ReNature

Promoting research excellence in nature-based solutions for innovation, sustainable economic growth and human well-being in Malta.

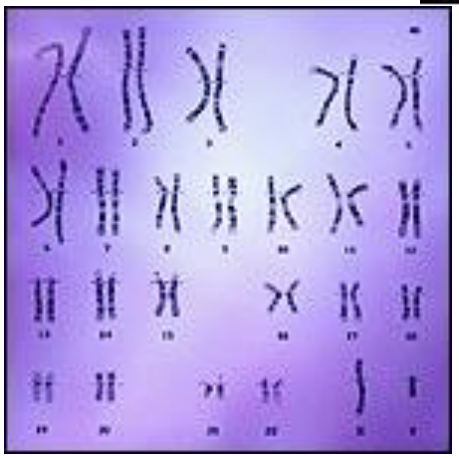
The ecological foundations: biodiversity and its relationship to ecological function

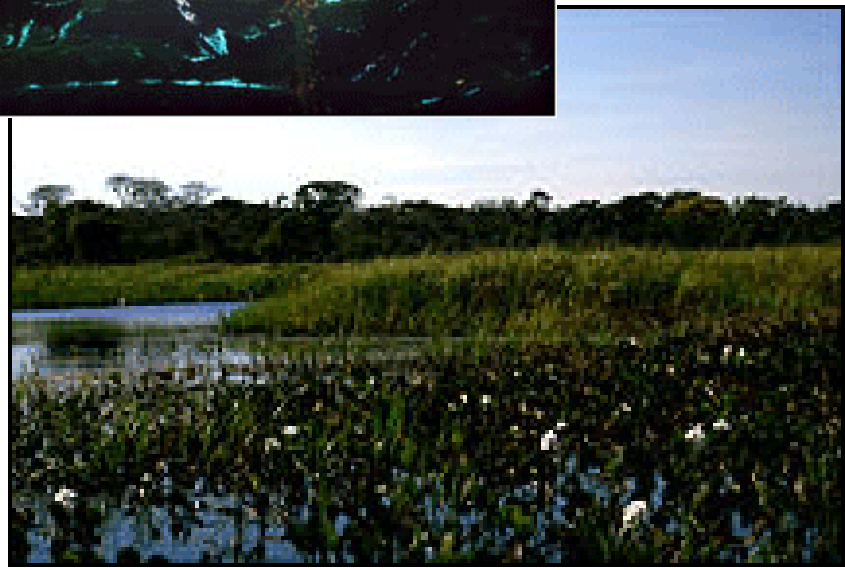
Dr Lynn Dicks, Dr Mario Balzan

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 809988.

Biodiversity is:

the variety of life on Earth at all its levels, from genes to ecosystems, and the ecological and evolutionary processes that sustain it.





Species diversity vs. richness

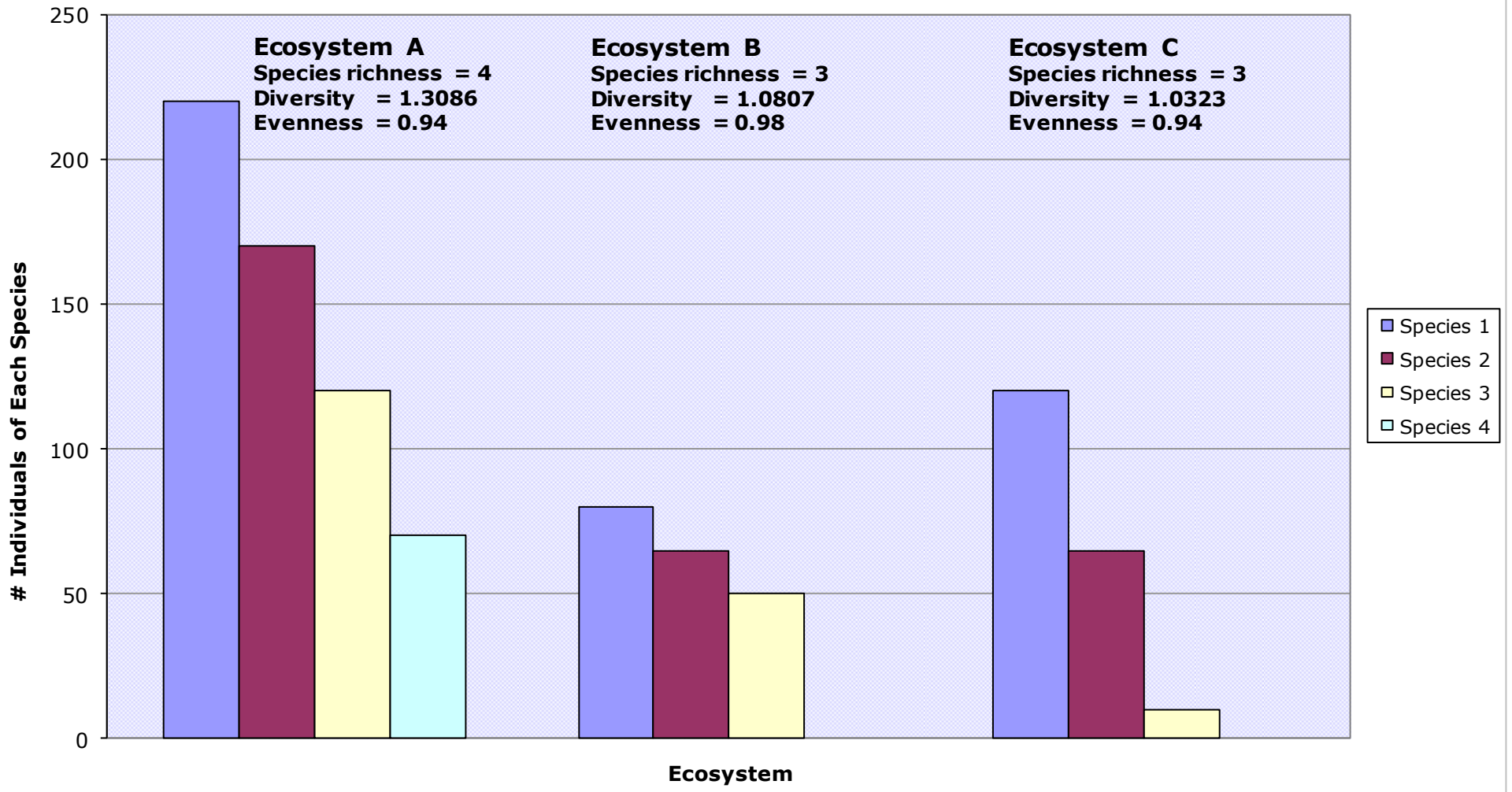
- **Species richness**: the number of species present in a given area
- **Species diversity**: species number weighted by measure of importance, such as abundance, productivity or size

Shannon's diversity index *(H)* = $-\sum \rho i \ ln \ \rho i$

ρi *is the proportion of the total number of specimens of species i expressed as a proportion of the total number of specimens for all species in the ecosystem.*

Many people use the term "species diversity" when they mean species richness

RICHNESS vs. EVENNESS



Adapted from: Hunter, M. Jr. 2002. Fundamentals of Conservation Biology. Second Edition. Blackwell Science, Massachusetts, U.S.A.

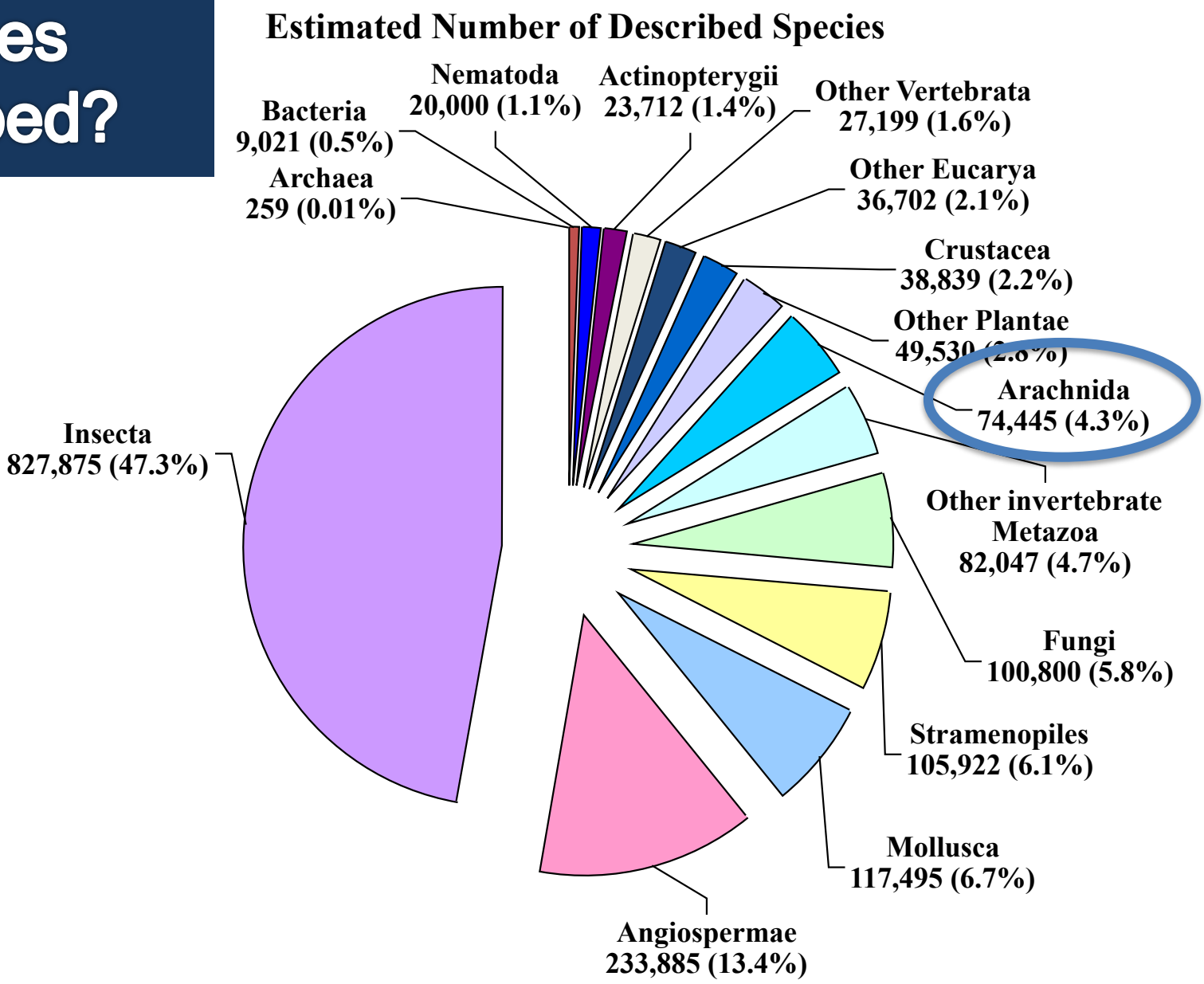
An extraordinary number

- So far, about 1.9 million species have been described.
- Scientists estimate that there may be between 3 and 100 million species.
- Most estimates range between 13-20 million

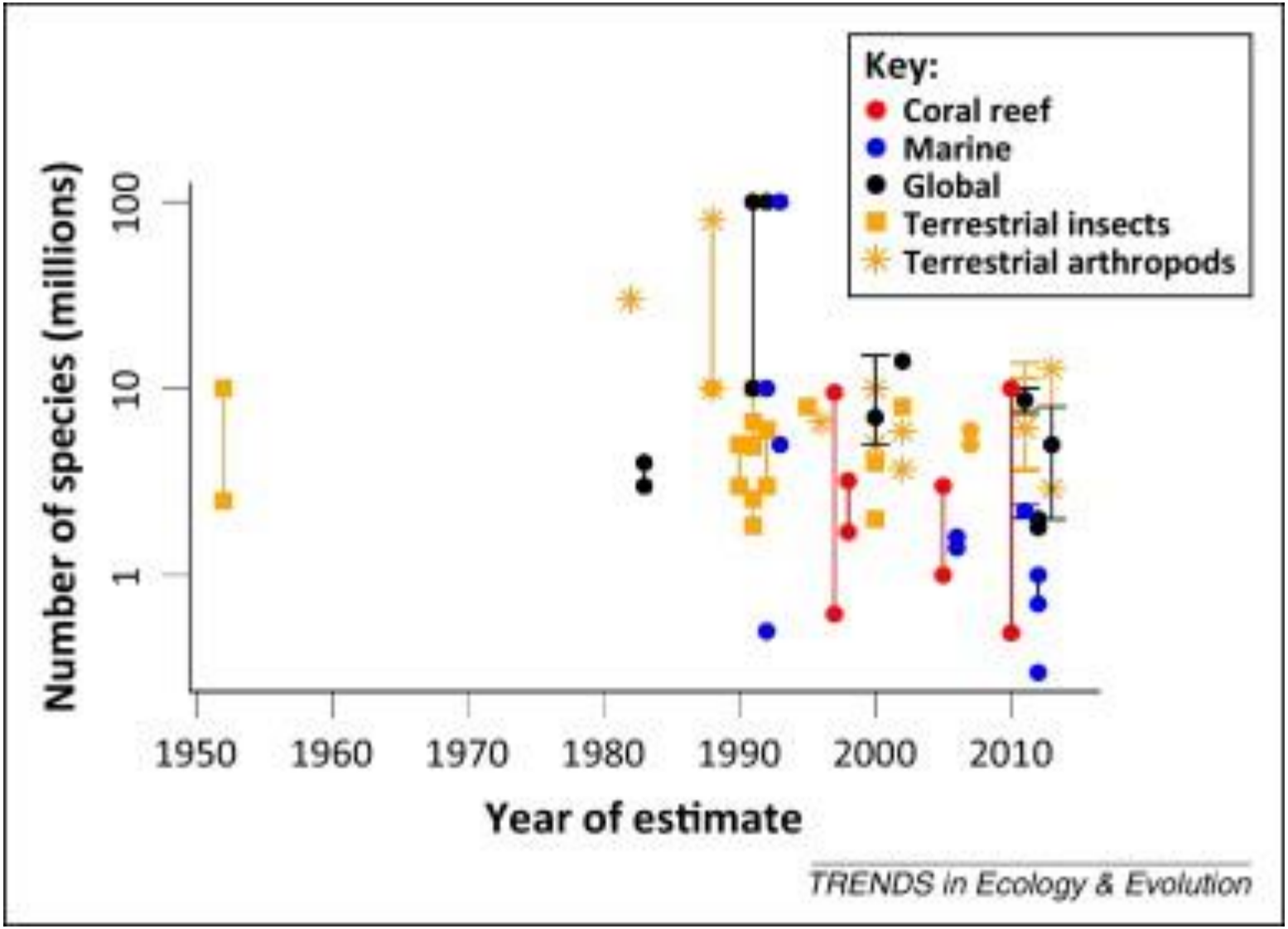
Spector ©AMNH-CBC

Cone head katydid

How many species described?



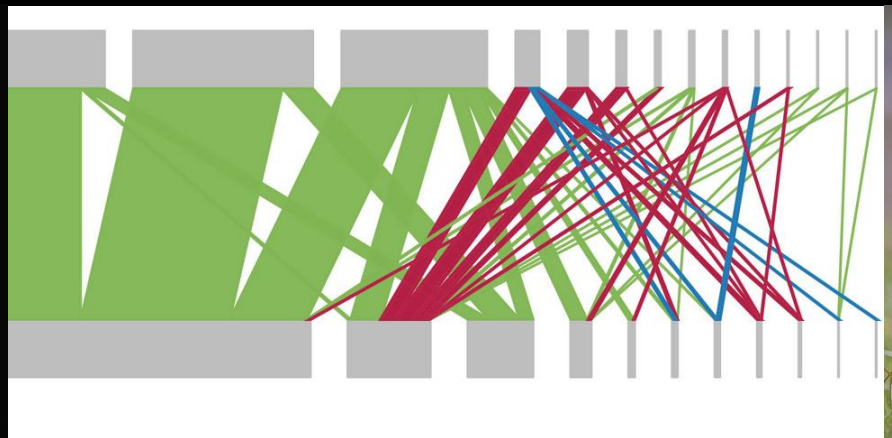
How many species altogether?



Source: Caley *et al.* (2014) Global species richness estimates have not converged. *TREE*, 29, 187-188

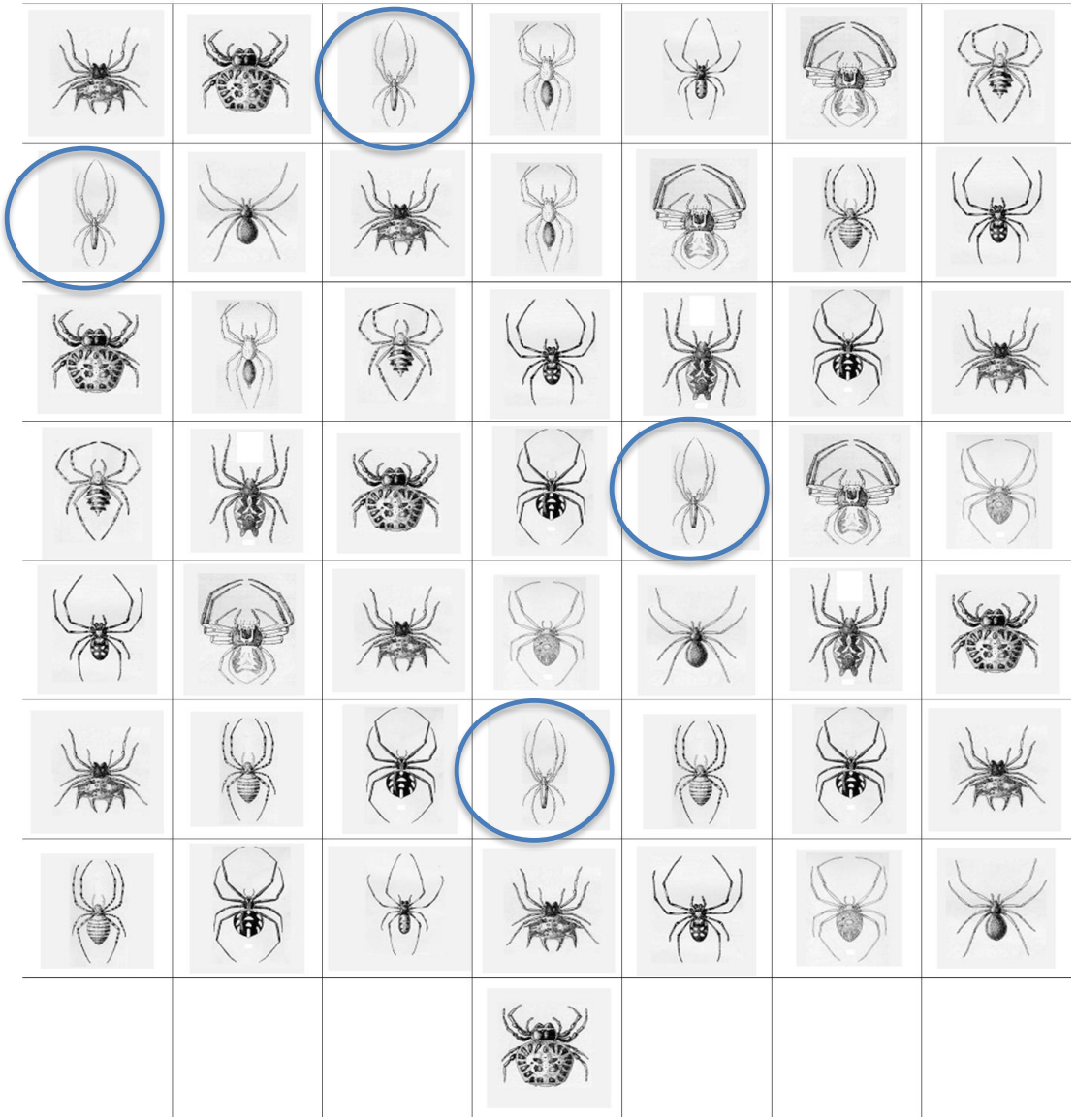
Species are not isolated entities.
They interact, relying on each other in complex webs

Ecology is the study of **how** species interact, **how** communities function



Measuring biodiversity

Site 1



What is biodiversity? A comparison of spider communities

1. Sort and classify a spider sample from one site

2. Assess the comprehensiveness of the sample
   - Draw a species accumulation curve

3. Compare diversity and species composition across five sites
   - Simpson diversity index
   - Number of endemics
   - Jaccard coefficient of community similarity

ReNature

- **354 individual trees** in ~1 ha of urban green space
- **16 species** in total

A
Tree
Casuarina equisetifolia
Cupressus semperivens
Austrocylindropuntia subulata
Cupressus semperivens
Cupressus semperivens
Cupressus semperivens
Cupressus semperivens
Punica granatum
Acacia saligna
Punica granatum
Cupressus semperivens
Punica granatum
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Cupressus semperivens
Cupressus semperivens

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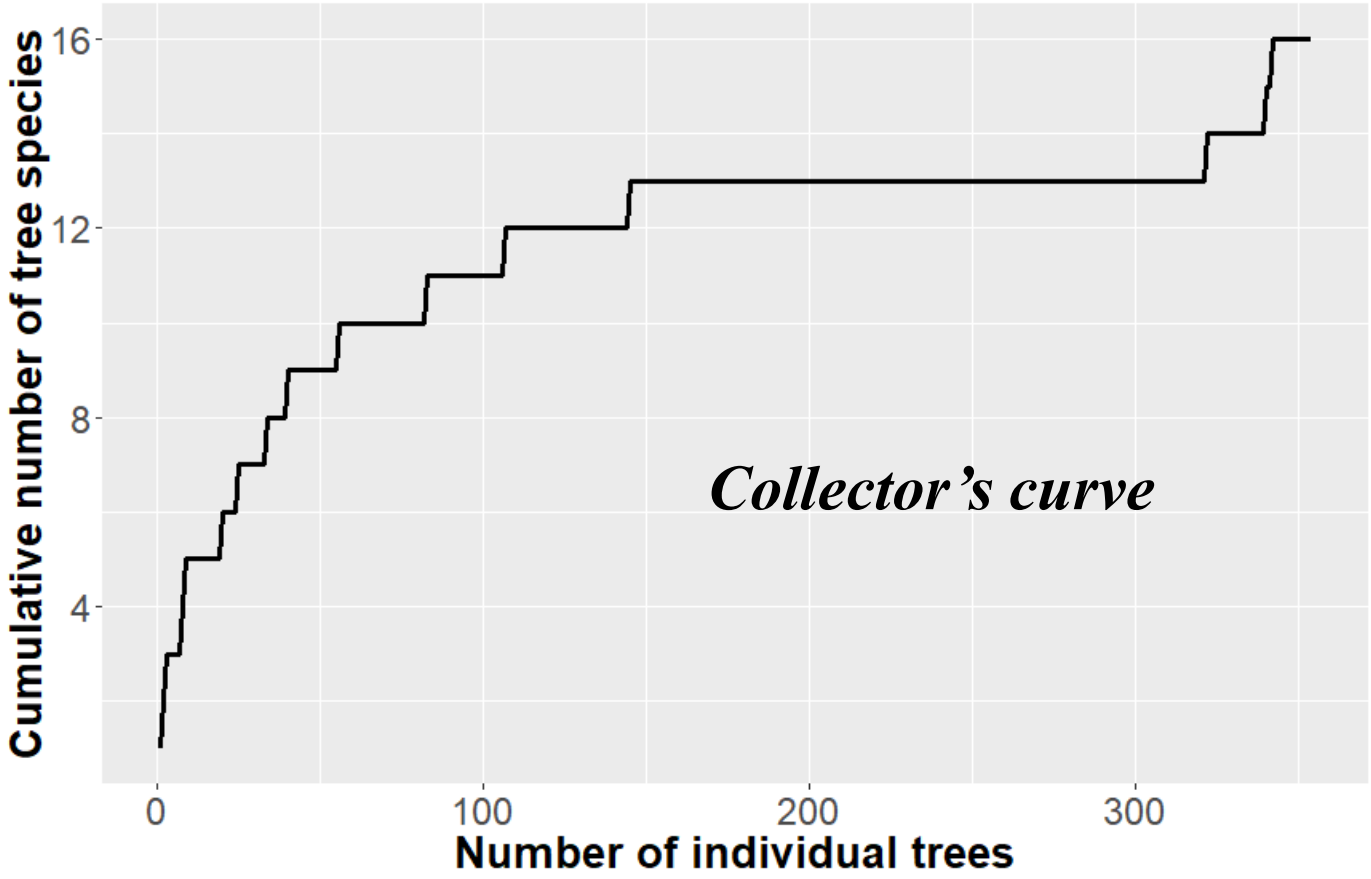

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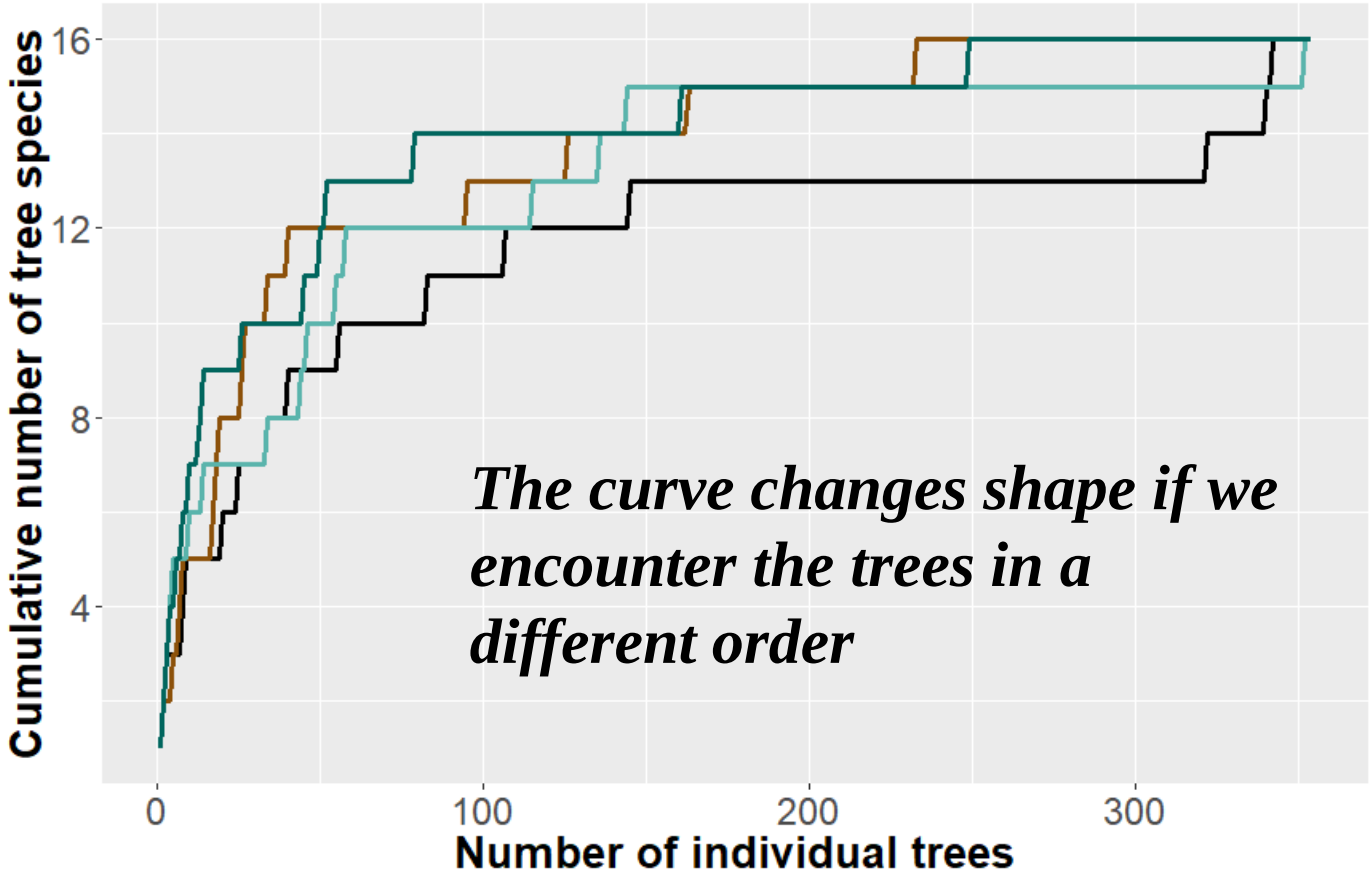
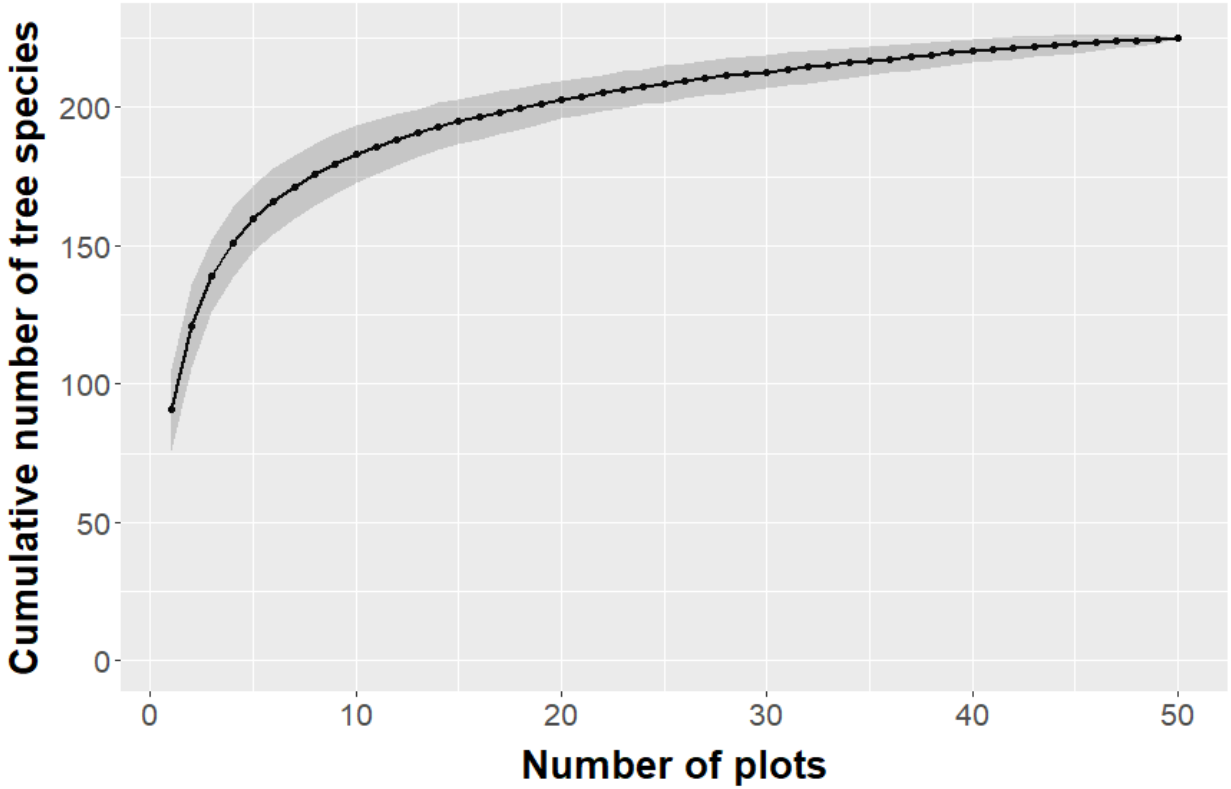


ReNature

*>**50,000 individual trees** in 50 x 1 ha of plots of tropical rainforest on Barro Colorado Island, Panama*

***225 species** in total*

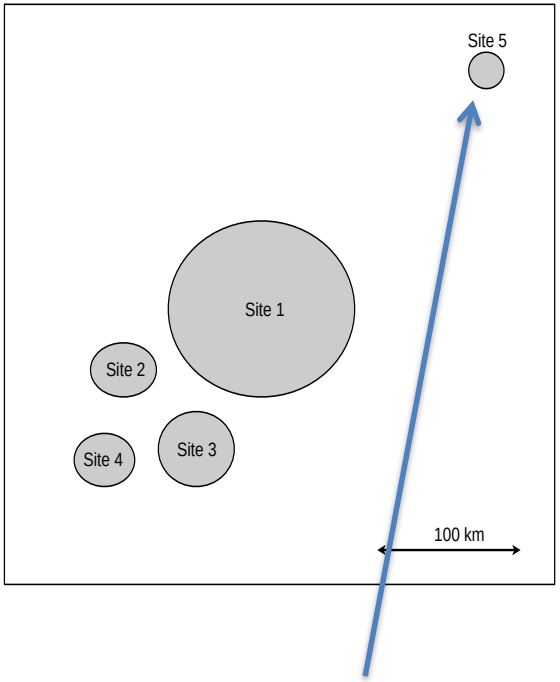


Data source: Pyke et al. (2001) Floristic composition across a climatic gradient in a neotropical lowland forest. Journal of Vegetation Science, 12: 553-566.

A comparison of spider communities

SIMILARITY MATRIX	Site 1	Site 2	Site 3	Site 4	Site 5
Site 1					
Site 2	0.47				
Site 3	0.47	1.00			
Site 4	0.12	0.15	0.15		
Site 5	0.12	0.15	0.15	0.09	

Richness	13	9	9	6	6
Diversity	11.79	8.62	1.48	5.32	5.95
# Endemics	5	0	0	4	3



Ladybird spider *Eresus kollari*

Eresidae
Velvet spiders
100 species in
the world

What is Biodiversity?

prepared by I.J. Harrison, N. Bynum, G. Cullman, J.P Gibbs, M.F. Laverty, A.L. Porzecanski and E.J. Sterling

Adapted by L.V. Dicks for ReNature Training Course, Trento, Italy, February 2020

This material is based on work supported by the National Science Foundation under the Course, Curriculum and Laboratory Improvement program (NSF 0127506), and the United States Fish and Wildlife Service (Grant Agreement No. 98210-1-G017).

Any opinions, findings and conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the American Museum of Natural History, the National Science Foundation, or the United States Fish and Wildlife Service.

Acknowledgements

Mac Hunter (University of Maine), Raoul Bain, Kevin Koy, Ned Horning, Ho-Ling Poon, and Armistead Booker (American Museum of Natural History) provided assistance for production of images and accompanying text

Pictures from Wikimedia commons: "A taxonomist at work“/ Fitryamandita; Cape Fynbos 1/Chris Eason. American avocet/Kevin Cole; Ladybird spider/Fritz Geller-Grimm

This is a product of the Network of Conservation Educators and Practitioners (NCEP)
http://ncep.amnh.org

Biodiversity and ecosystem functioning

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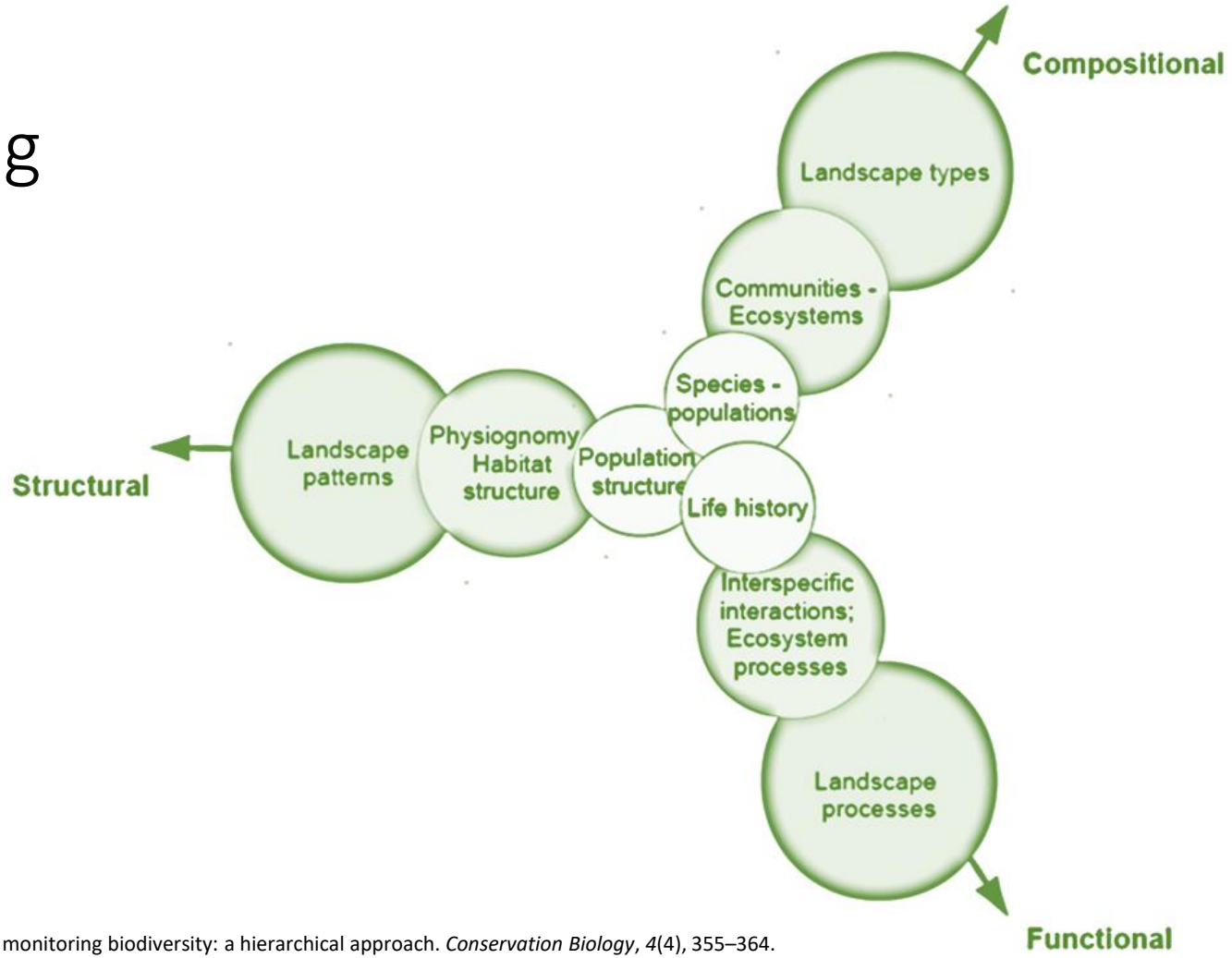
This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 809988.

Characterising biodiversity

- Ecosystems can be characterised in terms of three attributes: composition, structure and function.
- These 3 attributes are interrelated at different spatio-temporal levels of organization going from the genetic to the landscape level.
- Different levels of this hierarchy becoming appropriate when answering different ecological questions

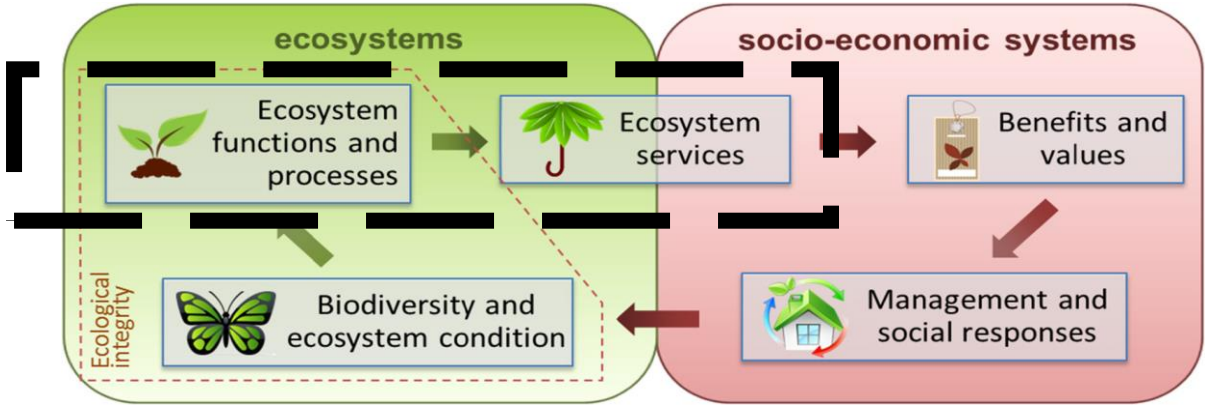


Adapted from Noss, R. F. (1990). Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, *4*(4), 355–364.

Ecosystem Functions

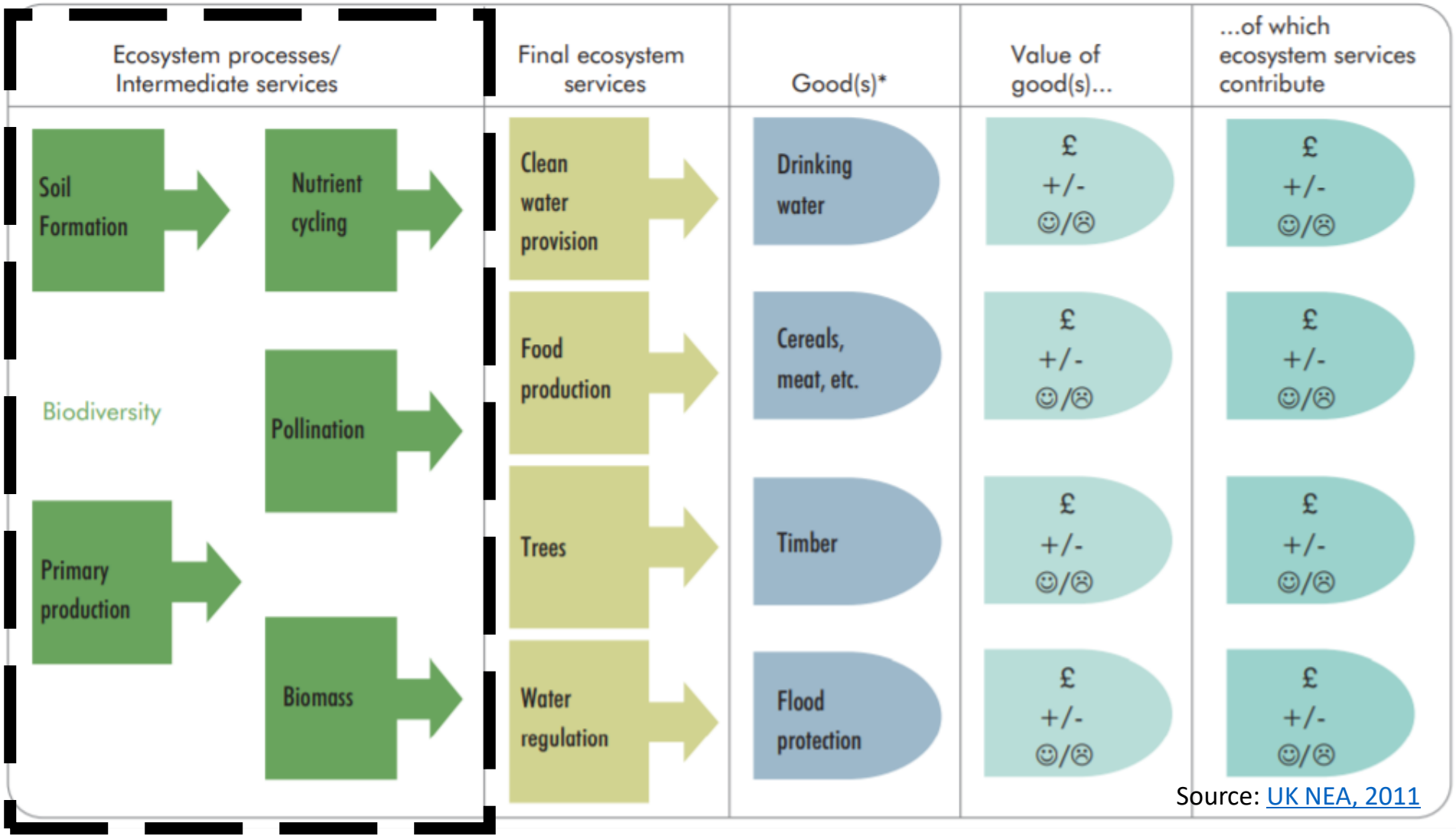
- By functional characteristics, or the 'functioning' of ecosystems, we mean the processes or properties of ecosystems that are influenced by its biota (Naeem, 2002)
- Ecosystem functions are ecological processes that control the fluxes of energy, nutrients and organic matter through an environment.
- Examples include: primary production, nutrient cycling, decomposition (Cardinale et al., 2012)

Ecosystem function-service relationship



- **Ecosystem functions** sustain the provision of specific ecosystem services thus indicating the natural capacity to provide that service.
- **Ecosystem services** are the actual contribution of ecosystem components (as goods or services) to human well-being.

Adapted from Liquete, C., Cid, N., Lanzanova, D., Grizzetti, B., & Reynaud, A. (2016). Perspectives on the link between ecosystem services and biodiversity: The assessment of the nursery function. *Ecological Indicators*, *63*, 249–257.



Source: UK NEA, 2011

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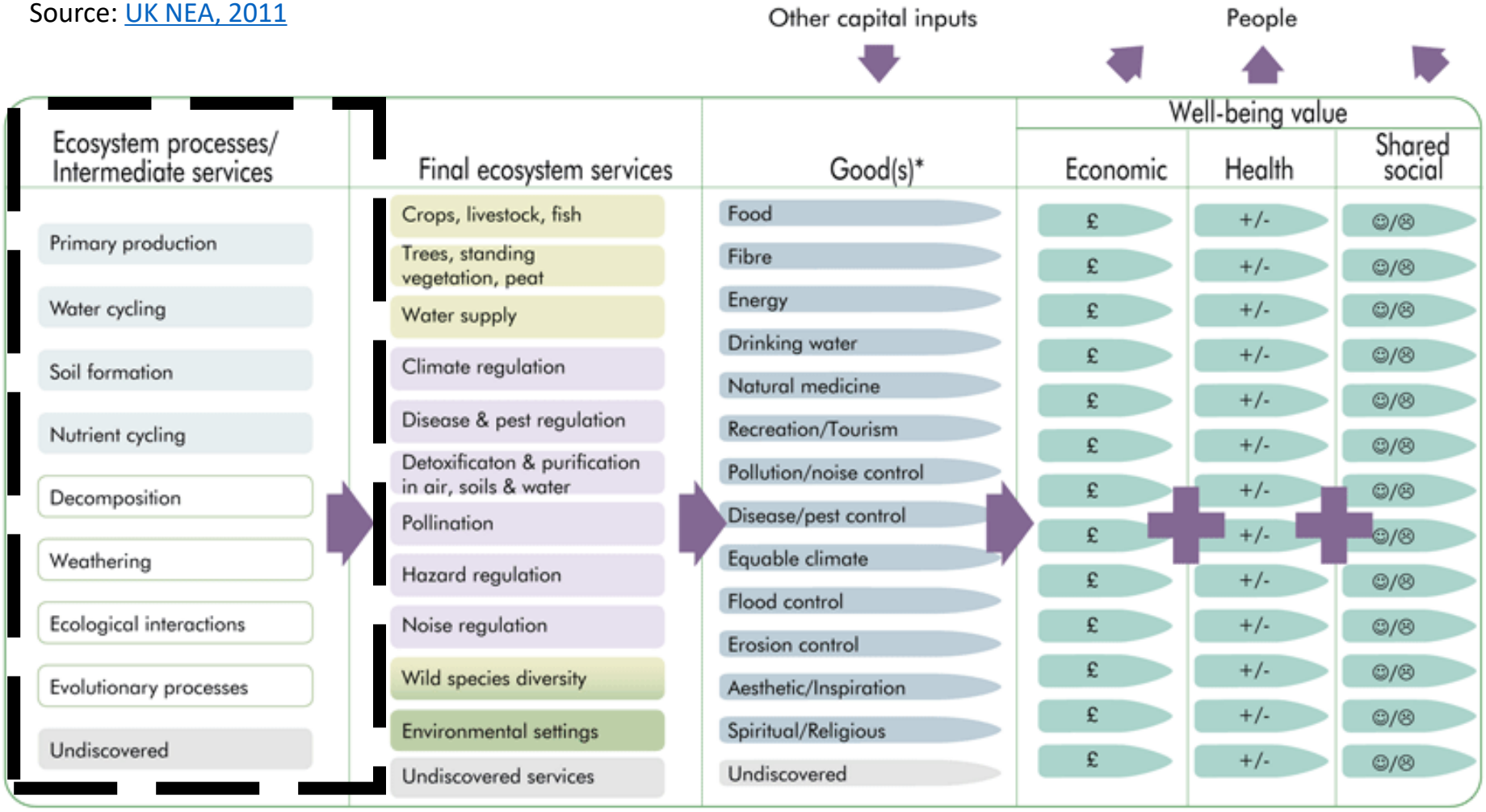
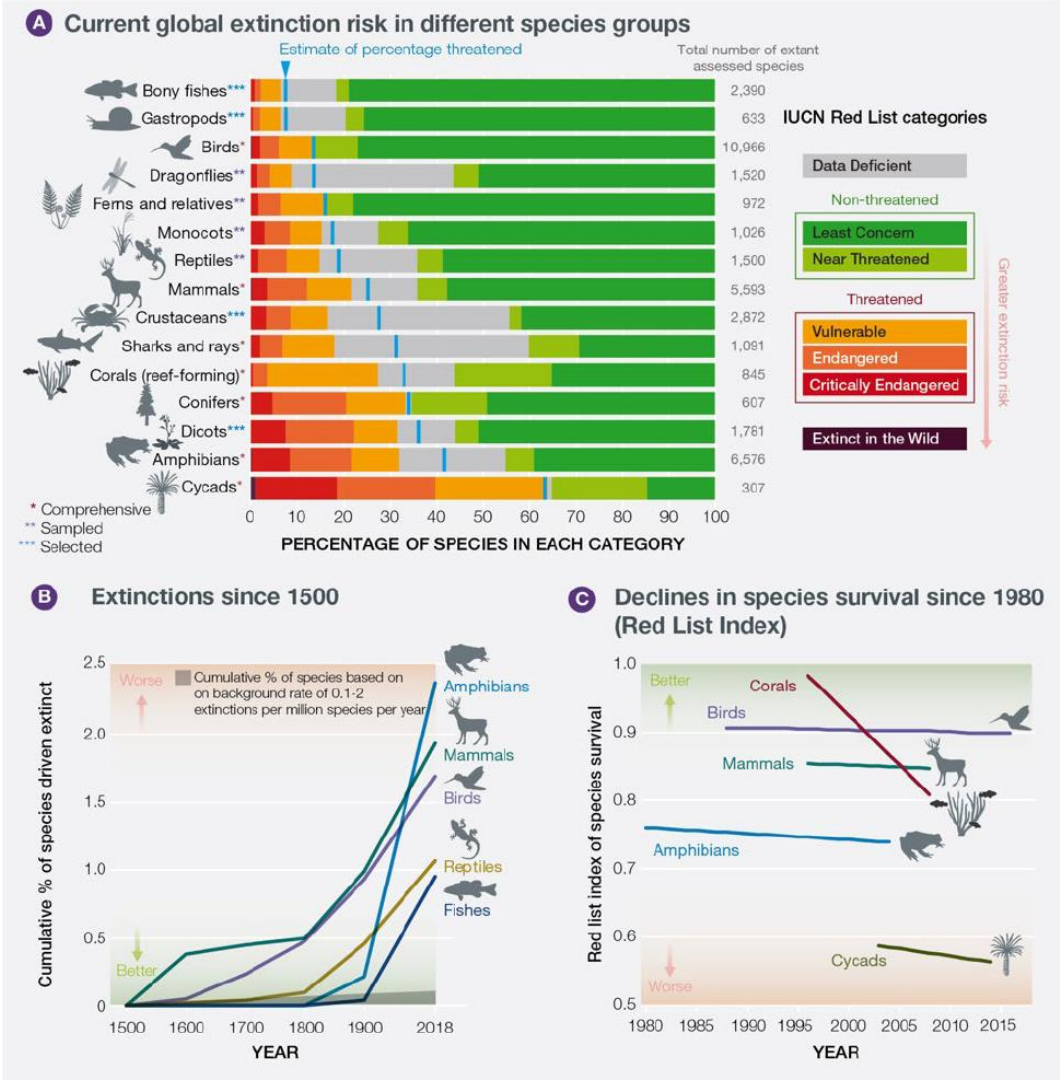


What is the impact of biodiversity loss on ecosystem functioning?

Infographic showing IPBES global assessment report (Source: [EC Science Hub, 2019](#))



Do species matter?

Does increased biodiversity translate into improved ecosystem functioning?

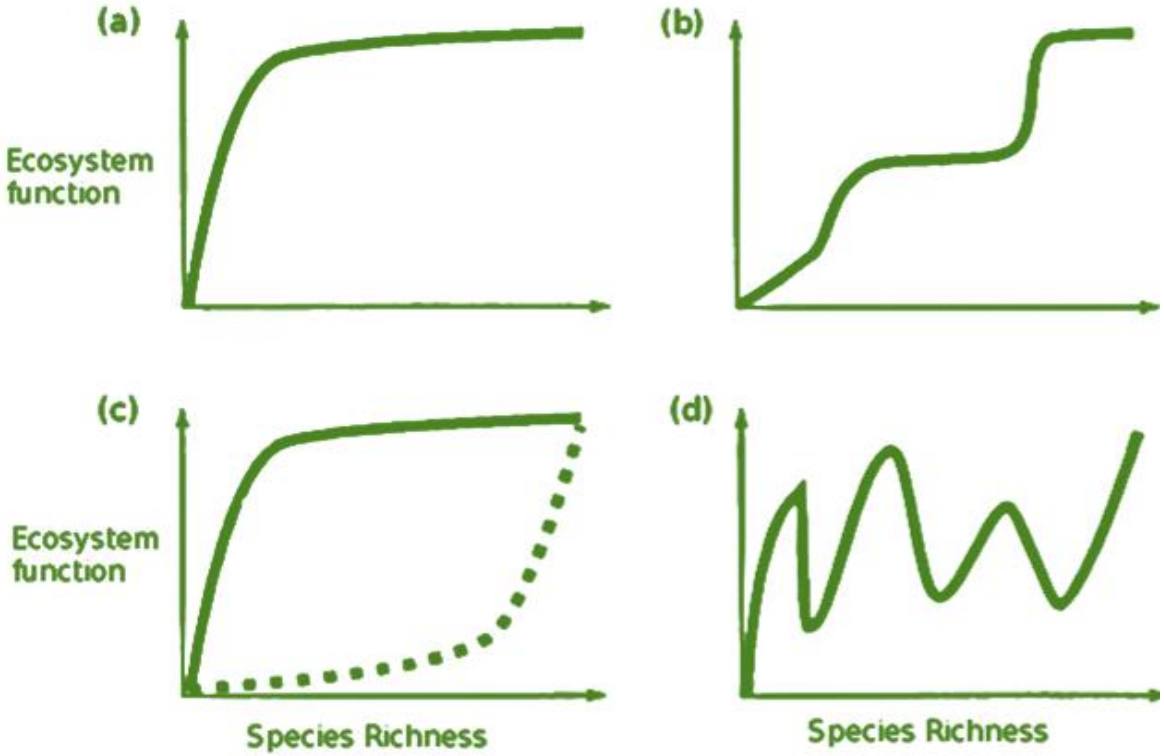
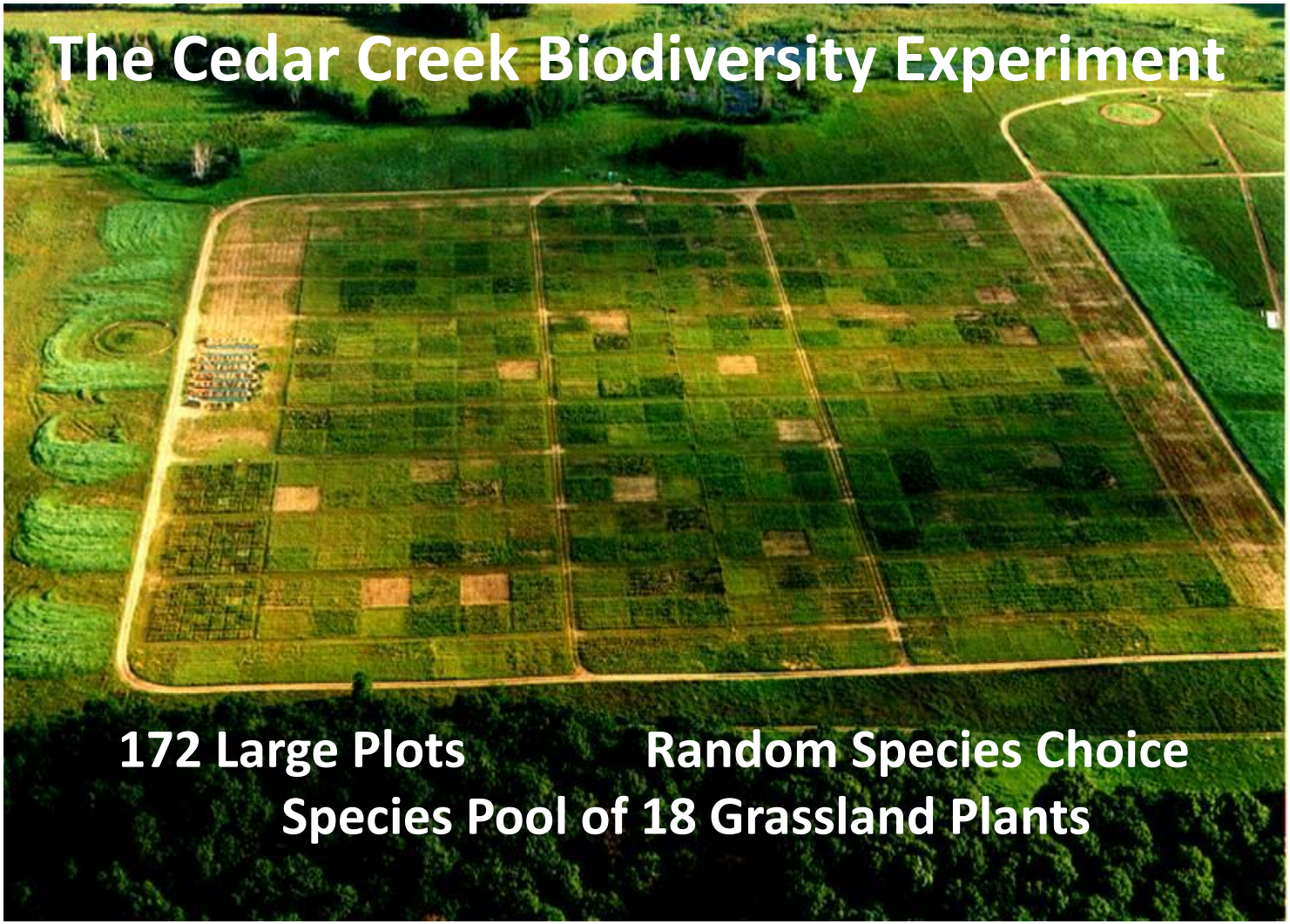
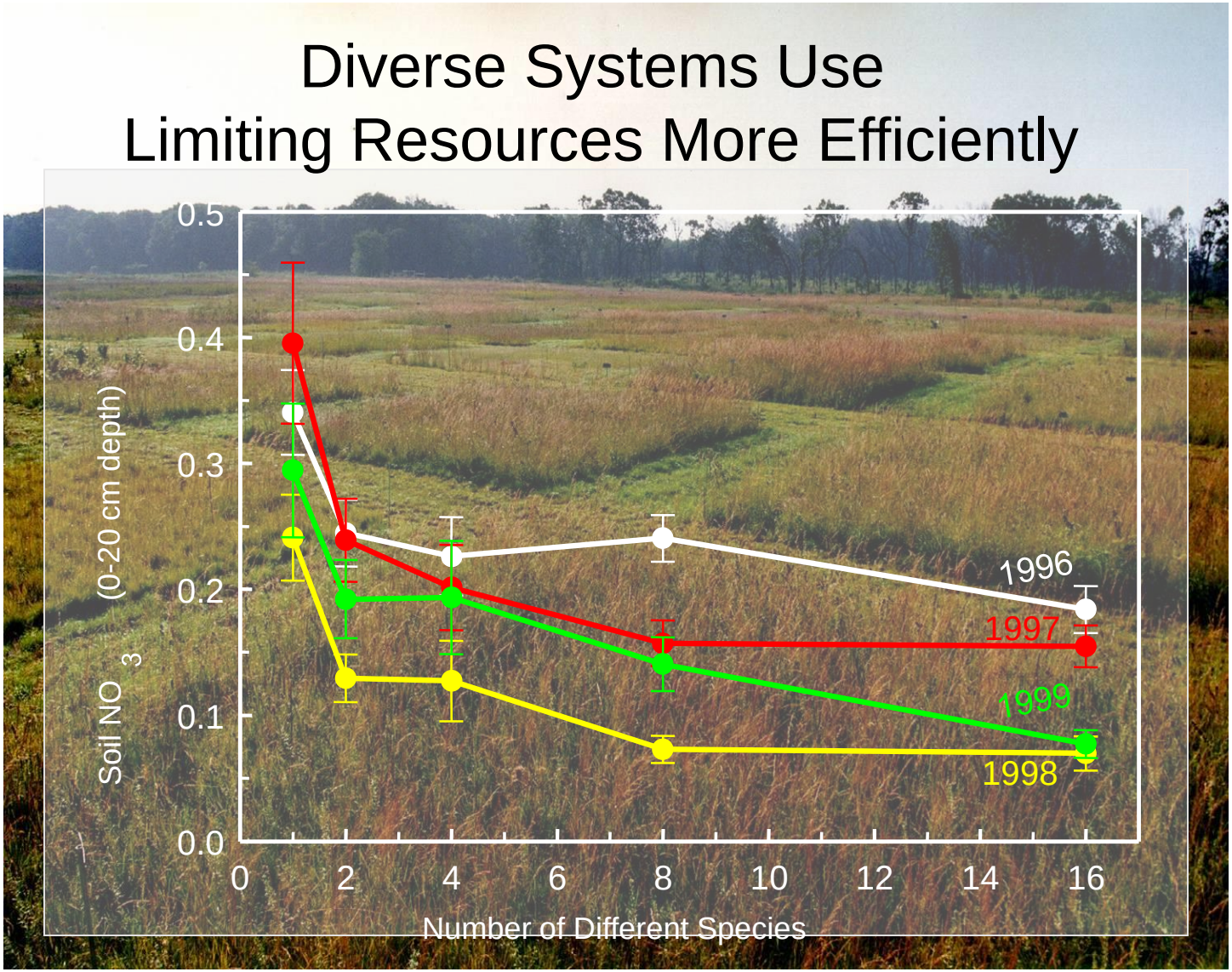


Diagram showing a grahical representation of early hypothetical relationships between biodiversity and ecosystem processes >



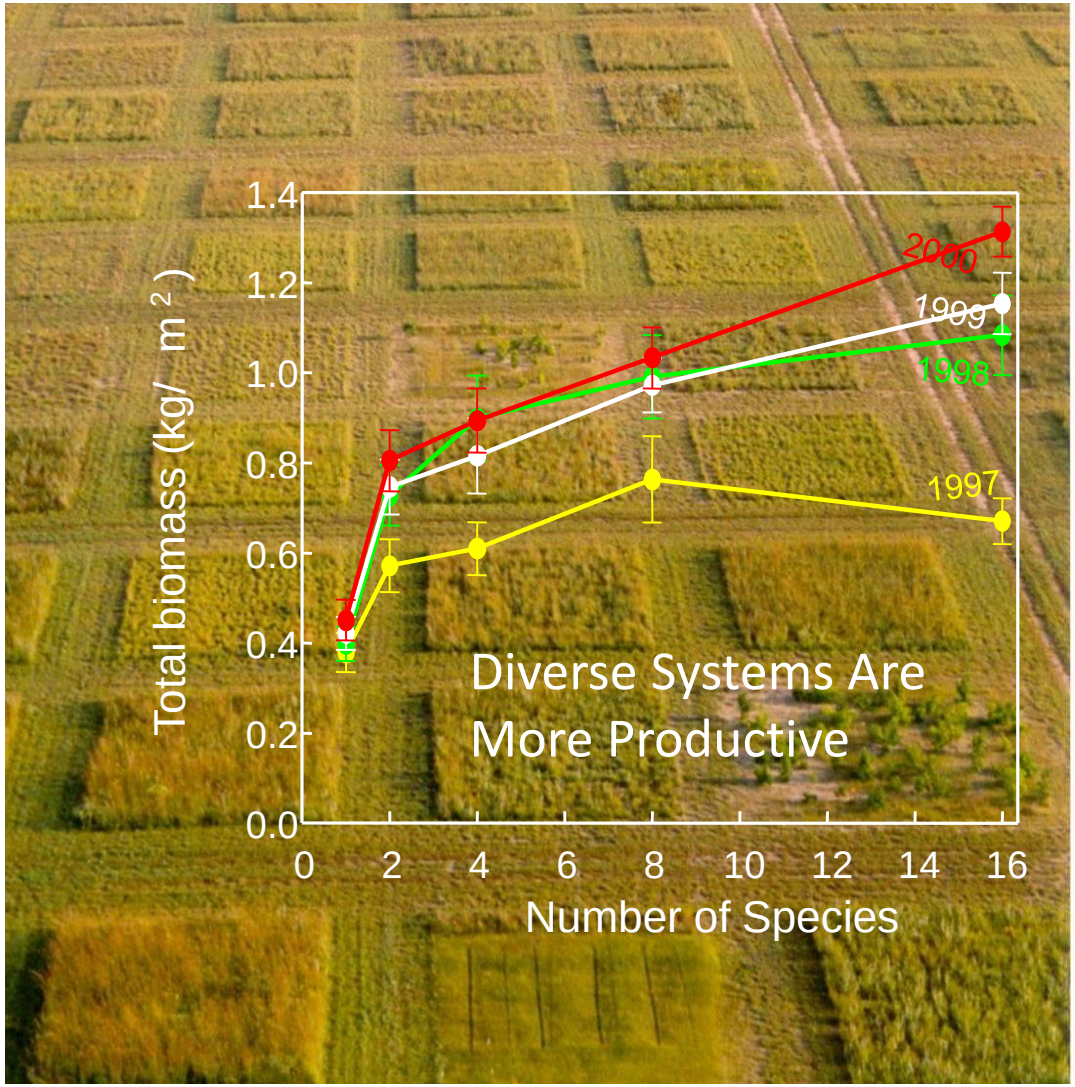
Tilman (2003) Ecosystem services and life on a human-dominated earth. The Challenges and Opportunities ahead.

Diverse Systems Use Limiting Resources More Efficiently



Tilman (2003) Ecosystem services and life on a human-dominated earth. The Challenges and Opportunities ahead.

- Ecosystem biodiversity enhances productivity, nutrient use efficiency
- Greater diversity leads to greater ecosystem stability and predictability
- Greater diversity leads to less disease
- The quality and quantity of ecosystem services depends on the diversity and composition of managed and natural ecosystems

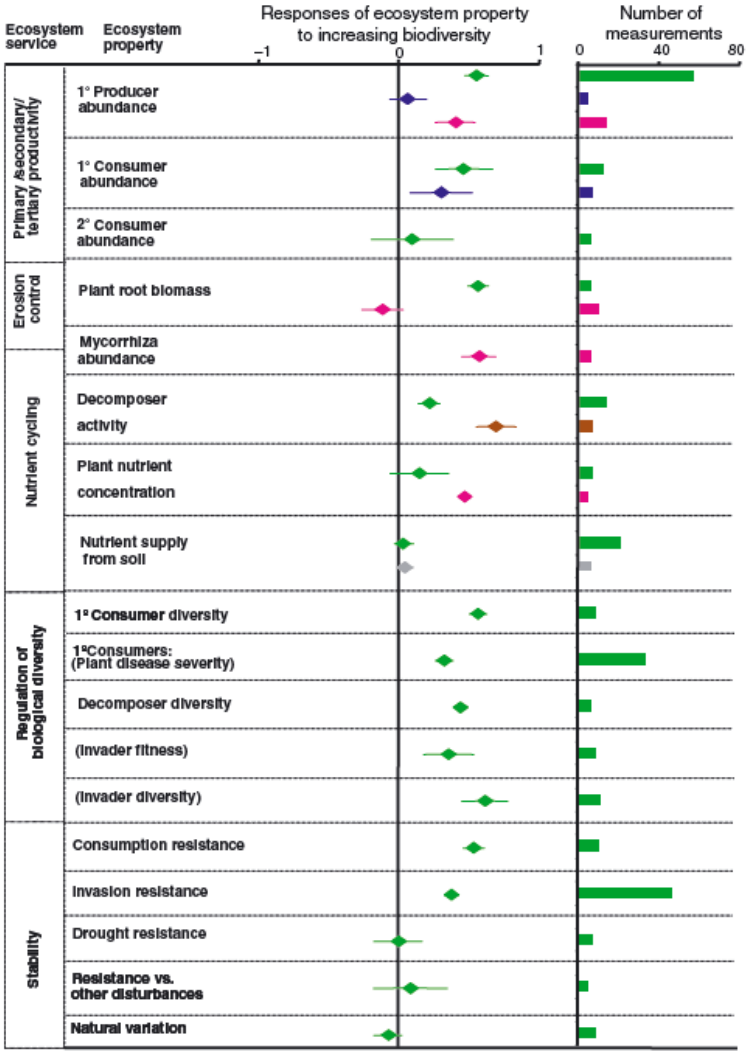


What is the impact of (functional) biodiversity on ecosystem services?

- Several studies indicating that biodiversity contributes to increased ecosystem service delivery (e.g. Balvanera et al. 2006).

Balvanera, P., Pfisterer, A. B., Buchmann, N., He, J.-S., Nakashizuka, T., Raffaelli, D., & Schmid, B. (2006). Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters*, *9*(10), 1146–1156. https://doi.org/10.1111/j.1461-0248.2006.00963.x

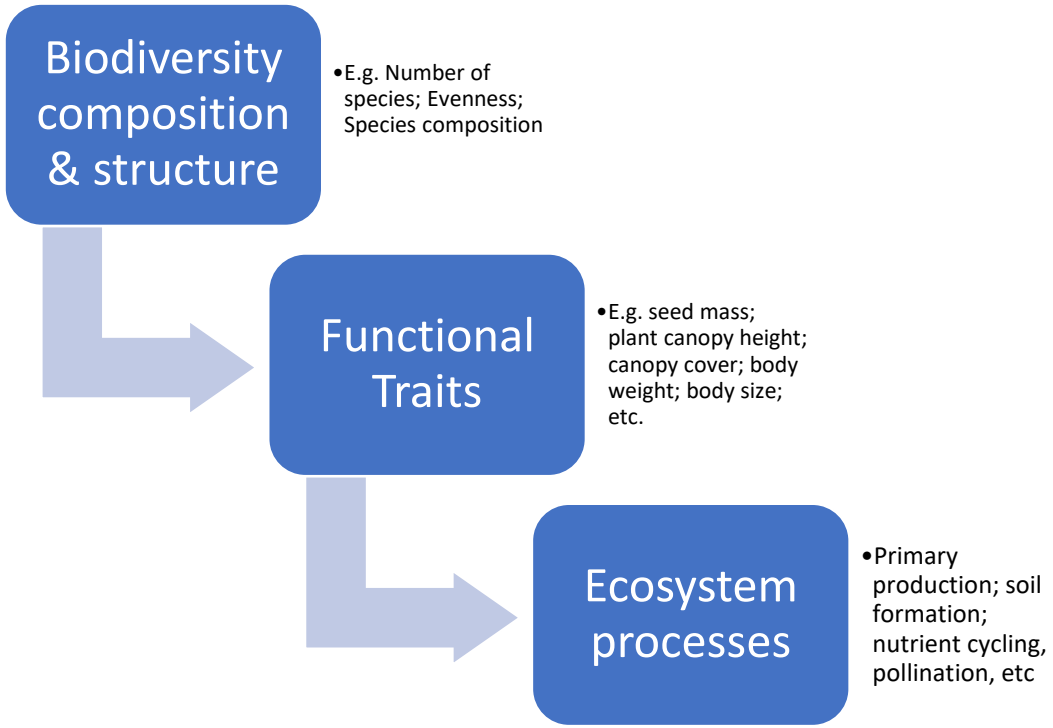
3 Magnitude and direction of biodi- effects (shown are mean values and normalized effect sizes Z_r, weighted reciprocal of the variance of the ual Z_r-values) and number of meas- its available for ecosystem properties zed into ecosystem services. Coloured ow differential effects of trophic level lated: green, primary producers; blue, y consumers; pink, mycorrhiza; , decomposer; grey, multitrophic le levels simultaneously manipulated). tem properties shown in parentheses onsidered of negative value for human ing, and thus opposite of effect sizes own.



Functional traits

Functional trait: a characteristic of an organism, which has demonstrable links to the organism's function.

A functional trait determines the organism's response to pressures (*response trait*), and its effects on ecosystem processes or services (*effect trait*).

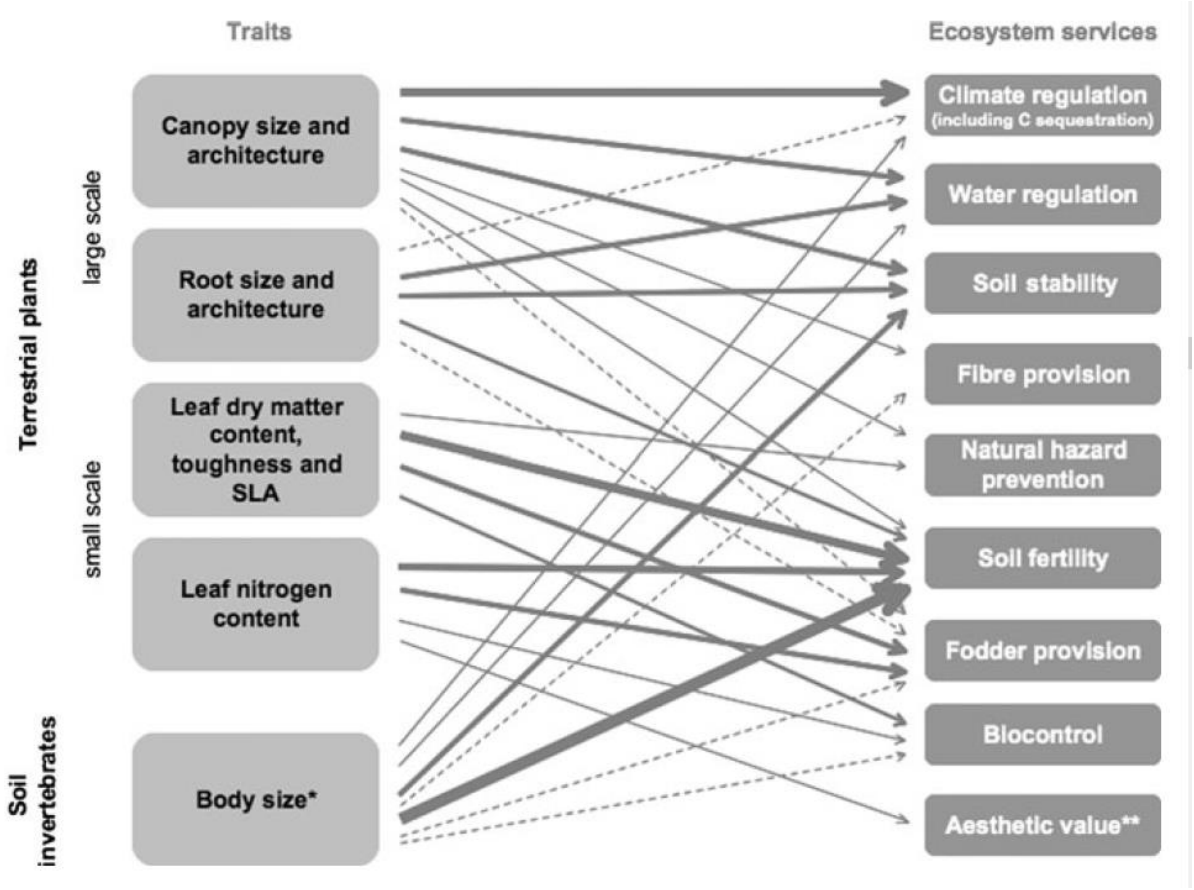


Structure-function relationships plants: plant functional traits

Function	Functional trait
Fecundity Dispersal Establishment	Seed mass
Light interception Competitive ability	Plant canopy height
Resorption of nutrients; decomposability of litter	Traits of living leaves NIRS spectrum
Absorption (nutrients, water) Carbon fluxes (exsudation…)	Density, diameter Specific root length

Source: Lavorel et al. Using plant functional traits to understand the landscape distribution of multiple ecosystem services

Most commonly reported plant and invertebrate traits and their involvement in multiple ecosystem service delivery: most services are underpinned by multiple traits.

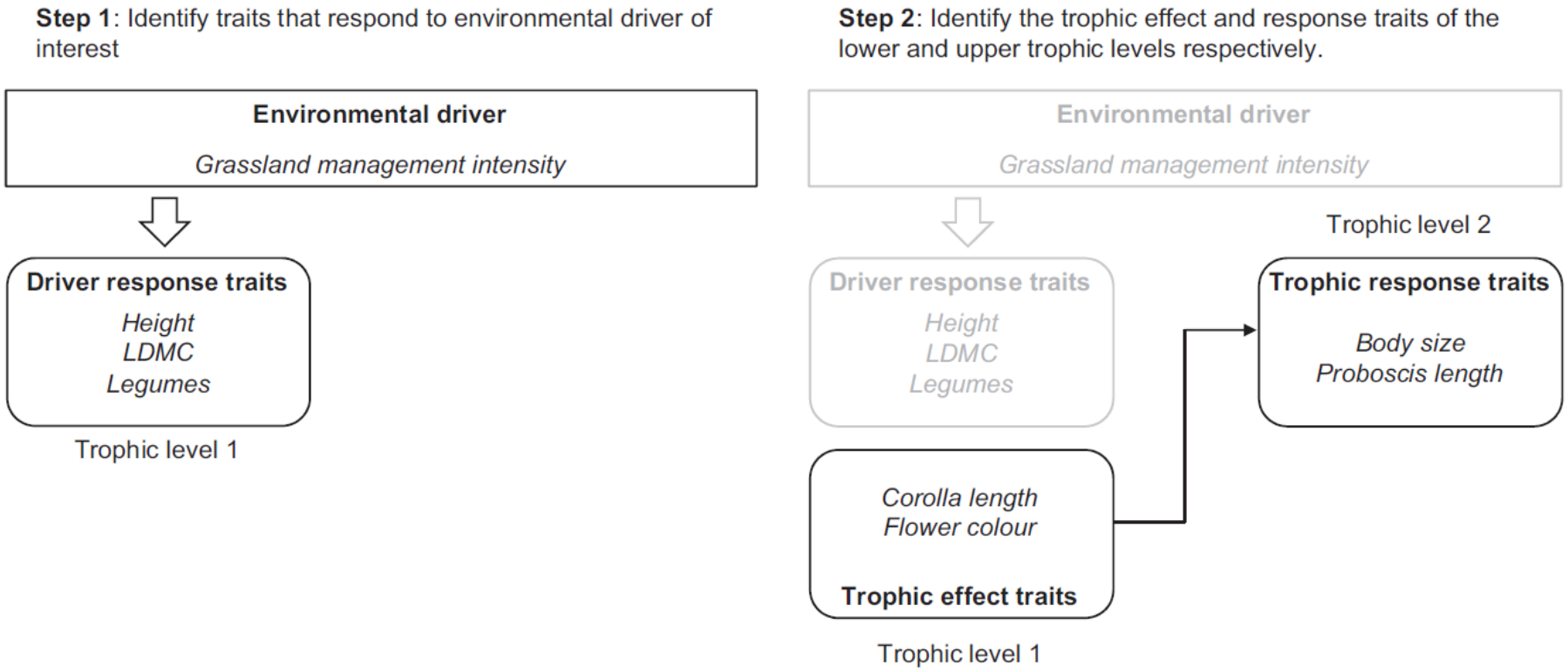


de Bello, F., Lavorel, S., Díaz, S., Harrington, R., Cornelissen, J. H. C., Bardgett, R. D., Berg, M. P., Cipriotti, P., Feld, C. K., Hering, D., da Silva, P. M., Potts, S. G., Sandin, L., Sousa, J. P., Storkey, J., Wardle, D. A., & Harrison, P. A. (2010). Towards an assessment of multiple ecosystem processes and services via functional traits. *Biodiversity and Conservation*, *19*(10), 2873–2893.

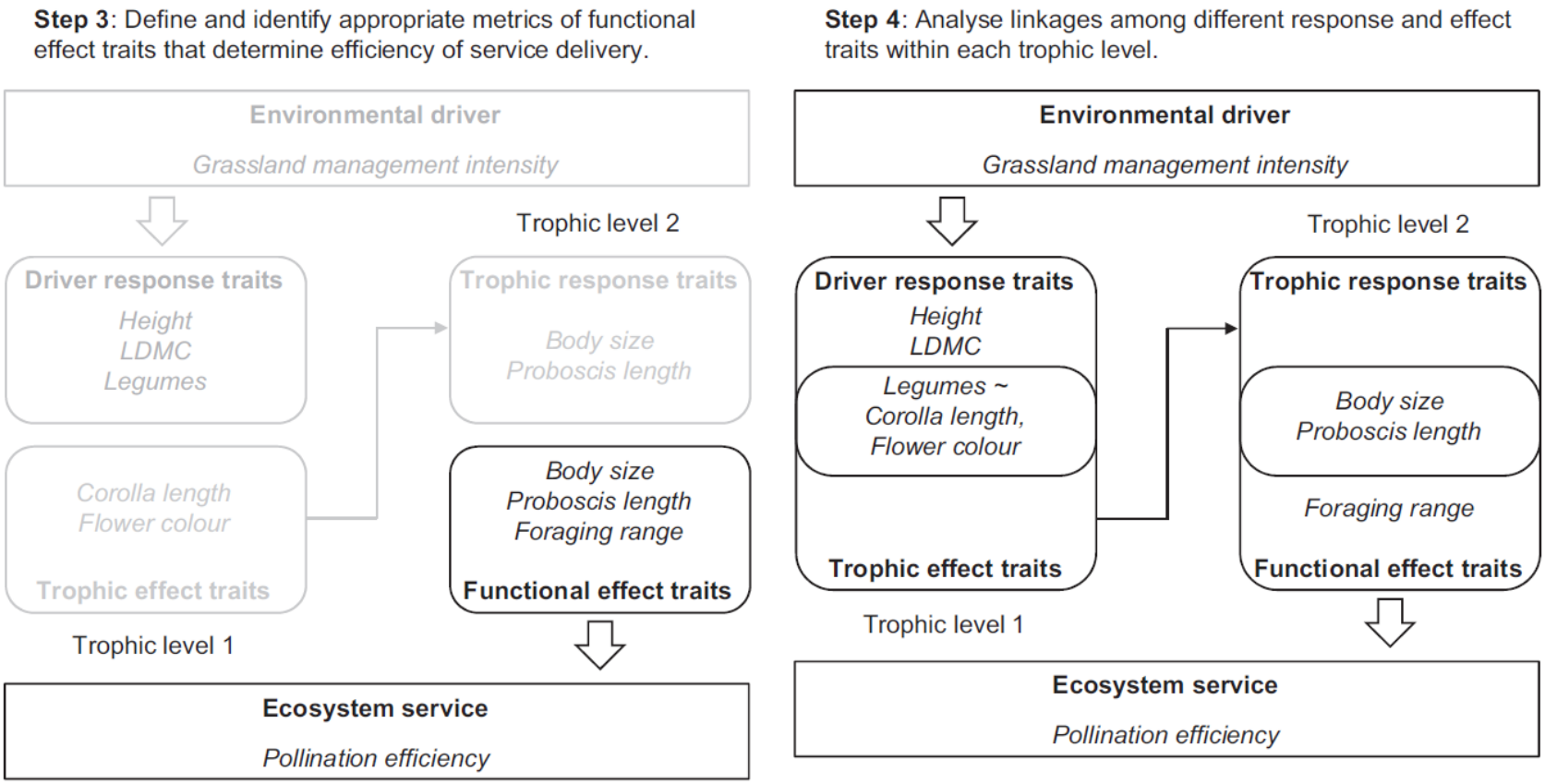
Ecosystem function-service relationship

- Understanding the processes that underpin ecosystem service delivery is crucial if the impact of change on current and future ecosystem services is to be quantified.
- But, there is a lack of proxies for ecological functions and the links between and ecosystem functions and ecosystem services may be context dependent (e.g. depending on ecosystem type) (Birkhofer et al. 2015).

Birkhofer, K., Diehl, E., Andersson, J., Ekroos, J., Früh-Müller, A., Machnikowski, F., Mader, V. L., Nilsson, L., Sasaki, K., Rundlöf, M., Wolters, V., & Smith, H. G. (2015). Ecosystem services-current challenges and opportunities for ecological research. *Frontiers in Ecology and Evolution*, *2*(JAN), 1–12. https://doi.org/10.3389/fevo.2014.00087



Lavorel, S., Storkey, J., Bardgett, R. D., De Bello, F., Berg, M. P., Le Roux, X., Moretti, M., Mulder, C., Pakeman, R. J., Díaz, S., & Harrington, R. (2013). A novel framework for linking functional diversity of plants with other trophic levels for the quantification of ecosystem services. *Journal of Vegetation Science*, *24*(5), 942–948. https://doi.org/10.1111/jvs.12083



Lavorel, S., Storkey, J., Bardgett, R. D., De Bello, F., Berg, M. P., Le Roux, X., Moretti, M., Mulder, C., Pakeman, R. J., Díaz, S., & Harrington, R. (2013). A novel framework for linking functional diversity of plants with other trophic levels for the quantification of ecosystem services. *Journal of Vegetation Science*, *24*(5), 942–948. https://doi.org/10.1111/jvs.12083

Sampling effect

- Increases in ecosystem functioning with increase diversity could occur through 2 mechanisms:
    1. Sampling effect - local and regional stochastic processes involved in community assembly, which are mimicked in experiments by random sampling from a species pool.

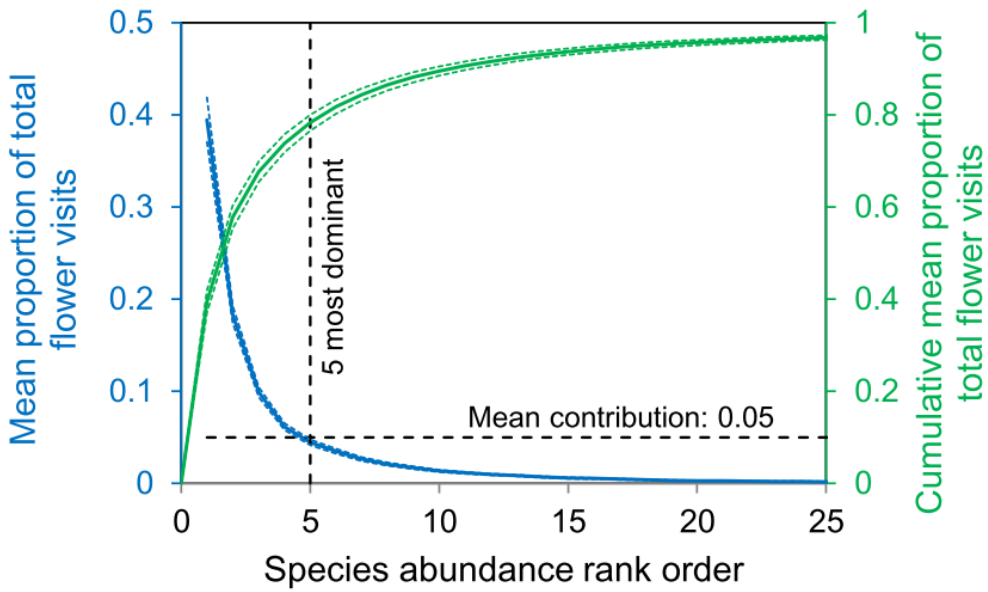
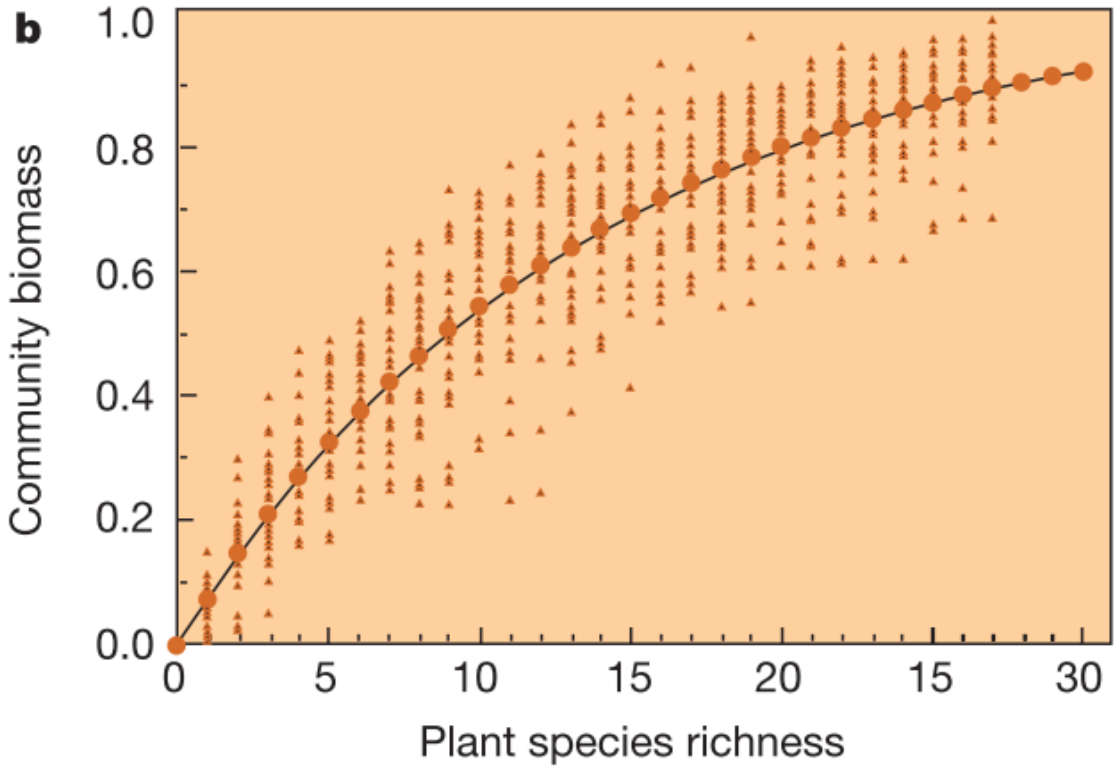


Figure from: Kleijn, D., Winfree, R., Bartomeus, I., Carvalheiro, L. G., Henry, M., Isaacs, R., Klein, A.-M., Kremen, C., … Potts, S. G. (2015). Delivery of crop pollination services is an insufficient argument for wild pollinator conservation. Nature Communications, 6(JANUARY), 7414.

Complementarity effects

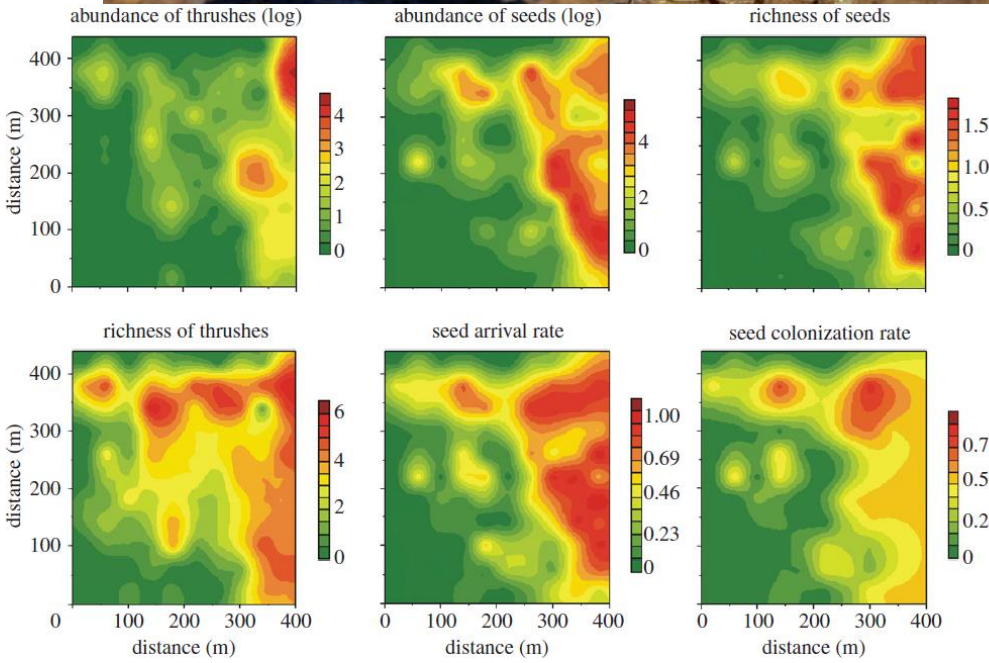
2. Complementarity: if niches are complementary, then adding species could increase the function linearly until a saturation point is reached
3. Facilitation occurs if certain species/functional groups alleviate harsh conditions or provide resources for other species.



Tilman, D. (2000). Causes, consequences and ethics of biodiversity. *Nature*, *405*(6783), 208–211. https://doi.org/10.1038/35012217

Seed dispersal by frugivorous birds

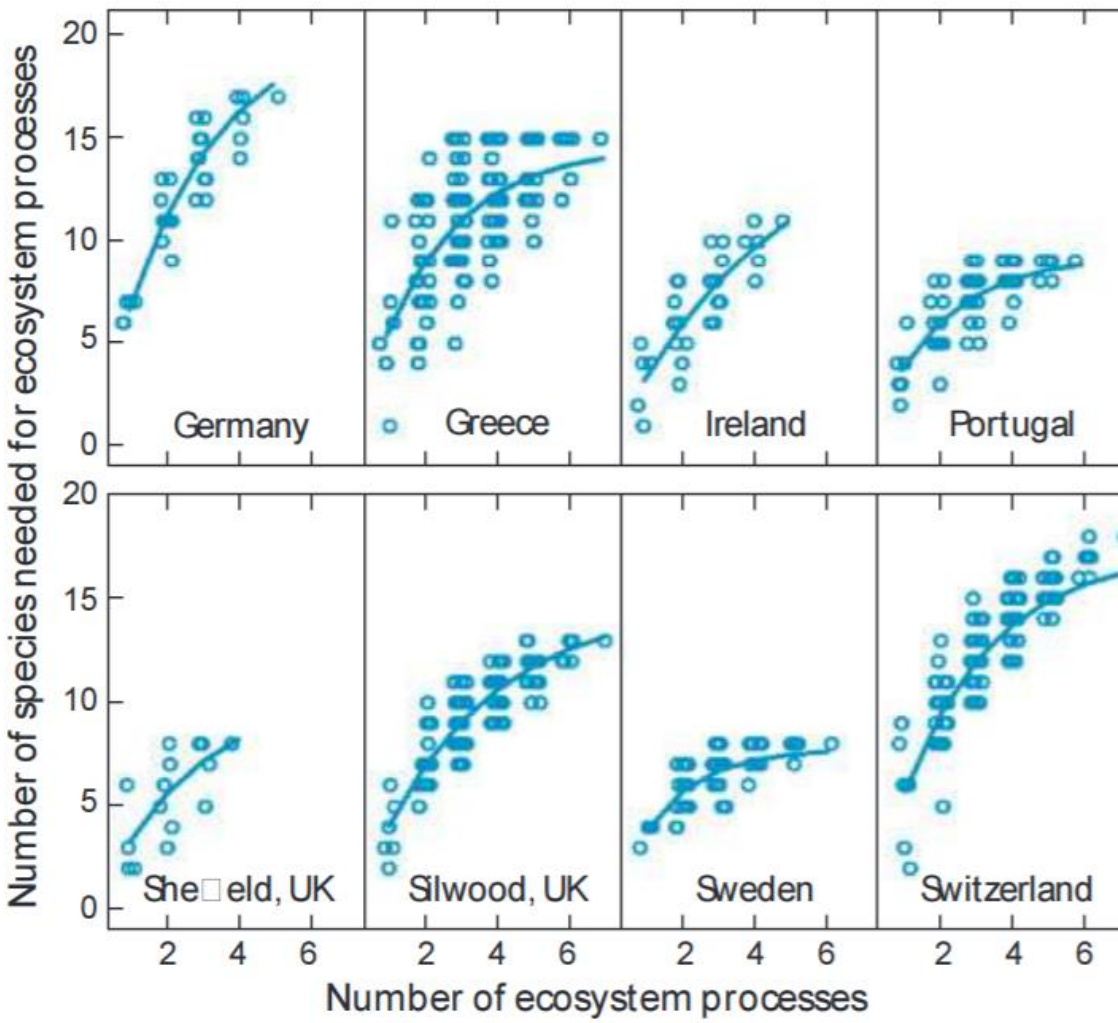
- Positive relationship between thrush abundance/richness and richness of seeds, seed arrival rate and seed colonisation rate.
- Complementarity effect due to niche partitioning (diet and spatial behaviour).
- Facilitation effect as some species of thrushes track the presence of others across the foraging landscape.
- Sampling effect as one bird species *Turdus iliacus* accounted for nearly 50% of the observations and its abundance was strongly correlated to seed dispersal magnitude



García, D., & Martínez, D. (2012). Species richness matters for the quality of ecosystem services: A test using seed dispersal by frugivorous birds. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1740), 3106–3113.

Biodiversity – ecosystem multifunctionality relationships

- Different species involved in the provisioning of different services. Thus, many more species are needed, in total, to provide many services than are needed to provide a single service.



Tilman, D., Isbell, F., & Cowles, J. (2014). Biodiversity and ecosystem functioning. *Annual Review of Ecology, Evolution, and Systematics*, *45*, 471–493.

Is greater biodiversity necessary to support more ecosystem functions?

- Recent theoretical and empirical work suggest that considering more functions does not necessarily strengthen the relationship between biodiversity and ecosystem functioning.
- This question remains therefore largely unresolved (Slade, 2019).

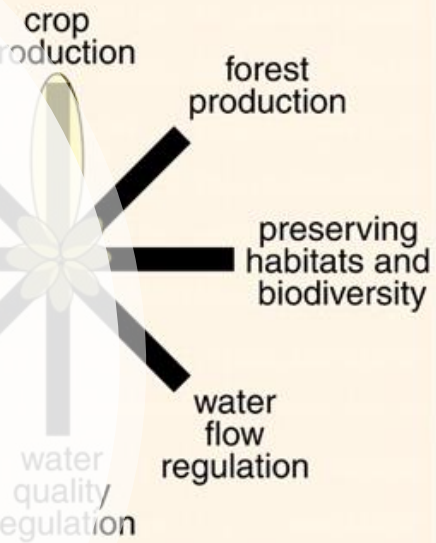
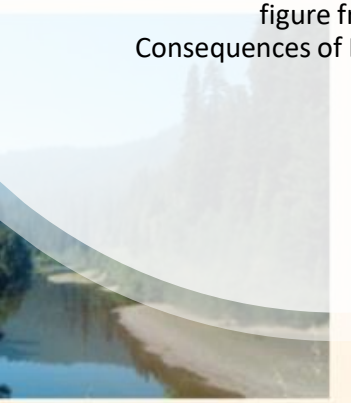
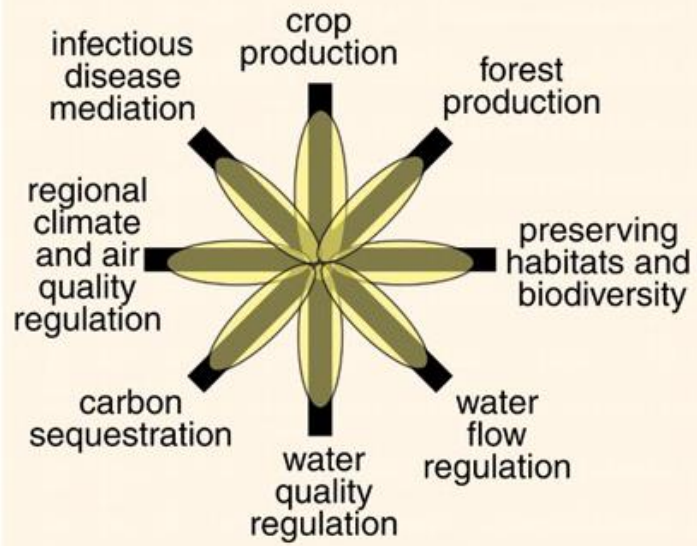


figure from Foley et al. (2005) Global Consequences of Land Use. Nature. 309(5734): 570-574.



natural ecosystem

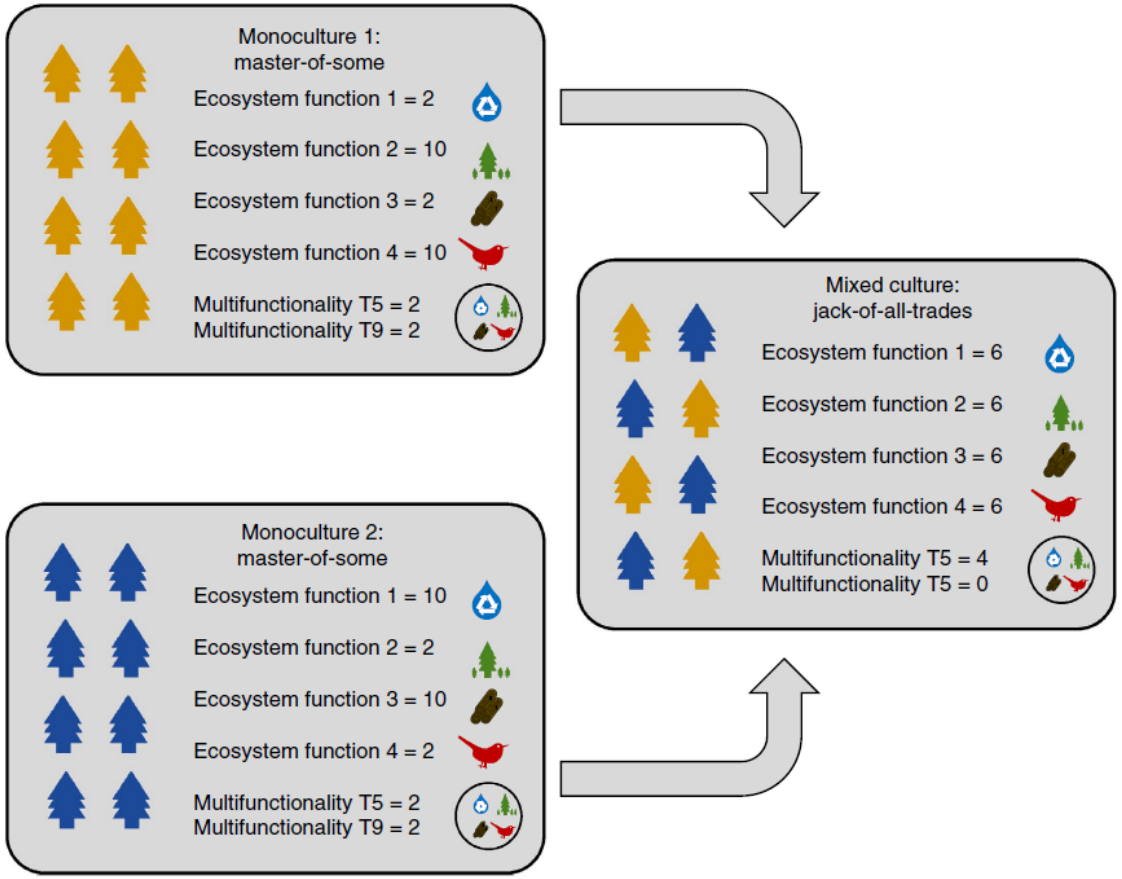
intensive cropland



cropland with restored ecosystem services

A “jack of all trades” effect?

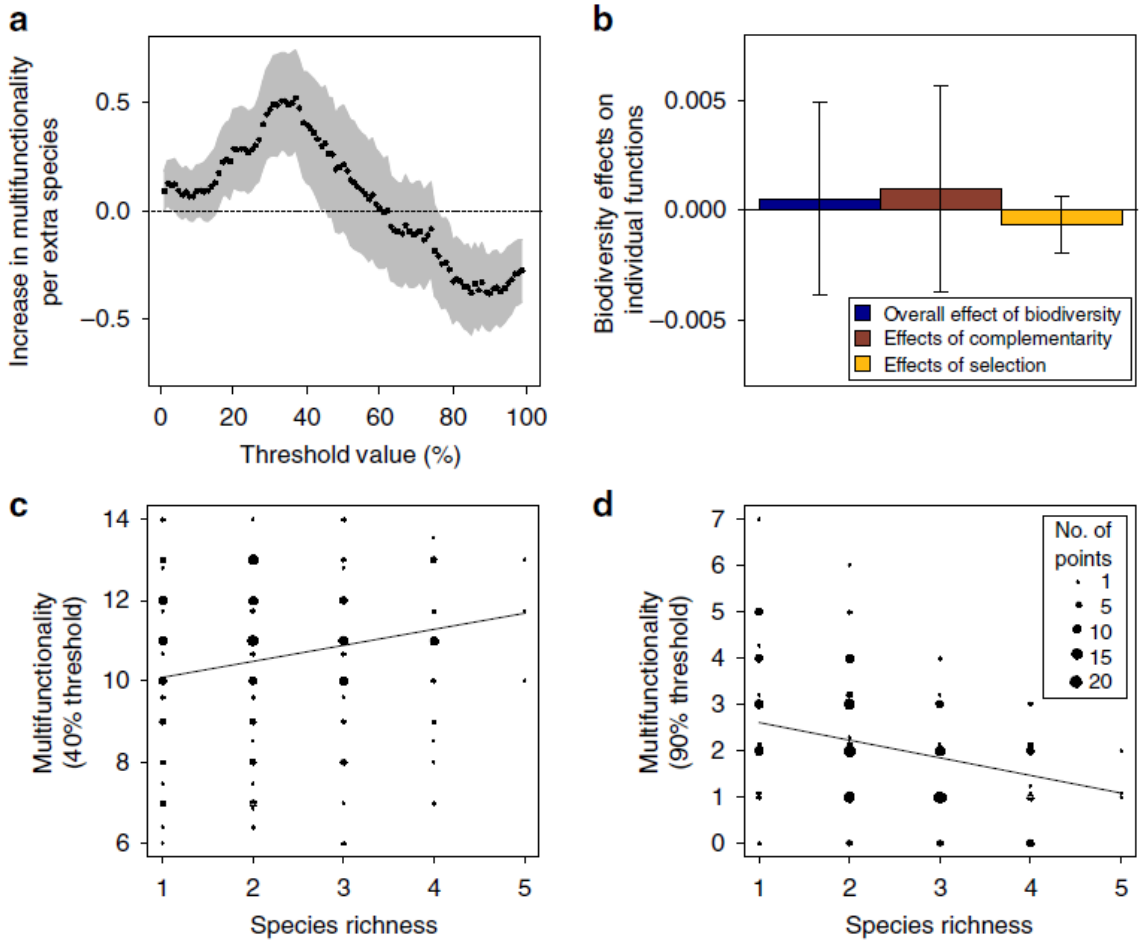
Hypothetical example where the mixing of two species causes a ‘jack-of-all-trades, but master-of-none’ effect.



Van Der Plas, F., Manning, P., Allan, E., Scherer-Lorenzen, M., Verheyen, K., Wirth, C., Zavala, M. A.,…Fischer, M. (2016). Jack-of-all-trades effects drive biodiversity-ecosystem multifunctionality relationships in European forests. *Nature Communications*, *7*, 1–11.

A “jack of all trades” effect?

- The effects of tree biodiversity on observed ecosystem multifunctionality and individual ecosystem functions.



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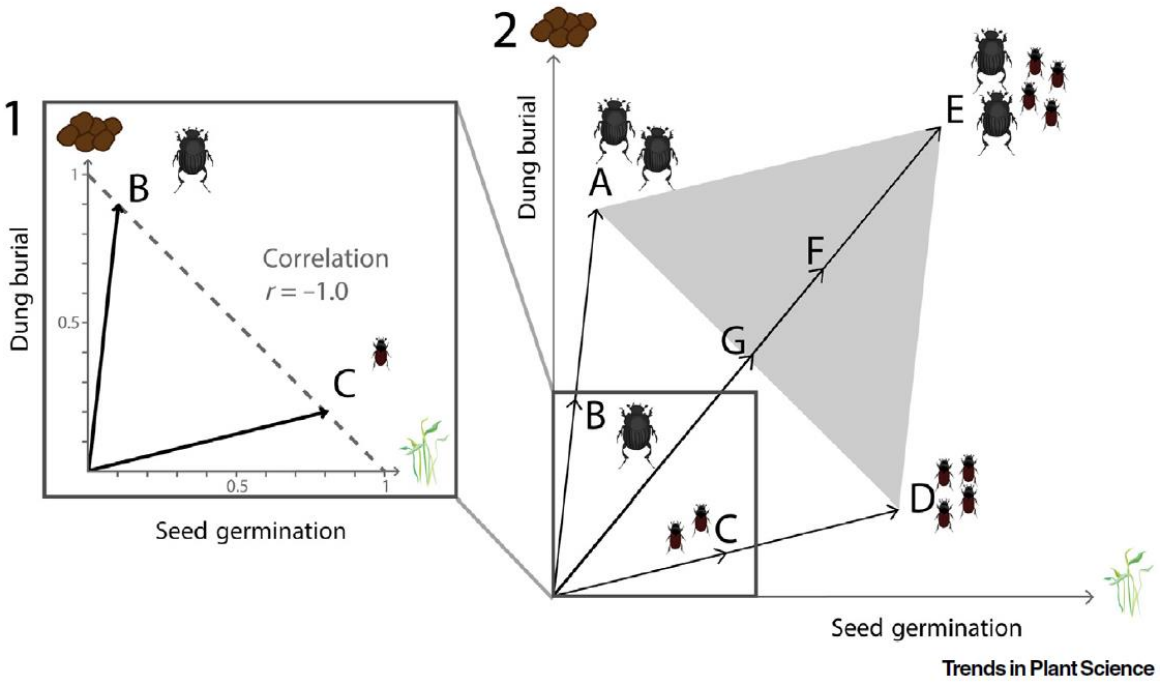
Trade-offs between functions

- Negative effects of species as demonstrated by inter/intra-specifici competition in two species of dung beetles supporting 2 ecosystem services: dung burial and seed germination.
- If no interspecific interaction, high dung burial and germination (E); Interspecific interaction reduces ES delivery (e.g. F, G). If high intraspecific competition, functioning will be below the A-D line.



Summary

- Ecosystem functions are ecological processes that control the fluxes of energy, nutrients and organic matter through an environment.
- Ecosystem functions sustain ecosystem services.
- Biodiversity is associated with increased ecosystem functioning but there is a saturation effects. Complementarity, facilitation and sampling effects are key mechanisms that explain this relationship.
- Biodiversity – ecosystem multifunctionality relationships are more complex to explain: traditionally, biodiversity was thought as being more strongly (steeper gradient) associated with multifunctionality but this has been contradicted by recent research (due to jack-of-all-trade and sampling effects and the negative effects arising when adding species)

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 809988.