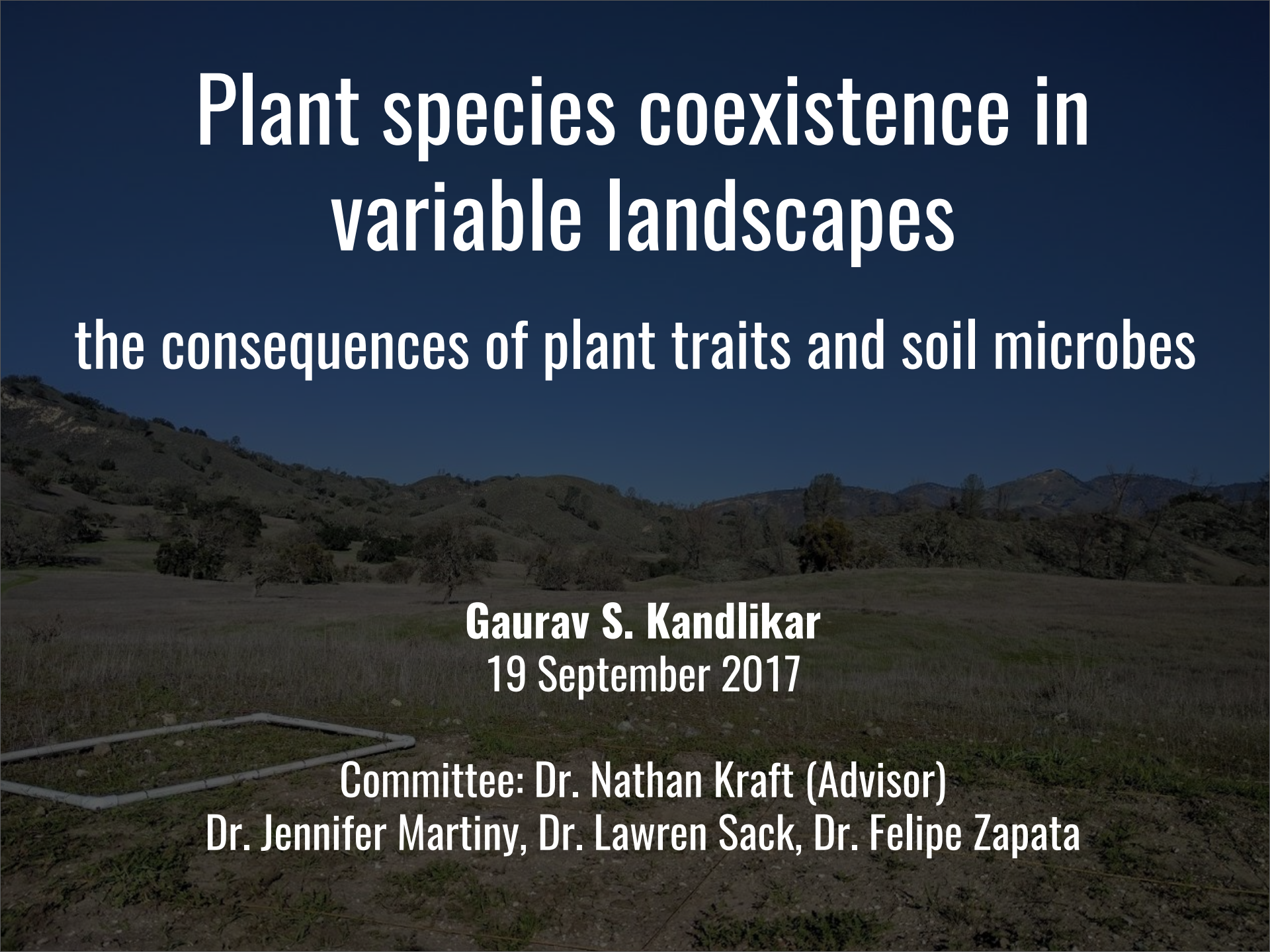
Plant species coexistence in variable landscapes

the consequences of plant traits and soil microbes



Gaurav S. Kandlikar

19 September 2017

Committee: Dr. Nathan Kraft (Advisor)
Dr. Jennifer Martiny, Dr. Lawren Sack, Dr. Felipe Zapata

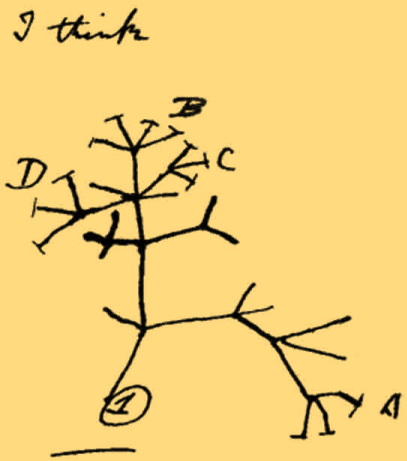
image: https://www.flickr.com/photos/rejik/
Kabani River, Kerala, India


image: https://www.flickr.com/photos/14723335@N05/

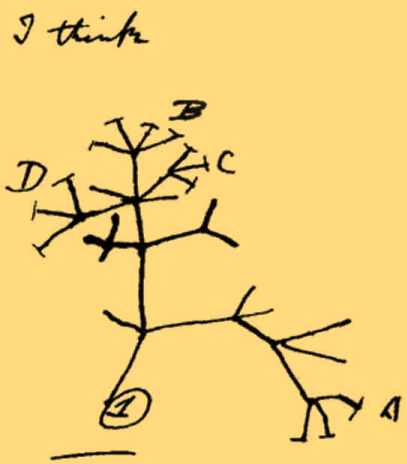

image: https://www.flickr.com/photos/14723335@N05/

Community structure is influenced by many ecological processes

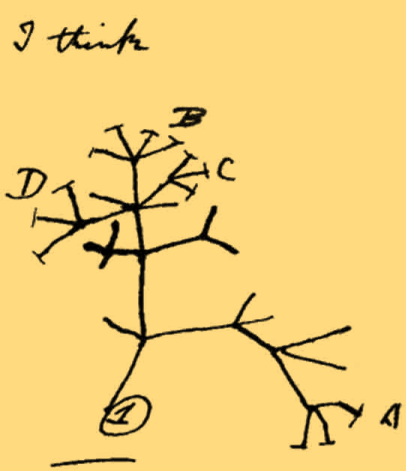
Evolution and speciation



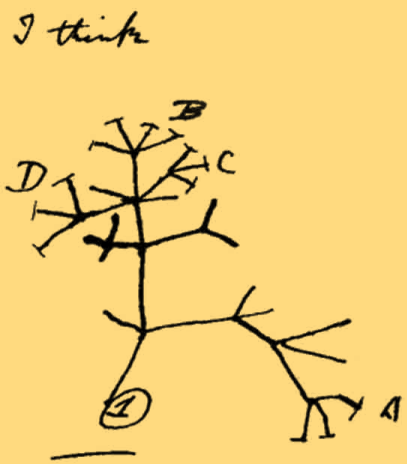
Seed dispersal



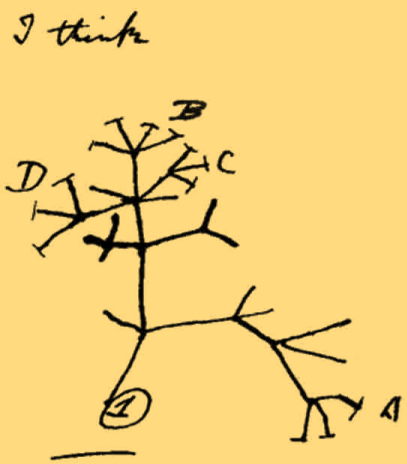
Multi-trophic interactions



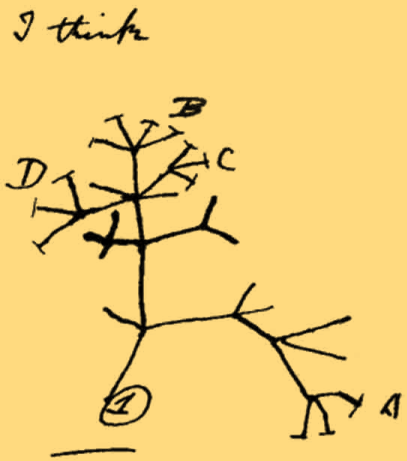
Environmental variation



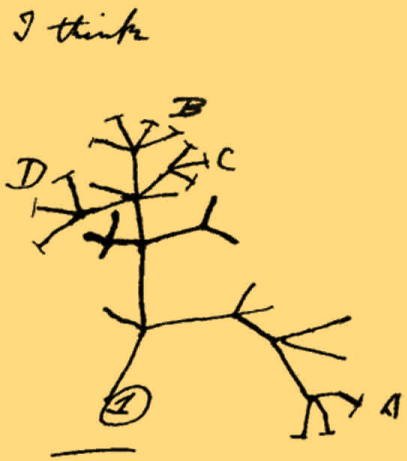
Interspecific interactions



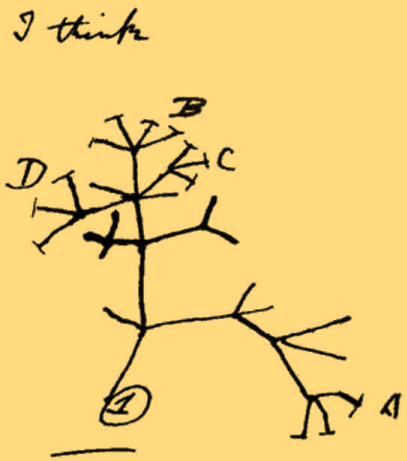
Variation between individuals



Feedbacks between plants and abiotic environment

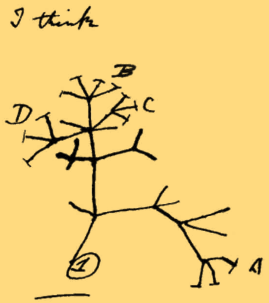


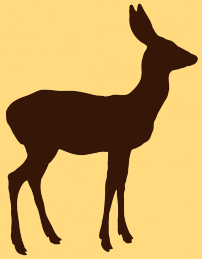
Feedbacks between plants and biotic environment



Fierer 2017 Nature Reviews

Evolution and speciation
Seed dispersal
Multi-trophic interactions
Environmental variation
Interactions between plants
Variation between individuals
Feedbacks between plants and environment





Evolution and speciation

Seed dispersal

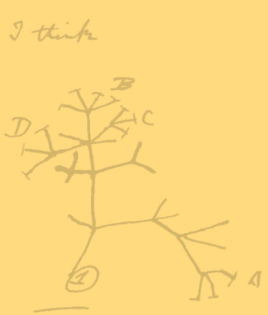
Multi-trophic interactions

Environmental variation

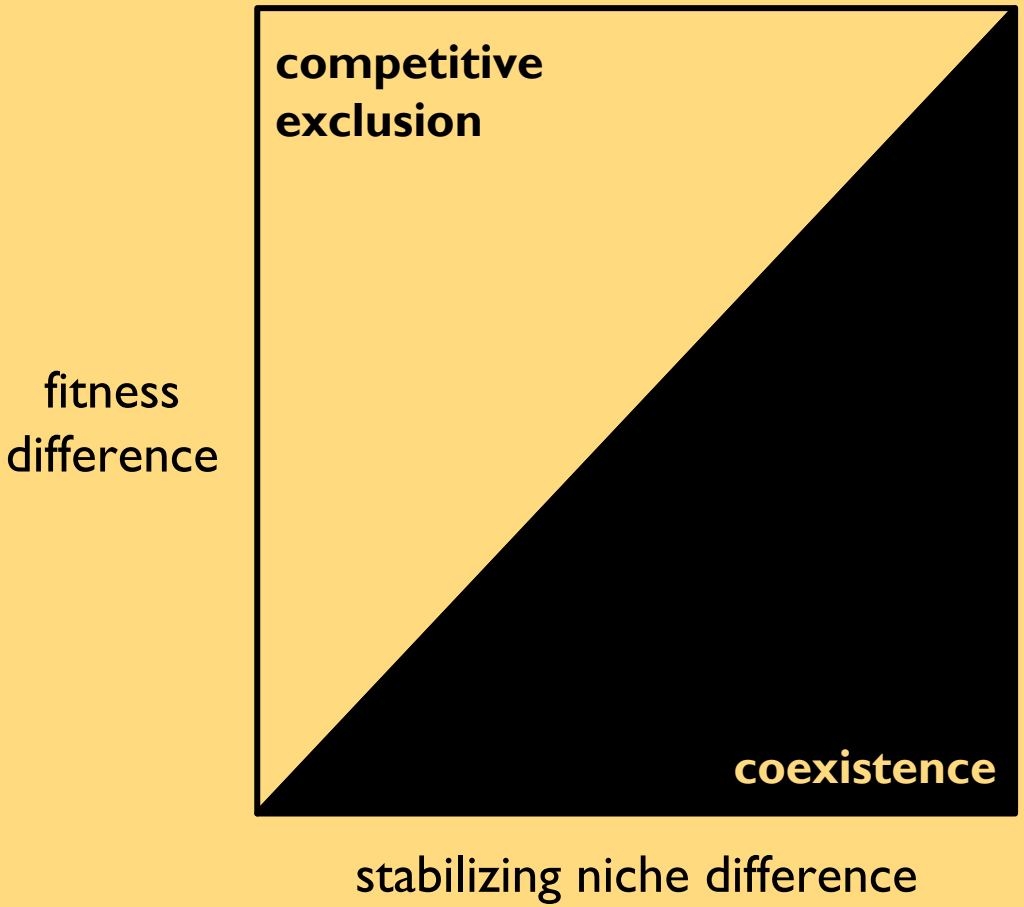
Interactions between plants

Variation between individuals

Feedbacks between plants and environment



Species coexistence depends on their niche and fitness differences



Adler et al. 2007 Ecol. Letters

What determines the magnitude of fitness and niche differences?

Adler et al. 2007 Ecol. Letters

Do functional traits correlate with fitness and niche differences?

fitness difference

stabilizing niche difference

Species 1 Species 2

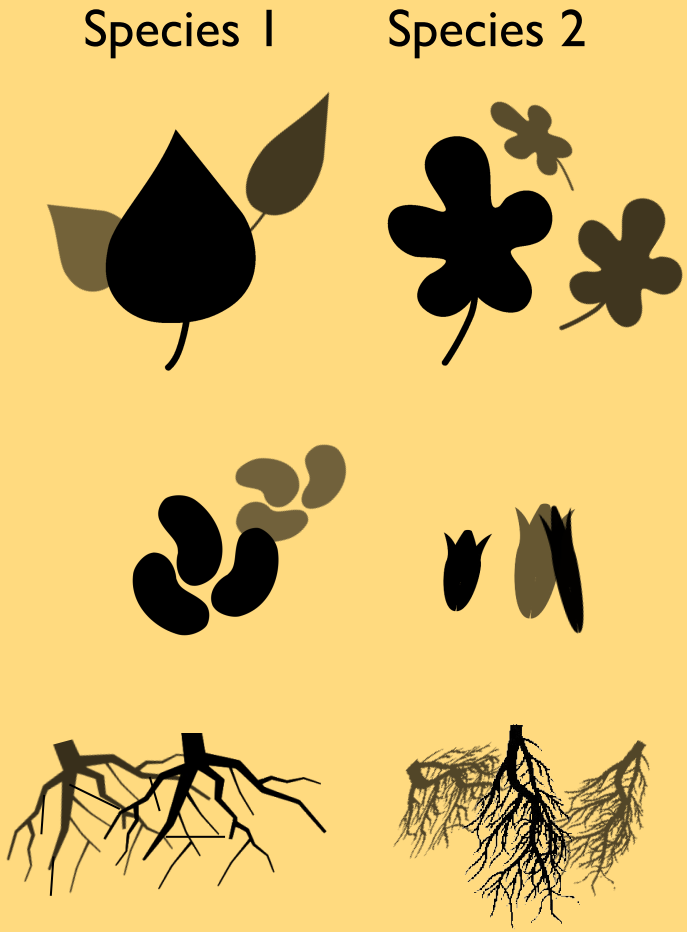
Note: This kinda highlights leaf shape, find better leaf

Adler et al. 2013 Ecol. Letters

How does ITV influence coexistence outcomes?

fitness difference

stabilizing niche difference



Turcotte & Levine 2016 TREE

How do resource competition and plant-microbe interactions jointly influence niche and fitness differences?

fitness difference

stabilizing niche difference

Bever et al. 2015 AREES

Dissertation Questions

1. How do differences in species functional traits relate to their demographic variation in patchy landscapes?

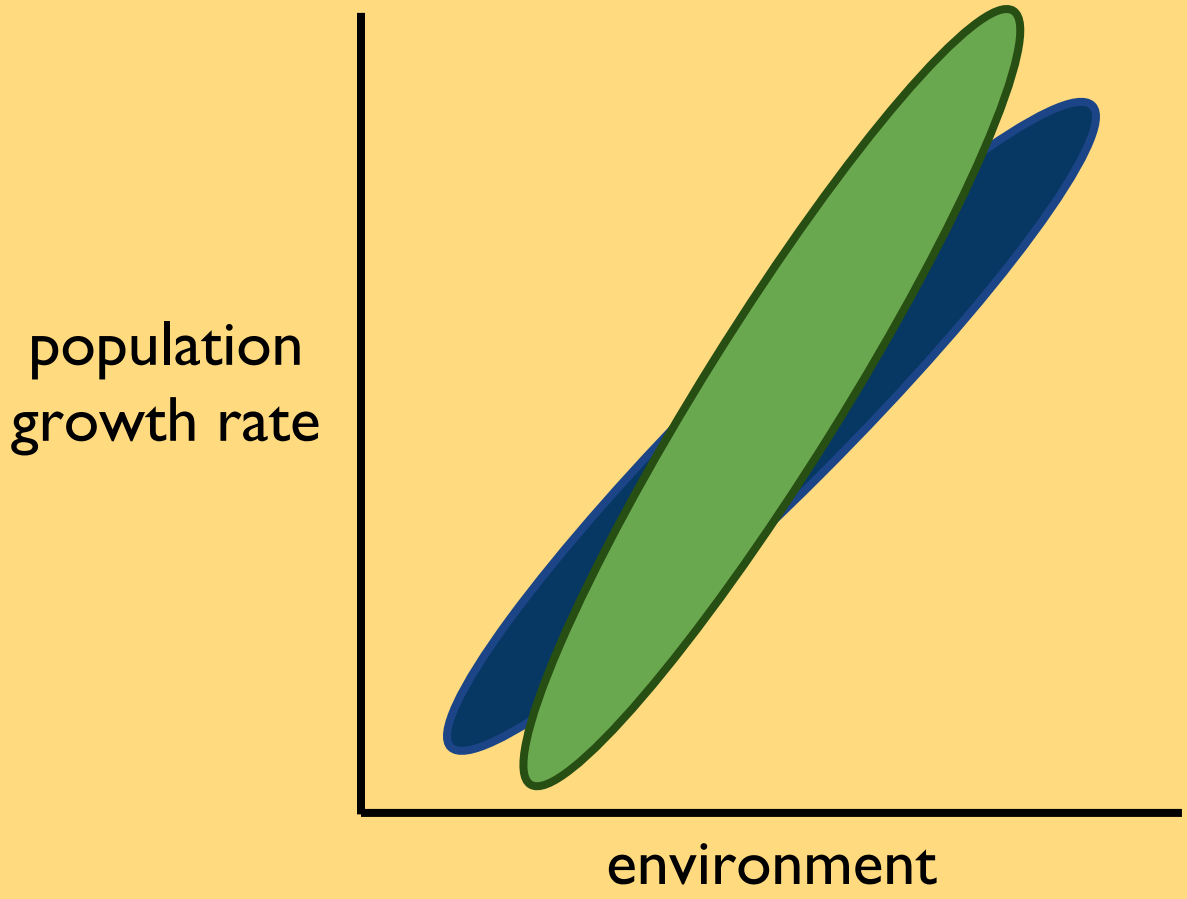
2. How does intra-specific trait variation influence competitive dynamics?

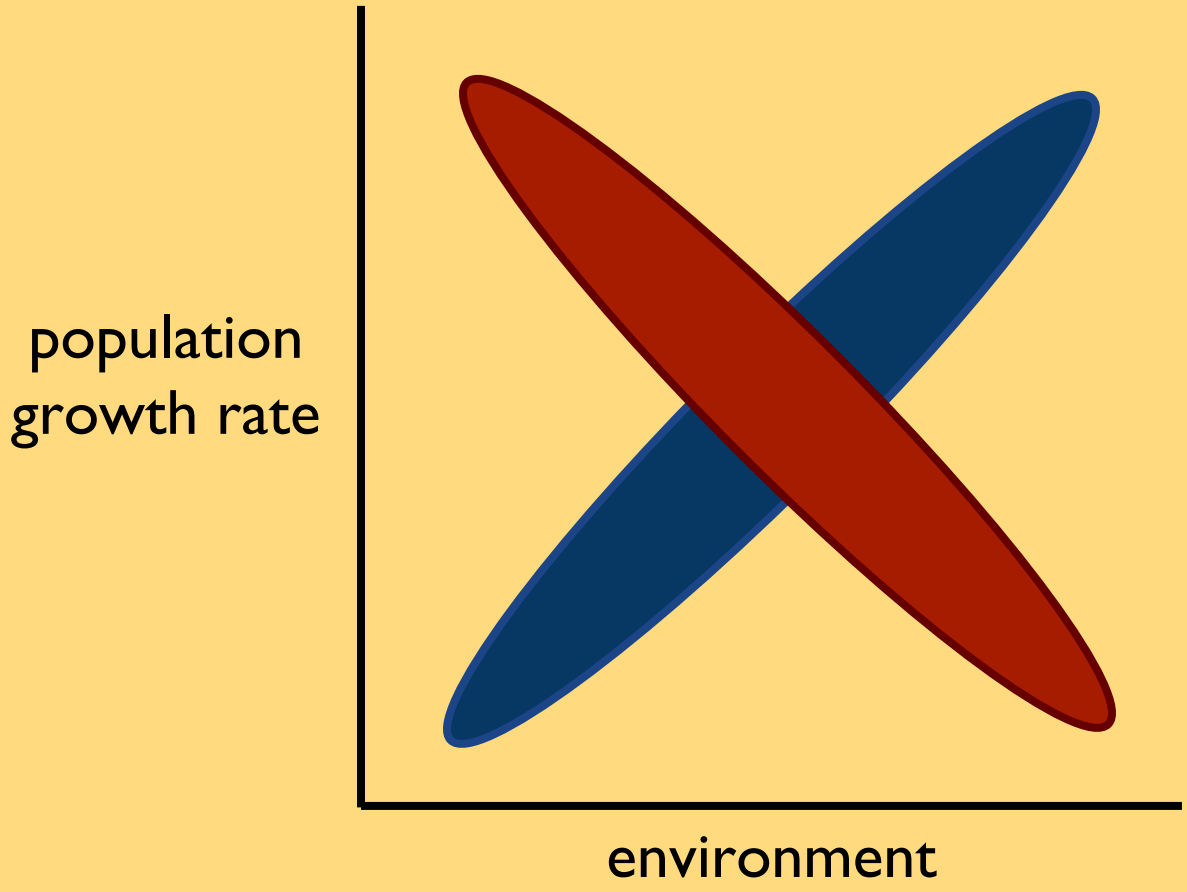
3. How can we jointly consider the consequences of resource competition and plant-microbe interactions in a unified framework?

Chapter 1

How do functional traits shape plant demographic responses to heterogeneous environments?


population
growth rate
environment

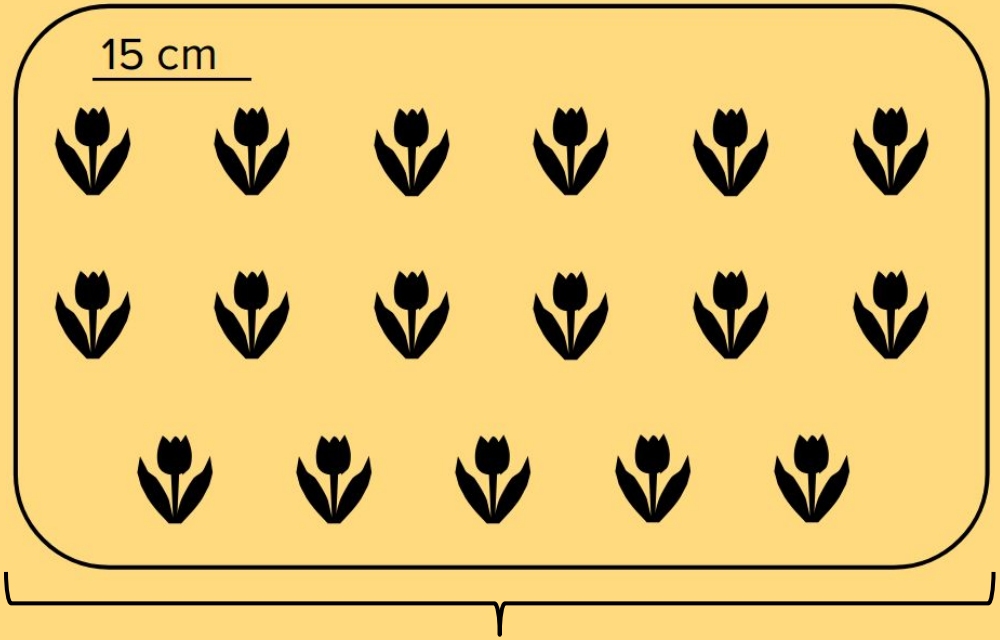

population
growth rate
environment


population
growth rate
environment

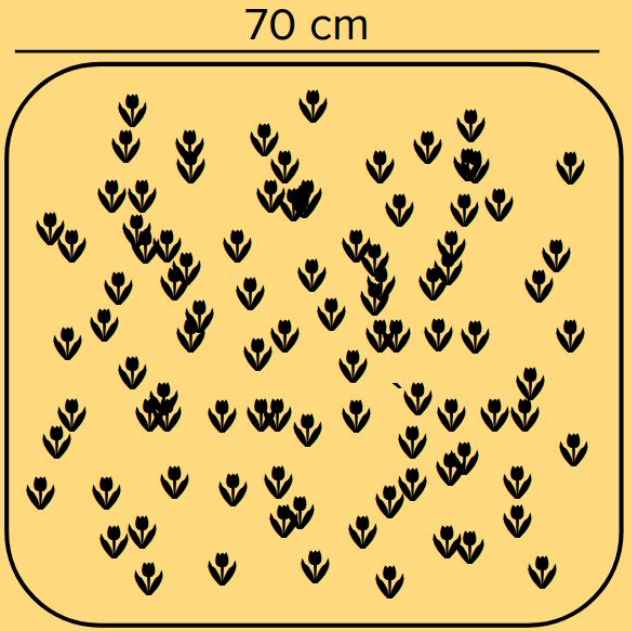
Chapter questions

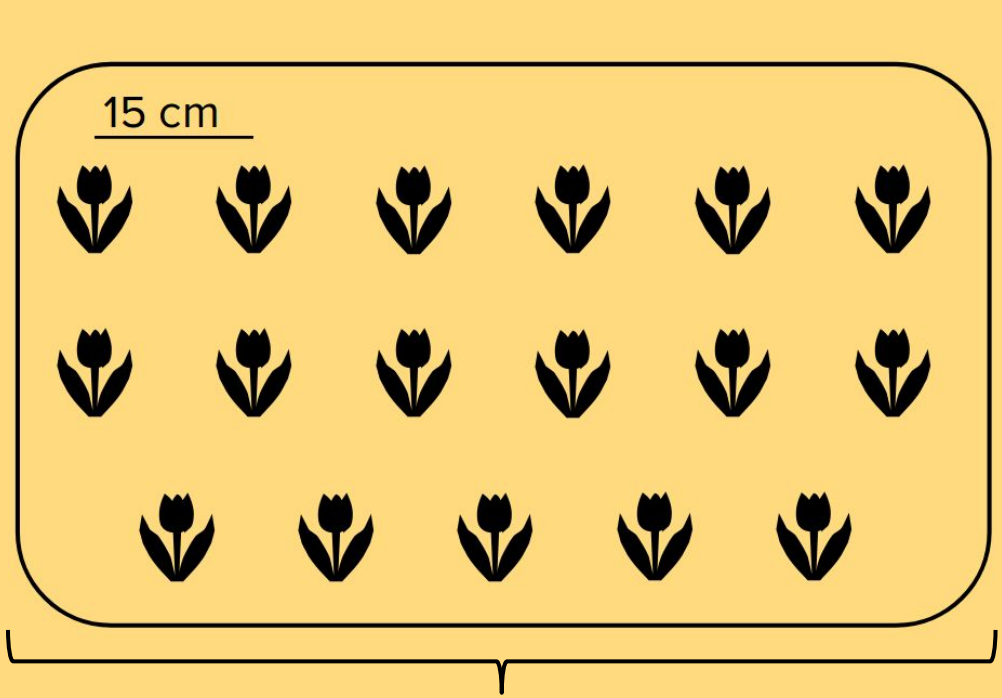
1. Which environmental factors drive variation in species responses to spatial heterogeneity?

2. Which functional traits mediate species responses to the environmental drivers?

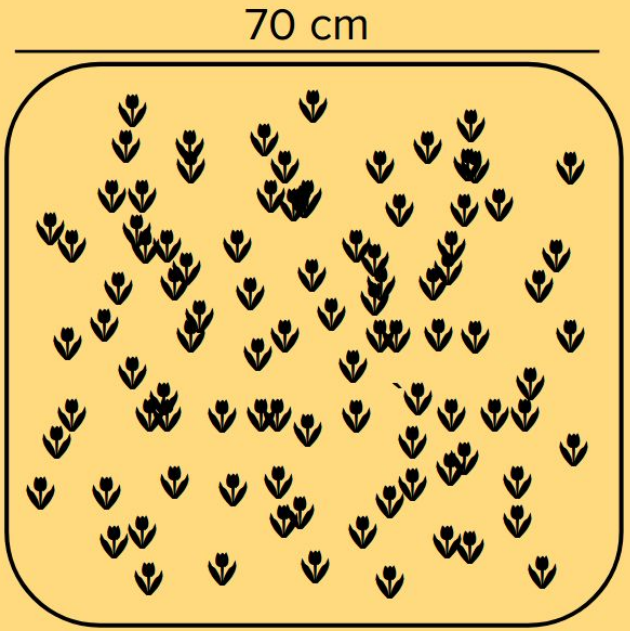


x 5 replicates/site





x 5 replicates/site

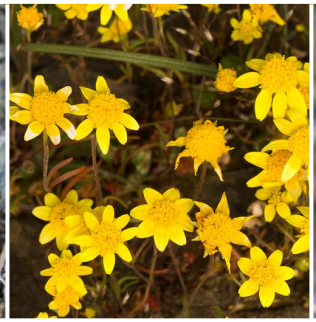


$$\frac{N_{t+1,j,x}}{N_{t,j,x}} = \overbrace{(1-g_{j,x})*s_j}^{seedbank\ survival} + \frac{\overbrace{g_{j,x}*\lambda_{j,x}}^{\substack{germiation\ rate\ \&\\ per-germinant\ fecundity}}}{\underbrace{1+r_{j,x}*\eta_x}_{\substack{sensitivity\ to\ competitors\ \&\\ number\ of\ competitors\ faced}}}$$

Uropappus lindleyi

Centaurea melitensis

Chaenactis glabriuscula



Lasthenia californica

Hemizonia congesta

Micropus californicus

Amsinckia menziesii

Clarkia purpurea

Clarkia bottae

Euphorbia peplus

Medicago polymorpha

Acmispon wrangelianus

Bromus madritensis

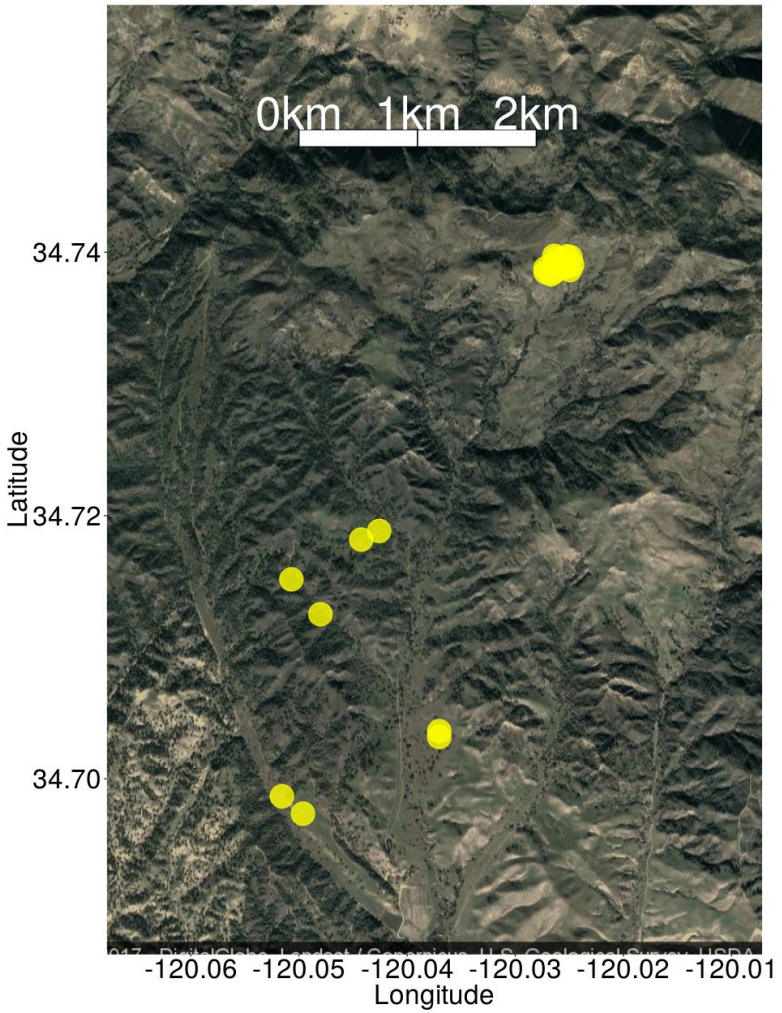
Hordeum murinum

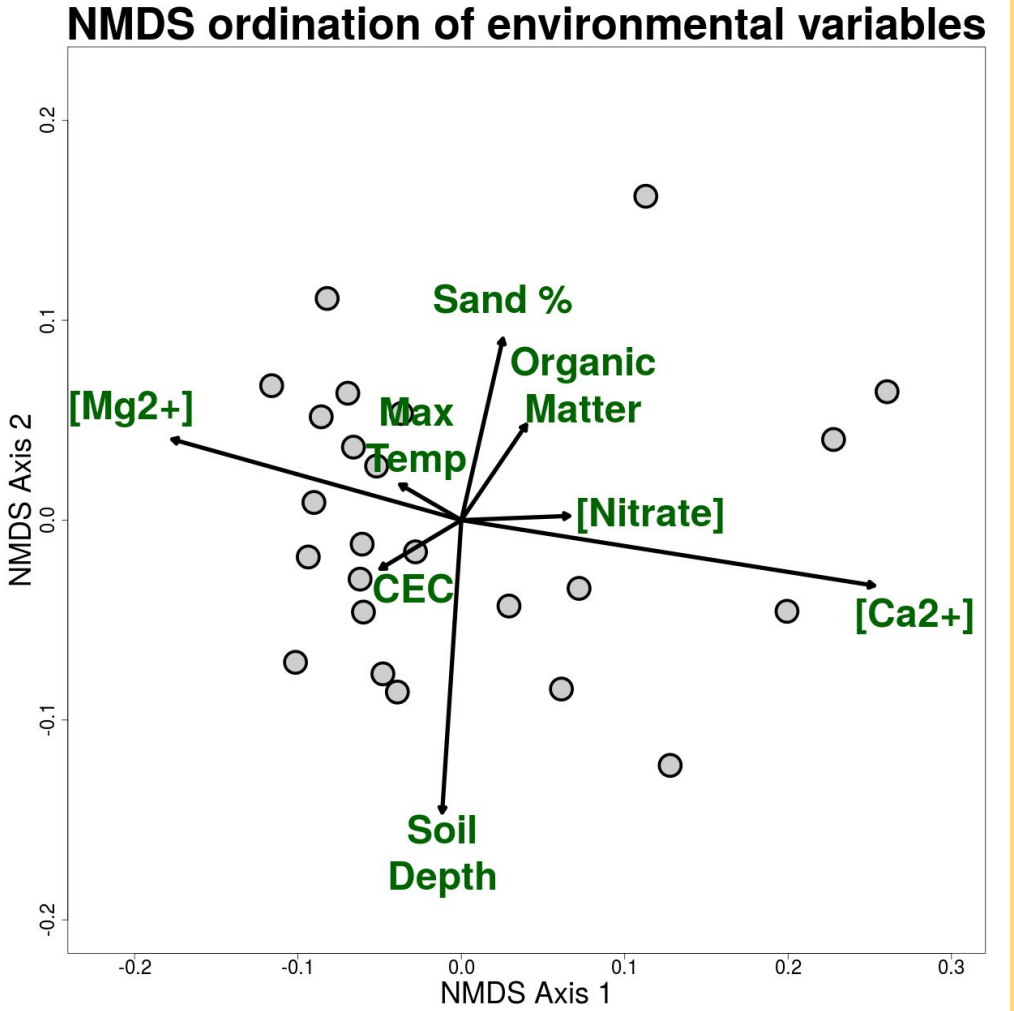
Vulpia microstachys

Salvia columbariae

Plantago erecta

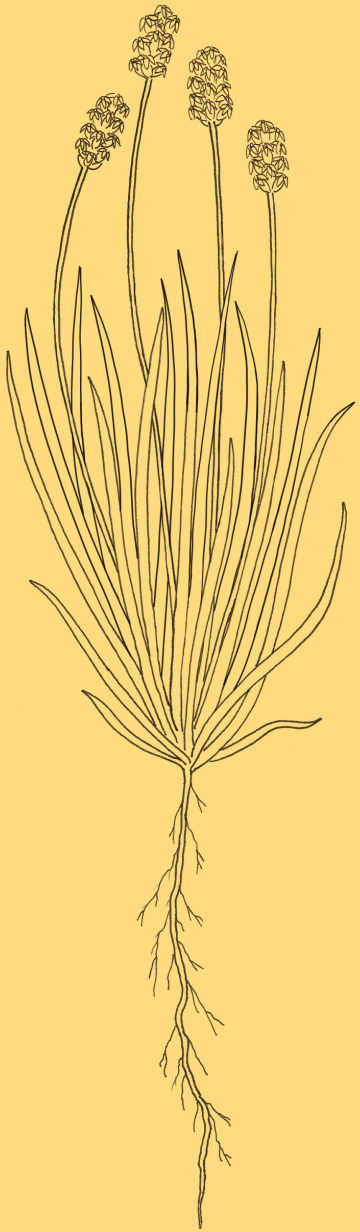
Images from CalPhotos (http://calphotos.berkeley.edu/)


0km 1km 2km
34.74
34.72
34.70
Latitude
-120.06 -120.05 -120.04 -120.03 -120.02 -120.01
Longitude


NMDS ordination of environmental variables
Sand %
Organic Matter
[Mg2+]
Max Temp
[Nitrate]
CEC
[Ca2+]
Soil Depth
NMDS Axis 2
NMDS Axis 1
0.2
0.1
0.0
-0.1
-0.2
-0.2
-0.1
0.0
0.1
0.2
0.3

Leaves
Leaf size
Specific leaf area
Leaf dry matter content
δC^{13} (Integrated WUE)
Leaf N concentration
Leaf osmotic potential

Roots
Specific root length
Rooting depth

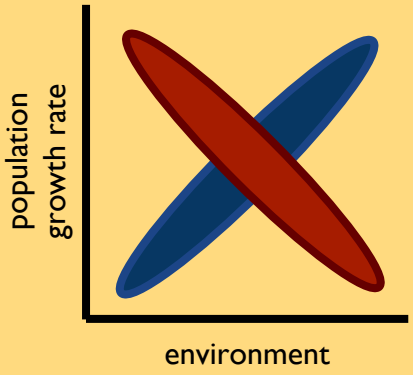


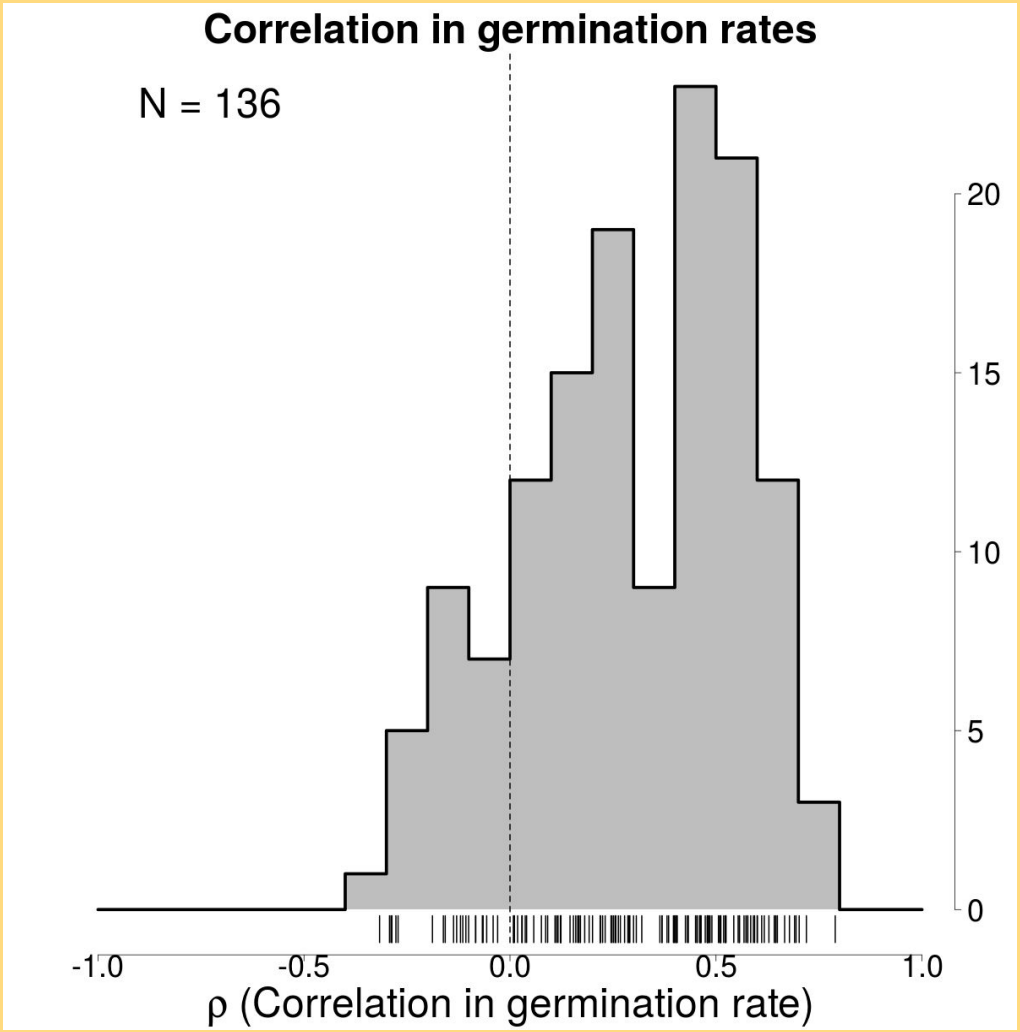
Reproduction
Seed mass
Fruiting phenology

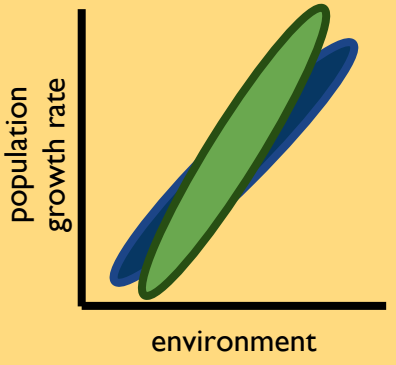
Whole-plant
Maximum height
Canopy shape index

Illustration of *Plantago erecta* by Joanna Shih (UCLA)

Species pairs tend to have distinct demographic responses to environmental gradients







$$p_{i,j} \sim \overbrace{a_0}^{species\ effect} + \underbrace{a_1 z_j}_{trait\ effect} + \overbrace{b_0 x_i}^{environment\ effect} + \underbrace{b_1 z_j x_i}_{interaction} + \overbrace{\epsilon_{\alpha j} + \epsilon_{\beta i} + \gamma_i}^{error\ terms}$$

Jamil et al. 2012 J. Veg. Sci

Q1: Which environmental factors drive variation in species responses to spatial heterogeneity?

$$p_{i,j} \sim \overbrace{a_0}^{species\ effect} + \underbrace{a_1 z_j}_{trait\ effect} + \overbrace{b_0 x_i}^{environment\ effect} + \underbrace{b_1 z_j x_i}_{interaction} + \overbrace{\epsilon_{\alpha j} + \epsilon_{\beta i} + \gamma_i}^{error\ terms}$$

Jamil et al. 2012 J. Veg. Sci

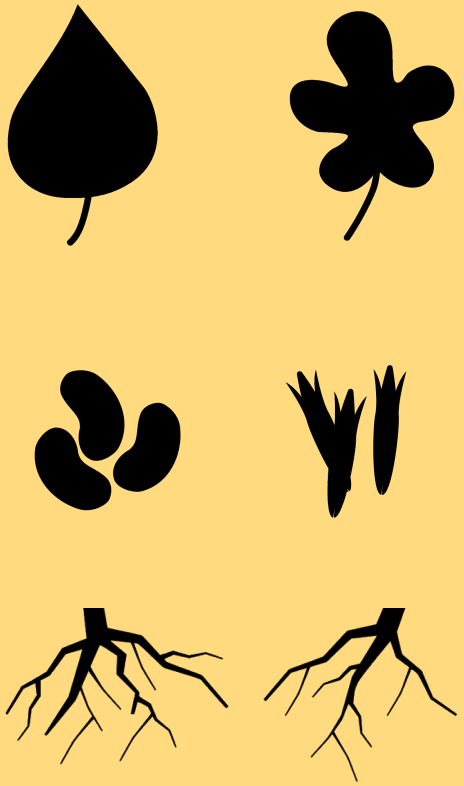
Q2: Which functional traits mediate species responses to the environmental drivers?

$$p_{i,j} \sim \overbrace{a_0}^{species\ effect} + \underbrace{a_1 z_j}_{trait\ effect} + \overbrace{b_0 x_i}^{environment\ effect} + \underbrace{b_1 z_j x_i}_{interaction} + \overbrace{\epsilon_{\alpha j} + \epsilon_{\beta i} + \gamma_i}^{error\ terms}$$

Jamil et al. 2012 J. Veg. Sci

fitness
difference

stabilizing niche difference



chapter 1 timeline

Data collection

Analyses

Writeup

Projected timeline

Finish analysis of soil microbe sequence data: October 2017
Run GLMM models: October - November 2017
Start writing ms: November - December 2017
Collect leaf osmotic potential on grasses: March/April 2018
Finish writing ms: March-May 2018
Submit MS: May 2018

Evolution and speciation

Seed dispersal

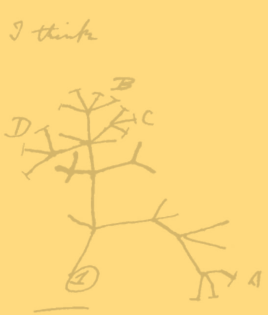
Multi-trophic interactions

Environmental variation

Interactions between plants

Variation between individuals

Feedbacks between plants and environment



Evolution and speciation

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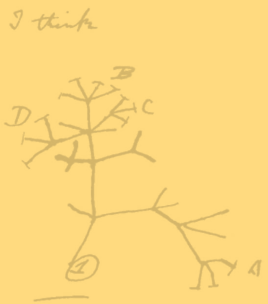


Chapter 2

What is the nature of intra-specific trait variation and how does it influence species coexistence?

Intra-specific trait variation has many drivers

Intra-specific trait variation has many drivers

ITV within individuals

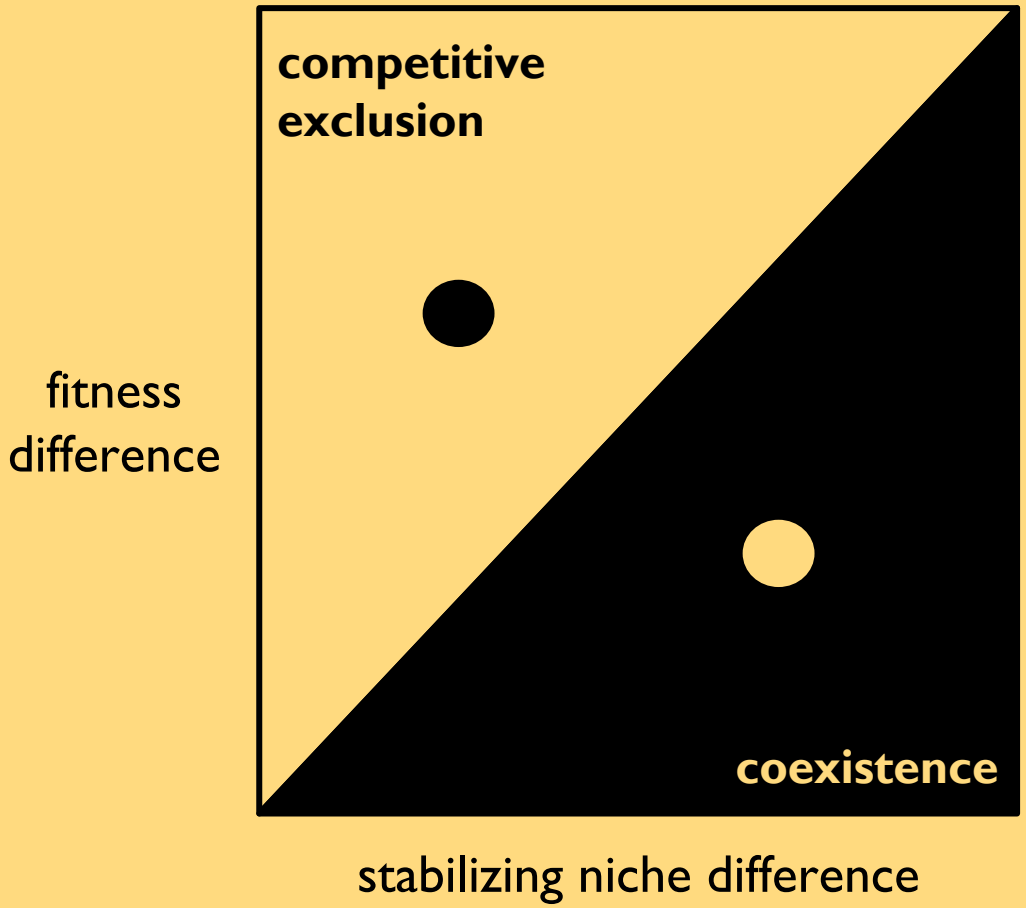
Intra-specific trait variation has many drivers

ITV within individuals

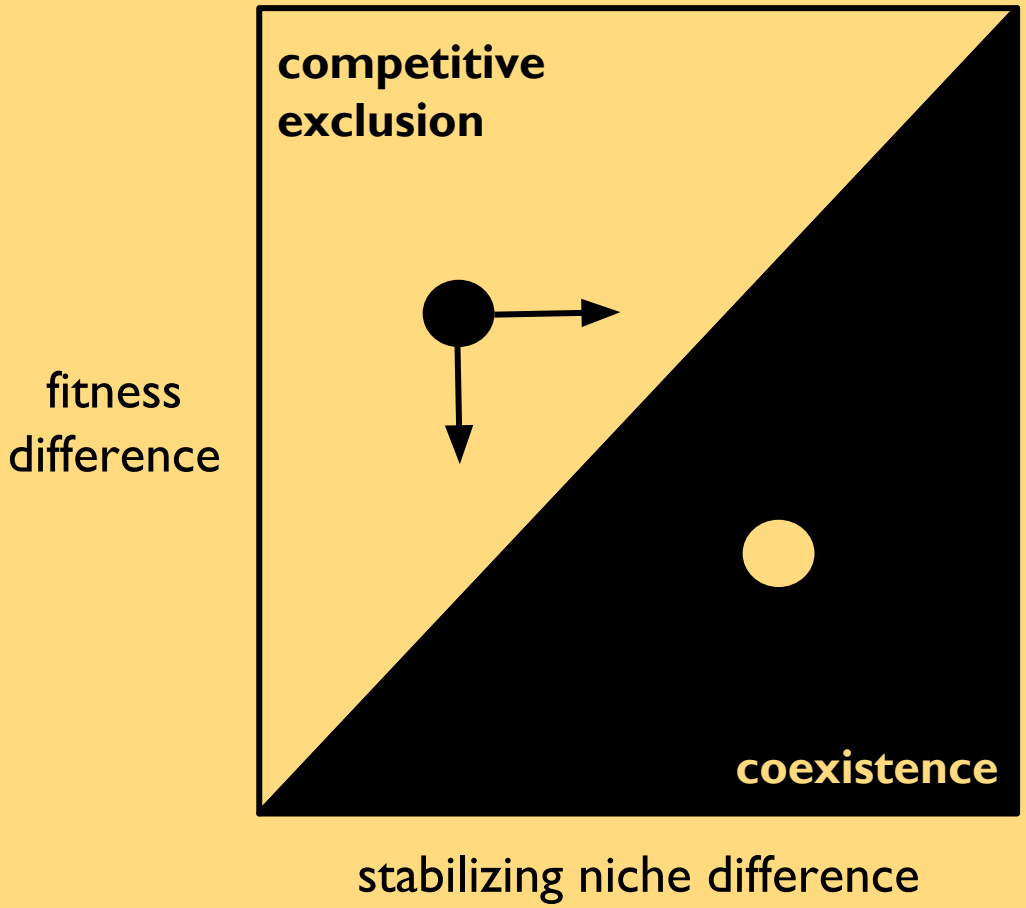
ITV between populations

Siefert et al. 2015 Ecol. Letters

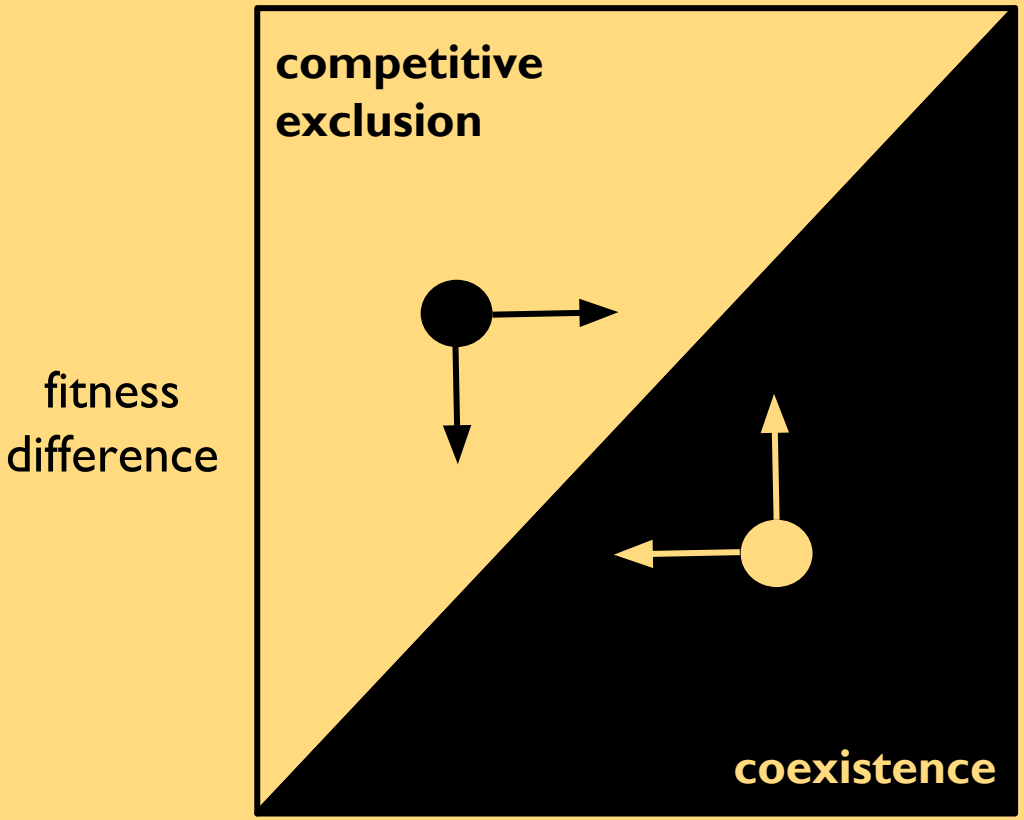
ITV may promote or destabilize coexistence



ITV may promote or destabilize coexistence



ITV may promote or destabilize coexistence



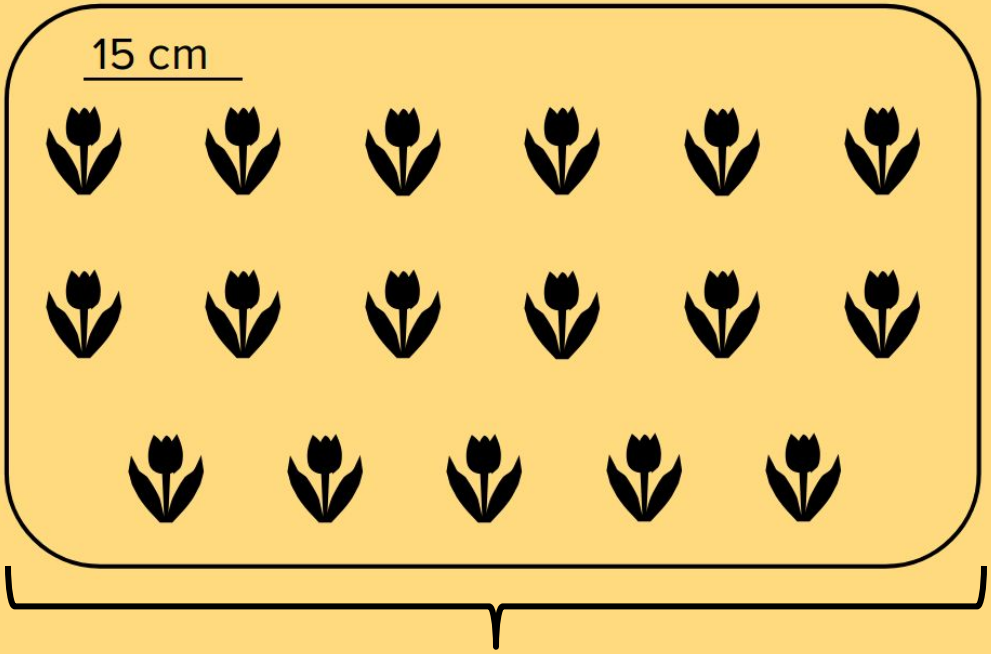
Hart et al. 2016 Ecol Letters

Chapter questions

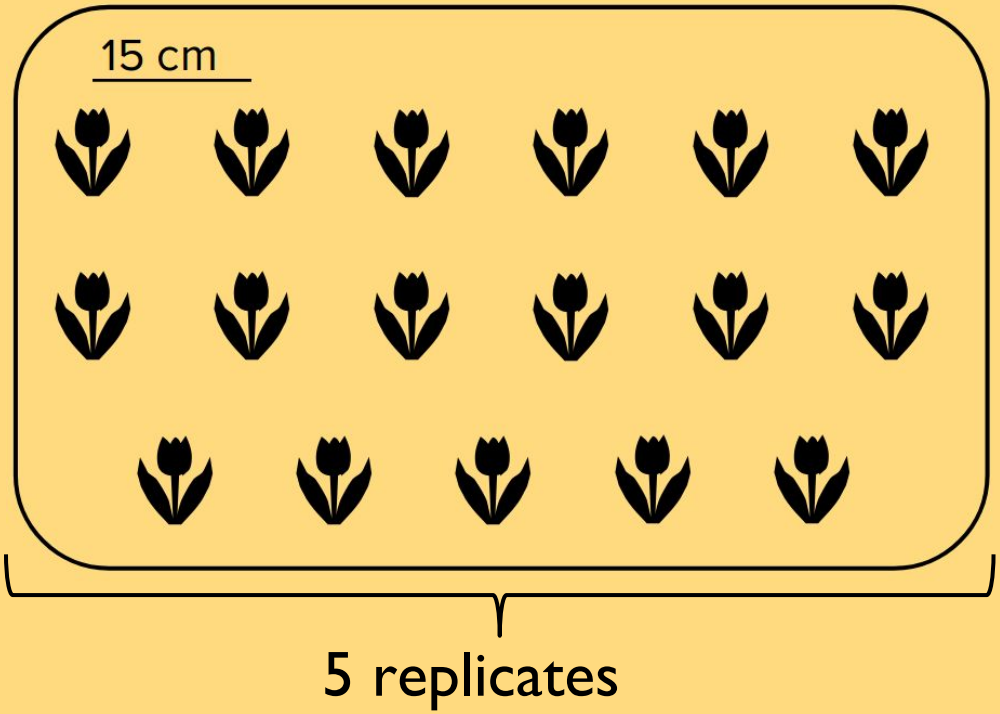
1. What is the structure of trait variation across an environmental gradient?

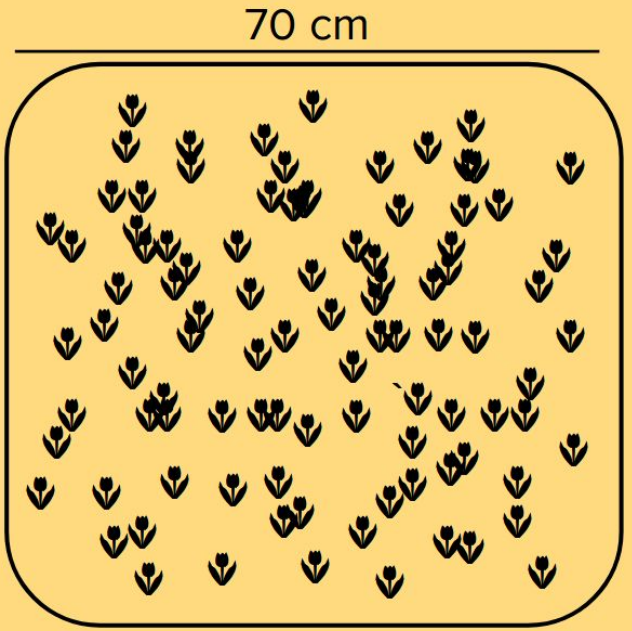
2. Do species shift their ecological strategies in competition, and how might this influence the outcome of competition?

At 24 sites, plants were grown with a very low density of competitors

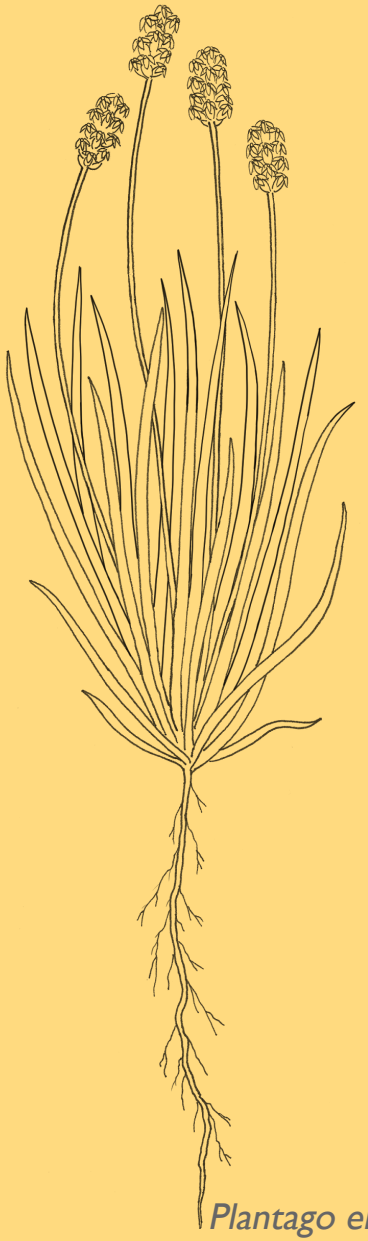


At one site, plants were grown with and without competitors





Leaves
Leaf size
Specific leaf area
Leaf dry matter content



Plantago erecta

Roots
Specific root length

Whole-plant
Canopy shape index
Height

Illustration: Joanna Shih (UCLA)

Q1: What is the structure of trait variation across an environmental gradient?

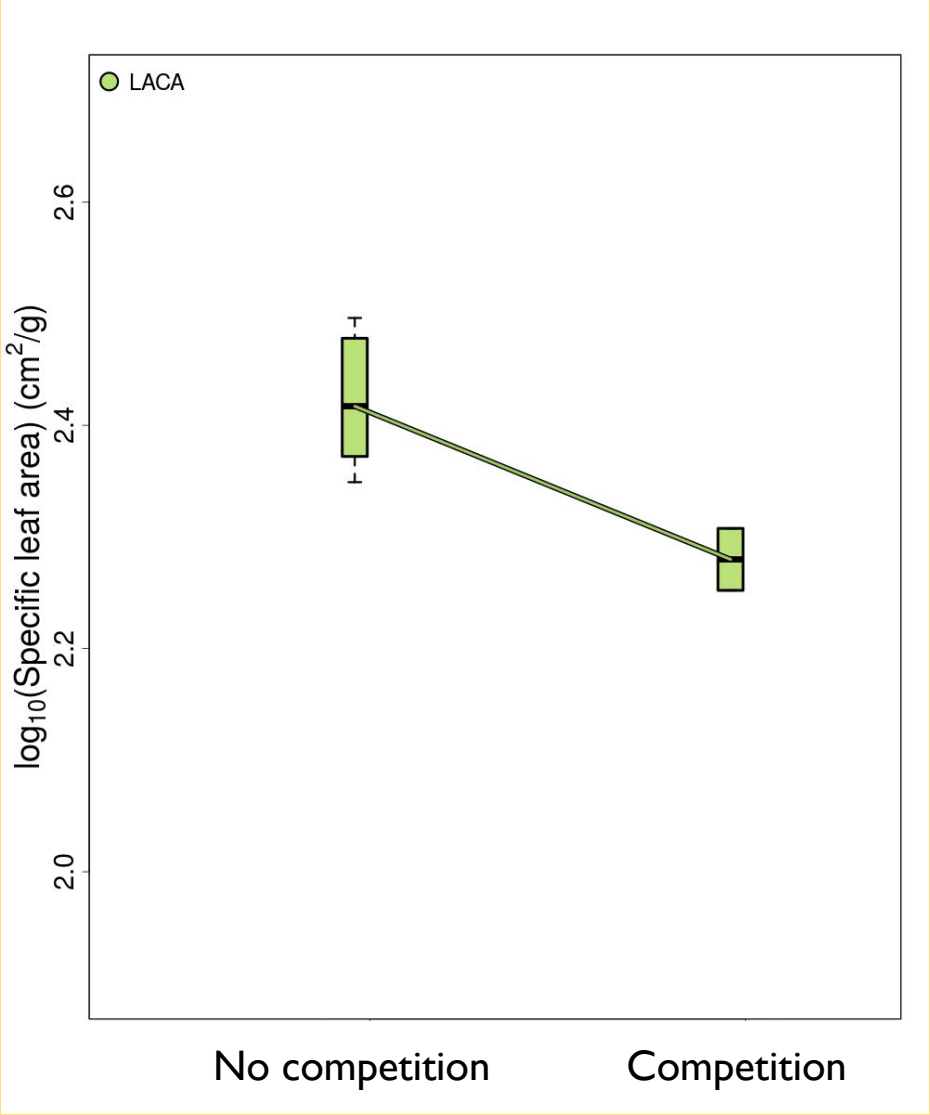
Q1: What is the structure of trait variation across an environmental gradient?

$$trait_{i,j} \sim \overbrace{a}^{\text{trait mean}} + \underbrace{b_0 x_i}_{\text{species effect}} + \overbrace{c_0 z_j}^{\text{environment effect}} + \underbrace{c_1 x_i z_j}_{\text{interaction}} + \overbrace{\epsilon_{\alpha j} + \epsilon_{\beta i} + \gamma_i}^{\text{error terms}}$$

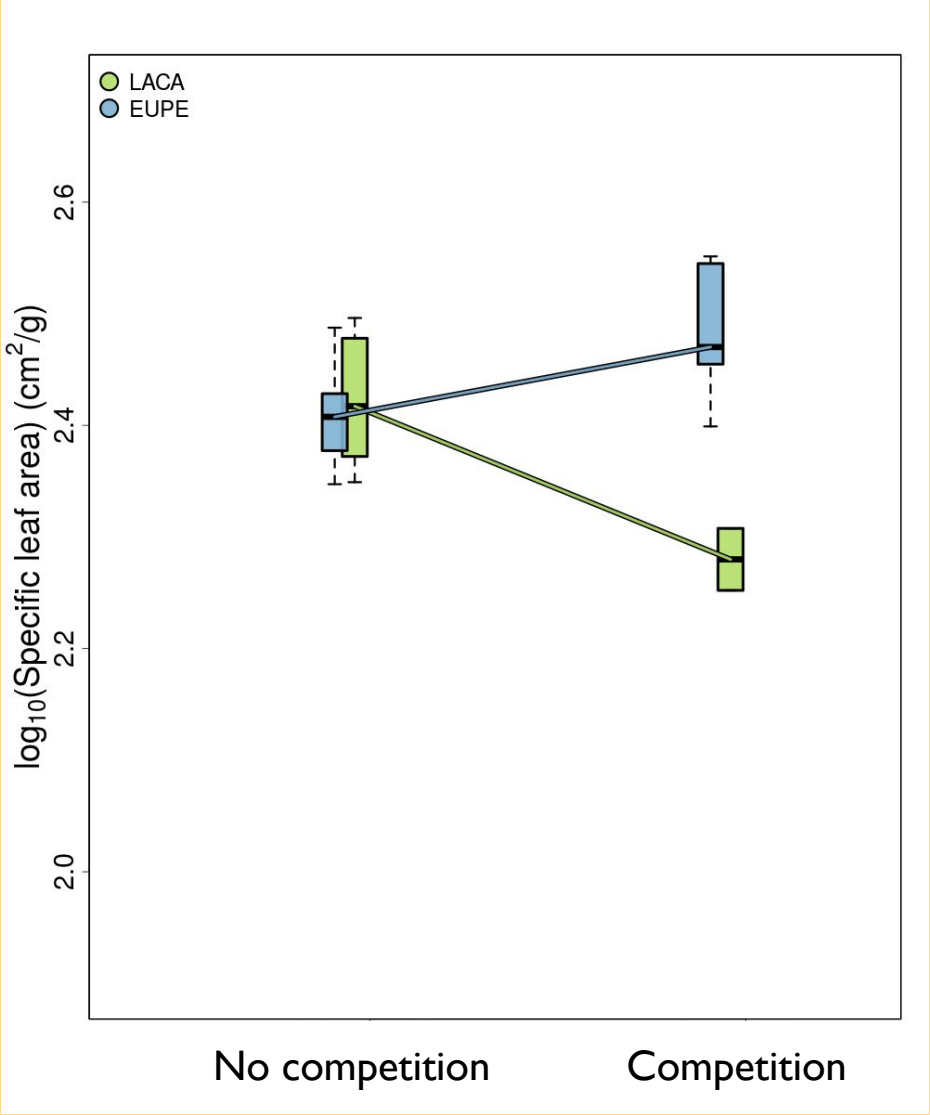
To do- figure out why equation is

Q2: Do species shift their ecological strategies in competition, and how might this influence the outcome of competition?

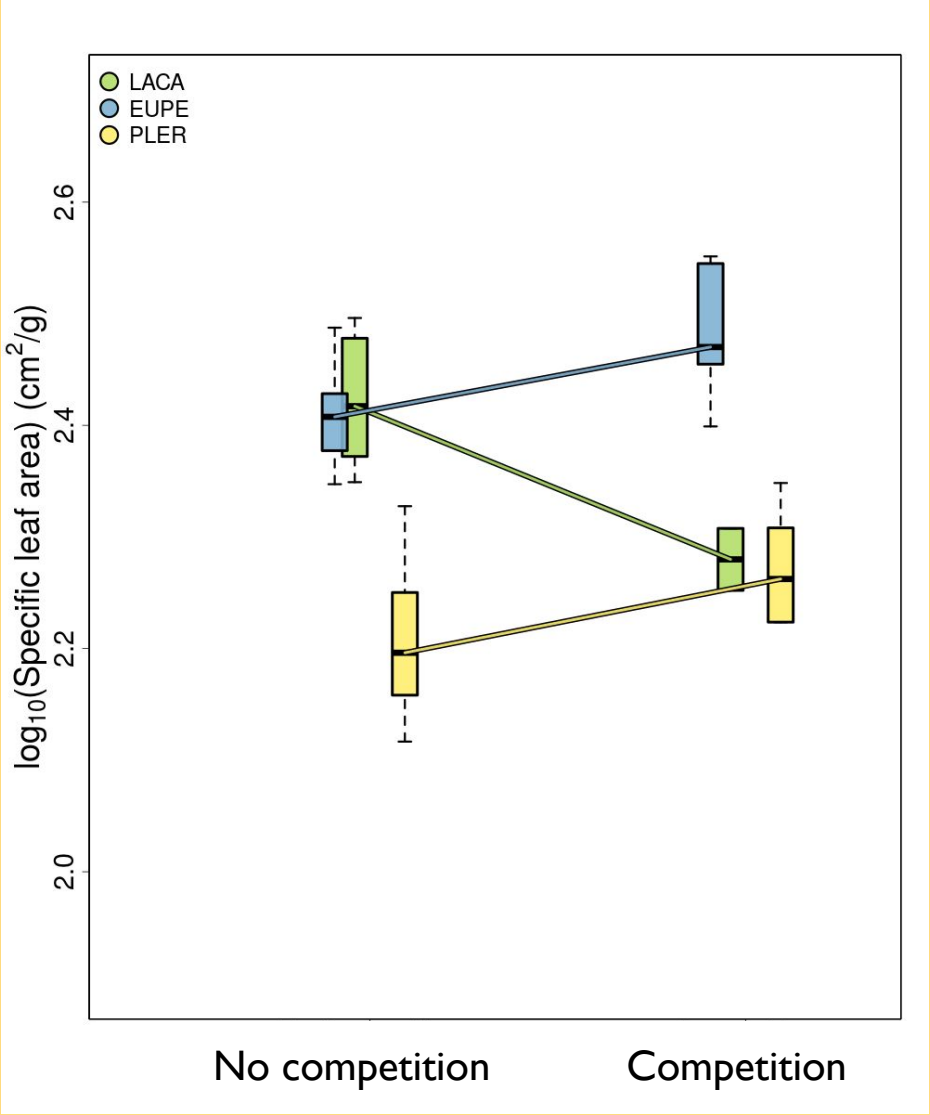
Trait changes in response to competition are species-specific



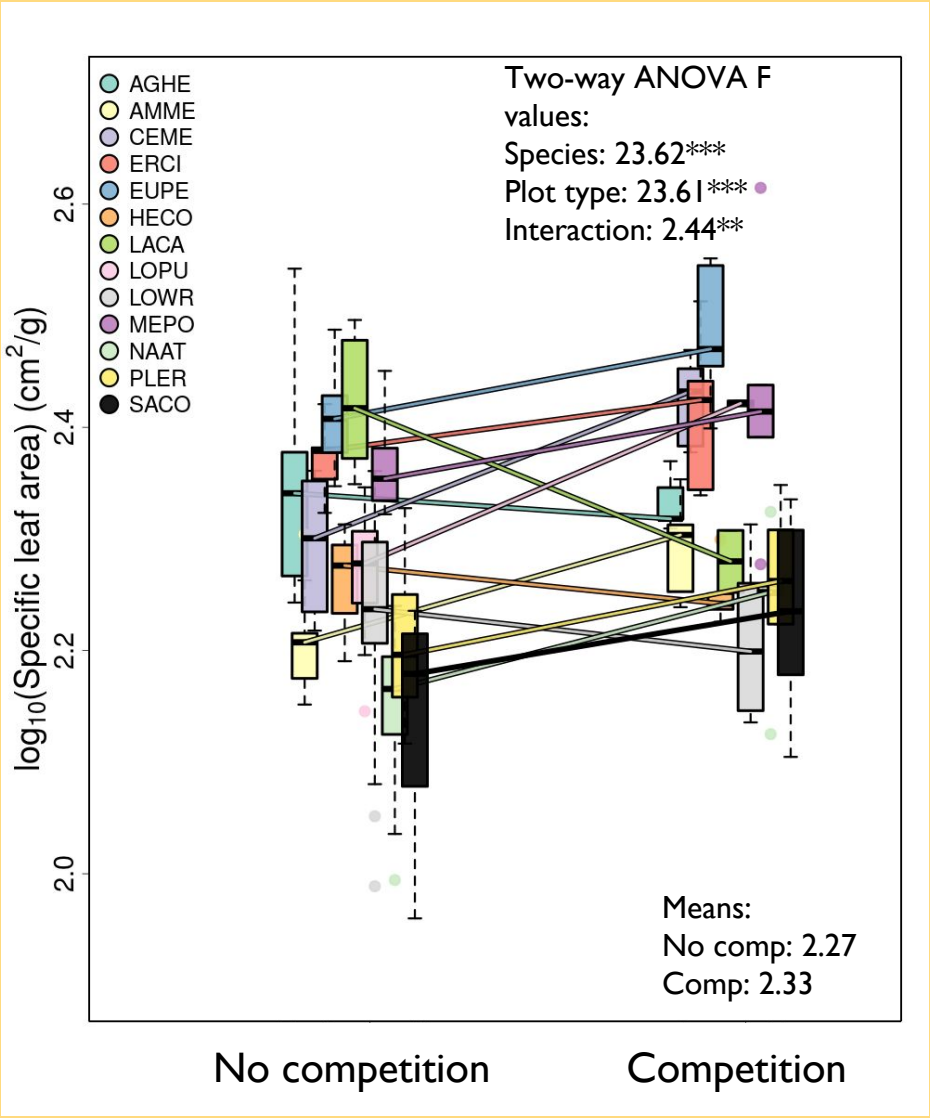
Trait changes in response to competition are species-specific



Trait changes in response to competition are species-specific

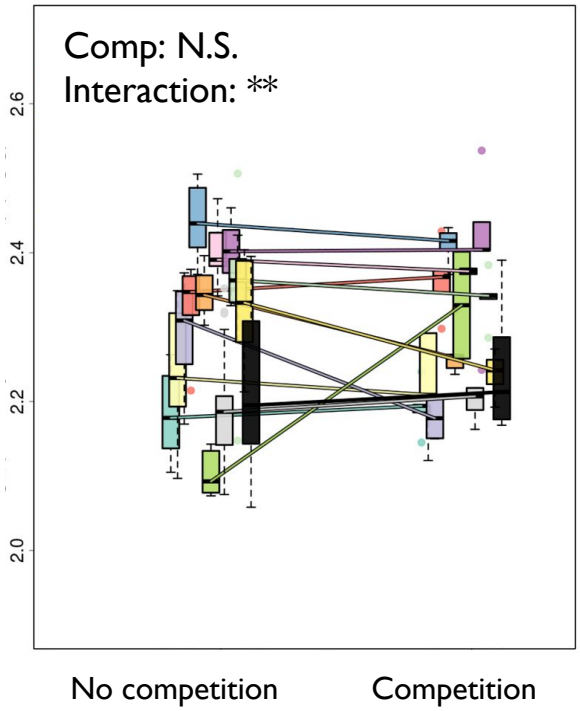


Trait changes in response to competition are species-specific

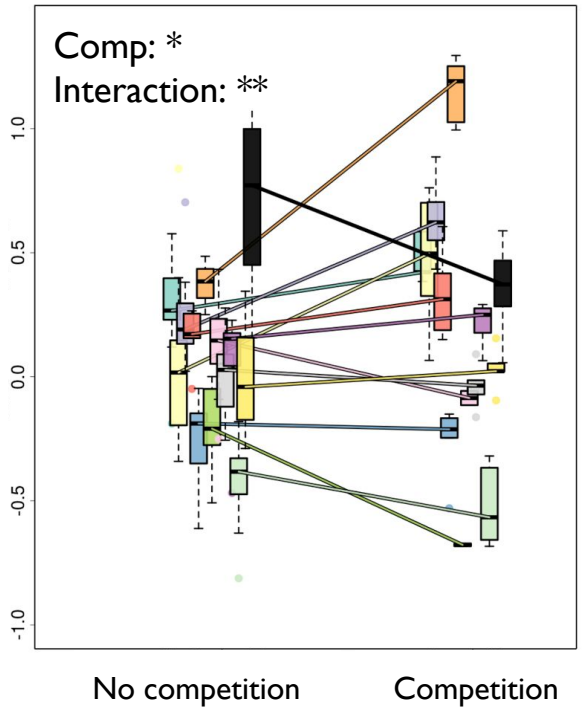


Trait changes in response to competition are species-specific

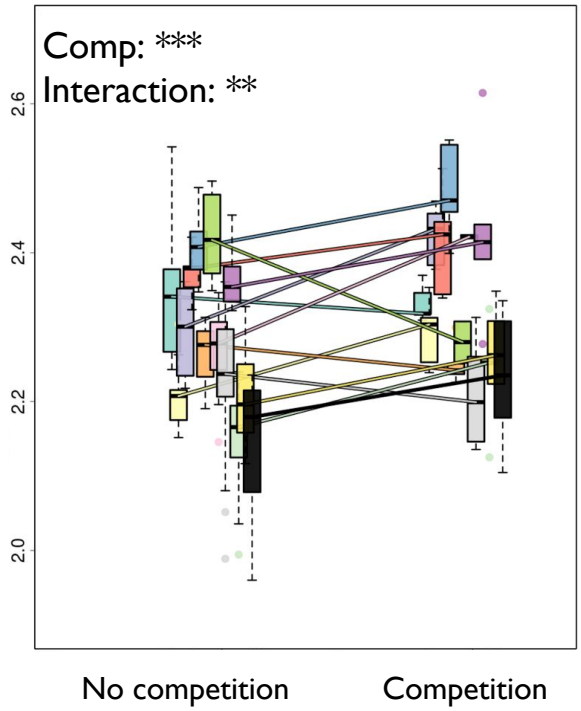
Leaf Dry Matter Content



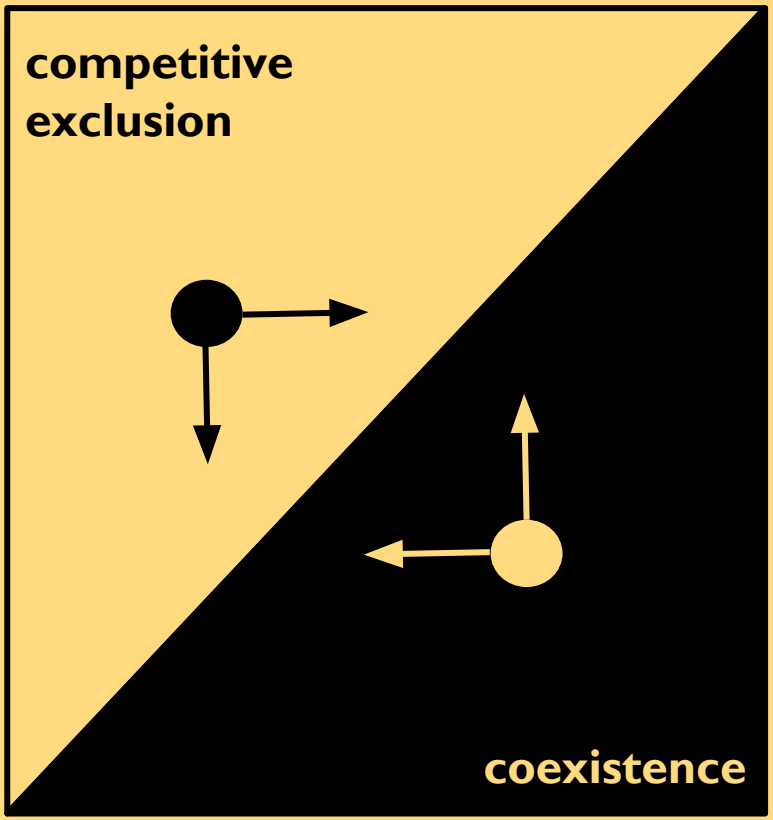
Leaf Size



Specific Leaf Area



To do- figure out better way to show this



To do- not a big fan of this slide rn

chapter 2 timeline

Data collection

Analyses

Writeup

Projected timeline

Process fine root samples for SRL: October-November 2018
Collect trait data in conspecific/heterospecific background: March-May 2018
Conduct analyses: September-December 2018
Write MS: January-April 2019
Submit MS: Summer 2019

Evolution and speciation

Seed dispersal

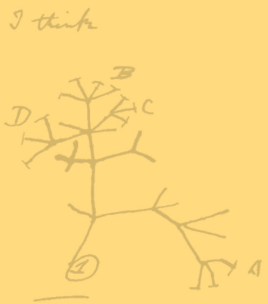
Multi-trophic interactions

Environmental variation

Interactions between plants

Variation between individuals

Feedbacks between plants and environment



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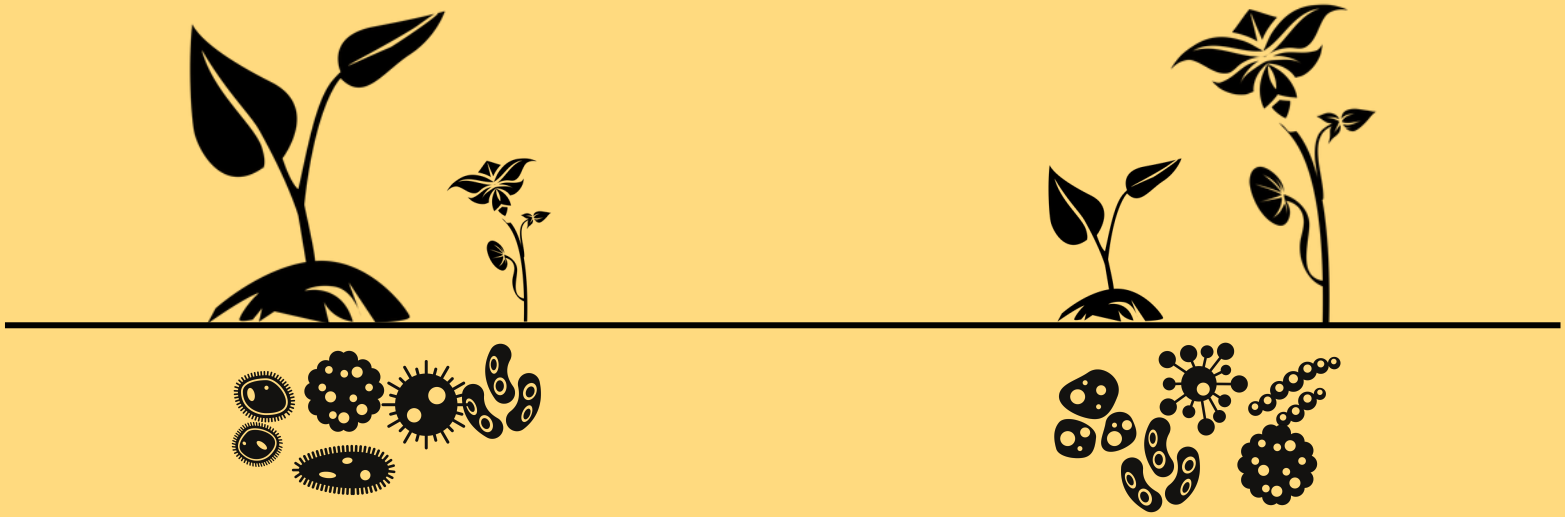
Chapter 3

How can we better investigate the joint effects of plant competition and plant-microbe interactions?

Microbes are ubiquitous and varied, and they can have dramatic impacts on plant community dynamics.



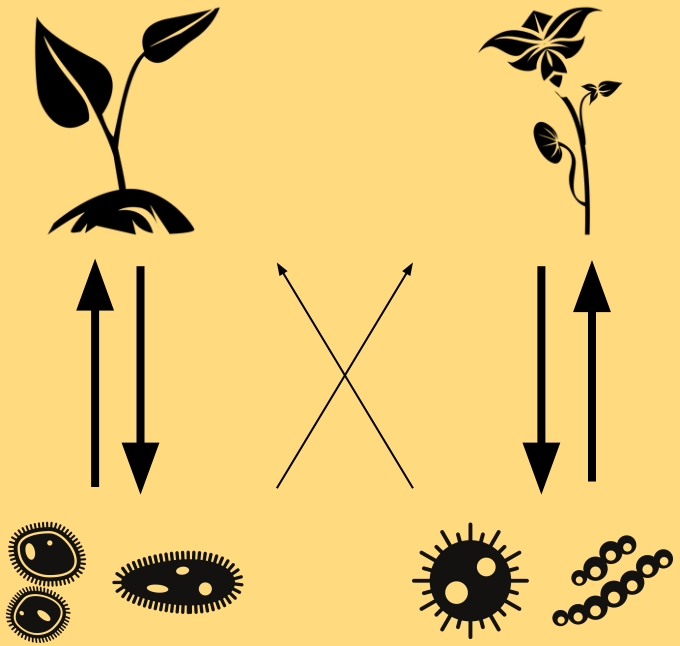
Redman 2002 Science

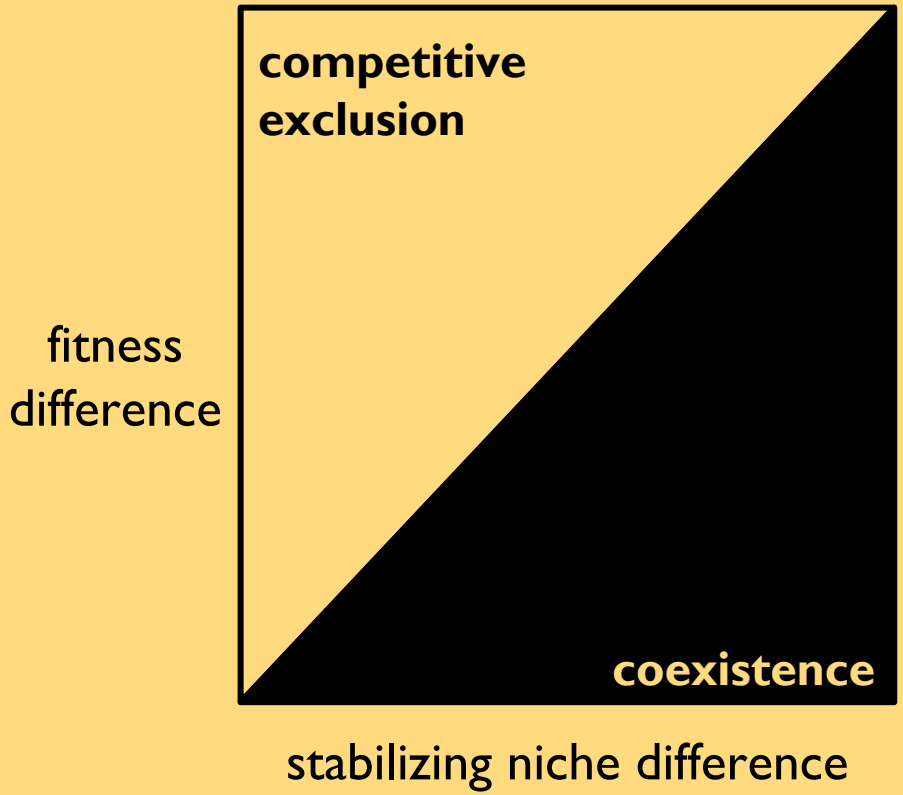
Plant-soil feedbacks can promote plant species coexistence

Bever et al. 1997 J Ecology

What is the relative importance of microbes and competition to plant coexistence?

Smith-Ramesh & Reynolds 2017 J. Veg. Sci; Van Der Putten et al. 2016 Func. Ecol.




competitive
exclusion
coexistence
fitness
difference
stabilizing niche difference

Chesson & Kuang 2008 model dynamics of focal species, resources, and enemies

Chesson & Kuang 2008 model dynamics of focal species, resources, and enemies

$$\frac{1}{N_j}\frac{dN_j}{dT} = \overbrace{\sum_l c_{jl} v_l R_l}^{growth\ due\ to\ resource\ uptake} - \overbrace{\sum_m a_{jm} P_m}^{loss\ to\ natural\ enemy} - \overbrace{\mu_j}^{maintenance\ cost}$$

$$\frac{1}{R_l}\frac{dR_l}{dT} = \overbrace{r_l(1-\alpha_l R_l)}^{resource\ replacement} - \overbrace{\sum_j N_j C_{jl}}^{consumption\ by\ focal\ species}$$

$$\frac{1}{P_m}\frac{dP_m}{dT} = \overbrace{r_m(1-\alpha_m P_m)}^{intrinsic\ growth\ rate} + \overbrace{\sum_j W a_{jm} P_m}^{growth\ due\ to\ consumption}$$

Species interactions with nutrients and enemies both influence niche and fitness differences.

Niche difference = $1 - \frac{\sum_l \frac{C_{jl} V_l C_{kl}}{r_l^R \alpha_I^R} + \sum_m \frac{a_{jm} w a_{km}}{r_m^P \alpha_m^P}}{\sqrt{\left(\sum_l \frac{c_{jl}^2 v_l}{r_l^R \alpha_l^R} + \sum_l \frac{a_{jm}^2 w}{r_m^P \alpha_m^P}\right)\left(\sum_l \frac{c_{kl}^2 v_l}{r_l^R \alpha_l^R} + \sum_l \frac{a_{km}^2 w}{r_m^P \alpha_m^P}\right)}}$

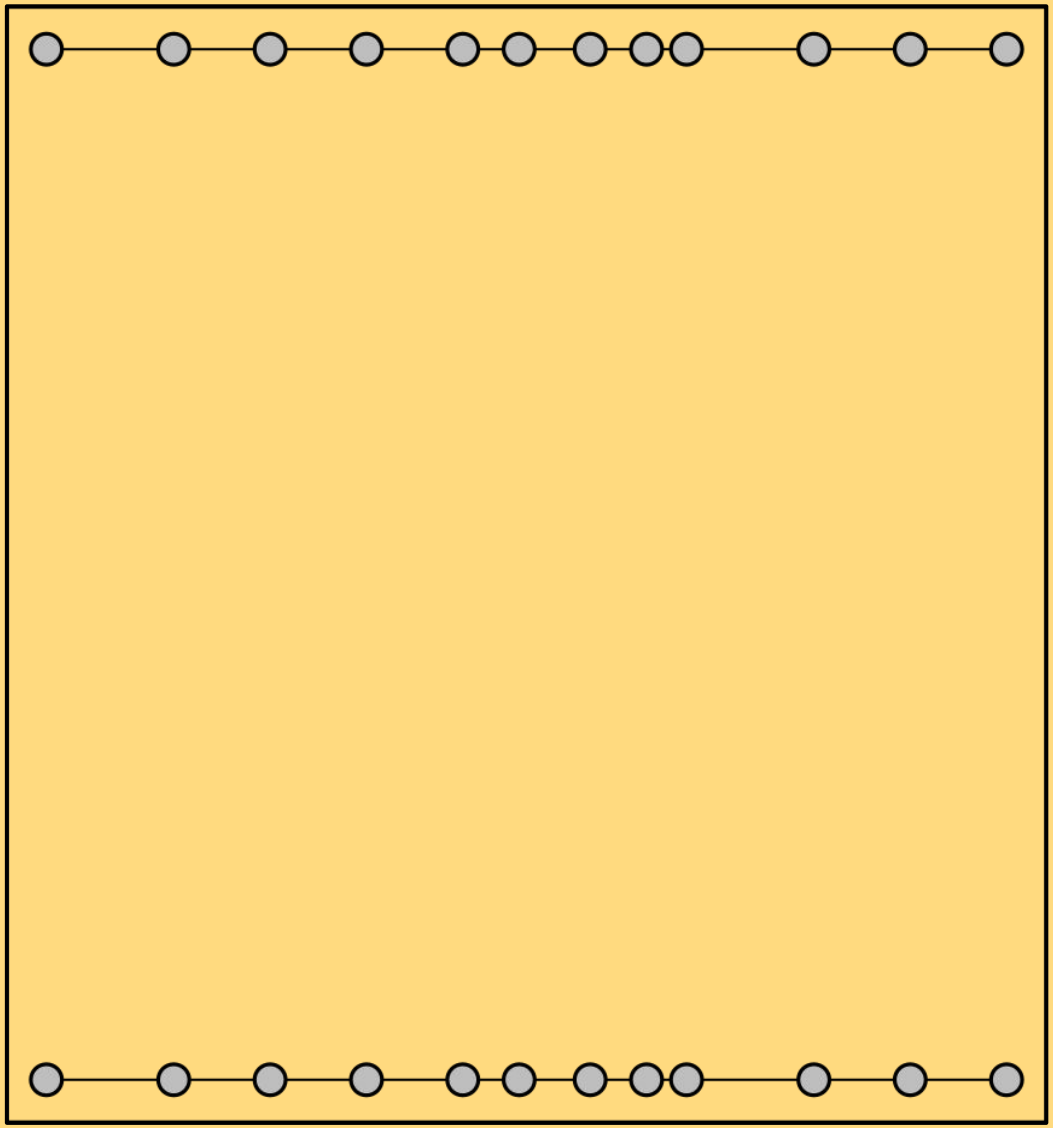
Species fitness = $\frac{\sum_l \frac{C_{jl} v_l}{\alpha_l^R} - \sum_m \frac{a_{jm}}{\alpha_m^P} - \mu_j}{\sqrt{\left(\sum_l \frac{c_{jl}^2 v_l}{r_l^R \alpha_l^R} + \sum_m \frac{a_{jm}^2 w}{r_m^P \alpha_m^P}\right)}}$

Due to natural enemies

Due to resource use

Chesson & Kuang (2008) Nature

Need to find better words for this part



Niche differences due to microbes

Niche differences due to resource use

Niche differences

Resource replacement rate (r^R)

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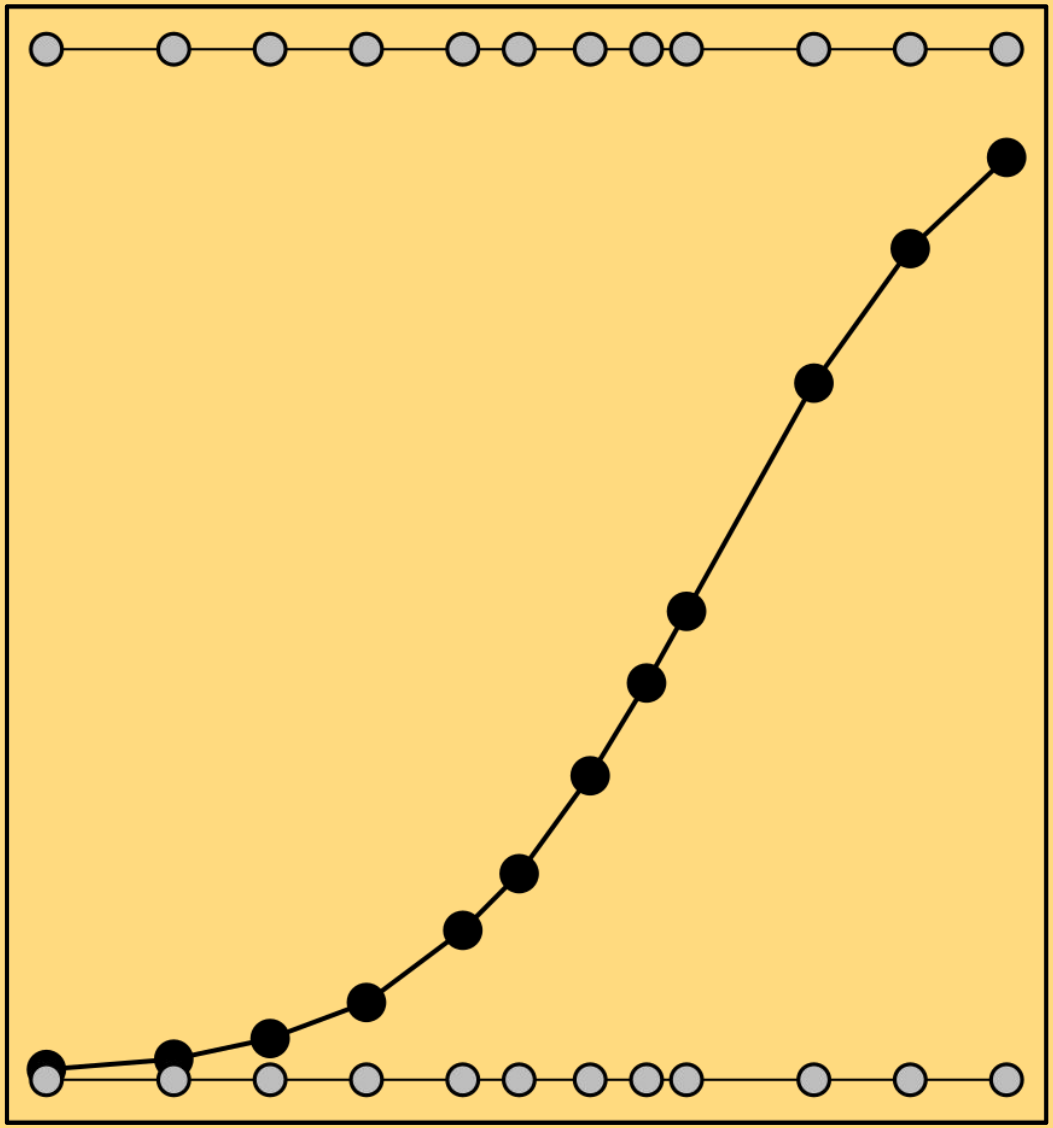


Niche differences

Resource replacement rate (r^R)

Niche differences due to microbes

Net niche differences

Niche differences due to resource use

chapter 3 timeline

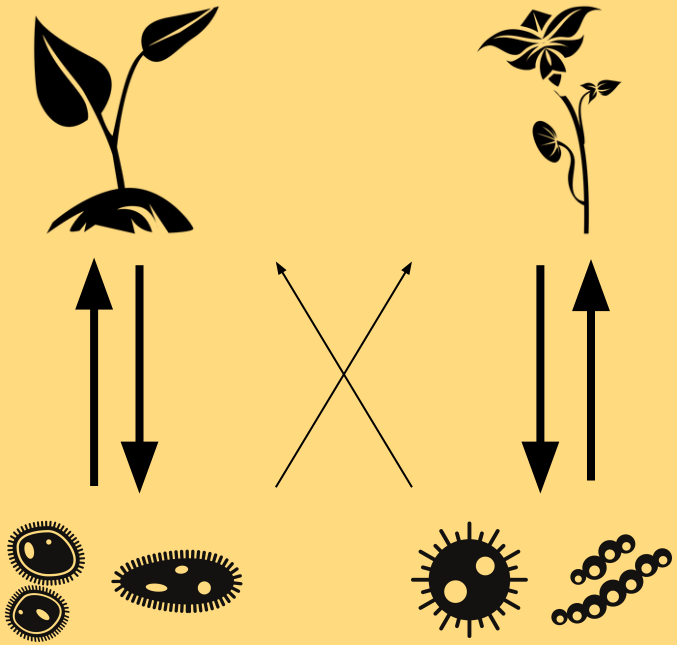
Modeling

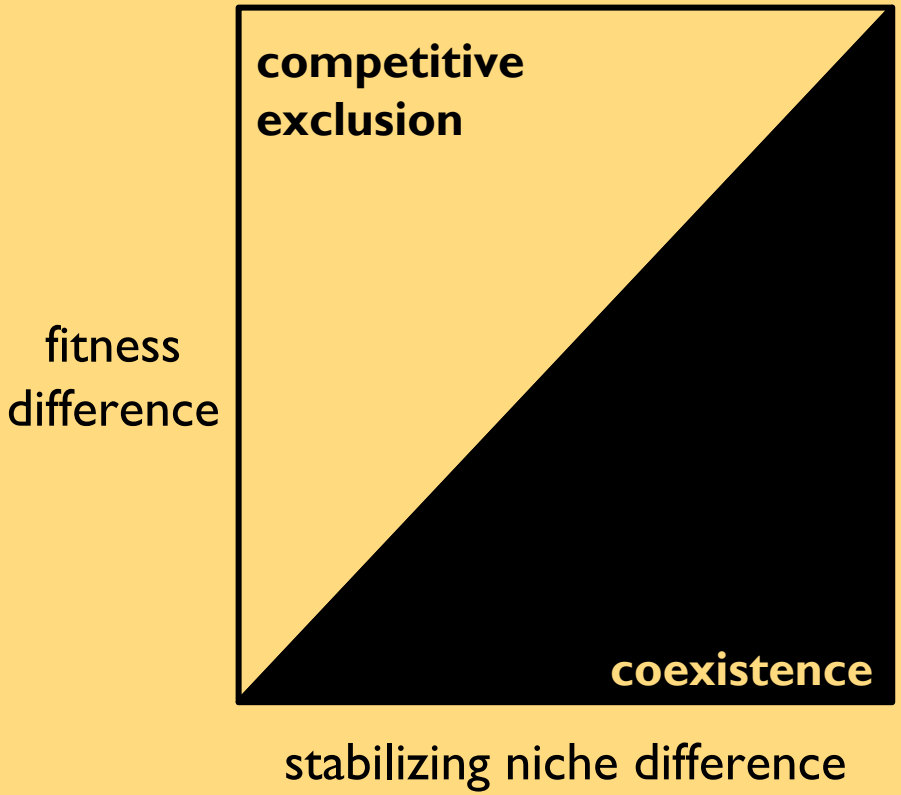
Literature review

Writeup

Projected timeline

Analyze model across parameter space: September 2017-May 2018
Review of PSF literature: September 2017-May 2018
Conduct greenhouse experiment informed by model: Fall 2018
Start writing MS: May 2018
Submit MS: May 2019




competitive
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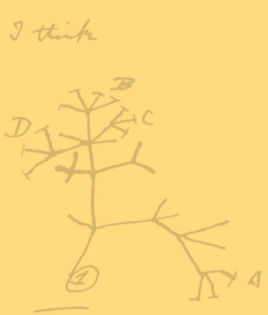

image: https://www.flickr.com/photos/rejik/
Kabani River, Kerala, India

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Angela Chen
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Aoife Galvin
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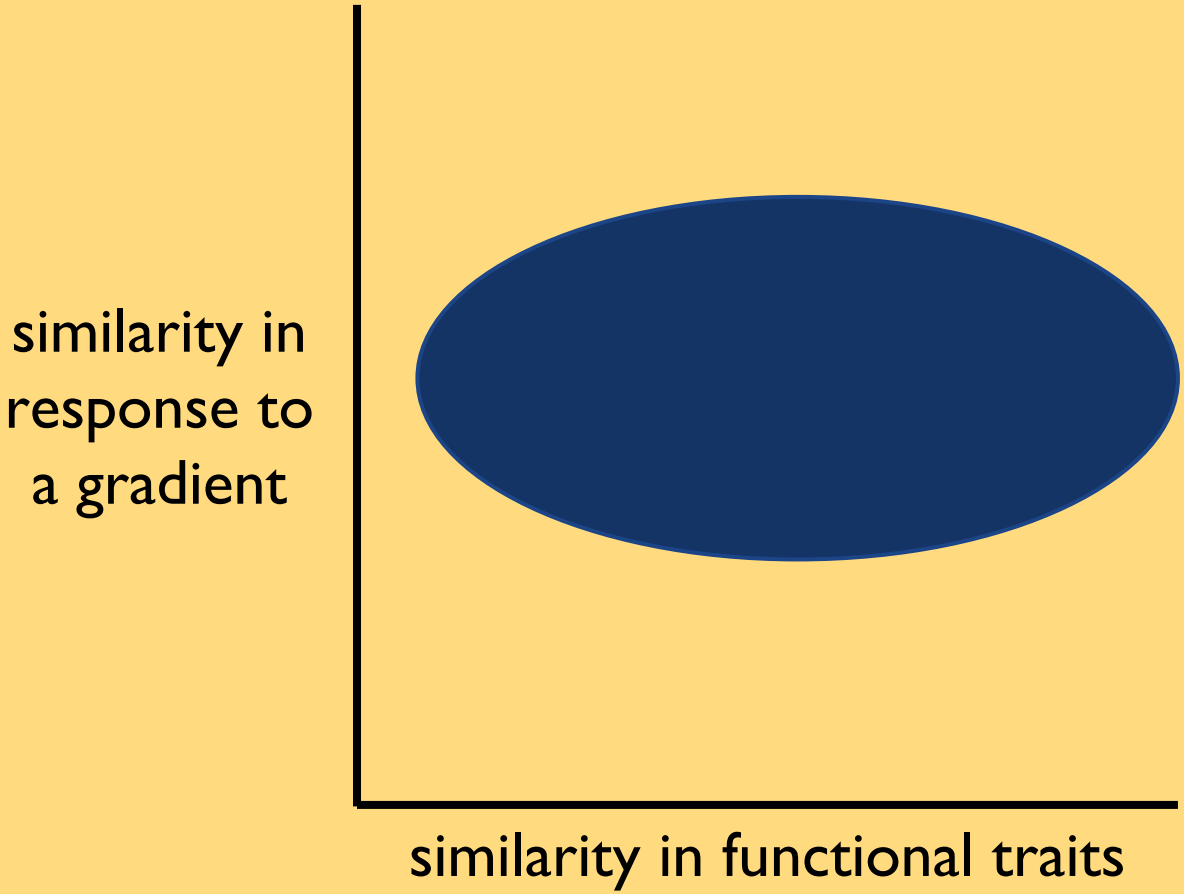
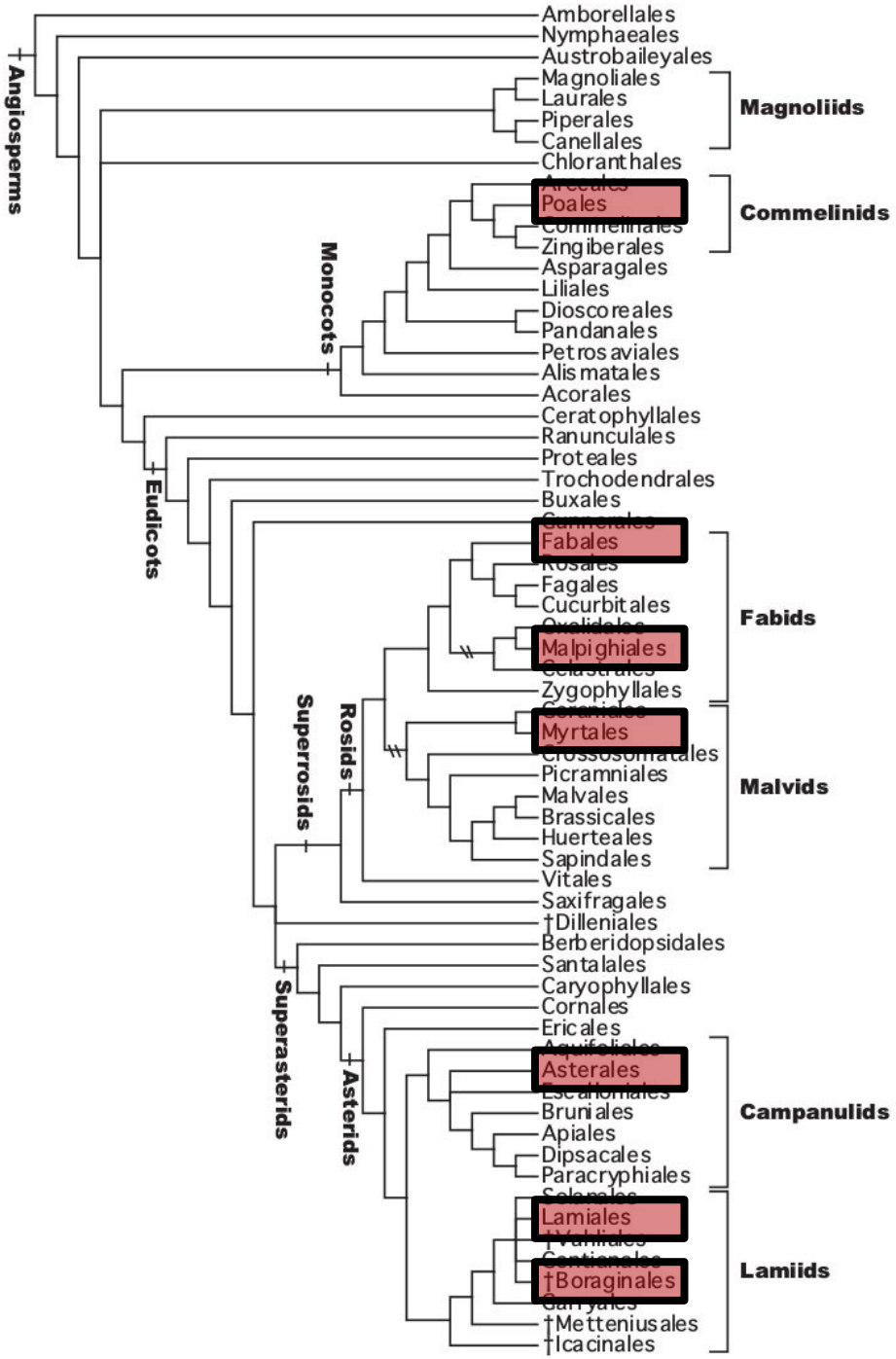
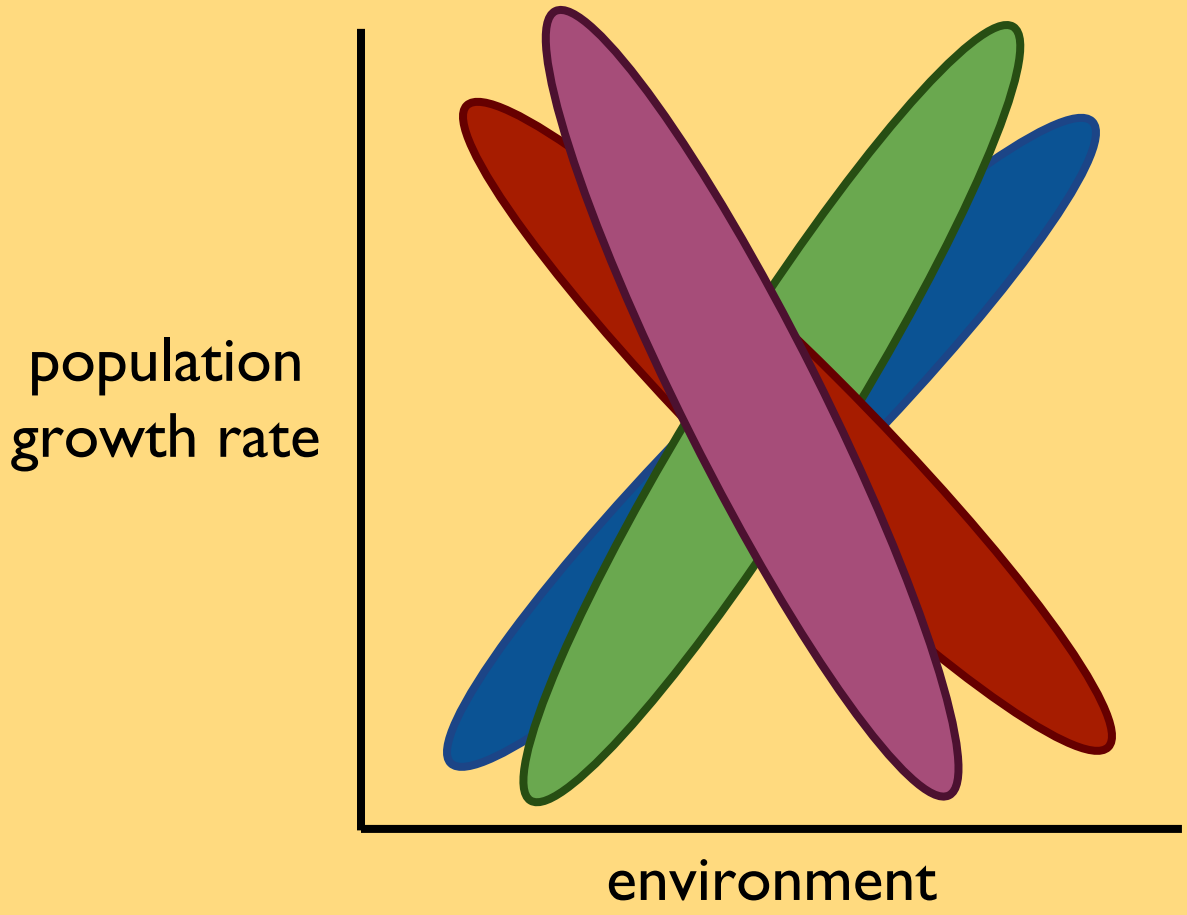
H_1- Similarity in species' demographic response is unrelated to similarity in traits




Amborellales
Nymphaeales
Austrobaileyales
Magnoliales
Laurales
Piperales
Canellales
Chloranthales
Poales
Zingiberales
Asparagales
Liliales
Dioscoreales
Pandanales
Petrosaviales
Alismatales
Acorales
Ceratophyllales
Ranunculales
Proteales
Trochodendrales
Buxales
Fabales
Fagales
Cucurbitales
Malpighiales
Zygophyllales
Myrtales
Picramniales
Malvales
Brassicales
Huerteales
Sapindales
Vitales
Saxifragales
†Dilleniales
Berberidopsidales
Santalales
Caryophyllales
Cornales
Ericales
Asterales
Bruniales
Apiales
Dipsacales
Paracryphiales
Lamiales
†Boraginales
†Metteniusales
†Icacinales
†Angiosperms
Monocots
Eudicots
Superrosids
Rosids
Superasterids
Asterids
Magnoliids
Commelinids
Fabids
Malvids
Campanulids
Lamiids


population
growth rate
environment


population
growth rate
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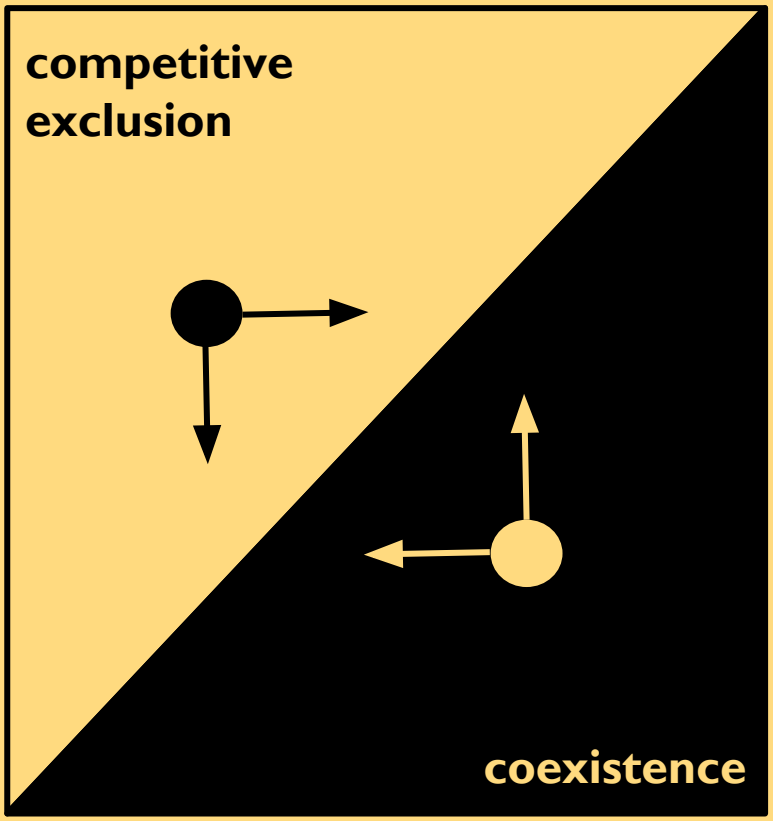


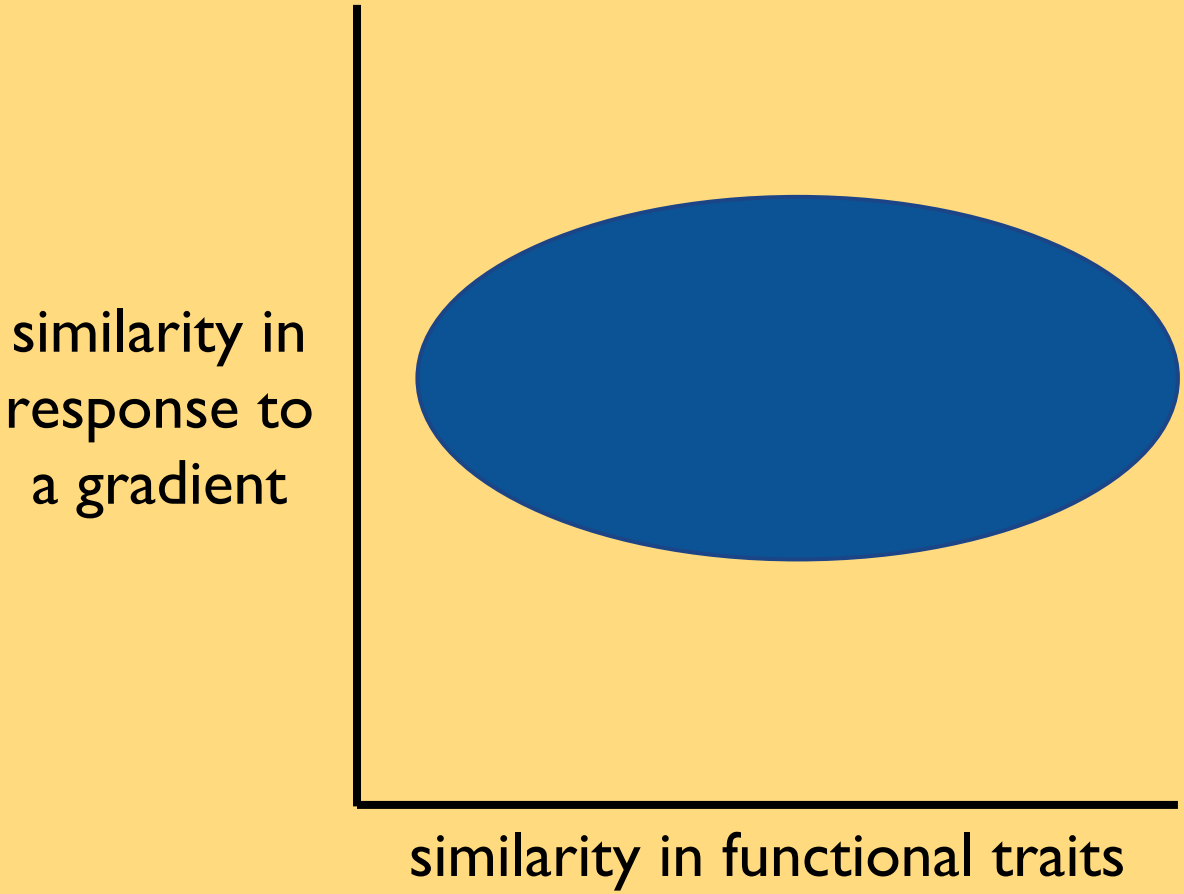
fitness
difference

stabilizing niche difference

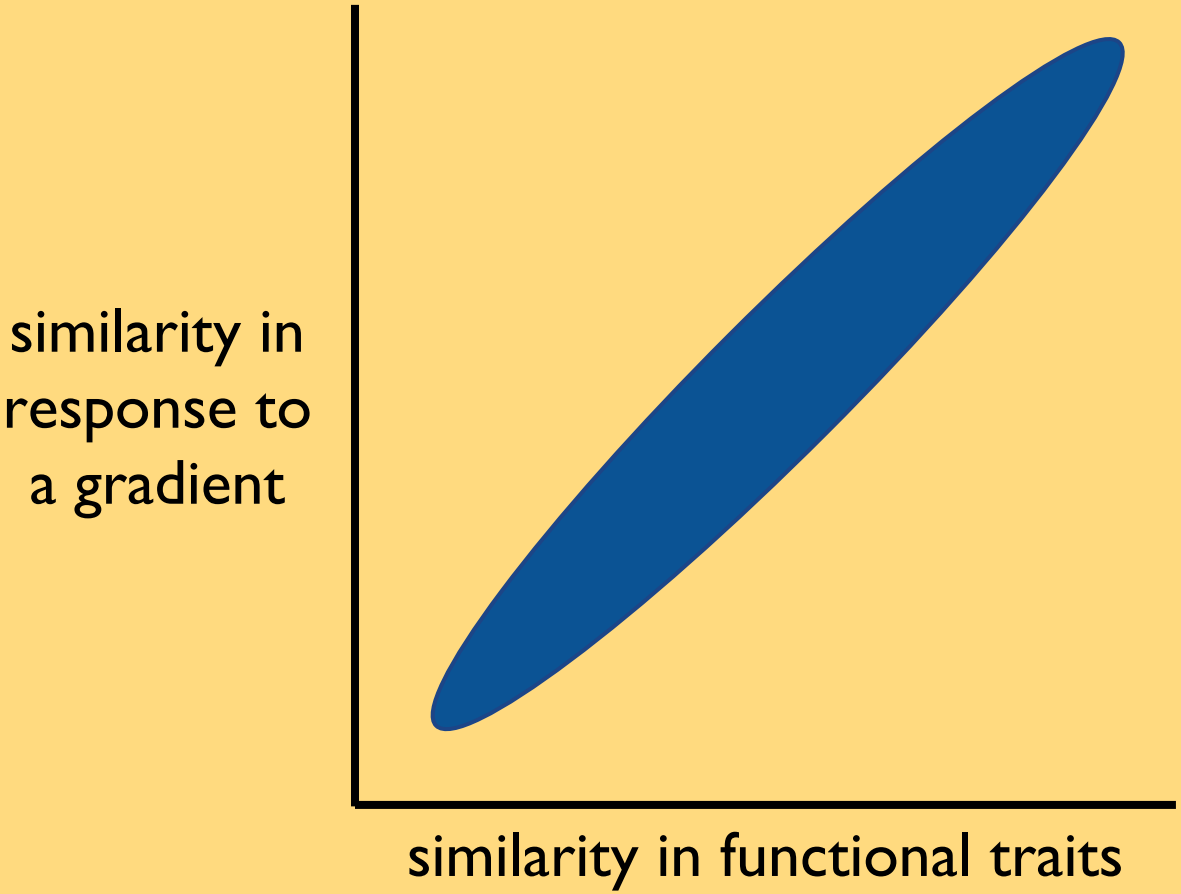
$$\rho = \frac{\Sigma_l \frac{C_{jl} V_l C_{kl}}{r_l^R \alpha_I^R} + \Sigma_m \frac{a_{jm} w a_{km}}{r_m^P \alpha_m^P}}{\sqrt{\left(\Sigma_l \frac{c_{jl}^2 v_l}{r_l^R \alpha_l^R} + \Sigma_l \frac{a_{jm}^2 w}{r_m^P \alpha_m^P}\right)\left(\Sigma_l \frac{c_{kl}^2 v_l}{r_l^R \alpha_l^R} + \Sigma_l \frac{a_{km}^2 w}{r_m^P \alpha_m^P}\right)}}$$

$$\kappa_j = \frac{\sum_l \frac{C_{jl} v_l}{\alpha_l^R} - \sum_m \frac{a_{jm}}{\alpha_m^P} - \mu_j}{\sqrt{\left(\sum_l \frac{c_{jl}^2 v_l}{r_l^R \alpha_l^R} + \sum_m \frac{a_{jm}^2 w}{r_m^P \alpha_m^P}\right)}}$$

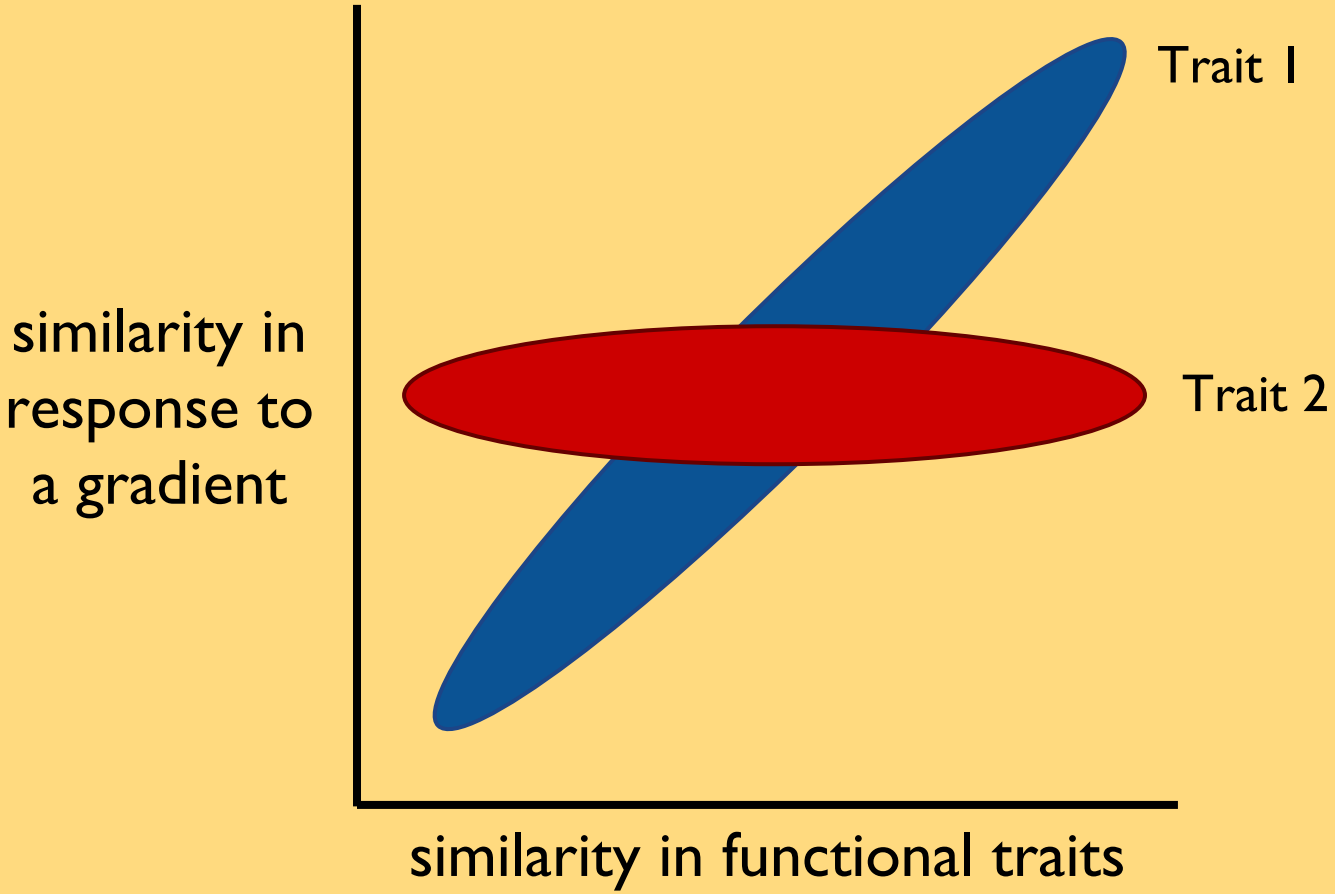
H_1- Similarity in species' demographic response is unrelated to similarity in traits

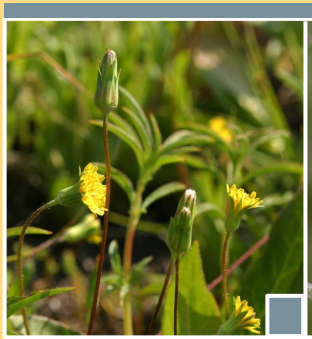


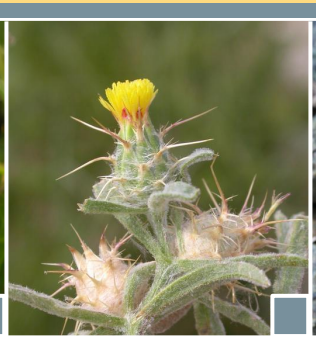
H_2- Similarity in species' demographic response is predicted by similarity in traits



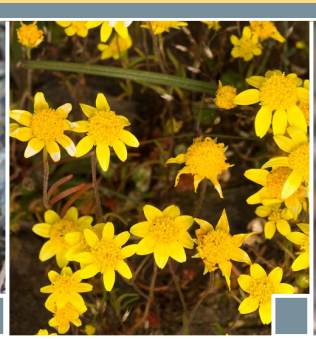
H_3- Species vary in their response to different environmental gradients, and similarity in response is predicted by similarity in different traits




Uropappus lindleyi

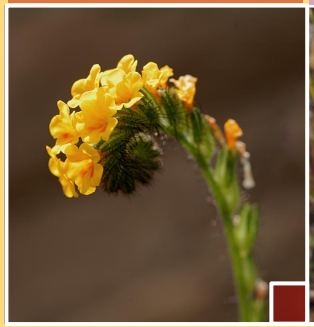

Centaurea melitensis


Chaenactis glabriuscula

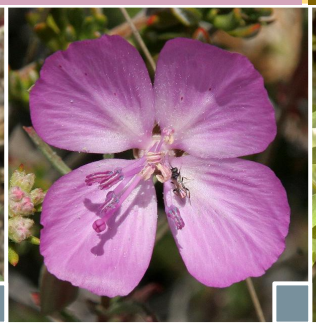

Lasthenia californica


Hemizonia congesta


Micropus californicus


Amsinckia menziesii


Clarkia purpurea


Clarkia bottae


Euphorbia peplus

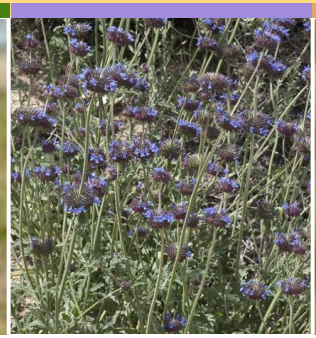

Medicago polymorpha

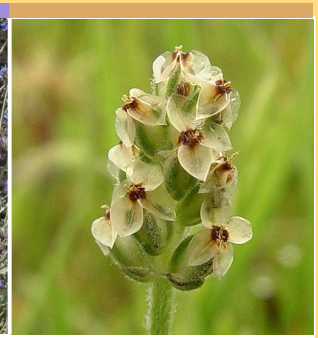

Acmispon wrangelianus


Bromus madritensis


Hordeum murinum


Vulpia microstachys


Salvia columbariae


Plantago erecta

Images from CalPhotos (http://calphotos.berkeley.edu/)