Recent temporal dynamics of arctic tundra vegetation within the context of spatial biomass-temperature relationships

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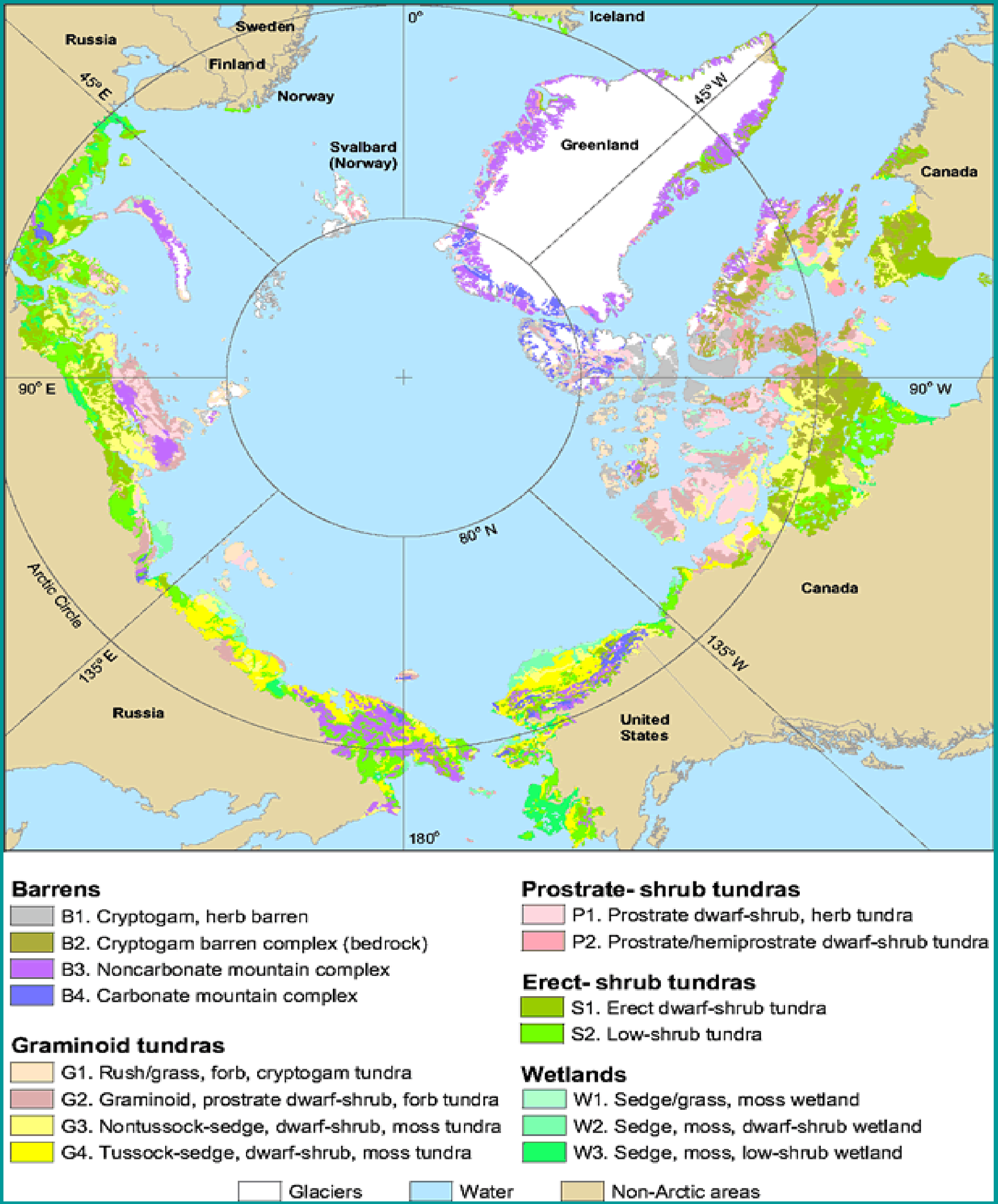
The Arctic Tundra Biome

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

Arctic tundra vegetation has been undergoing substantive changes recently, at least since the mid 20th century.

These changes have been rather heterogeneous from a circumpolar perspective.

What are the patterns of this hetero-geneity, and is vegetation changing in a predictive manner?



Outline of Study

1) Develop spatial relationships between arctic tundra biomass and temperature
2) Use a remotely sensed temperature index to project tundra biomass dynamics over the satellite record
3) Compare observed vegetation dynamics (also using remote sensing) to projected changes

Setting the Context

Heterogeneous Arctic “Greening”

Normalized Difference Vegetation Index (NDVI)

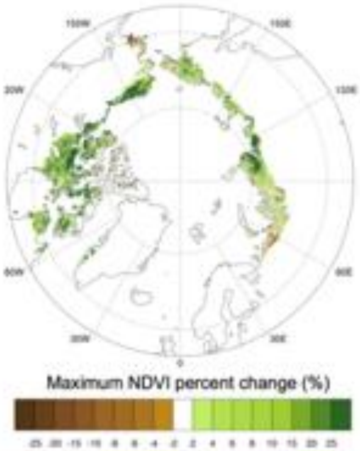
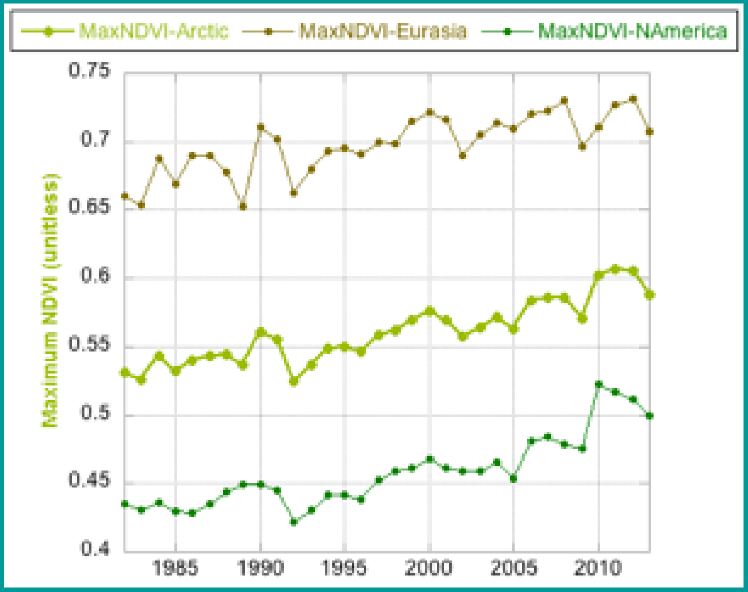
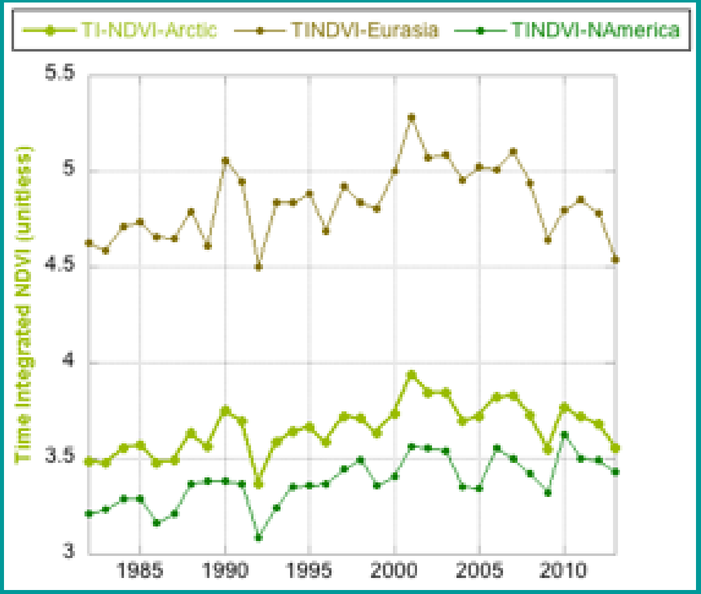


Fig. 34. Trend of change (in %) in annual MaxNDVI between 1982 and 2012 calculated using a least squares regression at each pixel (from Bhatt et al. 2013).

MaxNDVI
(peak greenness)

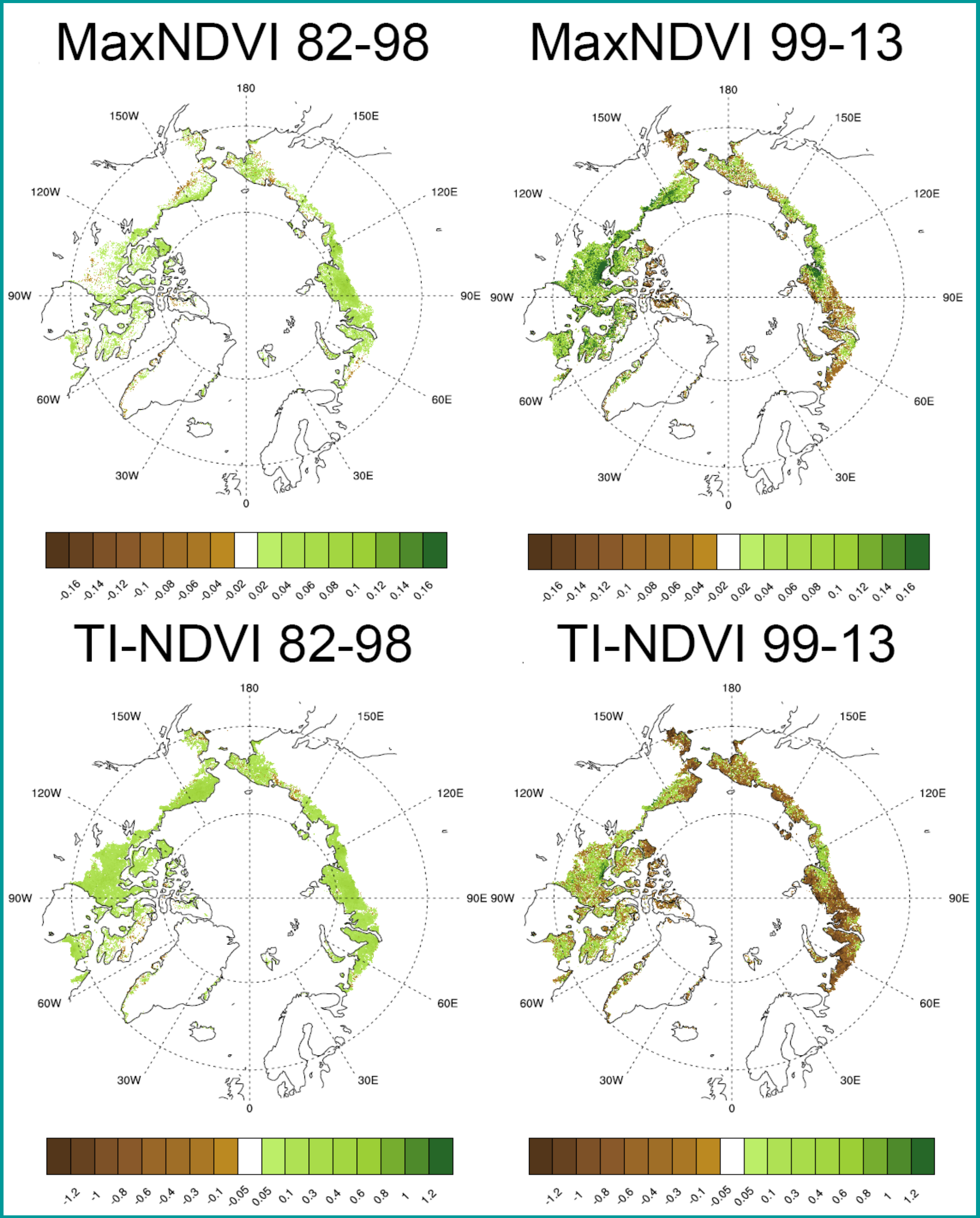


TI-NDVI
(temporally integrated greenness)

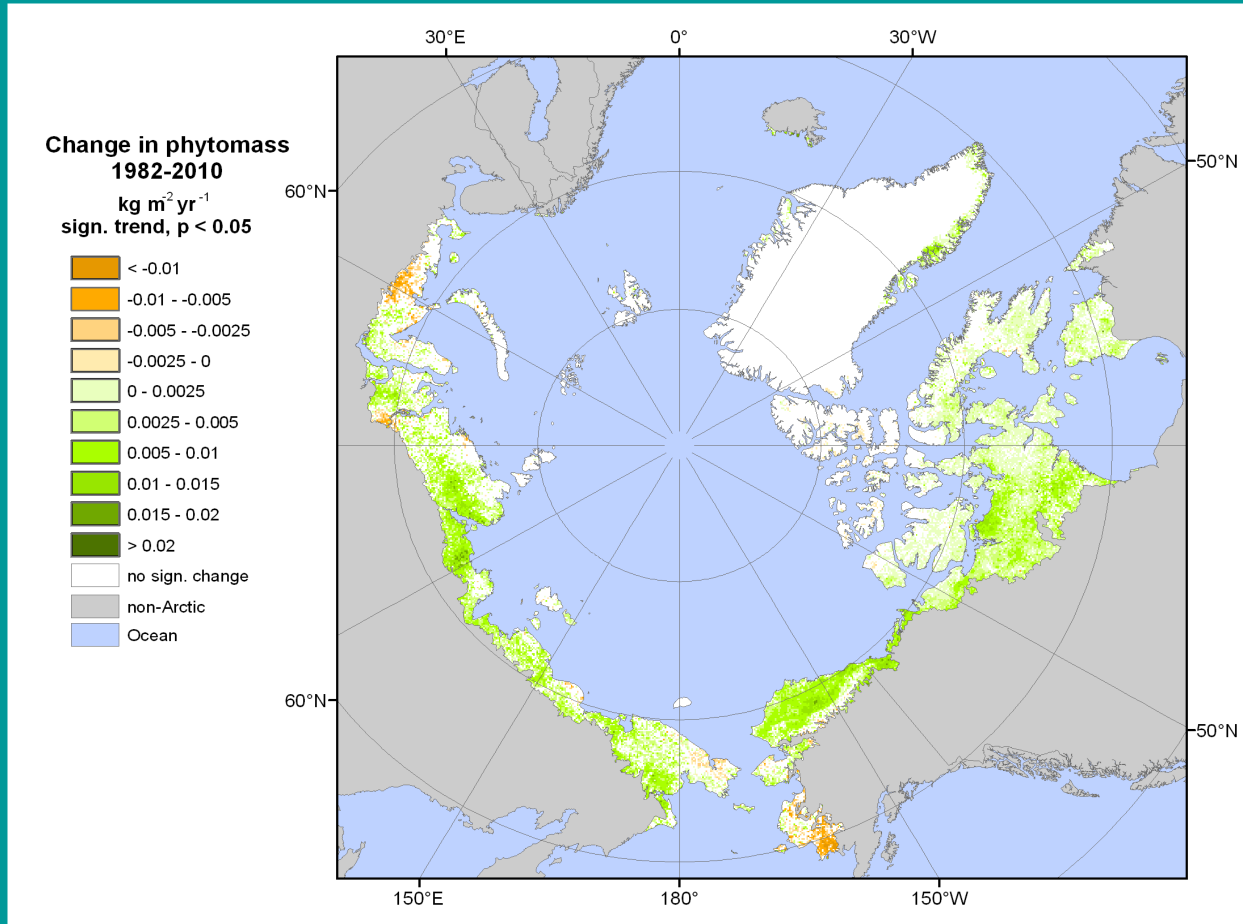


Bhatt et al. (2013), Epstein et al. (NOAA Arctic Report Card 2014)

Trends are changing, particularly for TI-NDVI, indicative of a shorter growing season (longer snow cover duration)



Bhatt et al. (2013, and in prep.)
Epstein et al. (NOAA Arctic Report Card 2014)

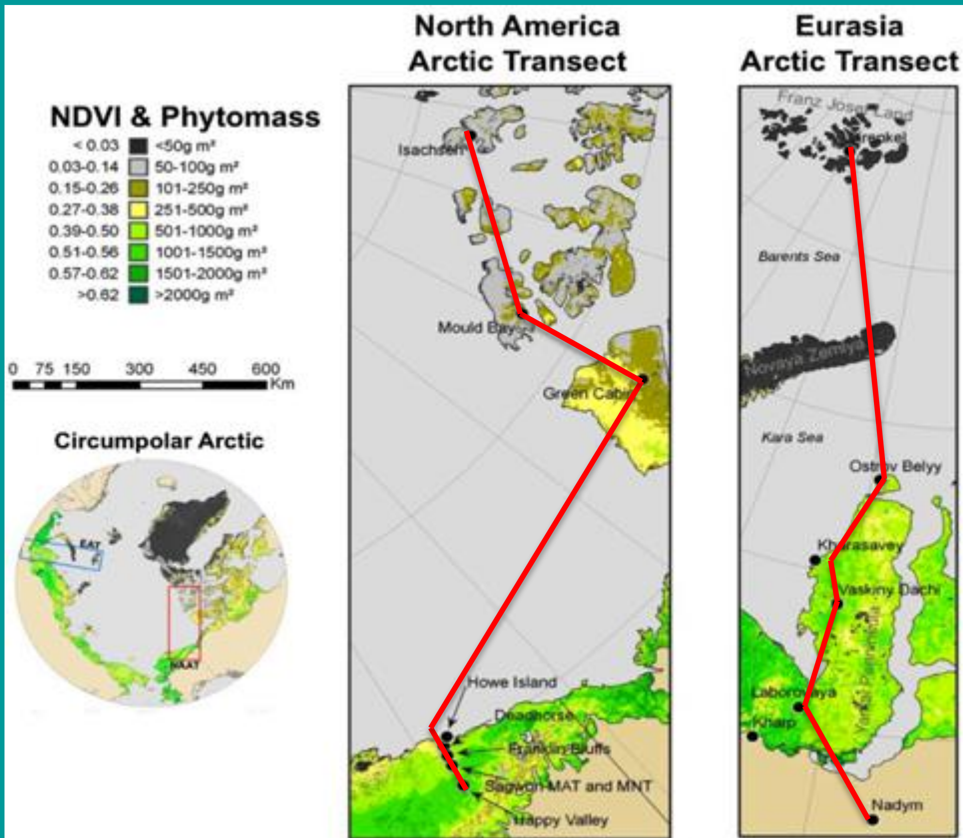


Bioclimate Subzone	Area (km²)	1982	SD	2010	SD	Change in mean biomass (g m⁻²)	Rate of change (g m⁻² y⁻¹)	1982	2010	Change	% change	Rate of change (% y⁻¹)
Greenland Ice Cap	1,795,920	83.8	14.0	84.4	18.0	0.6	0.02	0.15	0.15	0.0011	0.70	0.025
A	200,964	98.3	39.2	100.3	53.4	2.0	0.07	0.02	0.02	0.0004	2.05	0.073
B	530,780	142.7	100.9	151.8	118.4	9.1	0.33	0.08	0.08	0.0048	6.39	0.228
C	1,388,760	199.6	116.6	241.2	148.7	41.6	1.49	0.28	0.33	0.0575	20.85	0.745
D	1,708,420	319.8	145.6	401.5	195.2	81.7	2.92	0.55	0.69	0.1396	25.56	0.913
E	2,027,020	467.5	142.5	563.6	153.1	96.1	3.43	0.95	1.14	0.1948	20.55	0.734

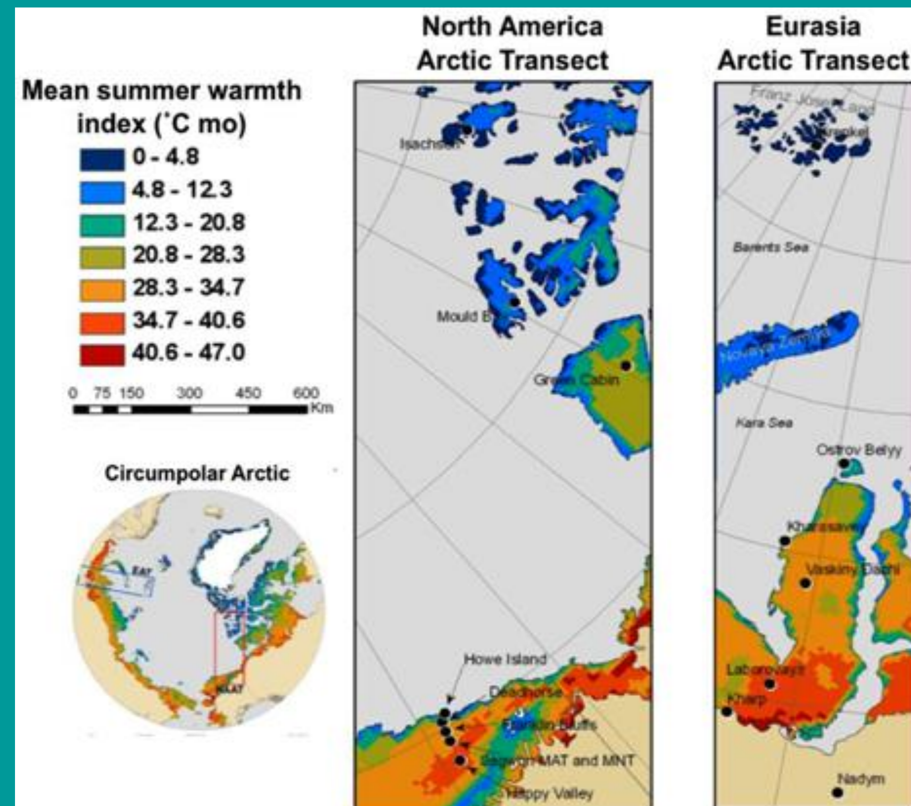
Aboveground biomass increases since 1982 have been particularly strong in the mid- to Low-Arctic (20-26%), compared the High Arctic (2-7%).

Epstein et al. (2012)

Spatial Relationships (Biomass-Temperature-NDVI)



Two full latitudinal arctic gradients, with research sites in all five bioclimatic subzones

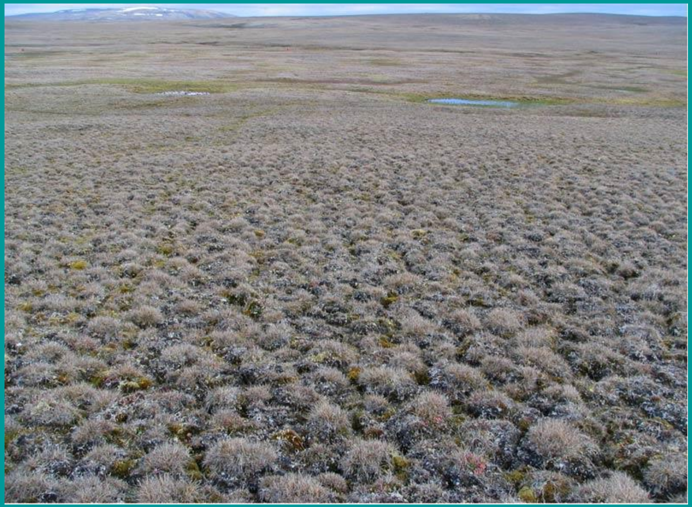


Two remotely sensed indices:
NDVI – vegetation
SWI – summer warmth index (sum of mean monthly temps > 0°C)
Field-collected biomass

(See Raynolds et al. 2012)

North American Arctic Transect

Subzone A



Subzone B

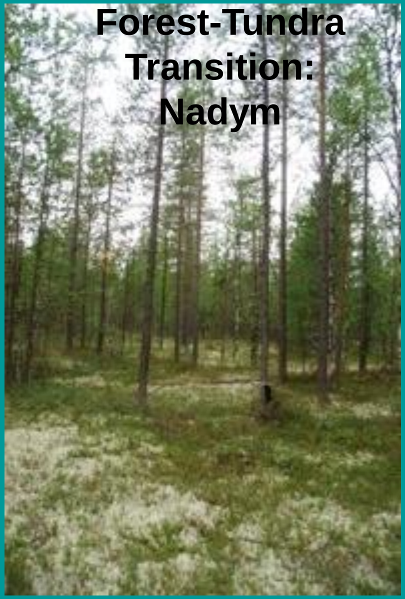
Subzone C

Subzone D

Subzone E

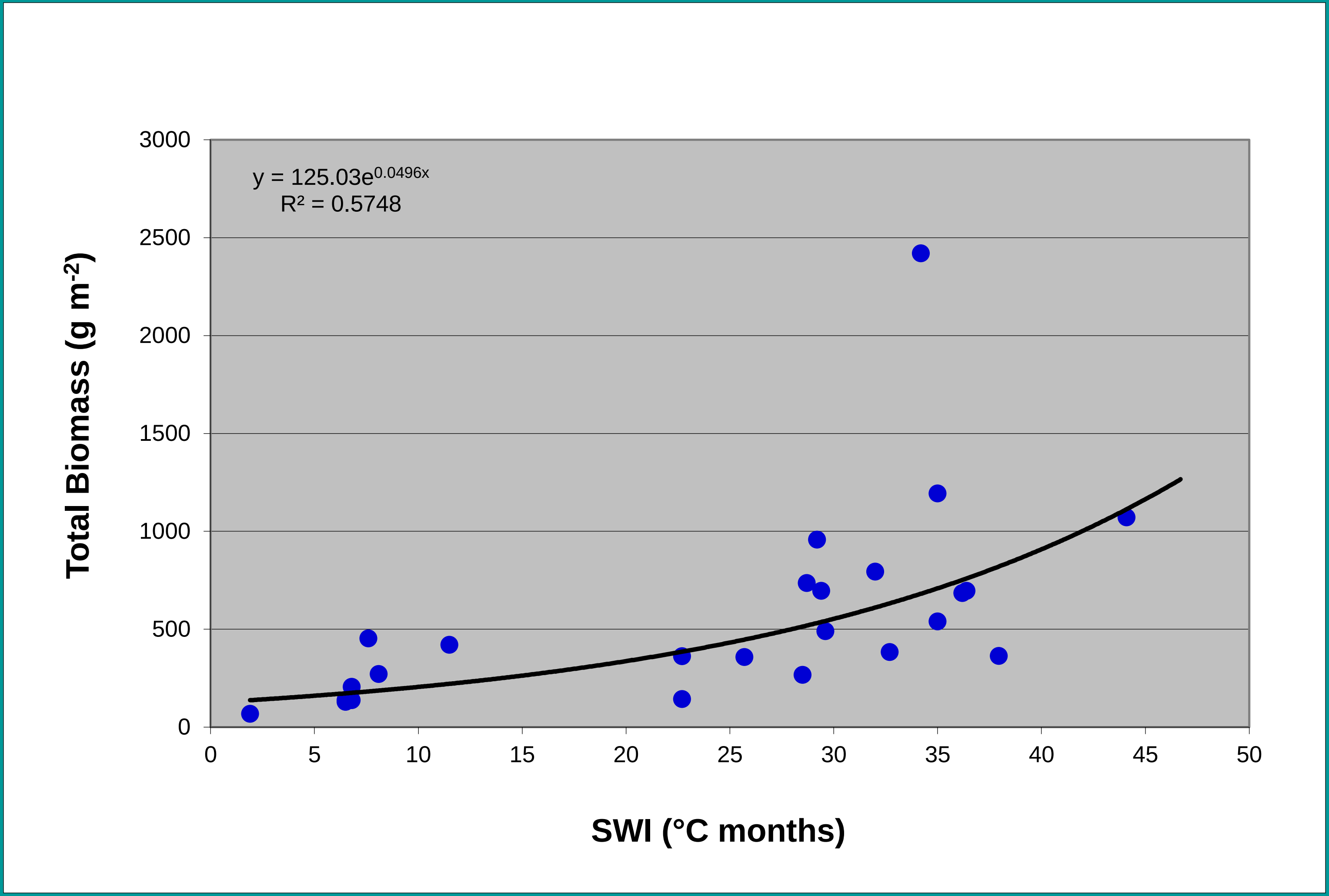
(Photos D.A. Walker and H.E. Epstein)

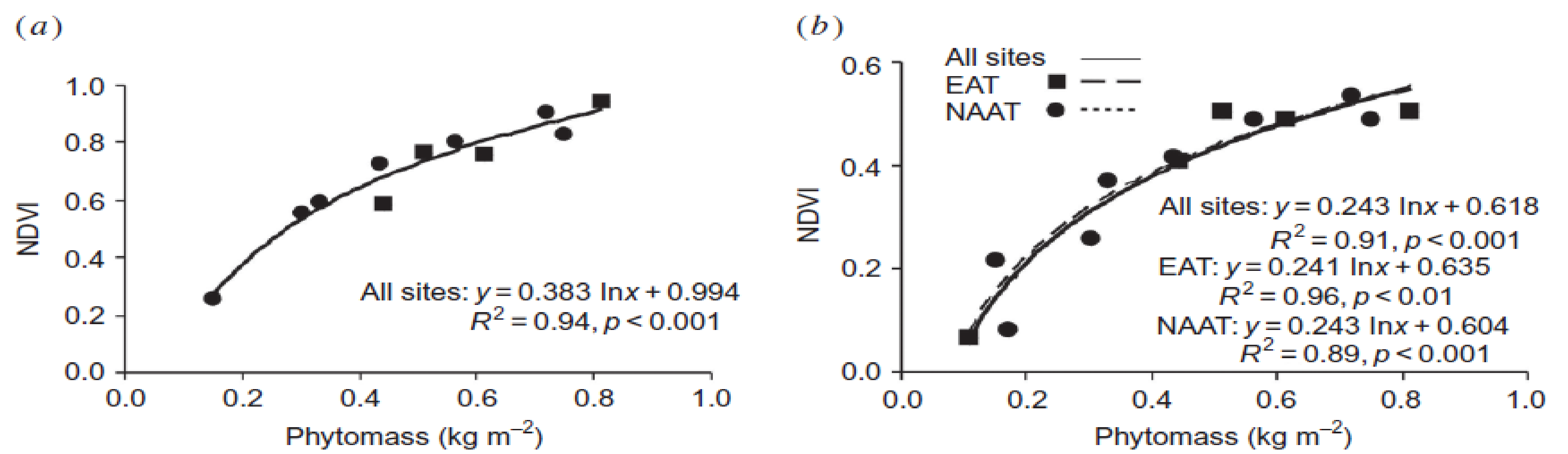
Eurasian Arctic Transect

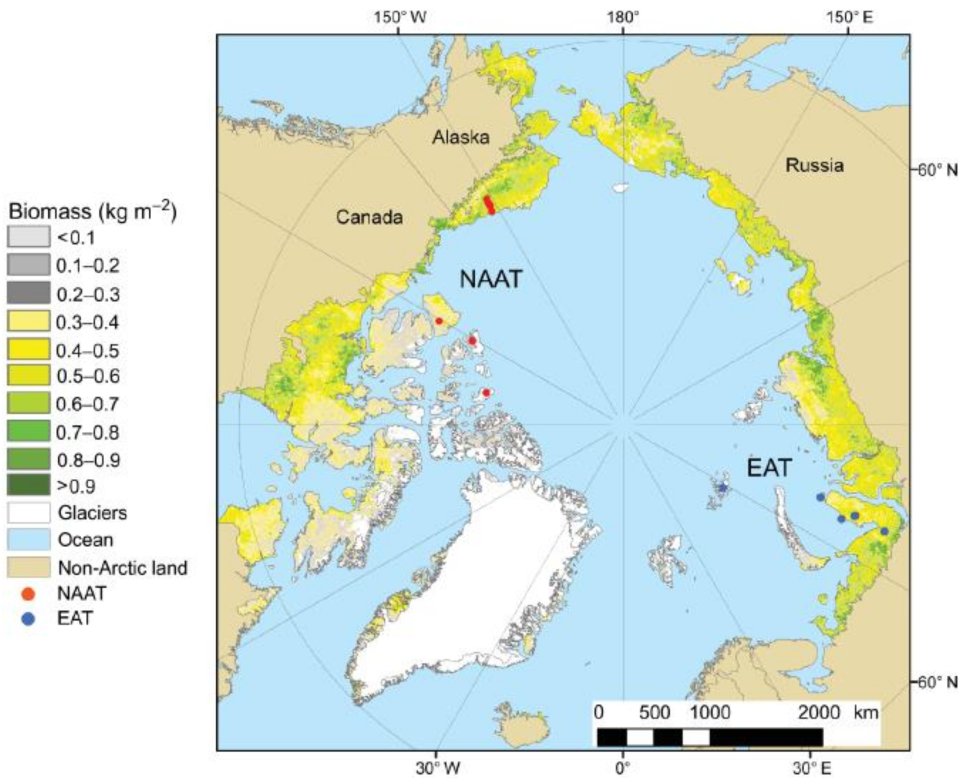


(photos D.A. Walker)

Spatial relationship between SWI and field-measured total aboveground biomass



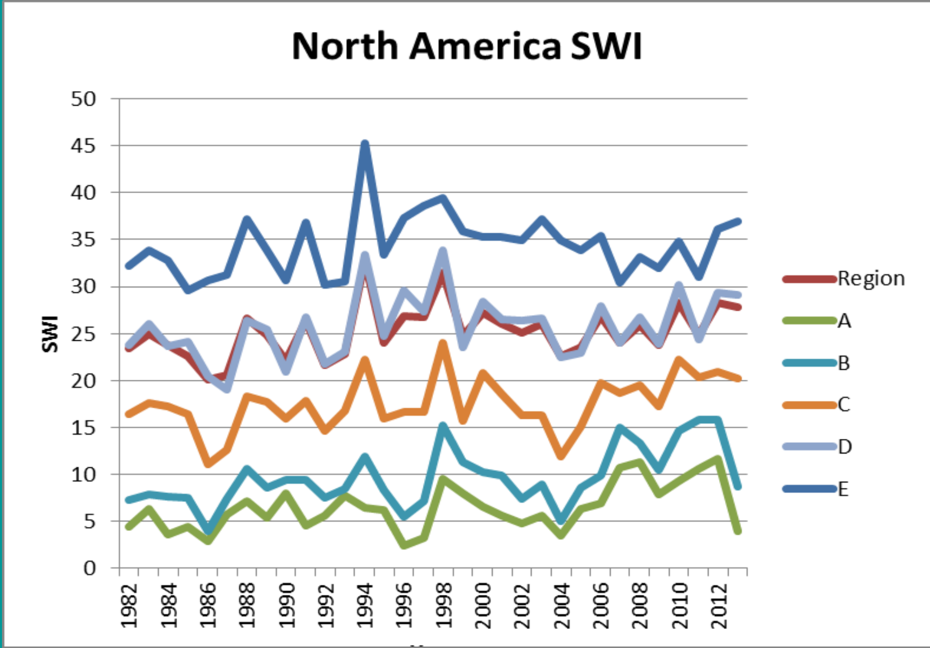


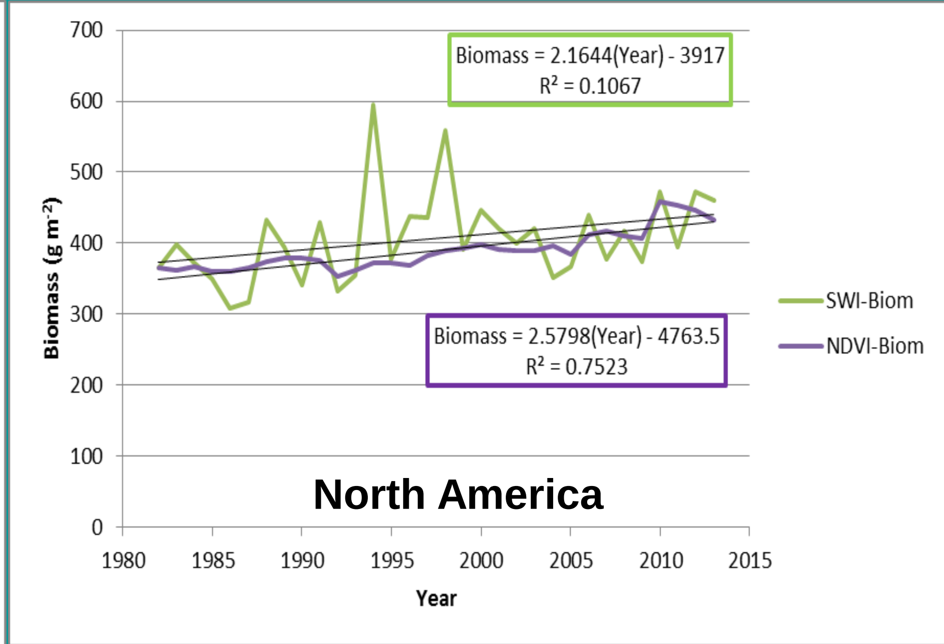


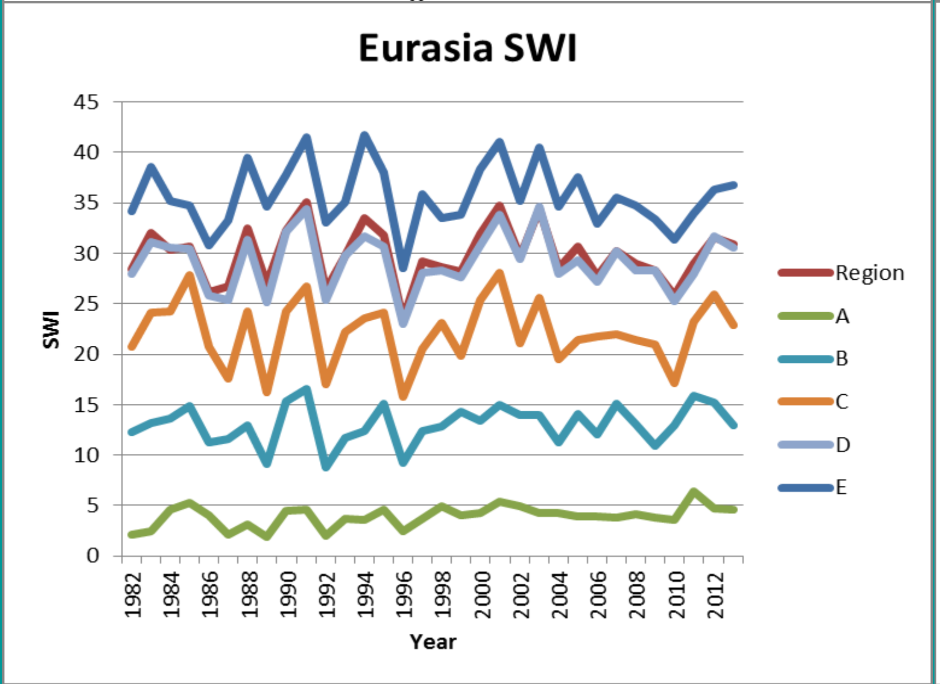
Spatial relationship between NDVI and field-measured total aboveground biomass

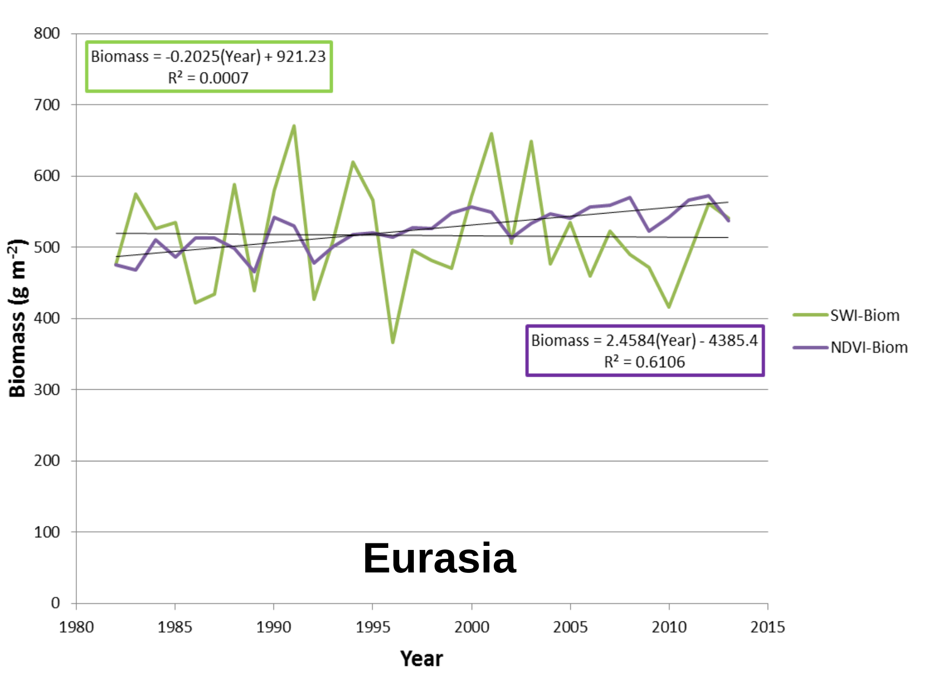
(Raynolds et al. 2012)

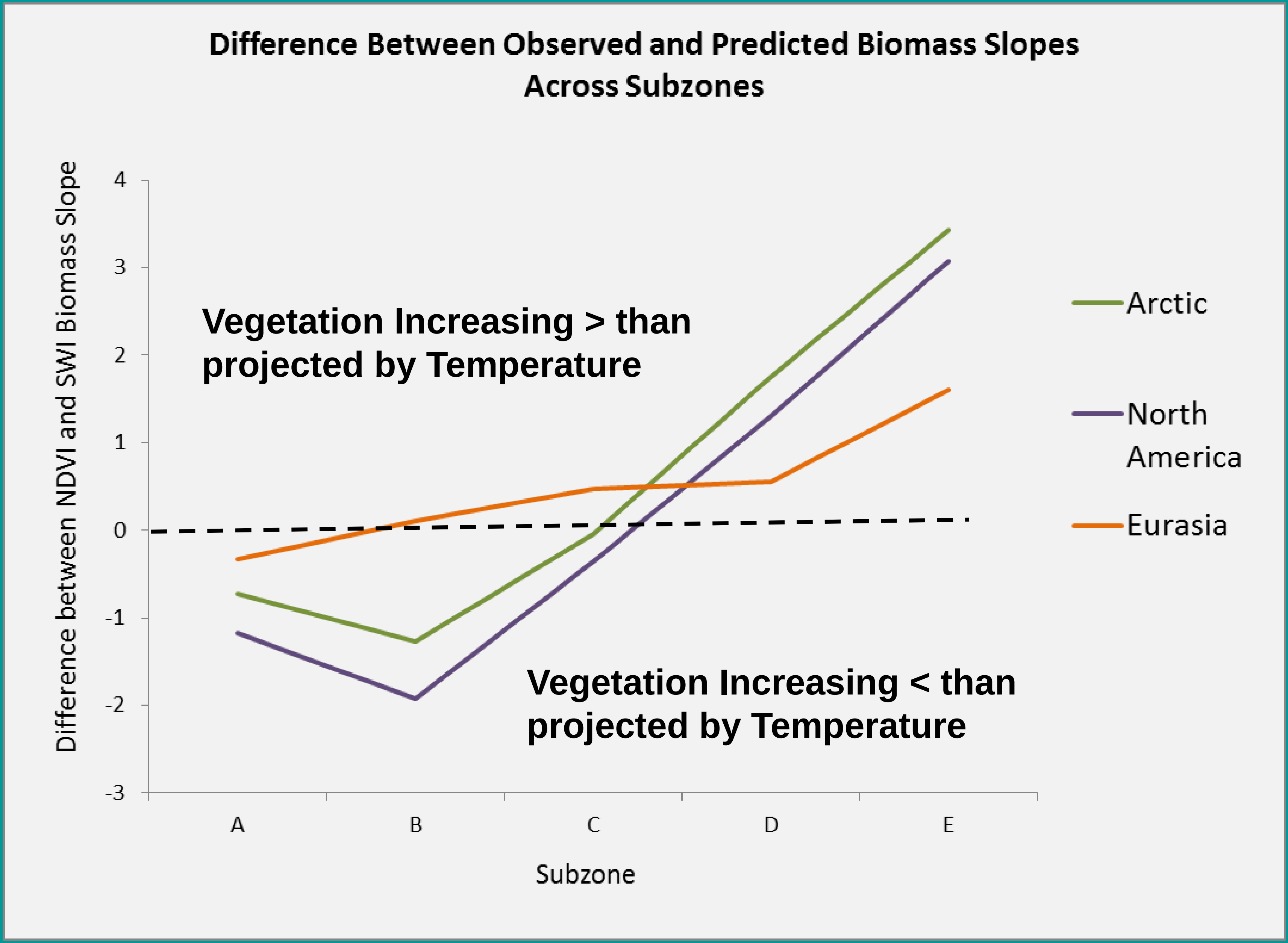
Results


North America SWI
SWI
50
45
40
35
30
25
20
15
10
5
0
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Region
A
B
C
D
E

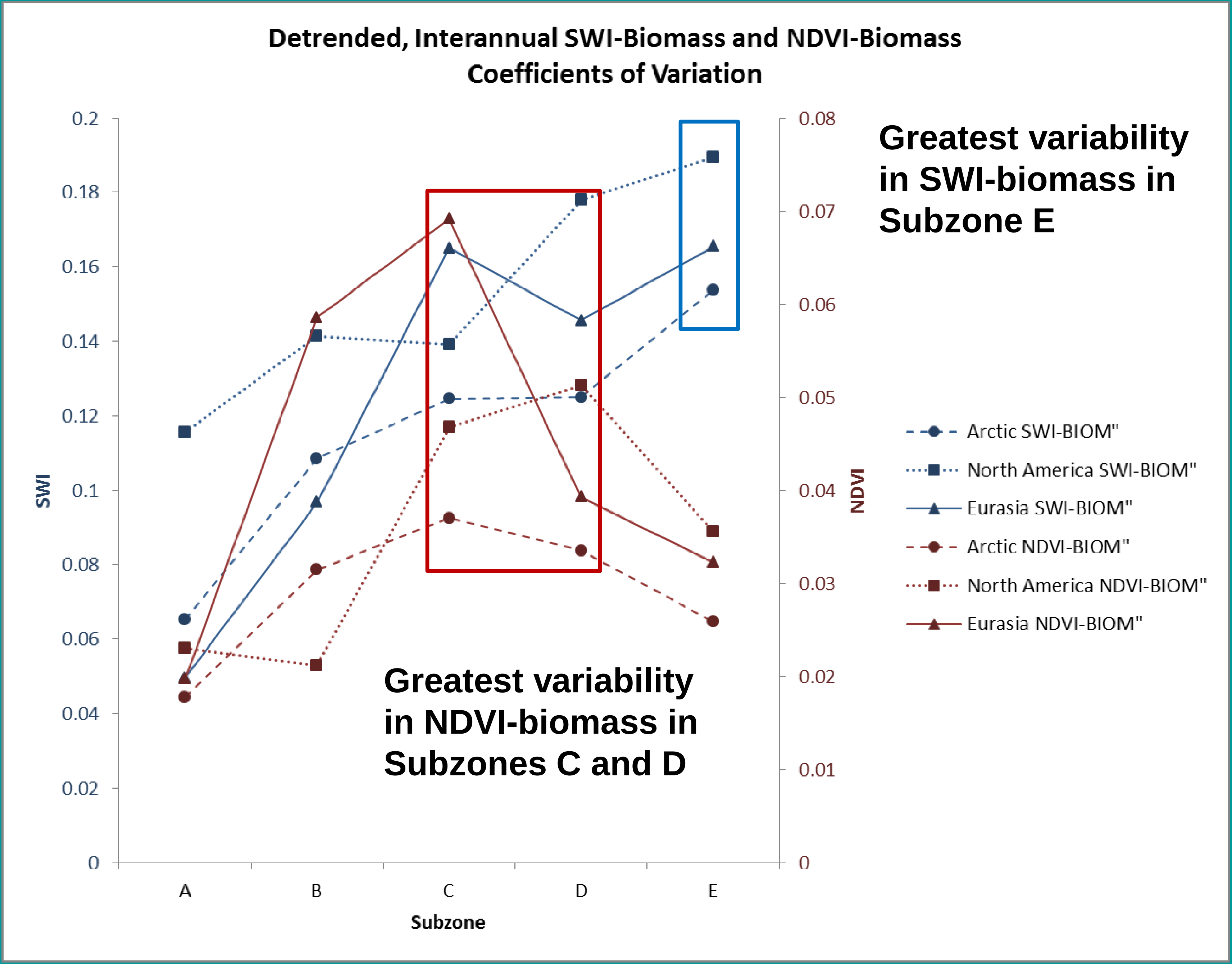

Biomass = 2.1644(Year) - 3917
R² = 0.1067
Biomass = 2.5798(Year) - 4763.5
R² = 0.7523
Biomass (g m⁻²)
700
600
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015
Year
North America
SWI-Biom
NDVI-Biom


Eurasia SWI
SWI
45
40
35
30
25
20
15
10
5
0
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
Year
Region
A
B
C
D
E


Biomass = -0.2025(Year) + 921.23
R² = 0.0007
Biomass = 2.4584(Year) - 4385.4
R² = 0.6106
Biomass (g m⁻²)
800
700
600
500
400
300
200
100
0
1980
1985
1990
1995
2000
2005
2010
2015
Year
Eurasia
SWI-Biom
NDVI-Biom



Difference Between Observed and Predicted Biomass Slopes Across Subzones
Difference between NDVI and SWI Biomass Slope
4
3
2
1
0
-1
-2
-3
A
B
C
D
E
Subzone
Vegetation Increasing > than projected by Temperature
Vegetation Increasing < than projected by Temperature
Arctic
North America
Eurasia


Detrended, Interannual SWI-Biomass and NDVI-Biomass Coefficients of Variation
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
SWI
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
NDVI
A
B
C
D
E
Subzone
Arctic SWI-BIOM"
North America SWI-BIOM"
Eurasia SWI-BIOM"
Arctic NDVI-BIOM"
North America NDVI-BIOM"
Eurasia NDVI-BIOM"
Greatest variability in SWI-biomass in Subzone E
Greatest variability in NDVI-biomass in Subzones C and D

Discussion - Trends

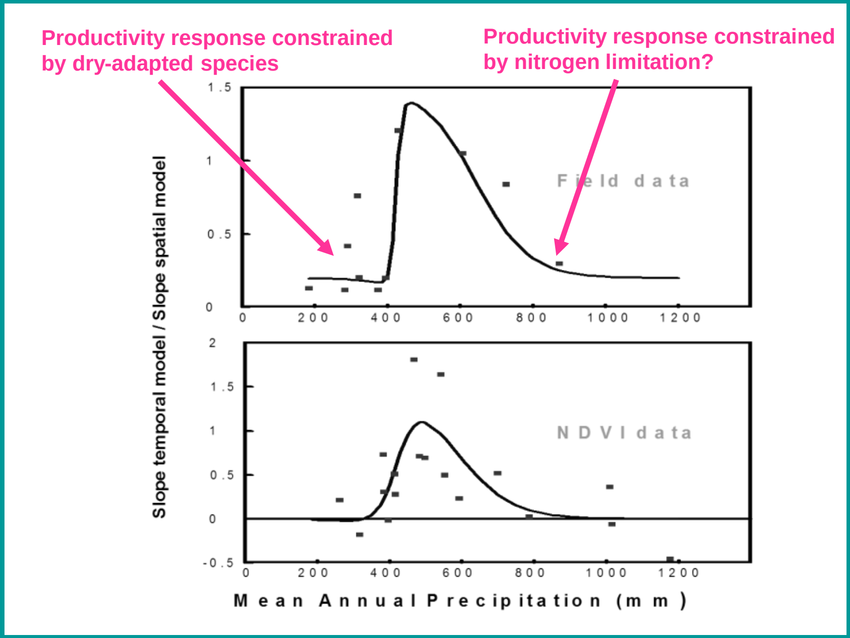
Greater responses in more southern subzones could be due to:

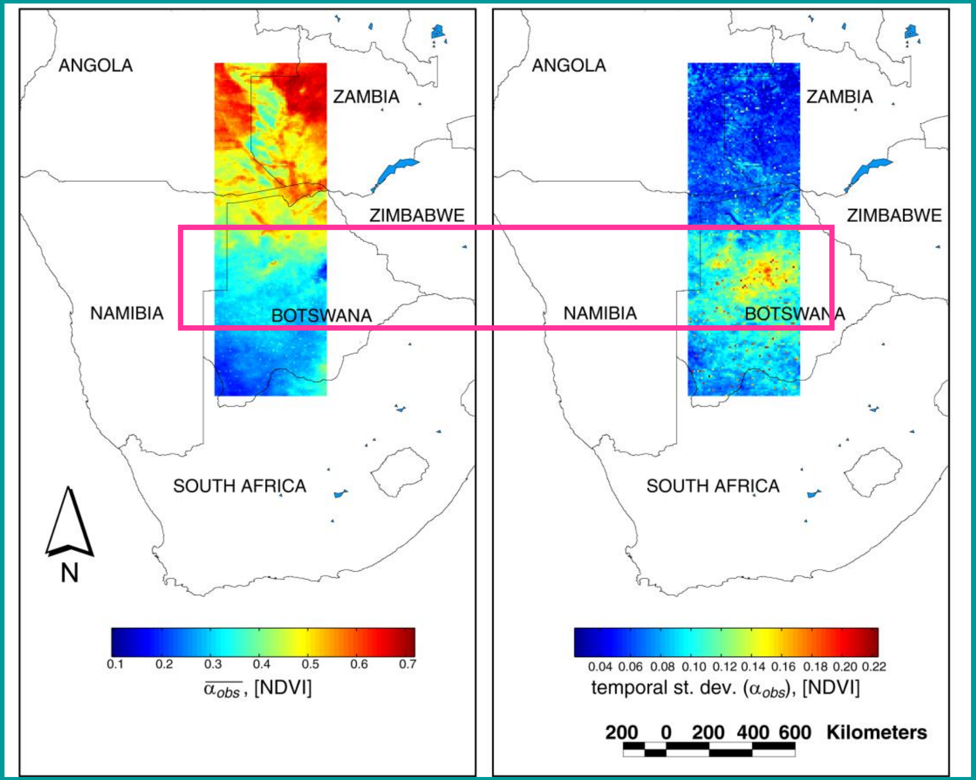
- disturbances such as fire, landslides, cryoturbation
- dispersal and availability of seed bank for low/tall shrubs
- precipitation dynamics

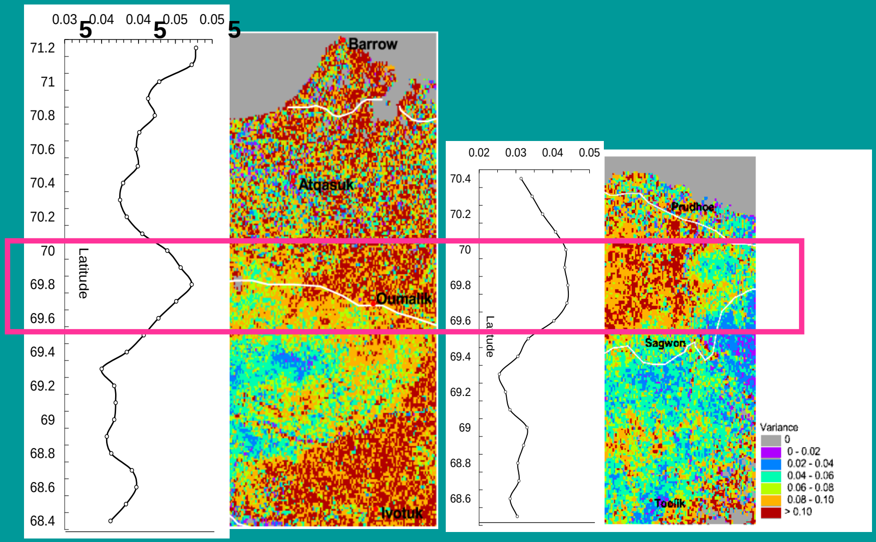
(D.A. Walker)

(G.V. Frost)

Discussion – Interannual Variability





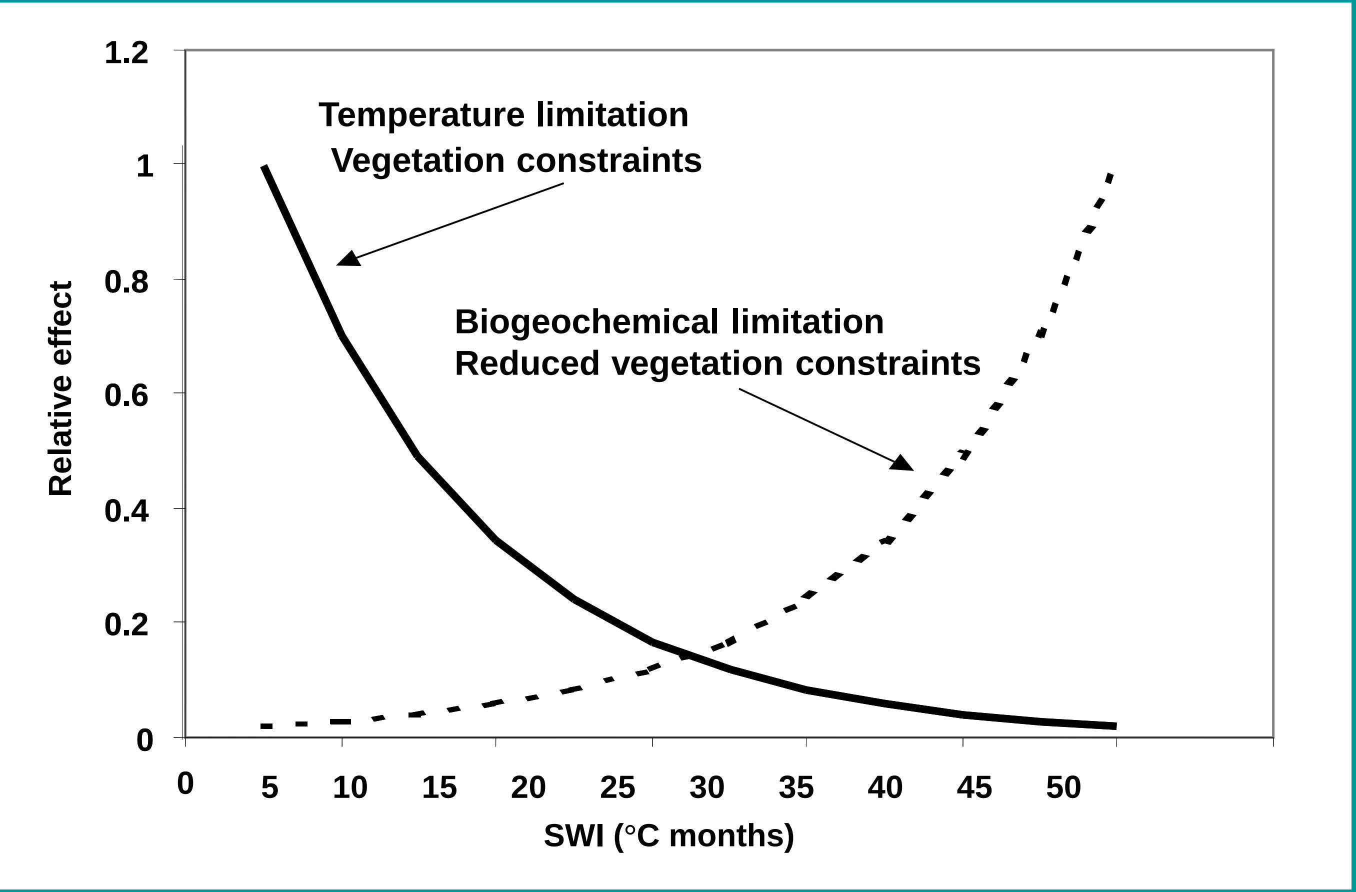


Several ecosystems have exhibited greatest interannual variability in biomass/productivity near the center of environmental gradients across biomes, including grasslands (Paruelo et al. 1999, savannas (Scanlon et al. 2002), and tundra (Jia et al. 2006)

Conclusions

1) Vegetation has increased faster than projected by spatial relationships with temperature in Subzones D and E (as well as Subzone C for Eurasia), potentially due to interactions with disturbances, precipitation dynamics, and other factors.

2) Interannual responses to temperature are greatest in Subzones C and D (mid-transect), potentially due to intermediate levels of vegetation and nutrient constraints, as well as a mix of High and Low Arctic plant types.



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