Linking Traits to Ecosystem Processes

Moira Hough

How do organisms impact ecosystems?

- Long history of study of ecological effects of biodiversity and species composition comes out of the diversity-stability debate (MacArthur 1955)

- More recent questions highlight relationships between biodiversity and ecosystem processes

Processes and Functions

- **Ecosystem Process** (also Ecosystem Resource Dynamics): "the magnitude (how much) and rate (how fast) of inputs, outputs, and internal cycling of key resources, such as carbon, water and mineral nutrients, in an ecosystem at a particular time" (Diaz & Cabido 2001)

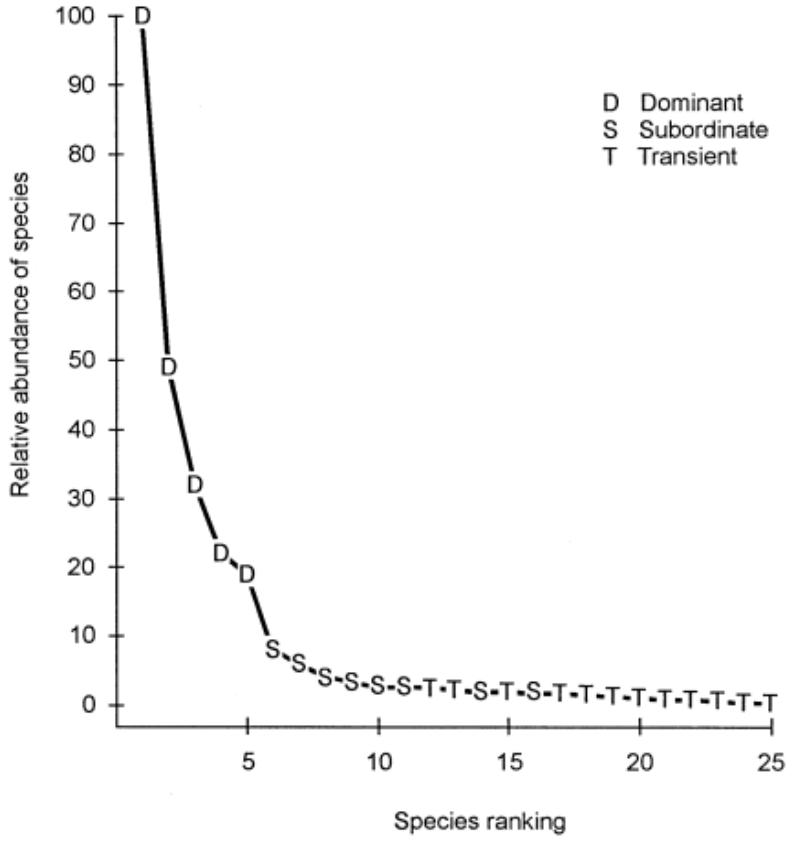
- **Ecosystem Function**: "the flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem. In a broad sense, ecosystem functioning includes two components, ecosystem resource dynamics and ecosystem stability." (Diaz & Cabido 2001)

- **Ecosystem Stability:** "capacity of an ecosystem to persist in the same state. It has two components, ecosystem resistance, the ability to persist in the same state in the face of a perturbation, and ecosystem resilience, the ability to return to its former state following a perturbation." (Diaz & Cabido 2001)

- **Ecosystem Service**: goods and services provided by ecosystem processes to humans (Diaz & Cabido 2001)

Mass Ratio Hypothesis

- "ecosystem properties should be determined to a large extent by the characteristics of the dominants and will be relatively insensitive to variation in species richness in circumstances where this is attributable to changes in the number of subordinates and transients."– Grime 1998



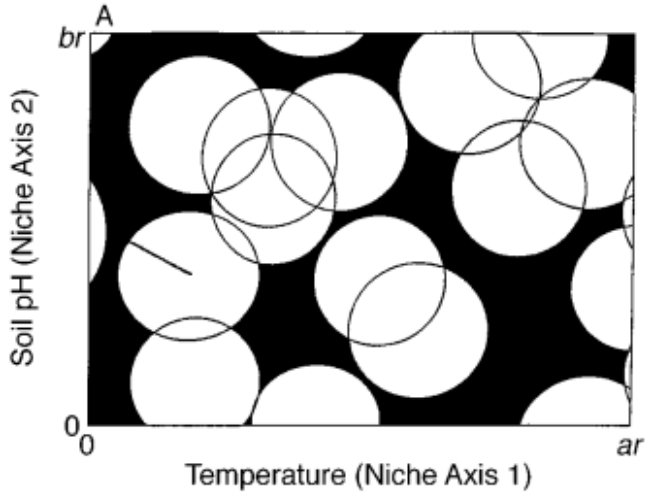
Biodiversity

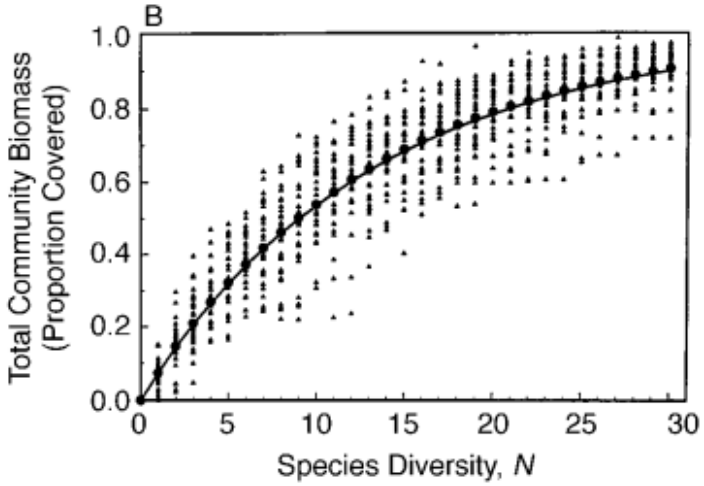
- Increasing biomass & productivity with increasing species richness

  -Tilman 1997, 1999, etc

- Altered ecosystem processes with biodiversity decline

  -Naeem 1994, etc



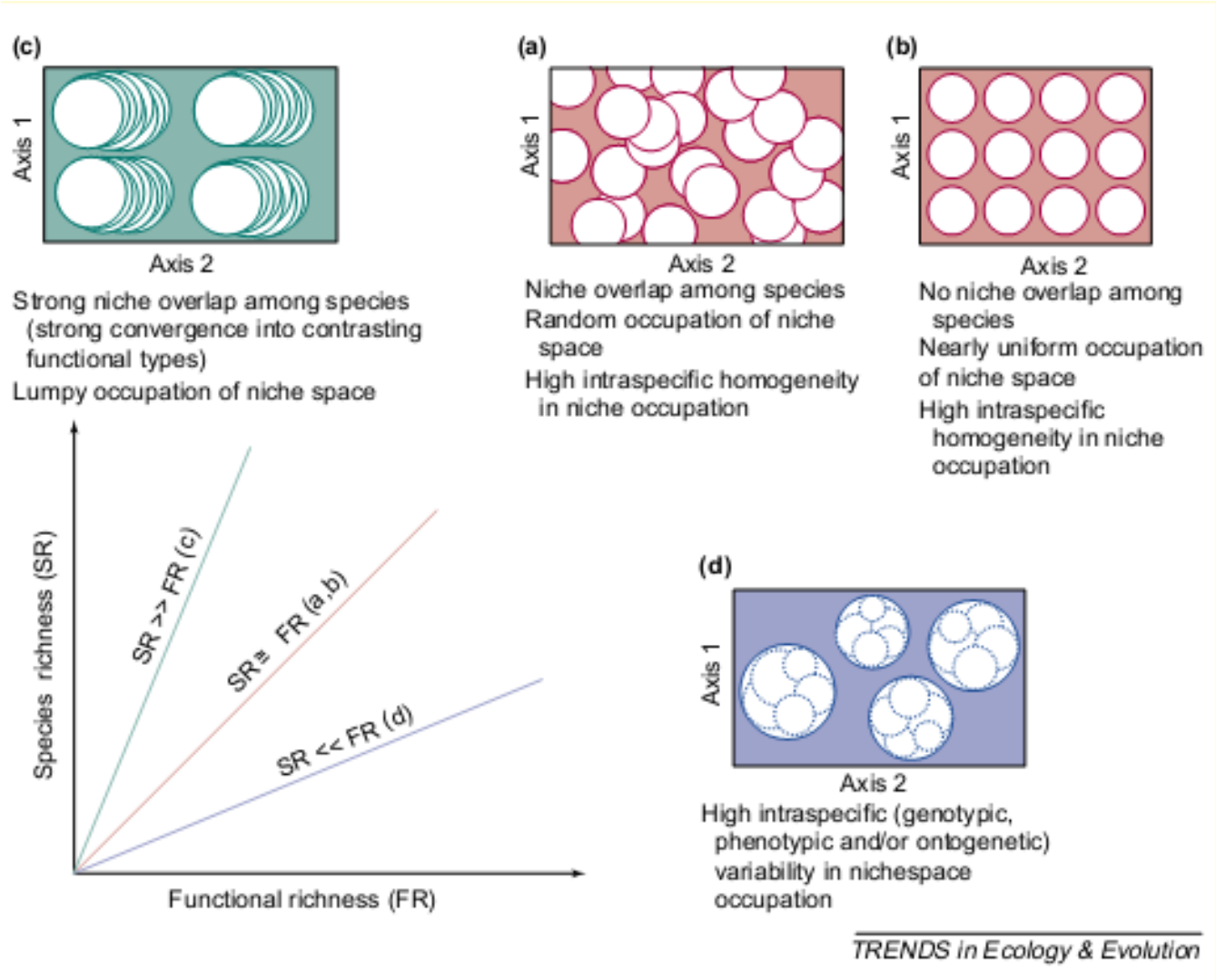


Diaz & Cabido 2001

- Functional diversity, not just species diversity, is important to ecosystem functioning
- Components of Diversity:
  - Species Richness
  - Functional Richness
  - Functional Composition

- Functional Richness & Composition are more predictive of Ecosystem Function than Species Richness

Species vs Functional Richness



Diaz & Cabido 2001

But note the terminology problem!

- **Functional Trait**: “any morphological, physiological, or phenological trait which impacts fitness indirectly via its effects on performance traits” (Violle et al 2007)

- **Functional Trait**: “the characteristics of an organism that are considered relevant to its response to the environment and/or its effects on ecosystem functioning” (Diaz & Cabido 2001)

Lost in Translation

Organismal

- **Ecological Performance**: the response of the whole-organism performance to an environmental variable
- **Ecosystem Property**: any feature or process measured at the ecosystem level
- **Community Functional Parameter**: any feature resulting from the community-aggregation of functional traits

(Violle et al 2007)

Ecological

- **Functional Trait**: characteristics of an organism considered relevant to its response to the environment and/or its effects on ecosystem functioning
- **Ecosystem Process:** the magnitude of inputs, outputs, and internal cycling of key resources
- **Ecosystem Function:** the flow of energy and materials through the arrangement of biotic and abiotic components of an ecosystem.

(Lavorel & Garnier 2002,
Diaz & Cabido 2001)

Species vs Functional Diversity

- Species diversity is limited by the regional pool of available species

- Functional diversity is limited by environmental conditions

Diaz and Cabido 2001

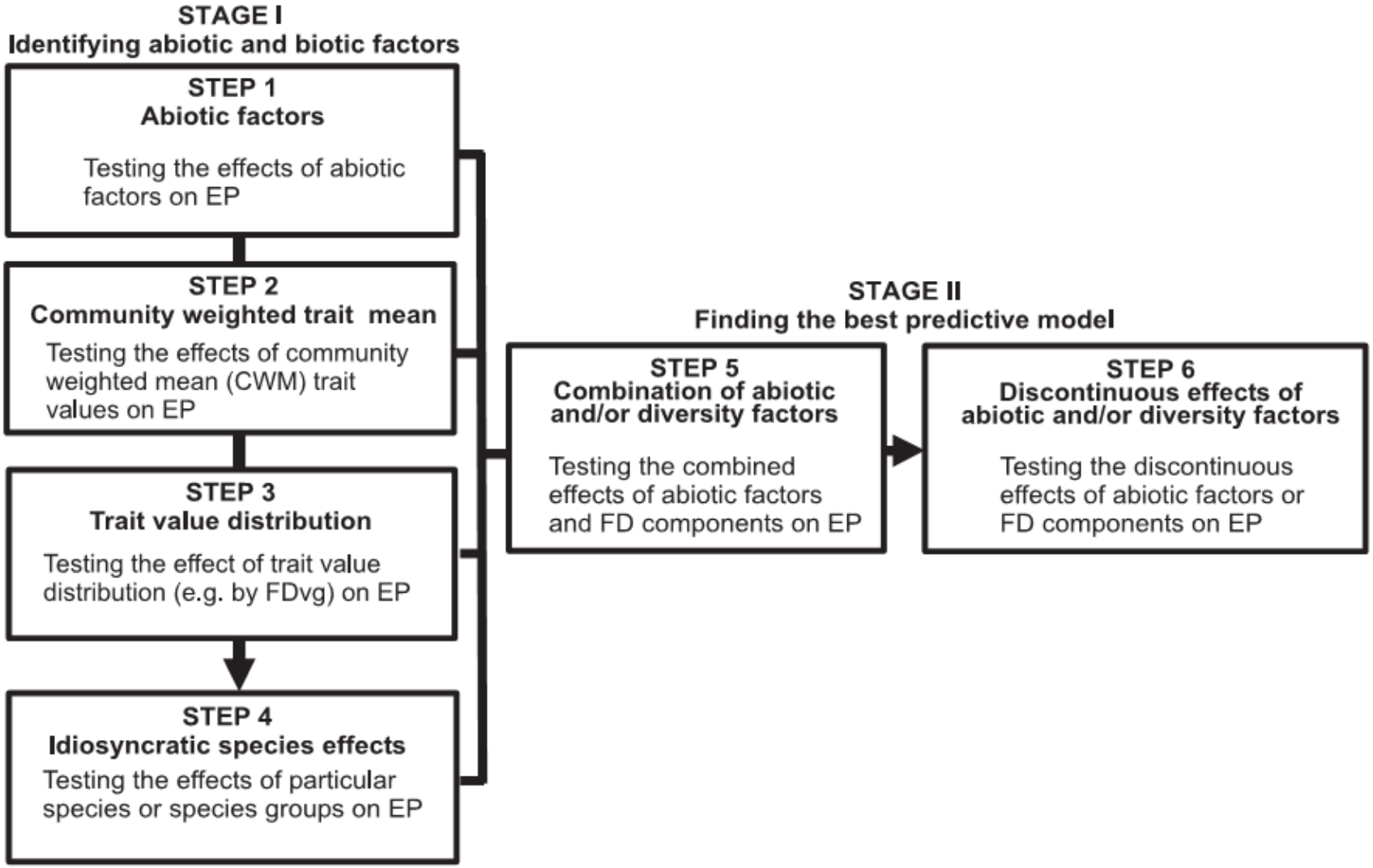
Functional Diversity

- Complementarity of resource use (temporal & spatial niche partitioning)
  - "Whereas complementarity facilitates the entry and persistence of species in the community it cannot be assumed that this will necessarily lead to complementary roles in sustaining the ecosystem" (Diaz et al 2007)
- Facilitation (especially of biomass production and invasion resistance)
  - Prevents predictability through the FD approach

How to Quantify impacts on Ecosystem Processes

- Mass Ratio Hypothesis: kind & relative abundance of dominant traits
  - Community Weighted Mean
- Functional Diversity: range of traits present
  - Degree of trait overlap (trait distance between species)
- Challenges:
  - Keystone species
  - Ecosystem engineers
  - Indirect effects

Diaz et al 2007

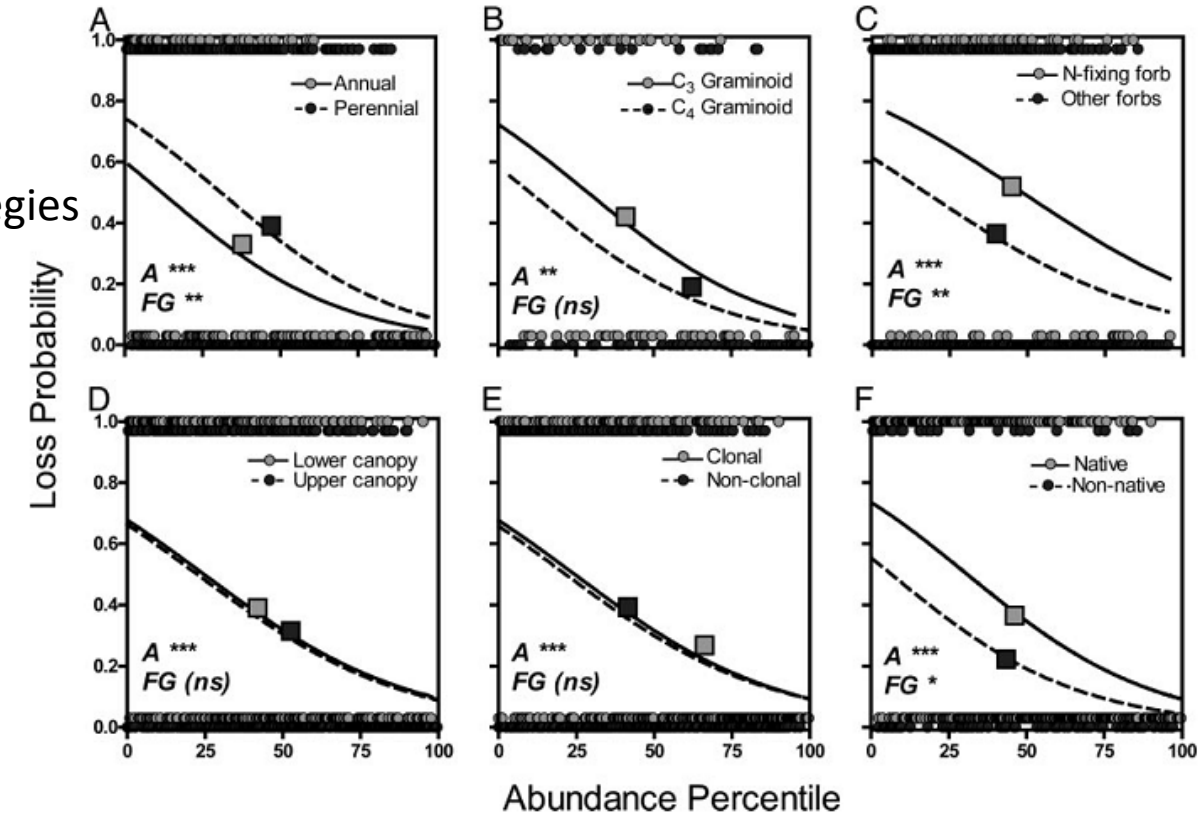


Diaz et al 2007

Suding et al 2005 PNAS

- N fertilization in terrestrial ecosystems of North America
- Groupings
  - C3/C4
  - N-fixing/not
  - Lower, middle, upper canopy
  - Annual, biennial, perennial
  - Nonclonal, caespitose, rhizomatous
  - Native/nonnativ e

Shift from conservative to acquisitive strategies



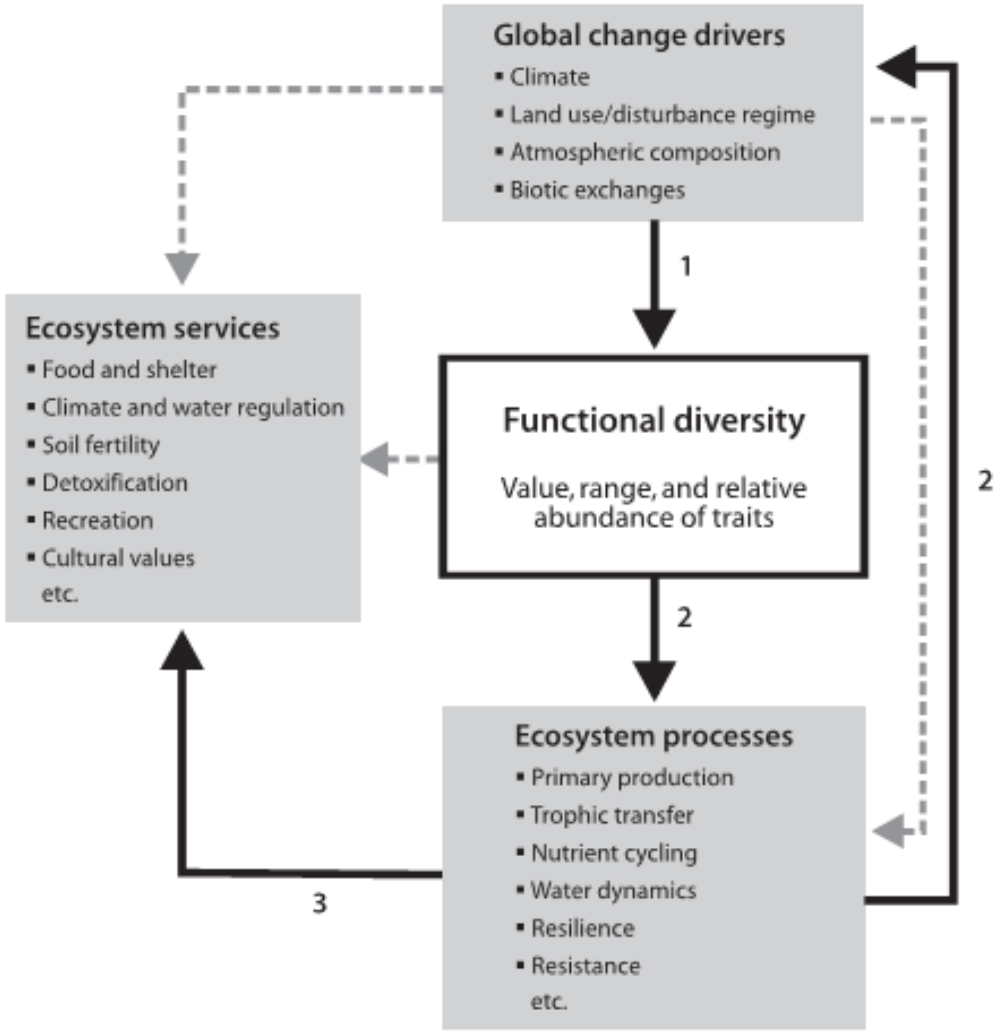
non-natives tended to be perennial & clonal

Fig. 3. Likelihood of local extinction in plots with added N for six trait groupings as a function of initial abundance. Circles indicate abundance of species that were lost (1) or not lost (0) because of fertilization. Squares indicate the average abundance and proportional loss for each functional group. Relative abundance measures are expressed in percentile, with 100 being the most abundant species in the data set and 0 being the least abundant species in the data set. Logistic regressions on species loss as a function of abundance in unfertilized (control) plots. A, abundance; FG, functional grouping. ***, $P < 0.001$; **, $P < 0.01$; *, $P < 0.05$; and ns (not significant), $P > 0.05$.

Findings

- Functional traits are best predictors of species loss at small scales in response to local variables
- At larger scales, initial abundance better predicts species loss

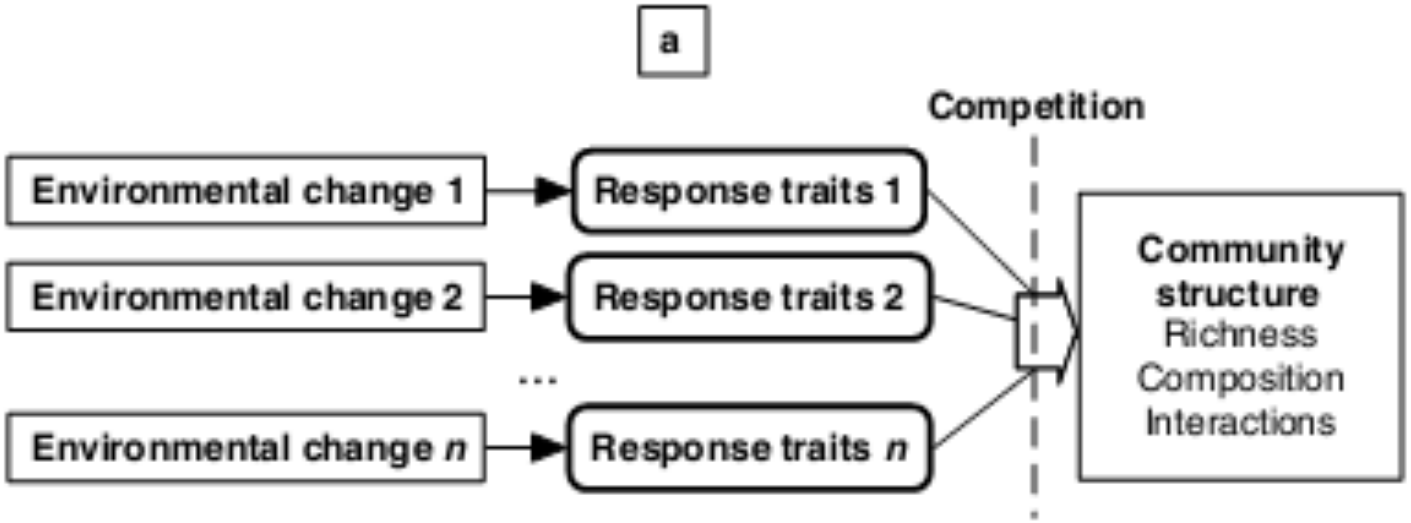
What about feedbacks?



Diaz et al 2007

Response Trait

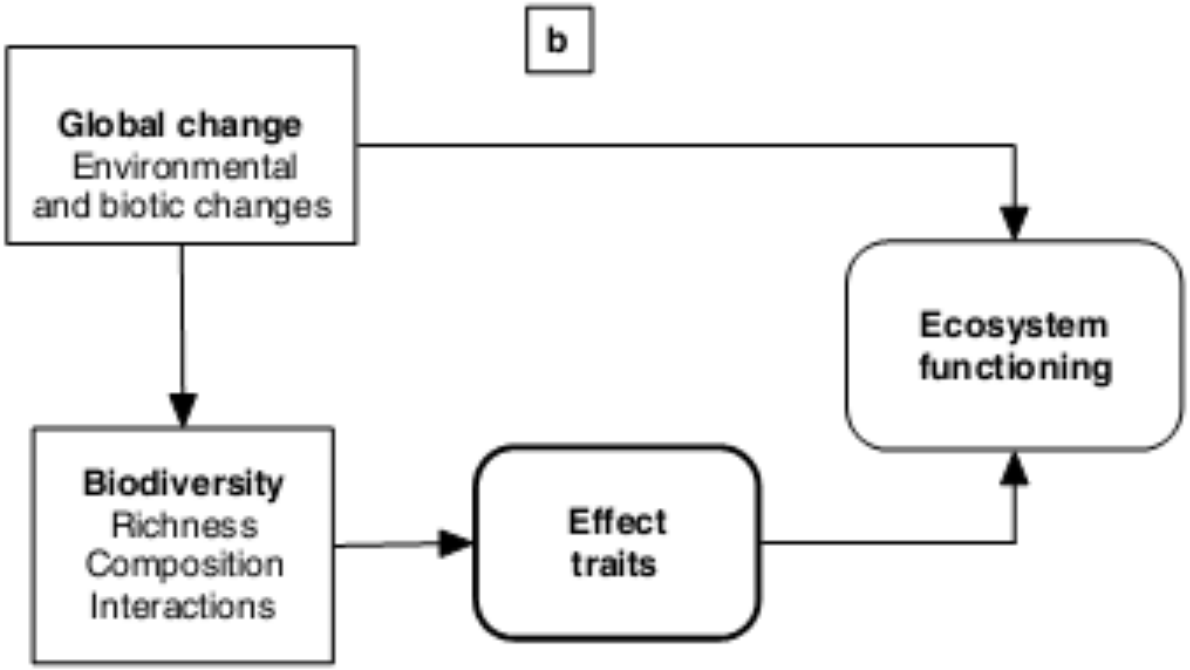
"traits associated with the response of plants to environmental factors such as resources and disturbances"



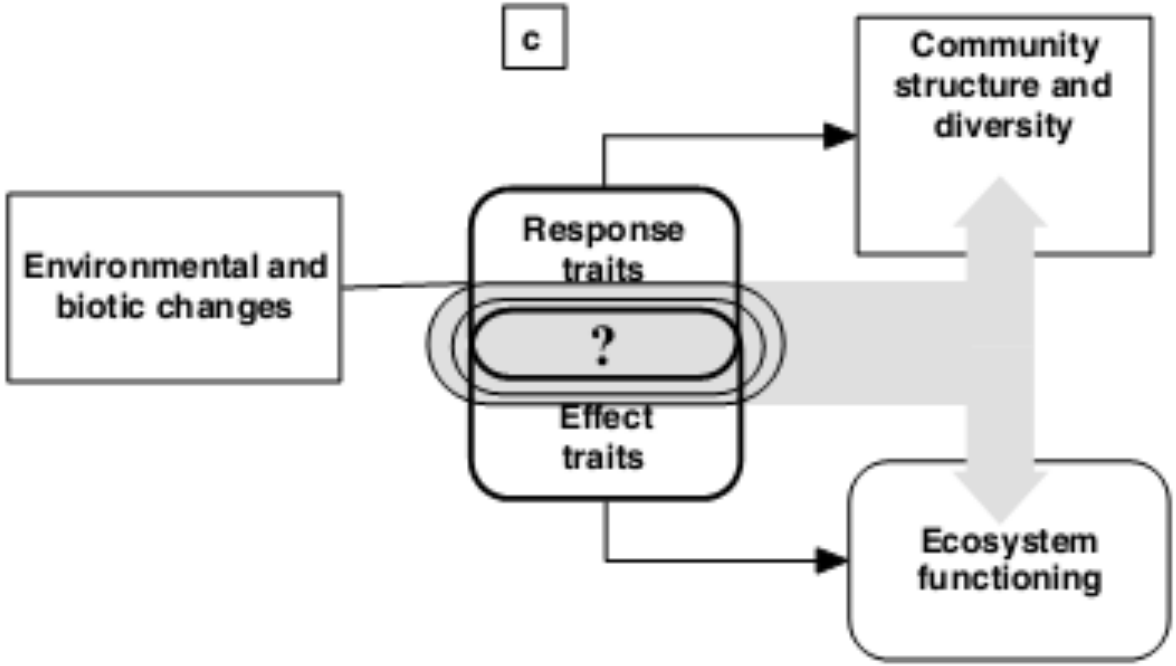
(Lavorel & Garnier 2002)

Effect Trait

"traits that determine effects of plants on ecosystem functions such as biogeochemical cycling or propensity to disturbance"



(Lavorel & Garnier 2002)



- overlap between traits determining response and those determining effects will be most common for biogeochemistry, where ecosystem fluxes may be calculated by scaling-up from individual physiological traits
- expect little convergence between traits and processes associated with disturbance response

Lavorel & Garnier 2002

Response-Effect Framework

1. Baseline conditions
   - Abundance
   - Relationship between response & effect traits
2. Community response to change
   - Altered representation of effect functional traits
3. Impact of community change on ecosystem processes

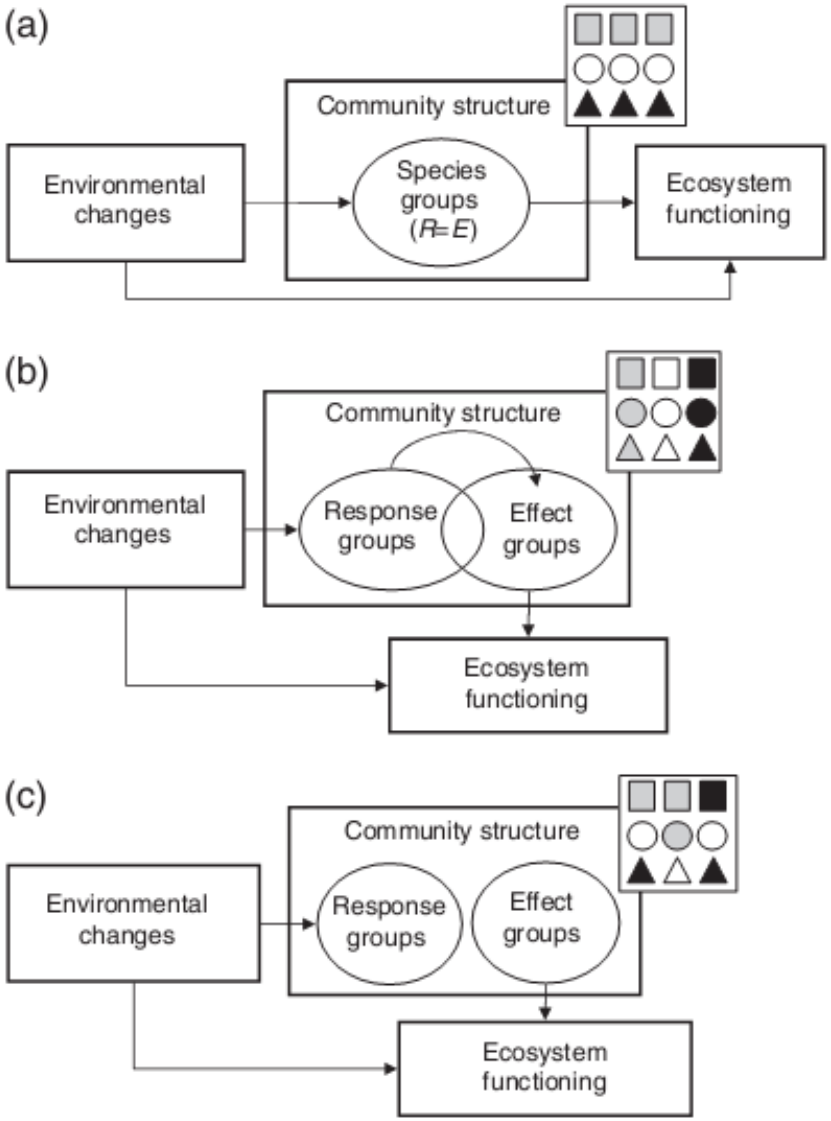
"The degree to which individuals with response traits favoured by the changed environment differ in their effect traits compared with the initial assemblage will determine the extent to which community change influences ecosystem function" – Suding et al 2008

Trait-Based Functional Groups

- **Functional Response Group**: groups of species with similar responses to particular environmental factors such as resource availability, disturbance or CO2

- **Functional Effect Groups**: groups of species that exert similar effects on one or several ecosystem functions

Effect vs Response

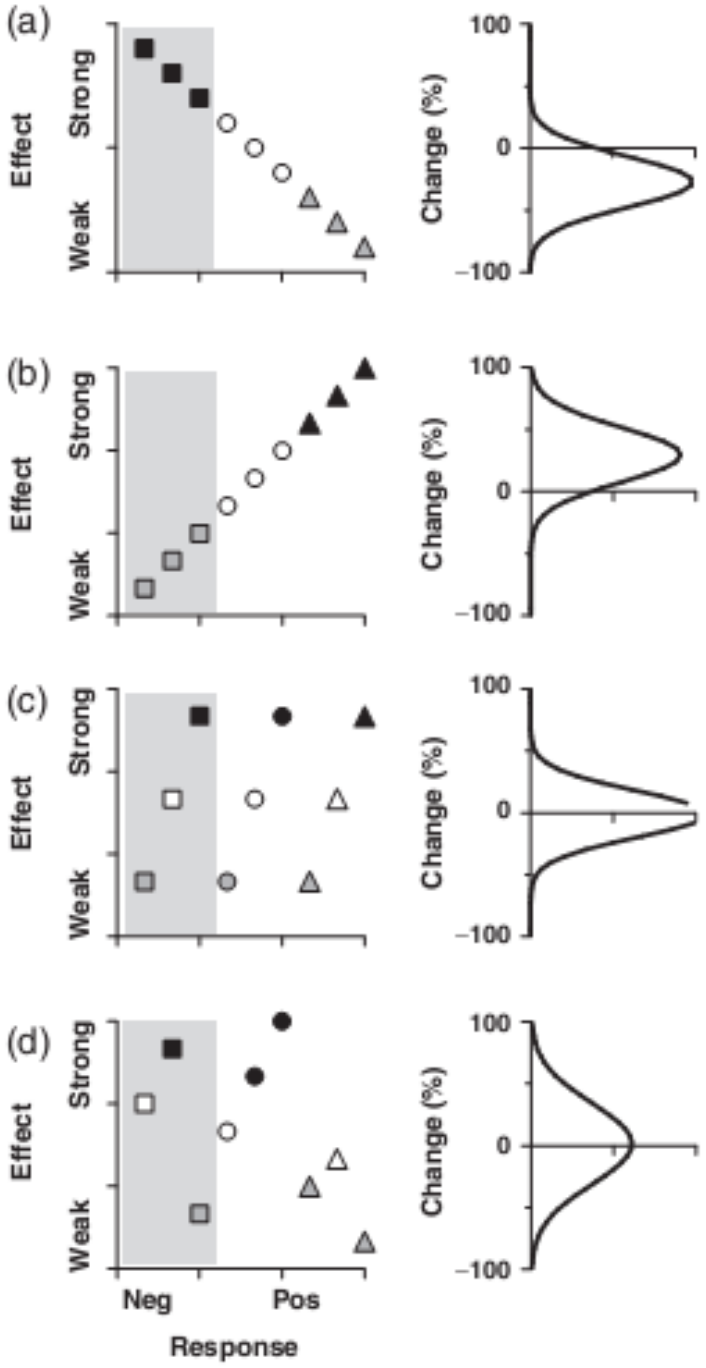


Complete overlap: reinforcement of changes

All response groups contain all effect groups: Resilience

Random effect & response groups

Suding et al 2008



Negative correlation (feedback) of response & effect: change in response trait decreases ecosystem function

Positive correlation (feedback): change in response trait frequency results in increased ecosystem function?

When response and effect are correlated expect nonlinear ecosystem change (tipping points?)

Complete overlap: resilience

No overlap: linear response

Suding et al 2008

Questions for Suding

- How do you see the response/effect framework being used in further ecological research?
  - In what directions is it headed?
  - Is it a useful way of assessing ecological resilience and identifying potential tipping points?
- How does this framework extend beyond the world of plants?
- What further developments do you think are most important for this model?

Questions for Suding (Global Change Biology 2008)

- You discuss changes in community composition in response to environmental changes, but what about changes in functioning of traits without a change in species composition? What if Rj is a change in the magnitude or impact of a trait? How do you measure that and incorporate it into the model?
- How do changes in different response traits impact the model through feedbacks (either direct or indirect)?
- Is the use of positive & negative to describe ecosystem function dangerously value based?
- If non-additive effects of species interactions should be considered the rule rather than the exception, how do we use the model? How useful are traits in this context? Why continue to use them?
- The mass-ratio hypothesis which you use in your model was designed primarily for plants and becomes less applicable when other taxa are included – so does the model still work? How is it useful?
- In general: you discus many reasons why your model does not include much of the complex interactions in natural systems. How do you balance ease of use with complexity? Is a much simplified model still useful?

Testing the Framework: Gross et al 2008

- Response-effect traits mediate environmental change impacts
- Response traits are likely to be continuous traits that co-vary with specialization strategy

1. Correlative approach: Response traits
   - Covariance of soil fertility and plant traits
2. Experimental approach: Effect traits
   - Removal experiment
3. Formulate and test statistical model

"multiple traits can predict ecosystem properties and overlapping/coinciding response-effect traits can provide a mechanistic link mediating changes in ecosystem function and land use change."

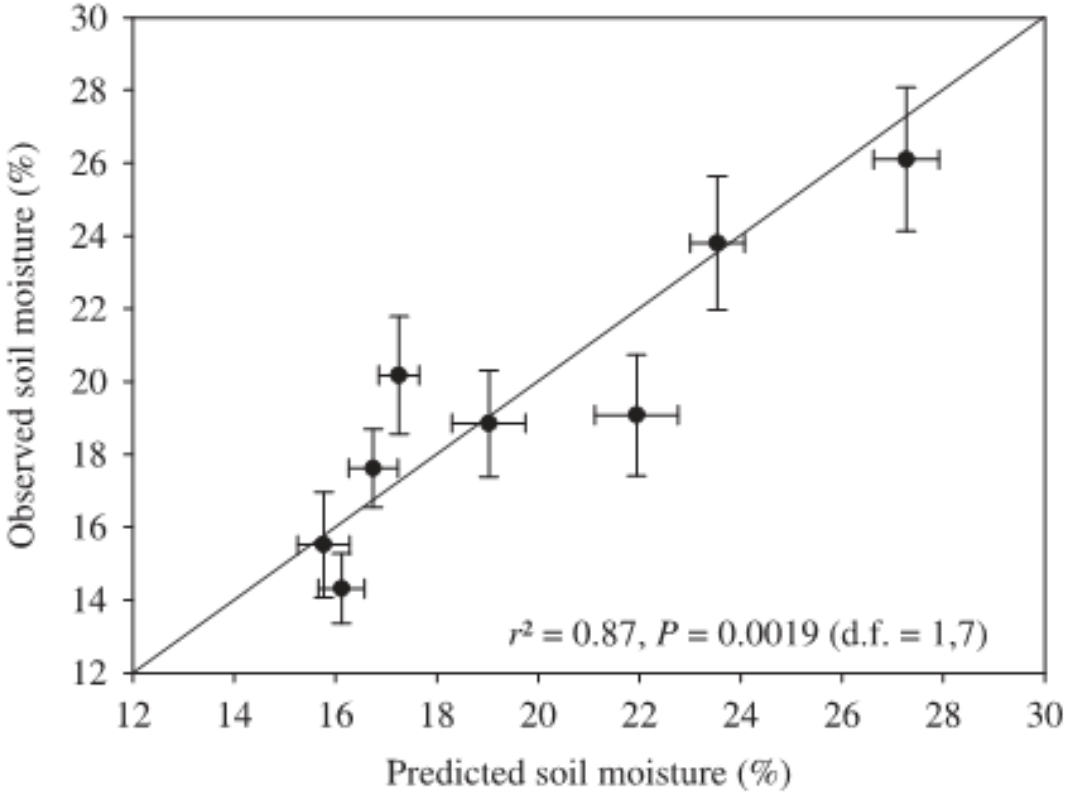


Fig. 4 Relationship between average predicted data and average observed data for soil moisture in the eight fields during the mid–late seasons. The value of the regression test (r^2) is indicated in the figure with degree of freedom (d.f.). Error bars represent the standard error across measurements or estimated values for different dates.

Gross et al 2008

Future Directions

- Ecosystem Services
  - "multiple associations between traits and ecosystem processes can help to identify predictable trait–service clusters that depend on several trophic levels, such as clusters of traits of plants and soil organisms that underlie nutrient cycling, her-bivory, and fodder and fibre production" – deBello et al 2011

- Resilience Predictions
  - "the identification of those functional traits or functional trait combinations that are more likely to trigger ecosystem and landscape level non-linearities" – Diaz et al 2007

Citations

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