How the International Tundra Experiment (ITEX) contributes to understanding of Arctic biomass change

Arctic Biomass Workshop

Longyearbyen, October 2015

Ingibjörg S. Jónsdóttir

Uneven greening of the Arctic

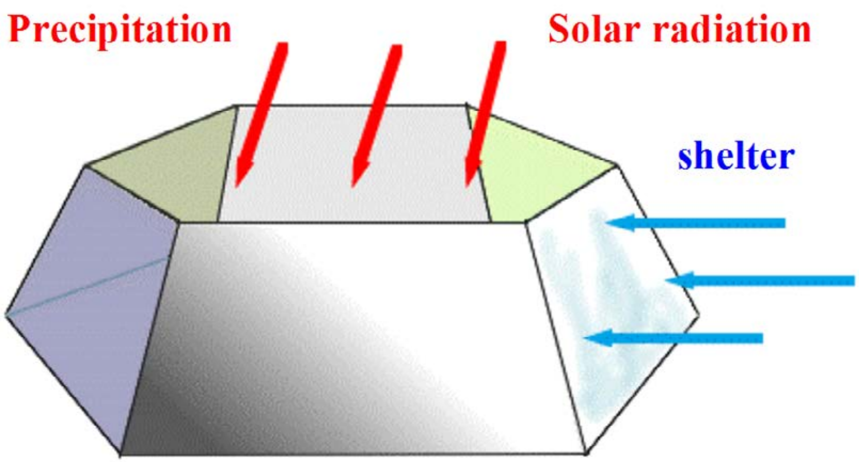
- Regional variation in greening has been <u>related</u> to
  - Closeness to coastal areas /impact of sea ice decline,
    - Bahtt et al. 2010, 2013, Dutrieux et al. 2012,
  - Large-scale climate variability.
    - Bahtt et al. 2013

- What is driving variation in greening on landscape and local scales?

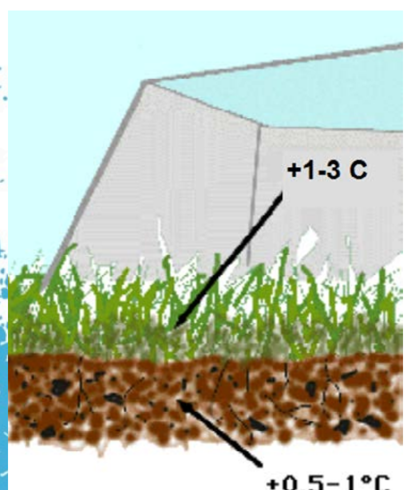
Outline

- What recent ITEX syntheses can tell us about local and landscape drivers of change
- What future ITEX networking and other networks, e.g. the Herbivory Network, can potentially reveal

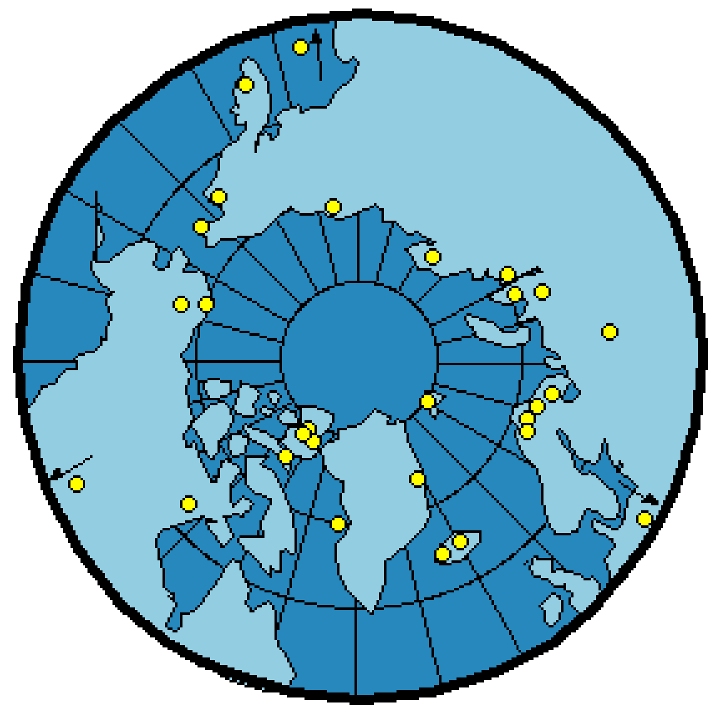
International Tundra Experiment - ITEX



A research network launched in 1990.
More than 30 arctic and alpine tundra sites

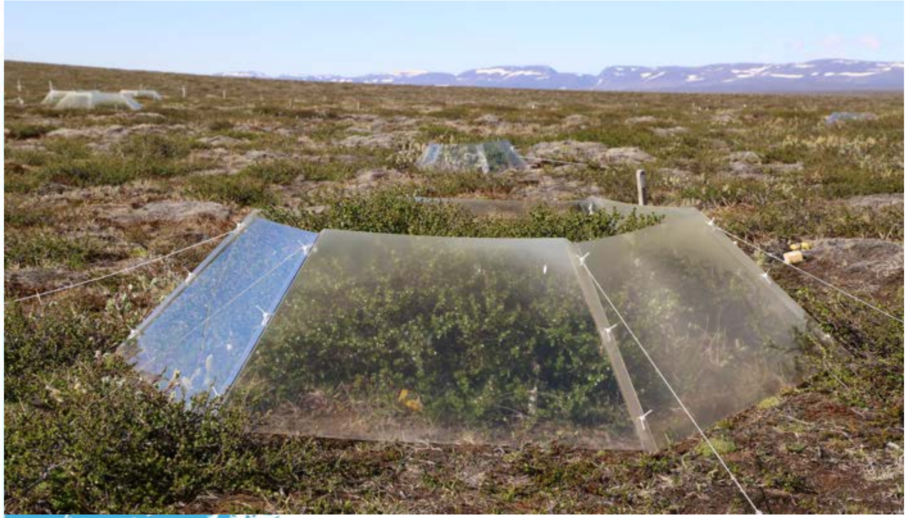


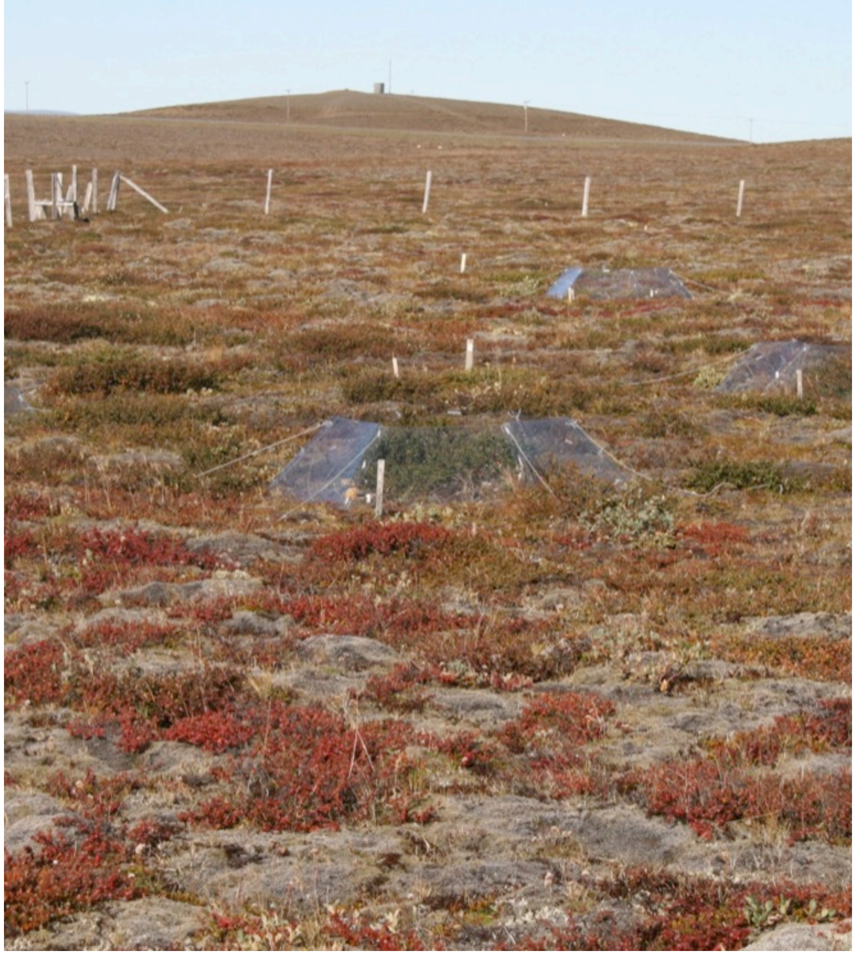
- ✓ The basic ITEX experiment: simulated warming by OTCs
- ✓ Standardized protocols



Audkuluheidi – Iceland, highland tundra

- Subarctic-alpine /low arctic tundra (subzone E?)
- *Betula nana*-heath
- Experiment started 1996 -

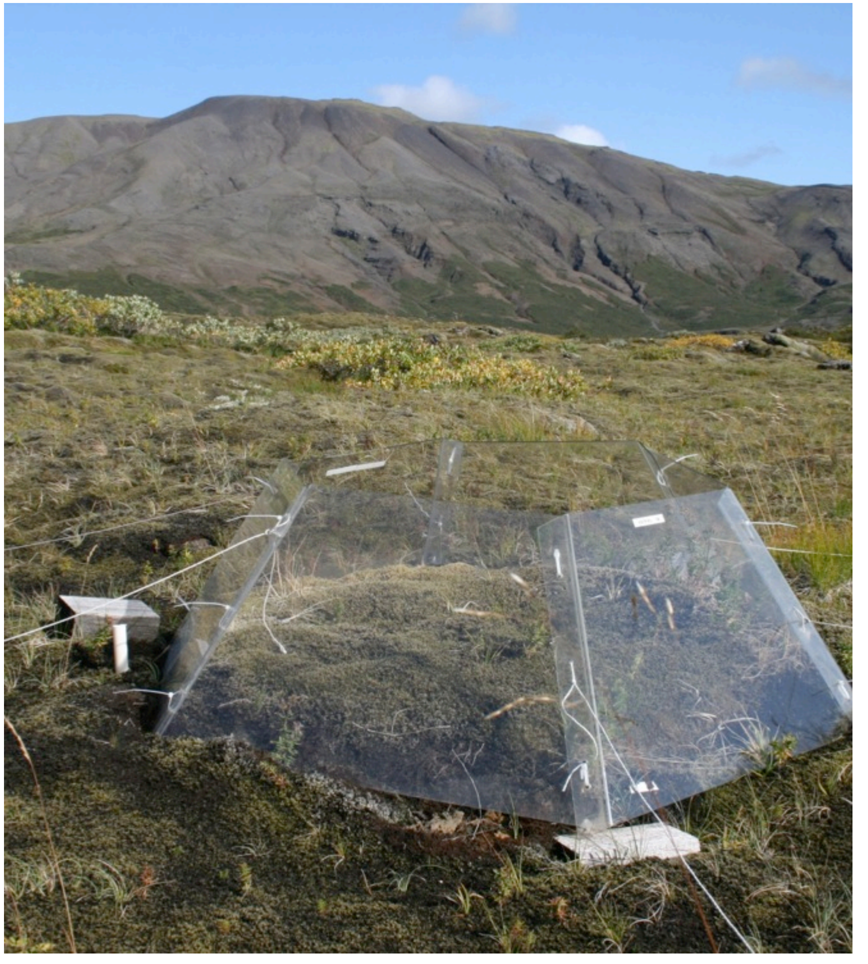




Collaborators:
Borgþór Magnússon, Jón Guðmundsson

Thingvellir, Iceland

- Subarctic (elevation120 m).
- *Racomitrium*-sedge heath
- Experiment started 1996 -



- Collaborators: Borgþór Magnússon, Jón Guðmundsson

Endalen – Svalbard

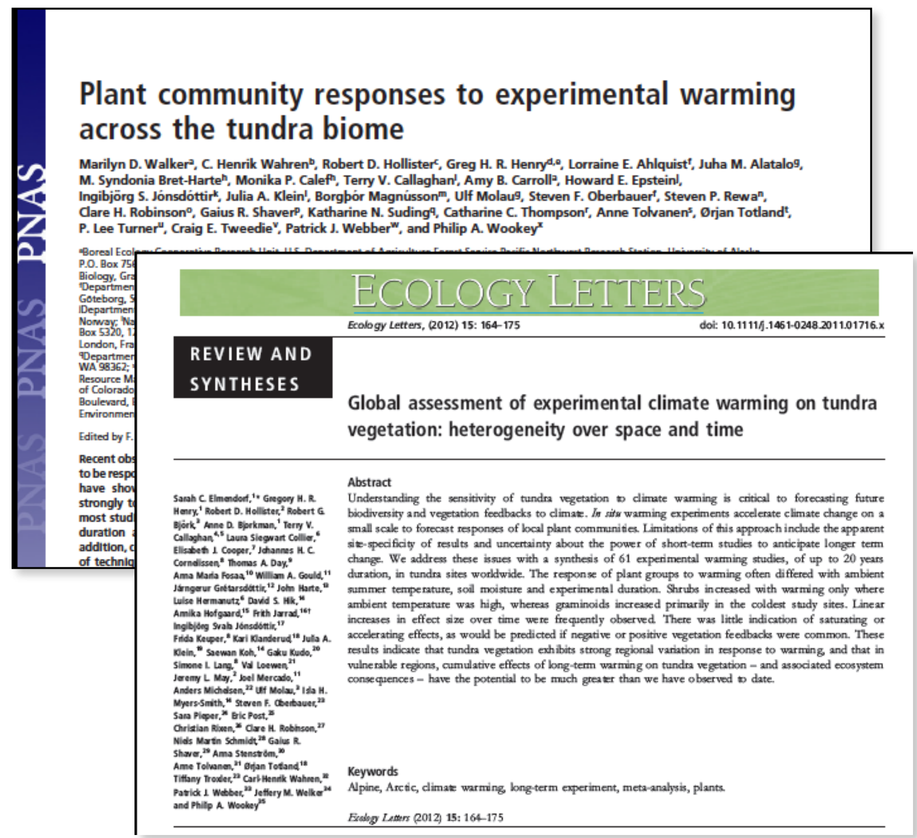
High arctic tundra, subzone C
Experiment started 2002

Three vegetations types:

- *Dryas*-heath
- *Cassiope*-heath (zonal),
- Snowbed

Syntheses of plant community data

- Plant community responses to four years of warming
  - *Walker et al. 2006. PNAS*.
- Plant responses to up to 20 years of warming
  - *Elmendorf et al. 2012a. Ecology Letters.*



PNAS

Plant community responses to experimental warming across the tundra biome

Marilyn D. Walker[a], C. Henrik Wahren[b], Robert D. Hollister[c], Greg H. R. Henry[d,e], Lorraine E. Ahlquist[f], Juha M. Alatalo[g], M. Syndonia Bret-Harte[h], Monika P. Calef[h], Terry V. Callaghan[i], Amy B. Carroll[a], Howard E. Epstein[j], Ingibjörg S. Jónsdóttir[k], Julia A. Klein[l], Borgþór Magnússon[m], Ulf Molau[g], Steven F. Oberbauer[f], Steven P. Rewa[n], Clare H. Robinson[o], Gaius R. Shaver[p], Katharine N. Suding[q], Catharine C. Thompson[r], Anne Tolvanen[s], Ørjan Totland[t], P. Lee Turner[u], Craig E. Tweedie[v], Patrick J. Webber[w], and Philip A. Wookey[x]

ECOLOGY LETTERS

Ecology Letters, (2012) 15: 164–175 doi: 10.1111/j.1461-0248.2011.01716.x

REVIEW AND SYNTHESES

Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time

Sarah C. Elmendorf,[1]* Gregory H. R. Henry,[1] Robert D. Hollister,[2] Robert G. Björk,[3] Anne D. Bjorkman,[1] Terry V. Callaghan,[4,5] Laura Siegwart Collier,[6] Elisabeth J. Cooper,[7] Johannes H. C. Cornelissen,[8] Thomas A. Day,[9] Anna Maria Fosaa,[10] William A. Gould,[11] Járngerur Grétarsdóttir,[12] John Harte,[13] Luise Hermanutz,[6] David S. Hik,[14] Annika Hofgaard,[15] Frith Jarrad,[16†] Ingibjörg Svala Jónsdóttir,[17] Frida Keuper,[8] Kari Klanderud,[18] Julia A. Klein,[19] Saewan Koh,[14] Gaku Kudo,[20] Simone I. Lang,[8] Val Loewen,[21] Jeremy L. May,[2] Joel Mercado,[11] Anders Michelsen,[22] Ulf Molau,[3] Isla H. Myers-Smith,[14] Steven F. Oberbauer,[23] Sara Pieper,[24] Eric Post,[25] Christian Rixen,[26] Clare H. Robinson,[27] Niels Martin Schmidt,[28] Gaius R. Shaver,[29] Anna Stenström,[30] Anne Tolvanen,[31] Ørjan Totland,[18] Tiffany Troxler,[23] Carl-Henrik Wahren,[32] Patrick J. Webber,[33] Jeffery M. Welker[34] and Philip A. Wookey[35]

Abstract

Understanding the sensitivity of tundra vegetation to climate warming is critical to forecasting future biodiversity and vegetation feedbacks to climate. *In situ* warming experiments accelerate climate change on a small scale to forecast responses of local plant communities. Limitations of this approach include the apparent site-specificity of results and uncertainty about the power of short-term studies to anticipate longer term change. We address these issues with a synthesis of 61 experimental warming studies, of up to 20 years duration, in tundra sites worldwide. The response of plant groups to warming often differed with ambient summer temperature, soil moisture and experimental duration. Shrubs increased with warming only where ambient temperature was high, whereas graminoids increased primarily in the coldest study sites. Linear increases in effect size over time were frequently observed. There was little indication of saturating or accelerating effects, as would be predicted if negative or positive vegetation feedbacks were common. These results indicate that tundra vegetation exhibits strong regional variation in response to warming, and that in vulnerable regions, cumulative effects of long-term warming on tundra vegetation – and associated ecosystem consequences – have the potential to be much greater than we have observed to date.

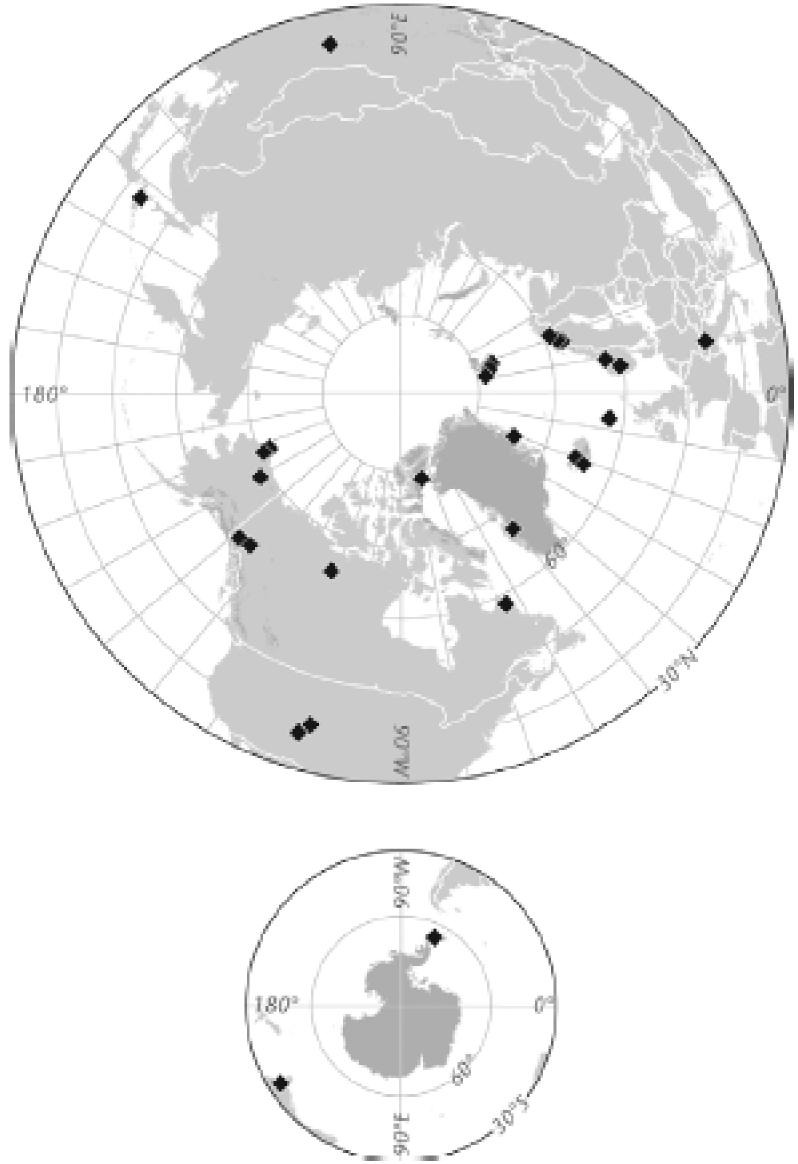
Keywords

Alpine, Arctic, climate warming, long-term experiment, meta-analysis, plants.

Ecology Letters (2012) 15: 164–175

Effect of up to 20 years of simulated warming on tundra plant communities

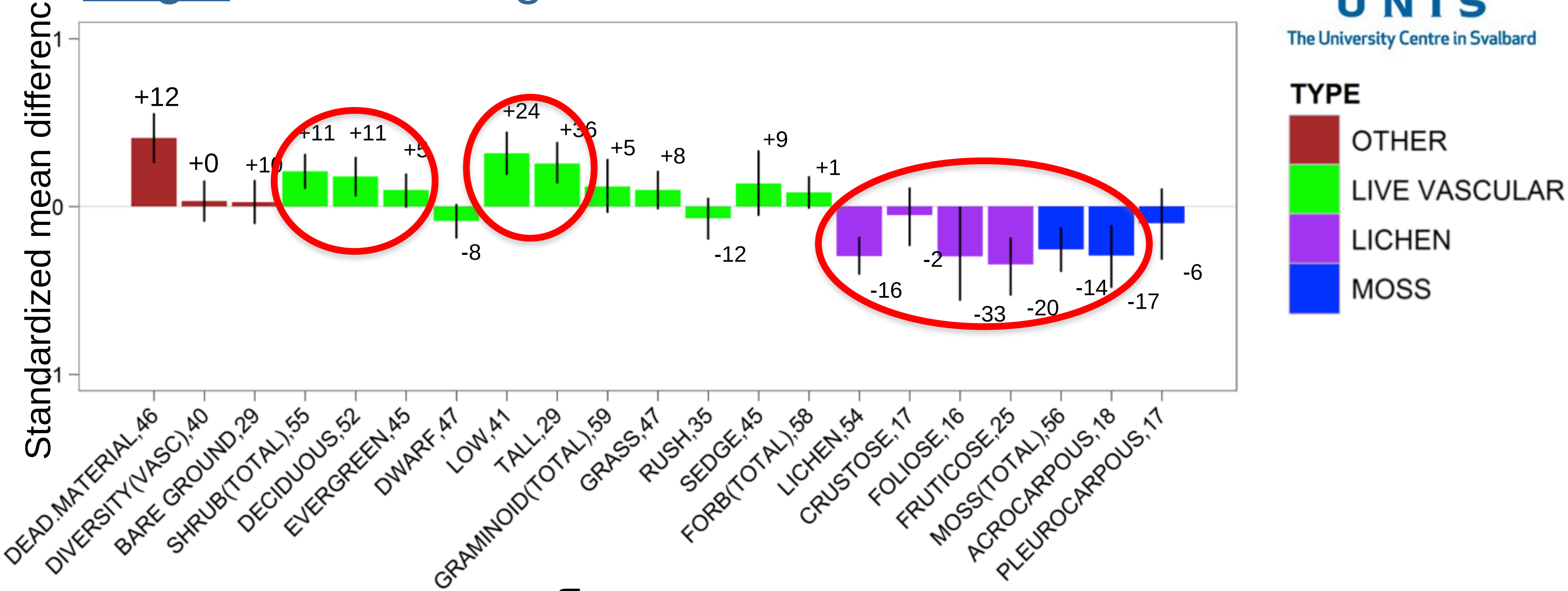
61 experiments at 27 tundra sites



Elmendorf et al. 2012a. Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. Ecology Letters 15: 164-175.

Effects of simulated warming on abundance and height of different growth forms

a)



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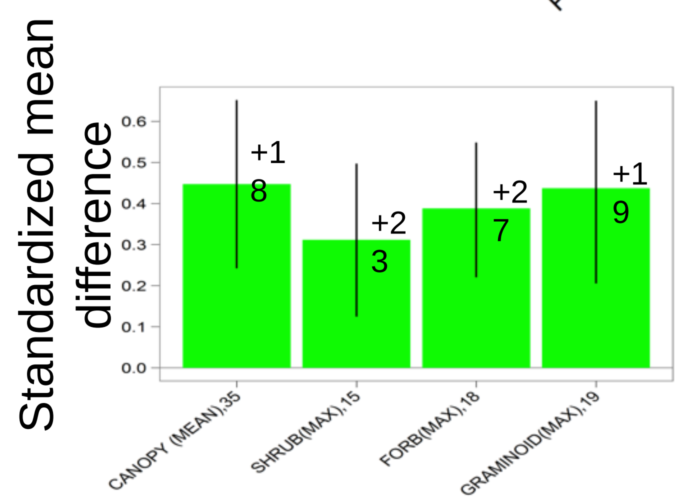
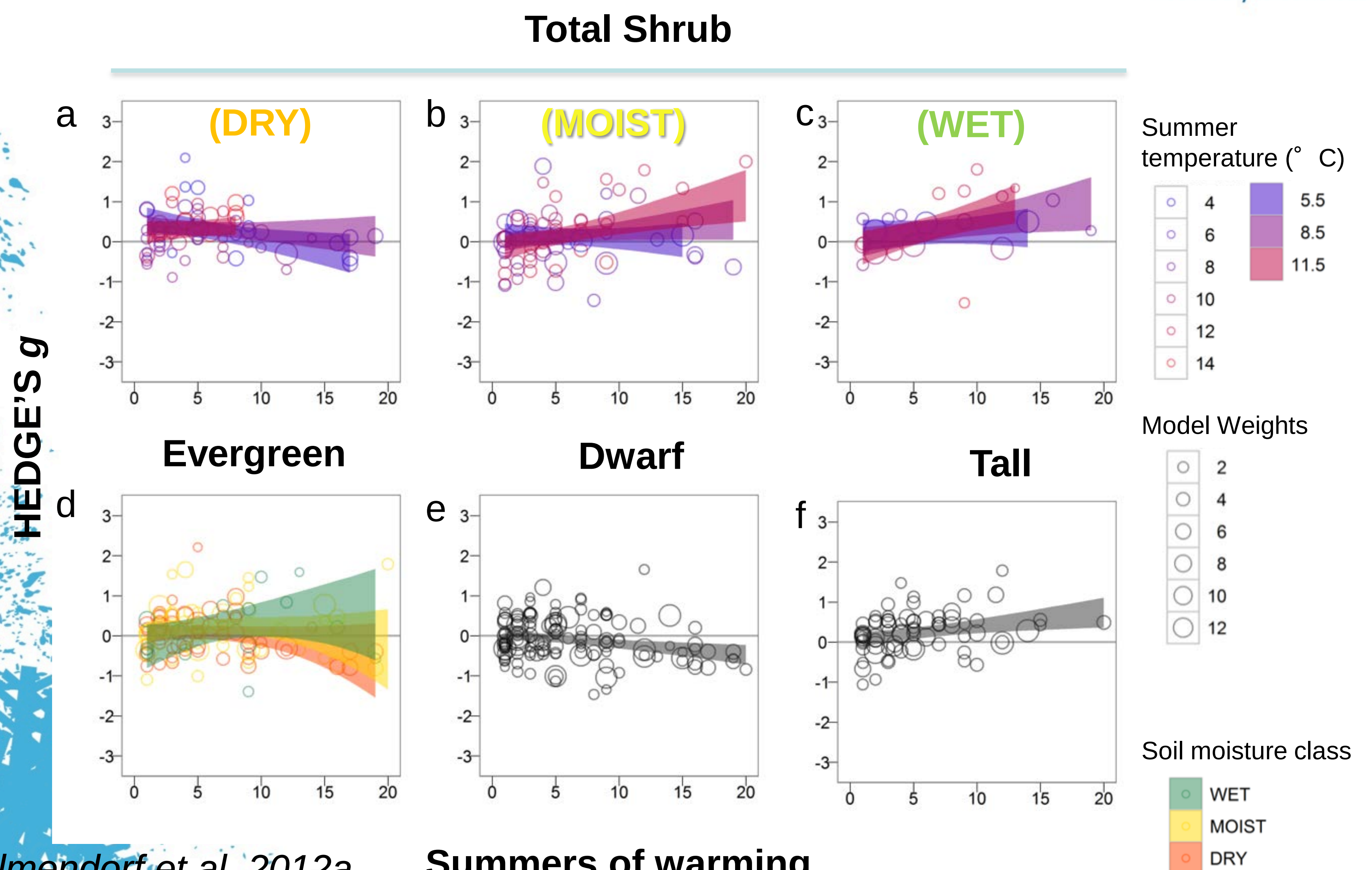


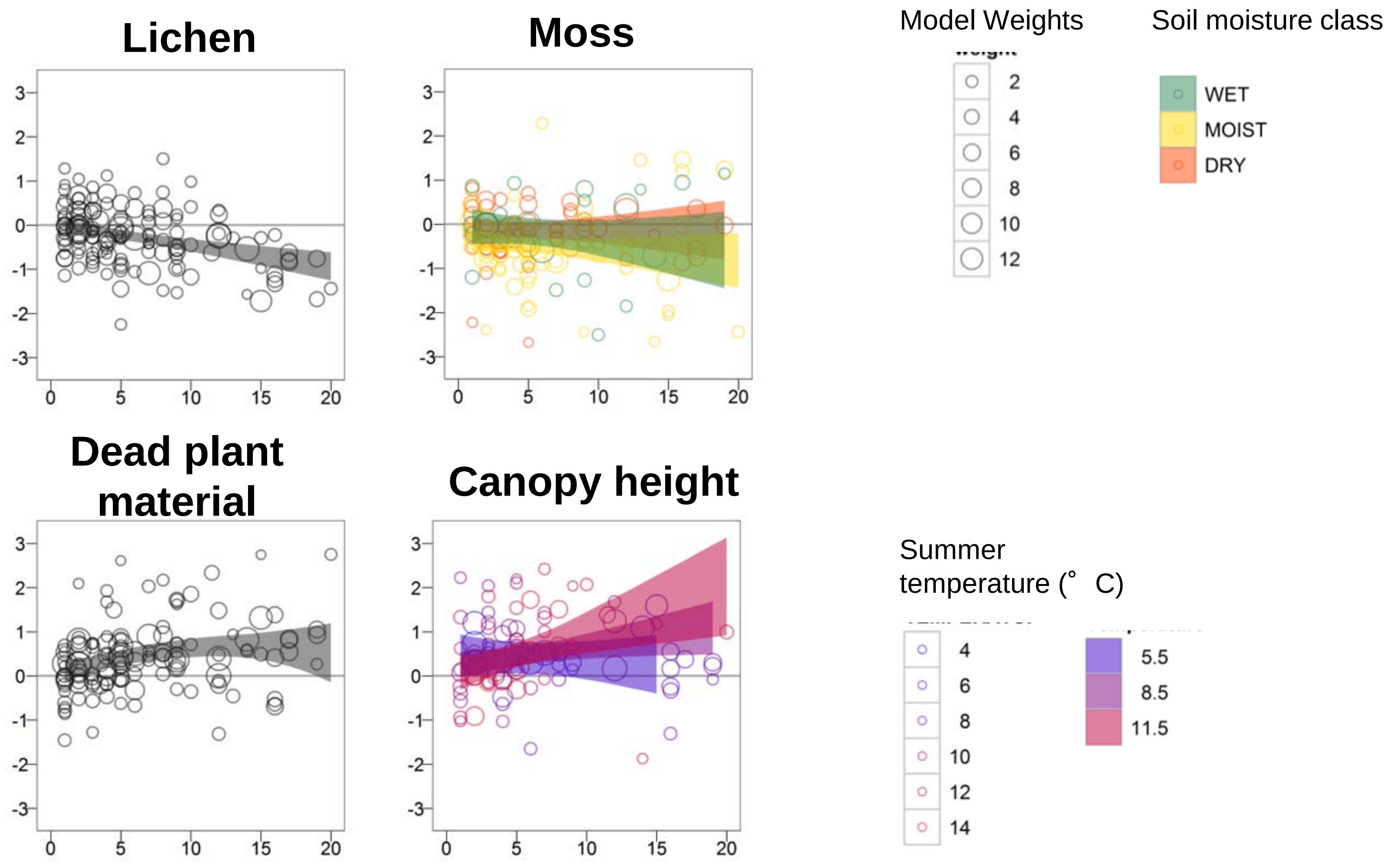
Elmendorf et al. 2012a

Effects of simulated warming on shrub abundance at various conditions



Elmendorf et al. 2012a

Effects of warming at different conditions



Summers of warming

Elmendorf et al. 2012a

ITEX in Iceland, after 19 years of warming, June 2014

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OTC | **Control**




***Betula nana*-heath**

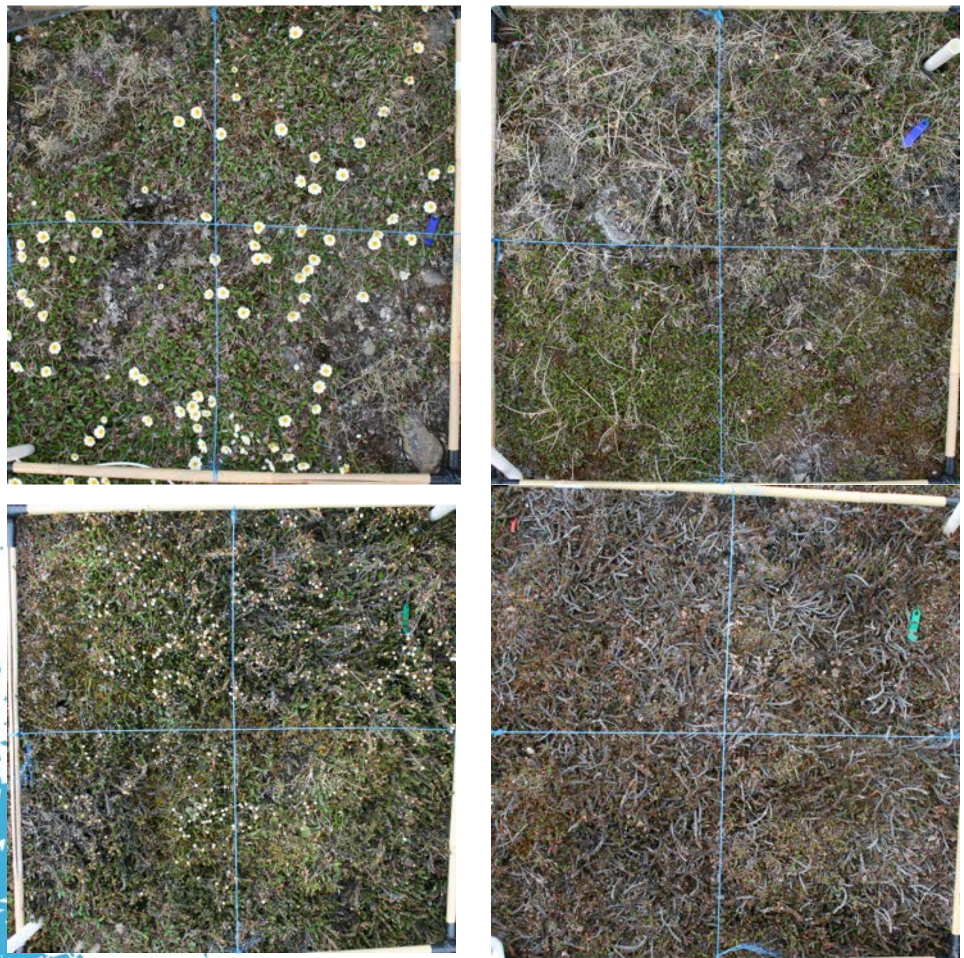
- ✓ Earlier phenology
- ✓ Increased abundance of deciduous shrubs
- ✓ Increased canopy height
- ✓ Reduced abundance of cryptogams

***Racomitrium*-heath**

- ✓ No significant change

ITEX at Endalen, Svalbard, after 14 years of warming, 21 June 2015

OTC **Control**



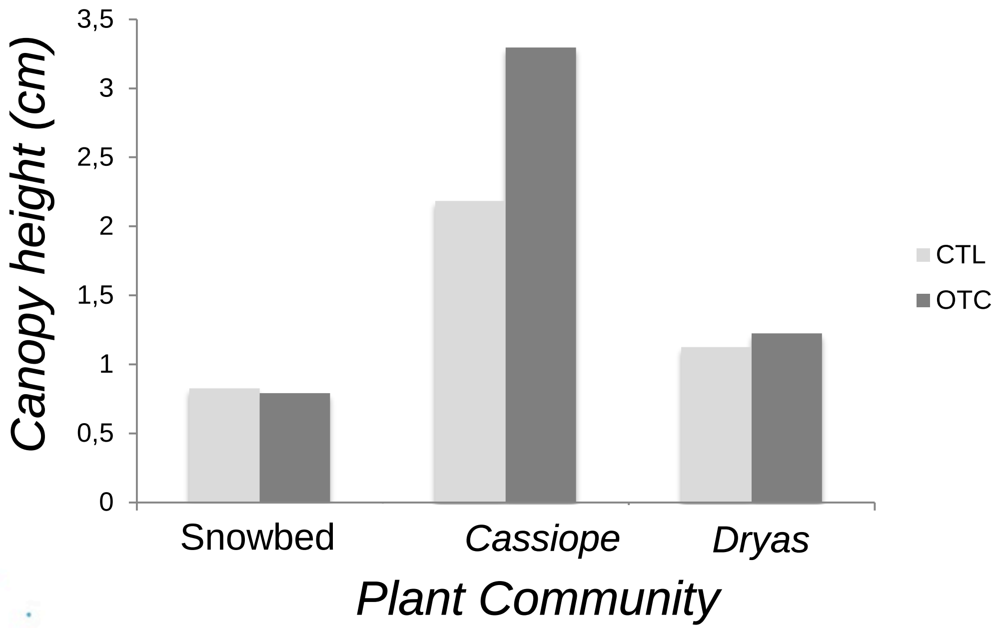
***Dryas*-heath**

- ✓ Earlier phenology
- ✓ No significant change in community composition
- ✓ or plant height

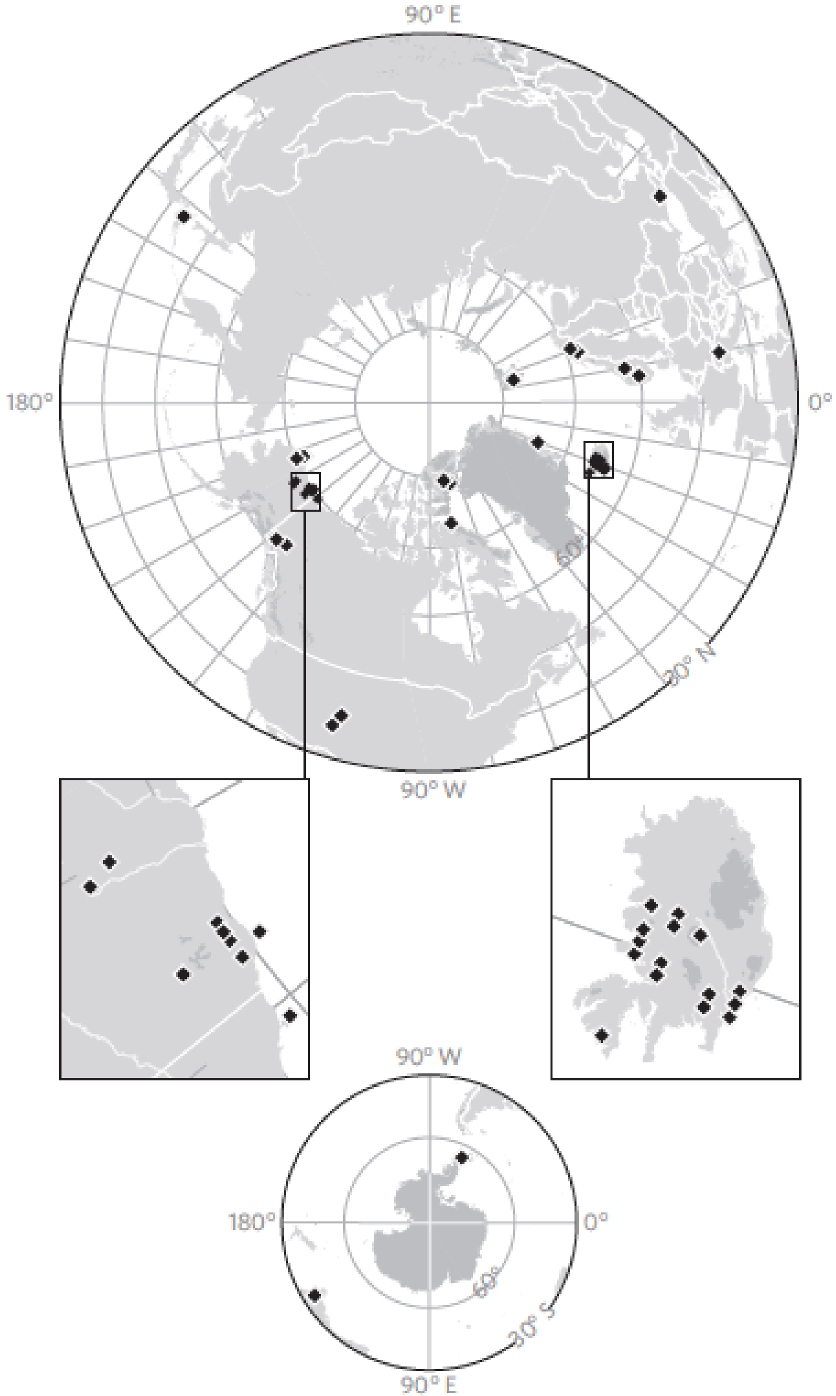
***Cassiope*-heath**

- ✓ Earlier phenology
- ✓ No significant change in community composition
- ✓ Significant greater plant height

Endalen, Svalbard 2009
Effect of OTC warming on canopy height



Meta-analysis of control plots only



158 plant communities from 46 sites in the period: 1980-2010

Elmendorf et al. 2012b

nature climate change
LETTERS
PUBLISHED ONLINE: 8 APRIL 2012 | DOI: 10.1038/NCLIMATE1465

Plot-scale evidence of tundra vegetation change and links to recent summer warming

Sarah C. Elmendorf, Gregory H. R. Henry, Robert D. Hollister *et al.**

Temperature is increasing at unprecedented rates across most of the tundra biome[1]. Remote-sensing data indicate that contemporary climate warming has already resulted in increased productivity over much of the Arctic[2,3], but plot-based evidence for vegetation transformation is not widespread. We analysed change in tundra vegetation surveyed between 1980 and 2010 in 158 plant communities spread across 46 locations. We found biome-wide trends of increased height of the plant canopy and maximum observed plant height for most vascular growth forms; increased abundance of litter; increased abundance of evergreen, low-growing and tall shrubs; and decreased abundance of bare ground. Intersite comparisons indicated an association between the degree of summer warming and change in vascular plant abundance, with shrubs, forbs and

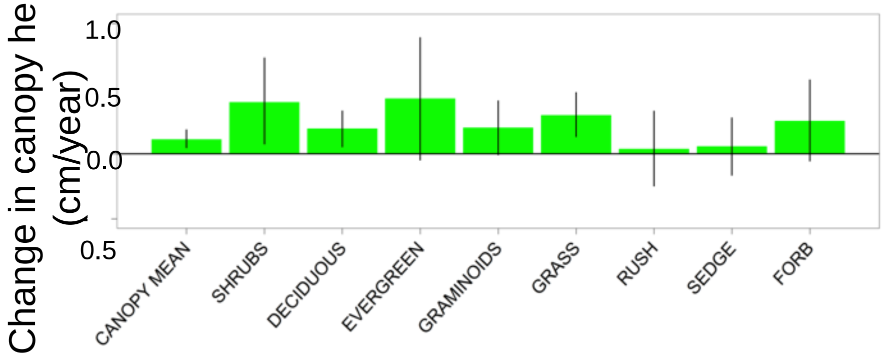
could be responsible for the observed changes. Thus, despite these compelling lines of evidence, uncertainty remains as to the extent of change in vegetation that has occurred across the tundra biome owing to climate change.

Cross-study synthesis offers an opportunity to take advantage of naturally occurring spatial variation in the rate and direction of climate change to test the association between site-specific environmental and biological change[14]. Here, we report on decadal scale vegetation changes that have occurred in Arctic and alpine tundra using the largest data set of plot-level tundra vegetation change ever assembled (Fig. 1; Supplementary Table S1). We hypothesized that tundra vegetation is undergoing directional change over time, with an increase in canopy height and abundance of vascular plants, particularly deciduous, tall and low-growing

Similar trends in control plots, but large noise

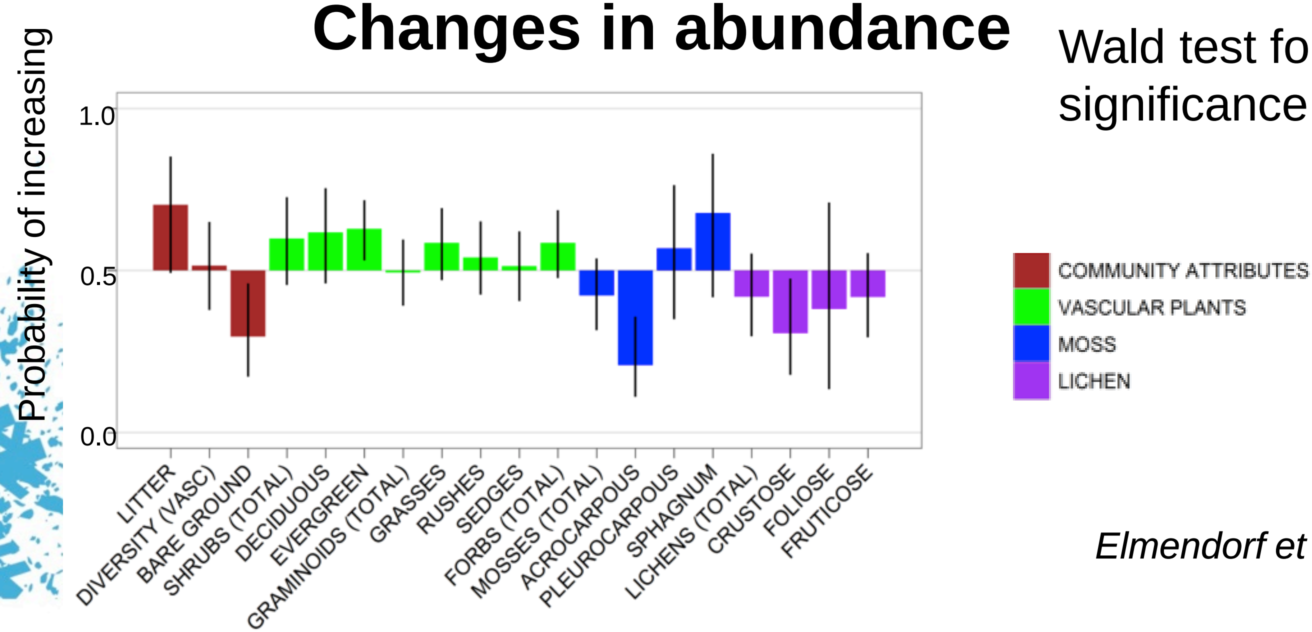
Figure 2.

Changes in canopy height

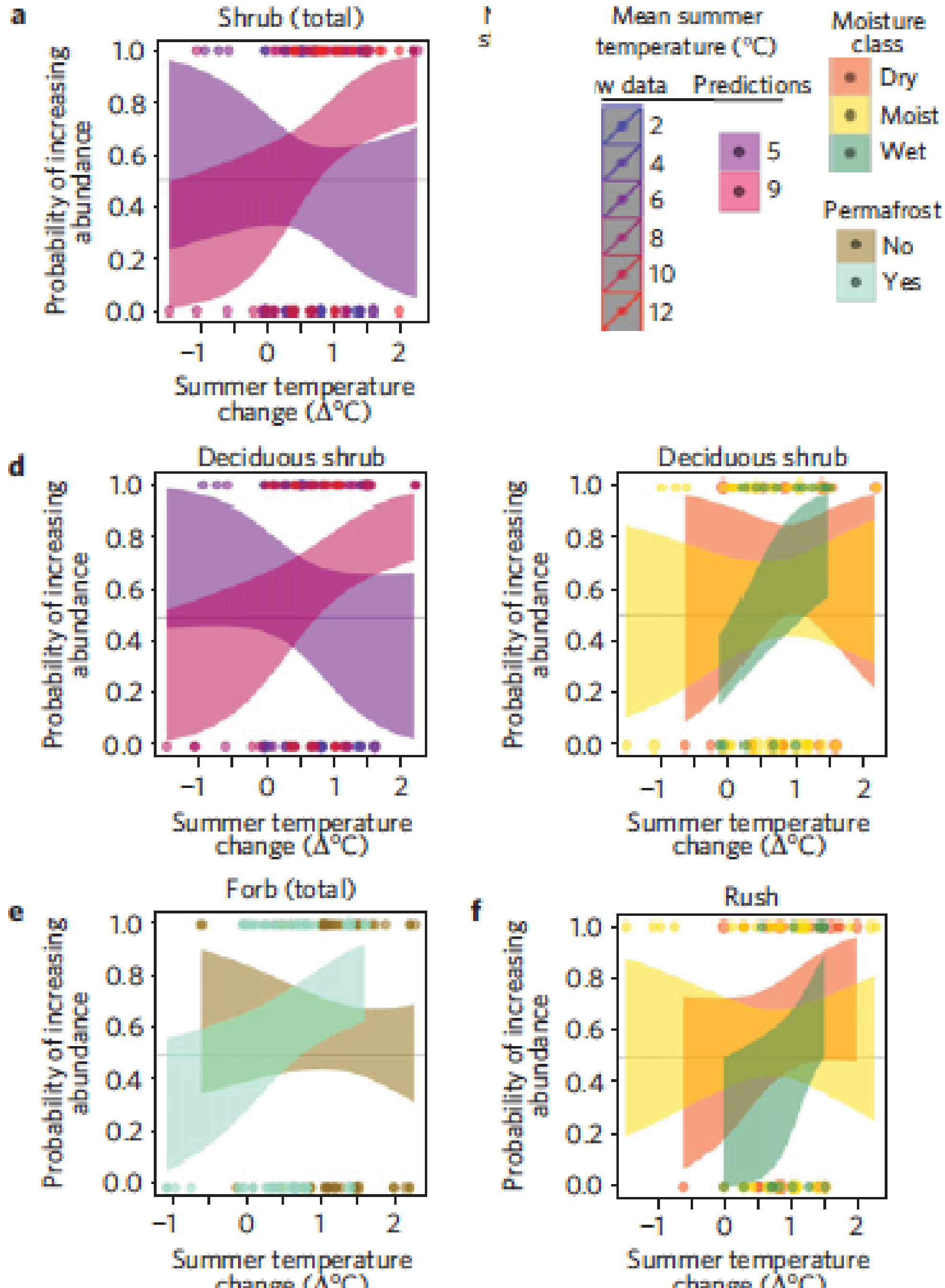


Changes in abundance

Wald test for significance



Elmendorf et al. 2012b



The University Centre in Svalbard

Shrubs responded positively to temperatures but only in low arctic sites.

Deciduous shrub responses were strongest in wet habitats.

Forbes responded to warming only in permafrost areas.

Rushes responded to temperatures in wet habitats.

Elmendorf et al. 2012b

Has the High Arctic vegetation changed?

Brucebyn 1936

Brucebyn 2008

Prach et al. 2010

The first ITEX synthesis: individual plant responses to simulated warming

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13 sites and 50 species

✓Warming resulted in earlier leaf bud burst and flowering

✓<u>Growth </u>increased in response to warming.
✓Stronger response at <u>low arctic</u> sites than high arctic.

✓<u>Reproductive </u>effort increased in response to warming.
✓Stronger response at <u>high arctic</u> than low arctic or alpine sites.

Ecological Monographs, 69(4), 1999, pp. 491–511

RESPONSES OF TUNDRA PLANTS TO EXPERIMENTAL WARMING: META-ANALYSIS OF THE INTERNATIONAL TUNDRA EXPERIMENT

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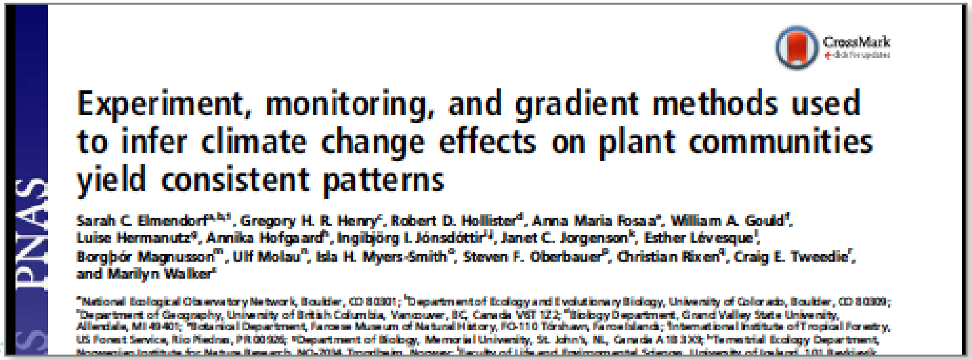

PNAS

CrossMark

Experiment, monitoring, and gradient methods used to infer climate change effects on plant communities yield consistent patterns

Sarah C. Elmendorf[a,b,1], Gregory H. R. Henry[c], Robert D. Hollister[d], Anna Maria Fosaa[e], William A. Gould[f], Luise Hermanutz[g], Annika Hofgaard[h], Ingibjörg I. Jónsdóttir[i,j], Janet C. Jorgenson[k], Esther Lévesque[l], Borgþór Magnusson[m], Ulf Molau[n], Isla H. Myers-Smith[o], Steven F. Oberbauer[p], Christian Rixen[q], Craig E. Tweedie[r], and Marilyn Walker[s]

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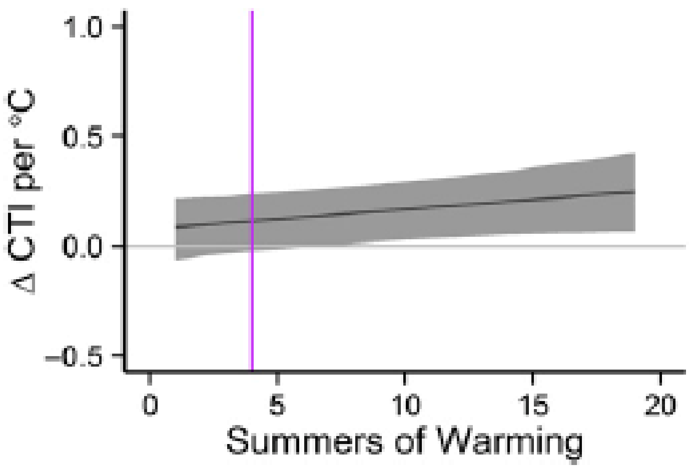
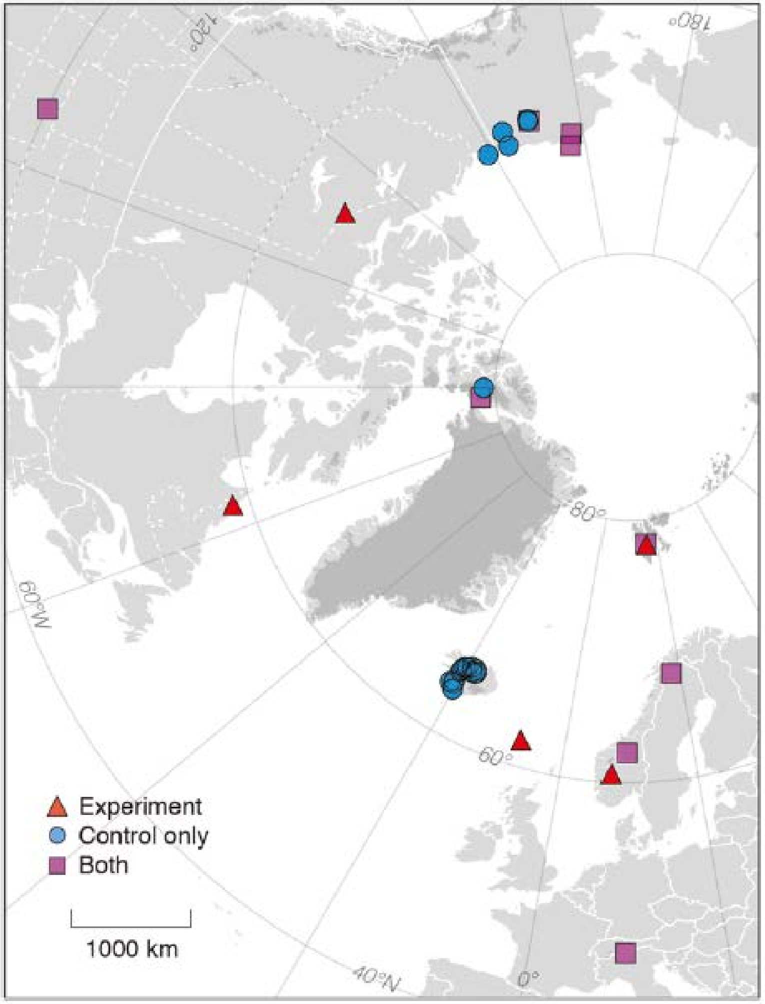
Thermophilization in response to climate warming





<u>CTI = Community temperature index (</u>mean of each species' thermal niche weighted by each species' total cover)

Higher CTI values are indicative of communities dominated by species with ranges centered in warmer environments and vice versa.

Drivers of change at landscape and local scales

- Based on ITEX syntheses:
  - – Summer temperatures – especially where summer T are relatively high already and responsive shrubs already in place (in the Low Arctic)
  - – Soil moisture – strongest responses by shrubs in wet habitats
  - – Community change is related to thermophilization.

- Based on the high arctic Svalbard ITEX studies
  - – Timing of snow melt – strongest plant height responses to warming in habitats of intermediate timing of snow melt (zonal, *Cassiope* heath) compared to early (dry *Dryas* heath) and late melting snowbeds (moist).

Other drivers may modulate responses to climate warming

- Land use
- Herbivory
  - plant community responses
    - Post 2013, Olofsson et al. 2009
  - Ecosystem processes (carbon balance)
    - Cahoon et al. 2012, Väisänen et al. 2014

HERBIVORY NETWORK

STUDYING HERBIVORY IN ARCTIC AND ALPINE ECOSYSTEMS

http://herbivory.biology.ualberta.ca/

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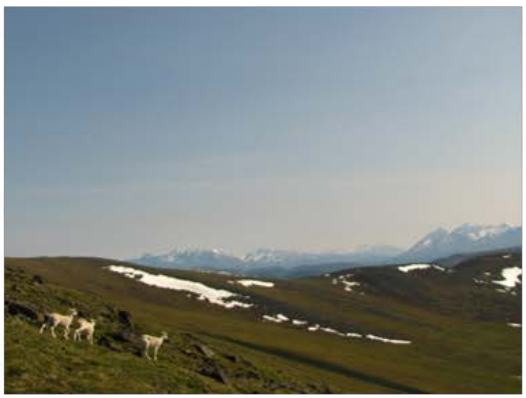
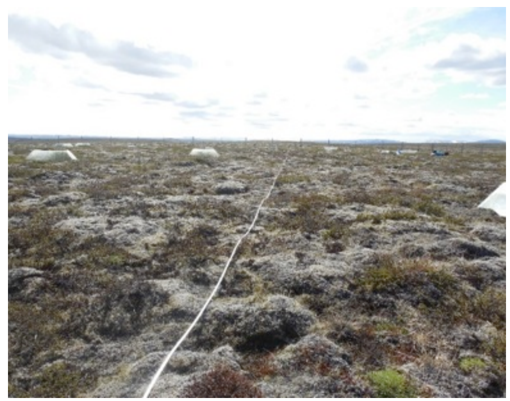
smaller spatial scale

1. Overall characteristics of the herbivore community



Overall description of the site, and relevant management practices that may affect herbivore populations

2. Site-level assessment



Local estimates of (vertebrate) herbivore presence and abundance in the area

Transects: pellet counts and other signs

3. Plot-level assessment

Fine-scale measures of herbivory and herbivore activity that can be related to plant measurements

Modified point-intercept method

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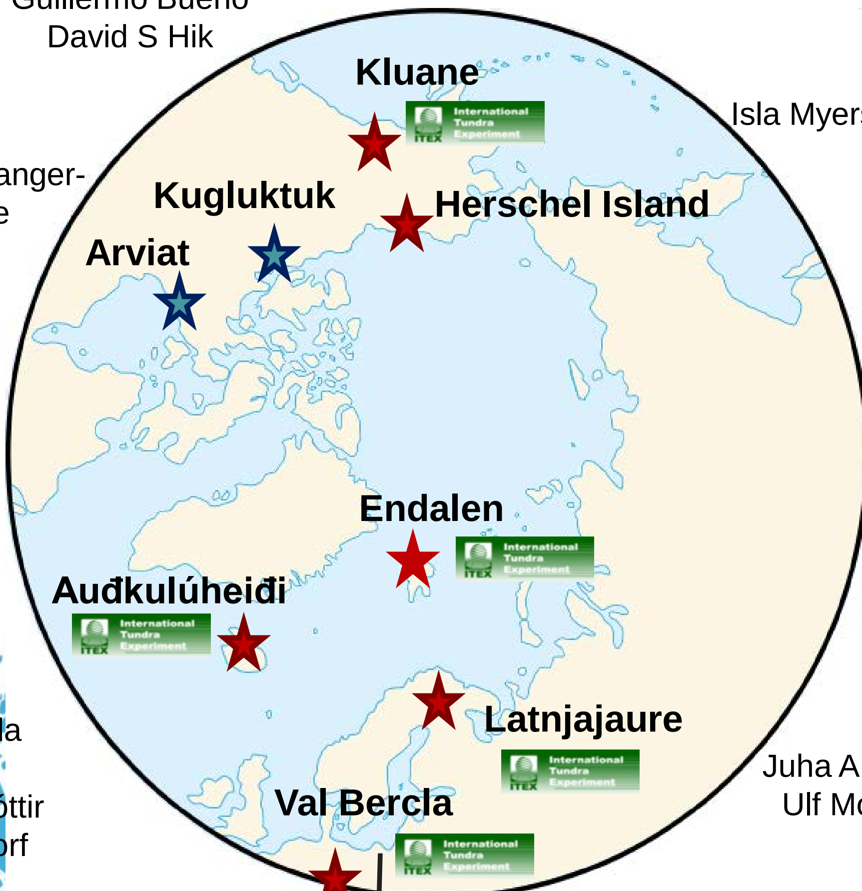
ITEX herbivory protocol
First trial 2014

Isabel C Barrio
Guillermo Bueno
David S Hik

Isla Myers-Smith

Noémie Boulanger-Lapointe

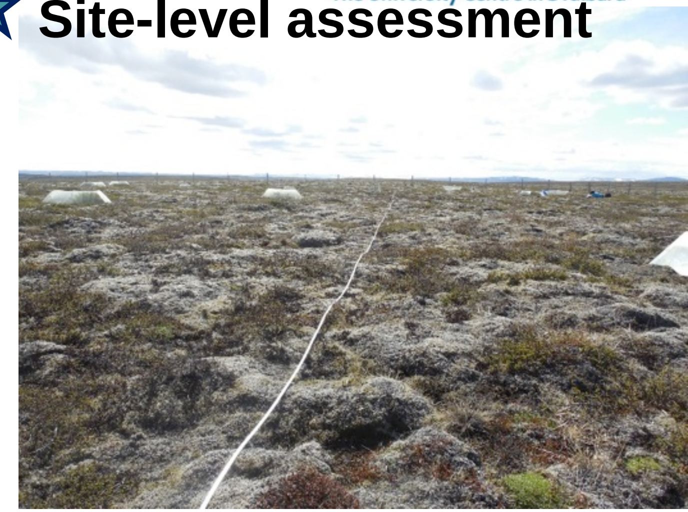


Ingibjörg Svala Jónsdóttir
Linda Arsælsdóttir
Martin Mörsdorf

Juha Alatalo
Ulf Molau

Janet Prevéy

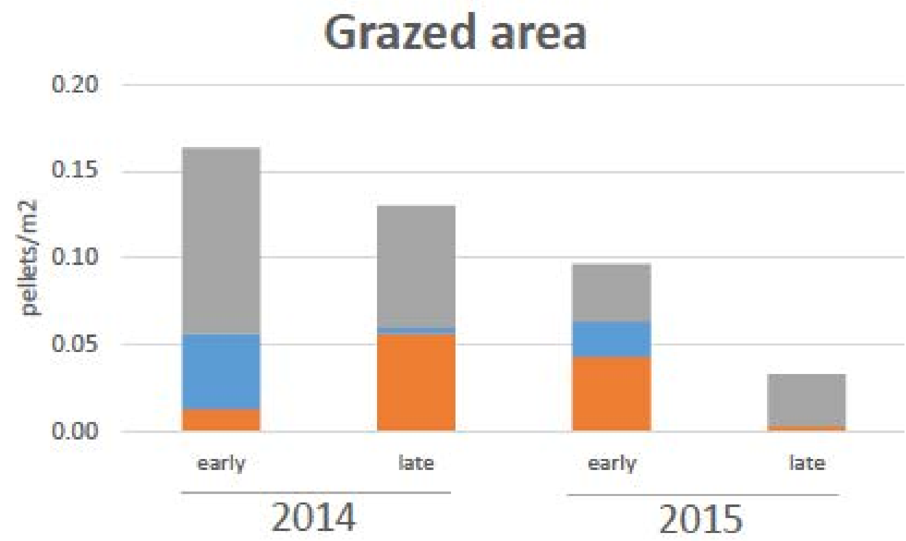
Site-level assessment

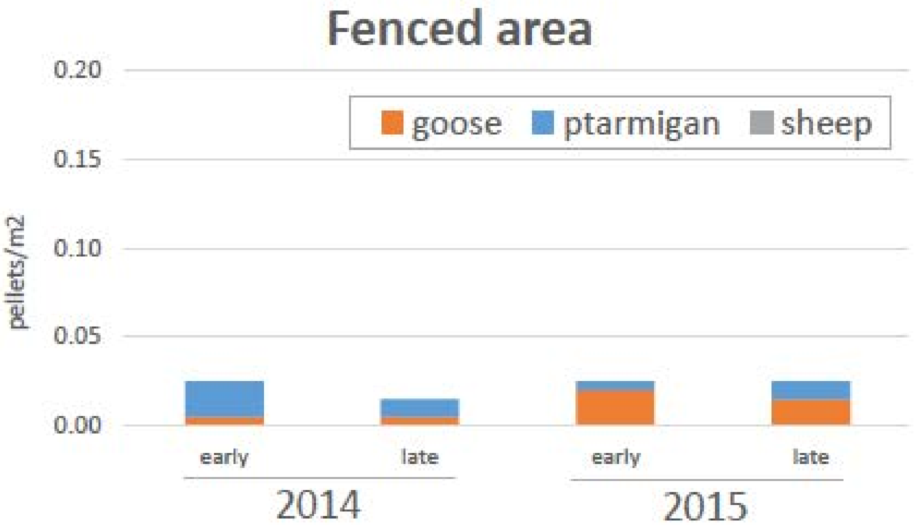


Plot-level assessment

Site-level assessment

Comparisons within sites. Auđkulúheiđi





HERBIVORY NETWORK

STUDYING HERBIVORY IN ARCTIC AND ALPINE ECOSYSTEMS

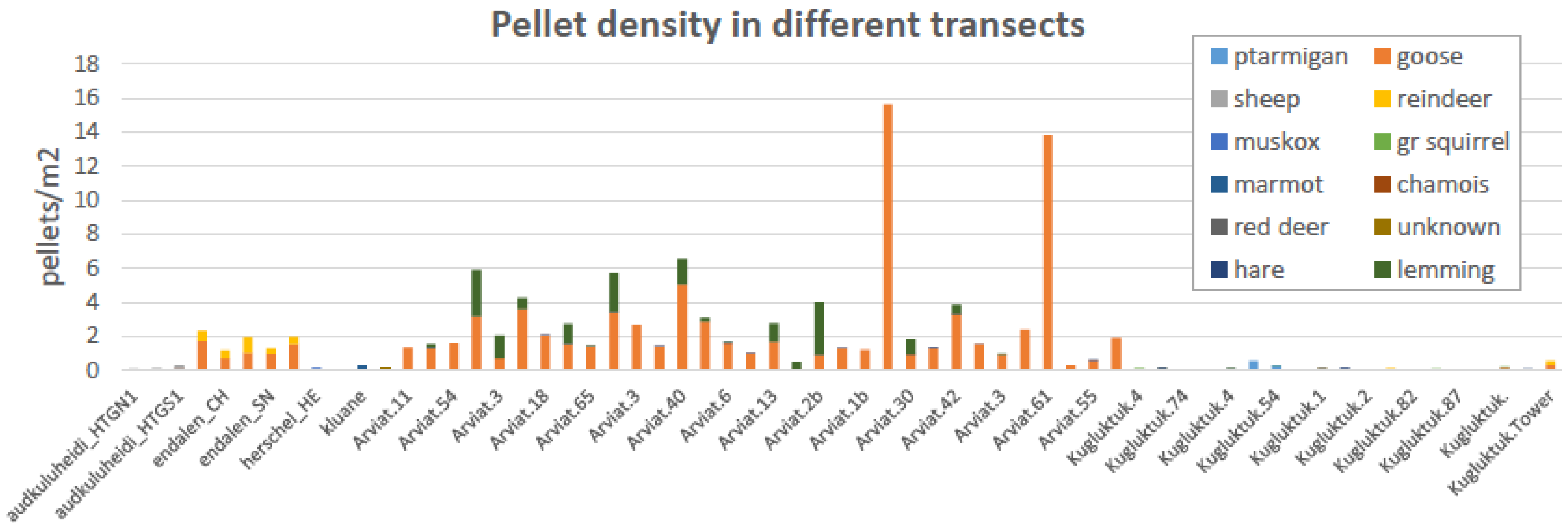
Site-level assessment

Differences in overall vertebrate herbivore activity across sites?

***Problems with this approach!** Cannot really compare across sites*

- *differences in pellet persistence*
- *different herbivores*

but still, useful for within-site comparisons



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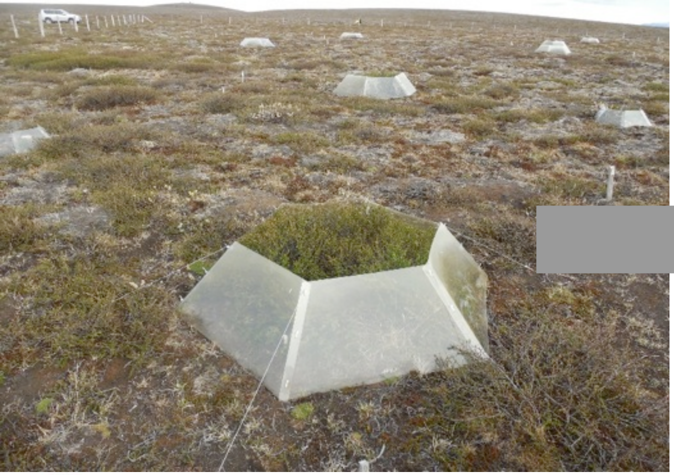
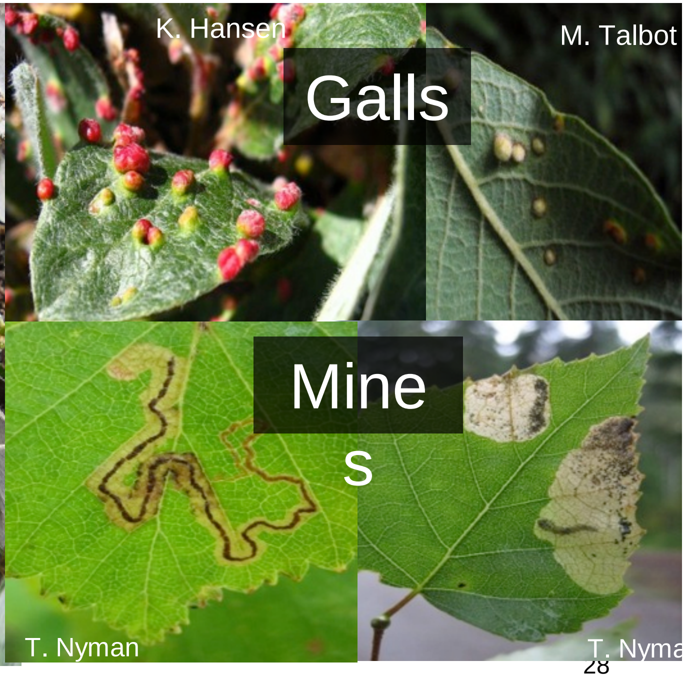
Plot-level assessment



Modified point intercept method:
Presence/absence of herbivory 1 cm around intercept



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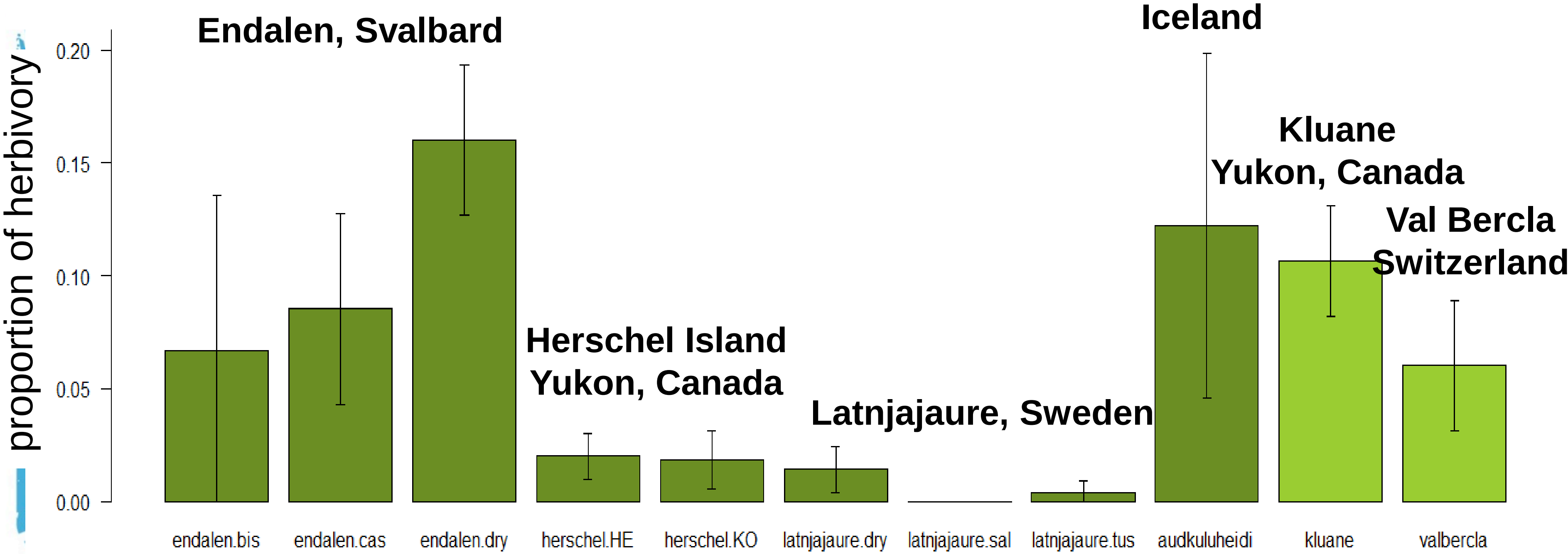
Plot-level assessment

Overall, the frequency of invertebrate herbivory in the **control plots** was low (~5-10%) and varied across sites

(LM; SITE=1.785, p=0.002)



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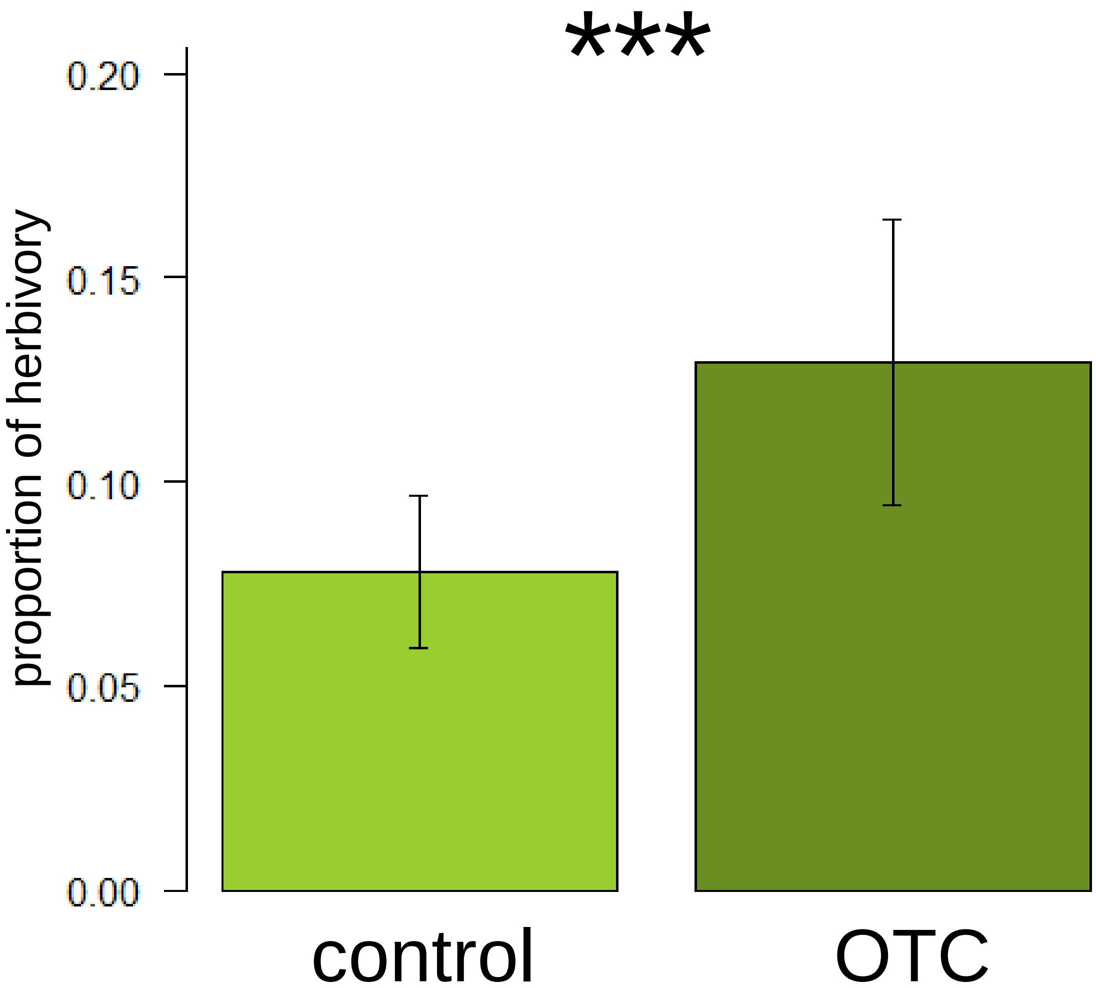
Plot-level assessment

Invertebrate herbivory was consistently higher in **warmed plots**



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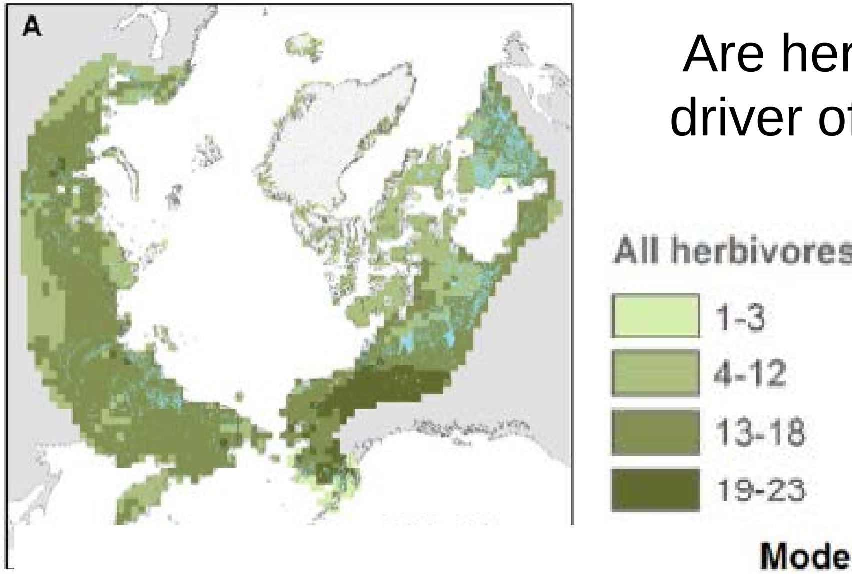
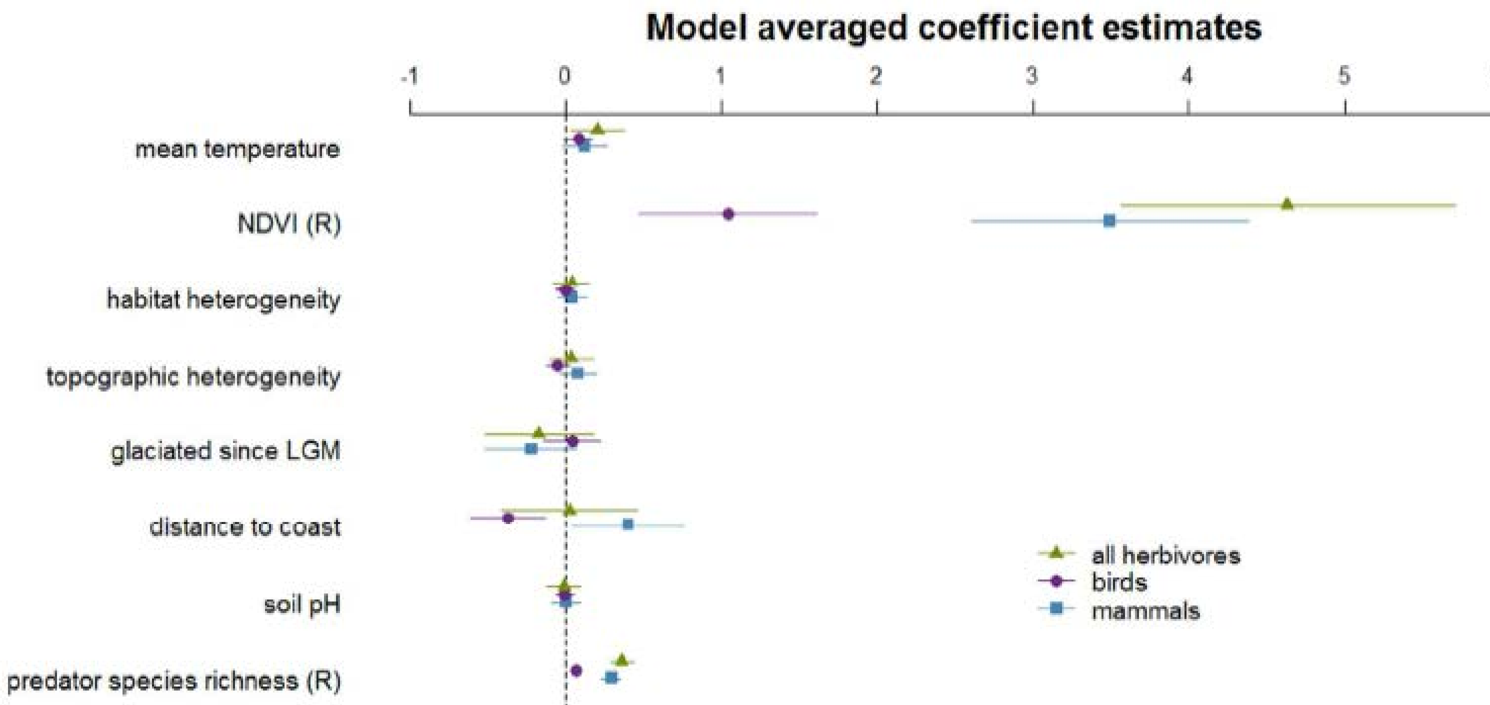
Are herbivores also a potential driver of biomass variability at a regional scale?





Barrio et al. submitted to Global Ecology and Biogeography

Conclusions ….

- The ITEX syntheses have demonstrated
  - Sites that are already relatively warm (low arctic) respond more strongly to warming than colder sites (high arctic)
  - the importance of the combined effect of summer temperatures and soil moisture as drivers of plant community change at various spatial scales.
- In addition, individual ITEX studies along natural gradients within landscapes have demonstrated the importance of timing of snow melt for plant height responses in the High Arctic.
- Changes in plant community compositions is due to thermophilization = species decline in cold adapted and increase in warm adapted species.
- Standardized protocols are being developed to disentangle the causal relationships between herbivory and plant community responses at various spatial scales