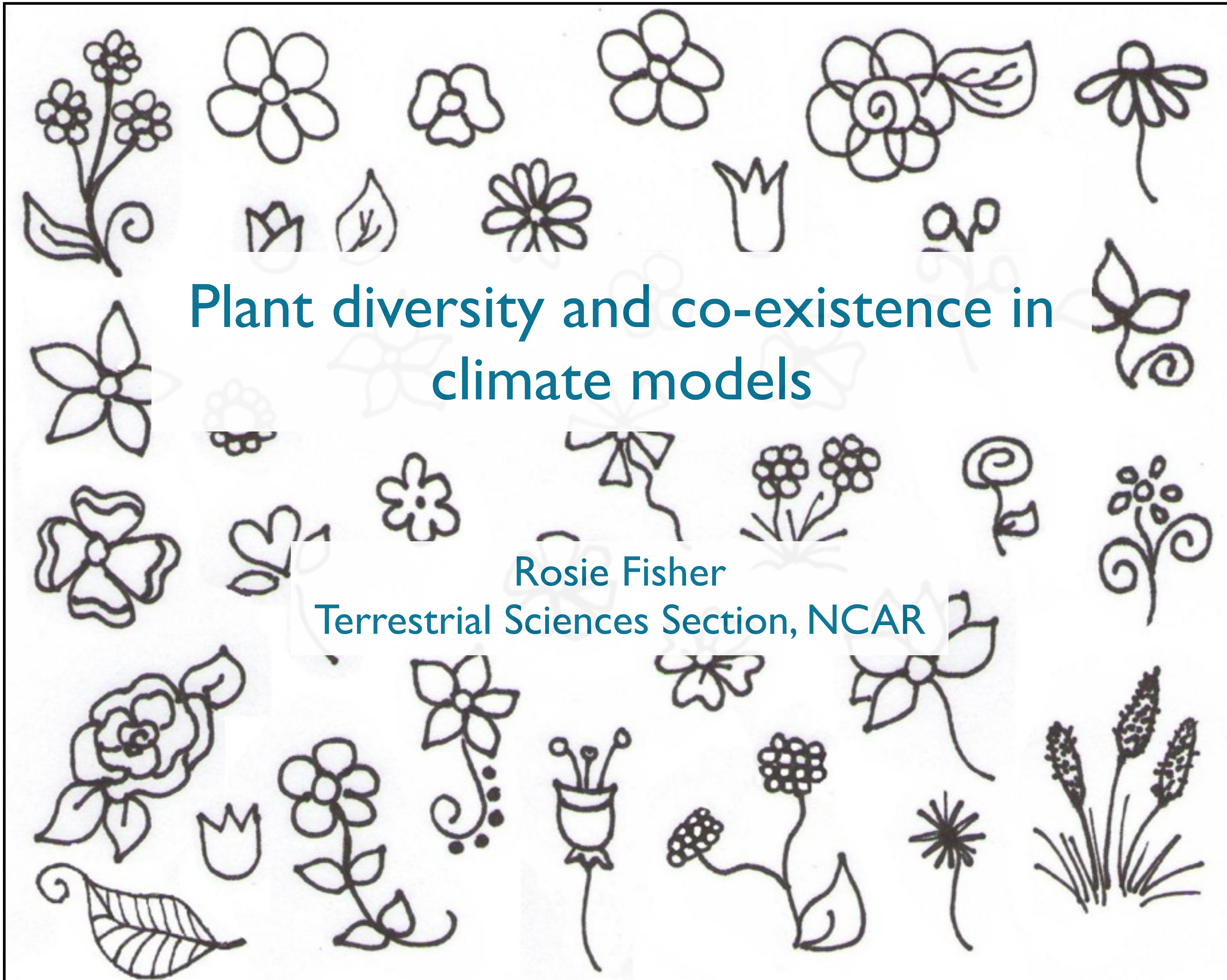


Plant diversity and co-existence in climate models

Rosie Fisher
Terrestrial Sciences Section, NCAR

Dynamic Global Vegetation Models

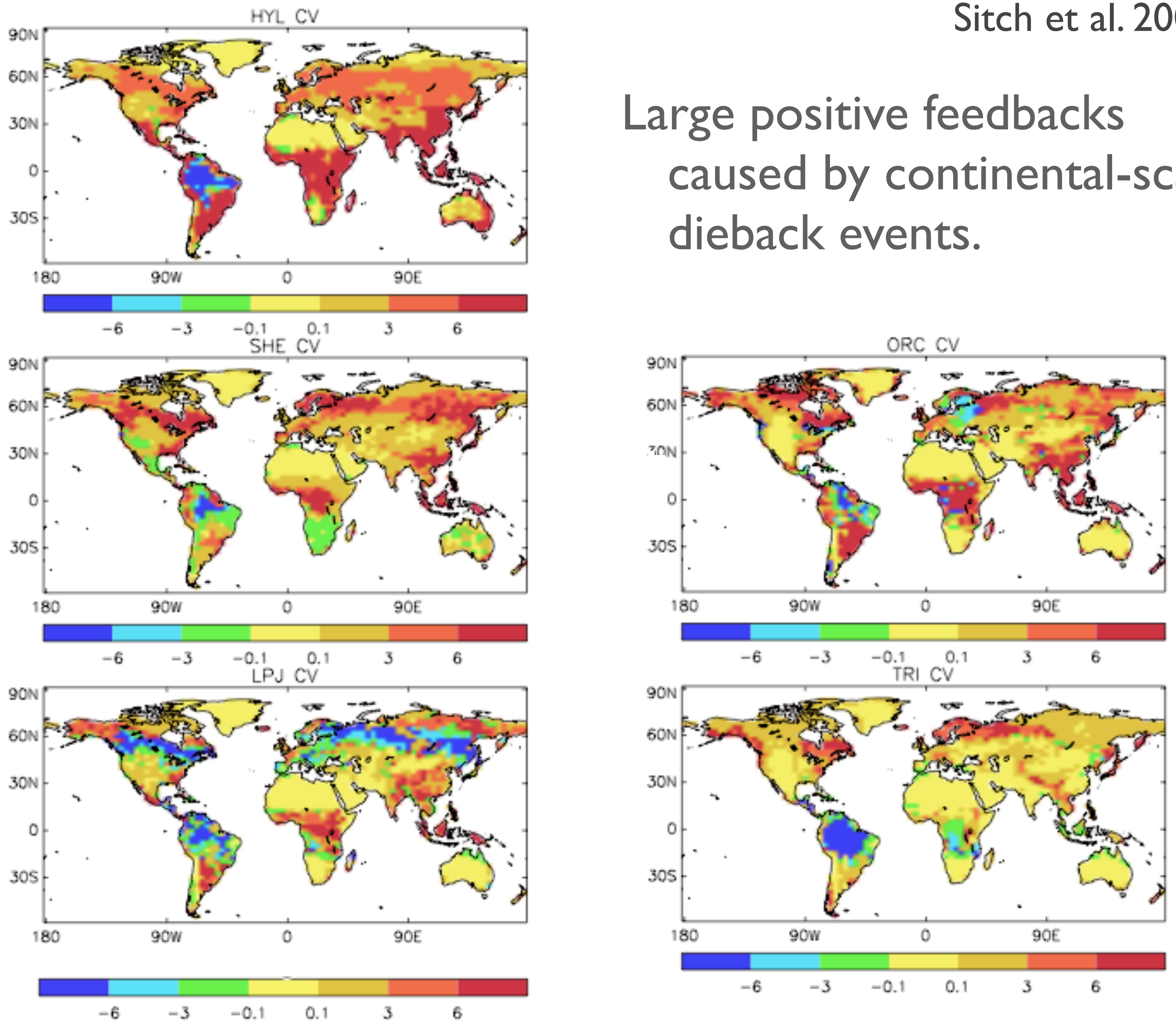
- Hourly leaf-level fluxes -> decadal ecosystem-scale consequences.
  - Fluxes ➠ growth ➠ competition, reproduction, death ➠ biome shift
- DGVMs attempt to predict the future of the entire biosphere.
- They are a **necessary** response to the possibility of climate-biosphere feedback.

- What criticisms are typically leveled at DGVM’s?
- What tools can we use to address them?
- What problems remain?

Predicted changes in vegetation carbon

Sitch et al. 2008

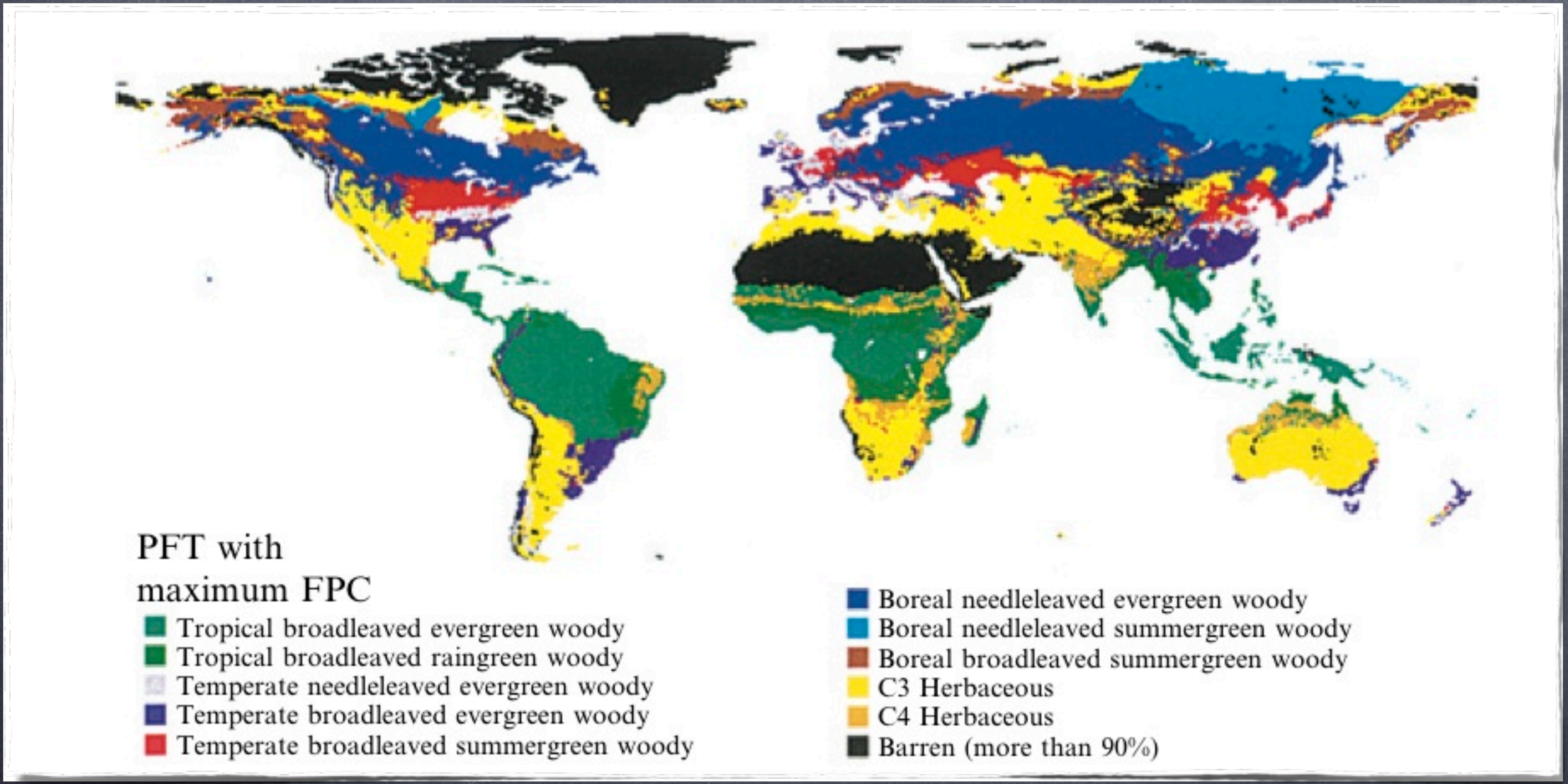
Large positive feedbacks caused by continental-scale dieback events.



Why dieback : aggregation of plant diversity?

- There are only ~10 kinds of plant.
- Dieback events occur at the physiological thresholds of single plant types.
- Is it realistic that, e.g. all boreal trees, have the same physiological thresholds?

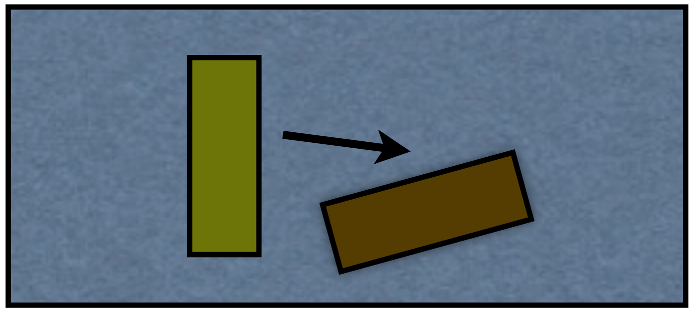
Plant Diversity in DGVMs



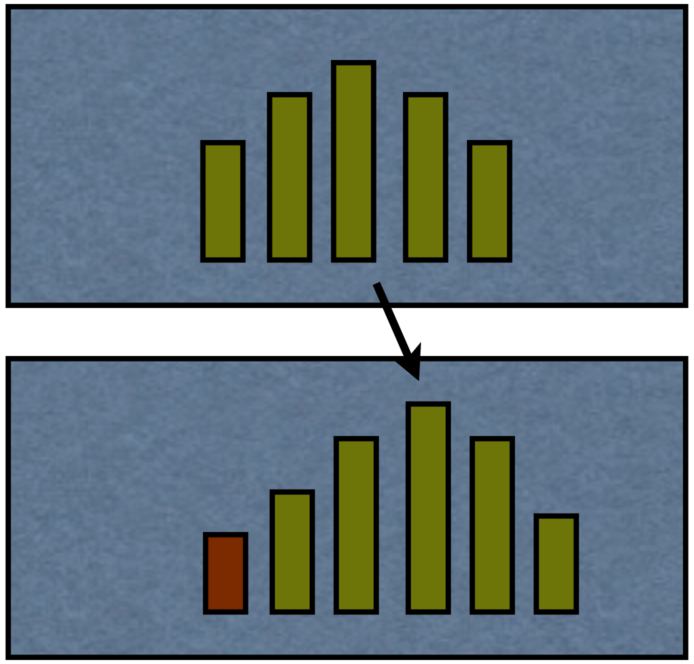
Sitch et al. 2003

“There are not enough plant types in climate models”
(*every living plant ecologist*)

- Low (functional) diversity causes low resilience to change.

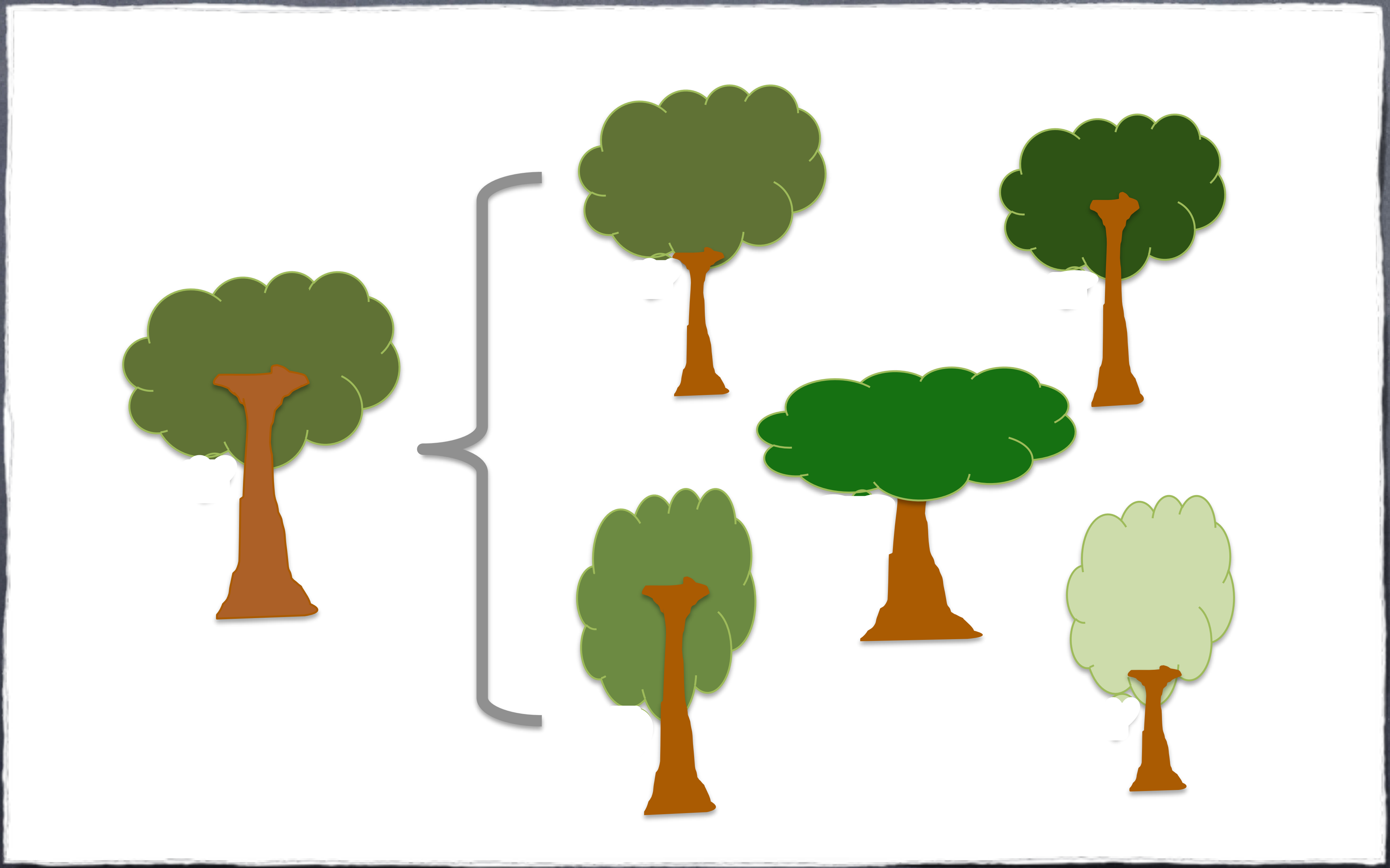


- Problem 1: How to better represent plant diversity.

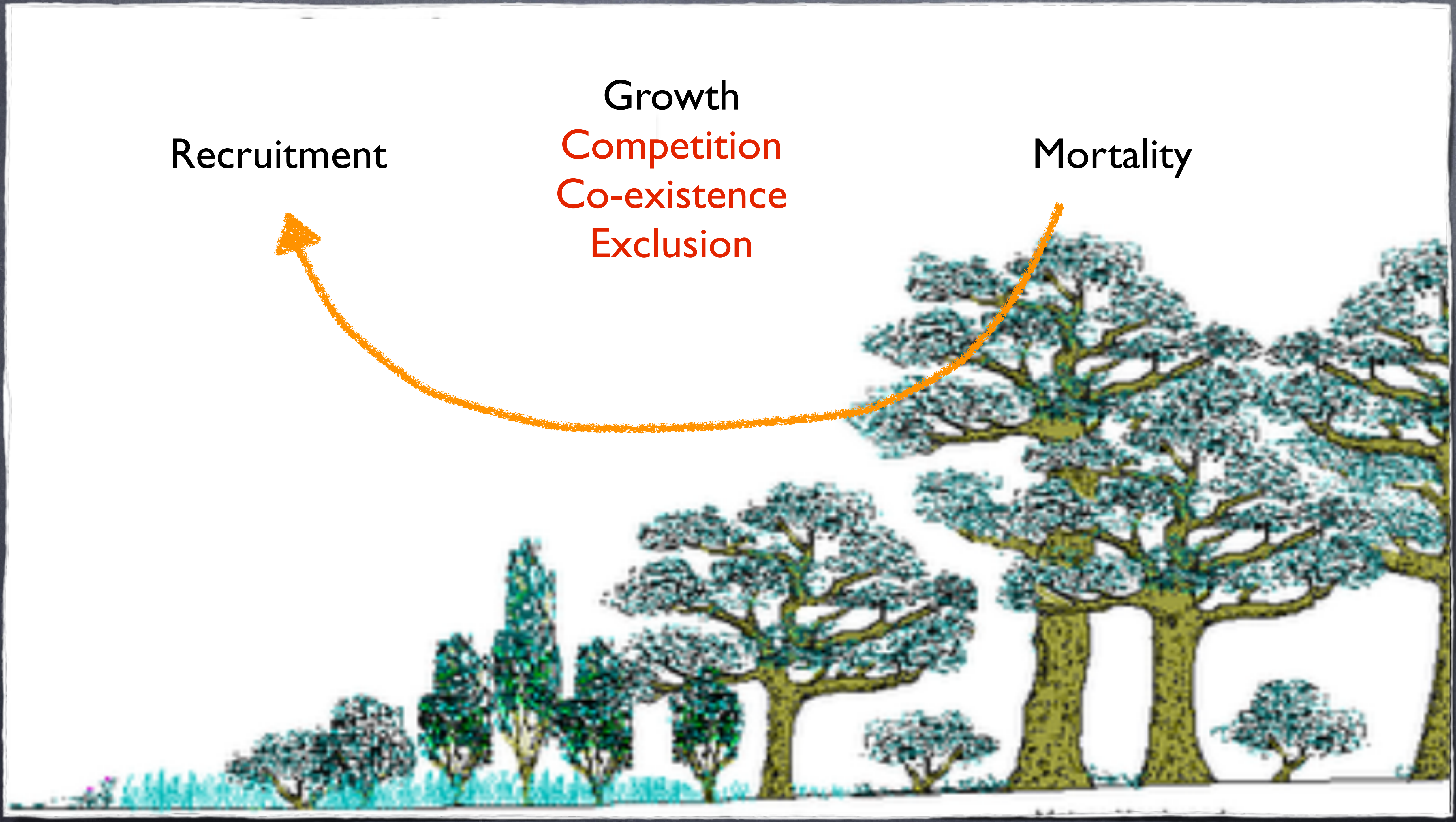


Improved resolution of plant functional types?

if diversity increases, how do we predict which plants will grow where?



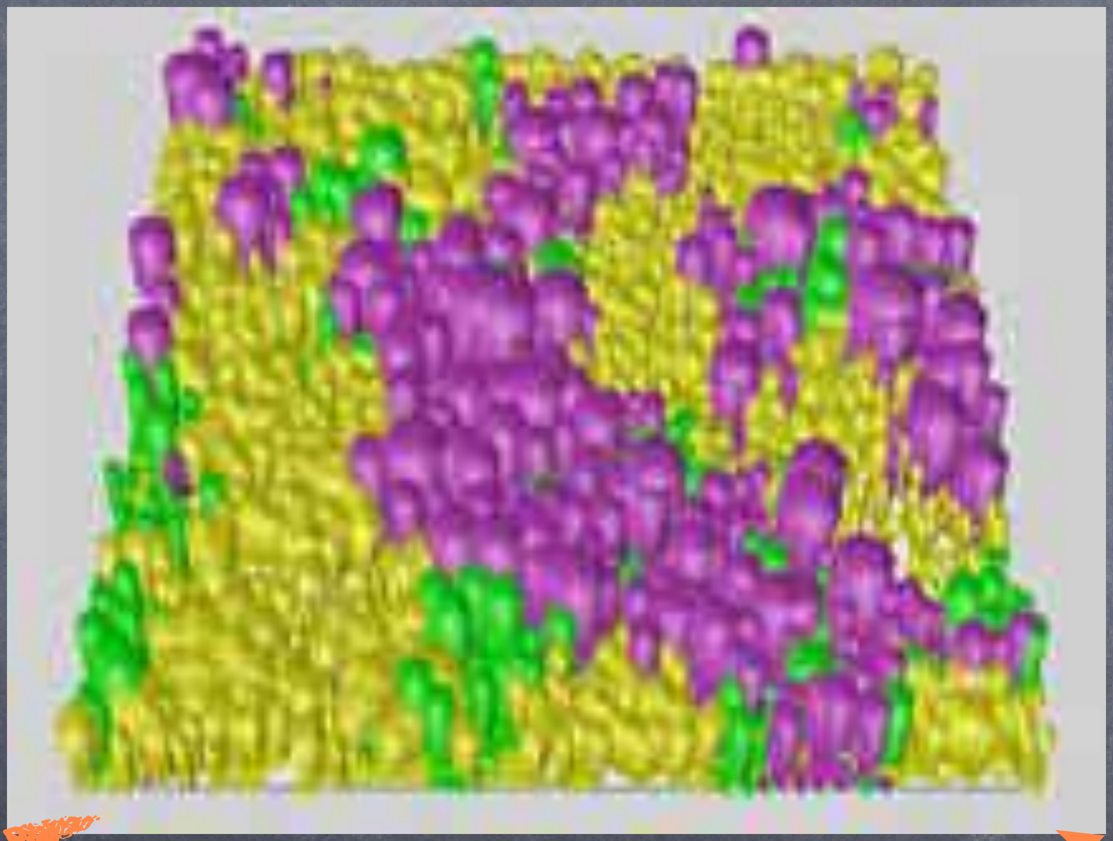
How do ecological systems organize the diversity of plant life?

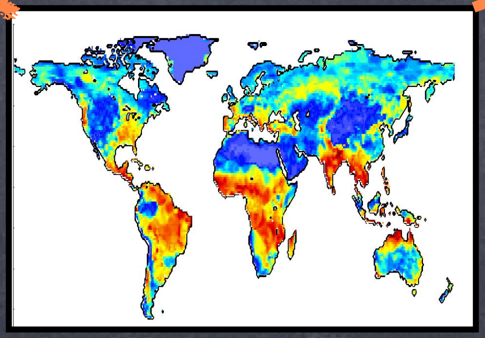


'Gap' Models

(e.g. SORTIE, LPJ-GUESS, SEIB, aDGVM)

- Individual Based
- 3D light environment
- Simulates: recruitment competition disturbance



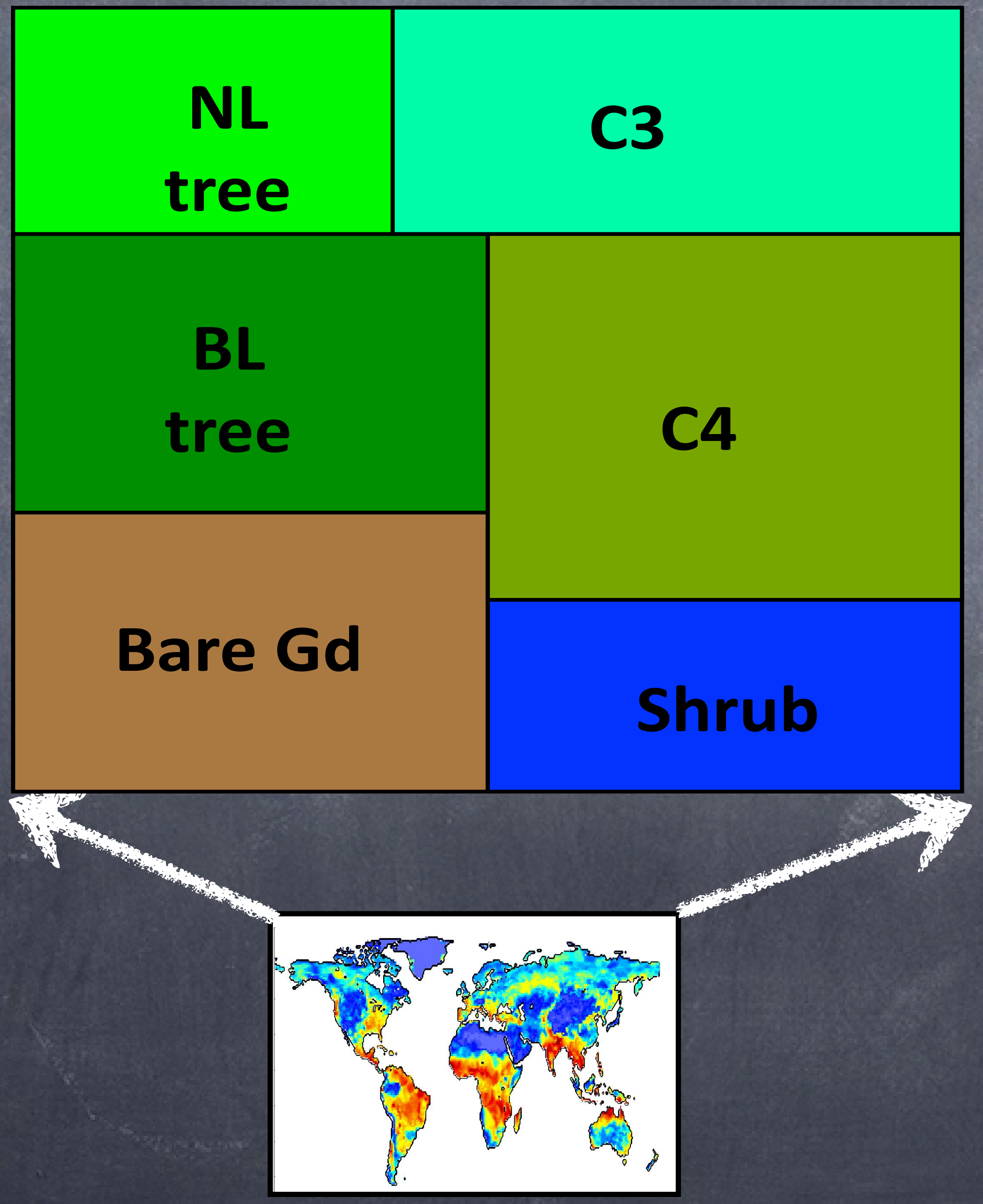


- Stochastic demographics
- Computationally intensive
- Inappropriate for climate simulations?

‘Area-based’ Models

(e.g. CLM, TRIFFID, LPJ, IBIS - models used in IPCC assessments)

- Cell divided into plant type ‘tiles’
- 1 ‘average tree’ per plant type
- No competition for light
- Expansion via relative growth rates



- Deterministic
- Computationally efficient
- Widely used in climate simulations

“Climate models don’t represent ecology realistically”

(*most living plant ecologists*)

Two related problems

- 1. How to better represent plant diversity.
- 2. How to simulate the organization of increased diversity communities.

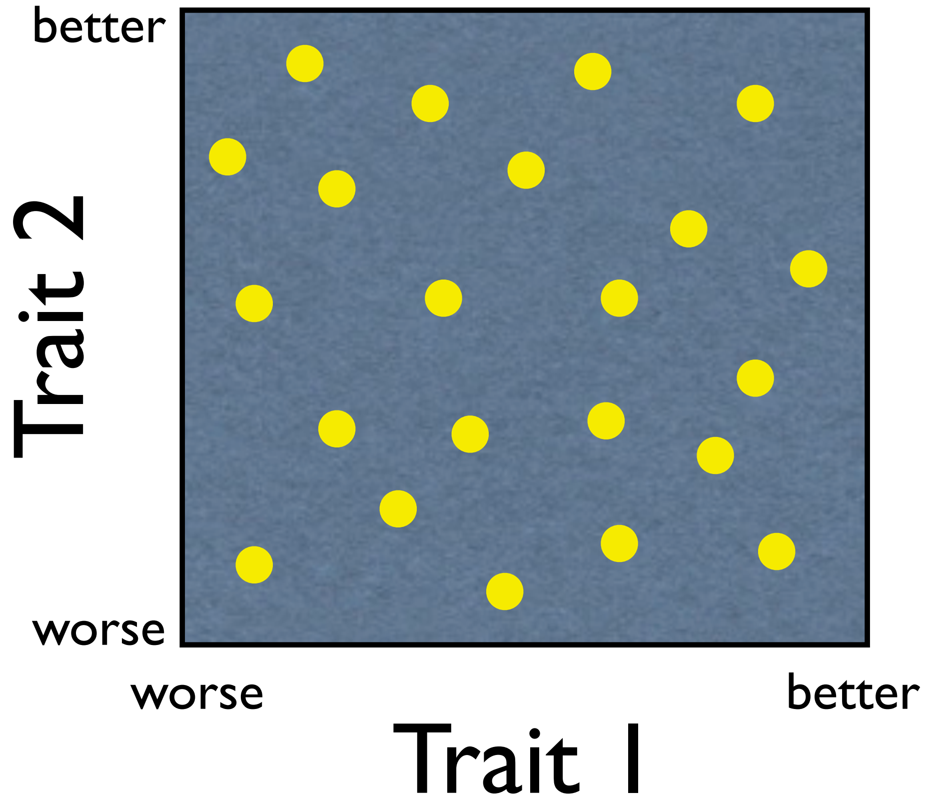
Problem 1
Representation of plant diversity in DGVMs

Plant Traits

- Functional properties of plants are called ‘traits’
- Models define plant properties according to a set of trait values
  - wood density, leaf lifespan, photosynthetic capacity,
  - root depth, allometry, reflectance, nitrogen content, etc.
- Representing diversity involves increased sampling of trait space.
- This is made easier by ‘trade-off’s between plant traits.

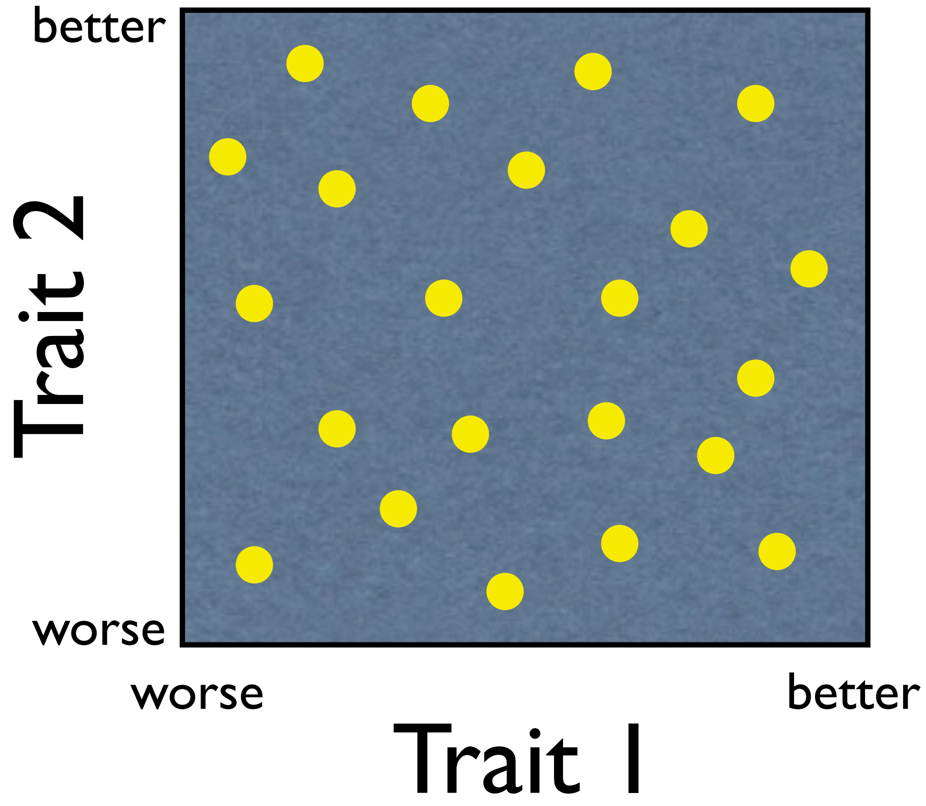
Plant variation through multi-dimensional 'trait space'

ALL THEORETICAL PLANTS

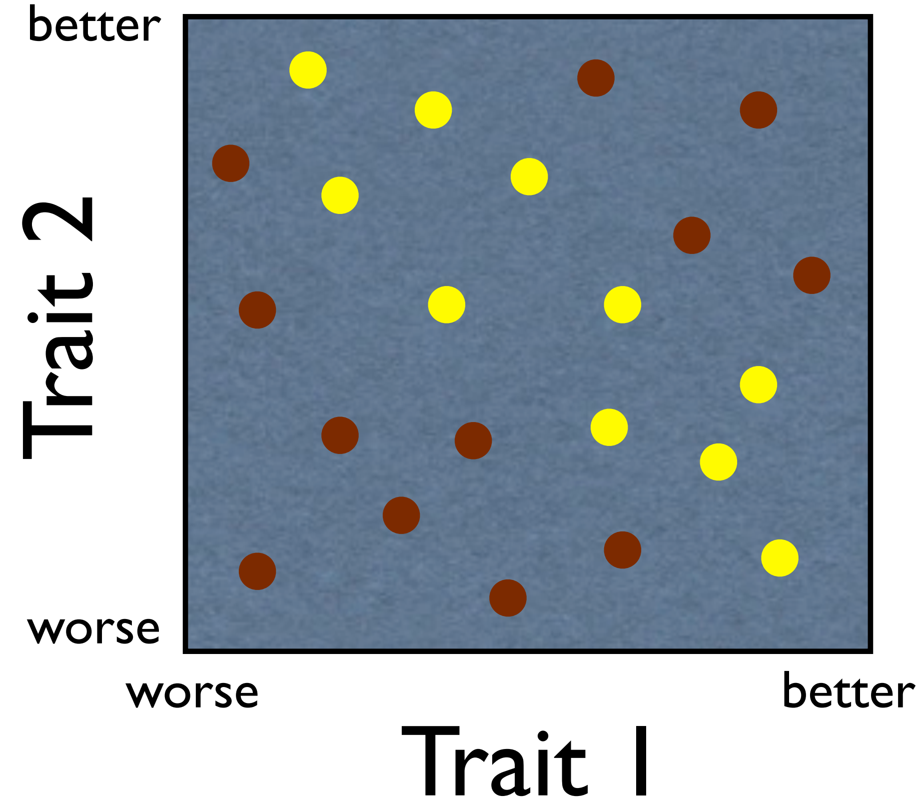


Plant variation through multi-dimensional ‘trait space’

ALL THEORETICAL PLANTS



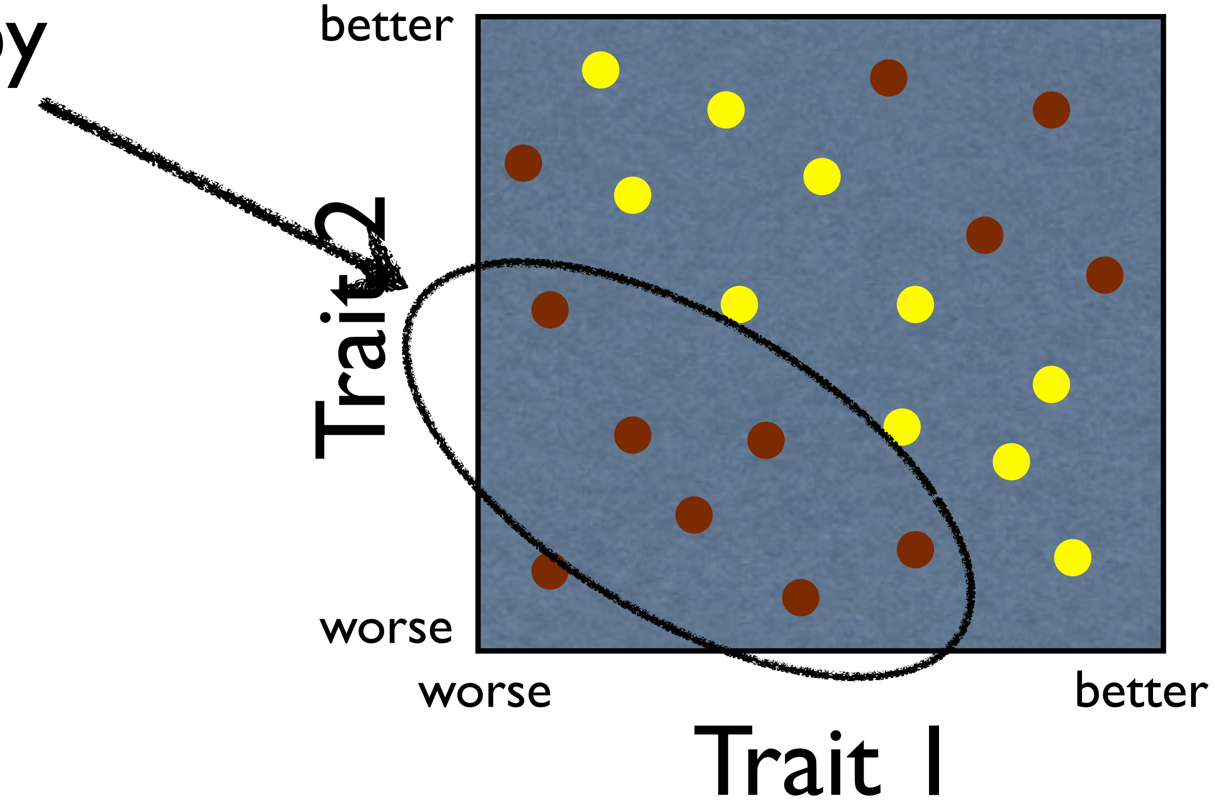
PLANTS THAT EXIST



Plant variation through multi-dimensional 'trait space'

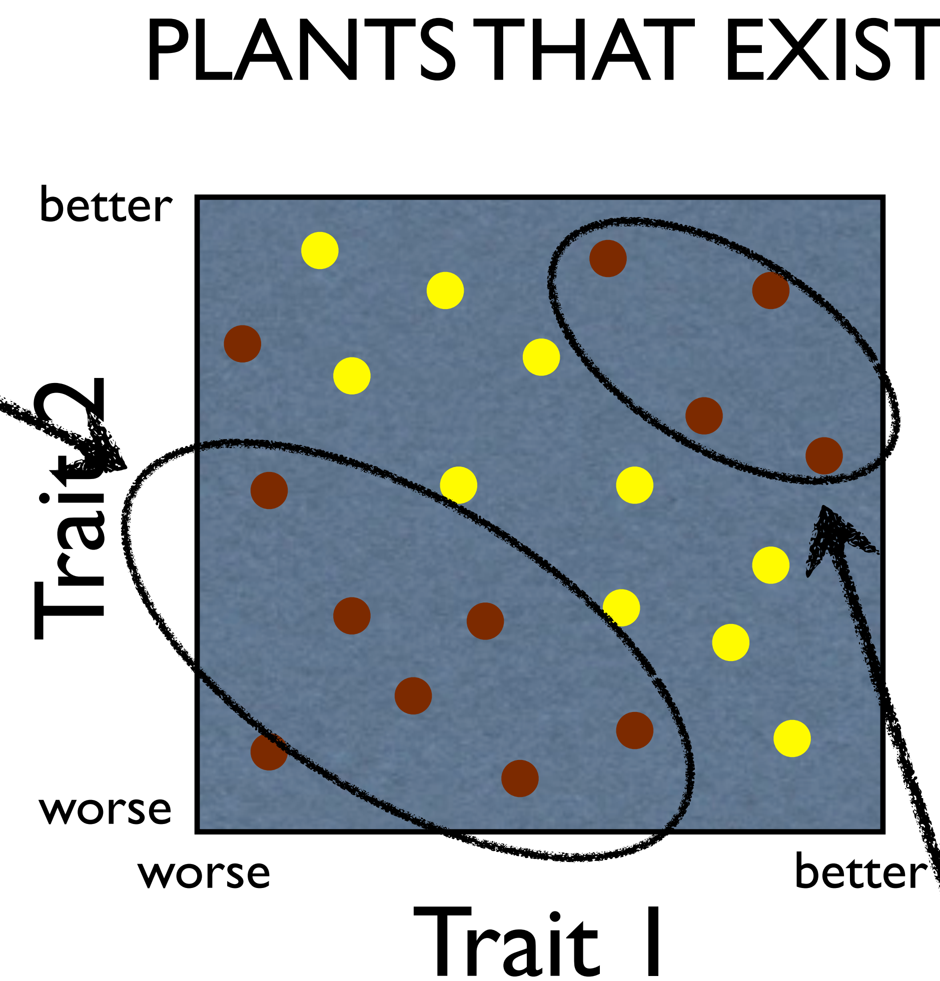
These plants do not exist because they are eliminated by natural selection

PLANTS THAT EXIST



Plant variation through multi-dimensional 'trait space'

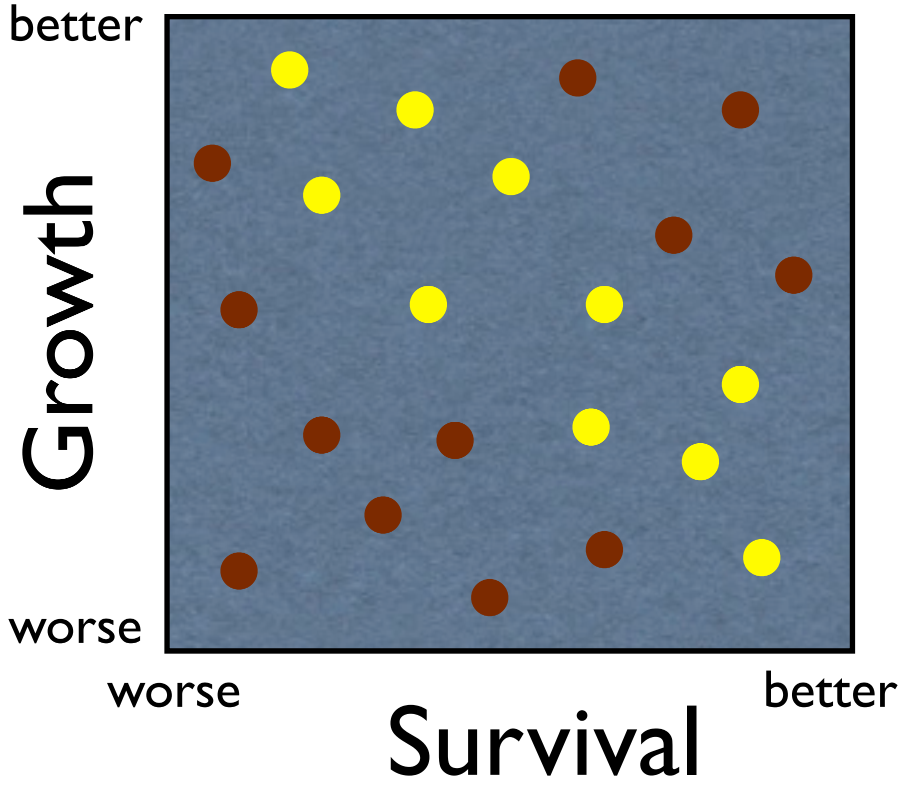
These plants do not exist because they are eliminated by natural selection



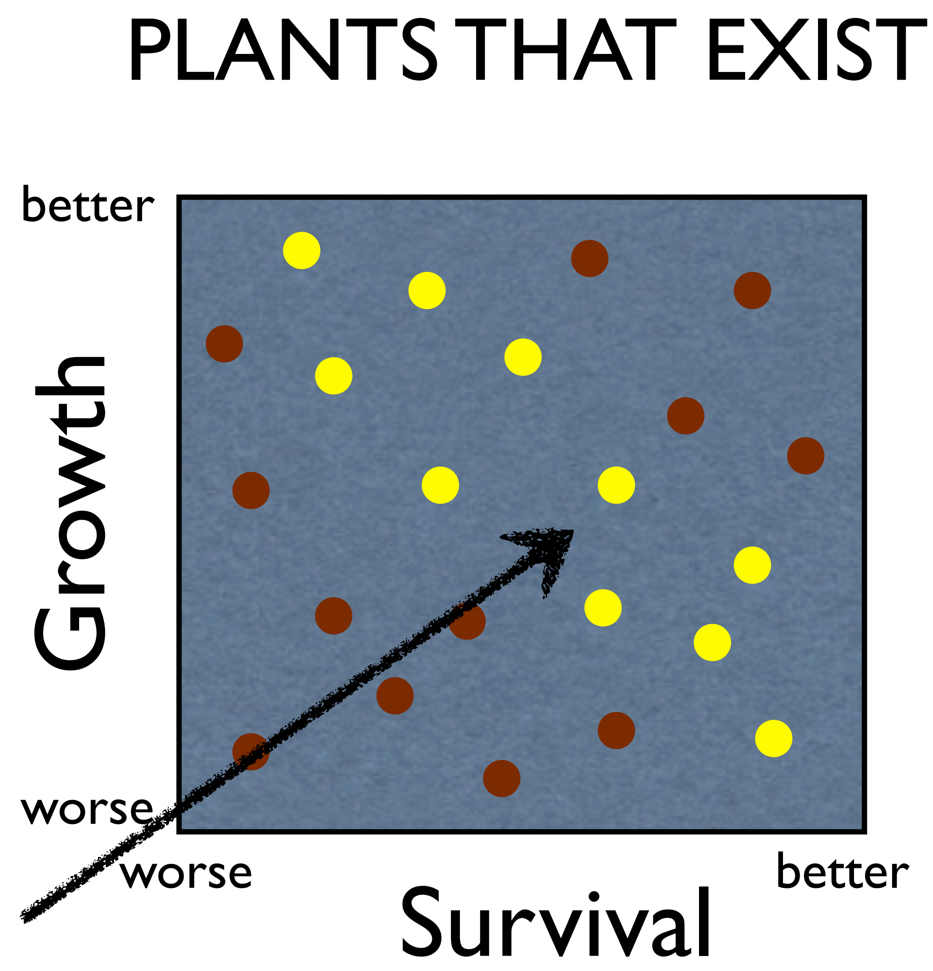
These plants do not exist because they are outside physiological limitations

Plant variation through multi-dimensional 'trait space'

PLANTS THAT EXIST

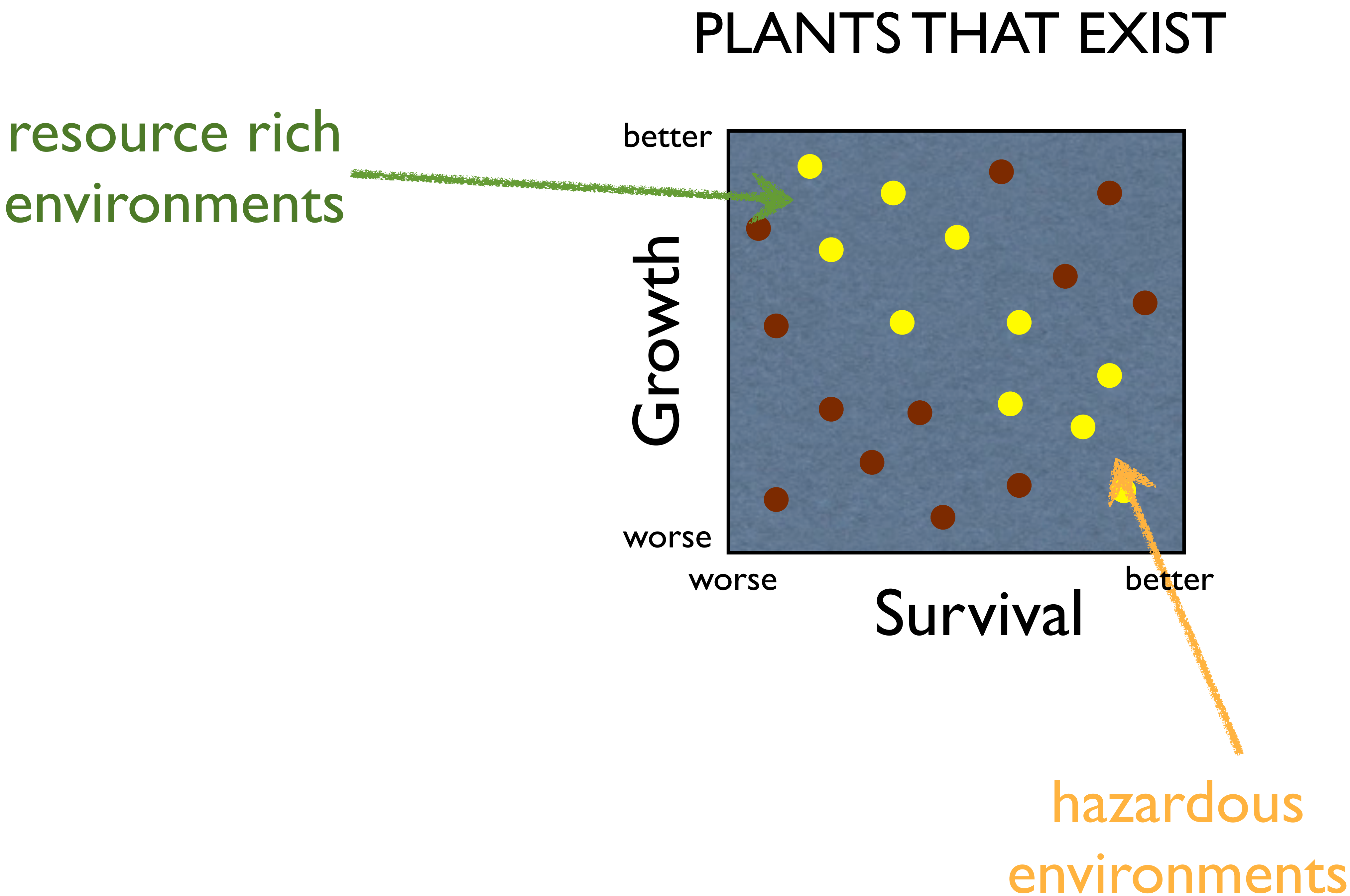


Plant variation through multi-dimensional 'trait space'

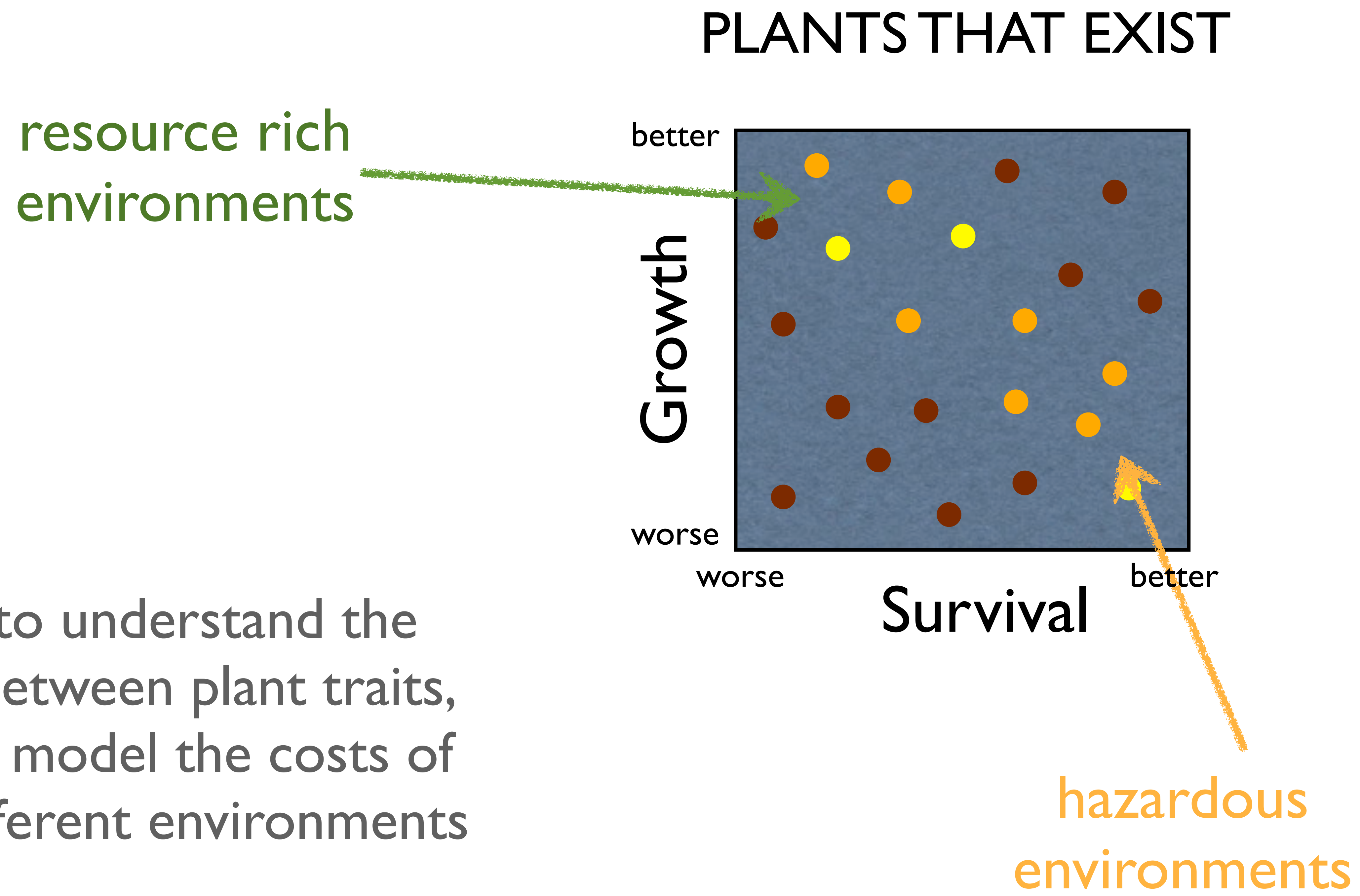


Where are we on this axis?

Plant variation through multi-dimensional 'trait space'

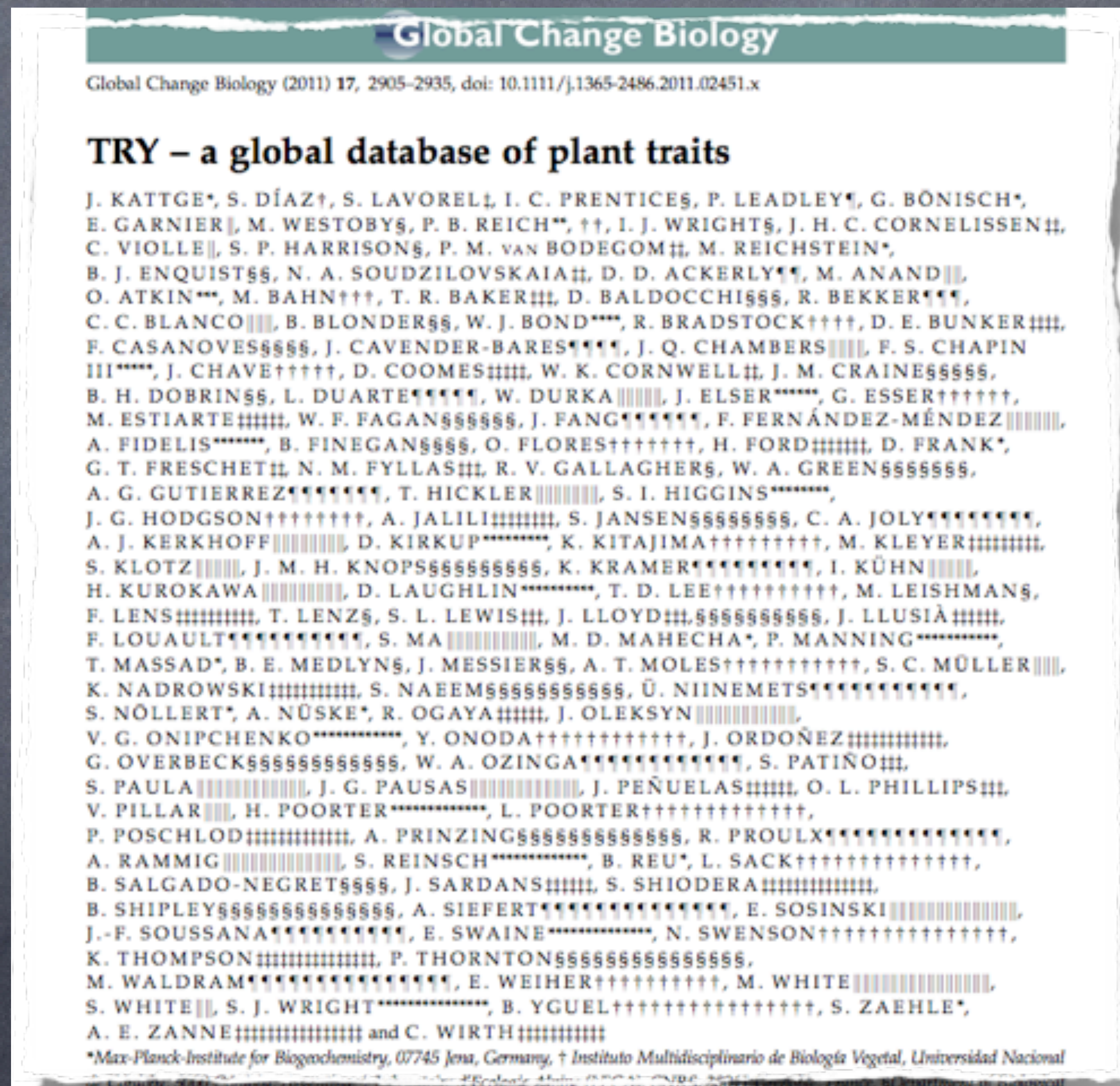


Plant variation through multi-dimensional 'trait space'



We need to understand the trade-offs between plant traits, to properly model the costs of surviving different environments

Our knowledge of trait space is increasing


Global Change Biology

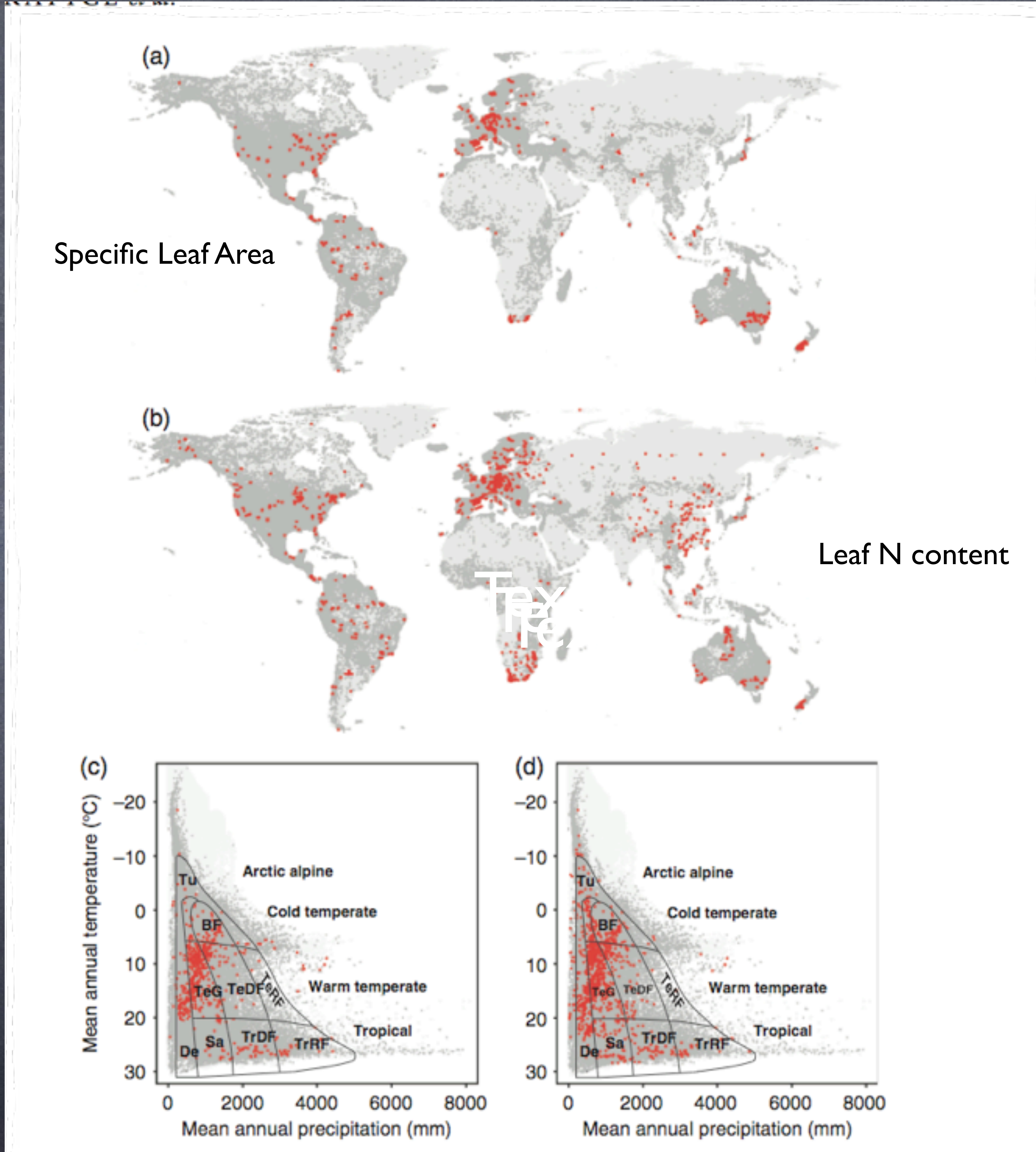
Global Change Biology (2011) 17, 2905–2935, doi: 10.1111/j.1365-2486.2011.02451.x

TRY – a global database of plant traits

J. KATTGE*, S. DÍAZ†, S. LAVOREL‡, I. C. PRENTICE§, P. LEADLEY¶, G. BÖNISCH*, E. GARNIER||, M. WESTOBY§, P. B. REICH**, ††, I. J. WRIGHT§, J. H. C. CORNELISSEN‡‡, C. VIOLLE||, S. P. HARRISON§, P. M. VAN BODEGOM‡‡, M. REICHSTEIN*, B. J. ENQUIST§§, N. A. SOUDZILOVSKAIA‡‡, D. D. ACKERLY¶¶, M. ANAND||||, O. ATKIN***, M. BAHN†††, T. R. BAKER‡‡‡, D. BALDOCCHI§§§, R. BEKKER¶¶¶, C. C. BLANCO||||||, B. BLONDER§§, W. J. BOND****, R. BRADSTOCK††††, D. E. BUNKER‡‡‡‡, F. CASANOVES§§§§, J. CAVENDER-BARES¶¶¶¶, J. Q. CHAMBERS||||||||, F. S. CHAPIN III*****, J. CHAVE†††††, D. COOMES‡‡‡‡‡, W. K. CORNWELL‡‡, J. M. CRAINE§§§§§, B. H. DOBRIN§§, L. DUARTE¶¶¶¶¶, W. DURKA||||||||||, J. ELSER******, G. ESSER††††††, M. ESTIARTE‡‡‡‡‡‡, W. F. FAGAN§§§§§§, J. FANG¶¶¶¶¶¶, F. FERNÁNDEZ-MÉNDEZ||||||||||||, A. FIDELIS*******, B. FINEGAN§§§§, O. FLORES†††††††, H. FORD‡‡‡‡‡‡‡, D. FRANK*, G. T. FRESCHET‡‡, N. M. FYLLAS‡‡‡, R. V. GALLAGHER§, W. A. GREEN§§§§§§§, A. G. GUTIERREZ¶¶¶¶¶¶¶, T. HICKLER||||||||||||||, S. I. HIGGINS********, J. G. HODGSON††††††††, A. JALILI‡‡‡‡‡‡‡‡, S. JANSEN§§§§§§§§, C. A. JOLY¶¶¶¶¶¶¶¶, A. J. KERKHOFF||||||||||||||||, D. KIRKUP*********, K. KITAJIMA†††††††††, M. KLEYER‡‡‡‡‡‡‡‡‡, S. KLOTZ||||||||||, J. M. H. KNOPS§§§§§§§§§, K. KRAMER¶¶¶¶¶¶¶¶¶, I. KÜHN||||||||||, H. KUROKAWA||||||||||||||||||, D. LAUGHLIN**********, T. D. LEE††††††††††, M. LEISHMAN§, F. LENS‡‡‡‡‡‡‡‡‡‡, T. LENZ§, S. L. LEWIS‡‡‡, J. LLOYD‡‡‡,§§§§§§§§§§, J. LLUSIÀ‡‡‡‡‡‡, F. LOUAULT¶¶¶¶¶¶¶¶¶¶, S. MA||||||||||||||||||||, M. D. MAHECHA*, P. MANNING***********, T. MASSAD*, B. E. MEDLYN§, J. MESSIER§§, A. T. MOLES†††††††††††, S. C. MÜLLER||||||||, K. NADROWSKI‡‡‡‡‡‡‡‡‡‡‡, S. NAEEM§§§§§§§§§§§, Ü. NIINEMETS¶¶¶¶¶¶¶¶¶¶¶, S. NÖLLERT*, A. NÜSKE*, R. OGAYA‡‡‡‡‡‡, J. OLEKSYN||||||||||||||||||||||, V. G. ONIPCHENKO************, Y. ONODA††††††††††††, J. ORDOÑEZ‡‡‡‡‡‡‡‡‡‡‡‡, G. OVERBECK§§§§§§§§§§§§, W. A. OZINGA¶¶¶¶¶¶¶¶¶¶¶¶, S. PATIÑO‡‡‡, S. PAULA||||||||||||||||||||||||, J. G. PAUSAS||||||||||||||||||||||||, J. PEÑUELAS‡‡‡‡‡‡, O. L. PHILLIPS‡‡‡, V. PILLAR||||||||, H. POORTER*************, L. POORTER†††††††††††††, P. POSCHLOD‡‡‡‡‡‡‡‡‡‡‡‡‡, A. PRINZING§§§§§§§§§§§§§, R. PROULX¶¶¶¶¶¶¶¶¶¶¶¶¶, A. RAMMIG||||||||||||||||||||||||||, S. REINSCH*************, B. REU*, L. SACK††††††††††††††, B. SALGADO-NEGRET§§§§, J. SARDANS‡‡‡‡‡‡, S. SHIODERA‡‡‡‡‡‡‡‡‡‡‡‡‡‡, B. SHIPLEY§§§§§§§§§§§§§§, A. SIEFERT¶¶¶¶¶¶¶¶¶¶¶¶¶¶, E. SOSINSKI||||||||||||||||||||||||||||, J.-F. SOUSSANA¶¶¶¶¶¶¶¶¶¶, E. SWAINE**************, N. SWENSON†††††††††††††††, K. THOMPSON‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡, P. THORNTON§§§§§§§§§§§§§§§, M. WALDRAM¶¶¶¶¶¶¶¶¶¶¶¶¶¶¶, E. WEIHER†††††††††††, M. WHITE||||||||||||||||||||||||||||||, S. WHITE||||, S. J. WRIGHT***************, B. YGUEL††††††††††††††††, S. ZAEHLE*, A. E. ZANNE‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡‡ and C. WIRTH‡‡‡‡‡‡‡‡‡‡

*Max-Planck-Institute for Biogeochemistry, 07745 Jena, Germany, † Instituto Multidisciplinario de Biología Vegetal, Universidad Nacional

www.try-db.org


Specific Leaf Area
Leaf N content
(a)
(b)
(c)
(d)
Mean annual temperature (°C)
Mean annual precipitation (mm)
Arctic alpine
Cold temperate
Warm temperate
Tropical
Tu
BF
TeG
TeDF
TeRF
De
Sa
TrDF
TrRF

How might we use all of this data?

Alternative approaches to plant trait modeling

How quickly do plant traits vary?

- Model 1: Plant traits are static, adaptation happens via change in plant types
- Model 2: Plant traits evolve through time
- Model 3: Plant traits optimize to prevailing environmental conditions

Pre-define trade-offs and allow the environment to select what survives?

1. The 'JeDi' model

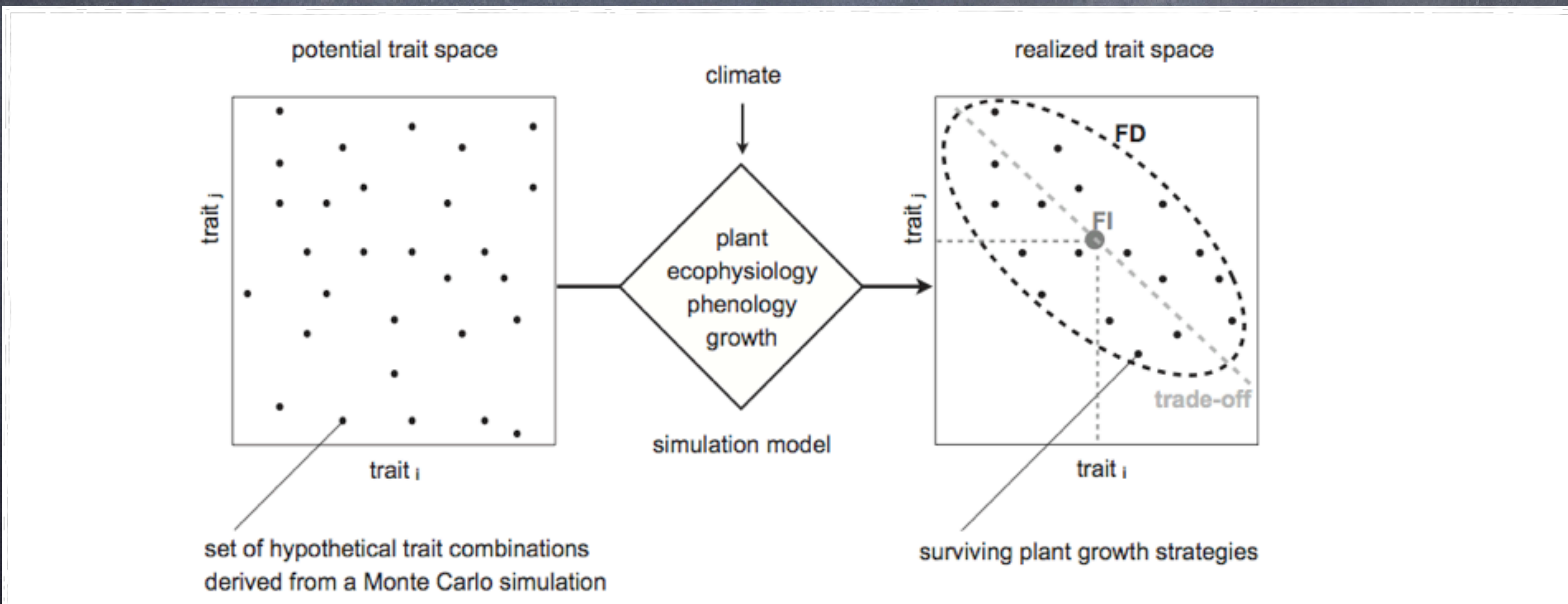
The role of climate and plant functional trade-offs in shaping global biome and biodiversity patterns

Björn Reu[1,2]*, Raphaël Proulx[1,3], Kristin Bohn[1], James G. Dyke[1], Axel Kleidon[1], Ryan Pavlick[1] and Sebastian Schmidtlein[2]

Table 2 Description of the 12 plant functional traits used in the Jena diversity model (JeDi).

Model trait	Effect on plant growth	Cost	Benefit
t01	Growth response time to soil moisture conditions	Less time for C assimilation	Tolerance to water shortage
t02	Growth response time to temperature conditions	Less time for C assimilation	Tolerance to frost damage
t03	Allocation to reproduction	Less growth	Increased reproduction
t04	Allocation of assimilates to above-ground growth	C expenditure for maintenance	Increased growth
t05	Allocation of assimilates to below-ground growth	C expenditure for maintenance	Increased growth
t06	Allocation of assimilates to storage	Less growth	Tolerance to C shortage
t07	Relative allocation to above-ground structure versus leaves	Less photosynthetic capacity	Increased access to light
t08	Relative allocation to below-ground structure versus fine roots	Less water uptake	Increased access to water
t09	Senescence response time to net productivity conditions	Less time for C assimilation	Tolerance to climatic variability
t10	Relative senescence of leaves versus roots	Less growth	Tolerance to climatic variability
t11	Initial amount of assimilates ('seed size')	C expenditure for maintenance	Increased seedling survival
t12	Regulation of light-use efficiency	Increased respiration	Increased photosynthetic capacity

All traits are associated to ecophysiological costs and benefits in terms of plant growth and survival.



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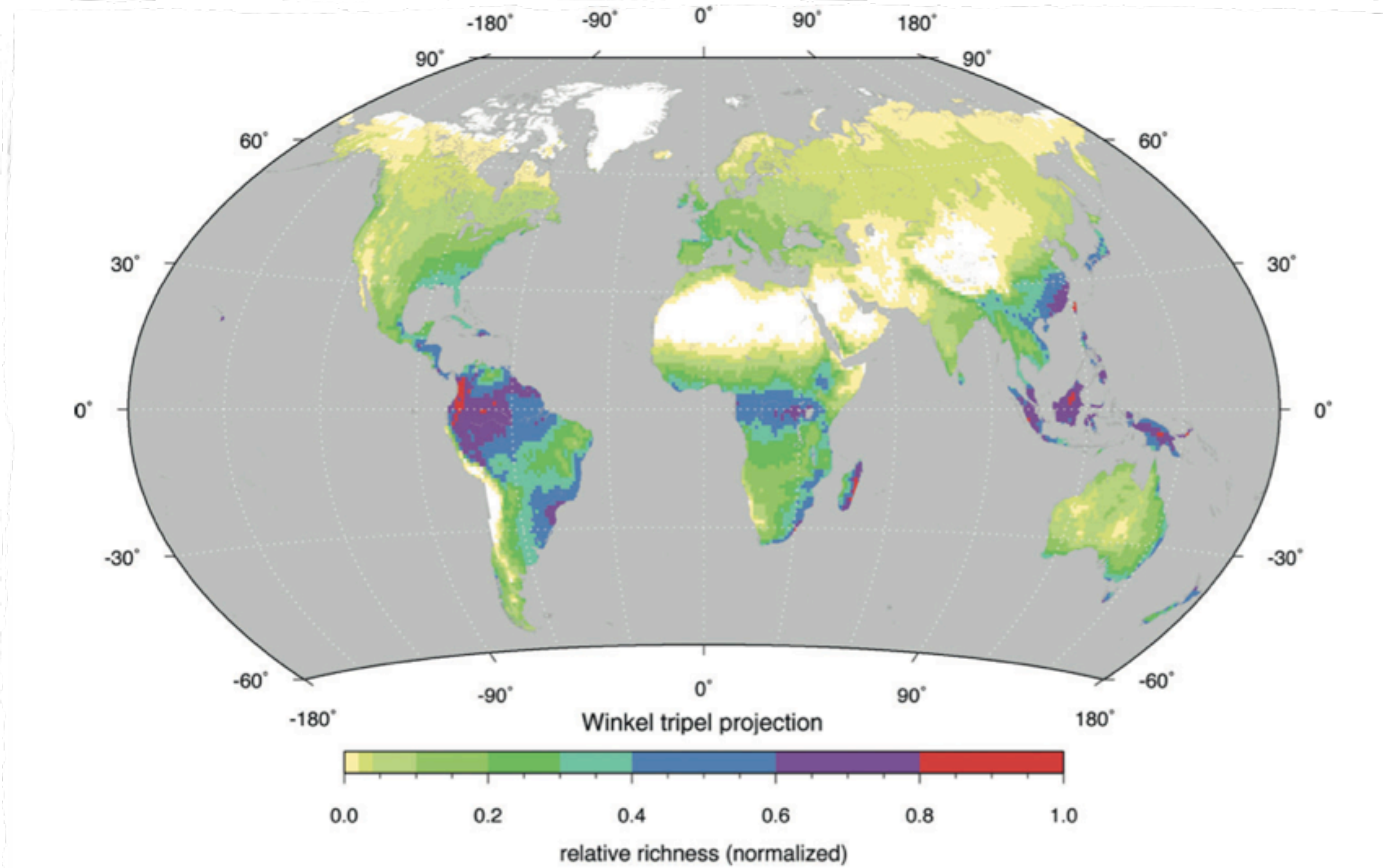


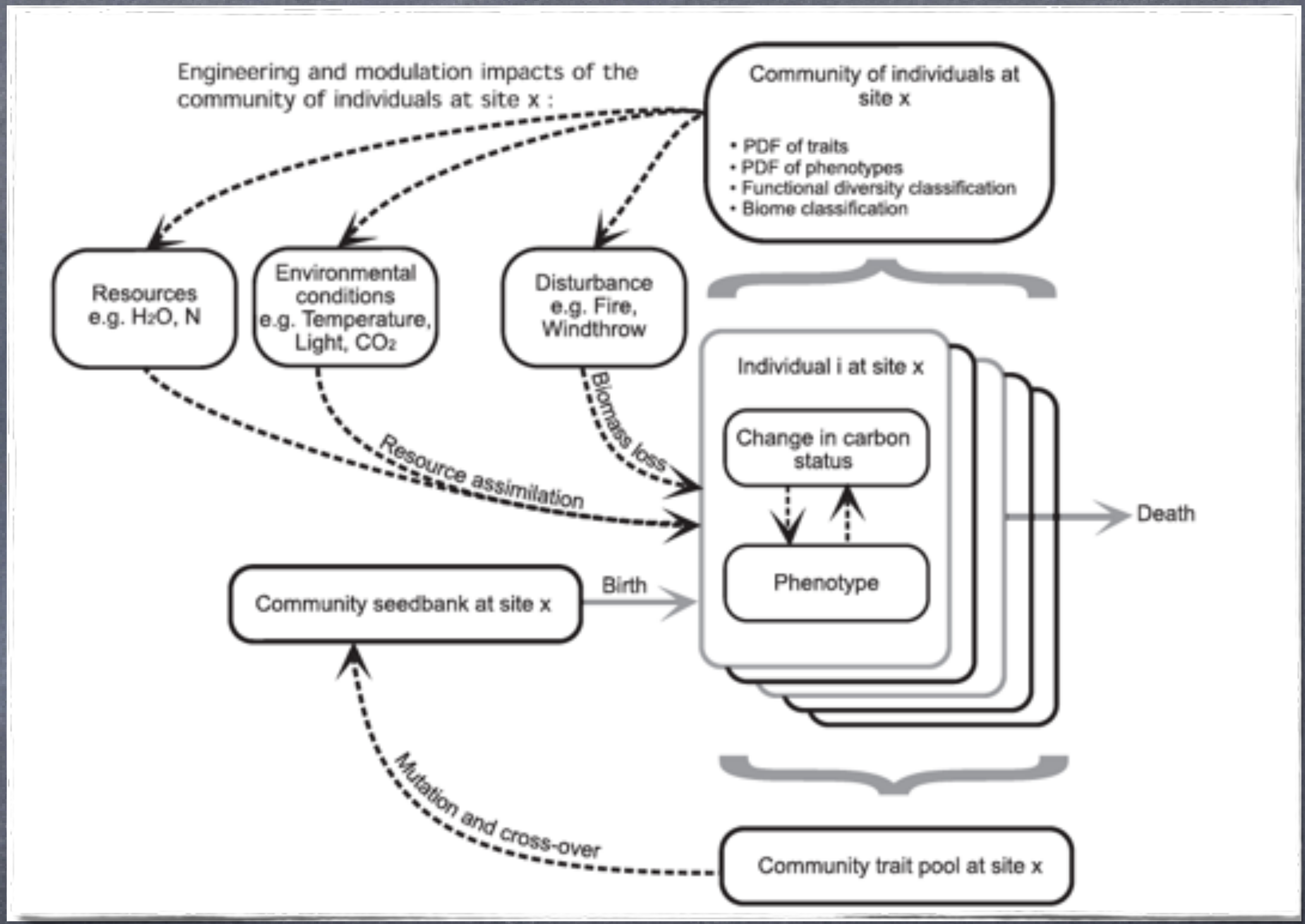
Next-generation dynamic global vegetation models: learning from community ecology

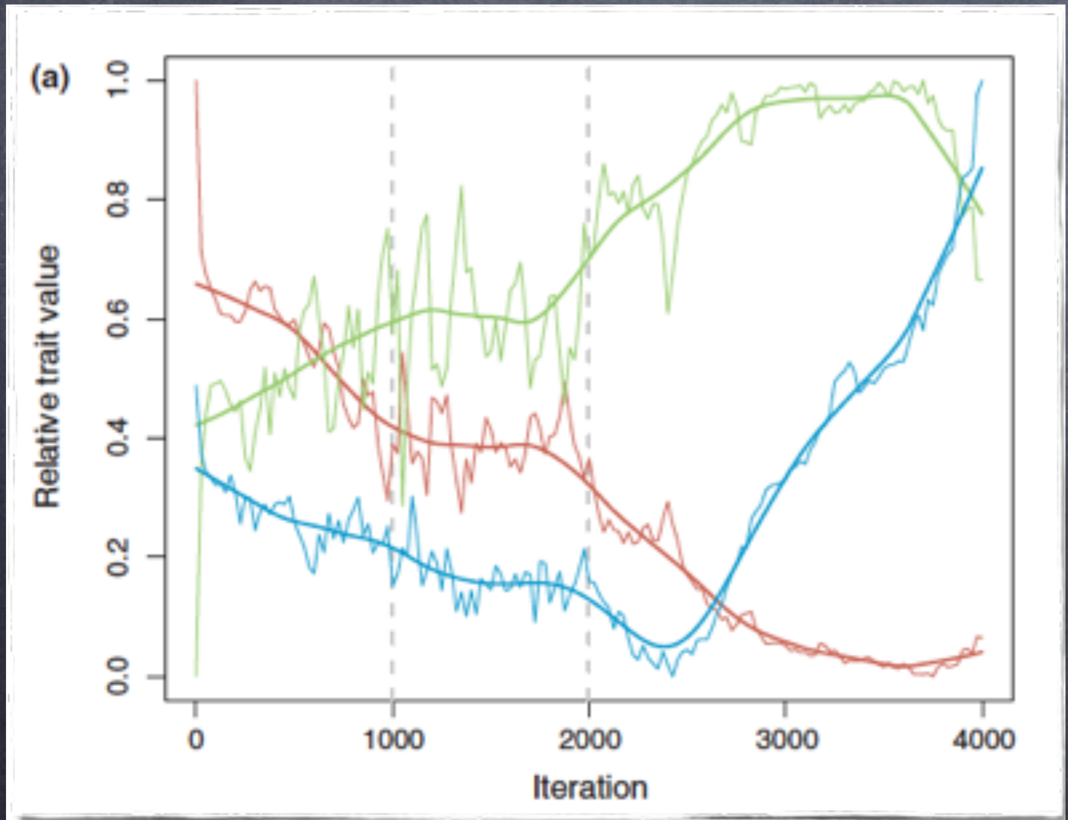
Simon Scheiter[1], Liam Langan[2] and Steven I. Higgins[2]

[1]Biodiversität und Klima Forschungszentrum (LOEWE BiK-F), Senckenberg Gesellschaft für Naturforschung, Senckenberganlage 25, D-60325, Frankfurt am Main, Germany; [2]Institut für Physische Geographie, Goethe-Universität Frankfurt am Main, Altenhöferallee 1, D-60438, Frankfurt am Main, Germany

2. The 'aDGVM' model

Plant traits evolve through time, within 'species'





Individual, population and community trait values adapt to conditions

3. Optimality: an emergent property of evolution?

- All existing species are the winners of evolution
- Competition selects the fittest species
- Sub-optimal plants should be eliminated
- What should a ‘fit’ plant do?

Optimal Function Explains Forest Responses to Global Change

RODERICK C. DEWAR, OSKAR FRANKLIN, ANNIKKI MÄKELÄ, ROSS E. McMURTRIE, AND HARRY T. VALENTINE

Optimality models identify an apparent goal or objective function *F* that is maximized with respect to one or more plant functional traits *f*.

The maximization of *F* is usually subjected to one or more physiological or environmental constraints *C*.

Optimality models—although recognized and applied in terrestrial ecology for more than 30 years—remain relatively underexploited by the global change research community as components of land-surface models.

Optimal models of plant function

Toward a mechanistic modeling of nitrogen limitation on vegetation dynamics

Chonggang Xu[1], Rosie Fisher[2], Cathy J. Wilson[1], Stan D. Wullschleger[3], Michael Cai[1], Nate G. McDowell[1]

Leaf-trait variation explained by the hypothesis that plants maximize their canopy carbon export over the lifespan of leaves

Ross E. McMurtrie[1,3] and Roderick C. Dewar[2]

Optimal nitrogen allocation controls tree responses to elevated CO_2

Oskar Franklin[1,2]
[1]IIASA, Institute for Applied Systems Analysis, 2361 Laxenburg, Austria; [2]School of Biological, Earth and Environmental Sciences, University of New South Wales, Sydney, NSW 2052, Australia

Resource Optimization and Symbiotic Nitrogen Fixation

E. B. Rastetter,[1]* P. M. Vitousek,[2] C. Field,[3] G. R. Shaver,[1] D. Herbert,[1] and G. I. Ågren[4]

Optimisation of photosynthetic carbon gain and within-canopy gradients of associated foliar traits for Amazon forest trees

J. Lloyd[1], S. Patiño[2], R. Q. Paiva[3,*], G. B. Nardoto[4], C. A. Quesada[1,3,5], A. J. B. Santos[3,5,†], T. R. Baker[1], W. A. Brand[6], I. Hilke[6], H. Gielmann[6], M. Raessler[6], F. J. Luizão[3], L. A. Martinelli[4], and L. M. Mercado[7]
[1]Earth and Biosphere Institute, School of Geography, University of Leeds, LS2 9JT, UK
[2]Grupo de Ecología de Ecosistemas Terrestres Tropicales, Universidad Nacional de Colombia, Sede Amazonia, Instituto Amazónico de Investigaciones-Imani, km. 2, vía Tarapacá, Leticia, Amazonas, Colombia
[3]Institito National de Pesquisas Amazônicas, Manaus, Brazil
[4]Centro de Energia Nuclear na Agricultura, Av. Centenário 303, 13416-000, Piracicaba-SP, Brazil

Challenges and Opportunities of the Optimality Approach in Plant Ecology

Annikki Mäkelä, Thomas J. Givnish, Frank Berninger, Thomas N. Buckley, Graham D. Farquhar and Pertti Hari

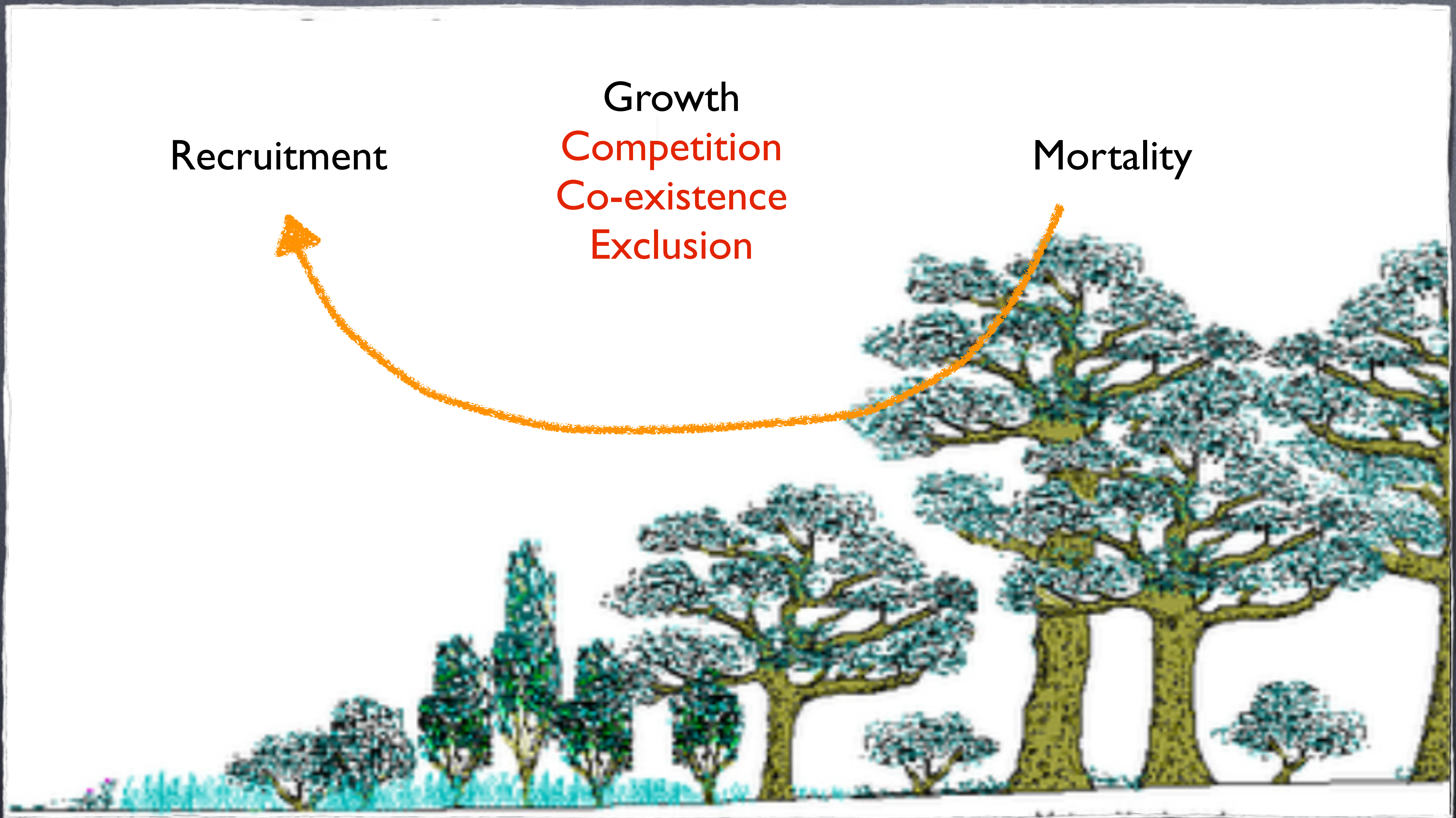
Optimal co-allocation of carbon and nitrogen in a forest stand at steady state

Annikki Mäkelä[1], Harry T. Valentine[2] and Heljä-Sisko Helmisaari[3]
[1]Department of Forest Ecology, PO Box 27, 00014 University of Helsinki, Finland; [2]USDA Forest Service, 271 Mast Road, Durham, NH 03824, USA; [3]Finnish Forest Research Institute, Vantaa Research Centre, PO Box 18, 01301 Vantaa, Finland

Summary

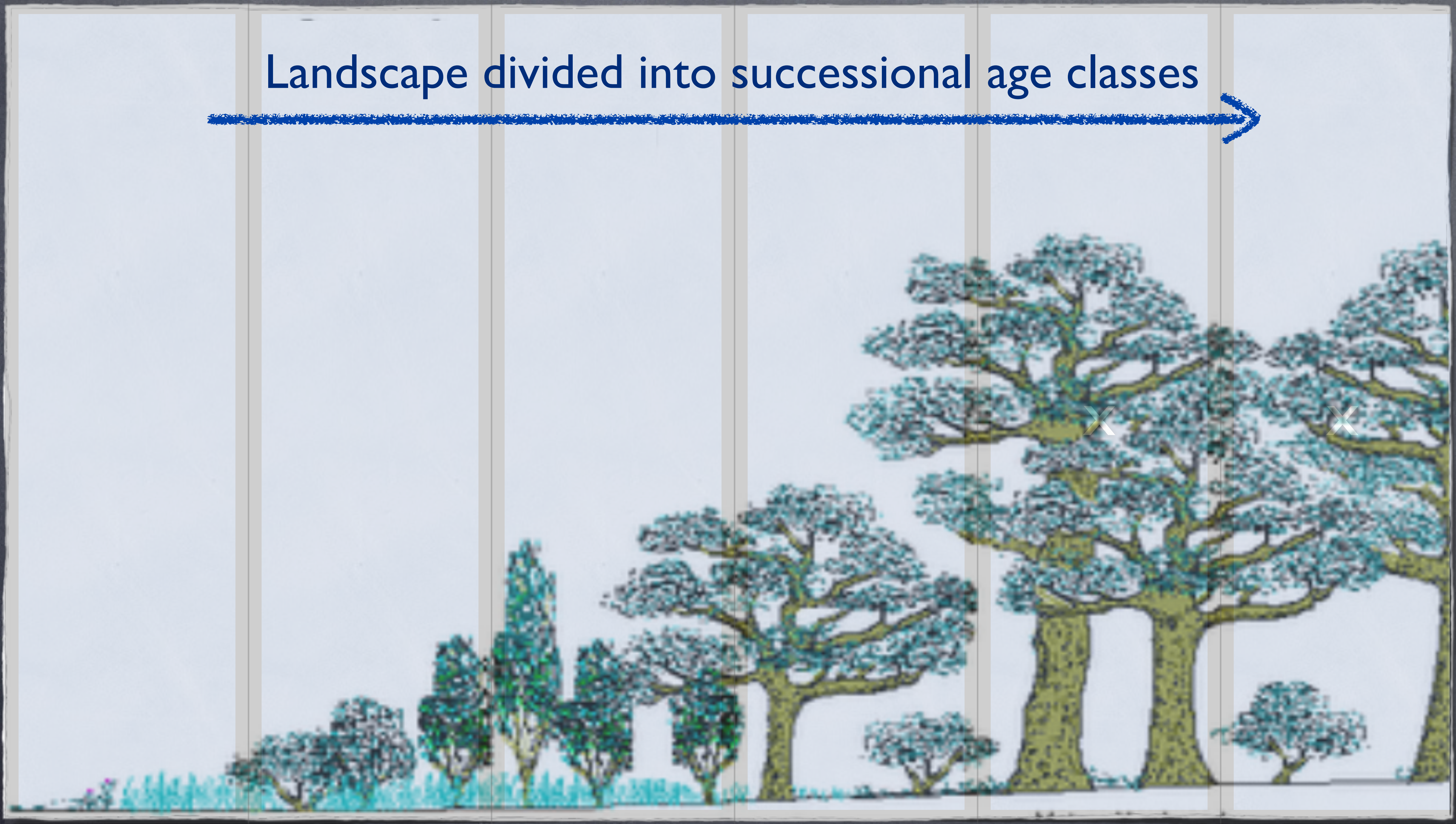
- Better representation of plant diversity is desirable and possible within vegetation models, if we incorporate sufficient knowledge of plant traits.
- Complexity results from (at least) two issues
  - 1. Incomplete knowledge of the costs and benefits of different plant strategies
  - 2. Poor understanding of the flexibility of plant traits through time.

Problem II
Ecosystem organization in DGVMs


Growth
Recruitment
Competition
Co-existence
Exclusion
Mortality

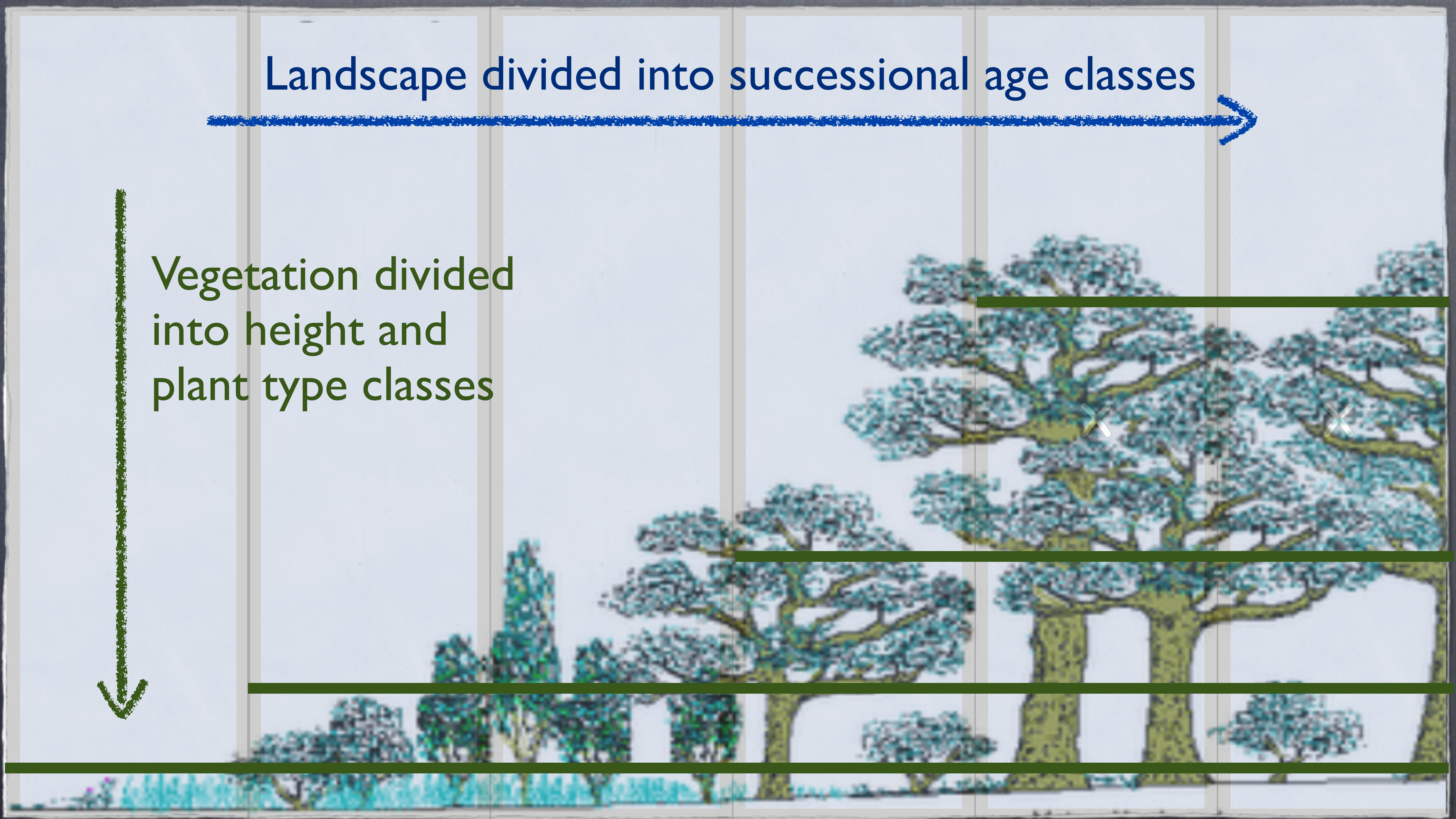
Ecosystem Demography Model (ED)

Moorcroft, Hurtt and Pacala. 2001



Ecosystem Demography Model (ED)

Moorcroft, Hurtt and Pacala. 2001



Merits of ED approach

- Computationally plausible simulations of ecological dynamics
- Represents vertical competition for light:
  - Representation of multiple niches & the possibility of plant co-existence
- Simulation of recovery from human and natural disturbance events.
- What issues remain unresolved?

Modeling competition for light resources

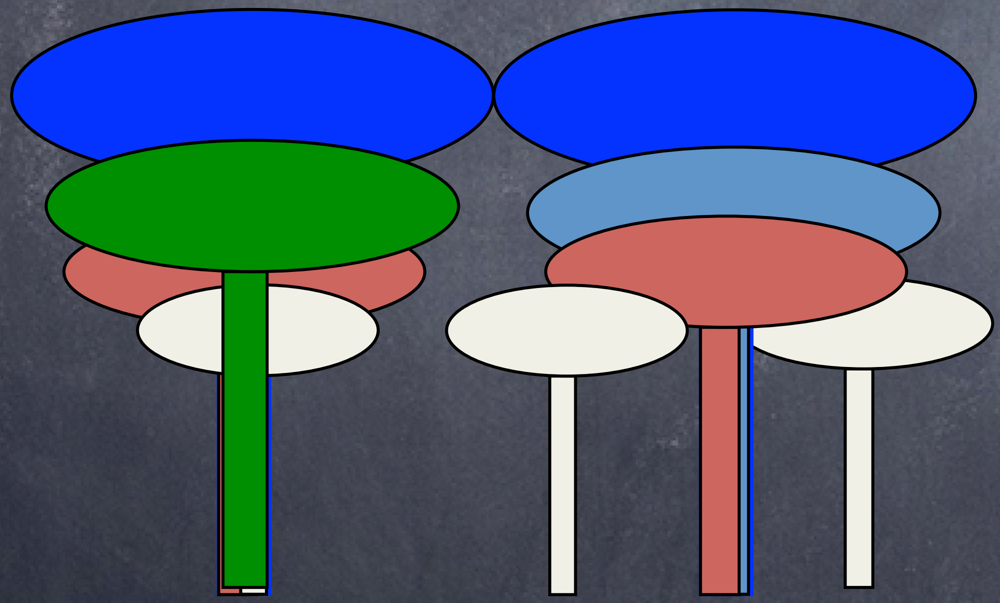
- Competition for light ~ competition for space
- Some trees get in the canopy, some stay in the understory

Modeling competition for light resources

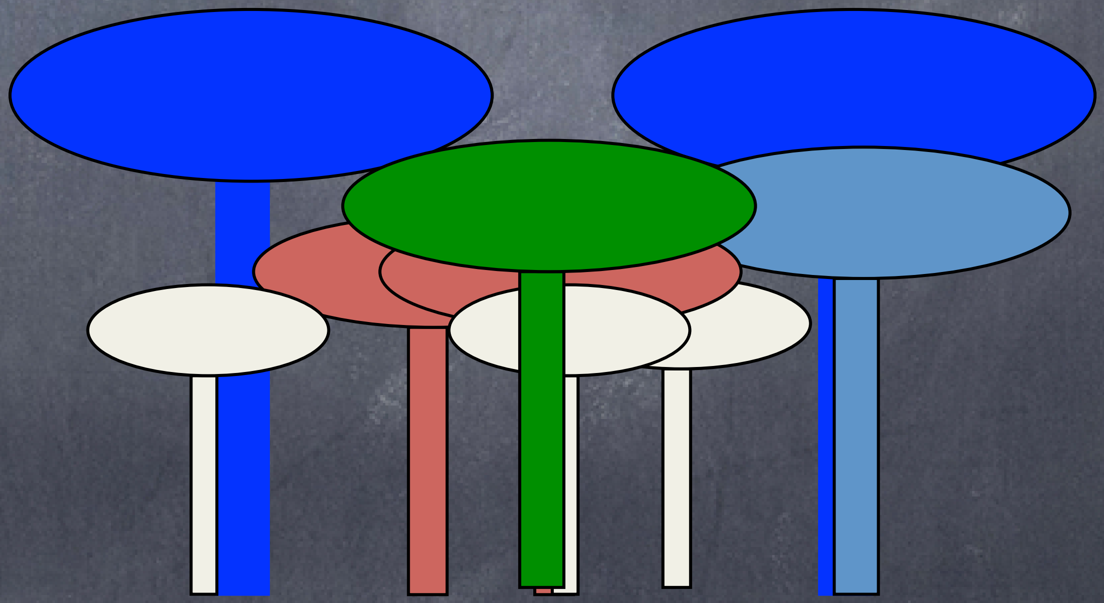
- Some trees get into the canopy, but which ones?
- How tall do you have to grow?

In a real forest, being slightly taller doesn't ***necessarily*** mean having more light. Some trees are lucky…

Perfect deterministic world
= mono-dominance



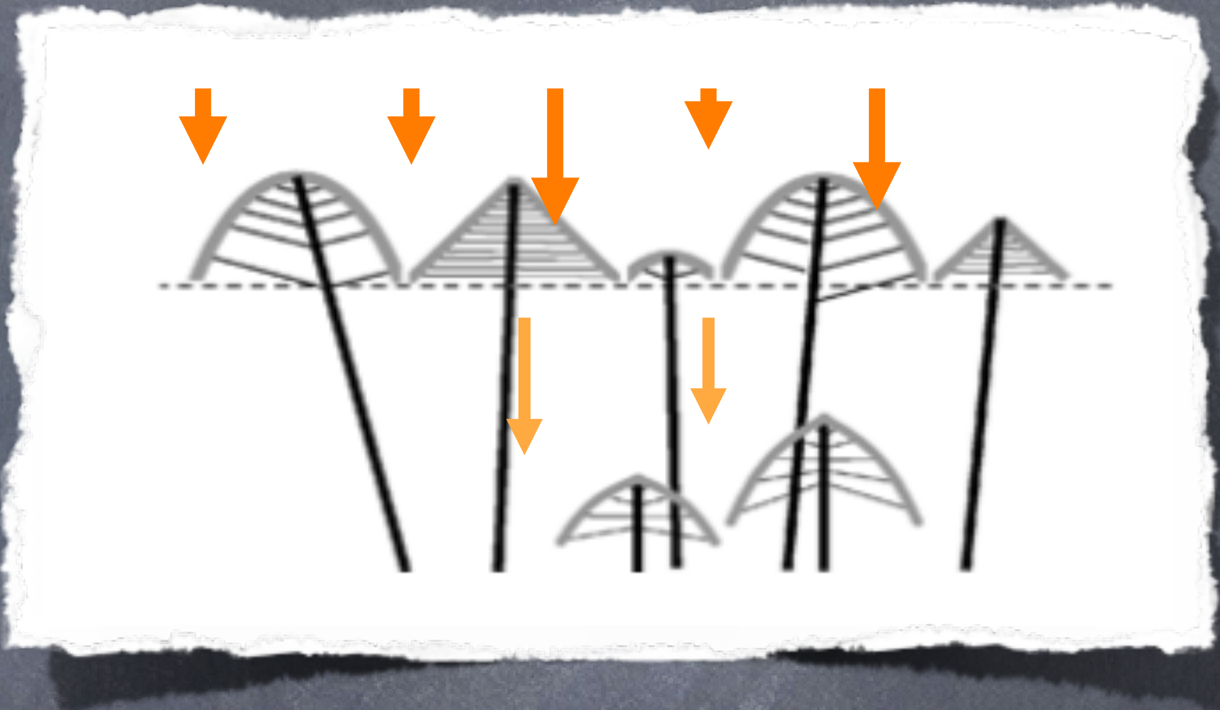
Imperfect stochastic world
= co-existence



Competitive Exclusion Parameter

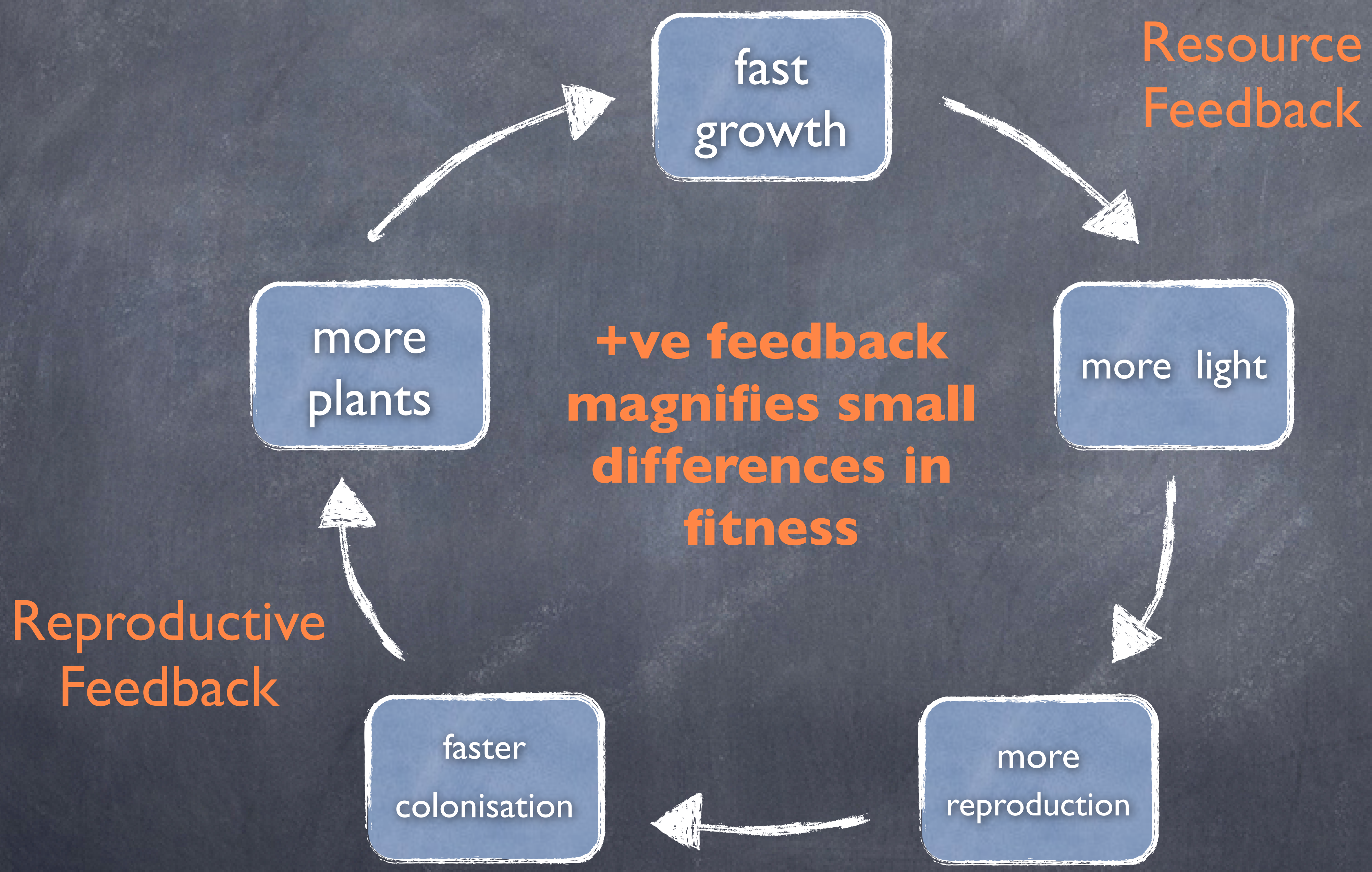
Excess Canopy Area → f_{canopy}

Excess Canopy Area → $1-f_{canopy}$

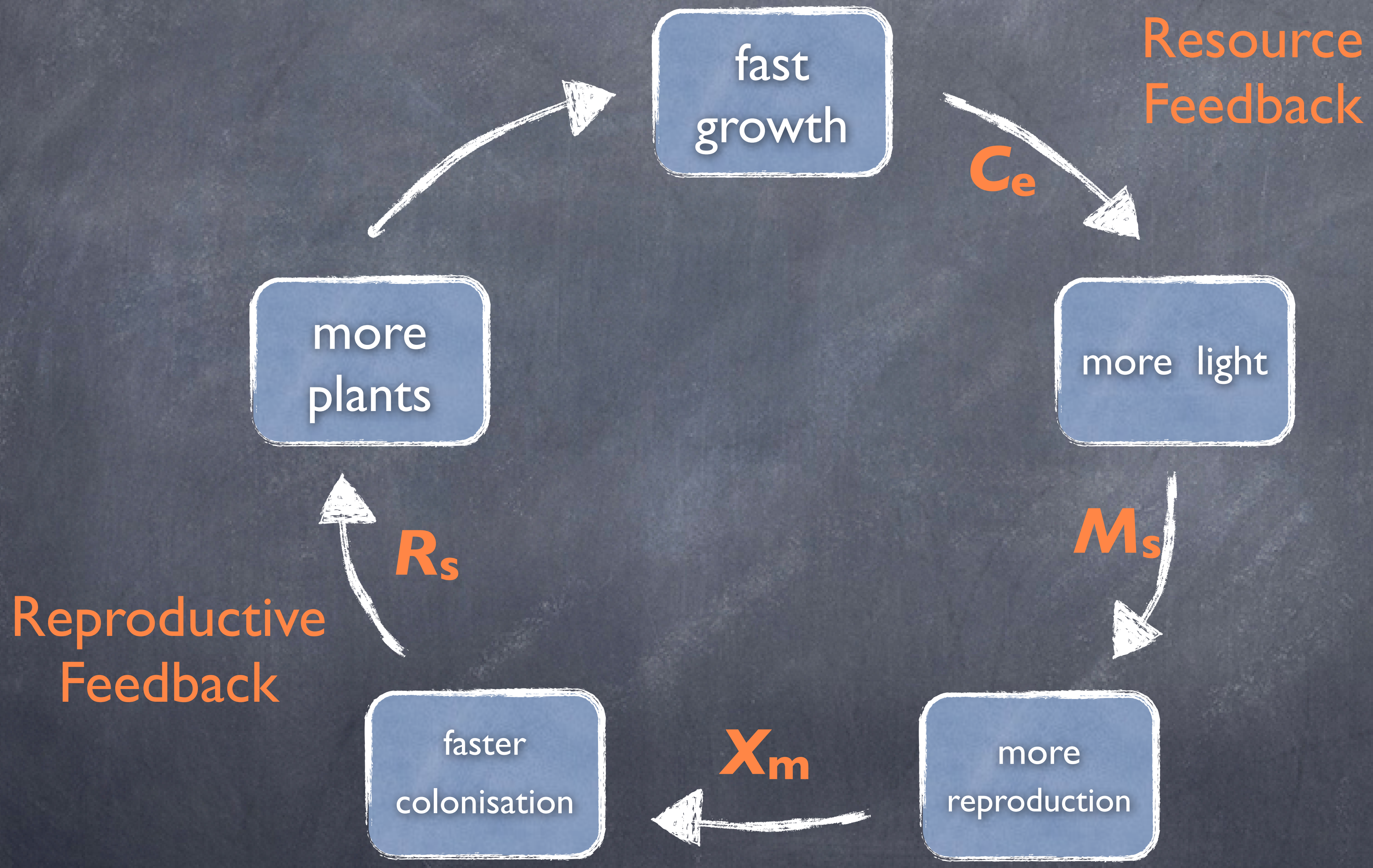


- $f_{canopy} \propto h.C_e$
- C_e = how do tall trees monopolise light resources?
- C_e = Stochasticity vs. Determinism of competition

Ecosystem level positive feedback



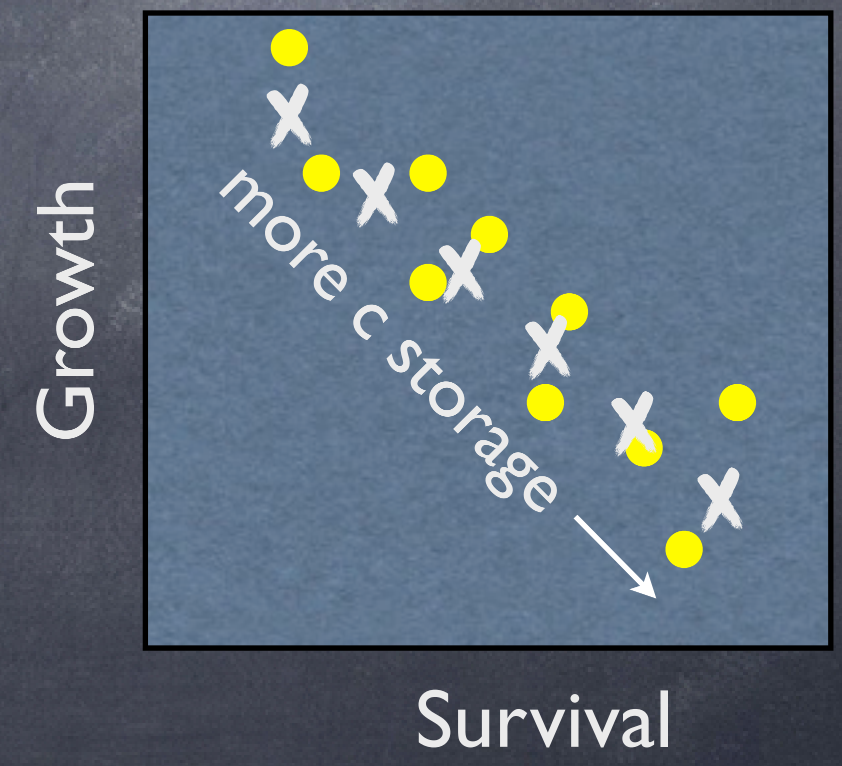
Ecosystem level positive feedback



Example plant community

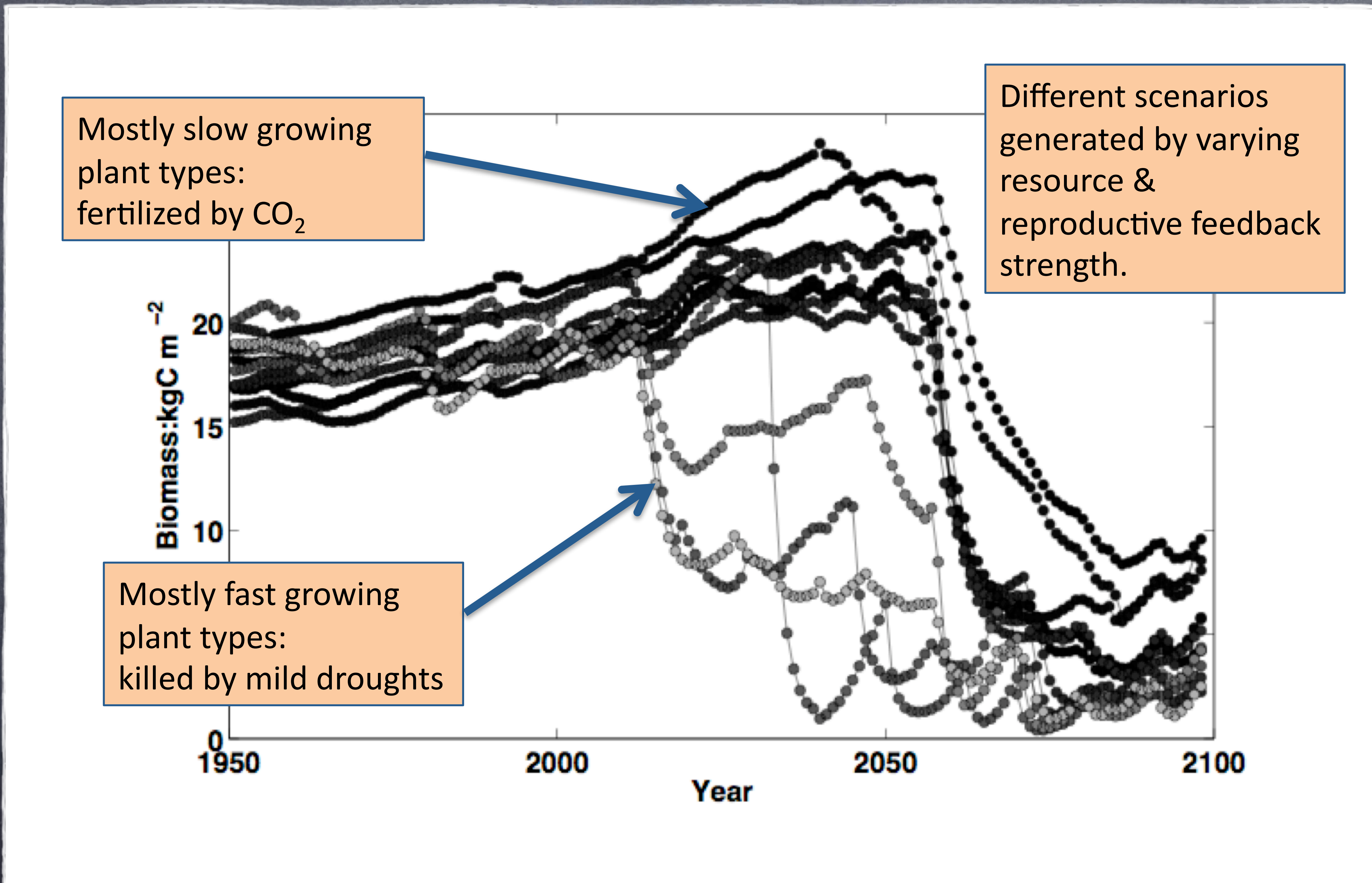
- One fundamental growth ➪ risk trade-off involves the storage vs deployment of carbon for growth
    - Less C storage = more growth
    - Less C storage = less resources during drought

- System exposed to increasing CO_2 and decreasing rainfall

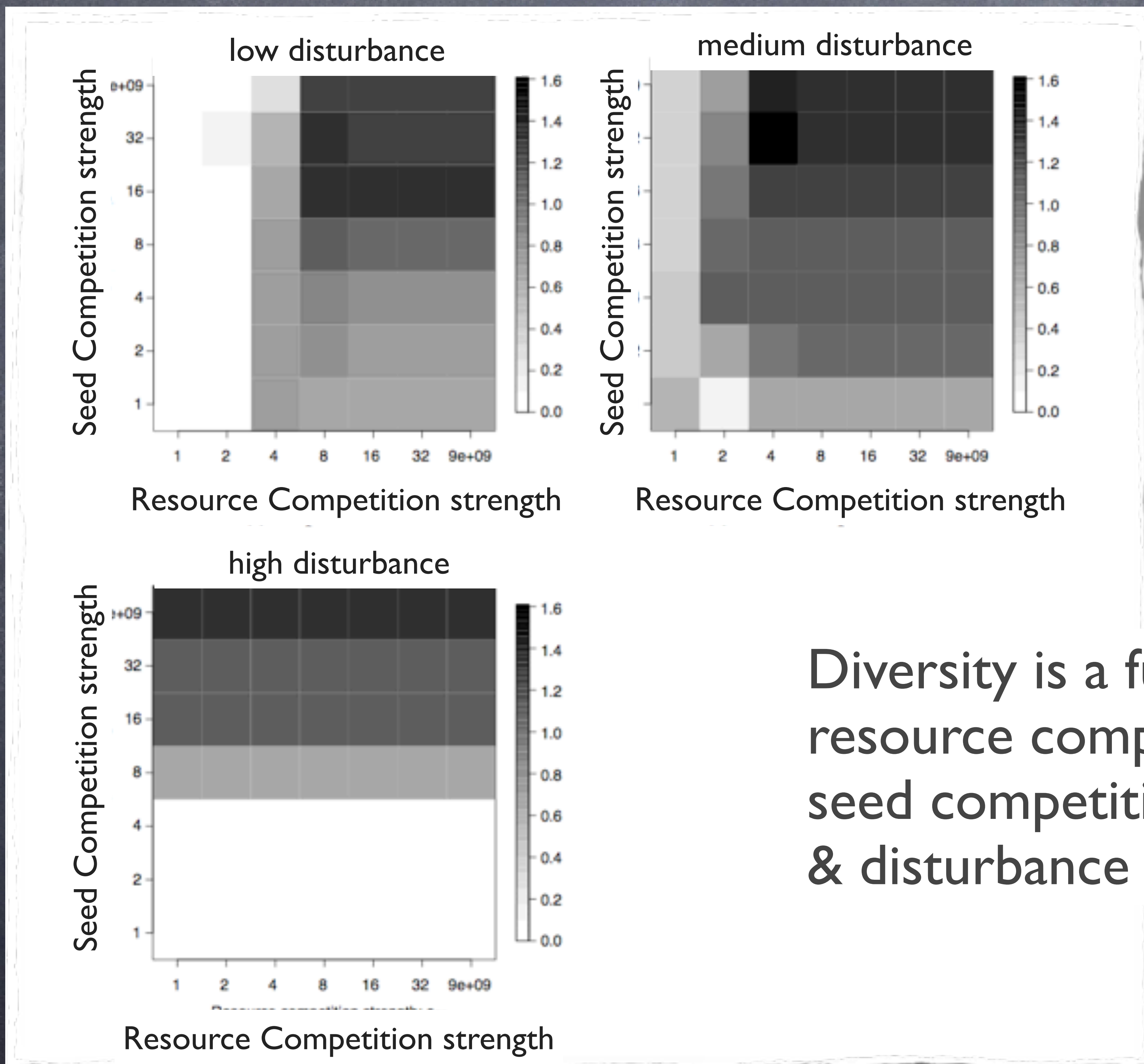


Fisher et al. New Phytologist 2010

Community Composition



Community Assembly in the **Je**na **Di**versity (JeDi) model



Diversity is a function of
resource competition strength,
seed competition strength
& disturbance frequency

Bohn et al. 2011

Summary

- Community assembly primarily happens at spatial scales not represented by a land surface model.
- There are multiple sources of heterogeneity that are unrepresented.
- The emergent properties of the system are functions of poorly constrained parameters.
- This is partially analogous to cloud parameterizations in ESM's