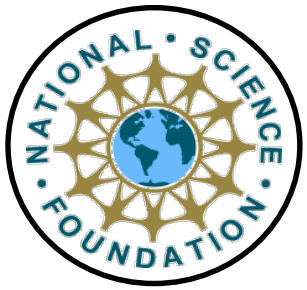
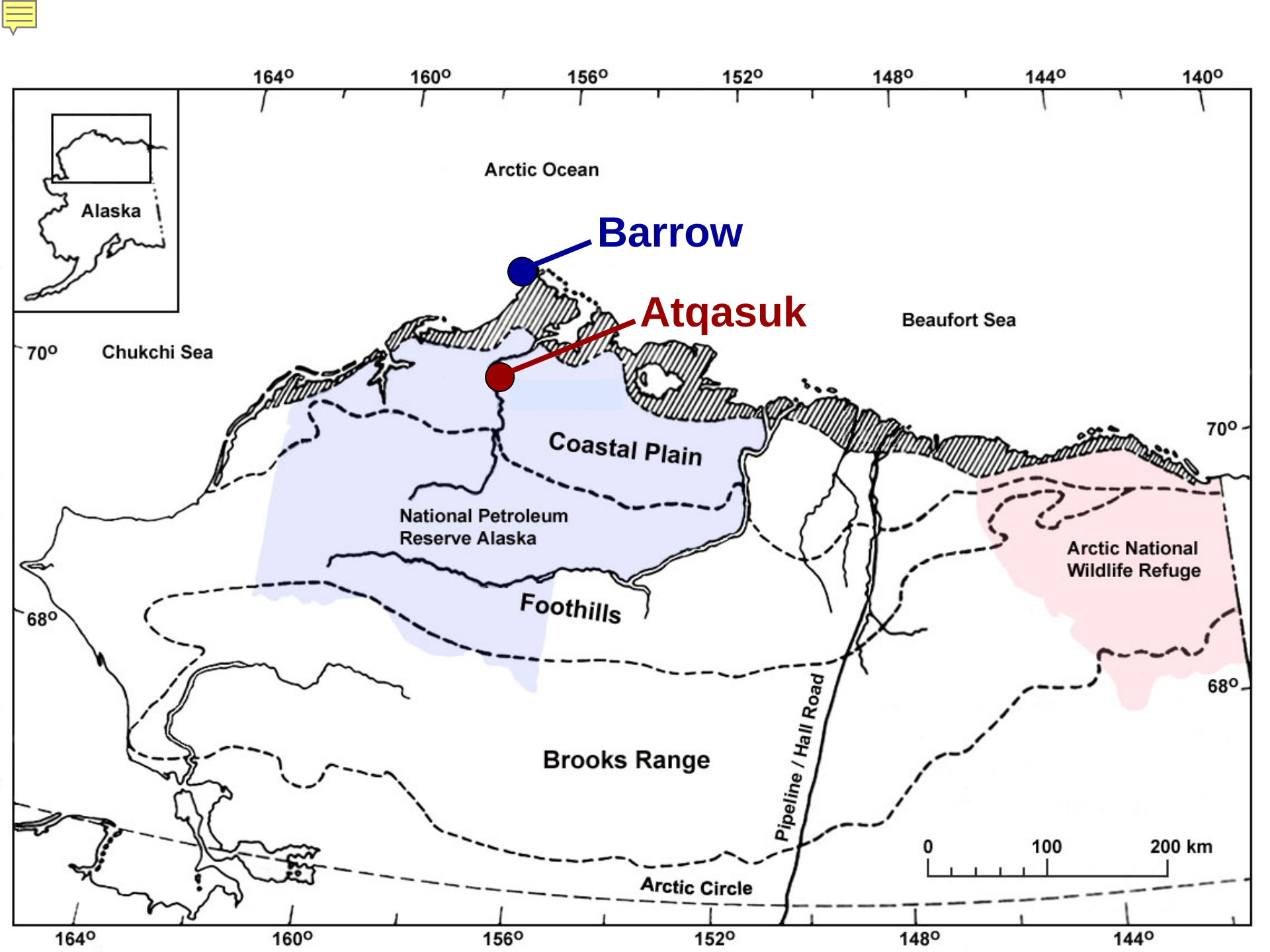
Making sense of two decades of vegetation change at Barrow and Atqasuk

Robert Hollister et al.




164°
160°
156°
152°
148°
144°
140°
Alaska
Arctic Ocean
Barrow
Atqasuk
Beaufort Sea
70°
Chukchi Sea
Coastal Plain
National Petroleum
Reserve Alaska
Arctic National
Wildlife Refuge
Foothills
68°
Brooks Range
Pipeline / Hall Road
0
100
200 km
Arctic Circle

Dry Heath

Wet Meadow

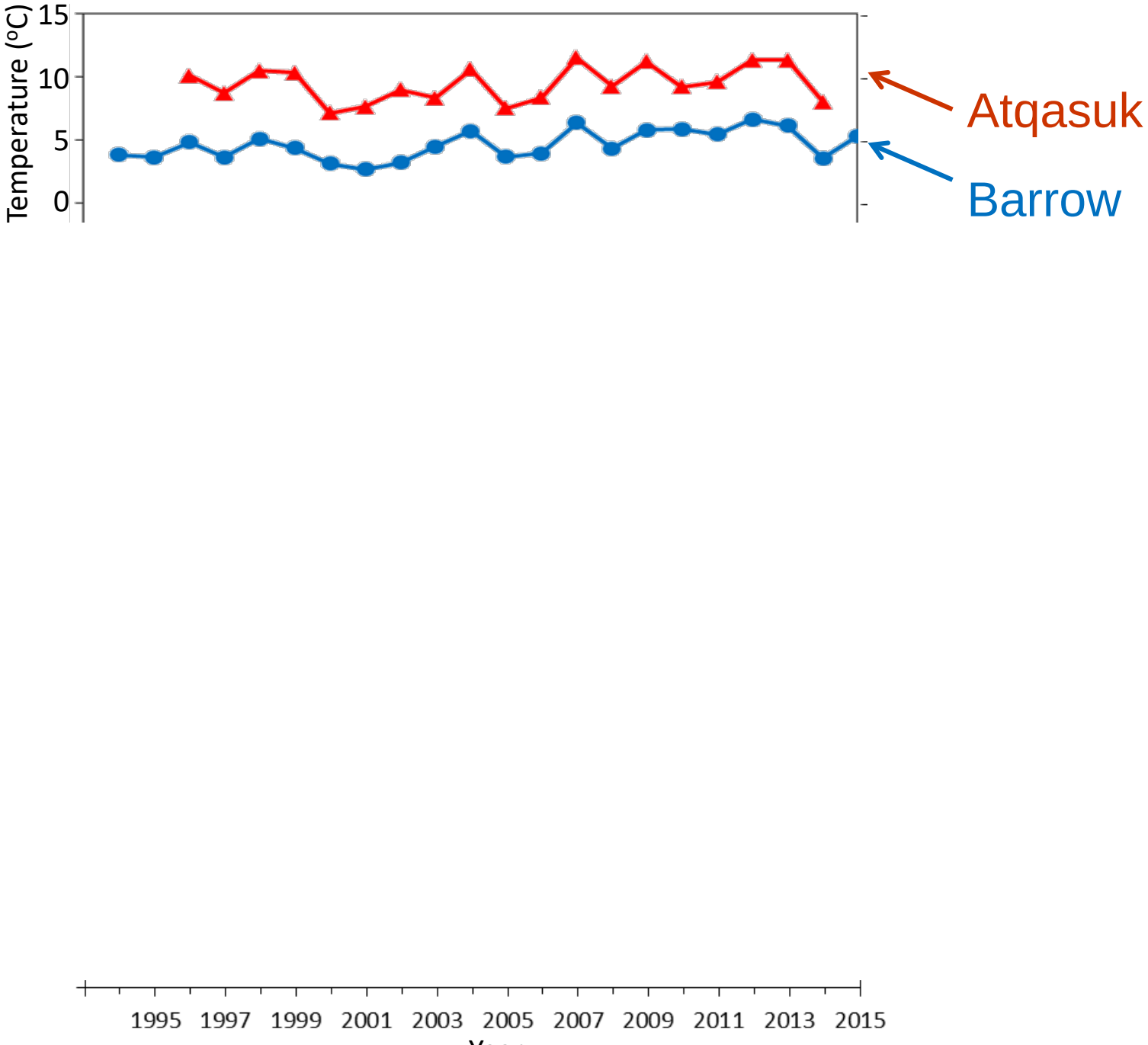
Atqasuk

Dry Heath

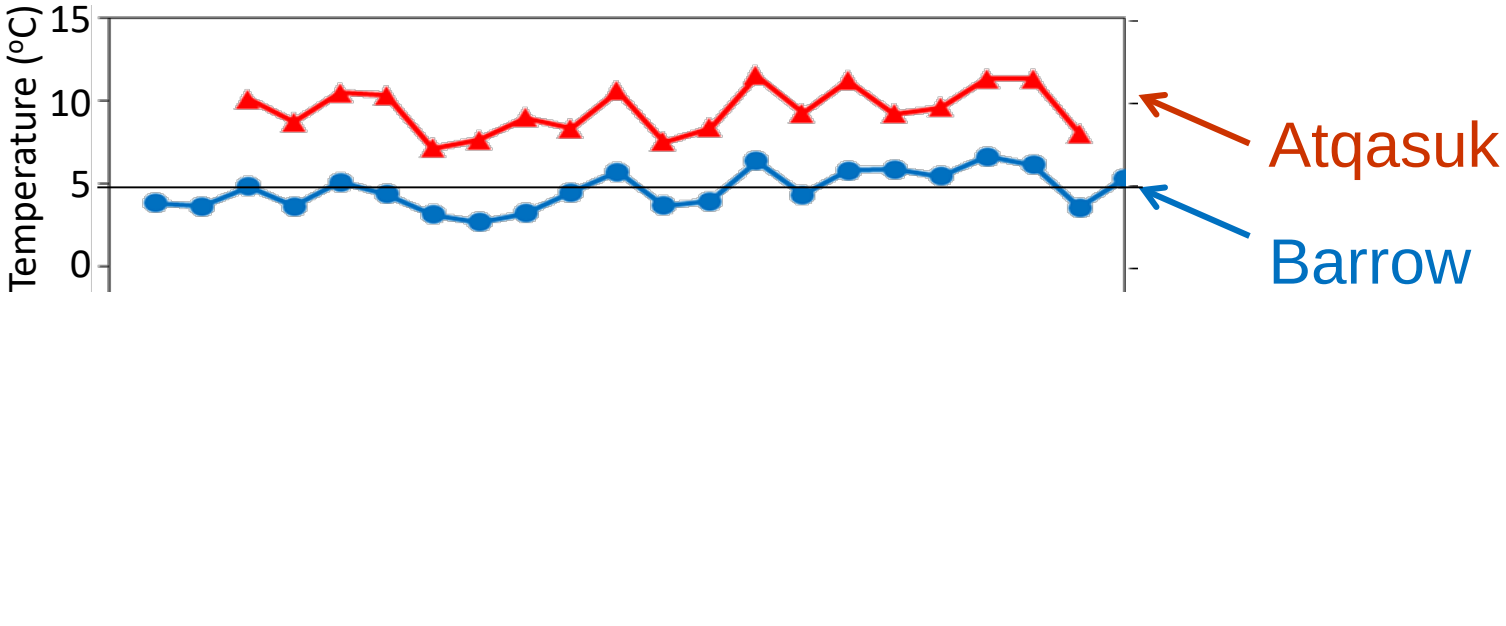
Wet Meadow

Barrow

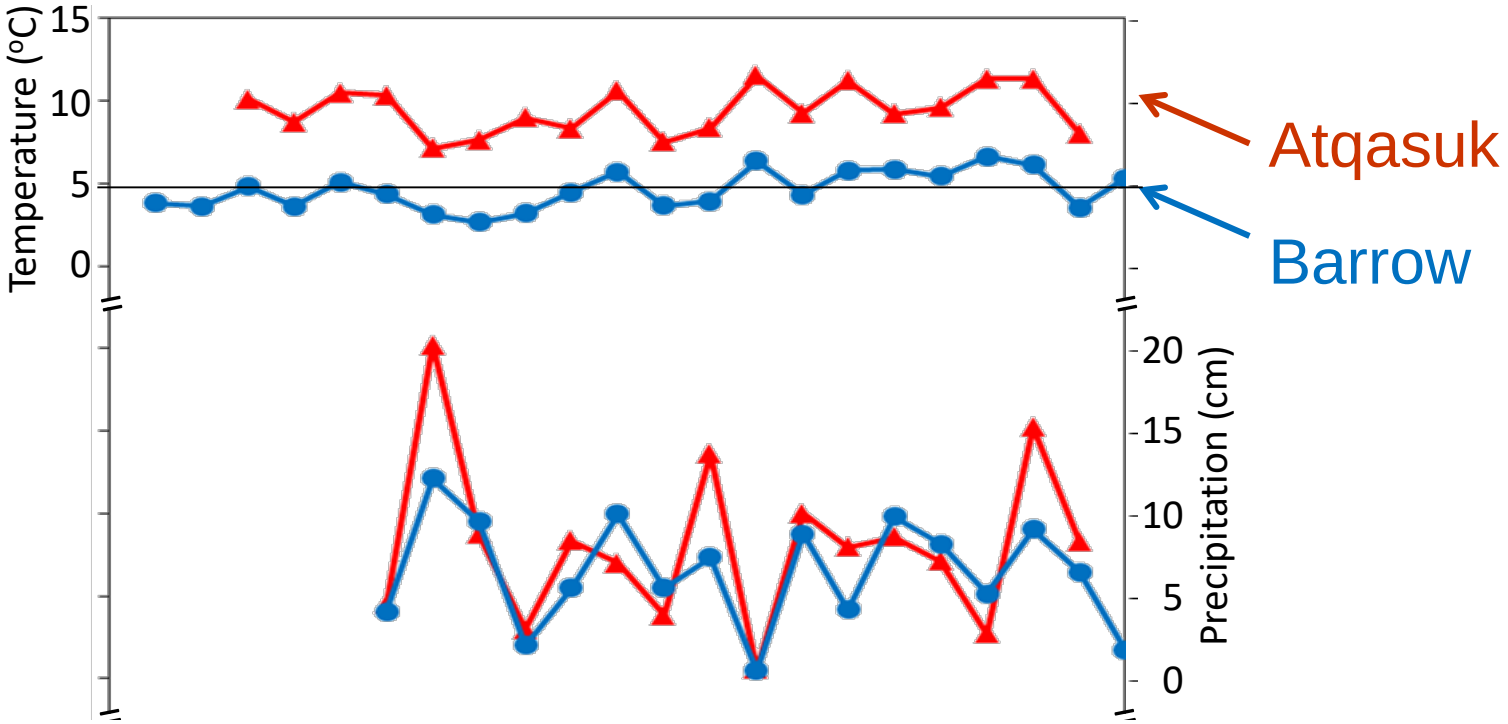
July

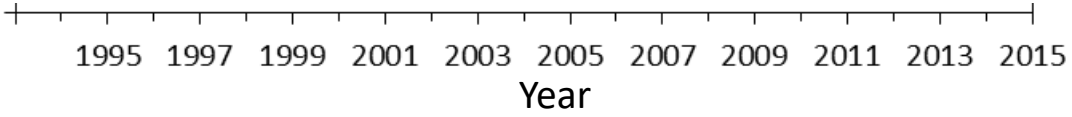

Temperature (°C)
15
10
5
0
Atqasuk
Barrow
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year

July

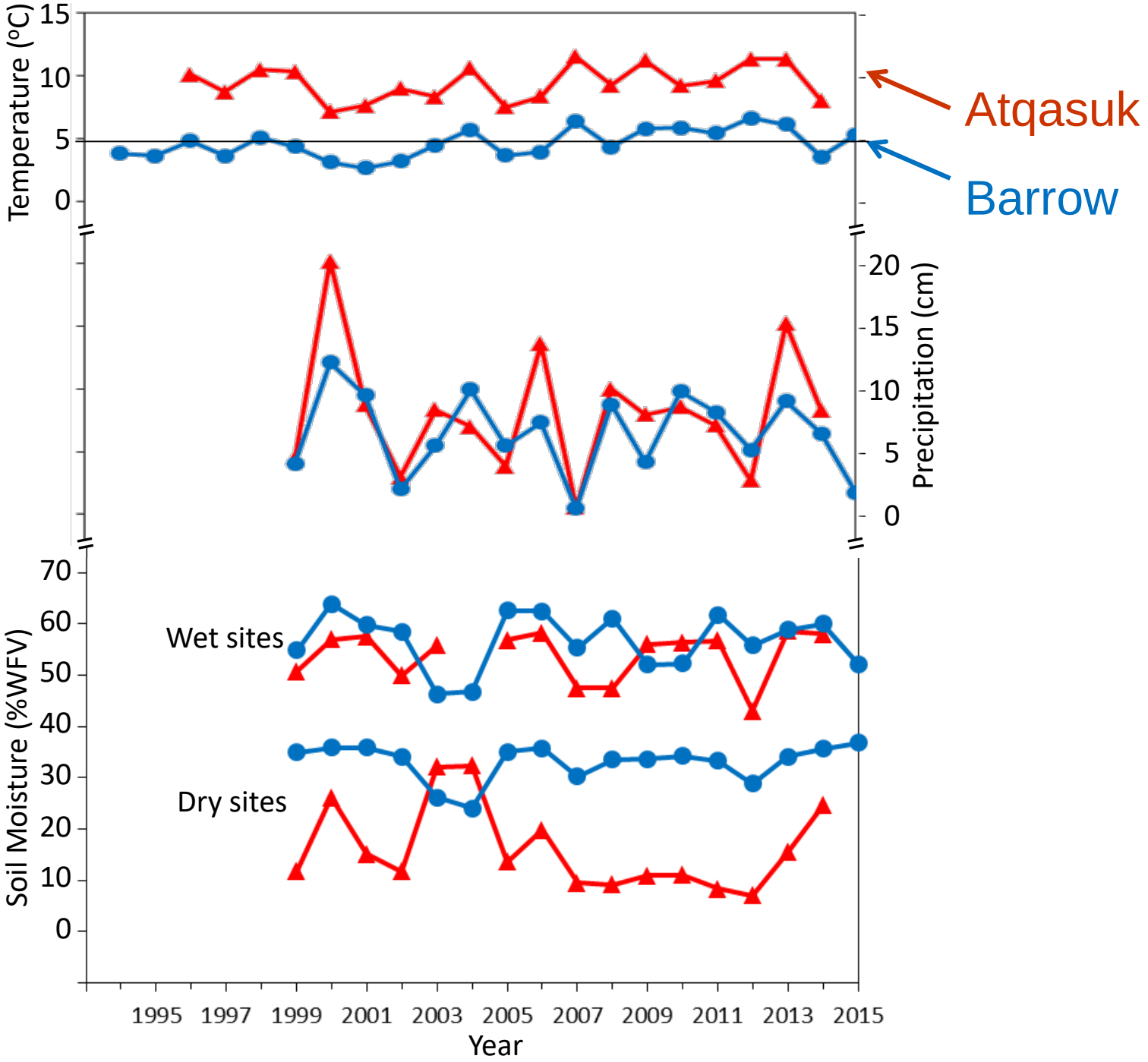

Temperature (°C)
15
10
5
0
Atqasuk
Barrow
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year

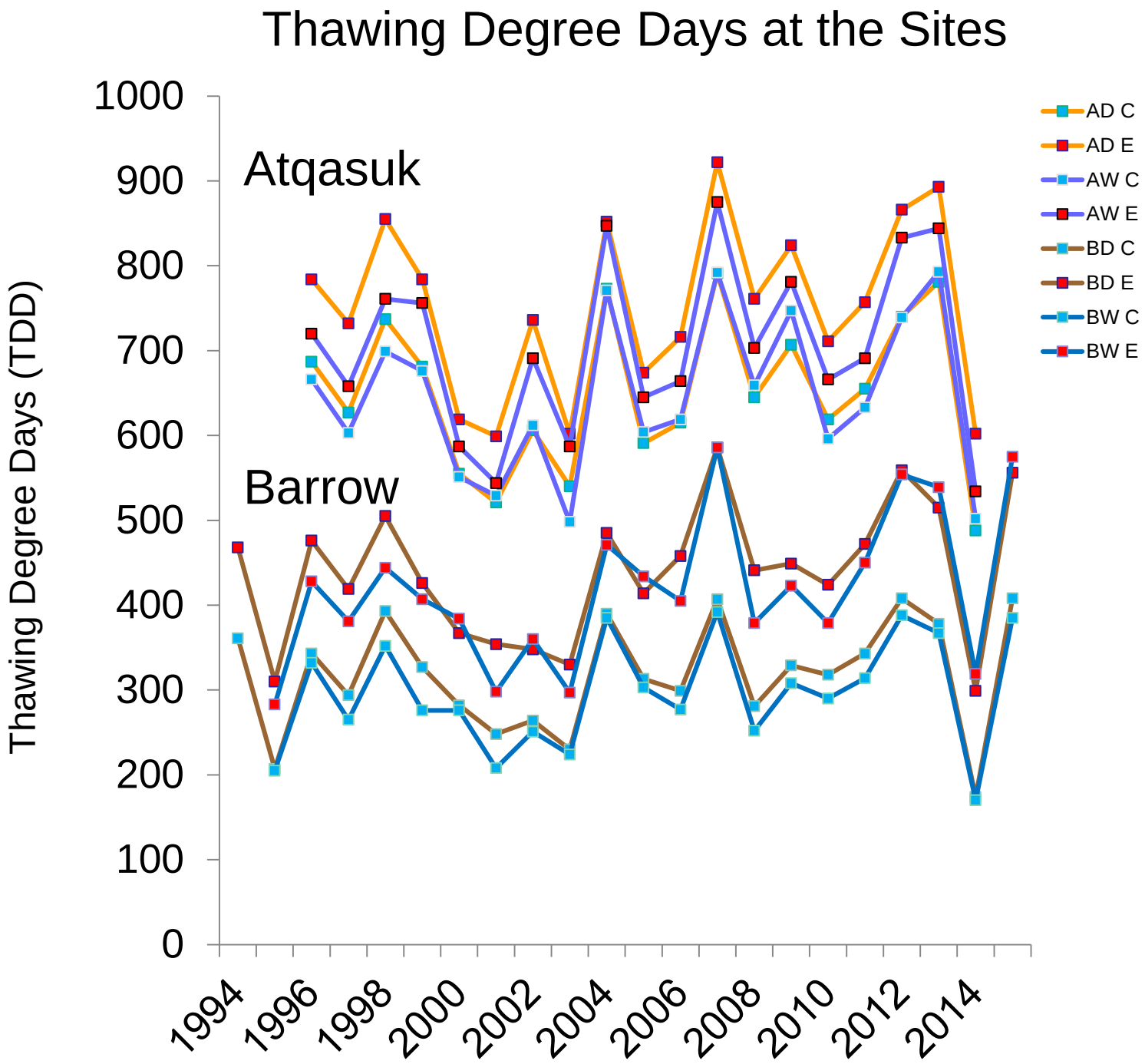
July


Temperature (°C)
15
10
5
0
20
15
10
5
0
Precipitation (cm)
Atqasuk
Barrow


1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year

July


Temperature (°C)
15
10
5
0
Atqasuk
Barrow
Precipitation (cm)
20
15
10
5
0
Soil Moisture (%WFV)
70
60
50
40
30
20
10
0
Wet sites
Dry sites
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Year


Thawing Degree Days at the Sites
Thawing Degree Days (TDD)
1000
900
800
700
600
500
400
300
200
100
0
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
Atqasuk
Barrow
AD C
AD E
AW C
AW E
BD C
BD E
BW C
BW E

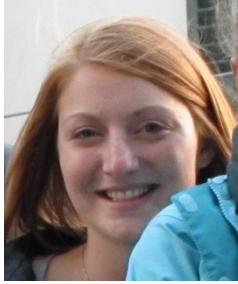
The work of my students

The GVSU Arctic Ecology Program
http://faculty.gvsu.edu/hollistr/

ARCTIC ECOLOGY
GRAND VALLEY STATE UNIVERSITY

Kremers et al. 2015. Diminished response of arctic plants to warming over time. *Plos One* 10(3): e0116586 1-13.

Kelsey Kremers



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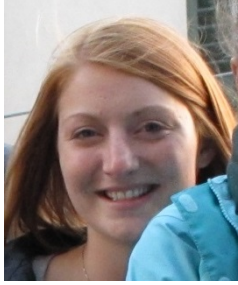


Plant traits
Phenology, Growth, Reproductive Effort

Years 1994-2000

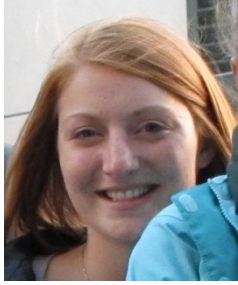
Years 2007-2012

Short Term (ST)

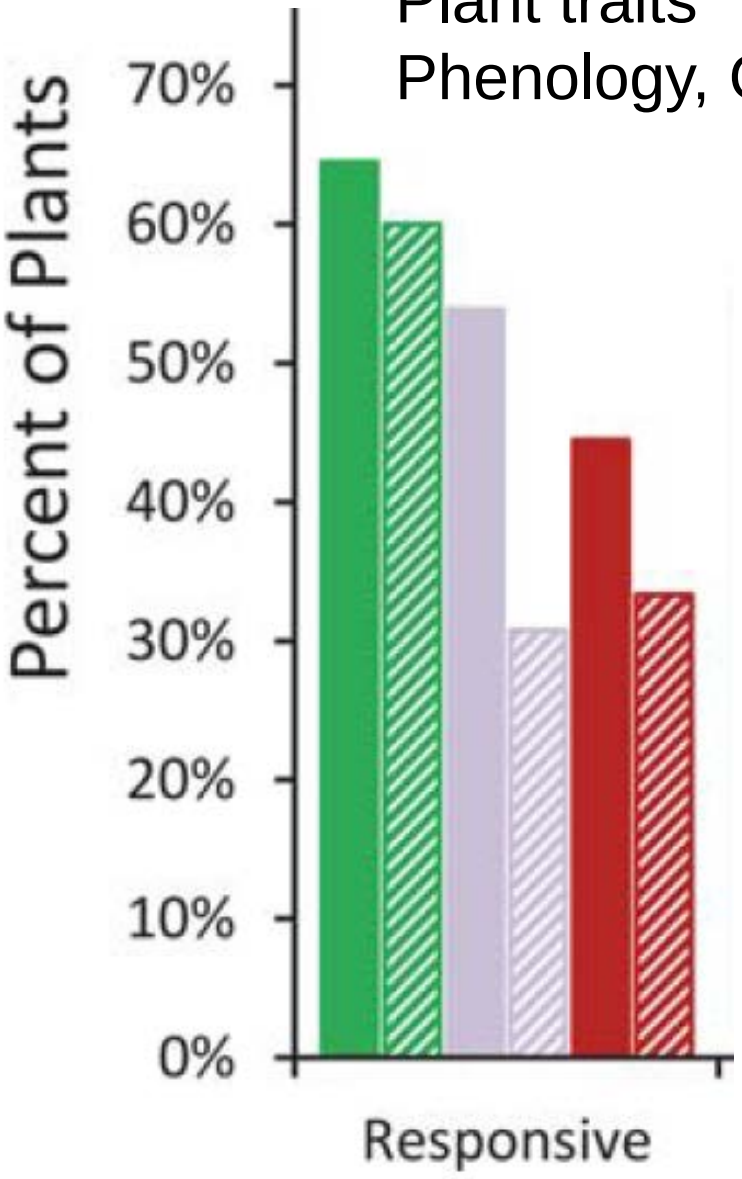
Long Term (LT)

Kremers et al. 2015. Diminished response of arctic plants to warming over time. *Plos One* 10(3): e0116586 1-13.

Kelsey Kremers



Plant traits
Phenology, Growth, Reproductive Effort



Graminoids (G)
Forbs (F)
Shrubs (S)

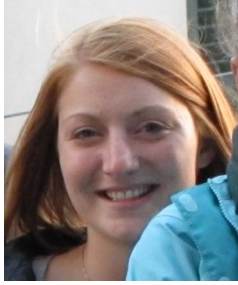
Short Term (ST)
Long Term (LT)

Years 1994-2000

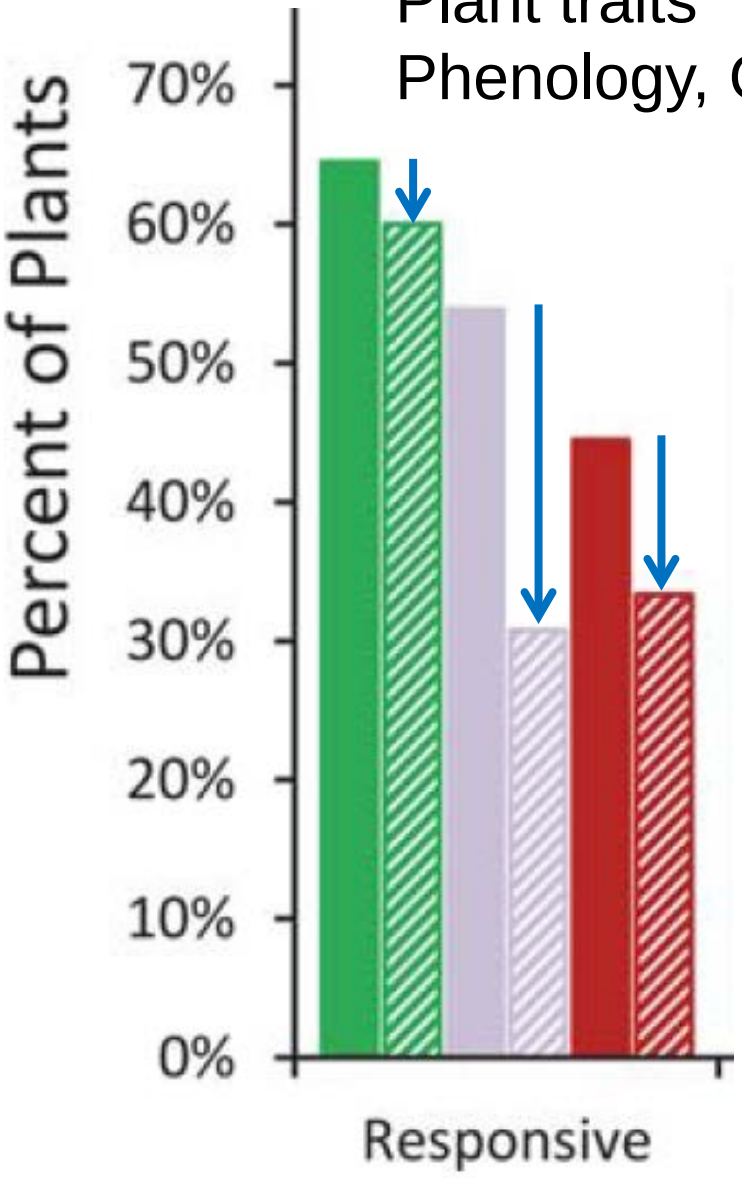
Years 2007-2012

Kremers et al. 2015. Diminished response of arctic plants to warming over time. *Plos One* 10(3): e0116586 1-13.

Kelsey Kremers



Plant traits
Phenology, Growth, Reproductive Effort



Graminoids (G)
Forbs (F)
Shrubs (S)

Short Term (ST)
Long Term (LT)

Years 1994-2000

Years 2007-2012

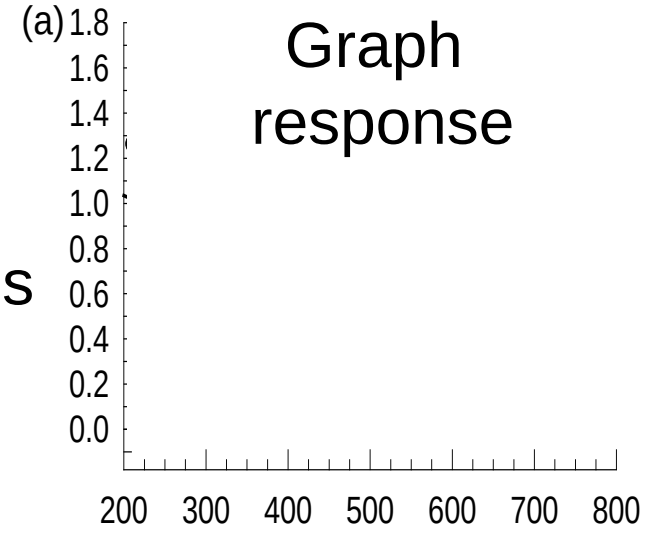
Consistent decrease in the number of species categorized as response

Barrett & Hollister. *In Press*. Arctic plants are capable of sustained responses to long-term warming. *Polar Research*.

Rob Barrett (Slider)

Barrett & Hollister. *In Press*. Arctic plants are capable of sustained responses to long-term warming. *Polar Research*.

Meta Analysis

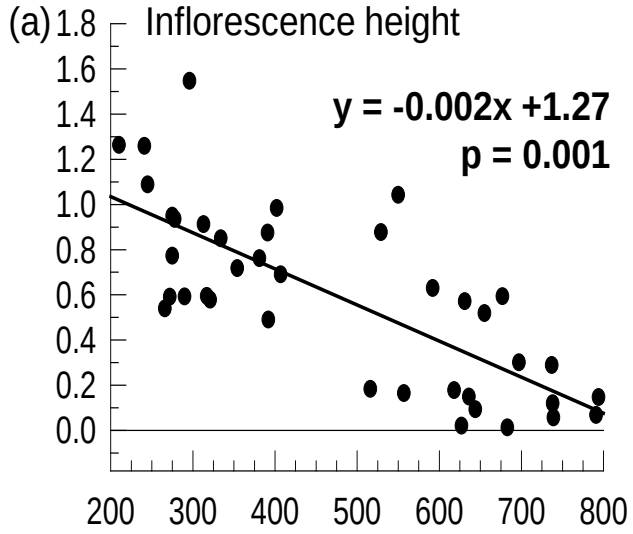


Graph response

Thawing Degree Days (TDD)

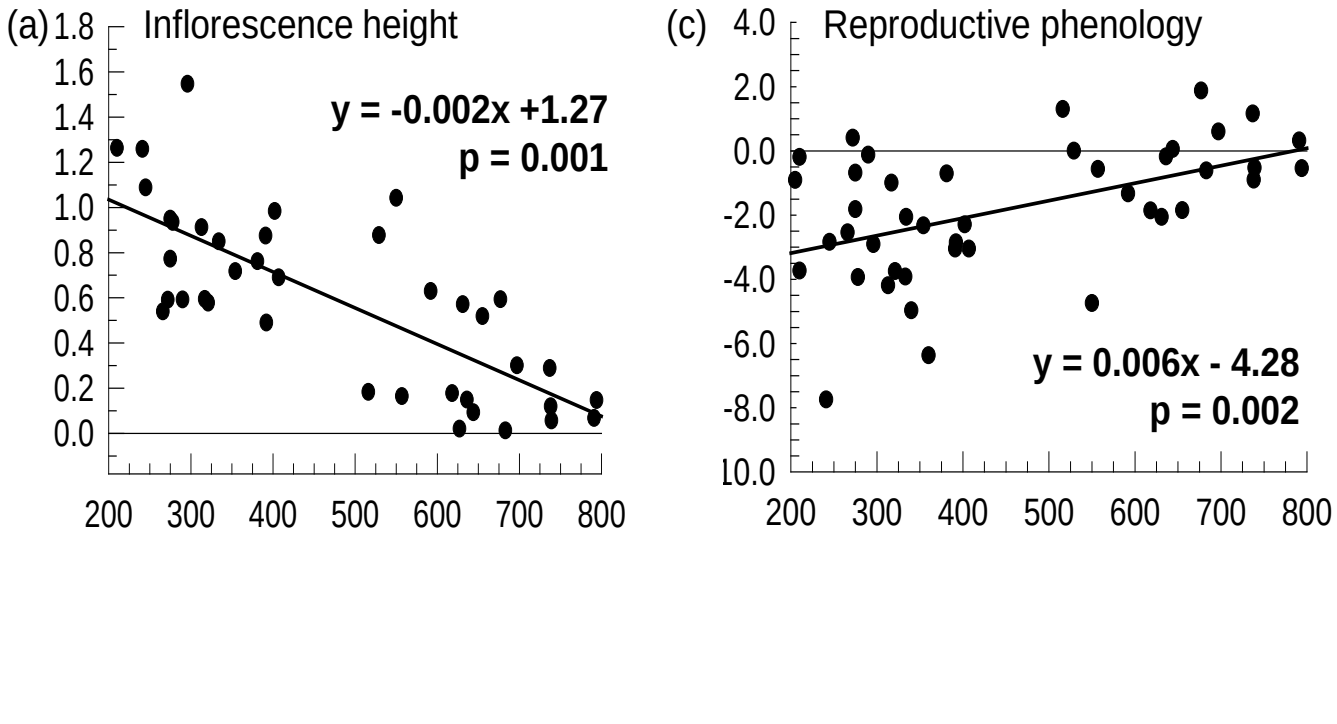
Rob Barrett (Slider)

Barrett & Hollister. *In Press*. Arctic plants are capable of sustained responses to long-term warming. *Polar Research*.



Rob Barrett (Slider)

Barrett & Hollister. *In Press*. Arctic plants are capable of sustained responses to long-term warming. *Polar Research*.



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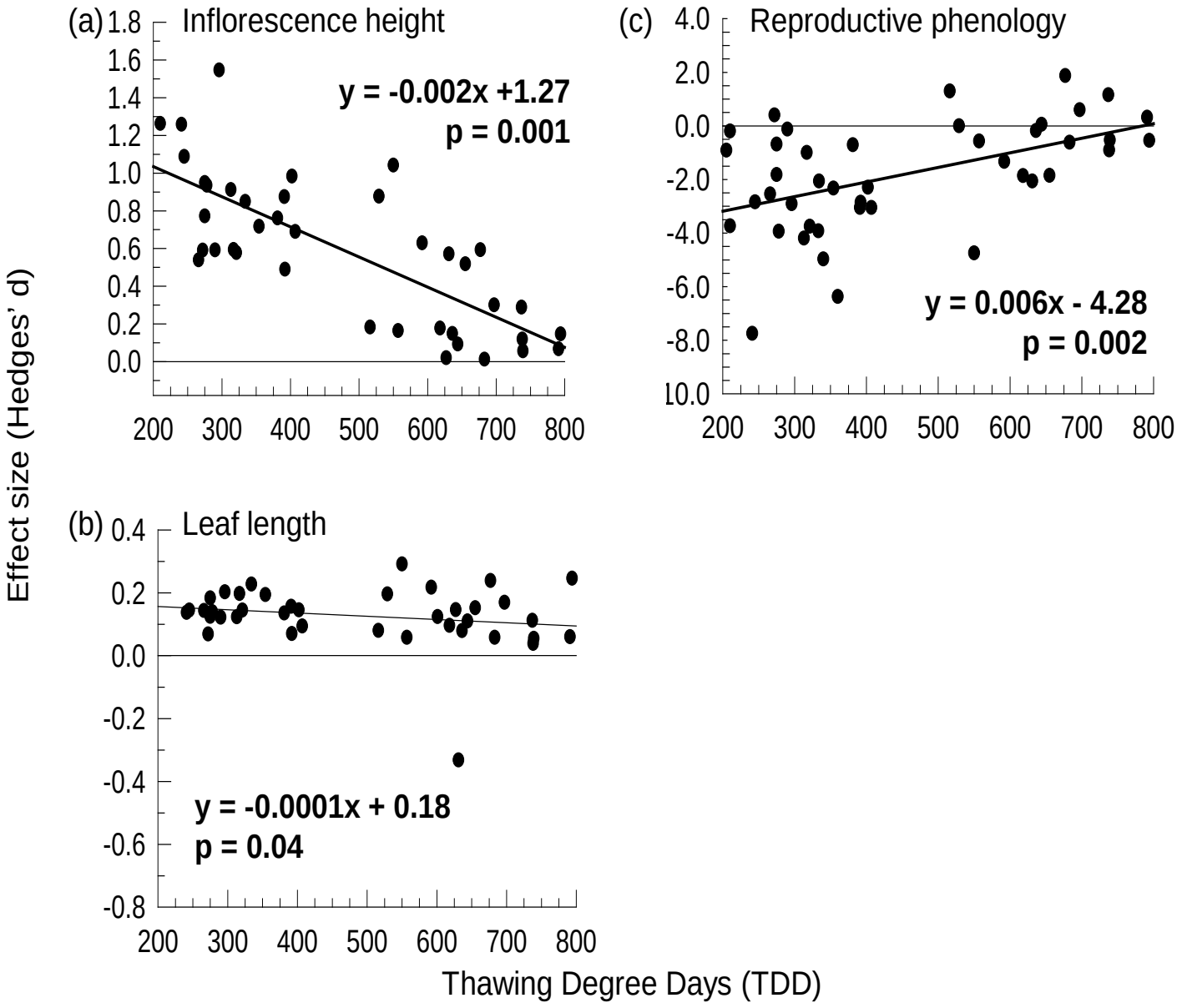

Rob Barrett (Slider)

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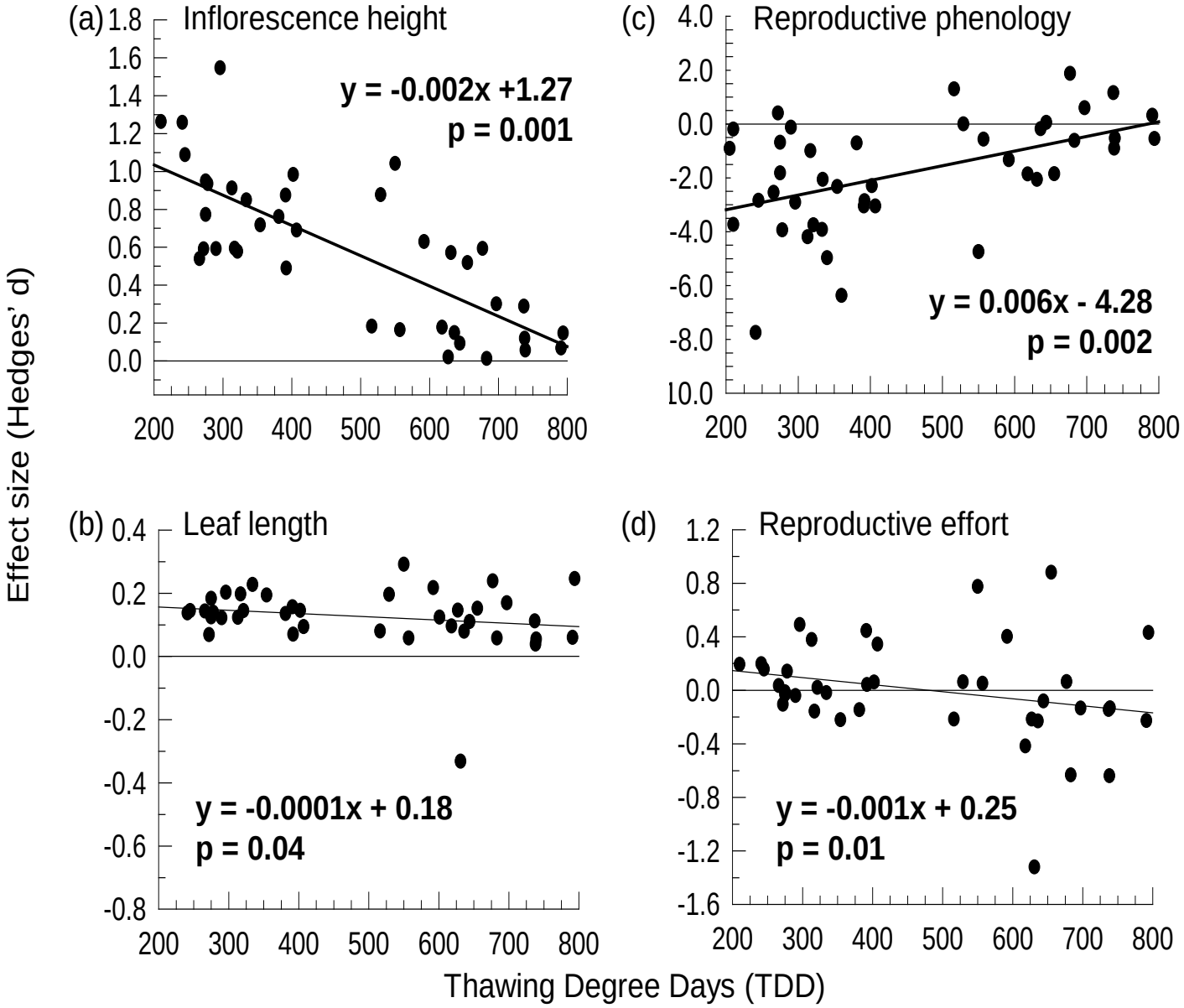
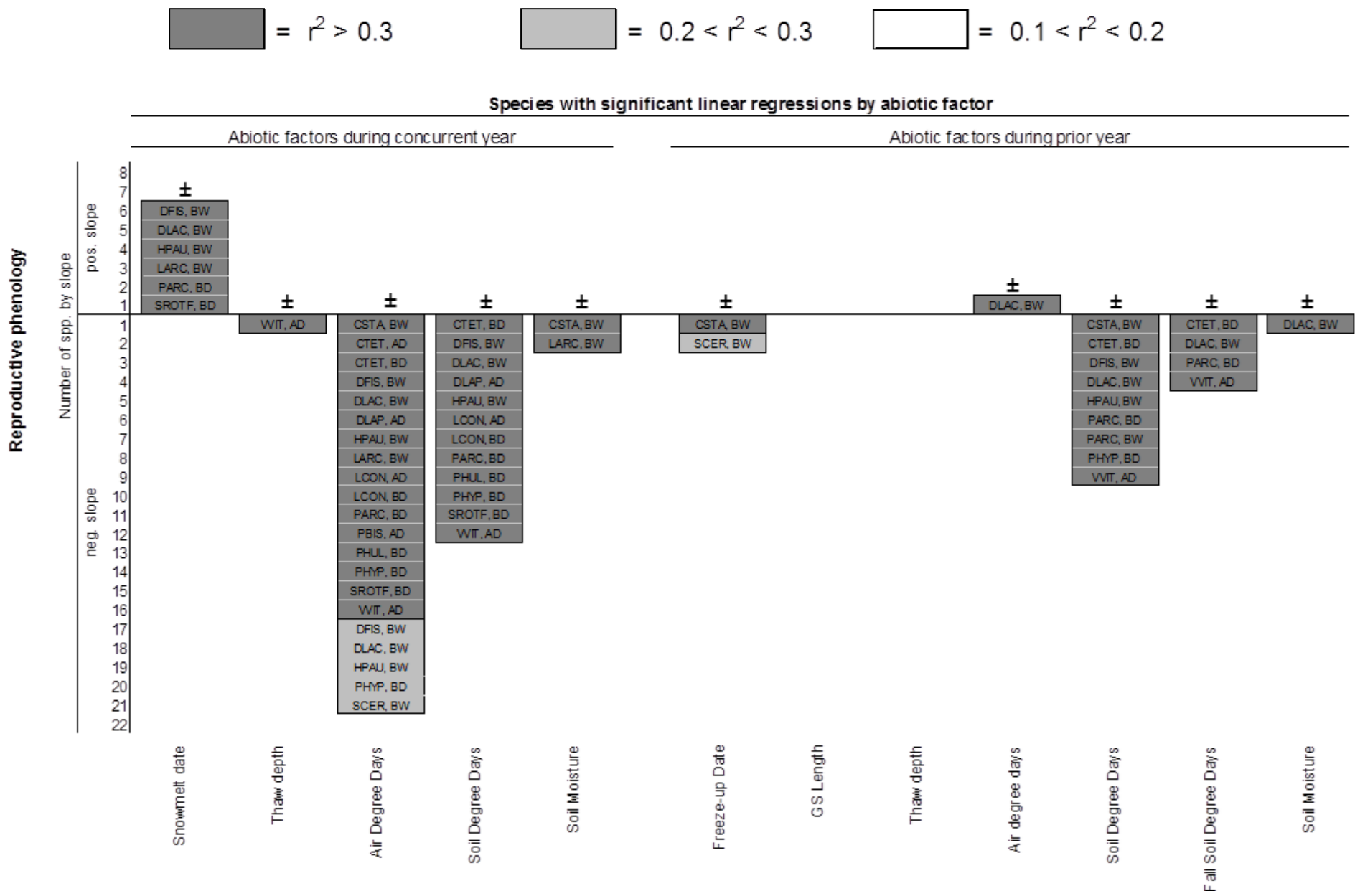
Rob Barrett (Slider)



Barrett et al. *In Review*. Arctic plant responses to changing abiotic factors in northern Alaska.

American *Journal of Botany*.



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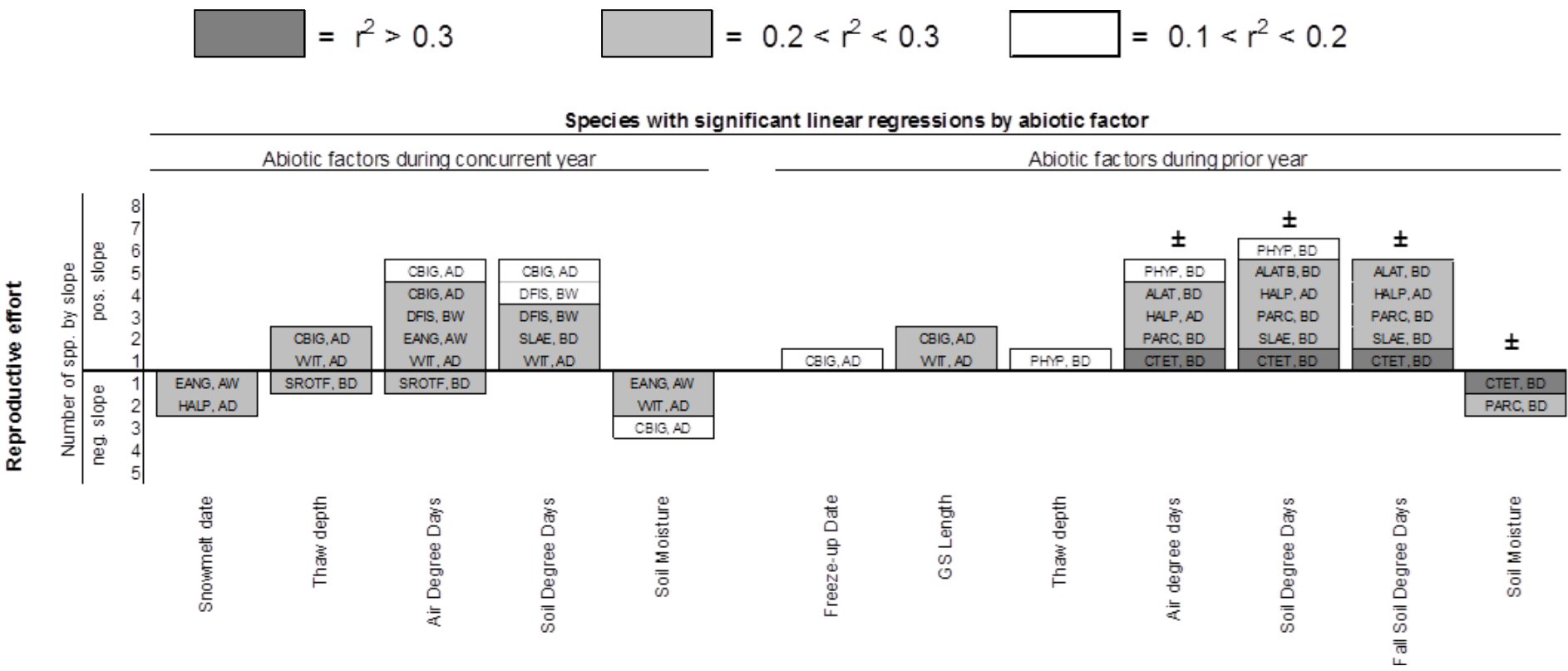
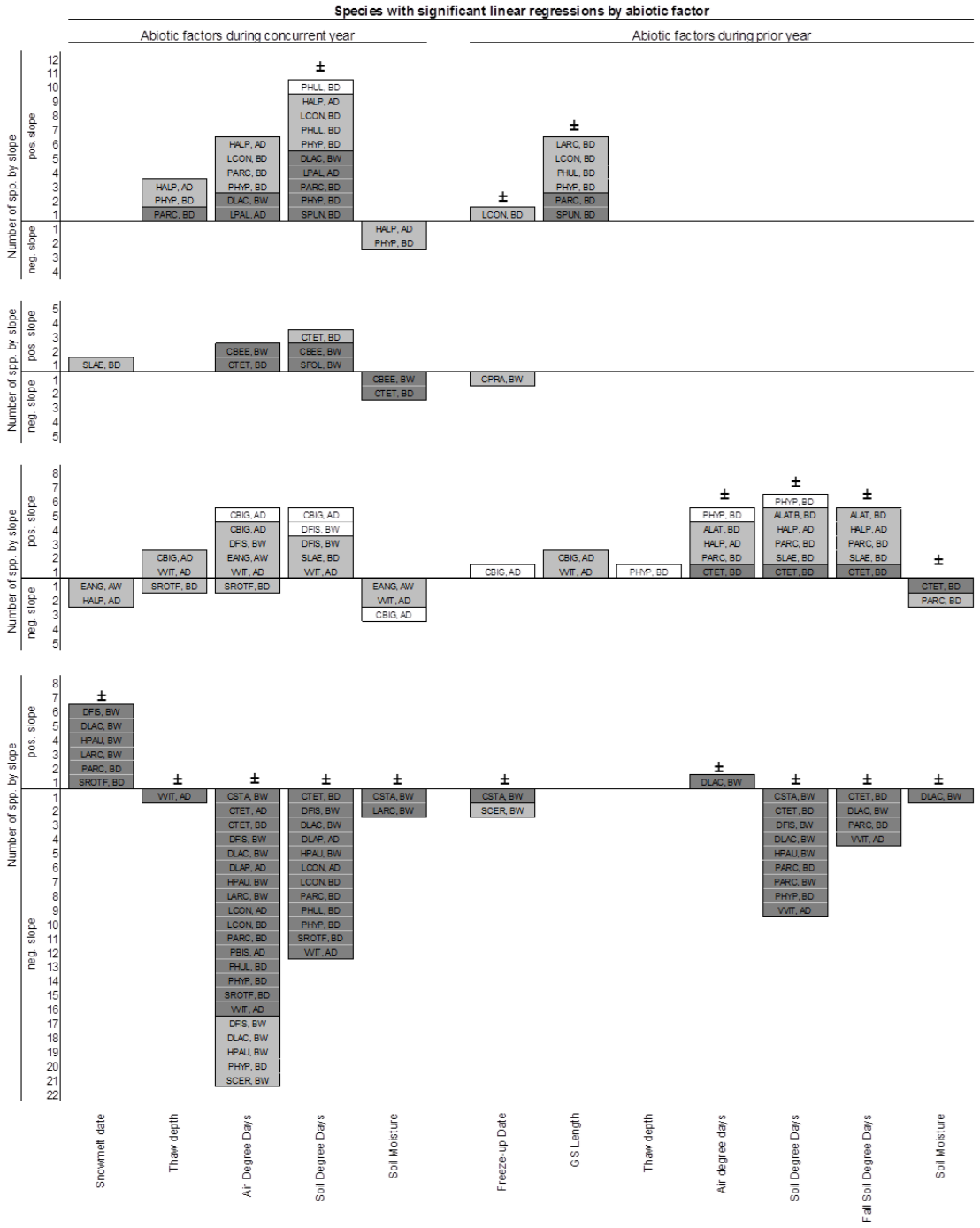


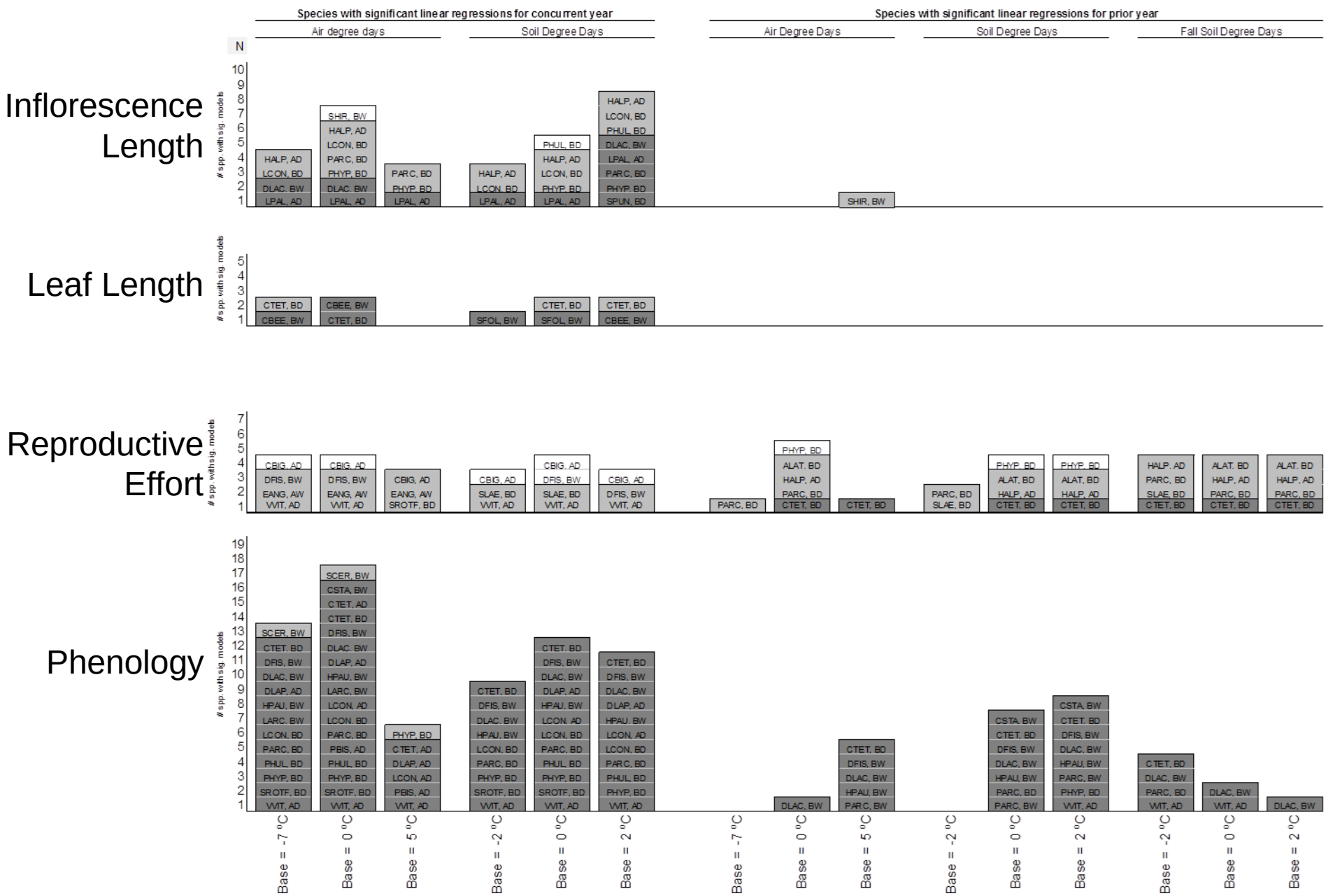
Inflorescence Length

Leaf Length

Reproductive Effort (number of flowers)

Reproductive Phenology (day of first flower)




Species with significant linear regressions for concurrent year
Species with significant linear regressions for prior year
Air degree days
Soil Degree Days
Air Degree Days
Soil Degree Days
Fall Soil Degree Days
N
Inflorescence Length
Leaf Length
Reproductive Effort
Phenology
# spp. with sig. models
Base = -7 °C
Base = 0 °C
Base = 5 °C
Base = -2 °C
Base = 0 °C
Base = 2 °C
Base = -7 °C
Base = 0 °C
Base = 5 °C
Base = -2 °C
Base = 0 °C
Base = 2 °C
Base = -2 °C
Base = 0 °C
Base = 2 °C

Jeremy May

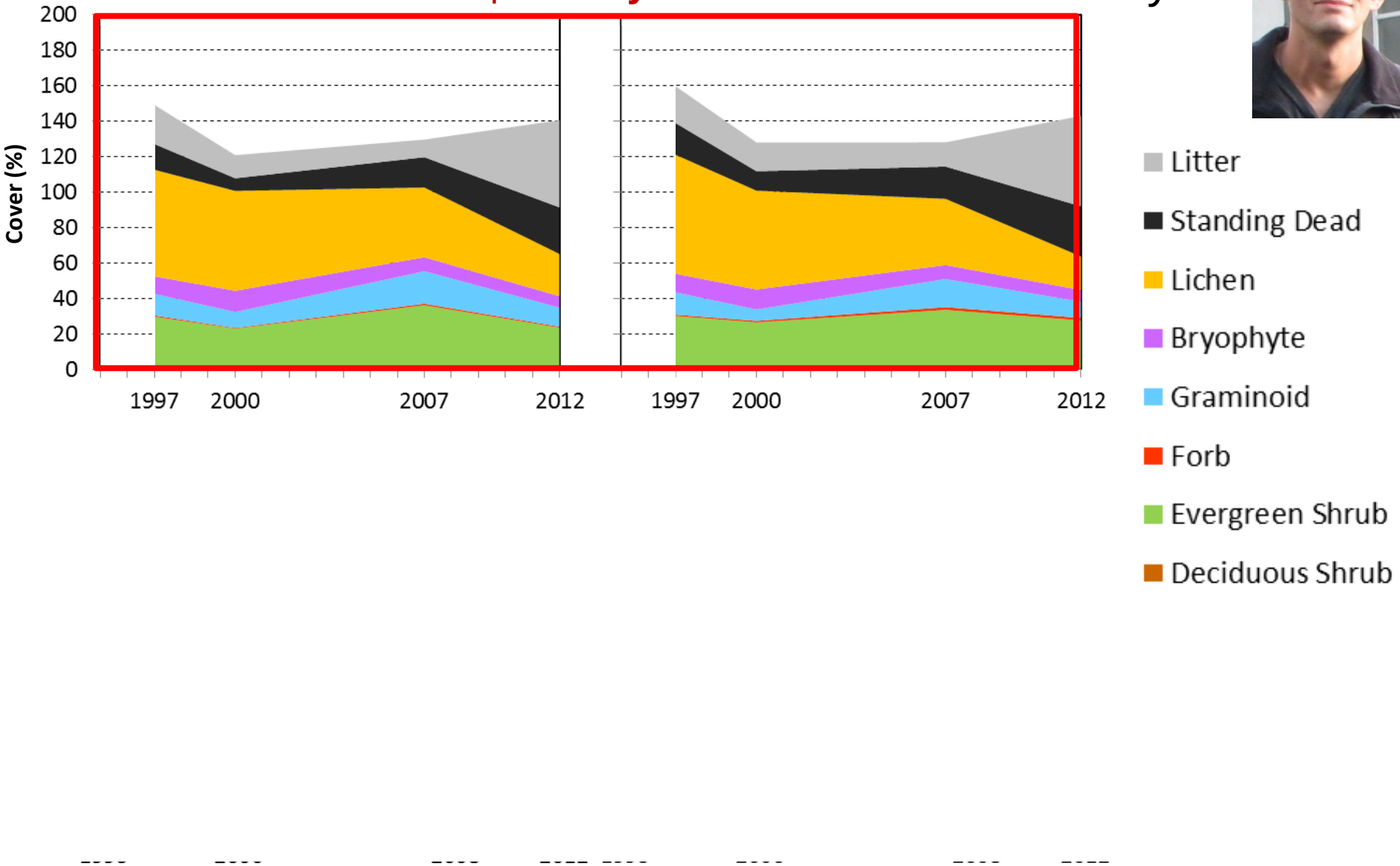
Hollister et al. 2015. Warming experiments elucidate the drivers of observed directional changes in tundra vegetation. *Ecology and Evolution* 5(9): 1881-1895.

Control

Warmed

Jeremy May

Atqasuk **Dry Site**



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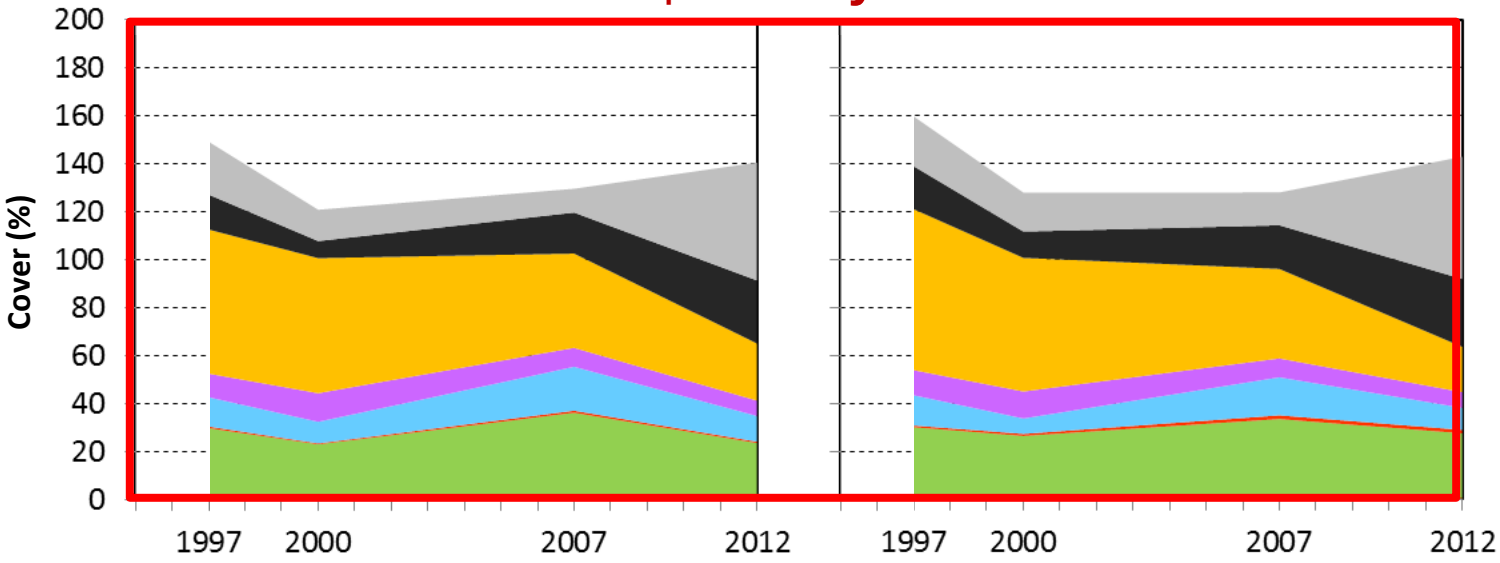
Control

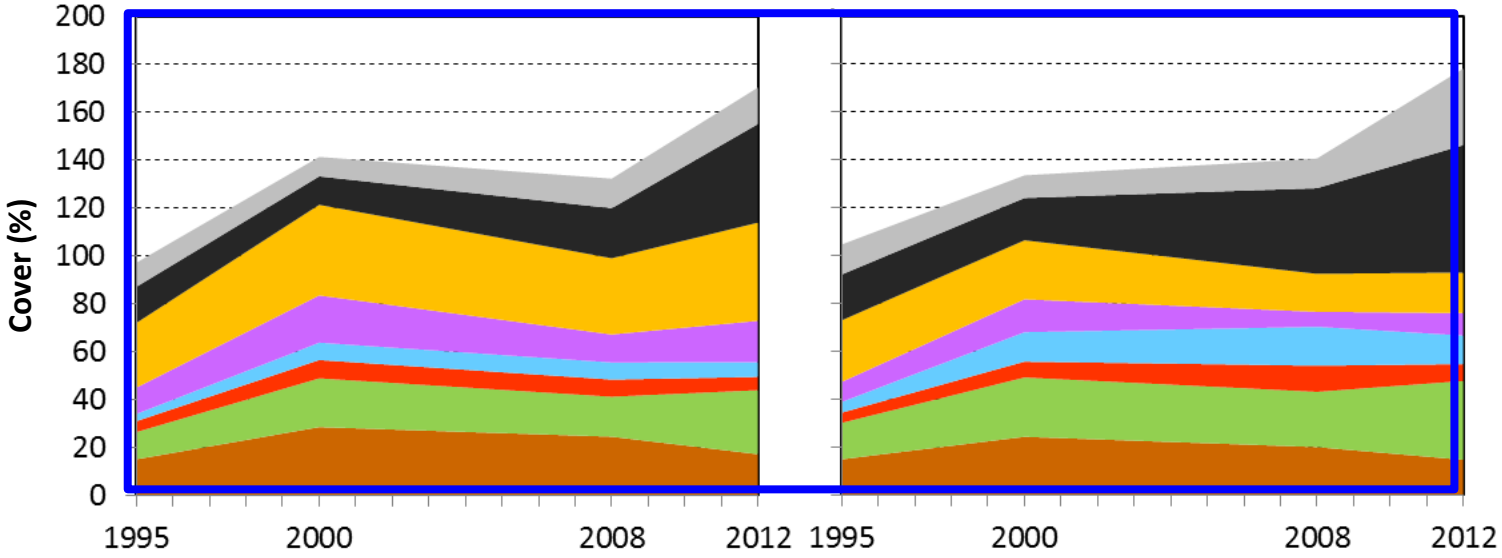
Warmed

Jeremy May

Atqasuk **Dry Site**



Barrow **Dry Site**



Litter

Standing Dead

Lichen

Bryophyte

Graminoid

Forb

Evergreen Shrub

Deciduous Shrub

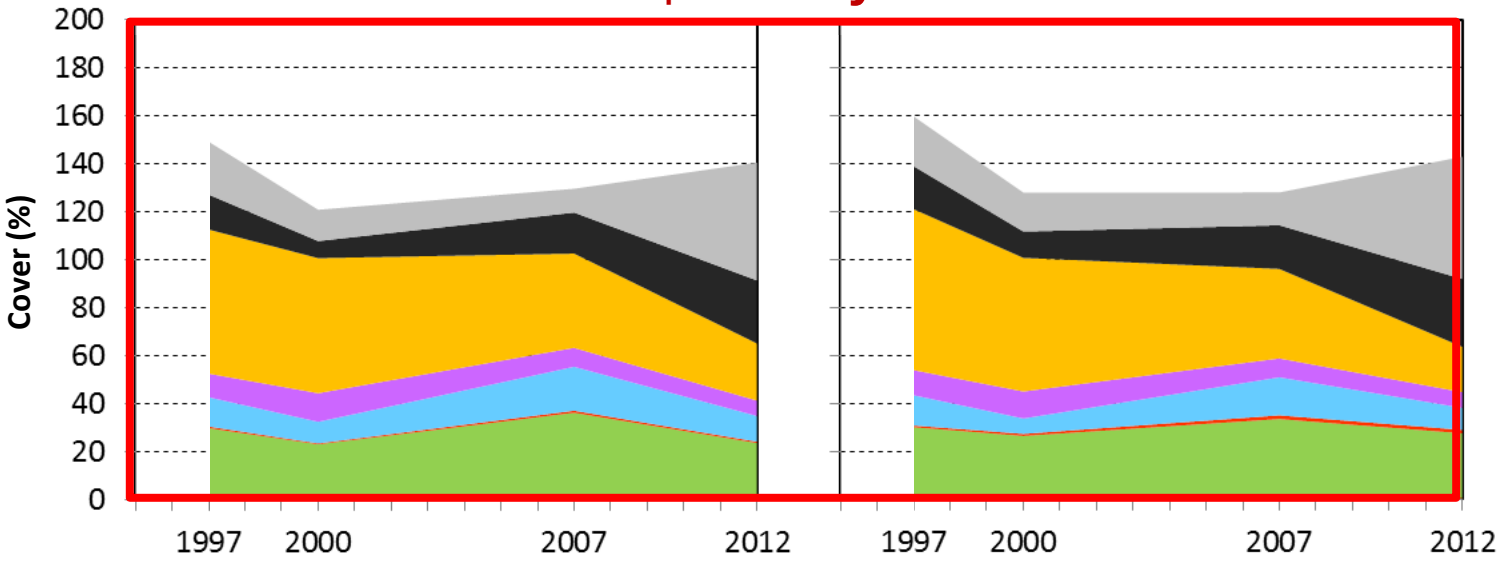
Hollister et al. 2015. Warming experiments elucidate the drivers of observed directional changes in tundra vegetation. *Ecology and Evolution* 5(9): 1881-1895.

Control

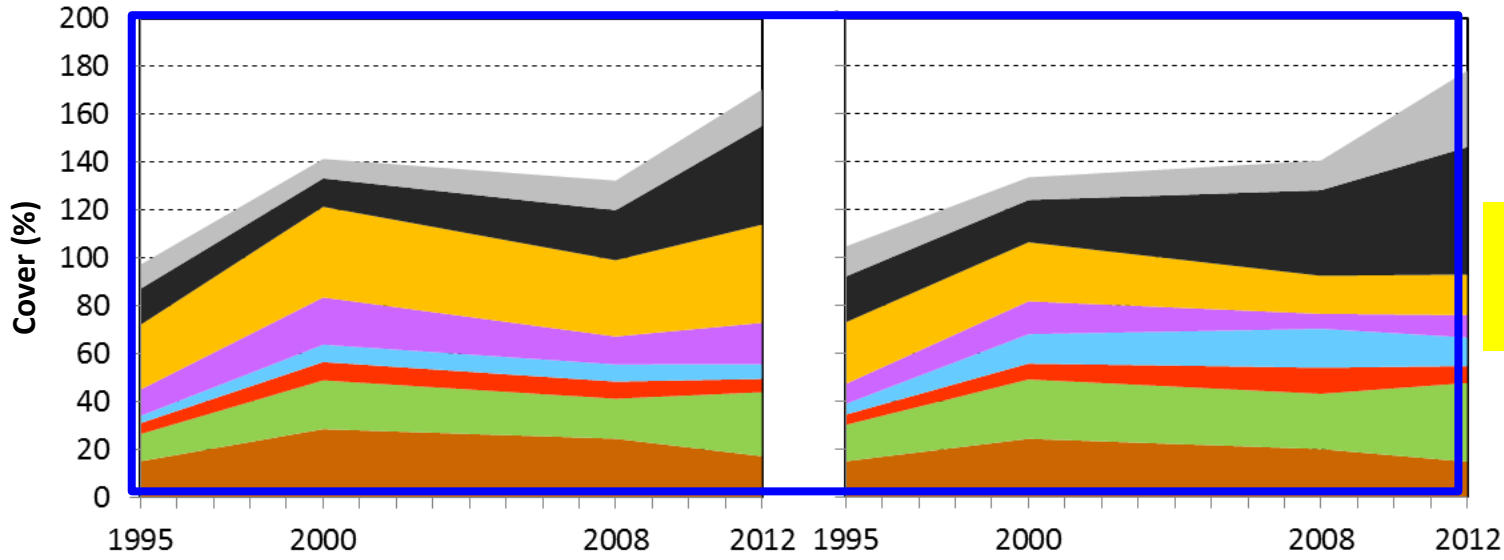
Warmed

Jeremy May

Atqasuk **Dry Site**



Barrow **Dry Site**



- Litter
- Standing Dead
- Lichen
- Bryophyte
- Graminoid
- Forb
- Evergreen Shrub
- Deciduous Shrub

Lichens decrease

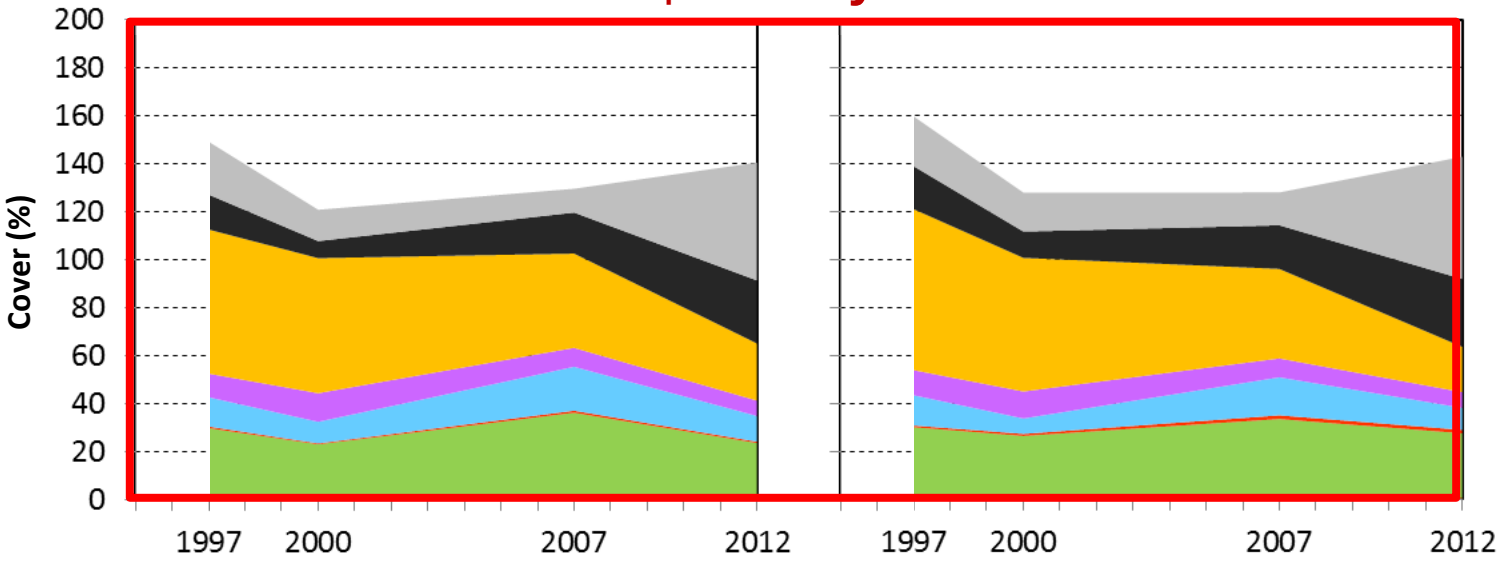
Hollister et al. 2015. Warming experiments elucidate the drivers of observed directional changes in tundra vegetation. *Ecology and Evolution* 5(9): 1881-1895.

Control

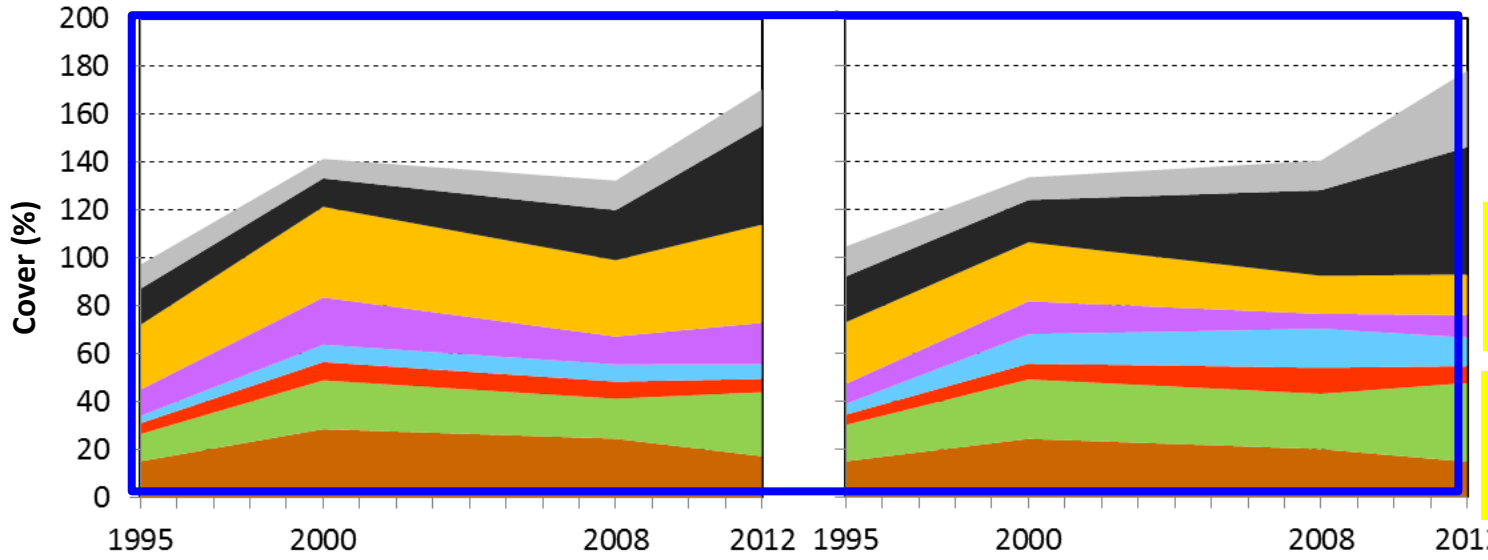
Warmed

Jeremy May

Atqasuk **Dry Site**



Barrow **Dry Site**

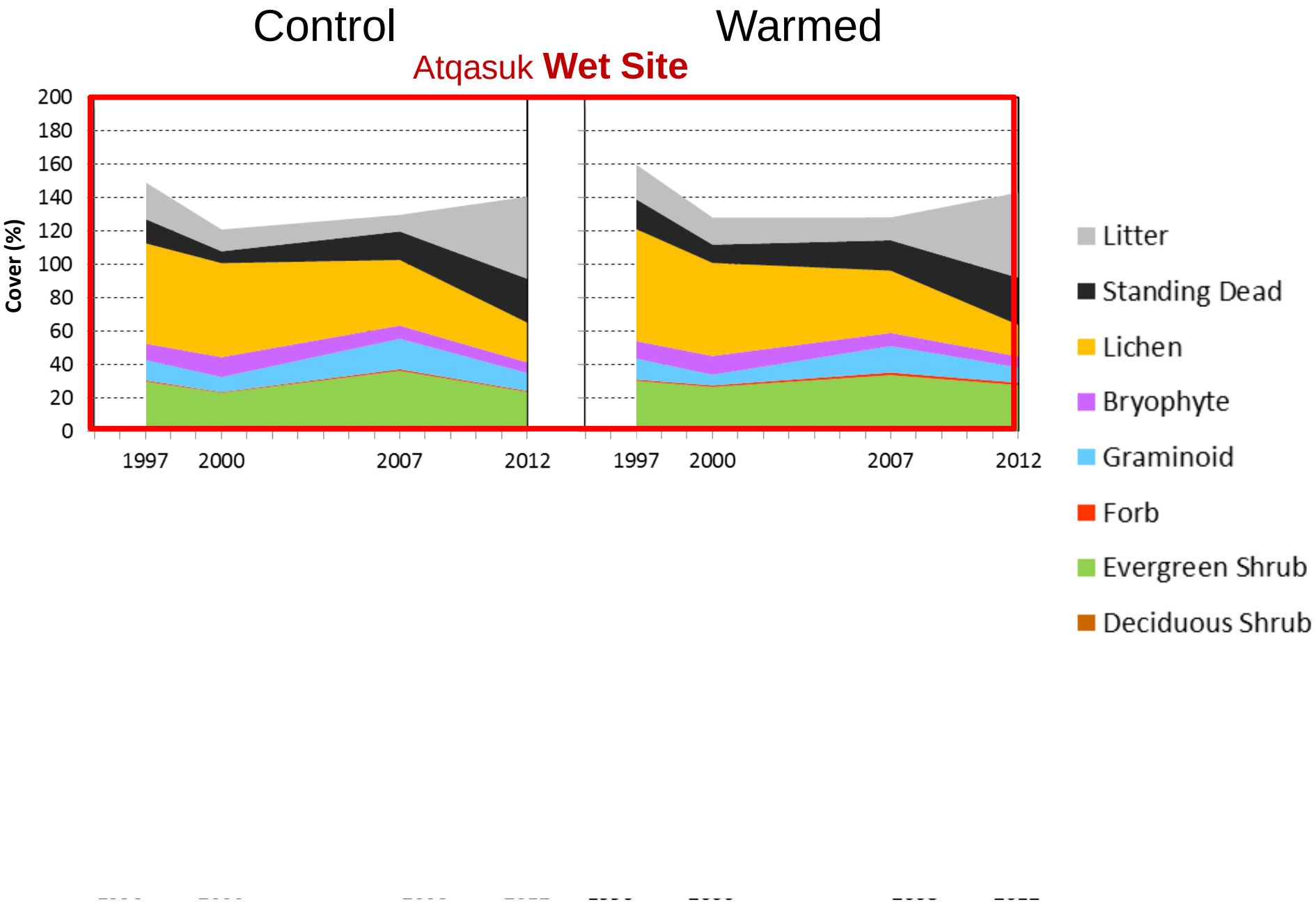


- Litter
- Standing Dead
- Lichen
- Bryophyte
- Graminoid
- Forb
- Evergreen Shrub
- Deciduous Shrub

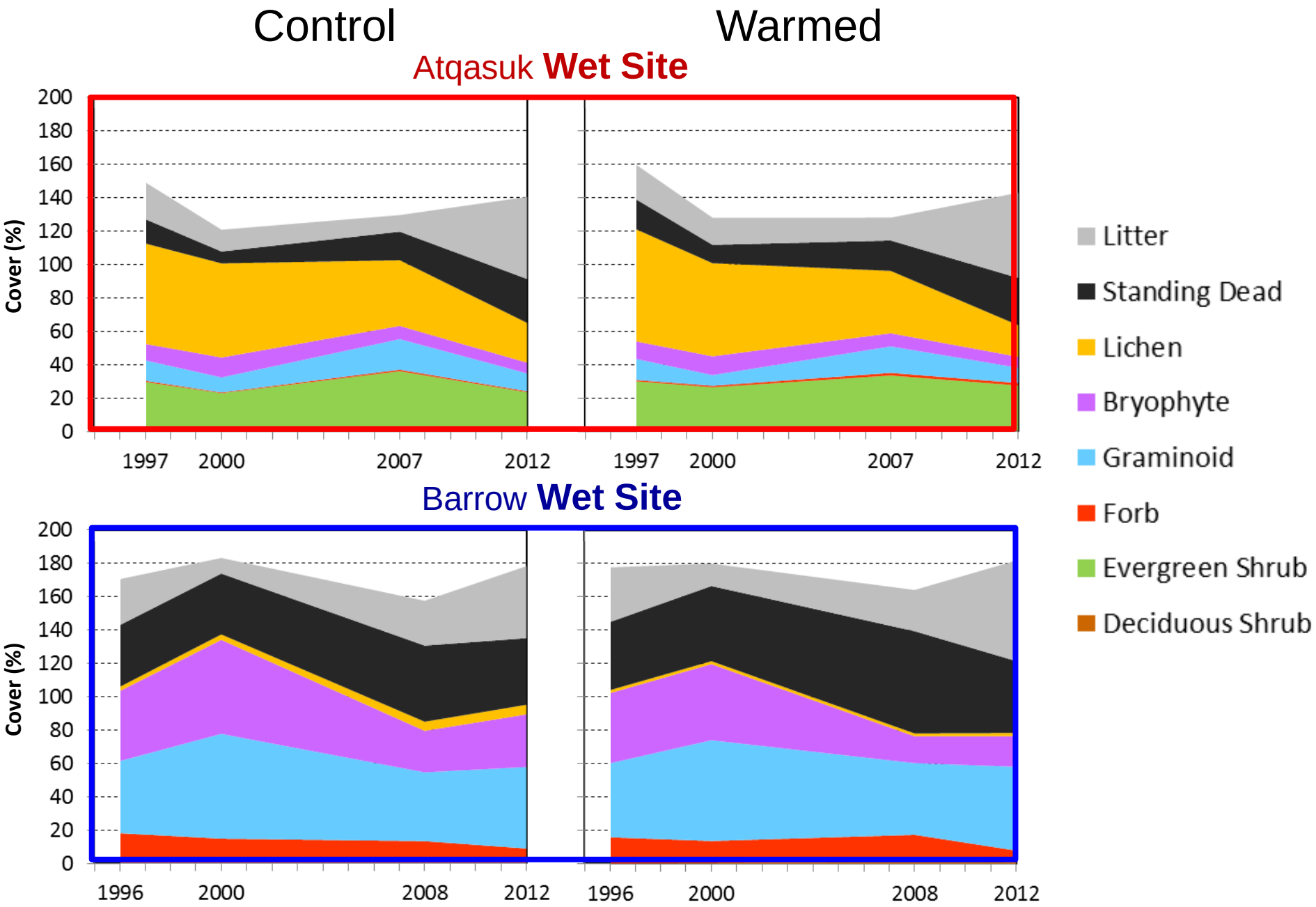
Lichens decrease

Shrubs increase

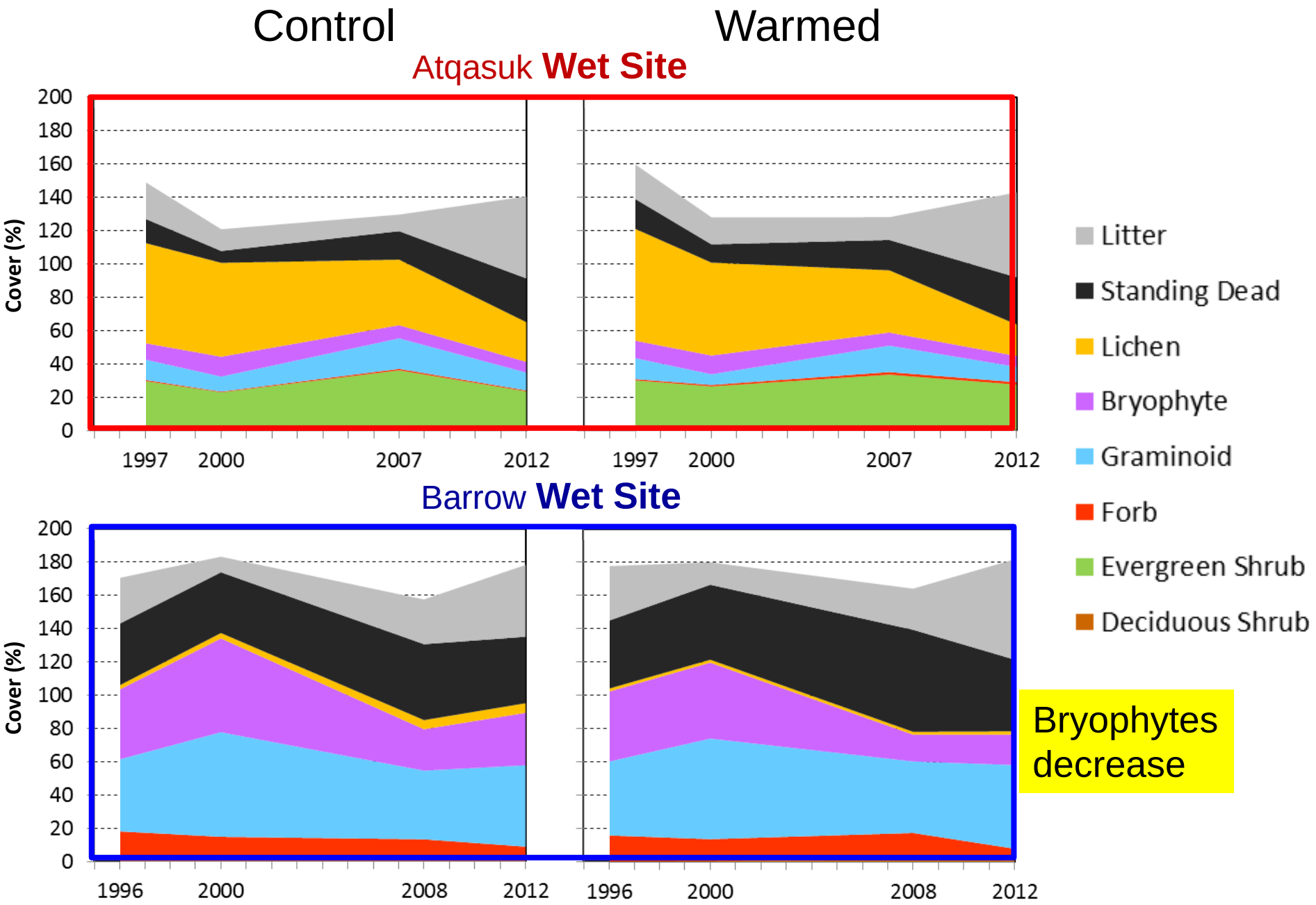
Hollister et al. 2015. Warming experiments elucidate the drivers of observed directional changes in tundra vegetation. *Ecology and Evolution* 5(9): 1881-1895.



Hollister et al. 2015. Warming experiments elucidate the drivers of observed directional changes in tundra vegetation. *Ecology and Evolution* 5(9): 1881-1895.



Hollister et al. 2015. Warming experiments elucidate the drivers of observed directional changes in tundra vegetation. *Ecology and Evolution* 5(9): 1881-1895.



Hollister et al. 2015. Warming experiments elucidate the drivers of observed directional changes in tundra vegetation. *Ecology and Evolution* 5(9): 1881-1895.

Table 2. Continued.

Taxa	C1	C2	C3	C4		E1	E2	E3	E4		W1	W2	W3	W4
Barrow Dry (BD) site														
Deciduous Shrub	**15.0 (1.1)**	**28.5 (1.1)**	**24.5 (1.5)**	**17.1 (1.6)**	**N**	**14.9 (1.3)**	**24.3 (2.0)**	**20.0 (1.8)**	**14.7 (1.2)**	**C⁻**	**−0.1**	**−4.2**	**−4.5**	**−2.5**
Salix rotundifolia	15.0 (1.1)	28.5 (1.1)	24.5 (1.5)	17.1 (1.6)	N	14.9 (1.3)	24.3 (2.0)	20.0 (1.8)	14.7 (1.2)	C⁻	−0.1	−4.2	−4.5	−2.5
Evergreen Shrub	**11.4 (1.0)**	**20.4 (1.0)**	**16.7 (1.2)**	**26.8 (1.7)**	**N**	**15.2 (1.1)**	**24.8 (1.8)**	**23.1 (2.0)**	**33.0 (2.5)**	***D*⁺**	**3.8**	**4.4**	**6.4**	**6.2**
Cassiope tetragona	11.3 (1.0)	19.8 (1.0)	16.6 (1.3)	26.5 (1.8)	N	15.2 (1.1)	24.8 (1.8)	23.1 (2.0)	33.0 (2.5)	*D*⁺	3.9	5.0	6.5	6.5
Forb	**4.5 (0.6)**	**7.7 (0.6)**	**7.2 (0.9)**	**5.5 (0.9)**	**N**	**4.3 (0.4)**	**6.6 (0.8)**	**10.9 (1.8)**	**7.0 (1.3)**	**.**	**−0.3**	**−1.0**	**3.8**	**1.5**
Potentilla hyparctica	2.0 (0.5)	2.4 (0.5)	3.0 (0.7)	2.5 (0.7)	.	1.8 (0.3)	1.2 (0.4)	4.0 (0.8)	3.0 (0.6)	.	−0.2	−1.3	1.1	0.4
Graminoid	**3.0 (0.6)**	**7.3 (0.6)**	**7.2 (0.7)**	**6.2 (0.8)**	**N**	**4.5 (0.8)**	**12.3 (1.9)**	**16.3 (1.8)**	**12.0 (1.4)**	**I**	**1.4**	**5.0**	**9.1**	**5.8**
Luzula confusa	1.3 (0.4)	3.0 (0.4)	3.6 (0.5)	2.3 (0.3)	N	1.3 (0.3)	2.8 (0.5)	4.4 (0.6)	2.2 (0.4)	.	0.0	−0.2	0.8	−0.1
Poa arctica	0.5 (0.1)	1.6 (0.1)	1.8 (0.3)	2.1 (0.4)	D⁺	0.6 (0.2)	3.8 (0.4)	6.2 (1.0)	5.8 (0.9)	D⁺	0.2	2.1	4.4	3.6
Bryophyte	**11.0 (1.0)**	**19.8 (1.0)**	**11.7 (1.0)**	**17.3 (1.9)**	**N**	**8.4 (0.9)**	**13.8 (1.4)**	**6.3 (0.9)**	**9.4 (1.4)**	**C⁻**	**−2.6**	**−6.0**	**−5.4**	**−7.9**
Acrocarpous Moss	7.5 (0.9)	11.8 (0.9)	7.7 (0.9)	7.9 (1.0)	N	5.4 (0.6)	9.6 (1.1)	3.6 (0.5)	5.6 (0.9)	C⁻	−2.1	−2.2	−4.1	−2.3
Pleurocarpous Moss	2.0 (0.6)	5.7 (0.6)	3.0 (0.7)	8.9 (1.8)	N	1.3 (0.5)	3.2 (0.8)	2.1 (0.5)	3.5 (1.0)	I	−0.7	−2.5	−0.9	−5.4
Lichen	**27.0 (1.2)**	**37.9 (1.2)**	**31.9 (2.0)**	**41.0 (1.9)**	**N**	**25.8 (2.0)**	**24.7 (2.7)**	**15.9 (1.9)**	**17.0 (2.3)**	**D⁻**	**−1.3**	**−13.2**	**−16.0**	**−24.1**
Foliose Lichen	6.3 (0.9)	8.5 (0.9)	8.5 (0.7)	9.0 (0.9)	.	6.0 (0.7)	6.0 (0.6)	4.3 (0.6)	5.2 (0.7)	*D*⁻	−0.3	−2.5	−4.3	−3.8
Fruticose Lichen	16.7 (1.0)	26.3 (1.0)	22.8 (1.6)	31.0 (1.7)	N	15.7 (1.6)	15.8 (2.2)	11.1 (1.6)	11.1 (1.9)	D⁻	−1.0	−10.5	−11.8	−19.9
Barrow Wet (BW) site														
Deciduous Shrub	**0.2 (0.1)**	**0.0 (0.1)**	**0.0 (0.0)**	**0.2 (0.1)**	**.**	**0.3 (0.2)**	**0.7 (0.4)**	**1.8 (1.0)**	**1.2 (0.6)**	**C⁺**	**0.2**	**0.6**	**1.8**	**1.0**
Forb	**17.8 (1.8)**	**14.6 (1.8)**	**13.2 (1.8)**	**8.5 (1.6)**	**D⁻**	**15.6 (1.7)**	**13.1 (1.9)**	**15.7 (2.0)**	**6.8 (0.9)**	**.**	**−2.2**	**−1.5**	**2.5**	**−1.8**
Saxifraga cernua	2.0 (0.4)	2.1 (0.4)	1.9 (0.5)	0.9 (0.2)	.	2.5 (0.4)	1.9 (0.4)	3.8 (0.7)	1.4 (0.3)	C⁺	0.4	−0.2	1.9	0.5
Stellaria laeta	4.0 (0.8)	2.1 (0.8)	1.8 (0.4)	1.3 (0.3)	N	4.0 (0.9)	3.1 (0.9)	1.6 (0.3)	1.1 (0.2)	.	0.0	1.0	−0.2	−0.2
Graminoid	**43.3 (1.8)**	**63.0 (1.8)**	**41.3 (2.4)**	**49.0 (2.2)**	**N**	**44.4 (1.2)**	**60.4 (6.8)**	**43.0 (2.2)**	**50.3 (2.8)**	**.**	**1.1**	**−2.5**	**1.7**	**1.3**
Carex aquatilis	18.5 (2.0)	14.6 (2.0)	19.0 (1.4)	20.3 (1.6)	N	23.1 (2.0)	16.6 (1.5)	26.6 (1.3)	25.5 (1.8)	C⁺	4.5	2.0	7.7	5.3
Dupontia fisheri	7.8 (0.9)	12.9 (0.9)	7.8 (1.0)	13.6 (2.0)	N	6.1 (0.8)	9.0 (1.4)	4.0 (0.6)	9.2 (1.5)	C⁻	−1.6	−3.8	−3.8	−4.4
Eriophorum angustifolium	9.9 (1.5)	19.0 (1.5)	4.9 (1.0)	7.8 (1.5)	N	8.4 (1.4)	18.6 (4.1)	4.0 (0.7)	7.0 (1.9)	.	−1.5	−0.4	−0.9	−0.8
Eriophorum russeolum	2.3 (0.4)	4.9 (0.4)	5.0 (0.6)	2.6 (0.6)	N	2.8 (0.6)	4.0 (0.9)	4.7 (0.7)	3.1 (0.7)	.	0.6	−0.9	−0.3	0.5
Poaceae spp.[2]	3.8 (0.7)	11.3 (0.7)	4.1 (0.8)	4.4 (0.7)	N	2.7 (0.4)	11.8 (1.5)	2.8 (0.7)	5.3 (0.9)	.	−1.1	0.5	−1.3	0.9
Bryophyte	**42.0 (3.1)**	**56.4 (3.1)**	**24.9 (3.0)**	**31.6 (4.2)**	**N**	**42.0 (4.1)**	**45.6 (3.3)**	**16.1 (2.2)**	**18.4 (3.0)**	**D⁻**	**0.0**	**−10.8**	**−8.8**	**−13.2**
Acrocarpous Moss	17.2 (1.9)	25.1 (1.9)	9.1 (1.3)	14.3 (2.4)	N	16.5 (2.7)	20.6 (2.7)	7.4 (1.0)	8.7 (1.8)	C⁻	−0.7	−4.5	−1.7	−5.6
Pleurocarpous Moss[1]	23.8 (2.2)	30.9 (2.9)	15.7 (2.7)	16.9 (4.0)	N	24.9 (3.0)	24.0 (2.1)	8.7 (1.7)	9.4 (2.0)	D⁻	1.1	−6.9	−7.0	−7.5
Lichen	**2.5 (0.8)**	**3.3 (0.8)**	**5.5 (1.8)**	**5.8 (2.1)**	**.**	**1.8 (0.7)**	**1.8 (0.9)**	**1.7 (0.7)**	**1.9 (0.8)**	***D*⁻**	**−0.8**	**−1.5**	**−3.8**	**−3.9**
Foliose Lichen	2.5 (0.8)	3.3 (0.8)	5.5 (1.8)	5.8 (2.1)	.	1.6 (0.7)	1.7 (0.9)	1.6 (0.7)	1.8 (0.8)	*D*⁻	−0.9	−1.6	−3.8	−4.0

Consistent change

Table 2. Continued.

Taxa	C1	C2	C3	C4		E1	E2	E3	E4		W1	W2	W3	W4
Barrow Dry (BD) site														
Deciduous Shrub	**15.0 (1.1)**	**28.5 (1.1)**	**24.5 (1.5)**	**17.1 (1.6)**	**N**	**14.9 (1.3)**	**24.3 (2.0)**	**20.0 (1.8)**	**14.7 (1.2)**	**C⁻**	**−0.1**	**−4.2**	**−4.5**	**−2.5**
Salix rotundifolia	15.0 (1.1)	28.5 (1.1)	24.5 (1.5)	17.1 (1.6)	N	14.9 (1.3)	24.3 (2.0)	20.0 (1.8)	14.7 (1.2)	C⁻	−0.1	−4.2	−4.5	−2.5
Evergreen Shrub	**11.4 (1.0)**	**20.4 (1.0)**	**16.7 (1.2)**	**26.8 (1.7)**	**N**	**15.2 (1.1)**	**24.8 (1.8)**	**23.1 (2.0)**	**33.0 (2.5)**	**D⁺**	**3.8**	**4.4**	**6.4**	**6.2**
Cassiope tetragona	11.3 (1.0)	19.8 (1.0)	16.6 (1.3)	26.5 (1.8)	N	15.2 (1.1)	24.8 (1.8)	23.1 (2.0)	33.0 (2.5)	D⁺	3.9	5.0	6.5	6.5
Forb	**4.5 (0.6)**	**7.7 (0.6)**	**7.2 (0.9)**	**5.5 (0.9)**	**N**	**4.3 (0.4)**	**6.6 (0.8)**	**10.9 (1.8)**	**7.0 (1.3)**	**.**	**−0.3**	**−1.0**	**3.8**	**1.5**
Potentilla hyparctica	2.0 (0.5)	2.4 (0.5)	3.0 (0.7)	2.5 (0.7)	.	1.8 (0.3)	1.2 (0.4)	4.0 (0.8)	3.0 (0.6)	.	−0.2	−1.3	1.1	0.4
Graminoid	**3.0 (0.6)**	**7.3 (0.6)**	**7.2 (0.7)**	**6.2 (0.8)**	**N**	**4.5 (0.8)**	**12.3 (1.9)**	**16.3 (1.8)**	**12.0 (1.4)**	**I**	**1.4**	**5.0**	**9.1**	**5.8**
Luzula confusa	1.3 (0.4)	3.0 (0.4)	3.6 (0.5)	2.3 (0.3)	N	1.3 (0.3)	2.8 (0.5)	4.4 (0.6)	2.2 (0.4)	.	0.0	−0.2	0.8	−0.1
Poa arctica	0.5 (0.1)	1.6 (0.1)	1.8 (0.3)	2.1 (0.4)	D⁺	0.6 (0.2)	3.8 (0.4)	6.2 (1.0)	5.8 (0.9)	D⁺	0.2	2.1	4.4	3.6
Bryophyte	**11.0 (1.0)**	**19.8 (1.0)**	**11.7 (1.0)**	**17.3 (1.9)**	**N**	**8.4 (0.9)**	**13.8 (1.4)**	**6.3 (0.9)**	**9.4 (1.4)**	**C⁻**	**−2.6**	**−6.0**	**−5.4**	**−7.9**
Acrocarpous Moss	7.5 (0.9)	11.8 (0.9)	7.7 (0.9)	7.9 (1.0)	N	5.4 (0.6)	9.6 (1.1)	3.6 (0.5)	5.6 (0.9)	C⁻	−2.1	−2.2	−4.1	−2.3
Pleurocarpous Moss	2.0 (0.6)	5.7 (0.6)	3.0 (0.7)	8.9 (1.8)	N	1.3 (0.5)	3.2 (0.8)	2.1 (0.5)	3.5 (1.0)	I	−0.7	−2.5	−0.9	−5.4
Lichen	**27.0 (1.2)**	**37.9 (1.2)**	**31.9 (2.0)**	**41.0 (1.9)**	**N**	**25.8 (2.0)**	**24.7 (2.7)**	**15.9 (1.9)**	**17.0 (2.3)**	**D⁻**	**−1.3**	**−13.2**	**−16.0**	**−24.1**
Foliose Lichen	6.3 (0.9)	8.5 (0.9)	8.5 (0.7)	9.0 (0.9)	.	6.0 (0.7)	6.0 (0.6)	4.3 (0.6)	5.2 (0.7)	D⁻	−0.3	−2.5	−4.3	−3.8
Fruticose Lichen	16.7 (1.0)	26.3 (1.0)	22.8 (1.6)	31.0 (1.7)	N	15.7 (1.6)	15.8 (2.2)	11.1 (1.6)	11.1 (1.9)	D⁻	−1.0	−10.5	−11.8	−19.9
Barrow Wet (BW) site														
Deciduous Shrub	**0.2 (0.1)**	**0.0 (0.1)**	**0.0 (0.0)**	**0.2 (0.1)**	**.**	**0.3 (0.2)**	**0.7 (0.4)**	**1.8 (1.0)**	**1.2 (0.6)**	**C⁺**	**0.2**	**0.6**	**1.8**	**1.0**
Forb	**17.8 (1.8)**	**14.6 (1.8)**	**13.2 (1.8)**	**8.5 (1.6)**	**D⁻**	**15.6 (1.7)**	**13.1 (1.9)**	**15.7 (2.0)**	**6.8 (0.9)**	**.**	**−2.2**	**−1.5**	**2.5**	**−1.8**
Saxifraga cernua	2.0 (0.4)	2.1 (0.4)	1.9 (0.5)	0.9 (0.2)	.	2.5 (0.4)	1.9 (0.4)	3.8 (0.7)	1.4 (0.3)	C⁺	0.4	−0.2	1.9	0.5
Stellaria laeta	4.0 (0.8)	2.1 (0.8)	1.8 (0.4)	1.3 (0.3)	N	4.0 (0.9)	3.1 (0.9)	1.6 (0.3)	1.1 (0.2)	.	0.0	1.0	−0.2	−0.2
Graminoid	**43.3 (1.8)**	**63.0 (1.8)**	**41.3 (2.4)**	**49.0 (2.2)**	**N**	**44.4 (1.2)**	**60.4 (6.8)**	**43.0 (2.2)**	**50.3 (2.8)**	**.**	**1.1**	**−2.5**	**1.7**	**1.3**
Carex aquatilis	18.5 (2.0)	14.6 (2.0)	19.0 (1.4)	20.3 (1.6)	N	23.1 (2.0)	16.6 (1.5)	26.6 (1.3)	25.5 (1.8)	C⁺	4.5	2.0	7.7	5.3
Dupontia fisheri	7.8 (0.9)	12.9 (0.9)	7.8 (1.0)	13.6 (2.0)	N	6.1 (0.8)	9.0 (1.4)	4.0 (0.6)	9.2 (1.5)	C⁻	−1.6	−3.8	−3.8	−4.4
Eriophorum angustifolium	9.9 (1.5)	19.0 (1.5)	4.9 (1.0)	7.8 (1.5)	N	8.4 (1.4)	18.6 (4.1)	4.0 (0.7)	7.0 (1.9)	.	−1.5	−0.4	−0.9	−0.8
Eriophorum russeolum	2.3 (0.4)	4.9 (0.4)	5.0 (0.6)	2.6 (0.6)	N	2.8 (0.6)	4.0 (0.9)	4.7 (0.7)	3.1 (0.7)	.	0.6	−0.9	−0.3	0.5
Poaceae spp.[2]	3.8 (0.7)	11.3 (0.7)	4.1 (0.8)	4.4 (0.7)	N	2.7 (0.4)	11.8 (1.5)	2.8 (0.7)	5.3 (0.9)	.	−1.1	0.5	−1.3	0.9
Bryophyte	**42.0 (3.1)**	**56.4 (3.1)**	**24.9 (3.0)**	**31.6 (4.2)**	**N**	**42.0 (4.1)**	**45.6 (3.3)**	**16.1 (2.2)**	**18.4 (3.0)**	**D⁻**	**0.0**	**−10.8**	**−8.8**	**−13.2**
Acrocarpous Moss	17.2 (1.9)	25.1 (1.9)	9.1 (1.3)	14.3 (2.4)	N	16.5 (2.7)	20.6 (2.7)	7.4 (1.0)	8.7 (1.8)	C⁻	−0.7	−4.5	−1.7	−5.6
Pleurocarpous Moss[1]	23.8 (2.2)	30.9 (2.9)	15.7 (2.7)	16.9 (4.0)	N	24.9 (3.0)	24.0 (2.1)	8.7 (1.7)	9.4 (2.0)	D⁻	1.1	−6.9	−7.0	−7.5
Lichen	**2.5 (0.8)**	**3.3 (0.8)**	**5.5 (1.8)**	**5.8 (2.1)**	**.**	**1.8 (0.7)**	**1.8 (0.9)**	**1.7 (0.7)**	**1.9 (0.8)**	**D⁻**	**−0.8**	**−1.5**	**−3.8**	**−3.9**
Foliose Lichen	2.5 (0.8)	3.3 (0.8)	5.5 (1.8)	5.8 (2.1)	.	1.6 (0.7)	1.7 (0.9)	1.6 (0.7)	1.8 (0.8)	D⁻	−0.9	−1.6	−3.8	−4.0

Clear Directional change

Table 2. Continued.

Taxa	C1	C2	C3	C4		E1	E2	E3	E4		W1	W2	W3	W4
Barrow Dry (BD) site														
Deciduous Shrub	**15.0 (1.1)**	**28.5 (1.1)**	**24.5 (1.5)**	**17.1 (1.6)**	**N**	**14.9 (1.3)**	**24.3 (2.0)**	**20.0 (1.8)**	**14.7 (1.2)**	**C⁻**	**−0.1**	**−4.2**	**−4.5**	**−2.5**
Salix rotundifolia	15.0 (1.1)	28.5 (1.1)	24.5 (1.5)	17.1 (1.6)	N	14.9 (1.3)	24.3 (2.0)	20.0 (1.8)	14.7 (1.2)	C⁻	−0.1	−4.2	−4.5	−2.5
Evergreen Shrub	**11.4 (1.0)**	**20.4 (1.0)**	**16.7 (1.2)**	**26.8 (1.7)**	**N**	**15.2 (1.1)**	**24.8 (1.8)**	**23.1 (2.0)**	**33.0 (2.5)**	***D*⁺**	**3.8**	**4.4**	**6.4**	**6.2**
Cassiope tetragona	11.3 (1.0)	19.8 (1.0)	16.6 (1.3)	26.5 (1.8)	N	15.2 (1.1)	24.8 (1.8)	23.1 (2.0)	33.0 (2.5)	*D*⁺	3.9	5.0	6.5	6.5
Forb	**4.5 (0.6)**	**7.7 (0.6)**	**7.2 (0.9)**	**5.5 (0.9)**	**N**	**4.3 (0.4)**	**6.6 (0.8)**	**10.9 (1.8)**	**7.0 (1.3)**	**.**	**−0.3**	**−1.0**	**3.8**	**1.5**
Potentilla hyparctica	2.0 (0.5)	2.4 (0.5)	3.0 (0.7)	2.5 (0.7)	.	1.8 (0.3)	1.2 (0.4)	4.0 (0.8)	3.0 (0.6)	.	−0.2	−1.3	1.1	0.4
Graminoid	**3.0 (0.6)**	**7.3 (0.6)**	**7.2 (0.7)**	**6.2 (0.8)**	**N**	**4.5 (0.8)**	**12.3 (1.9)**	**16.3 (1.8)**	**12.0 (1.4)**	**I**	**1.4**	**5.0**	**9.1**	**5.8**
Luzula confusa	1.3 (0.4)	3.0 (0.4)	3.6 (0.5)	2.3 (0.3)	N	1.3 (0.3)	2.8 (0.5)	4.4 (0.6)	2.2 (0.4)		0.0	0.2	0.8	0.1
Poa arctica	0.5 (0.1)	1.6 (0.1)	1.8 (0.3)	2.1 (0.4)	D⁺	0.6 (0.2)	3.8 (0.4)	6.2 (1.0)	5.8 (0.9)	D⁺	0.2	2.1	4.4	3.6
Bryophyte	**11.0 (1.0)**	**19.8 (1.0)**	**11.7 (1.0)**	**17.3 (1.9)**	**N**	**8.4 (0.9)**	**13.8 (1.4)**	**6.3 (0.9)**	**9.4 (1.4)**	**C**	**−2.6**	**−6.0**	**−5.4**	**−7.9**
Acrocarpous Moss	7.5 (0.9)	11.8 (0.9)	7.7 (0.9)	7.9 (1.0)	N	5.4 (0.6)	9.6 (1.1)	3.6 (0.5)	5.6 (0.9)	C⁻	−2.1	−2.2	−4.1	−2.3
Pleurocarpous Moss	2.0 (0.6)	5.7 (0.6)	3.0 (0.7)	8.9 (1.8)	N	1.3 (0.5)	3.2 (0.8)	2.1 (0.5)	3.5 (1.0)	I	−0.7	−2.5	−0.9	−5.4
Lichen	**27.0 (1.2)**	**37.9 (1.2)**	**31.9 (2.0)**	**41.0 (1.9)**	**N**	**25.8 (2.0)**	**24.7 (2.7)**	**15.9 (1.9)**	**17.0 (2.3)**	**D⁻**	**−1.3**	**−13.2**	**−16.0**	**−24.1**
Foliose Lichen	6.3 (0.9)	8.5 (0.9)	8.5 (0.7)	9.0 (0.9)	.	6.0 (0.7)	6.0 (0.6)	4.3 (0.6)	5.2 (0.7)	*D⁻*	−0.3	−2.5	−4.3	−3.8
Fruticose Lichen	16.7 (1.0)	26.3 (1.0)	22.8 (1.6)	31.0 (1.7)	N	15.7 (1.6)	15.8 (2.2)	11.1 (1.6)	11.1 (1.9)	D⁻	−1.0	−10.5	−11.8	−19.9
Barrow Wet (BW) site														
Deciduous Shrub	**0.2 (0.1)**	**0.0 (0.1)**	**0.0 (0.0)**	**0.2 (0.1)**	**.**	**0.3 (0.2)**	**0.7 (0.4)**	**1.8 (1.0)**	**1.2 (0.6)**	**C⁺**	**0.2**	**0.6**	**1.8**	**1.0**
Forb	**17.8 (1.8)**	**14.6 (1.8)**	**13.2 (1.8)**	**8.5 (1.6)**	**D⁻**	**15.6 (1.7)**	**13.1 (1.9)**	**15.7 (2.0)**	**6.8 (0.9)**	**.**	**−2.2**	**−1.5**	**2.5**	**−1.8**
Saxifraga cernua	2.0 (0.4)	2.1 (0.4)	1.9 (0.5)	0.9 (0.2)	.	2.5 (0.4)	1.9 (0.4)	3.8 (0.7)	1.4 (0.3)	C⁺	0.4	−0.2	1.9	0.5
Stellaria laeta	4.0 (0.8)	2.1 (0.8)	1.8 (0.4)	1.3 (0.3)	N	4.0 (0.9)	3.1 (0.9)	1.6 (0.3)	1.1 (0.2)	.	0.0	1.0	−0.2	−0.2
Graminoid	**43.3 (1.8)**	**63.0 (1.8)**	**41.3 (2.4)**	**49.0 (2.2)**	**N**	**44.4 (1.2)**	**60.4 (6.8)**	**43.0 (2.2)**	**50.3 (2.8)**	**.**	**1.1**	**−2.5**	**1.7**	**1.3**
Carex aquatilis	18.5 (2.0)	14.6 (2.0)	19.0 (1.4)	20.3 (1.6)	N	23.1 (2.0)	16.6 (1.5)	26.6 (1.3)	25.5 (1.8)	C⁺	4.5	2.0	7.7	5.3
Dupontia fisheri	7.8 (0.9)	12.9 (0.9)	7.8 (1.0)	13.6 (2.0)	N	6.1 (0.8)	9.0 (1.4)	4.0 (0.6)	9.2 (1.5)	C⁻	−1.6	−3.8	−3.8	−4.4
Eriophorum angustifolium	9.9 (1.5)	19.0 (1.5)	4.9 (1.0)	7.8 (1.5)	N	8.4 (1.4)	18.6 (4.1)	4.0 (0.7)	7.0 (1.9)	.	−1.5	−0.4	−0.9	−0.8
Eriophorum russeolum	2.3 (0.4)	4.9 (0.4)	5.0 (0.6)	2.6 (0.6)	N	2.8 (0.6)	4.0 (0.9)	4.7 (0.7)	3.1 (0.7)	.	0.6	−0.9	−0.3	0.5
Poaceae spp.[2]	3.8 (0.7)	11.3 (0.7)	4.1 (0.8)	4.4 (0.7)	N	2.7 (0.4)	11.8 (1.5)	2.8 (0.7)	5.3 (0.9)	.	−1.1	0.5	−1.3	0.9
Bryophyte	**42.0 (3.1)**	**56.4 (3.1)**	**24.9 (3.0)**	**31.6 (4.2)**	**N**	**42.0 (4.1)**	**45.6 (3.3)**	**16.1 (2.2)**	**18.4 (3.0)**	**D⁻**	**0.0**	**−10.8**	**−8.8**	**−13.2**
Acrocarpous Moss	17.2 (1.9)	25.1 (1.9)	9.1 (1.3)	14.3 (2.4)	N	16.5 (2.7)	20.6 (2.7)	7.4 (1.0)	8.7 (1.8)	C⁻	−0.7	−4.5	−1.7	−5.6
Pleurocarpous Moss[1]	23.8 (2.2)	30.9 (2.9)	15.7 (2.7)	16.9 (4.0)	N	24.9 (3.0)	24.0 (2.1)	8.7 (1.7)	9.4 (2.0)	D⁻	1.1	−6.9	−7.0	−7.5
Lichen	**2.5 (0.8)**	**3.3 (0.8)**	**5.5 (1.8)**	**5.8 (2.1)**	**.**	**1.8 (0.7)**	**1.8 (0.9)**	**1.7 (0.7)**	**1.9 (0.8)**	***D⁻***	**−0.8**	**−1.5**	**−3.8**	**−3.9**
Foliose Lichen	2.5 (0.8)	3.3 (0.8)	5.5 (1.8)	5.8 (2.1)	.	1.6 (0.7)	1.7 (0.9)	1.6 (0.7)	1.8 (0.8)	*D⁻*	−0.9	−1.6	−3.8	−4.0

Table 2. Change in plant cover over time in control plots and in response to warming at the four sites. The average cover and standard error are presented at sampling 1, sampling 2, sampling 3, and sampling 4 for control (C1, C2, C3, and C4) and experimentally warmed (E1, E2, E3, and E4) plots. For convenience, the warming response is also presented as the differences between control and experimental plots at the four samplings (W1, W2, W3, and W4). The change over time in response to the ambient environment and to experimental warming is categorized as no change (.), inconsistent change (I), nondirectional change (N), and cumulative directional change (D^+ – increase, D^- – decrease); because the response to warming could also be considered relative to the change in the control plots, the warming response could be categorized as consistent change (C^+ – increase, C^- – decrease) and a cumulative directional change observed only in relation to the control plots is noted with an italicized *D* (see methods for further details). Taxa include all growth forms (in bold) present at a site and vascular plant species or narrower growth from (for nonvascular plants) that occurred in at least half the plots.

Taxa	C1	C2	C3	C4		E1	E2	E3	E4		W1	W2	W3	W4
Atqasuk dry (AD) site														
Deciduous Shrub	**0.5 (0.3)**	**0.4 (0.3)**	**0.6 (0.4)**	**0.4 (0.2)**	**.**	**0.3 (0.2)**	**0.3 (0.2)**	**0.5 (0.2)**	**0.6 (0.4)**	**.**	**−0.3**	**−0.1**	**−0.2**	**0.2**
Evergreen Shrub	**29.2 (1.5)**	**22.6 (1.5)**	**35.5 (1.7)**	**23.2 (2.1)**	**N**	**29.8 (2.3)**	**26.1 (2.4)**	**33.0 (1.7)**	**26.9 (1.9)**	**.**	**0.6**	**3.5**	**−2.5**	**3.8**
Cassiope tetragona	6.3 (0.5)	4.7 (0.5)	6.0 (0.6)	3.3 (0.7)	N	7.2 (0.9)	5.5 (0.8)	7.7 (1.2)	6.2 (0.9)	D^+	0.9	0.8	1.7	2.8
Diapensia lapponica	3.8 (0.7)	2.2 (0.7)	3.8 (0.7)	2.6 (0.6)	.	3.5 (0.6)	3.3 (0.5)	3.9 (0.6)	2.5 (0.5)	.	−0.2	1.0	0.1	−0.1
Ledum palustre	11.5 (1.6)	9.8 (1.6)	14.5 (1.6)	9.8 (1.3)	.	11.9 (1.6)	10.6 (1.8)	13.8 (1.6)	11.5 (1.3)	.	0.3	0.8	−0.7	1.7
Vaccinium vitis-idaea	7.6 (0.8)	6.0 (0.8)	11.3 (1.4)	7.4 (1.1)	N	7.2 (0.8)	6.8 (0.7)	7.6 (0.7)	6.7 (0.9)	.	−0.4	0.8	−3.6	−0.7
Forb	**0.7 (0.3)**	**0.4 (0.3)**	**0.8 (0.3)**	**0.6 (0.2)**	**.**	**0.7 (0.2)**	**0.8 (0.3)**	**1.5 (0.4)**	**1.4 (0.5)**	**.**	**0.0**	**0.5**	**0.7**	**0.8**
Graminoid	**12.3 (1.7)**	**9.0 (1.7)**	**18.3 (1.9)**	**10.7 (1.4)**	**N**	**12.6 (1.6)**	**6.4 (1.0)**	**15.9 (1.4)**	**9.2 (1.4)**	**.**	**0.4**	**−2.6**	**−2.5**	**−1.5**
Hierochloe alpina	3.0 (0.8)	1.4 (0.8)	3.3 (0.8)	2.3 (0.5)	.	2.8 (0.7)	1.3 (0.3)	4.9 (0.9)	2.2 (0.5)	.	−0.1	−0.1	1.6	−0.1
Luzula confusa	5.3 (0.8)	4.4 (0.8)	9.4 (1.1)	3.6 (0.6)	N	6.3 (1.1)	3.1 (0.6)	7.1 (1.1)	3.4 (0.7)	.	0.9	−1.3	−2.3	−0.3
Bryophyte	**9.8 (0.8)**	**12.0 (0.8)**	**7.9 (0.7)**	**6.4 (0.6)**	**N**	**10.5 (1.3)**	**11.3 (1.1)**	**7.9 (1.0)**	**6.5 (1.0)**	**.**	**0.7**	**−0.7**	**0.0**	**0.1**
Acrocarpous Moss	8.0 (0.7)	10.2 (0.7)	4.5 (0.6)	5.3 (0.6)	N	7.2 (0.9)	8.3 (0.9)	4.6 (0.8)	5.3 (0.9)	.	−0.8	−2.0	0.2	0.0
Lichen	**60.1 (1.8)**	**56.3 (1.8)**	**39.3 (2.3)**	**23.8 (1.7)**	**D^-**	**67.2 (2.2)**	**55.8 (3.5)**	**37.4 (2.3)**	**18.9 (1.6)**	**D^-**	**7.0**	**−0.5**	**−2.0**	**−4.9**
Crustose Lichen	1.8 (0.3)	8.1 (0.3)	2.1 (0.4)	4.8 (0.8)	N	1.5 (0.3)	7.8 (1.0)	2.3 (0.5)	4.3 (0.8)	.	−0.3	−0.3	0.1	−0.6
Foliose Lichen	16.6 (1.2)	12.3 (1.2)	10.7 (0.8)	5.8 (0.7)	D^-	15.9 (1.1)	8.5 (0.8)	9.2 (0.9)	4.8 (0.6)	C^-	−0.8	−3.8	−1.5	−1.1
Fruticose Lichen	41.8 (1.7)	36.0 (1.7)	26.5 (2.1)	13.2 (1.1)	D^-	49.8 (1.9)	39.5 (2.6)	25.9 (1.8)	9.9 (1.0)	D^-	8.0	3.5	−0.6	−3.3
Atqasuk wet (AW) site														
Deciduous Shrub	**8.0 (1.5)**	**8.6 (1.5)**	**8.0 (1.5)**	**7.8 (1.2)**	**.**	**6.2 (0.9)**	**8.0 (1.2)**	**7.0 (0.9)**	**7.5 (0.9)**	**.**	**−1.8**	**−0.6**	**−1.0**	**−0.3**
Salix pulchra	6.5 (1.5)	7.3 (1.5)	5.5 (1.1)	5.0 (1.1)	.	5.3 (0.9)	6.6 (1.2)	6.0 (0.8)	4.7 (1.0)	.	−1.3	−0.7	0.5	−0.3
Forb	**0.5 (0.2)**	**0.5 (0.2)**	**0.3 (0.1)**	**0.1 (0.1)**	**.**	**0.5 (0.2)**	**0.3 (0.2)**	**0.2 (0.1)**	**0.2 (0.1)**	**.**	**0.0**	**−0.1**	**−0.2**	**0.1**
Graminoid	**27.8 (1.5)**	**19.7 (1.5)**	**32.8 (1.4)**	**26.8 (1.1)**	**N**	**26.5 (1.5)**	**23.6 (1.8)**	**40.0 (1.7)**	**32.3 (1.8)**	**I**	**−1.3**	**3.9**	**7.1**	**5.5**
Carex aquatilis	19.8 (1.2)	12.6 (1.2)	24.5 (1.2)	18.1 (1.1)	N	18.5 (1.2)	15.2 (1.0)	30.1 (1.1)	23.0 (1.4)	I	−1.3	2.6	5.6	4.9
Eriophorum angustifolium	3.3 (0.8)	4.5 (0.8)	4.6 (0.8)	4.9 (0.6)	.	3.1 (0.6)	3.6 (0.7)	4.9 (0.7)	5.7 (0.7)	.	−0.2	−0.9	0.3	0.8
Eriophorum russeolum	4.5 (0.8)	2.4 (0.8)	2.8 (0.5)	3.2 (0.4)	.	4.5 (0.6)	4.5 (0.8)	3.8 (0.6)	3.1 (0.6)	.	0.1	2.1	1.0	−0.1
Bryophyte	**87.8 (0.9)**	**91.8 (0.9)**	**86.5 (2.6)**	**55.0 (3.1)**	**N**	**86.7 (1.2)**	**90.8 (1.4)**	**94.1 (0.8)**	**47.9 (3.0)**	**I**	**−1.1**	**−1.1**	**7.6**	**−7.1**
Acrocarpous Moss	31.5 (4.1)	32.0 (4.1)	29.5 (3.9)	22.5 (3.4)	.	31.8 (3.4)	31.0 (4.6)	29.0 (3.4)	17.0 (2.5)	.	0.2	−1.0	−0.5	−5.4
Pleurocarpous Moss[1]	49.7 (3.9)	54.9 (5.2)	48.8 (5.5)	27.1 (2.7)	N	48.6 (3.1)	55.9 (4.2)	56.9 (3.6)	24.0 (2.6)	.	−1.1	1.0	8.1	−3.1
Sphagnum Moss	3.5 (0.9)	4.5 (0.9)	8.1 (1.8)	5.4 (1.5)	.	3.8 (1.4)	3.5 (1.6)	8.2 (2.7)	6.7 (2.7)	.	0.3	−1.0	0.0	1.3

Table 3. Change in community indices over time in control plots and in response to warming at the four sites (AD – Atqasuk dry, AW – Atqasuk wet, BD – Barrow dry, and BW – Barrow wet). The community indices used were cover of live, standing dead, and dead unattached (litter) plant material; the percent of the canopy that was not occupied by vascular plants (Open Canopy); and the diversity metrics species richness and Shannon index. See Table 2 for an explanation of the table layout.

Site	C1	C2	C3	C4		E1	E2	E3	E4		W1	W2	W3	W4
Total Live Plants														
AD	112.6 (2.3)	100.7 (2.3)	102.6 (3.1)	65.3 (2.7)	N	121.0 (3.2)	100.8 (4.6)	96.1 (2.3)	63.8 (2.6)	.	8.4	0.1	−6.5	−1.5
AW	125.0 (1.3)	121.2 (1.3)	128.0 (2.2)	90.5 (3.5)	N	121.0 (1.7)	122.9 (1.7)	141.4 (1.4)	88.4 (2.5)	I	−4.0	1.8	13.4	−2.1
BD	72.0 (1.0)	121.4 (1.0)	99.3 (1.8)	114.1 (2.4)	N	73.0 (1.5)	106.4 (3.9)	92.6 (1.8)	93.1 (2.7)	I	1.0	−15.0	−6.7	−21.0
BW	106.1 (3.2)	137.3 (3.2)	85.3 (2.2)	97.8 (5.0)	N	104.5 (4.7)	121.7 (6.8)	78.5 (2.9)	81.0 (3.7)	I	−1.6	−15.7	−6.8	−16.8
Standing Dead														
AD	14.6 (1.2)	7.1 (1.2)	17.1 (1.9)	26.3 (2.5)	N	18.0 (1.4)	11.0 (1.4)	18.2 (1.6)	28.3 (2.4)	C^+	3.4	3.8	1.1	2.0
AW	36.2 (1.4)	43.8 (1.4)	18.0 (2.1)	60.8 (2.8)	N	41.5 (1.6)	48.5 (2.2)	24.0 (2.0)	62.0 (2.7)	C^+	5.3	4.8	6.0	1.3
BD	15.1 (0.8)	11.9 (0.8)	20.9 (1.9)	41.2 (3.3)	N	19.2 (1.3)	17.7 (1.4)	35.8 (1.9)	53.2 (3.6)	D^+	4.1	5.8	14.9	12.0
BW	37.1 (2.6)	36.5 (2.6)	45.7 (2.7)	40.0 (2.1)	.	40.8 (2.3)	45.0 (4.4)	61.3 (4.3)	43.1 (3.4)	C^+	3.8	8.5	15.6	3.2
Litter														
AD	22.0 (1.0)	13.0 (1.0)	9.9 (1.2)	49.1 (2.2)	N	20.8 (1.2)	16.3 (2.2)	13.7 (1.5)	51.0 (2.7)	.	−1.3	3.2	3.8	1.9
AW	8.4 (0.9)	4.2 (0.9)	9.7 (1.9)	27.8 (2.4)	N	9.4 (1.1)	4.3 (0.8)	3.7 (0.7)	31.9 (2.5)	I	1.0	0.0	−6.0	4.1
BD	10.1 (0.7)	8.1 (0.7)	12.3 (0.9)	15.3 (1.6)	N	12.5 (1.2)	9.5 (1.5)	12.4 (1.0)	32.0 (2.6)	I	2.4	1.3	0.0	16.7
BW	27.6 (1.5)	9.4 (1.5)	26.9 (1.5)	43.2 (4.3)	N	32.8 (1.4)	13.5 (1.7)	24.7 (2)	60.2 (3.8)	I	5.2	4.1	−2.2	17.0
Open Canopy														
AD	53.0 (2.4)	61.2 (2.4)	42.8 (2.2)	45.4 (3.5)	N	54.5 (2.4)	56.3 (3.1)	46.2 (1.8)	40.5 (3.5)	.	1.5	−4.9	3.4	−5.0
AW	24.6 (1.9)	23.6 (1.9)	38.5 (1.9)	13.1 (1.7)	N	22.3 (1.9)	15.5 (1.6)	26.5 (2.3)	9.8 (1.2)	I	−2.3	−8.2	−12.0	−3.3
BD	48.4 (1.6)	35.9 (1.6)	40.0 (2.4)	30.4 (1.7)	N	41.8 (1.9)	27.9 (2.3)	24.6 (1.9)	13.6 (1.8)	D^-	−6.6	−8.0	−15.5	−16.8
BW	15.2 (2.2)	9.6 (2.2)	28.3 (2.4)	9.8 (1.6)	N	11.3 (1.2)	8.0 (0.9)	21.3 (2.3)	6.7 (1.0)	C^-	−3.9	−1.7	−7.0	−3.2
Species Richness														
AD	6.4 (0.2)	5.7 (0.2)	6.8 (0.2)	6.0 (0.2)	N	6.3 (0.2)	5.8 (0.2)	6.6 (0.2)	6.2 (0.2)	.	−0.1	0.1	−0.2	0.2
AW	5.0 (0.2)	4.9 (0.2)	5.3 (0.3)	5.2 (0.1)	.	4.9 (0.2)	4.8 (0.1)	5.0 (0.2)	5.1 (0.2)	.	−0.1	−0.1	−0.3	0.0
BD	5.3 (0.2)	6.5 (0.2)	6.5 (0.2)	6.0 (0.2)	N	5.5 (0.2)	6.7 (0.2)	7.5 (0.2)	6.6 (0.2)	C^+	0.2	0.2	1.0	0.6
BW	7.3 (0.2)	7.6 (0.2)	7.3 (0.3)	6.9 (0.2)	.	7.3 (0.3)	7.4 (0.3)	7.1 (0.2)	6.3 (0.2)	.	0.0	−0.2	−0.2	−0.5
Shannon Index														
AD	0.97 (0.01)	1.02 (0.02)	0.99 (0.02)	0.92 (0.02)	D^-	0.95 (0.01)	1.00 (0.02)	1.00 (0.01)	0.93 (0.02)	.	−0.02	−0.02	0.00	0.01
AW	0.32 (0.01)	0.37 (0.02)	0.34 (0.02)	0.35 (0.02)	N	0.33 (0.01)	0.35 (0.01)	0.31 (0.01)	0.32 (0.01)	.	0.01	−0.02	−0.02	−0.03
BD	0.76 (0.01)	0.77 (0.02)	0.80 (0.01)	0.69 (0.01)	N	0.75 (0.02)	0.71 (0.02)	0.70 (0.02)	0.63 (0.02)	D^-	−0.01	−0.05	−0.10	−0.07
BW	0.44 (0.02)	0.44 (0.02)	0.41 (0.01)	0.37 (0.01)	N	0.41 (0.02)	0.40 (0.01)	0.40 (0.01)	0.33 (0.01)	C^-	−0.03	−0.04	0.00	−0.04

Table 4. Change in canopy height over time in control plots and in response to warming at the four sites. Height was calculated as the maximum height recorded in a plot for each taxon. See Table 2 for an explanation of the table layout.

	C1	C2	C3	C4		E1	E2	E3	E4		W1	W2	W3	W4
Atqasuk dry (AD) site														
Plot Maximum	**9.6 (1.2)**	**7.0 (1.2)**	**12.7 (0.9)**	**11.0 (0.9)**	**N**	**11.7 (1.2)**	**6.4 (0.5)**	**14.9 (1.2)**	**12.5 (1.2)**	**.**	**2.1**	**−0.6**	**2.2**	**1.6**
Evergreen Shrub	**3.7 (0.4)**	**3.5 (0.4)**	**4.2 (0.4)**	**4.6 (0.5)**	**.**	**3.1 (0.2)**	**2.6 (0.2)**	**3.9 (0.3)**	**5.1 (0.3)**	**.**	**−0.6**	**−0.9**	**−0.3**	**0.5**
Cassiope tetragona	3.5 (0.4)	2.2 (0.4)	4.1 (0.4)	3.6 (0.4)	N	2.7 (0.2)	2.4 (0.2)	2.7 (0.4)	4.5 (0.3)	I	−0.8	0.1	−1.4	0.8
Diapensia lapponica	0.3 (0.2)	0.3 (0.2)	0.7 (0.3)	0.6 (0.3)	.	0.1 (0.0)	0.2 (0.1)	0.5 (0.2)	0.6 (0.3)	.	−0.3	−0.1	−0.2	0.0
Ledum palustre	2.1 (0.2)	2.3 (0.2)	1.8 (0.2)	3.2 (0.5)	N	1.9 (0.2)	1.9 (0.2)	2.9 (0.5)	4.1 (0.4)	.	−0.3	−0.4	1.1	0.9
Vaccinium vitis-idaea	1.1 (0.1)	1.1 (0.1)	0.5 (0.1)	1.3 (0.3)	.	1.4 (0.2)	1.0 (0.2)	0.2 (0.1)	1.2 (0.2)	.	0.2	−0.1	−0.2	0.0
Graminoid	**9.4 (1.3)**	**6.6 (1.3)**	**12.2 (1.0)**	**10.9 (1.0)**	**N**	**11.6 (1.3)**	**6.3 (0.5)**	**14.9 (1.2)**	**12.0 (1.2)**	**.**	**2.2**	**−0.3**	**2.7**	**1.1**
Hierochloe alpina	7.7 (1.6)	4.9 (1.6)	11.9 (1.3)	9.6 (1.3)	N	10.0 (1.7)	5.3 (0.6)	12.1 (1.6)	10.1 (1.4)	.	2.3	0.4	0.2	0.6
Luzula confusa	5.6 (0.8)	4.7 (0.8)	7.5 (0.8)	7.5 (1.0)	N	6.5 (0.9)	3.8 (0.5)	9.6 (1.2)	6.2 (0.8)	.	0.8	−0.9	2.0	−1.4
Atqasuk wet (AW) site														
Plot Maximum	**21.9 (1.1)**	**19.2 (1.1)**	**24.1 (1.2)**	**20.7 (1.0)**	**N**	**24.4 (0.9)**	**22.7 (0.8)**	**27.8 (1.1)**	**24.2 (1.1)**	**C⁺**	**2.5**	**3.5**	**3.7**	**3.5**
Deciduous Shrub	**9.5 (0.9)**	**10.2 (0.9)**	**10.9 (0.4)**	**11.4 (0.6)**	**.**	**10.2 (0.9)**	**12.1 (0.9)**	**13.6 (1.2)**	**12.8 (0.9)**	**C⁺**	**0.6**	**1.8**	**2.7**	**1.3**
Salix pulchra	10.0 (0.9)	9.9 (0.9)	10.6 (0.6)	11.2 (0.7)	.	10.7 (0.9)	12.2 (1.0)	13.4 (1.2)	11.9 (1.2)	C⁺	0.7	2.2	2.8	0.7
Graminoid	**21.9 (1.1)**	**19.2 (1.1)**	**24.1 (1.2)**	**20.5 (1.0)**	**N**	**24.4 (0.9)**	**22.7 (0.8)**	**27.7 (1.1)**	**24.2 (1.1)**	**C⁺**	**2.5**	**3.5**	**3.5**	**3.7**
Carex aquatilis	21.8 (1.2)	18.8 (1.2)	23.5 (1.3)	19.9 (1.2)	N	24.0 (0.9)	22.3 (0.8)	27.5 (1.1)	24.0 (1.1)	C⁺	2.2	3.5	4.1	4.2
Eriophorum angustifolium	12.0 (1.1)	12.6 (1.1)	15.7 (1.3)	12.5 (0.9)	.	14.3 (1.4)	14.6 (0.8)	16.6 (1.1)	15.3 (1.1)	C⁺	2.3	2.0	1.0	2.8
Eriophorum russeolum	12.6 (1.0)	9.8 (1.0)	12.3 (1.1)	10.7 (1.1)	.	13.2 (1.0)	14.0 (1.1)	14.4 (1.1)	13.0 (1.0)	C⁺	0.6	4.2	2.2	2.3
Barrow Dry (BD) site														
Plot Maximum	**3.6 (0.4)**	**6.0 (0.4)**	**8.1 (0.7)**	**7.9 (0.6)**	**D⁺**	**6.6 (0.6)**	**9.3 (1.4)**	**12.8 (0.7)**	**12.7 (0.8)**	**D⁺**	**2.9**	**3.3**	**4.6**	**4.8**
Deciduous Shrub	**0.1 (0.1)**	**1.3 (0.1)**	**0.6 (0.2)**	**1.8 (0.1)**	**N**	**0.3 (0.1)**	**1.6 (0.2)**	**0.2 (0.1)**	**2.2 (0.2)**	**.**	**0.2**	**0.3**	**−0.4**	**0.4**
Salix rotundifolia	0.1 (0.1)	1.3 (0.1)	0.6 (0.2)	1.8 (0.1)	N	0.3 (0.1)	1.6 (0.2)	0.2 (0.1)	2.2 (0.2)	.	0.2	0.3	−0.4	0.4
Evergreen Shrub	**2.1 (0.5)**	**3.1 (0.5)**	**4.2 (0.2)**	**5.4 (0.3)**	**D⁺**	**3.3 (0.5)**	**4.1 (0.3)**	**5.2 (0.3)**	**7.9 (0.5)**	**D⁺**	**1.2**	**1.0**	**0.9**	**2.5**
Cassiope tetragona	2.1 (0.5)	3.1 (0.5)	4.2 (0.2)	5.4 (0.3)	D⁺	3.3 (0.5)	4.1 (0.3)	5.2 (0.3)	7.9 (0.5)	D⁺	1.2	1.0	0.9	2.5
Forb	**1.1 (0.4)**	**3.0 (0.4)**	**4.9 (0.8)**	**5.1 (0.8)**	**D⁺**	**3.5 (0.7)**	**4.4 (1.2)**	**7.0 (1.2)**	**7.8 (1.2)**	**D⁺**	**2.4**	**1.4**	**2.1**	**2.8**
Potentilla hyparctica	1.0 (0.6)	2.5 (0.6)	3.3 (0.8)	3.2 (0.5)	D⁺	2.2 (0.5)	1.0 (0.5)	6.9 (1.2)	8.7 (1.2)	D⁺	1.2	−1.5	3.6	5.5
Graminoid	**2.1 (0.4)**	**4.9 (0.4)**	**6.6 (0.6)**	**5.9 (0.5)**	**N**	**4.0 (0.7)**	**7.0 (1.3)**	**11.7 (0.7)**	**10.5 (0.8)**	**D⁺**	**1.9**	**2.1**	**5.1**	**4.7**
Luzula confusa	1.3 (0.4)	3.2 (0.4)	4.9 (0.4)	4.2 (0.4)	D⁺	2.2 (0.4)	2.8 (0.4)	7.2 (0.8)	6.6 (0.5)	D⁺	0.8	−0.4	2.3	2.4
Poa arctica	0.2 (0.2)	2.4 (0.2)	4.2 (0.6)	3.9 (0.5)	D⁺	0.6 (0.2)	3.2 (0.5)	8.9 (0.9)	8.5 (0.9)	D⁺	0.4	0.8	4.7	4.6
Barrow Wet (BW) site														
Plot Maximum	**8.9 (0.6)**	**11.4 (0.6)**	**13.1 (0.6)**	**14.2 (0.4)**	**D⁺**	**11.4 (0.5)**	**12.9 (0.6)**	**15.0 (0.5)**	**16.8 (0.8)**	**D⁺**	**2.5**	**1.6**	**1.9**	**2.7**
Forb	**3.5 (0.5)**	**3.4 (0.5)**	**5.4 (0.9)**	**7.0 (0.9)**	**D⁺**	**5.6 (0.9)**	**3.2 (0.6)**	**7.4 (1.2)**	**7.8 (1.1)**	**.**	**2.1**	**−0.1**	**2.0**	**0.8**
Saxifraga cernua	0.4 (0.2)	0.9 (0.2)	2.7 (1.0)	3.8 (1.3)	D⁺	1.5 (0.6)	0.8 (0.4)	2.5 (1.2)	4.4 (1.0)	.	1.1	−0.1	−0.2	0.6
Stellaria laeta	2.1 (0.6)	2.3 (0.6)	3.0 (0.4)	2.8 (0.5)	.	3.7 (0.6)	2.1 (0.7)	3.0 (0.6)	3.8 (0.6)	.	1.6	−0.2	0.0	1.0
Graminoid	**8.9 (0.6)**	**11.4 (0.6)**	**12.8 (0.5)**	**14.1 (0.4)**	**D⁺**	**10.5 (0.6)**	**12.9 (0.6)**	**14.7 (0.5)**	**16.4 (0.8)**	**D⁺**	**1.6**	**1.6**	**1.9**	**2.3**
Carex aquatilis	8.0 (0.5)	9.9 (0.5)	11.0 (0.6)	12.7 (0.4)	D⁺	10.3 (0.7)	12.7 (0.6)	14.0 (0.4)	14.8 (0.6)	D⁺	2.3	2.8	3.0	2.1
Dupontia fisheri	6.6 (0.7)	9.0 (0.7)	10.6 (0.7)	11.3 (0.6)	D⁺	6.1 (0.6)	8.1 (0.7)	10.5 (0.8)	12.5 (1.0)	.	−0.5	−0.9	−0.1	1.1
Eriophorum angustifolium	3.9 (0.4)	7.6 (0.4)	6.6 (0.7)	9.4 (0.4)	N	4.9 (0.5)	8.6 (0.8)	9.0 (0.9)	9.9 (0.7)	C⁺	1.1	1.0	2.4	0.5
Eriophorum russeolum	2.6 (0.3)	4.4 (0.3)	6.7 (0.4)	6.0 (0.5)	D⁺	2.4 (0.5)	5.3 (0.8)	8.5 (0.7)	7.6 (0.8)	D⁺	−0.2	0.9	1.8	1.6
Poaceae spp.[1]	4.2 (0.5)	4.7 (0.5)	6.8 (0.7)	8.4 (1.3)	D⁺	3.6 (0.5)	4.3 (0.5)	8.4 (0.9)	10.0 (1.3)	.	−0.5	−0.4	1.6	1.5

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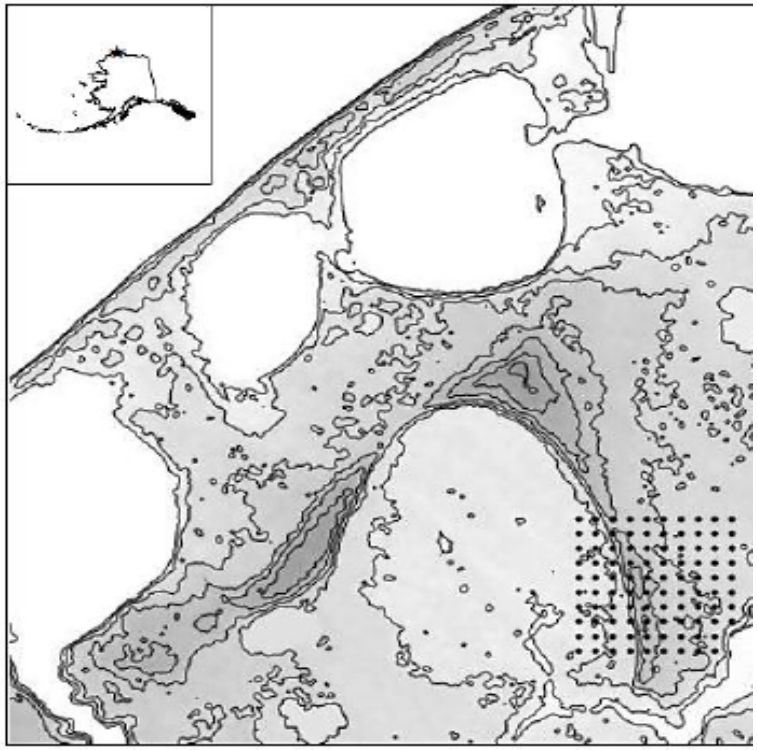

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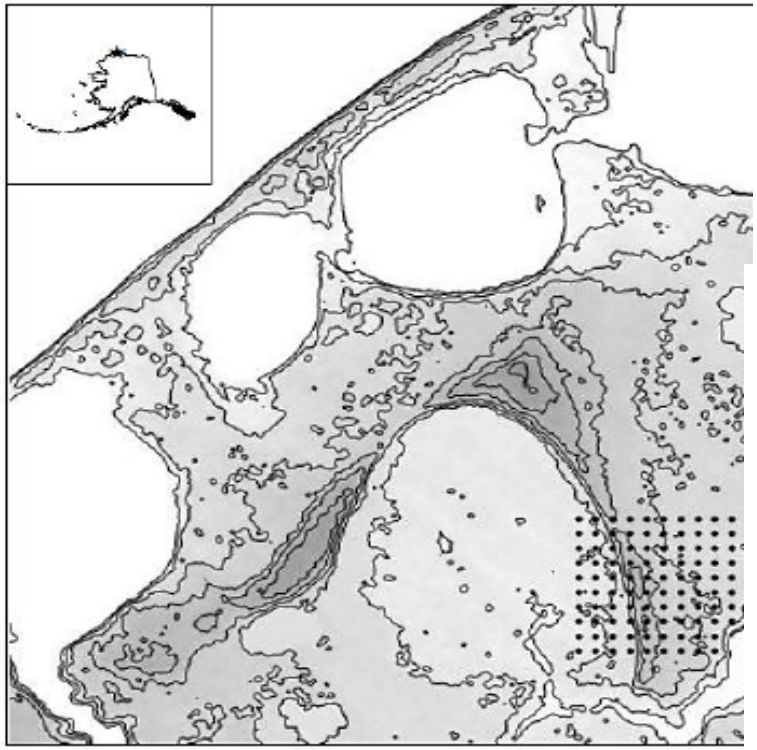
10 meters between plots



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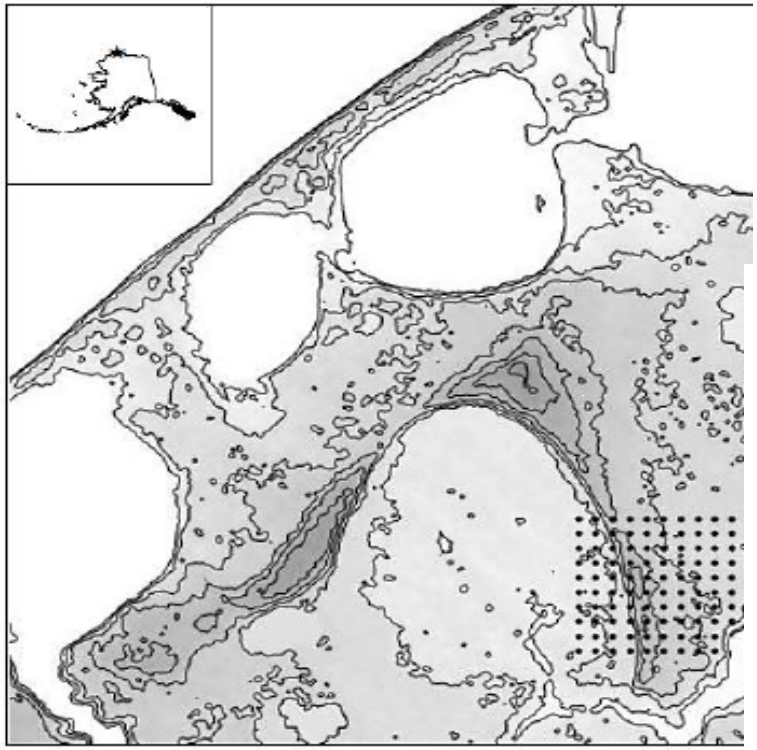
Community Type
- Dry
- Dry-moist
- Moist
- Wet

10 meters between plots



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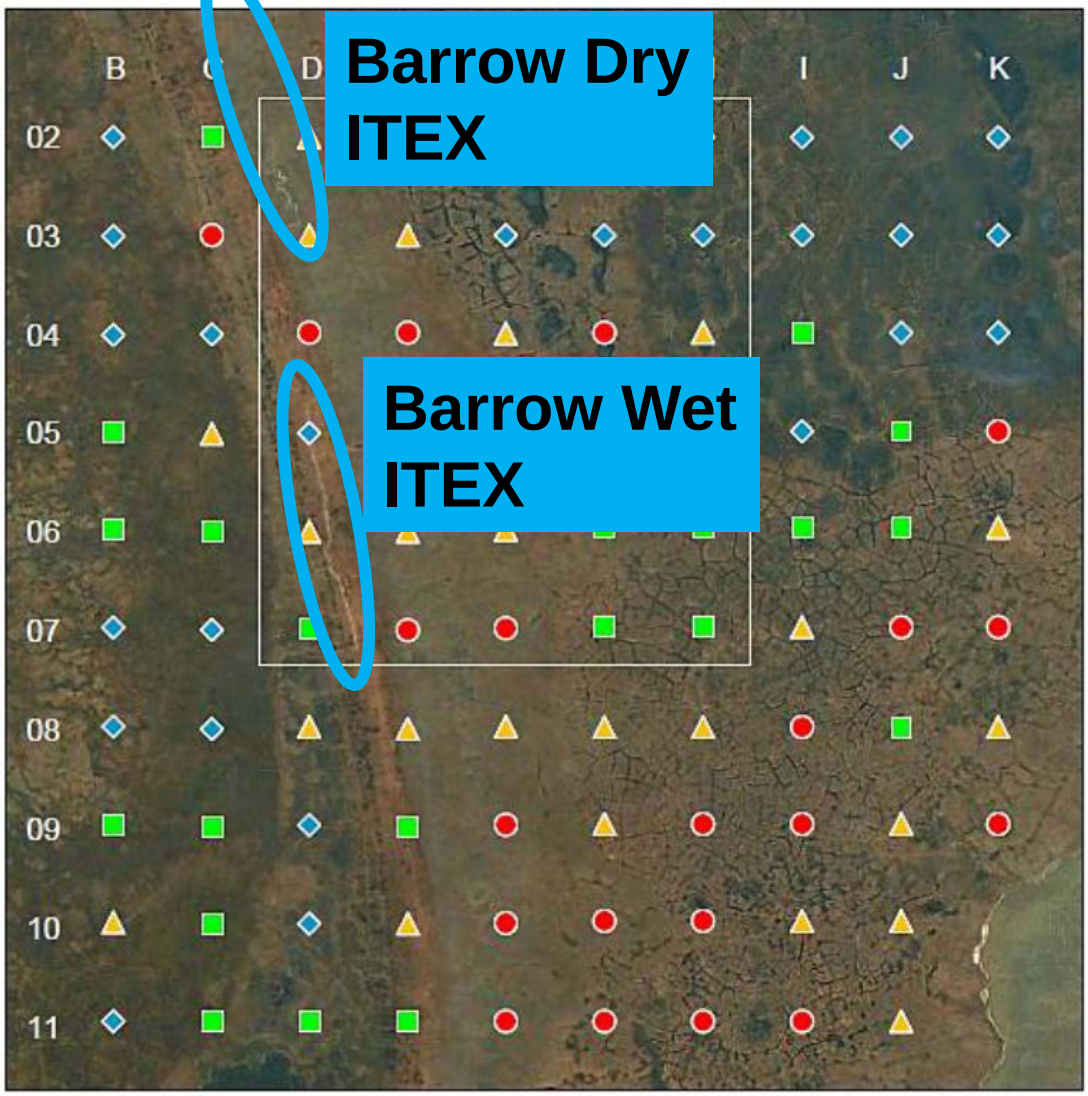
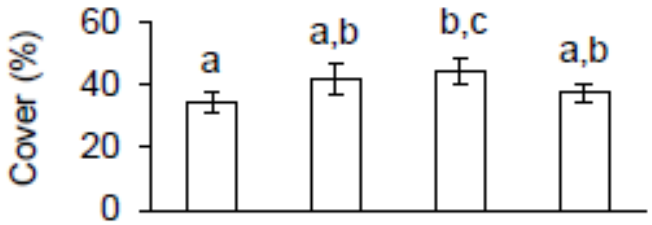
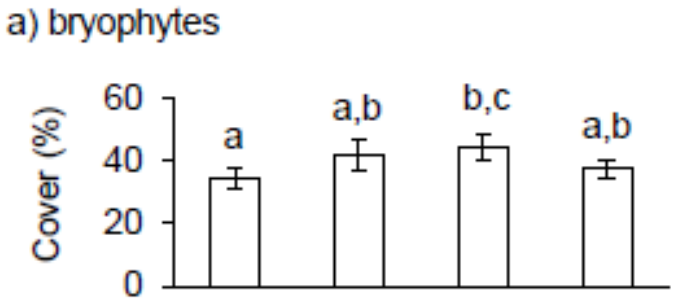


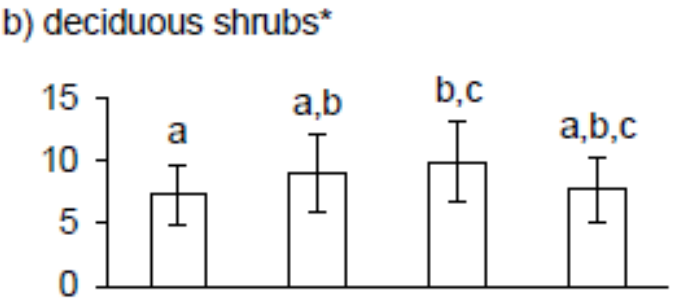
Community Type
- Dry
- Dry-moist
- Moist
- Wet

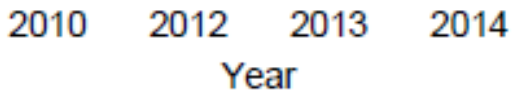
10 meters between plots

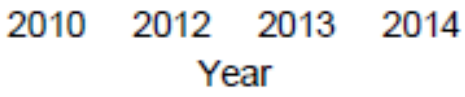
a) bryophytes

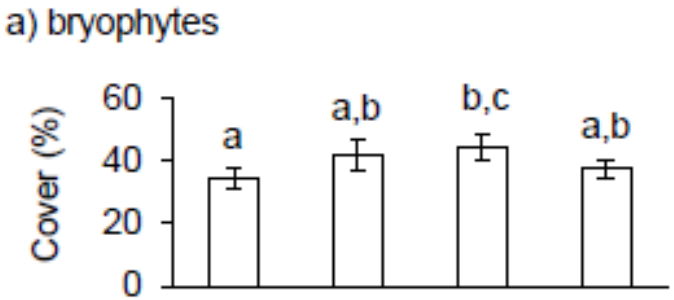


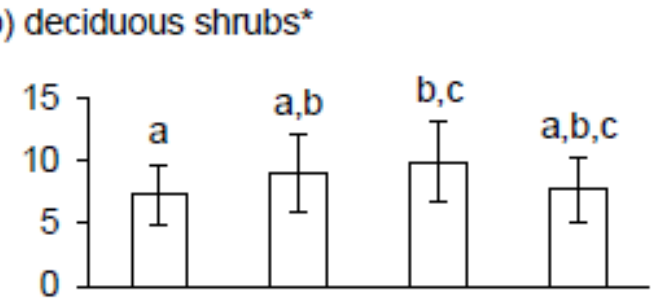

a) bryophytes
Cover (%)
60
40
20
0
a
a,b
b,c
a,b

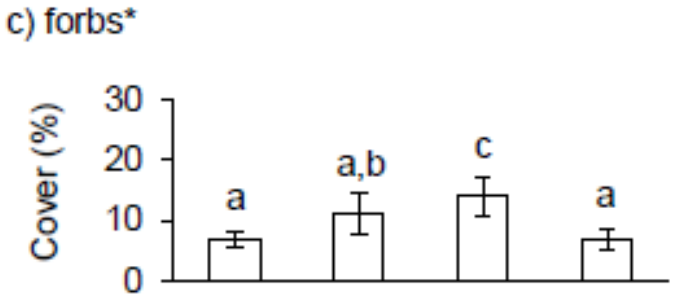

b) deciduous shrubs*
15
10
5
0
a
a,b
b,c
a,b,c

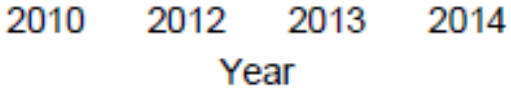

2010
2012
2013
2014
Year

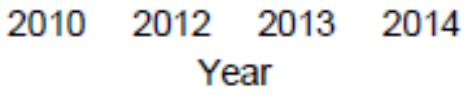

2010
2012
2013
2014
Year

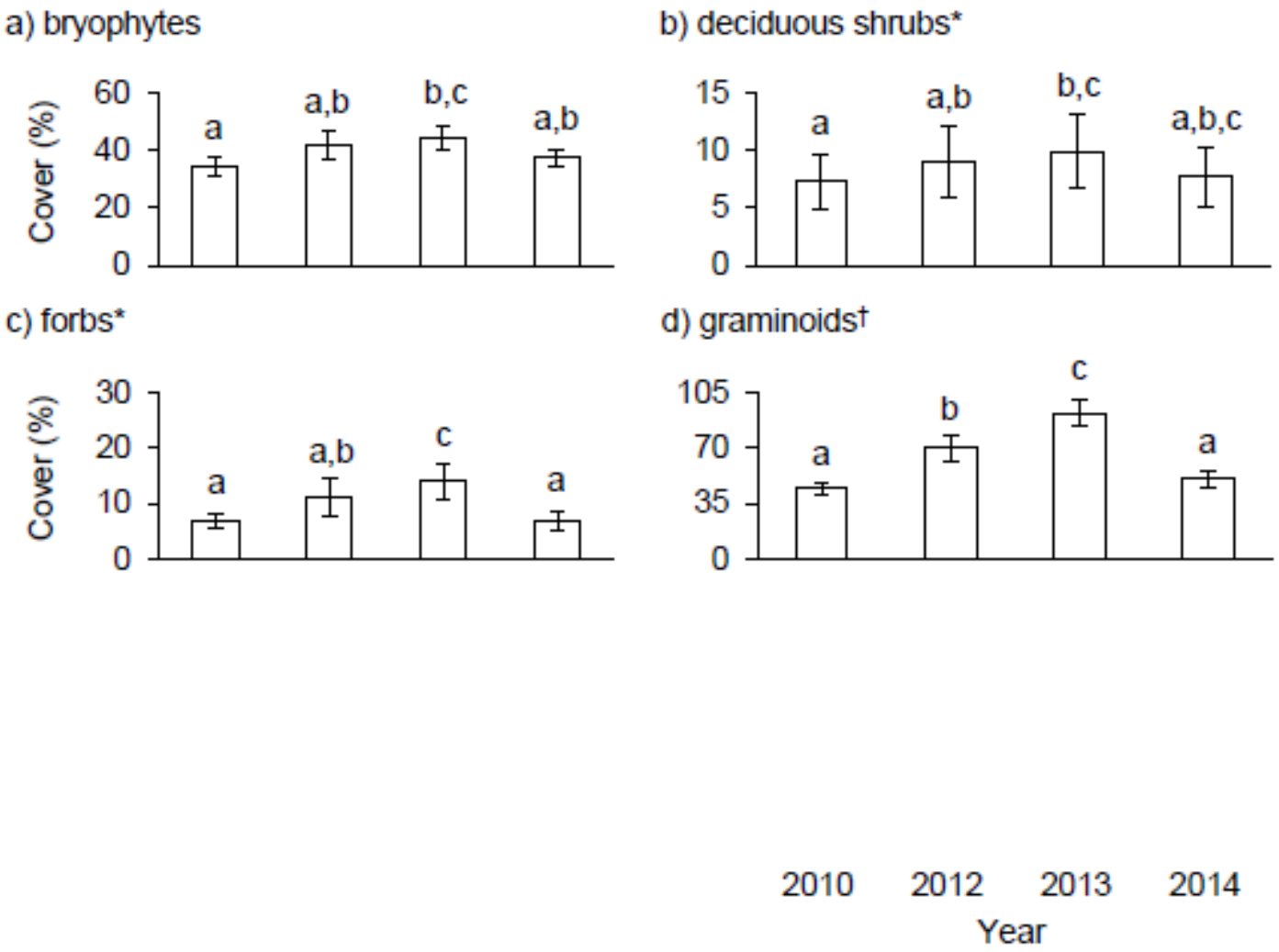

a) bryophytes
Cover (%)
60
40
20
0
a
a,b
b,c
a,b

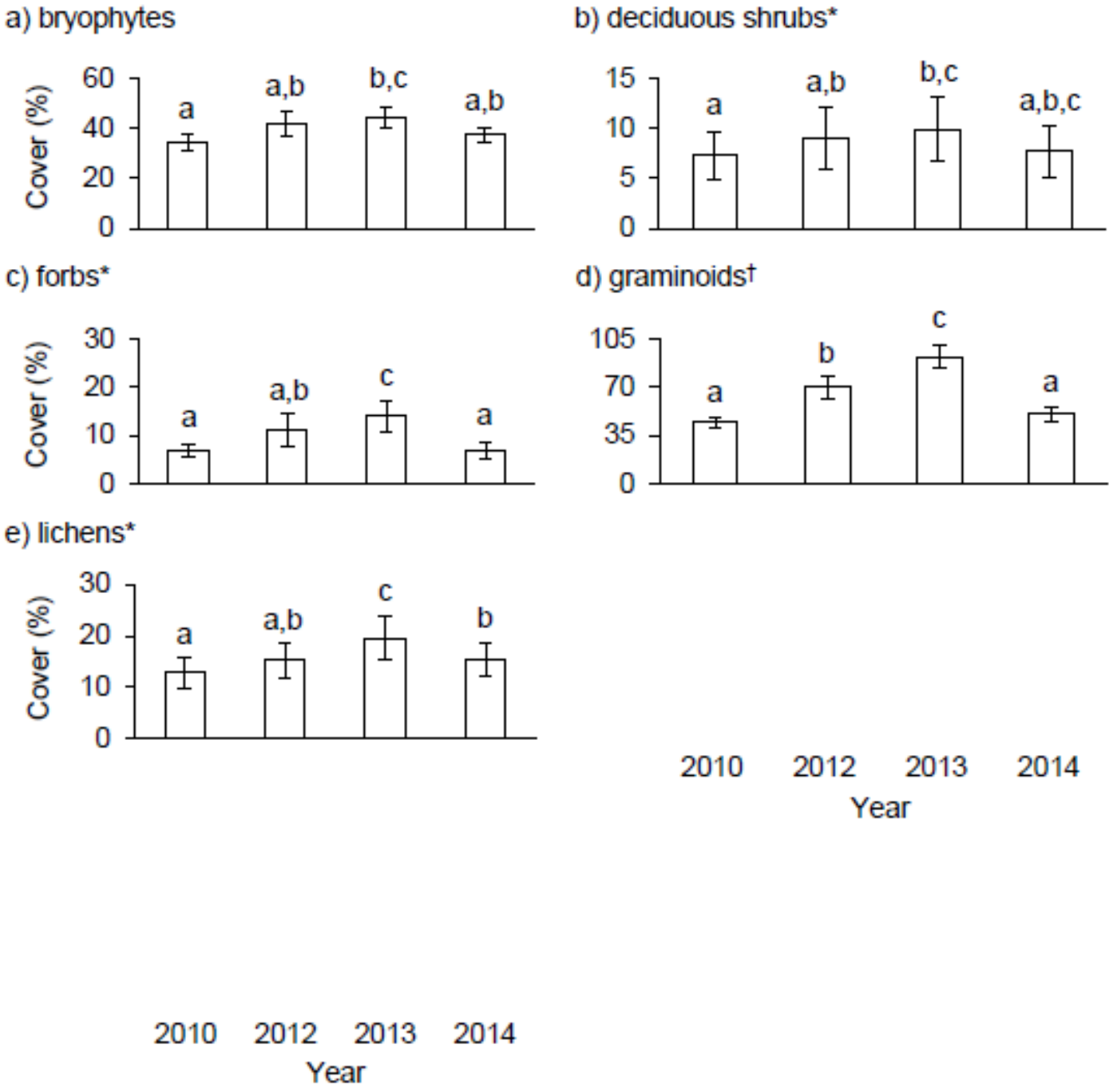

b) deciduous shrubs*
15
10
5
0
a
a,b
b,c
a,b,c

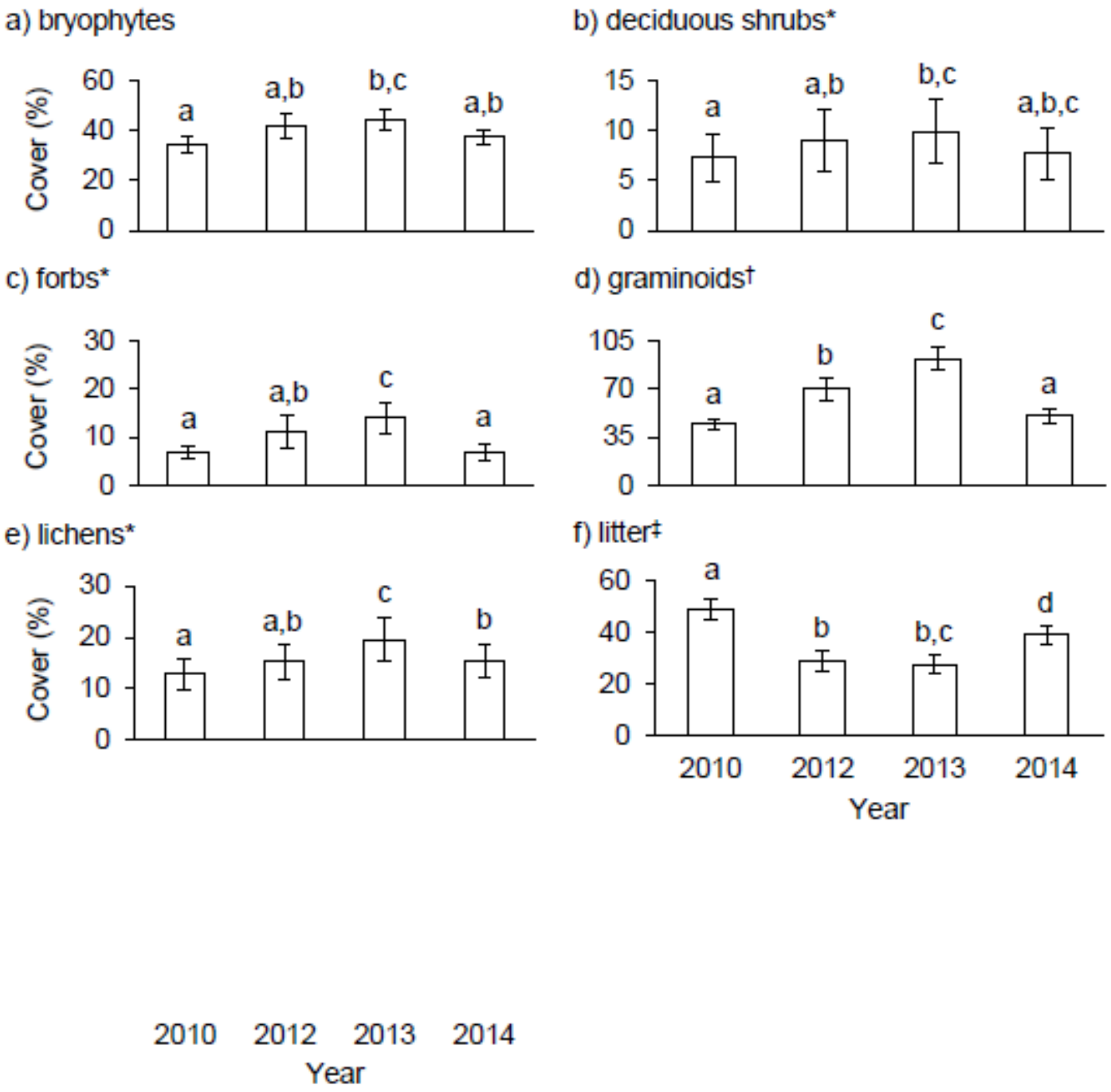

c) forbs*
Cover (%)
30
20
10
0
a
a,b
c
a

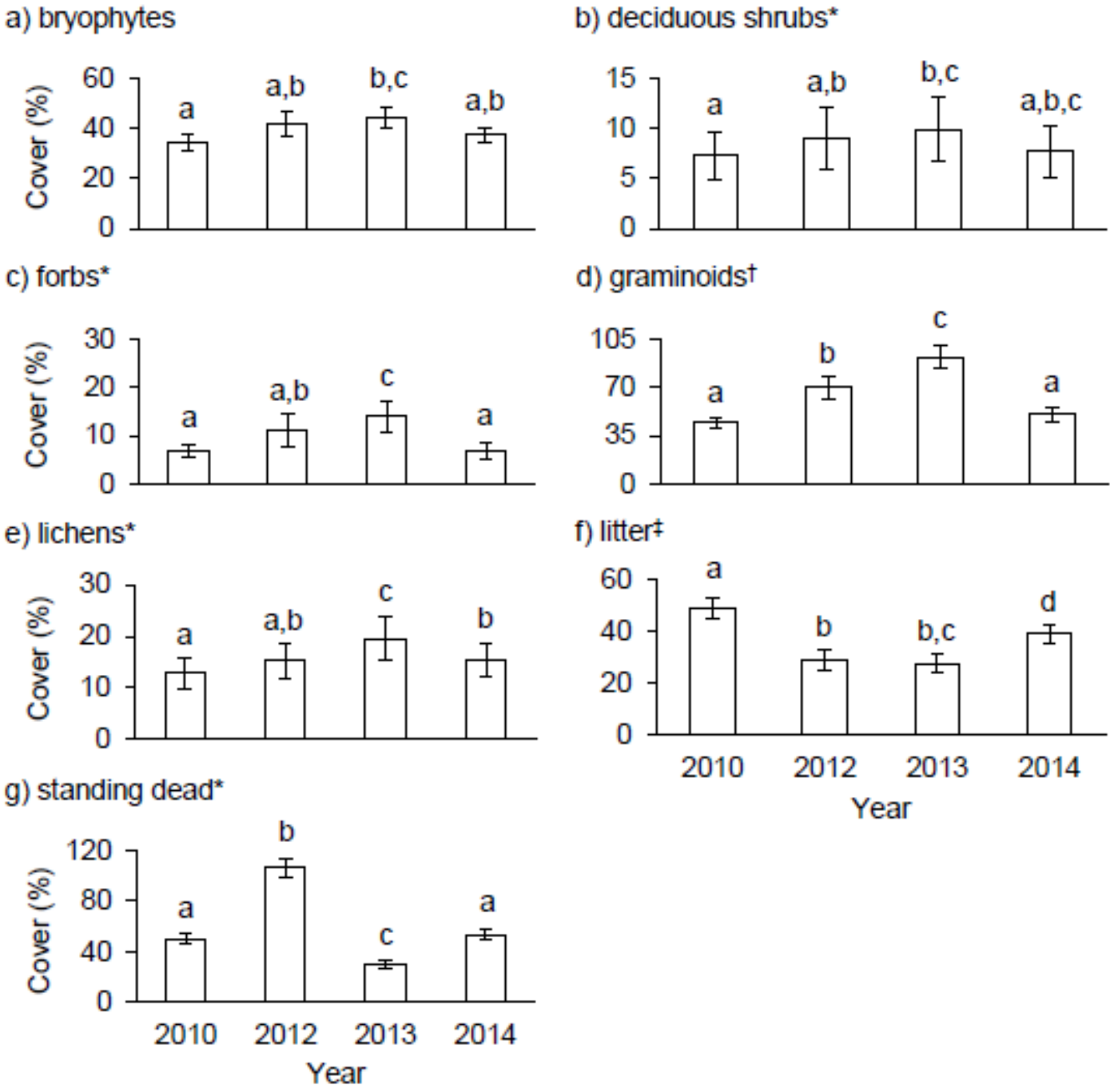

2010
2012
2013
2014
Year


2010
2012
2013
2014
Year

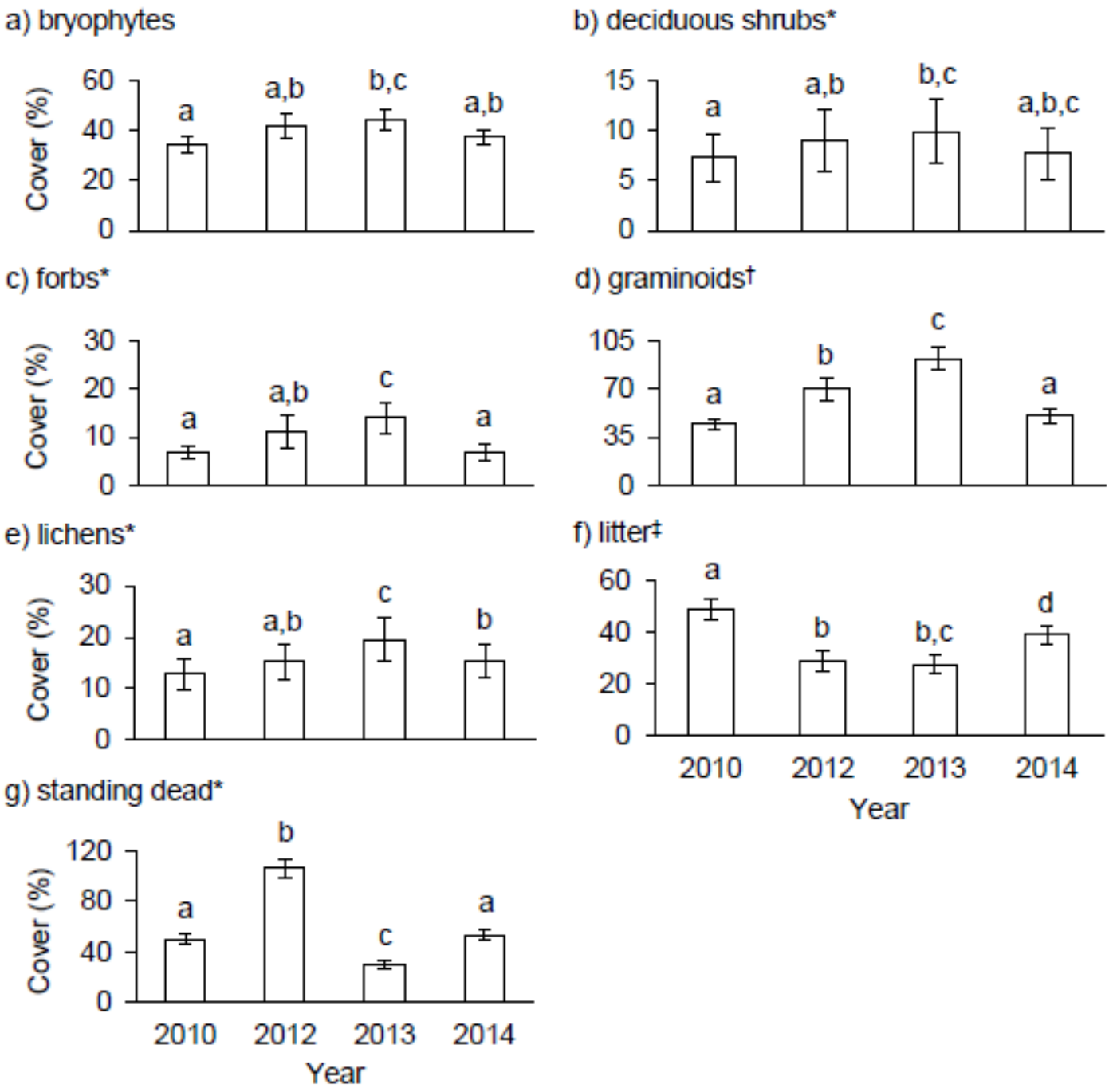

a) bryophytes
Cover (%)
60
40
20
0
a
a,b
b,c
a,b
b) deciduous shrubs*
15
10
5
0
a
a,b
b,c
a,b,c
c) forbs*
Cover (%)
30
20
10
0
a
a,b
c
a
d) graminoids†
105
70
35
0
a
b
c
a
2010
2012
2013
2014
Year

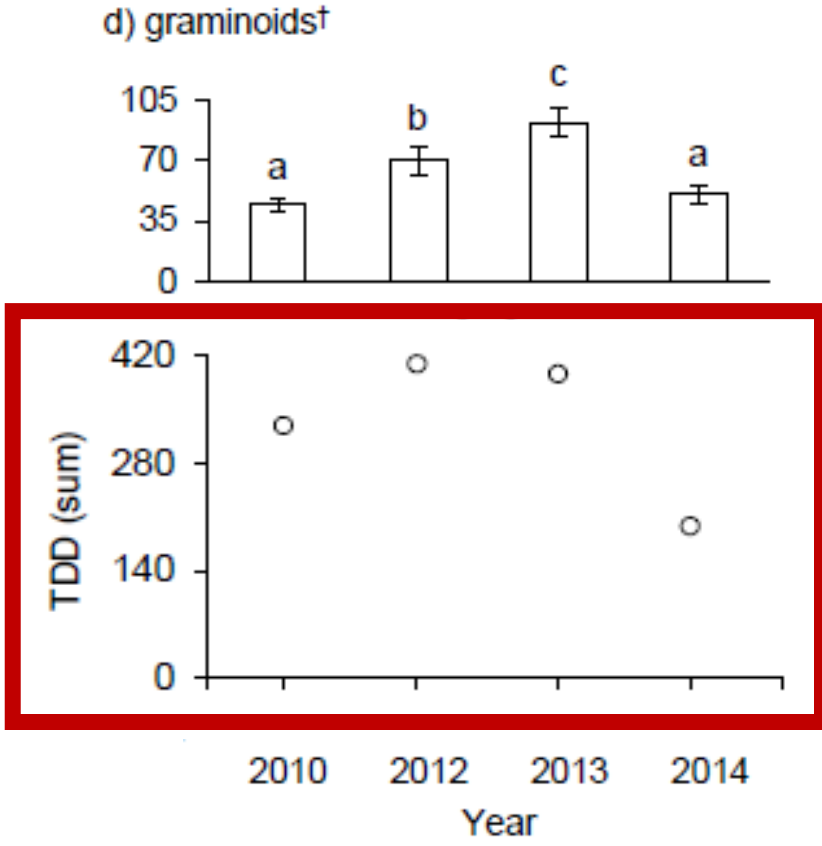

a) bryophytes
Cover (%)
60
40
20
0
a
a,b
b,c
a,b
b) deciduous shrubs*
15
10
5
0
a
a,b
b,c
a,b,c
c) forbs*
30
20
10
0
a
a,b
c
a
d) graminoids†
105
70
35
0
a
b
c
a
e) lichens*
30
20
10
0
a
a,b
c
b
2010
2012
2013
2014
Year


a) bryophytes
Cover (%)
60
40
20
0
a
a,b
b,c
a,b
b) deciduous shrubs*
15
10
5
0
a
a,b
b,c
a,b,c
c) forbs*
30
20
10
0
a
a,b
c
a
d) graminoids†
105
70
35
0
a
b
c
a
e) lichens*
30
20
10
0
a
a,b
c
b
f) litter‡
60
40
20
0
a
b
b,c
d
2010
2012
2013
2014
Year

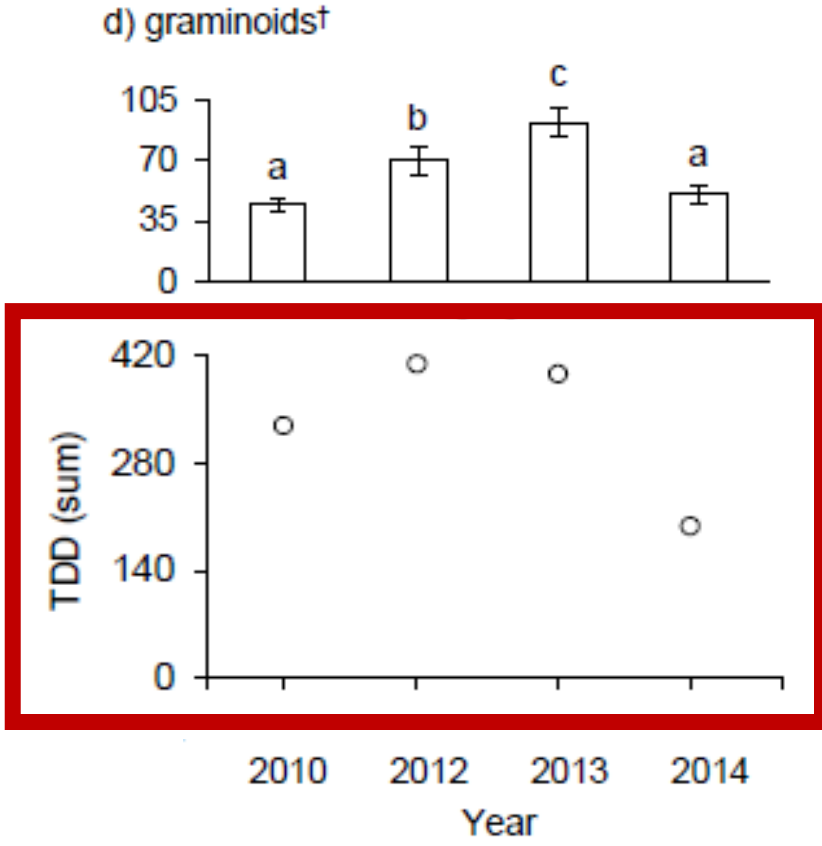

a) bryophytes
Cover (%)
60
40
20
0
a
a,b
b,c
a,b
b) deciduous shrubs*
15
10
5
0
a
a,b
b,c
a,b,c
c) forbs*
30
20
10
0
a
a,b
c
a
d) graminoids†
105
70
35
0
a
b
c
a
e) lichens*
30
20
10
0
a
a,b
c
b
f) litter‡
60
40
20
0
a
b
b,c
d
g) standing dead*
120
80
40
0
a
b
c
a
2010
2012
2013
2014
Year

Huge difference between years!




d) graminoids†
105
70
35
0
a
b
c
a
420
280
140
0
TDD (sum)
2010
2012
2013
2014
Year

In many cases the cover of a given year was correlated with the abiotic factor of that year

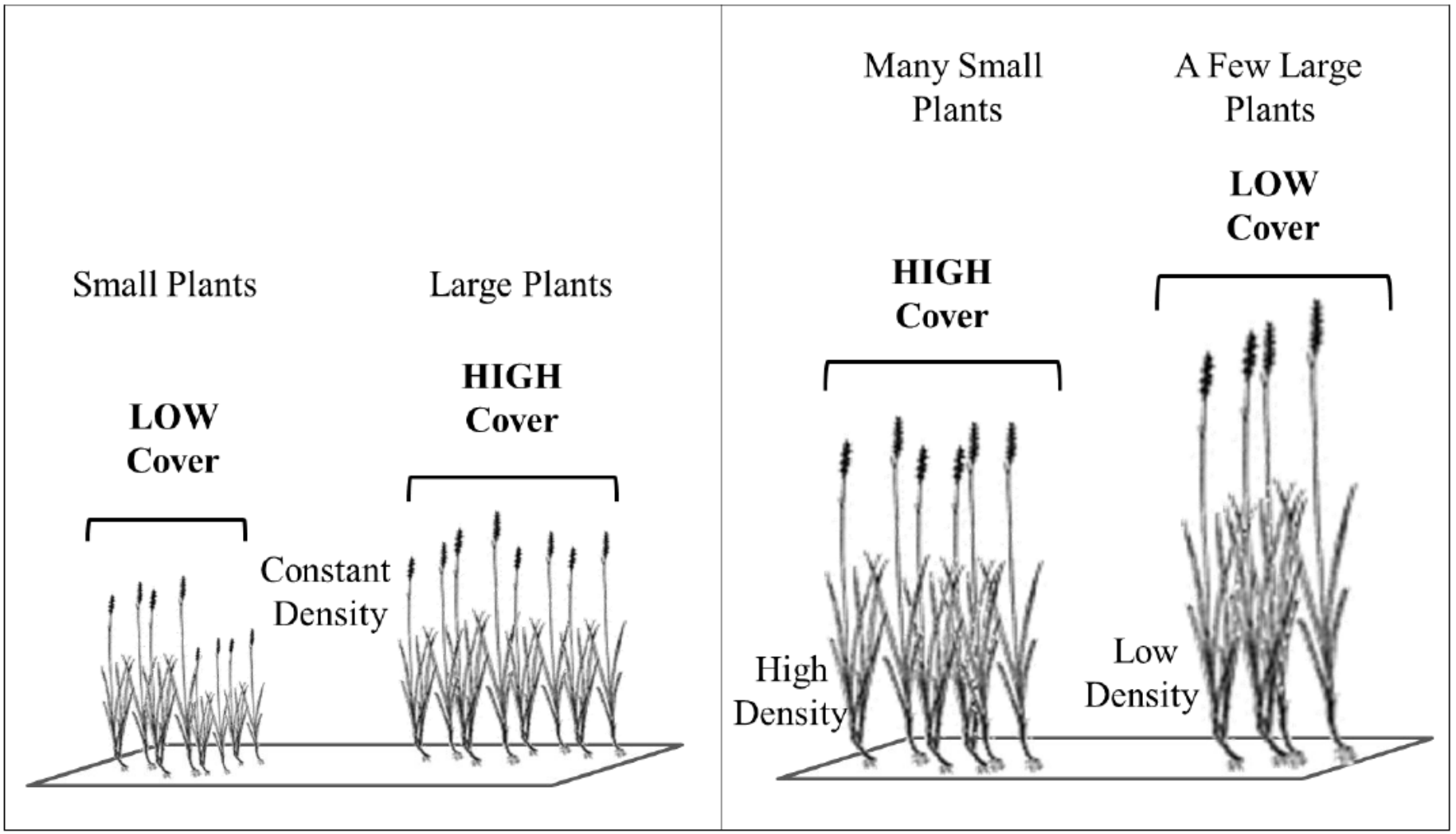


Gregory. 2014. Structural Comparison of Arctic Plant Communities Across the Landscape and with Experimental Warming in Northern Alaska. *Master's Thesis*. 87 pp.

Jessica Gregory

Gregory. 2014. Structural Comparison of Arctic Plant Communities Across the Landscape and with Experimental Warming in Northern Alaska. *Master's Thesis*. 87 pp.

Jessica Gregory


a) Control plots
b) Warmed plots
Small Plants
Large Plants
LOW
Cover
HIGH
Cover
Constant
Density
Many Small
Plants
A Few Large
Plants
HIGH
Cover
LOW
Cover
High
Density
Low
Density

Summary of Change over two decades of experimental warming at Barrow & Atqasuk:

- The phenological and growth responses to experimental warming have diminished in recent years

  Kremers et al. 2015. *Plos One* 10(3): e0116586 1-13.

- This is because the response to warming is less in a warmer year

  Barrett & Hollister. *In Press*. *Polar Research*.

- Growth and phenology respond to many abiotic factors in addition to temperature

  Barrett et al. *In Review*. American *Journal of Botany*.

- The cover at the sites has changed over time

  Hollister et al. 2015. *Ecology and Evolution* 5(9): 1881-1895.

- The cover of vegetation changes greatly in response to the weather in a given year

  Botting. 2015. *Master's Thesis*. 66 pp.

- The increase in graminoid cover is often due to larger yet less dense plants

  Gregory. 2014. *Master's Thesis*. 87 pp.

- Understanding change takes a lot of observations/work

People that made this work possible

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Questions?