Ecosystem functioning and biodiversity

Rob Britton

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Questions

1. What is biodiversity?

2. What is ecosystem functioning?

3. Why is biodiversity important for ecosystem functioning?

Questions

1. What do we really mean by biodiversity?
2. Why is it important to measure biodiversity
3. What is meant by the term ‘function(ing)’?
4. What is a functional group? How does it differ from a functional guild? What about functional diversity and redundancy?
5. What is the relationship between biodiversity and ecosystem functioning?

1. What is biodiversity?

Biodiversity? Some definitions

- **OED:** “**biodiversity** *Ecol.*, diversity of plant and animal life, as represented by the number of extant species”

- **Ricklefs & Miller**: Biodiversity includes a number of different levels of variation in the natural world: genetic, species, ecosystem

- Begon *et al.* “The term may be used to describe the number of species, the amount of genetic variation or the number of community types present in an area”.

- But…most studies do focus on species diversity

Biodiversity

- Alpha: within habitat diversity (e.g number of species in a quadrat)
- Beta: species diversity along transects & gradients
  - High Beta indicates number of species increases rapidly with additional sampling sites along the gradient
- Gamma: diversity of a larger geographical unit (regional diversity)

Biodiversity measures

- What can we measure?
- Possibilities
  - Species (<u>richness</u>)
  - Abundance
  - Diversity
    - relationship between richness & abundance
  - Guilds
  - Trophic structures
  - Genetic diversity
  - Within species diversity (genetic, morphological)

Biodiversity

- Two key features: Richness & Abundance
- Evenness is a simple way to combine richness and abundance
- Are all species likely to be equally abundant? If not, why not?

Biodiversity

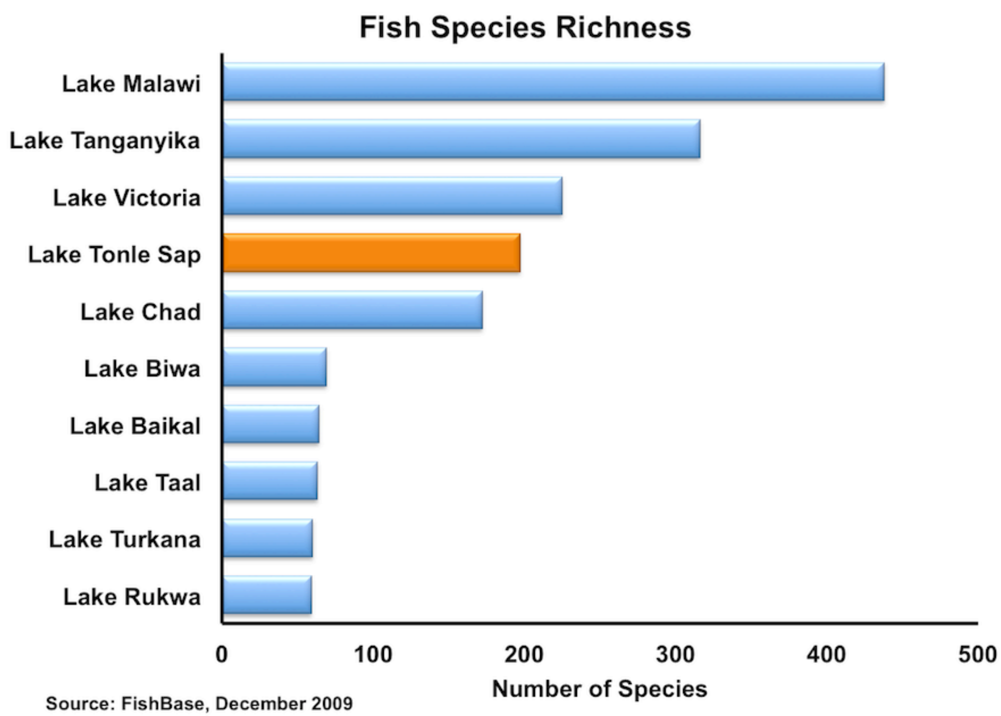
- As evenness increases, diversity tends to increase
- High evenness may be seen as a sign of ecosystem health
  - A single species is not dominating the ecosystem
  - (Eutrophication and enrichment does tend to lead to dominance of a few species)

Biodiversity

- Comparing diversity between ecosystems is difficult
  - Some areas have lower biodiversity naturally than others
    - Taiga (coniferous forest in high northern latitudes) is naturally much less even than the deciduous forest
    - Often dominated by a single species (Pine or spruce)
  - Seasonality may confound the comparison as well
    - Earlier in temperate growing season, less even than later

Biodiversity

- How to measure biodiversity?
- Might be very simple, e.g. counts of species



Biodiversity

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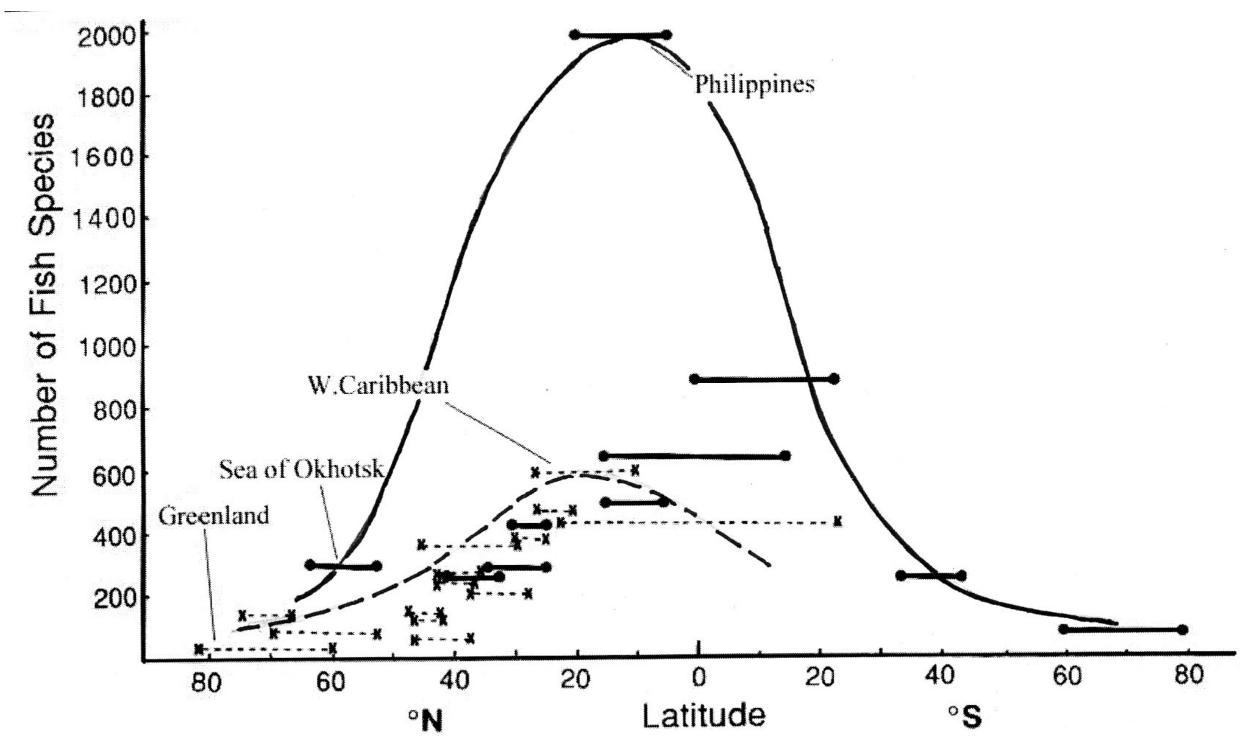

Biodiversity

- How to measure biodiversity?
- Based on diversity Indices, e.g. based on species richness and/ or abundance

Diversity index	Values
Number of species	23
Number of individuals	517
Simpson's index (D) = $--\Sigma(n-1)/N(N-1)$	0.292
Simpson's index of diversity = (1-D)	0.708
Simpson's reciprocal index = (1/D)	3.423
Shannon-weiner index (H) = $-\Sigma pi \ln pi$	1.799
Shannon's equitability (E_H) = $H/\ln S$	0.574
Evenness (E) = eH/S	0.263
Margalef Index (Dmn) = $S-1/\ln N$	3.52

Biodiversity

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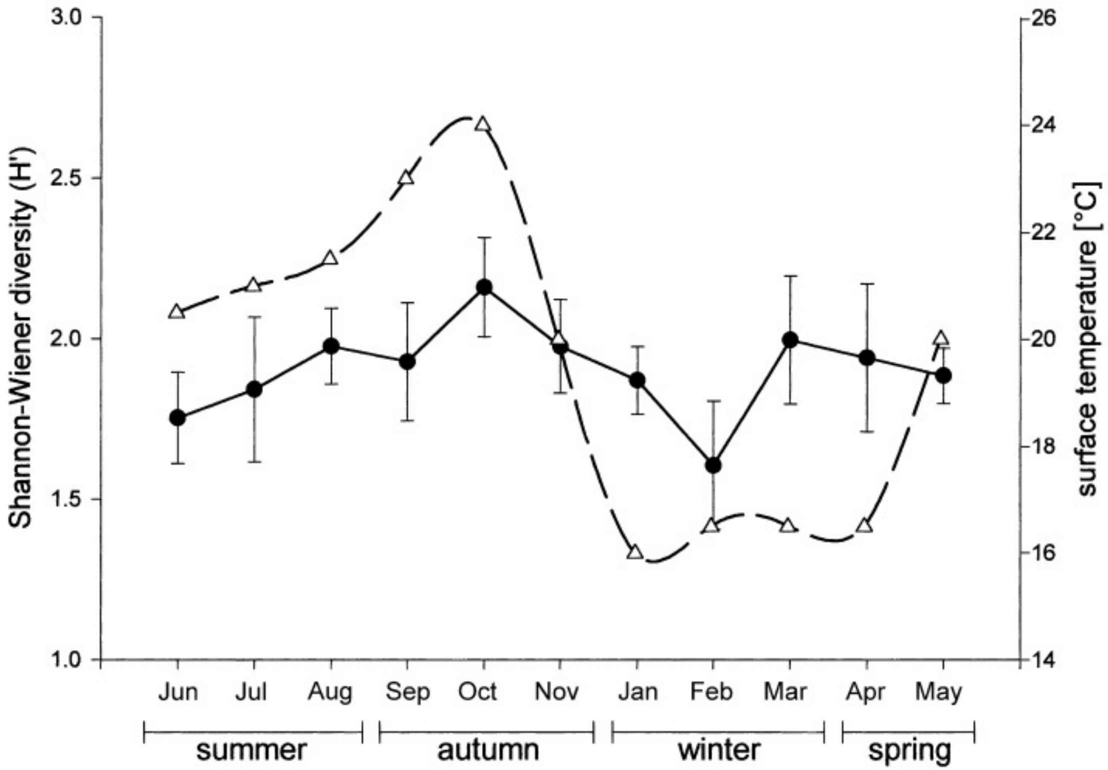
- Based on diversity Indices, e.g. based on species richness and/ or abundance



Biodiversity

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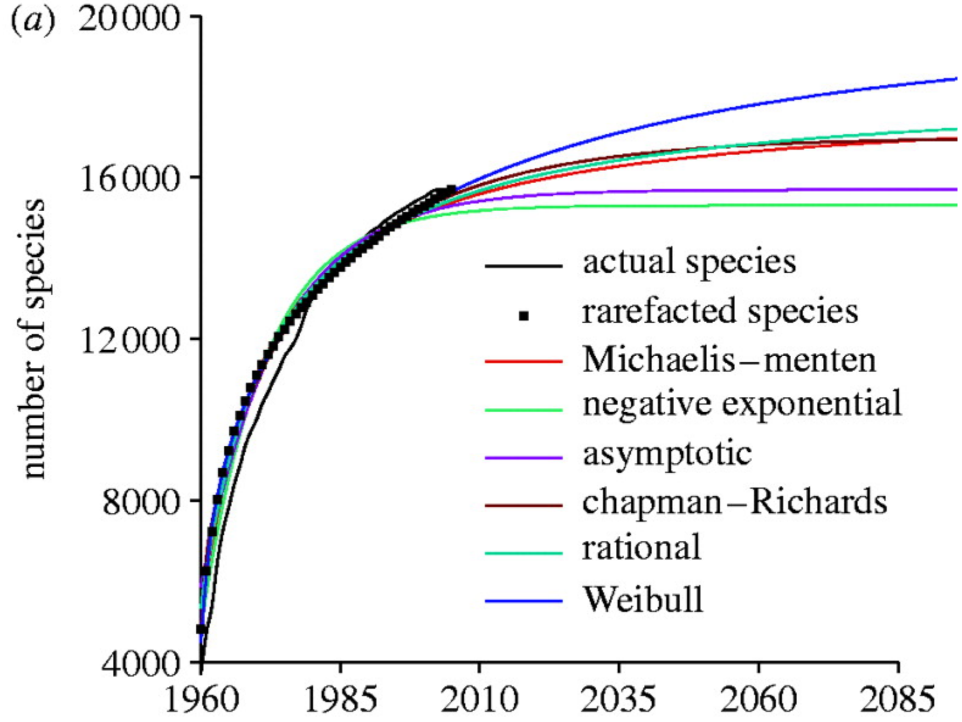


Biodiversity?

- But why our focus on biodiversity?

- If we use species richness as our indicator, then species richness can be important for *ecosystem functioning*……..

Questions

1. *What do we really mean by biodiversity?*

2. *Why is it important to measure biodiversity?*

3. What is meant by the term ‘function(ing)’?

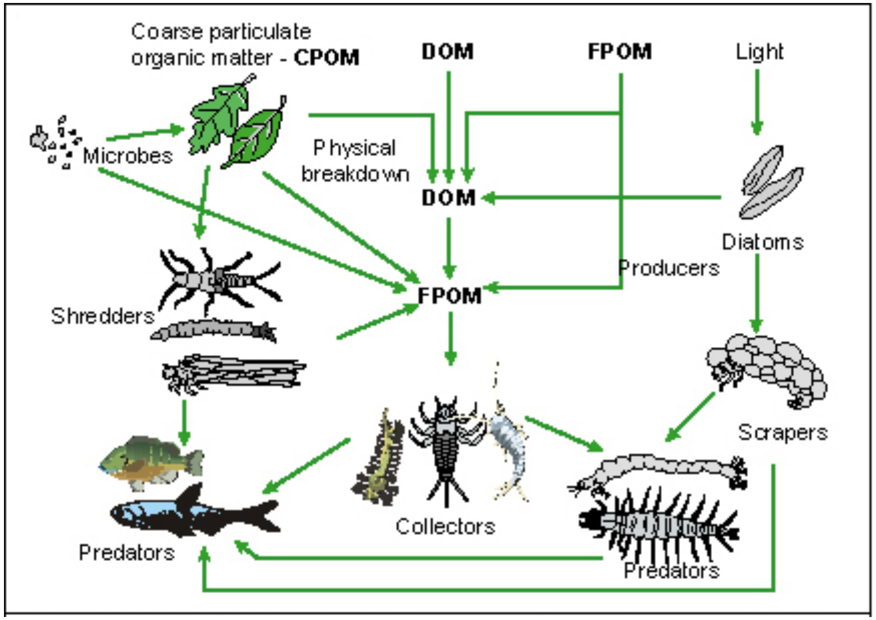
4. What is a functional group? How does it differ from a functional guild?

5. What is the relationship between biodiversity and ecosystem functioning?

2. What is ecosystem functioning?

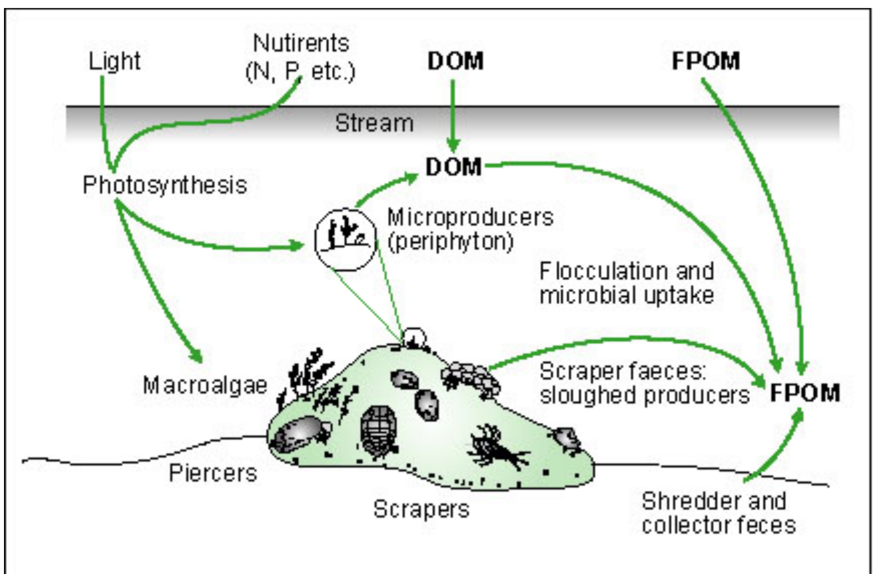
Functioning

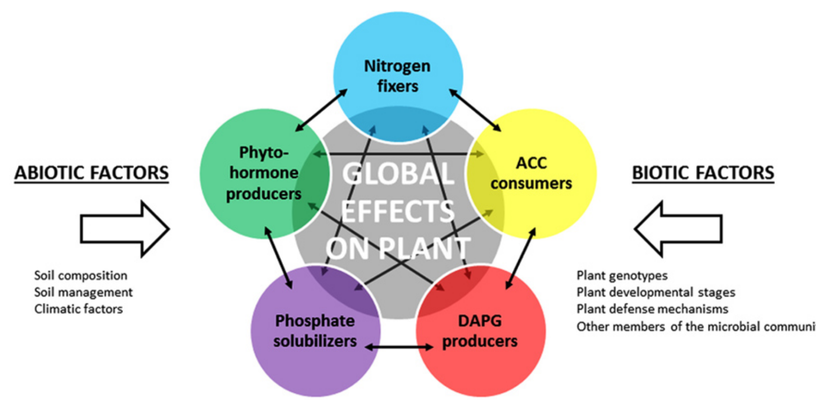
- Before we consider ecosystem functioning, we must first consider what we mean by function and functioning in an ecological context.....



These images show a range of processes that occur within ecosystems

If a leaf from a tree fall in the water, what is its fate?





Functional groups

- Functional groups can be considered as non-phylogenetic, aggregated units of *species* sharing an important ecological characteristic and playing an equivalent **role** in the community
- Role = function

Functional guilds?

OIKOS 100: 223–231. 2003

MINI-REVIEW

Minireviews provides an opportunity to summarize existing knowledge of selected ecological areas, with special emphasis on current topics where rapid and significant advances are occurring. Reviews should be concise and not too wide-ranging. All key references should be cited. A summary is required.

Guilds or functional groups: does it matter?

Jacques Blondel

Blondel, J. 2003. Guilds or functional groups: does it matter? – Oikos 100: 223–231.

Although most researchers use the terms "guild" and "functional group" more or less synonymously, these two concepts bear different meanings. The guild concept refers primarily to the mechanisms of resource sharing by species in a competitive context whereas the functional groups concept is concerned with how a resource or any other ecological component is processed by different species to provide a specific ecosystem service or function. In many cases but not necessarily all, the two concepts are the two "faces" or "sides" of the same coin: the sharing by species of a similar resource is the guild facet (structural), while the ecosystem processes these species eventually perform through resource exploitation is the functional group facet. The two concepts differ in that competitive relationships within groups of species are not the focus of the functional group approach, exactly as processes or functions are not the focus of the guild approach. A group of species can be considered either as a guild or a functional group depending on the question addressed. Guild and functional group membership is independent of phylogenetic relationships but because species tend to share similar life history traits and adaptations through common evolutionary history, guild and functional group associates are often closely related. The concept of guild has had broader application in animal studies than in plant studies, whereas the reverse is true for the concept of functional group. Recent methodological advances to objectively partition species into guilds and functional groups, taking into consideration the most relevant characters or traits for delineating them, provide the means to construct an operational framework for making in situ and ex situ experiments that are urgently needed for a better understanding of the role of species in ecosystem functioning, especially in relation to global change concerns.

- Although most researchers use the terms "guild" and "functional group" more or less synonymously, these two concepts bear different meanings.
- The guild concept refers primarily to the mechanisms of resource sharing by species in a competitive context whereas the functional groups concept is concerned with how a resource or any other ecological component is processed by different species to provide a specific ecosystem service or function.

Table 1. Attributes, characteristics and fields of application of guilds and functional groups.

	Guilds	Functional groups
Definition based on	Similarity in resource sharing	Similarity in ecosystem function
What they are	Permanent or temporary structural subunits of communities; depend on resources	Permanent or temporary assemblages of species performing a same ecosystem process
What they do	Exploit resources in a similar way	Process the same resources or habitat features (e.g. soil) for an ecosystem service
How they are described	Structural criteria	Process-oriented criteria
Questions addressed	Structure at the community scale, arenas for deciphering differences (coexistence) in an evolutionary context	Processes at the ecosystem scale, arenas for deciphering similarities (redundancy) for achieving ecosystems functions
Predictions from removal experiments	Changes in the abundance of the remaining species (compensation)	No response if redundancy (compensation); change in ecosystem response if not
Intra-group interspecific relationships	Competition between species in a "species packing" context	Similarities between species in a functional context
Inter-group interspecific relationships	More competition within guilds than between guilds	Not relevant
Taxonomic scale	Often within-taxon assemblages	Often across-taxon assemblages

Fisheries Management and Ecology, 2007, **14**, 381–392

Assessing the health of European rivers using functional ecological guilds of fish communities: standardising species classification and approaches to metric selection

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Hull International Fisheries Institute, University of Hull, Hull, UK

D. GOFFAUX & P. KESTEMONT

University of Namur, Namur, Belgium

Abstract The functional ecological guild approach is the cornerstone for the development of Indices of Biotic Integrity and multi-metric indices to assess the ecological status of aquatic systems. These indices combine metrics (unit-specific measures of a functional component of the fish community known to respond to degradation) into a single measure of ecological assessment. The guild approach provides an operational unit linking individual species characteristics with the community as a whole. Species are grouped into guilds based on some degree of overlap in their ecological niches, regardless of taxonomic relationships. Despite European fish species having been classified into ecological guilds, classification has not been standardised Europe-wide or within the context of classifying species into guilds from which metrics can be developed for ecological assessment purposes. This paper

Table 1. Proposed trophic guild classification for European fishes

Guild	Adult diet	Physiology/comment
Planktivores	High proportion of zooplankton and/or phytoplankton	Fine gill-rakers, elongated pharyngeal teeth, no stomach, and elongated undifferentiated intestine
Herbivores	High proportion of plant material	Terminal/sub-terminal mouth, bony slashing jaw, long digestive tract
Detritivores	High proportion of detritus	Digestive tract simple/unspecialised
Omnivores	Diet 'generalist', including a wide range of flora and fauna	
Insectivores/ invertivores	High proportion of invertebrates/insects	Terminal/supra-terminal mouth, feed in the whole of the water column
Benthivores	High proportion of benthic organisms	Ventro-terminal, often highly protractile mouth. File-like teeth to comb and sort small organisms
Piscivores	Consists of > 75% fish	Restricted to obligate piscivores
Parasite	Parasitic feeding mode	

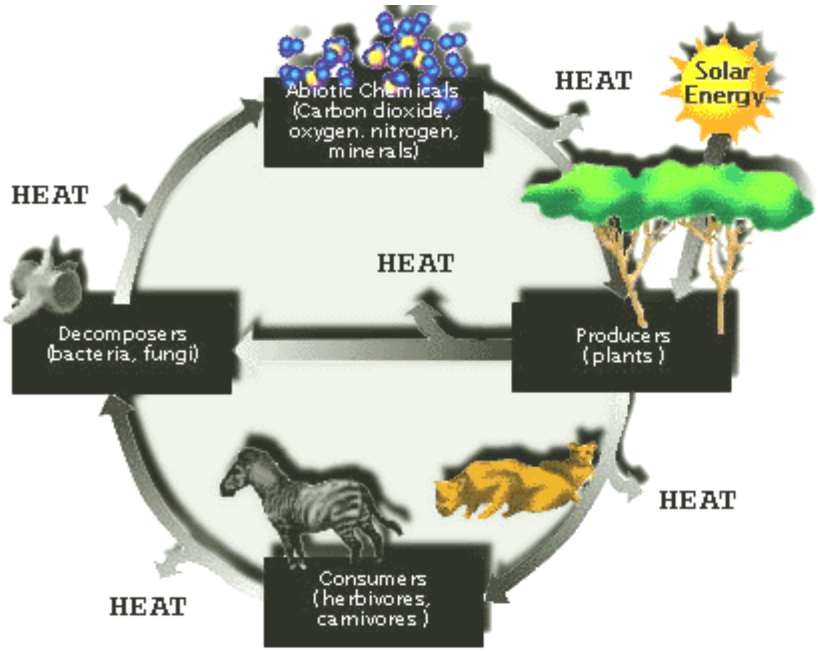
Functioning

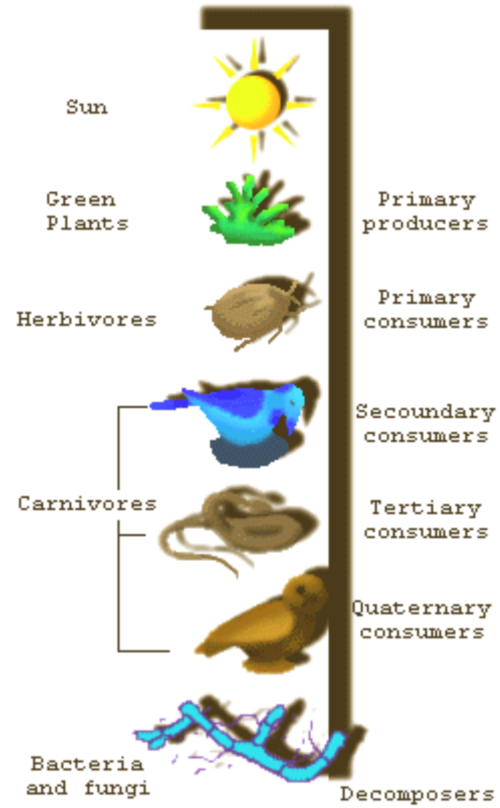
- So, some prefer to refer to functional groups rather than functional guilds in an ecosystem functioning perspective

Ecosystem functioning

- The term '**Ecosystem function**' defines the biological, geochemical and physical processes and components that take place or occur within an **ecosystem**.
- It involves solar energy flow, mineral cycling and water cycling
- The functional groups of species associated with ecosystem functioning are thus those involved in the flow of energy through the ecosystem (e.g. food webs) and the cycling of minerals and water.
- These then map onto ecosystem services

Functioning





Diversity and functional groups

- Functional diversity?
- The diversity of a functional group, usually measured as species richness
- Is it good to have high functional diversity?

Importance of individual species?

- Functional redundancy?
- Some species perform similar roles in communities and ecosystems, and may therefore be substitutable with little impact on ecosystem processes

Rosenfeld, J. S. (2002), Functional redundancy in ecology and conservation. Oikos, 98: 156–162.

Questions

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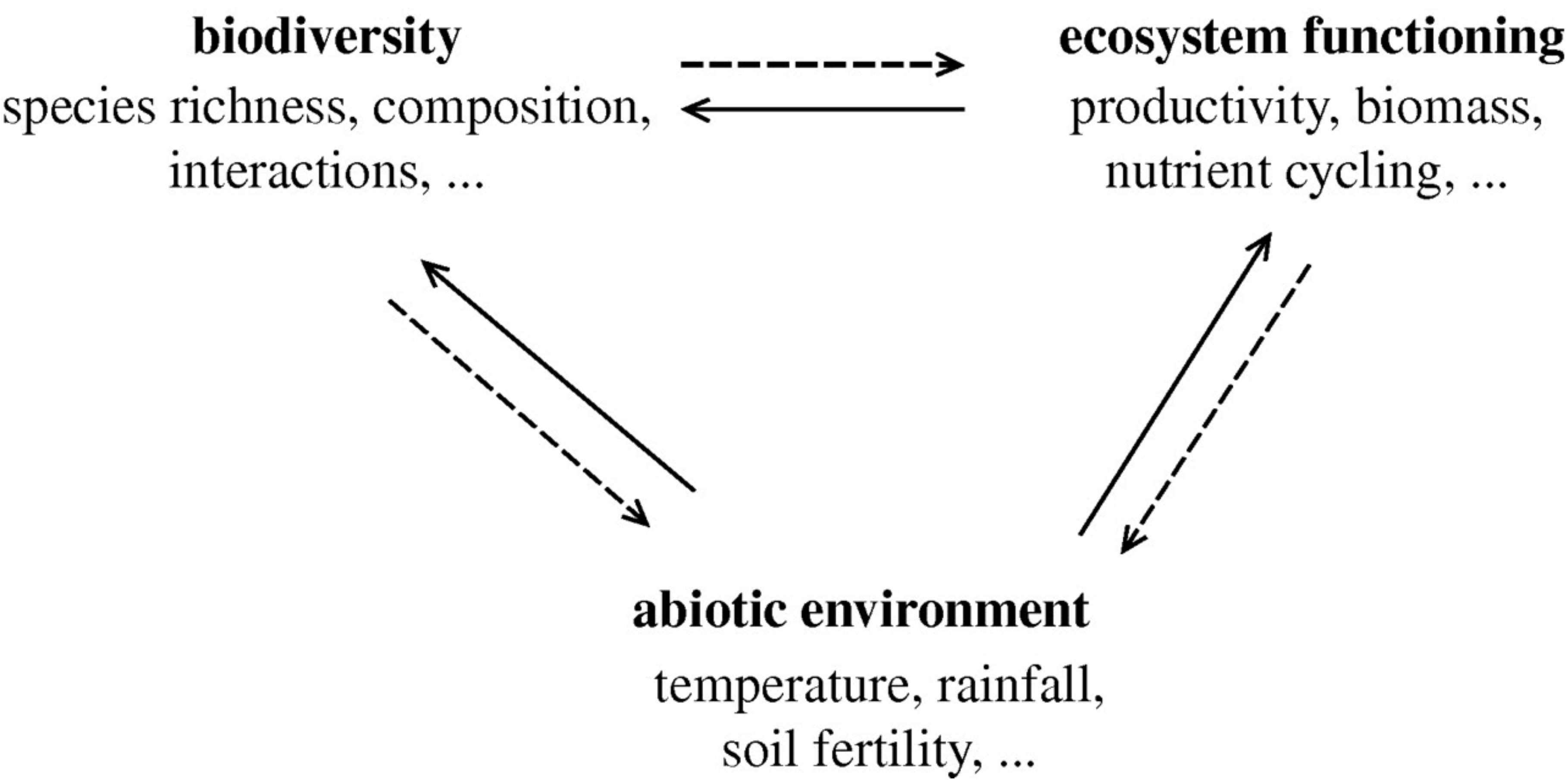
Theory

- A lot of research effort has been expended on exploring the relationship between biodiversity (usually as species richness) and ecosystem functioning

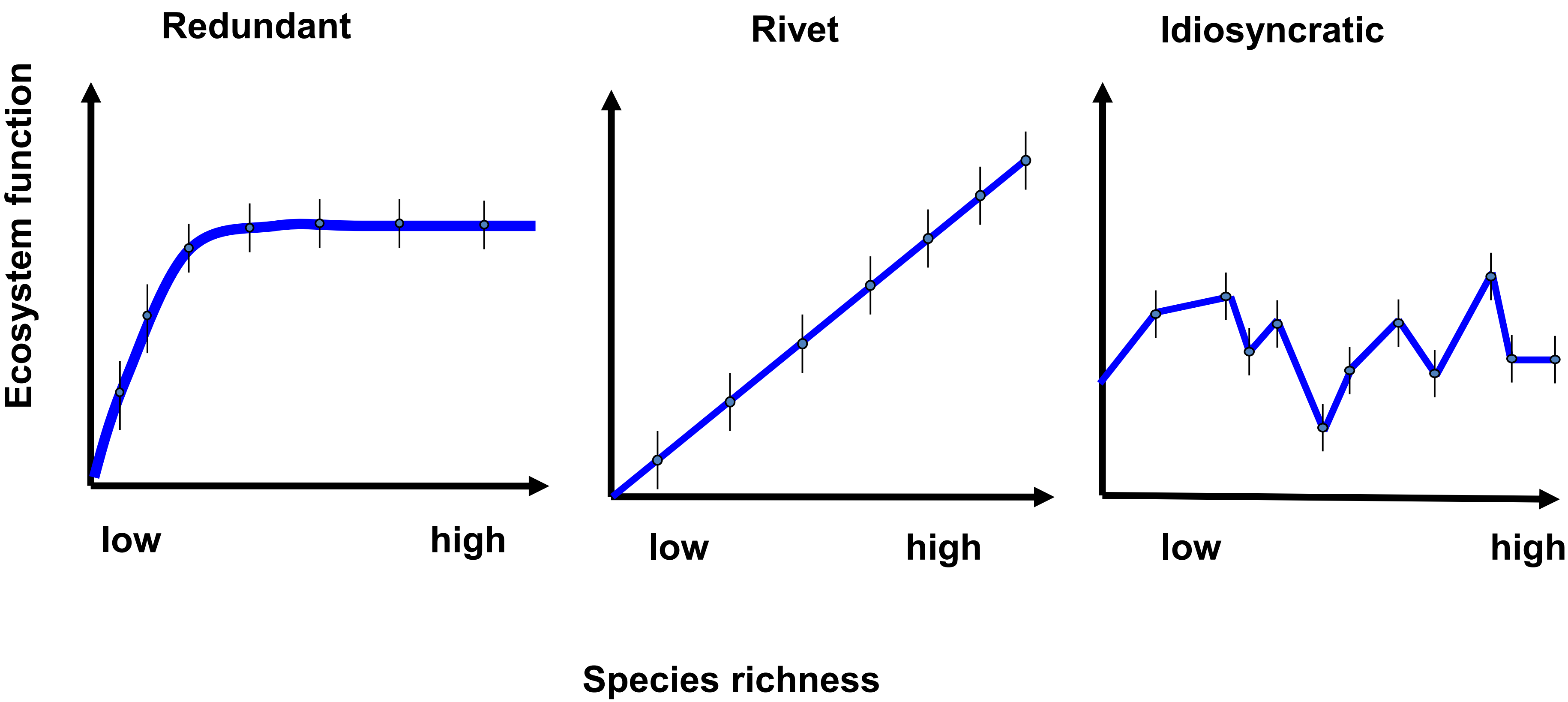
Dynamic relationship



Theoretical perspectives

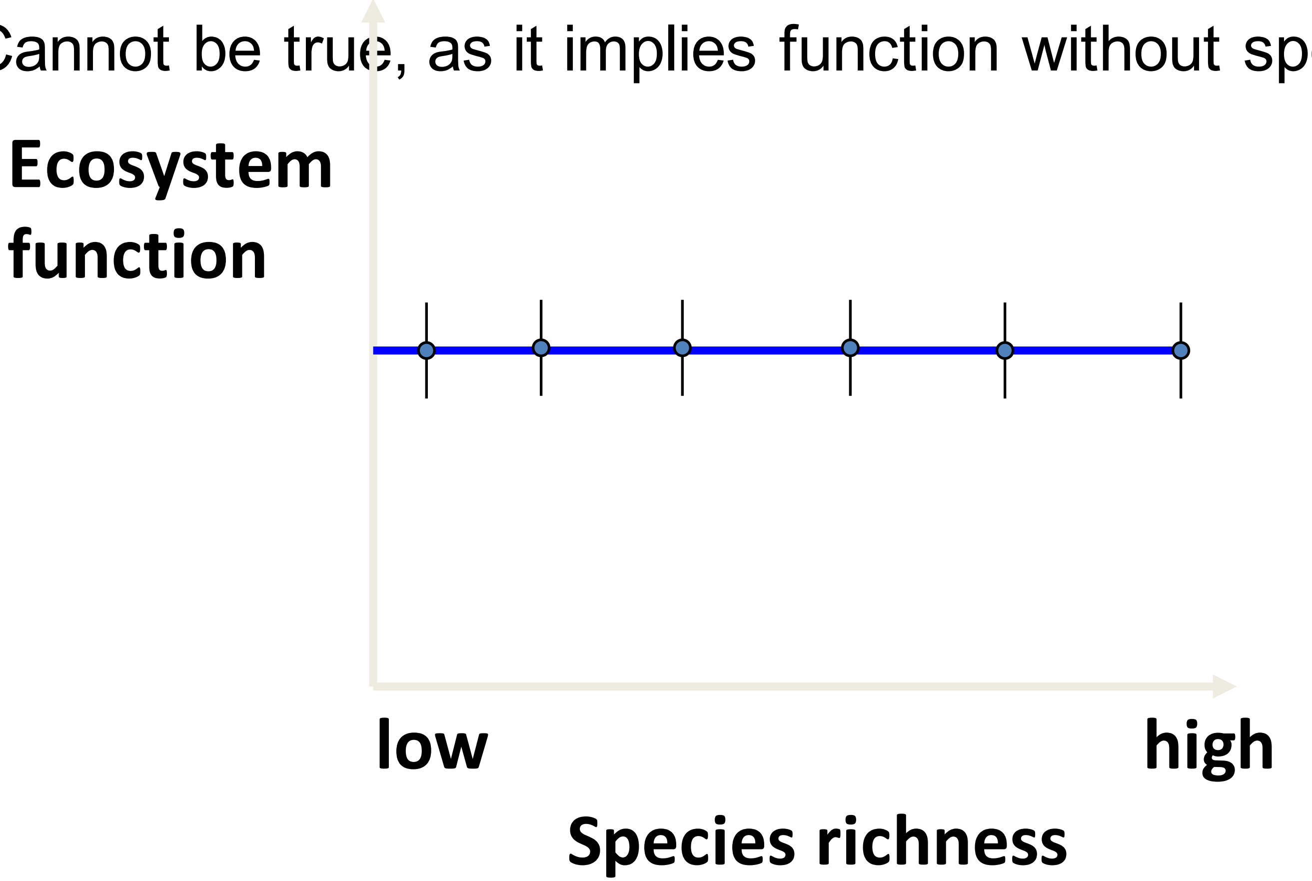
- Research on biodiversity vs. ecosystem functioning predicts the relationship might potentially have a number of different ‘shapes’…..

Is species richness correlated with ecosystem function?


Redundant
Rivet
Idiosyncratic
Ecosystem function
low
high
low
high
low
high
Species richness

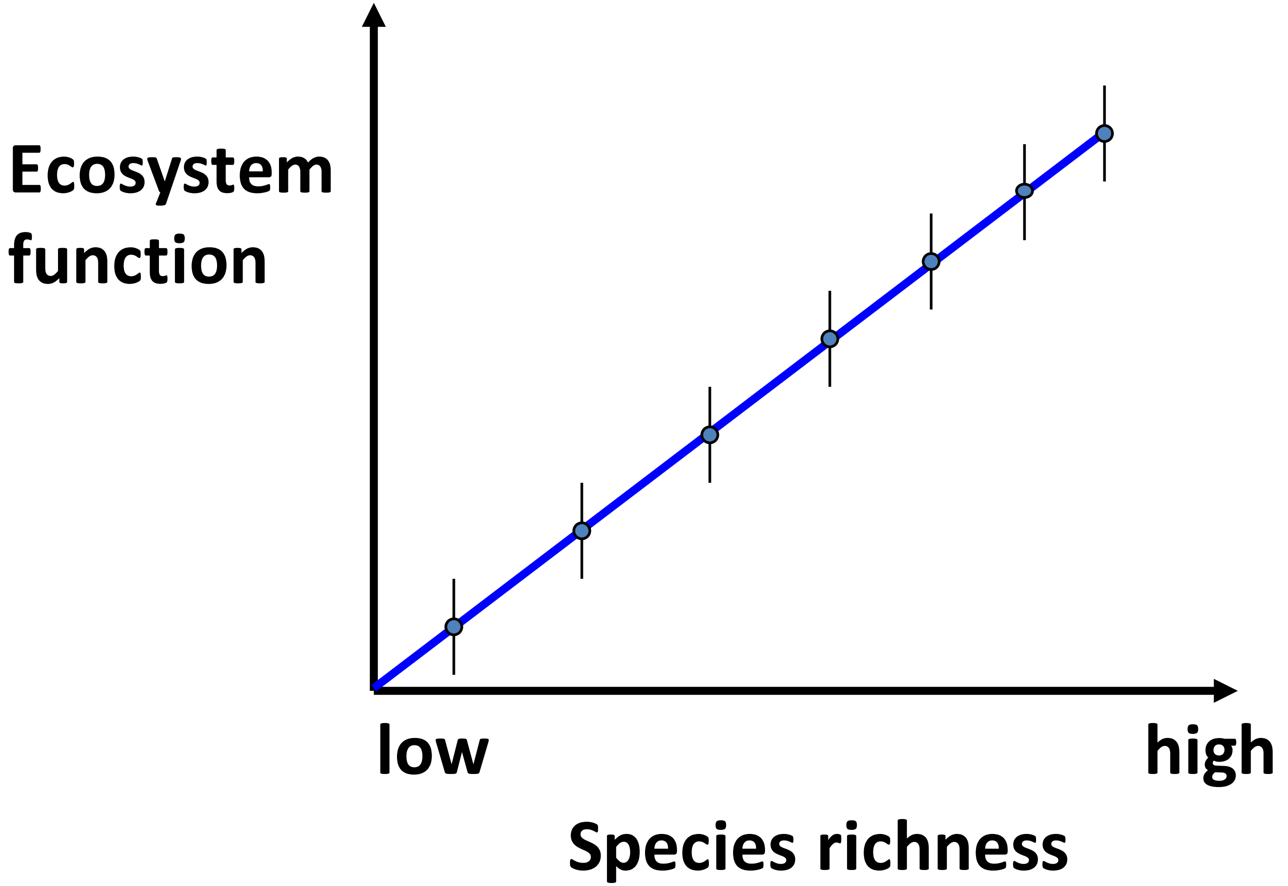
Ecological theory….

- Null hypothesis: ecosystem function is insensitive to species additions or deletions (the trivial case)
- Cannot be true, as it implies function without species!



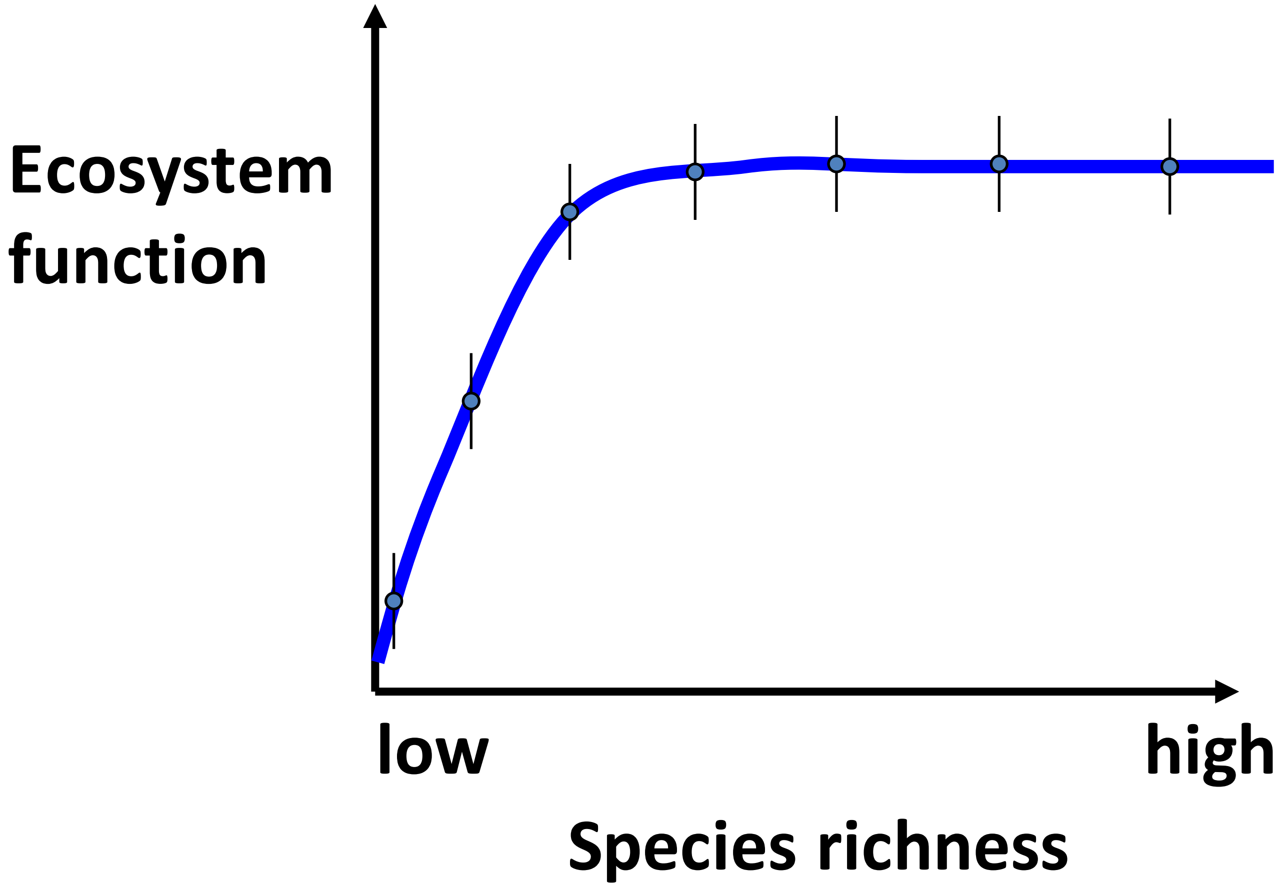
Ecological theory….

- Rivet: all species contribute to the integrity of an ecosystem in a small but significant way such that a progressive loss of species steadily damages ecosystem function.



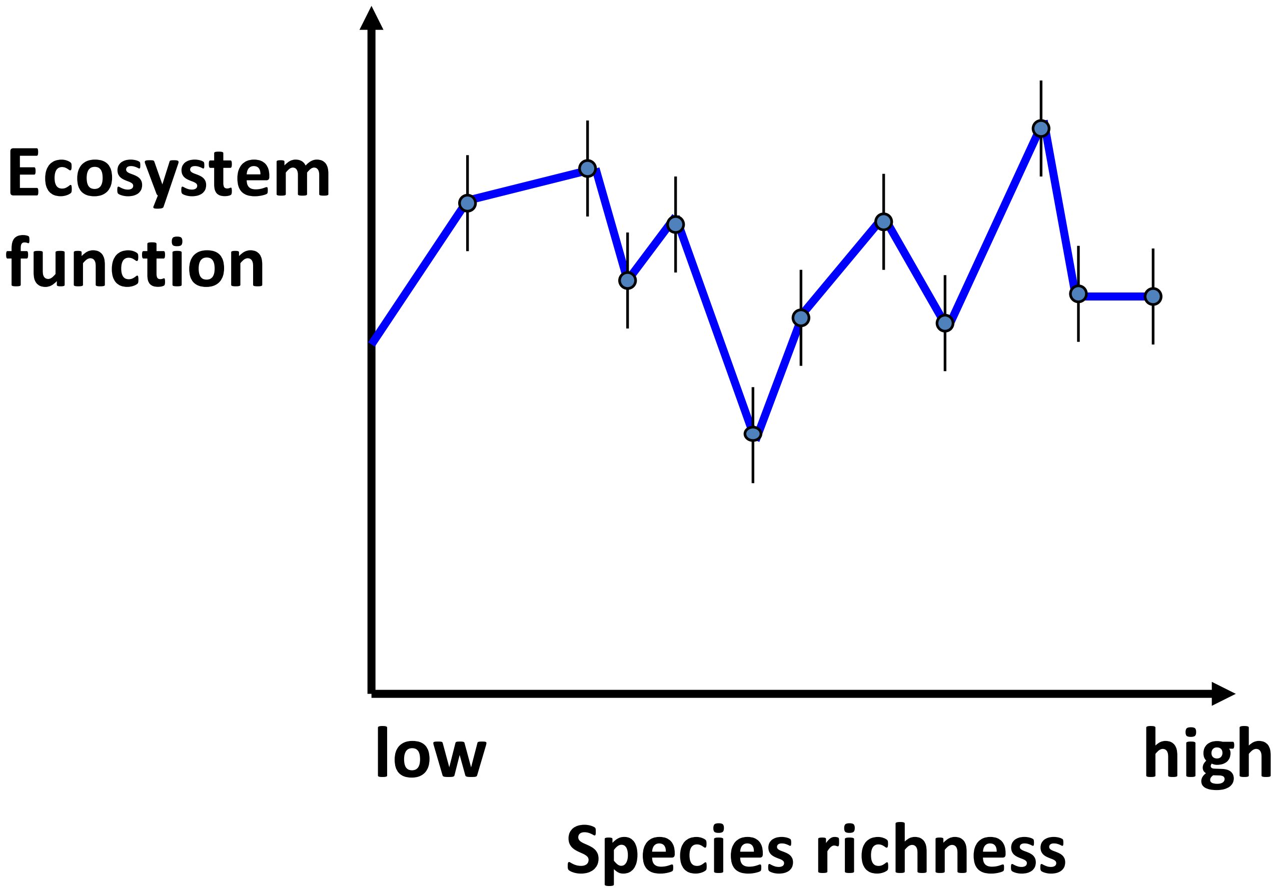
Ecological theory…….

- <u>Redundant</u>: the contribution of additional species is redundant above a critical level



Ecological theory

- Idiosyncratic hypothesis: ecosystem function changes unpredictably as species richness changes



Testing theory
Is species richness positively correlated with ecosystem function?

- There is (very) general agreement that as species richness decreases, ecosystem functioning is adversely impacted
- ‘Recent work has now clearly established that biodiversity does indeed affect ecosystem processes. The strongest evidence to date comes from field experimental studies that have manipulated plant species richness in temperate grasslands’ (Loreau, 2009)

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Linking biodiversity and ecosystems: towards a unifying ecological theory

Michel Loreau

Published 24 November 2009. DOI: 10.1098/rstb.2009.0155

Article | Figures & Data | Info & Metrics | eLetters | PDF

Abstract

Community ecology and ecosystem ecology provide two perspectives on complex ecological systems that have largely complementary strengths and weaknesses. Merging the two perspectives is necessary both to ensure continued scientific progress and to provide society with the scientific means to face growing environmental challenges. Recent research on biodiversity and ecosystem functioning has contributed to this goal in several ways. By addressing a new question of high relevance for both science and society, by challenging existing paradigms, by tightly linking theory and experiments, by building scientific consensus beyond differences in opinion, by integrating fragmented disciplines and research fields, by connecting itself to other disciplines and management issues, it has helped transform ecology not only in content, but also in form. Creating a genuine evolutionary ecosystem ecology that links the evolution of species traits at the individual level, the dynamics of species interactions, and the overall functioning of ecosystems would give new impetus to this much-needed process of unification across ecological disciplines. Recent community evolution models are a promising step in that direction

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Theme Issue 'Personal perspectives in the life sciences for the Royal Society's 350th anniversary' compiled and edited by Georgina Mace

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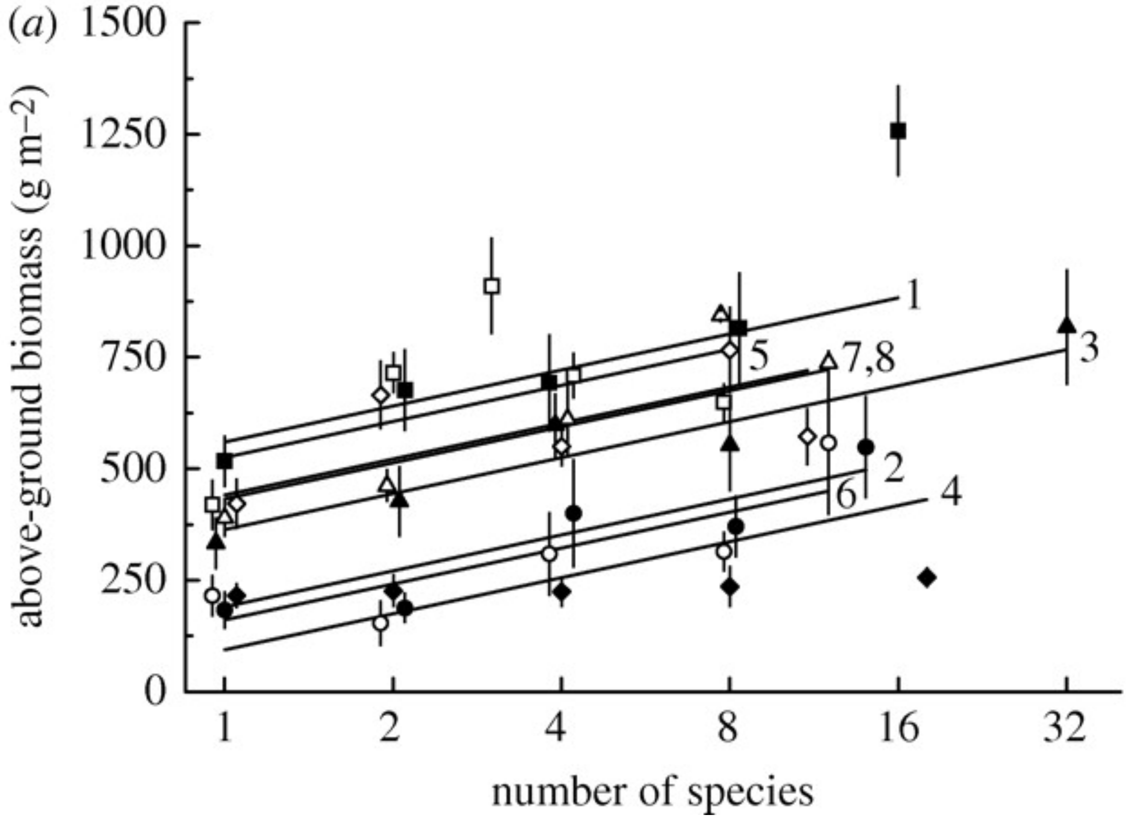
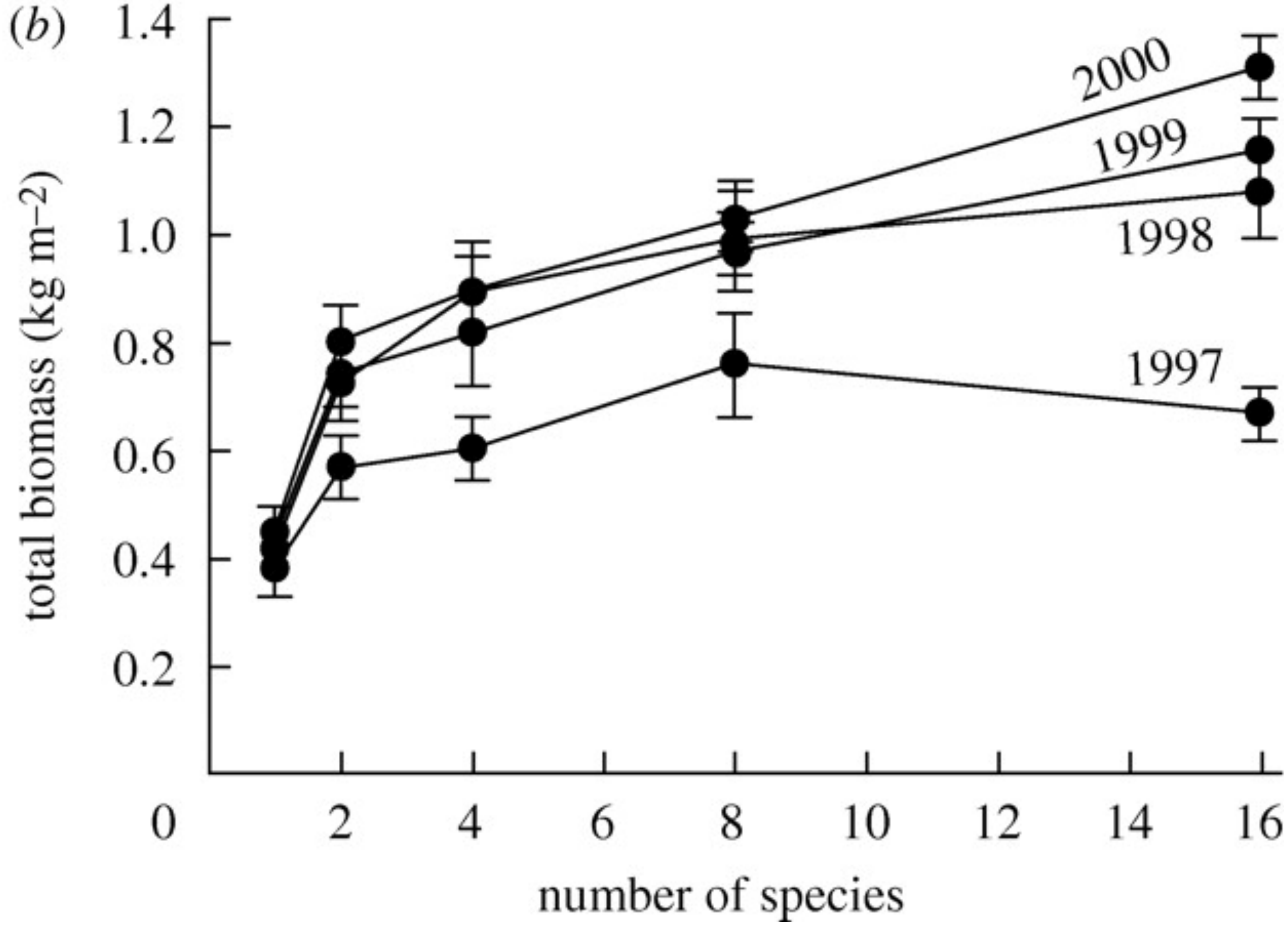
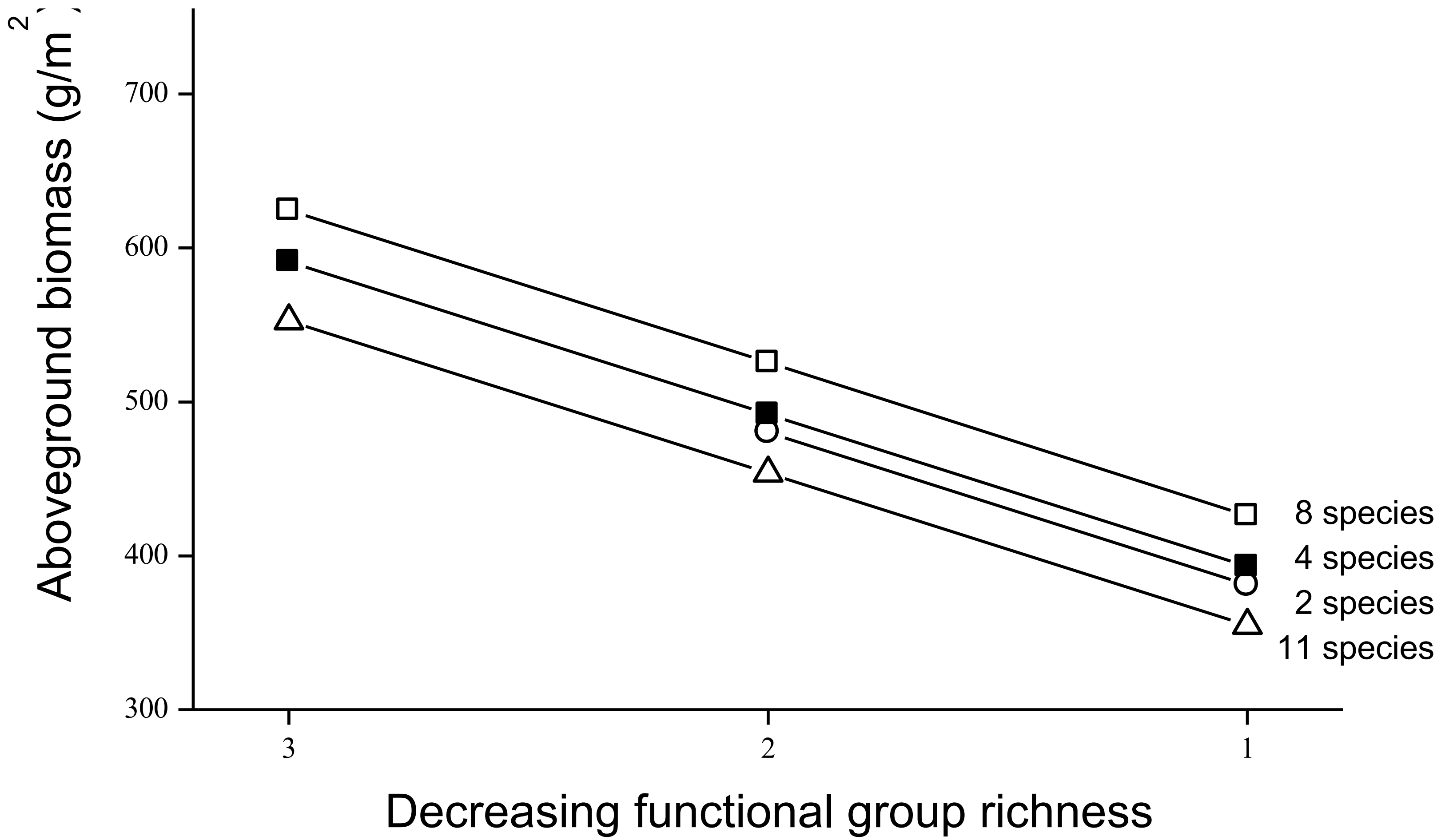


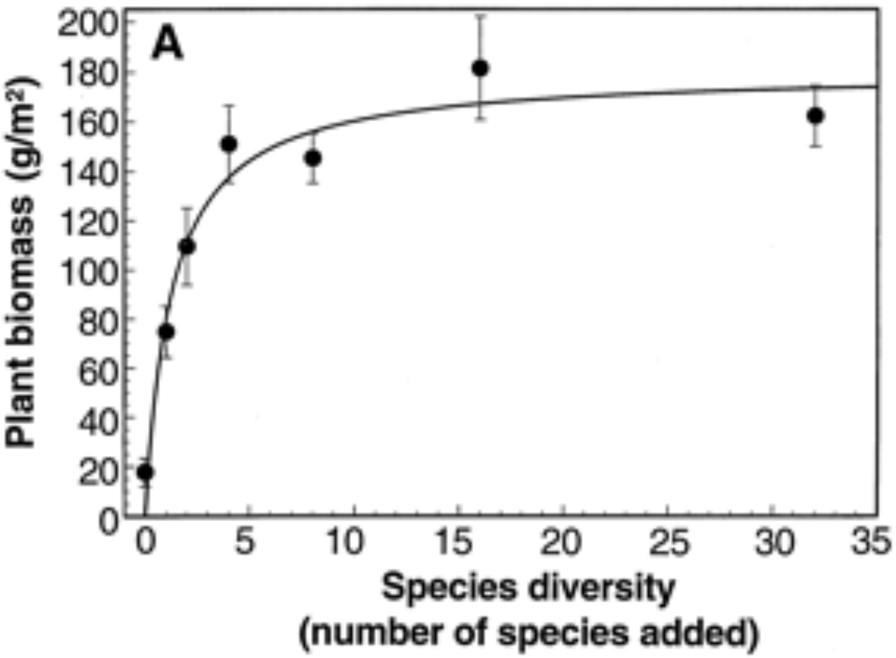
Long-term experiment reported in Loreau (2009):
A log-linear increase in plant above-ground biomass production with species richness across sites



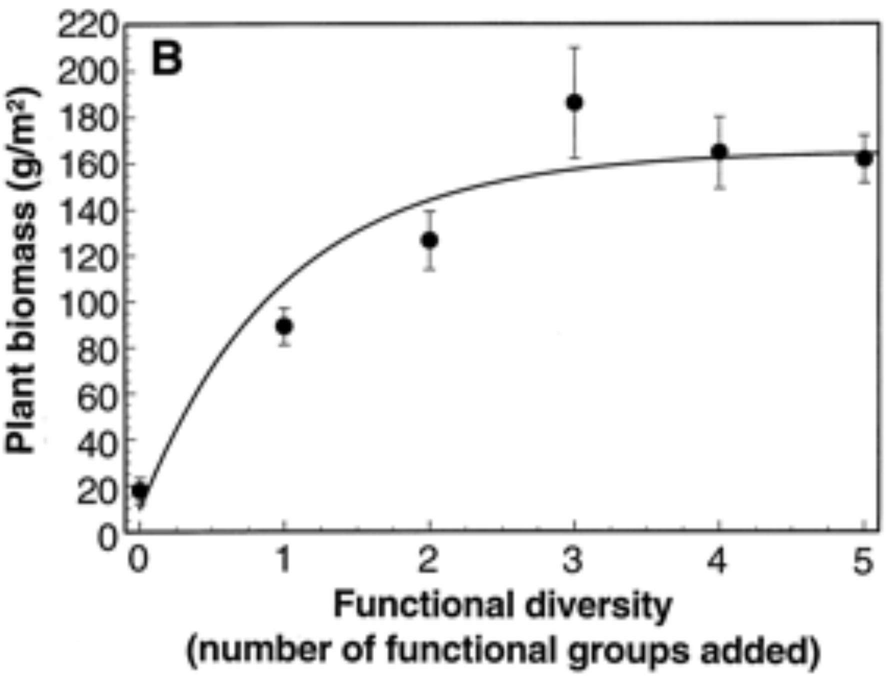
Long-term experiment reported in Loreau (2009):
a positive response of total plant biomass production to species richness, which became stronger through time



Aboveground biomass (g/m2)
700
600
500
400
300
3
2
1
8 species
4 species
2 species
11 species
Decreasing functional group richness



(A) Dependence of 1996 aboveground plant biomass (that is, productivity) (mean and SE) on the number of plant species seeded into the 289 plots.



(B) Dependence of 1996 above-ground plant biomass on the number of functional groups seeded into each plot. Curves shown are simple asymptotic functions fitted to treatment means. More complex curves did not provide significantly better fits

From: Tilman et al. (1997) Science
https://science.sciencemag.org/content/277/5330/1300

What about aquatic systems?

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doi: 10.1111/oik.01549

Subject Editor: Sa Xiao. Editor-in-Chief: Christopher Lortie. Accepted 14 August 2014

Marine biodiversity and ecosystem functioning: what's known and what's next?

Lars Gamfeldt, Jonathan S. Lefcheck, Jarrett E. K. Byrnes, Bradley J. Cardinale, J. Emmett Duffy and John N. Griffin

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Marine ecosystems are experiencing rapid and pervasive changes in biodiversity and species composition. Understanding the ecosystem consequences of these changes is critical to effectively managing these systems. Over the last several years, numerous experimental manipulations of species richness have been performed, yet existing quantitative syntheses have focused on a just a subset of processes measured in experiments and, as such, have not summarized the full data available from marine systems. Here, we present the results of a meta-analysis of 110 marine experiments from 42 studies that manipulated the species richness of organisms across a range of taxa and trophic levels and analysed the consequences for various ecosystem processes (categorised as production, consumption or biogeochemical fluxes).

Our results show that, generally, mixtures of species tend to enhance levels of ecosystem function relative to the average component species in monoculture, but have no effect or a negative effect on functioning relative to the 'highest-performing' species. These results are largely consistent with those from other syntheses, and extend conclusions to ecological functions that are commonly measured in the marine realm (e.g. nutrient release from sediment bioturbation). For experiments that manipulated three or more levels of richness, we attempted to discern the functional form of the biodiversity–ecosystem functioning relationship. We found that, for response variables related to consumption, a power-function best described the relationship, which is also consistent with previous findings. However, we identified a linear relationship between richness and production. Combined, our results suggest that changes in the number of species will, on average, tend to alter the functioning of marine ecosystems. We outline several research frontiers that will allow us to more fully understand how, why, and when diversity may drive the functioning of marine ecosystems.

Free download: https://www.researchgate.net/profile/Jonathan_Lefcheck/publication/268235931_Marine_biodiversity_and_ecosystem_functioning_What%27s_known_and_what%27s_next/links/546a009a0cf2397f78300d9a.pdf

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Marine biodiversity and ecosystem functioning: what's known and what's next?

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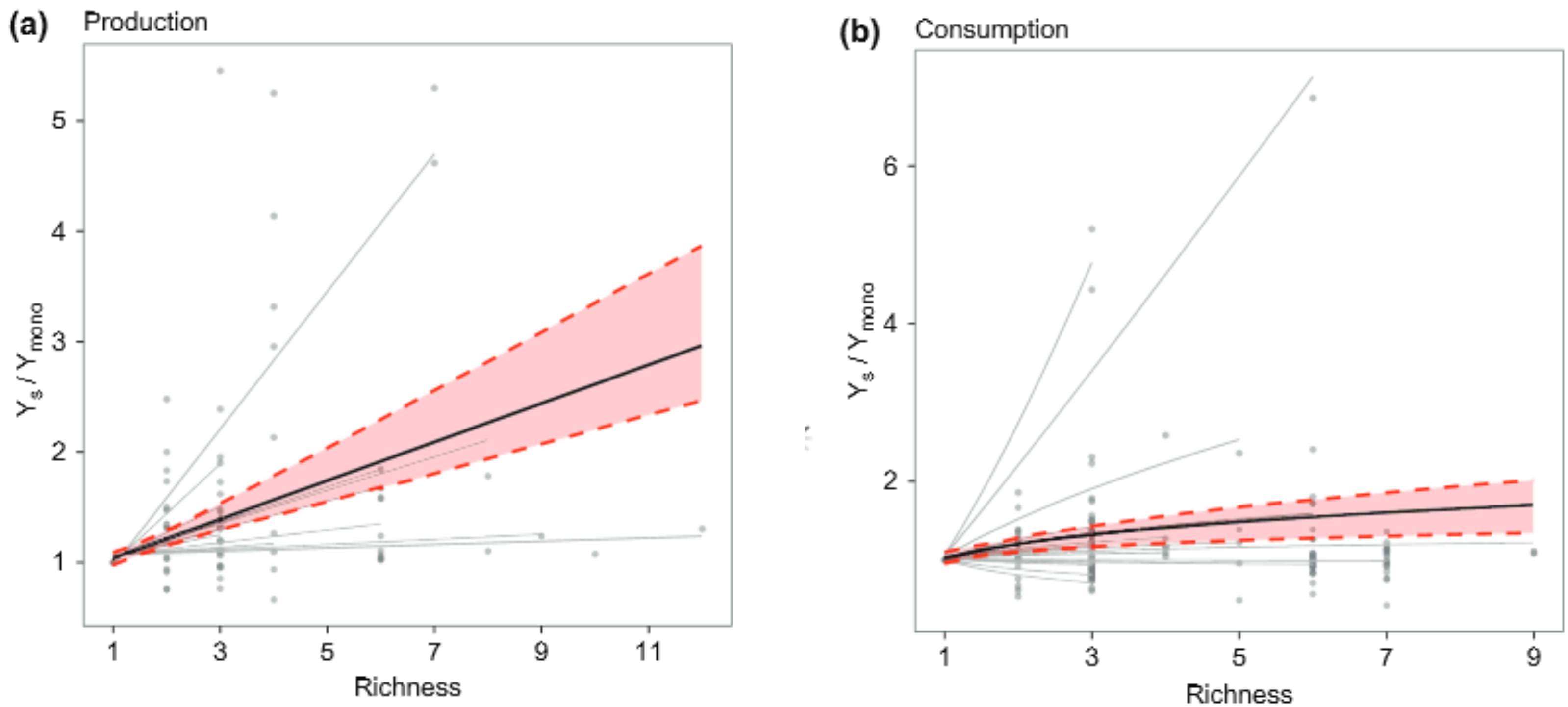
Abstract:

'….results show that, generally, mixtures of species tend to enhance levels of ecosystem function relative to the average component species in monoculture….'

Table 2. A description of the different response variables included in each main category of function (production, consumption, biogeochemical fluxes), and their units. Some variables have been measured as both state and rate variables.

Function category	Functions	Units
Production	- biomass/volume/abundance/cover/size - chlorophyll a - production of offspring or eggs - survival - hatching success - abundance of epifauna	weight volume^{-1} (e.g. g l^{-1}, no. volume^{-1}, O_2 time^{-1}, weight (e.g. g), weight area^{-2}, cover area^{-2}, shoots per plot, length (e.g. mm), numbers pair^{-1} (brood production or eggs), % (survival, gonad index, hatching success), weight time^{-1}, no. of eggs time^{-1}
Consumption	- biomass/volume/abundance/ - cover of resource or prey - nutrient uptake/incorporation - ingestion rate	weight volume^{-1} (e.g. g l^{-1}), number volume^{-1}, number/cover/weight/volume area^{-2}, l g^{-1} h^{-1}, proportional change, weight, mg g^{-1}, concentration (e.g. molar), weight time^{-1}
Biogeochemical fluxes	- water exchange - fluxes of nutrients - fecal production - oxygen flux and oxidized sediments	volume, concentration, concentration area^{-2} time^{-1}, number area^{-2} time^{-1}, number time^{-1} , depth (of O_2 layer)


(a)
Production
Y_s / Y_{mono}
1
2
3
4
5
1
3
5
7
9
11
Richness
(b)
Consumption
Y_s / Y_{mono}
2
4
6
1
3
5
7
9
Richness

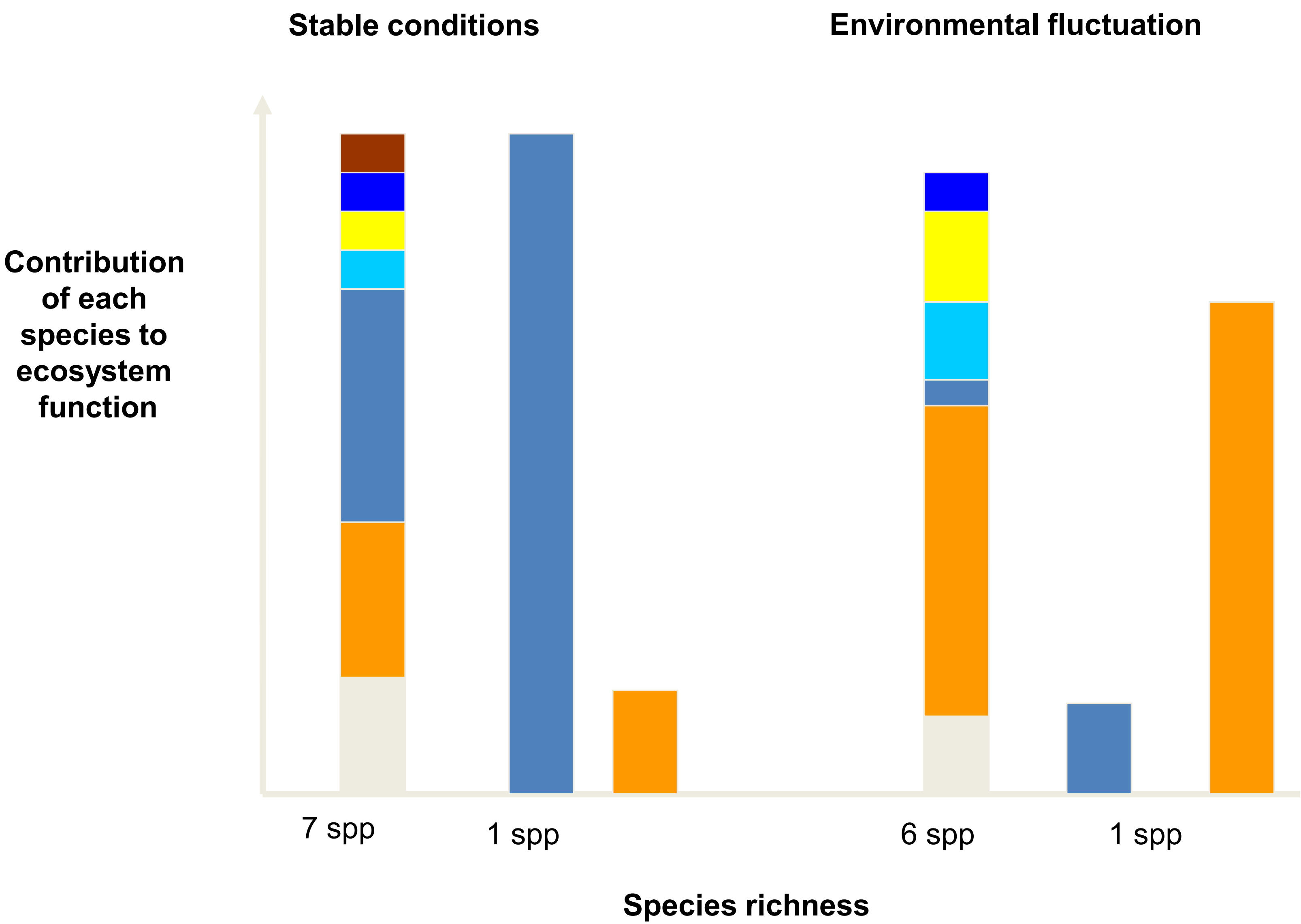
Final theory: living with environmental change

- We are living through a period of environmental change, e.g.

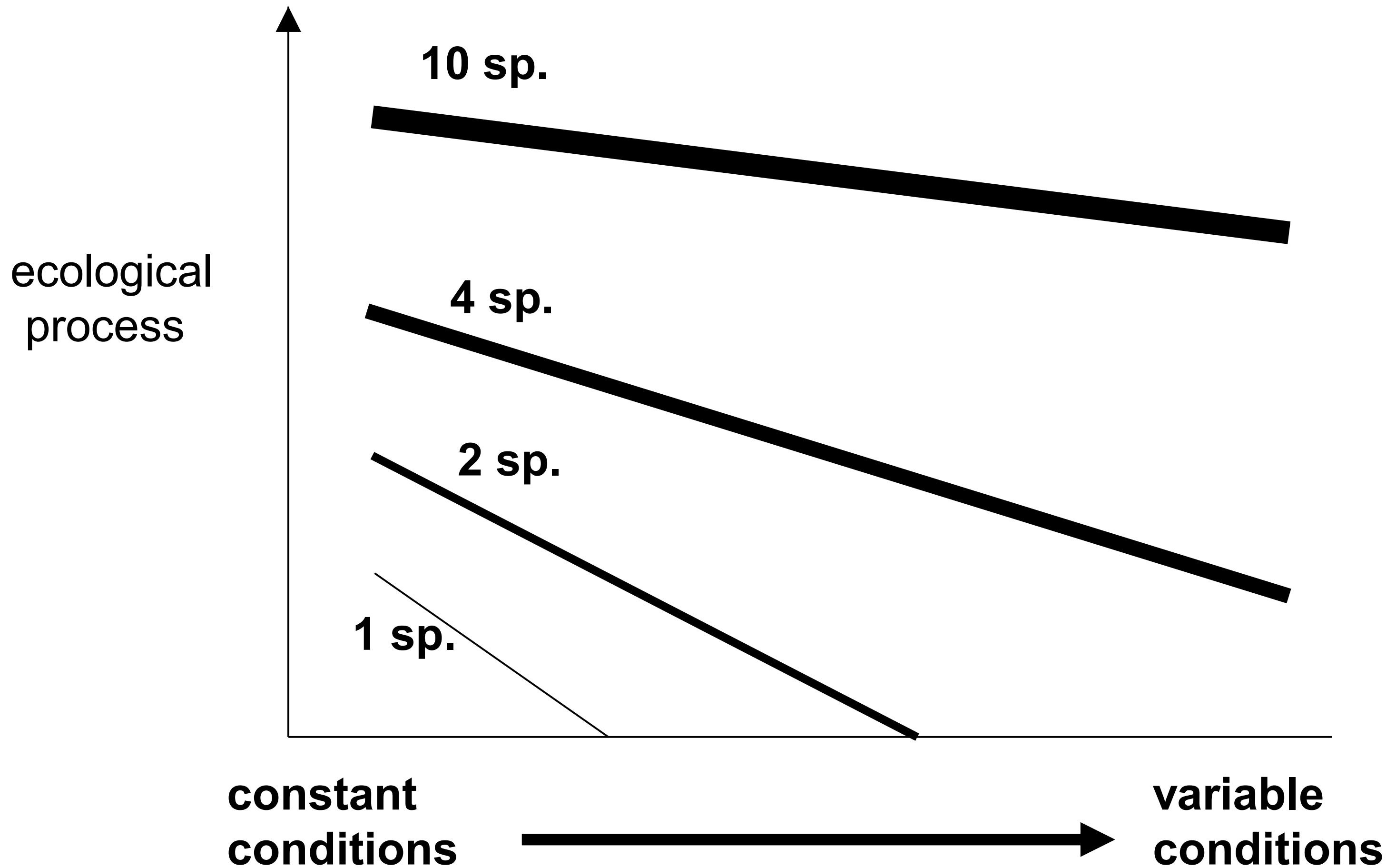
- Land use
- Habitat fragmentation
- Climate change

- Ecosystem resilience is important to preserve functioning… The insurance hypothesis….

The insurance hypothesis: More diverse assemblages will have a greater probability of having species that are adapted to changed conditions



<u>The Insurance Hypothesis</u>: more diverse assemblages have a greater probability of containing species that are adapted to changed conditions



Summary

- More species = greater biodiversity = higher functional diversity (= potential for functional redundancy) = benefits to ecosystem functioning
- Often shown empirically by increased production (of plant biomass) as species richness increases
- But highly complex and general rules difficult to formulate

Questions

1. *What do we really mean by biodiversity?*

2. *Why is it important to measure biodiversity?*

3. *What is meant by the term 'function(ing)'?*

4. *What is a functional group? How does it differ from a functional guild? What about functional diversity and redundancy?*

5. *What is the relationship between biodiversity and ecosystem functioning?*