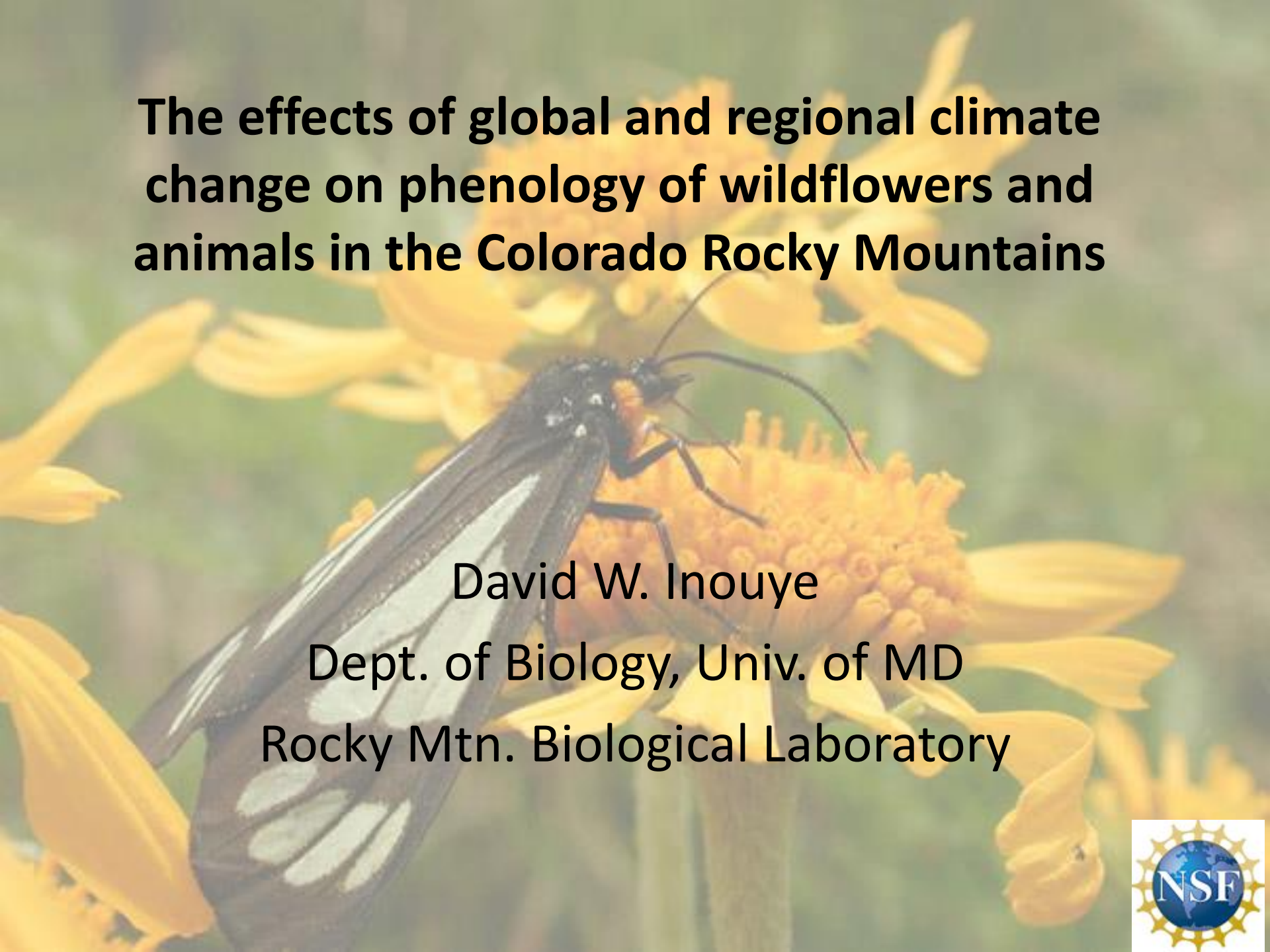
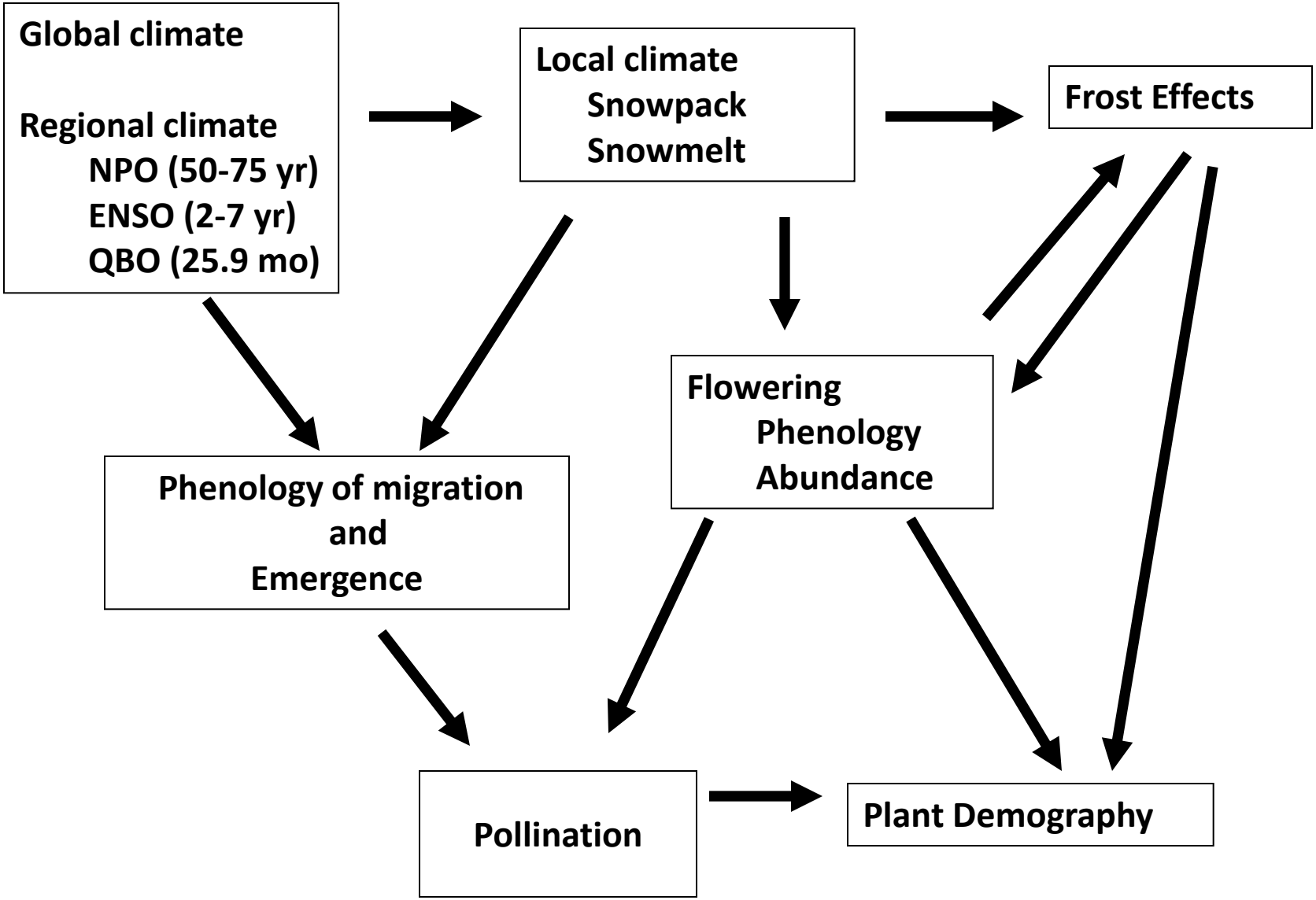
The effects of global and regional climate change on phenology of wildflowers and animals in the Colorado Rocky Mountains

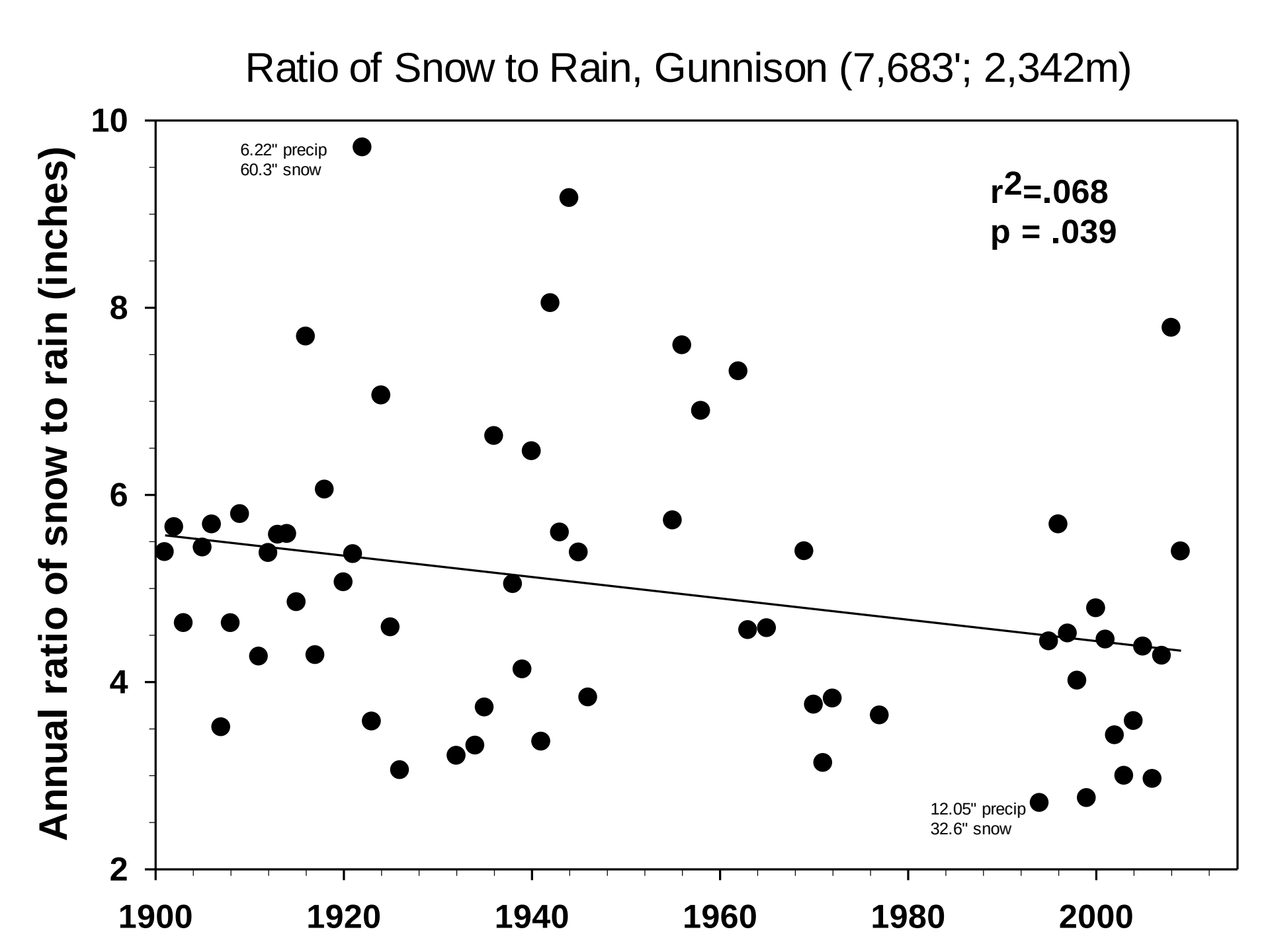


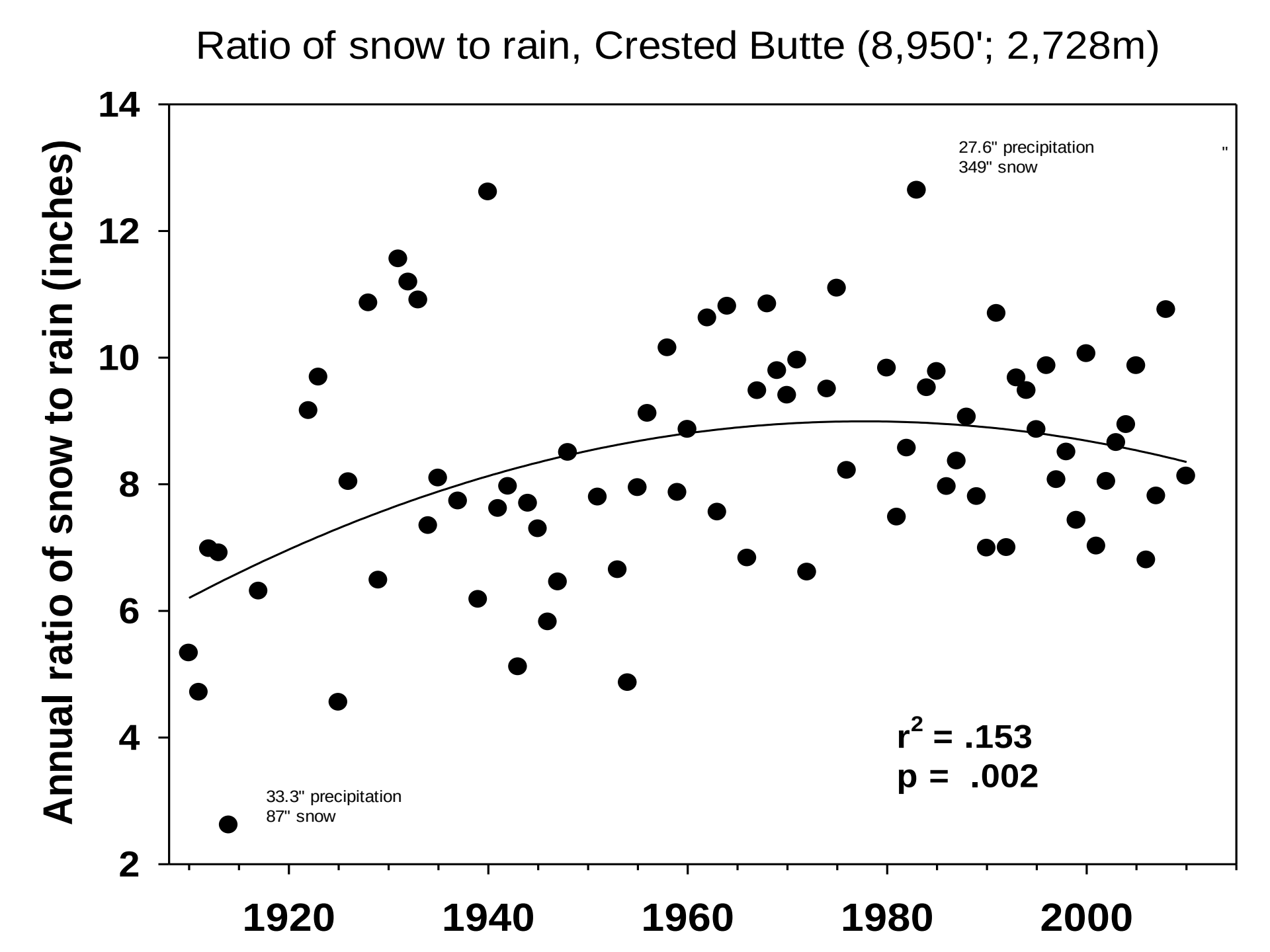
David W. Inouye

Dept. of Biology, Univ. of MD

Rocky Mtn. Biological Laboratory


Global climate
Regional climate
NPO (50-75 yr)
ENSO (2-7 yr)
QBO (25.9 mo)
Local climate
Snowpack
Snowmelt
Frost Effects
Flowering
Phenology
Abundance
Phenology of migration
and
Emergence
Pollination
Plant Demography


Ratio of Snow to Rain, Gunnison (7,683'; 2,342m)
Annual ratio of snow to rain (inches)
10
8
6
4
2
1900
1920
1940
1960
1980
2000
6.22" precip
60.3" snow
12.05" precip
32.6" snow
r2=.068
p = .039


Ratio of snow to rain, Crested Butte (8,950'; 2,728m)
Annual ratio of snow to rain (inches)
14
12
10
8
6
4
2
1920
1940
1960
1980
2000
27.6" precipitation
349" snow
33.3" precipitation
87" snow
r2 = .153
p = .002

Cartoon: Seppo Leinonen, www. seppo.net/e

Changing Environment

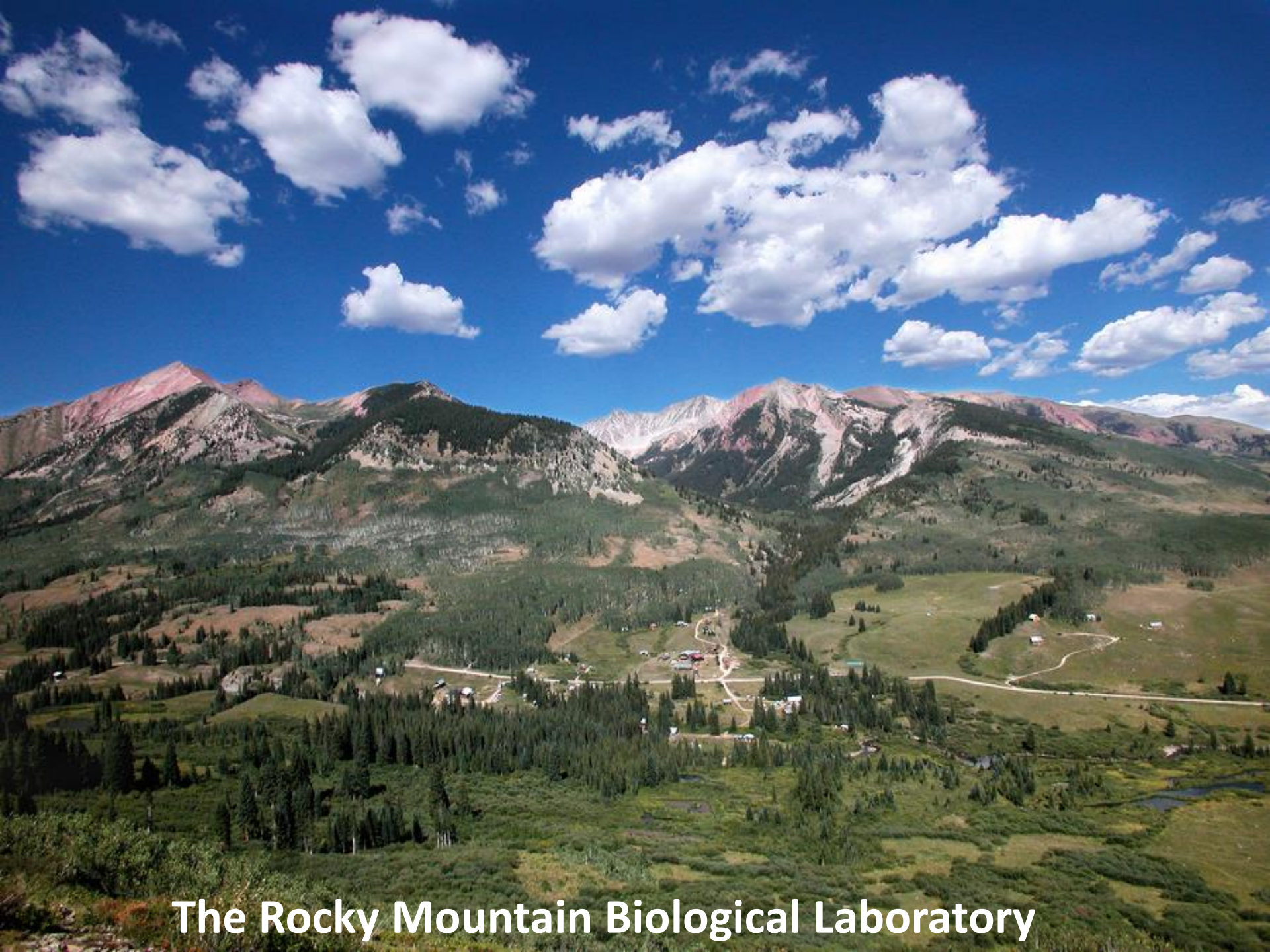
- **Changes in temperature**
- **Changes in precipitation**
- **Increased variation**

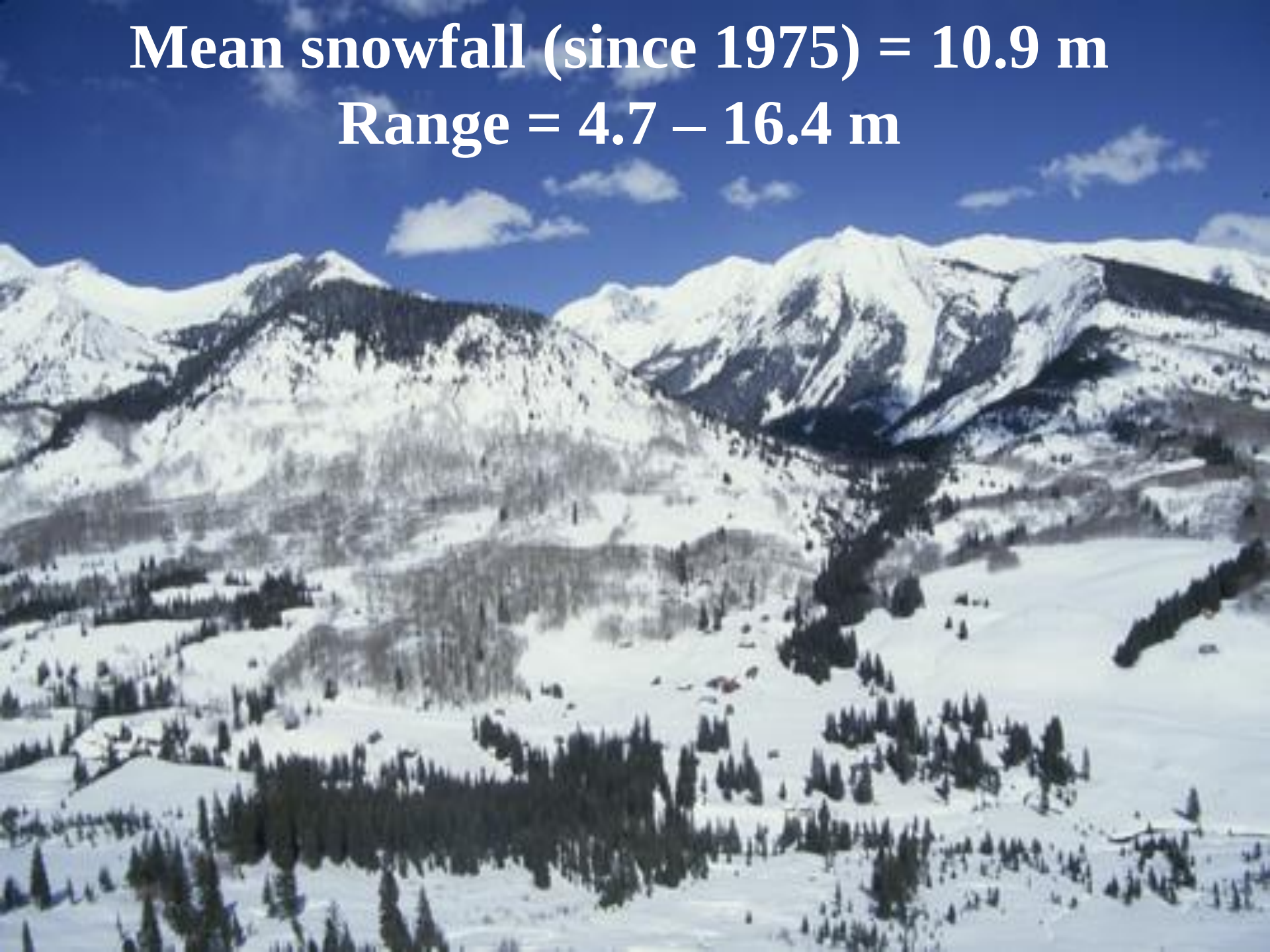
- **Changes can be global, regional, or local**

In short:

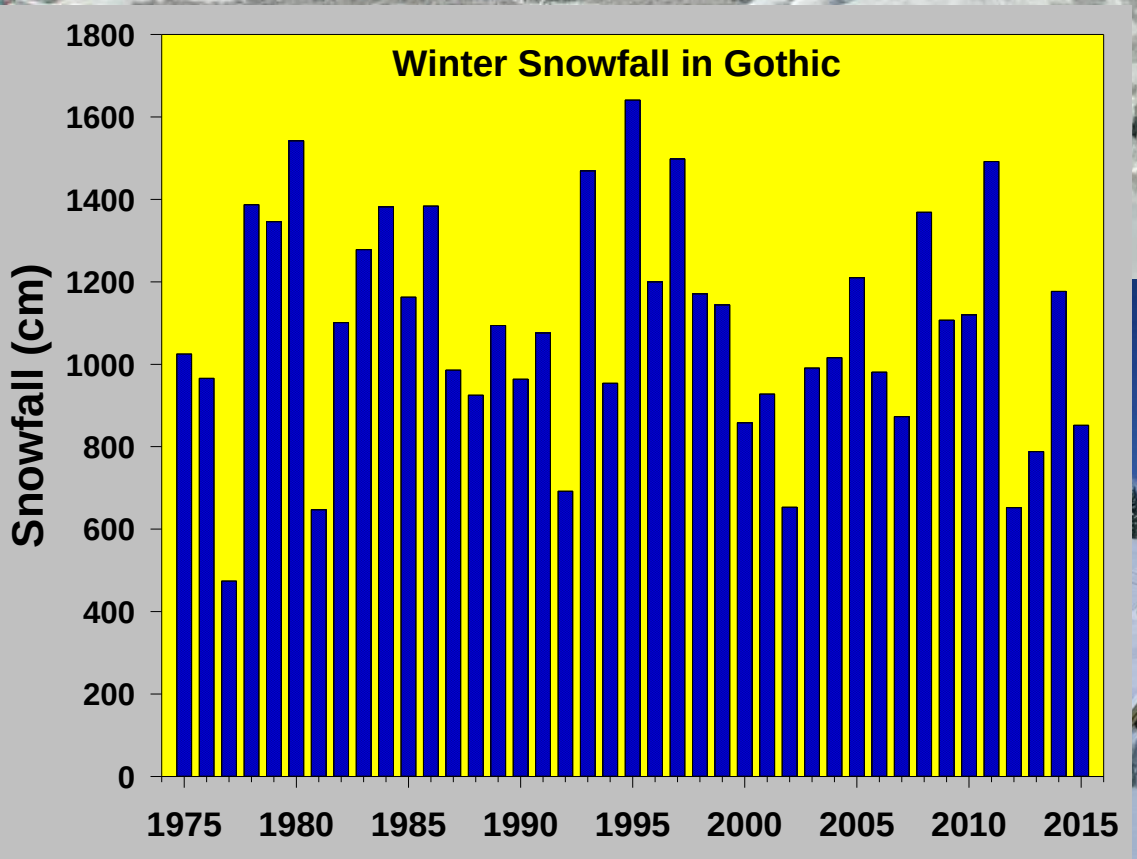
- **A changing ecological environment**

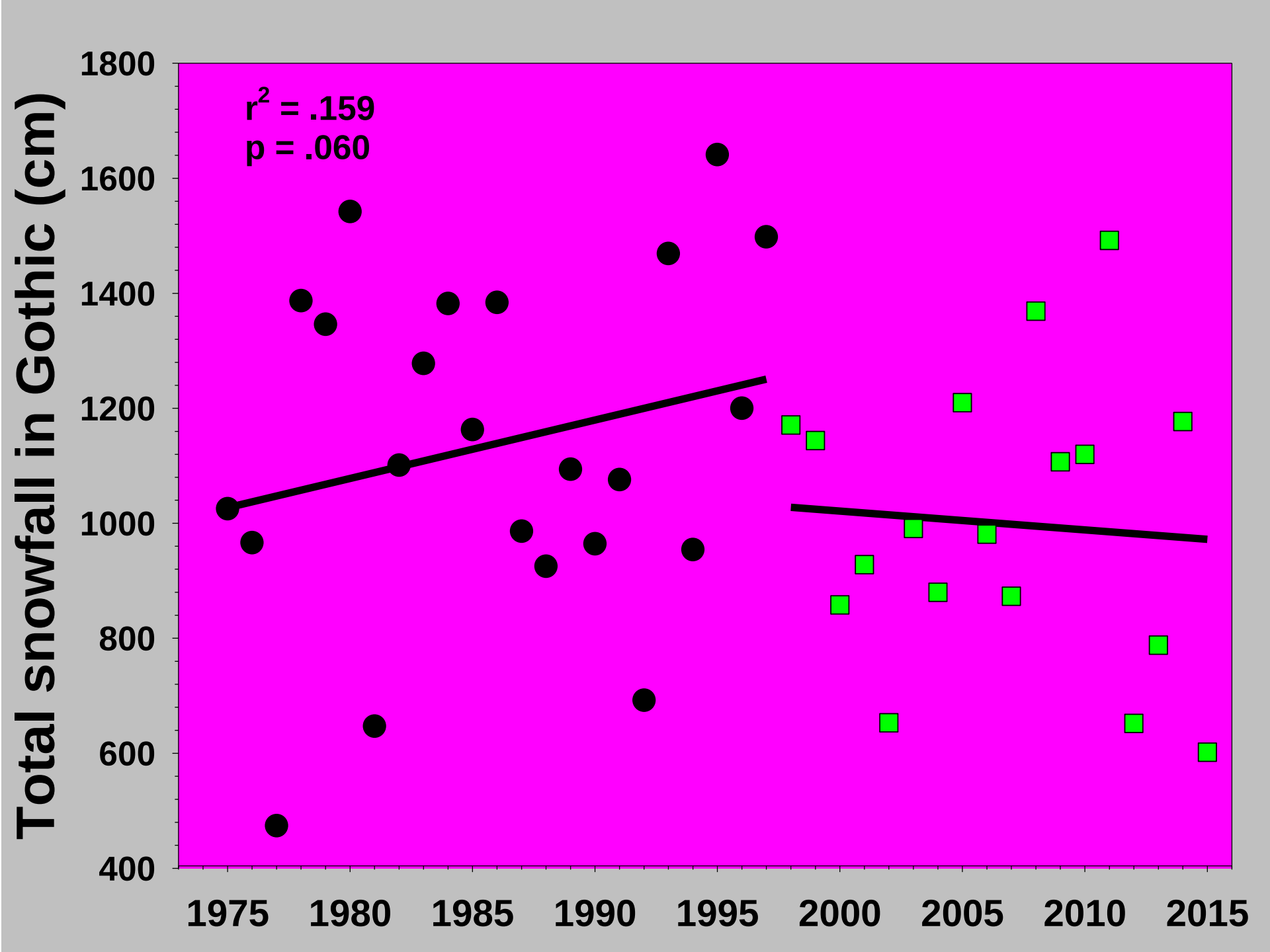
Changes in phenology (timing of seasonal events)


The Rocky Mountain Biological Laboratory


Mean snowfall (since 1975) = 10.9 m
Range = 4.7 – 16.4 m

12,631’

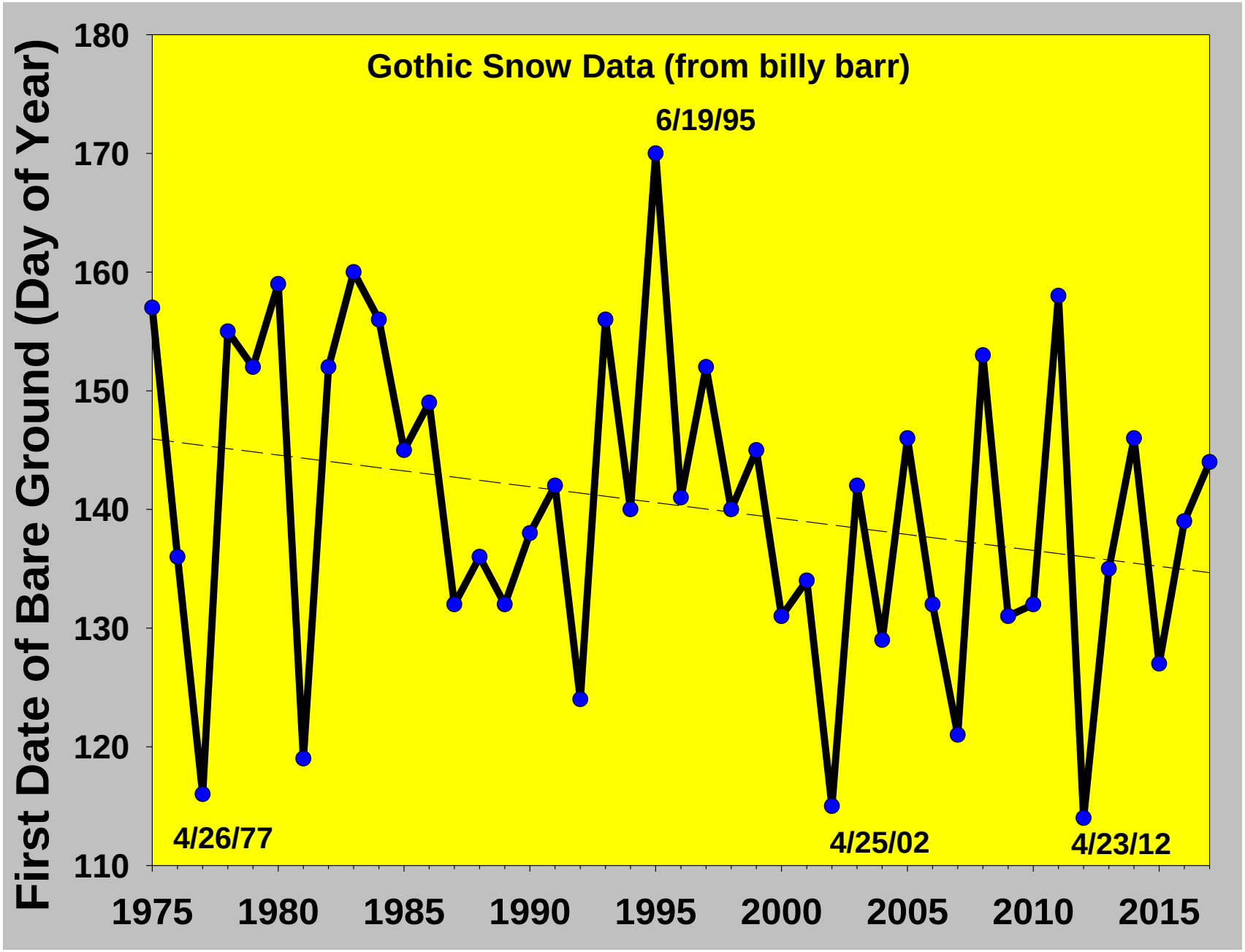

Winter Snowfall in Gothic
Snowfall (cm)
1800
1600
1400
1200
1000
800
600
400
200
0
1975
1980
1985
1990
1995
2000
2005
2010
2015

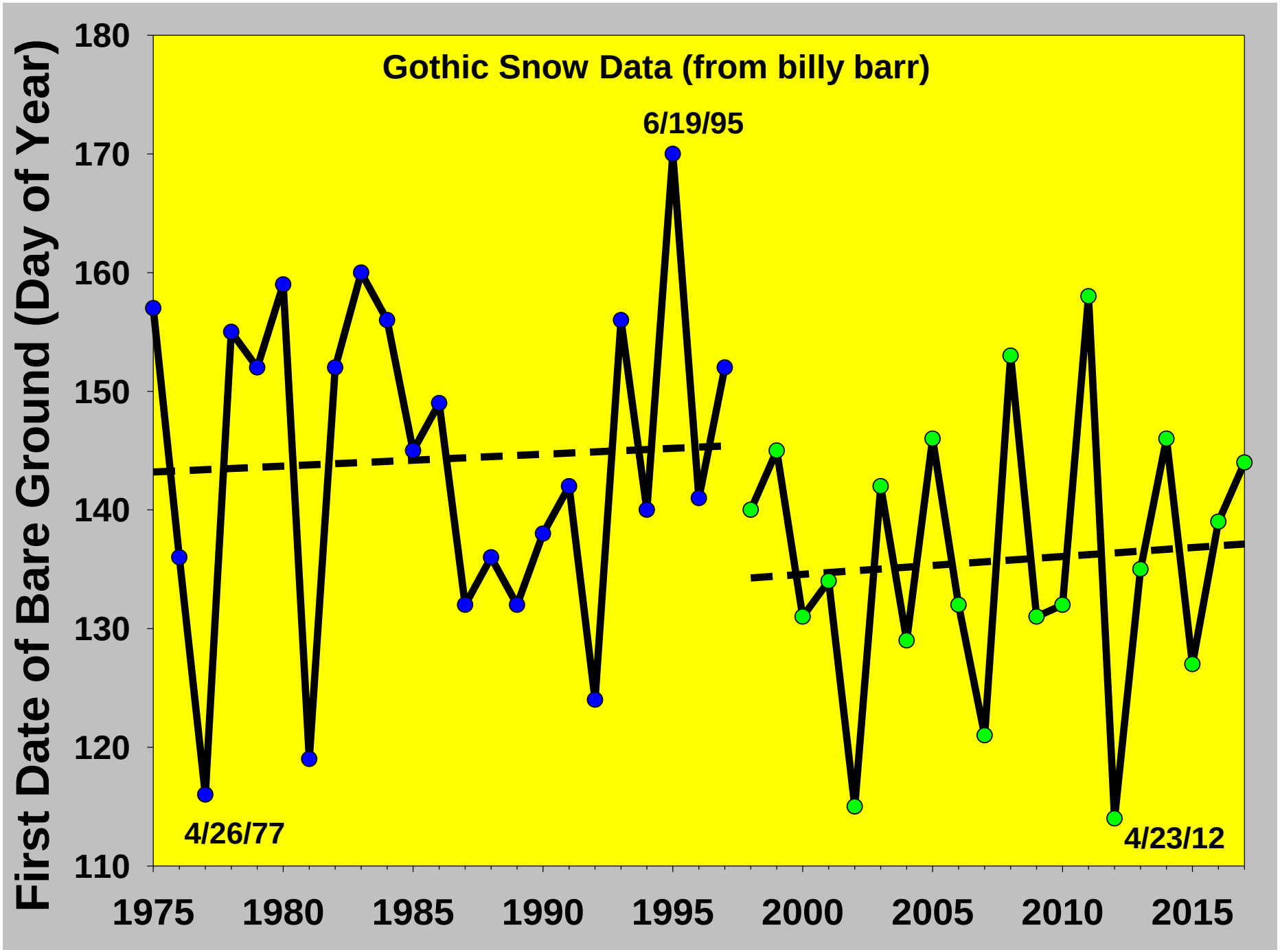

Total snowfall in Gothic (cm)
1800
1600
1400
1200
1000
800
600
400
1975
1980
1985
1990
1995
2000
2005
2010
2015
r2 = .159
p = .060

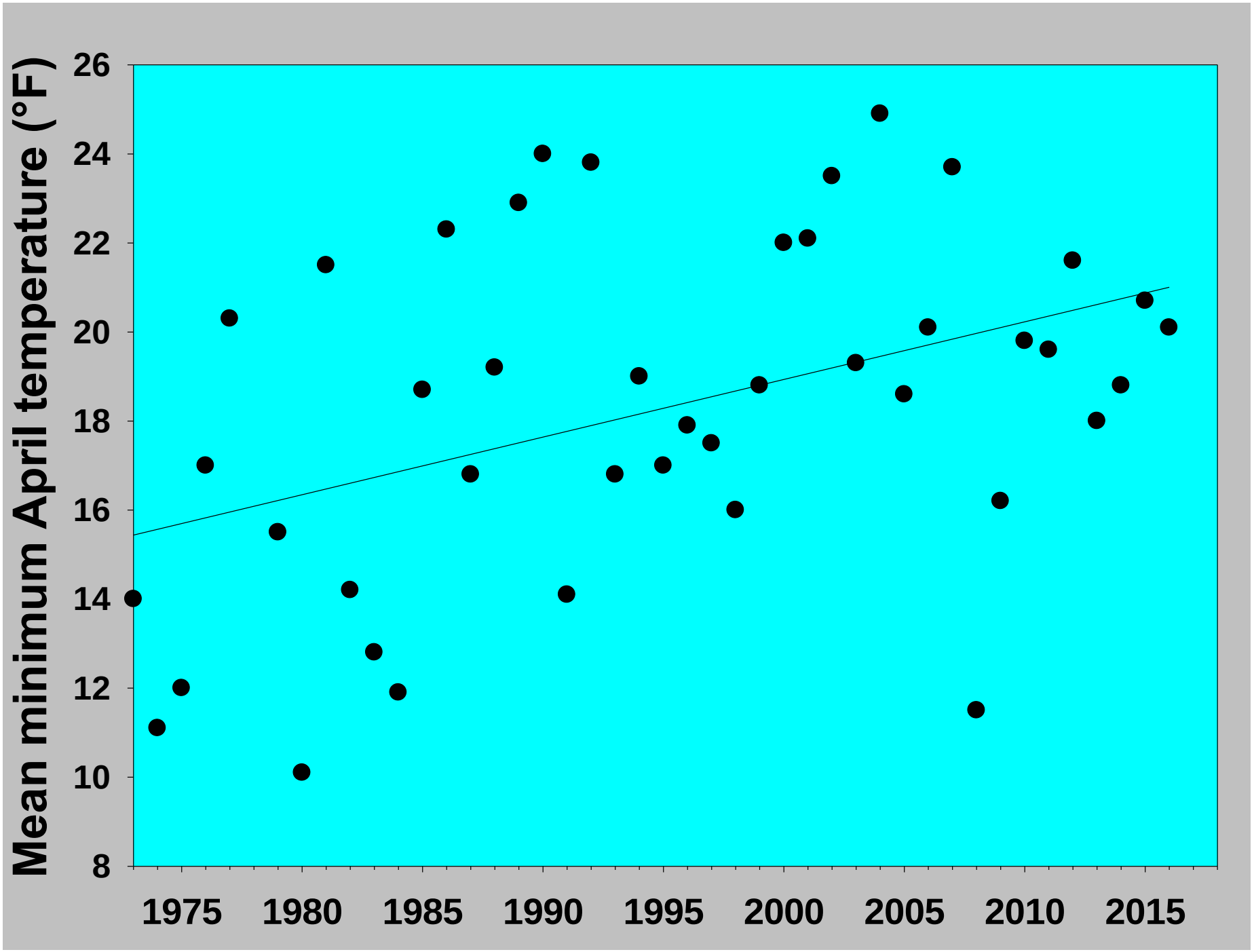
billy barr

at RMBL since 1972

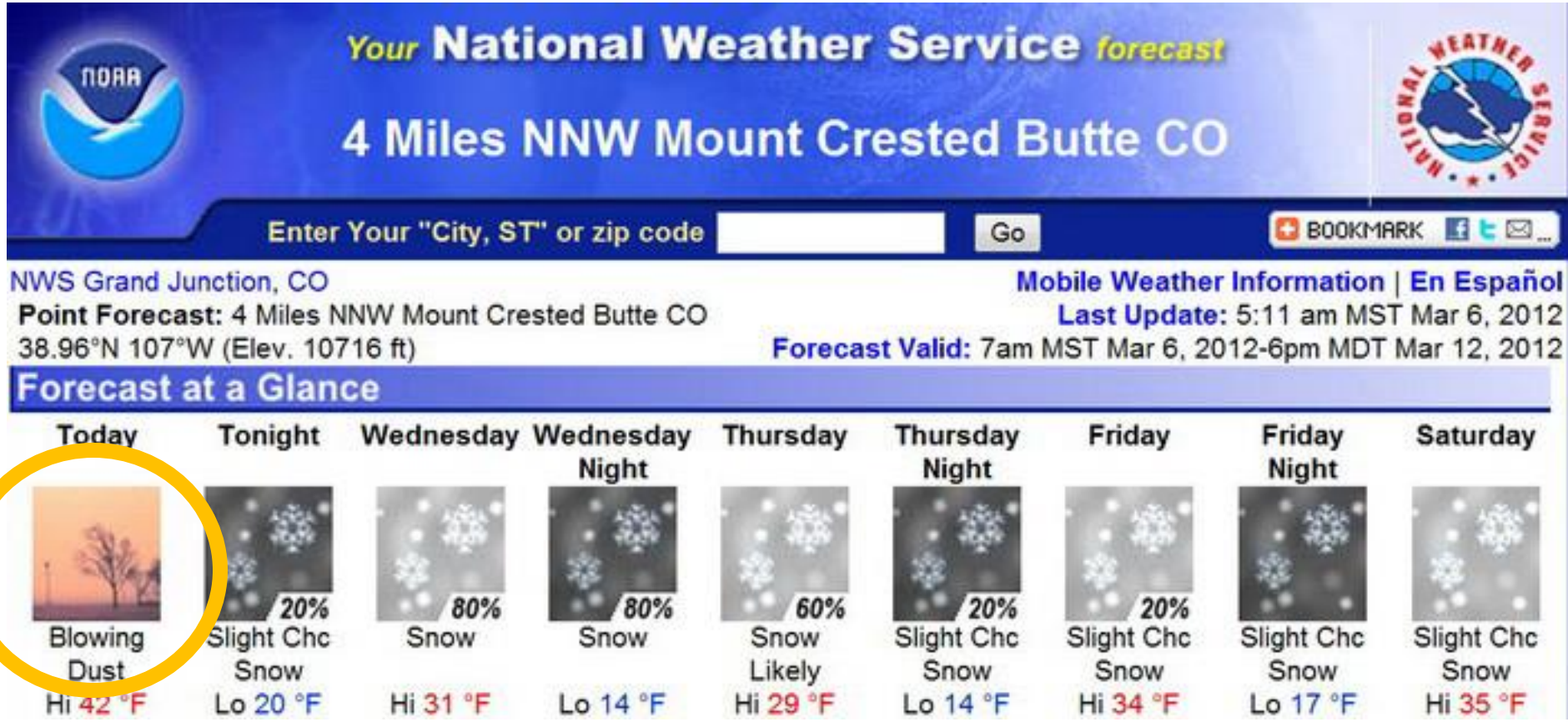
When does the snow melt?




Gothic Snow Data (from billy barr)
6/19/95
4/26/77
4/23/12
First Date of Bare Ground (Day of Year)
180
170
160
150
140
130
120
110
1975
1980
1985
1990
1995
2000
2005
2010
2015


Mean minimum April temperature (°F)
26
24
22
20
18
16
14
12
10
8
1975
1980
1985
1990
1995
2000
2005
2010
2015

Dust storm approaching Phoenix, AZ, July 5, 2011, photo by Daniel Bryant

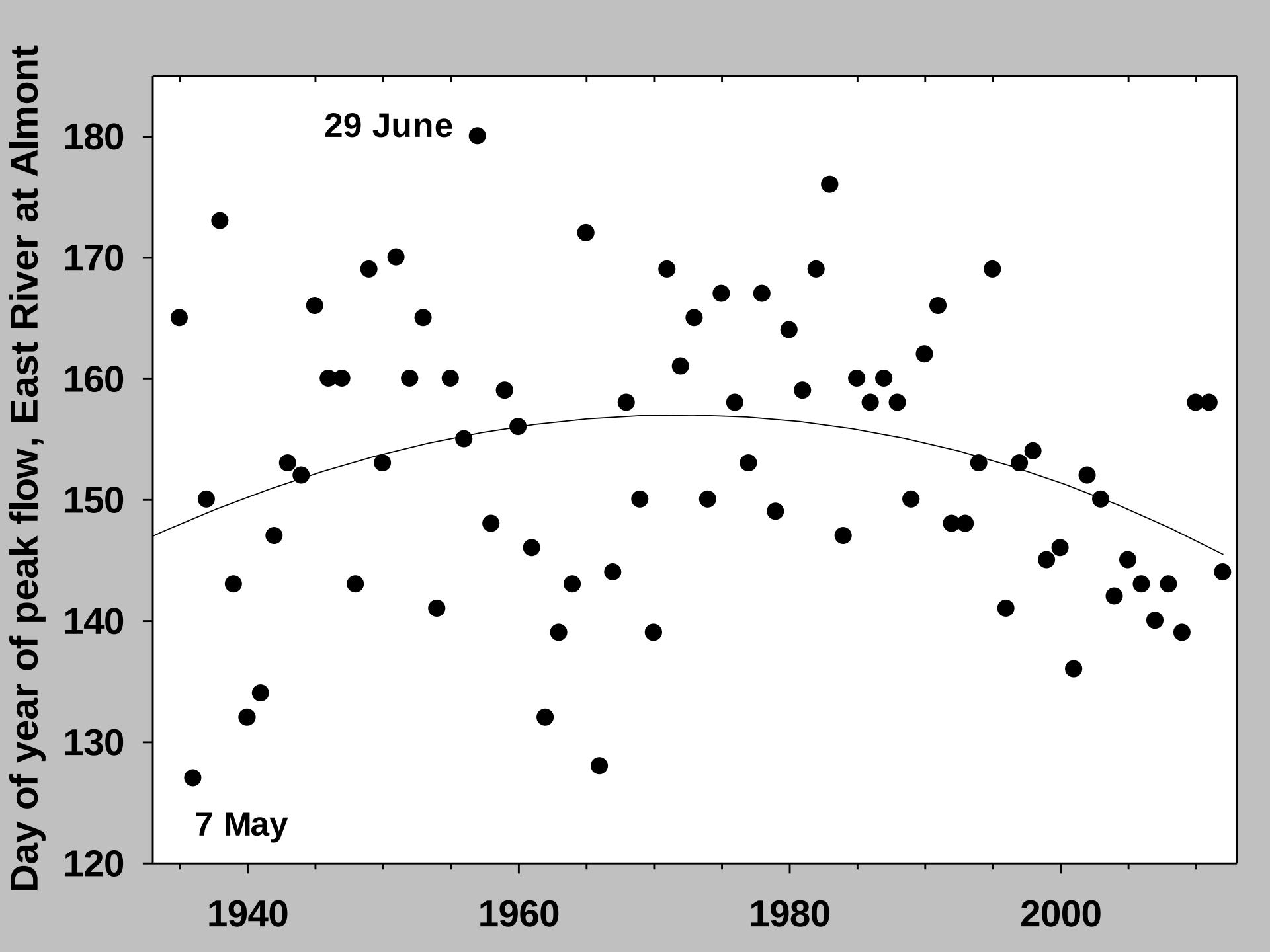


Was also forecast for:

Montrose, CO
Grand Junction, CO
Gunnison, CO
Aspen, CO
Telluride, CO
Rifle, CO

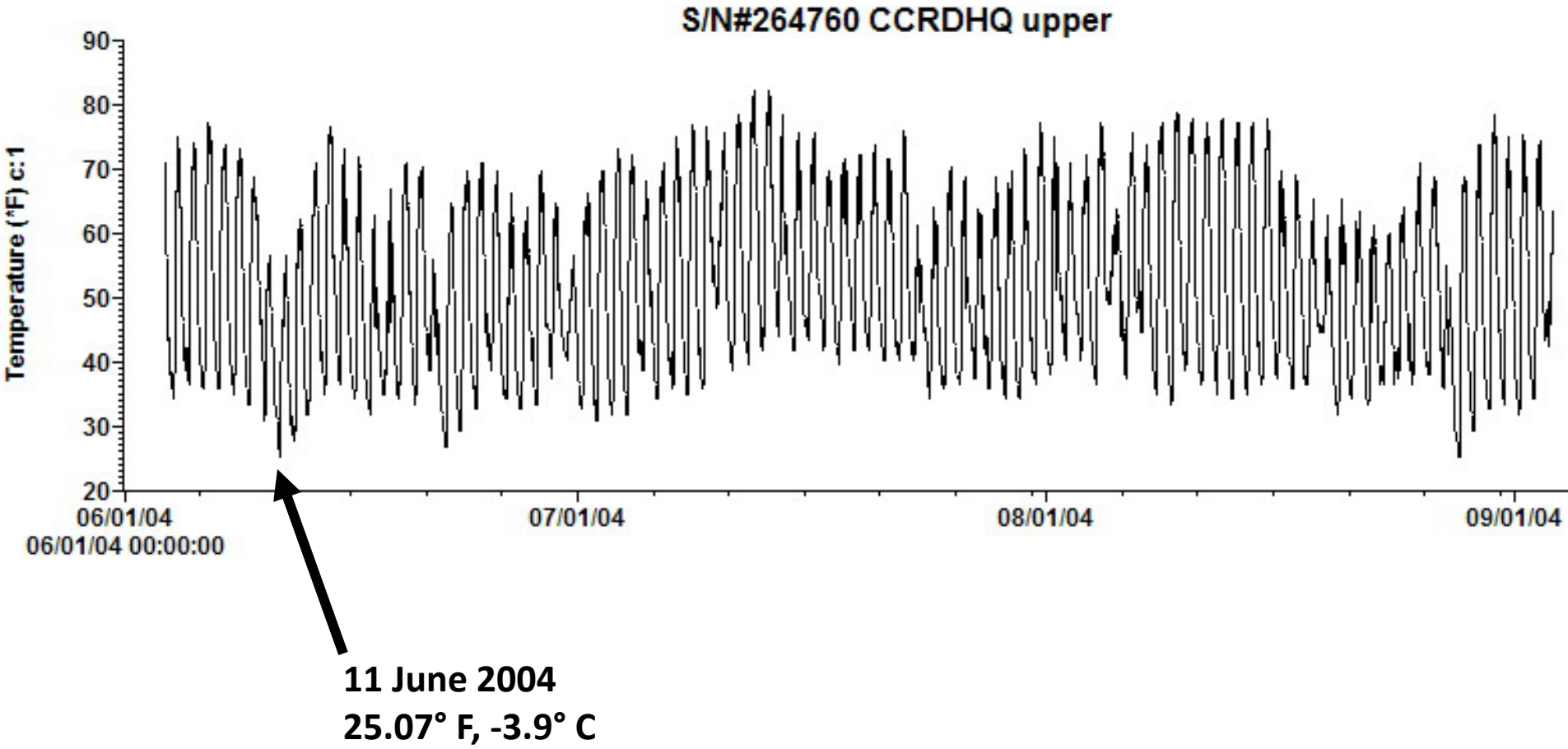
Cahone, CO
Dove Creek, CO
Cisco, UT
Thompson, UT
Moab, UT
Bluff, UT

Mexican Water, AZ


Day of year of peak flow, East River at Almont
29 June
7 May
180
170
160
150
140
130
120
1940
1960
1980
2000

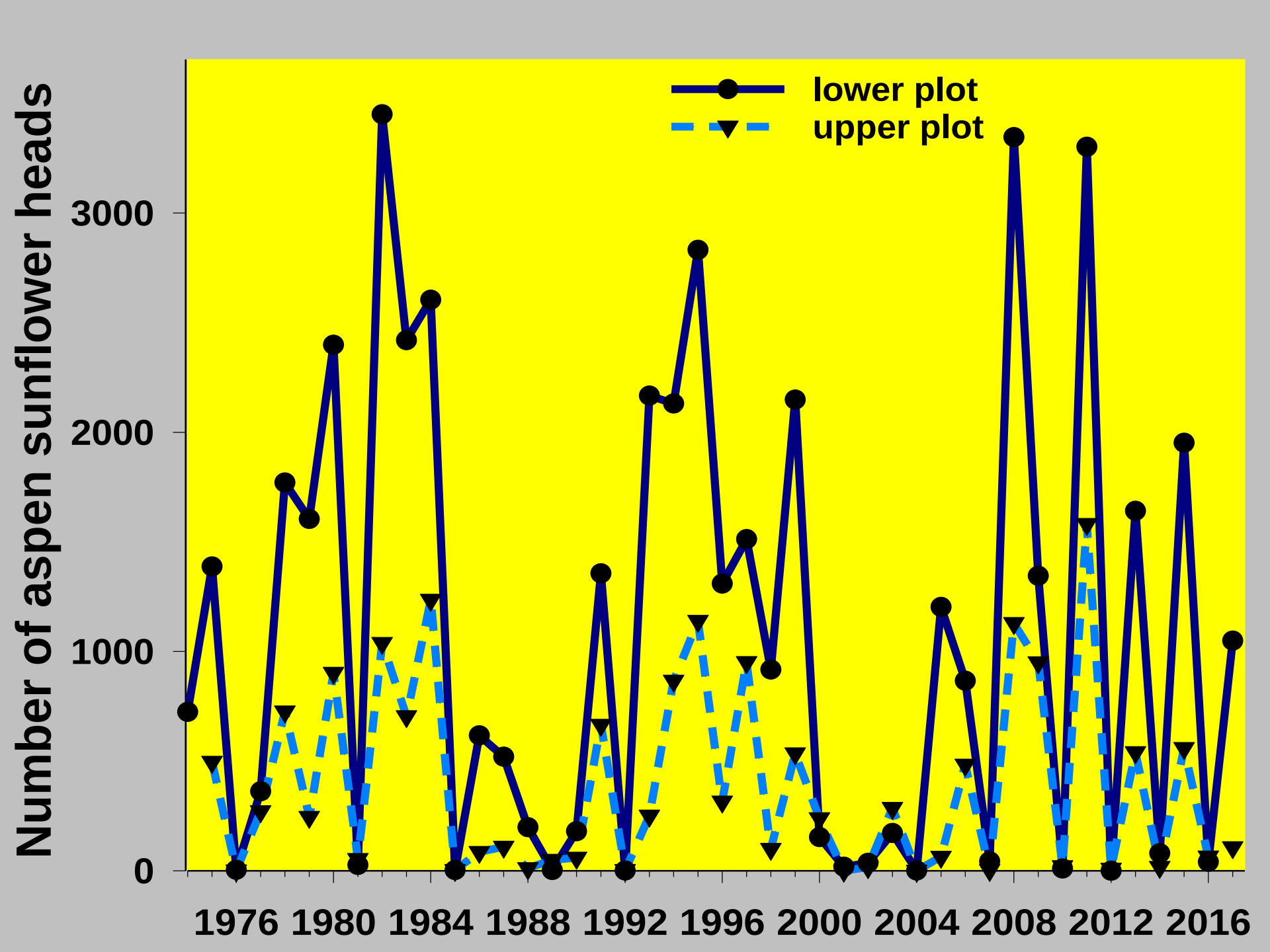
Frost can significantly reduce flower abundance


13 June 2001
21.55 (F) -5.81 (C)



11 June 2004
25.07° F, -3.9° C


Helianthella quinquenervis


lower plot
upper plot
Number of aspen sunflower heads
3000
2000
1000
0
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016

Number of unfrosted flower heads

5000
4000
3000
2000
1000
0

2011
2008
1982
1995
1984
1980
1983
1994
1999
1978
1993
2009
1991
1979
1975
1996
2006
2005
1998
1986
1977
1987
2003
2000
1990
1985

110 120 130 140 150 160 170

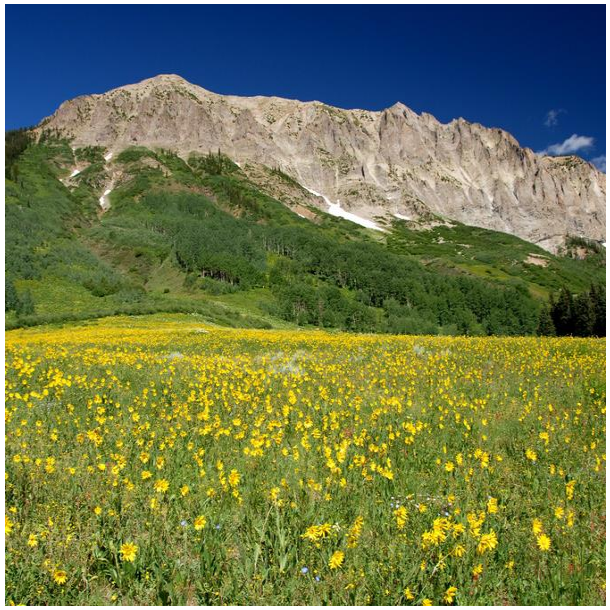
20 April

Day of year of snowmelt

19 June

Stochastic Integral Projection Model (IPM)

$\lambda = 1.78$



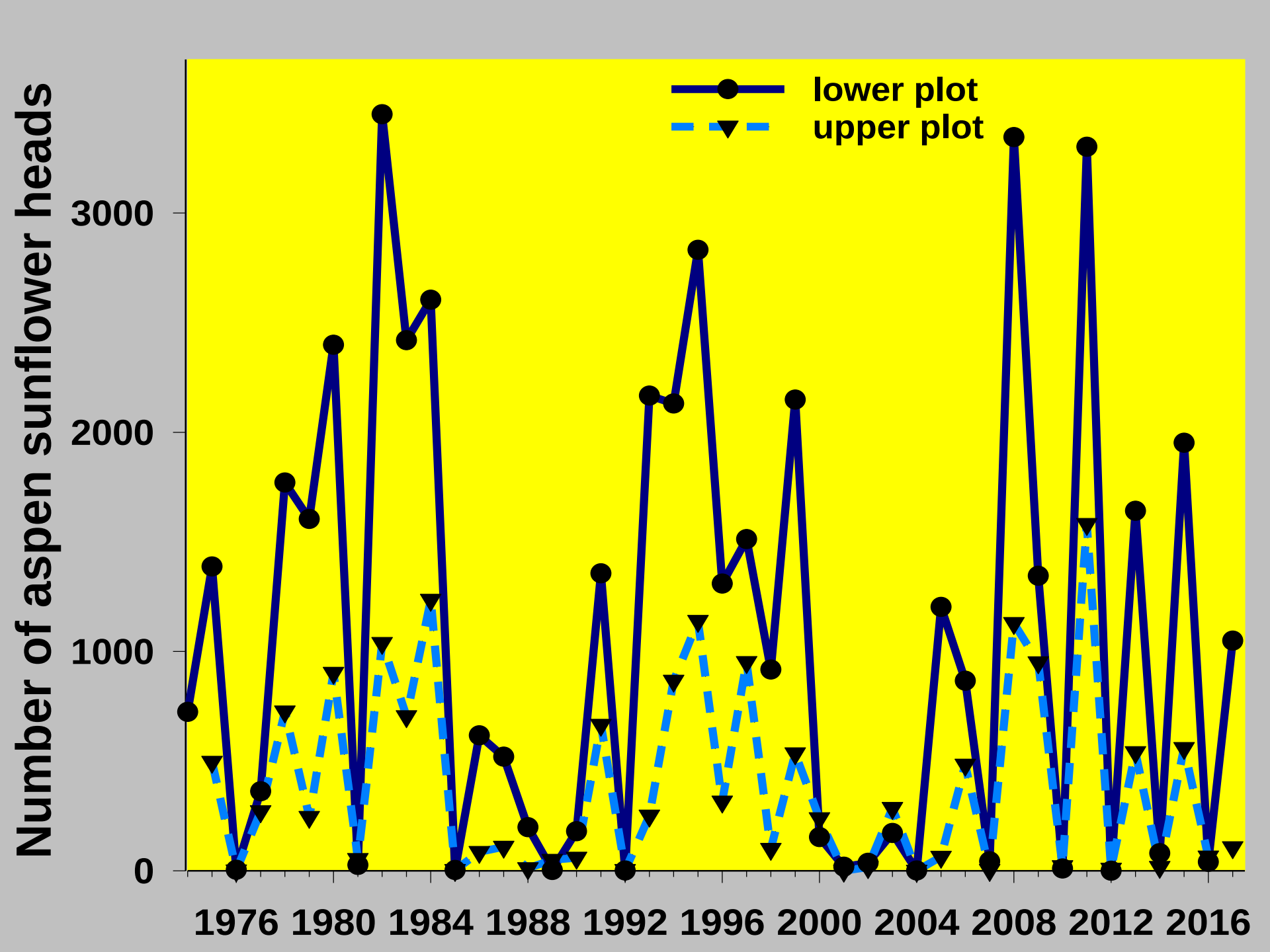
$\lambda = 1.08$

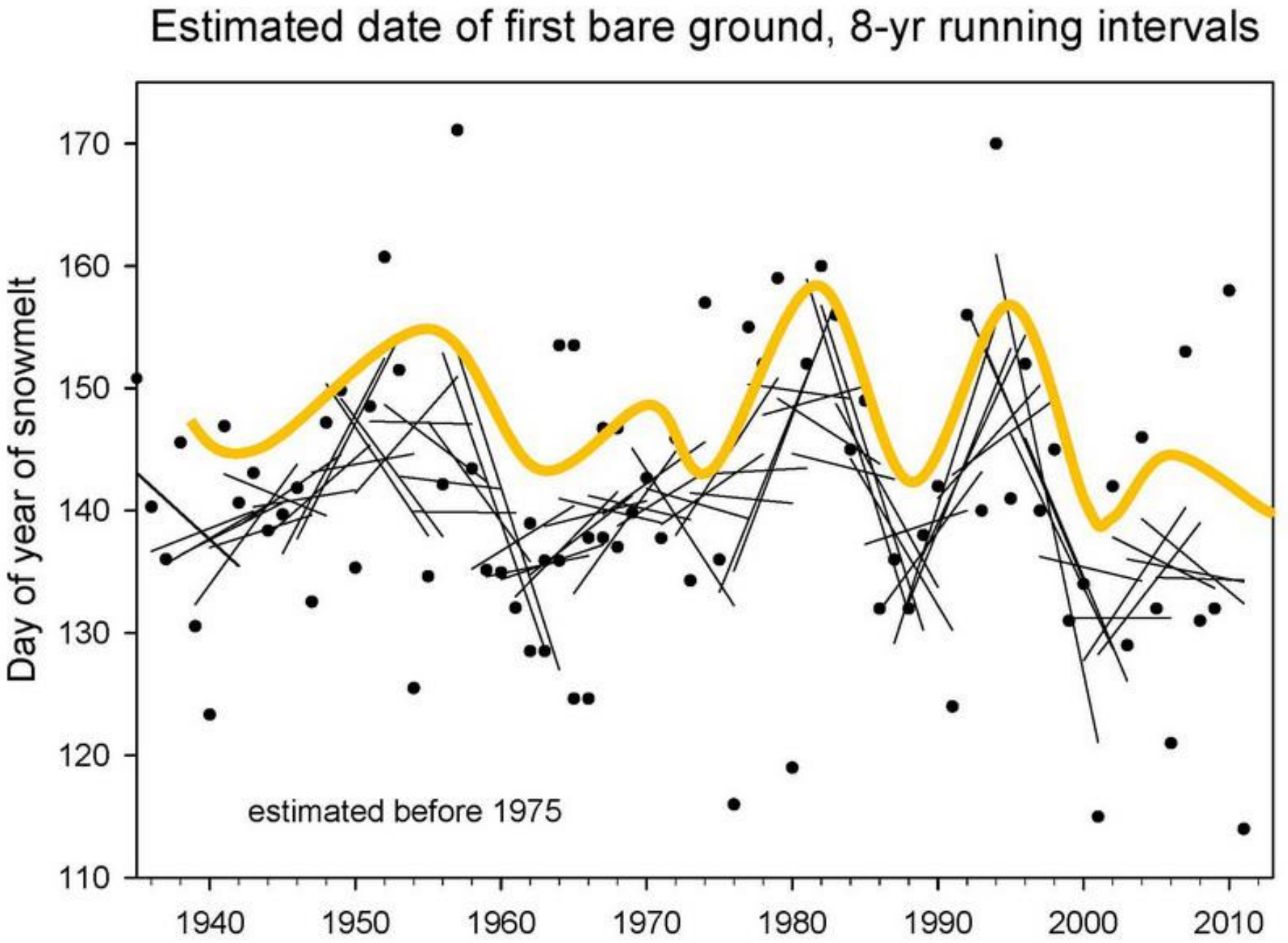
Compagnoni, A., Bibian, A.J., Ochocki, B.M., Rogers, H.S., Schultz, E., Sneck, M.E., Elderd, B.D., Iler, A., Inouye, D., Jacquemyn, H. and T.E.X. Miller. (2016) The effect of demographic correlations on the stochastic population dynamics of perennial plants. *Ecological Monographs* 86: 480–494.

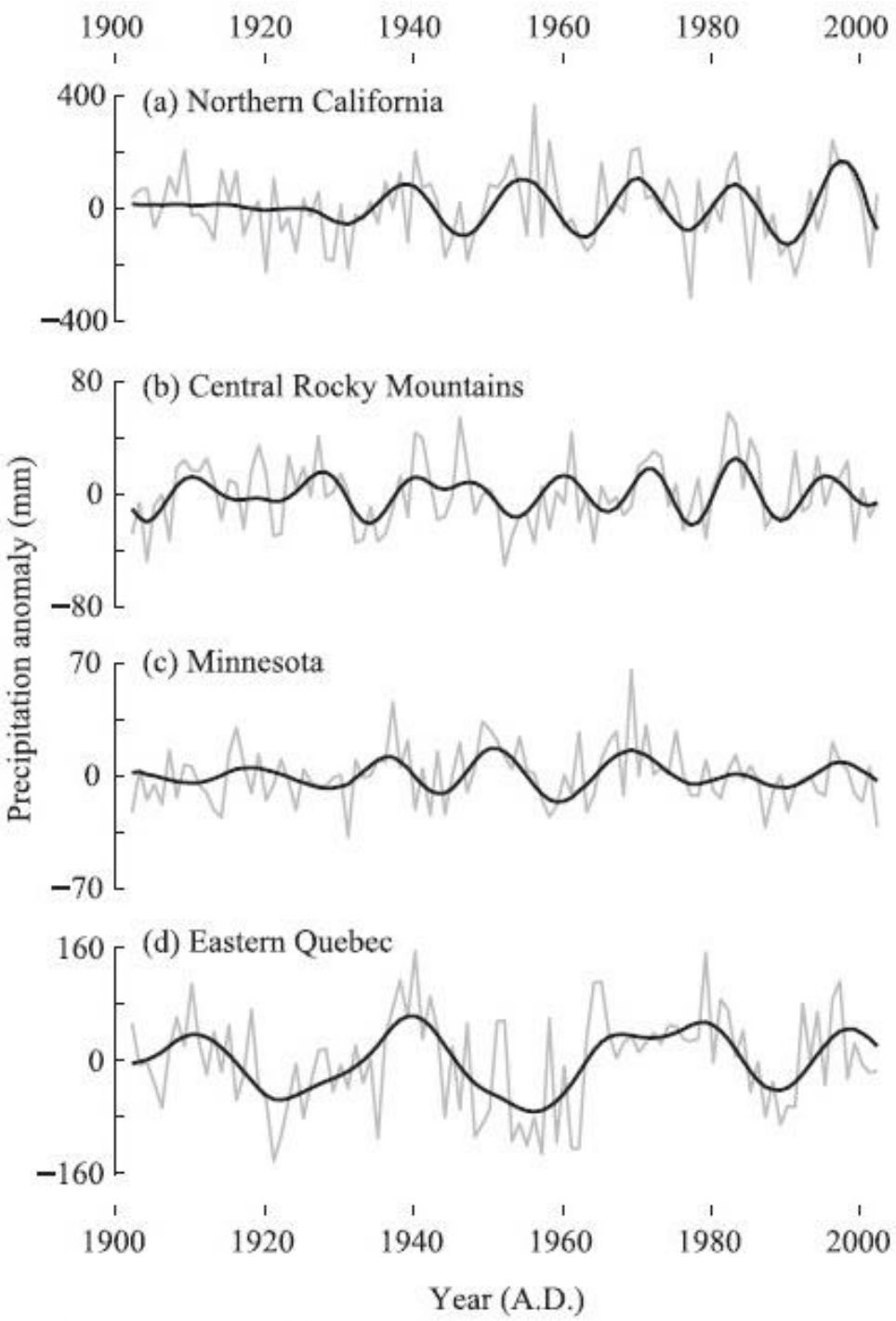
Hierarchical Bayesian parameterization of population projection models, and stochastic simulations.

Iler, Amy M., A. Compagnoni, D. W. Inouye, J. L. Williams, P. J. CaraDonna, A. Anderson, T. E.X. Miller. 2017. Negative effects of survival outweigh the consequences of climate change-induced phenological shifts for plant population dynamics.

Front Range peach buyers are finding out it's not that easy to find the prized fruit in the worst weather year for peaches in more than two decades. – August 2013, Denver Post


lower plot
upper plot
Number of aspen sunflower heads
3000
2000
1000
0
1976
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016


Estimated date of first bare ground, 8-yr running intervals
Day of year of snowmelt
170
160
150
140
130
120
110
1940
1950
1960
1970
1980
1990
2000
2010
estimated before 1975



Evolution of decadal and multidecadal signals in precipitation (thick lines) in (a) northern California (winter), (b) the central Rocky Mountains (autumn), (c) Minnesota (winter), and (d) eastern Québec (annual). The thin lines illustrate the original seasonal precipitation record for each region.

The decadal component of autumn precipitation over the central Rocky Mountains operates on a 12–14-yr time scale.

Ault & St. George 2010

Are pollinators being affected?

Speyeria mormonia and ***Erigeron speciosus***

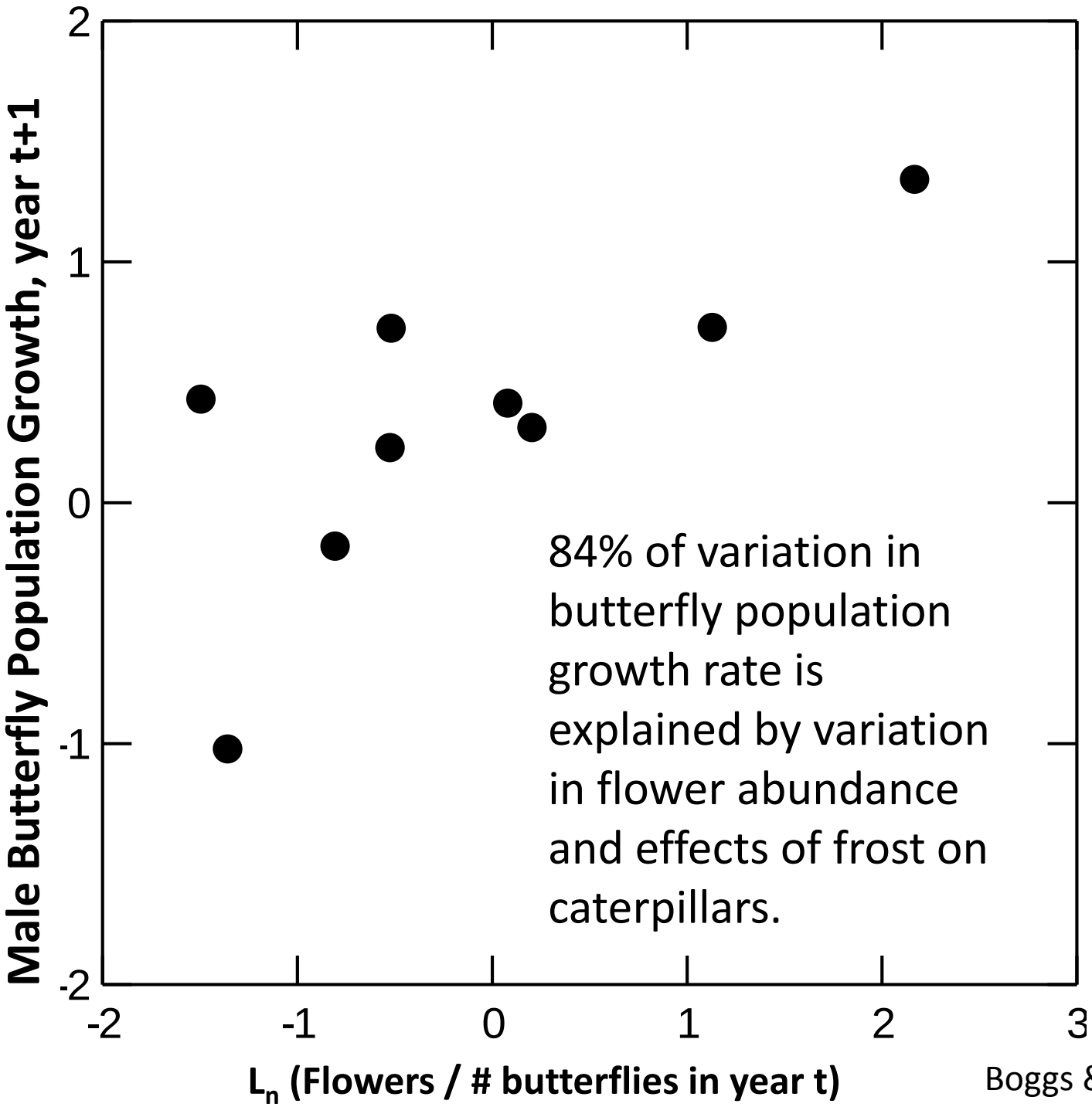
Maximum Number of Flowers Counted

1800
1600
1400
1200
1000
800
600
400
200
0

2011
1979
1984
1983
1980
1982
2005
1998
1999
1996
1975
1995
2009
2008
2004
1978
2003
1981
1986
1991
1997
1993
1992
1974
1977
2006
1988
2007
2010
2000
2001
1976
1987
2002
1989
1994
1985

0 25 50 75 100 125 150 175 200 225

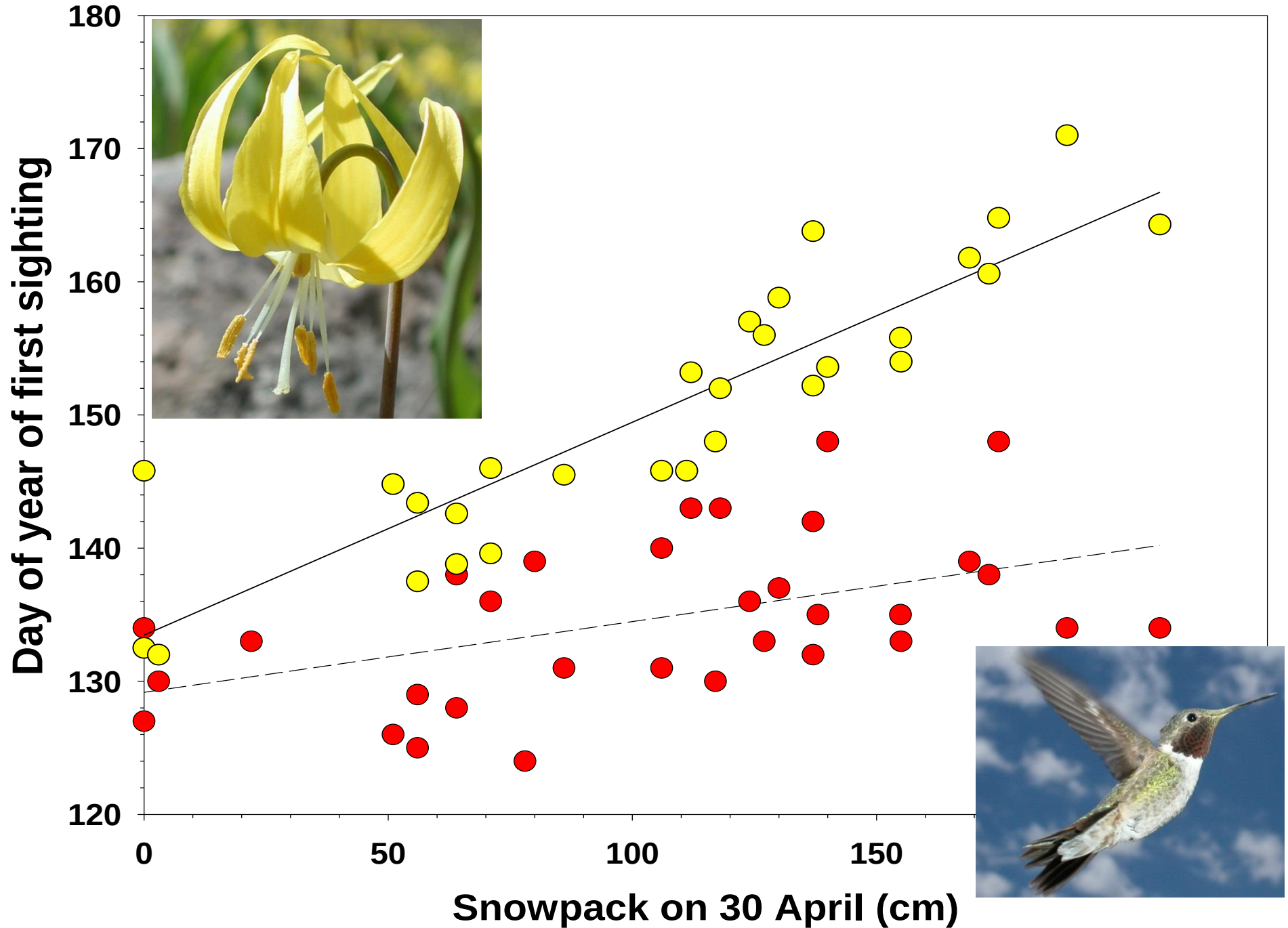
Snowpack on 30 April (cm)



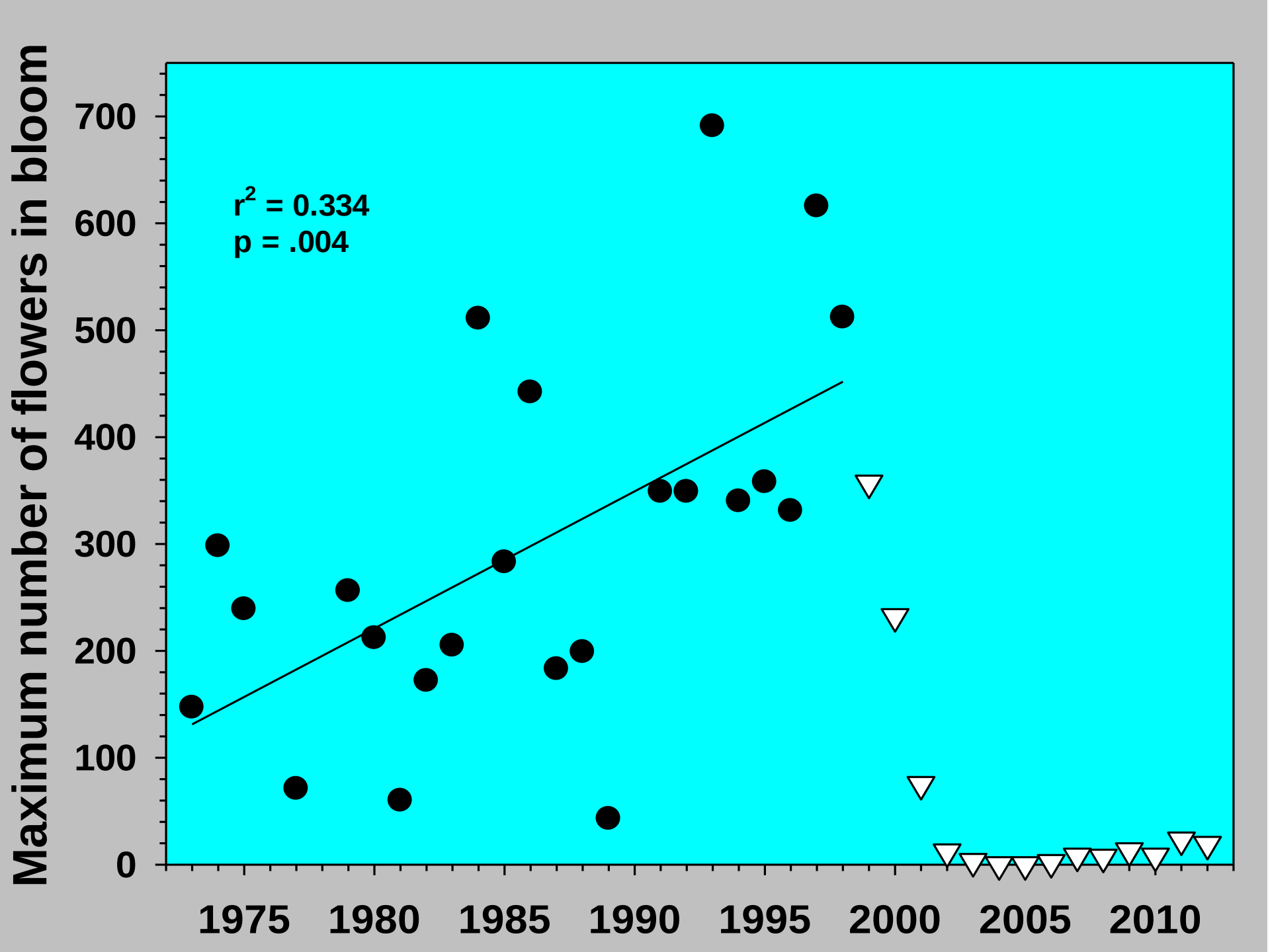
Boggs & Inouye 2012

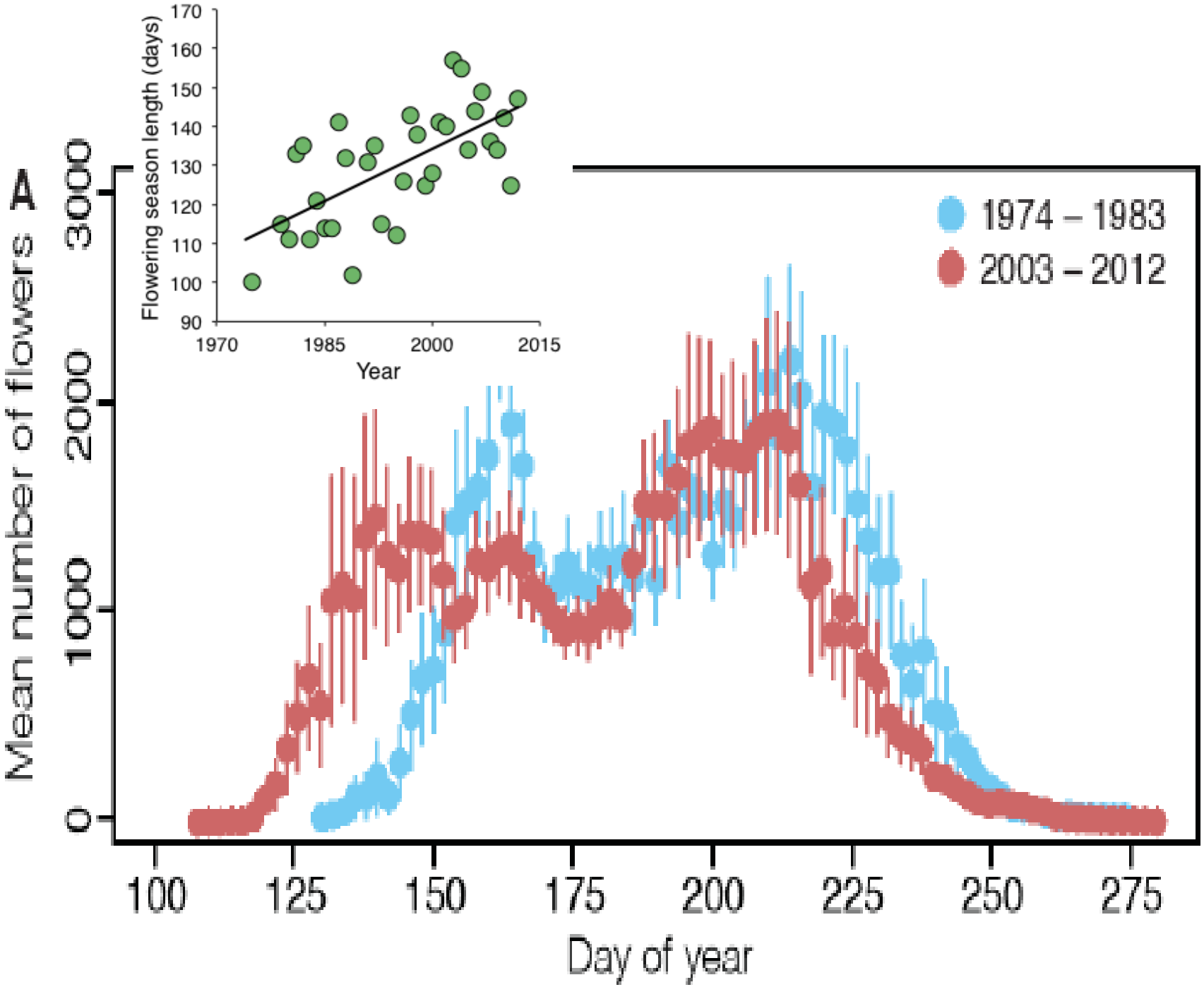
The *Erigeron – Speyeria* story

- Decreasing snowpack
- Warmer springs
- Earlier snowmelt
- Increased incidence of frost damage
- Fewer flowers (less nectar) for butterflies
- Fewer butterflies


180
170
160
150
140
130
120
Day of year of first sighting
0
50
100
150
Snowpack on 30 April (cm)

Mertensia ciliata **(Boraginaceae)**


Maximum number of flowers in bloom
700
600
500
400
300
200
100
0
r^2 = 0.334
p = .004
1975
1980
1985
1990
1995
2000
2005
2010


A
Mean number of flowers
0
1000
2000
3000
100
125
150
175
200
225
250
275
Day of year
1974 – 1983
2003 – 2012
Flowering season length (days)
90
100
110
120
130
140
150
160
170
1970
1985
2000
2015
Year

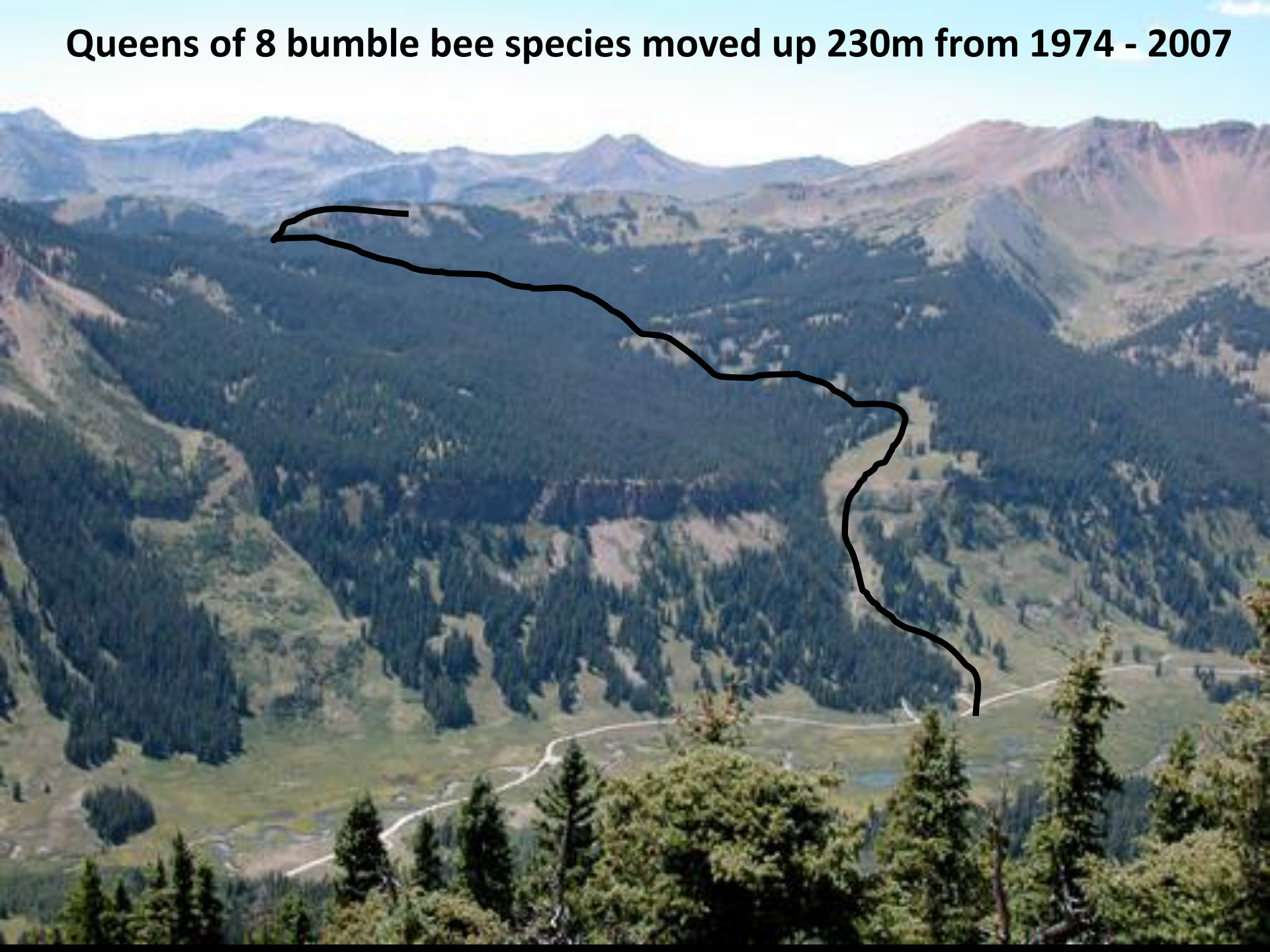
43 years of data

- For 120 species
  - Flowering phenology
  - Flowering abundance

- About 30 publications so far, but only includes about 7 individual species

- Need any data??

Queens of 8 bumble bee species moved up 230m from 1974 - 2007

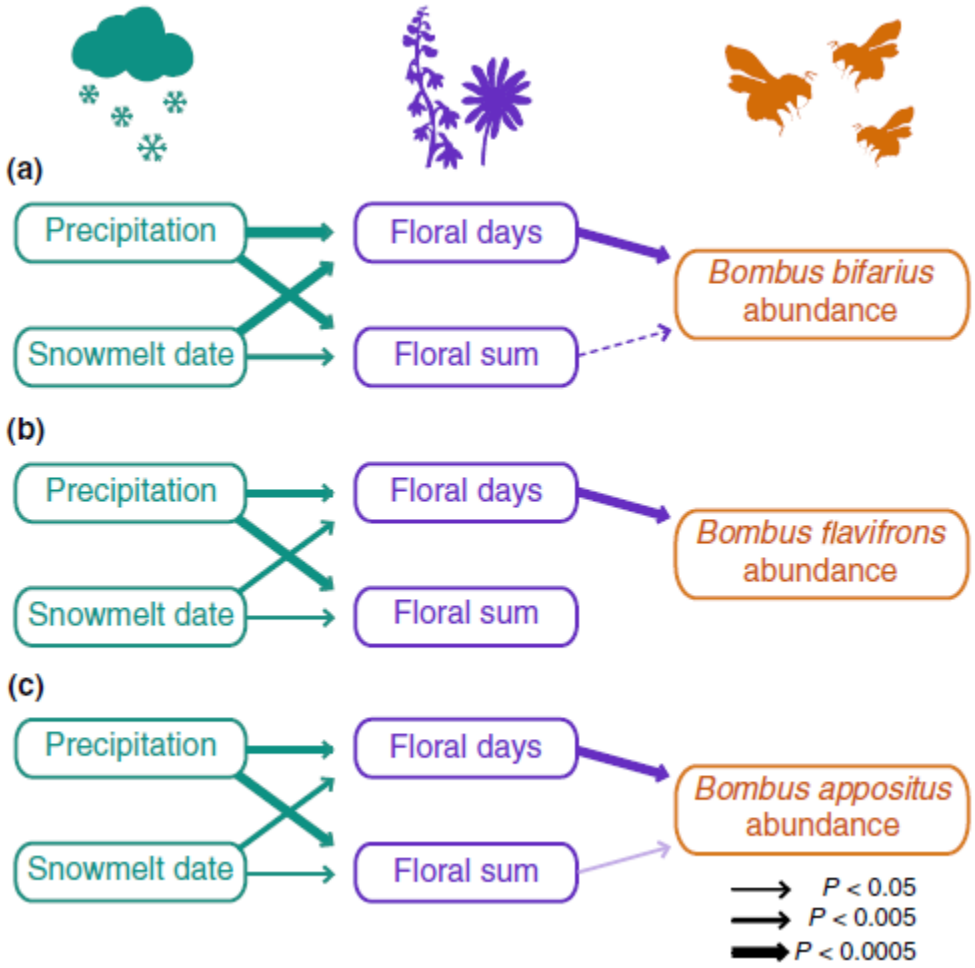


ECOLOGY LETTERS

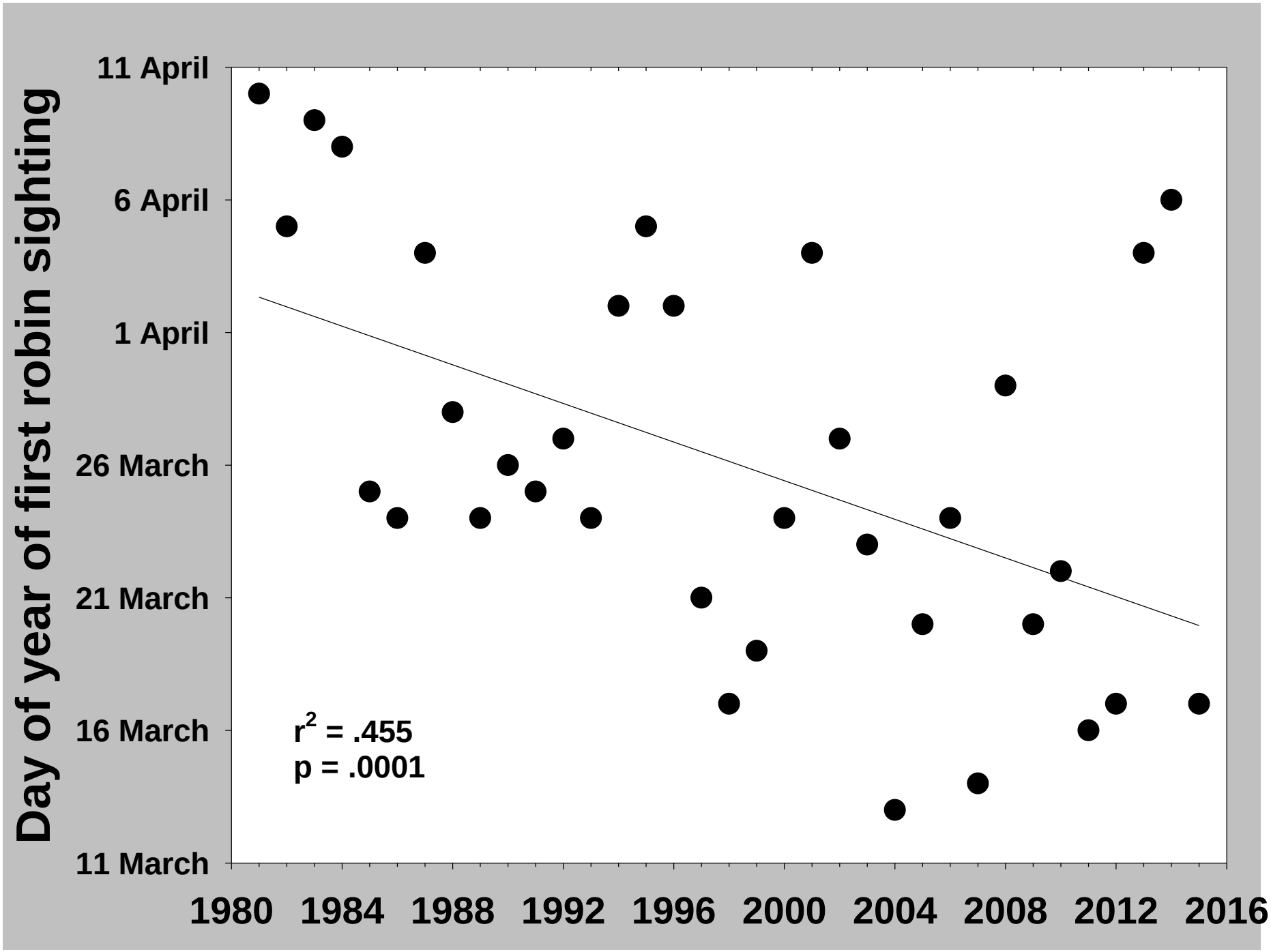
Ecology Letters, (2017) doi: 10.1111/ele.12854

LETTER

Interannual bumble bee abundance is driven by indirect climate effects on floral resource phenology



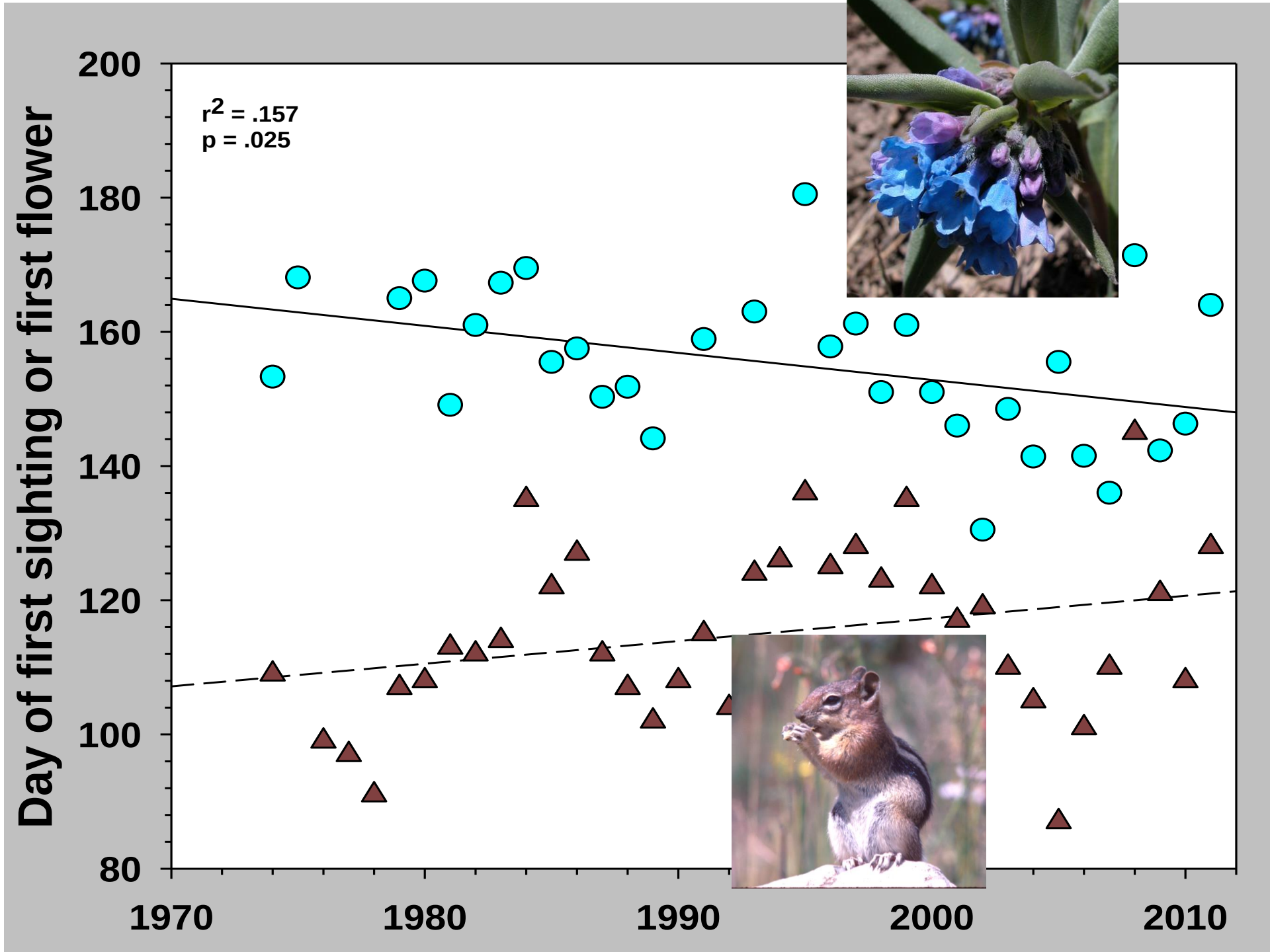
Jane E. Ogilvie,[1,2]* Sean R. Griffin,[1,3] Zachariah J. Gezon,[1,4,5] Brian D. Inouye,[1,2] Nora Underwood,[1,2] David W. Inouye[1,6] and Rebecca E. Irwin[1,3]


Day of year of first robin sighting
11 April
6 April
1 April
26 March
21 March
16 March
11 March
1980
1984
1988
1992
1996
2000
2004
2008
2012
2016
r2 = .455
p = .0001

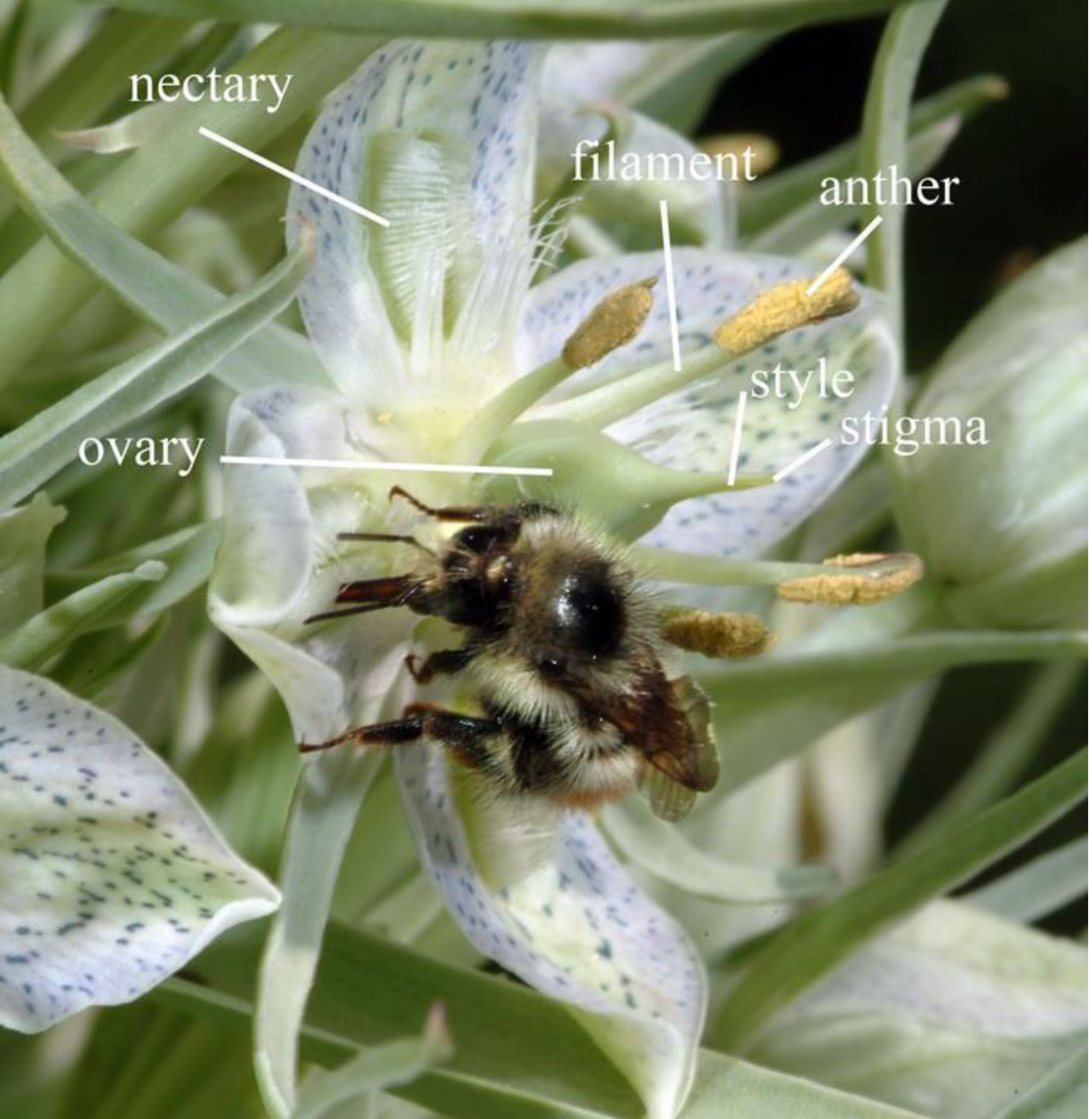
Wyoming ground squirrel (*Spermophilus elegans*) – moving up valleys

Foxes – moving up valleys

Moose overwintering
Mosquitoes moving up
Didymosphenia **blooms**


200
180
160
140
120
100
80
1970
1980
1990
2000
2010
Day of first sighting or first flower
r2 = .157
p = .025

Mast flowering by *Frasera speciosa* (monument plant, green gentian)



Frasera speciosa **(Gentianaceae) being visited by *Bombus flavifrons*.**

Cumberland Pass, 12,300 ft.

1982	1983	1984	1985	1986	1987	1988	1989	1990	1991
Rec.	G	G	2	2	2	2	2	2	2

1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
2	2	2	2	2	2	2	2	2	2

2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
2	4	2	2	2	2	2	2	2	2

2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
?	4								

The history of *Frasera* plant #911

Frasera plant #911 in 2011; a seedling in 1982

1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
2	2	2	2		2	4	2	2	4

1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
4	4	4	2	4	4	2	4	2	4

1994	1995	1996	1997	1998	1999	2000	2001	2002	2003
3	2	4	2	4	4	3	4	4	6

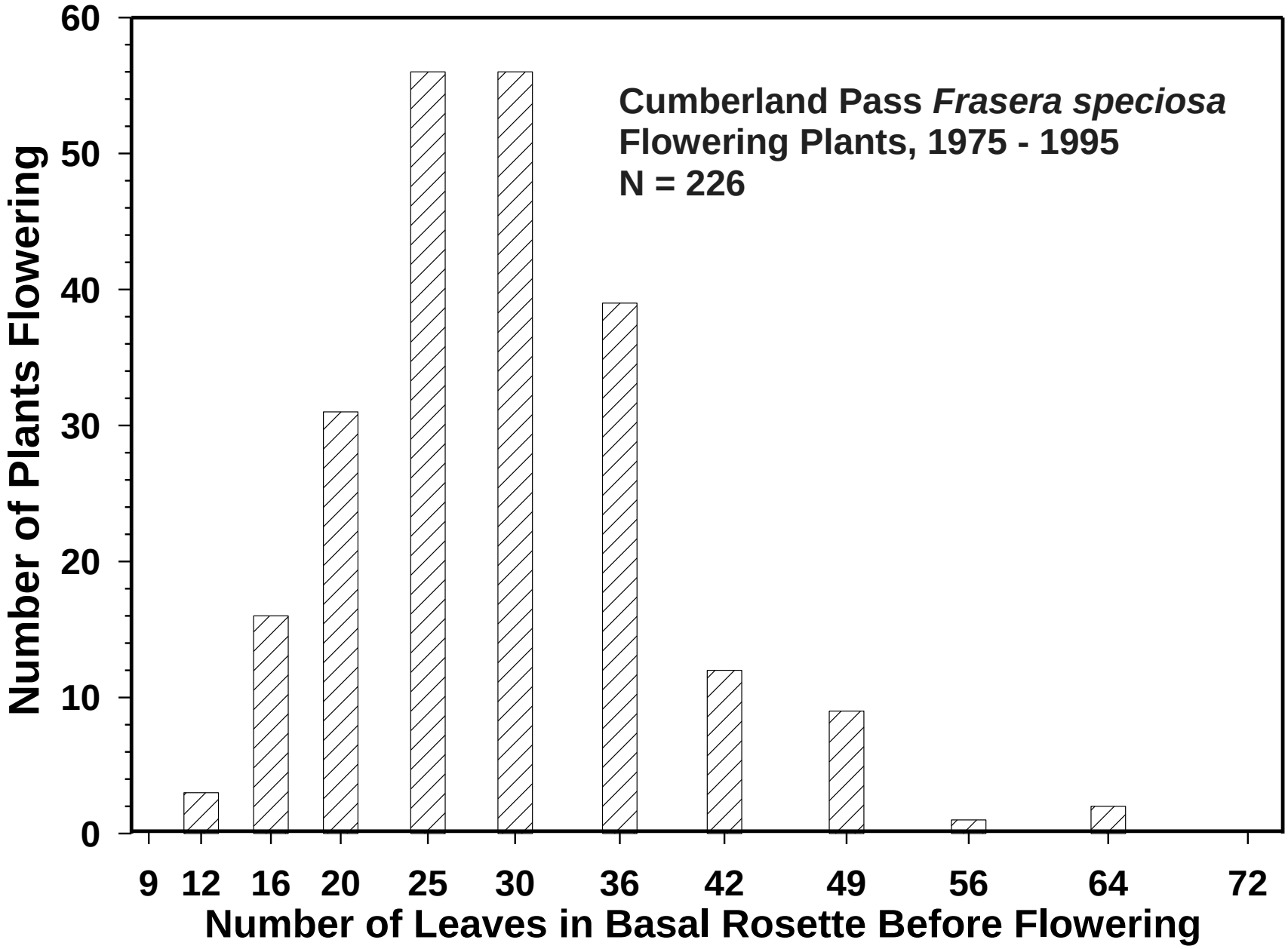
2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
4	4	4	4	4	4	2	4	6	6

The history of *Frasera* plant #46

40+ years old

Frasera plant #221D

Tagged in 1973,
41+ years old in 2013

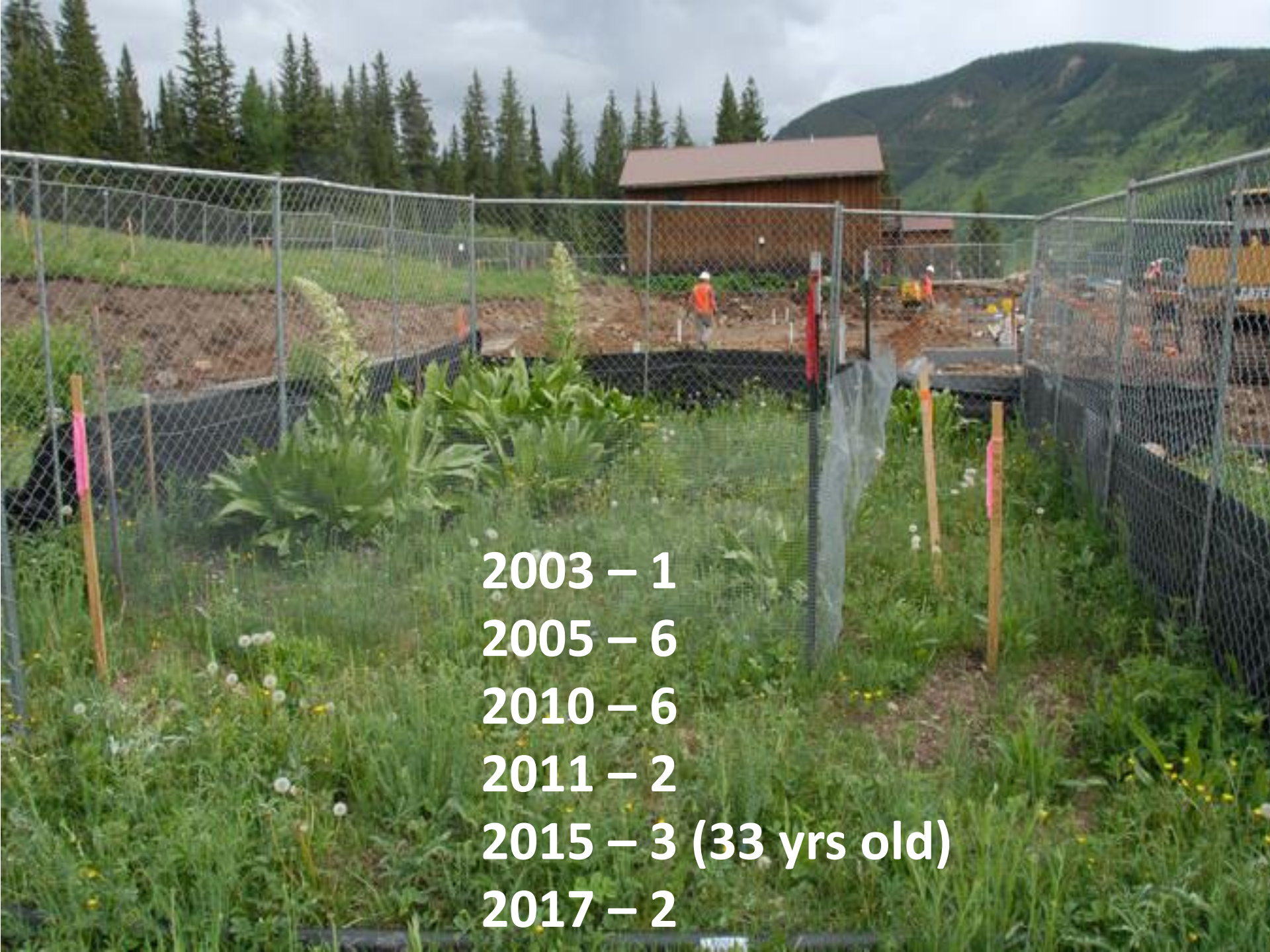

Cumberland Pass *Frasera speciosa*
Flowering Plants, 1975 - 1995
N = 226
Number of Plants Flowering
0
10
20
30
40
50
60
9
12
16
20
25
30
36
42
49
56
64
72
Number of Leaves in Basal Rosette Before Flowering

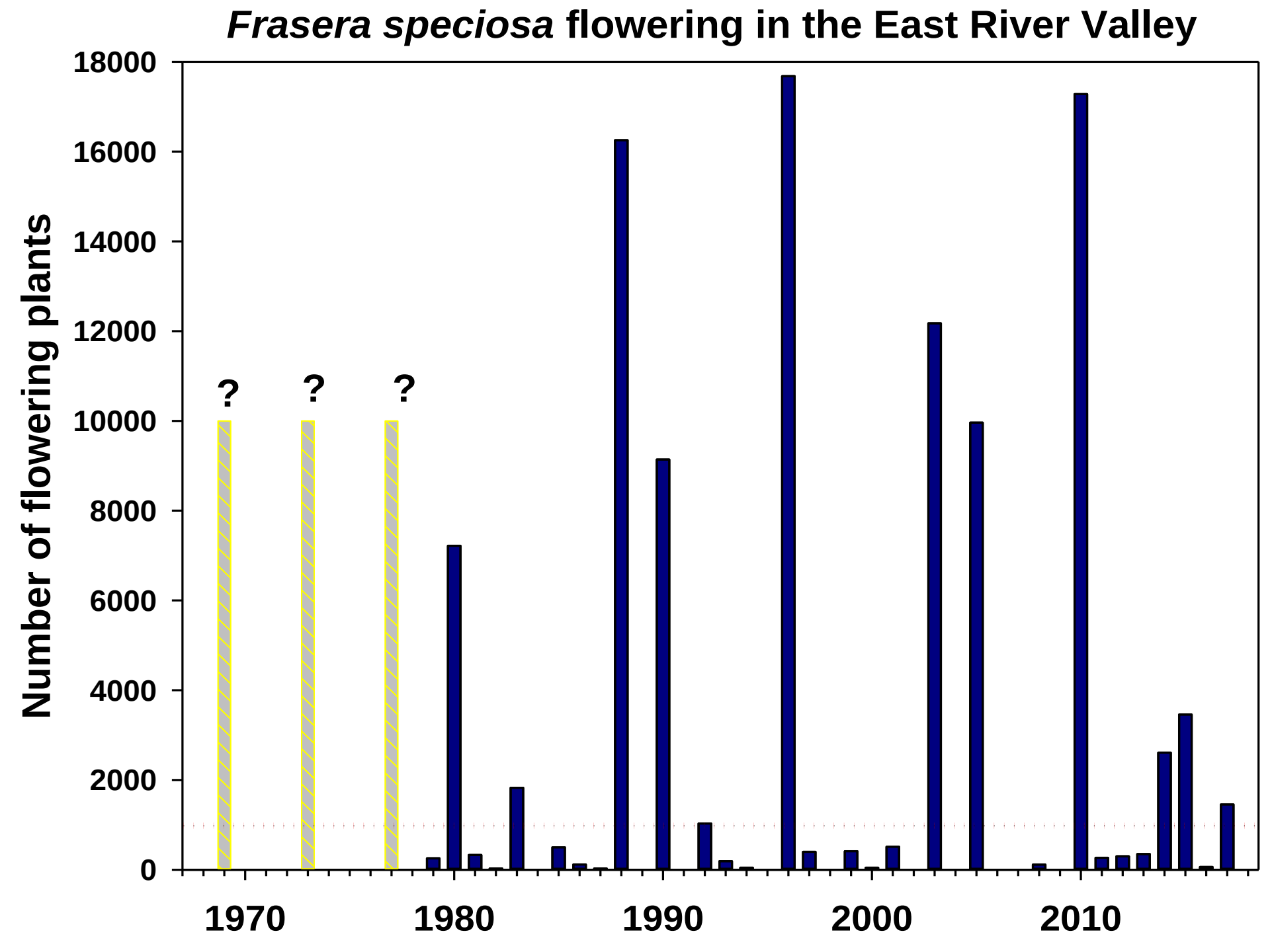
Planted from seed 1982

Flowered 2003

20 years old

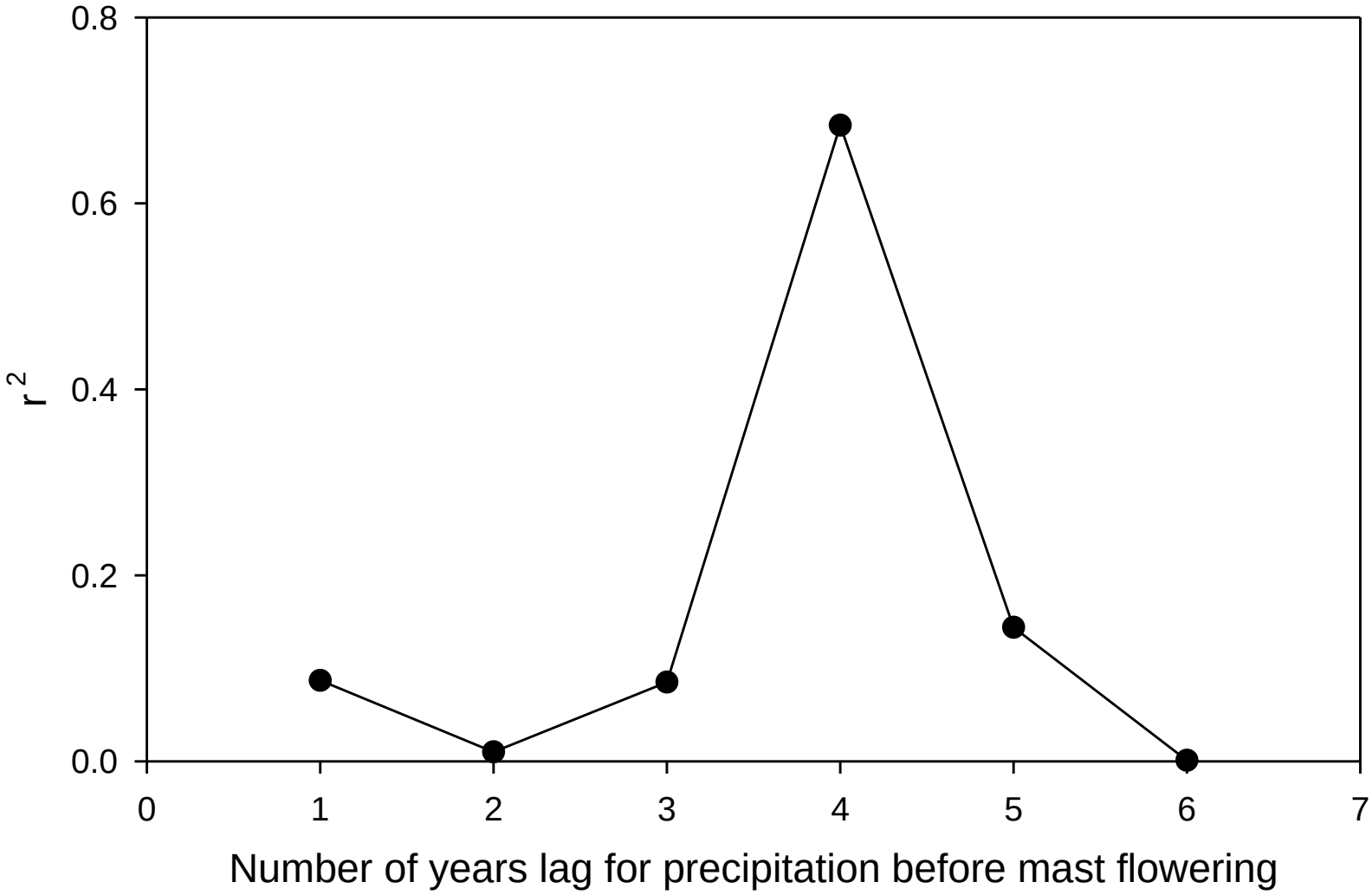
Some now 35 and growing

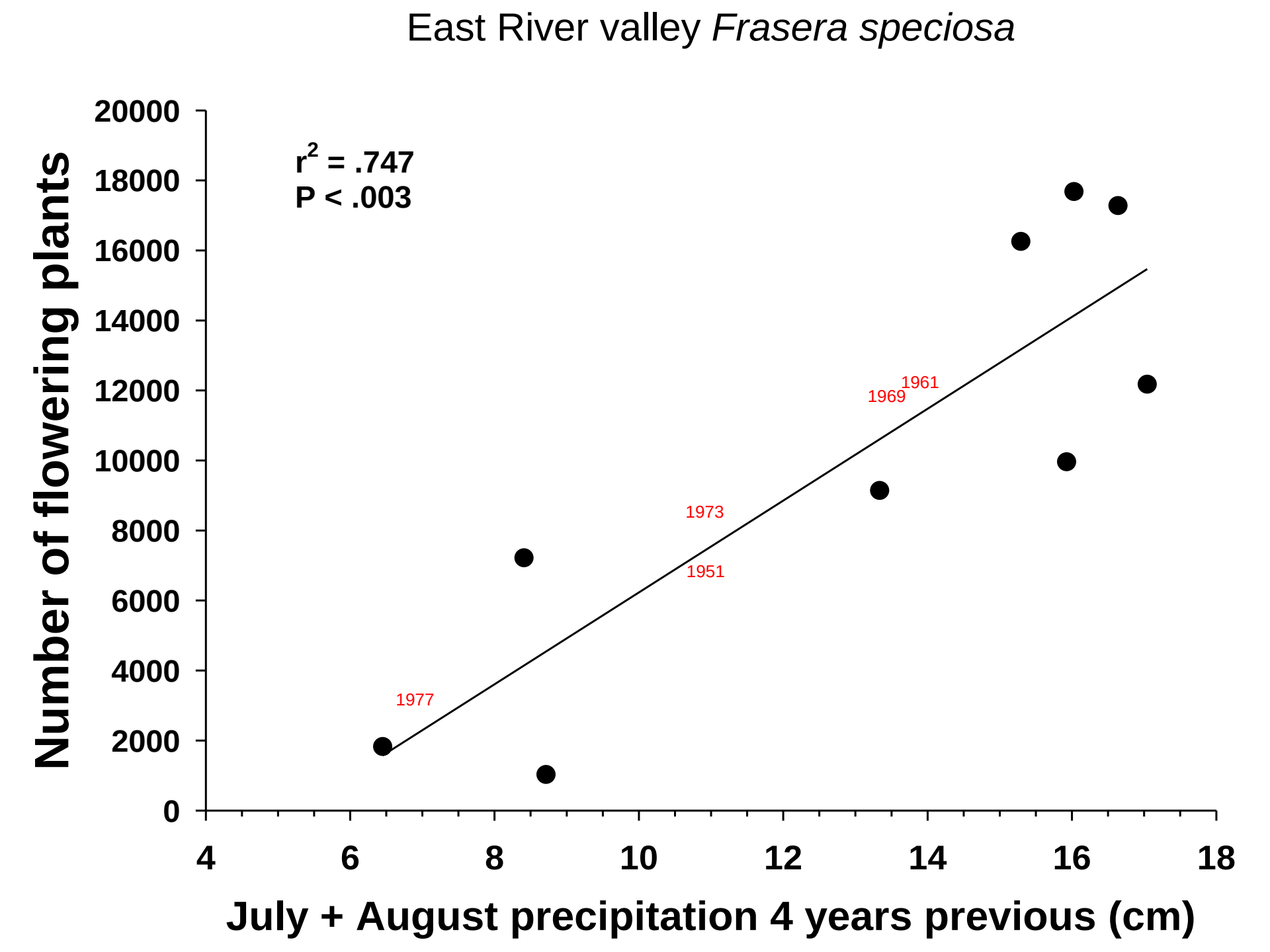

2003 – 1
2005 – 6
2010 – 6
2011 – 2
2015 – 3 (33 yrs old)
2017 – 2


Frasera speciosa flowering in the East River Valley
Number of flowering plants
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
?
?
?
1970
1980
1990
2000
2010

What triggers the mast flowering events in *Frasera speciosa*?

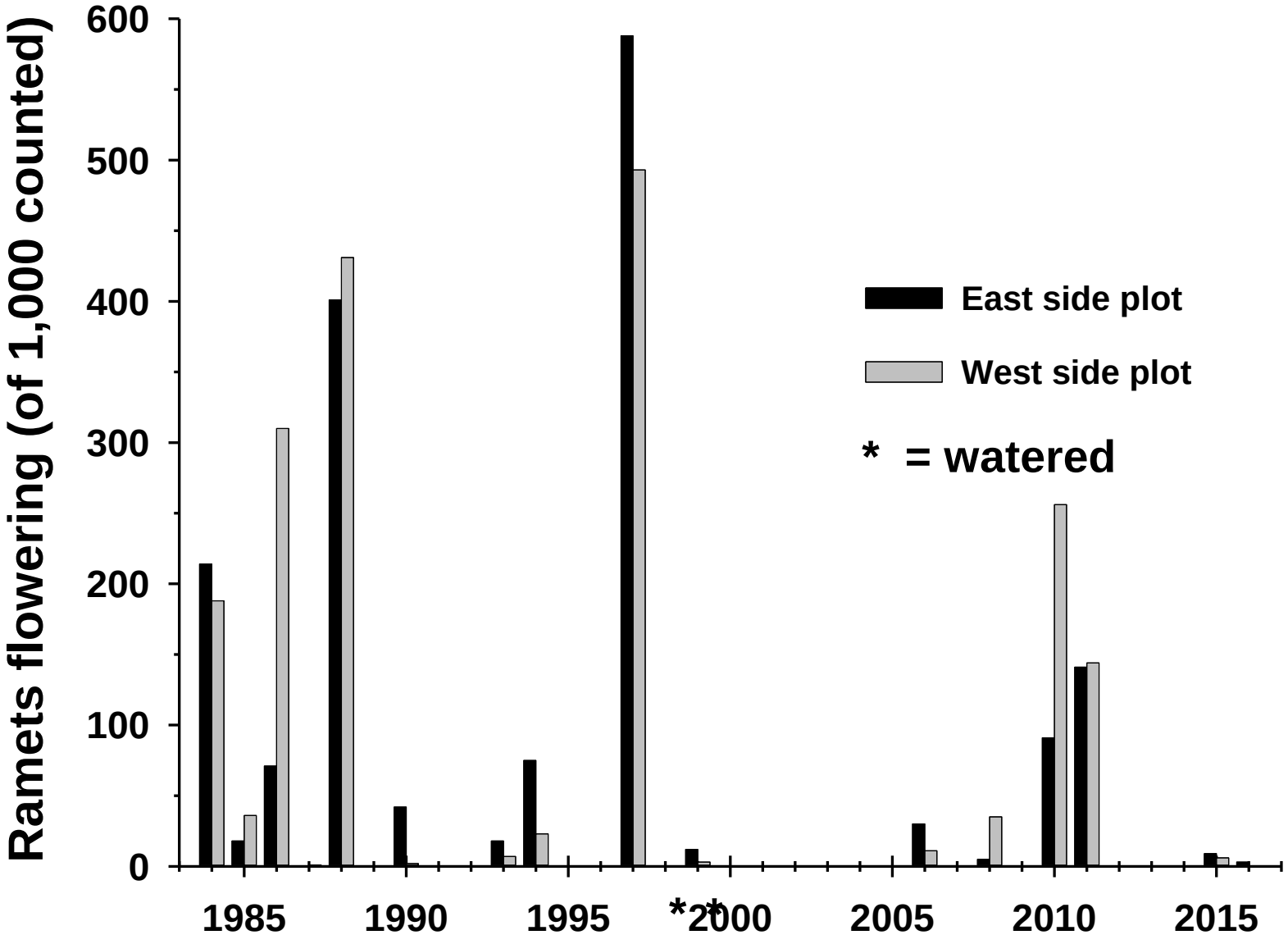
Frasera speciosa flowering in East River valley
N = 8 years with > 1,700 flower stalks (1980-2010)




East River valley *Frasera speciosa*
r^2 = .747
P < .003
1977
1951
1973
1969
1961
Number of flowering plants
July + August precipitation 4 years previous (cm)
0
2000
4000
6000
8000
10000
12000
14000
16000
18000
20000
4
6
8
10
12
14
16
18


Veratrum tenuipetalum

Is there an environmental cue that triggers *Veratrum* flowering?



Yes!

A dry summer: 2.9 inches of rain June-August 2008 (mean = 5.3)

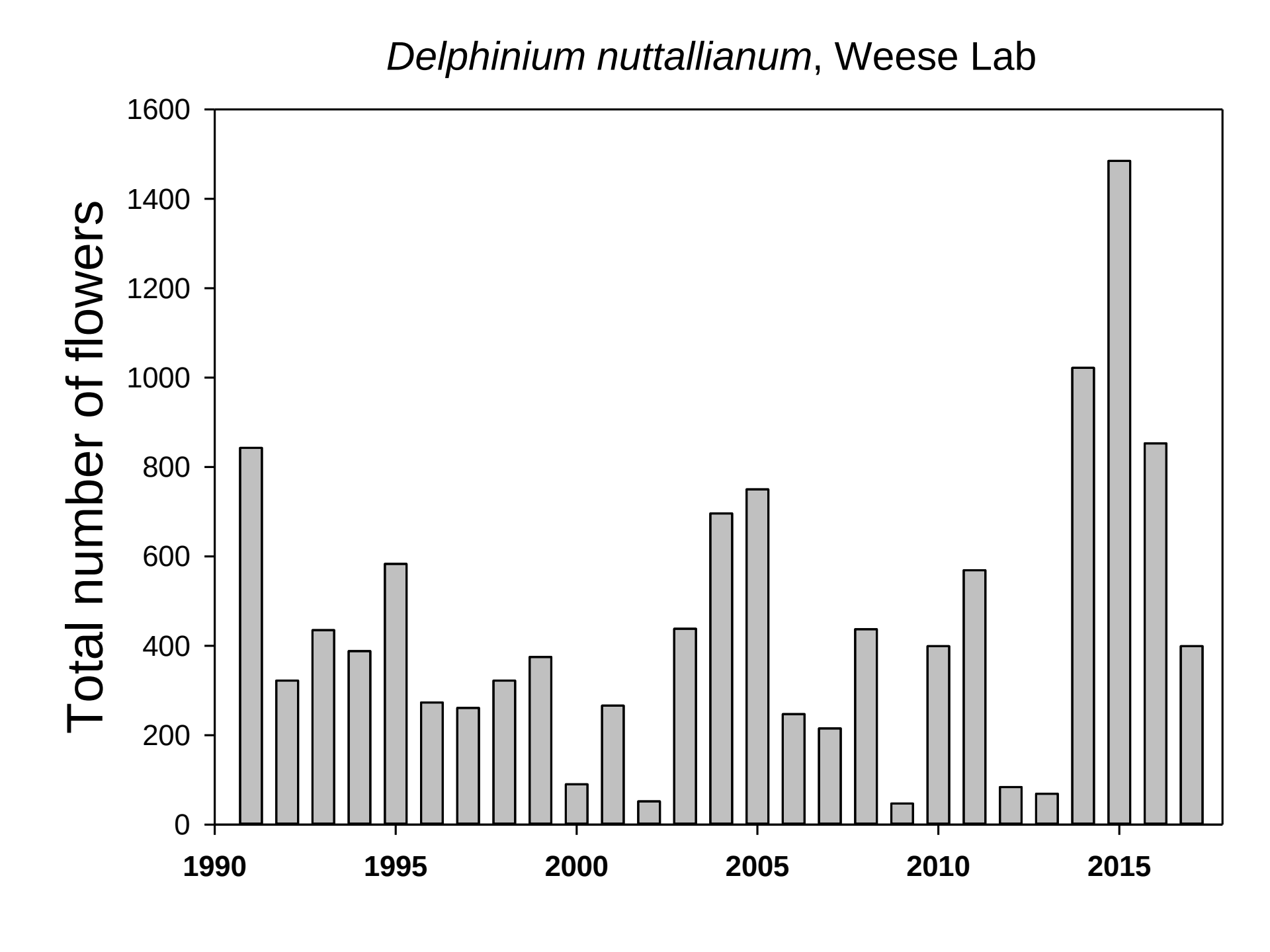
Followed by a cool summer: mean 49.8° in June 2009 (mean = 51.3°)
mean 56.5° in July 2009 (mean = 57.0°)

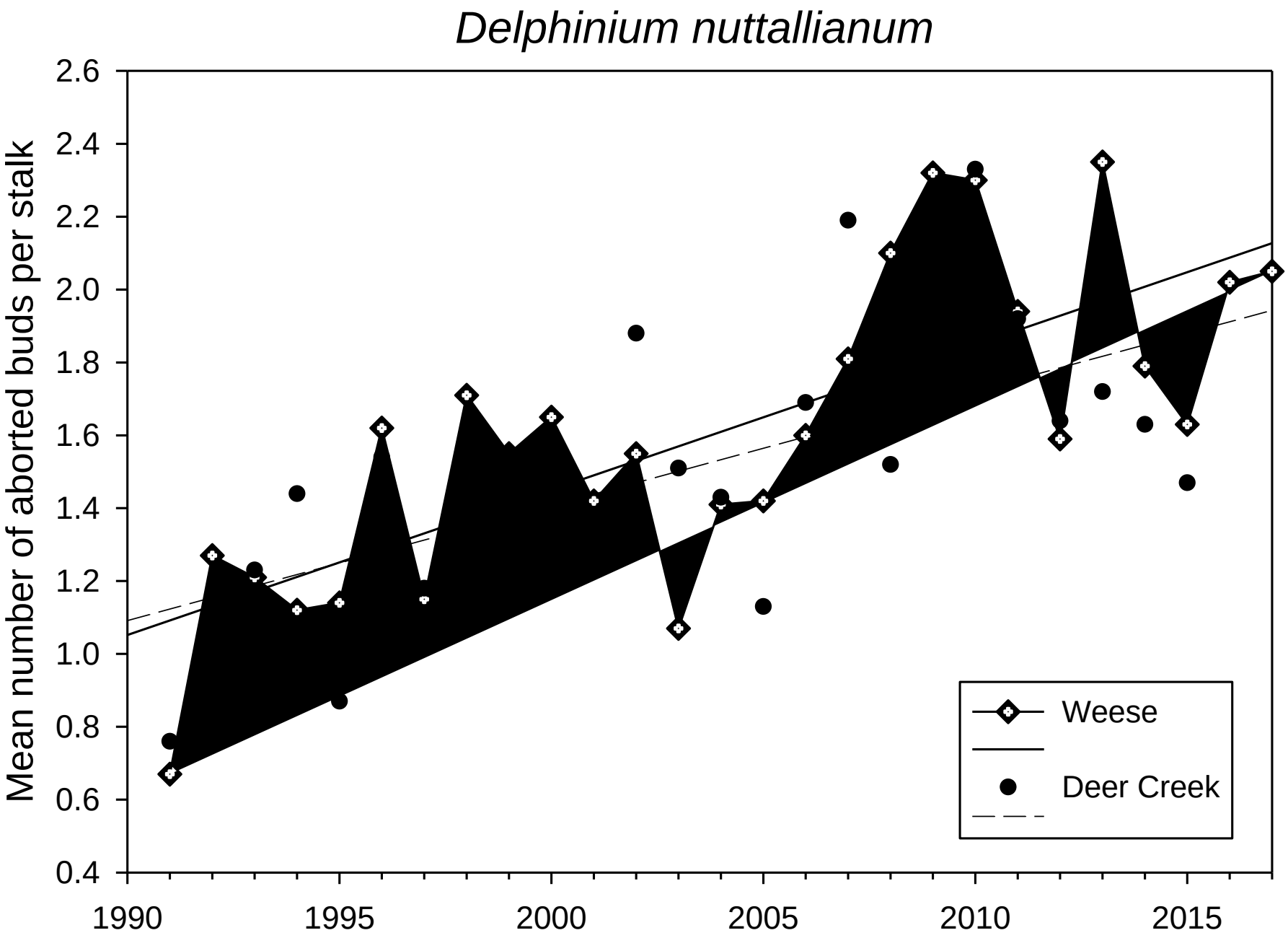
Wait another year for preformation: 2010

Then a flowering year: 2011

Is there an effect of climate change?

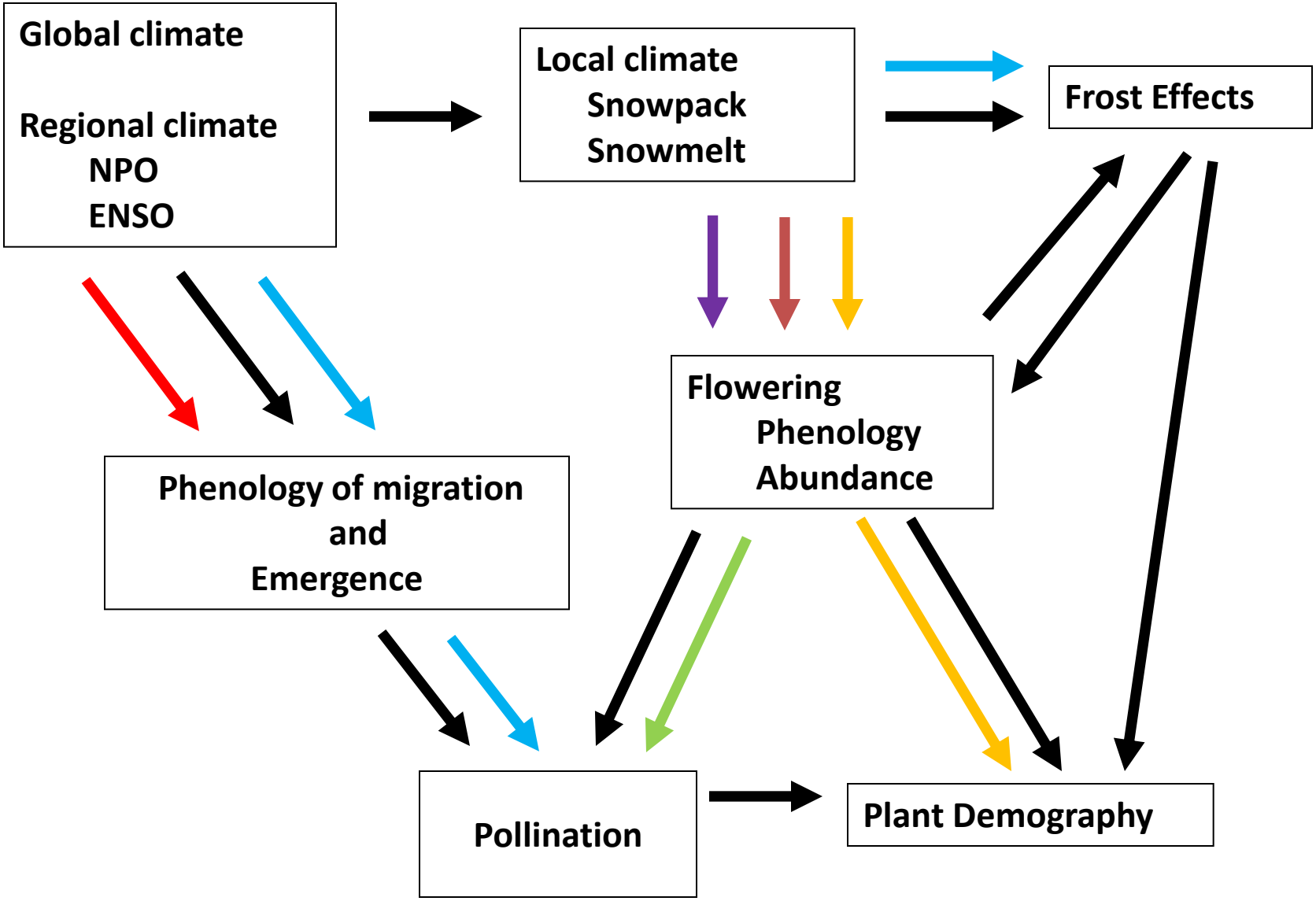
Environmental conditions were conducive to flowering in 21.6% of the years from 1928-1983 compared to 14.8% from 1984 to 2010.


Delphinium nuttallianum, Weese Lab
Total number of flowers
1600
1400
1200
1000
800
600
400
200
0
1990
1995
2000
2005
2010
2015


Delphinium nuttallianum
Mean number of aborted buds per stalk
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
1990
1995
2000
2005
2010
2015
Weese
Deer Creek

Conclusions

- **The climate is changing**
- **Snowmelt dates are getting earlier**
- **Flowering is starting earlier**
- **Frequency of frost damage is increasing**
- **Plant demography is being affected**
- **Pollinators may be affected**
- **Variation in species responses may lead to altered and new interactions**


Global climate
Regional climate
NPO
ENSO
Local climate
Snowpack
Snowmelt
Frost Effects
Flowering
Phenology
Abundance
Phenology of migration
and
Emergence
Pollination
Plant Demography

16(?) More years of data collection

December 2009

Stimulus Checkup

A closer look at 100 projects funded by the American Recovery and Reinvestment Act.

Sen. Tom Coburn

Sen. John McCain

"…. billions of dollars of stimulus funding have been wasted, mismanaged, or directed towards silly and shortsighted projects."

35. Study of Wildflowers in a Ghost Town ($448,995)

A few dilapidated buildings are largely what remains in Gothic, Colorado, a ghost town that is also home to the Rocky Mountain Biological Laboratory. Over the next five years, however, Gothic will host a $448,995 National Science Foundation study by Dr. David Inouye on the impact of climate change on the town's wildflowers. In recent years [they] have been reportedly impacted by late season frost that he believes is caused by global warming.

According to the Denver Post, however, after a visit to the town this past spring, with the bounty of wildflowers filling the meadows and blooming in the crannies of Colorado's high country, you'd never guess that some of them are in trouble.

An Australian agency plans to pull the plug on a long-term ecological monitoring program in the stunning Simpson Desert.

Aaron Greenville

Australia to ax support for long-term ecology sites

By **John Pickrell** | Aug. 11, 2017 , 5:10 PM