Response of plant biomass production and soil respiration to experimental warming and precipitation manipulation in a northern Great Plains grassland

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REVIEW

Responses of terrestrial ecosystems to temperature and precipitation change: a meta-analysis of experimental manipulation

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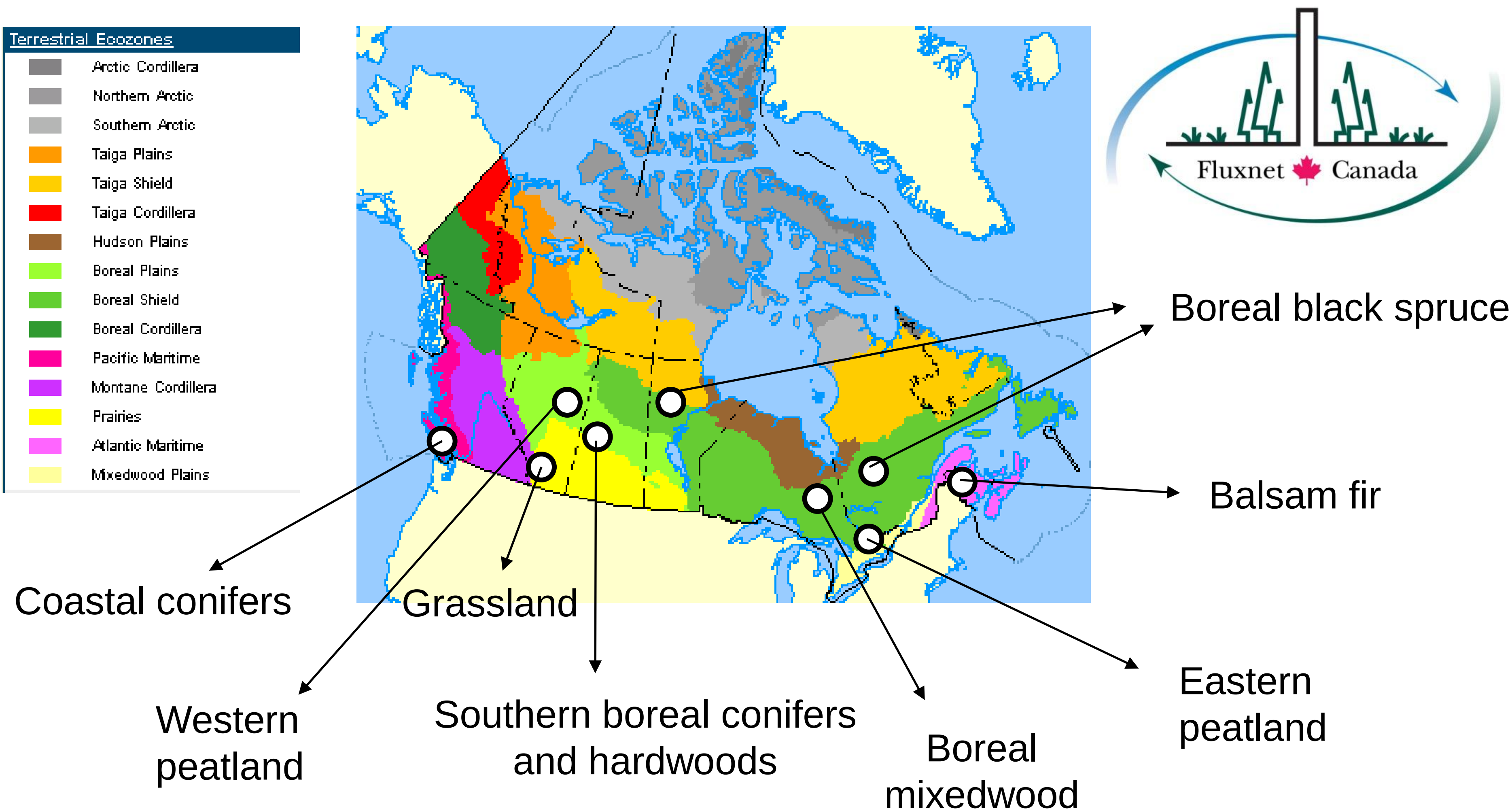
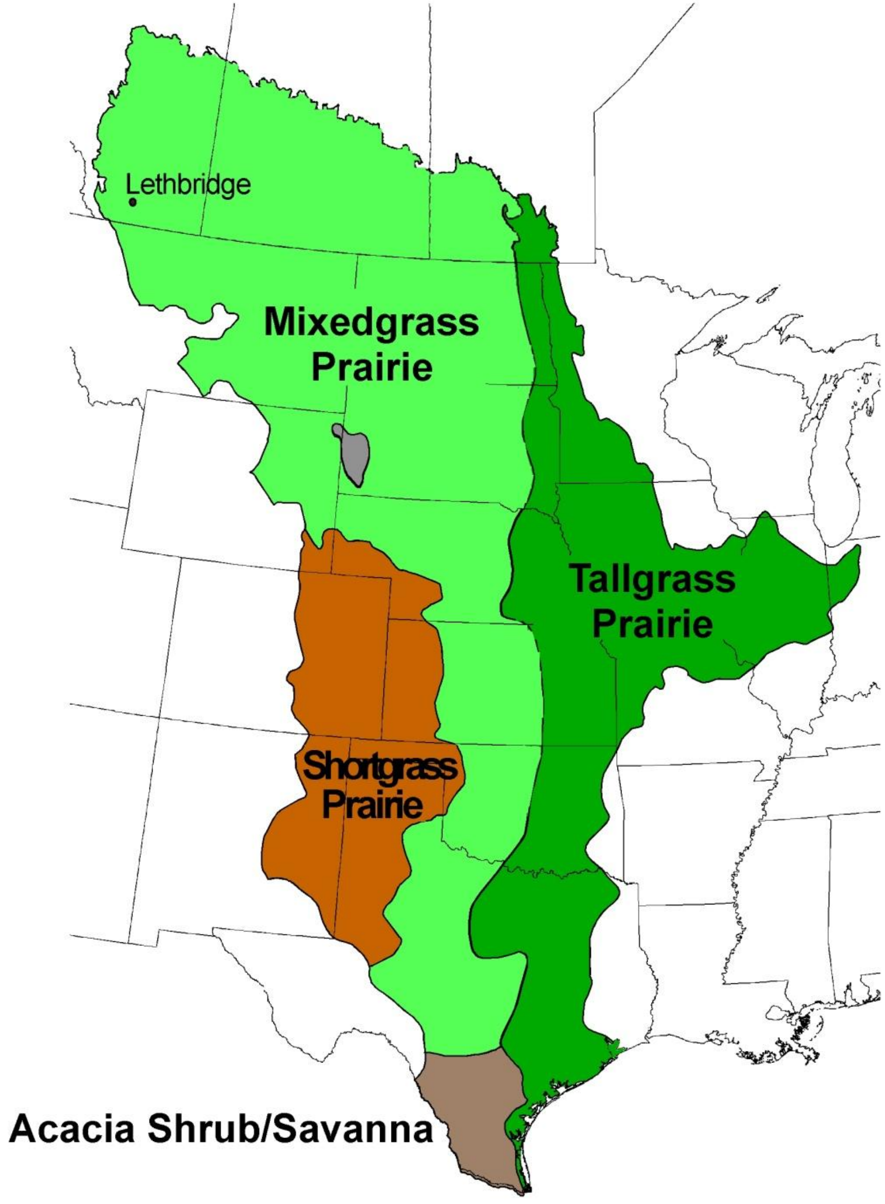
“New experiments with combined temperature and precipitation manipulations are needed to conclusively determine the importance of temperature-precipitation interactions on the C balance of terrestrial ecosystems under future climate conditions.”

“Complex interactions do exist (between temperature-precipitation) and may not be consistent among ecosystems and treatments.”

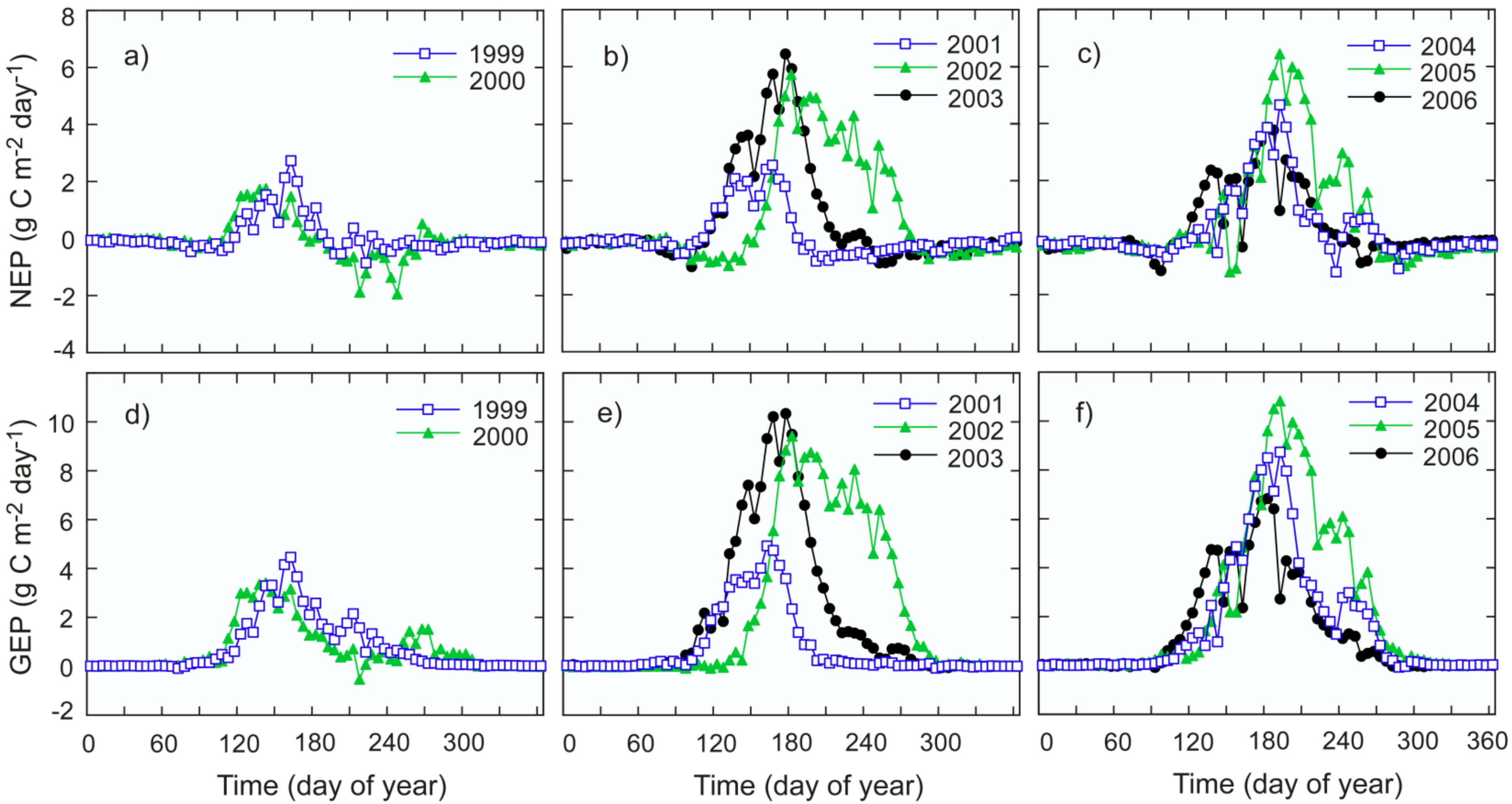
Fluxnet-Canada Carbon Flux Stations



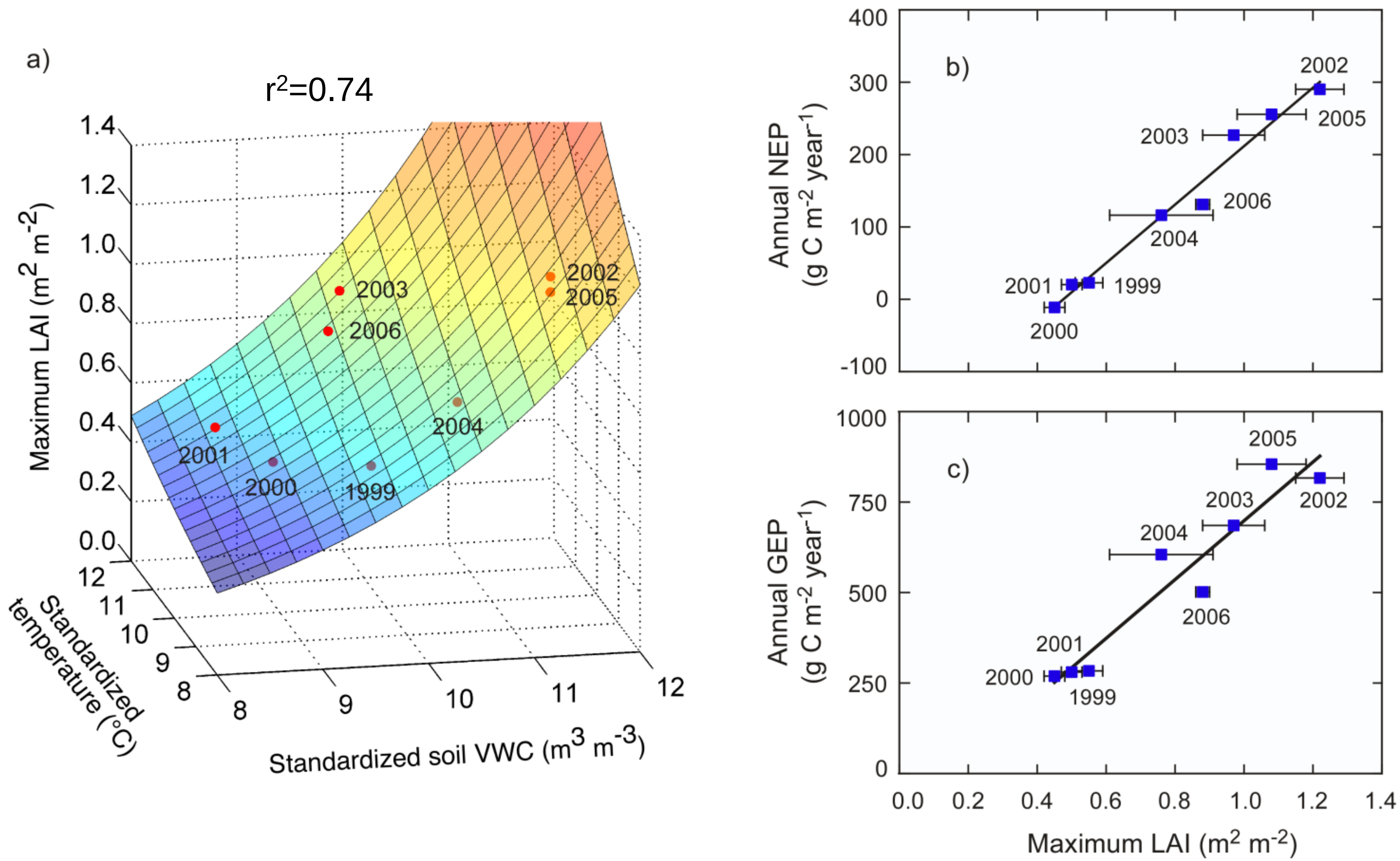


Grasslands of the Great Plains (Ostlie *et al*. 1997)

Lethbridge Grassland: Associate Site in Fluxnet-Canada

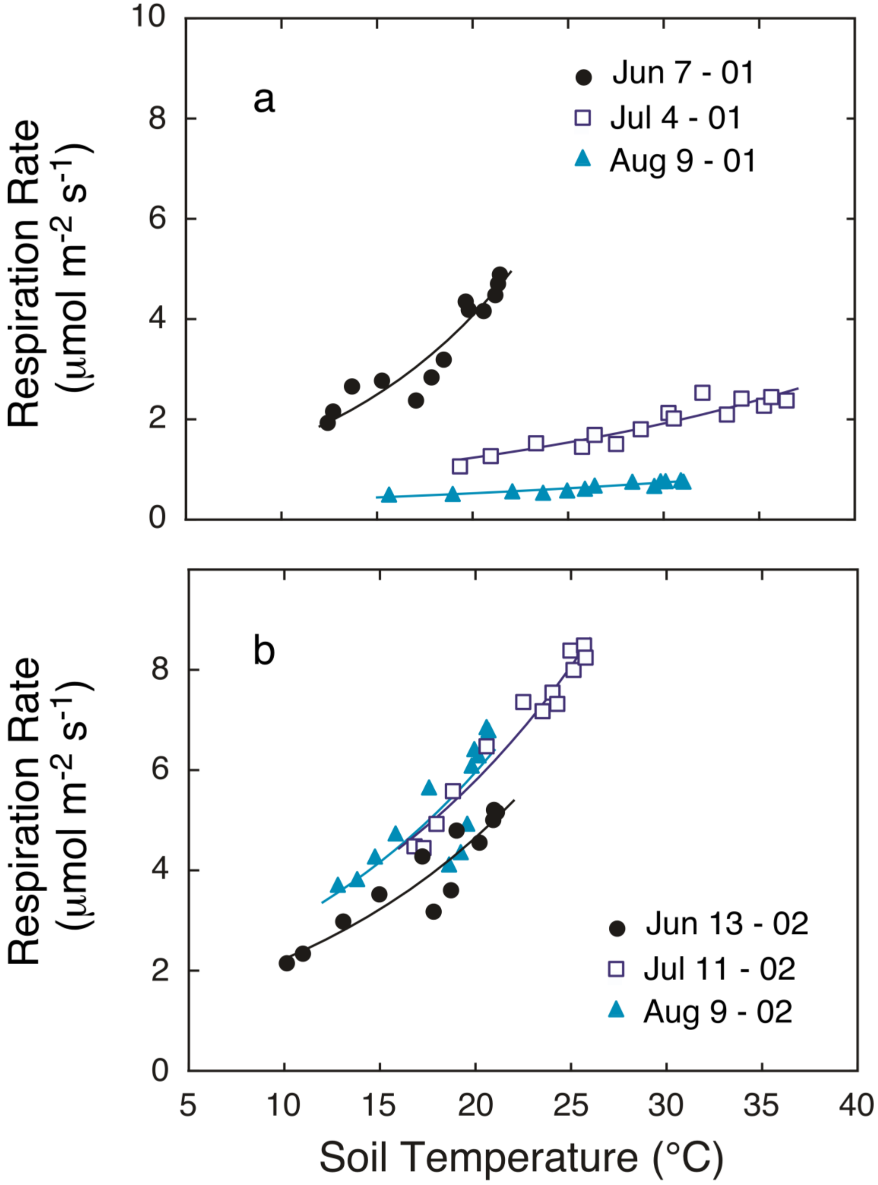

a)
b)
c)
d)
e)
f)
1999
2000
2001
2002
2003
2004
2005
2006
NEP (g C m-2 day-1)
GEP (g C m-2 day-1)
Time (day of year)
Time (day of year)
Time (day of year)

Interaction between moisture and temperature in mixed grass prairie



Flanagan & Adkinson (2011) Global Change Biology 17: 3293

Interaction between moisture and temperature in mixed grass prairie



May-October 2001
Precipitation= 90 mm

May-October 2002
Precipitation= 453 mm

Flanagan & Johnson (2005) AgForMet 130: 237

Research Approaches

1) Ecosystem CO_2 & H_2O flux measurements in response to annual weather variation

2) Ecosystem manipulation experiments

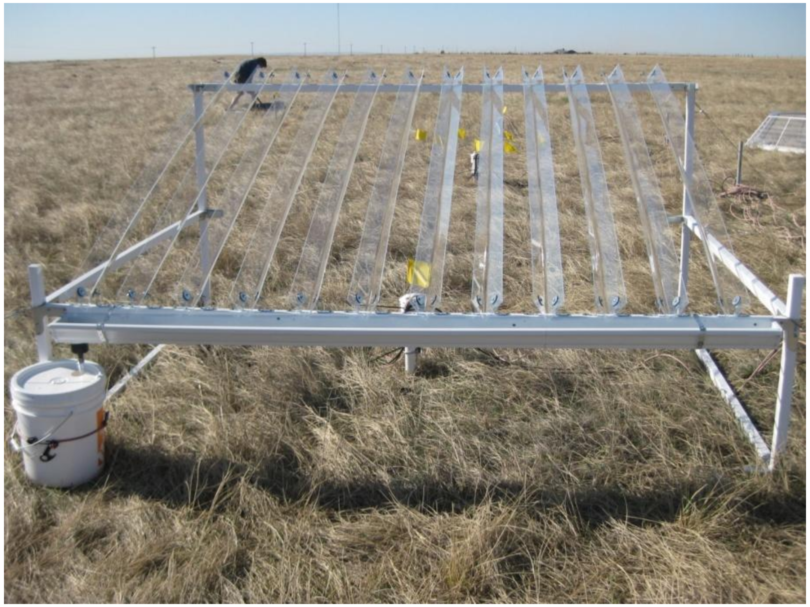
altered temperature

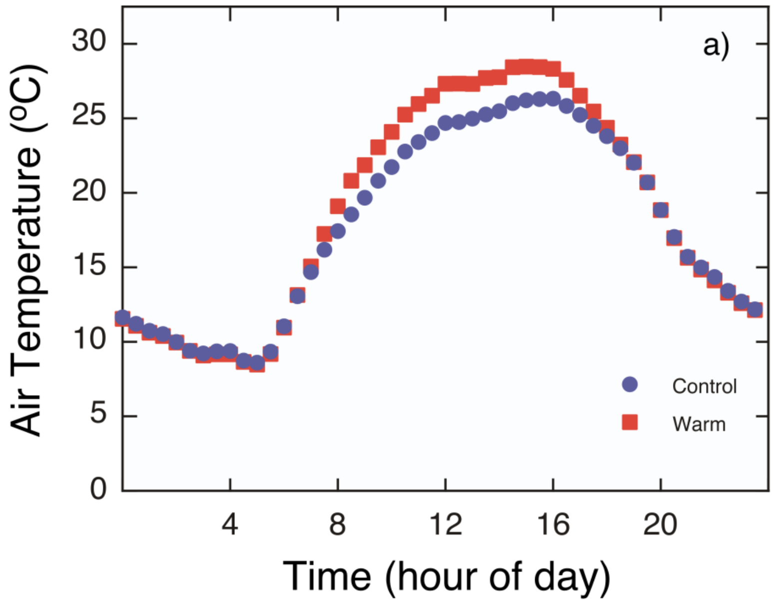
altered summer rain amounts

Manipulation Experiments 2011:
Temperature (2) & Precipitation (3)

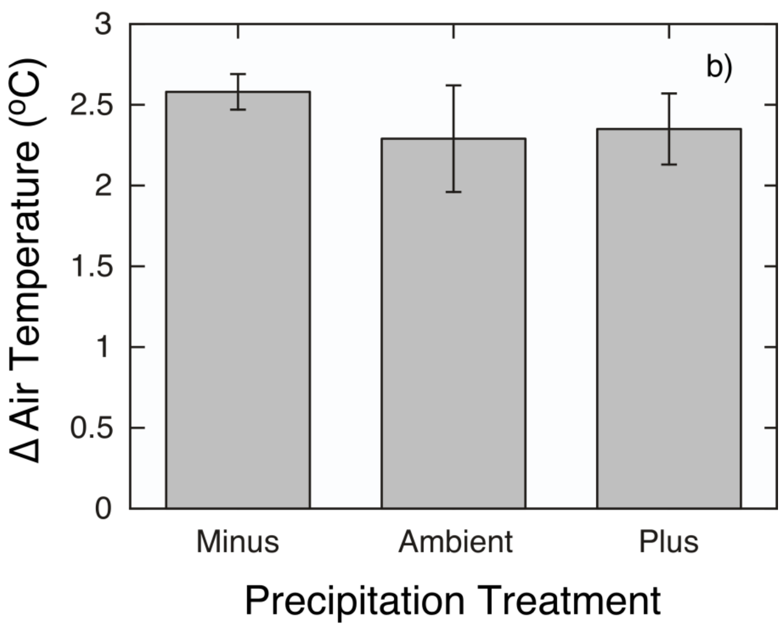
- open-top chambers (warm) vs. control
- rain-out shelters (minus)
- precipitation addition (plus) vs. ambient
- 2 x 3 factorial experiment

2012 only Temperature Treatments



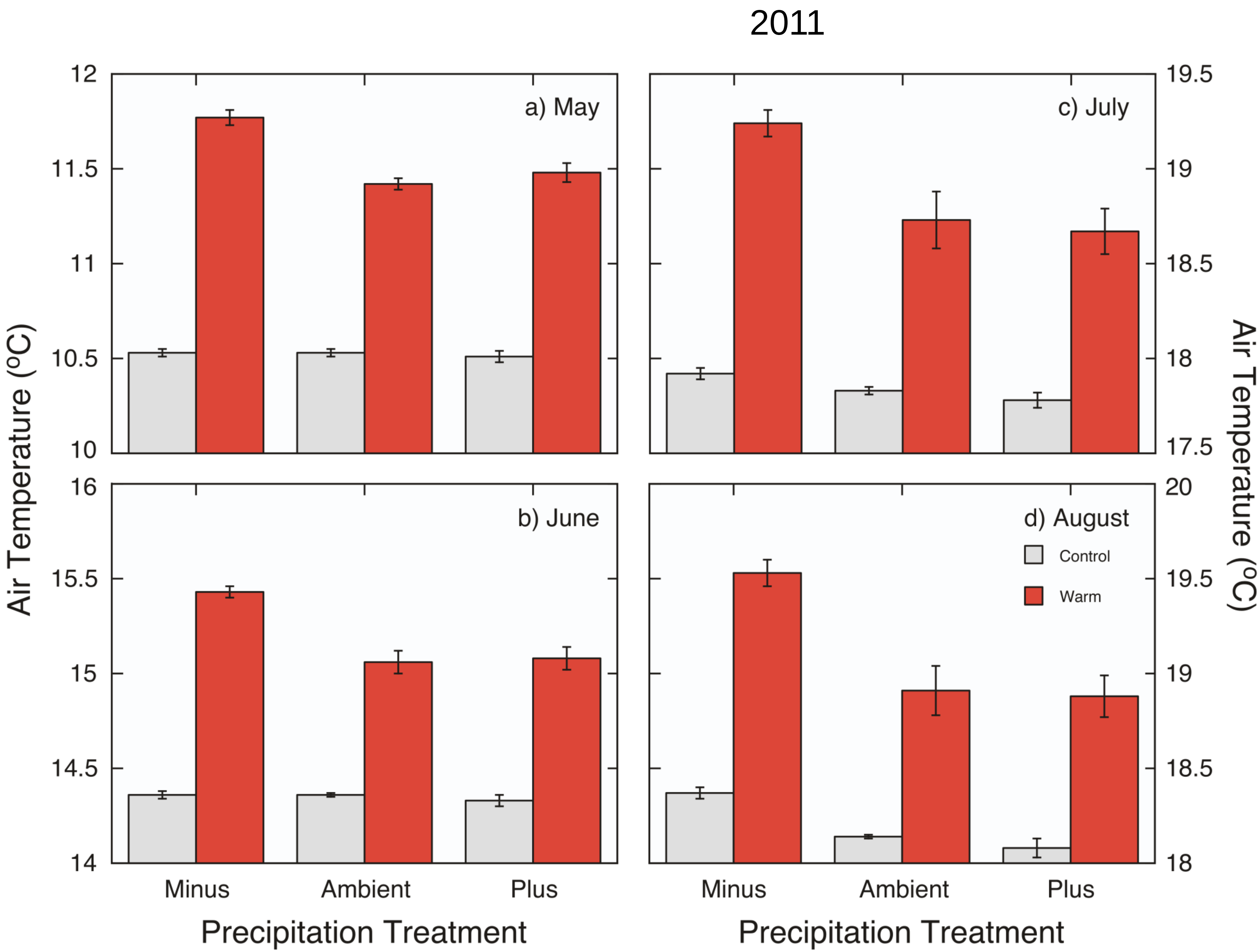


July 2011



July 2011

Warm – Control
at 14:00 hours



2011
a) May
b) June
c) July
d) August
Control
Warm
Air Temperature (oC)
Precipitation Treatment
Minus
Ambient
Plus
12
11.5
11
10.5
10
16
15.5
15
14.5
14
19.5
19
18.5
18
17.5
20

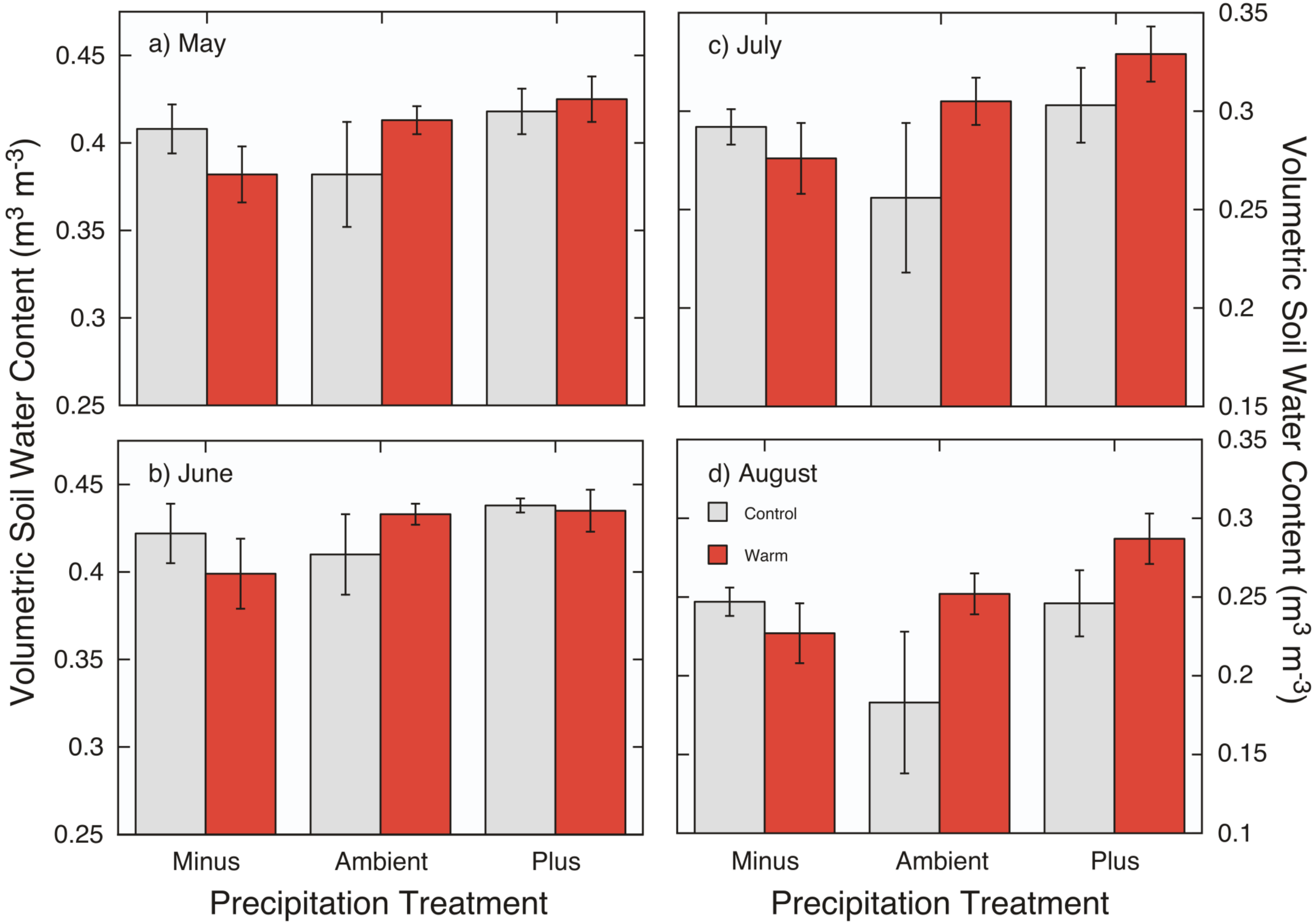
Comparison of cumulative growing-degree-days (GDD) during March-September in 2011 and 2012.

Normal represents the 30-year average ± SD for 1971-2000.

	2011	2012	Normal ± SD
Control	1642	1769	1697 ± 118
Warm	1776	2028	
GDD Difference (Warm – Control)	134	259	

$$GDD = \sum Max\ (T_{Avg} - 5,0°C)$$

2011

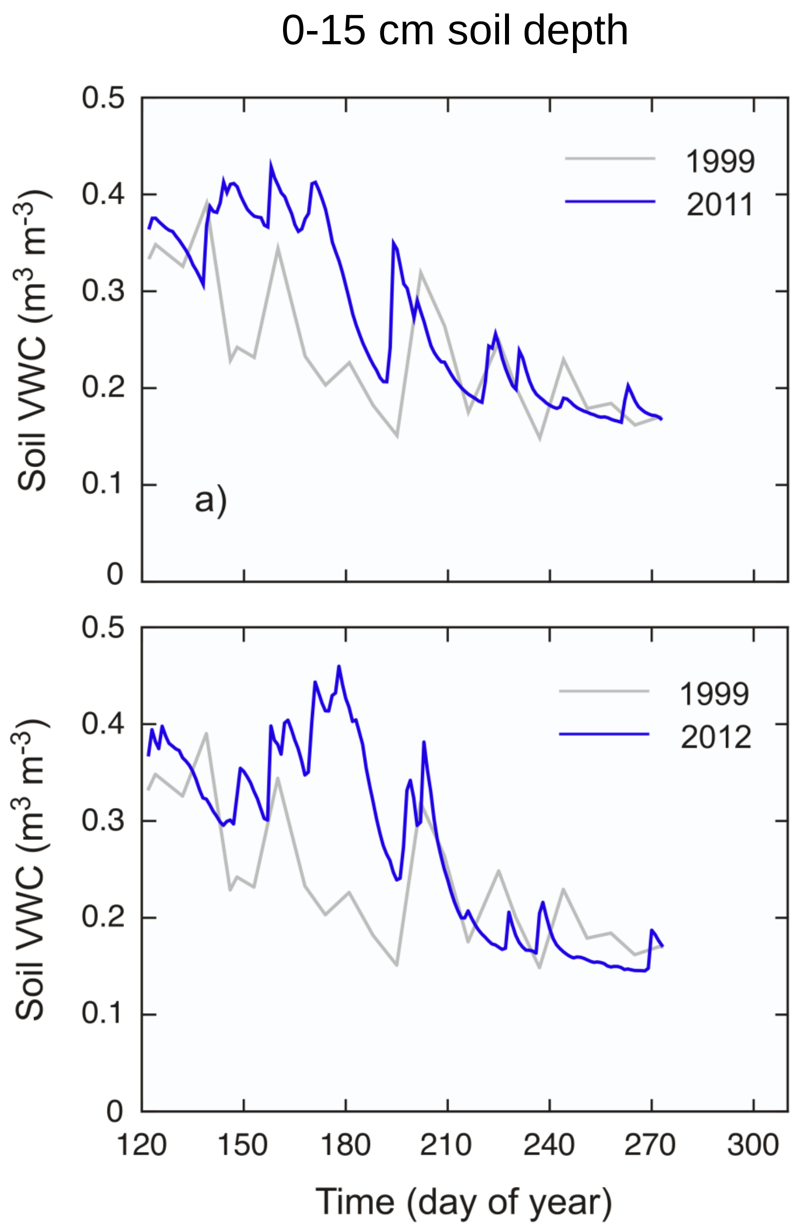


0-30 cm depth

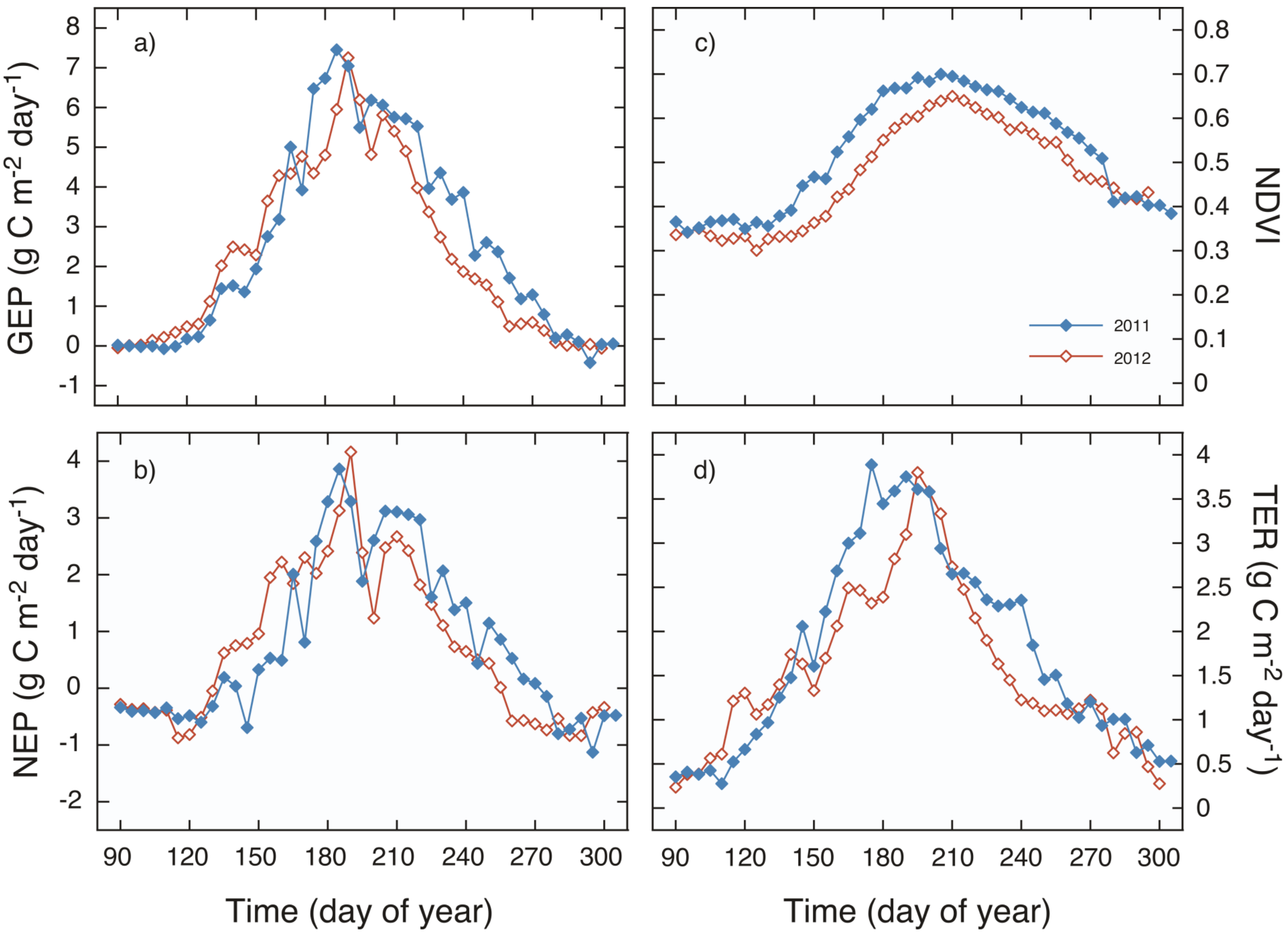
Comparison of total precipitation (P) during May-October in Lethbridge.

Year	P (mm)
1999	240
2011	323
2012	256
Normal	268

1999 – close to normal temperature and precipitation conditions



Ecosystem Eddy Covariance Fluxes in 2011 and 2012



Comparison of integrated carbon flux rates (g C m^{-2} $period^{-1}$) during May-September calculated based on eddy covariance measurements during 2011 and 2012.

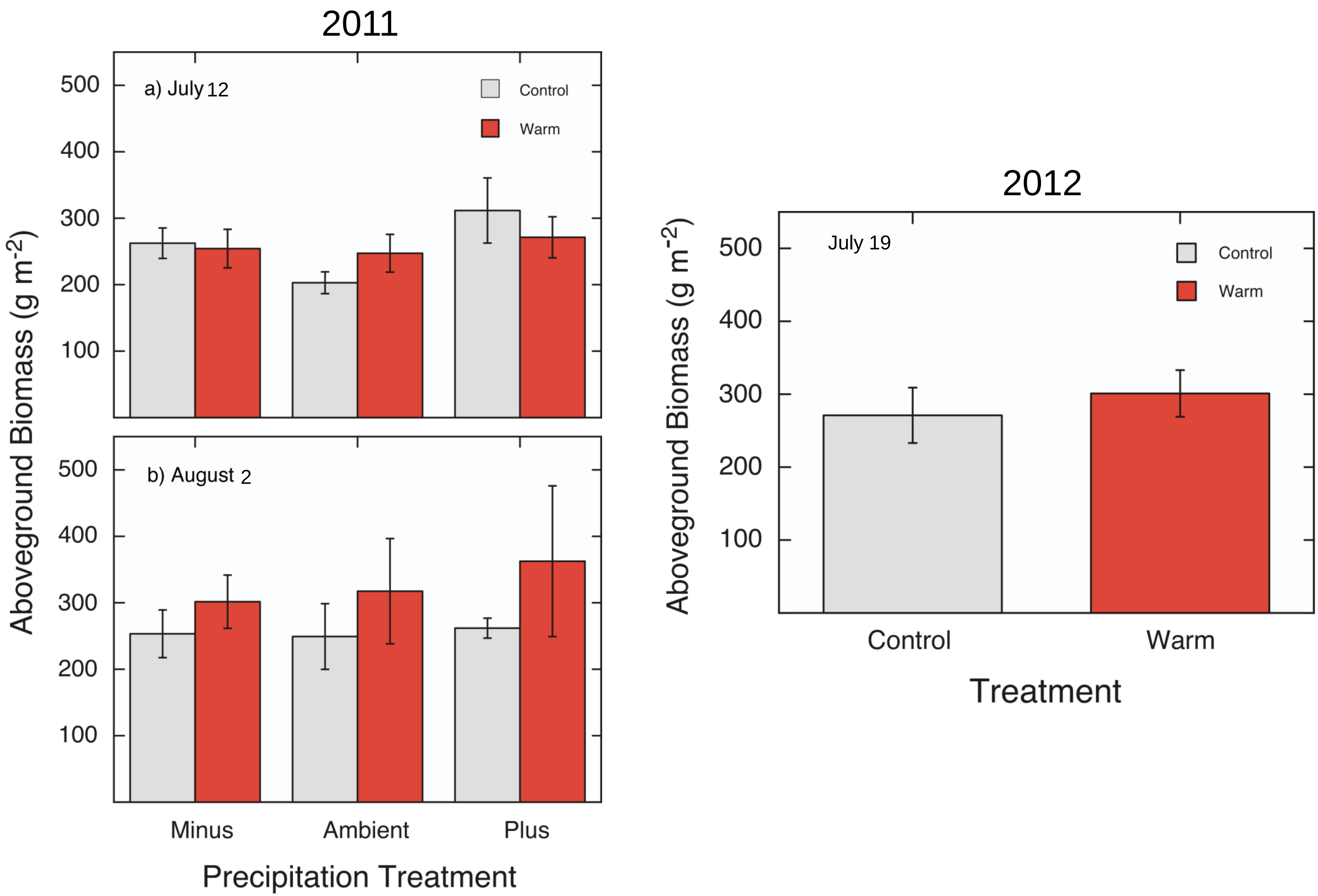
Error bars represent ± uncertainty values.

	2011	**2012**
Respiration (TER)	350 ± 15	296 ± 13
Photosynthesis (GEP)	562 ± 16	487 ± 14
Net Uptake (NEP)	212 ± 6	192 ± 6

NEP = GPP - TER

Hypothesis: BIOMASS PRODUCTION

Warmer temperatures will stimulate increased biomass production, particularly given the high precipitation and soil moisture content in 2011 and 2012.


2011
a) July 12
Control
Warm
b) August 2
Aboveground Biomass (g m-2)
500
400
300
200
100
Minus
Ambient
Plus
Precipitation Treatment
2012
July 19
Control
Warm
Treatment

RESULTS:

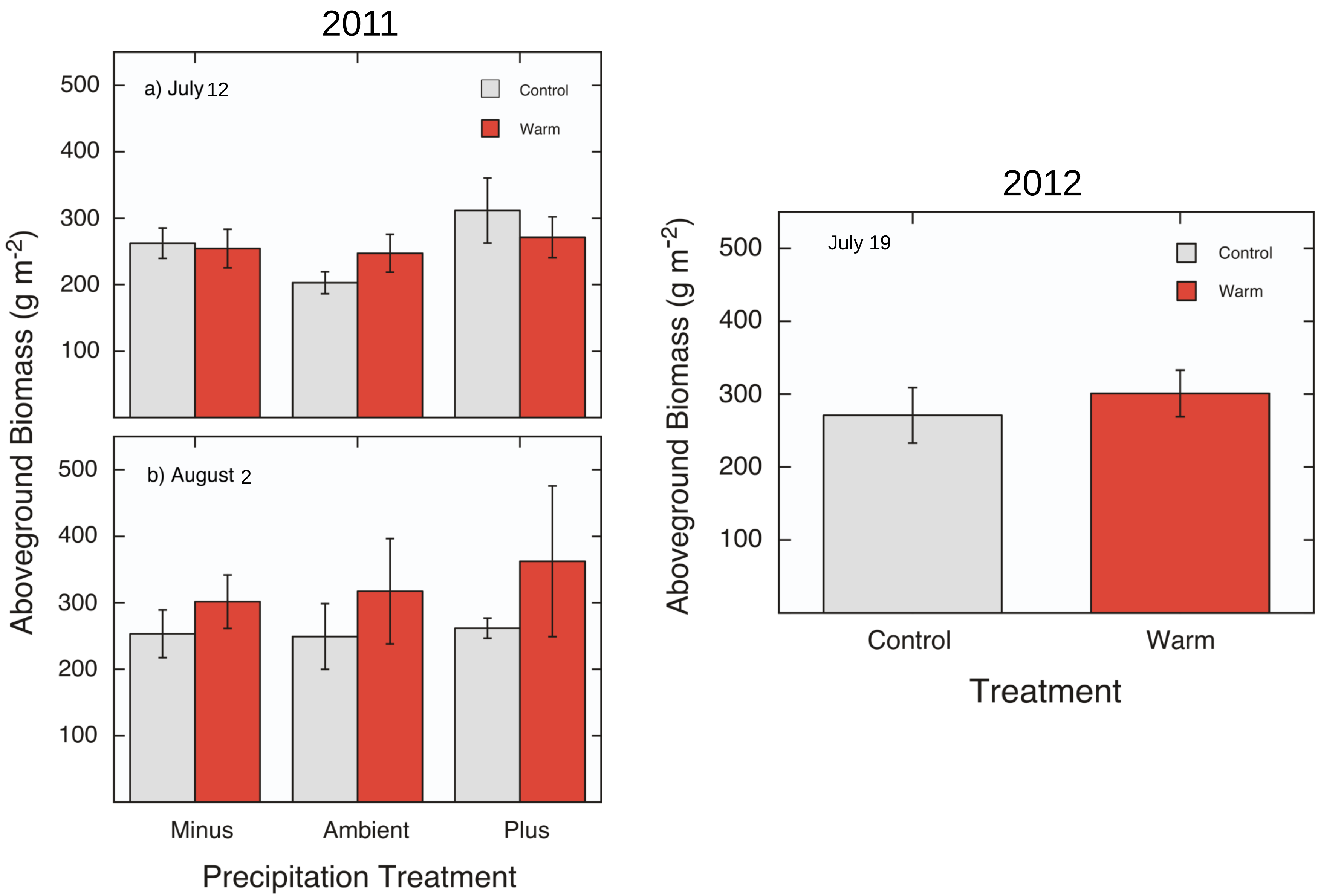
What effect did warmer temperature have on grassland BIOMASS PRODUCTION?

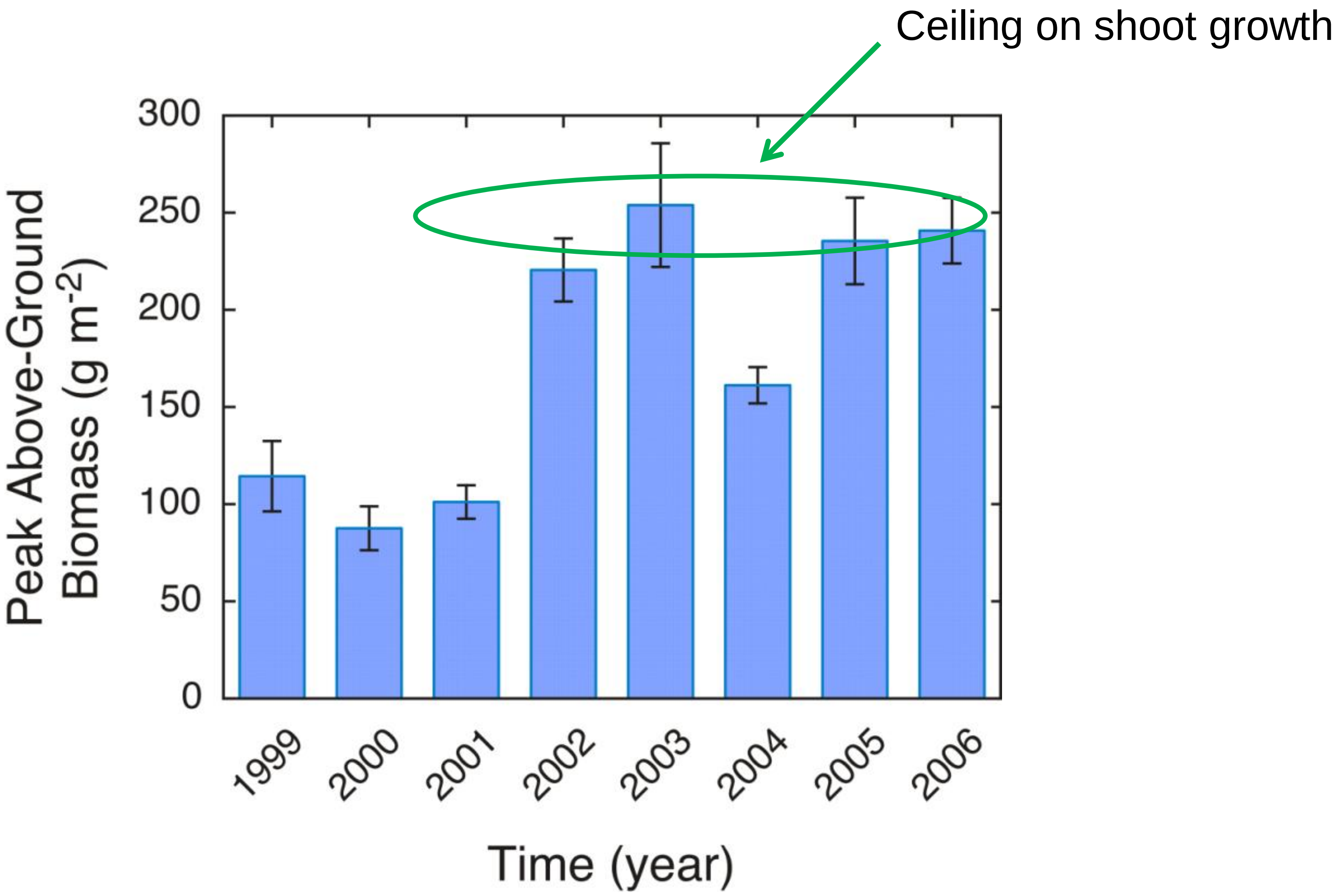
- no significant temperature treatment effect on biomass production in 2011 or 2012

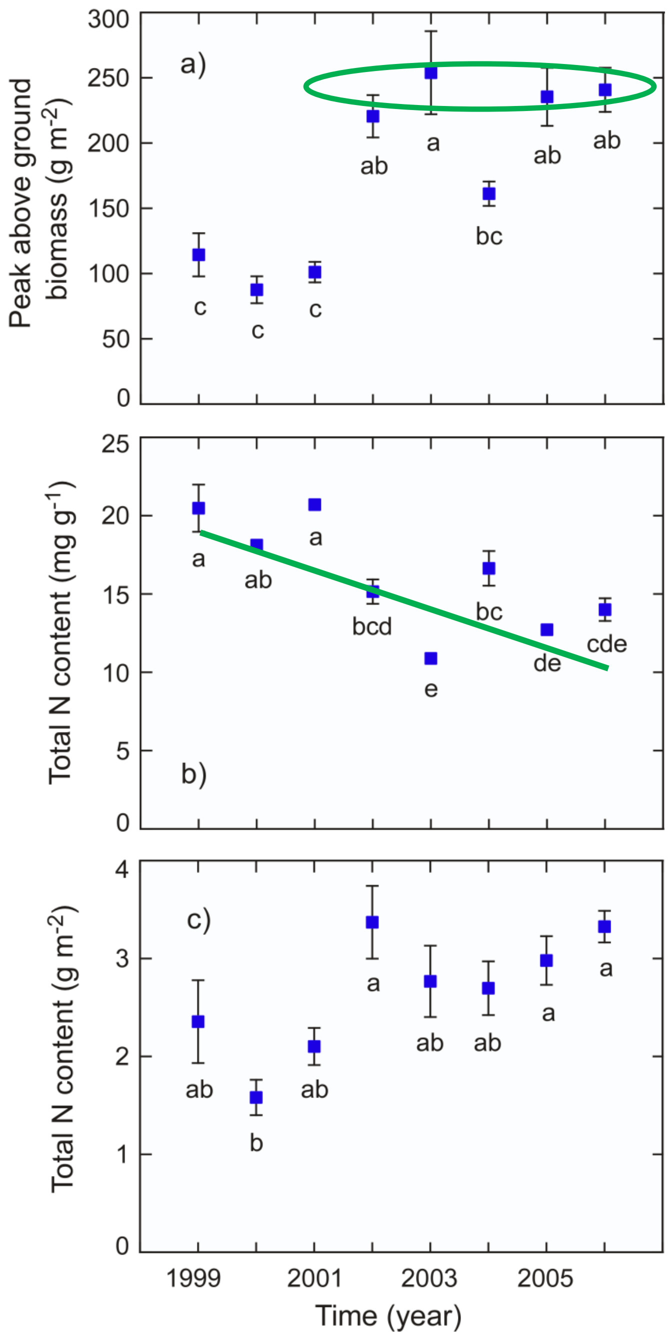
DISCUSSION:

- aboveground biomass production may have been at a ceiling imposed by nutrient limitation

- nutrient limitation was imposed because of relatively high precipitation and water availability in both 2011 and 2012


2011
a) July 12
Control
Warm
b) August 2
Aboveground Biomass (g m-2)
500
400
300
200
100
Minus
Ambient
Plus
Precipitation Treatment
2012
July 19
Control
Warm
Aboveground Biomass (g m-2)
Control
Warm
Treatment


Ceiling on shoot growth
Peak Above-Ground Biomass (g m-2)
300
250
200
150
100
50
0
1999
2000
2001
2002
2003
2004
2005
2006
Time (year)



Ceiling on shoot growth

Due to N-limitation
as suggested by lower
tissue N concentration
in years with high biomass

DISCUSSION:

What effect did warmer temperature have on grassland BIOMASS PRODUCTION?

- aboveground biomass production may have been at a ceiling imposed by nutrient limitation

HYPOTHESIS:

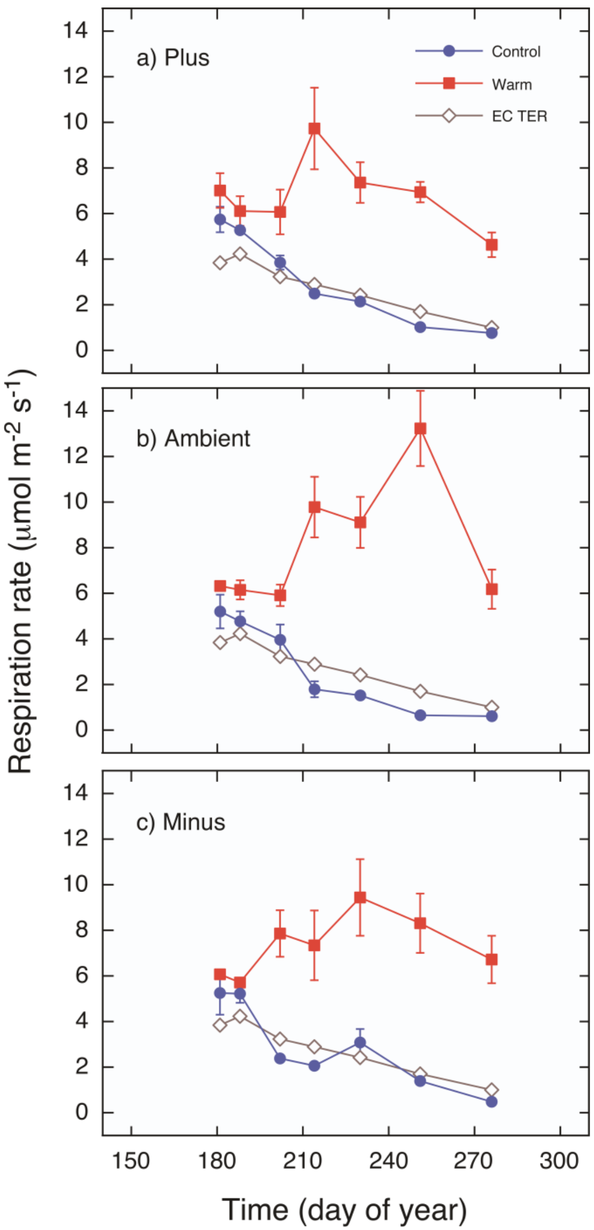
- nutrient limitation may have stimulated allocation of carbon to roots, mycorrhizae and exudates, particularly after the peak of shoot growth

Hypothesis: SOIL RESPIRATION RATE

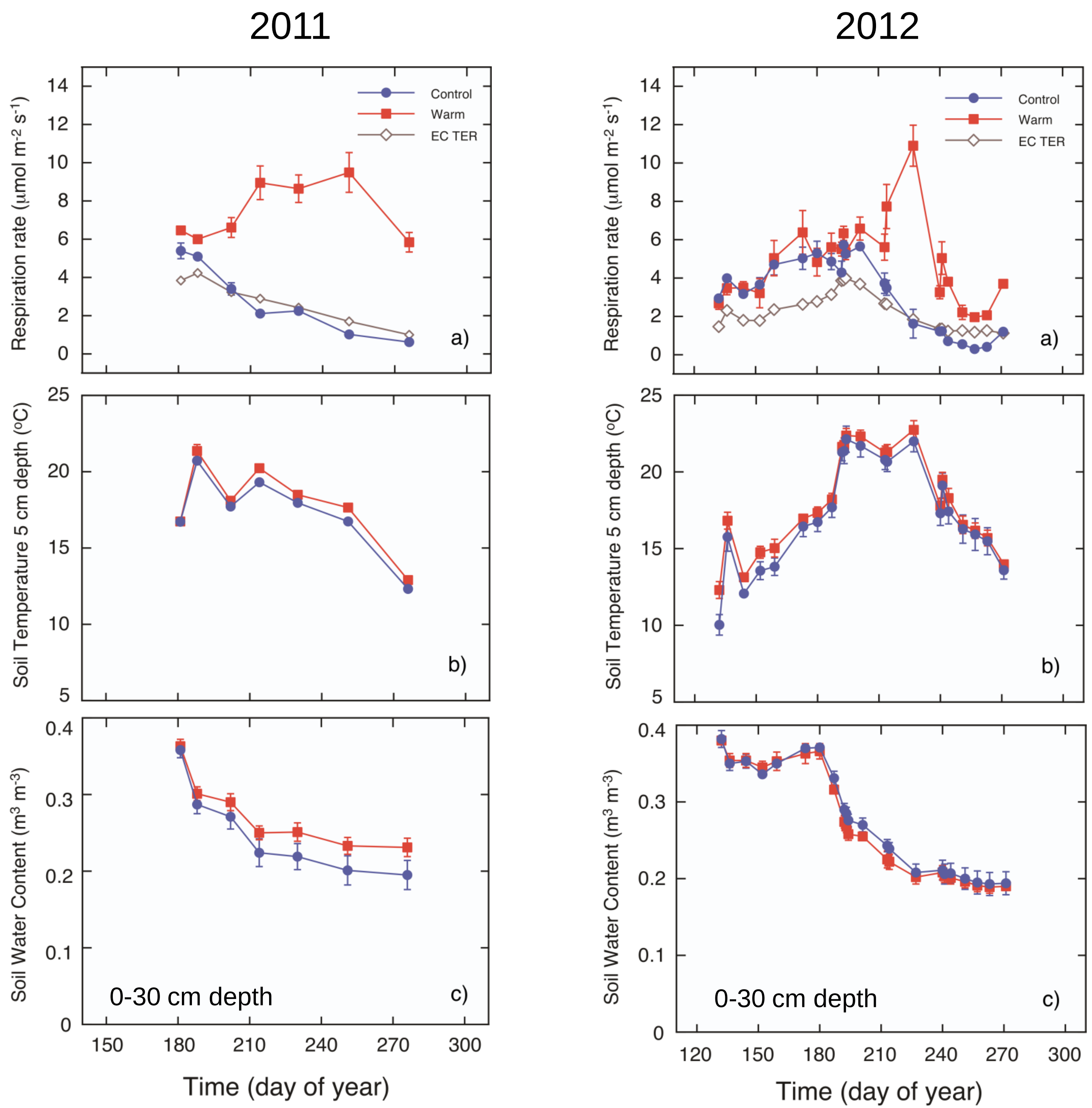
The magnitude of the treatment temperature increase is too small to DIRECTLY cause a significant increase in soil respiration rate (mean 2.5°C increase at midday)

Soil respiration will be stimulated INDIRECTLY via an increase in carbon allocation belowground to roots, mycorrhizae and exudates

2011



a) Plus
b) Ambient
c) Minus
Control
Warm
EC TER
Respiration rate (μmol m-2 s-1)
Time (day of year)
14
12
10
8
6
4
2
0
150
180
210
240
270
300



2011
2012
Control
Warm
EC TER
Respiration rate (μmol m-2 s-1)
Soil Temperature 5 cm depth (oC)
Soil Water Content (m3 m-3)
a)
b)
c)
0-30 cm depth
Time (day of year)

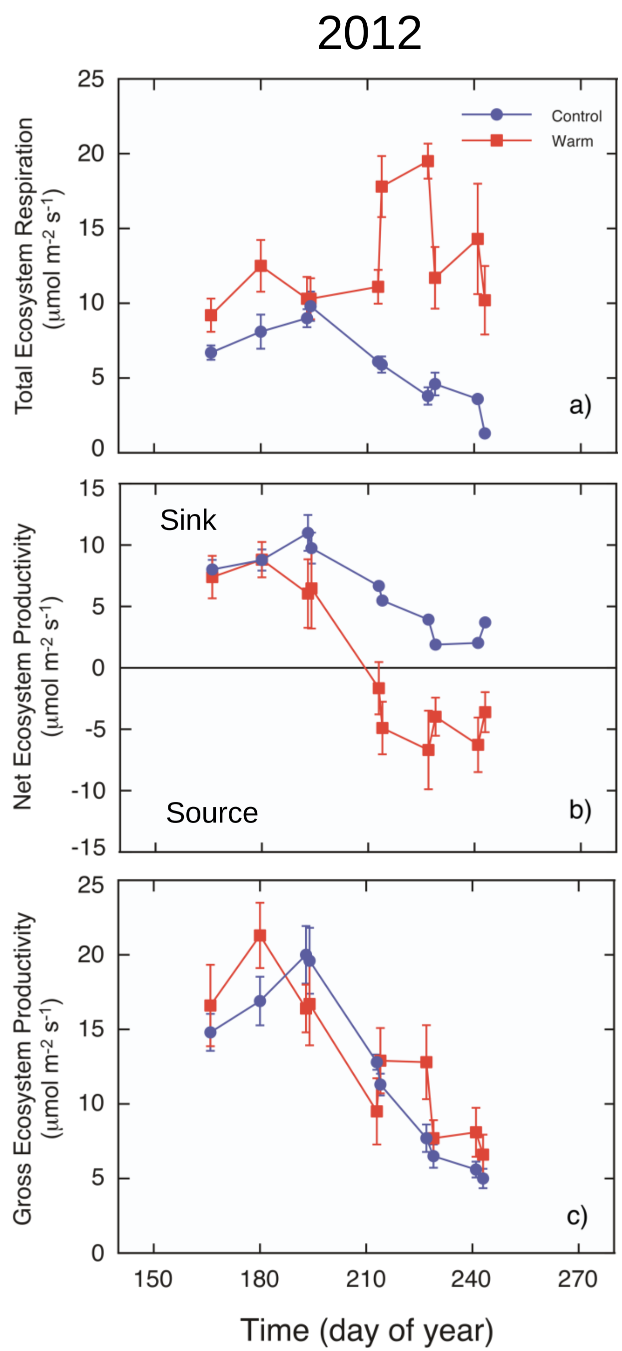
Comparison of integrated carbon flux rates calculated based on chamber soil respiration measurements for control and warmed treatment plots and total ecosystem respiration from eddy covariance measurements during 2011 and 2012.

Error bars represent ± uncertainty values.

	2011	**2012**
Chamber Respiration (July-September)	(g C m^{-2} $period^{-1}$)	(g C m^{-2} $period^{-1}$)
Control	219 ± 76	155 ± 46
Warm	716 ± 225	341 ± 99
Eddy Covariance (July-September)		
Ecosystem Respiration	214 ± 9	185 ± 8

Dynamic Closed Chamber
for
CO_2 Exchange Measurements
in
Treatment Plots

Net Ecosystem CO_2 Exchange
and
Total Ecosystem Respiration
(in darkened chamber)



2012
Total Ecosystem Respiration
(μmol m-2 s-1)
Control
Warm
a)
Net Ecosystem Productivity
(μmol m-2 s-1)
Sink
Source
b)
Gross Ecosystem Productivity
(μmol m-2 s-1)
c)
Time (day of year)

RESULTS:

What effect did warmer temperature have on grassland SOIL RESPIRATION RATE?

- soil respiration was increased after the peak of shoot growth in the warm treatment
- cumulative soil respiration during July-Sept was doubled (2012) or tripled (2011) by the warm treatment
- carbon lost in soil respiration was higher in 2011 likely because of greater precipitation in that year

CONCLUSION:

What effect did warmer temperature have on grassland SOIL RESPIRATION RATE?

- the observed increase in soil respiration was too large to be explained only by a direct effect of temperature-stimulated metabolism

- soil respiration was likely increased indirectly by greater carbon allocation belowground to roots, mycorrhizae and exudates because of the hypothesized nutrient-limitation of shoot growth

What unintended effects do open-top chambers have on environmental conditions?

- reduced solar radiation: measured at ~5% reduction in PPFD

- reduced soil moisture content: no significant effect in 2011 and 2012
- higher vapor pressure deficit:

- reduced wind speed: likely the most important unintended effect

Journal of Applied Ecology (1978), **16,** 507–514

THE EFFECT OF WINDSPEED ON THE GROWTH OF GRASSES

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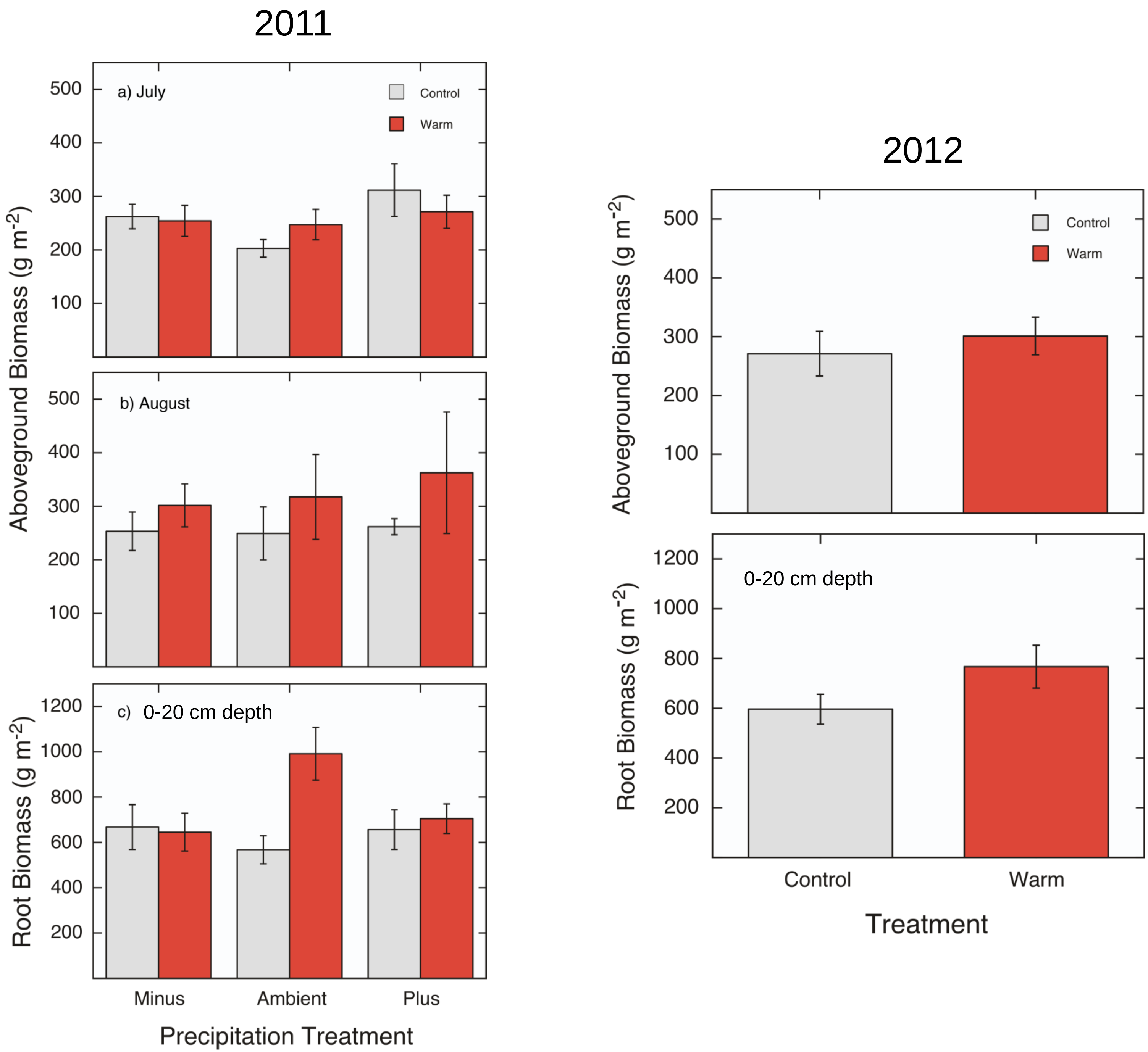
SUMMARY

(1) Plants of *Festuca arundinacea* and *Lolium perenne* were exposed to constant windspeeds of 1·1, 4·0, 7·4, or 10·0 m s^{-1}, in a controlled-environment wind-tunnel, for periods of 14 days.

(2) Increasing windspeed reduced the rate of leaf extension, the relative growth rate and the leaf area ratio, but increased the net assimilation rate in both species. There was no effect of windspeed on the rate of appearance of leaves or on the leaf water potential.

What effect does reduced wind speed have on plant growth?

- increases leaf area and plant relative growth rate
- decreases root/shoot ratio


2011
a) July
Control
Warm
b) August
c) 0-20 cm depth
Aboveground Biomass (g m-2)
Root Biomass (g m-2)
500
400
300
200
100
1200
1000
800
600
400
200
Minus
Ambient
Plus
Precipitation Treatment
2012
Control
Warm
0-20 cm depth
Aboveground Biomass (g m-2)
Root Biomass (g m-2)
Control
Warm
Treatment