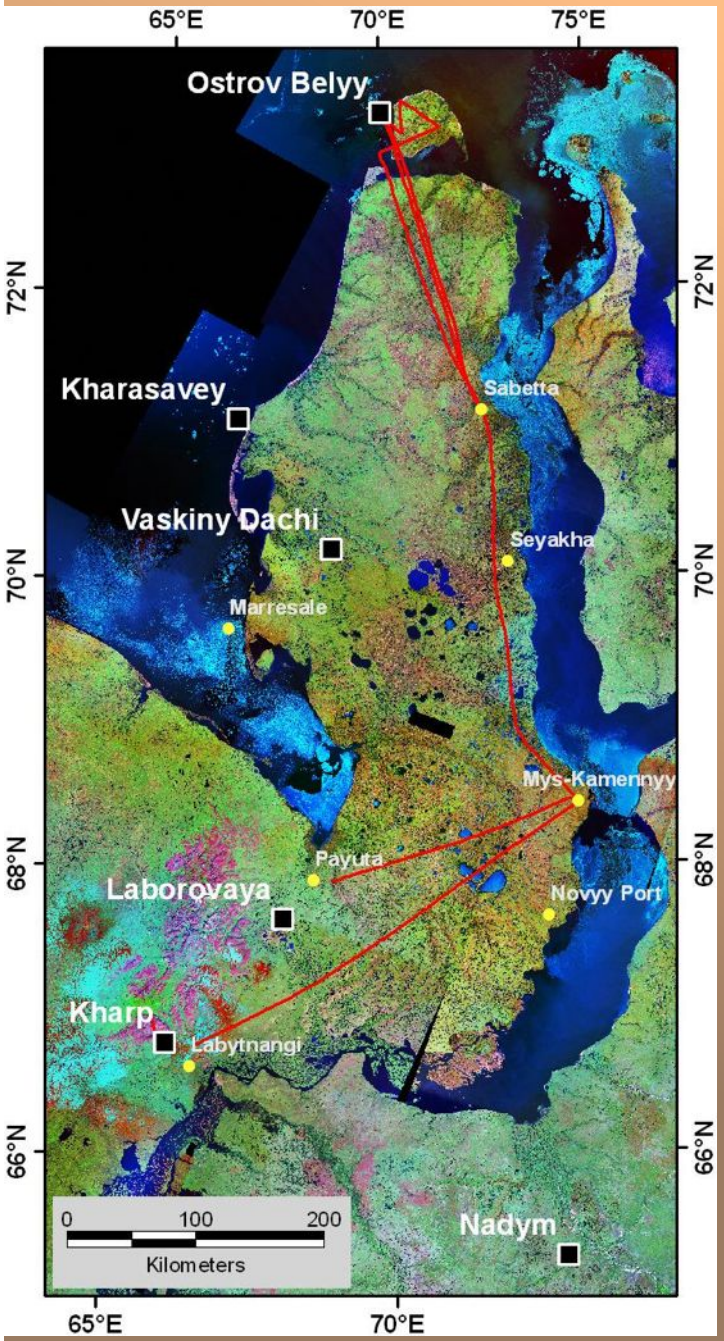


- Most variation is related to soil texture (sands vs. loamy soils).
- Broad river channels have highest NDVI despite large amount of lakes in the valleys.
- 1-km data is not fine enough to resolve the greening patterns within the highly eroded upland areas.

NDVI on marine terrace uplands and drainages of differing soil texture



M.K. Raynolds. 2010. Yamal LCLUC Workshop. Rovaniemi, FI



Yamal Transect (2007-2009)

- **Forest-tundra transition: Nadym (2007) and Kharp (2009)**
- **Subzone E: Laborovaya (2007)**
- **Subzone D: Vaskiny Dachi (2007)**
- **Subzone C: Kharasavey (2008)**
- **Subzone B: Ostrov Belyy (2009)**

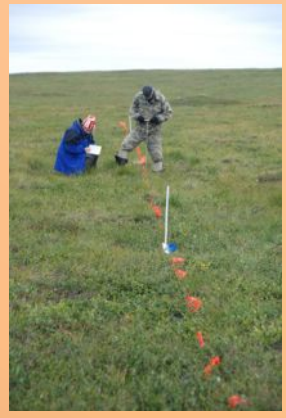
Red line is the 2009 helicopter path.

Data collected

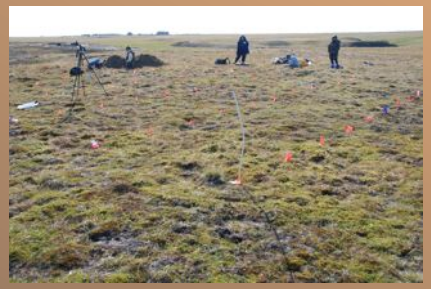
- Transects
- Plots
- Soils

NDVI and LAI

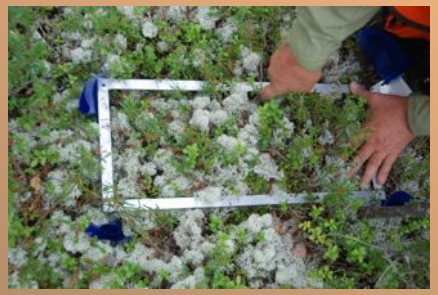
Species cover



Active layer depth



Cover abundance, site factors



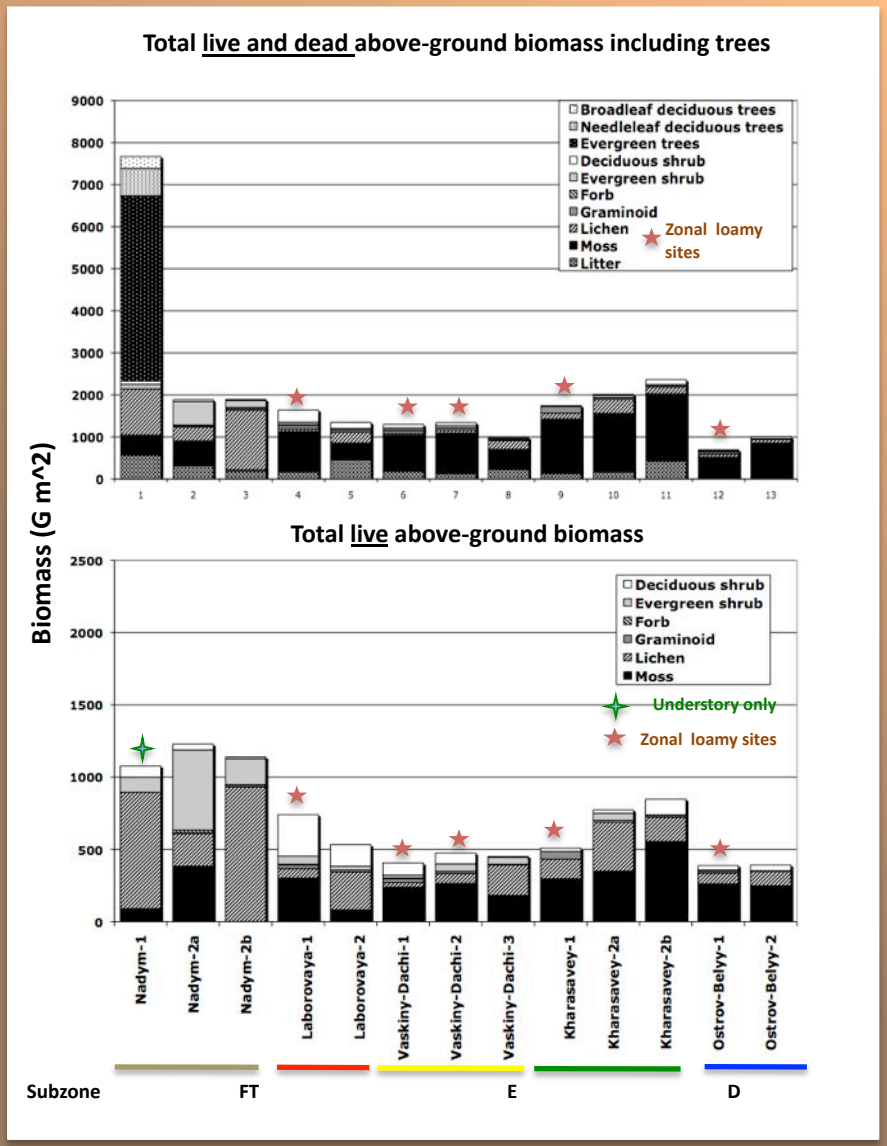
Biomass

N-factor

Soil pit profile descriptions

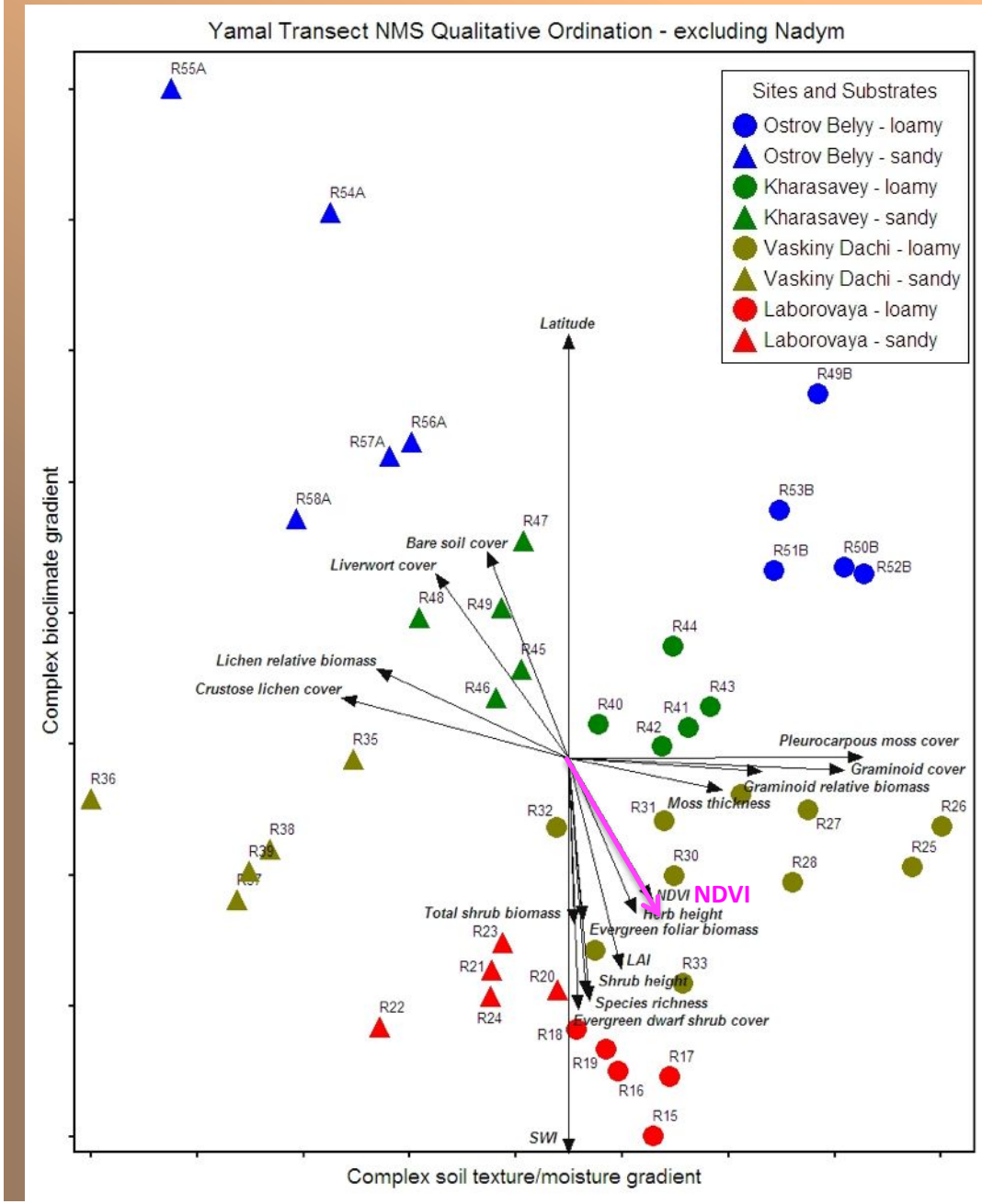
Soil chemical and physical analyses

Yamal transect biomass



- Zonal sites show little variation across the peninsula, except in subzone E.
- Biomass values for zonal site in subzone E is close to tussock tundra values for Alaska (≈ 750 g m^2).
- Total live biomass values of zonal loamy sites in subzones C and D are close published values for mesic tundra Barrow and Prudhoe Bay (≈ 450 g m^2).

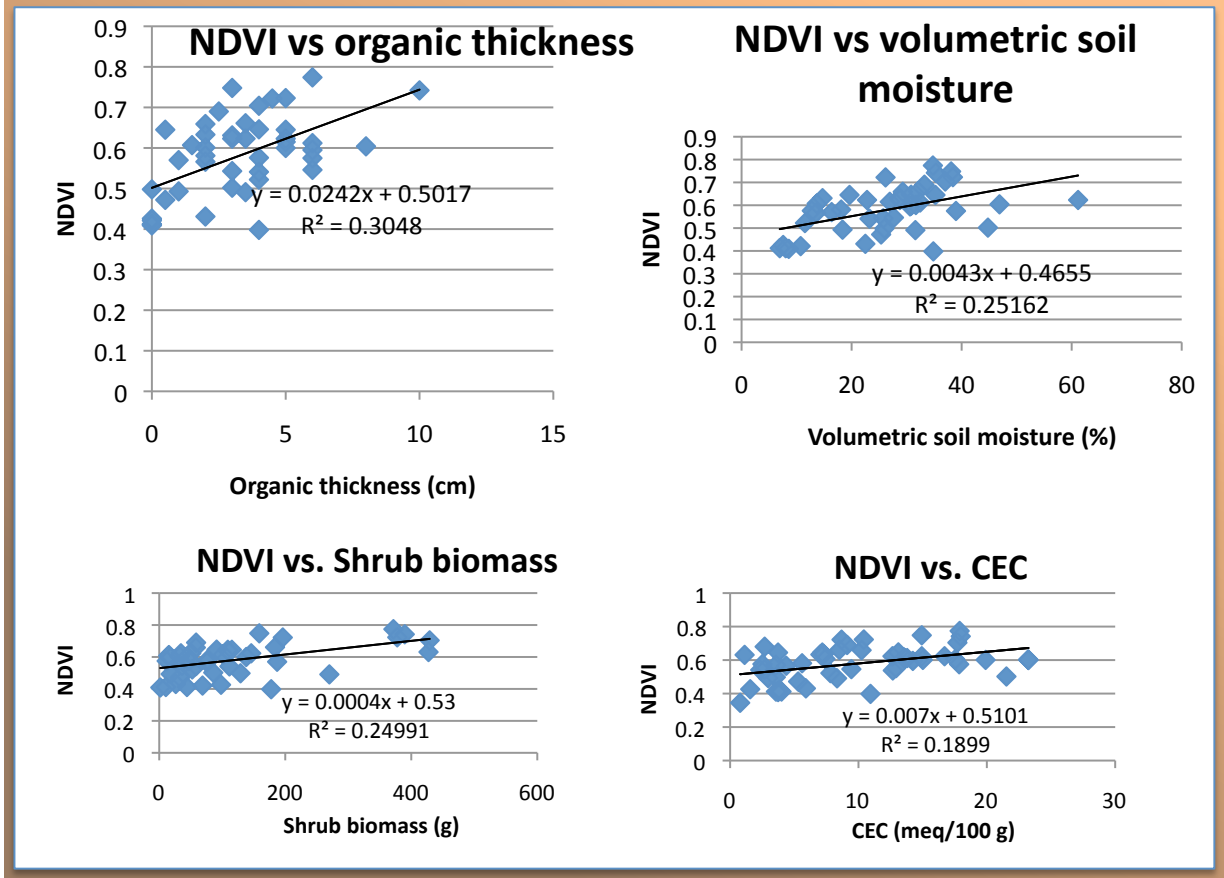
Relation of NDVI to vegetation and environmental variables



- **Ordination analysis shows the relationship of the study plots to each other based on floristic similarity.**
- **And with respect to environmental and plant variables (cover, biomass, NDVI)**

JJ Frost et al. 2010, Yamal LCLUC Workshop

Relationships between hand-held NDVI measurements and other variables



Key variables

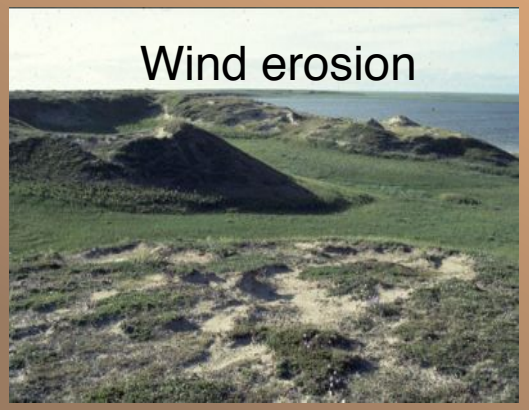
Variable	r-squared
%C_DShbE	0.378
%C_BryAc	0.3473
LAI	0.3402
%C_DeShb	0.3219
Moss_Ht	0.3175
Herb_Ht	0.3136
Org_Thk	0.3048
Moss_Thk	0.2876
Elev	0.2868
Dec_Stem	0.2637
%C_Dead	0.2552
Dec_Tot	0.2528
Volumetr	0.2516
Sand%	0.2499
Shrb_Tot	0.2499
Shrub_Ht	0.2433
Latitude	0.2316
Silt%	0.2273
Lichen%	0.2233
SWI	0.21
Mg	0.209
CEC	0.2048
Clay%	0.2039

key biometric relationship

key environmental relationship

- Strongest NDVI relationships are with some plant cover variables (e.g. pct. cover of evergreen shrubs, acrocarpous mosses, deciduous shrubs, LAI, moss height, organic thickness).
- Also strong environmental correlations (e.g. vol. soil moisture, pct. sand, latitude, SWI) mostly related to soil moisture and warmth gradients.

Disturbance has major effect on NDVI patterns but it is hard to partition the various effects



Photos: Bruce Forbes.

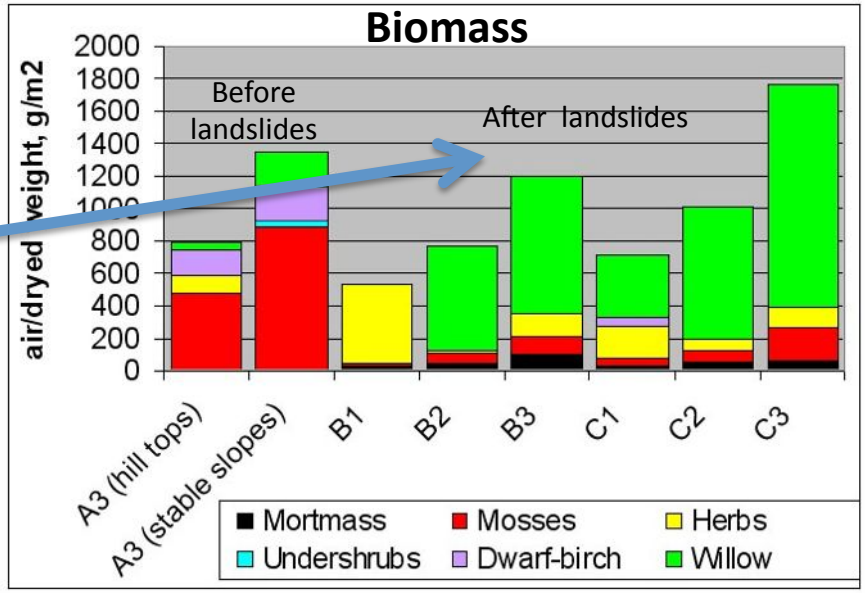
Effects of reindeer

- Entire peninsula is heavily grazed but effects on NDVI are unknown at present because of lack of control areas to study the effects (exclosures).
- Potential major effect in sandy areas.

Photos D.A. Walker

Landslides and cryogenic erosion

- Large effect on patterns of greenness in many areas.
- Quantitative measures of frerquency of slides are needed to determine effects on regional greening trends.
- Need temporal series of high-resolution satellite images and/or photos in landslide areas to assess the rate of change.



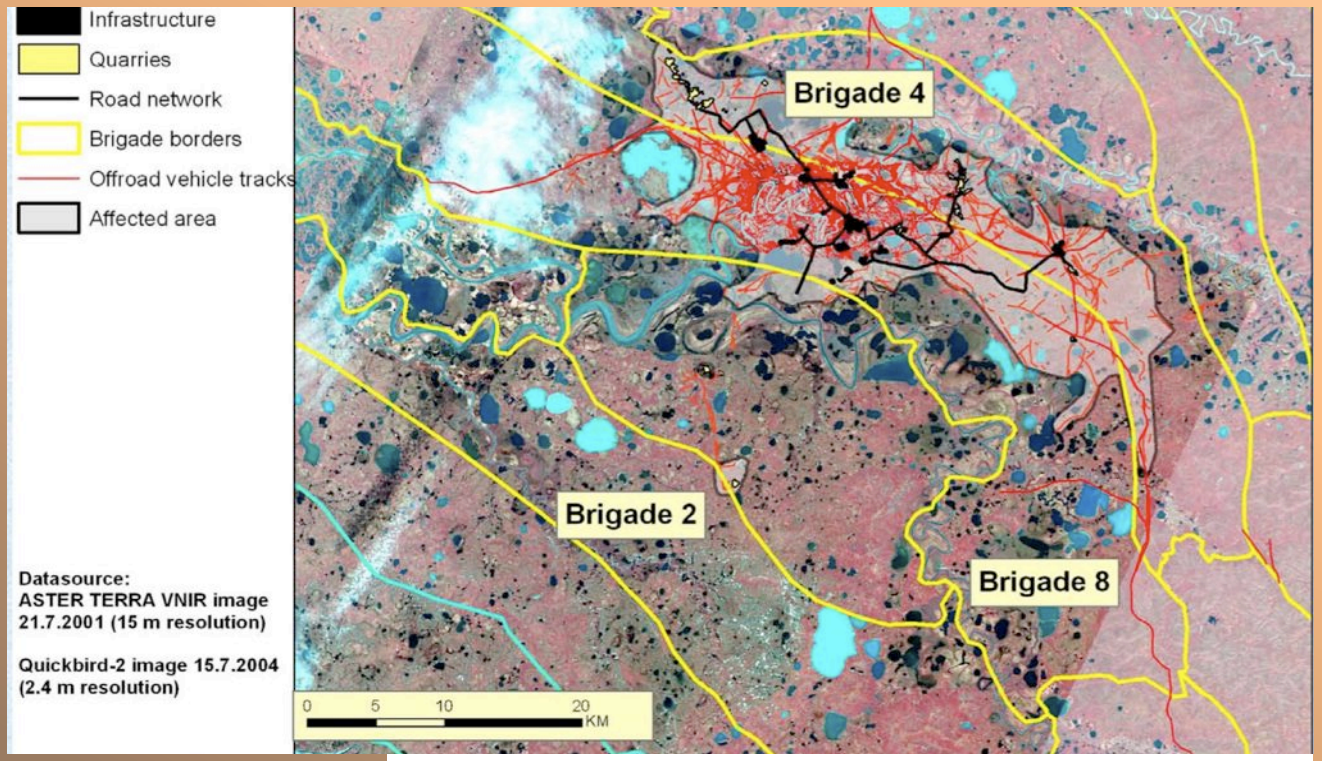
Key:

A – stable areas	1 – young landslide
B – shear surface	2 – old landslide
C – landslide body	3 – very old landslide

Ukraintseva and Leibman et al. 2000, 2007, 2008

Impacts of gas development

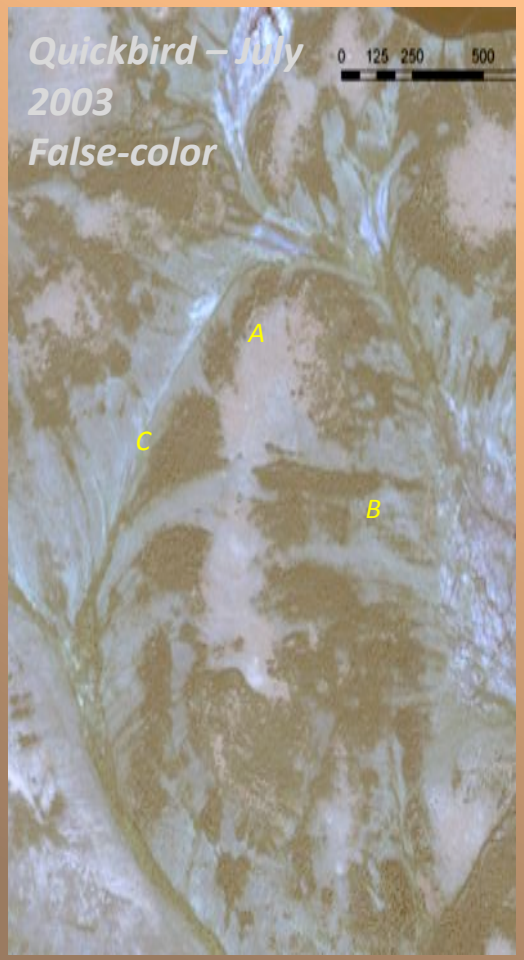
- Potential large effects on reindeer assess to rangelands.
- Locally important effects on NDVI but still relatively small extent.
- Need development scenario models to help predict and plan for expansion of road networks.

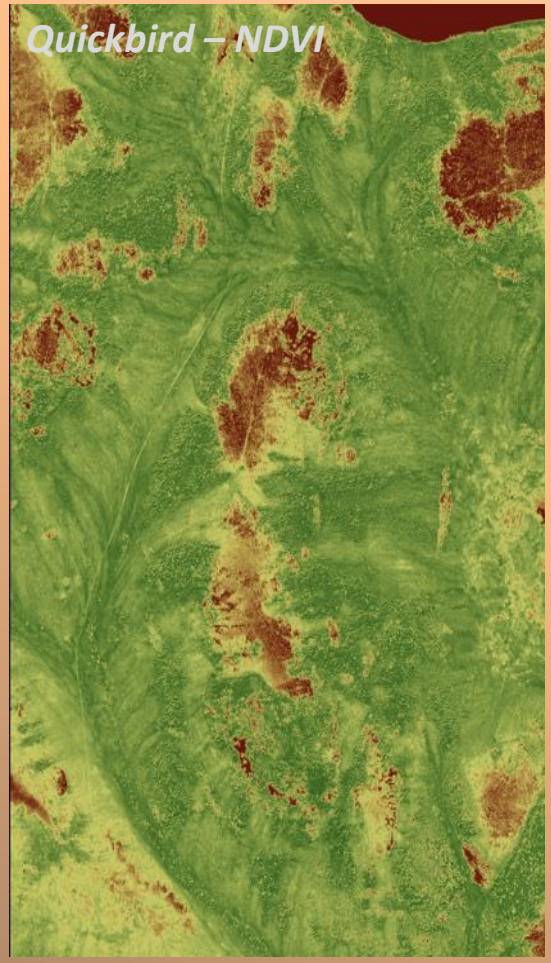


- **Brigade 4: 225 km² out of total 1019 km² summer pasture**
- **Brigade 8: 200 km² out of total 796 km² summer pasture**

Timo Kumpula: Yamal LCLUC Workshop, Moscow, 28-30 Jan 2008.

Corona and Quickbird: Detailed analysis of 35-yr alder expansion at treeline near Kharp

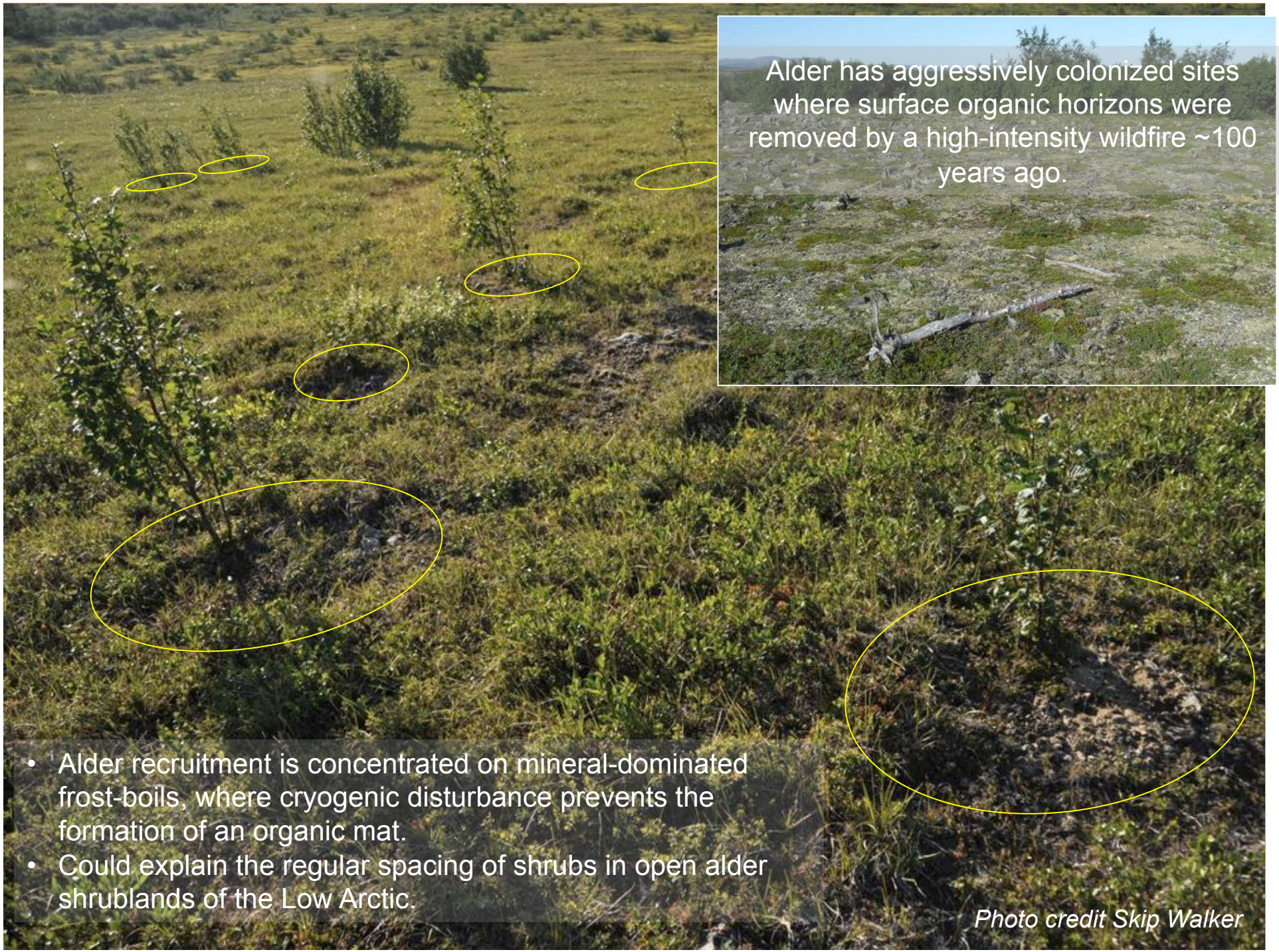




Panchromatic-sharpened 60-cm resolution Quickbird images provide detailed view of shrub expansion at the plant level, and…..

picture of productivity patterns in relationship to geology, hydrology and patterned ground.

Frost et al. 2010. Yamal LCLUC Workshop.

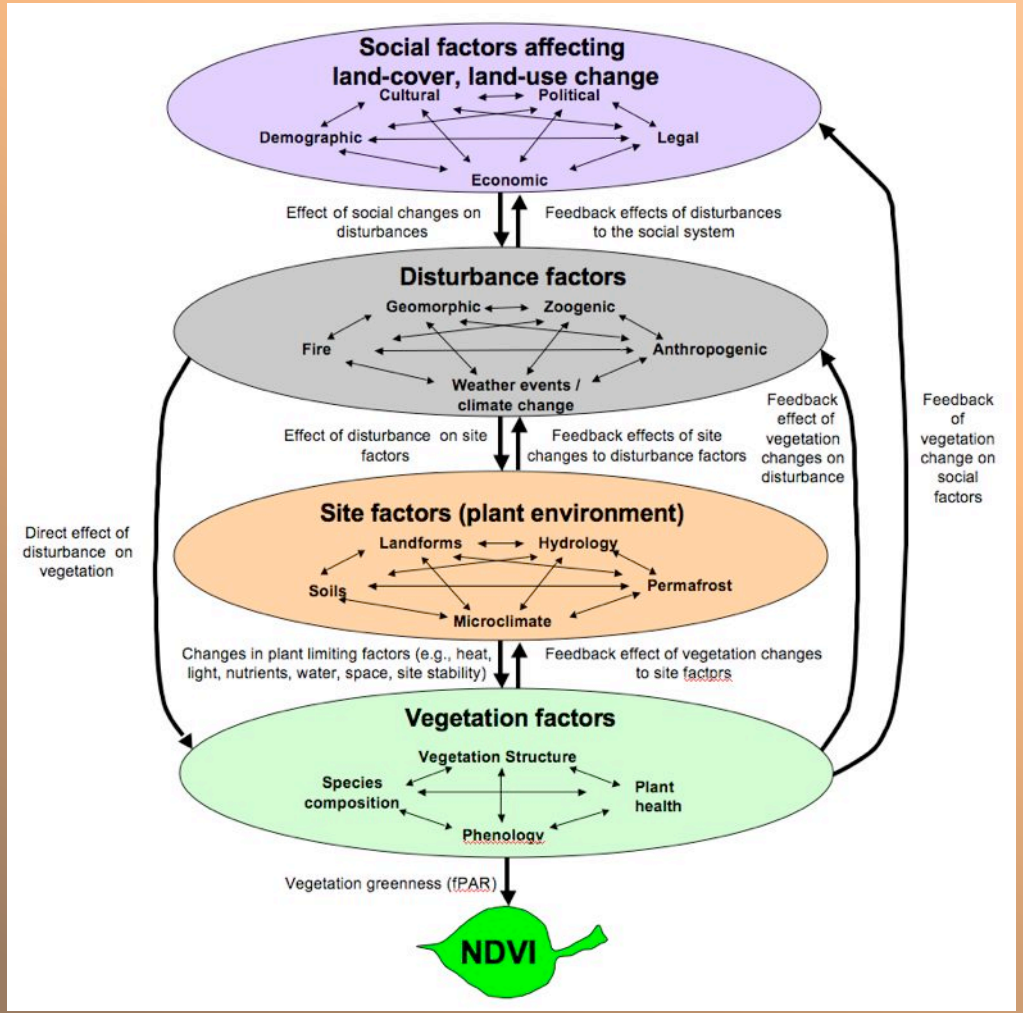

Alder has aggressively colonized sites where surface organic horizons were removed by a high-intensity wildfire ~100 years ago.
• Alder recruitment is concentrated on mineral-dominated frost-boils, where cryogenic disturbance prevents the formation of an organic mat.
• Could explain the regular spacing of shrubs in open alder shrublands of the Low Arctic.
Photo credit Skip Walker

Arctic plants respond mainly to changes to their immediate plant environment (summer temperature, moisture, and nutrients)

NDVI is a good integrator of the total changes to plant productivity, but is a poor tool for determining the causes.

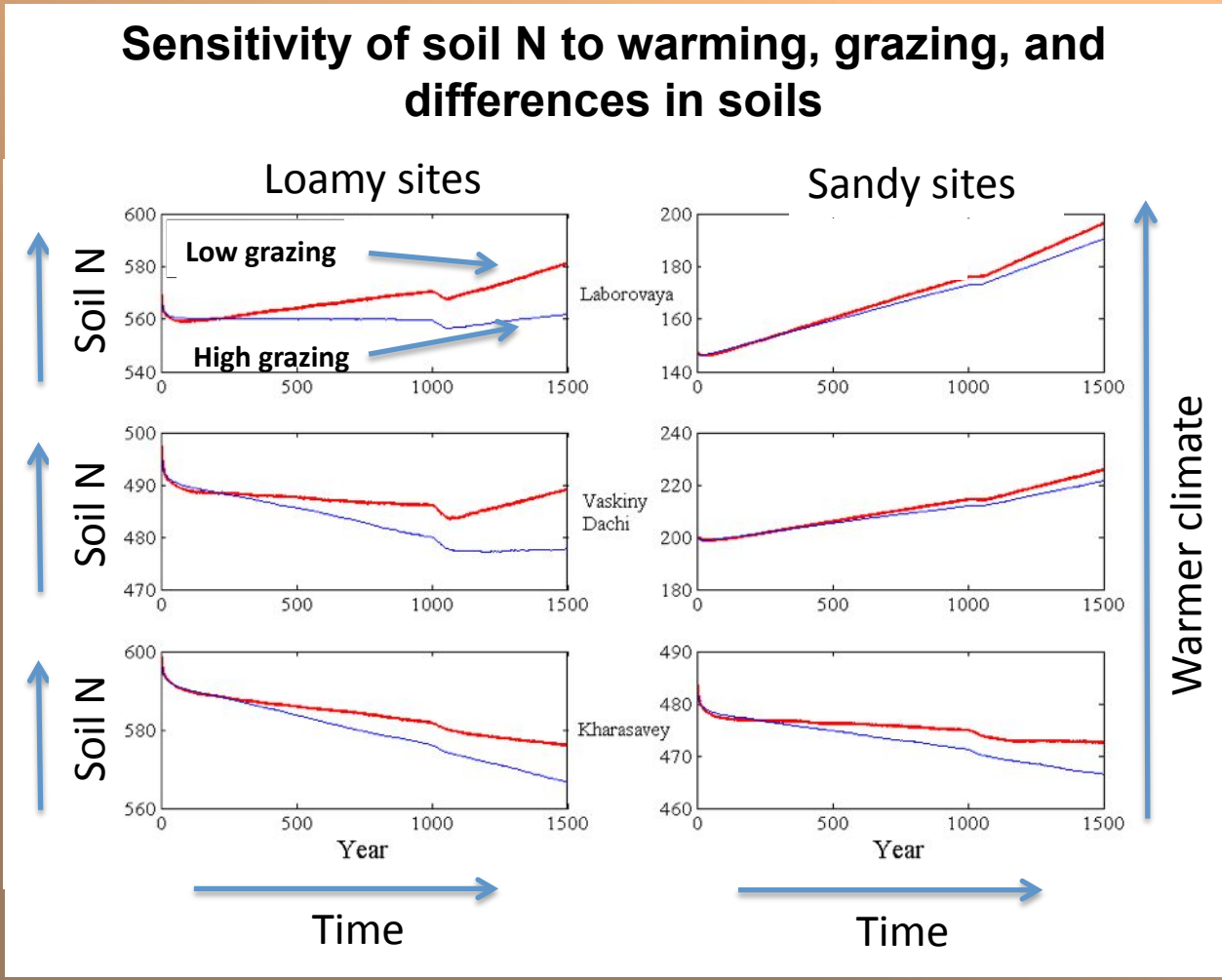
It is usually not possible to ascribe causality to the changes.

Vegetation change models can help here.



Walker et al. 2009. Environmental Research Letters

ArcVeg is helping to unravel the effects of various types of disturbance



- Grazing suppresses vegetation response to warming.
- Herbivory has greater effect in loamy (nutrient-rich) sites.

Yu, Q. et al. 2009. Environmental Research Letters.

Credits

- NSF, ARCSS: Synthesis of Arctic System Science and Seasonality initiatives
- NASA: LCLUC
- NEESPI project
- Russian Academy of Science
- ENSINOR project