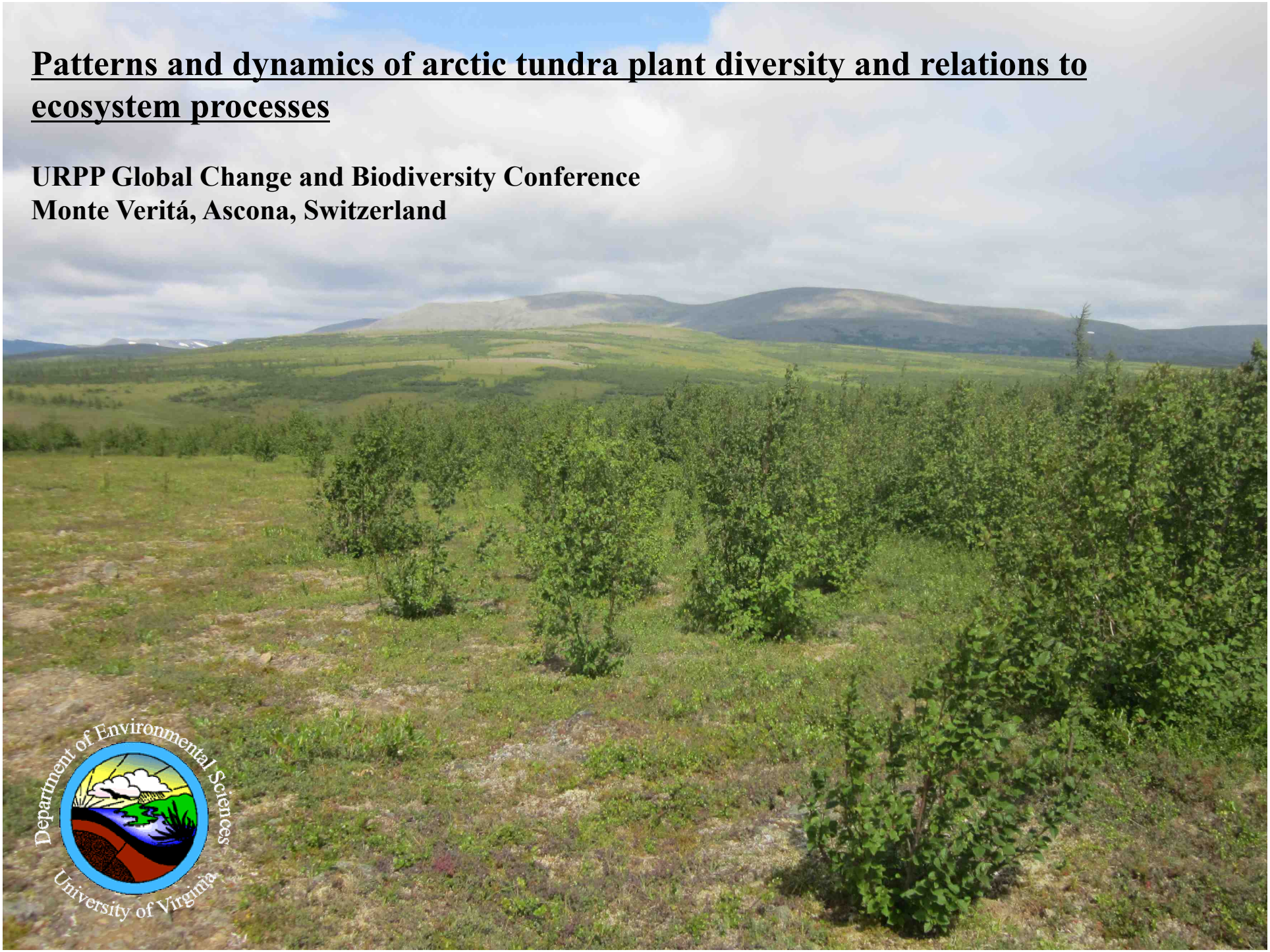
Patterns and dynamics of arctic tundra plant diversity and relations to ecosystem processes

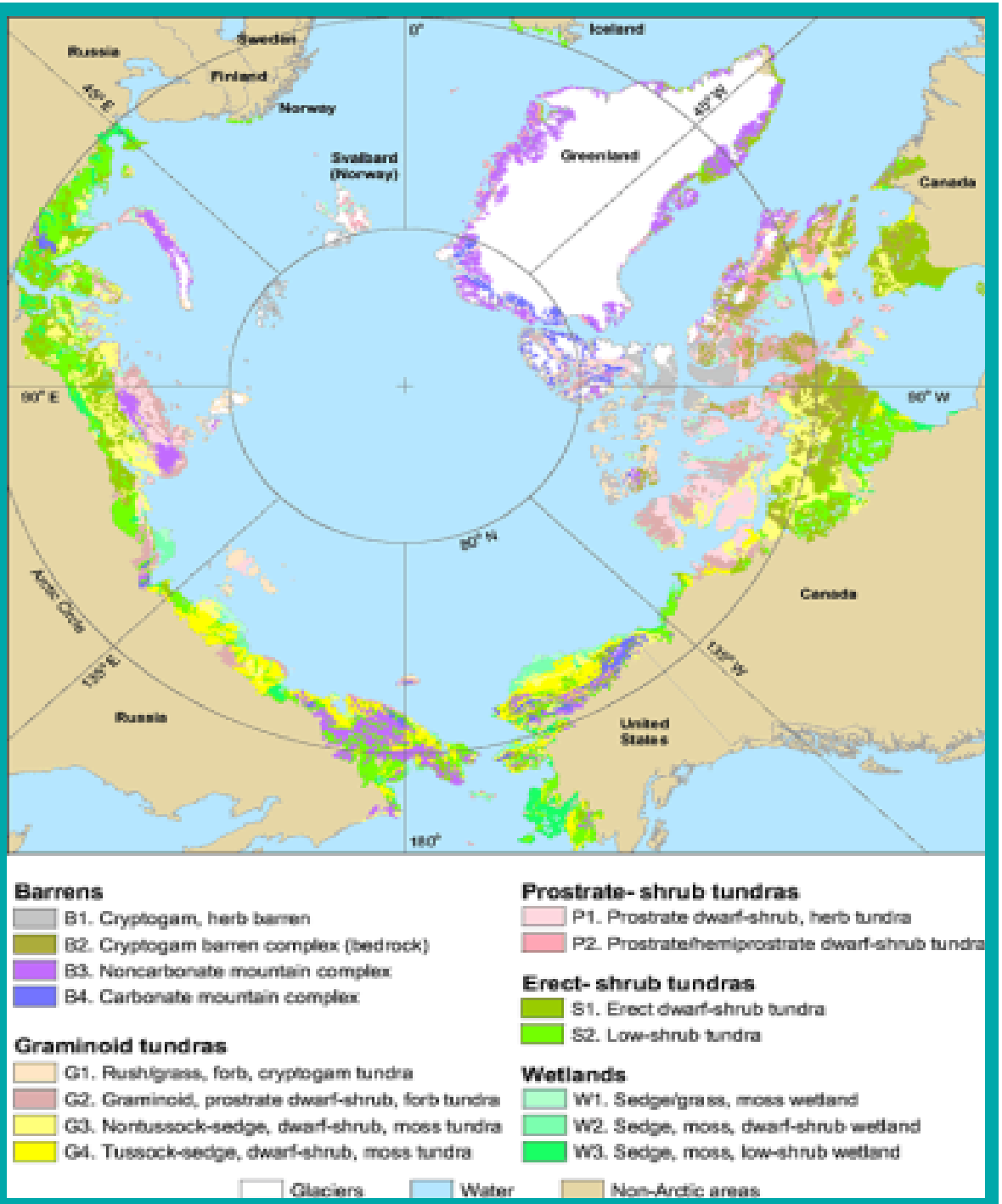
URPP Global Change and Biodiversity Conference
Monte Veritá, Ascona, Switzerland



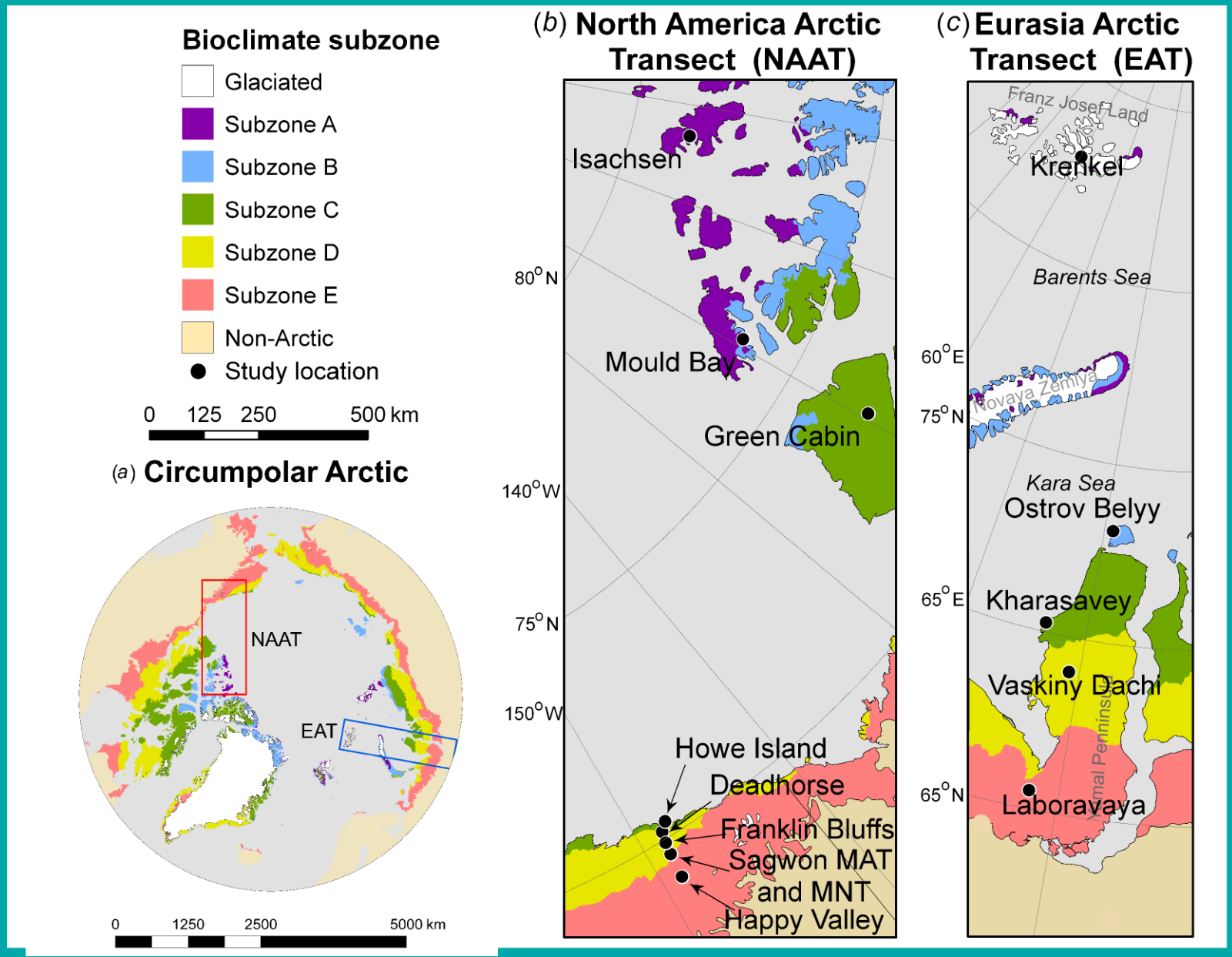
Presentation Topics

1) Patterns of arctic tundra plant diversity along complete latitudinal gradients
2) Tall shrub expansion at the forest-tundra ecotone in Siberia and implications for biodiversity
3) Ecosystem effects of a change from short-statured tundra to tall shrubland

The Arctic Tundra Biome



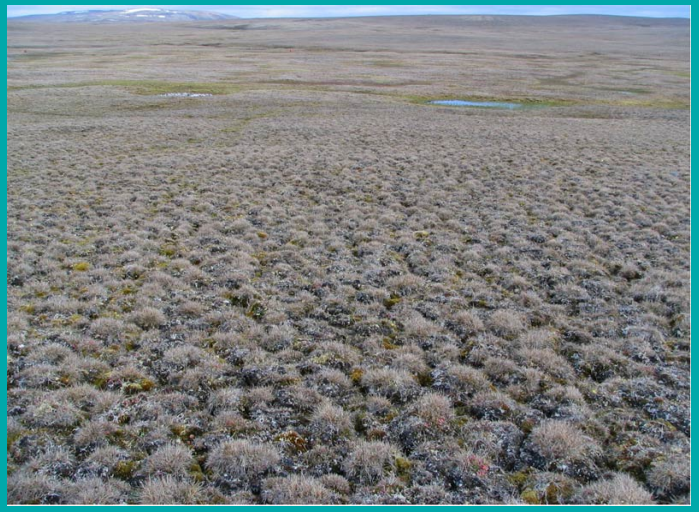
Walker, D. A., 2005. The Circumpolar Arctic Vegetation Map. Journal of Vegetation Science.



Raynolds et al. 2012 (Remote Sensing Letters)

North American Arctic Transect

Subzone A



Subzone B

Subzone C

Subzone D

Subzone E

(Photos D.A. Walker and H.E. Epstein)

Eurasian Arctic Transect

Subzone A

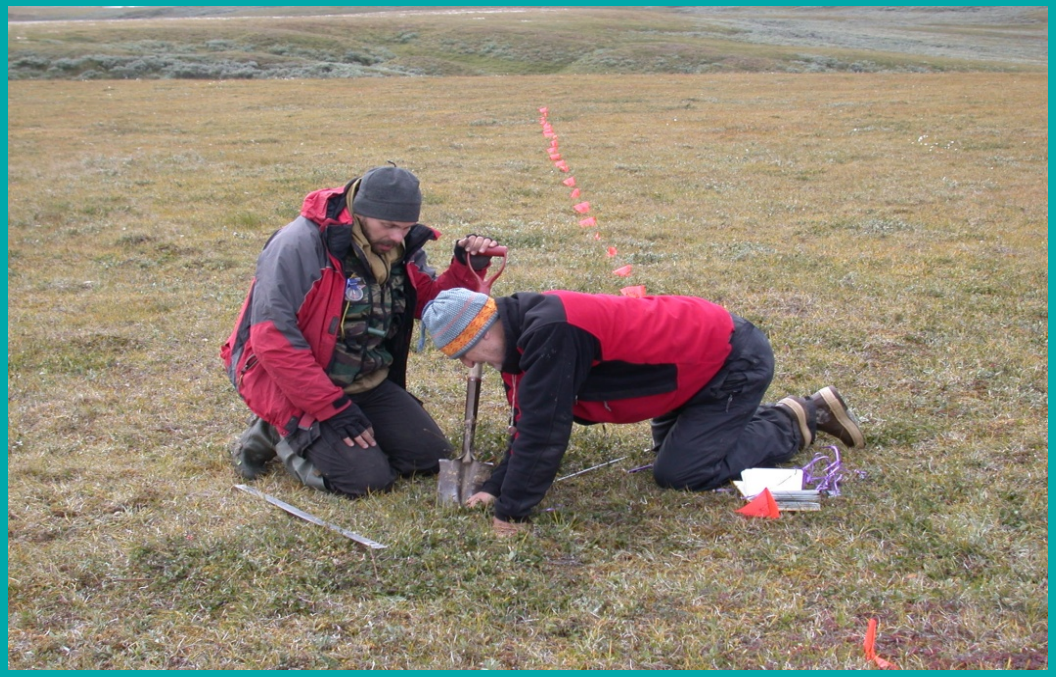
Subzone B

Subzone C

Subzone D

Subzone E

(Photos D.A. Walker and H.E. Epstein)



Field Data Collection

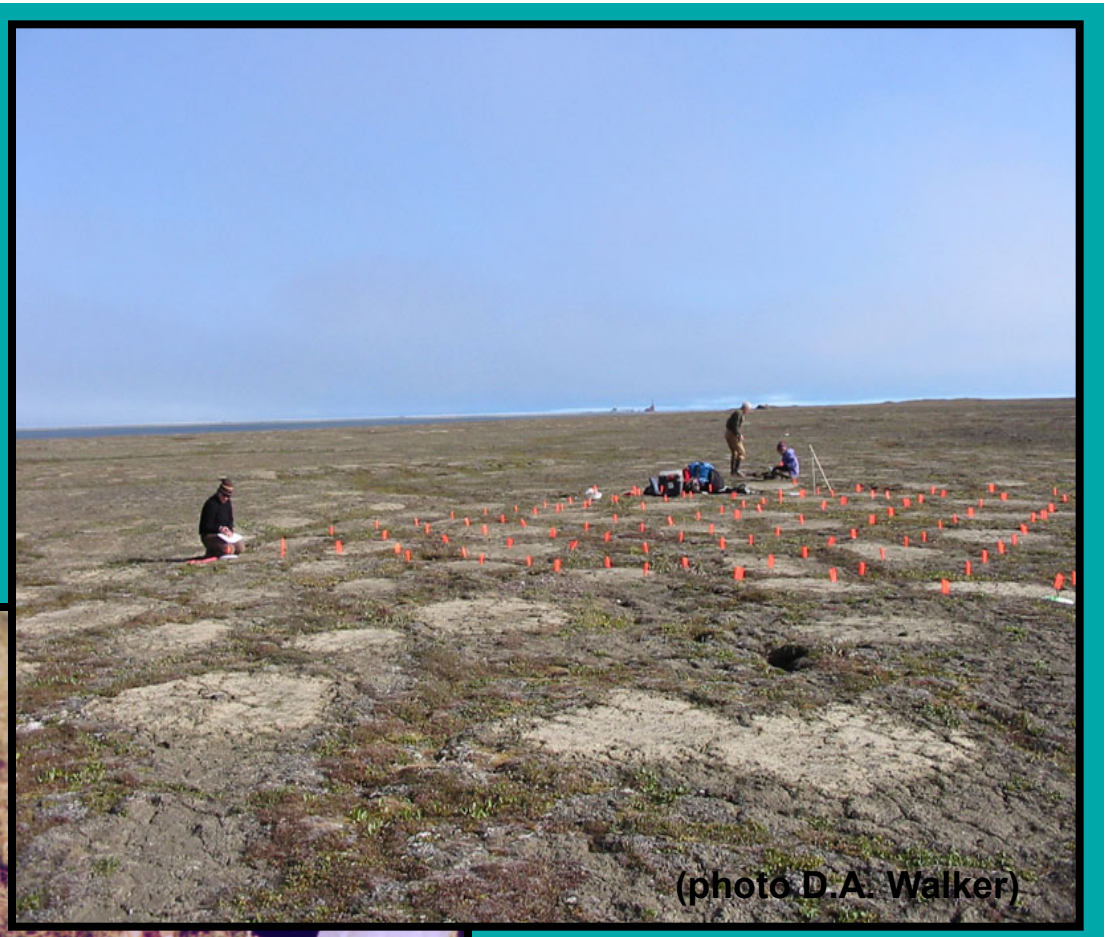
- locations along latitudinal gradients with multiple sites at each location to capture topographic and patterned-ground (NAAT) and soil texture (EAT) variability

- *relevés for plant community composition and species richness*

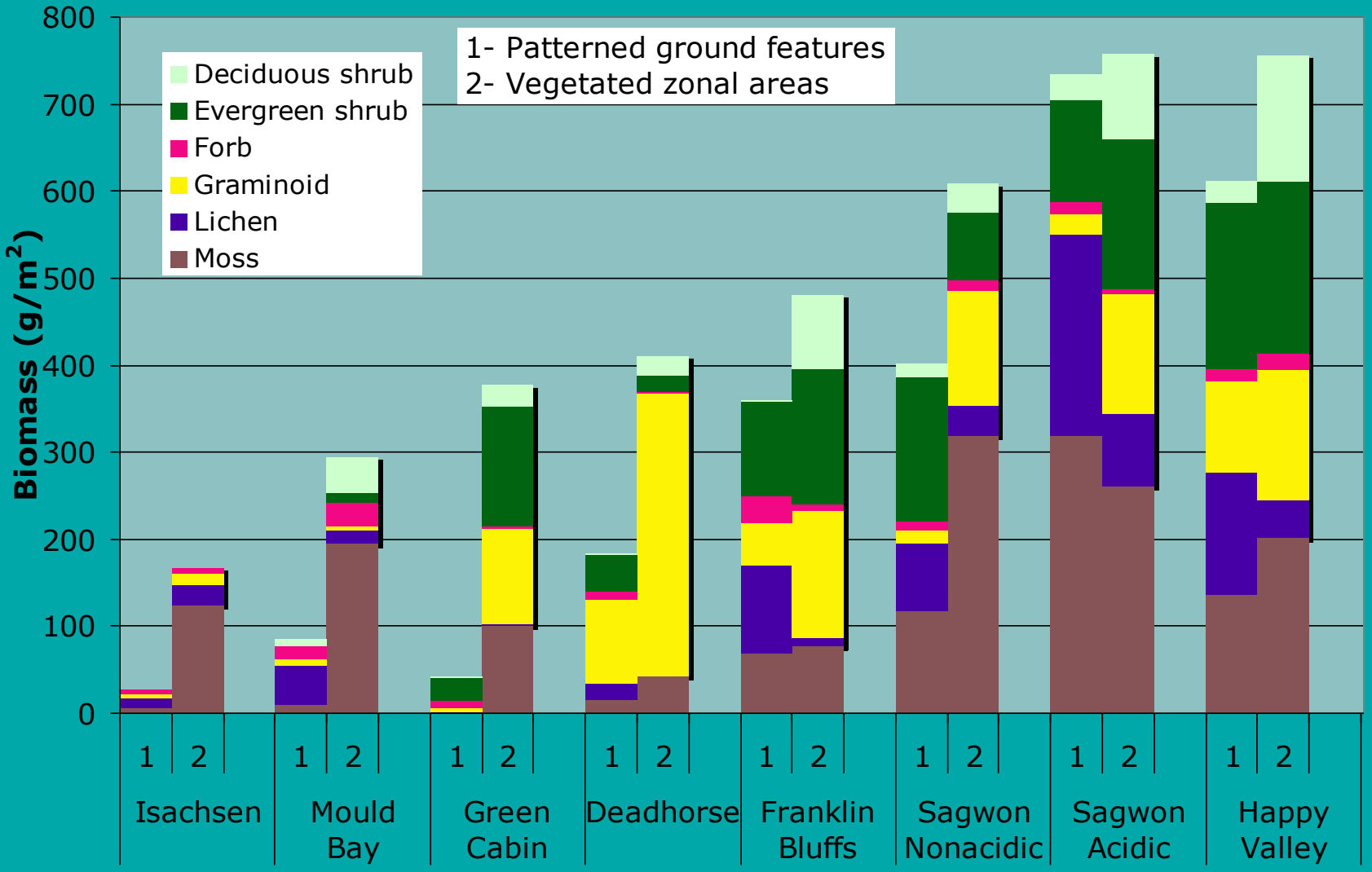
- aboveground biomass harvests

- handheld NDVI and LAI along transects

Patterned ground features (frost circles) along the NAAT (NSF Biocomplexity)

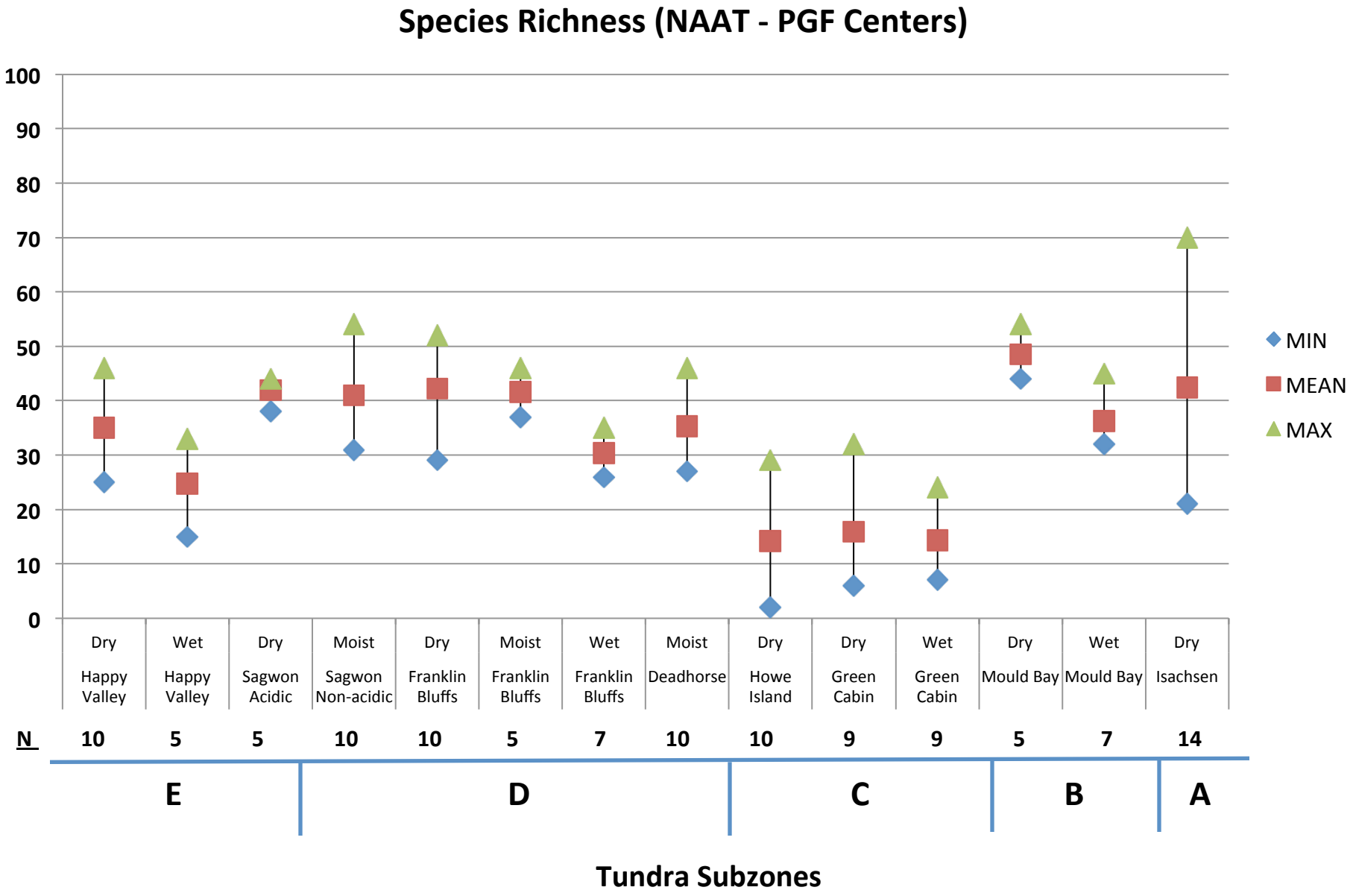


(photo D.A. Walker)



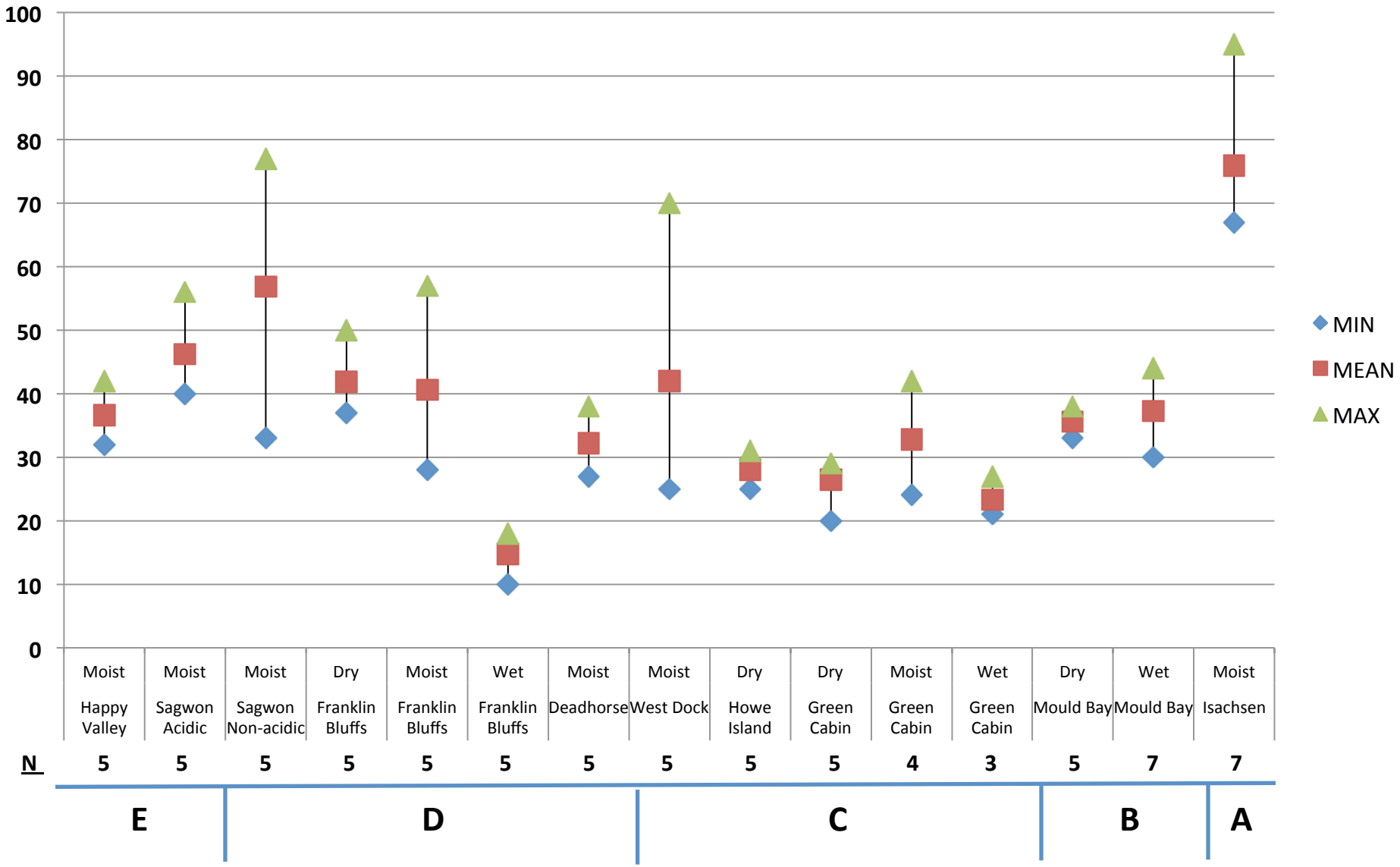
Data represented is the means of 5, 20 x 50 cm plots in each vegetation type

(Walker et al. 2008)



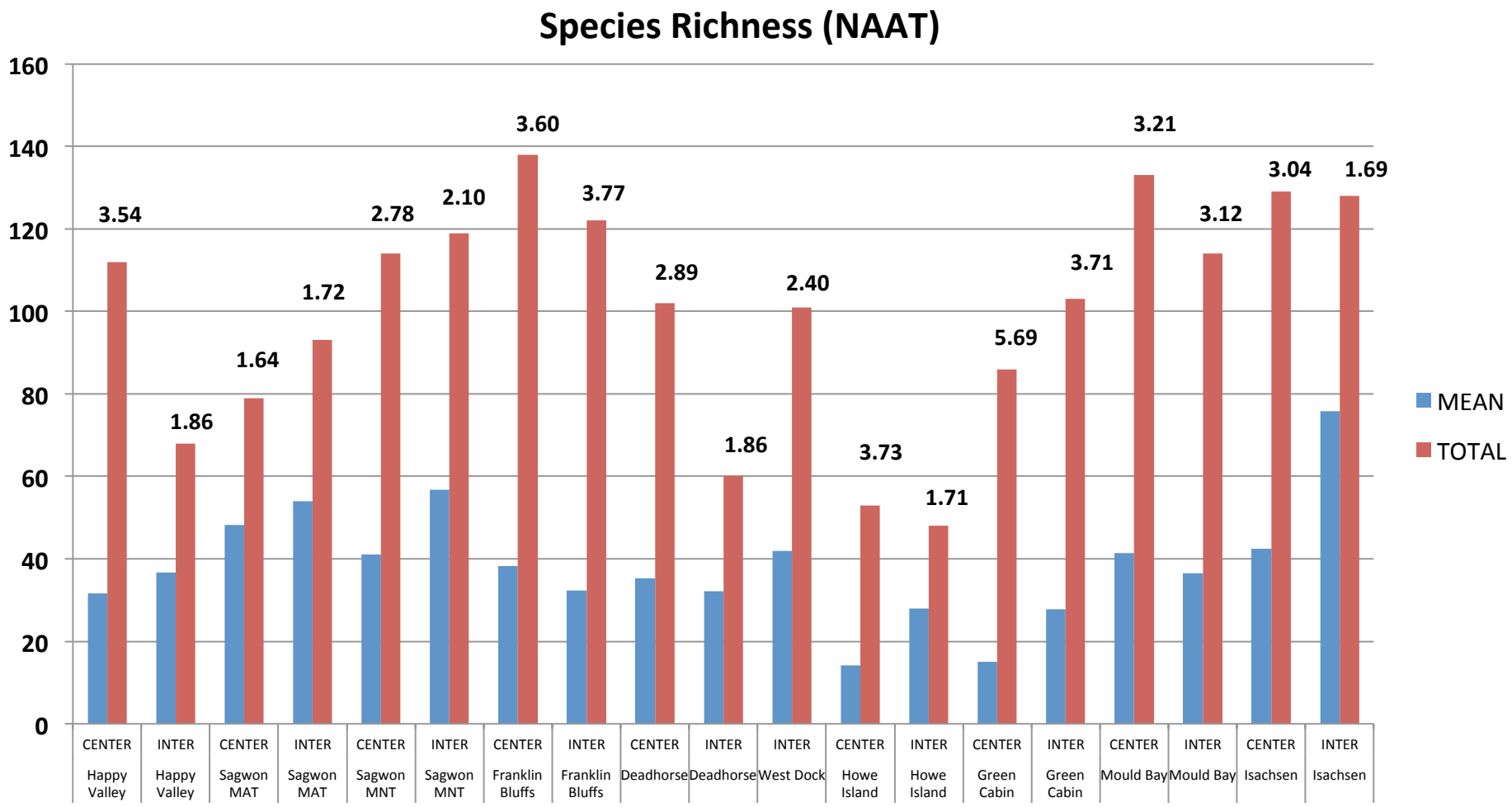
- Species richness relatively consistent along latitudinal transect (lower in Subzone C)
- Generally consistent among moisture regimes (slightly lower on Wet plots)

Species Richness (NAAT - Between PGFs)



Tundra Subzones

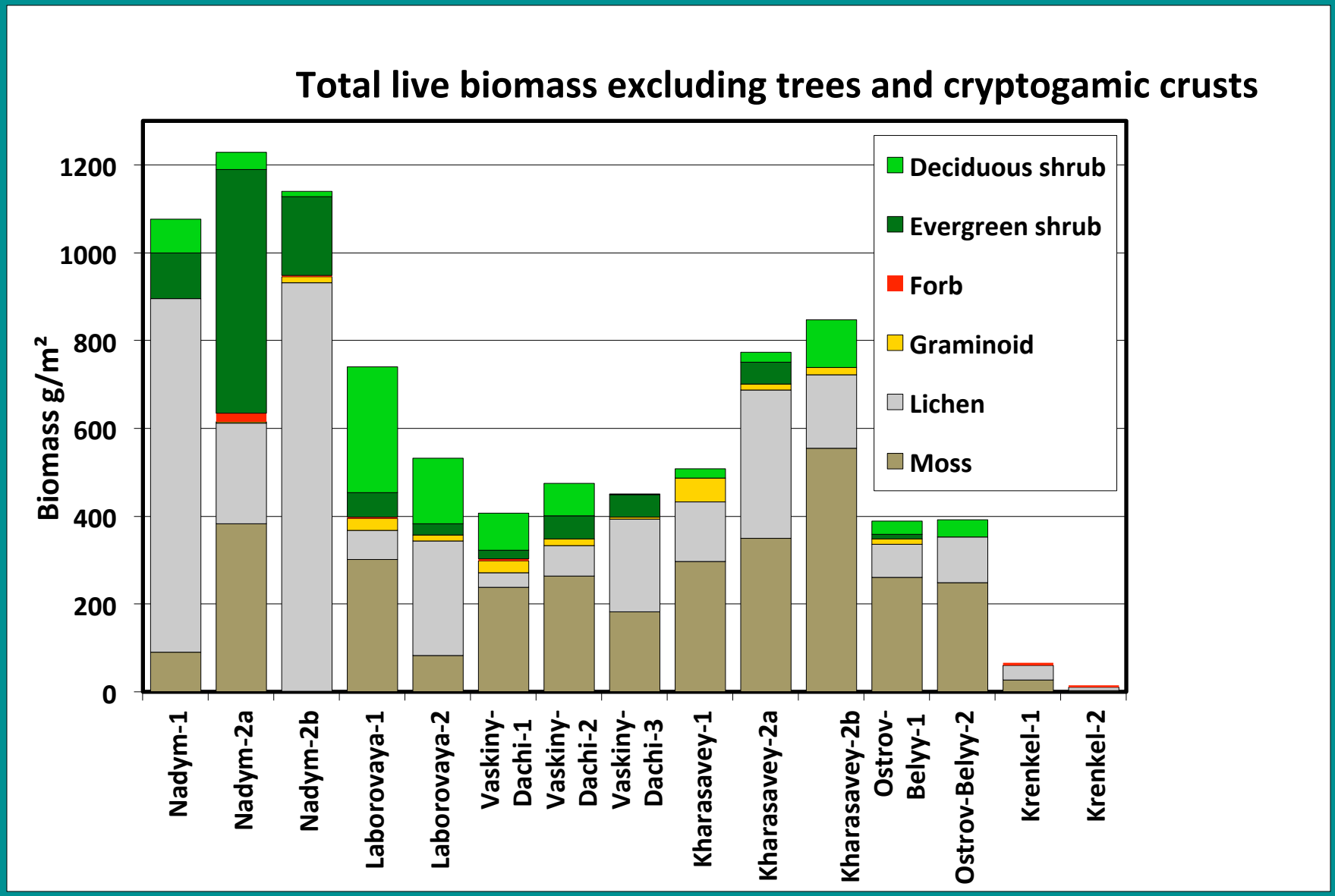
- Species richness generally consistent among patterned ground positions (slightly greater density between PGFs)
- Species richness relatively consistent along latitudinal transect (highest in Subzone A)



- Sampling across moisture results in average multiplication of species richness by **2.85** (i.e. ~tripling of richness)
- Sampling across PGF positions multiplies species richness on average by **1.34** (i.e. 34% increase in richness)
- Sampling across latitudinal gradient multiplies species richness by **4.36** (i.e. >quadrupling of richness)

Mean species richness by PGF position within location:	**100**
Mean species richness by location:	**134**
Total species richness for entire gradient:	**584**

Aboveground biomass by plant functional type (Walker et al. 2012)



SOUTH → NORTH

Temporal Dynamics - Arctic “Greening”

Normalized Difference Vegetation Index (NDVI)

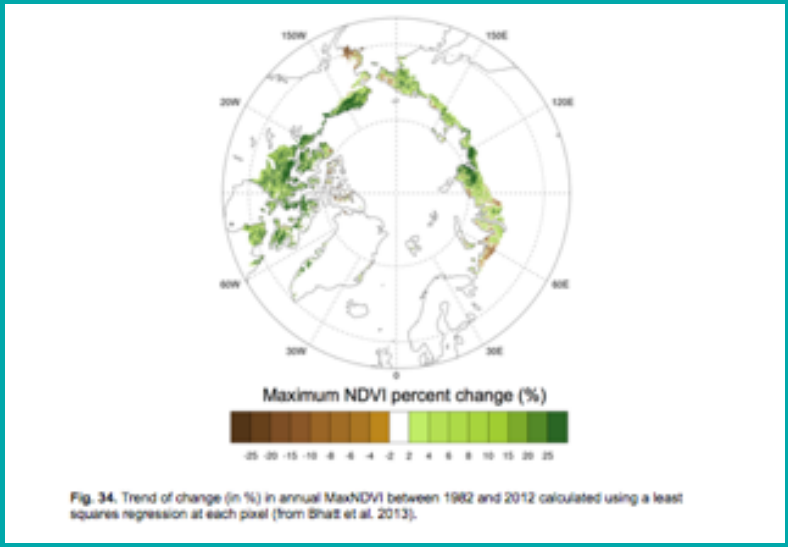
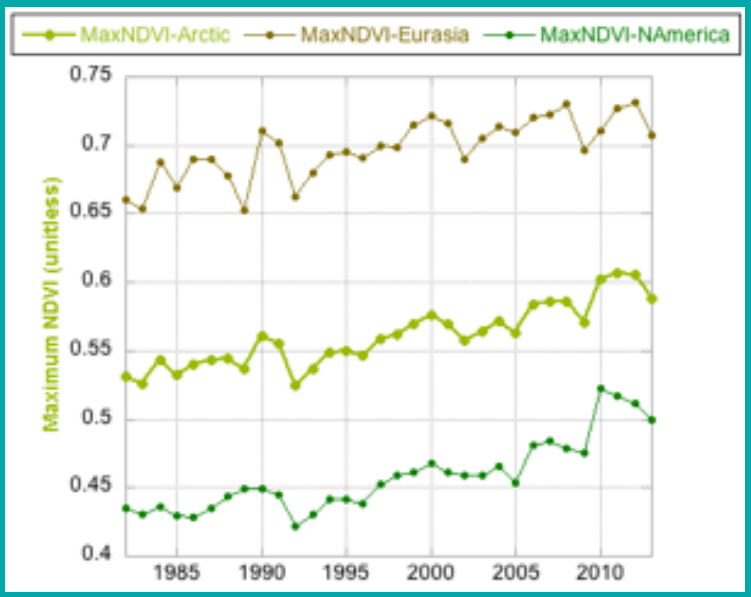
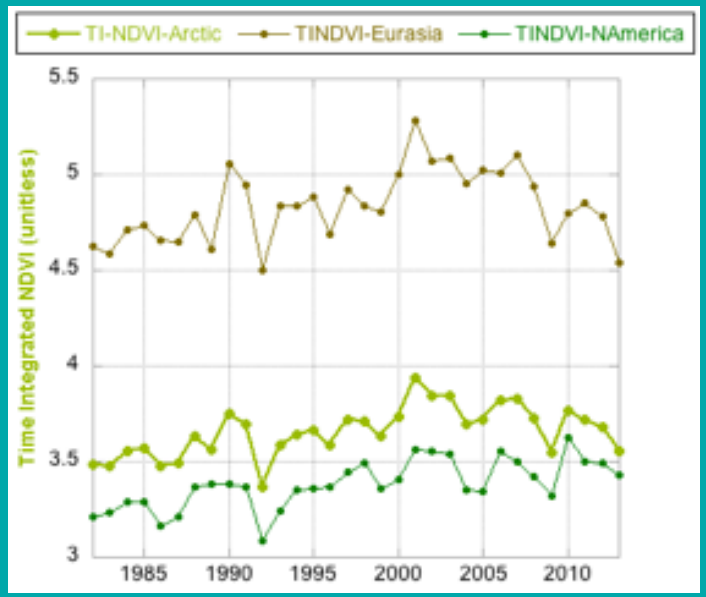


Fig. 34. Trend of change (in %) in annual MaxNDVI between 1982 and 2012 calculated using a least squares regression at each pixel (from Bhatt et al. 2013).

MaxNDVI
(peak greenness)

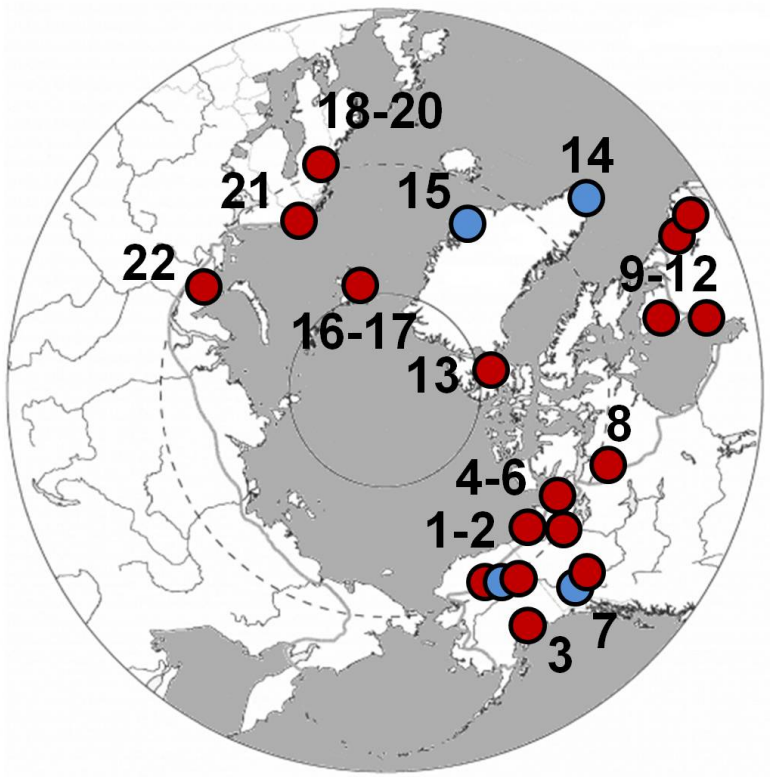


TI-NDVI
(temporally integrated greenness)



Bhatt et al. 2013 (Remote Sensing)

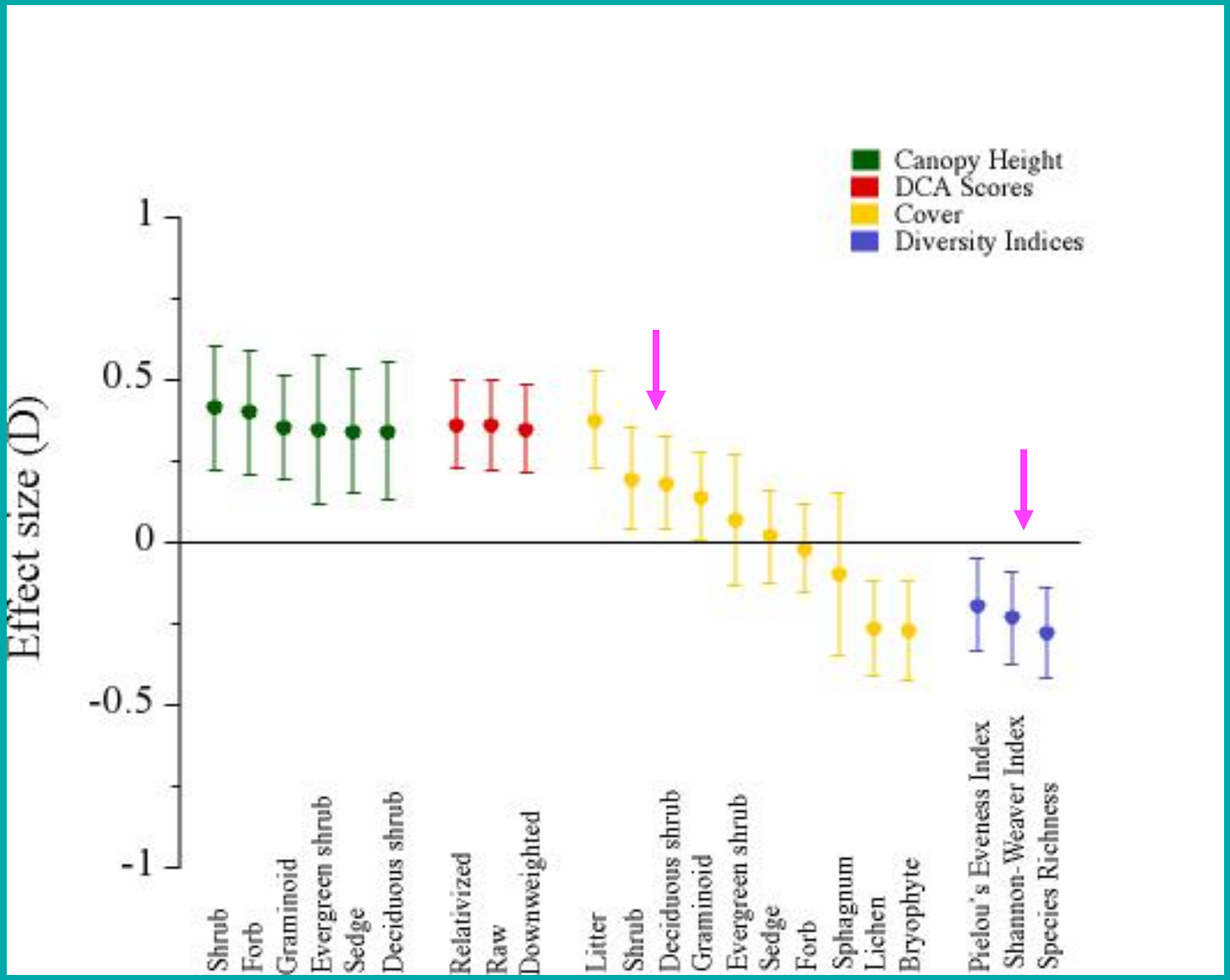
Studies of shrub expansion

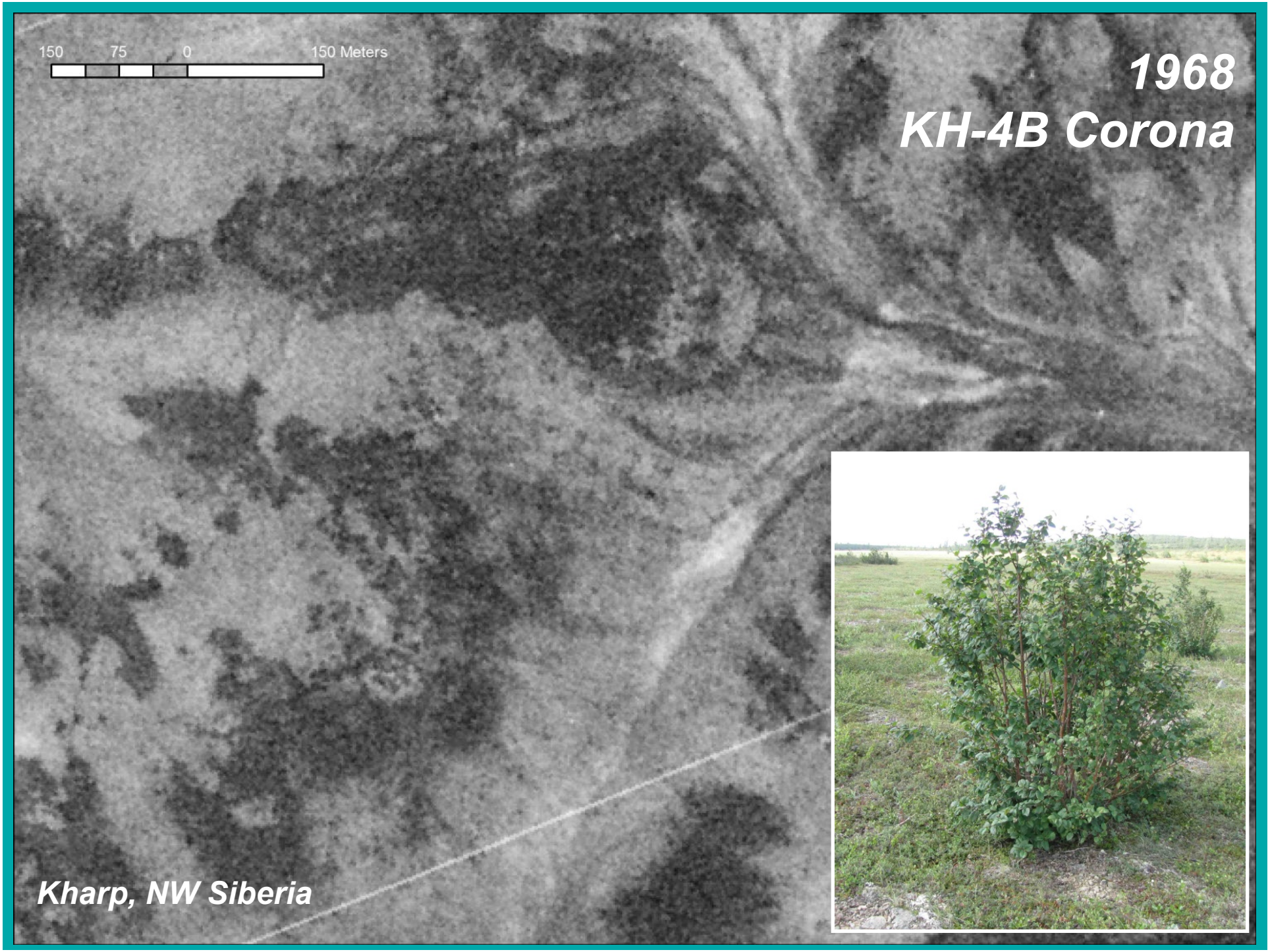


- Observations of increasing shrubs
- Observations of stable shrub populations

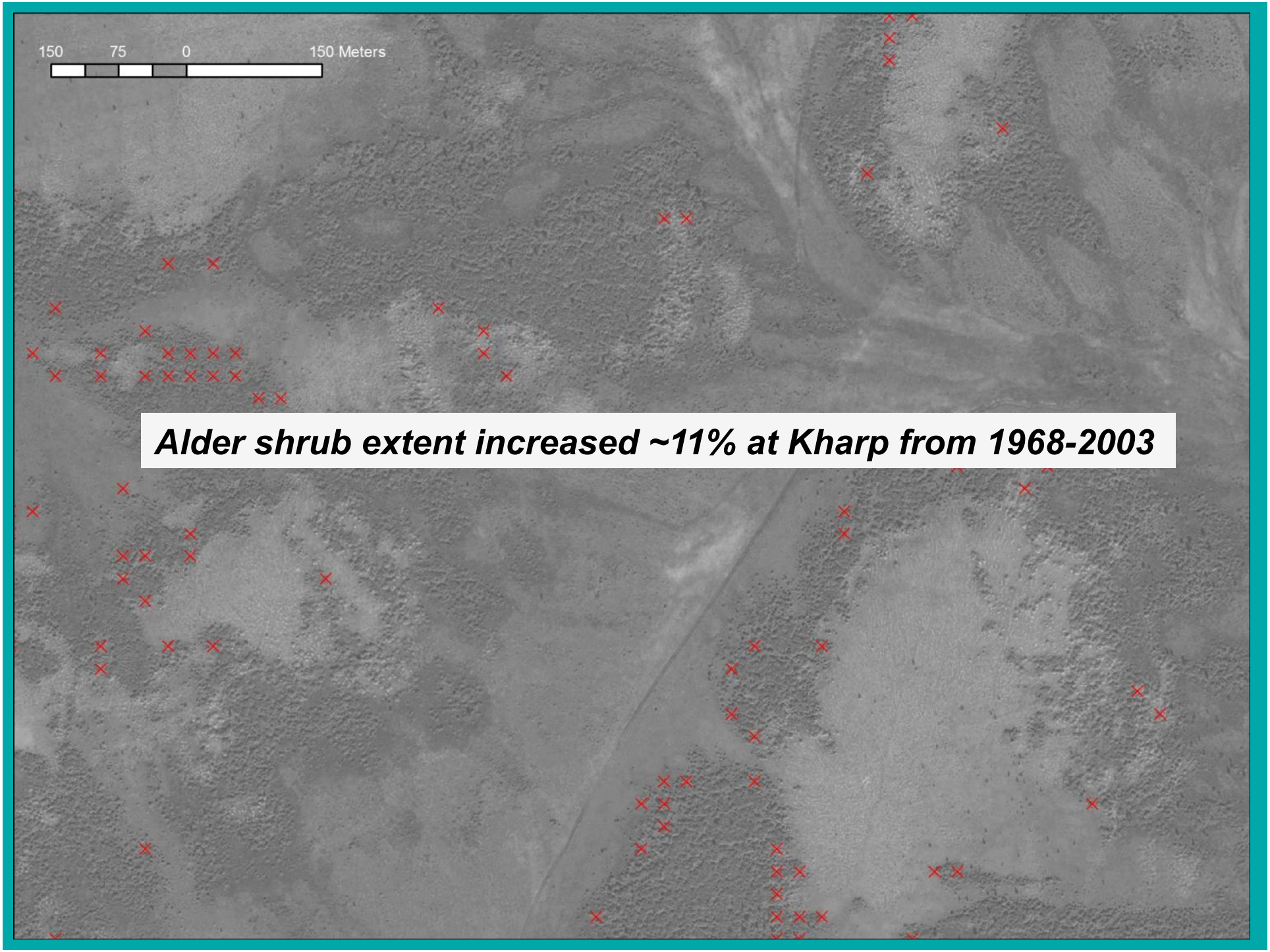
Myers-Smith *et al.* 2011, ERL

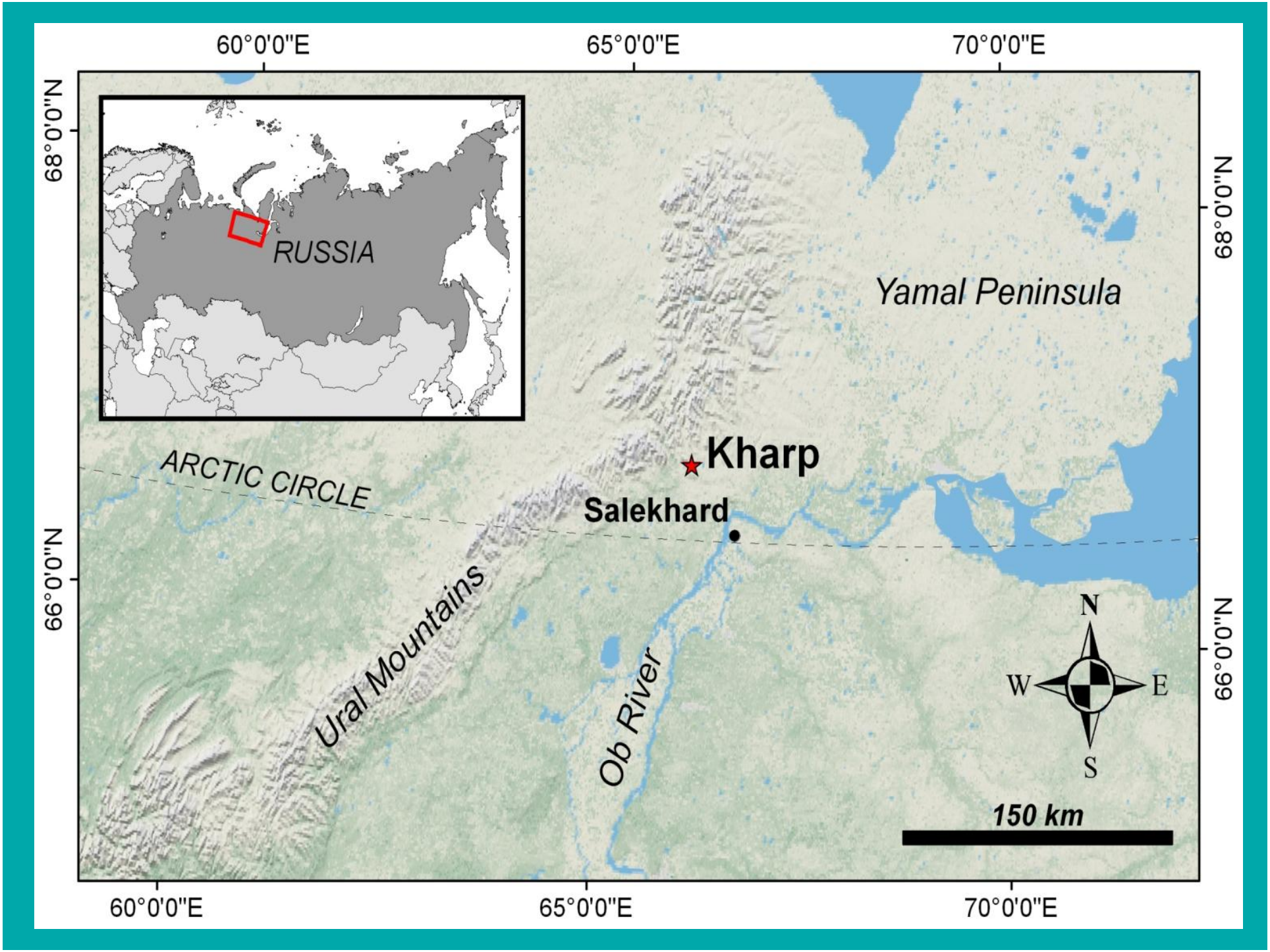
Meta-analysis of ITEX field data (Walker et al. 2006)




150 75 0 150 Meters
1968
KH-4B Corona
Kharp, NW Siberia

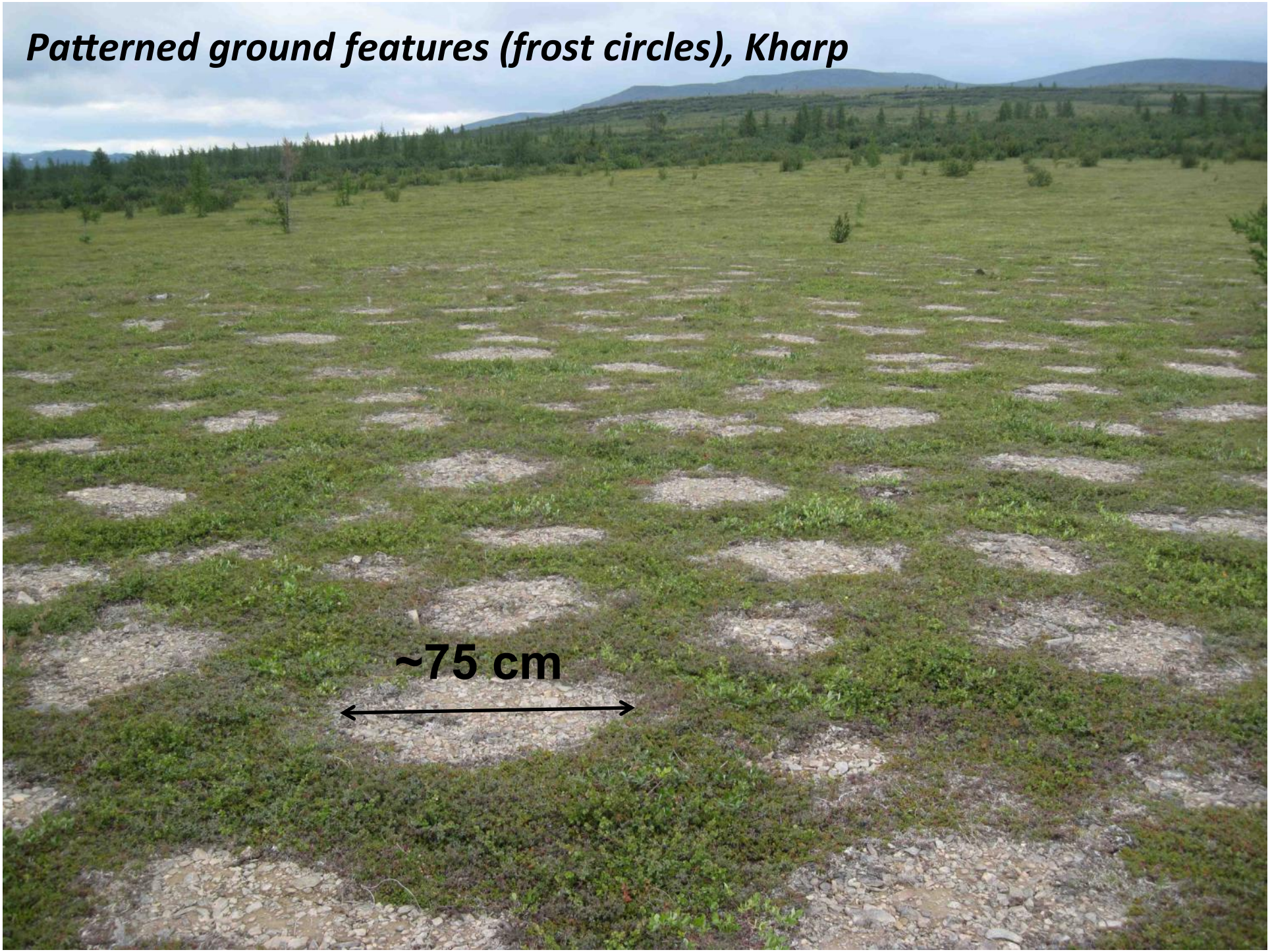

150 75 0 150 Meters
2003
Quickbird
Kharp, NW Siberia


150 75 0 150 Meters
Alder shrub extent increased ~11% at Kharp from 1968-2003


60°0'0"E
65°0'0"E
70°0'0"E
68°0'0"N
66°0'0"N
RUSSIA
Yamal Peninsula
Kharp
Salekhard
ARCTIC CIRCLE
Ural Mountains
Ob River
N
W
E
S
150 km

We can get there… all we need is one of these things.

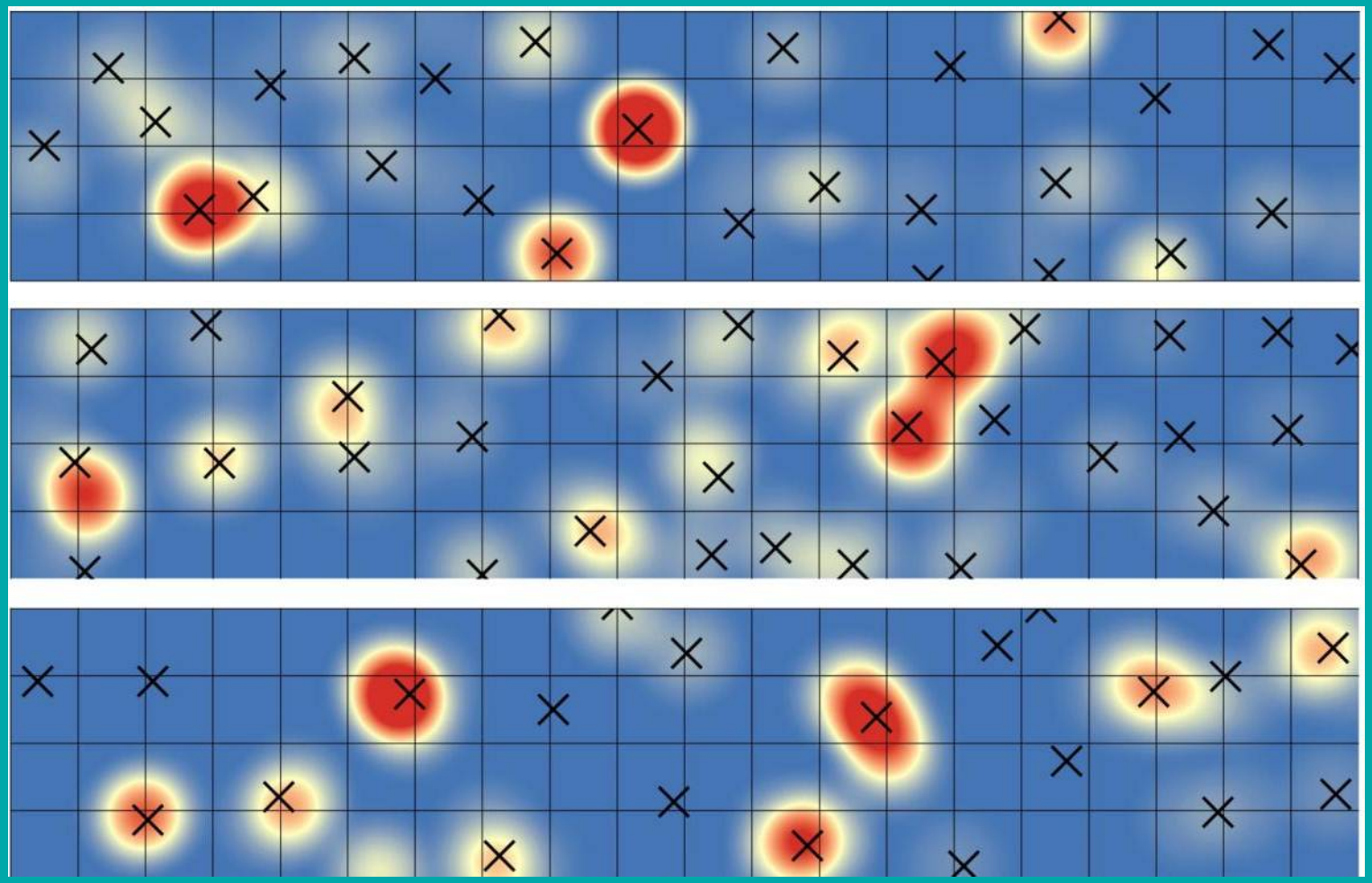
(photo H. Epstein)


Patterned ground features (frost circles), Kharp
~75 cm

Young alders growing exclusively on patterned-ground features

Field observations led us to hypothesize that alder recruitment is facilitated by patterned ground.

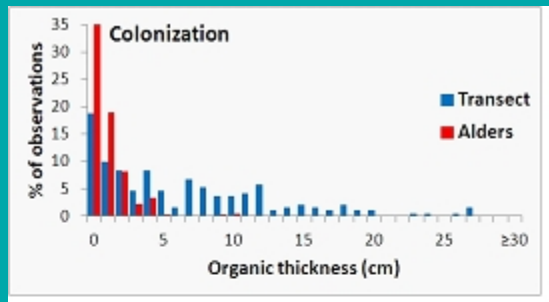
Alders almost exclusively on non-sorted circles

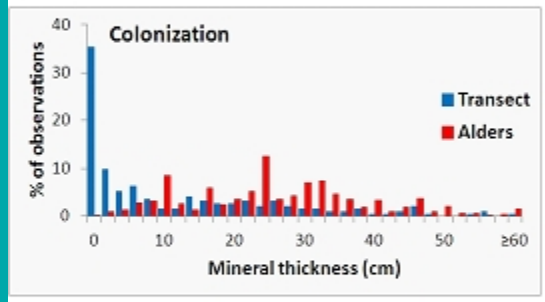


Frost et al. 2013 (Environmental Research Letters)

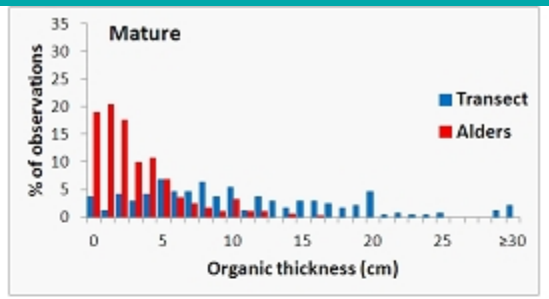
Alder Expansion Chronosequence

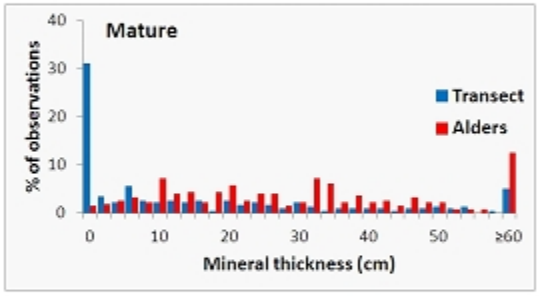
Alder Colonization



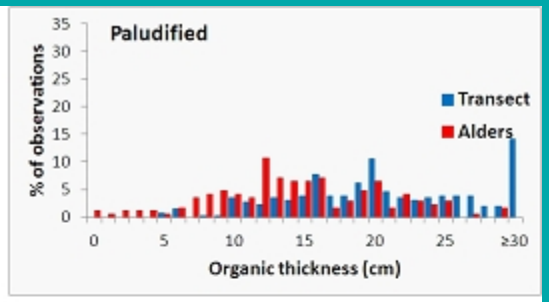


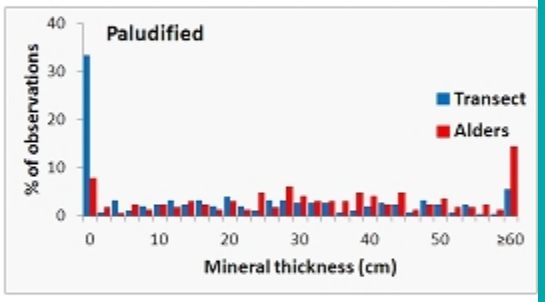
Mature Alder





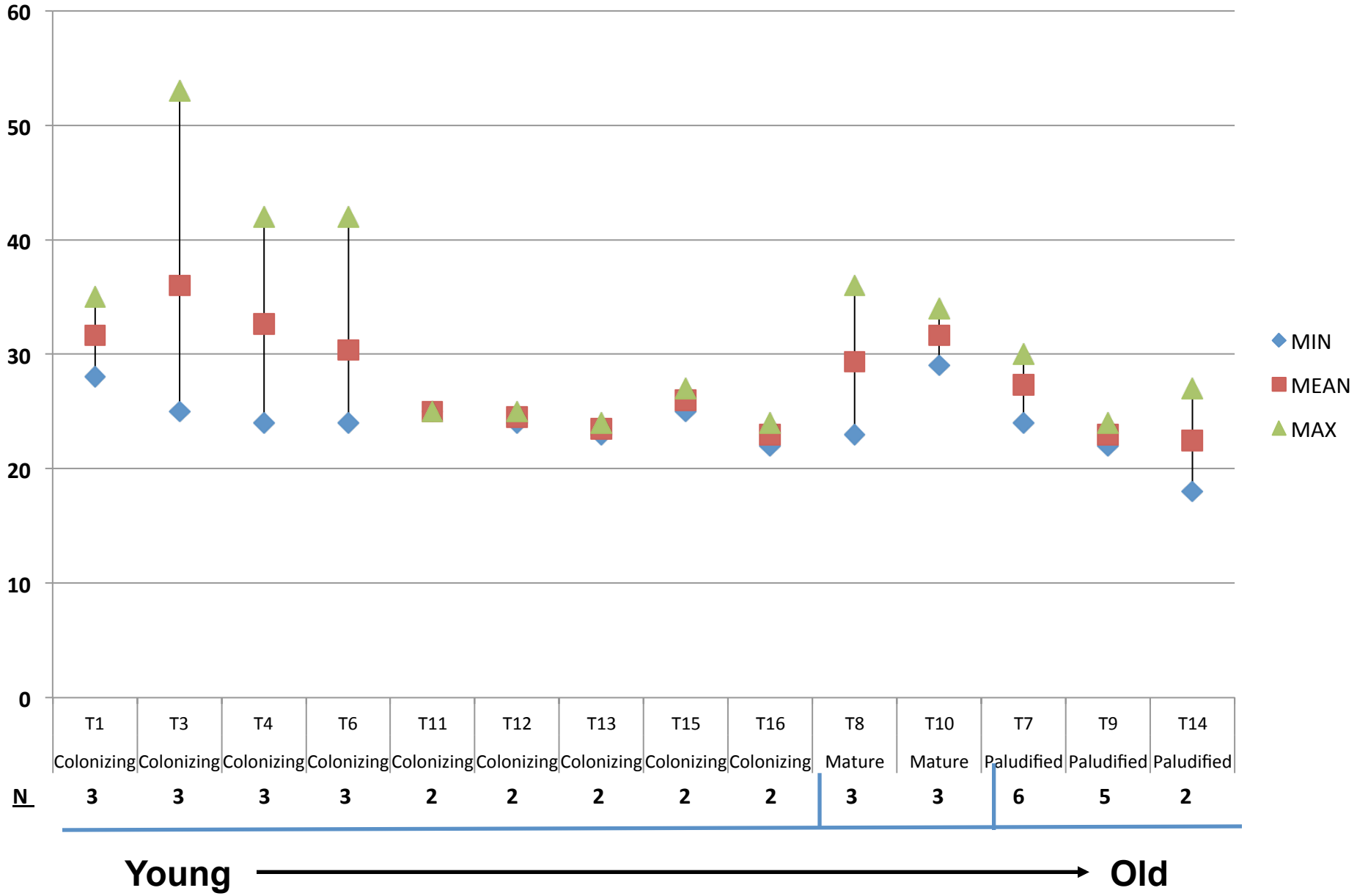
Paludified Alder Stand

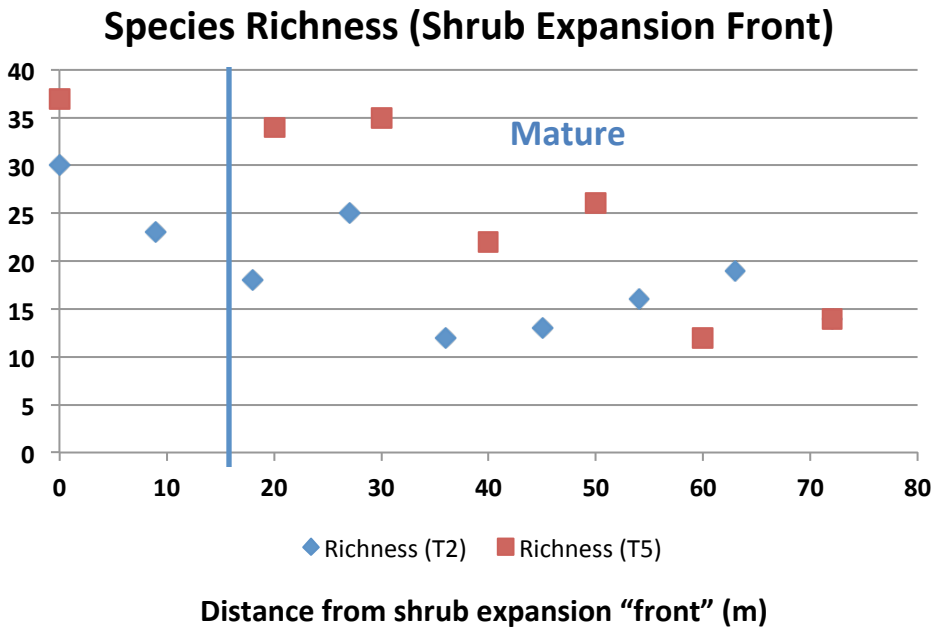




- Even mature alders were on remnants of frost circles
- Alder colonization led to a thickening of the organic layer
- Ultimately, lowland alder stands became mossy and acidic (paludified)

Species Richness (Shrub Expansion)





Leaf Area Index (LAI) profiles along chronosequences

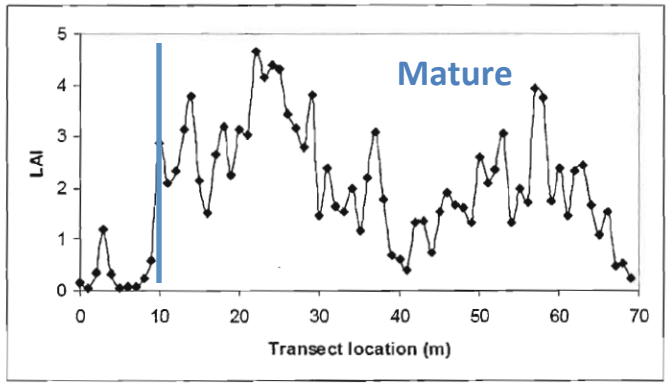


Figure 21. Scatterplot of LAI measurements along transect K-T02. Alder-free tundra extends from approximately 0-5 m; colonization zone ~5-10 m; mature shrubland 10-70 m.

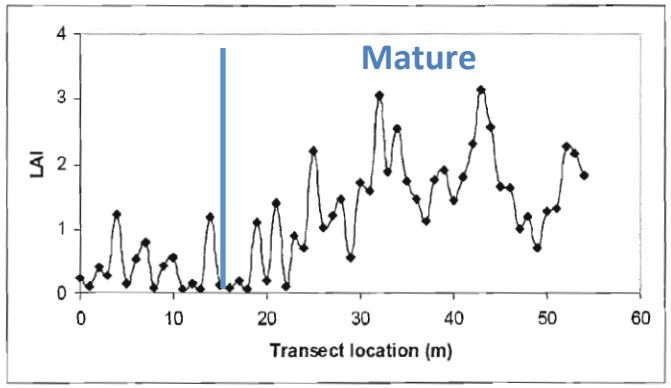
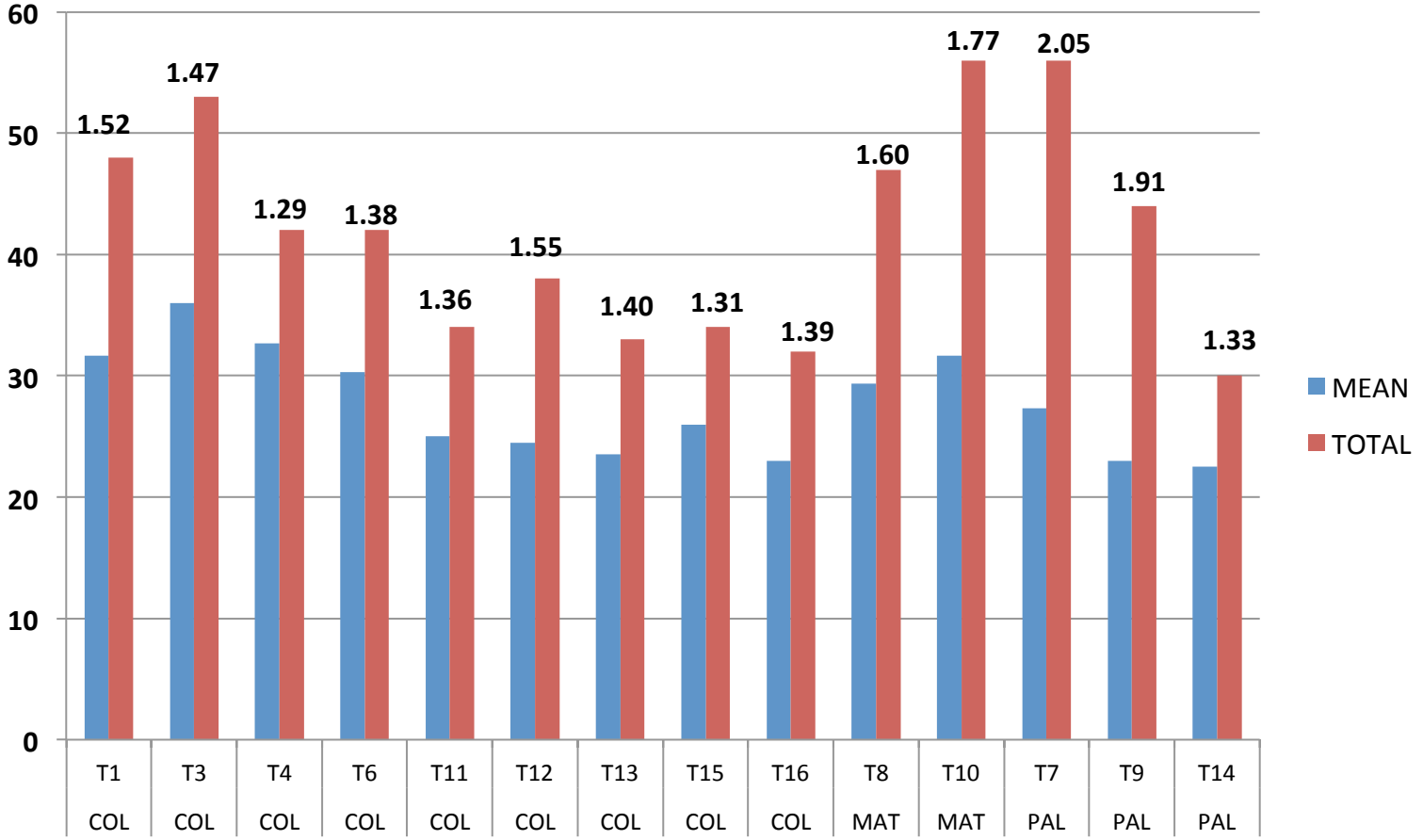


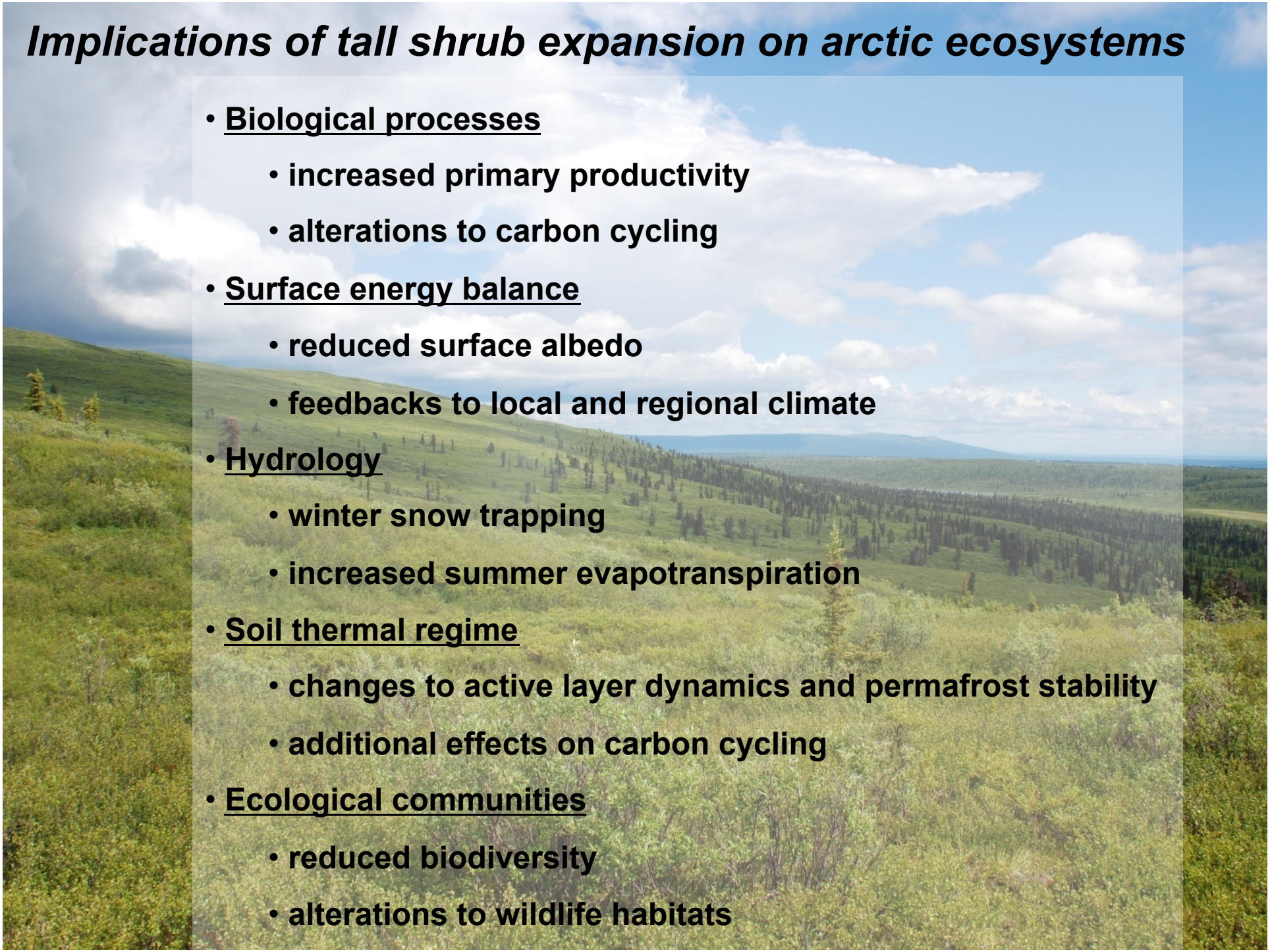
Figure 22. Scatterplot of LAI measurements along transect K-T05. Alder-free tundra extends from approximately 0-5 m; colonization zone ~5-15 m; mature shrubland 15-55 m.

Species Richness (Shrub Expansion)



- Multiple plots within transects results in average multiplication of species richness by **1.52**
- Sampling across transects multiplies species richness on average by **2.67**
- Sampling across shrub expansion stages multiplies species richness by **2.40**

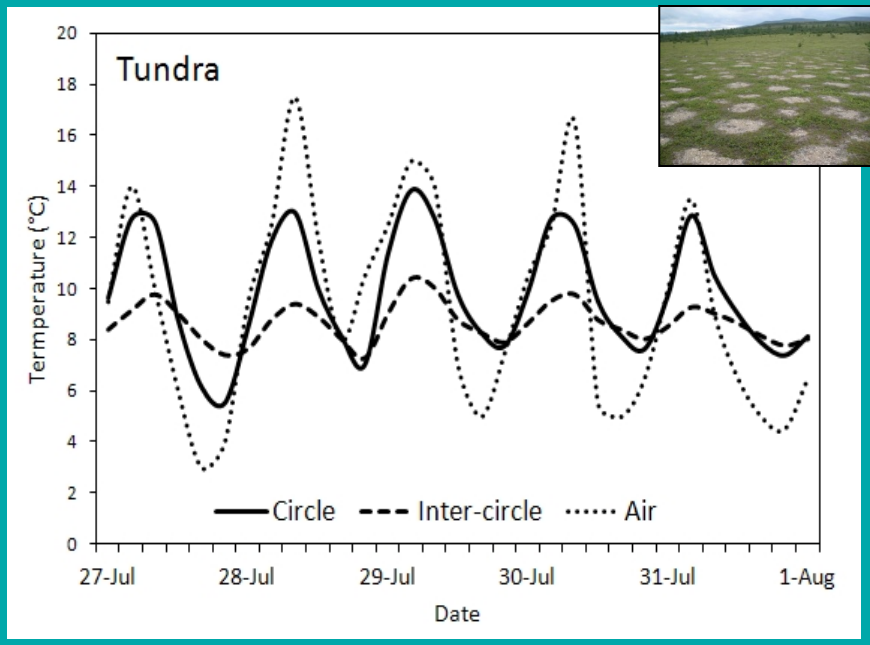
Mean species richness by transect: **42**
Mean species richness by stage: **83** (COL-107, MAT-71, PAL-73)
Total species richness for entire gradient: **200**

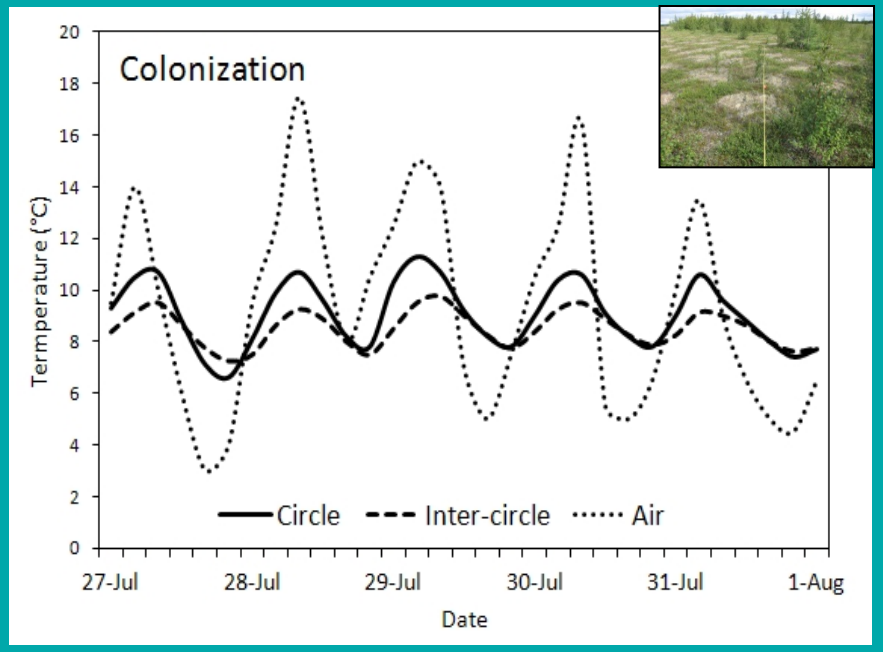


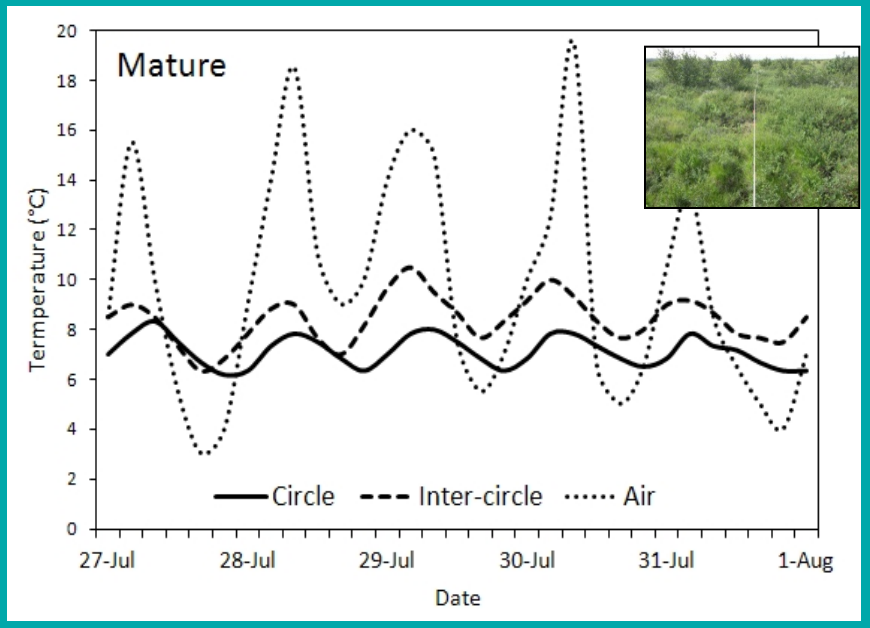
Implications of tall shrub expansion on arctic ecosystems

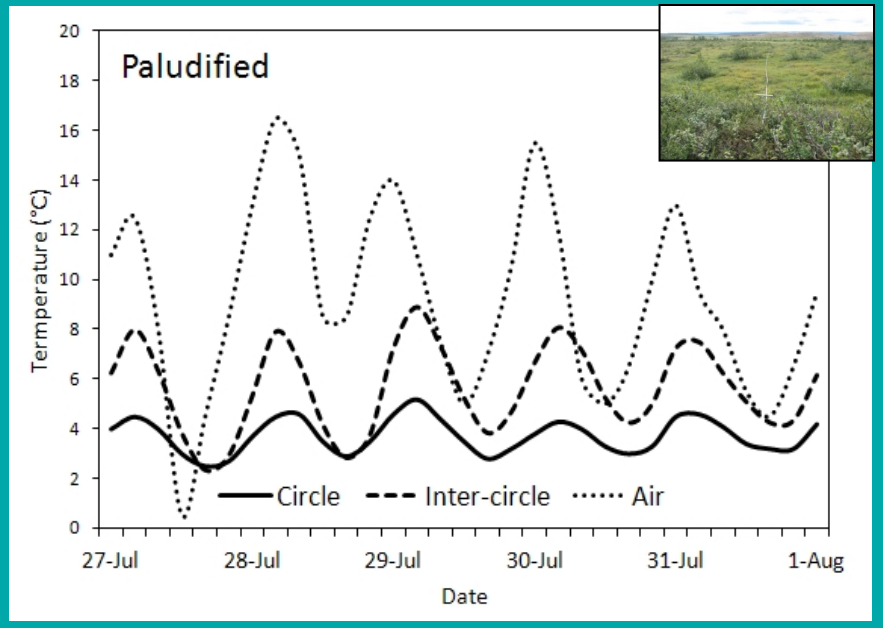
- **Biological processes**
  - **increased primary productivity**
  - **alterations to carbon cycling**
- **Surface energy balance**
  - **reduced surface albedo**
  - **feedbacks to local and regional climate**
- **Hydrology**
  - **winter snow trapping**
  - **increased summer evapotranspiration**
- **Soil thermal regime**
  - **changes to active layer dynamics and permafrost stability**
  - **additional effects on carbon cycling**
- **Ecological communities**
  - **reduced biodiversity**
  - **alterations to wildlife habitats**

Summer soil temperature changes throughout shrubland succession



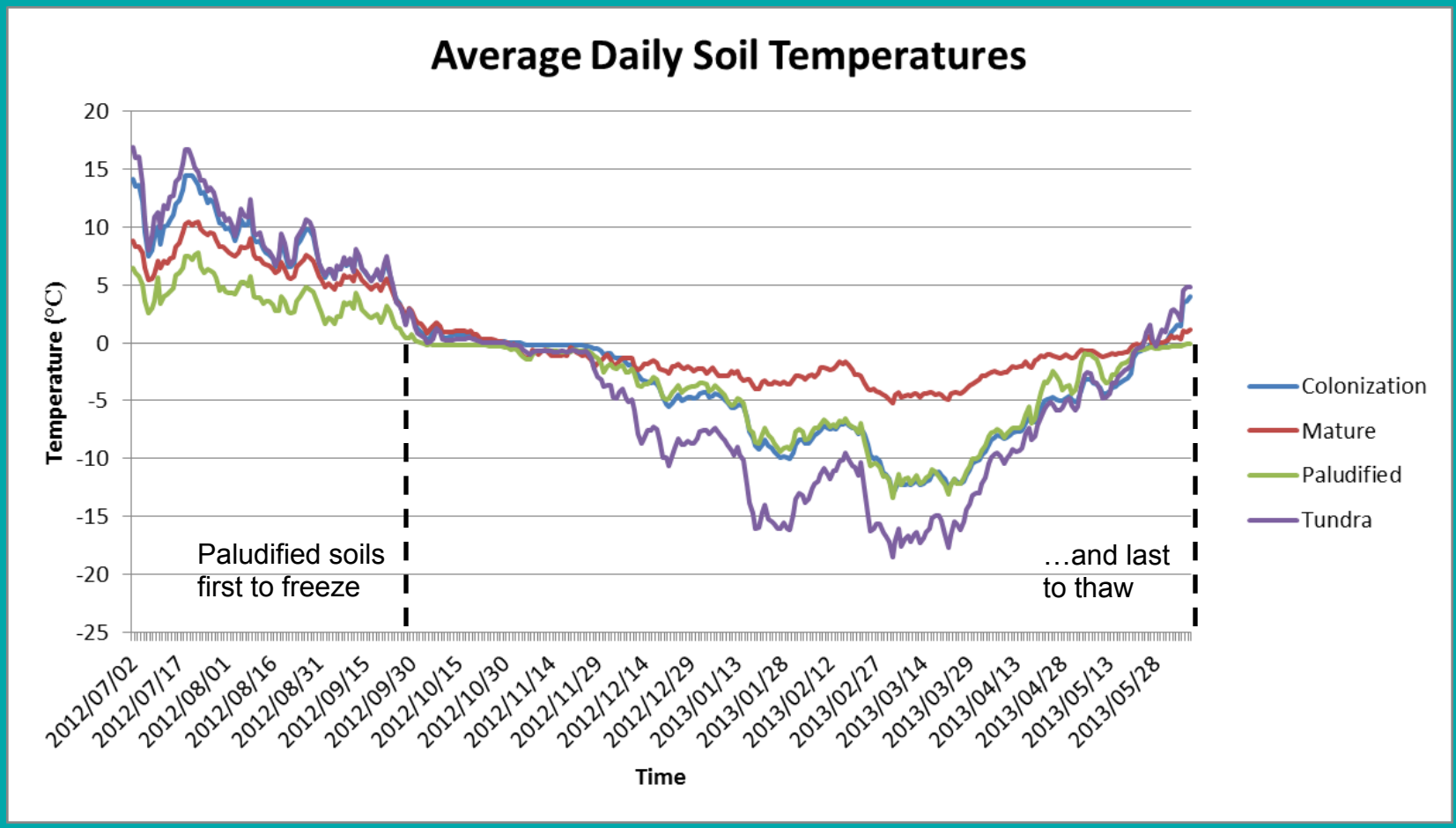






- 8 °C decrease in 5 cm depth soil temperature between uncolonized and paludified

Mean daily soil temperatures (5 cm depth) under frost circles / alders



- Bare circles up to ~10 °C warmer than soils under mature alders in summer.
- Bare circles up to ~12 °C colder than soils under mature alders in winter.

- **Shrub encroachment increases summer shading, increases organic layer depth, increases winter snow trapping**

Summary

1) Landscape scale heterogeneity in arctic tundra systems (e.g. patterned-ground features, soil moisture, soil texture) contributes substantively to biodiversity.

2) The full latitudinal arctic tundra gradient provides ~3-4 fold increase in biodiversity relative to single locations.

3) Shrub expansion in Low Arctic tundra likely reduces biodiversity (maybe by 30-60%) and also alters ecosystem functioning.

Questions/Next Steps

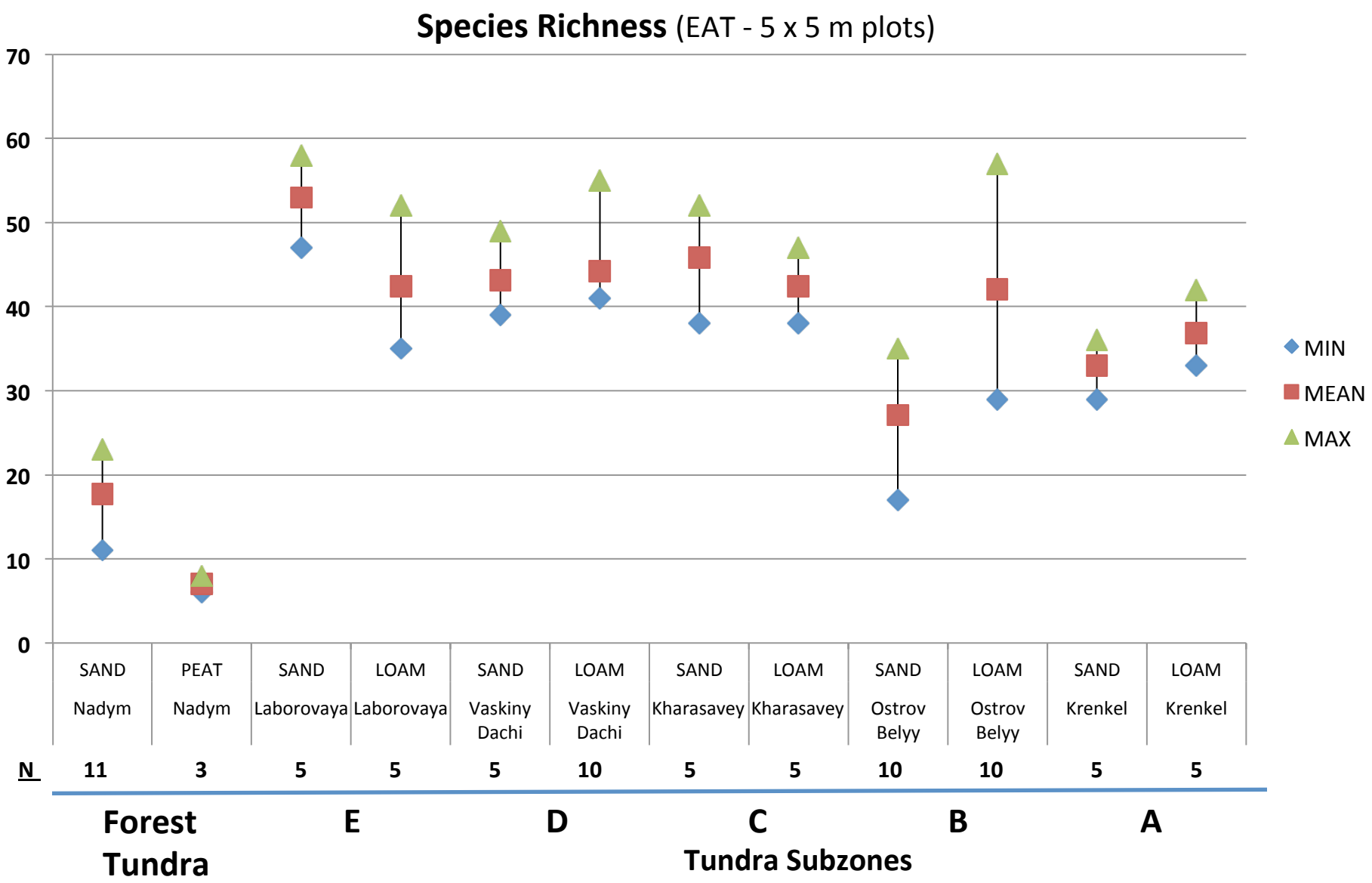
1) Have we adequately sampled to capture the full species richness?

2) How do other aspects of diversity (dominance, evenness, functional type richness) vary in space and time?

3) What species / functional types are added by landscape heterogeneity, removed by shrub expansion?

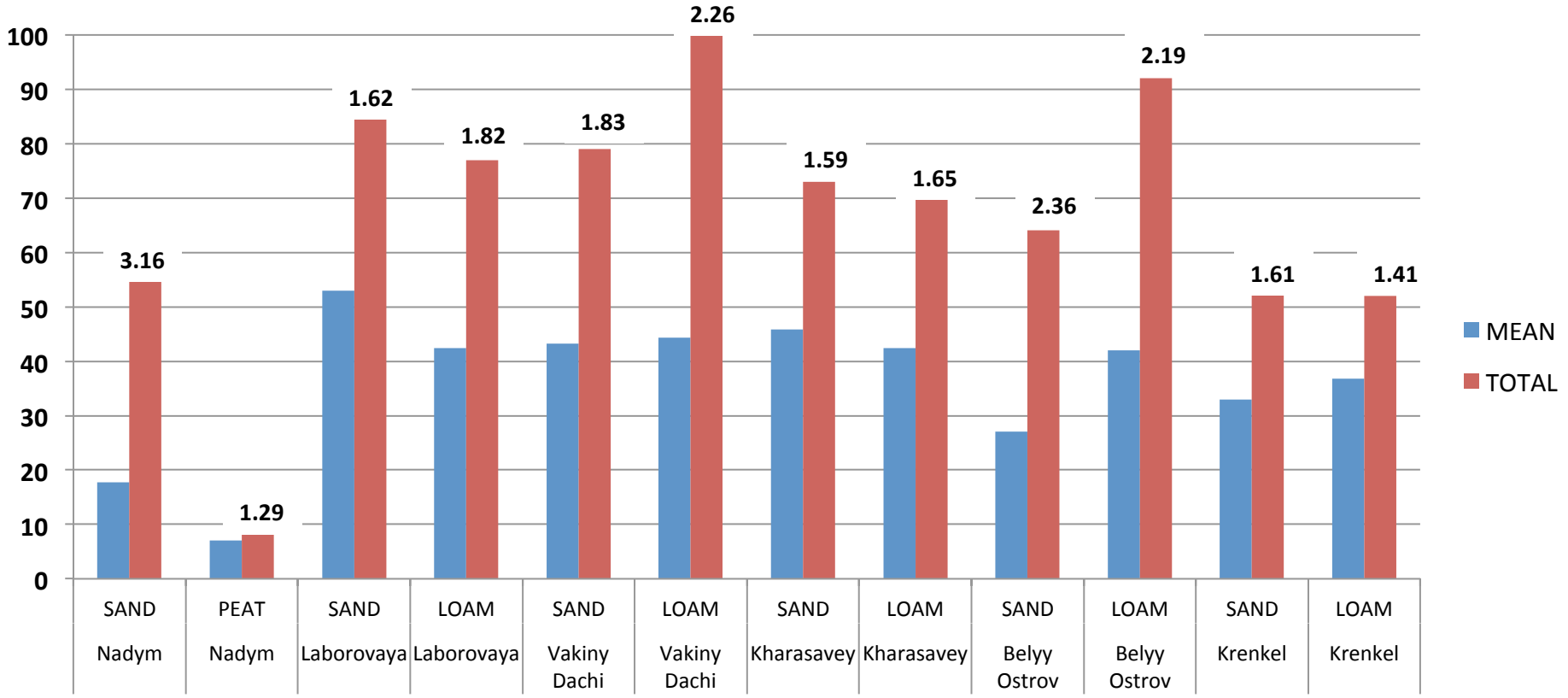
4) What components of diversity are contributing most to ecosystem functioning?

This work was funded by the NASA Land-Cover Land-Use Change (LCLUC) program, Grant Nos. NNG6GE00A, NNX09AK56G, NNX14AD906, and NSF Grant Nos. ARC-0531180 (part of the Synthesis of Arctic System Science initiative - Greening of the Arctic) and ARC-0902152 (part of the Changing Seasonality of Arctic Systems initiative)



- Species richness relatively consistent along latitudinal transect (lower in forest-tundra and in Subzones B and A)
- Generally consistent between Sand and Loam soils (higher on Loam soils in Subzones B and A)

Species Richness (EAT)

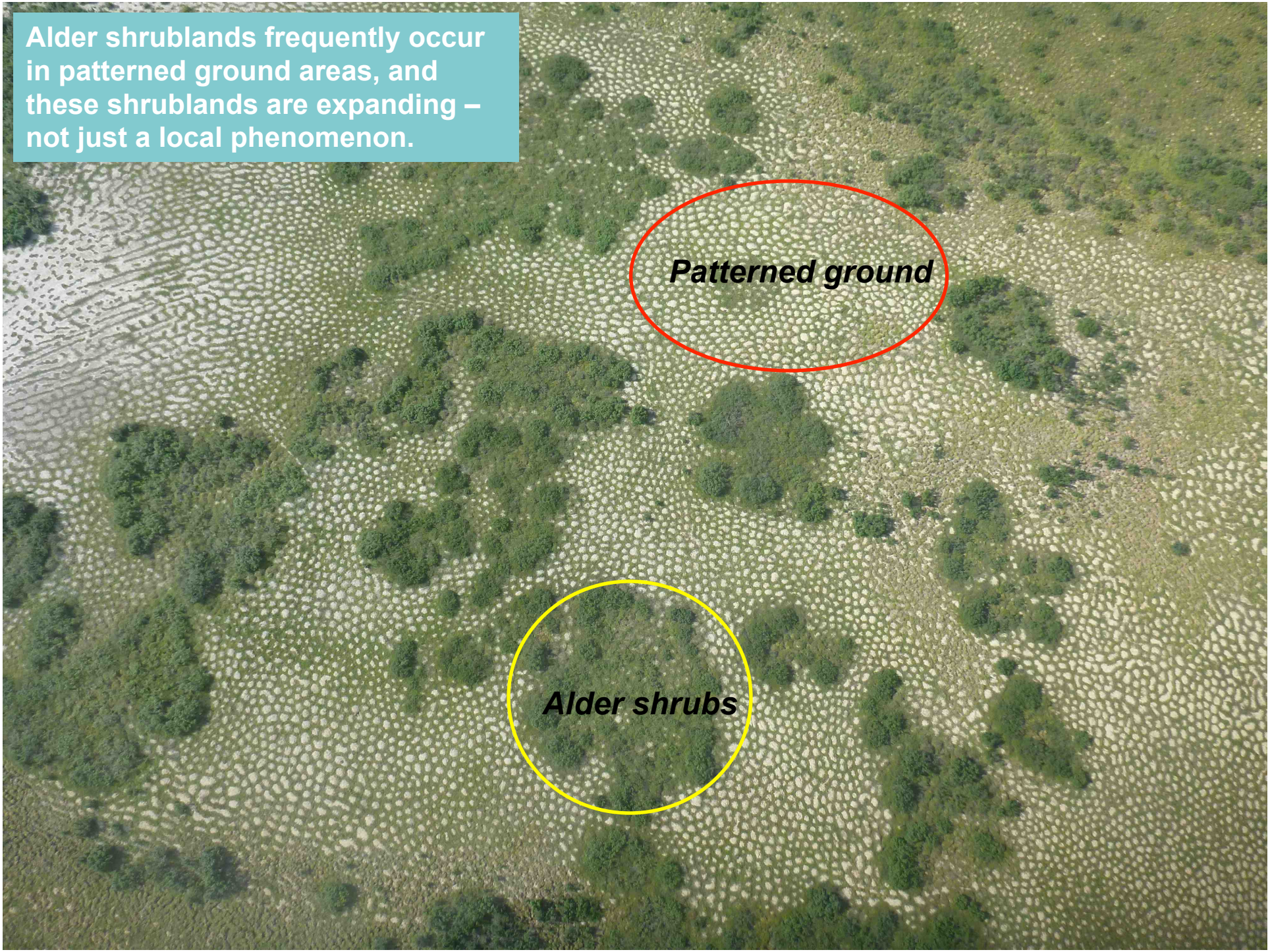


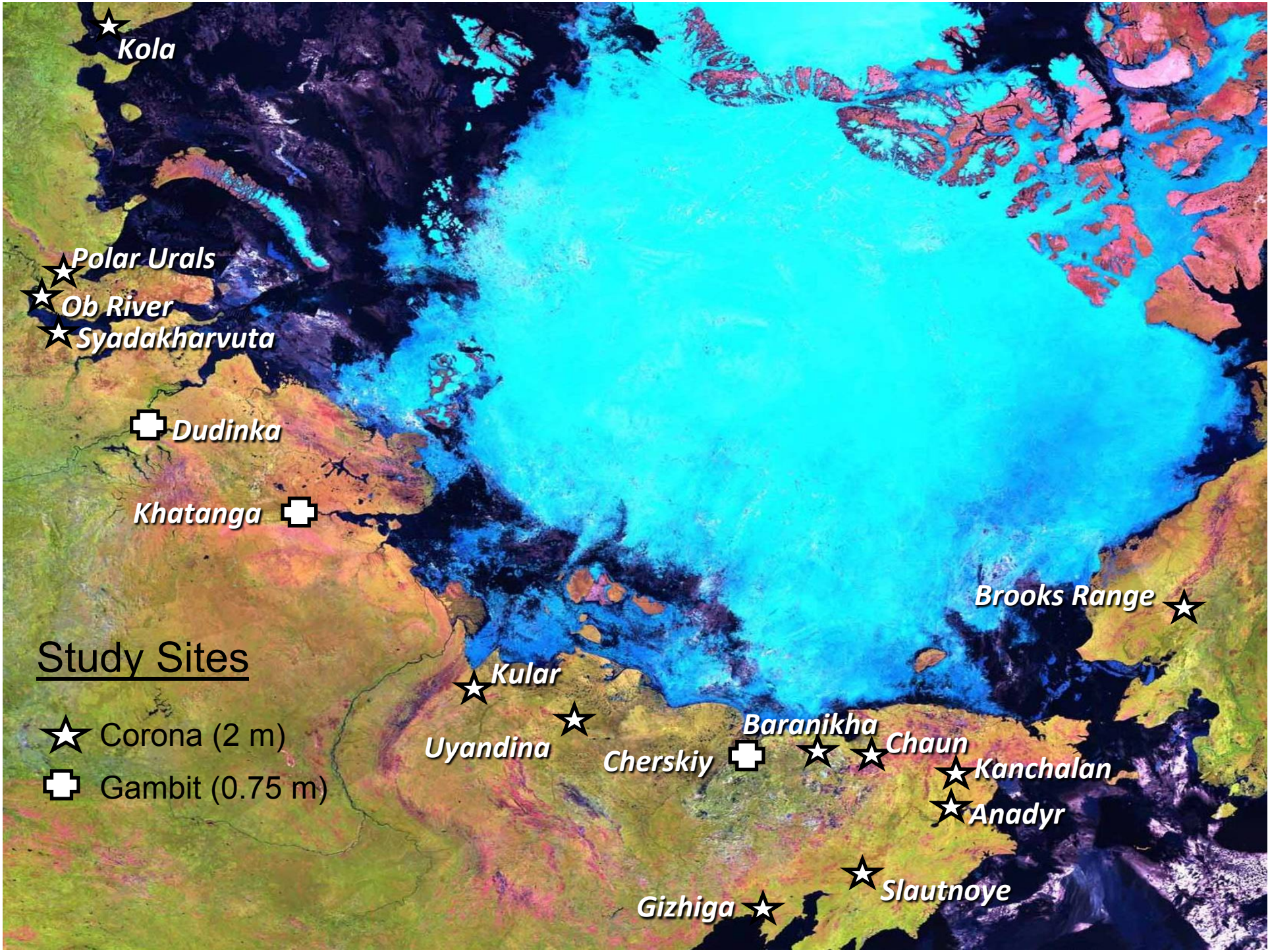
- Plot replicates result in average multiplication of species richness by **1.90** (i.e. ~doubling of richness)
- Sampling across textures multiplies species richness on average by **1.47** (i.e. 47% increase in richness)
- Sampling across latitudinal gradient multiplies species richness by **2.89** (i.e. ~tripling of richness)

Mean species richness by texture within location: **68**
Mean species richness by location: **97**
Total species richness for entire gradient: 281

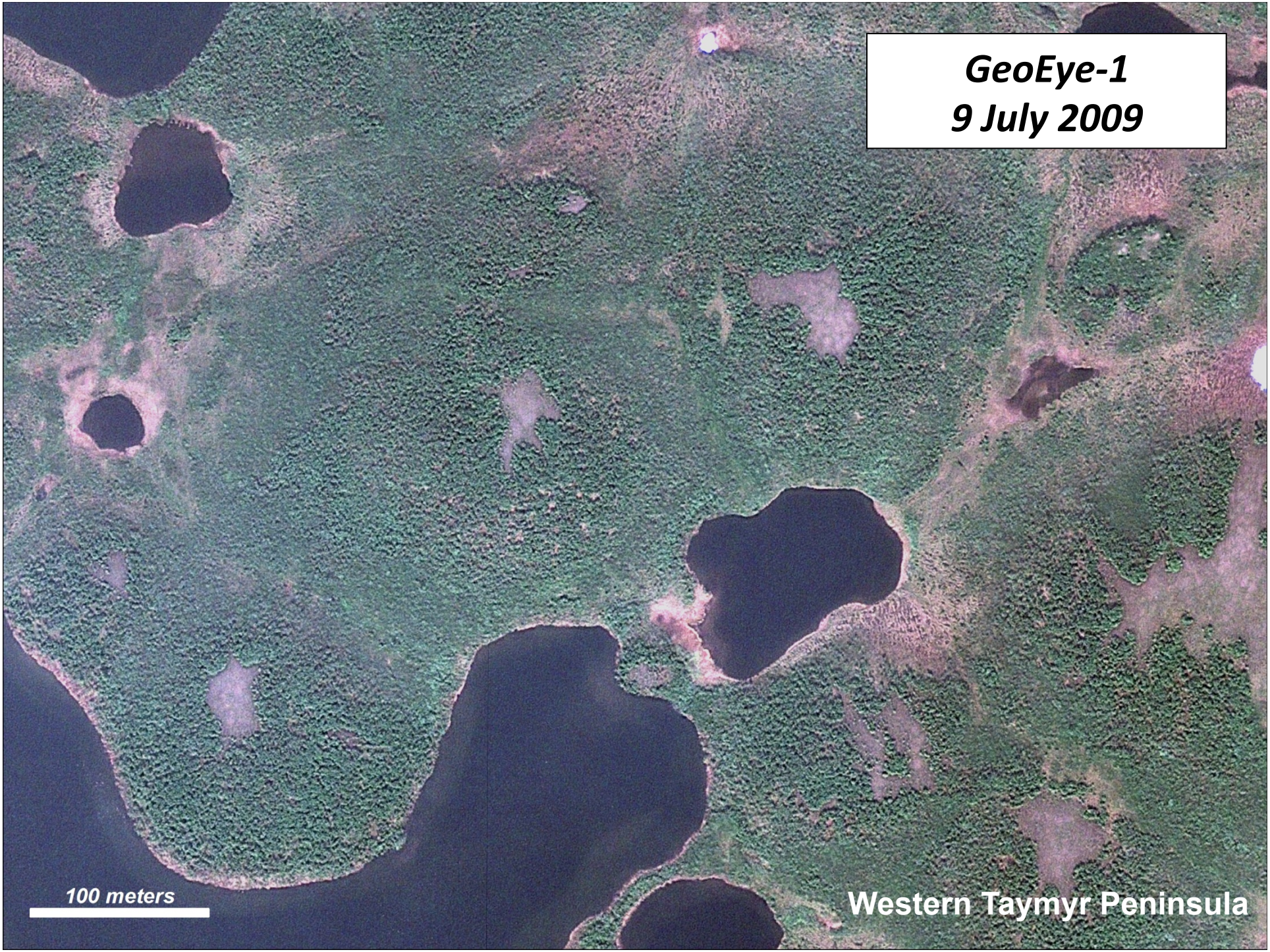
Changes in shrub cover, northern Alaska 1950-2003

Sturm, M., C. Racine, and K. Tape. 2001. Increasing shrub abundance in Arctic. Nature **411**:547-548.

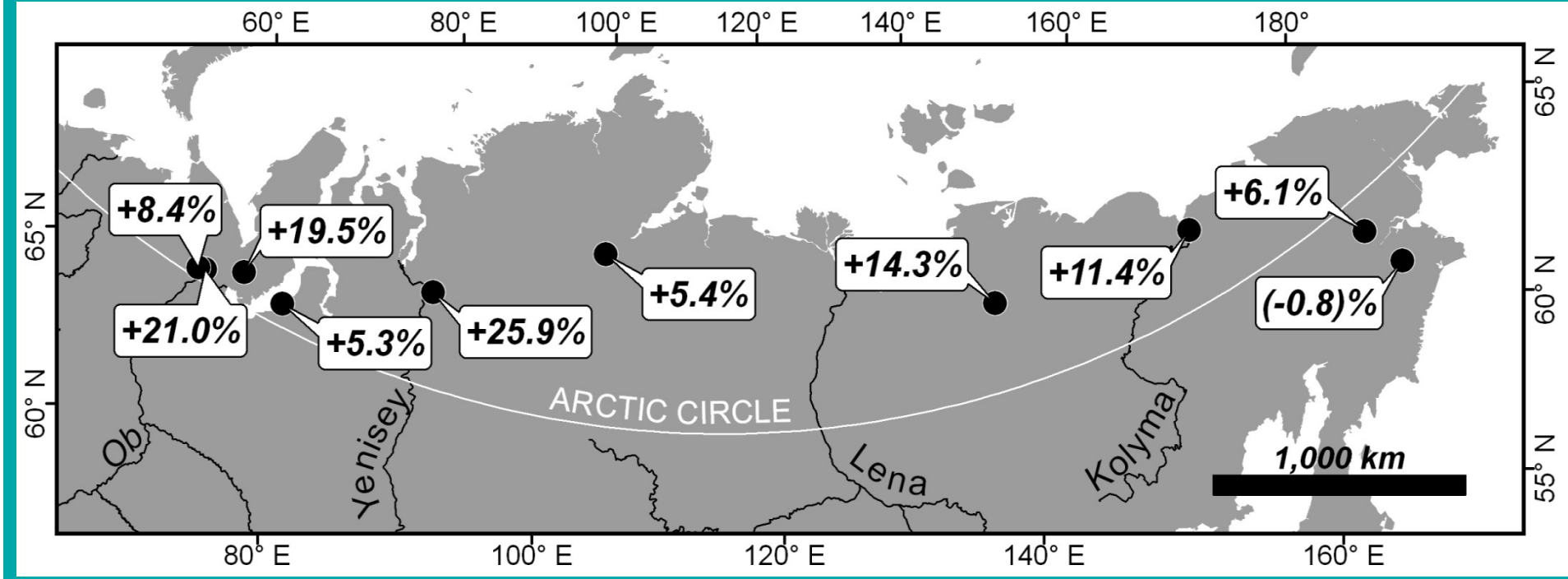

Alder shrublands frequently occur in patterned ground areas, and these shrublands are expanding – not just a local phenomenon.
Patterned ground
Alder shrubs


Kola
Polar Urals
Ob River
Syadakharvuta
Dudinka
Khatanga
Brooks Range
Study Sites
Corona (2 m)
Gambit (0.75 m)
Kular
Uyandina
Cherskiy
Baranikha
Chaun
Kanchalan
Anadyr
Slautnoye
Gizhiga


Gambit KH-7
15 July 1966
100 meters
Western Taymyr Peninsula


GeoEye-1
9 July 2009
100 meters
Western Taymyr Peninsula

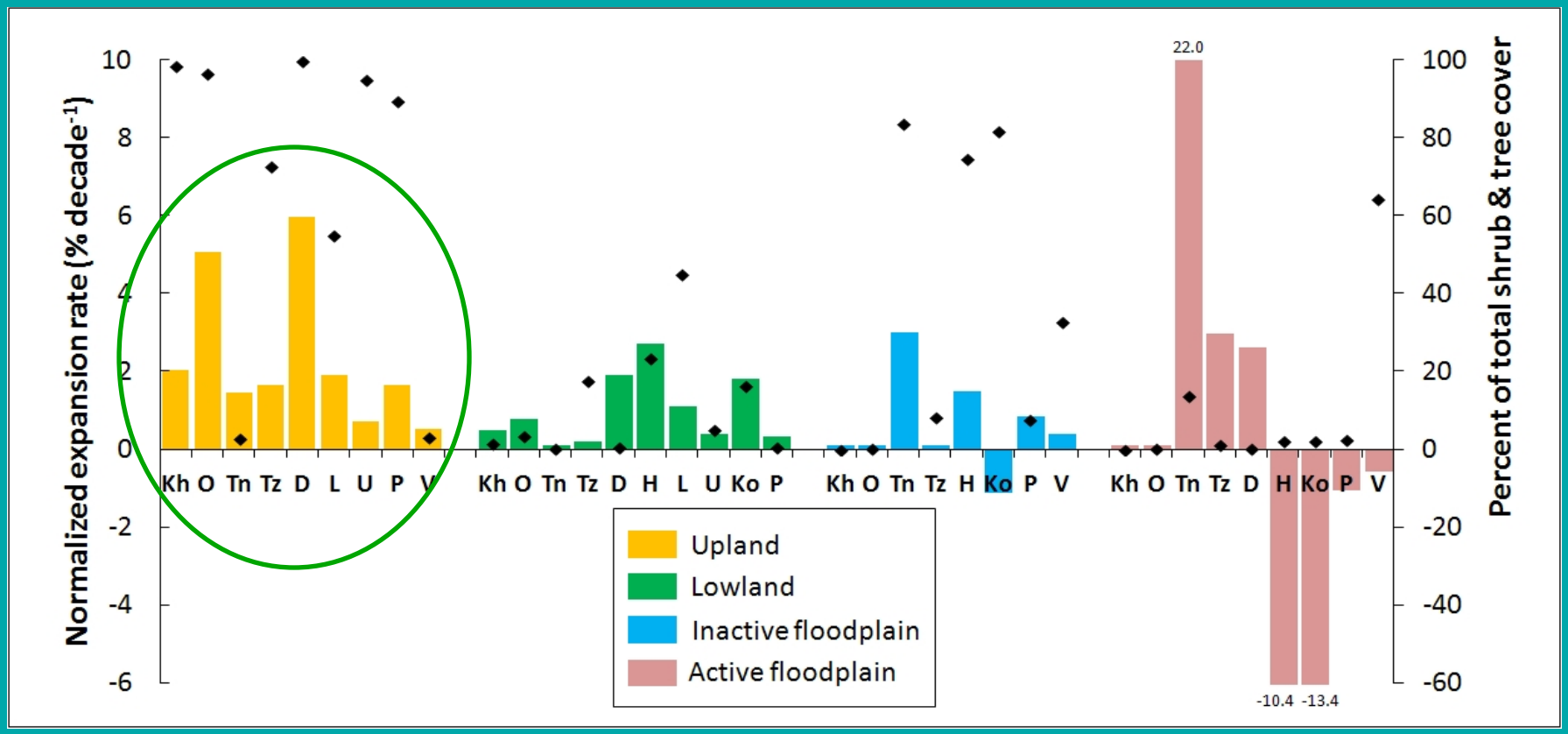
Percent changes in tall shrubland cover



Shrub cover increased at all examined ecotones except one
Most changes associated with Siberian alder (Alnus fruticosa)

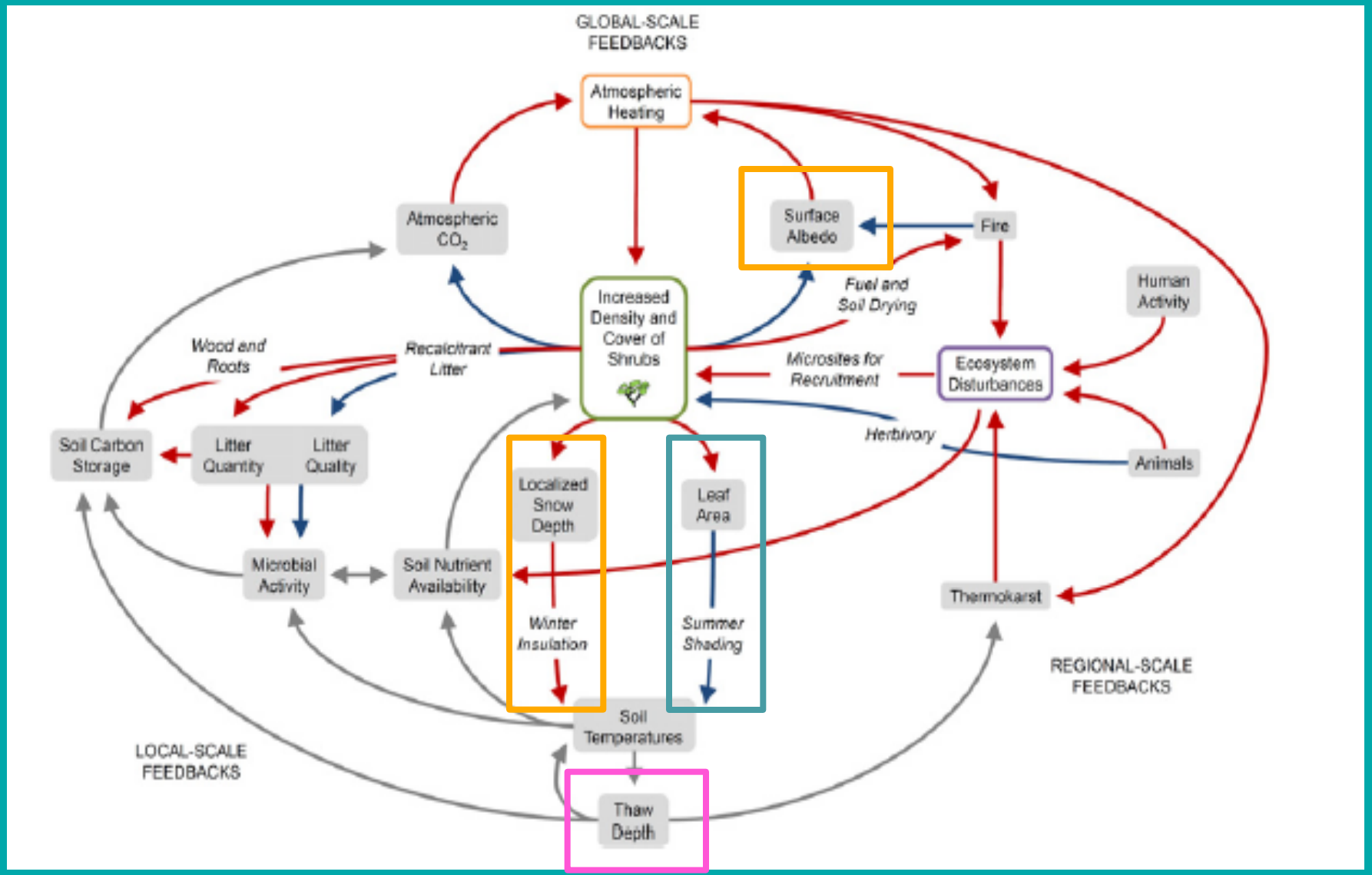
Frost and Epstein 2014 (*Global Change Biology*)

Landscape heterogeneity of shrub and tree dynamics



Frost and Epstein 2014 (*Global Change Biology*)

Conceptual model of shrub expansion effects



From Myers-Smith et al. 2011 (Environmental Research Letters)