Biodiversity and information theory

William Godsoe

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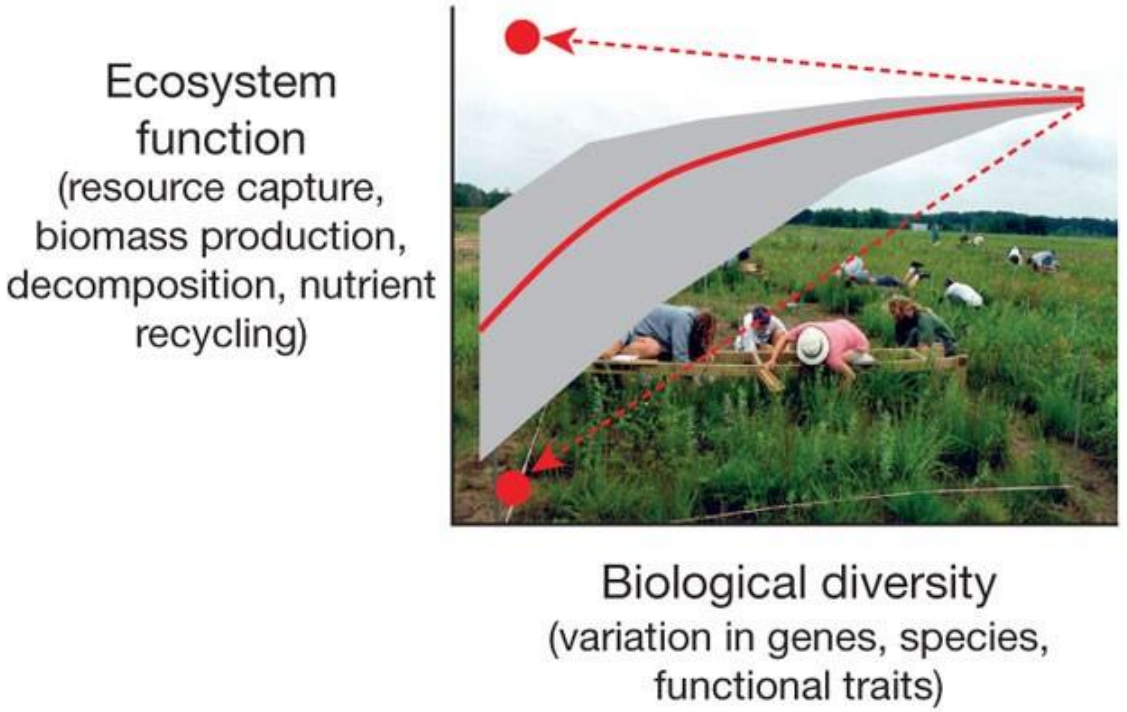
Diversity is important



Cardinale et al. (2012) Science

Changes in diversity are hard to predict

Trends in Ecology & Evolution

Review

How Should Beta-Dive
Inform Biodiversity
Conservation?

Jacob B. Socolar,[1,*] James J. Gilroy,[2] William E
David P. Edwards[4,*]

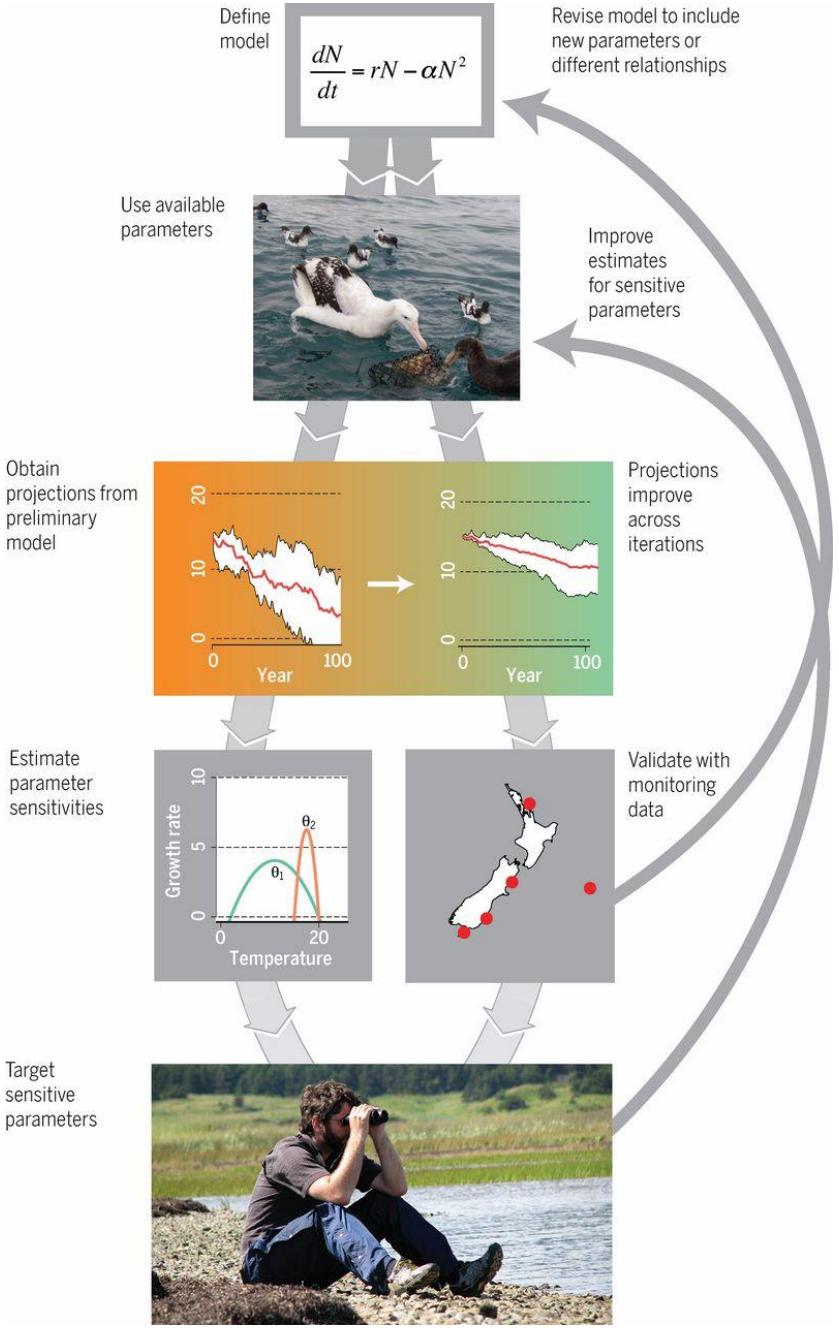
To design robust protected area networks, accurately
losses, or understand the processes that maintain specie
vation science must consider the organization of biodive
tral is beta-diversity – the component of regional diversi

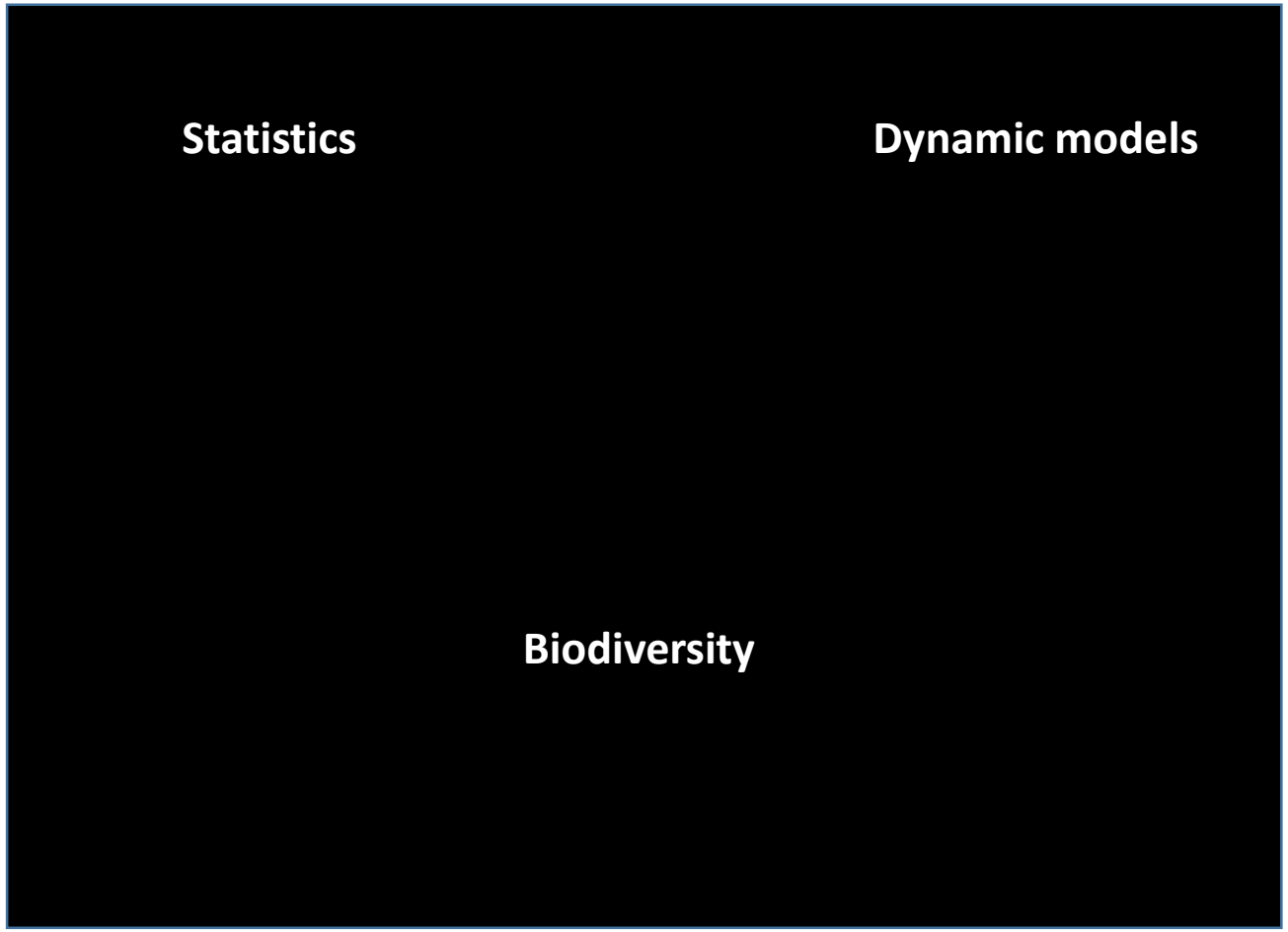
REVIEW SUMMARY

CLIMATE CHANGE

Improving the forecast for biodiversity under climate change

M. C. Urban,* G. Bocedi, A. P. Hendry, J.-B. Mihoub, G. Pe'er, A. Singer, J. R. Bridle, L. G. Crozier, L. De Meester, W. Godsoe, A. Gonzalez, J. J. Hellmann, R. D. Holt, A. Huth, K. Johst, C. B. Krug, P. W. Leadley, S. C. F. Palmer, J. H. Pantel, A. Schmitz, P. A. Zollner, J. M. J. Travis




Statistics
Dynamic models
Biodiversity

Statistics

$$-\sum p_i log(p_i)$$

Dynamic models

$$-\sum p_i log(p_i)$$

Biodiversity

$$-\sum p_i log(p_i)$$

Outline

- Biodiversity obscures the mechanisms ecologists tend to study
- Mechanisms that change species' rarity change biodiversity
- Contemporary changes reflect these mechanisms

OIKOS

Forum

Species interactions and diversity: a unified framework using Hill numbers

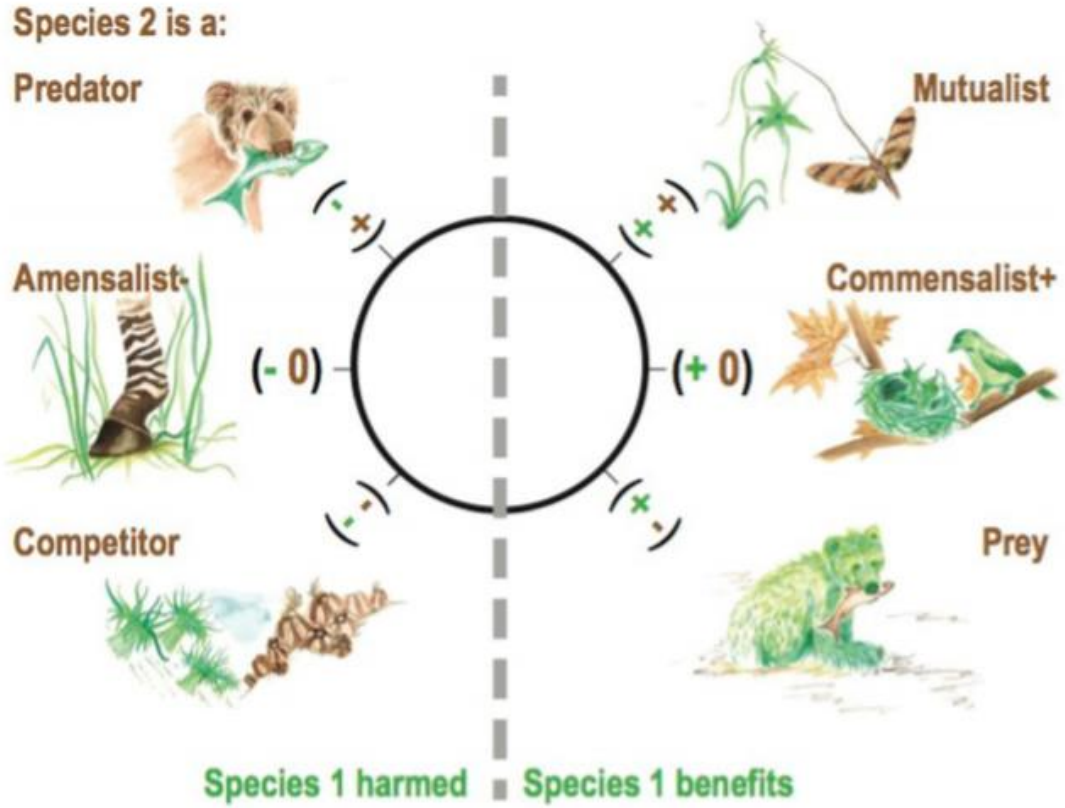
William Godsoe, Rua Murray and Ryosuke Iritani

W. Godsoe (https://orcid.org/0000-0003-1697-6916) ✉ (william.godsoe@lincoln.ac.nz), Dept of Pest Managament and Conservation, Lincoln Univ., Lincoln, New Zealand. – R. Murray, School of Mathematics and Statistics, Univ. of Canterbury, Christchurch, New Zealand. – R. Iritani, RIKEN Interdisciplinary Theoretical and Mathematical Sciences (iTHEMS), Wako, Japan.

Part 1: Biodiversity obscures the mechanisms ecologists tend to study

- Biotic interactions and diversity have different units
- Graphical methods can be used to link the units
- These show how different biotic interactions can have identical effects on diversity

Community ecology has been concerned with biotic interactions



Biotic interactions change absolute abundances

$$\frac{1}{n_i}\frac{dn_i}{dt} = \underbrace{r_i - f_i(n_i)}_{\substack{intraspecific \\ growth}} + \underbrace{\sum_k g_{ij}(n_i, n_j)}_{\substack{biotic \\ interactions}}$$

Diversity summarizes information on relative abundances

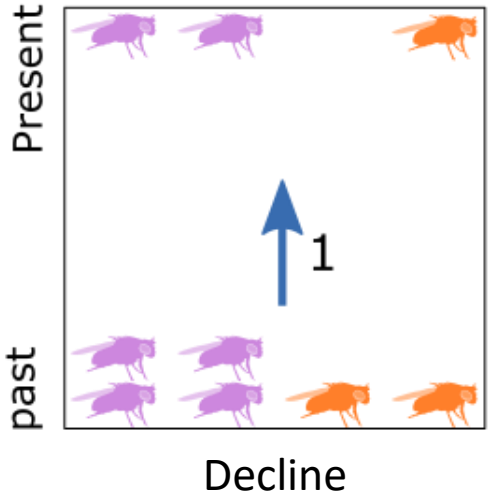
$$\sum_i p_i(-log(p_i))$$

Shannon entropy

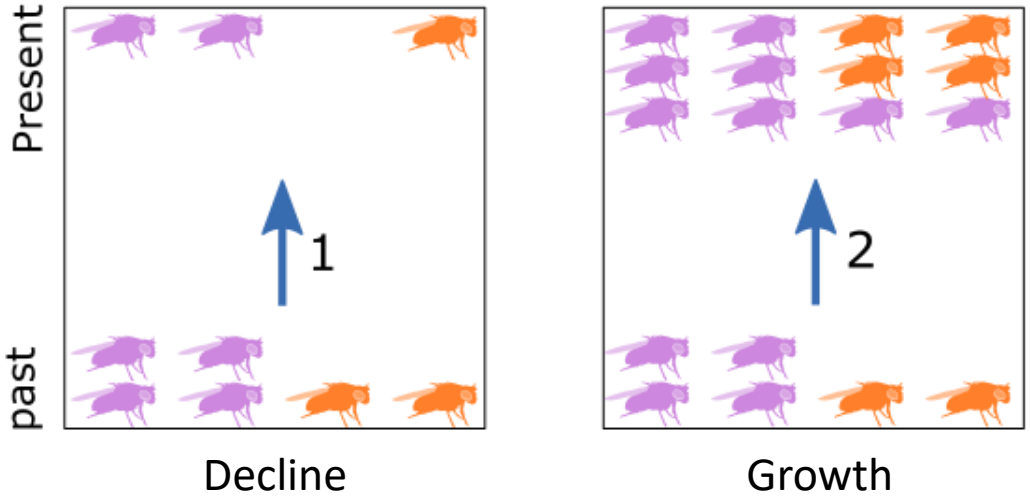
$${}^{q}D = \left(\sum_i p_i^q\right)^{\frac{1}{1-q}}$$

Hill numbers

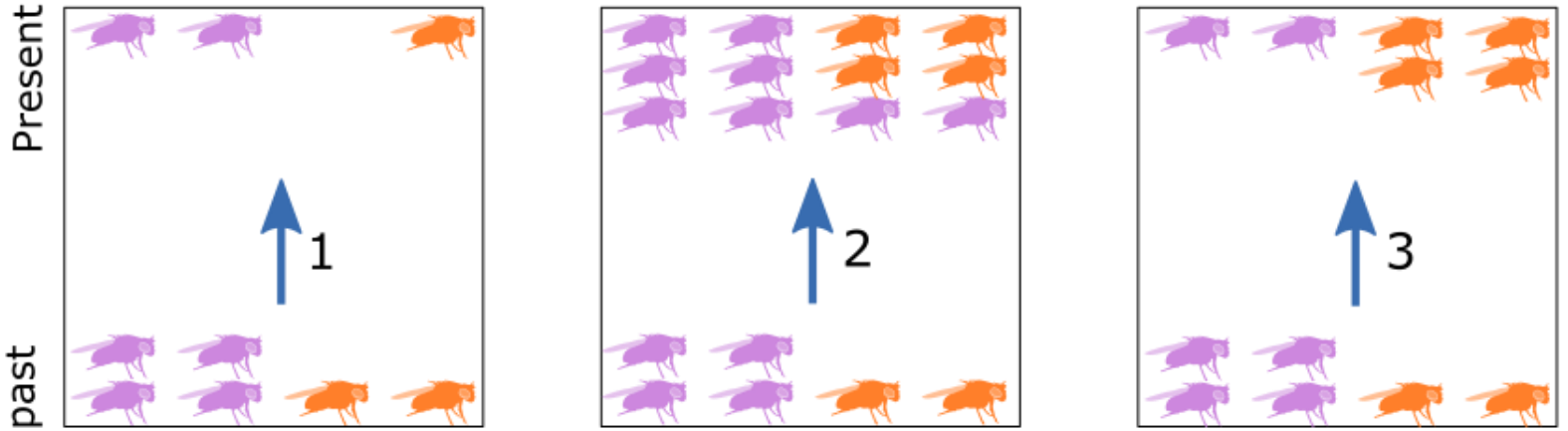
Diversity misses changes in abundance



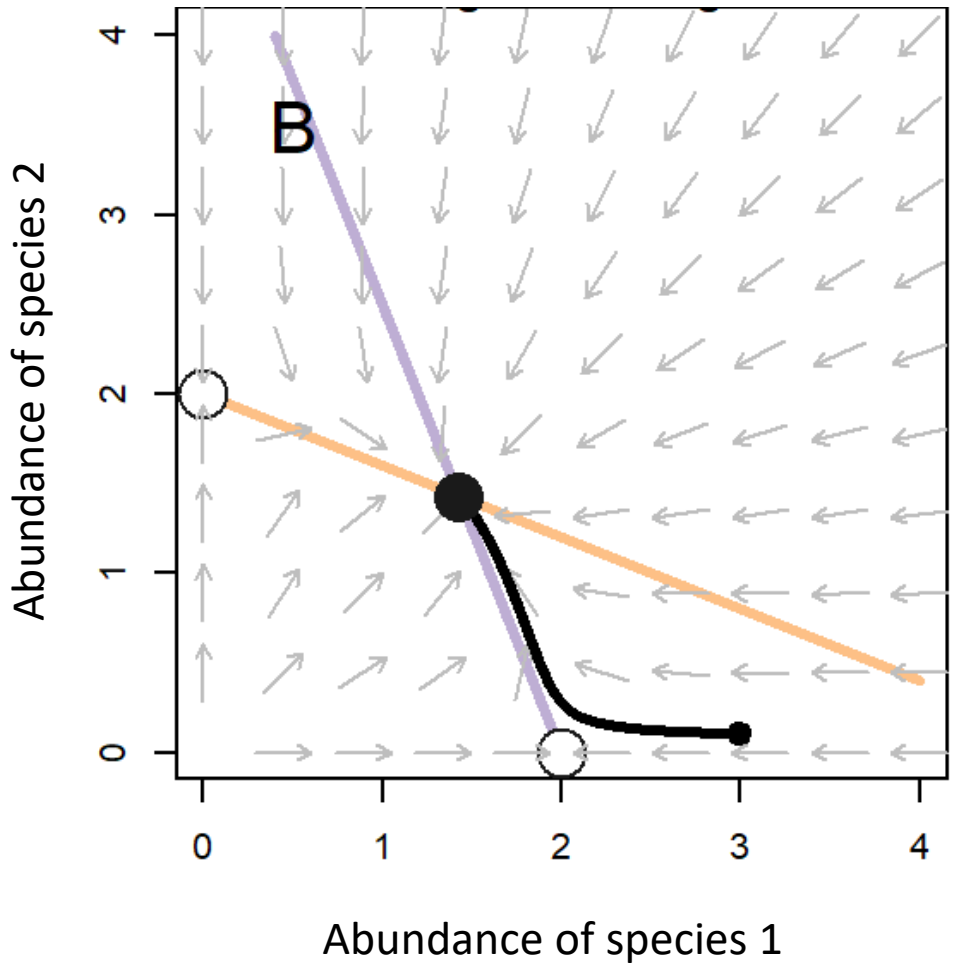
Diversity misses changes in abundance



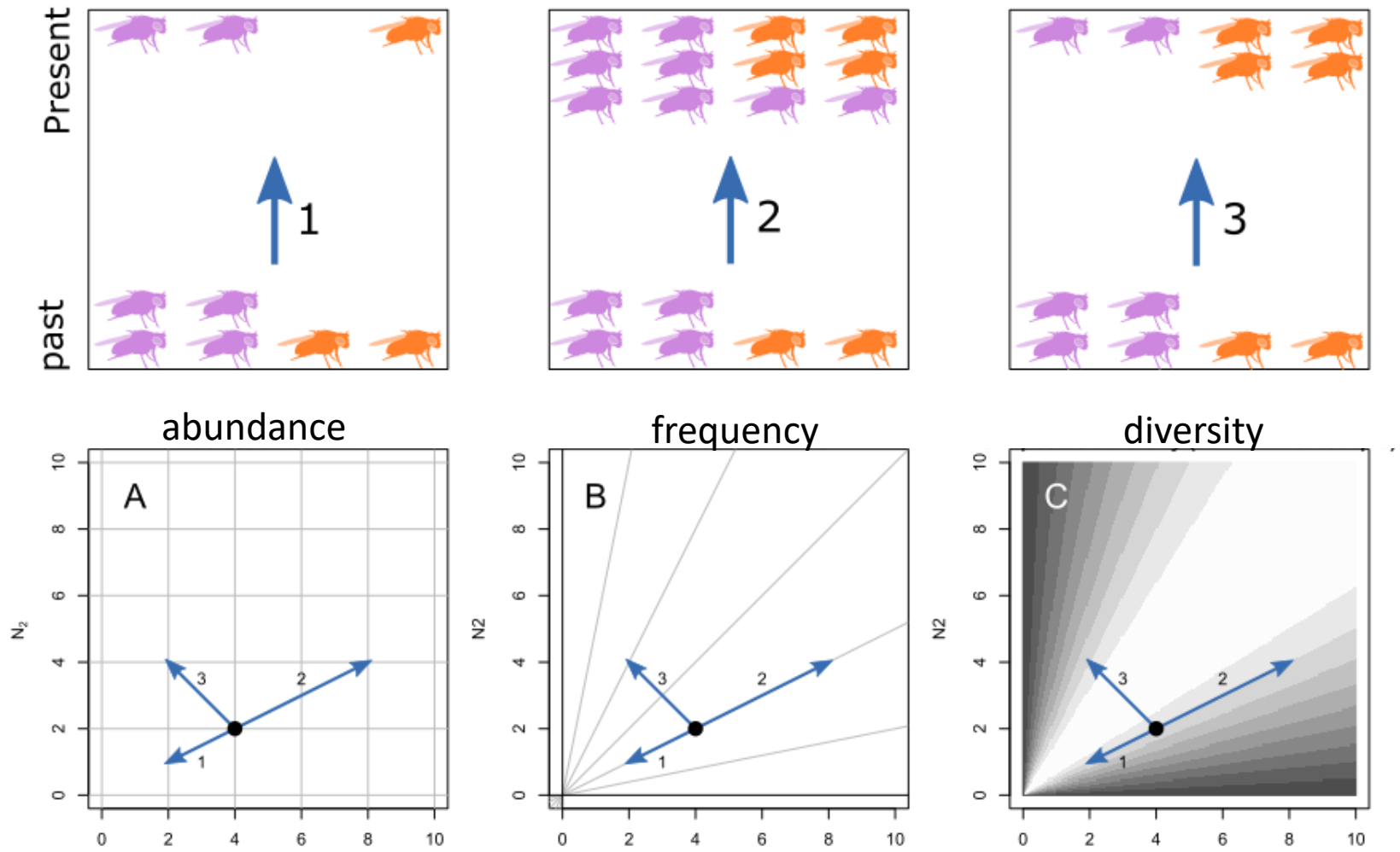
Diversity misses changes in abundance



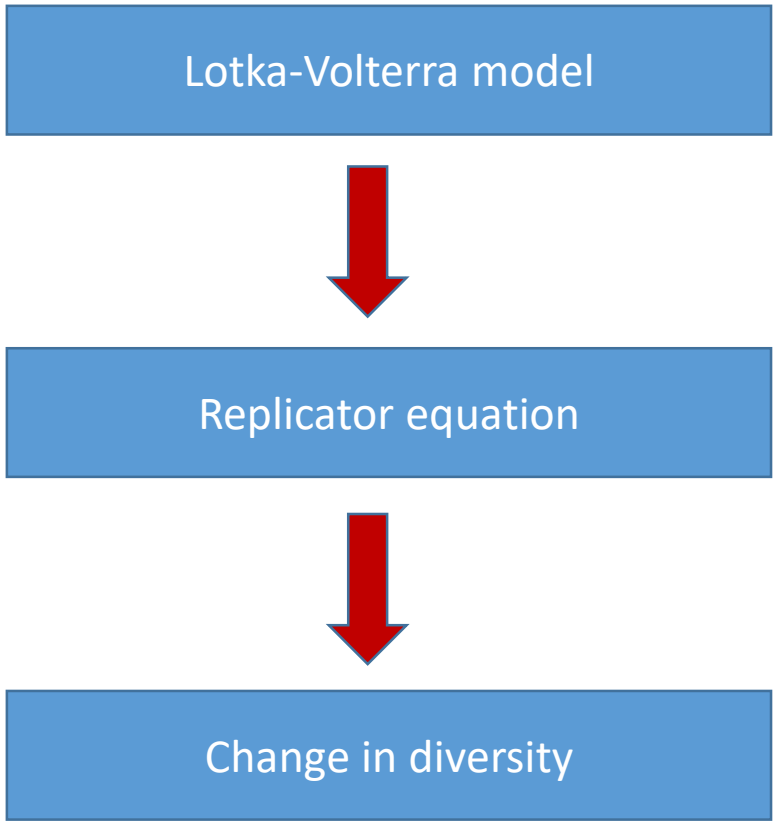
Phase portraits tend to present absolute abundances



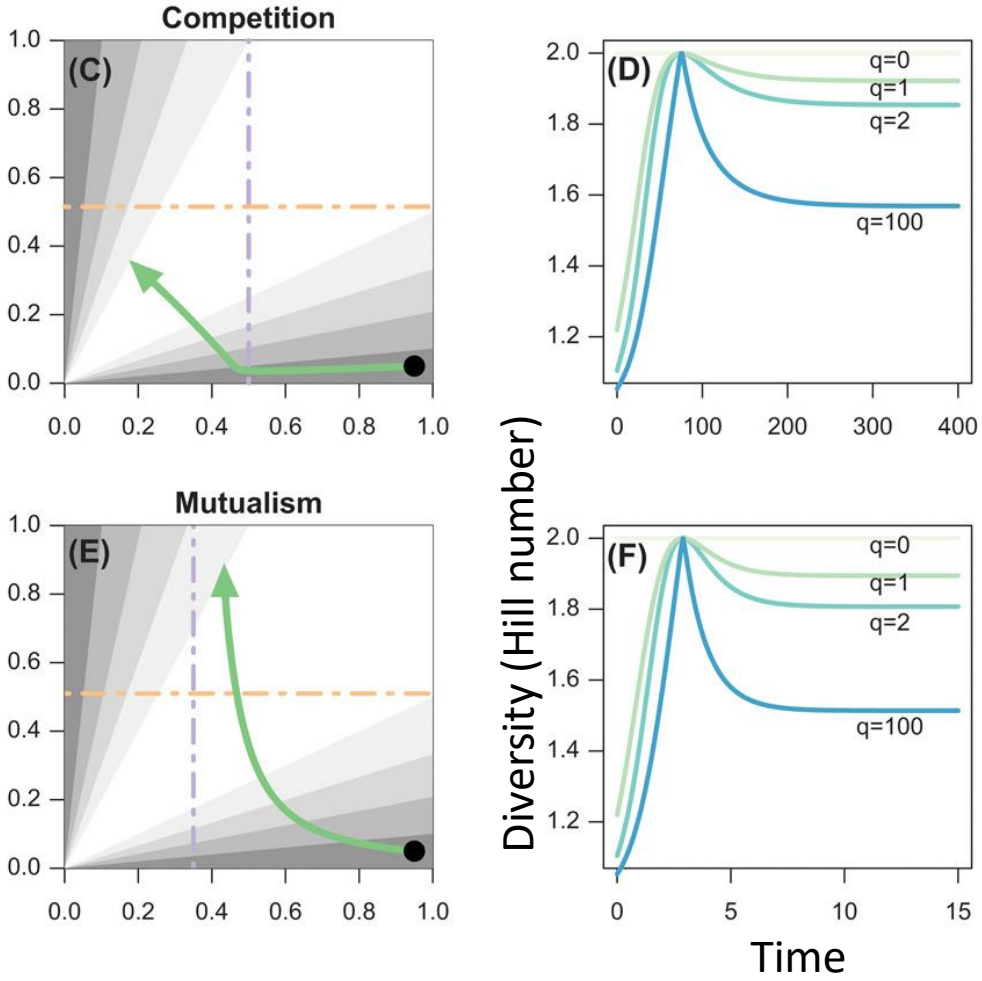
We can fix this



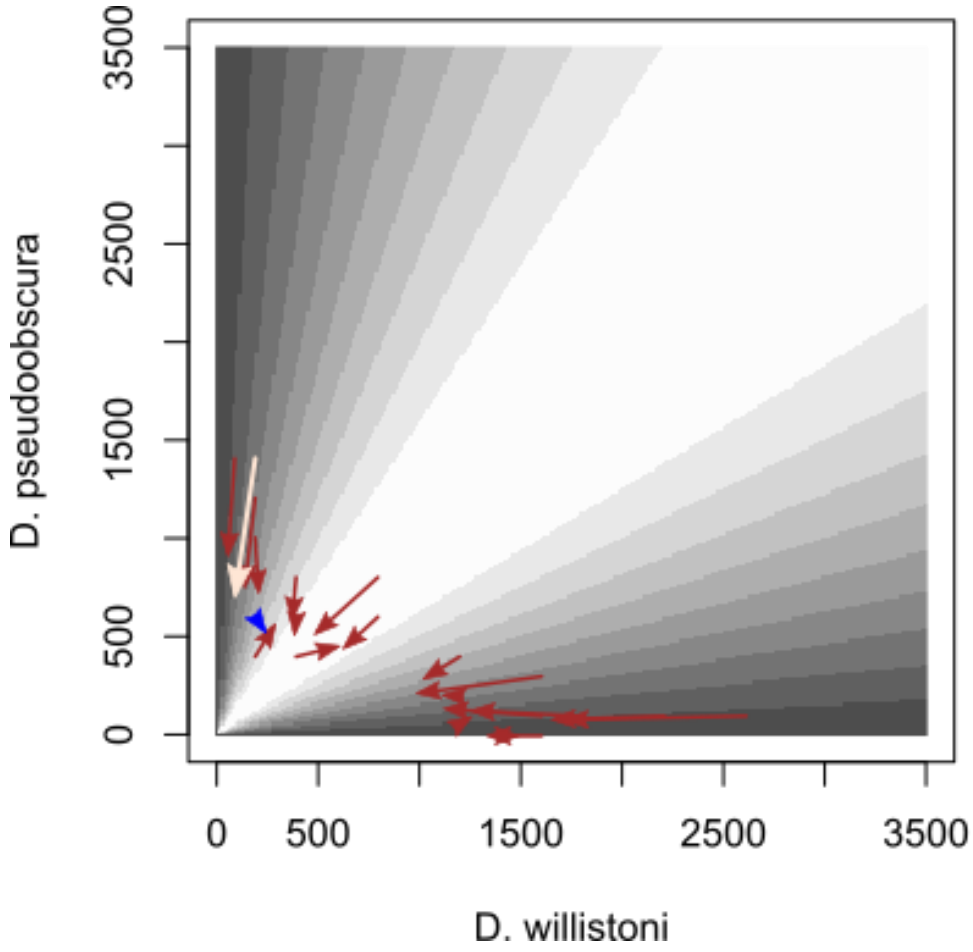
The paper outlines the math



Different species interactions can produce the same diversity change

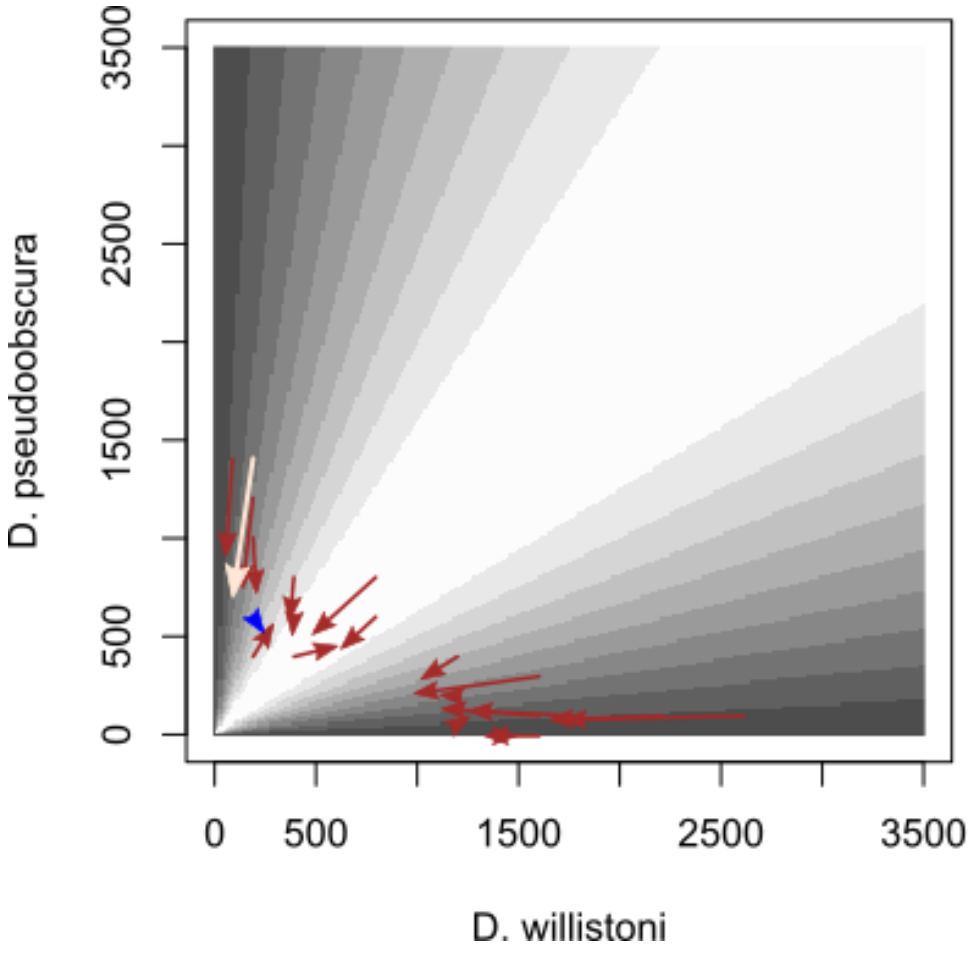


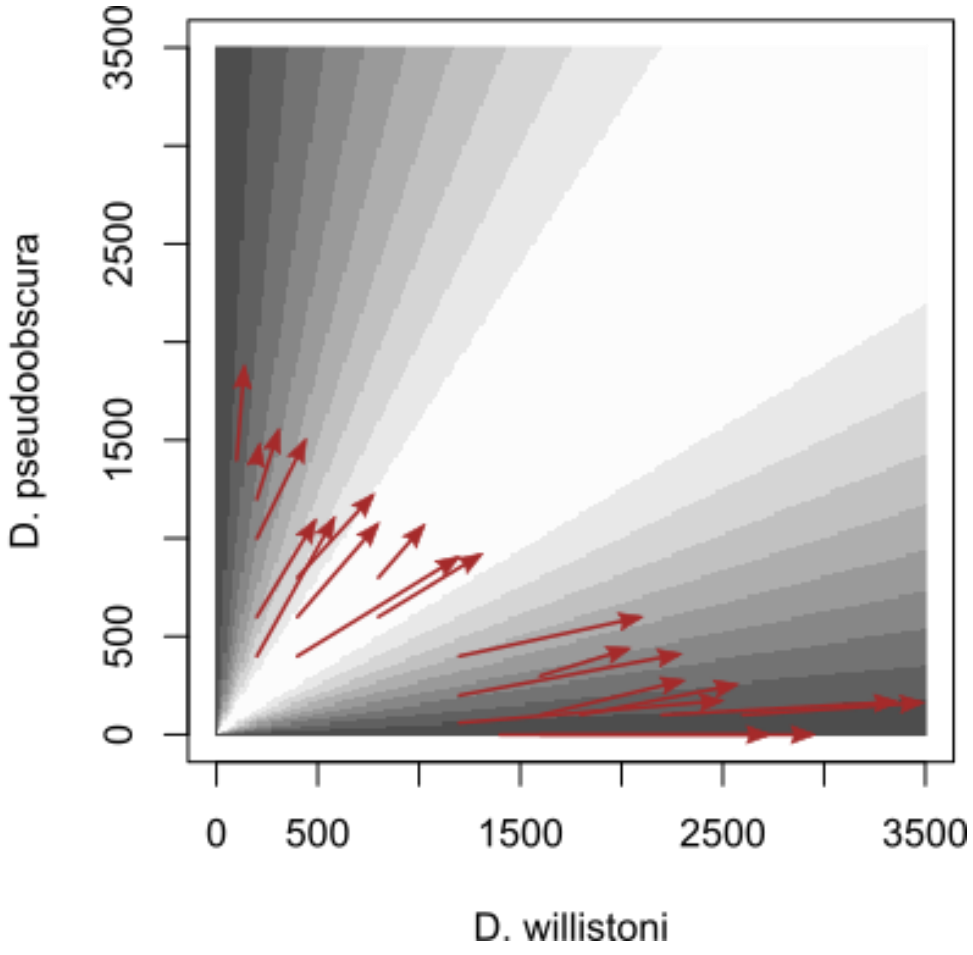
Different species interactions can produce the same diversity change



Ayala et al. 1973

Different species interactions can produce the same diversity change





When it comes to diversity, we can learn from (old) twitter

Summary part I

- Biotic interactions change absolute abundances but diversity depends on relative abundances
- Phase portraits can be modified to link biotic interactions and diversity
- These methods make clear that many biotic interactions can produce the same changes in diversity

Part II: Mechanisms that change species' rarity change biodiversity

Theoretical Ecology
https://doi.org/10.1007/s12080-020-00478-3

ORIGINAL PAPER

Selection and biodiversity change

William Godsoe[1] · Katherine E. Eisen[2] · Daniel Stanton[3] · Katherine M. Sirianni[4]

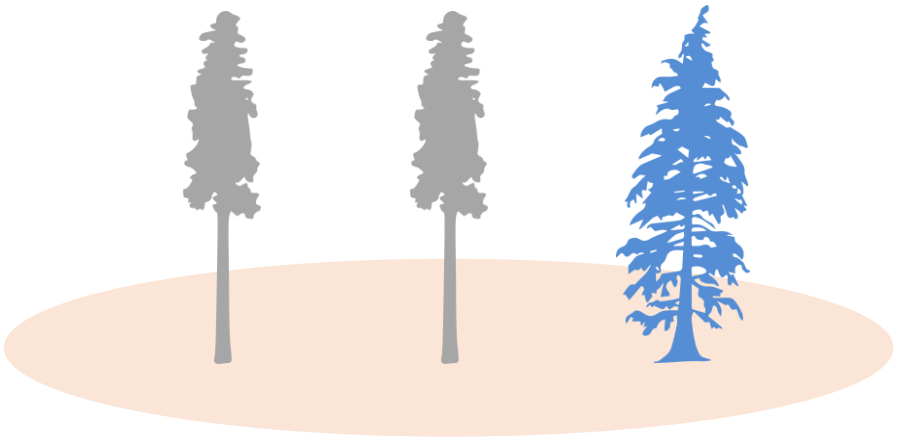
Received: 9 February 2020 / Accepted: 29 July 2020

Individuals and biodiversity

$$\sum_i p_i \left(-log(p_i)\right)$$

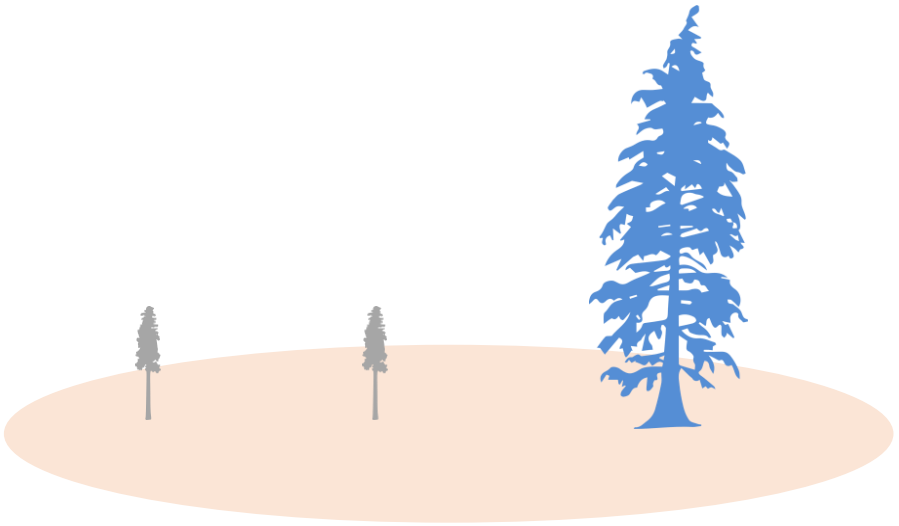
Each individual is assigned a rarity score

$$\sum_i p_i \left(-log(p_i)\right)$$



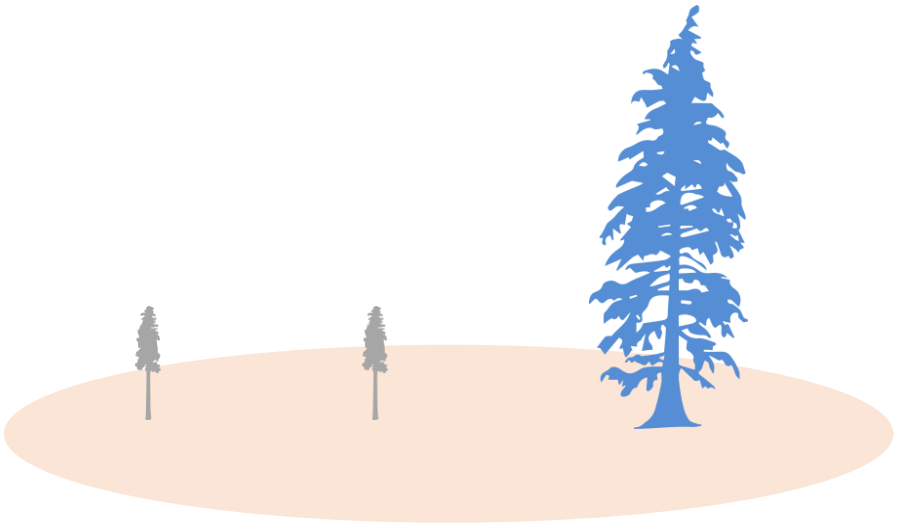
It helps me to picture these rarity scores

$$\sum_i p_i \underbrace{\left(-log(p_i)\right)}_{rarity}$$



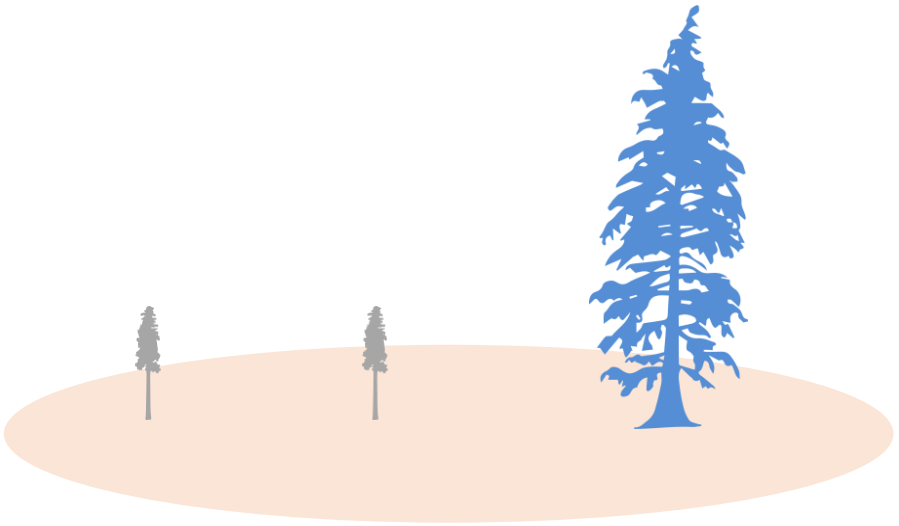
Overall diversity is an average of these scores

$$\sum_i p_i \underbrace{\left(-log(p_i)\right)}_{rarity}$$



I'll call these rarity scores z

$$\sum_i p_i z_i$$



Change in diversity

$$\frac{d}{dt}\left(\sum_i p_i z_i\right)$$

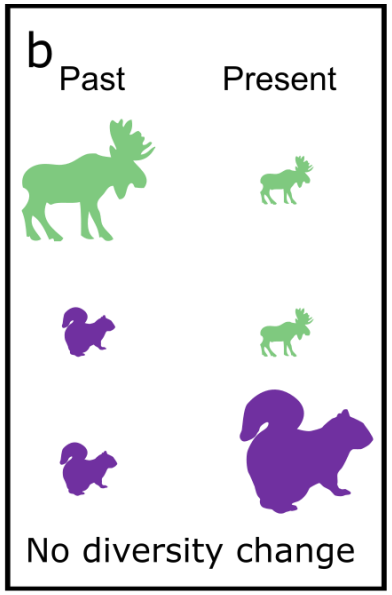
Change in diversity

$$\frac{d}{dt}\left(\sum_i p_i z_i\right) = \text{selection} + \text{transmission}$$

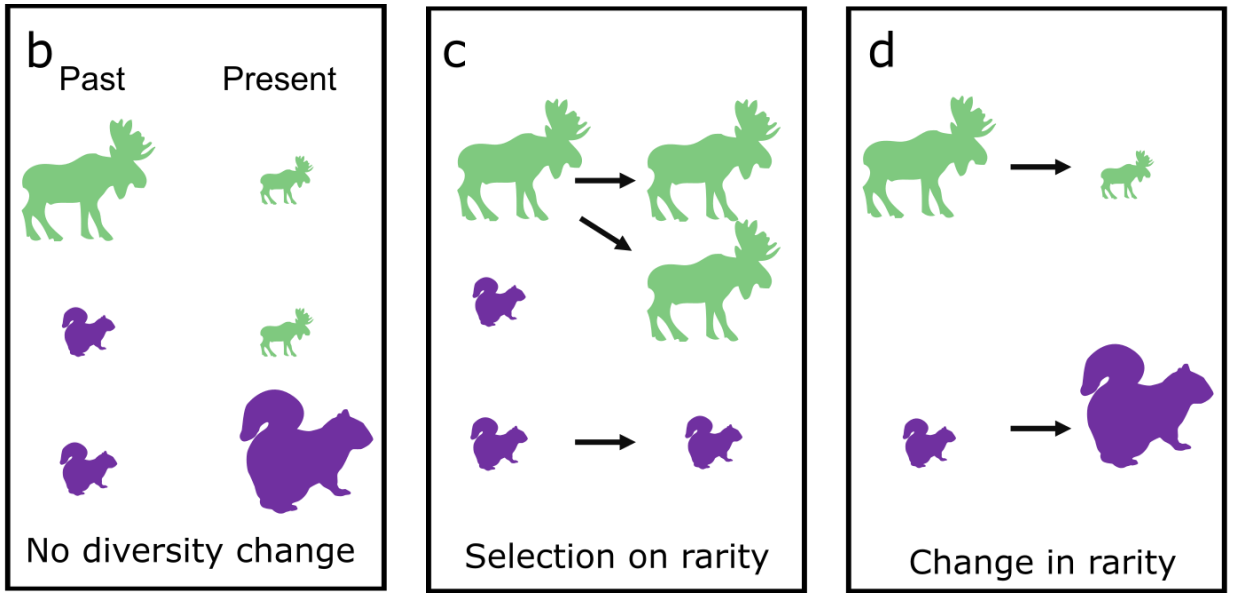
Analogous to the Price equation in evolutionary theory

- Selection describes changes in relative abundances
- Transmission describes unintuitive changes in diversity, often due to species replacements

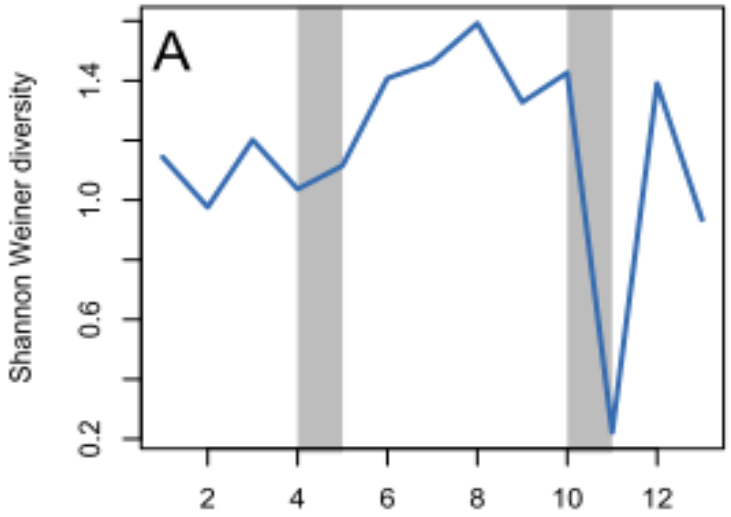
Selection and transmission can cancel



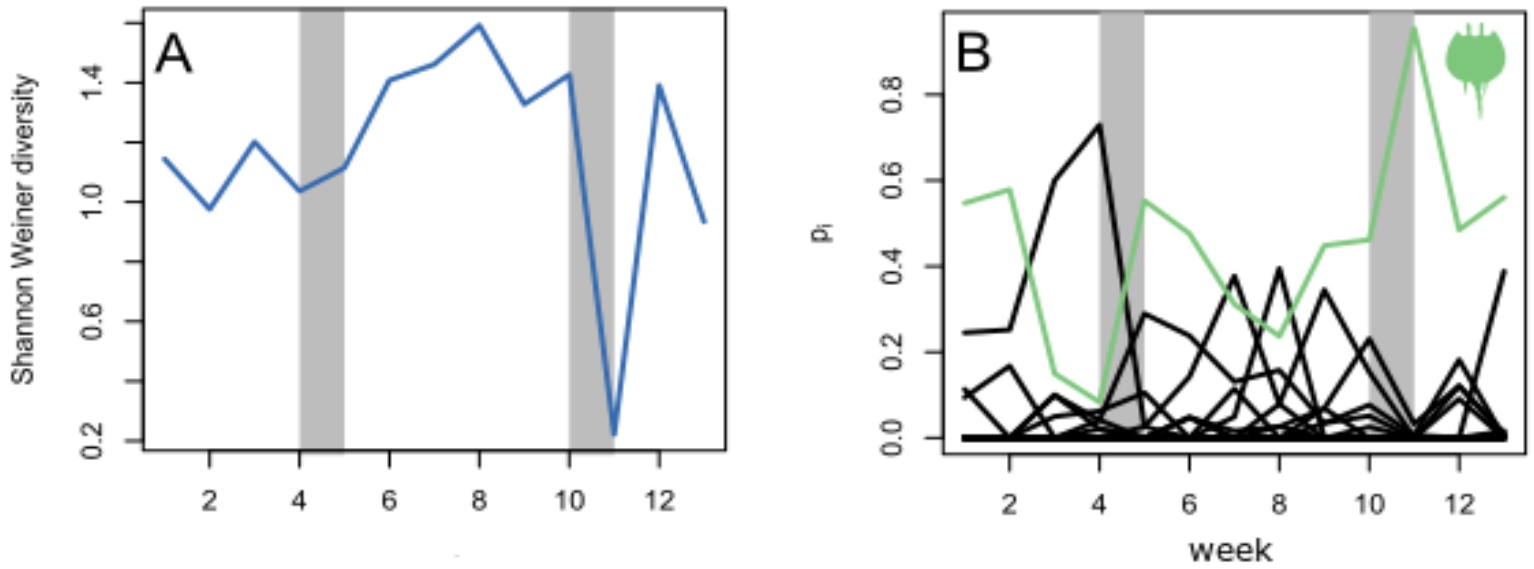
Selection and transmission can cancel



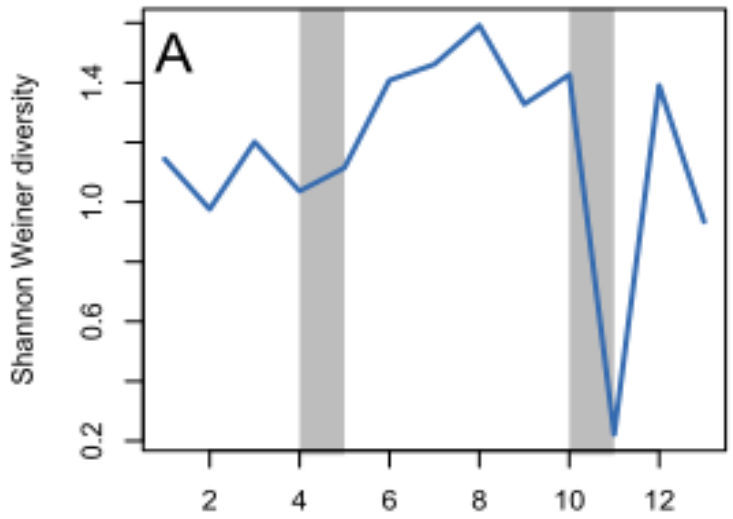
The mechanisms interact in nature

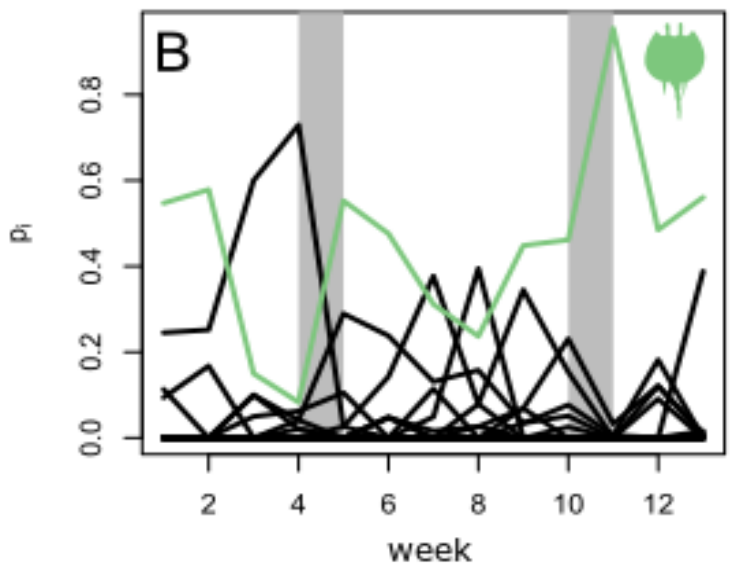


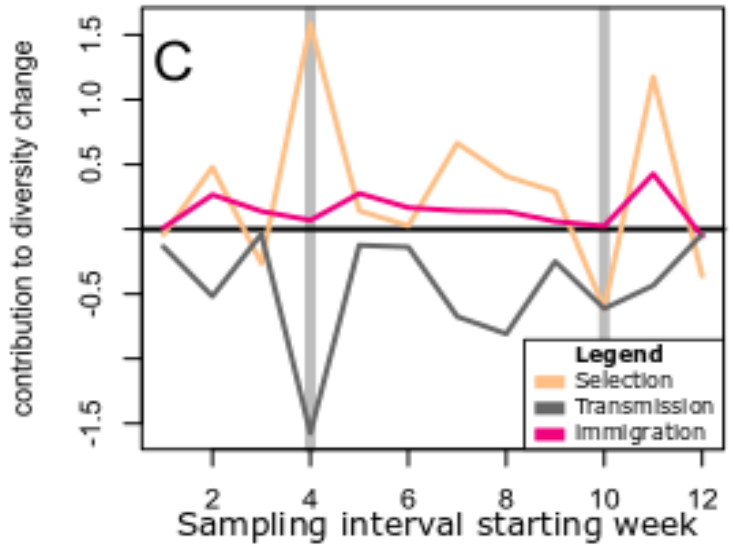
Two bouts of selection for *Brachionus rubens*



In one period rarity changes mask selection







New rules for diversity change

- Diversity summarizes individual rarity scores
- Selection occurs when rare species increase in relative abundance
- Transmission describes unintuitive shifts in rarity

Part III: measuring diversity change at large spatial scales

VOL. 199, NO. 4 THE AMERICAN NATURALIST APRIL 2022

Disentangling Niche Theory and Beta Diversity Change

William Godsoe,[1,*] Peter J. Bellingham,[2] and Elena Moltchanova[3]

1. BioProtection Research Centre, Lincoln University, Lincoln, New Zealand; 2. Manaaki Whenua–Landcare Research, Lincoln, New Zealand; and School of Biological Sciences, University of Auckland, Auckland, New Zealand; 3. School of Mathematics and Statistics, University of Canterbury, Christchurch, New Zealand

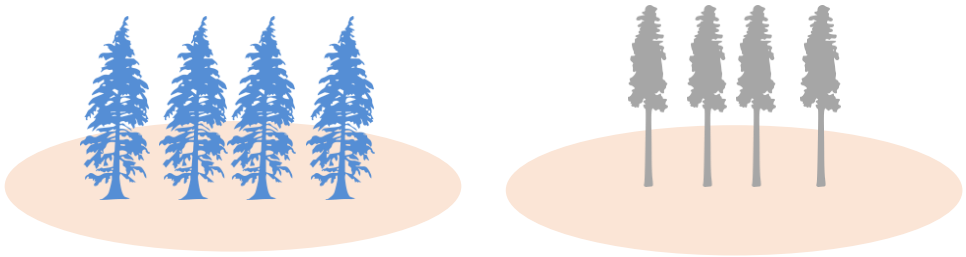
Submitted March 31, 2021; Accepted October 14, 2021; Electronically published February 18, 2022

Online enhancements: appendixes, R code. *Dryad data:* https://doi.org/10.5061/dryad.sxksn033s.

Diversity is organized spatially

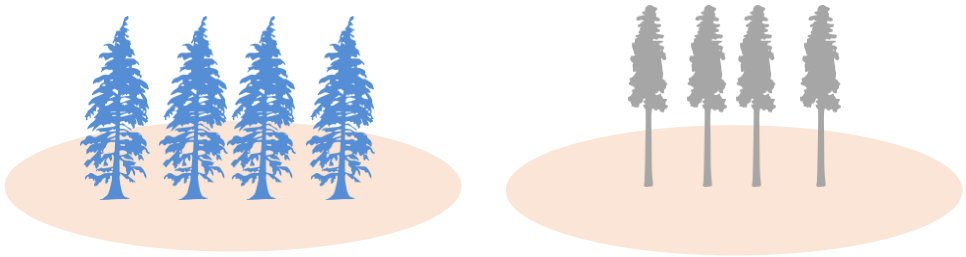
Beta diversity: dissimilarity among communities

Past



Spatial patterns of diversity change over time

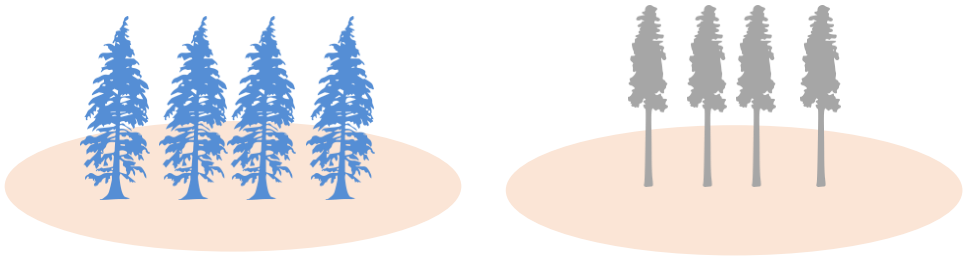
Past



Present

Biotic homogenization: decrease in beta diversity

Past

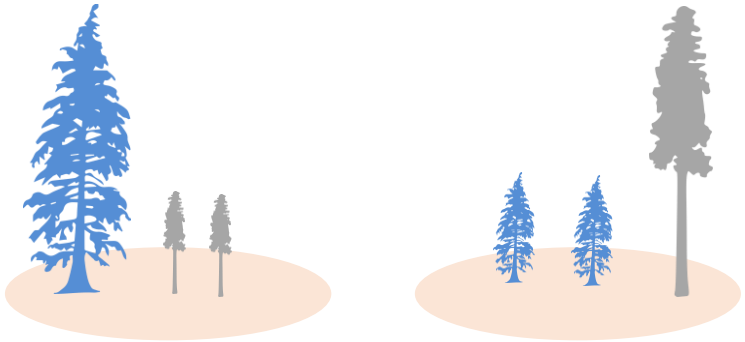


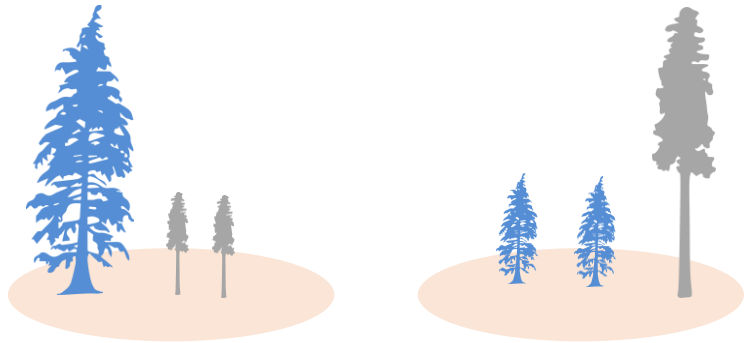
Present

In this section I will

- Identify individual contributions to beta diversity
- Use this to define mechanisms shaping diversity
- Measure these contributions in nature

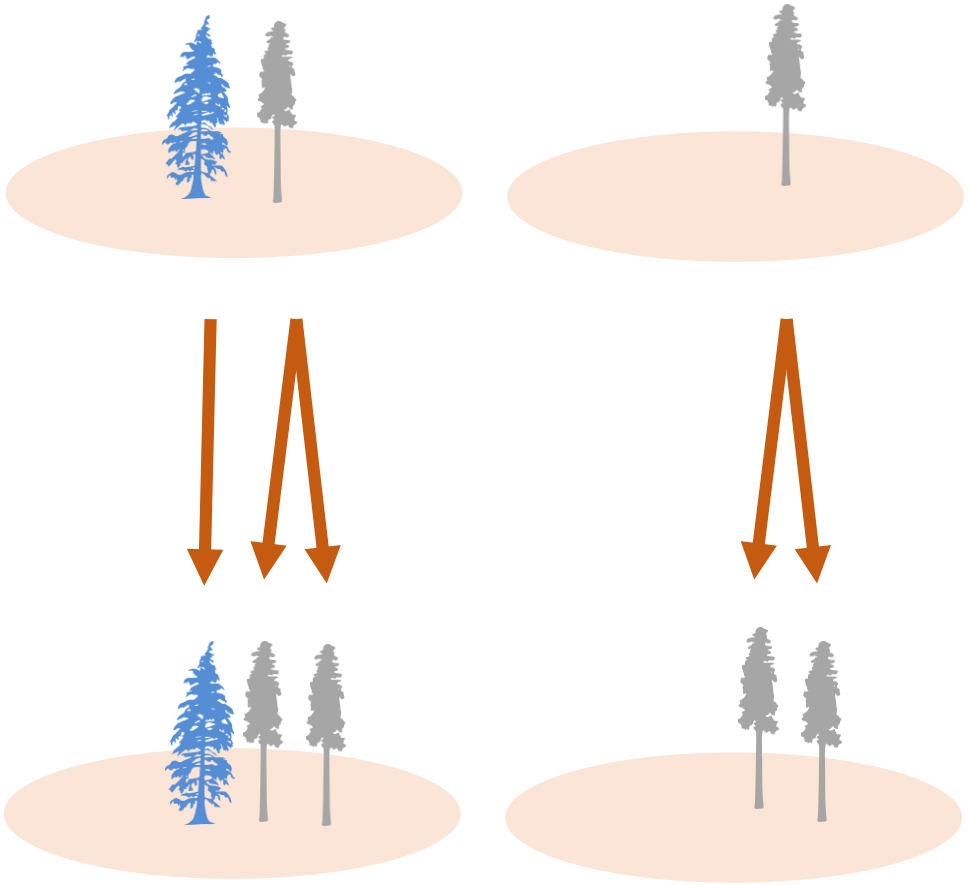
Diversity component	Individual's contribution	Visualized
Overall diversity (gamma)	$-log(p_i)$	
Diversity within communities (alpha)		
Diversity among communities (beta)		

Diversity component	Individual's contribution	Visualized
Overall diversity (gamma)	$-log(p_i)$	
Diversity within communities (alpha)	$-log(p_{i\|j})$	
Diversity among communities (beta)		

Diversity component	Individual's contribution	Visualized
Overall diversity (gamma)	$-log(p_i)$	
Diversity within communities (alpha)	$-log(p_{i\|j})$	
Diversity among communities (beta)	$z_{i\beta} = log(p_i) - log(p_{i\|j})$	

Selection on $z_{i\beta}$

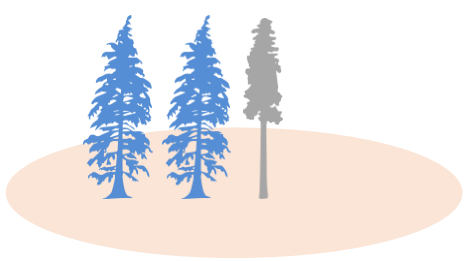
Past

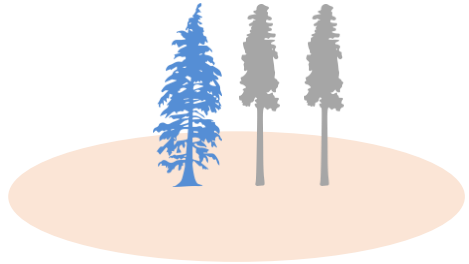


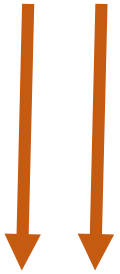
Present

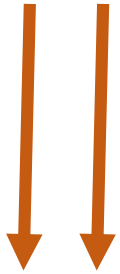
Transmission on $z_{i\beta}$

Past









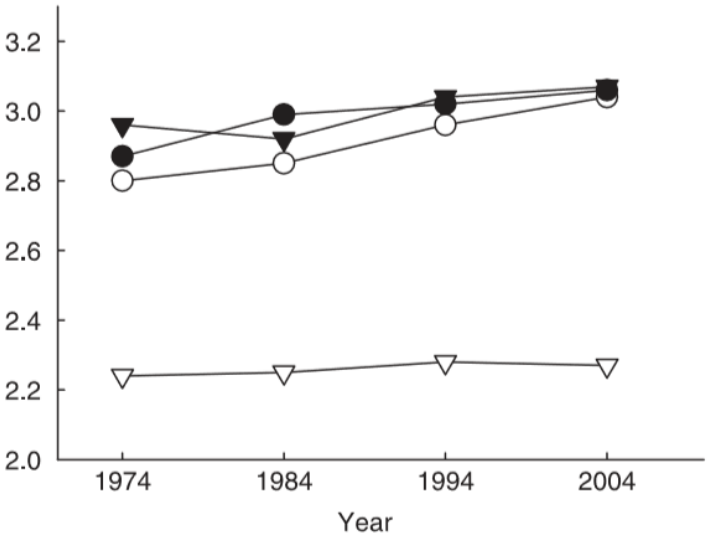
Present

Blue mountains of Jamaica

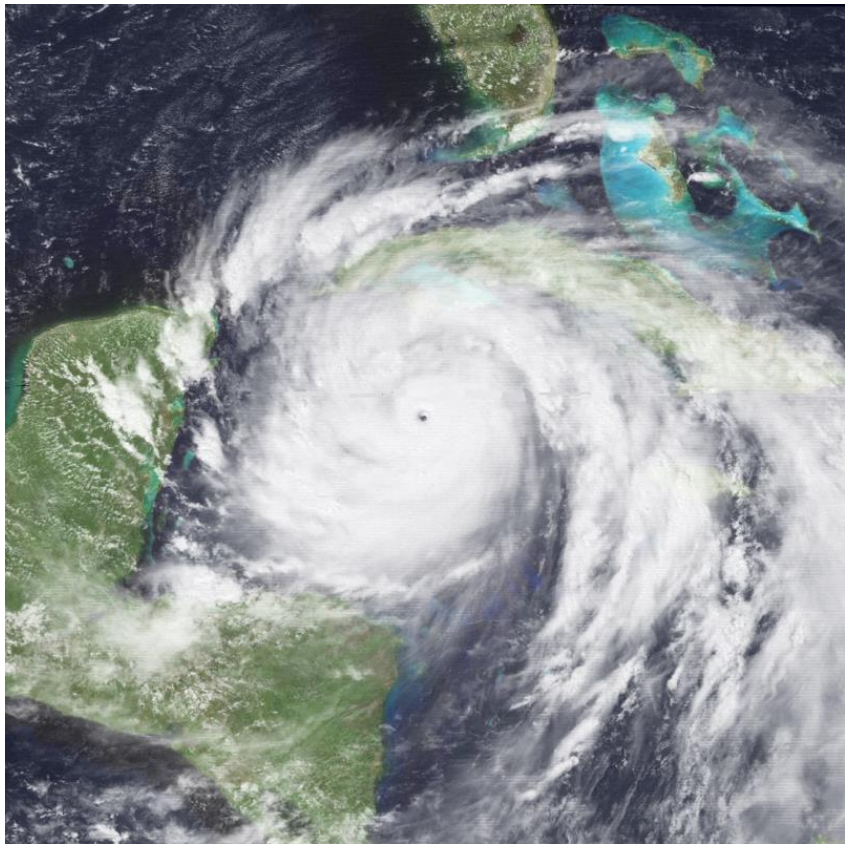
Nutrient poor Mor site

Tanner 1977 plots established to compare nutrient rich and nutrient poor forests

Long-term diversity change

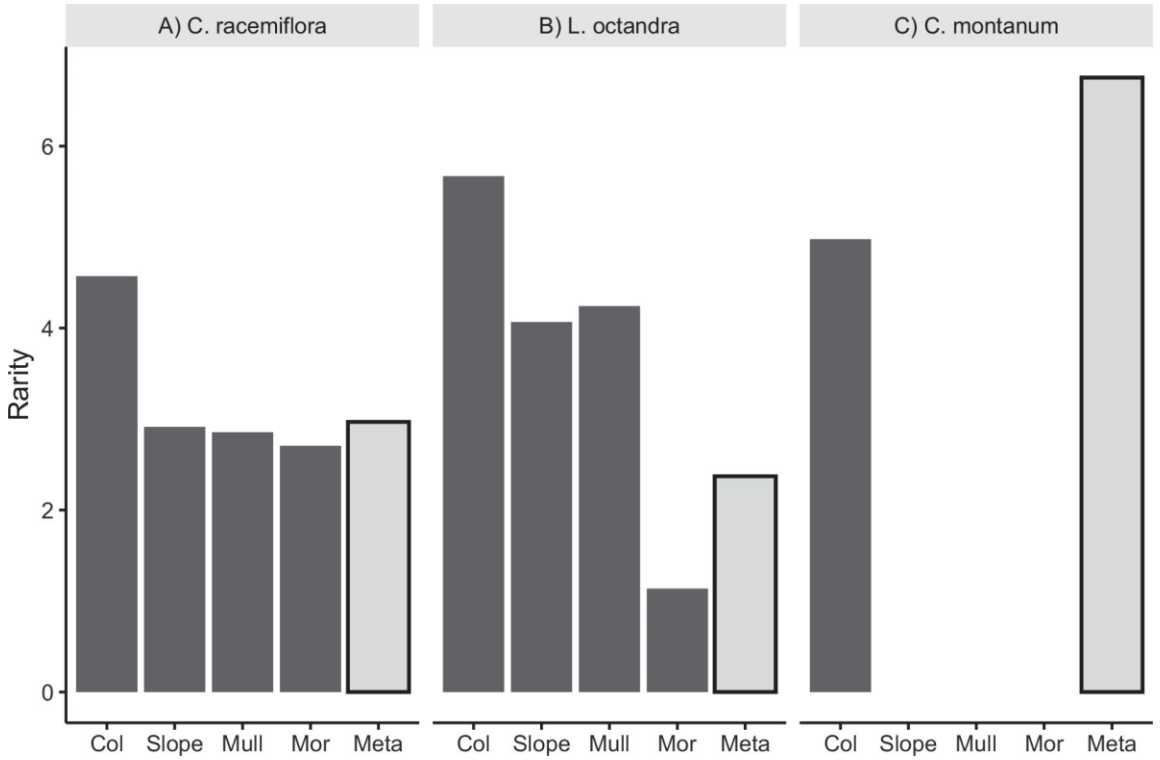


Shannon entropy for
four sites in the blue mountains



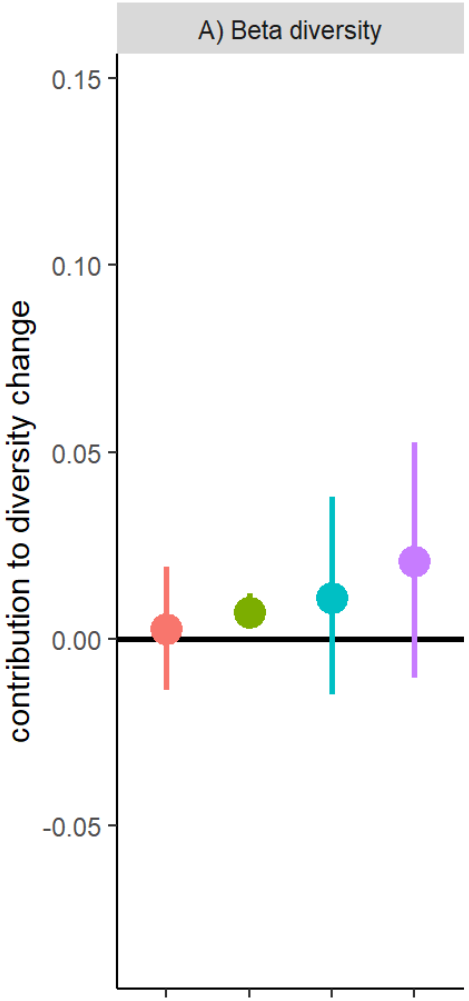
(Tanner and Bellingham 2006)

rarity of individuals among sites

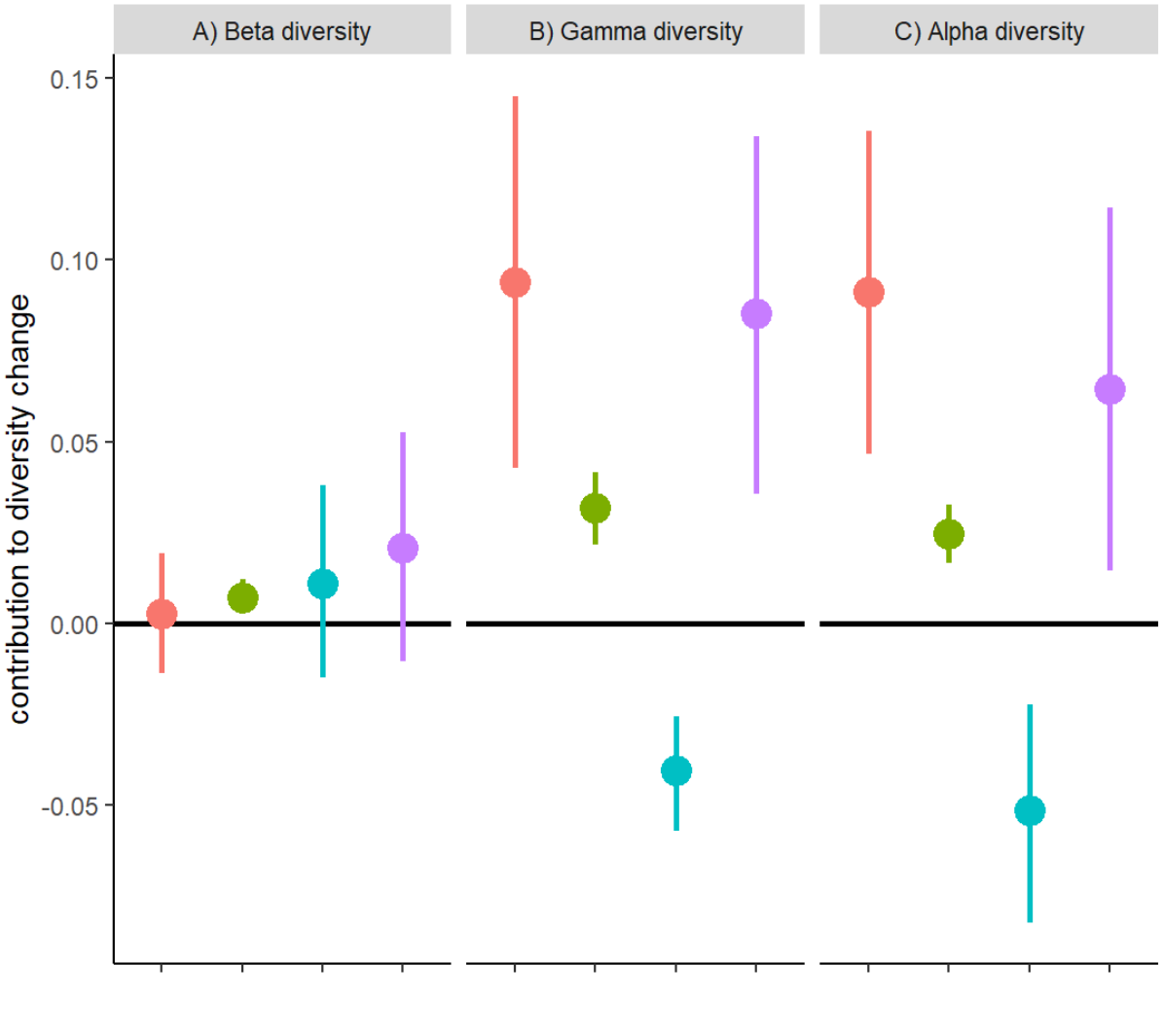


Generalist Specialist Rare

Biotic homogenization post hurricane?



- Selection on relative rarity
- Change in relative rarity
- Recruitment (arrival of new species)



Selection

Transmission

Recruitment (arrival of new species)

Conclusions part III

- Individuals make contributions to diversity at large spatial scales
- Mechanisms such as selection, transmission and immigration can be measured
- In the blue mountains, these mechanisms were indifferent to hurricane damage

Overall summary

- Biotic interactions have unintuitive effects on diversity
- Tracking individual contributions helps us to recognize the mechanisms of diversity change
- These mechanisms can be generalized across spatial scales

Thanks to

- Te Pūnaha Matatini and BioProtection Research centres of research excellence

Example similar competitors

Example from a dynamic model