Plant ecology of desert annuals

Travis E. Huxman

Steele/Burnand Anza-Borrego Desert Research Center
Center for Environmental Biology
Ecology and Evolutionary Biology
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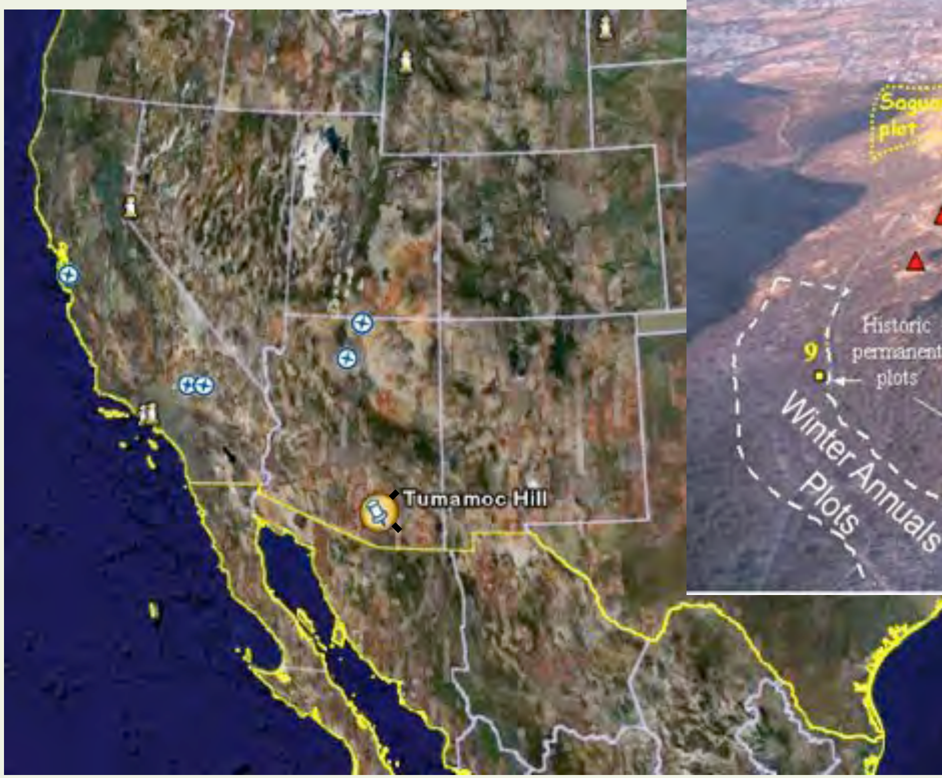
Collaborations with Larry Venable, Sarah Kimball, Amy Angert, Jenny Gremer, Greg Barron-Gafford, Kathy Gerst, Darrel Jenerette, Peter Chesson (among others)

Big ecological questions – towards prediction

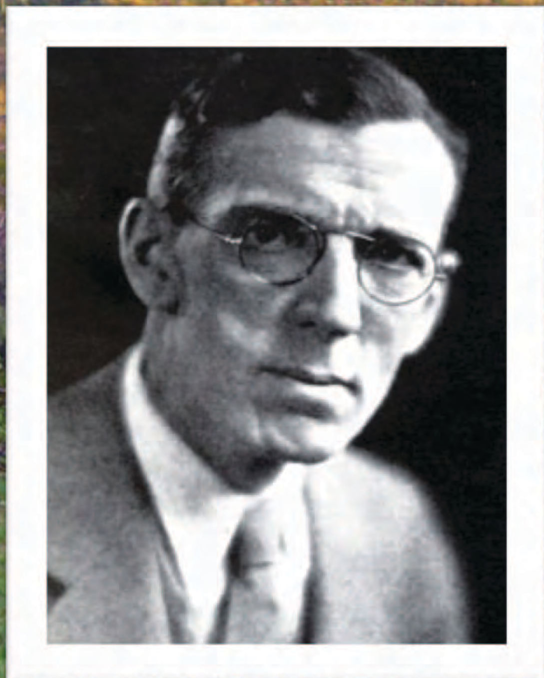
- How does organismal function lead to population / community processes?
- What is the role of ecology versus evolution?
- What maintains species diversity?
- What is the role of climate?

Desert Annual Plant Community
Desert Lab at Tumamoc Hill Tucson, AZ



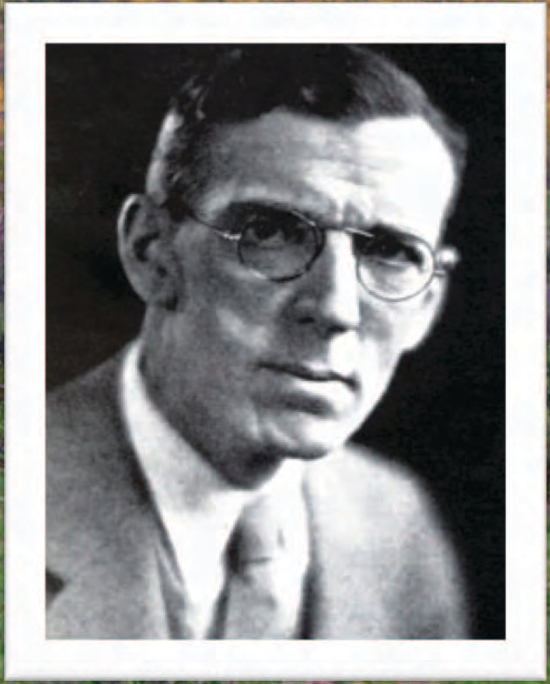
Highly variable environment (deserts have been the test-beds of many ecophysiological investigations)

Forrest Shreve – Plant Physiological Ecology

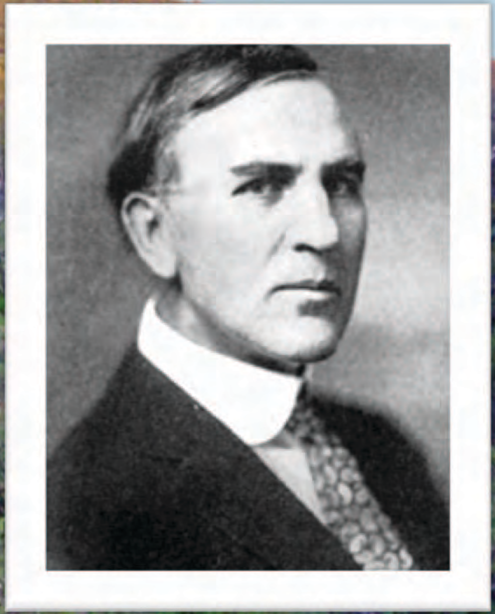


Greening of the wastelands – understanding plants to build a better foundation for society

Forrest Shreve – Plant Physiological Ecology



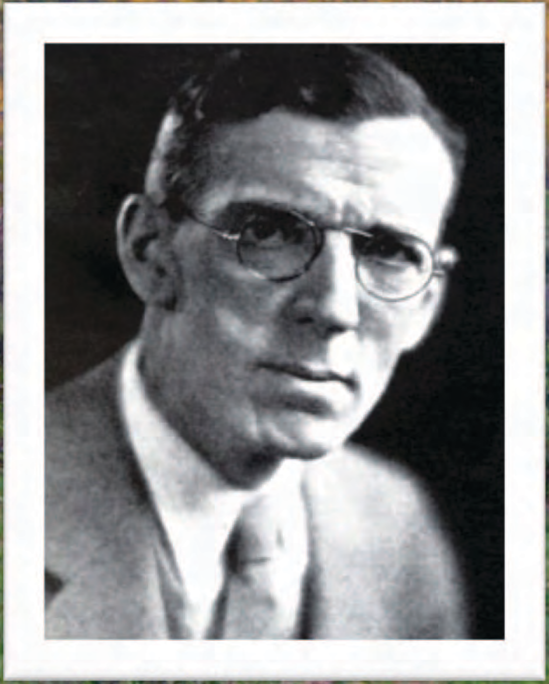
Fredric Clements – Ecologist, Botanist, Geographer



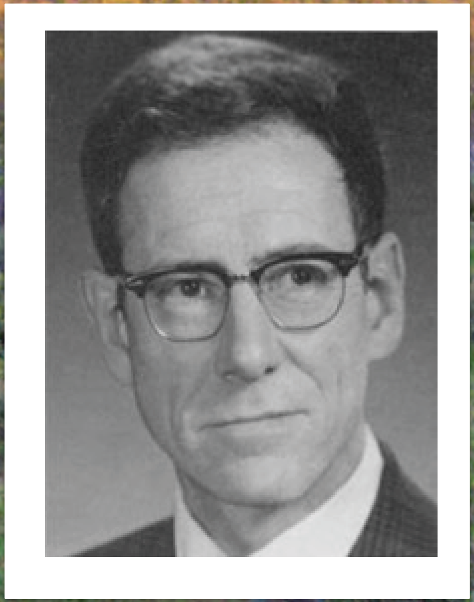
How do plant communities form?

The individualistic theory of plant community ecology

Forrest Shreve – Plant Physiological Ecology



Robert Whitteker – Community Ecology



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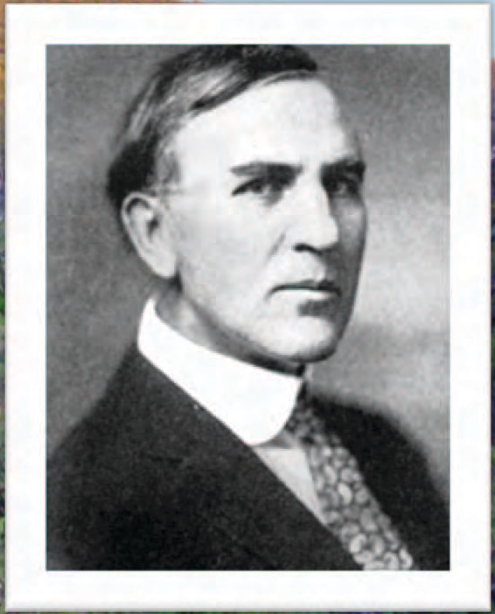
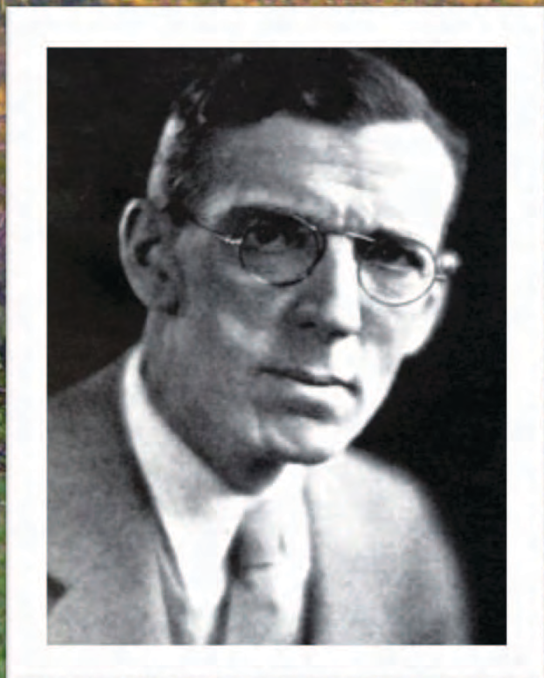
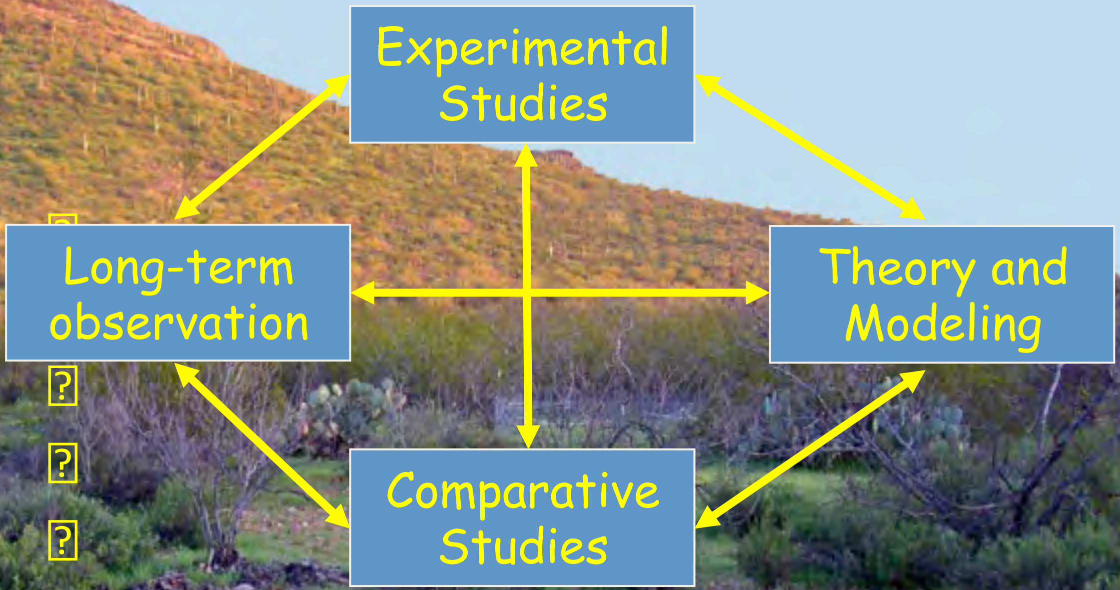
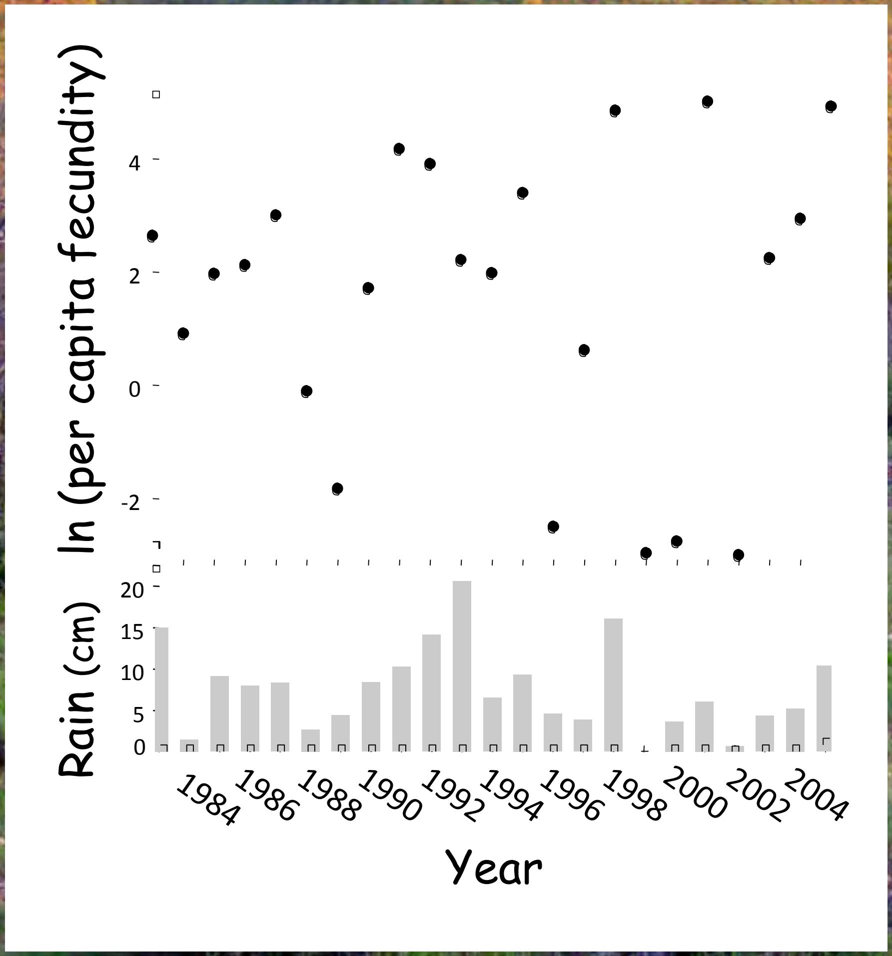


Forrest Shreve – Plant Physiological Ecology

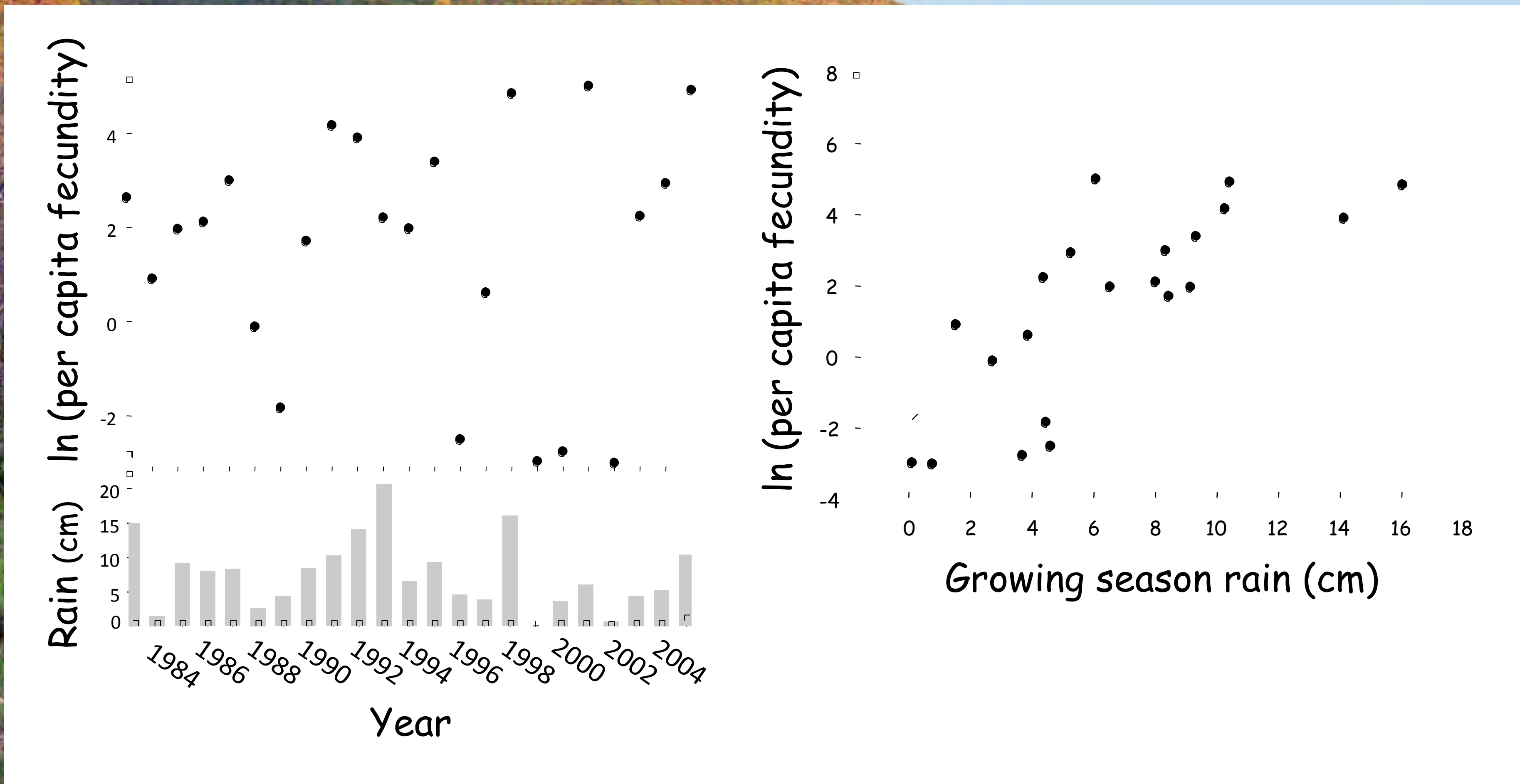




Long term patterns of seed production



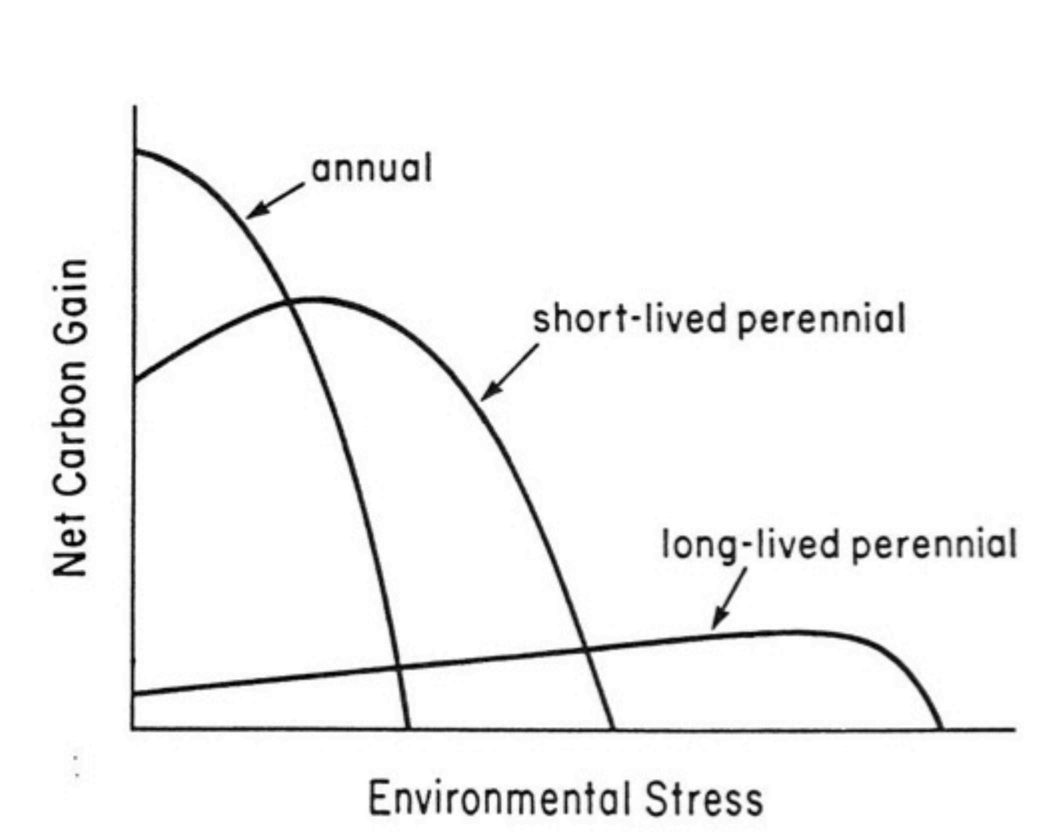
Long term patterns of seed production



Environmental variation . *functional traits* ▶ Demographic variation . ▶ Community dynamics

- Species with low demographic variance should be more stress tolerant

- High variance species should have 'fast-growing' traits



Major Species

Erodium texanum

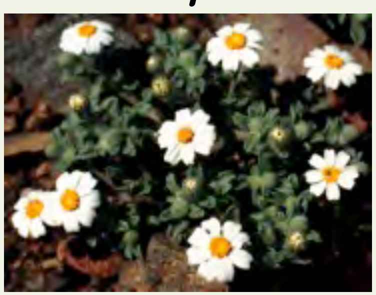
Lotus tomentellus

Pectocarya recurvata

Stylocline micropoides

Evax multicaulis

Plantago patagonica



Eriophyllum lanosum

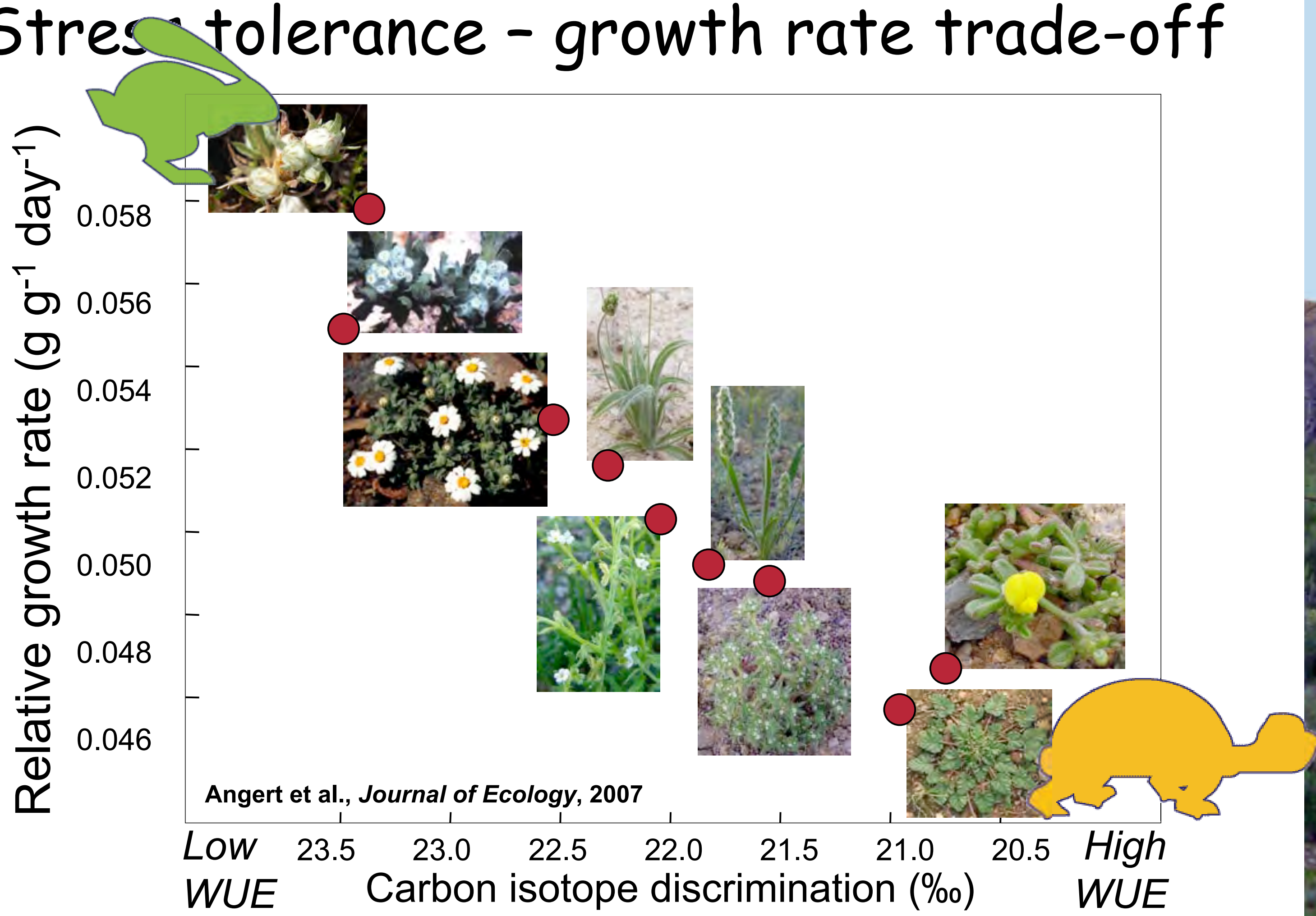
Plantago insularis

Focus on:

- Growth analysis (which has both morphological and physiological determinants)
- Isotopic proxies of stress tolerance
- Phenological and life history patterns


STMI
I-3
Shrub

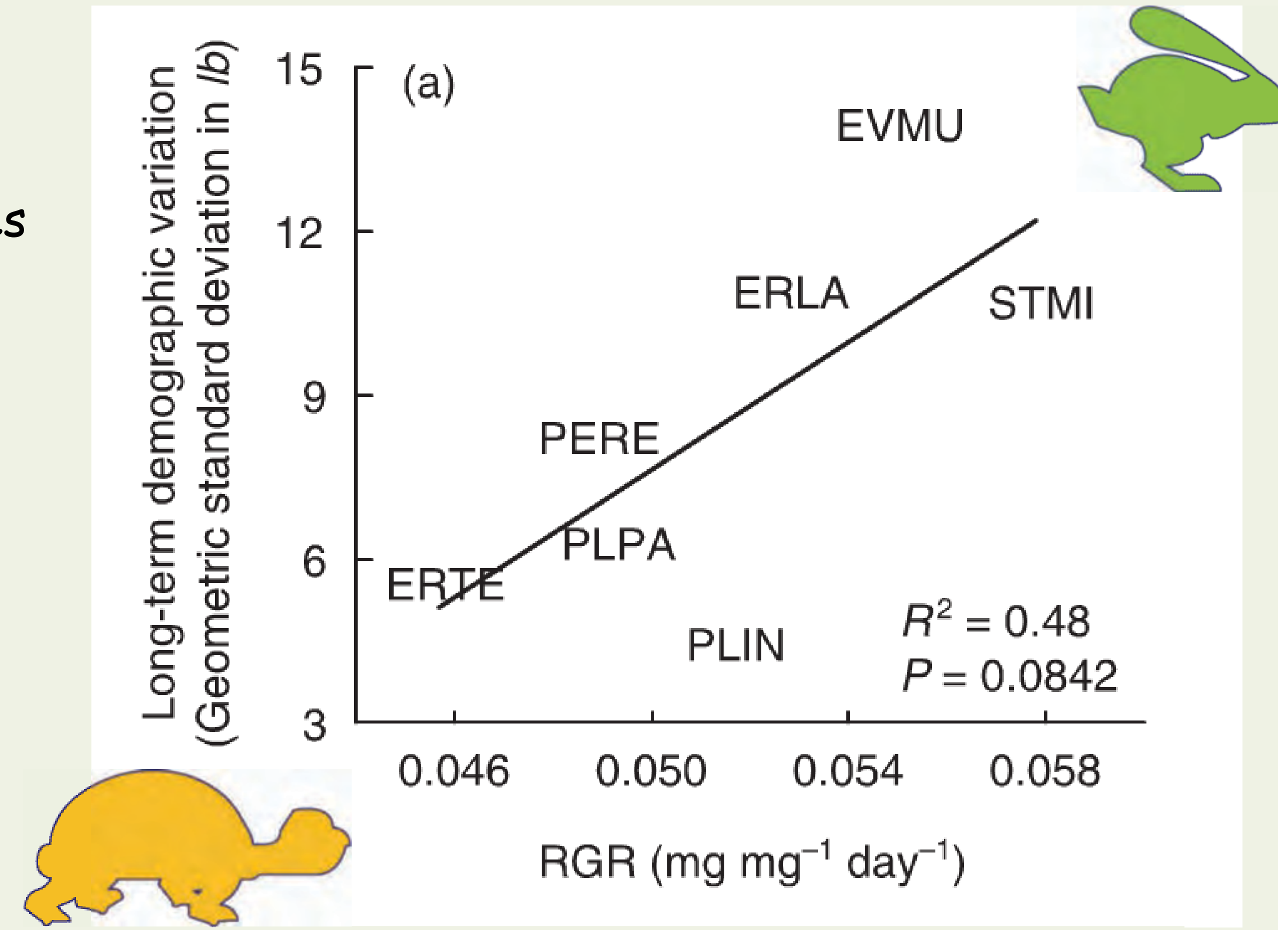
Stress tolerance - growth rate trade-off



Environmental variation → **functional traits** → Demographic variation → Community dynamics

– High growth rates results in high variance

– Stress tolerance buffers demographic variation?

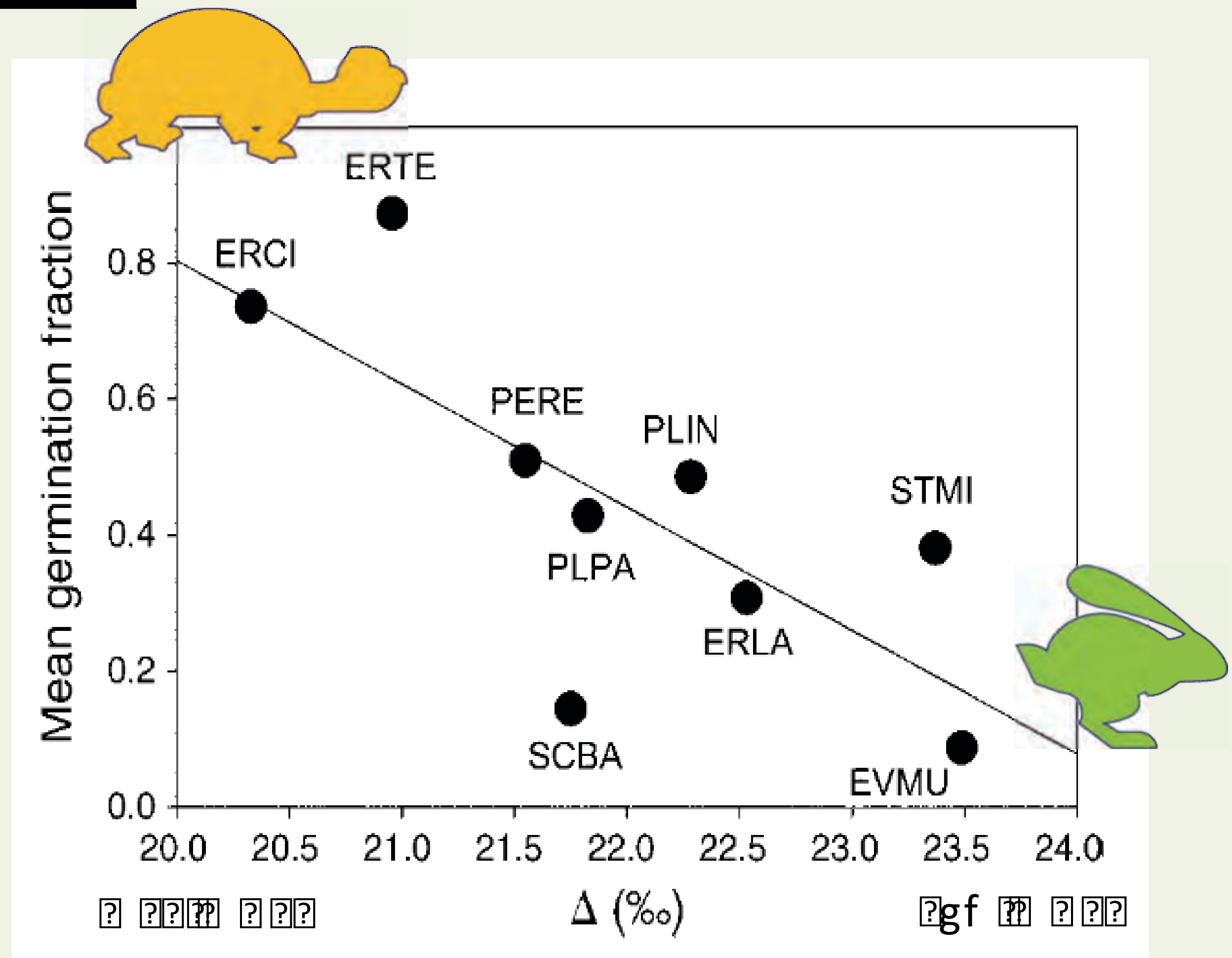


What are the life history consequences?

Environmental variation → *functional traits* → Demographic variation → Community dynamics

- Inverse relationship between stress tolerance and the fraction of seeds that germinate in a given year

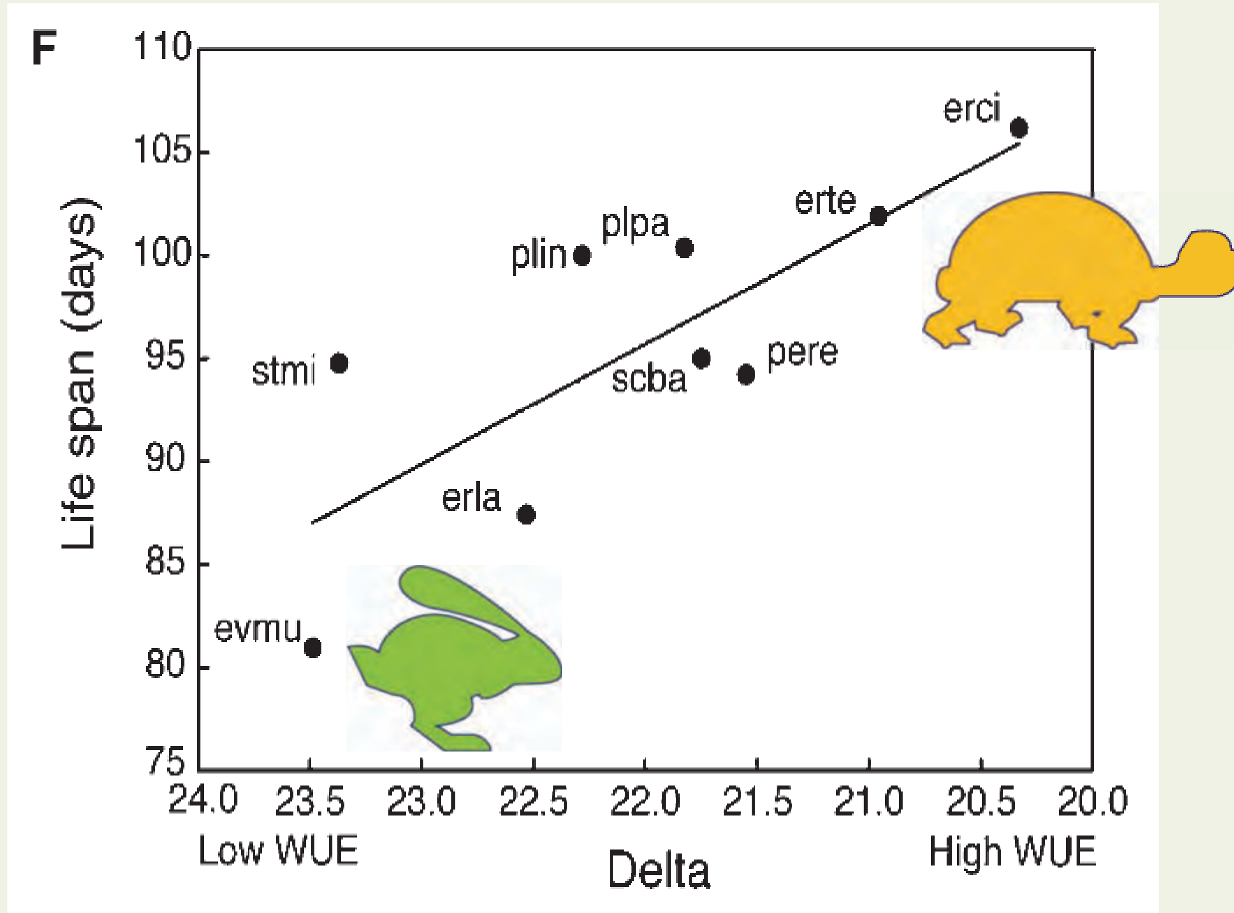
*Sorry about the change in axis!



How does buffering influence phenology?

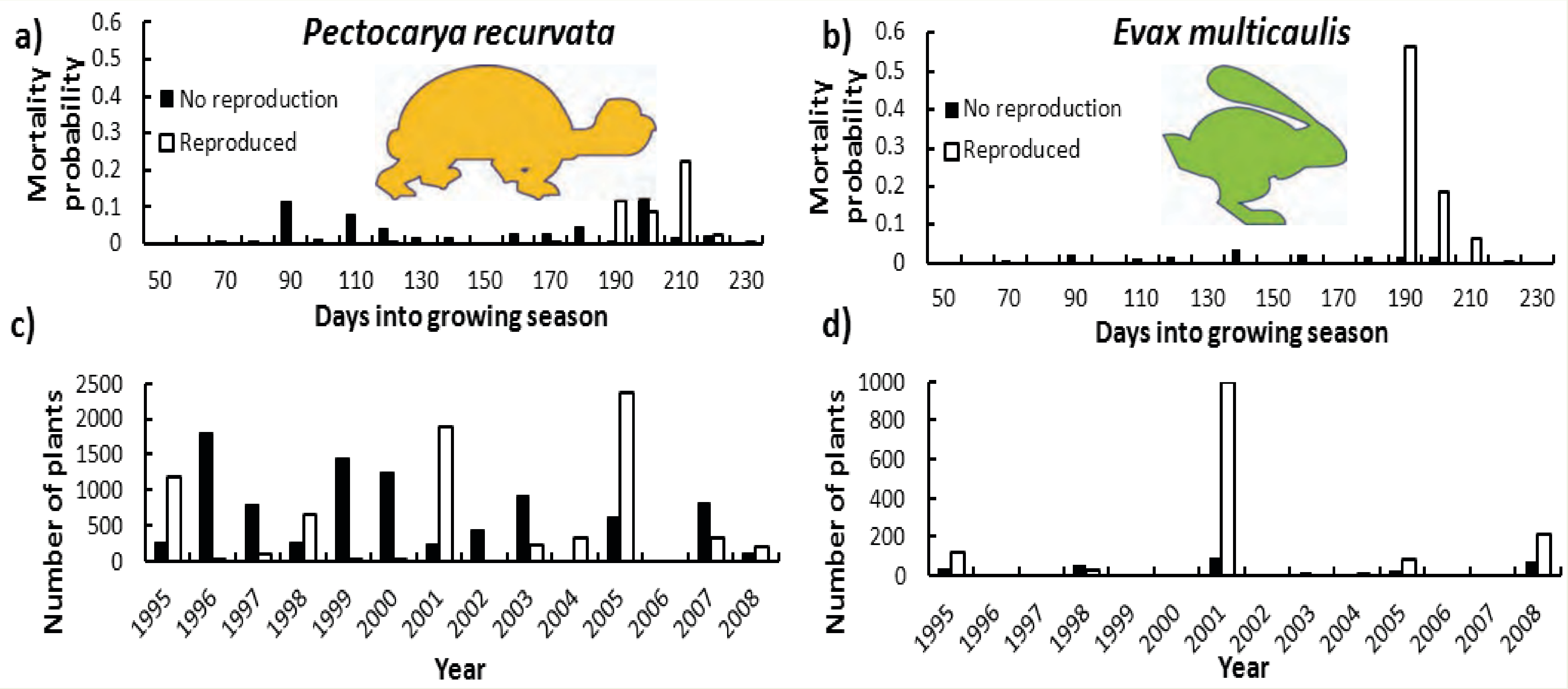
Environmental variation → *functional traits* → Demographic variation → Community dynamics

– Stress tolerant species germinate early and have extended seasons, while fast growers are much shorter lived



Combined trait effects on phenology & life-span

Plant strategy and the probability of mortality



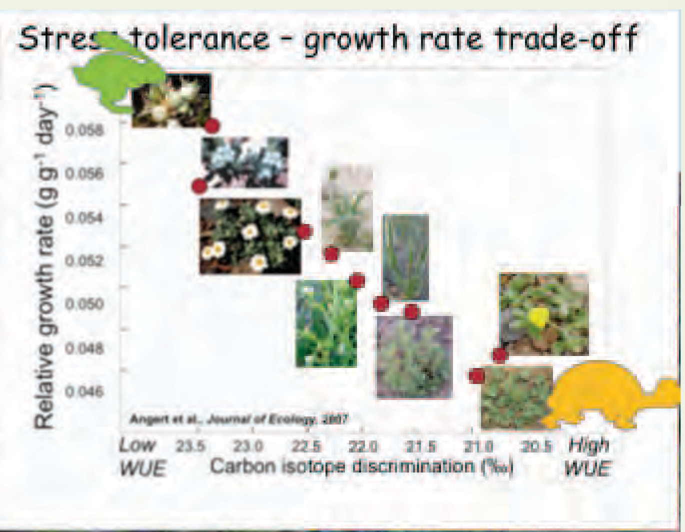
How has this interplay between life history strategy, seed germination strategy and growth rate / stress tolerance traits evolved?

Big take home point:

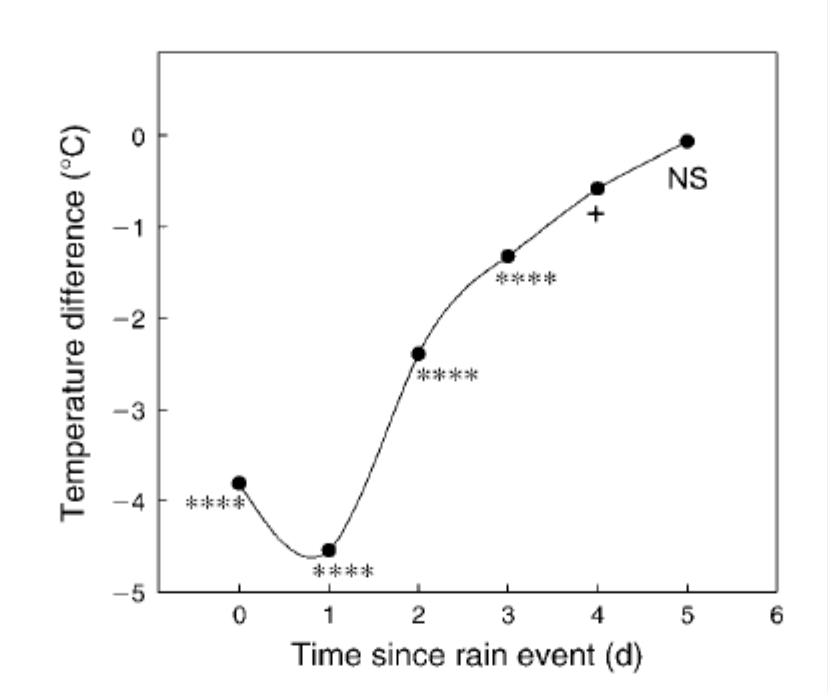
- How evolution shapes species also influences the dynamics of communities

Environmental variation → Functional traits → Demographic variation → Community dynamics

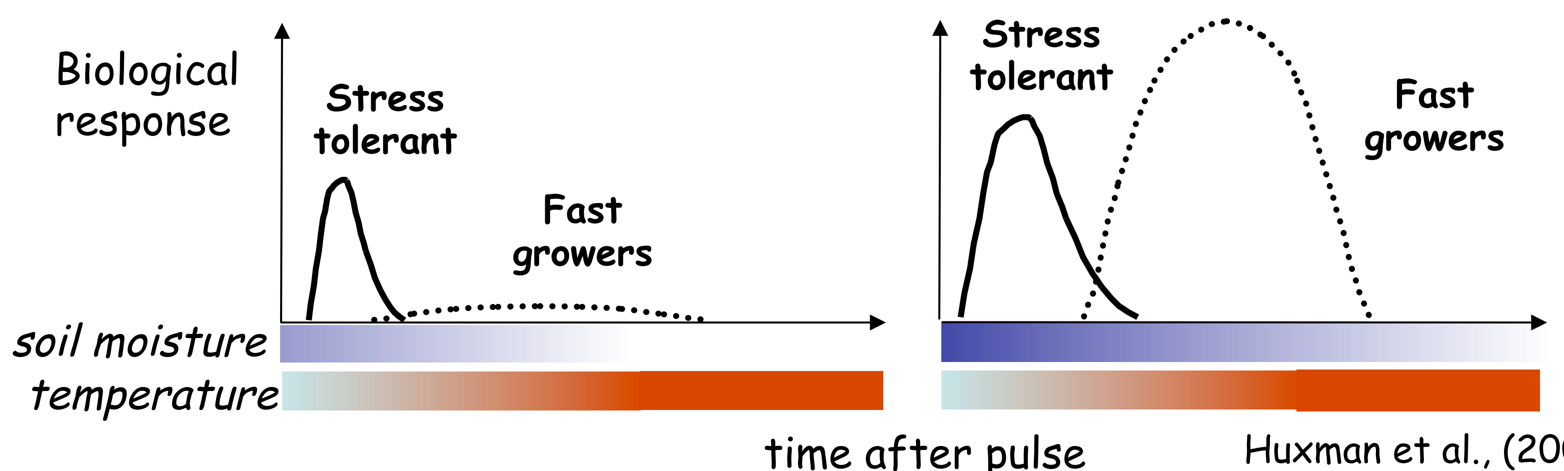
Natural selection and trait constraints



What controls the abundance and community dynamics of desert annual plants?

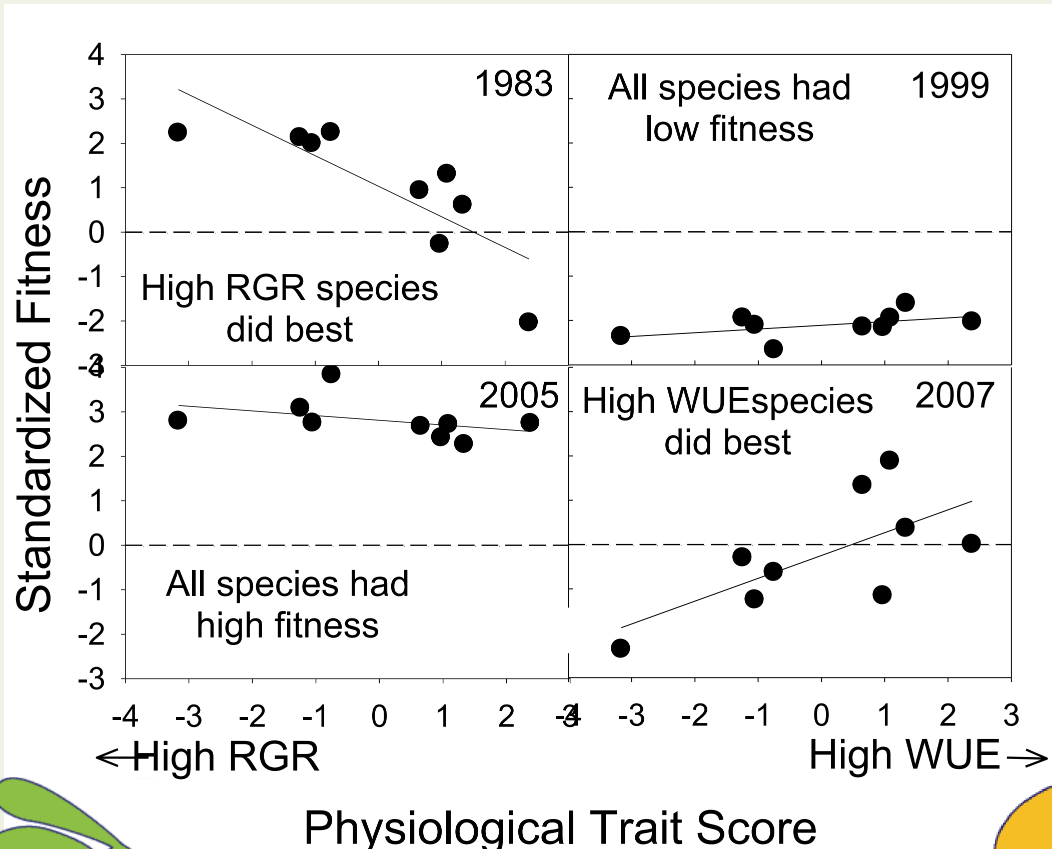


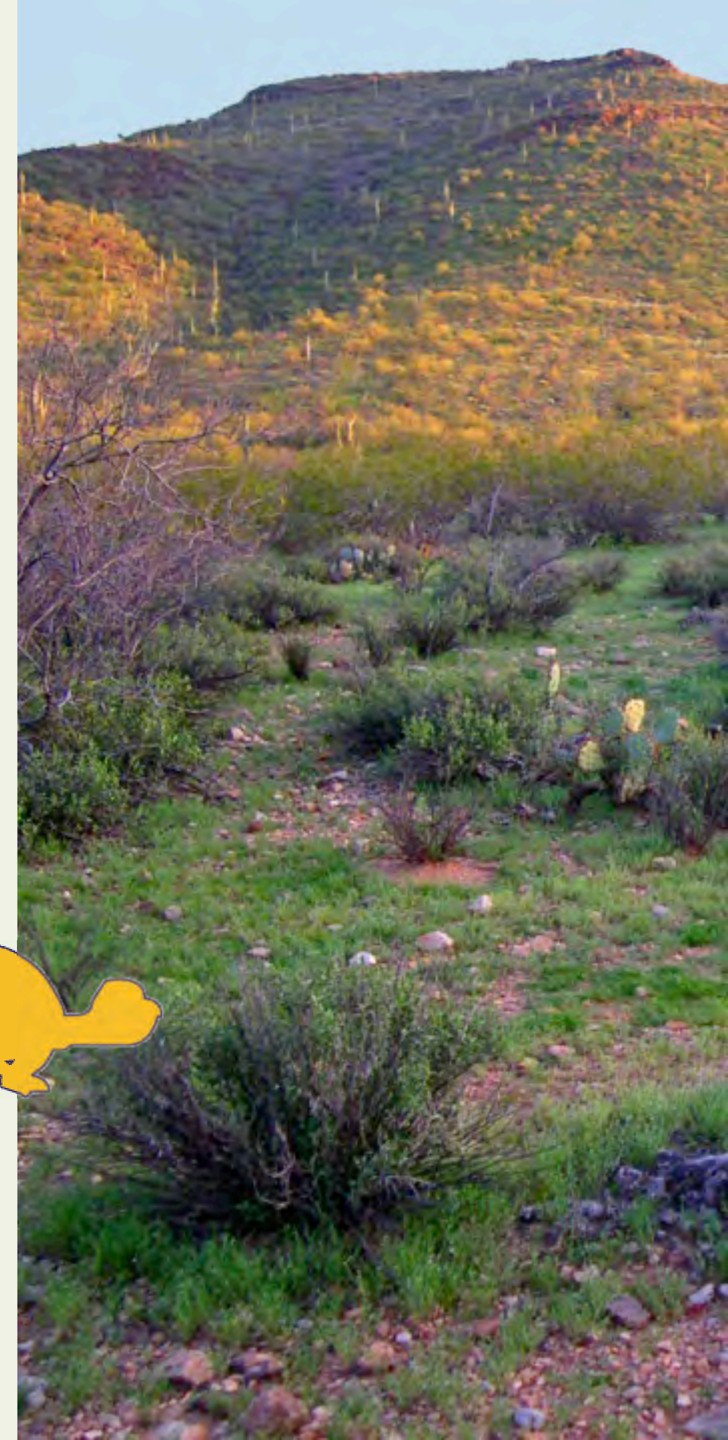
Small precipitation pulse *Large precipitation pulse*

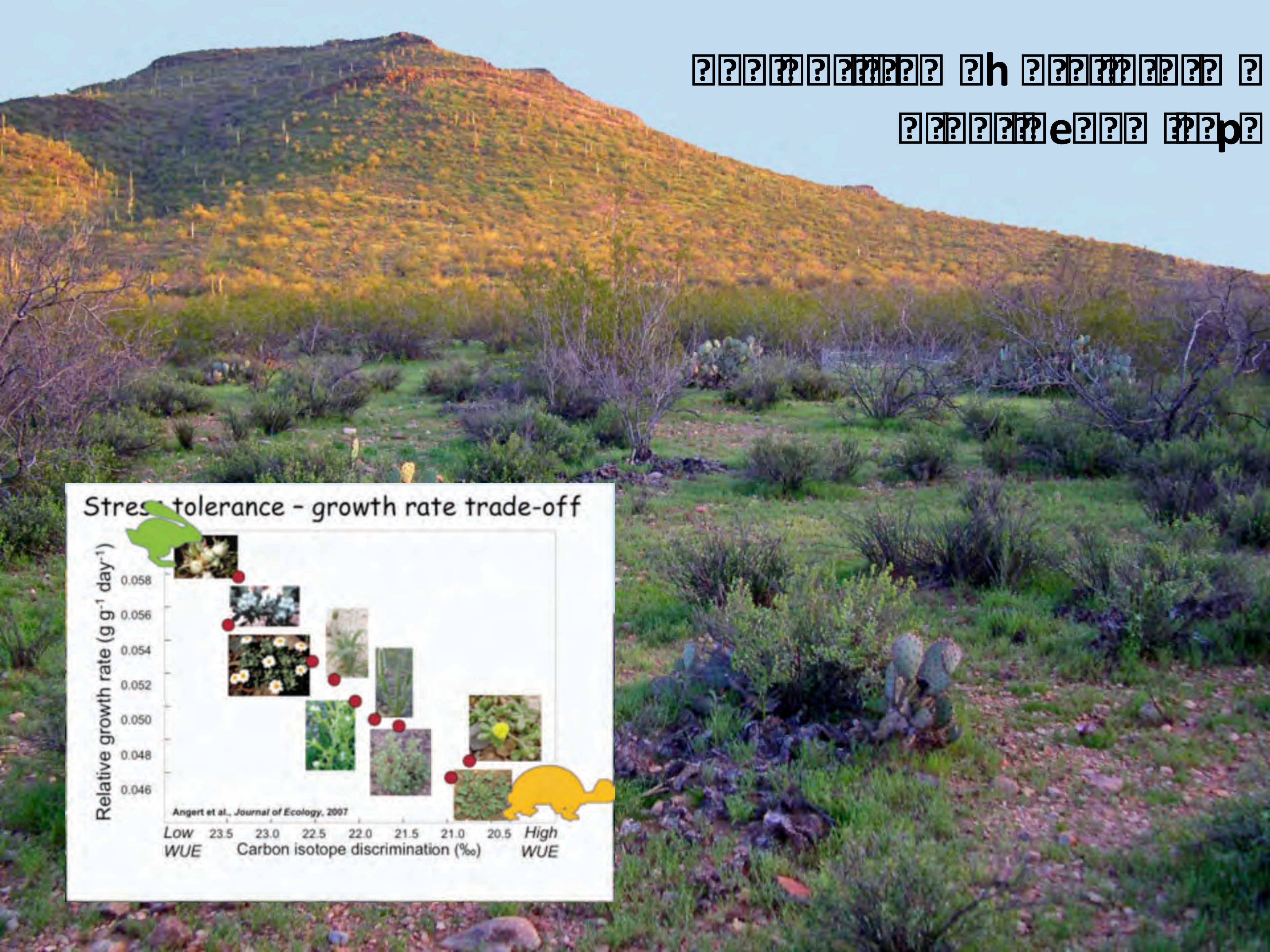


Huxman et al., (2008) Ecology

What weather matters?






Stress tolerance - growth rate trade-off
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Angert et al., Journal of Ecology, 2007
Low WUE
23.5
23.0
22.5
22.0
21.5
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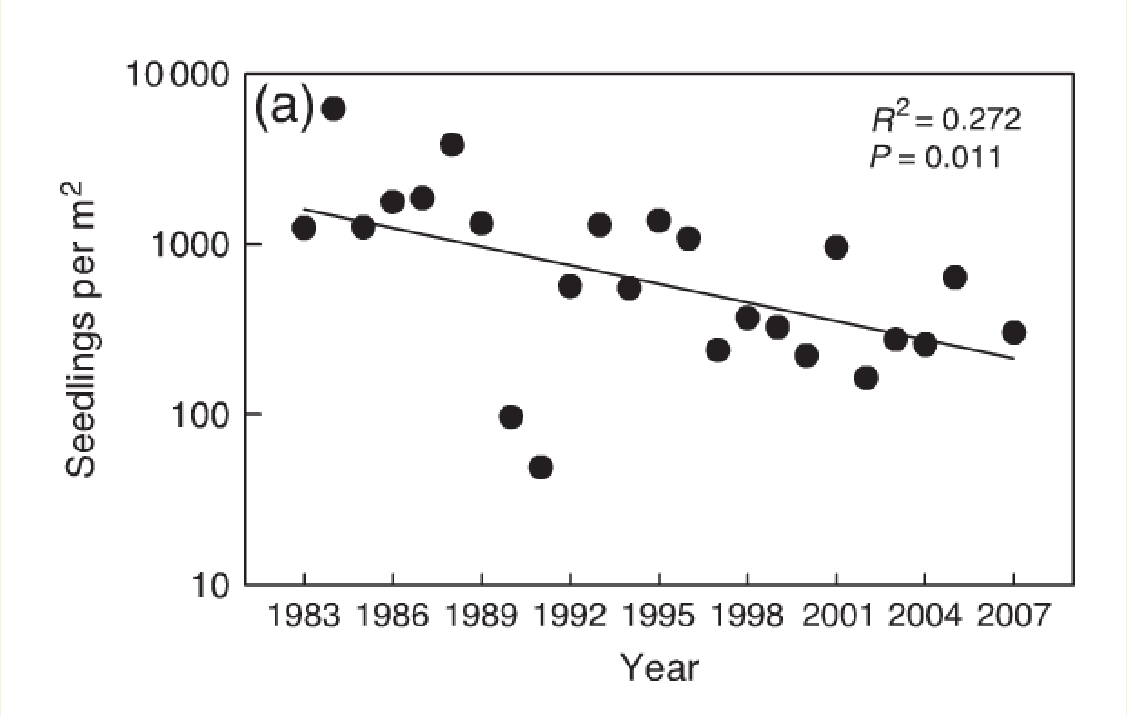
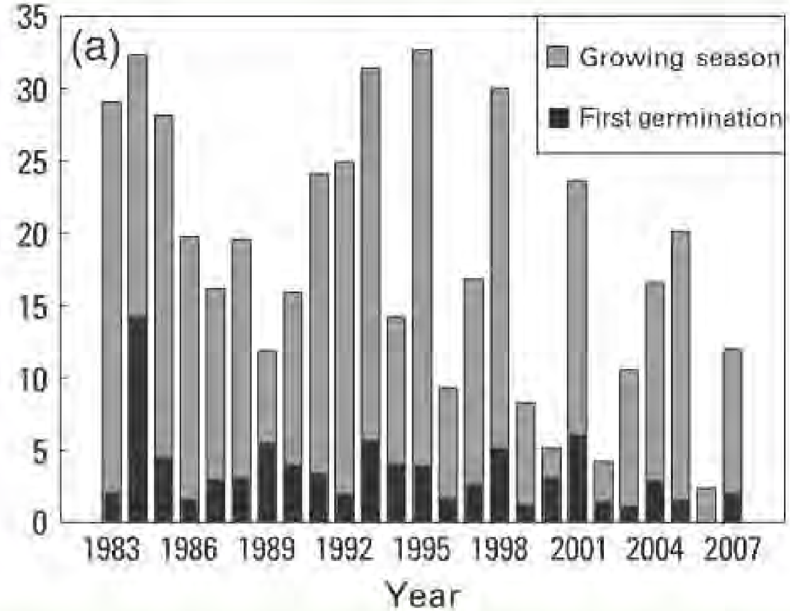
High WUE
Carbon isotope discrimination (‰)

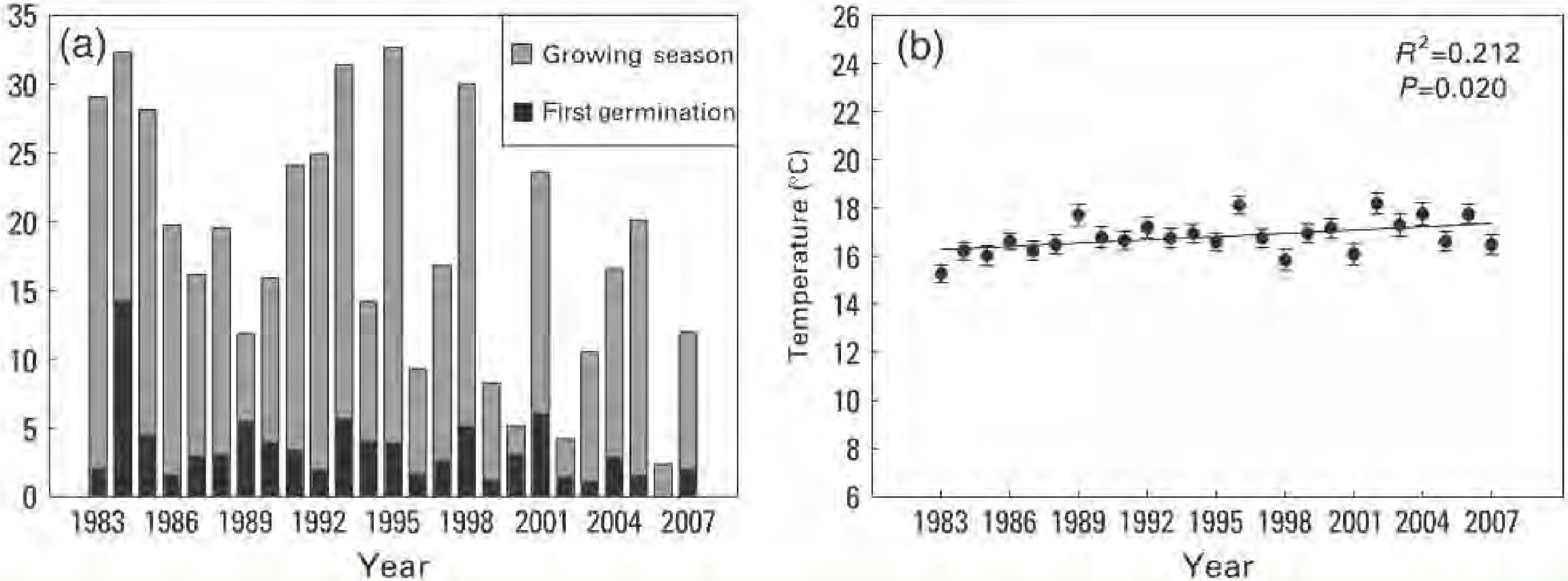
A decrease in plant density over 30 years due to differences in germination and mortality

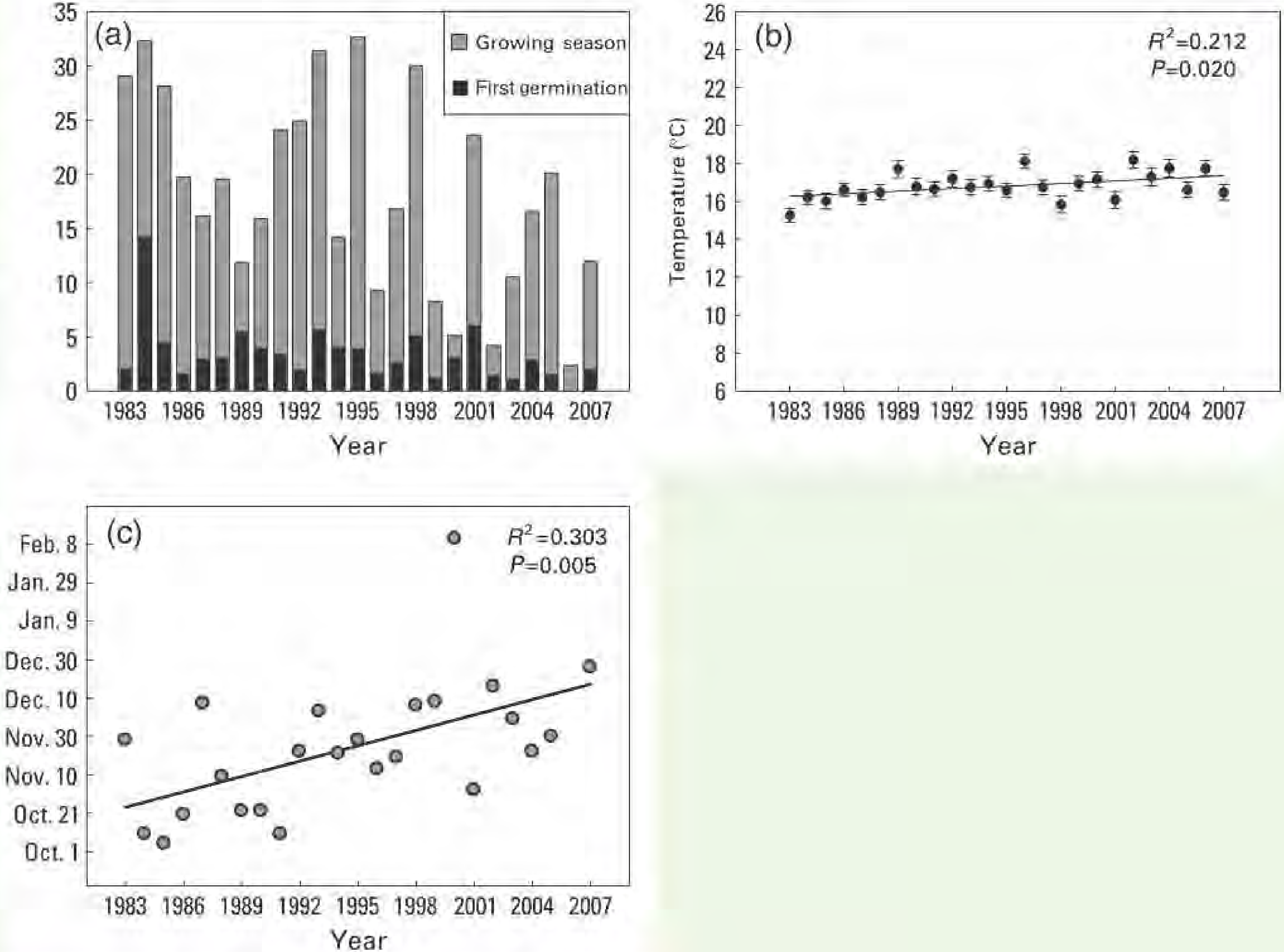


What is driving this change and is it related to species-specific responses to local climatic warming and drying?

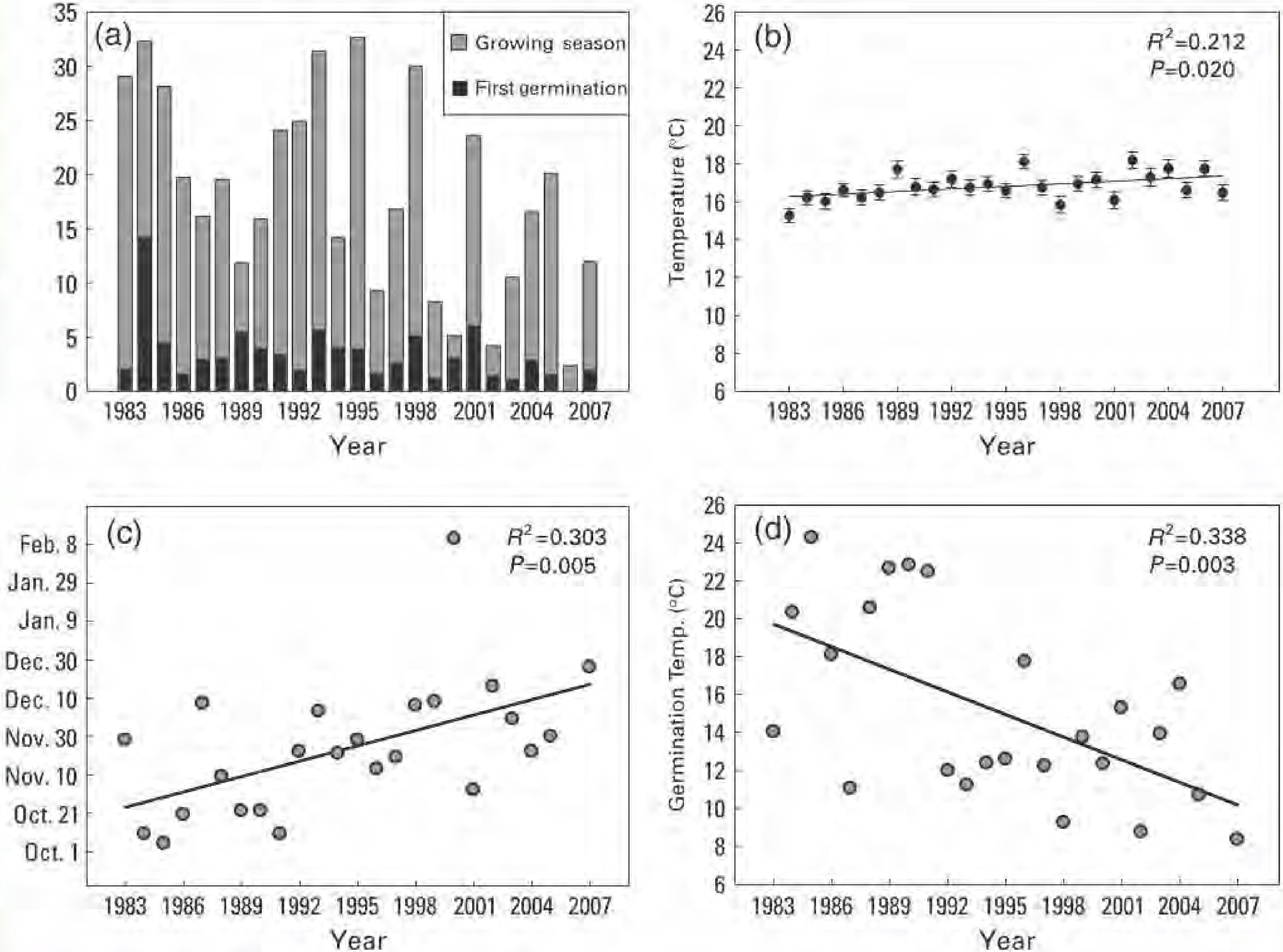


(a)
Growing season
First germination
35
30
25
20
15
10
5
0
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year

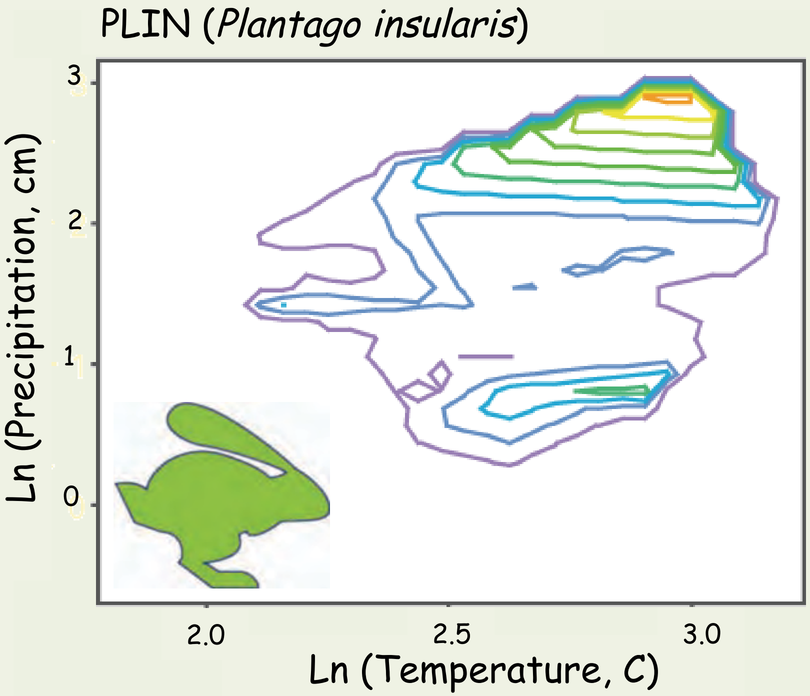

(a)
Growing season
First germination
0
5
10
15
20
25
30
35
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year
(b)
R2=0.212
P=0.020
Temperature (°C)
6
8
10
12
14
16
18
20
22
24
26
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year

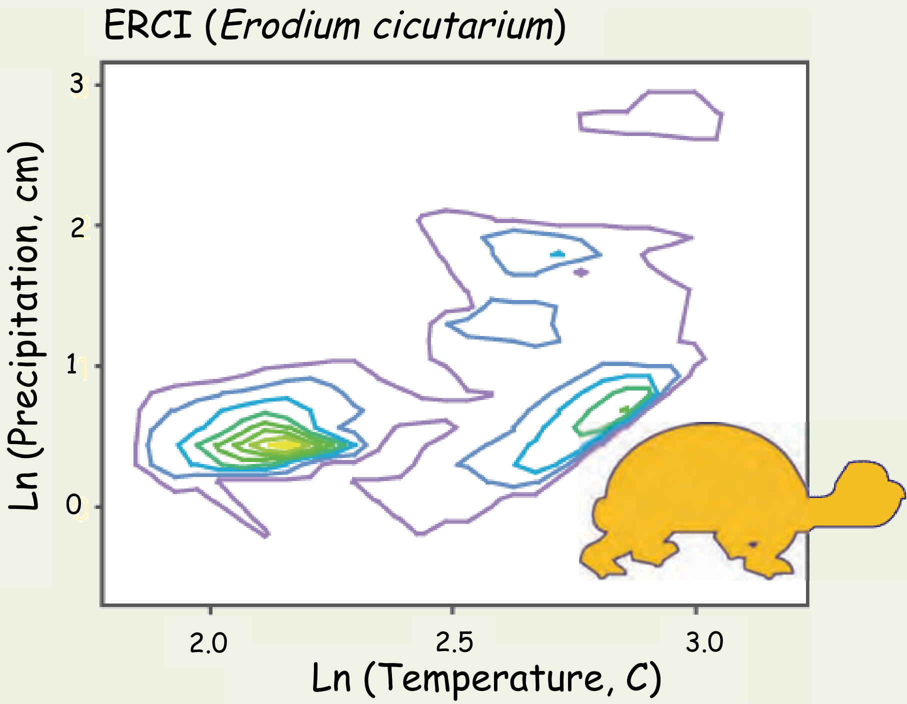


(a)
Growing season
First germination
0
5
10
15
20
25
30
35
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year
(b)
R^2=0.212
P=0.020
Temperature (°C)
6
8
10
12
14
16
18
20
22
24
26
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year
(c)
R^2=0.303
P=0.005
Feb. 8
Jan. 29
Jan. 9
Dec. 30
Dec. 10
Nov. 30
Nov. 10
Oct. 21
Oct. 1
1983
1986
1989
1992
1995
1998
2001
2004
2007
Year

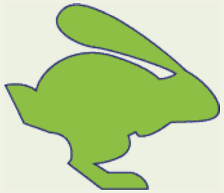

(a)
Growing season
First germination
Year
(b)
R^2=0.212
P=0.020
Temperature (°C)
Year
(c)
R^2=0.303
P=0.005
Feb. 8
Jan. 29
Jan. 9
Dec. 30
Dec. 10
Nov. 30
Nov. 10
Oct. 21
Oct. 1
Year
(d)
R^2=0.338
P=0.003
Germination Temp. (°C)
Year

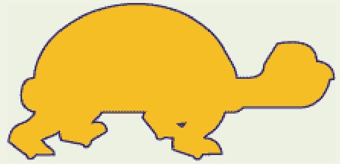
Species specific germination Niches





Consistent pattern of species abundance change



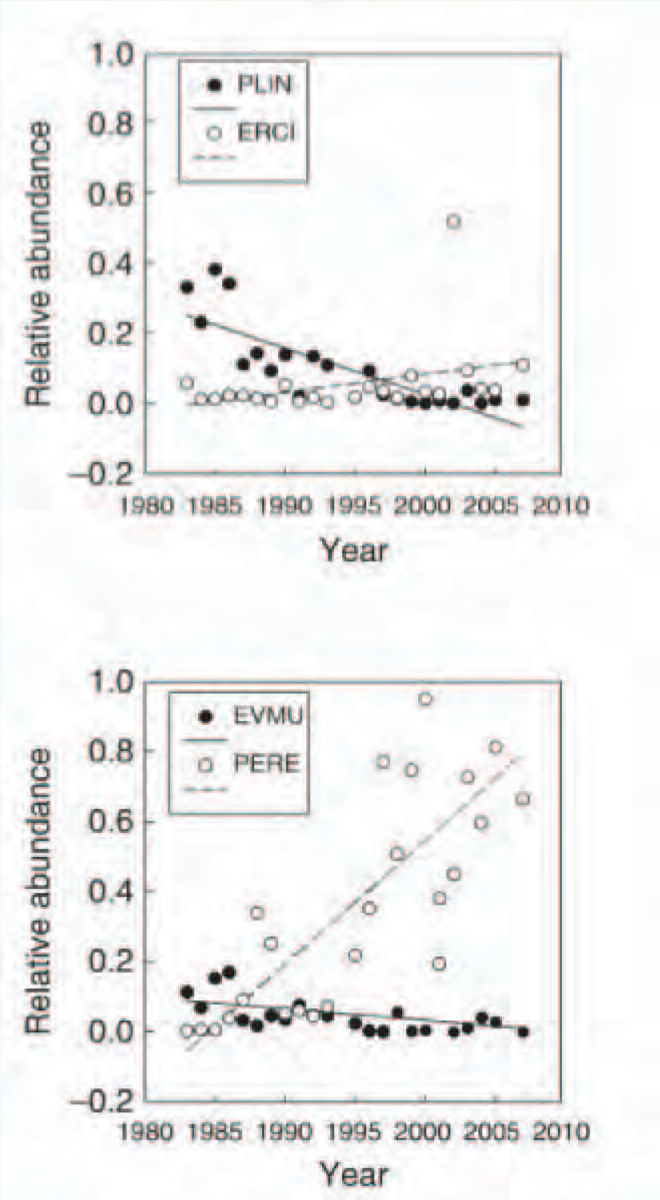


PLIN (*Plantago insularis*)

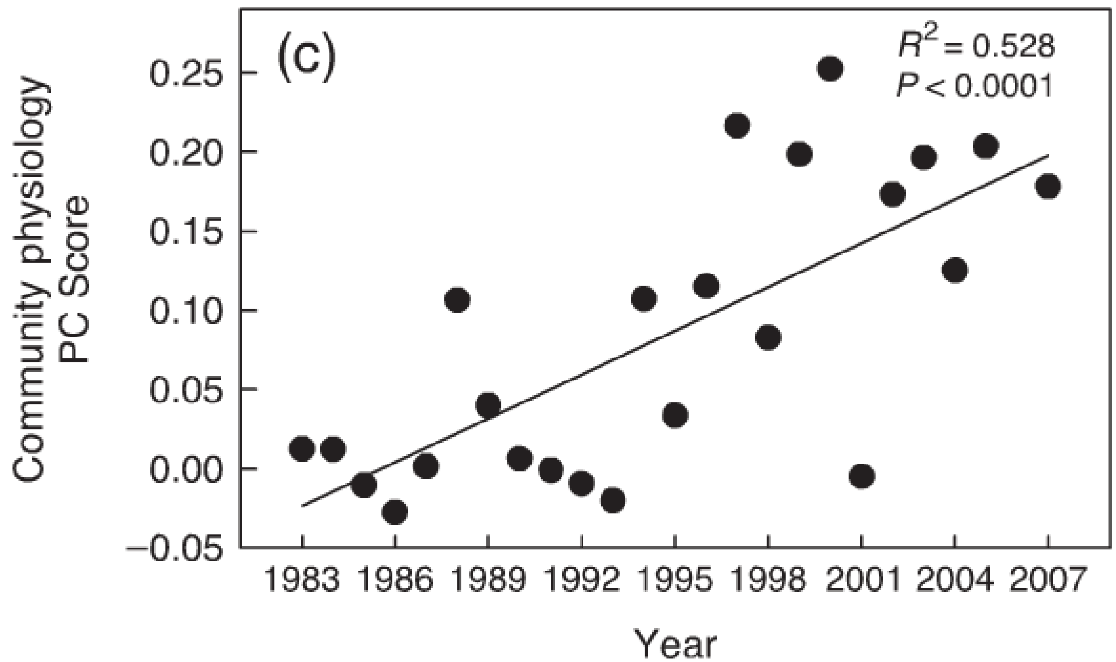
ERCI (*Erodium cicutarium*)

EVMU (*Evax multicaulis*)

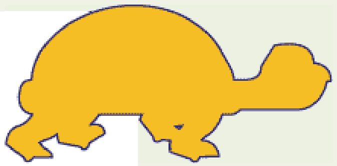
PERE (*Pectocarya recurvata*)

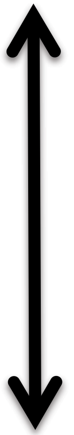


Shifts in community composition driven by the change in water balance associated with the germination window

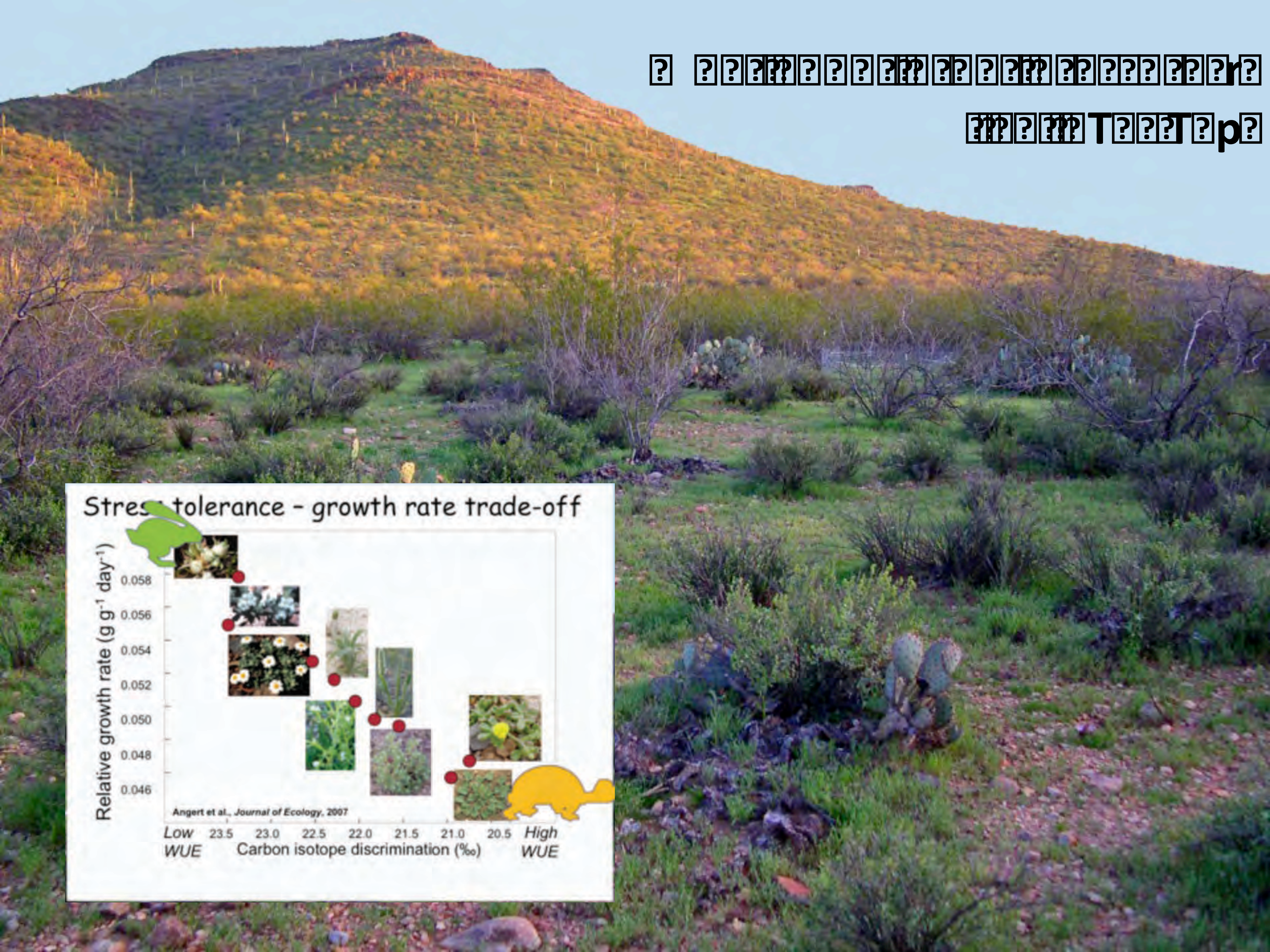


Stress tolerant





Rapid growth rates



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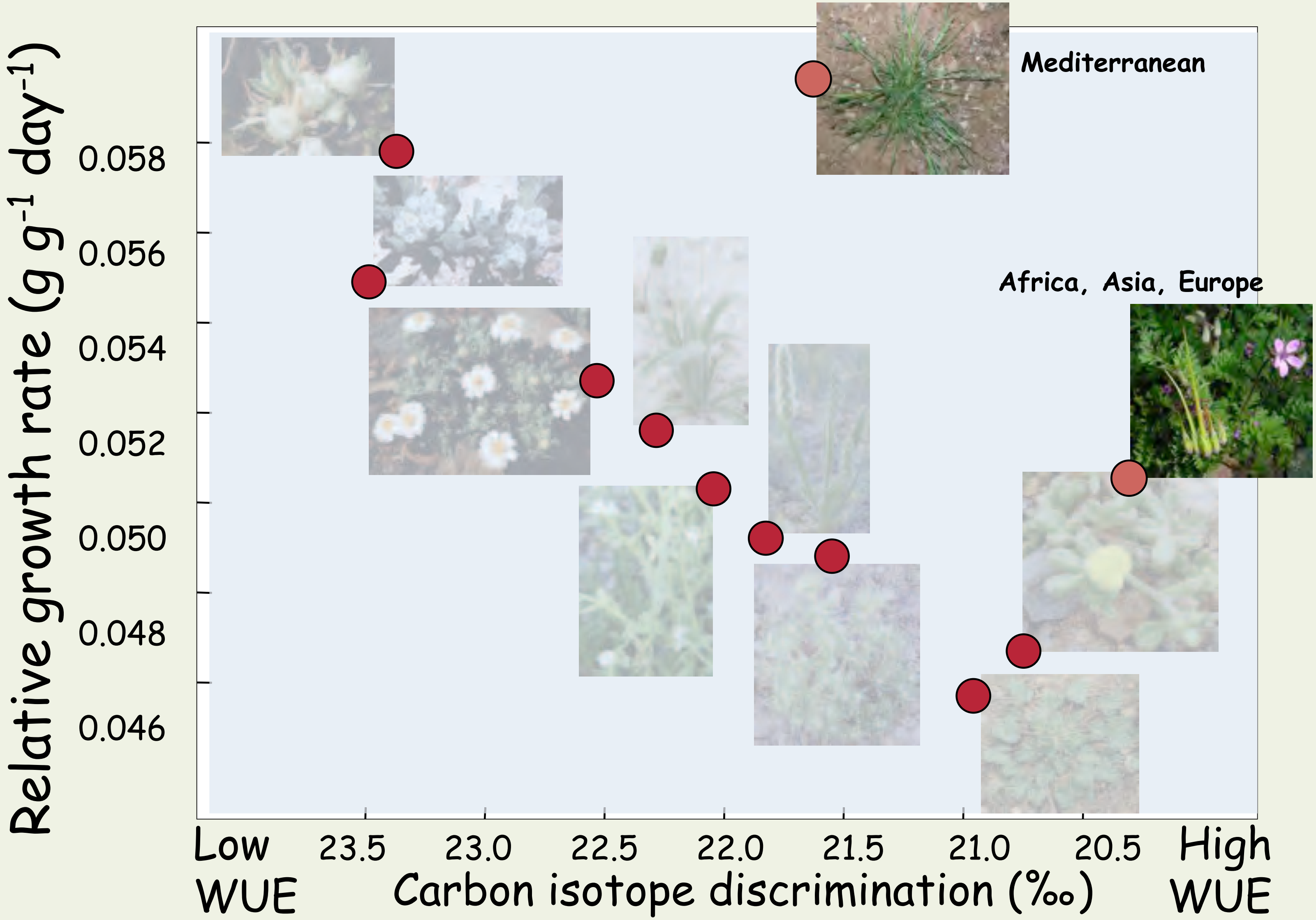
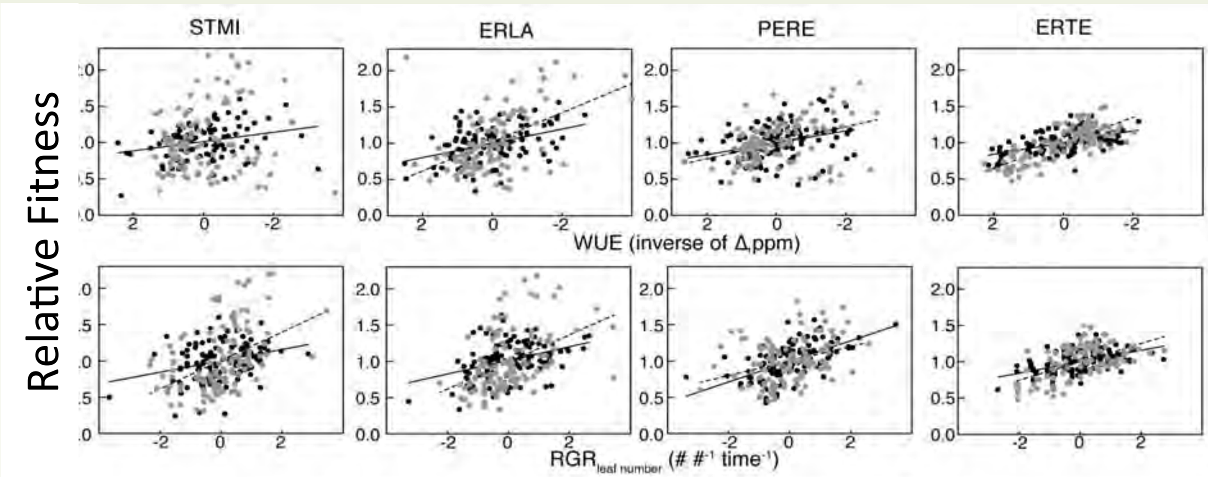
Invasive species and the trade-off?

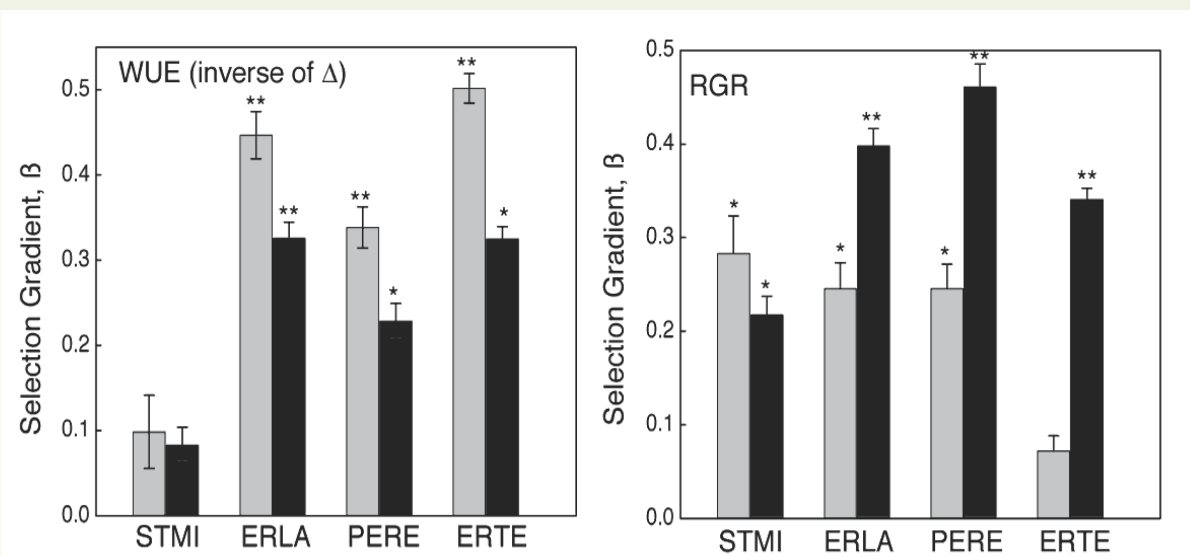


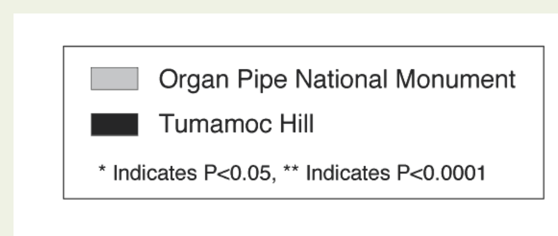
Evolution of the missing phenotype – existing strong selection on RGR and WUE



Apparent selection at each site on most traits

Greater selection on WUE at the 'dry' site; greater selection on RGR at the 'wet' site





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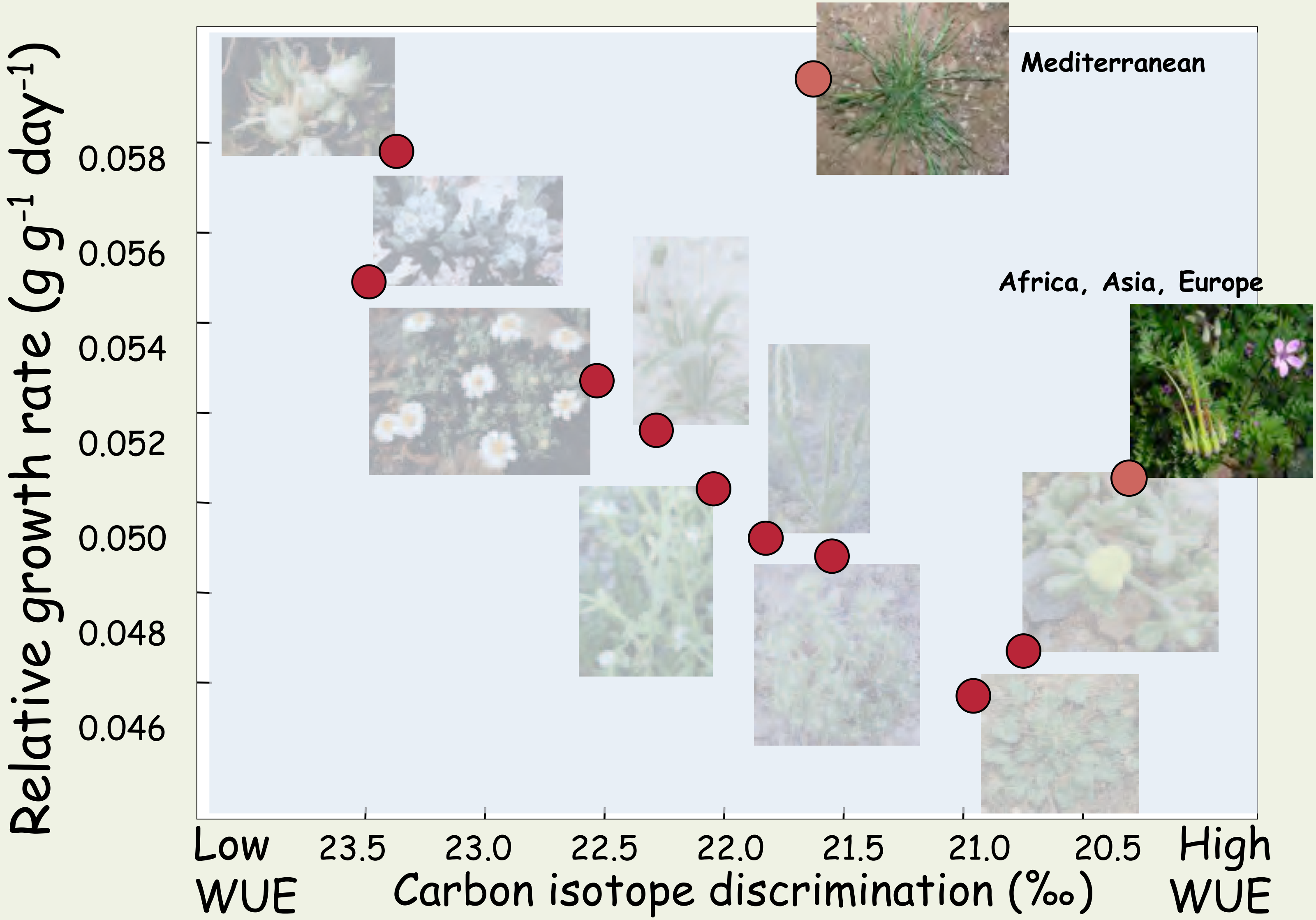
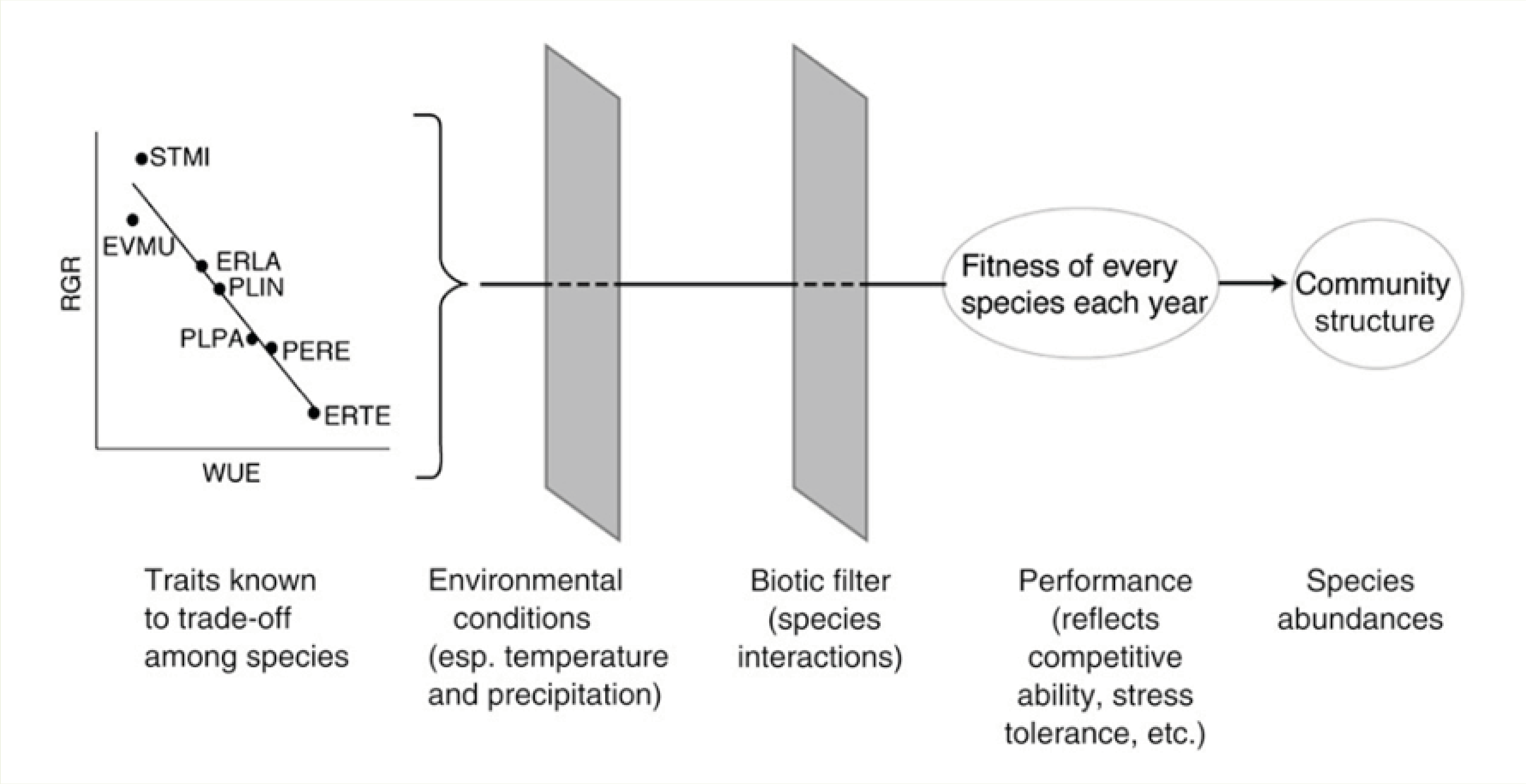
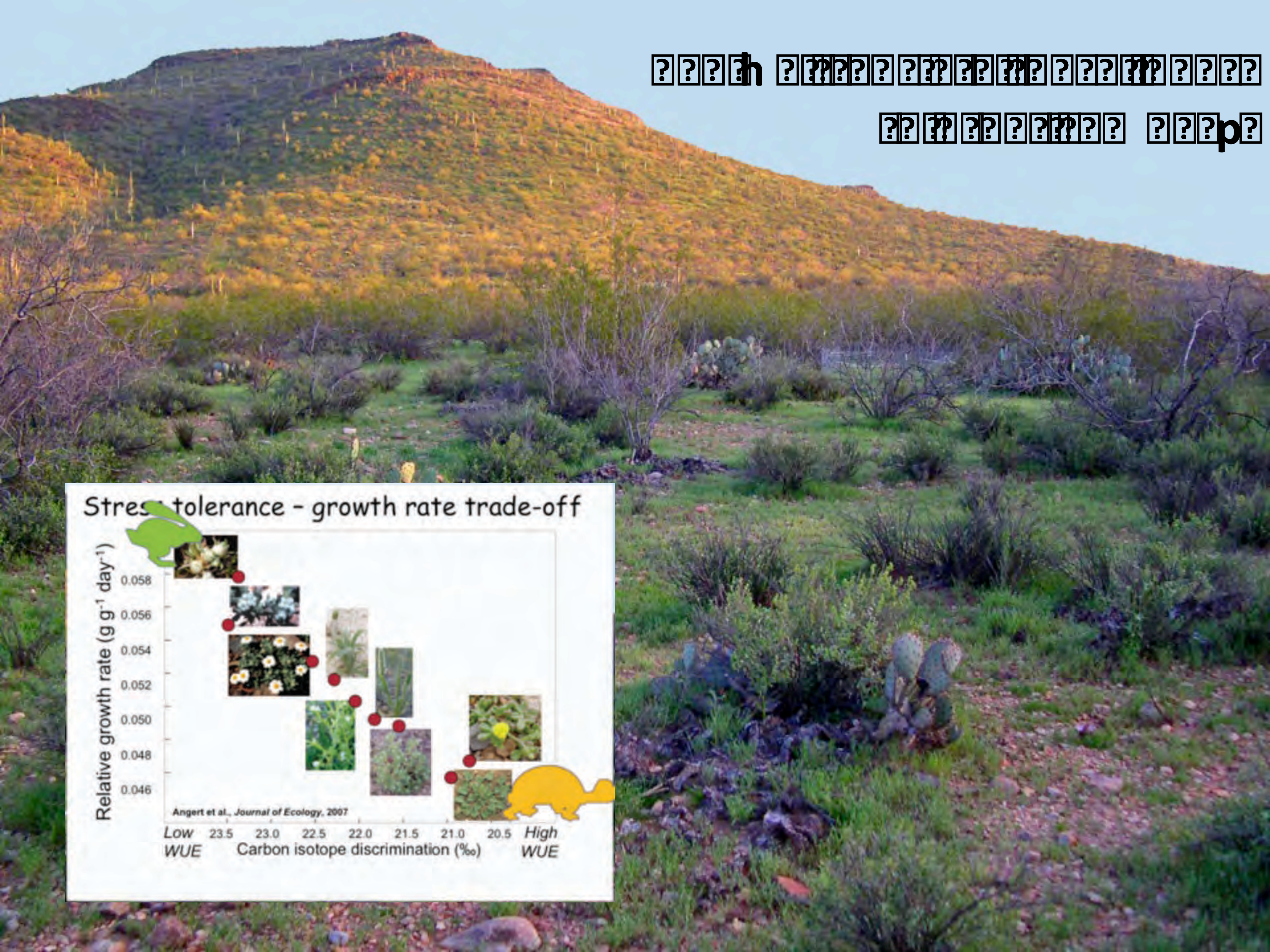


A trait-based approach to predicting community dynamics



Insight into:

- bet-hedging strategies in the different phases of the life cycle
- complex coupling with climate resulting in surprises
- invasiveness resulting from advantages of the missing phenotype and novel climate opportunities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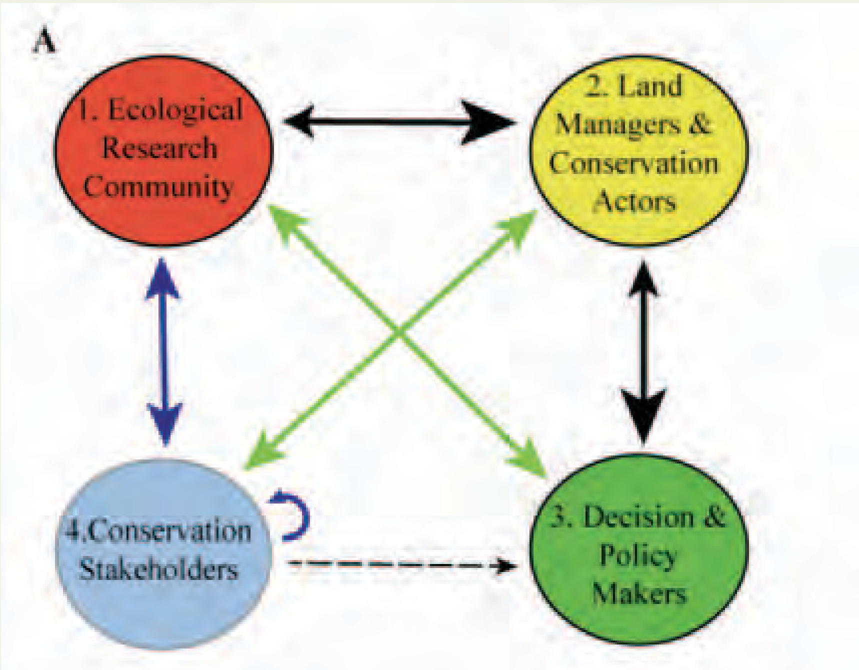
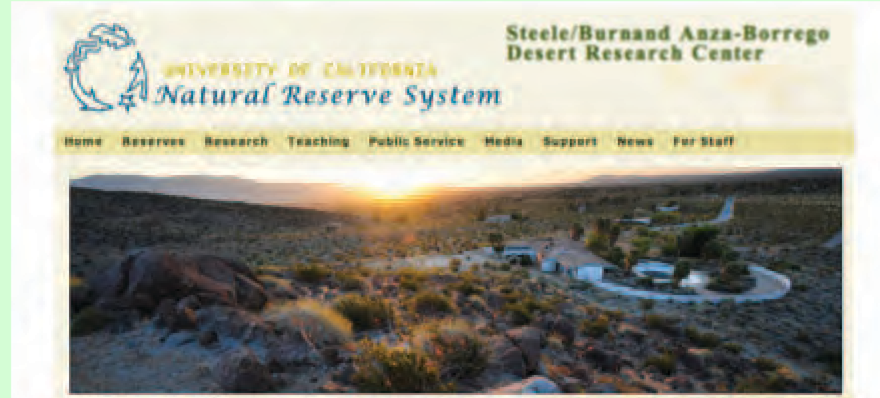

A
1. Ecological Research Community
2. Land Managers & Conservation Actors
3. Decision & Policy Makers
4.Conservation Stakeholders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UNIVERSITY OF CALIFORNIA
Natural Reserve System
Home Reserves Research Teaching Public Service Media Support News For Staff


ANZA BORREGO FOUNDATION
CALIFORNIA STATE PARKS

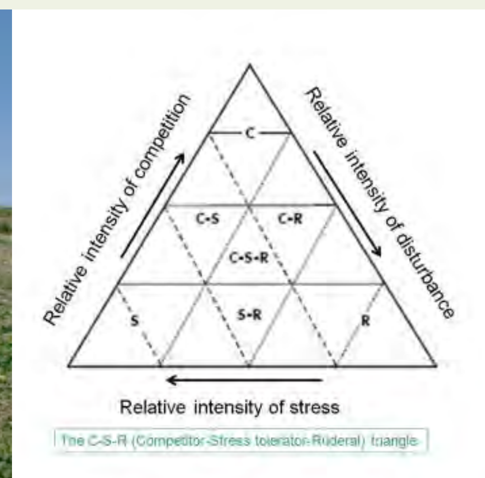

ECOLOGICAL DATA PORTAL

Using Plant Traits to Understand Invasiveness in Restoration

Center for Environmental Biology
School of Biological Sciences
University of California • Irvine

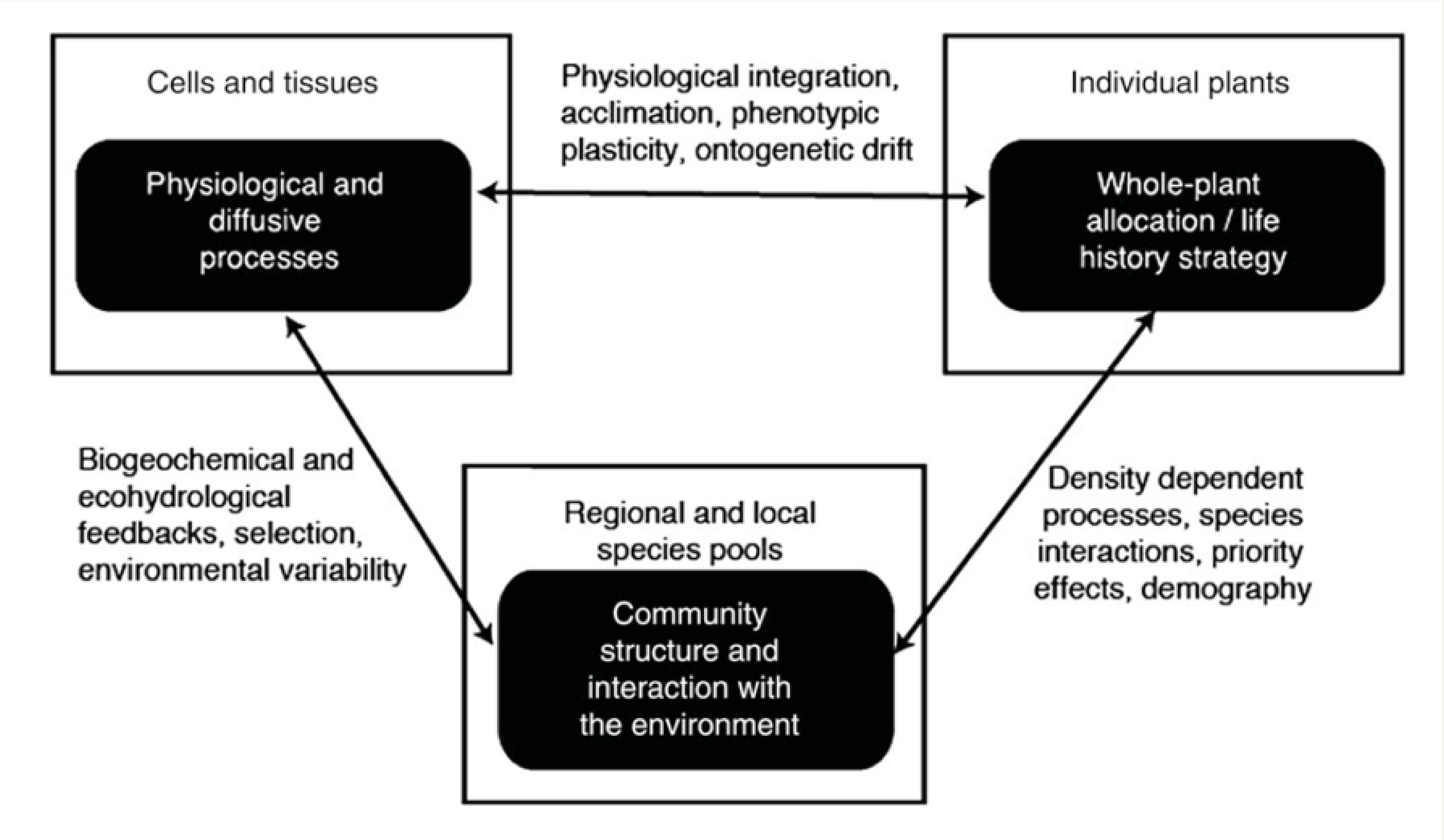
Irvine Ranch Conservancy

Sarah Kimball, Jennifer Funk, Jutta Burger, Megan Lulow
(& a growing list of UCI affiliated folks)



The C-S-R (Competitor-Stress tolerator-Ruderal) triangle

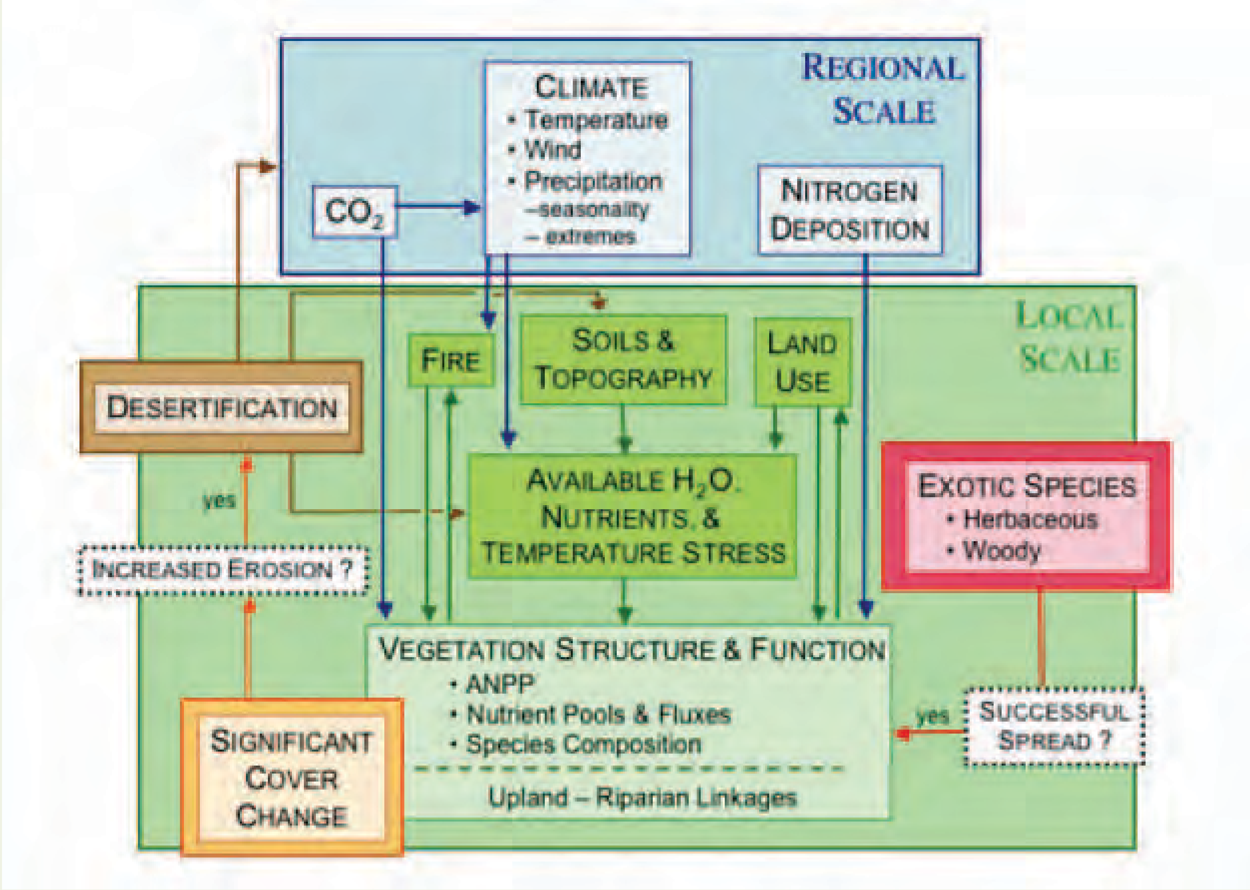
This has all influenced how we think about traits…



Huxman et al., (2013) Am. J. Botany

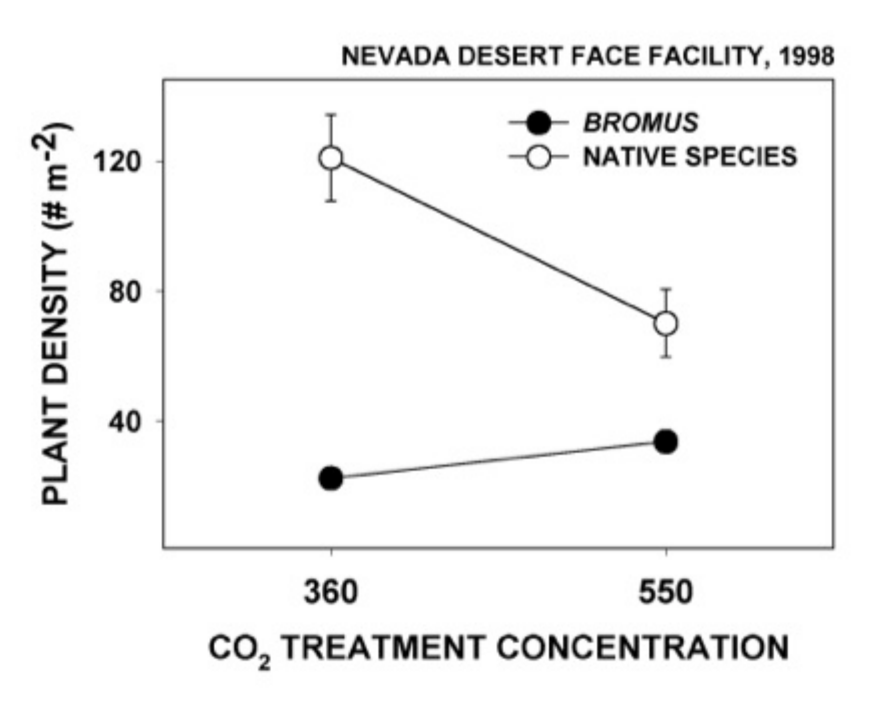
Big ecological questions – towards prediction

- How does organismal function lead to population / community processes?
- What is the role of ecology versus evolution?
- What maintains species diversity?
- What is the role of climate?



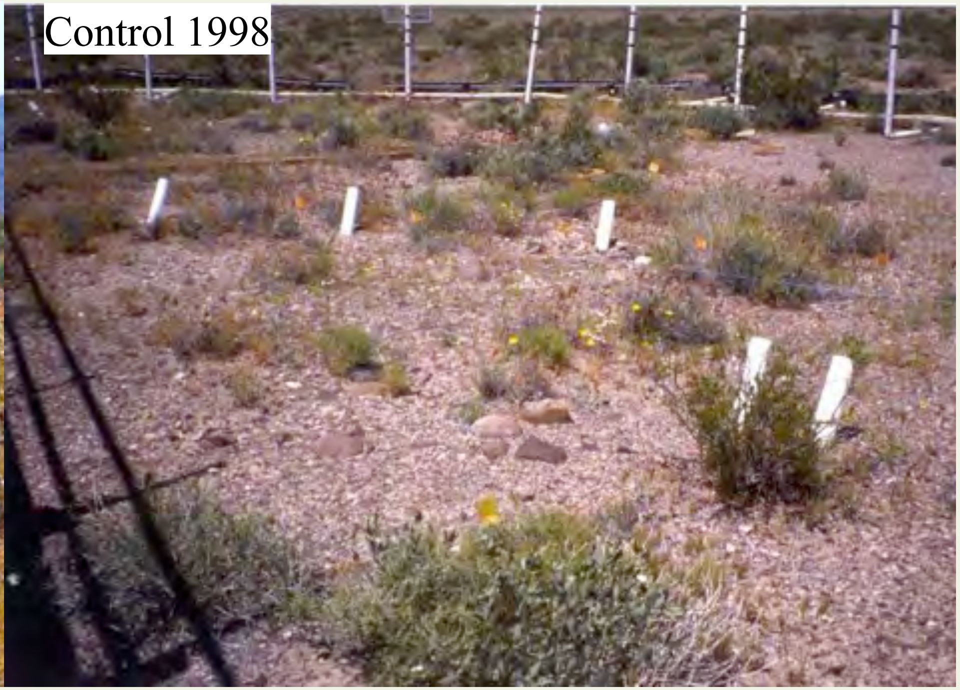
"Proliferation of non-native annual and perennial grass will predispose sites to fire resulting in a loss of native woody plants and charismatic macroflora. Low elevation arid ecosystems will henceforth experience climate-fire synchronization where none previously existed. The climate-driven dynamics of the fire cycle is likely to become the single most important feature controlling future plant distributions in U.S. arid lands."

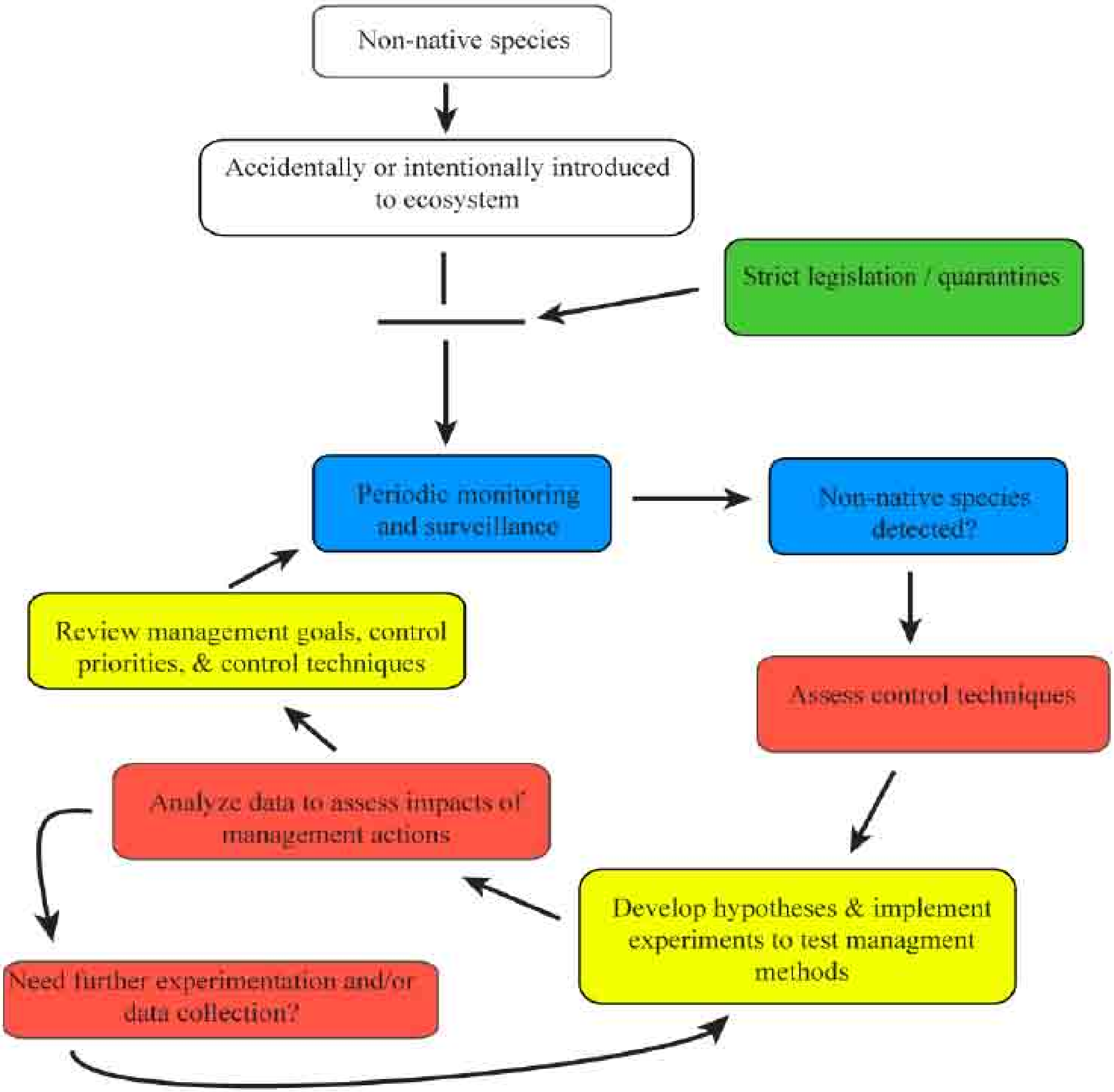
[illegible]



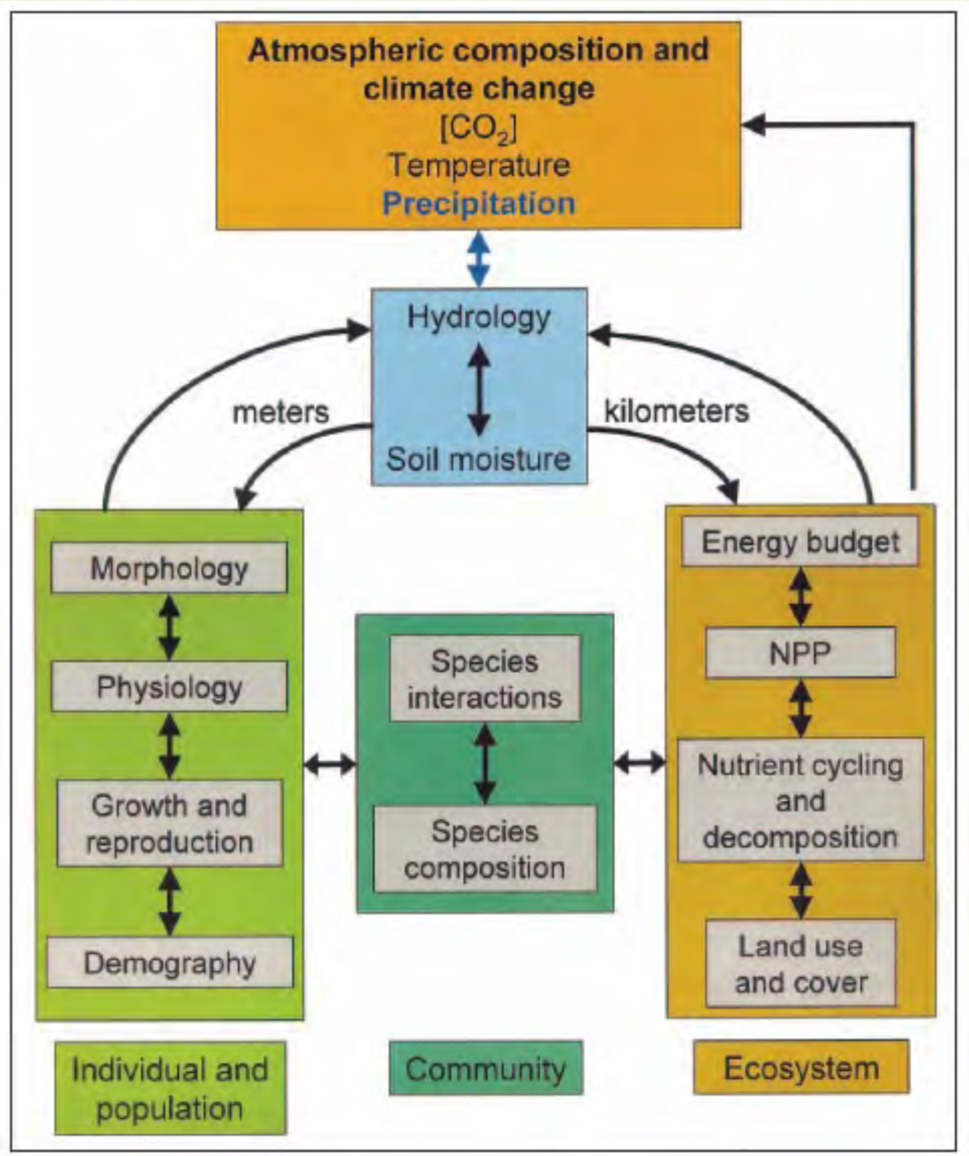
Red Brome (non-native grass) is a prolific invader in the western U.S.

Rising CO_2 dramatically increases it's relative abundance



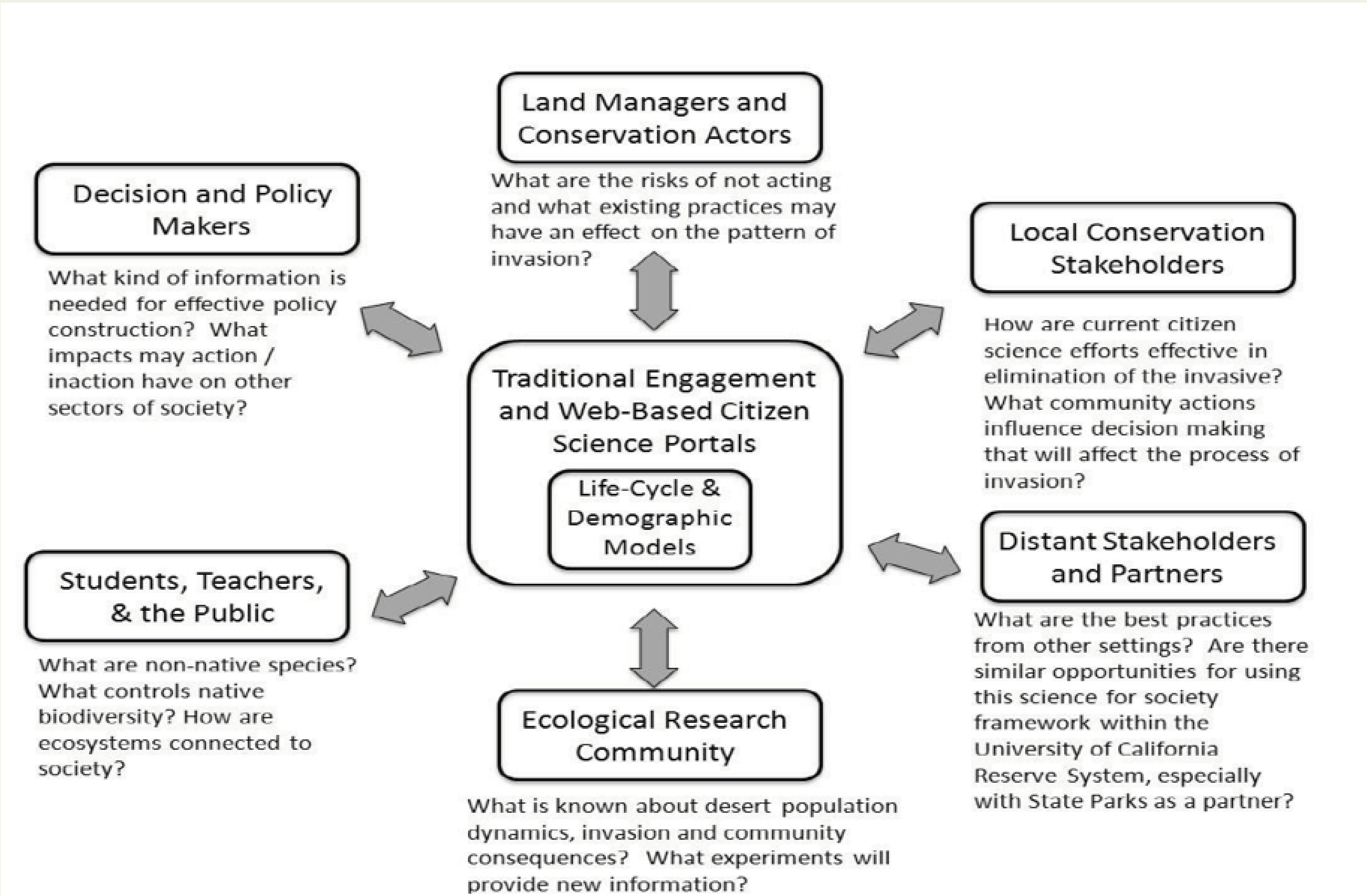

Non-native species
Accidentally or intentionally introduced to ecosystem
Strict legislation / quarantines
Periodic monitoring and surveillance
Non-native species detected?
Assess control techniques
Develop hypotheses & implement experiments to test managment methods
Analyze data to assess impacts of management actions
Review management goals, control priorities, & control techniques
Need further experimentation and/or data collection?

Why focus on water balance and response to water availability?



Integrating nature of landscape water balance with respect to understanding challenges

Weltzin et al., (2001) *BioScience*


Land Managers and Conservation Actors
What are the risks of not acting and what existing practices may have an effect on the pattern of invasion?
Decision and Policy Makers
What kind of information is needed for effective policy construction? What impacts may action / inaction have on other sectors of society?
Local Conservation Stakeholders
How are current citizen science efforts effective in elimination of the invasive? What community actions influence decision making that will affect the process of invasion?
Traditional Engagement and Web-Based Citizen Science Portals
Life-Cycle & Demographic Models
Students, Teachers, & the Public
What are non-native species? What controls native biodiversity? How are ecosystems connected to society?
Distant Stakeholders and Partners
What are the best practices from other settings? Are there similar opportunities for using this science for society framework within the University of California Reserve System, especially with State Parks as a partner?
Ecological Research Community
What is known about desert population dynamics, invasion and community consequences? What experiments will provide new information?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Functional ecology of desert annuals

- Driven by a stress tolerance-growth rate trade-off
- Affected by bet-hedging strategies in the different phases of the life cycle
- Complex coupling with climate resulting in surprises
- Invasiveness resulting from advantages of the missing phenotype and recent climate change

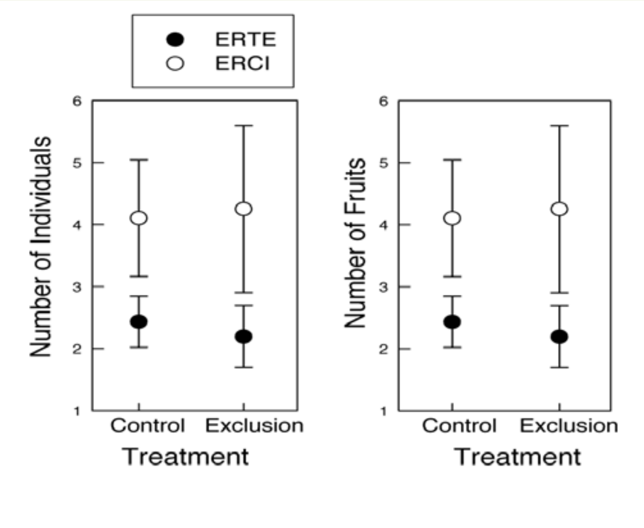
Understanding how traits control the assembly of communities to inform decision making

CENTER FOR ENVIRONMENTAL BIOLOGY
SCHOOL OF BIOLOGICAL SCIENCES
UNIVERSITY of CALIFORNIA • IRVINE

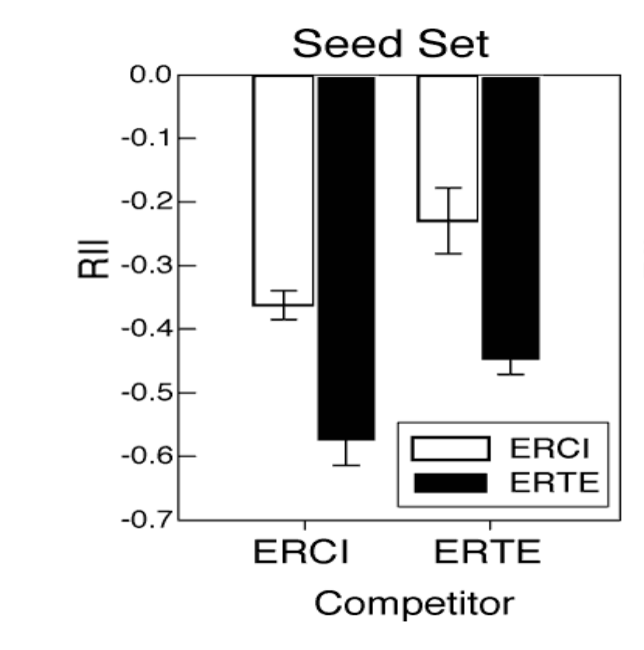
IRVINE RANCH
CONSERVANCY

Sarah Kimball (&a growing laundry list of UCI affiliated folks) in collaboration with Megan Lulow (& the IRC's research staff)

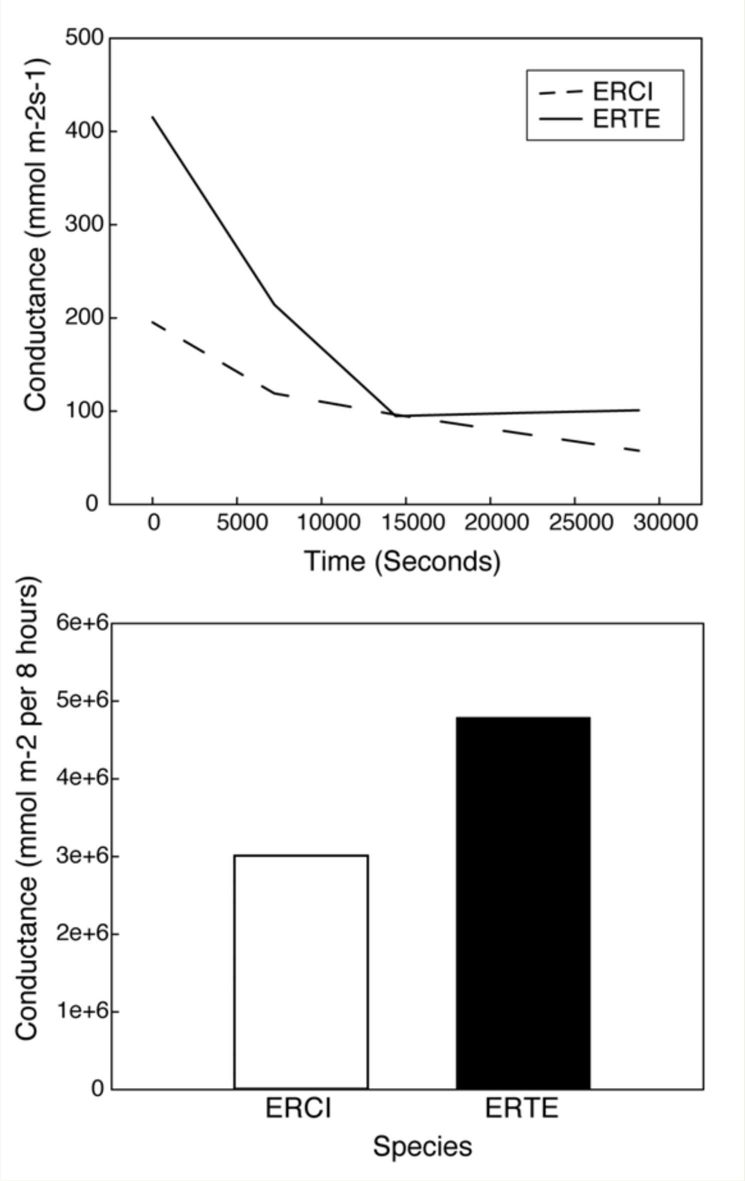
Escape from herbivory doesn't seem to explain the invasiveness



ERCI simply sees to be a better competitor (more effectively reduces resource levels)



ERCI has higher intrinsic water use efficiency across many conditions, but also achieves greater biomass during a season….likely from a different allocation scheme?



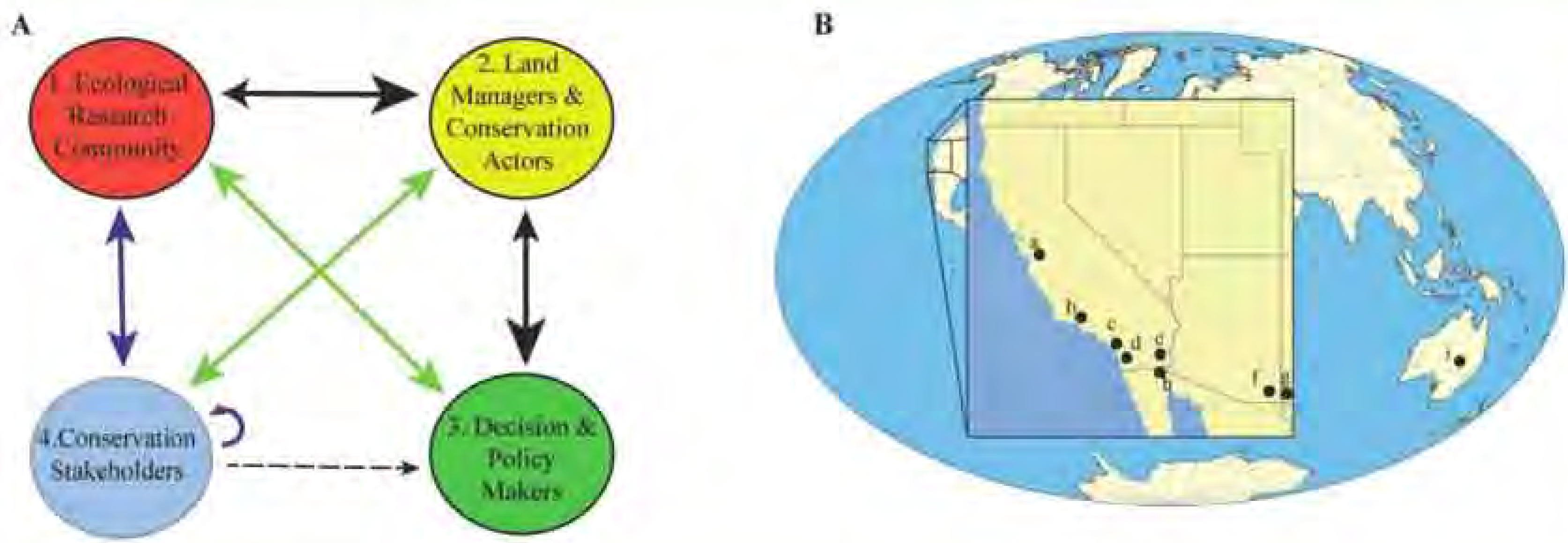
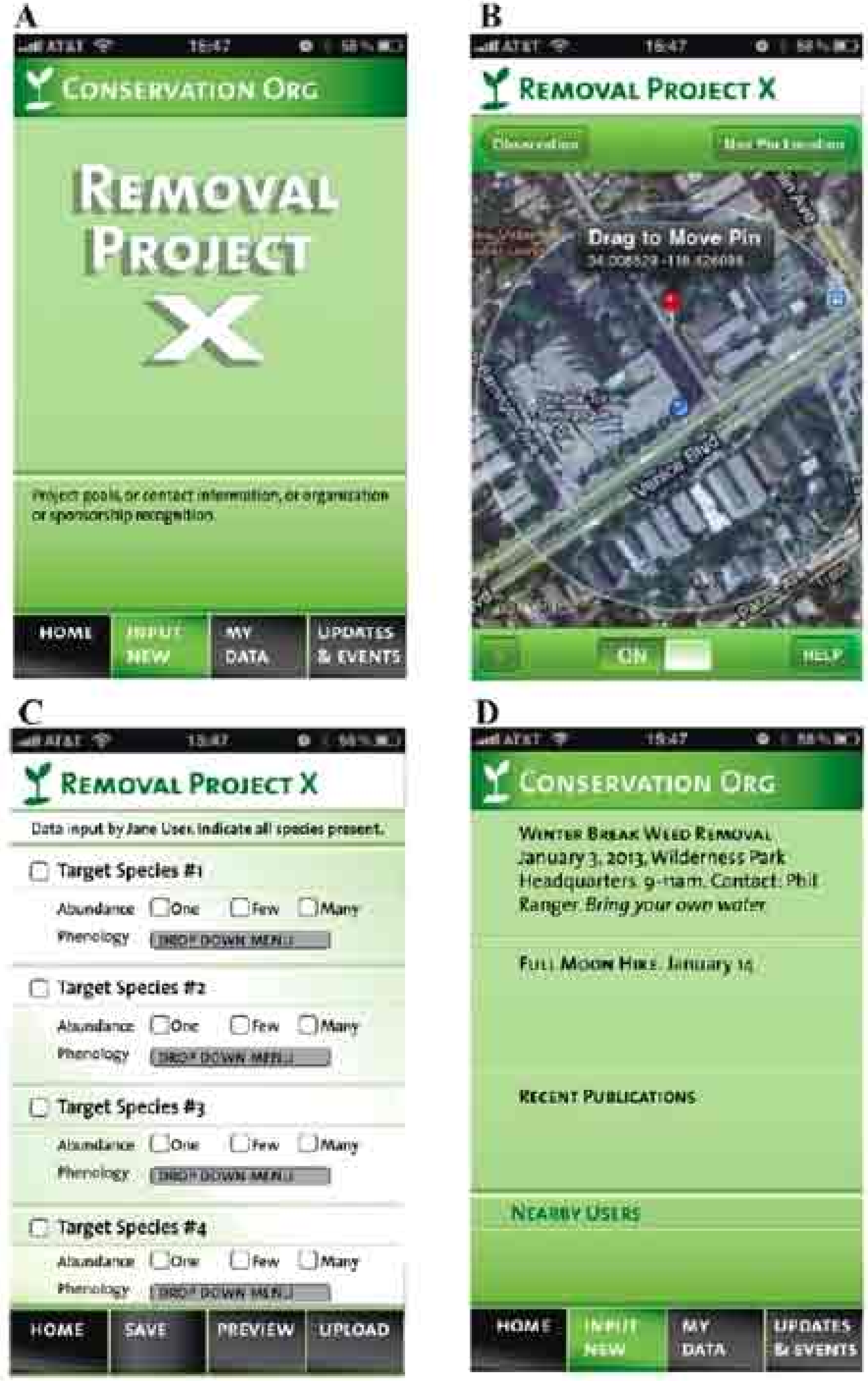
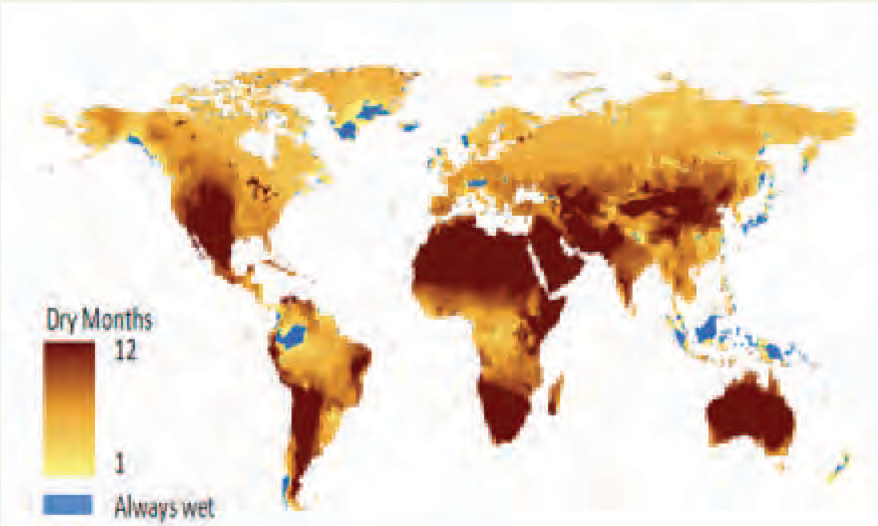


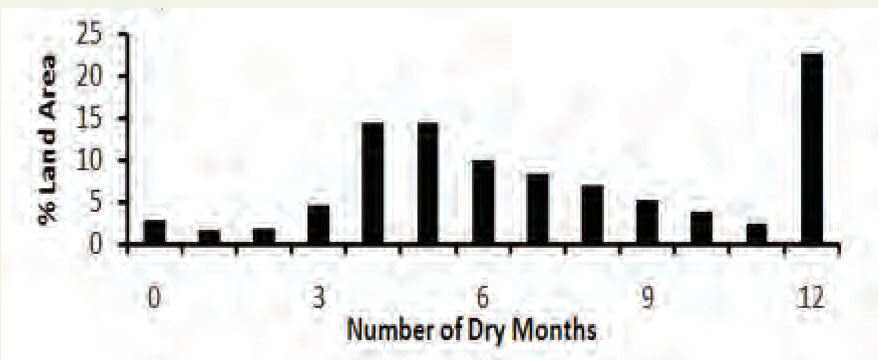
Table 1. Partial list of citizen science apps and types of data currently being collected. Each have exceptional potential, but are focused in design. How to best coordinate data collection across settings is our interest.

Name of App	Type of data	URL
Project Budburst	phenology	budburst.org
Nature's Notebook	phenology	usanpn.org/natures_notebook
MeteorCounter	location and brightness of meteors	meteorcounter.com
CreekWatch	water level and trash in creeks	creekwatch.researchlabs.ibm.com/
eBird	bird identity and location	ebird.org
SplatterSpotter	location and identity of roadkill	roadkill.csuci.edu
WildObs	animal identity and location	wildobs.com
What's Invasive	identify and map invasive species	whatsinvasive.com
Project Noah	identify and map wildlife	projectnoah.org
iNaturalist	documents all naturalist observations	inaturalist.org

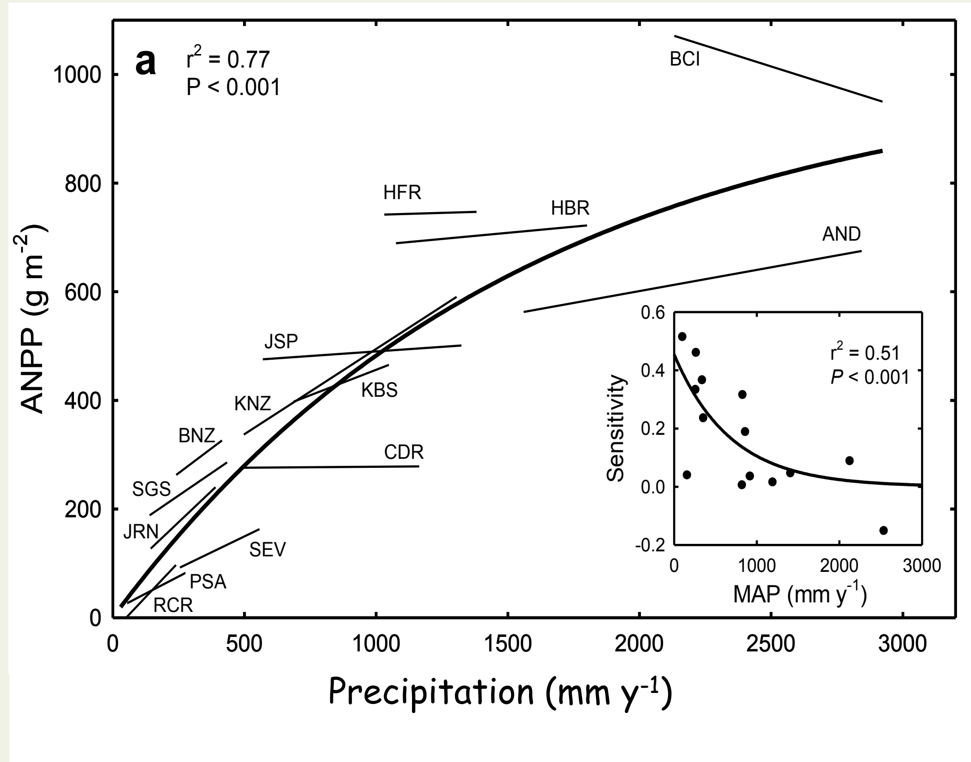

A
Conservation Org
Removal Project X
Project goals, or contact information, or organization or sponsorship recognition
HOME
INPUT NEW
MY DATA
UPDATES & EVENTS
B
Removal Project X
Drag to Move Pin
ON
HELP
C
Removal Project X
Data input by Jane User. Indicate all species present.
Target Species #1
Abundance One Few Many
Phenology DROP DOWN MENU
Target Species #2
Abundance One Few Many
Phenology DROP DOWN MENU
Target Species #3
Abundance One Few Many
Phenology DROP DOWN MENU
Target Species #4
Abundance One Few Many
Phenology DROP DOWN MENU
HOME
SAVE
PREVIEW
UPLOAD
D
Conservation Org
Winter Break Weed Removal January 3, 2013, Wilderness Park Headquarters. 9-11am. Contact: Phil Ranger. Bring your own water
Full Moon Hike. January 14
Recent Publications
Nearby Users
HOME
INPUT NEW
MY DATA
UPDATES & EVENTS

Why focus on water balance and response to water availability?



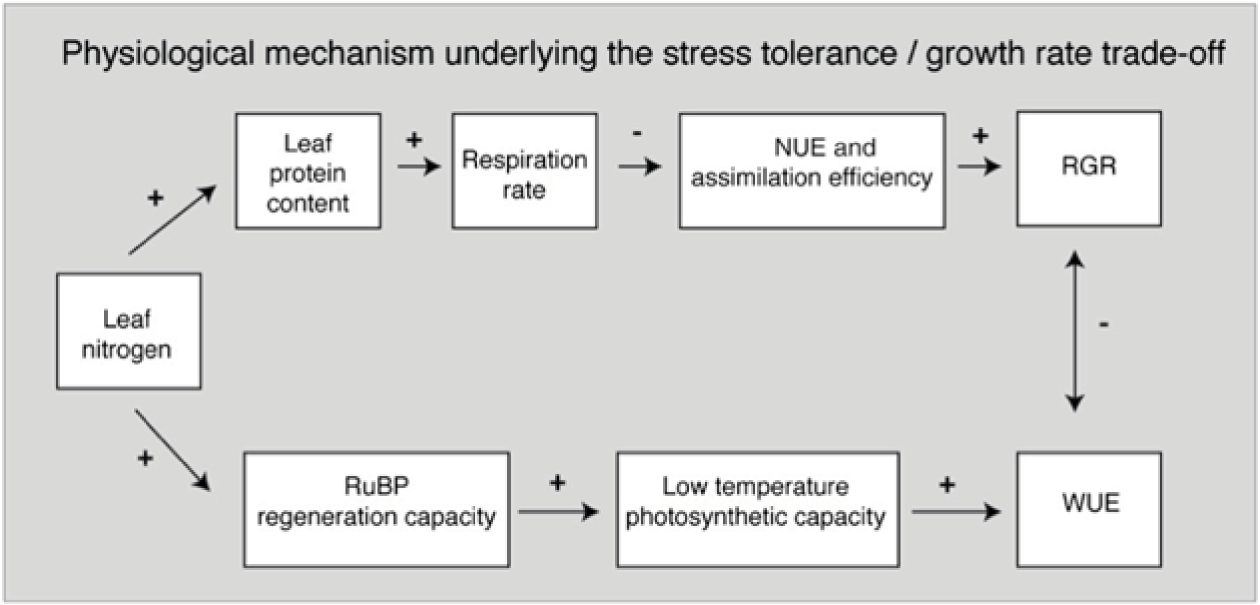


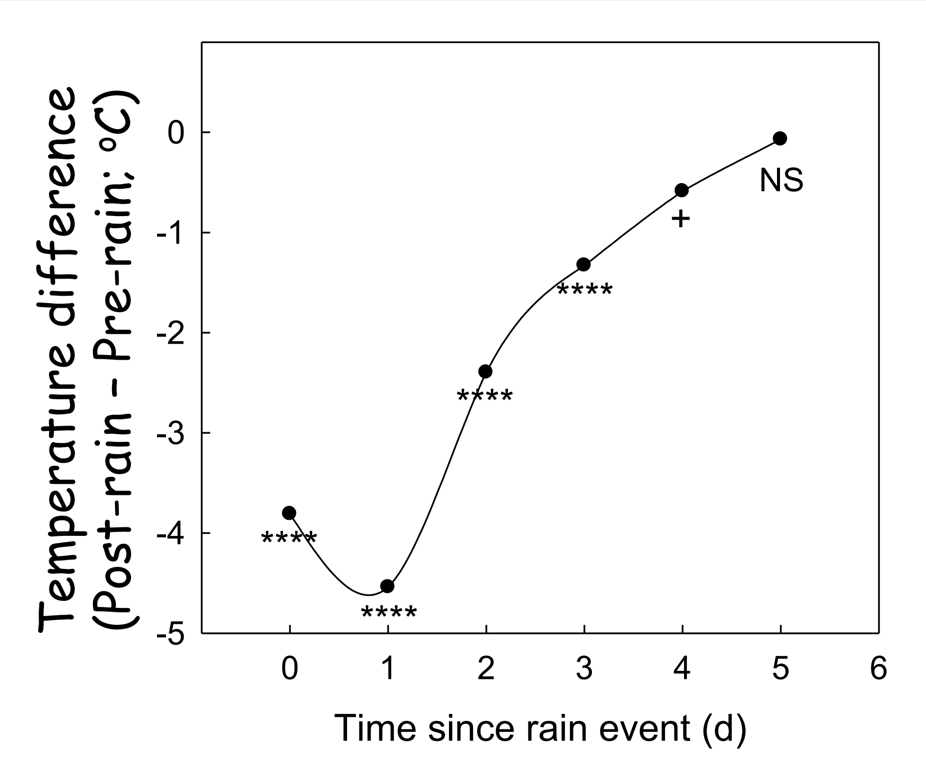
Jenerette et al. Ecohydrology. In press



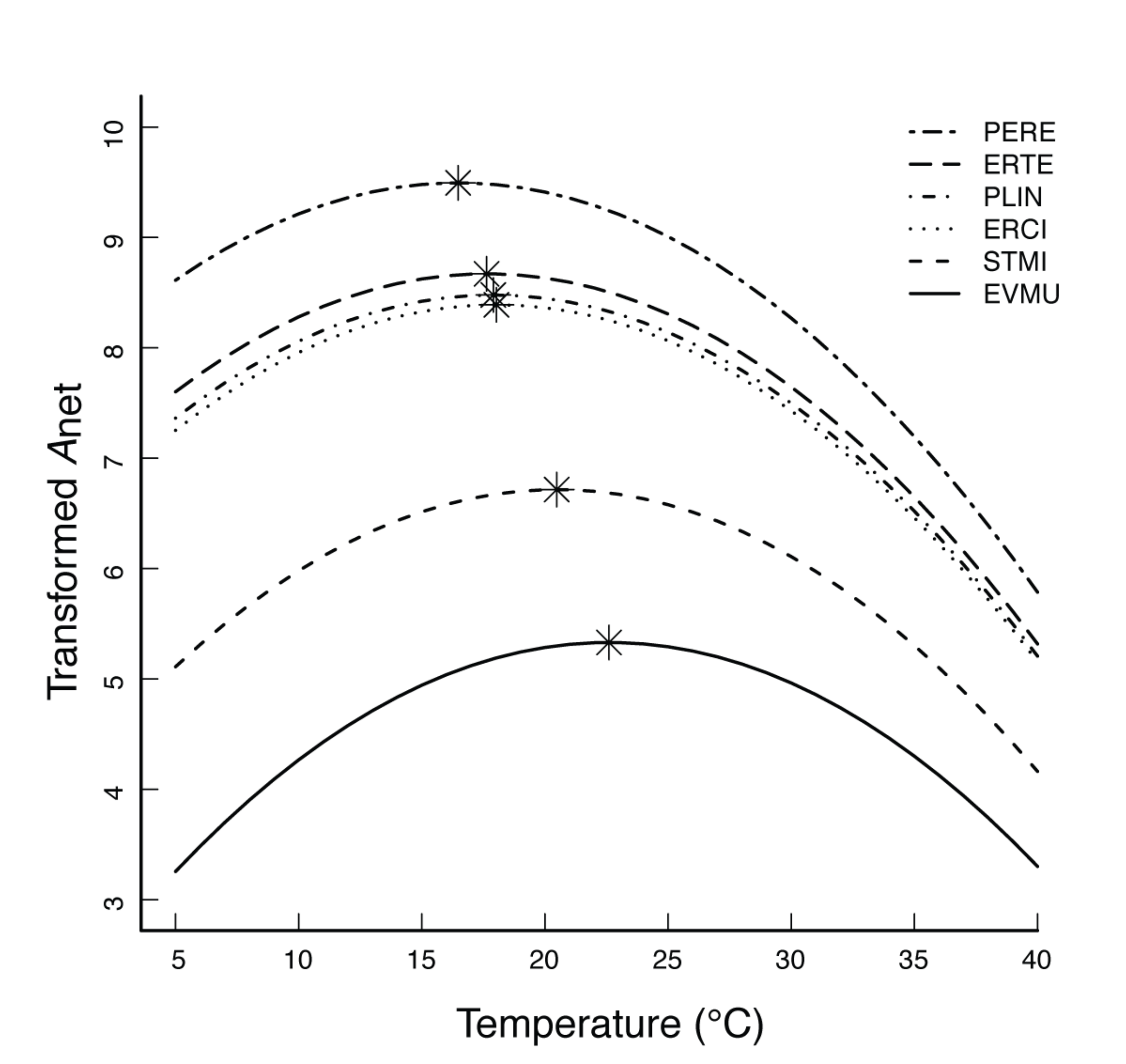
Huxman et al., (2004) Nature

Water limitation is a common phenomena across nearly all terrestrial biome types


Physiological mechanism underlying the stress tolerance / growth rate trade-off
Leaf nitrogen
Leaf protein content
Respiration rate
NUE and assimilation efficiency
RGR
RuBP regeneration capacity
Low temperature photosynthetic capacity
WUE
+
-


Temperature difference (Post-rain – Pre-rain; °C)
Time since rain event (d)
0
-1
-2
-3
-4
-5
0
1
2
3
4
5
6
****
+
NS

Photosynthetic response to temperature

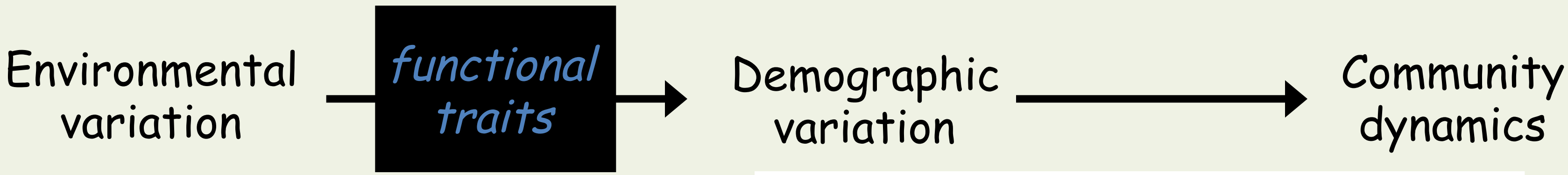


Temperature optima differs by species identity.

High WUE species have relatively higher photosynthesis rates and cooler temperature optima.

(remember the LAR, NAR and J_{max} patterns)

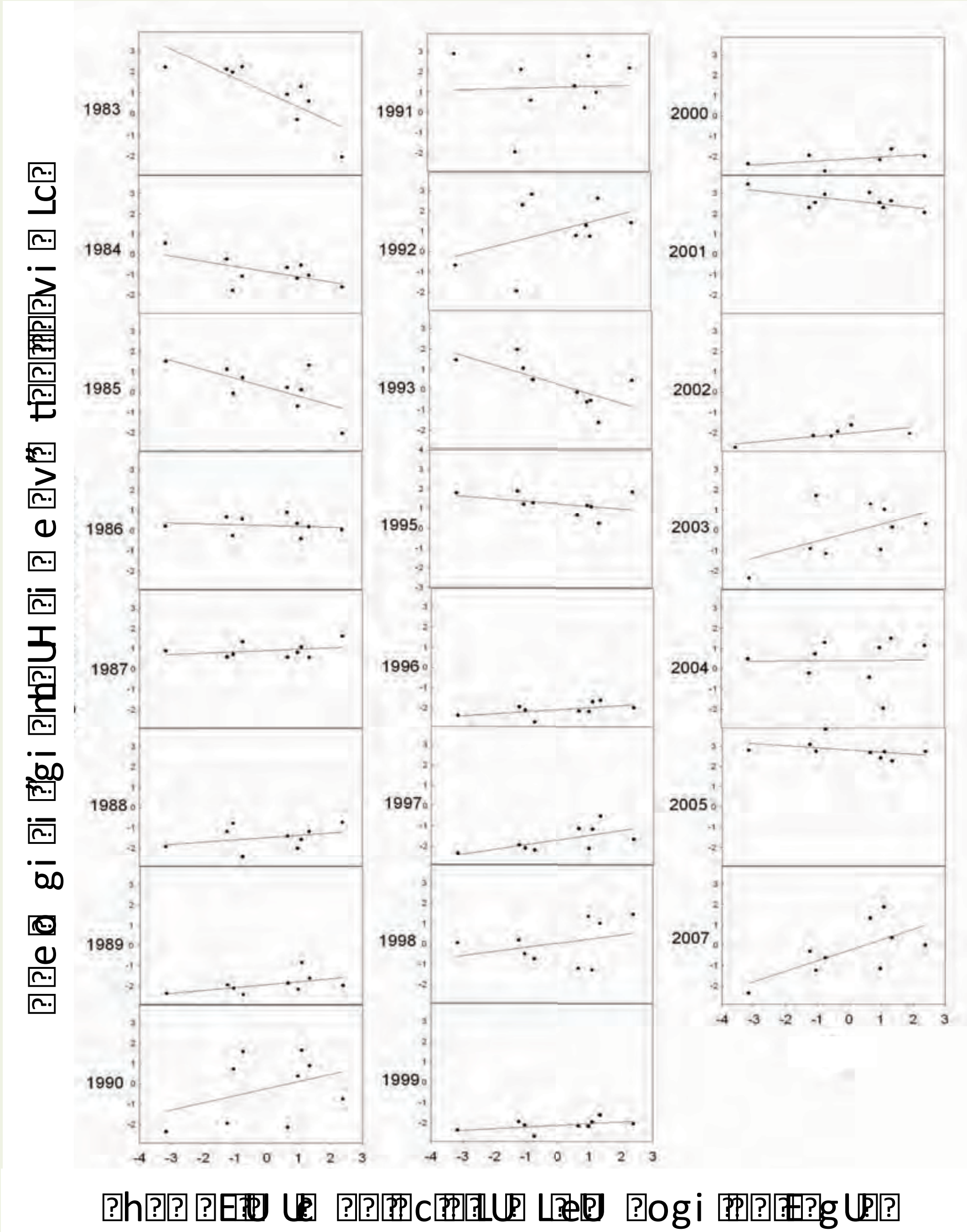
Why do species respond differently to the same environmental variation?



- Using principle component analysis to understand trait variation
- Condense the variation to a single PC score
- Create difference matrix

Table 1. Trait loadings, species scores, and percent variation explained by the first principal component of variation (PC I) in functional traits

PC I results	Species or trait	Analysis 1
Trait loading		
	Δ	0.9914
	RGR	0.9914
Species score	*ERCI*	−1.3221
	ERLA	0.6663
	ERTE	−1.7816
	EVMU	1.7764
	LOHU	−1.7539
	PEHE	−0.1351
	PERE	−0.7760
	PLIN	0.2810
	PLPA	−0.4976
	SCBA	1.3805
	STMI	2.2205
Variation explained		98%


1983
1984
1985
1986
1987
1988
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1995
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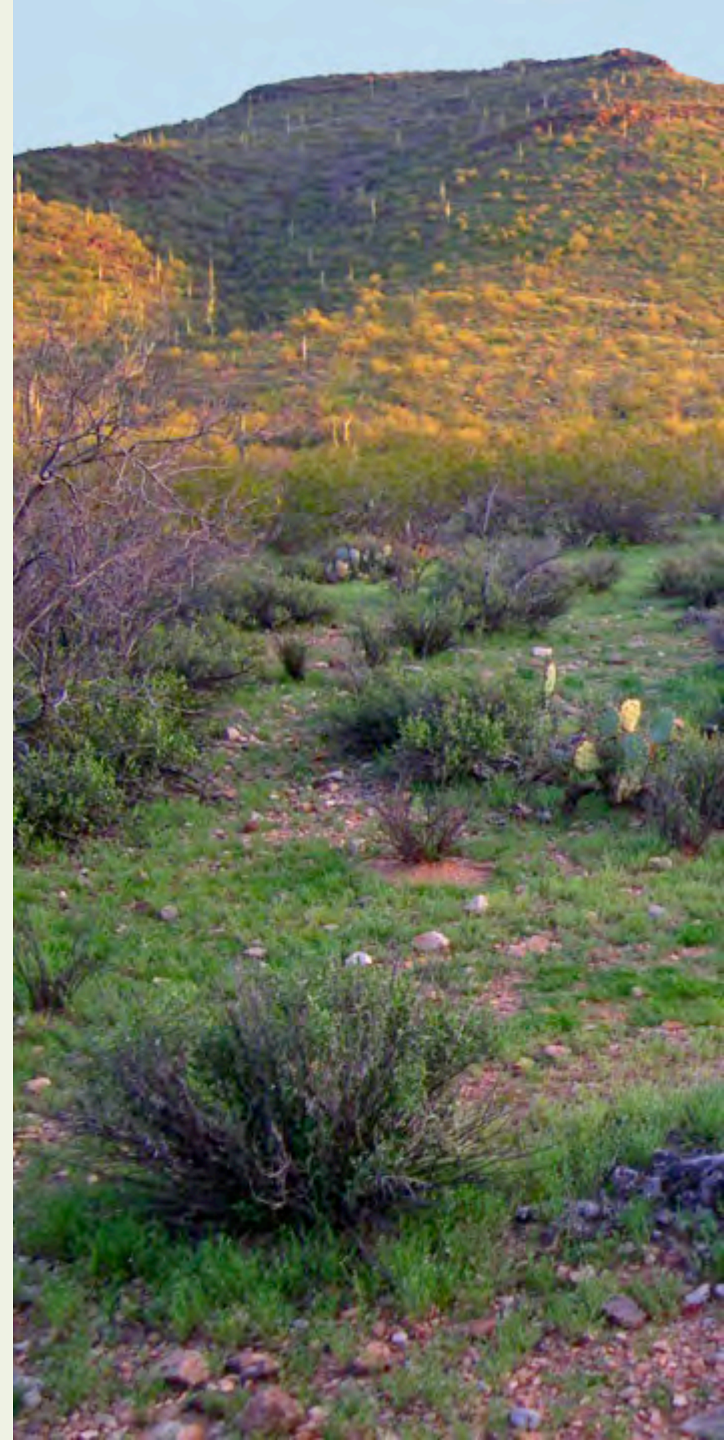
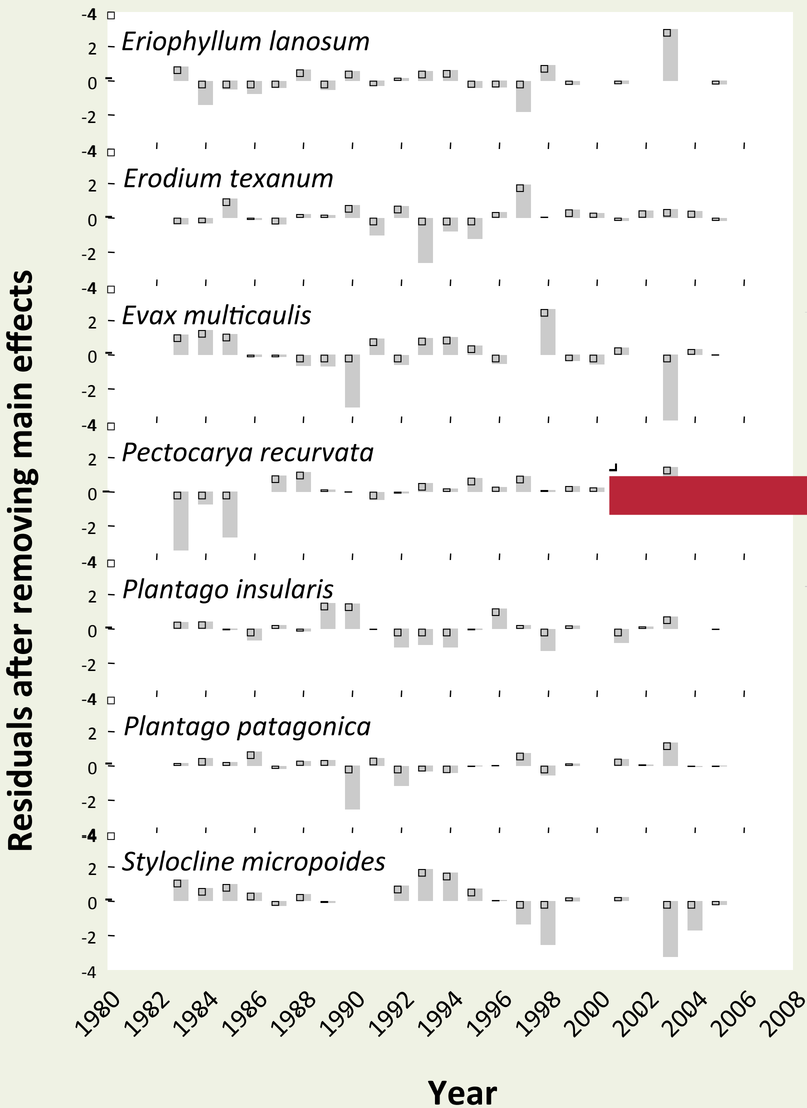
1998
1999
2000
2001
2002
2003
2004
2005
2007
-4 -3 -2 -1 0 1 2 3



Decomposing the species x year interaction



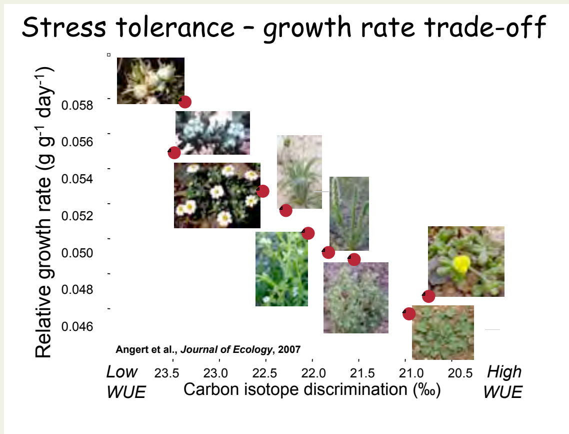
Differences in response to yearly variation

	ERLA	ERTE	EVMU	PERE	PLIN	PLPA	STMI
ERLA	0	21.18	24.37	20.48	21.62	21.25	22.08
ERTE	21.18	0	30.03	22.00	17.64	19.03	25.94
EVMU	24.37	30.03	0	32.30	29.37	20.81	16.13
PERE	20.48	22.00	32.30	0	23.46	19.58	28.31
PLIN	21.62	17.64	29.37	23.46	0	14.39	21.23
PLPA	21.25	19.03	20.81	19.58	14.39	0	21.23
STMI	22.08	25.94	16.13	28.31	21.23	21.23	0

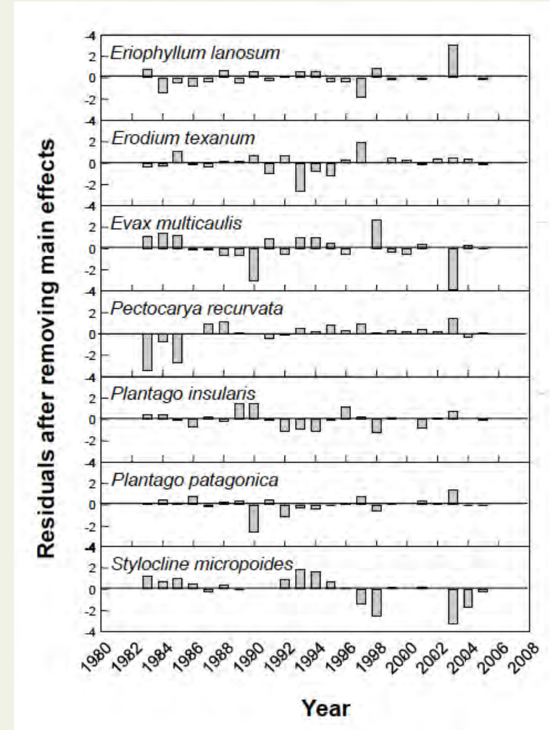
These differences highlight how species are decoupled in their environmental response – prerequisite for coexistence

Structure of trait combinations in species promotes coexistence in this variable environment – evolutionary and ecological linkages

Differences in position along RGR-WUE trade-off axis



Response differences to yearly variation



	ERLA	ERTE	EVMU	PERE	PLIN	PLPA	STMI
ERLA	0	2.45	1.11	1.44	0.39	1.16	1.55
ERTE	2.45	0	3.56	1.01	2.06	1.28	4.00
EVMU	1.11	3.56	0	2.55	1.50	2.27	0.44
PERE	1.44	1.01	2.55	0	1.06	0.28	3.00
PLIN	0.39	2.06	1.50	1.06	0	0.79	1.94
PLPA	1.16	1.28	2.27	0.28	0.79	0	2.72
STMI	1.55	4.00	0.44	3.00	1.94	2.72	0

	ERLA	ERTE	EVMU	PERE	PLIN	PLPA	STMI
ERLA	0	21.18	24.37	20.48	21.62	21.25	22.08
ERTE	21.18	0	30.03	22.00	17.64	19.03	25.94
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PLPA	21.25	19.03	20.81	19.58	14.39	0	21.23
STMI	22.08	25.94	16.13	28.31	21.23	21.23	0

Mantel test, P < 0.05

Angert et al., (2009) PNAS

Forrest Shreve – Plant Physiological Ecology