

Ecological acclimation: modeling climate change impacts on ecosystem functioning from seconds to centuries

Michael Stemkovski and Peter Adler



PIs

Peter Adler
John Bradford
Abby Lynch
Christy Rollinson
Michael Stemkovski

Collaborators

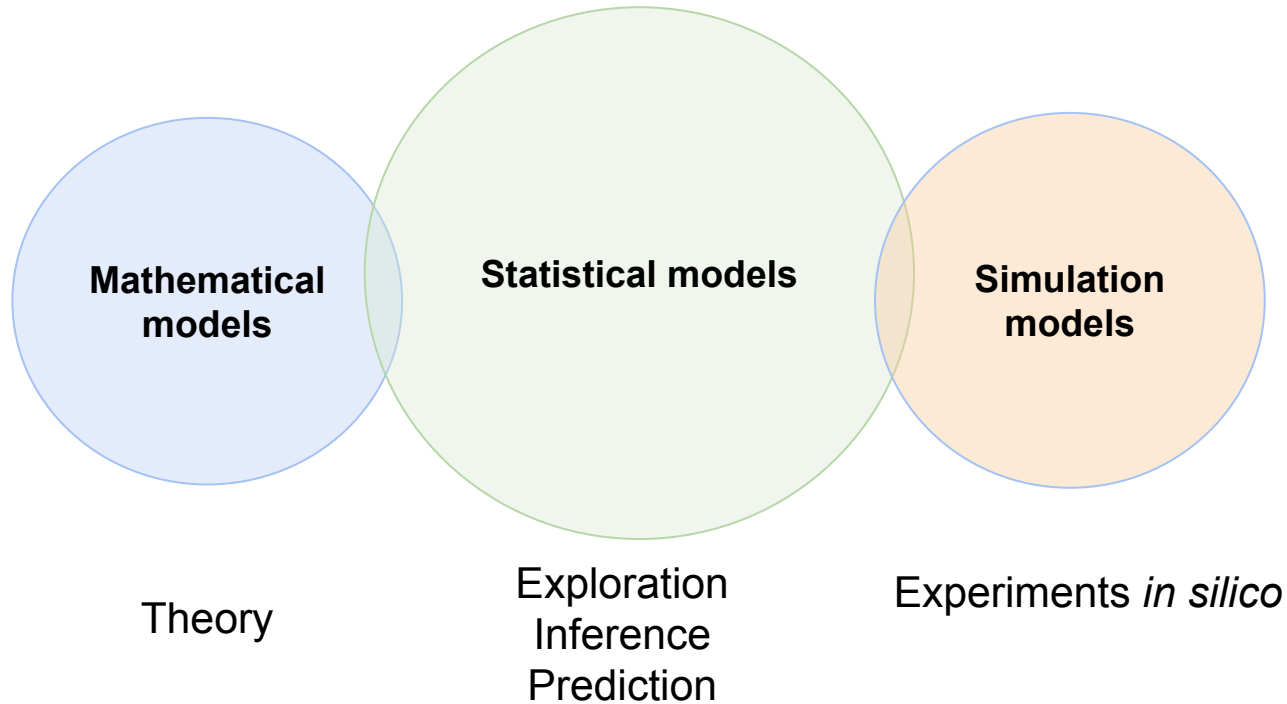
Kelvyn Bladen
Michael Cortez
Giles Hooker
Lucy Lu
Peter Reich
Anna Trugman
Greg Quetin
Kai Zhu

Working group members

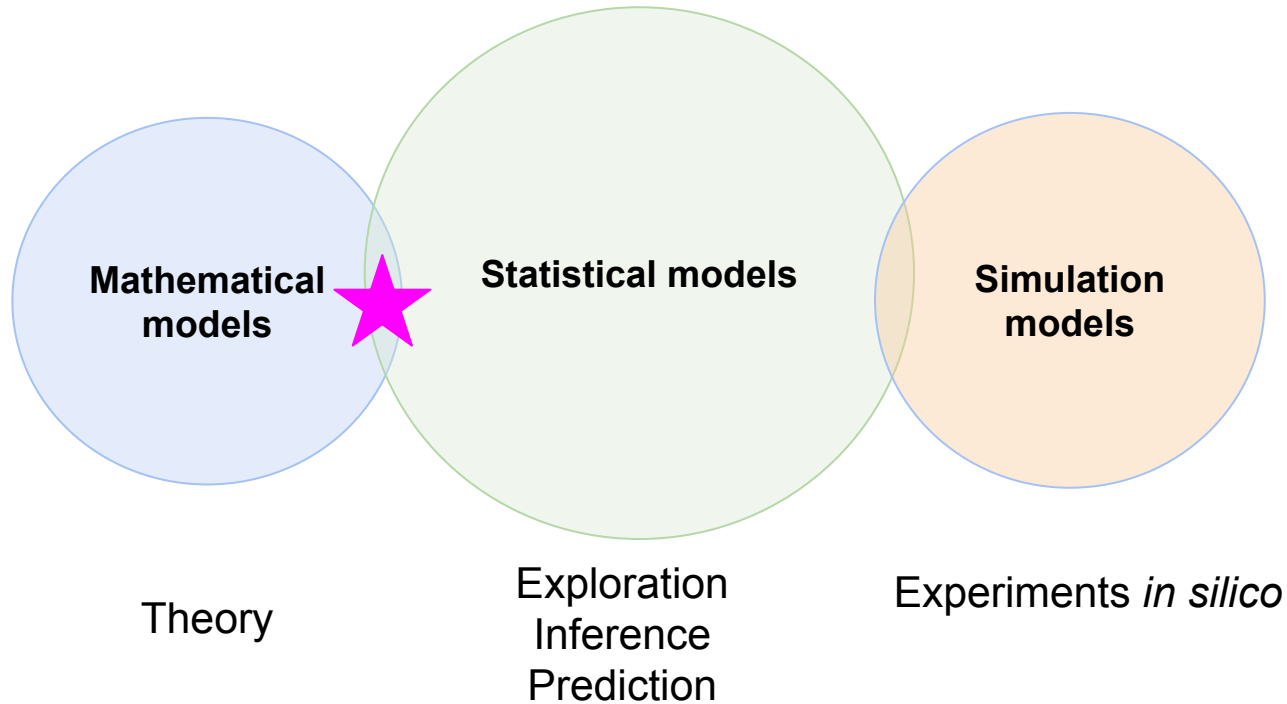
Joey Bernhardt
Benjamin Blonder
Kyra Clark-Wolf
Shelley Crausby
Laura Dee
Margaret Evans
Virginia Iglesias
Loretta Johnson
Sparkle Malone
Brooke Osborne
Melissa Pastore
Michael Paterson
Malin Pinsky
Karen Prentice
Oliver Selmoni
Katie Suding
Jason Venkiteswaran
Anthony Walker
Nicole Ward
Jack Williams
Claire Zarakas



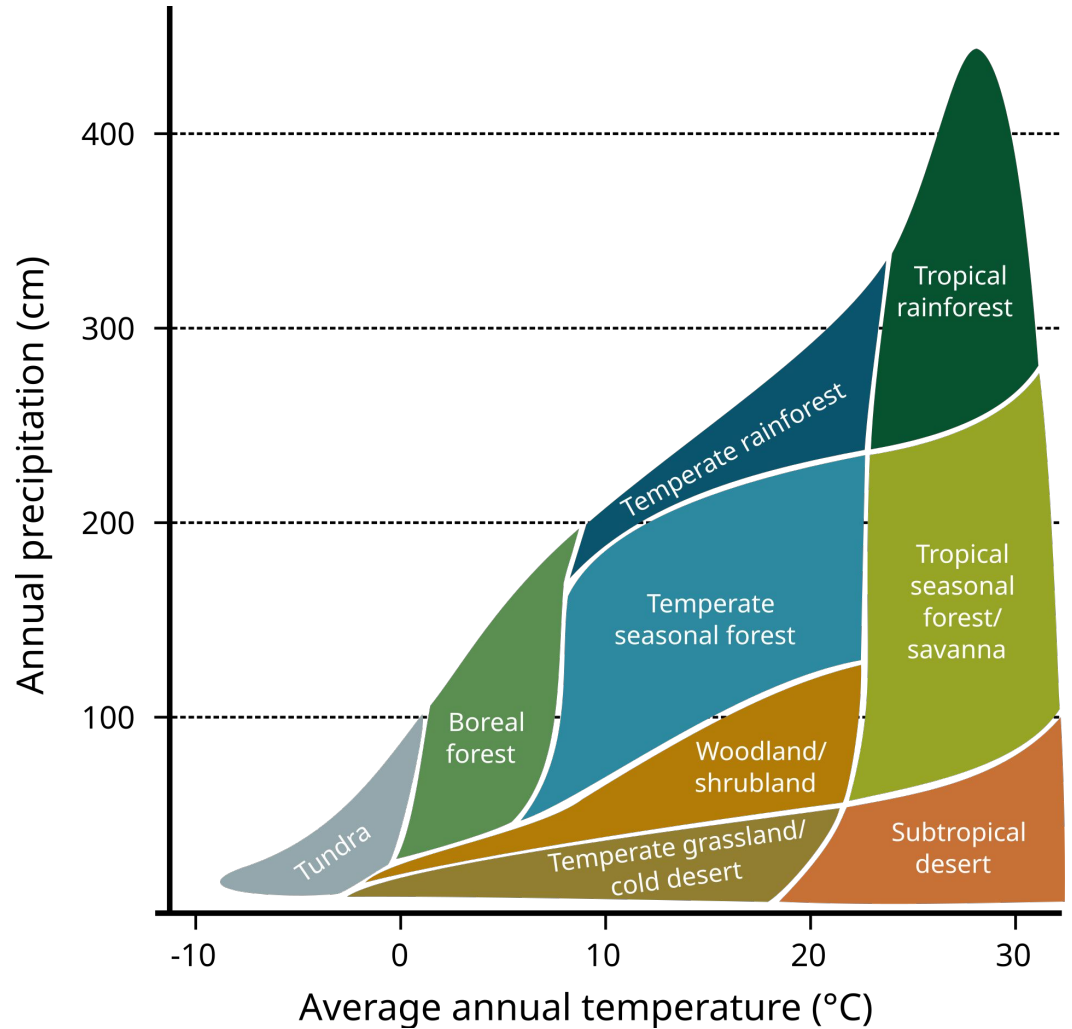
Common classes of models in ecology



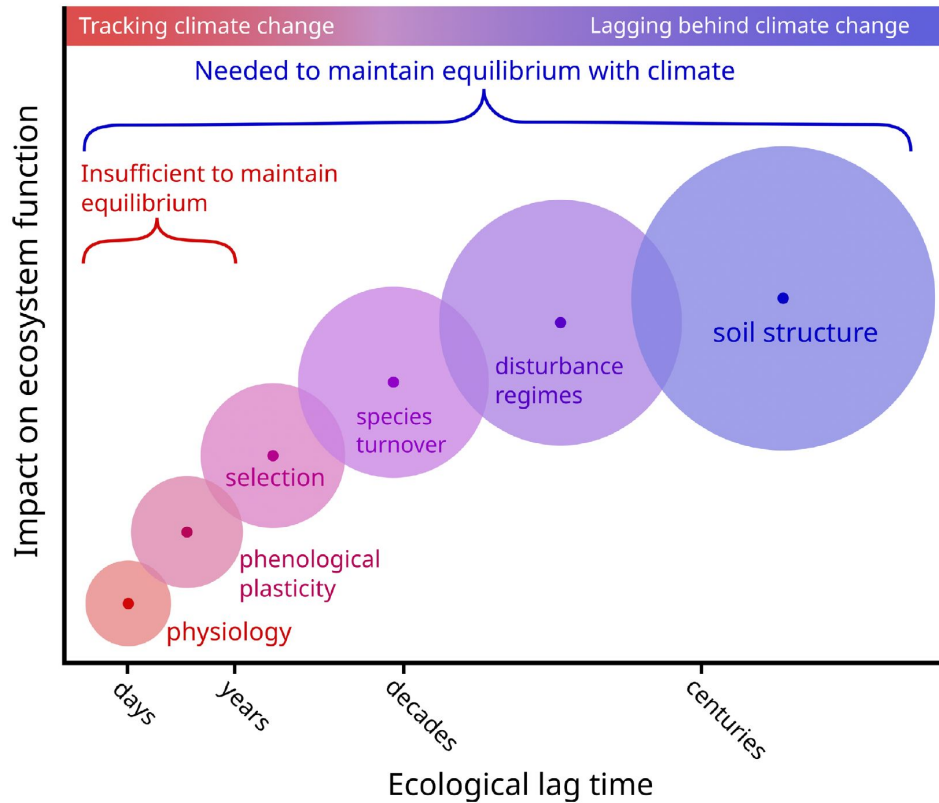
Common classes of models in ecology



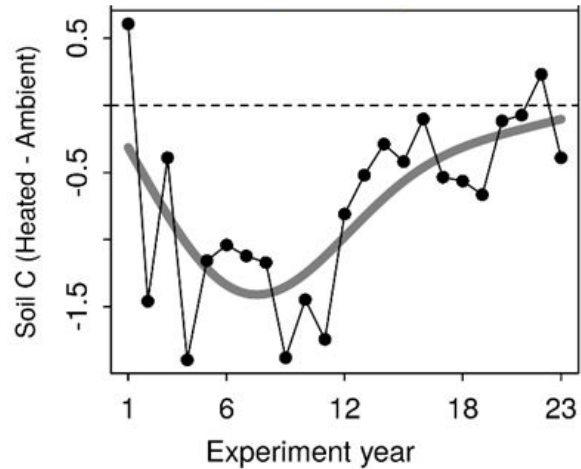
How will climate change transform ecosystem structure and function?



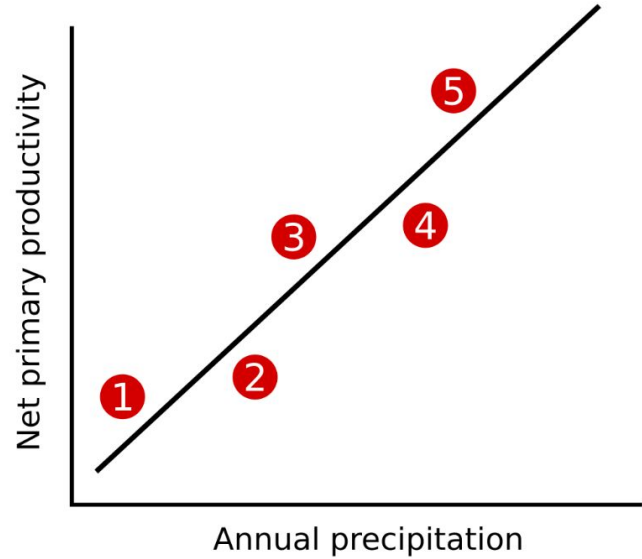
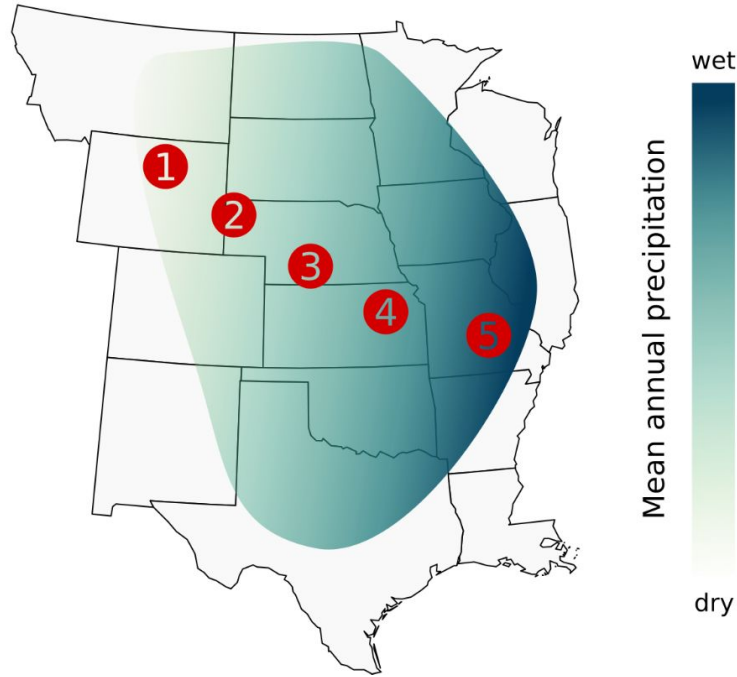
Predicting the ecological impacts of climate change is hard



Surprising results from long-term warming experiments

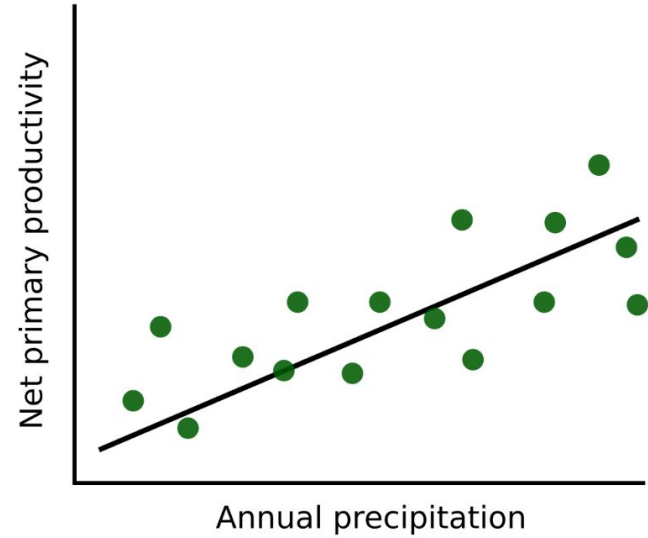
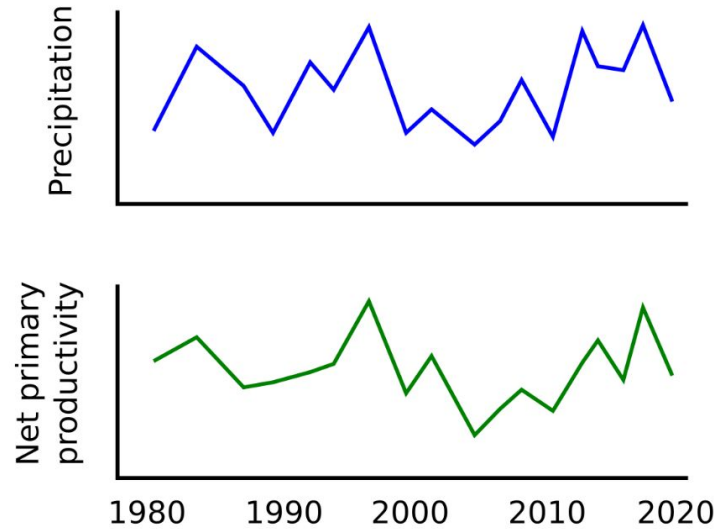


Contrasting climate sensitivities in space and time



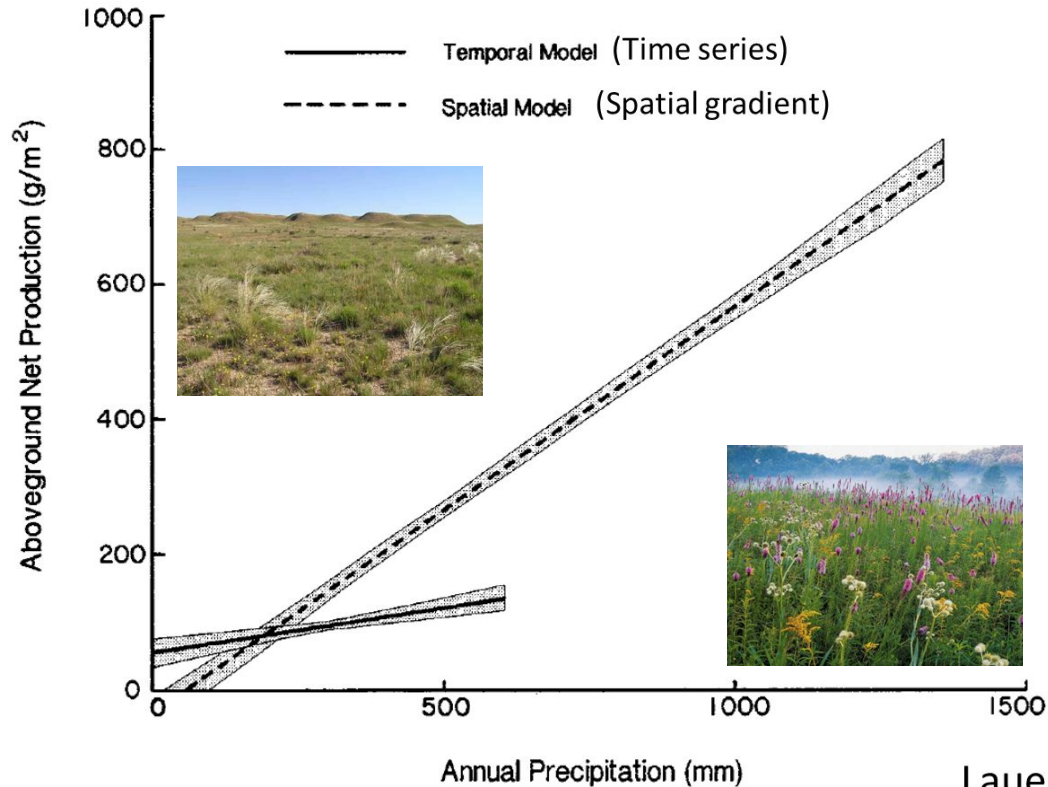
Spatial gradient approach

Contrasting climate sensitivities in space and time

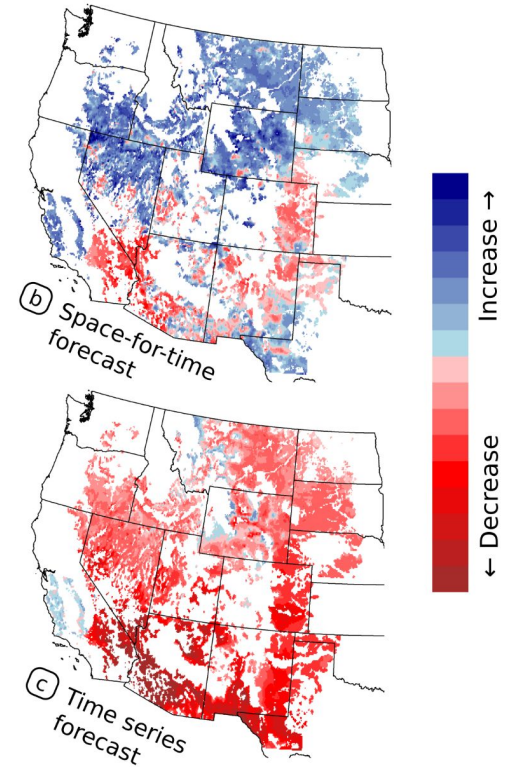


Time series approach

Contrasting climate sensitivities in space and time

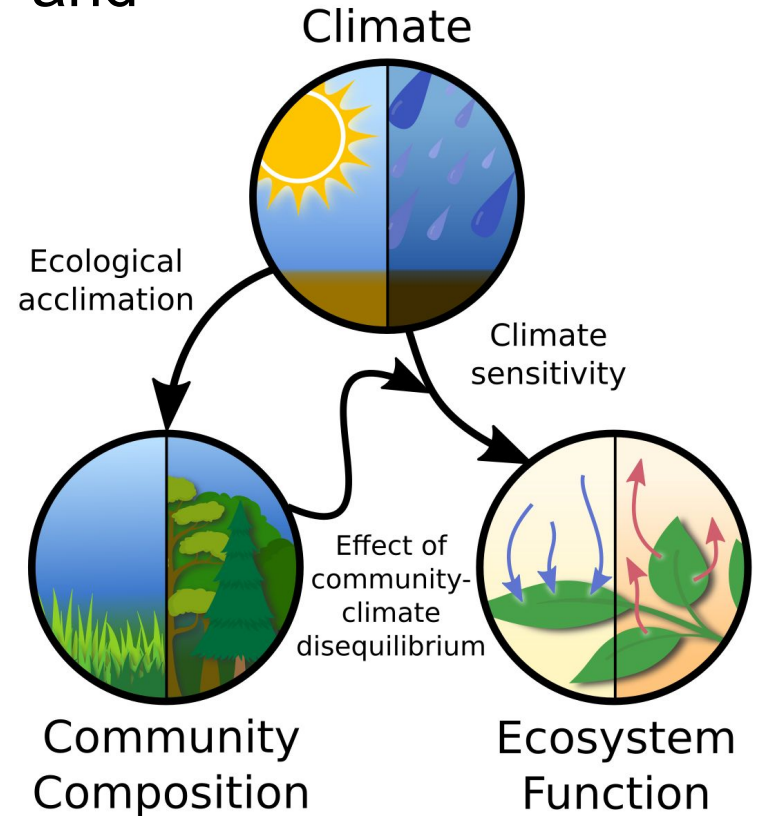


Contrasting climate sensitivities in space and time



The goal: develop theory to explain “surprising” dynamics and patterns—and predict them

1. Background: Community-climate indices and disequilibrium
2. A dynamic, predictive model



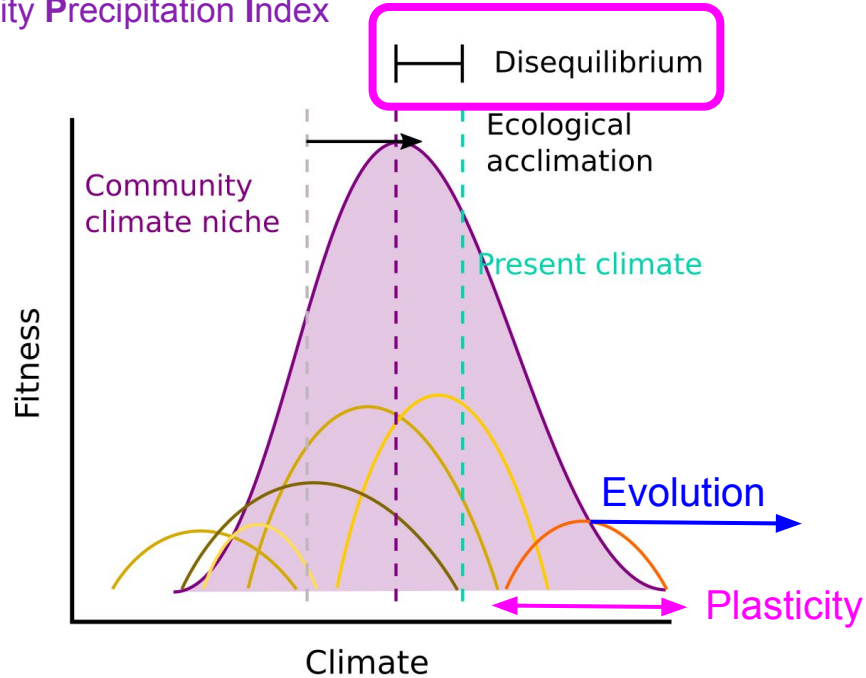
Can the solution really depend on a single-number summary of the community?



- Species richness
- Species diversity indices
- Functional diversity indices
- Phylogenetic diversity indices

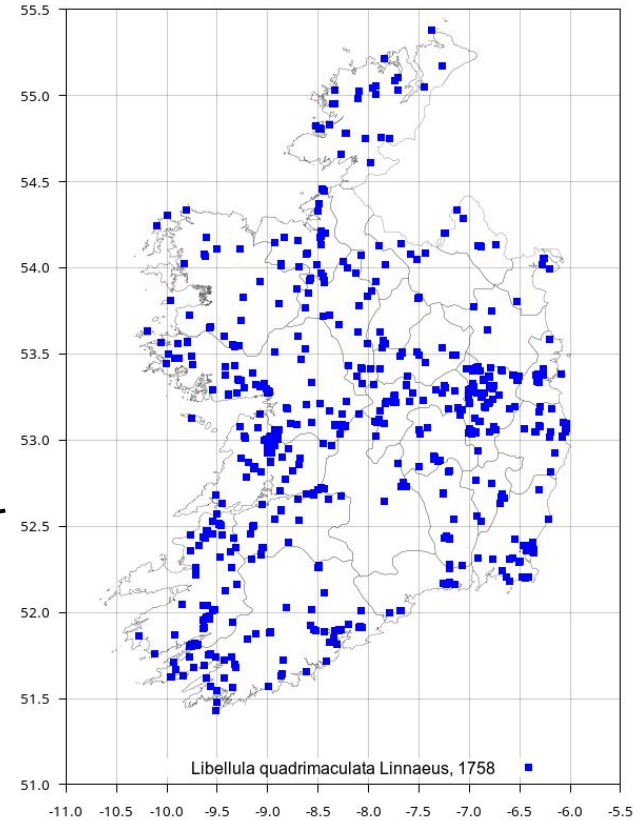
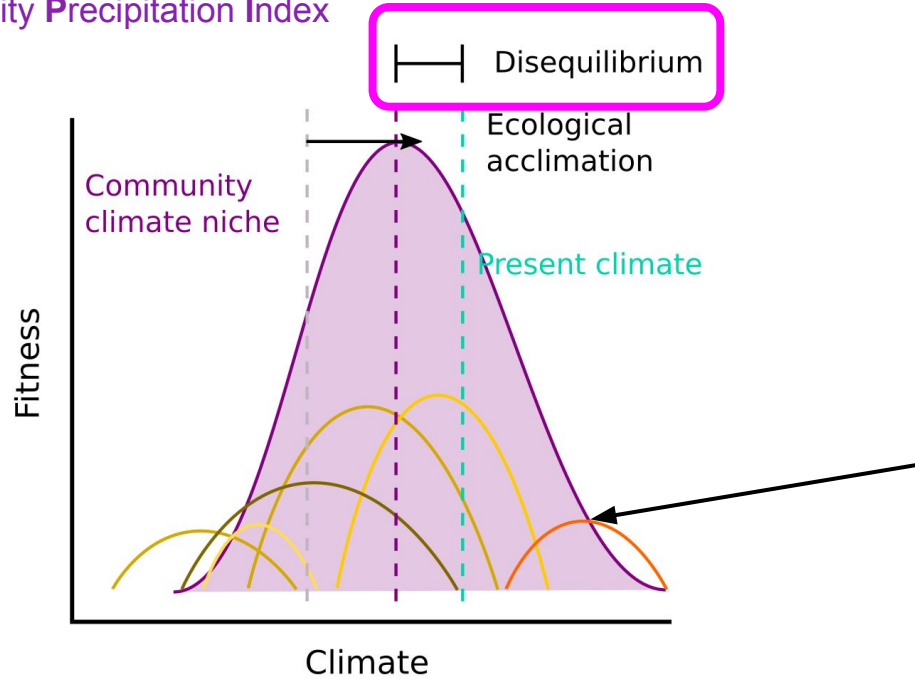
Community climate indices

Community Temperature Index
Community Precipitation Index

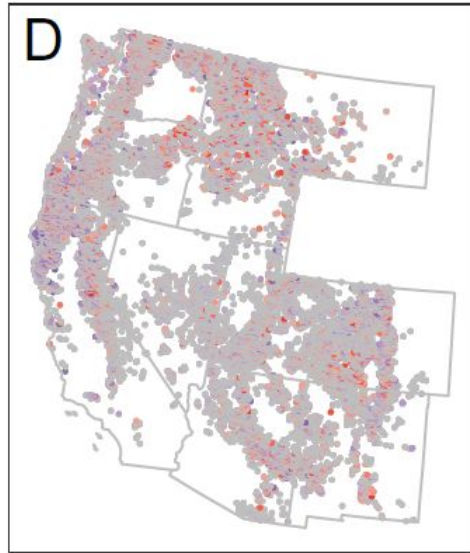
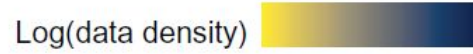


Community climate indices

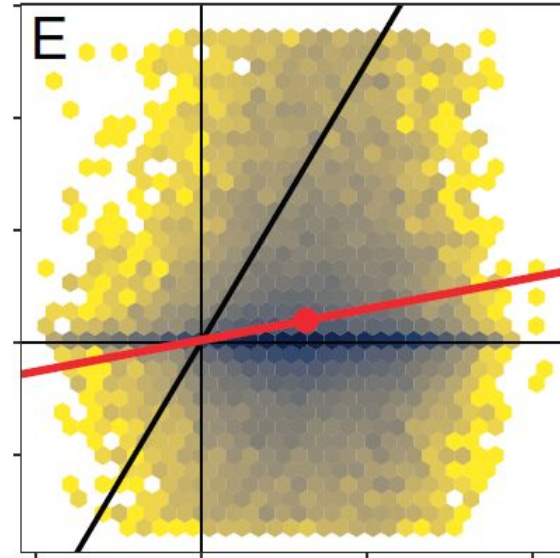
Community Temperature Index
Community Precipitation Index



Community climate indices are informative

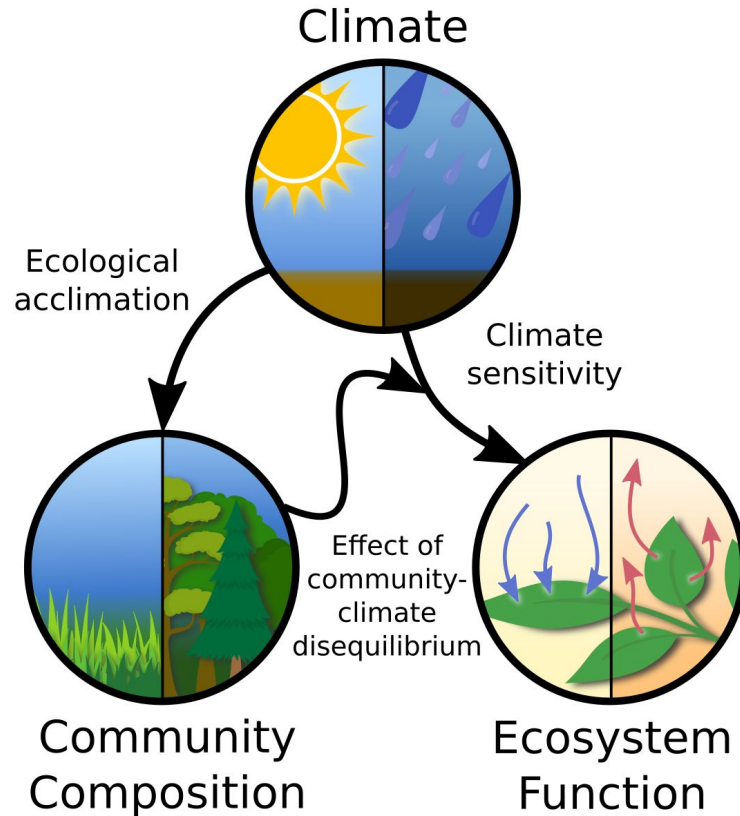


Community temp. change ($^{\circ}\text{C}/\text{yr}$)



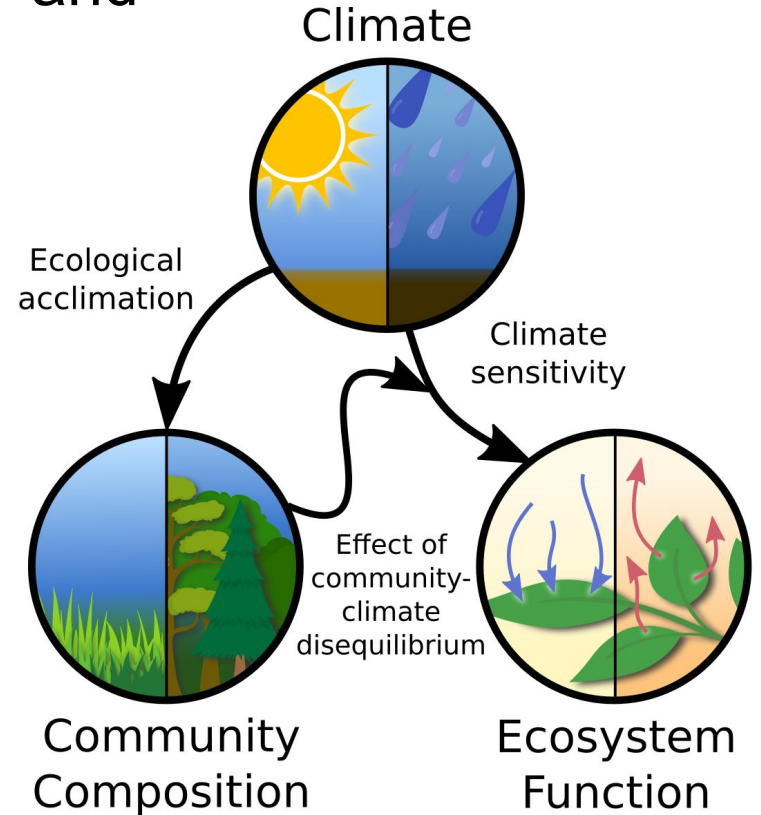
Temp. change ($^{\circ}\text{C}/\text{yr}$)

The ecological acclimation framework

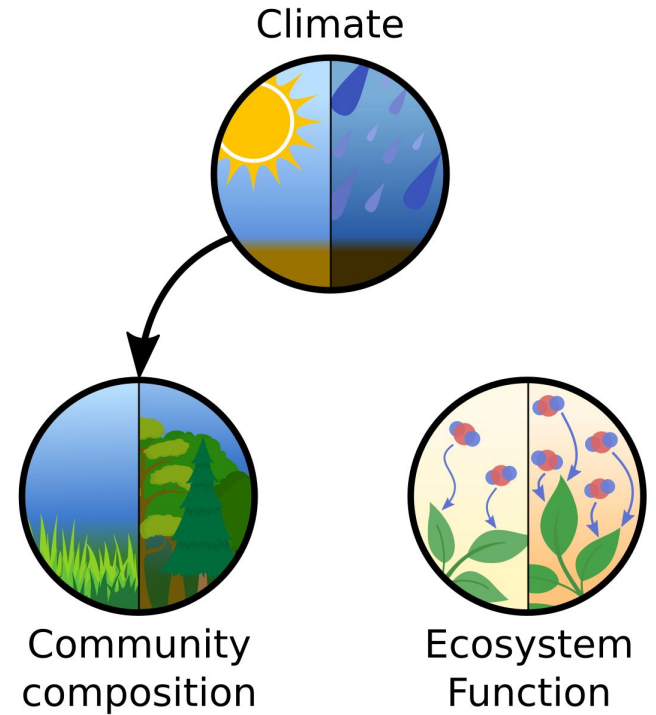


The goal: develop theory to explain “surprising” dynamics and patterns—and predict them

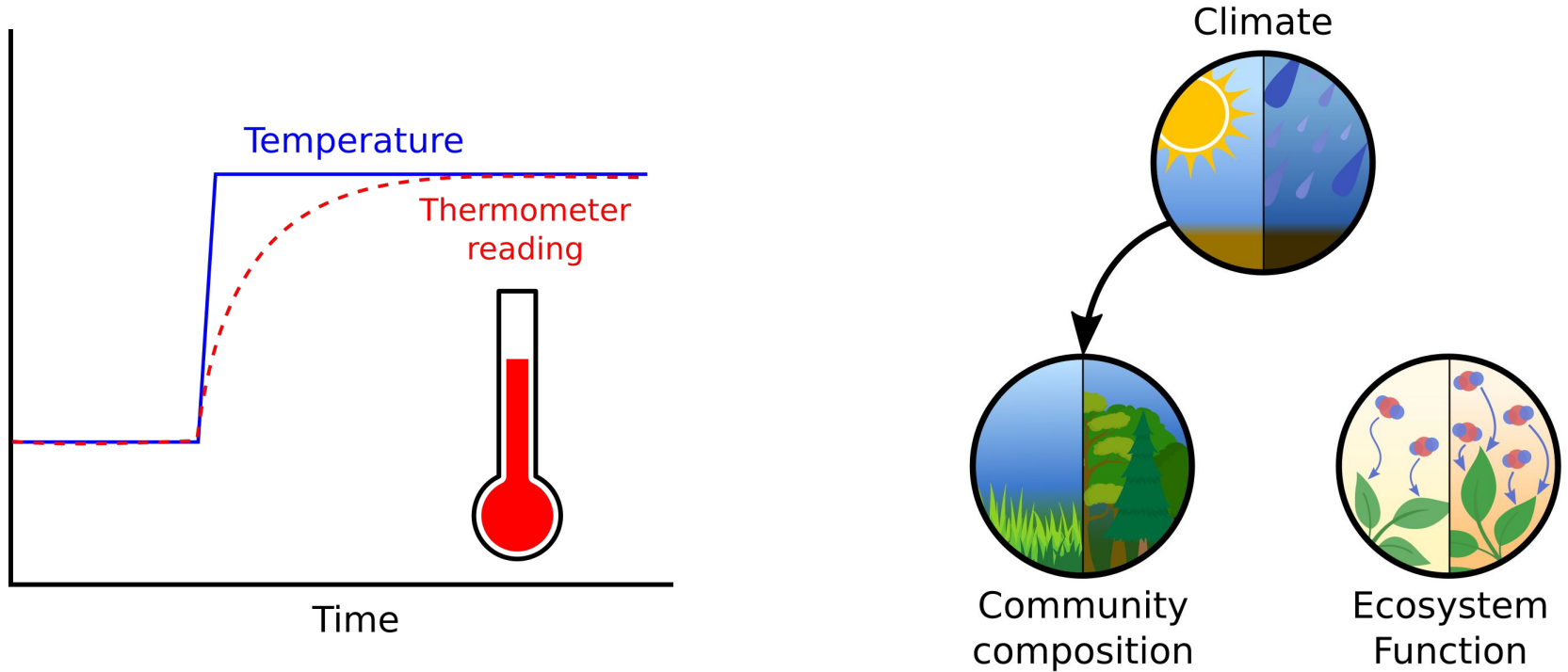
1. Background: Community-climate indices and disequilibrium
2. A dynamic, predictive model



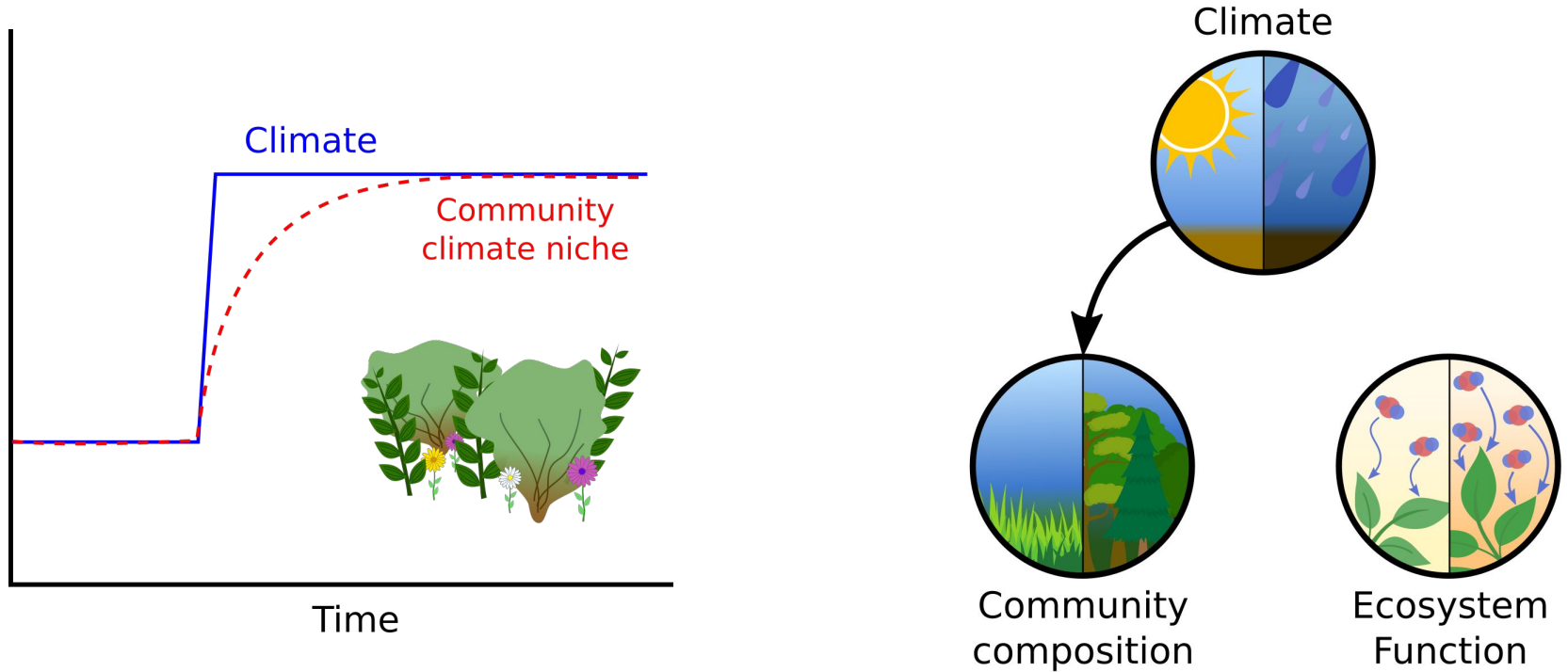
How can we simply describe ecological acclimation?



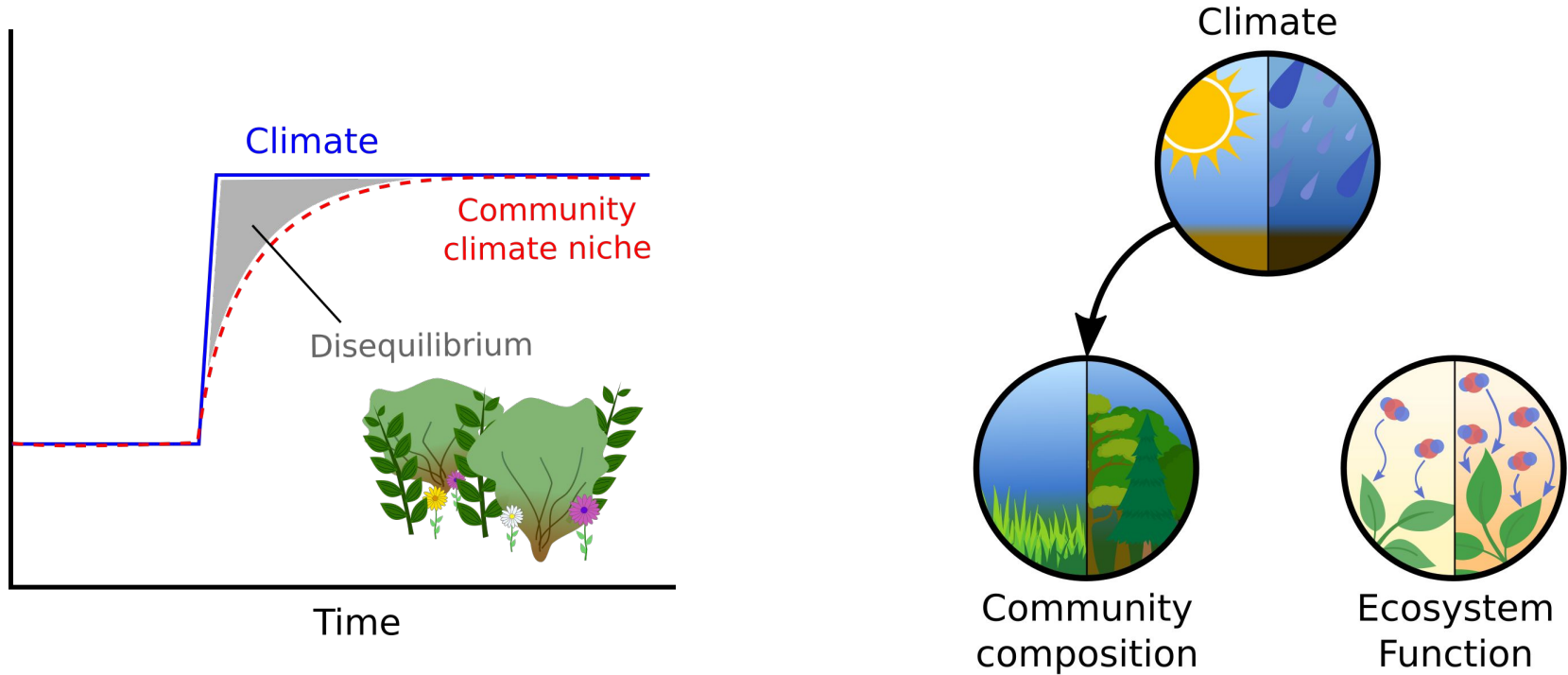
We can think of a community as a thermometer



We can think of a community as a thermometer



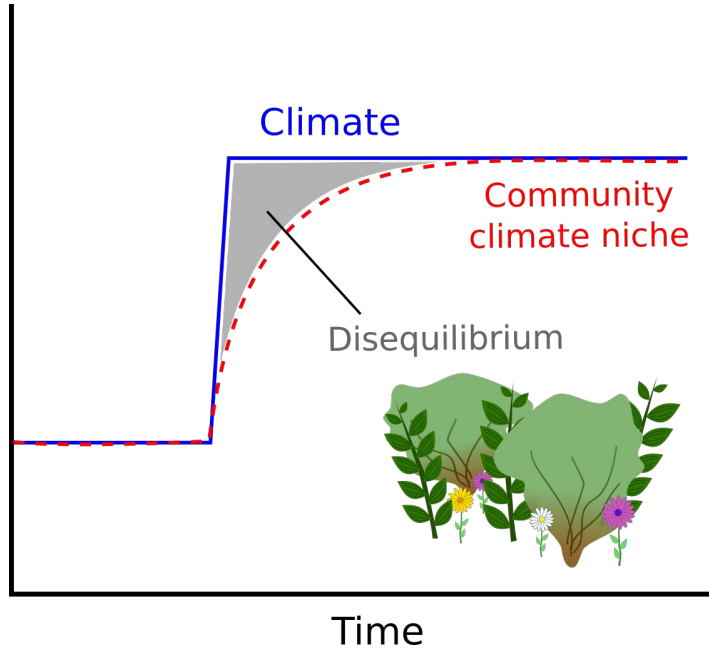
Ecological lags cause community-climate disequilibrium



Ecological lags cause community-climate disequilibrium

Newton's Law of Cooling
Harper (1912)

$$\frac{dE}{dt} = \frac{1}{\lambda}(C_t - E_t)$$



E : Community climate niche

C_t : Present climate

E_t : Community climate niche at time t

λ : Acclimation timescale

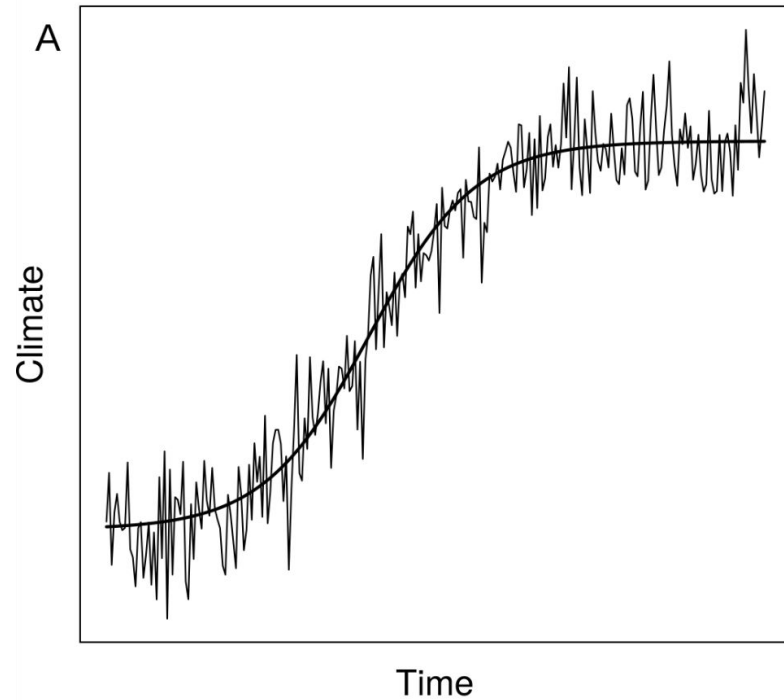
$(C_t - E_t)$: Disequilibrium

Webb (1986)

Blonder et al. (2017)

Williams et al. (2020)

Ecological lags cause community-climate disequilibrium



$$\frac{dE}{dt} = \frac{1}{\lambda}(C_t - E_t)$$

E : Community climate niche

C_t : Present climate

E_t : Community climate niche at time t

λ : Acclimation timescale

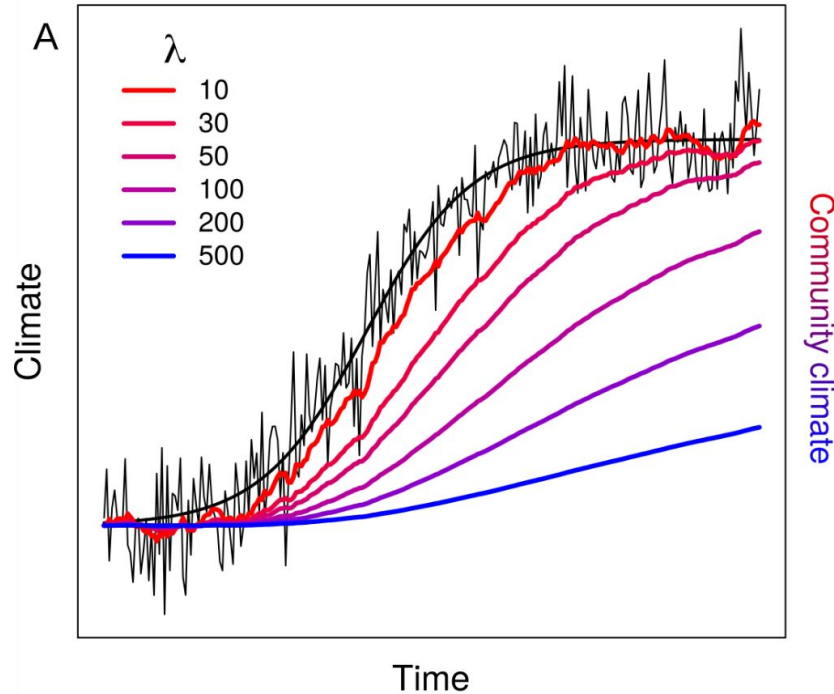
$(C_t - E_t)$: Disequilibrium

Webb (1986)

Blonder et al. (2017)

Williams et al. (2020)

Ecological lags cause community-climate disequilibrium



$$\frac{dE}{dt} = \frac{1}{\lambda}(C_t - E_t)$$

E : Community climate niche

C_t : Present climate

E_t : Community climate niche at time t

λ : Acclimation timescale

$(C_t - E_t)$: Disequilibrium

Webb (1986)

Blonder et al. (2017)

Williams et al. (2020)

Disequilibrium in structure affects ecosystem function

$$\frac{dE}{dt} = \frac{1}{\lambda}(C_t - E_t)$$

$$F_t = \alpha + \beta C_t$$

$$\beta = \beta_0 - \gamma(C_t - E_t)^2$$

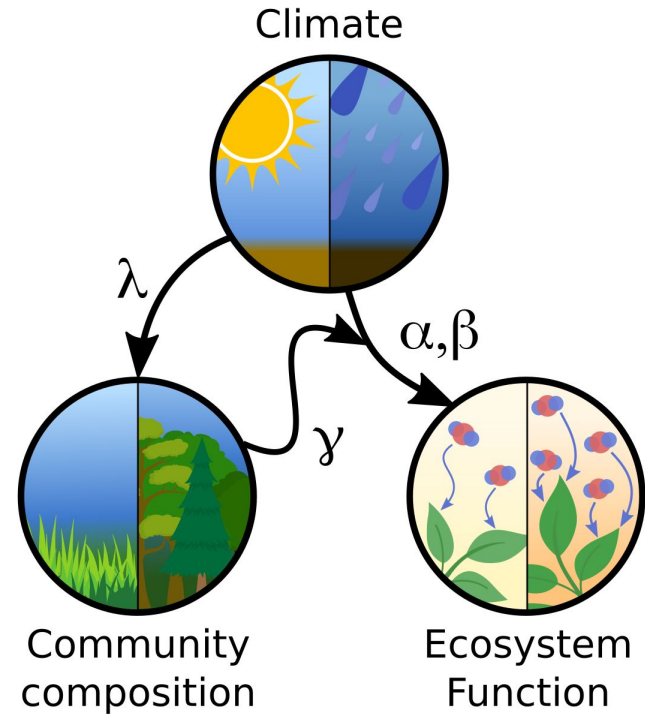
F_t : Ecosystem function at time t

C_t : Climate at t

α : baseline function

β : sensitivity of function to climate

γ : strength of disequilibrium effect on function



Disequilibrium may cause transient losses of function

$$\frac{dE}{dt} = \frac{1}{\lambda}(C_t - E_t)$$

$$F_t = \alpha + \beta C_t$$

$$\beta = \beta_0 - \gamma(C_t - E_t)^2$$

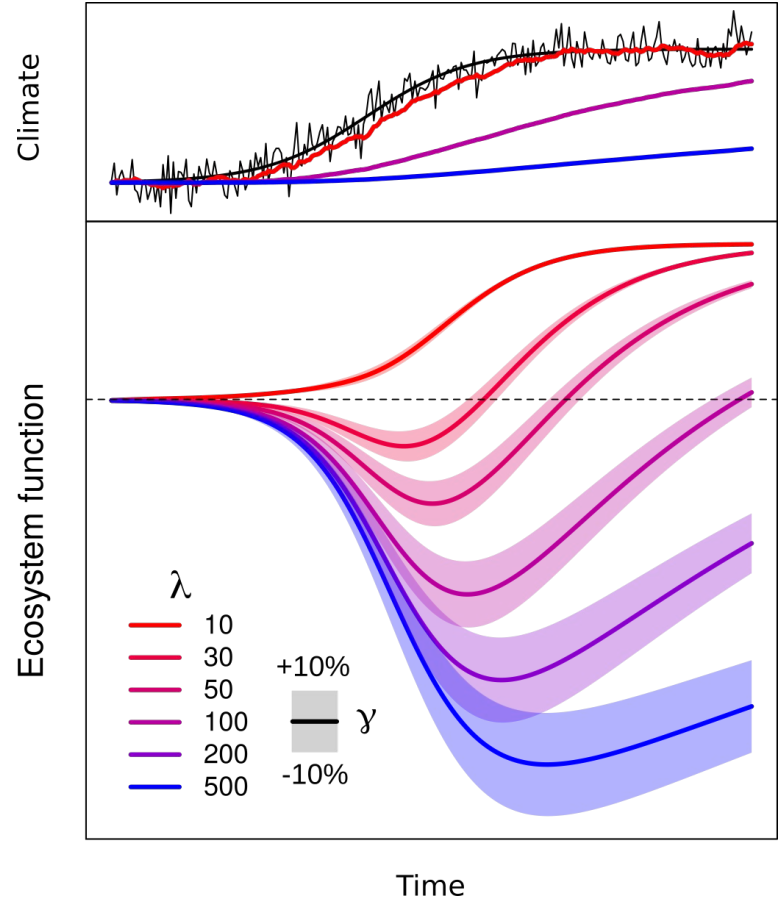
F_t : Ecosystem function at time t

C_t : Climate at t

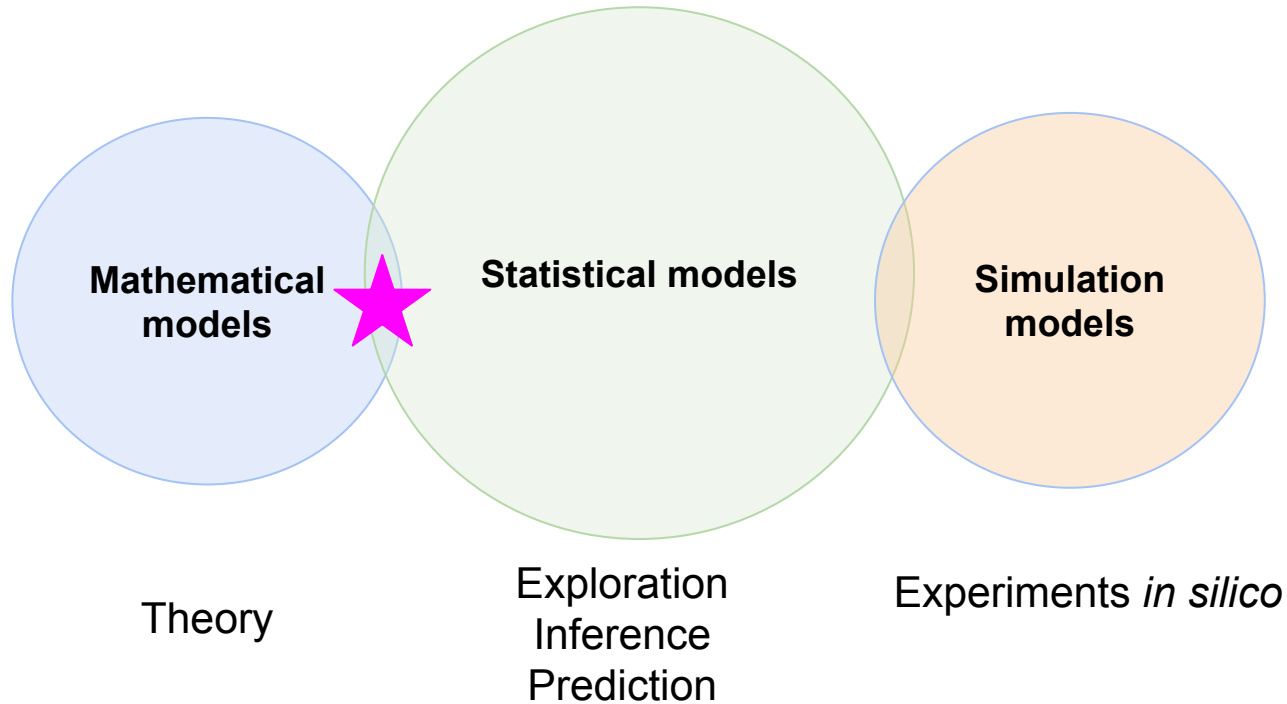
α : baseline function

β : sensitivity of function to climate

γ : strength of disequilibrium effect on function



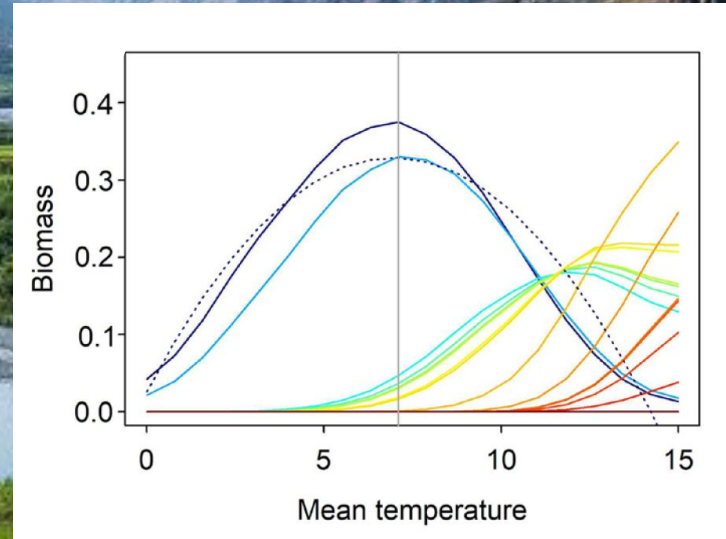
Common classes of models in ecology



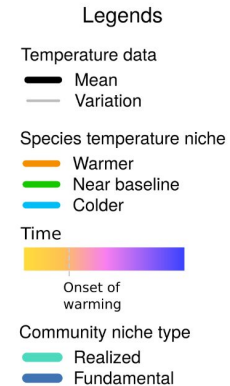
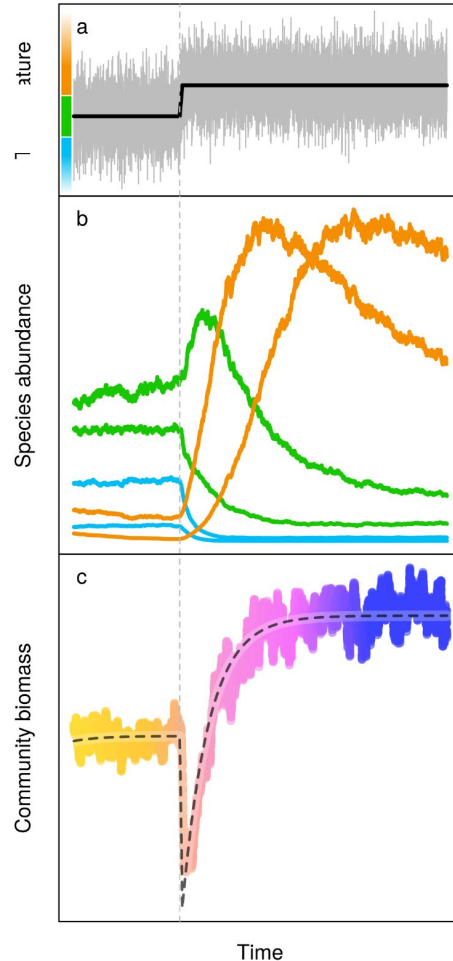
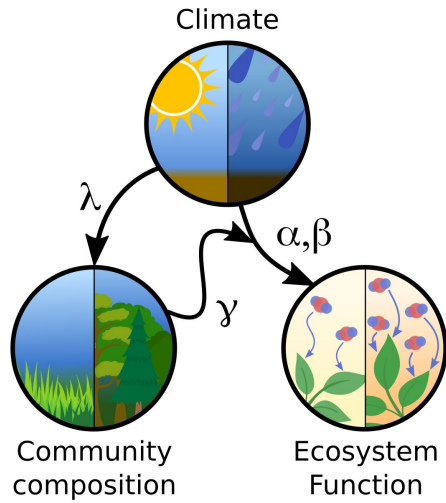
A simulation test



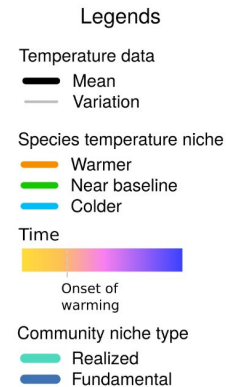
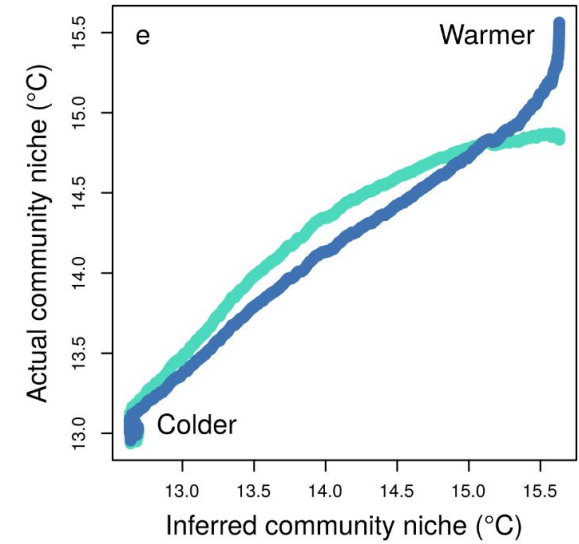
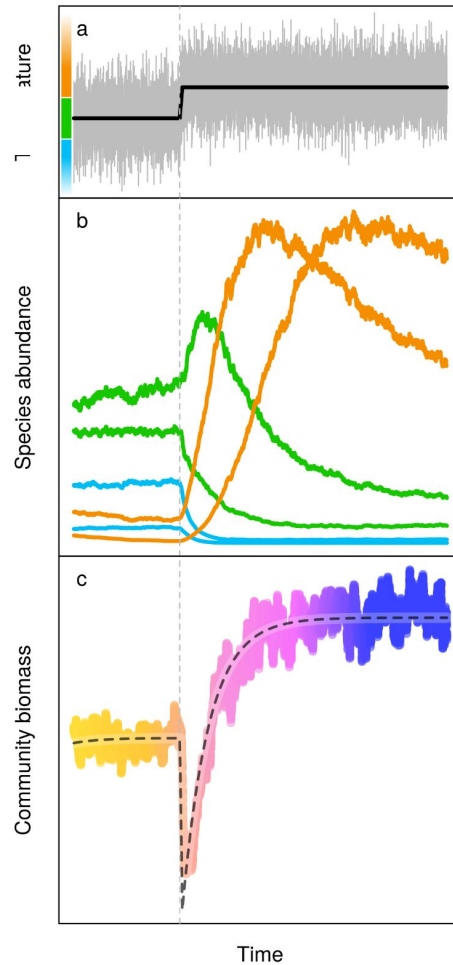
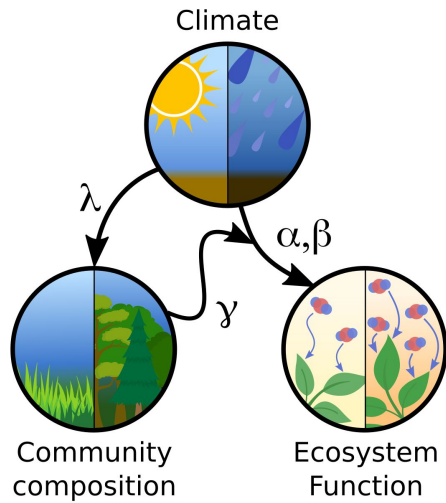
- Growth $f(T)$
- Competition
- Dispersal



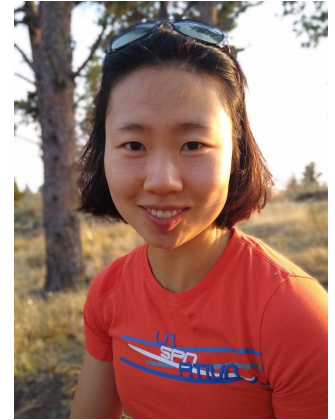
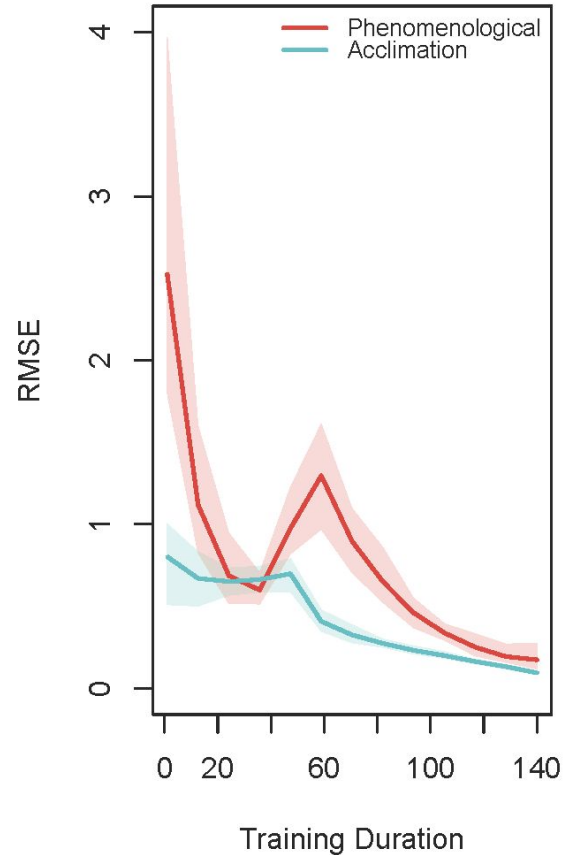
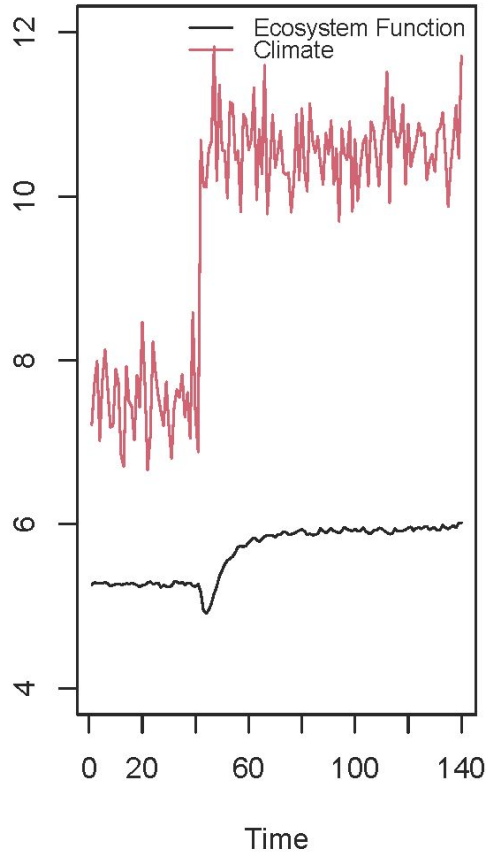
A simulation test



A simulation test



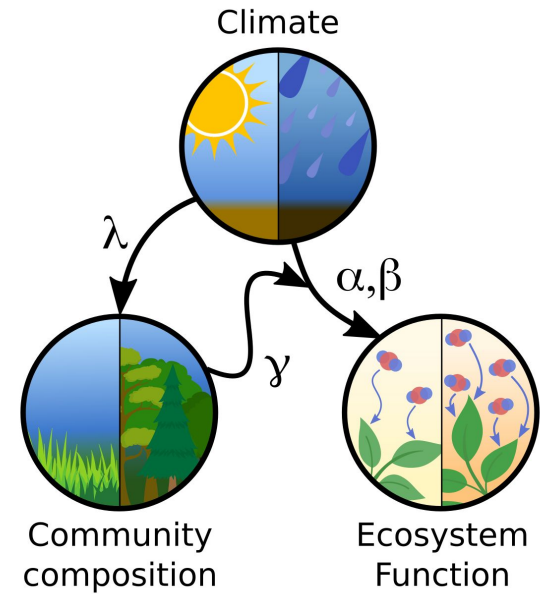
The “acclimation” model makes better forecasts than a time series model



Lucy Lu, USU
























Conclusions

- Community-climate indices are useful for understanding ecosystem functioning
- To forecast climate change impacts on function, we need to quantify the rate of ecological acclimation (λ) and the effect of disequilibrium on function (γ)
- We may have to choose between conserving historical composition and maintaining ecosystem function



REVIEW

Ecological acclimation: A framework to integrate fast and slow responses to climate change

Michael Stenkovski¹  | Joey R. Bernhardt²  | Benjamin Wong Blonder³  |
John B. Bradford⁴  | Kyra Clark-Wolf⁵  | Laura E. Dee⁶  | Margaret E. K. Evans⁷  |
Virginia Iglesias⁸  | Loretta C. Johnson⁹  | Abigail J. Lynch¹⁰  | Sparkle L. Malone¹¹  |
Brooke B. Osborne¹²  | Melissa A. Pastore¹³  | Michael Paterson¹⁴  |
Malin L. Pinsky¹⁵  | Christine R. Rollinson¹⁶  | Oliver Selmoni¹⁷  |
Jason J. Venkiteswaran¹⁸  | Anthony P. Walker¹⁹  | Nicole K. Ward²⁰  |
John W. Williams²¹  | Claire M. Zarakas²²  | Peter B. Adler¹ 



















ecological acclimation



PERSPECTIVE

Linking Community-Climate Disequilibrium to Ecosystem Function

Michael Stemkovski¹  | Michael H. Cortez²  | Joey R. Bernhardt³  | Kelvyn K. Bladen⁴  | John B. Bradford⁵  |
Kyra Clark-Wolf⁶  | Margaret E. K. Evans⁷  | Loretta C. Johnson⁸  | Abigail J. Lynch⁹  | Melissa A. Pastore¹⁰  |
Malin L. Pinsky¹¹  | Christine R. Rollinson¹²  | Oliver Selmoni¹³  | Anthony P. Walker¹⁴  | John W. Williams¹⁵  |
Peter B. Adler¹ 

Stemkovski et al. 2026

<https://doi.org/10.1111/ele.70314>