7. Biodiversity and Ecosystem Function

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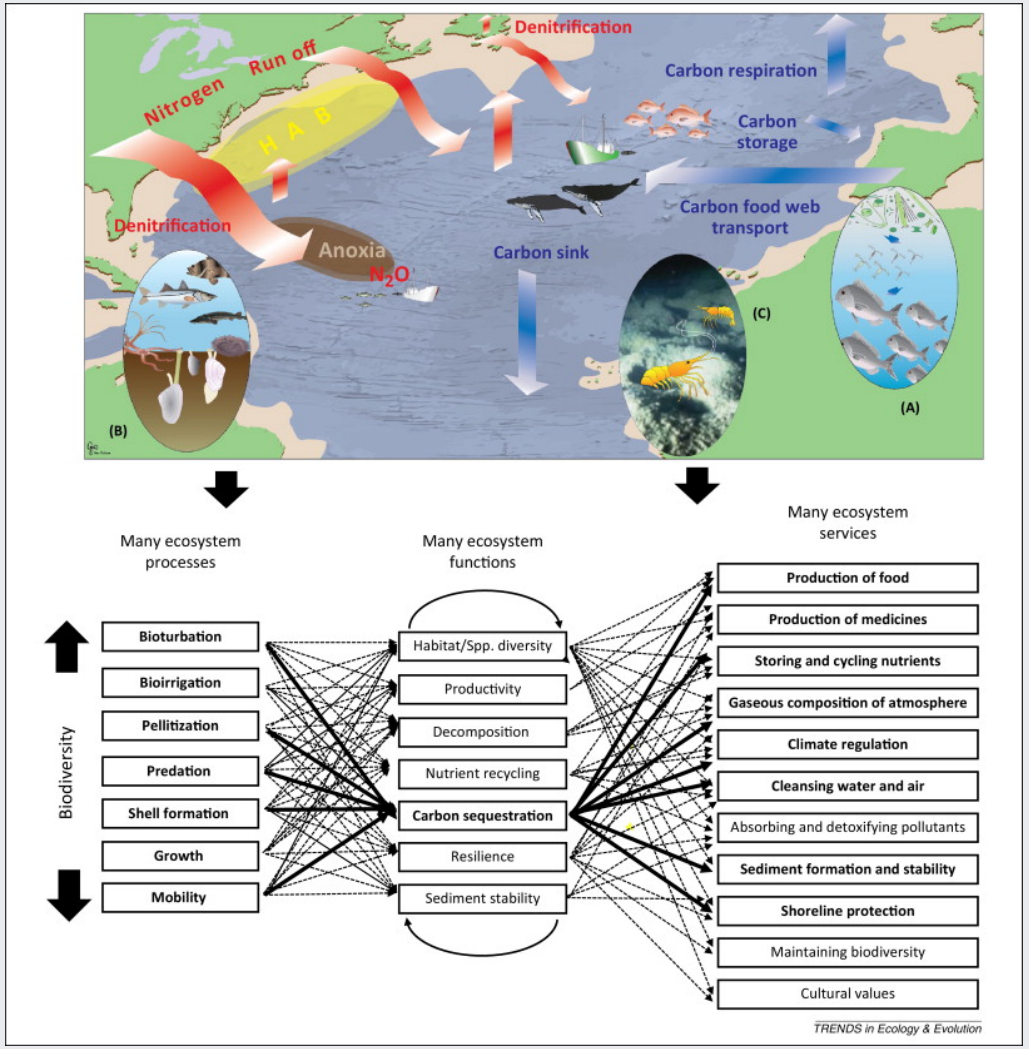
How does biodiversity affect ecosystem function?

Ecosystem functions?

- Productivity (C sequestration)
- Decomposition
- Respiration
- Water filtration
- Pollination
- Predation
- Herbivory
- Habitat (for other organisms)
- Etc



Snelgrove et al. 2014 (Marine)

The evolution of B-EF research

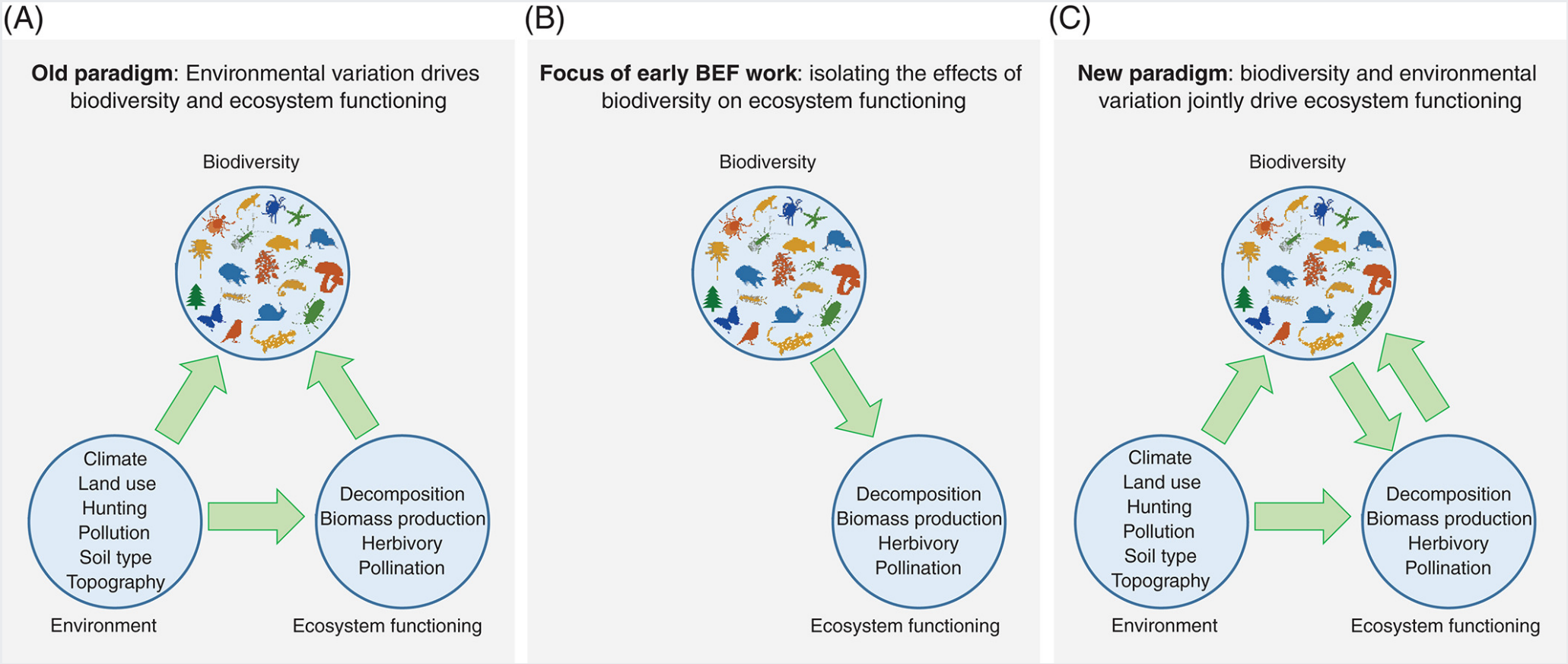


Figure from van der Plas 2019

Trait vs diversity effects?

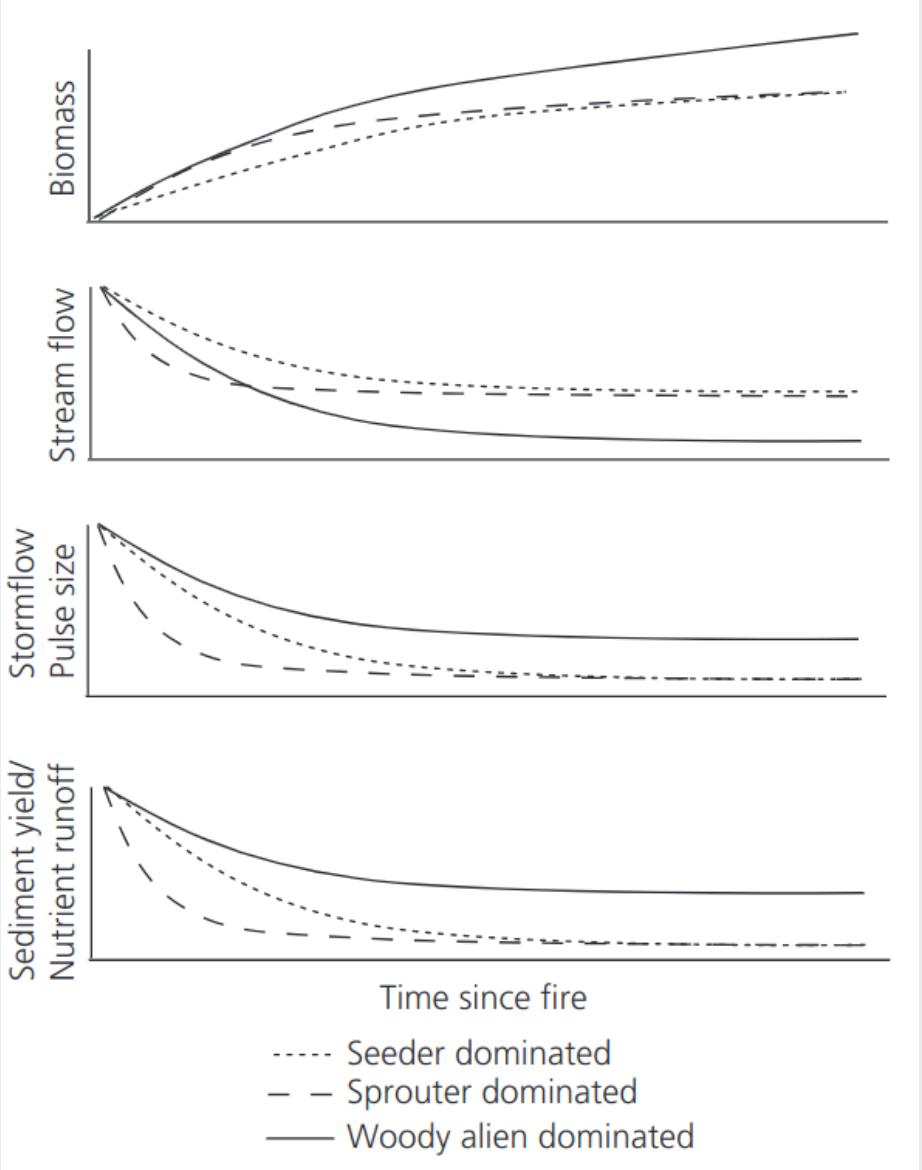
Direct trait effects

Dominance by indigenous seeders versus sprouters affects rate of biomass accumulation, change in total stream flow, peak storm-flow pulse, and sediment yield or nutrient runoff in fynbos stands/catchments

- it also changes with a shift to woody alien trees

Hypothetical curves are based on information from a range of sources, see book chapter. The temporal range spans c.15 yr and any seasonal variation is excluded.

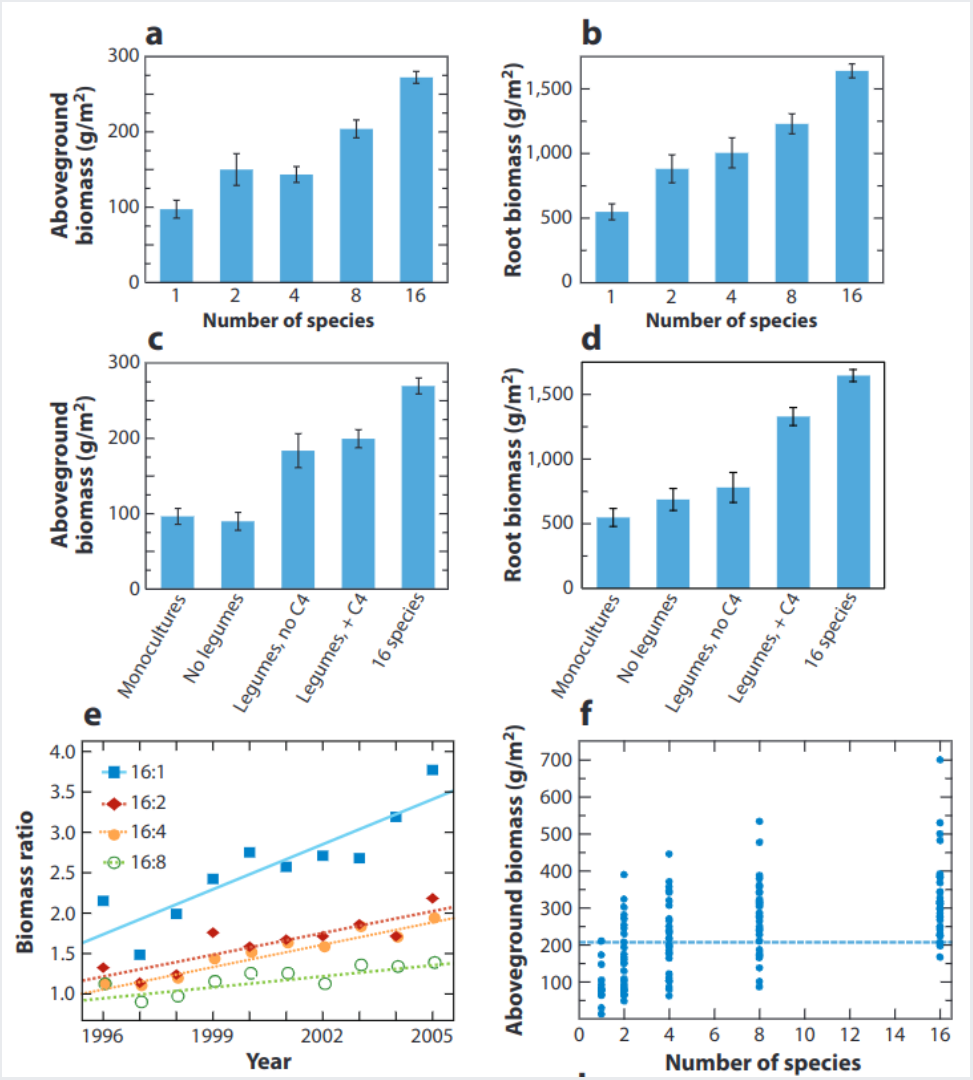
Figure from Slingsby et al. 2014



Trait vs diversity effects?

Diversity effects

Experimental communities (e.g. Cedar Creek) reveal diversity effects on several ecosystem properties...



Tilman et al. 2014

Theoretical mechanisms driving B-EF

More species = greater probability of higher trait diversity, affecting ecosystem processes through:

The selection effect

More species = more likely to have species that can dominate ecosystem processes

Niche complementarity

More species = better filling of available niche space and use of resources (links with community assembly)

A mix of the two…

Complementarity among and/or dominance by subsets of species or functional groups

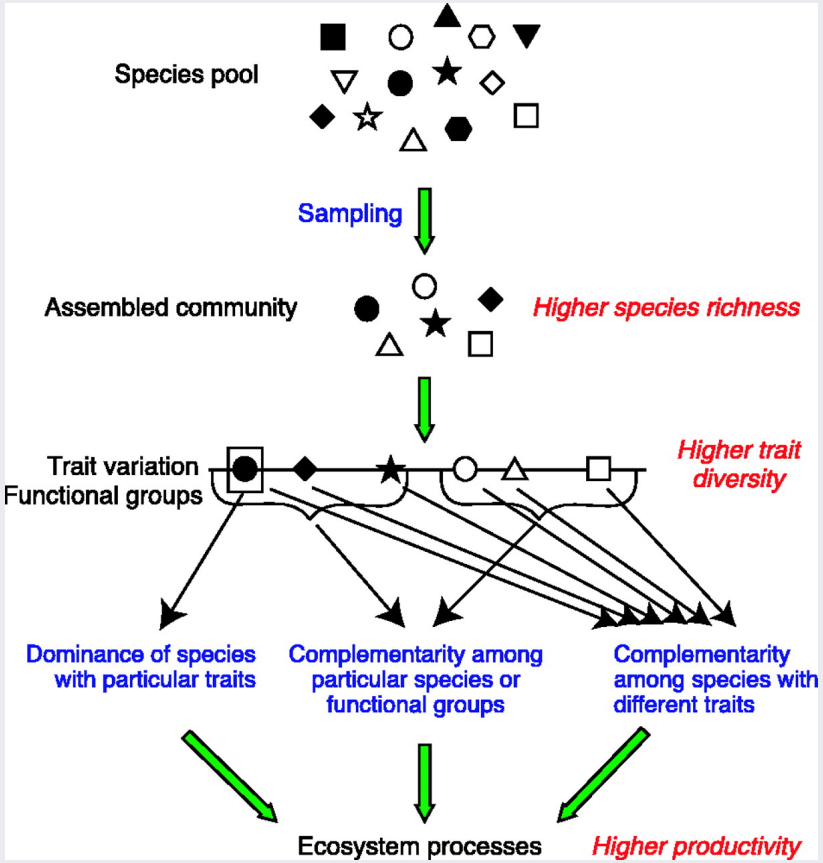
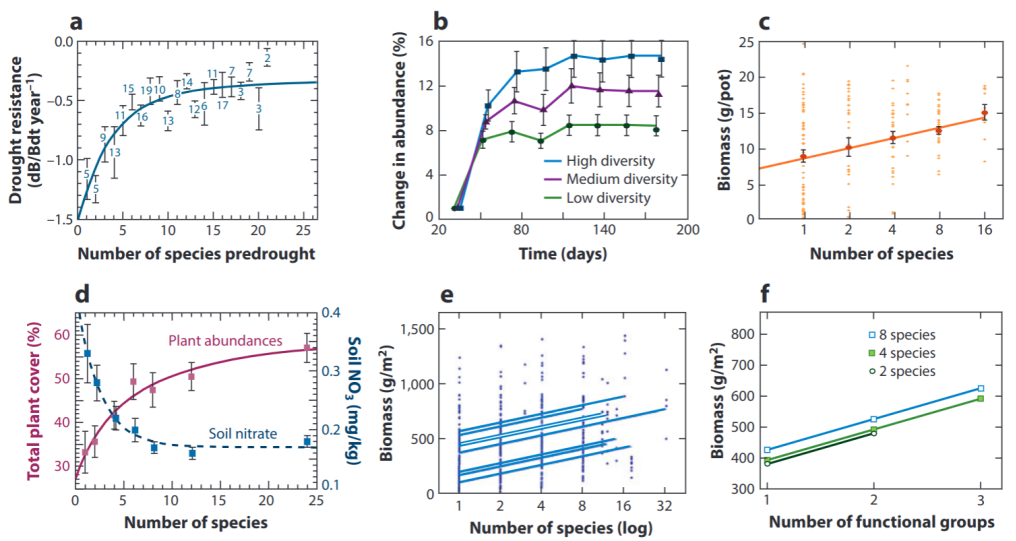


Figure from Loreau et al. 2001

Types of B-EF effects

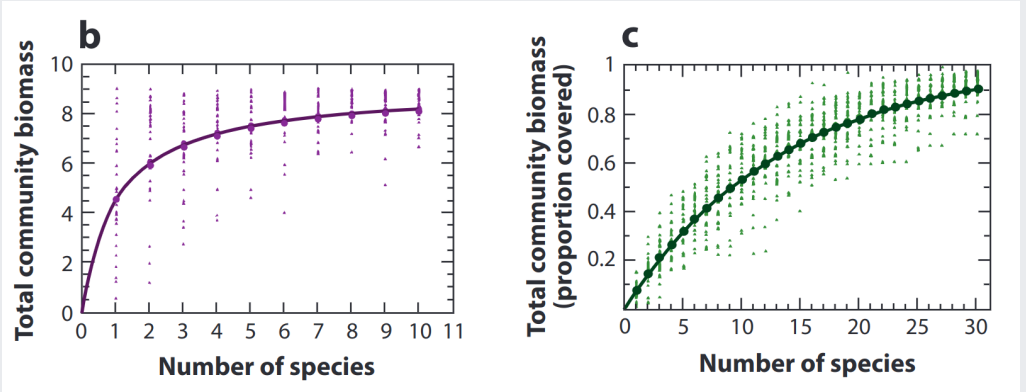
Diversity-Productivity

Productivity has been the primary focus of most B-EF research, and is supported by many experiments



Tilman et al. 2014

"Productivity" has been measured in a number of ways, including biomass, plant abundance or % cover



Generally results are consistent with "niche complementarity" (modelled in panel c)

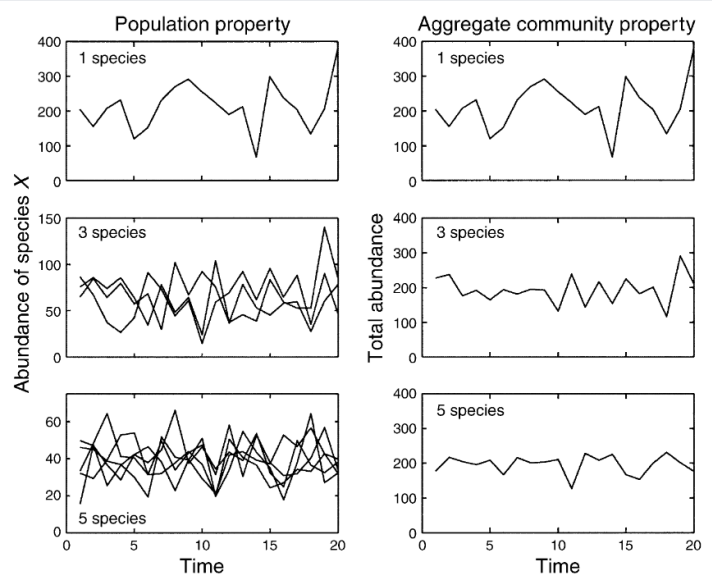
- biomass increases with diversity above that of the most productive monoculture - a phenomenon termed "overyielding"

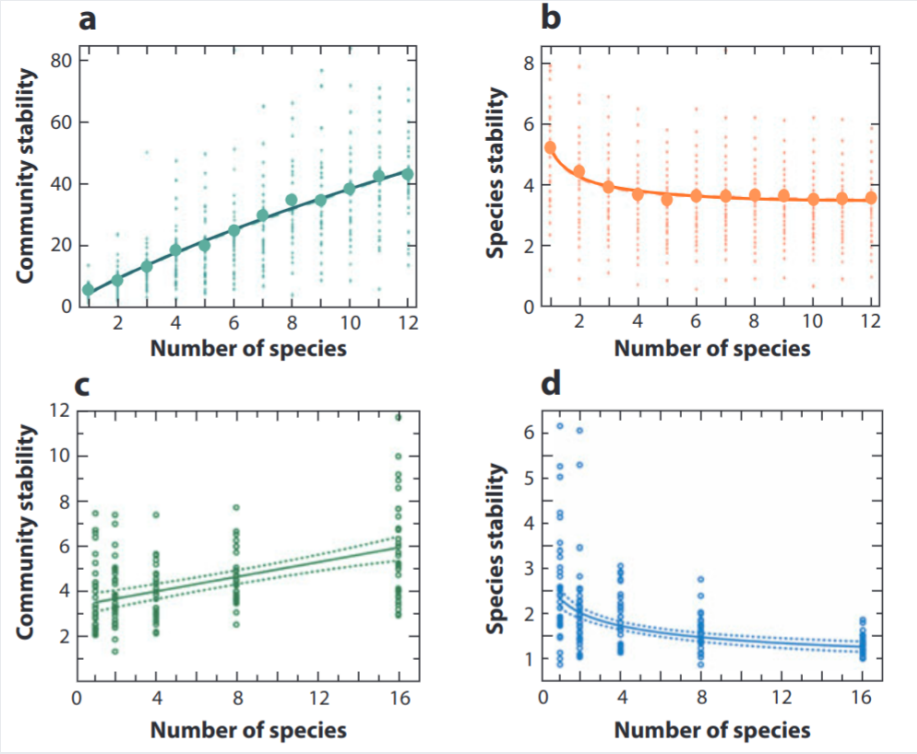
Under "the selection effect" (panel b) the expected maximum cannot exceed that of the most productive monoculture

Types of B-EF effects

Diversity-Stability

"Biodiversity as insurance" - species respond differently to environmental change, but averaging results in lower community variance





Species loss = less compensation (or redundancy) and increasing instability

Interestingly, more species = less species-level stability

Hooper et al. 2005 | Tilman et al. 2014

Types of B-EF effects

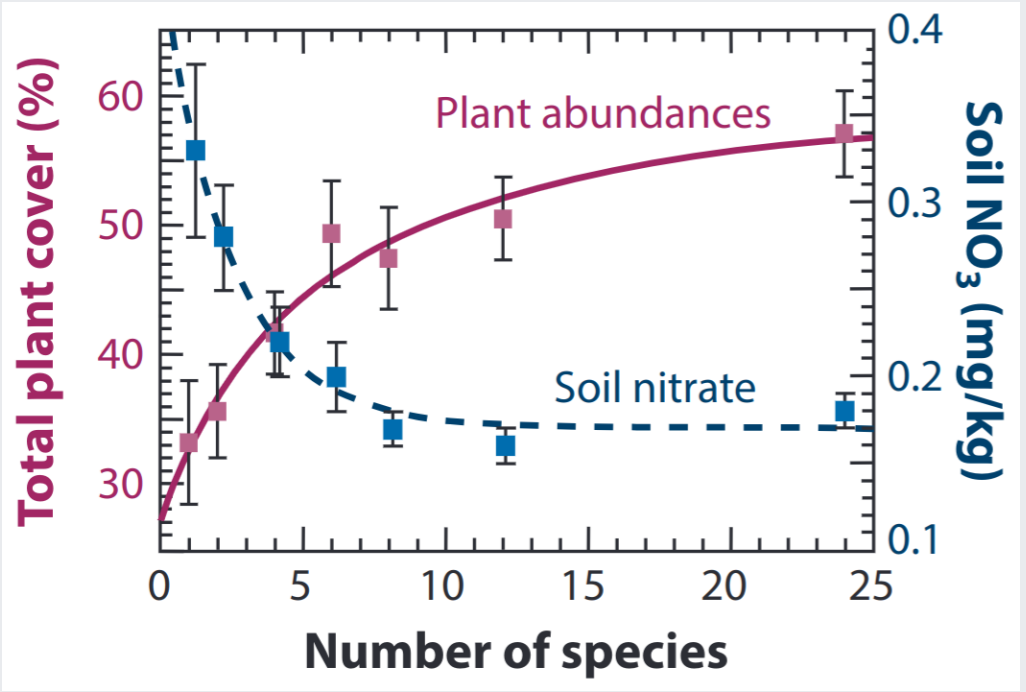
Diversity-Invasibility

More diverse communities are more resistant to invasion - Elton 1958

- A corollary of niche theory

Invaders must find resources to survive and grow, but B-EF experiments show that the levels of unconsumed resources decline as diversity increases...

Biomass attained by invaders of a given functional group often most strongly inhibited by the existing biomass of that same functional group - consistent with the predictions of limiting similarity



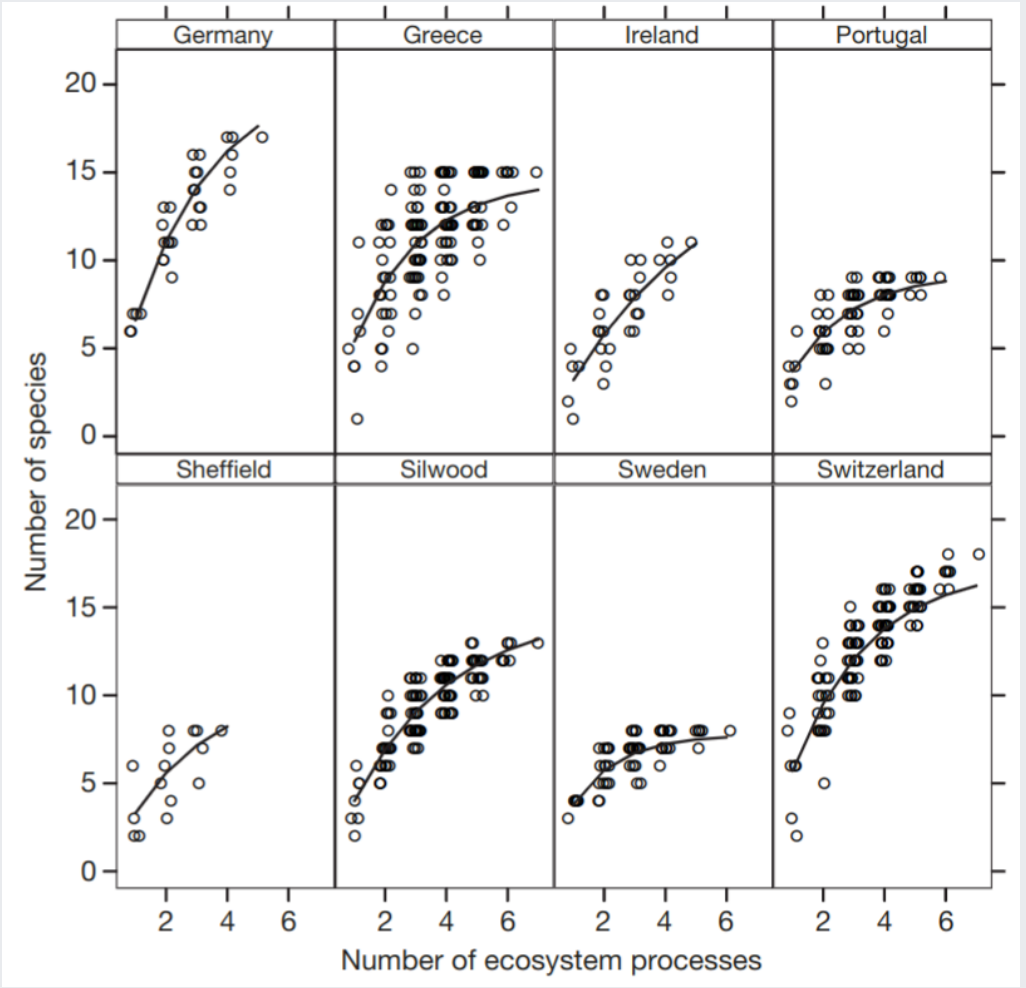
Tilman et al. 2014

Types of B-EF effects

Diversity-Multifunctionality

Many more species are needed to maintain multiple types of ecosystem processes than are demonstrably linked to any given process

Not all species have desirable effects on the suite of ecosystem processes measured

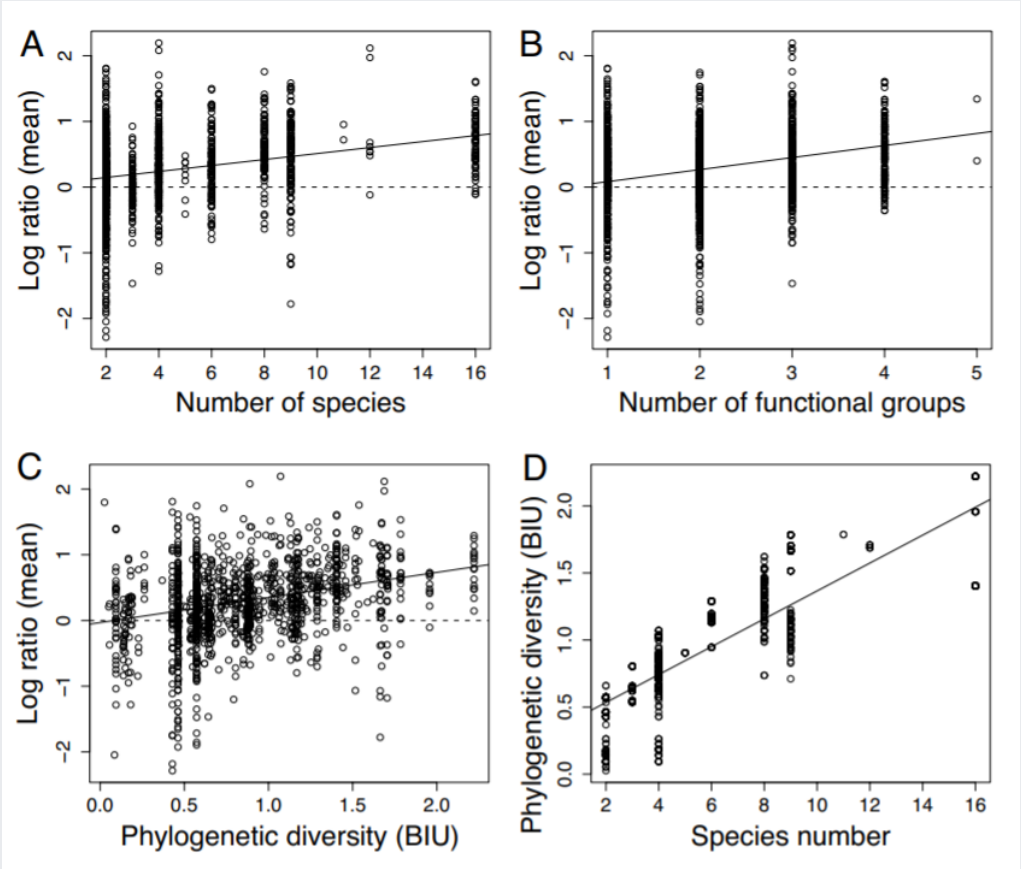


Other considerations?

Metrics of biodiversity used?

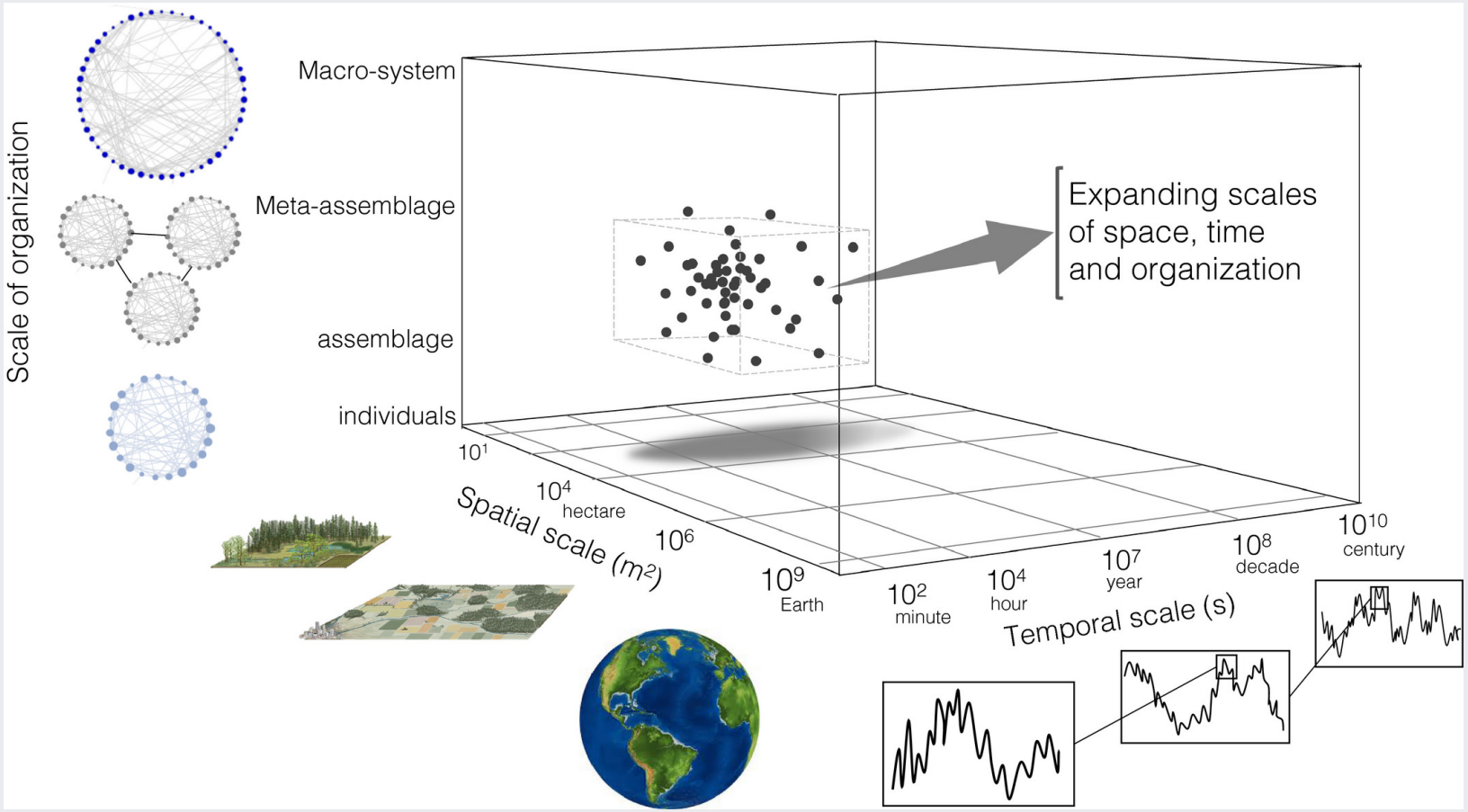
Most B-EF studies measure species diversity, assuming its a good proxy for functional diversity, and that the mechanism behind B-EF is mediated by traits.

Increasingly, studies are using FD or PD and often getting better results.



Cadotte et al. 2008

Does B-EF scale up in space and time?



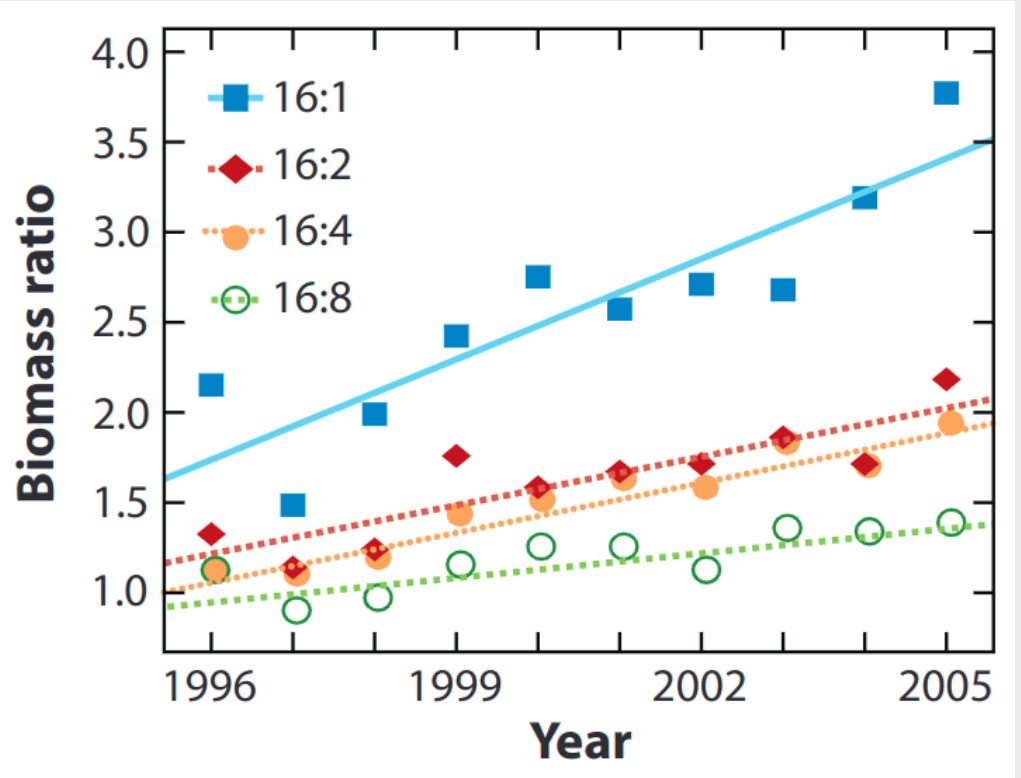
Gonzalez et al. 2020

Does B-EF scale up in space and time?

Time?

Most B-EF studies are experiments using microcosms or sets of plots each <10m^2. The oldest have been running for ~30 years.

Most have shown an increasing B-EF effect with time...



Tilman et al. 2014

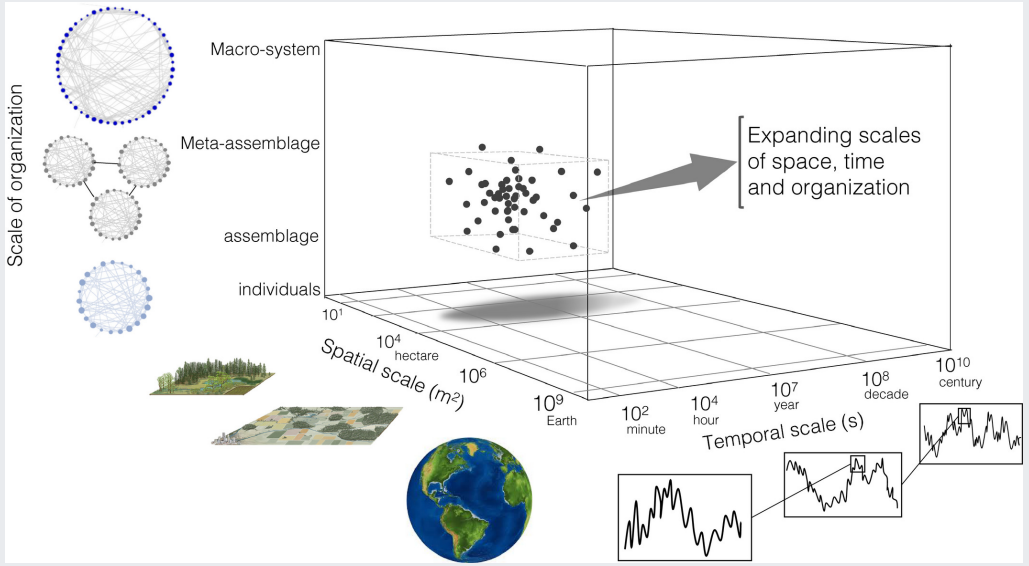
Does B-EF scale up in space and time?

Space? - It's complicated!!!

Niche complementarity is a local co-existence mechanism, but becomes less important at the regional scale, so the effect on EF should decrease

Greater heterogeneity at the regional scale means adding species with different niche preferences should increase EF (but not so in homogenous regions)

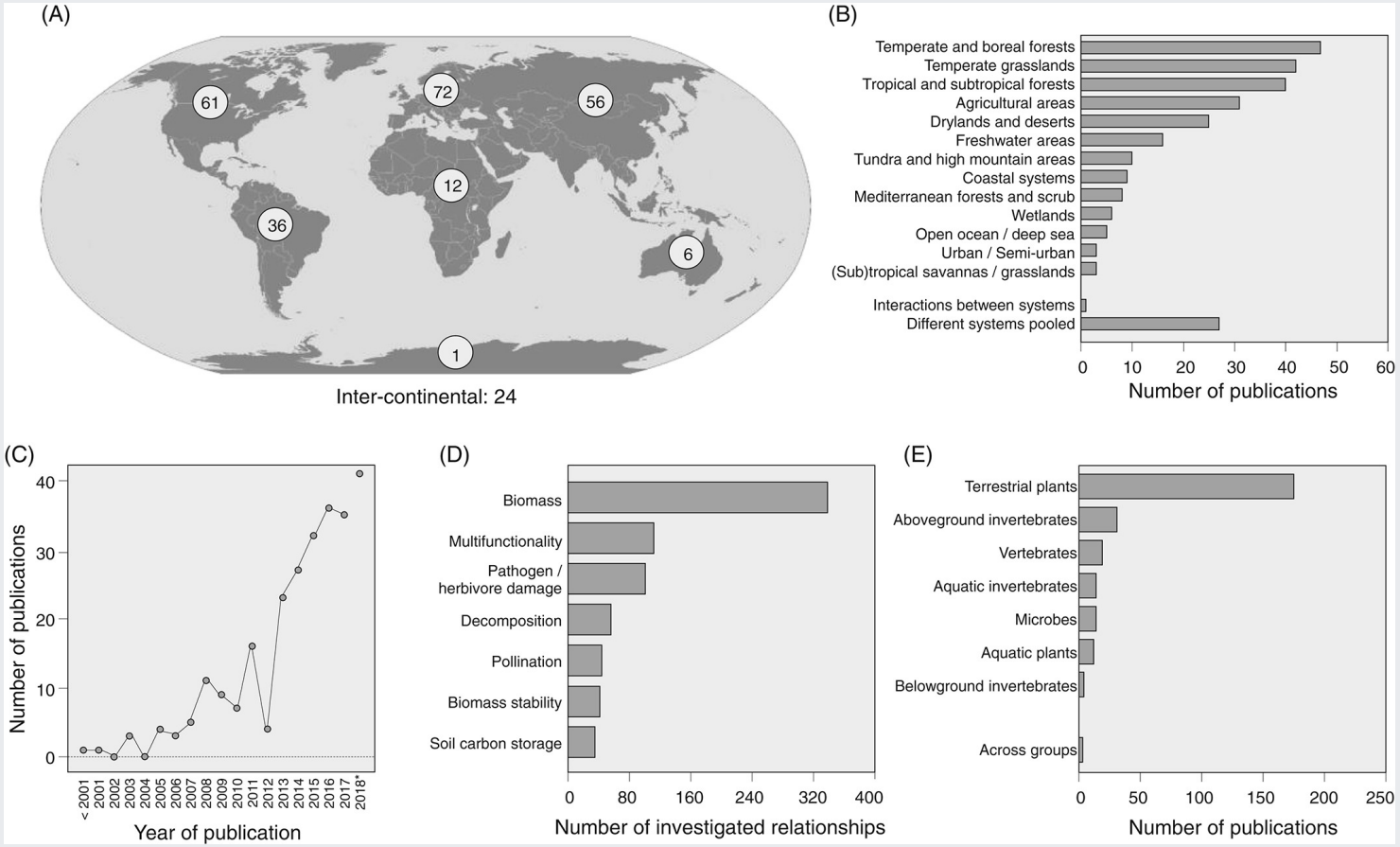
The actual ecosystem functions themselves often change with scale!



A very active area of research!

Gonzalez et al. 2020

Experiments vs the real world?



van der Plas 2019 - a review of 258 published empirical (non-experimental) studies

Experiments vs the real world?

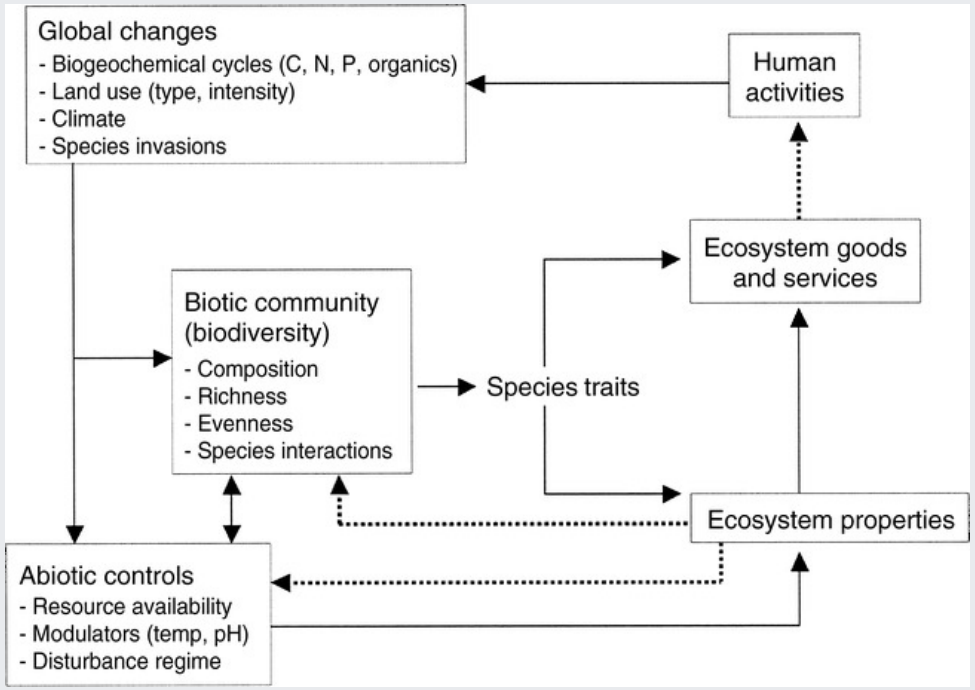
Category of function	Ecosystem function	Ecosystem type	Focal group	Theory	Observed relationships: Experiments	Observed relationships: Non-experimental studies N	
Biomass	Tree biomass stock	Temperate forests	Trees	↗ a,b,c	↗ m	38	↗
	Tree biomass production	Temperate forests	Trees	↗ a,b,c		61	↗
	Tree biomass stock	Tropical forests	Trees	↗ a,b,c	↗ m	44	→
	Tree biomass production	Tropical forests	Trees	↗ a,b,c		17	→
	Plant biomass*	Grasslands	Plants	↗ a,b,c	↗ n	102	↗
	Plant biomass*	Aquatic systems	Plants	↗ a,b,c	↗ n	21	↗
	Consumer biomass	All	Consumers	↗ a,b,c		24	↗
Decomposition	Decomposition	All	Plants	↘ d	↗ o	33	↗
	Decomposition	All	Decomposers	↗ d	↗ p	20	→
Soil carbon storage	Soil organic carbon stock	All	Plants		↗ o	35	→
Biomass stability	Plant biomass stability	All	Plants	↗ e,f,g	↗ q,r	27	↗
	Consumer biomass stability	All	Consumers	↗ e,f,g		13	↗
Pathogen / herbivore damage	Overall pathogen damage	All	Hosts		↘ o	17	→
	Damage by specialist pathogen	All	Hosts	↘ h		18	↘
	Herbivore damage	All	Plants	↘ h,i	↘→ o	45	→
	Herbivore damage	All	Herbivores	↗ j,k		10	→
	Herbivore damage	All	Predators	↘ k	→ o	11	→
Pollination	Fruit or seed set	All	Plants			8	→
	Fruit or seed set	All	Pollinators	↗ l		36	↗
Ecosystem multi-functionality	Ecosystem multifunctionality	All	All		↗ s	111	↗
	Ecosystem multifunctionality	Temperate forests**	All			16	↗
	Ecosystem multifunctionality	Tropical forests**	All			17	→
	Ecosystem multifunctionality	Grasslands**	All			55	→

*In grasslands and aquatic systems, distinguishing between biomass stocks and production is challenging, hence I pooled biomass stock and production BEF relationships in grasslands.
**These analyses rely on a subset of the data (and are therefore not independent) of the analysis on ecosystem multifunctionality across all ecosystem types.

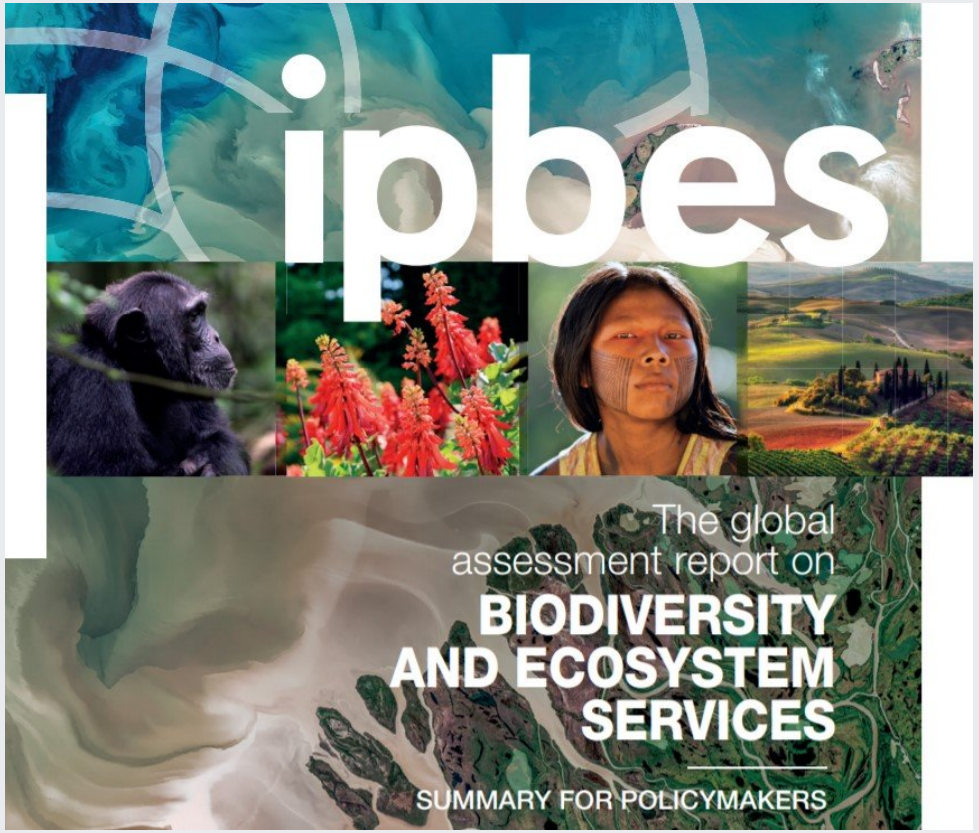
van der Plas 2019

B-EF and global change: Where are we headed?

We depend on EF for ecosystem services, but we're dramatically altering ecosystems...



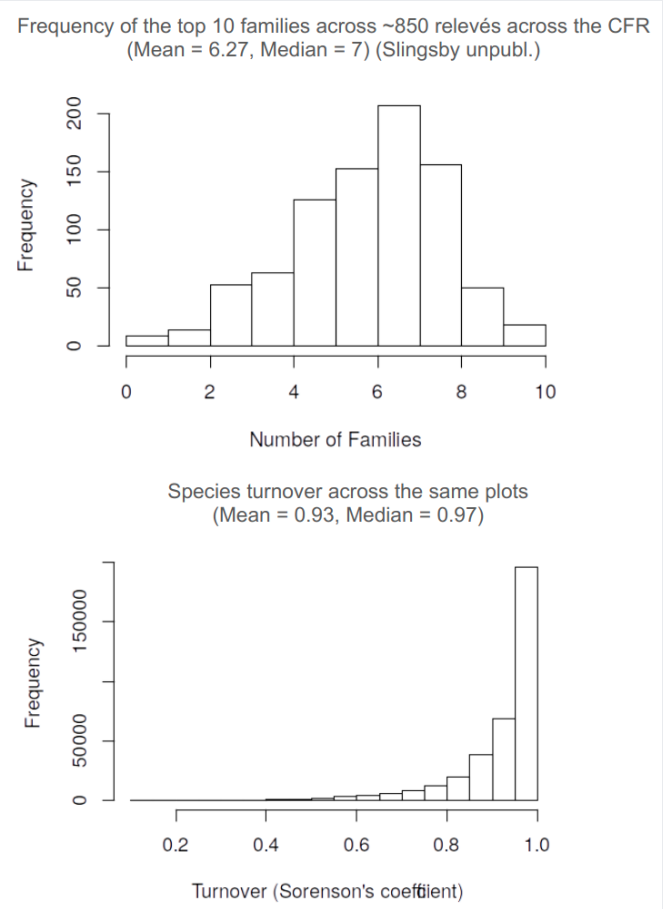
Hooper et al. 2005



https://ipbes.net/global-assessment

B-EF and global change: Response vs effect types?

- Fynbos is physiognomally and functionally similar across huge variation in climate, soils etc.
- This is largely because most lineages are dominated by the same 10 or so lineages.
- These species look similar, and have similar effects in the environment, but must be responding differently to occur in such different environments



B-EF and global change: Climate change

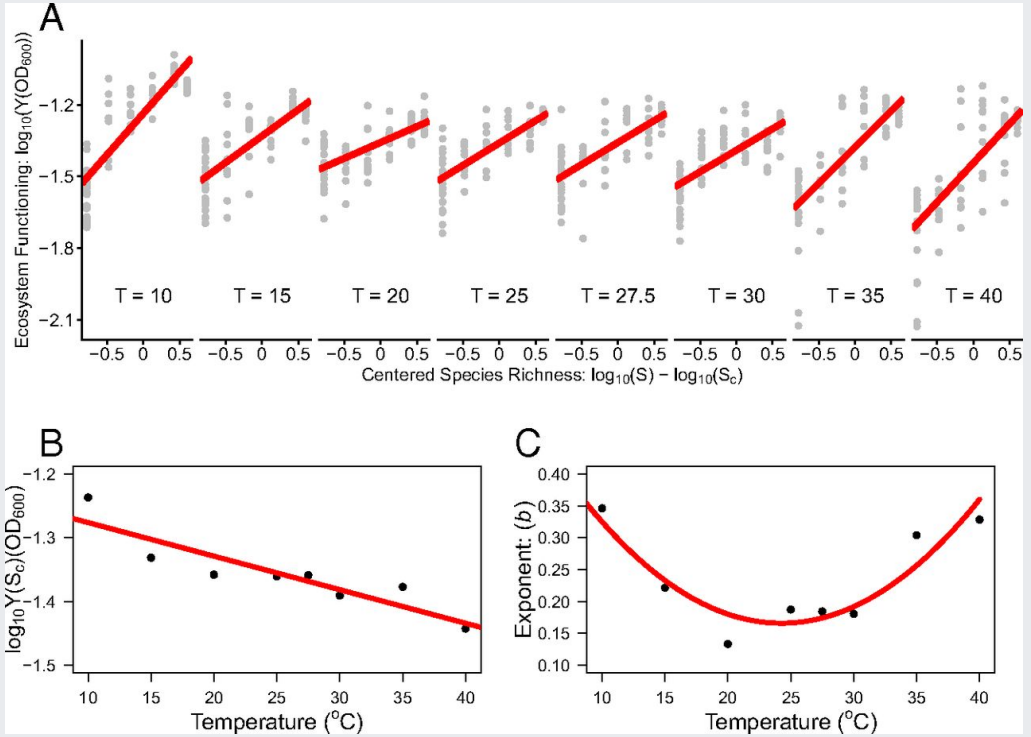
The jury is out, but here's one example from an experiment with microbial communities.

Results

↑ temperature = ↓ in the intercept of the B-EF relationship (panel B), but the slope hump-shaped, being highest at low and high temperatures.

Conclusion

\(\Delta\) temperature alters the B-EF relationship, & more species are required to maintain EF under thermal stress.



Garcia et al. 2018

B-EF and global change: Fragmentation

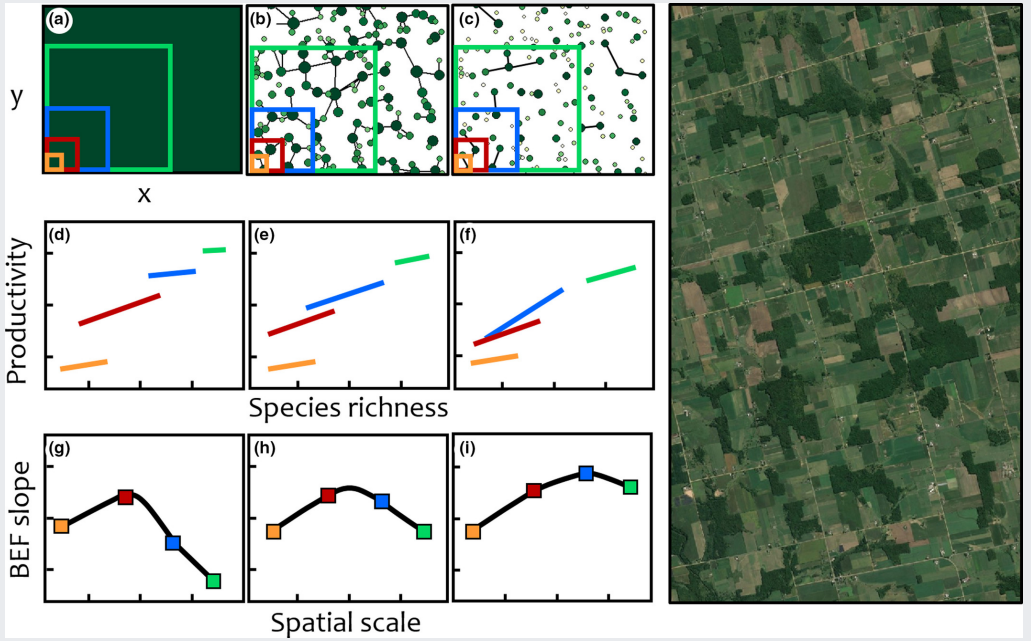
The jury is out, but here's a model simulation.

Results

↑ fragmentation = ↓ total landscape productivity, but stronger B-EF relationships at larger spatial scales (steeper slopes of blue lines in panels e and f)

Conclusion

Fragmentation is bad, but B-EF may actually compensate for some of the impacts



Gonzalez et al. 2020

B-EF and global change: Regime Shifts

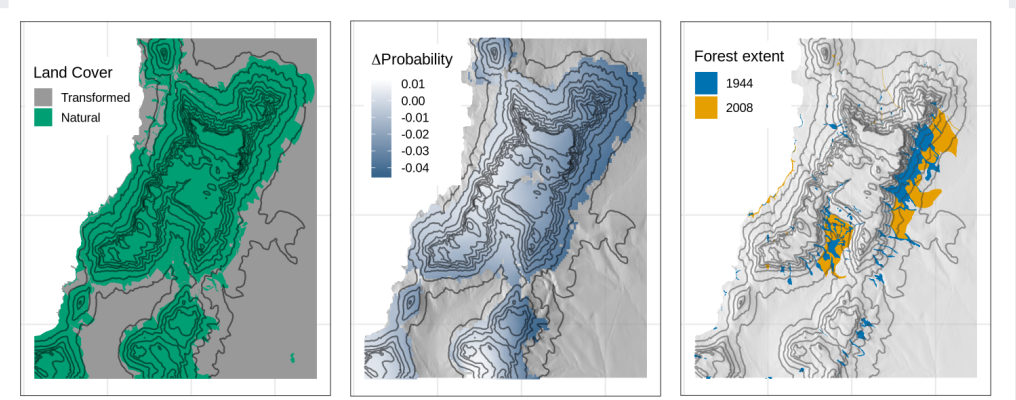
Alternative vegetation states can exist on the same abiotic template. They often contrast dramatically in various ecosystem functions (productivity, decomposition, habitat, etc).

They occur naturally, e.g.

- Open (Fynbos, grassland, savanna) vs closed (forest)

Or can be created unnaturally, e.g.

- Fynbos/grassland vs pine invasion
- Expansion of closed into open ecosystems (or vice versa)



Vegetation type	Historical extent	Forested by 1944	Forested by 2008	Intact in 2009
Cape Flats Dune Strandveld	41.089	0.168	0.173	17.818
Cape Flats Sand Fynbos	71.843	0.13	0.13	3.9
Cape Lowland Freshwater Wetlands	3.543	0	0	1.079
Hangklip Sand Fynbos	32.968	0.02	0.025	18.486
Peninsula Granite Fynbos[a]	92.274	2.096	4.339	34.803
Peninsula Sandstone Fynbos[a]	219.467	1.273	1.777	208.907
Peninsula Shale Fynbos[a]	12.634	0.233	1.435	5.172
Peninsula Shale Renosterveld[a]	21.583	0	0.004	2.761
Southern Afrotemperate Forest	3.447	–	–	3.445[b]

Slingsby et al. 2020

Take-home

Community assembly, ecosystem function and global change are intricately linked!!!

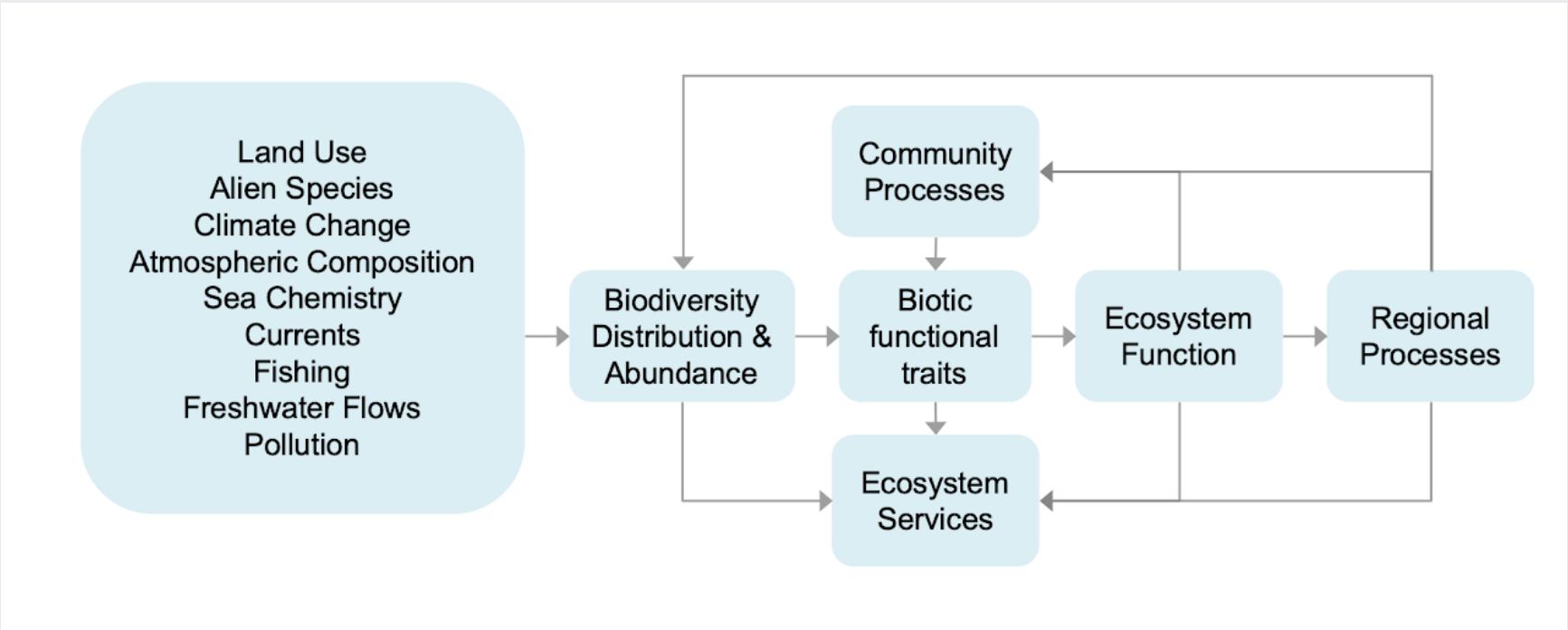


Figure modified from Chapin et al. 1997, *Science*

References

Gotelli, N. J. and R. K. Colwell (2001). "Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness". In: *Ecology letters* 4.4, pp. 379-391. ISSN: 1461-023X, 1461-0248. DOI: 10.1046/j.1461-0248.2001.00230.x.

Slingsby, J. A., C. Merow, M. Aiello-Lammens, et al. (2017). "Intensifying postfire weather and biological invasion drive species loss in a Mediterranean-type biodiversity hotspot". En. In: *Proceedings of the National Academy of Sciences of the United States of America* 114.18, pp. 4697-4702. ISSN: 0027-8424, 1091-6490. DOI: 10.1073/pnas.1619014114.

Whittaker, R. H. (1972). "Evolution and measurement of species diversity". En. In: *Taxon* 21.2-3, pp. 213-251. ISSN: 0040-0262, 1996-8175. DOI: 10.2307/1218190.

Thanks!

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