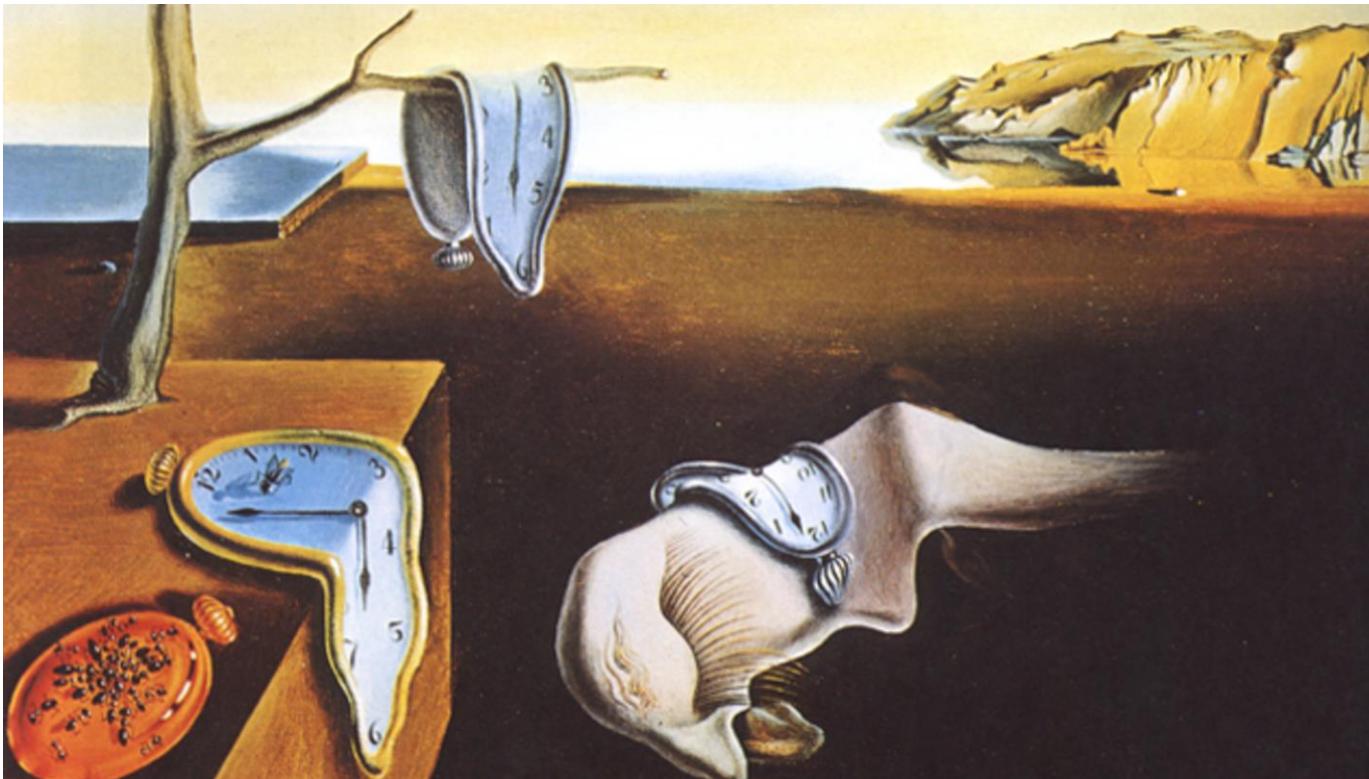


Biodiversity patterns across space and time



Federico Riva, PhD

McGill, BIOL 310

February 9th, 2022

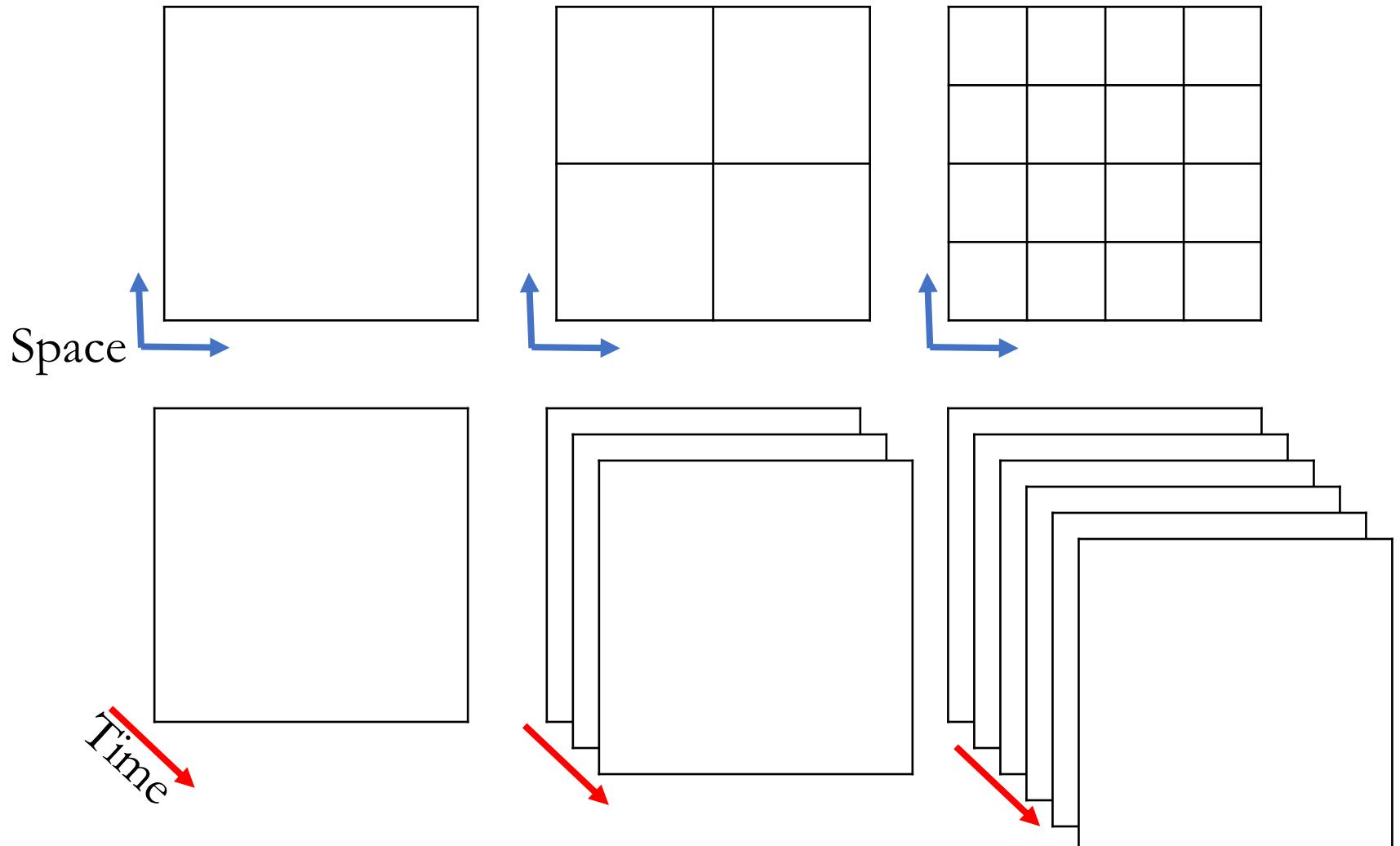
federicoriva@cunet.carleton.ca

<https://github.com/FedericoRiva>

 @riva_ecology

Today, my goal is convincing you that the spatial and temporal scales of your analysis are crucial to interpreting your findings

Spatial scale



Temporal scale

Resolution

Summary

- The complexity of natural systems
- Scaling in ecology and conservation
 - History of research on scales
 - Theory developed to understand biodiversity across scales
 - The role of scaling in solving long-standing debates
 - Implications for applied conservation
- Conclusions
 - Some suggestions on how to deal with it in your work
 - R workshop

Complexity in ecology

Trends in Ecology & Evolution

CellPress
REVIEWS

Opinion

Protecting Biodiversity (in All Its Complexity): New Models and Methods

nature
ecology & evolution

ARTICLES

<https://doi.org/10.1038/s41559-021-01644-4>



Ecological network complexity scales with area

ECOGRAPHY

Forum

Future restoration should enhance ecological complexity and emergent properties at multiple scales

PNAS

Proceedings of the
National Academy of Sciences
of the United States of America

Key

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Articles

Front Matter

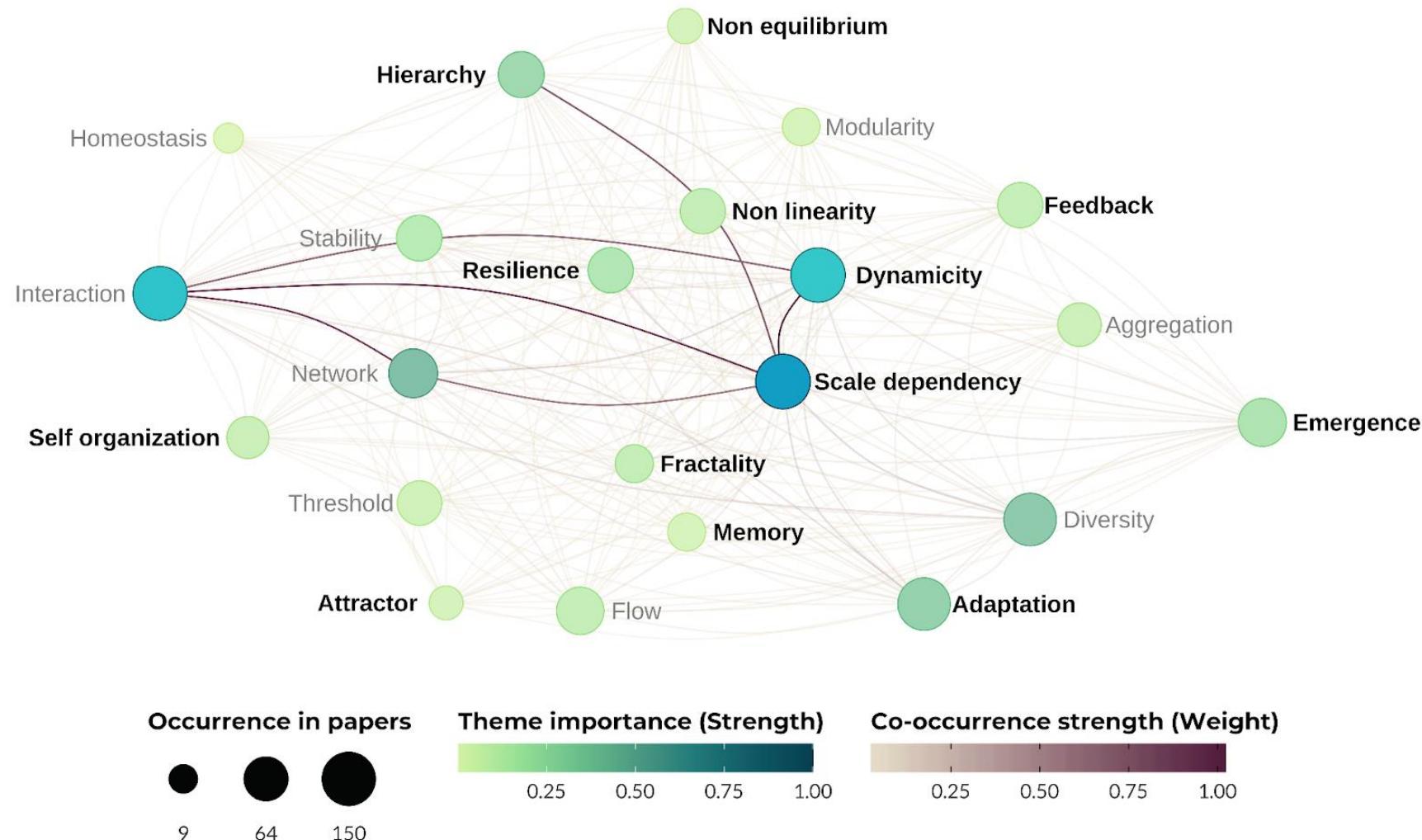
News

Podcasts

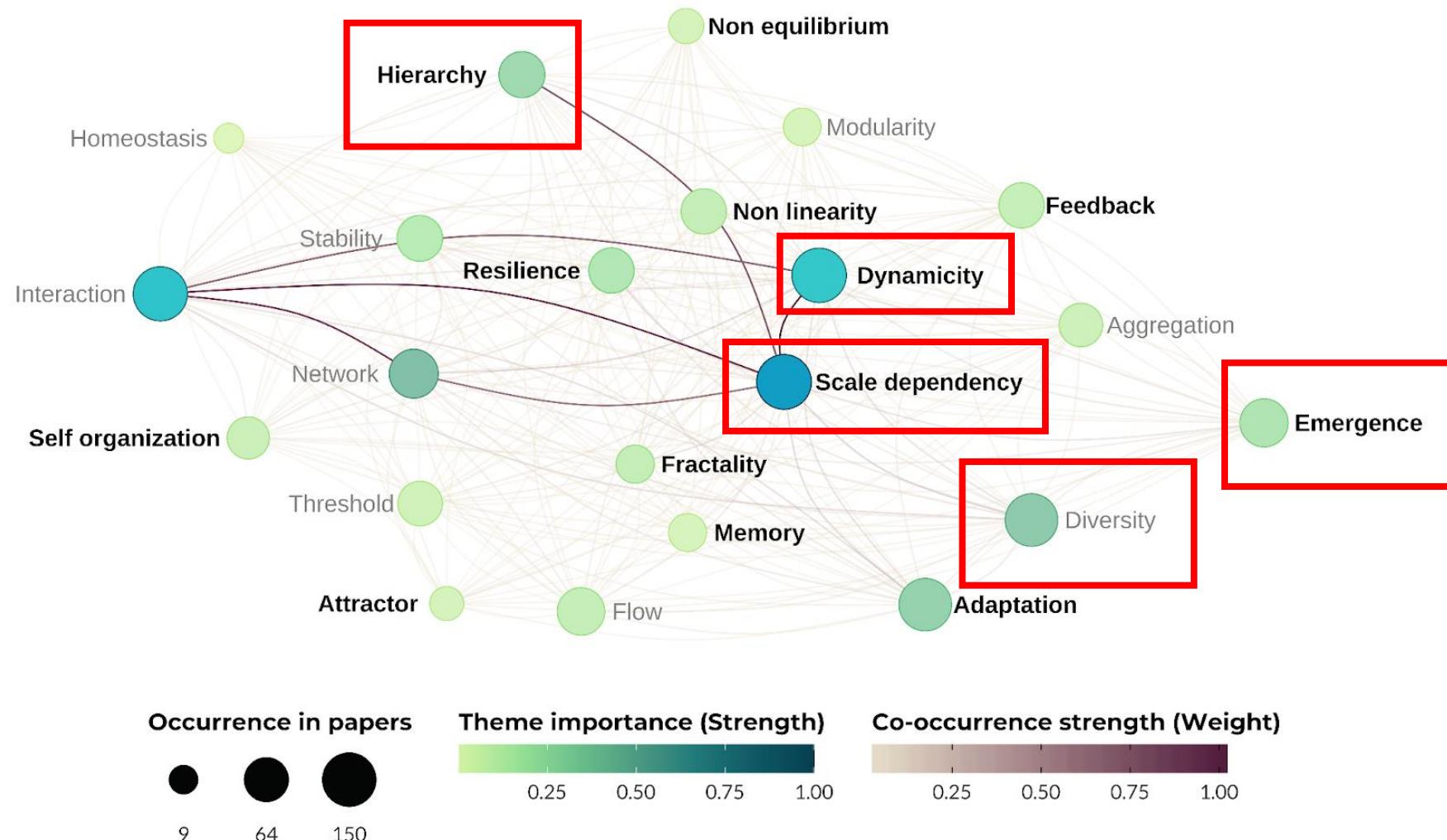
RESEARCH ARTICLE

Multiscale structural complexity of natural patterns

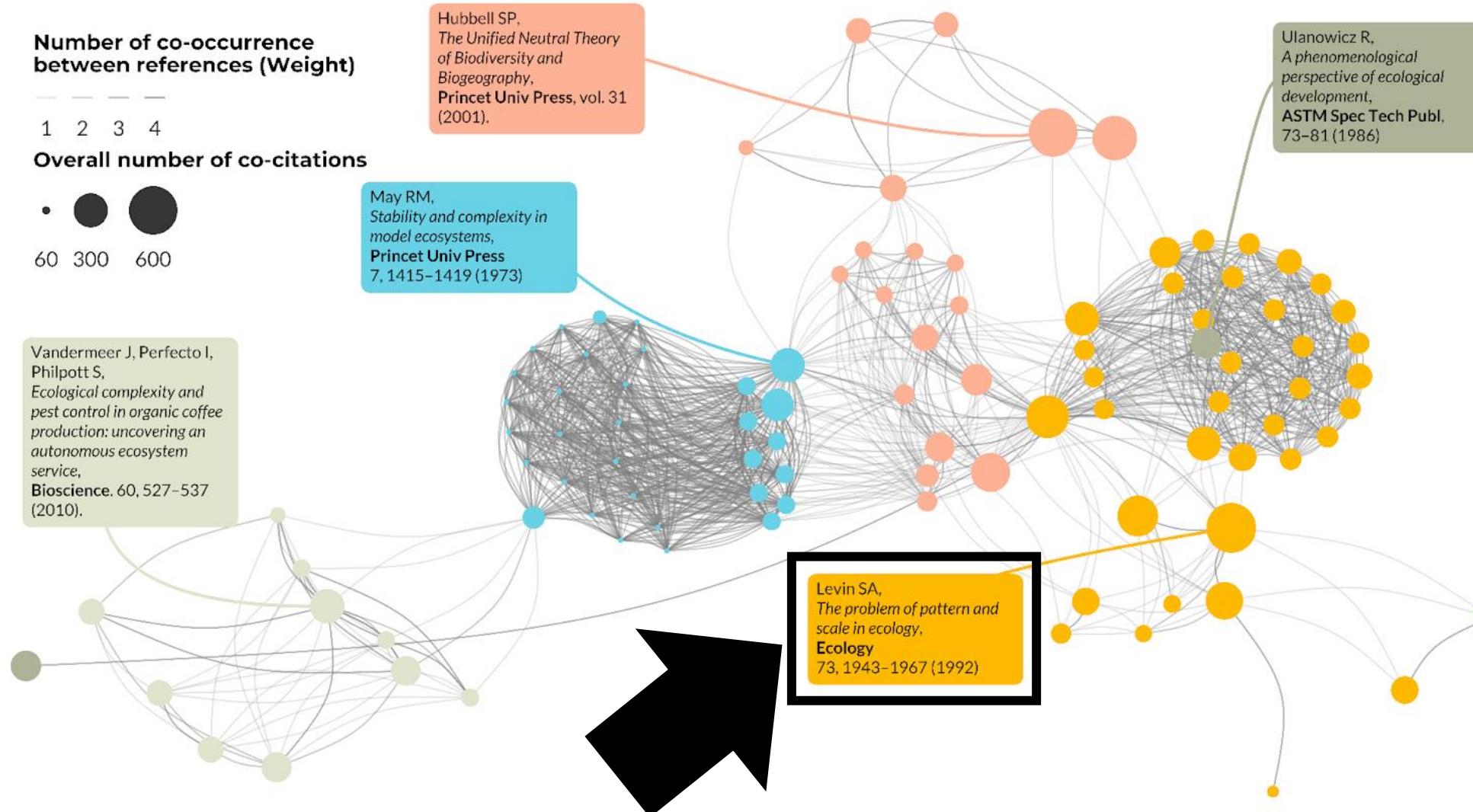
Natural systems are prototypical complex adaptive systems



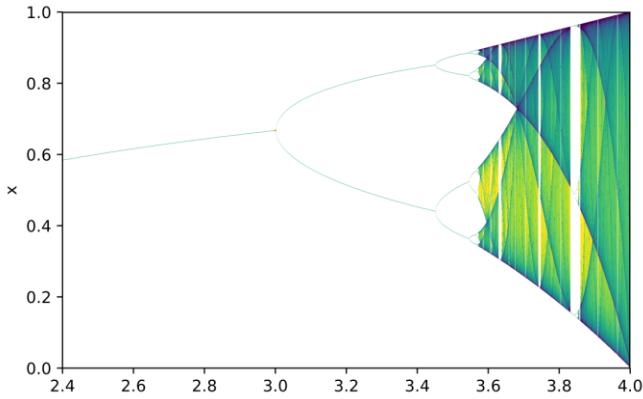
Natural systems are prototypical complex adaptive systems



How do we deal with this complexity?



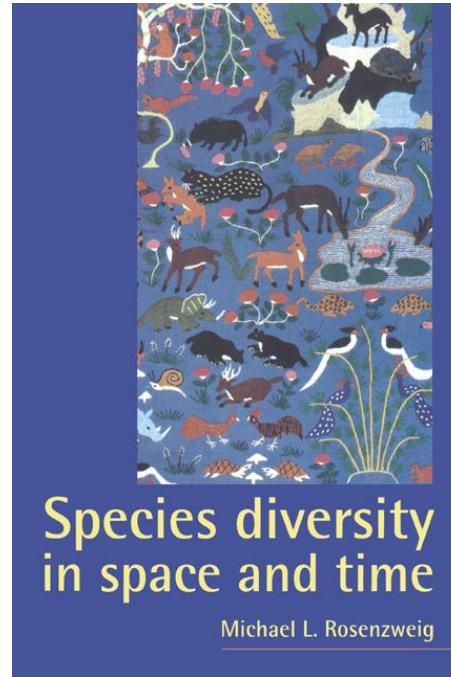
Hard theory



$$x_{n+1} = rx_n(1 - x_n)$$

May 1976

Macroecology



Species diversity
in space and time

Michael L. Rosenzweig

Rosenzweig 1995

Scaling

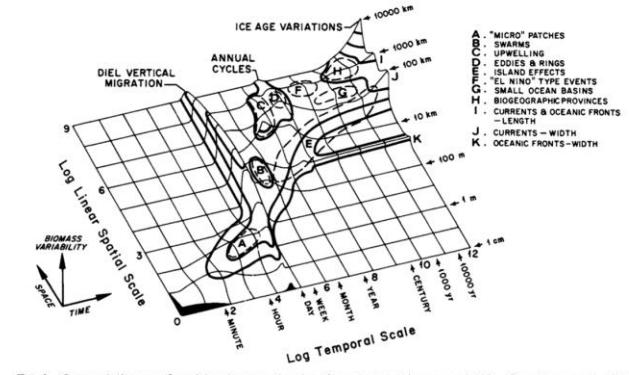


FIG. 3. Stommel diagram of spatial and temporal scales of zooplankton biomass variability (from Haury et al. 1978).

Levin 1992

By reducing the focus to manageable scenarios, scaling simplifies the complexity of natural systems that otherwise span multiple, interconnected levels of biological organization and change dynamically through time

**Growing awareness of the
importance of scales**

Wiens 1989 – Space

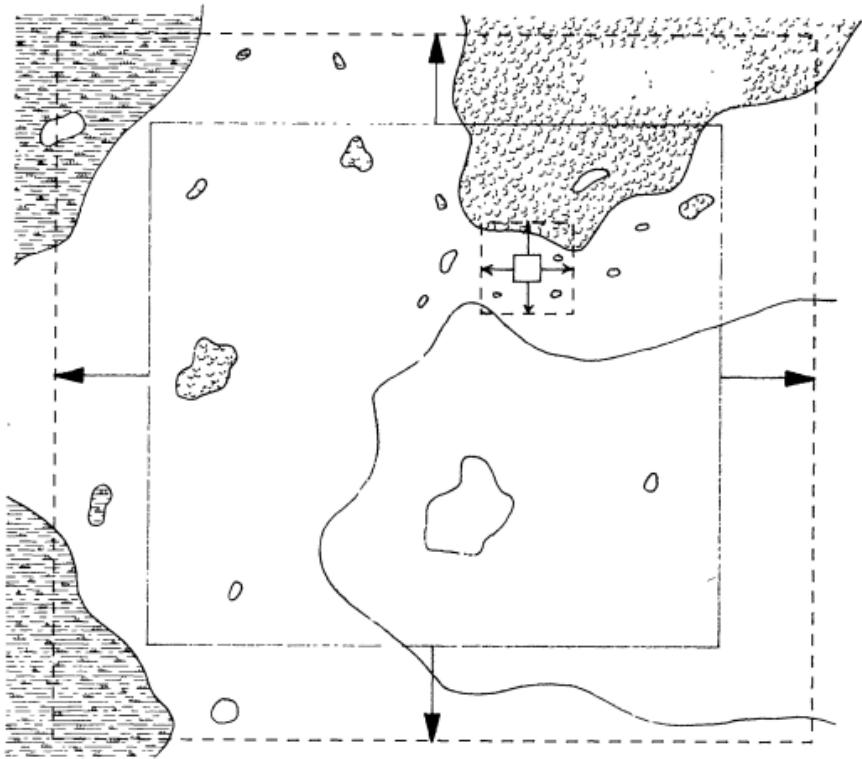


Fig. 1. The effects of changing the grain and extent of a study in a patchy landscape. As the extent of the study is increased (large squares), landscape elements that were not present in the original study area are encountered. As the grain of samples is correspondingly increased (small squares), small patches that initially could be differentiated are now included within samples and the differences among them are averaged out.

Grain vs. extent

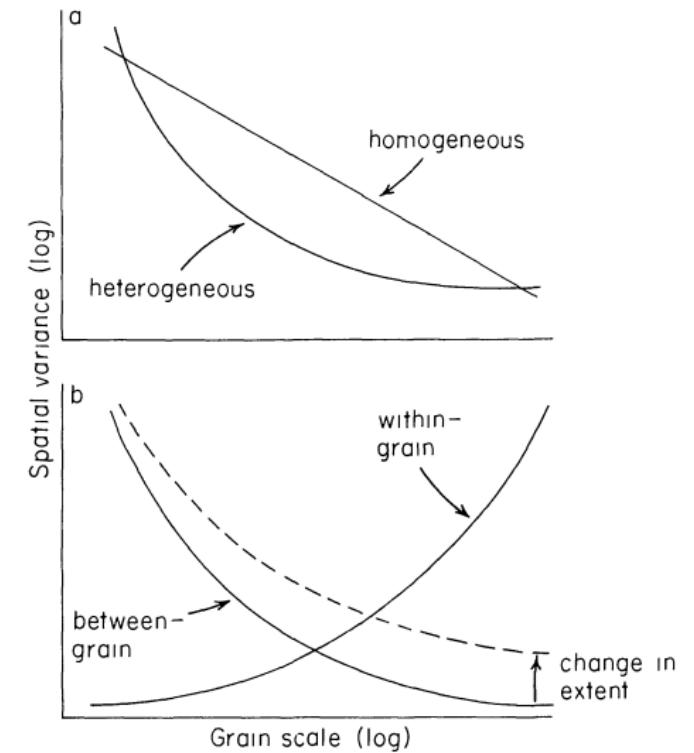


Fig. 2. (a) As the grain of samples becomes larger, spatial variance in the study system as a whole decreases, albeit differently for homogeneous and heterogeneous areas. This is related to the within- and between-grain (sample) components of variation. (b) With increasing grain scale, less of the variance is due to differences between samples and more of the overall variation is included within samples (and therefore averaged away). An increase in the extent of the investigation may increase the between-grain component of variance by adding new patch types to the landscape surveyed (Fig. 1), but within-grain variance is not noticeably affected.

Levin 1992 – Space and time

THE PROBLEM OF PATTERN AND SCALE IN ECOLOGY

THE ROBERT H. MACARTHUR AWARD LECTURE
Presented August 1989
Toronto, Ontario, Canada

by

SIMON A. LEVIN

Department of Ecology and Evolutionary Biology, Princeton University, Princeton, New Jersey 08544-1003 USA, and
Section of Ecology and Systematics, Cornell University, Ithaca, New York 14853-2701 USA



Simon A. Levin
MacArthur Award Recipient

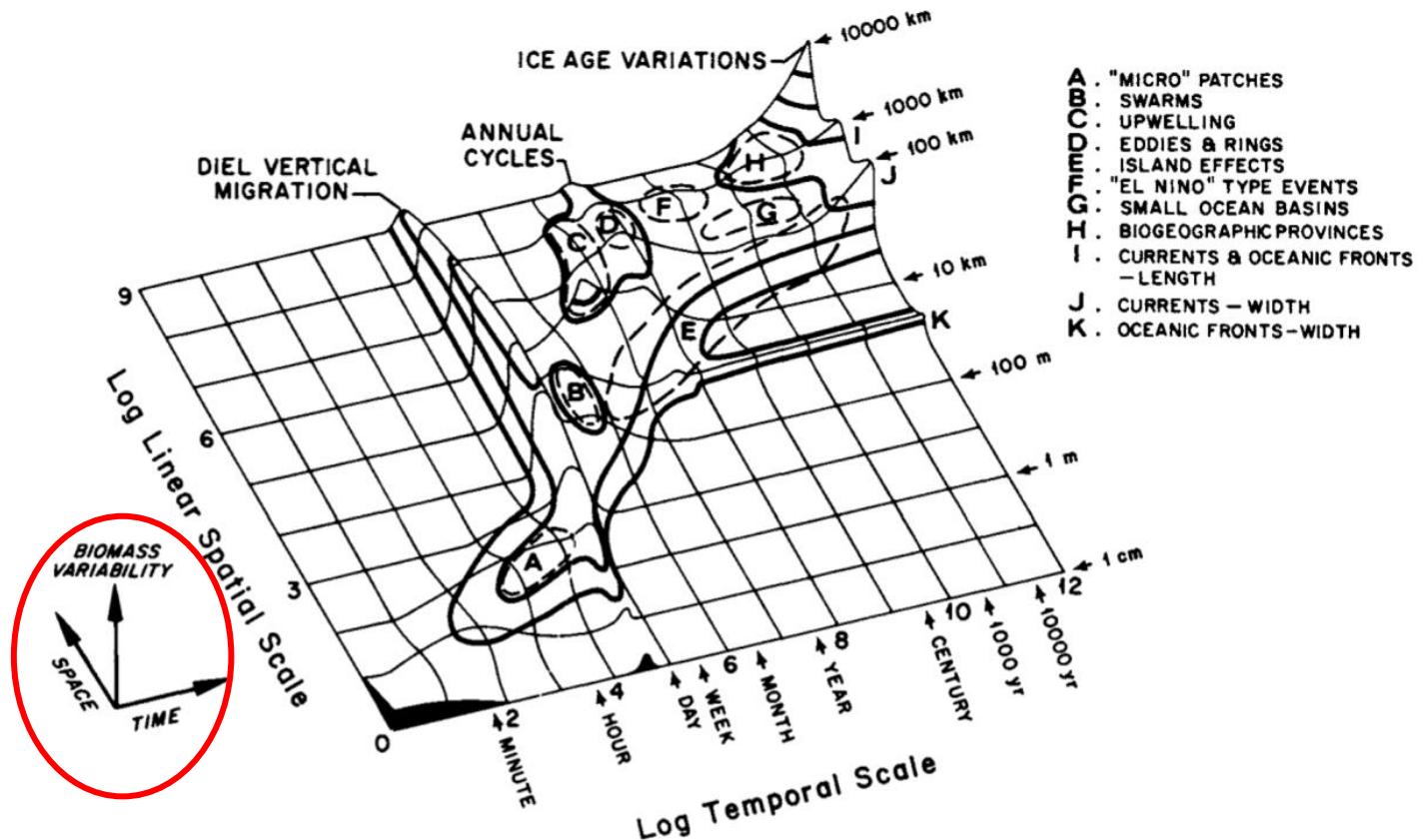


FIG. 3. Stommel diagram of spatial and temporal scales of zooplankton biomass variability (from Haury et al. 1978).

Levin 1992 – Space and time

THE PROBLEM OF PATTERN AND SCALE IN ECOLOGY

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MacArthur Award Recipient

MACARTHUR AWARD LECTURE

1957

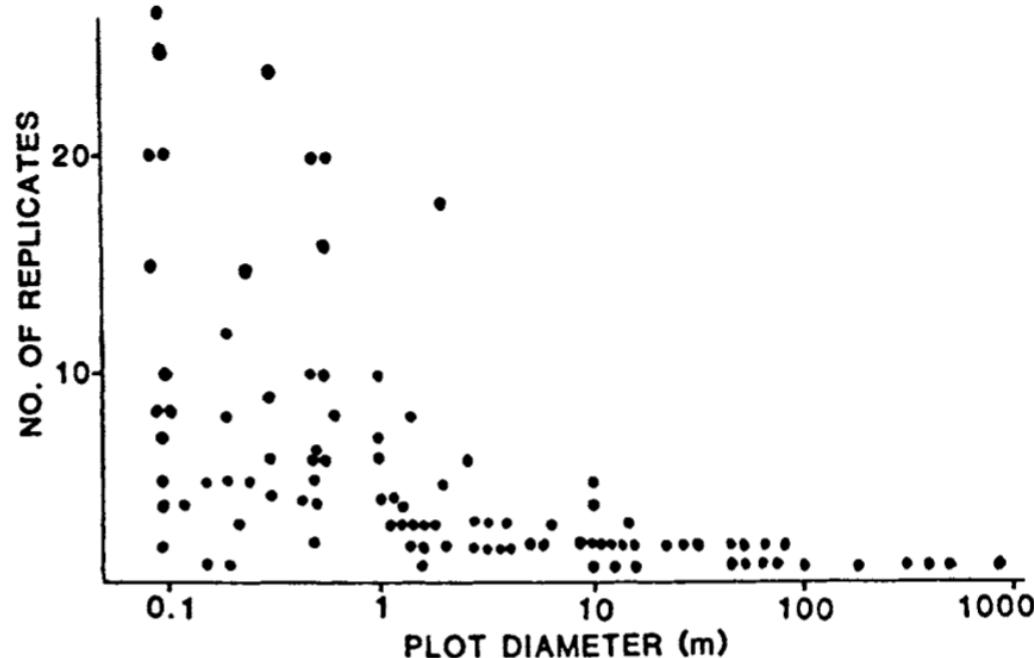
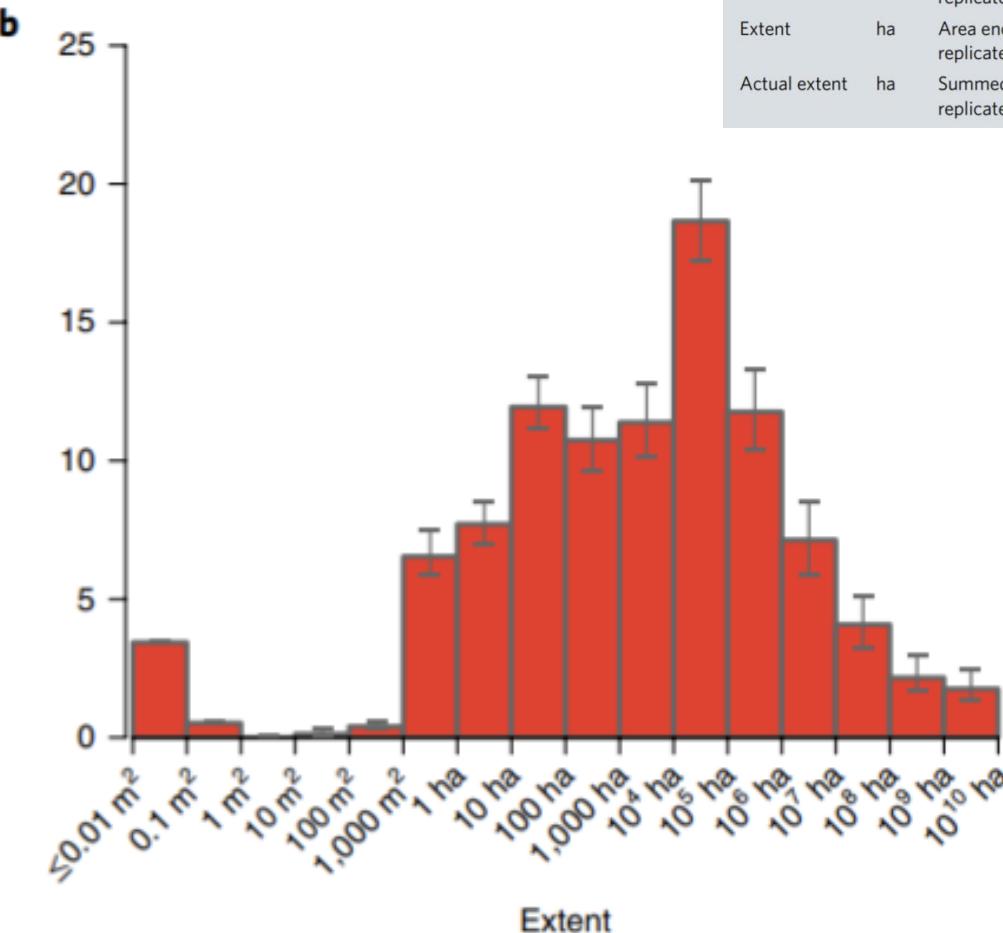
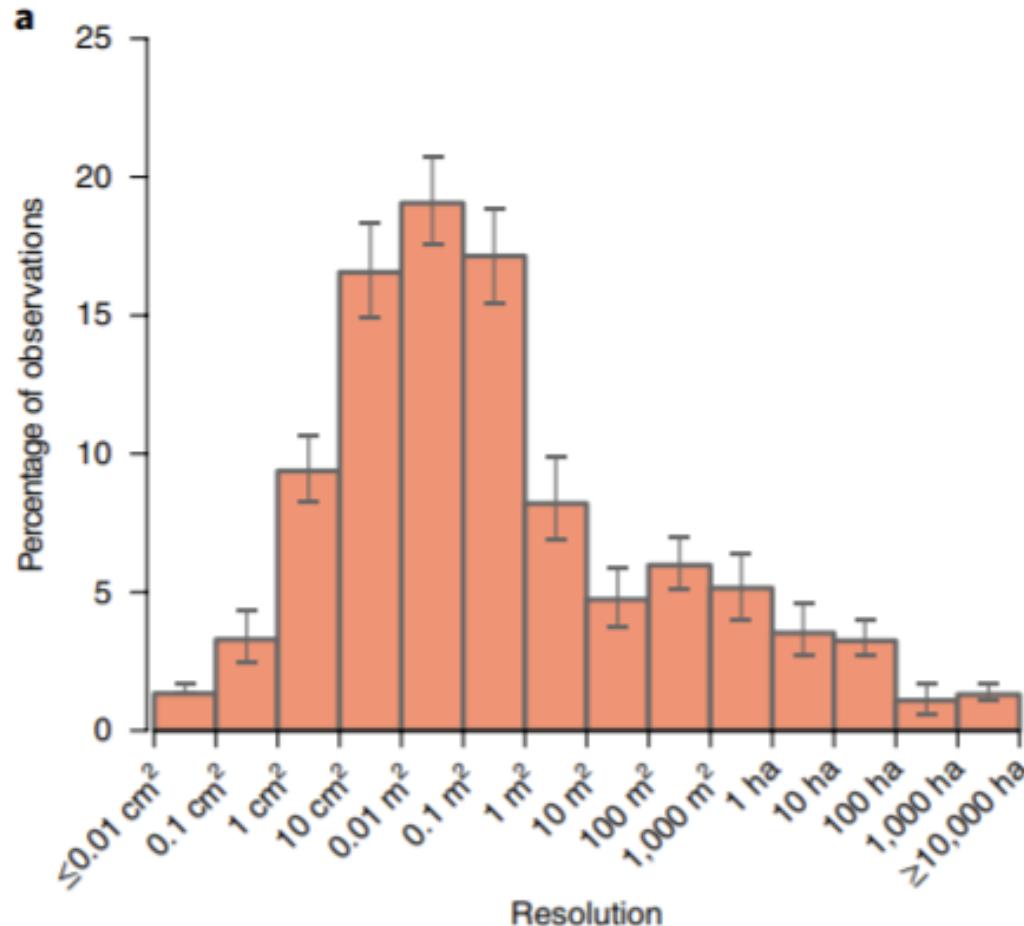


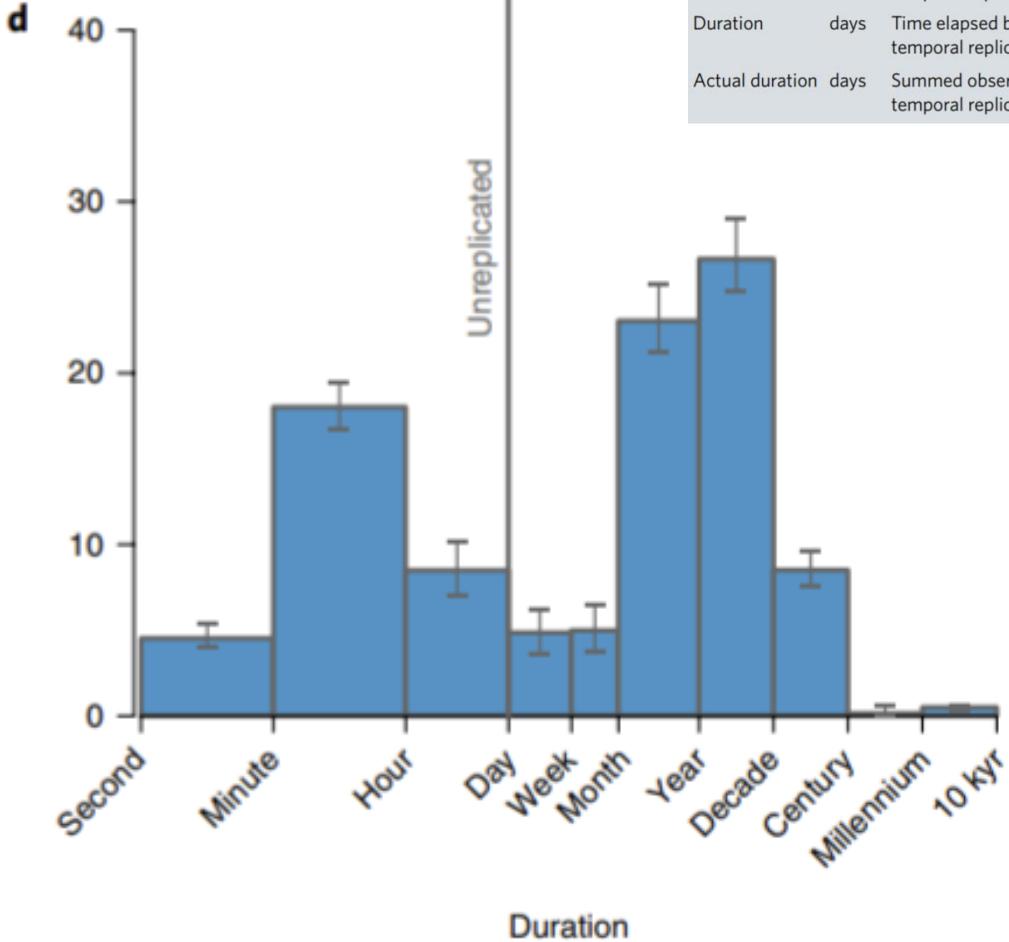
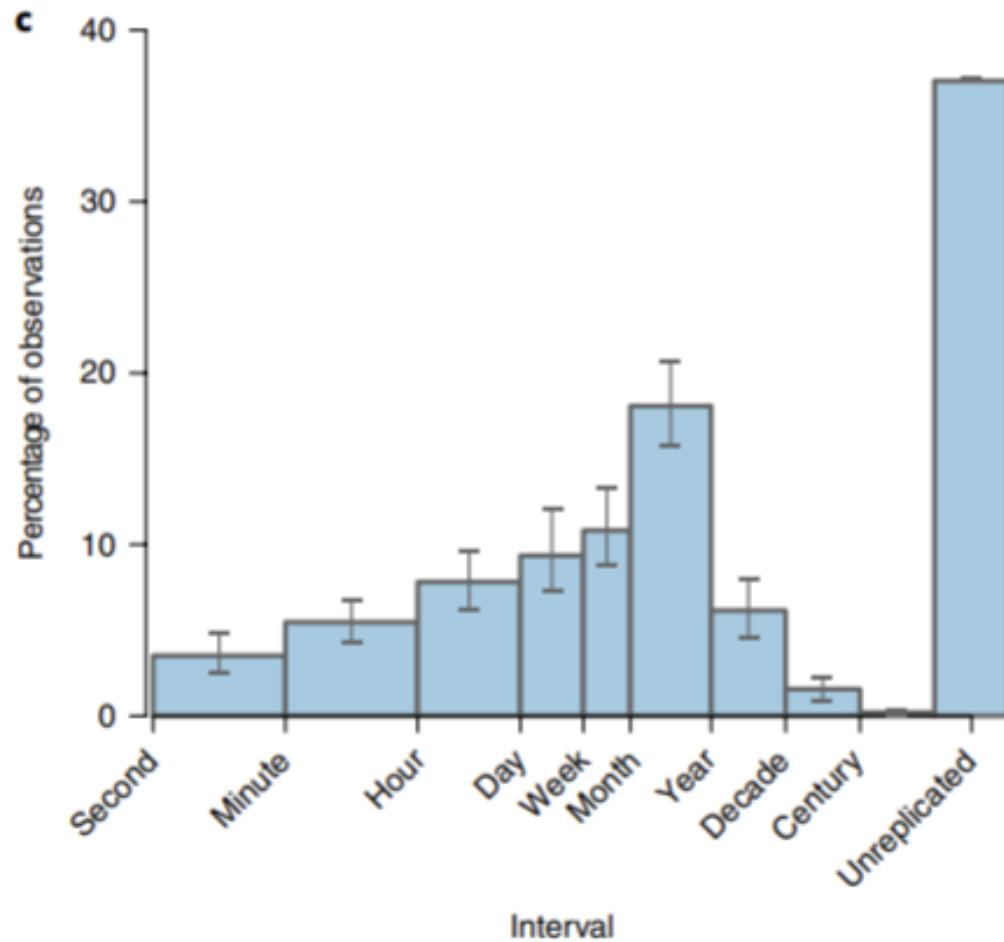
FIG. 14. Size and number of replicates in experimental community ecology. Each point is taken from a different paper published in *Ecology*. Every paper from January 1980 to August 1986 was included if it involved experimental manipulation of resources or populations “in order to learn about community dynamics or community properties” (from Kareiva and Anderson 1988).

Estes et al. (2018) – after 30+ years, our perspective is still very biased towards short studies, small spatial resolutions



Resolution	m ²	Area of an individual spatial replicate (for example, plot)
Extent	ha	Area encompassed by all spatial replicates
Actual extent	ha	Summed area of all spatial replicates

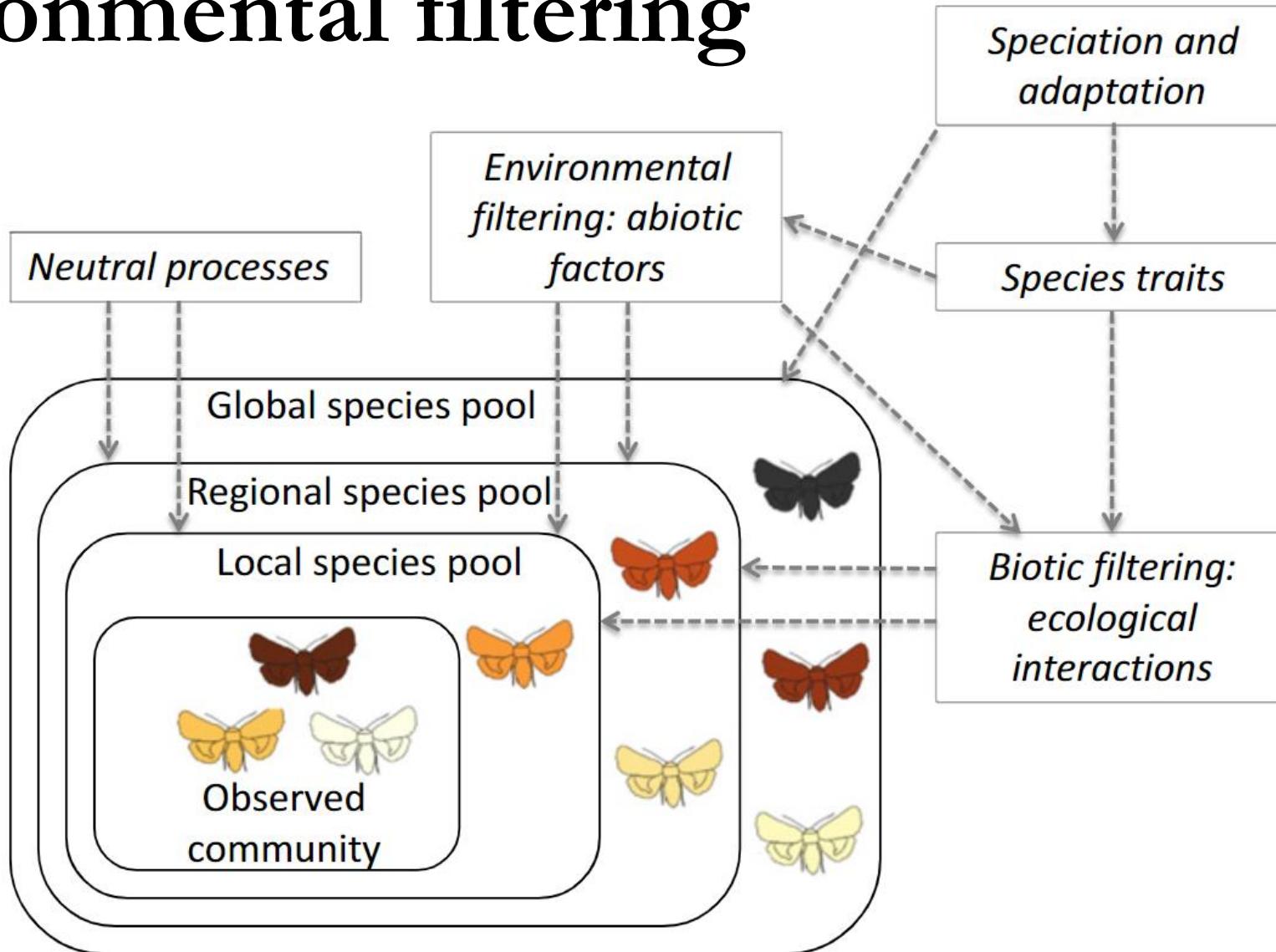
Estes et al. (2018) – after 30+ years, our perspective is still very biased towards short studies, small spatial resolutions



Interval	days	Time elapsed between successive temporal replicates
Duration	days	Time elapsed between first and last temporal replicates
Actual duration	days	Summed observational time of all temporal replicates

Theoretical paradigms that
incorporate scaling in the
study of biodiversity

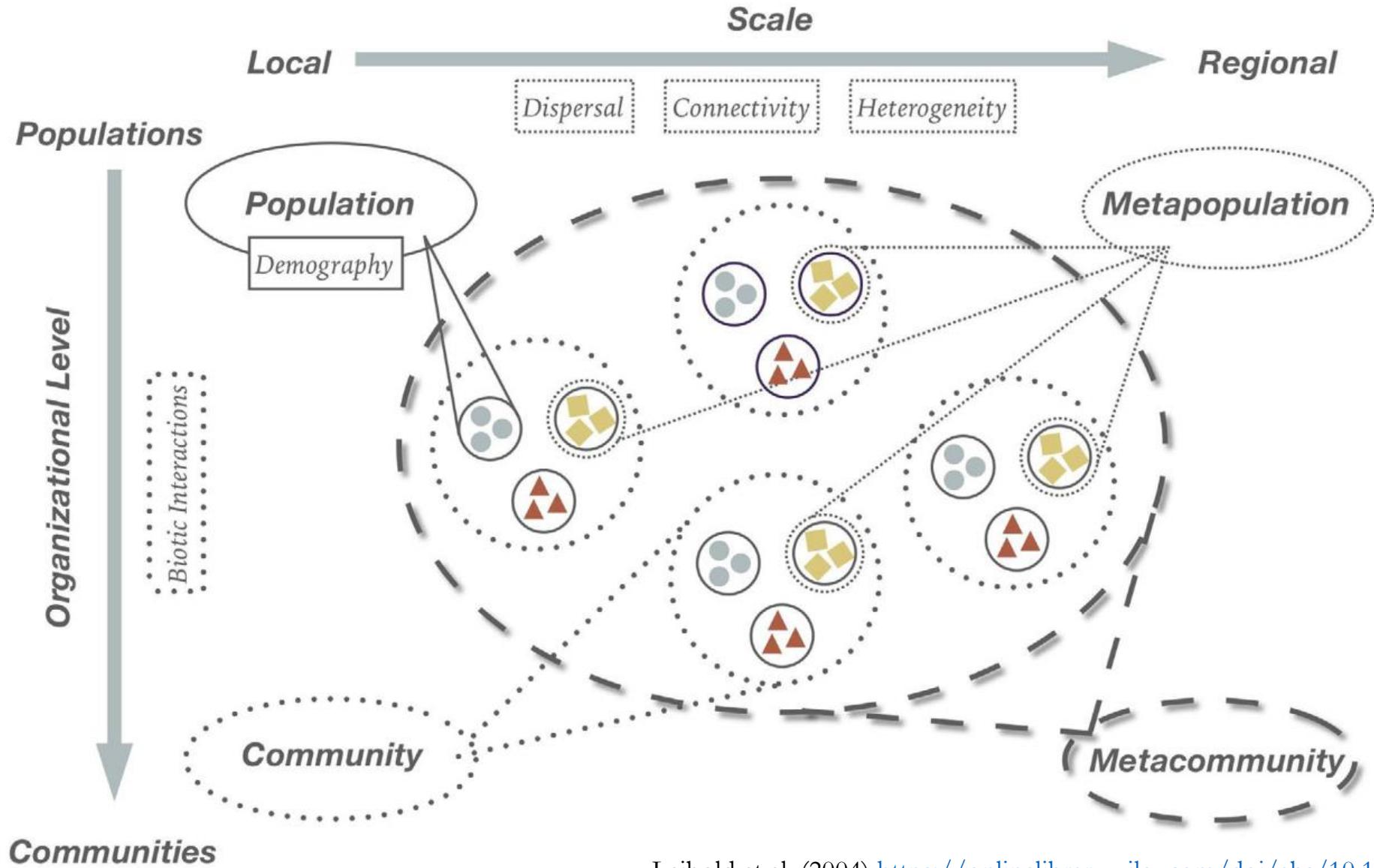
Environmental filtering



Ovaskainen et al. (2017) <https://onlinelibrary.wiley.com/doi/10.1111/ele.12757>

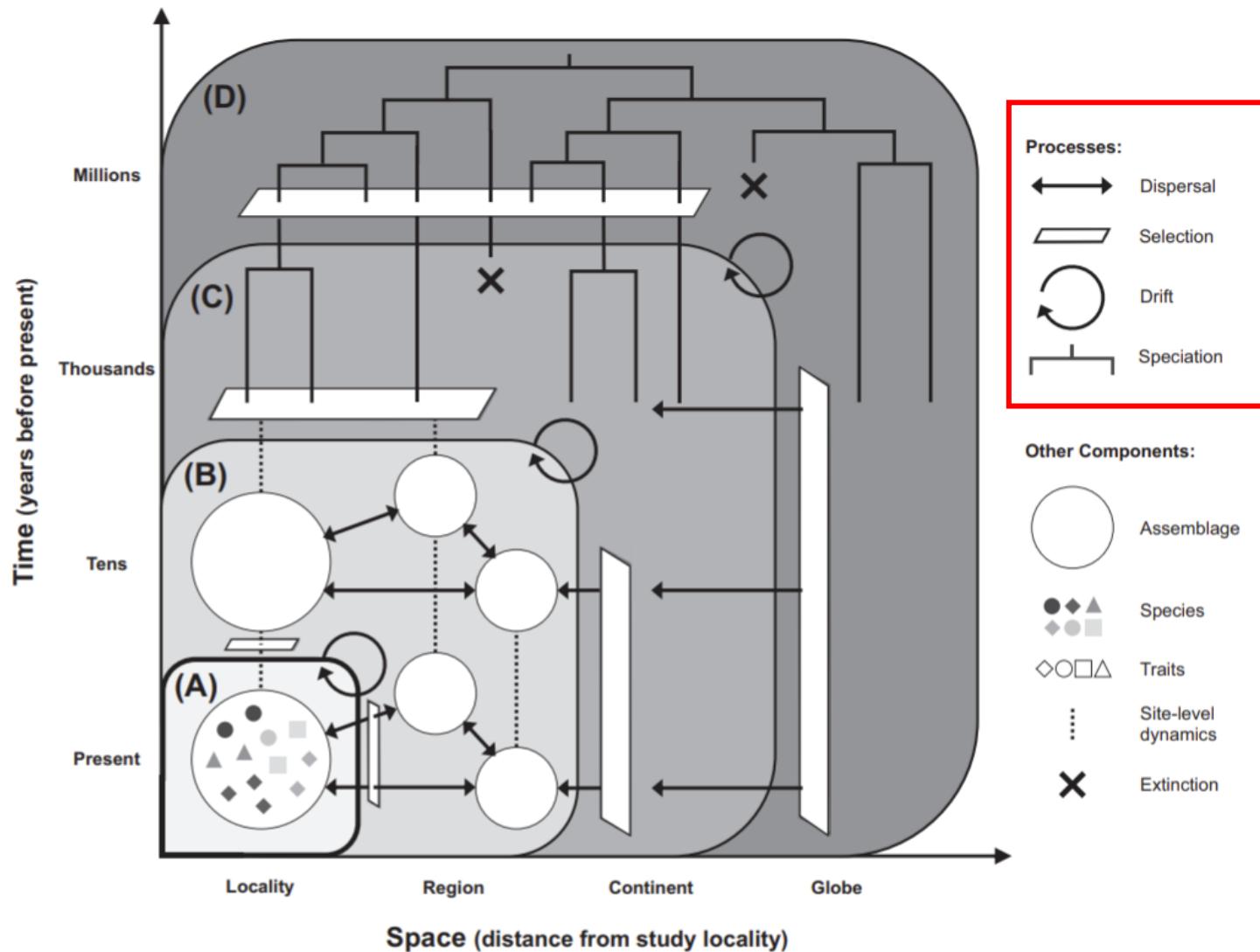
Kraft et al. (2015) <https://besjournals.onlinelibrary.wiley.com/doi/10.1111/1365-2435.12345>

Metacommunity theory



Leibold et al. (2004) <https://onlinelibrary.wiley.com/doi/abs/10.1111/j.1461-0248.2004.00608.x>
Chase et al. (2020) <https://nyaspubs.onlinelibrary.wiley.com/doi/10.1111/nyas.14378>

The Theory of Ecological Communities

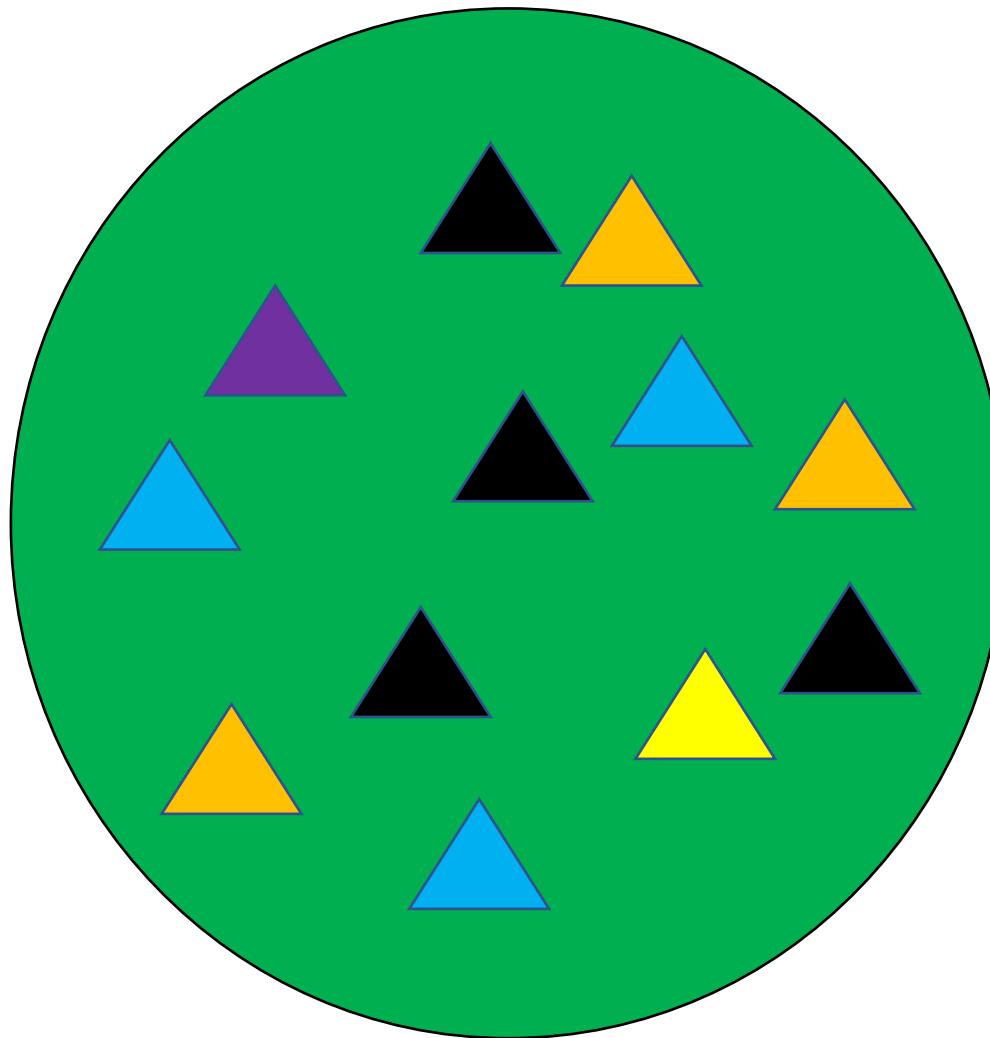


Vellend (2010) <https://www.researchgate.net/publication/44689600> Conceptual Synthesis in Community Ecology
Rapacciulo and Blois (2019) <https://onlinelibrary.wiley.com/doi/pdf/10.1111/ecog.04616>

More or less explicitly, most theoretical paradigms developed to address biodiversity patterns have to tackle the concept of spatial and temporal scales

Yes, but

The concept of ecological community



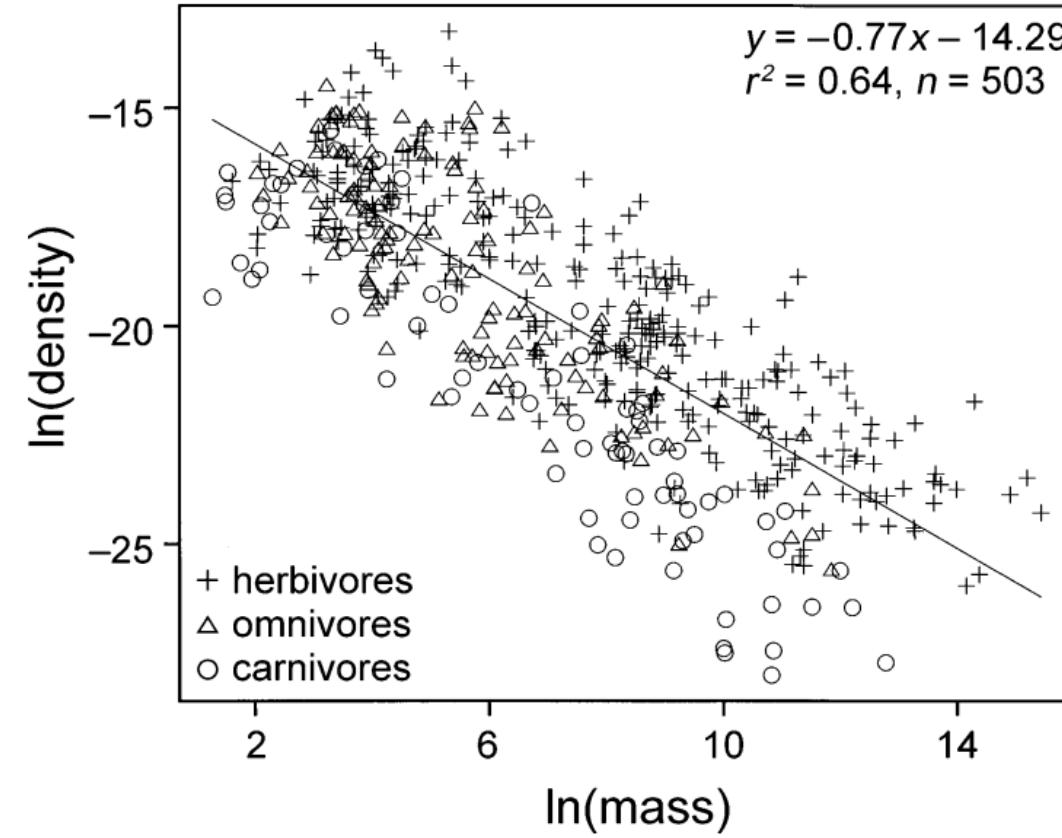
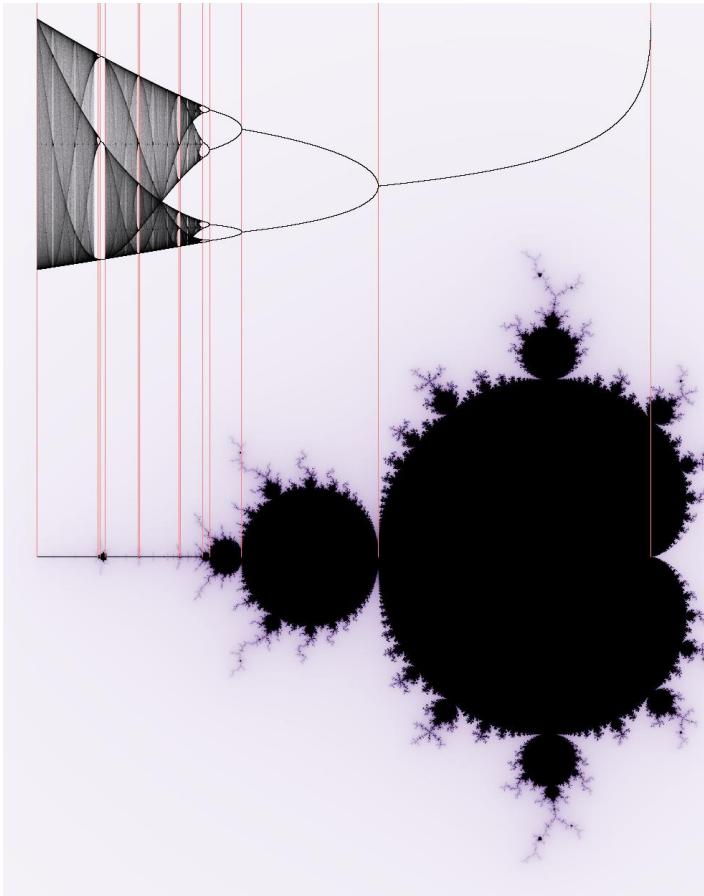
N species
at a site s ,
at time t

Disintegration of the ecological community

ABSTRACT: In this essay, I argue that the seemingly indestructible concept of the community as a local, interacting assemblage of species has hindered progress toward understanding species richness at local to regional scales. I suggest that the distributions of species within a region reveal more about the processes that generate diversity patterns than does the co-occurrence of species at any given point. The local community is an epiphenomenon that has relatively little explanatory power in ecology and evolutionary biology. Local coexistence cannot provide insight into the ecogeographic distributions of species within a region, from which local assemblages of species derive, nor can local communities be used to test hypotheses concerning the origin, maintenance, and regulation of species richness, either locally or regionally. Ecologists are moving toward a community concept based on interactions between populations over a continuum of spatial and temporal scales within entire regions, including the population and evolutionary processes that produce new species.

Also, some processes do not change with scales

E.g., fractals (self-similarity across different scales) and metabolic constraints

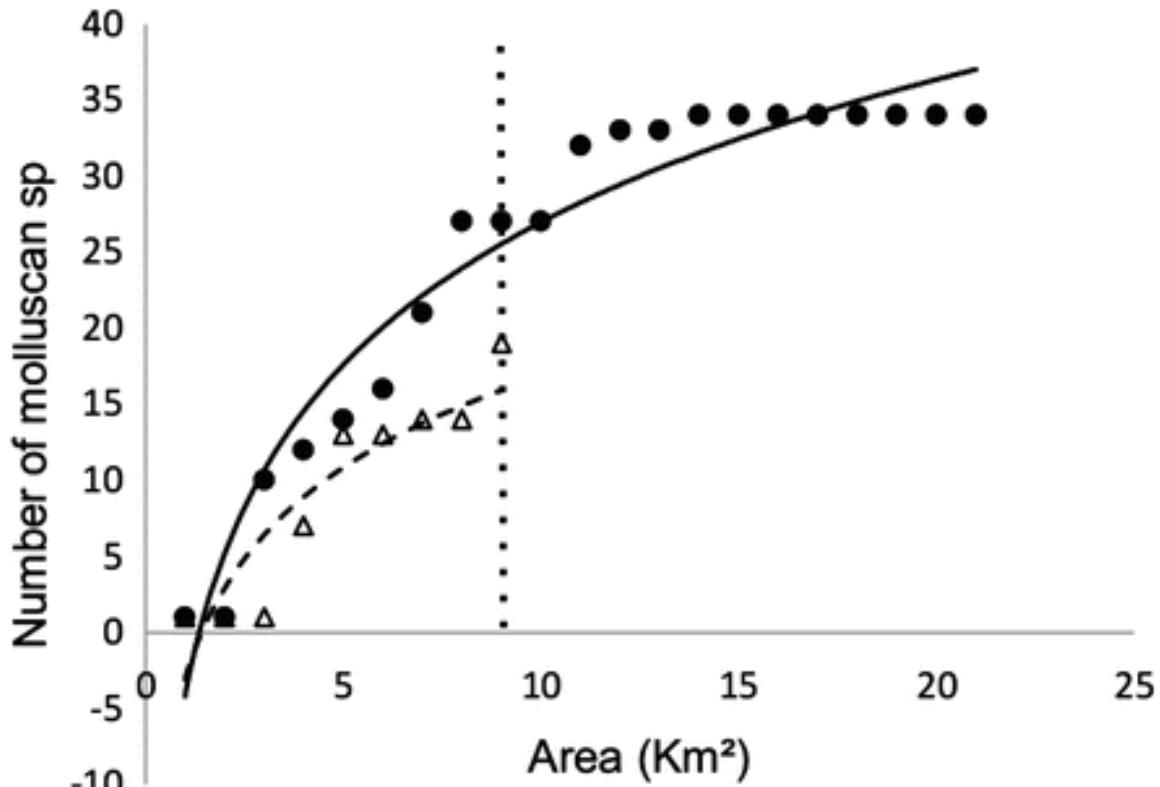


<https://commons.wikimedia.org/wiki/File:Verhulst-Mandelbrot-Bifurcation.jpg>

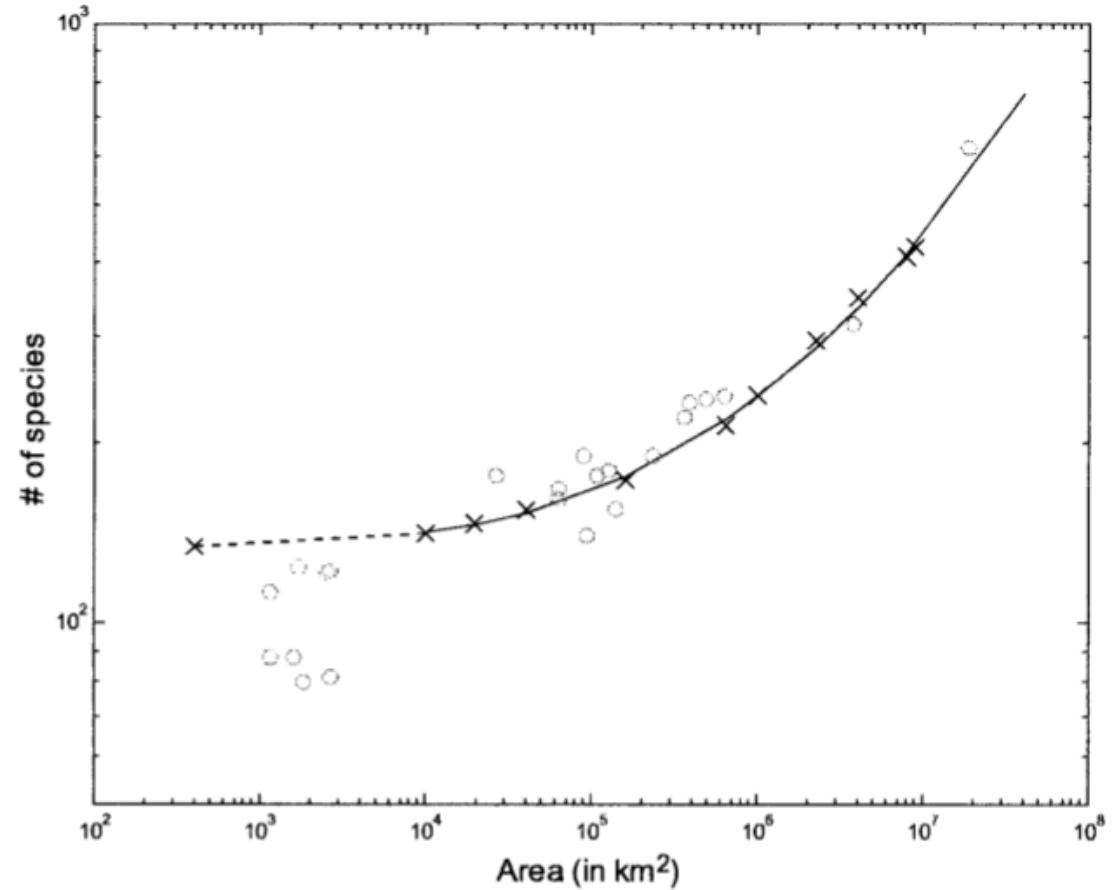
Brown et al. (2004) https://www.esa.org/history/Awards/papers/Brown_JH_MA.pdf
Halley et al. (2004) <https://pdodds.w3.uvm.edu/files/papers/others/everything/halley2004a.pdf>

Scales as a mediator of contrasting perspectives

Species-area relationship

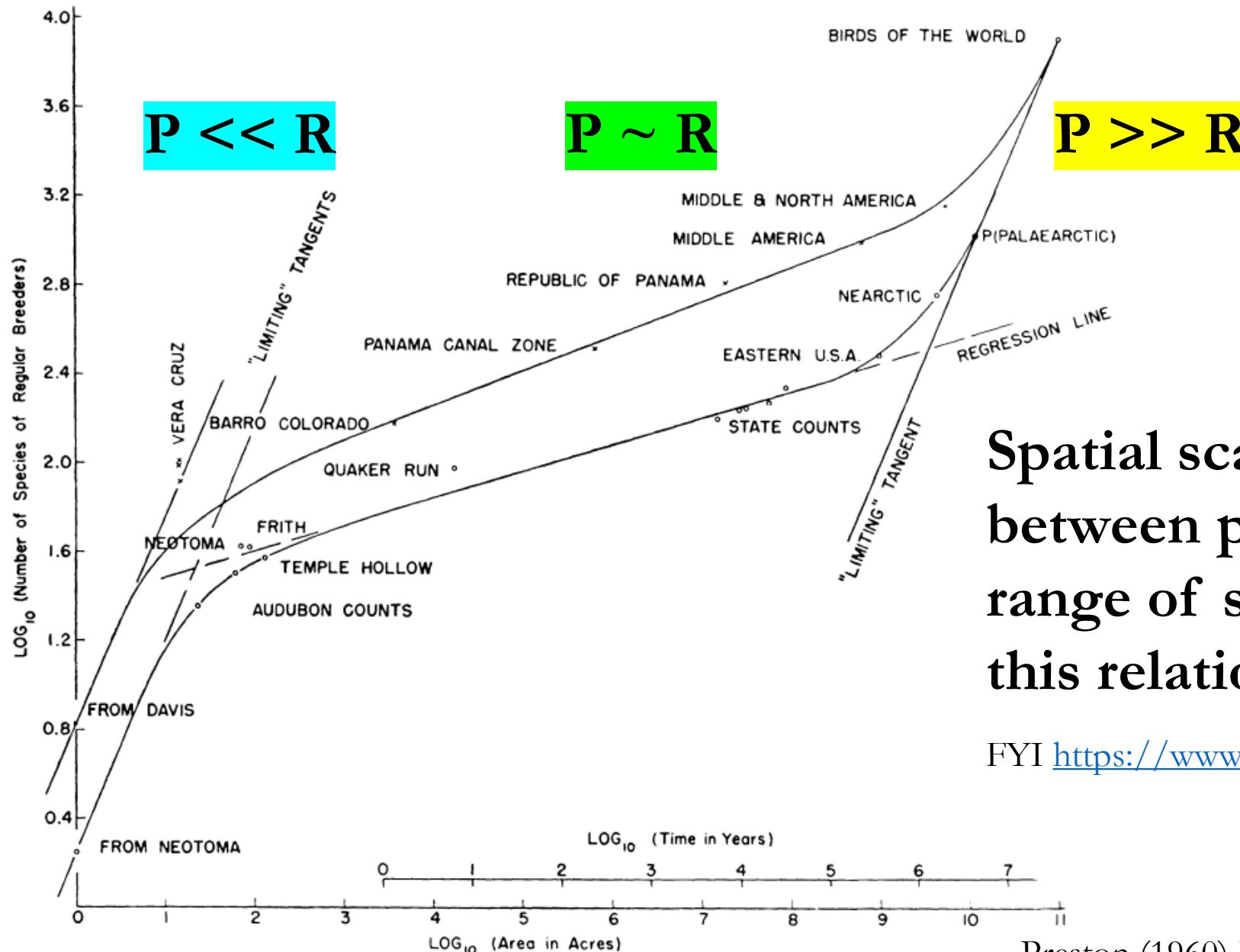


McGill and Collins



Pruden and Leighton (2018) https://link.springer.com/chapter/10.1007/978-3-319-73795-9_7

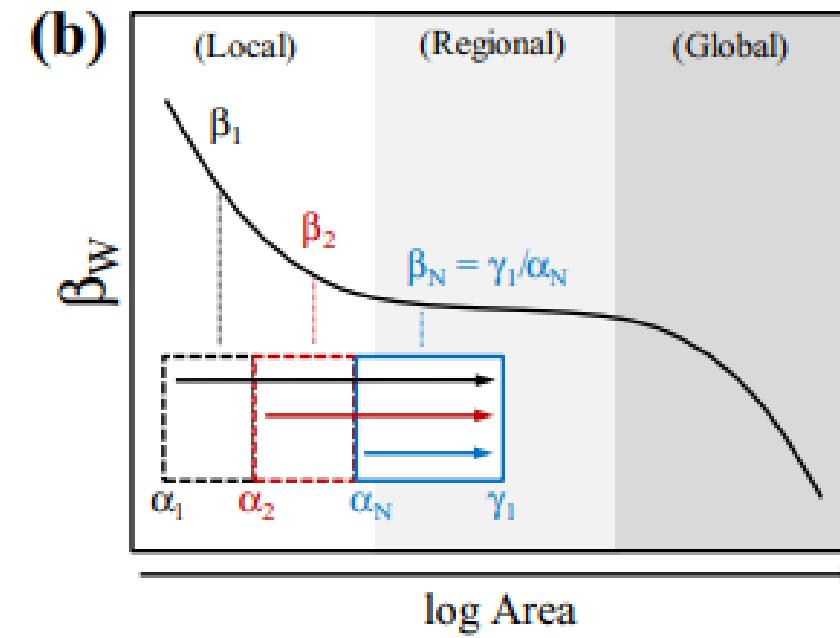
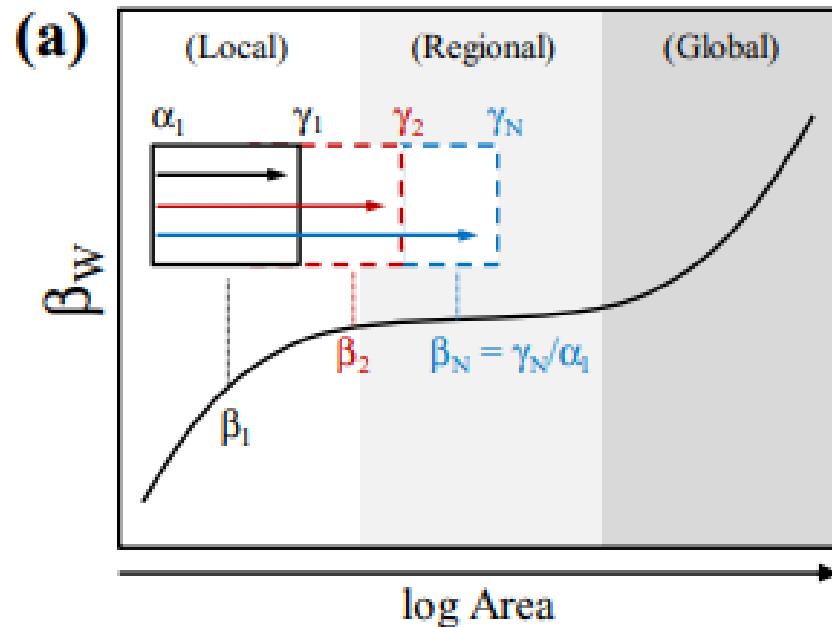
McGill and Collins (2003) <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.499.9375&rep=rep1&type=pdf>



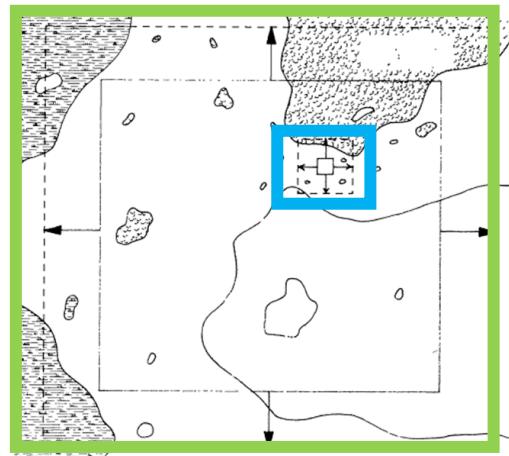
Spatial scale: the relationship between plot size (P) and the range of species (R) mediates this relationship

FYI <https://www.youtube.com/watch?v=YfbKYKPUzdo>

Beta diversity ($\alpha \times \beta = \gamma$)

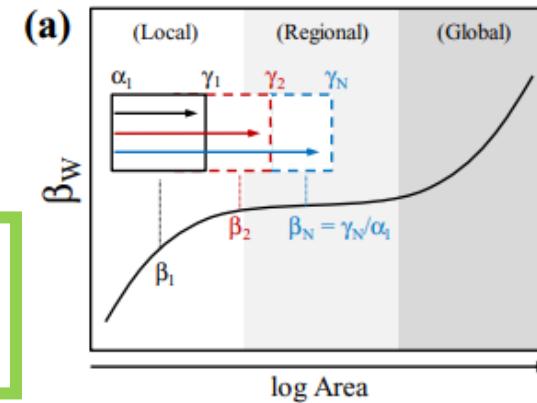


Wiens 1989 – grain vs extent



Whittaker's beta diversity
(multiplicative partitioning)

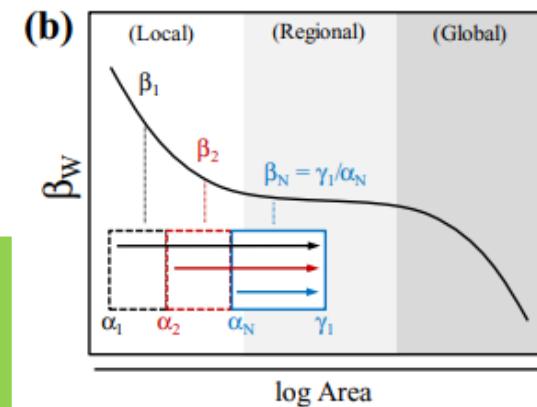
(a)



Fixed grain,
varying extent



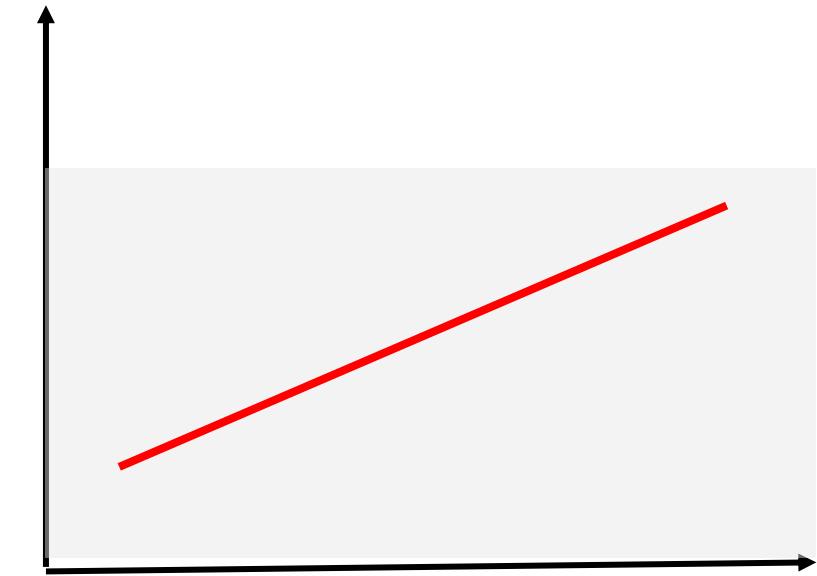
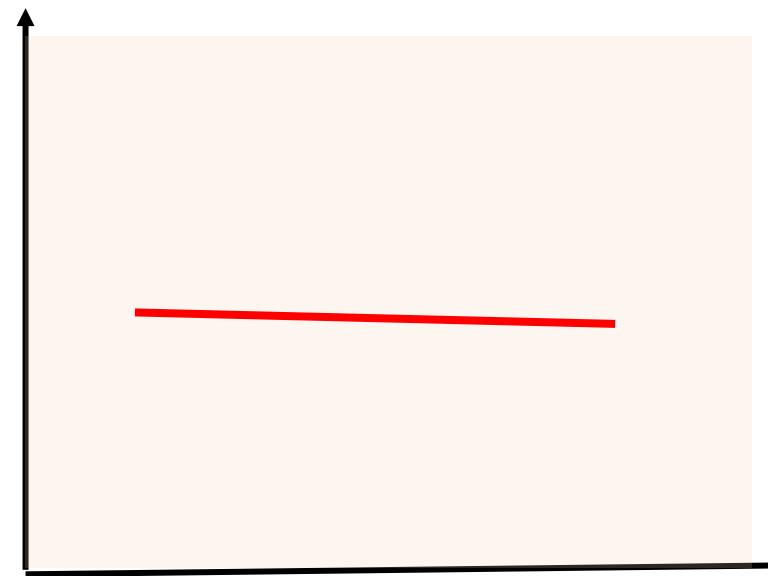
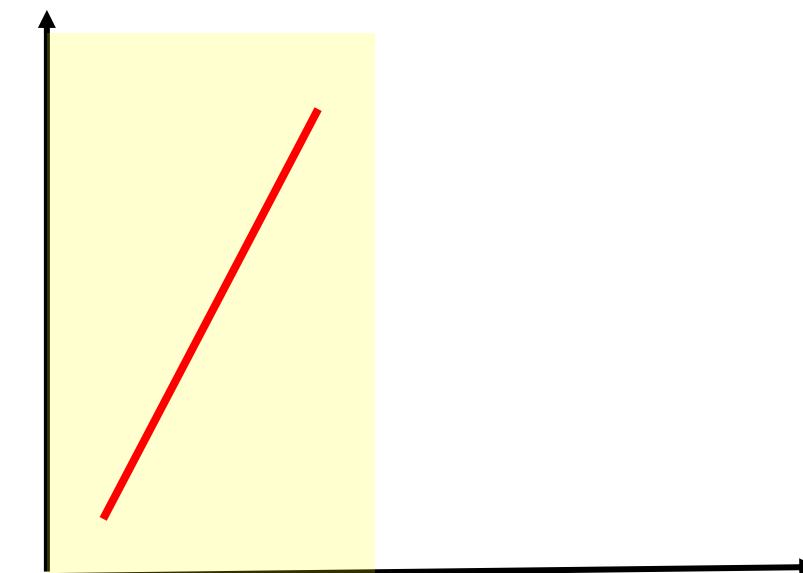
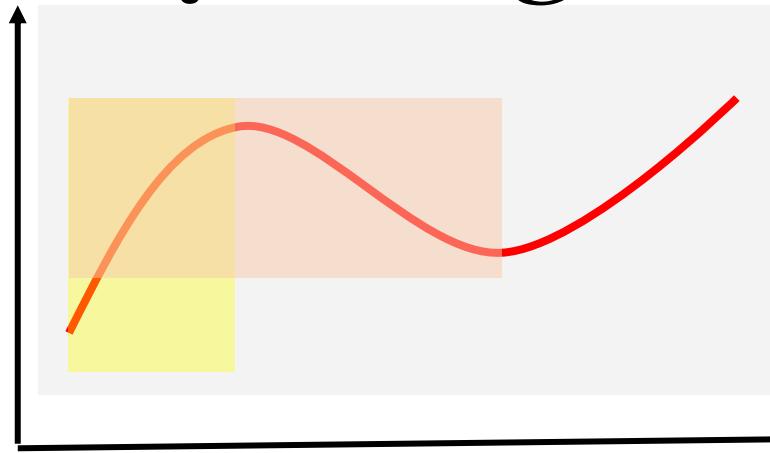
(b)



Varying grain,
fixed extent



Trends in biodiversity change in time



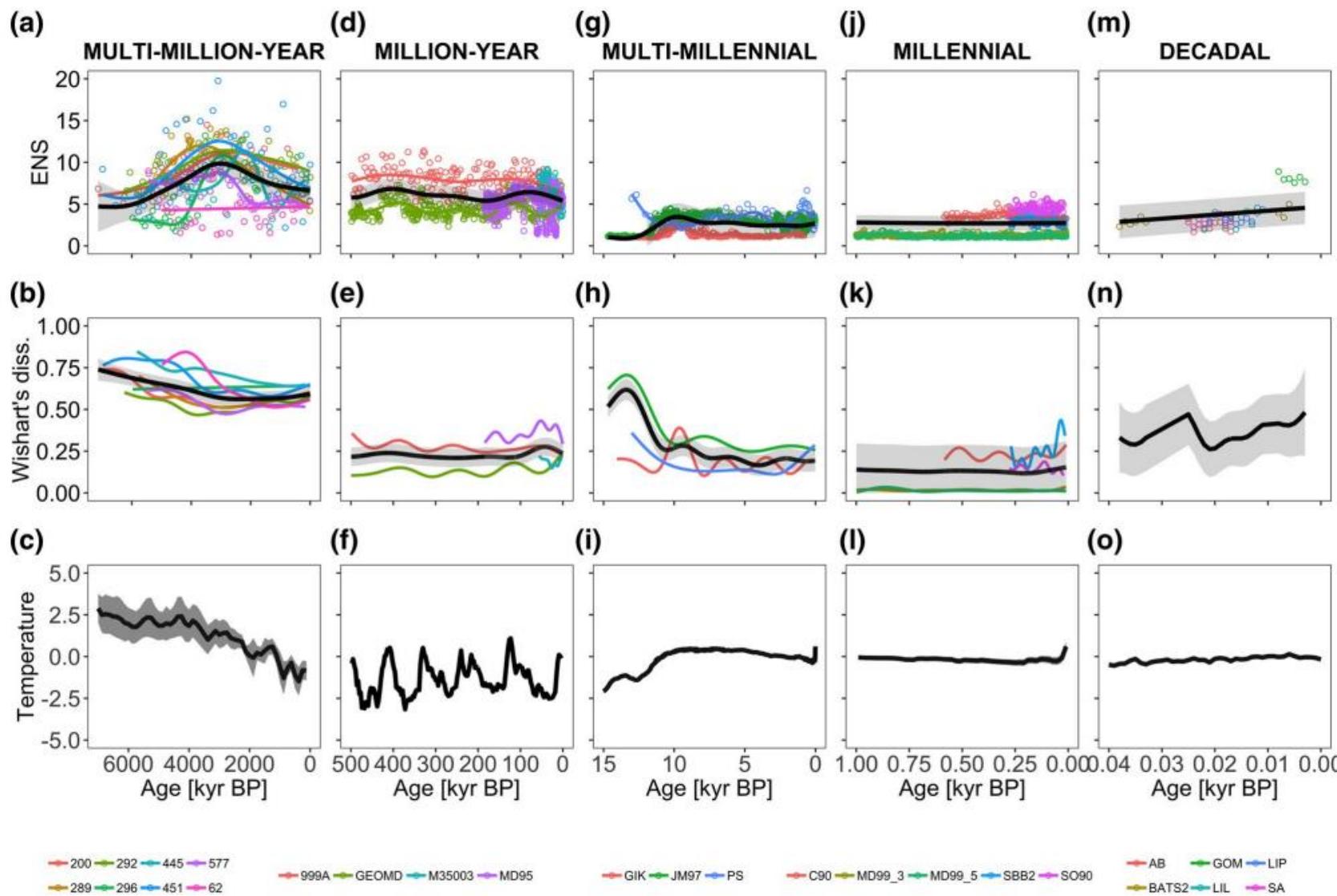


FIGURE 5 Temporal trends of foraminifera biodiversity over different time periods (as in Figure 2) as effective number of species (upper panels) and Wishart's dissimilarity (mid panels) in relation to temperature (bottom panels). Colours represent different sites, which are listed in the Supporting Information Appendix S1: Table S1. Black solid lines are general trends ($\pm 95\%$ confidence intervals) calculated using generalized additive models (GAMs) [Colour figure can be viewed at wileyonlinelibrary.com]

Temporal trends in diversity, abundance, and detectability

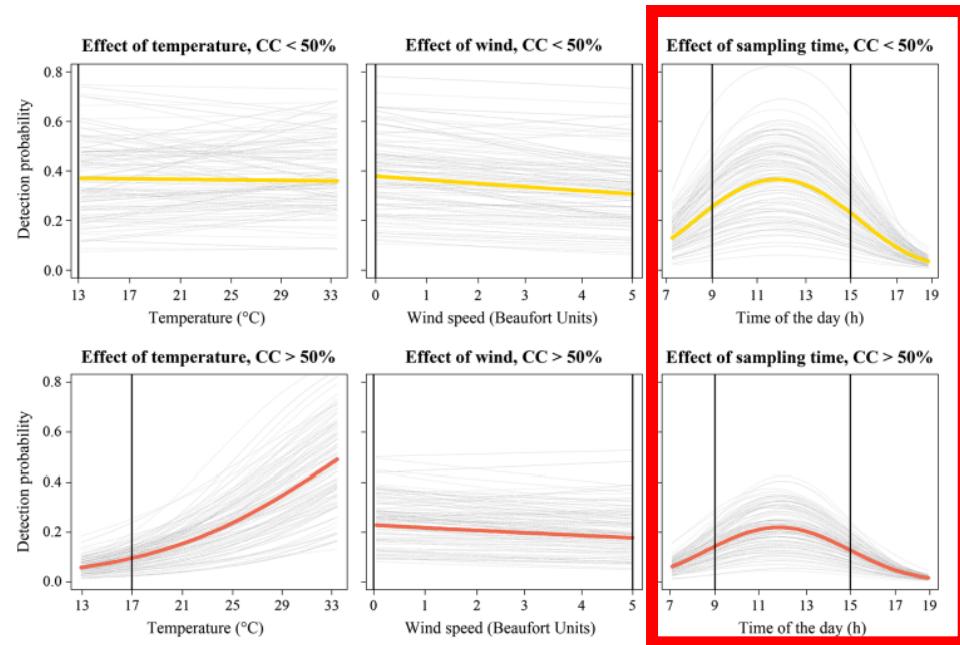


Fig. 3. Trends in detectability with temperature, hour of samples, and wind speed at cloud cover (CC) >50% (top row, in gold) and <50% (bottom row, in red). Predictions are calculated holding the other covariates at their average value (i.e., temperature ~ 24°C, wind speed ~ 1 BU, time of the day ~ noon). Black vertical lines represent the sampling criteria recommended for PW for monitoring schemes (i.e., temperature >13°C with cloud cover <50% and >17°C when cloud cover >50%; wind speed <5 BU; sampling hour between 9:00 and 15:00).

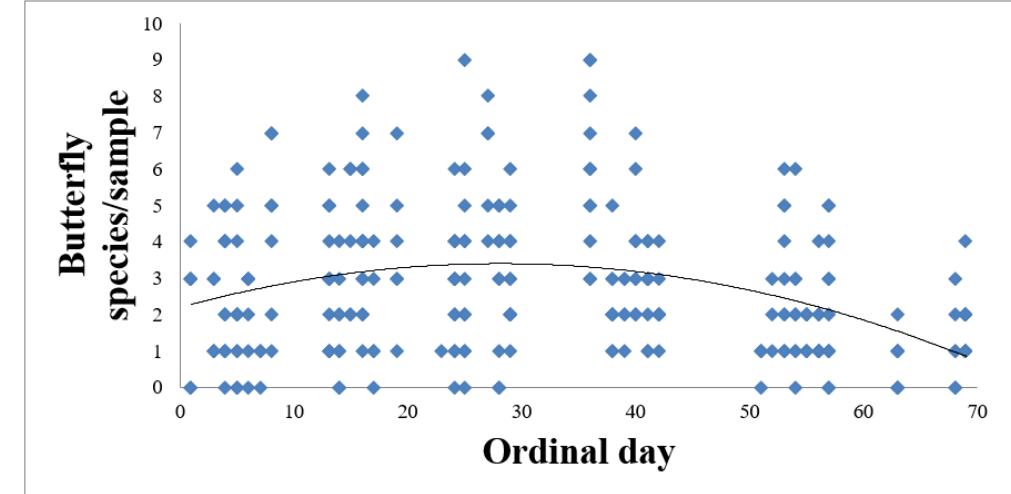
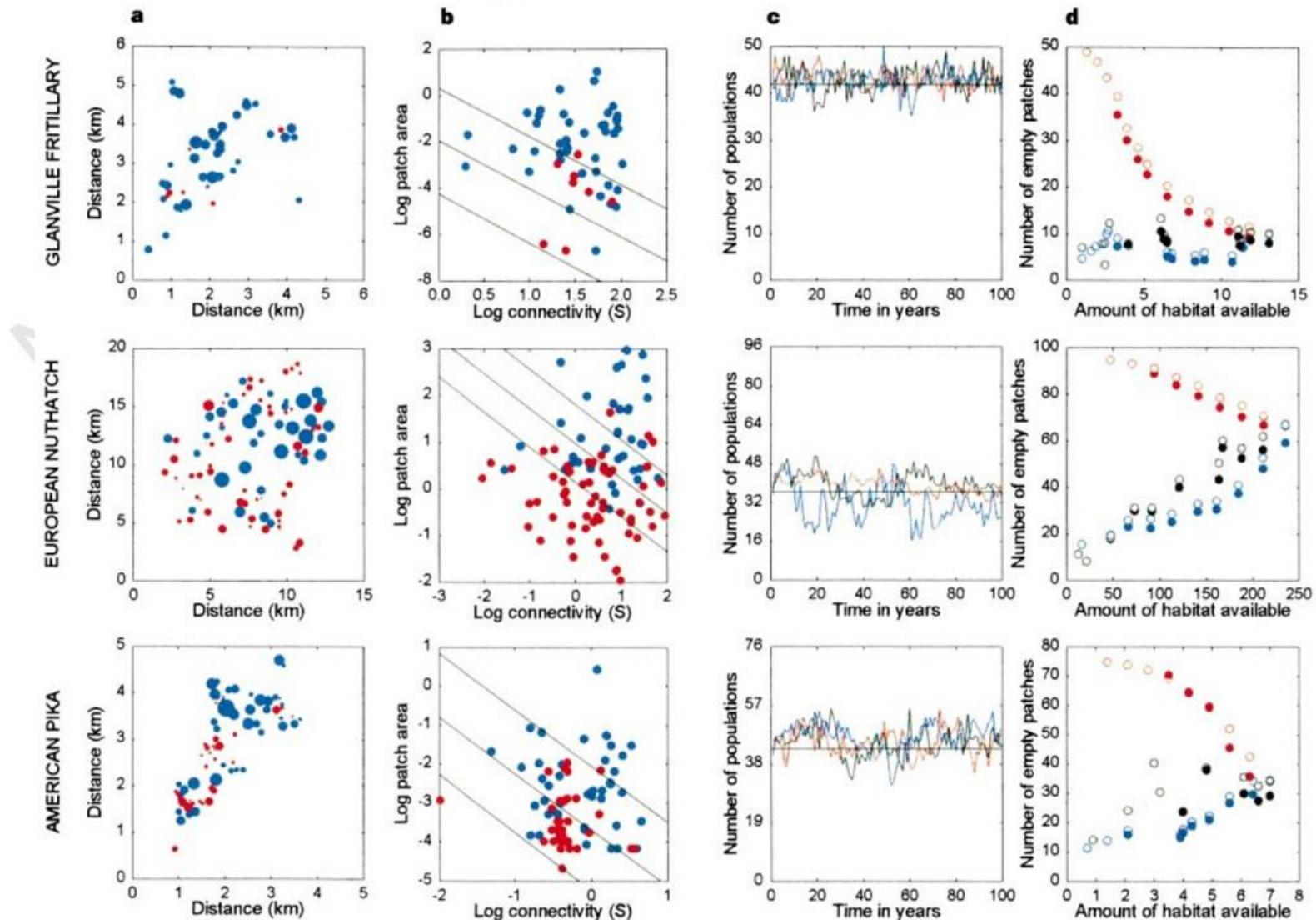


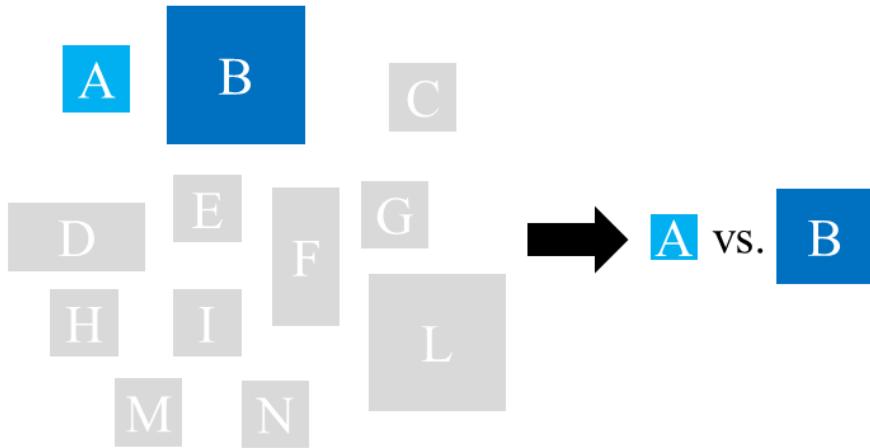
Figure 6: Number of butterfly species observed per sample ($n = 275$) between June 14th (ordinal day = 1) and August 24th (ordinal day = 69). Diversity of butterflies peaks around the second week of July. A quadratic function is fitted to represent the unimodal diversity trend.

Metacommunity dynamics

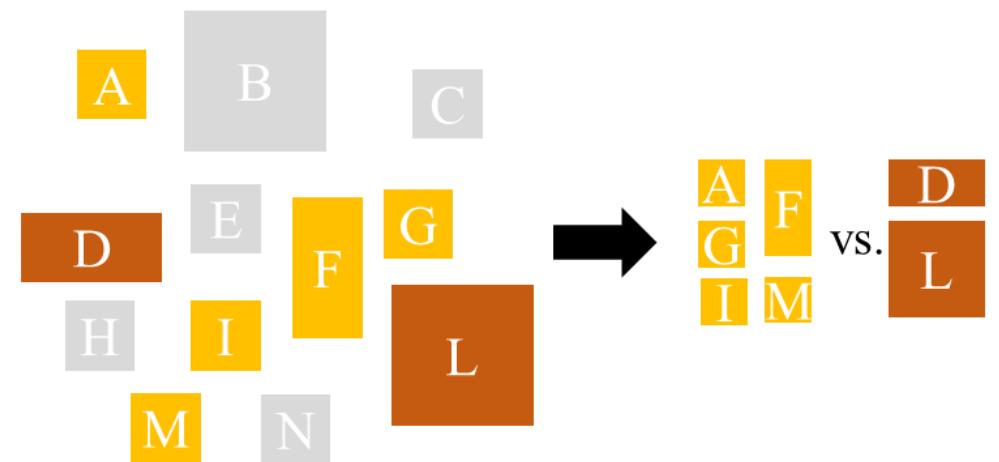


Extinction risk and patch size across spatial scales

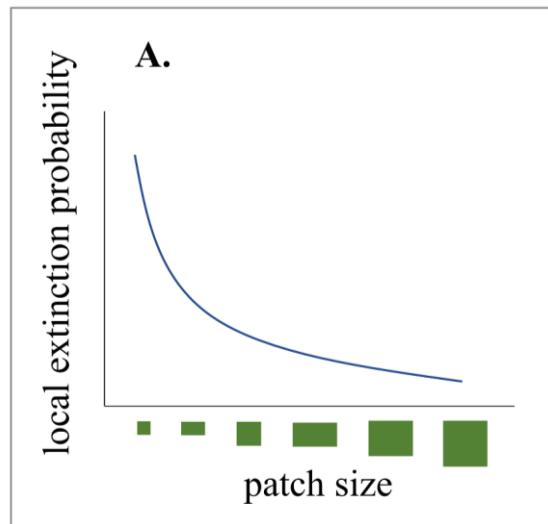
Patch scale



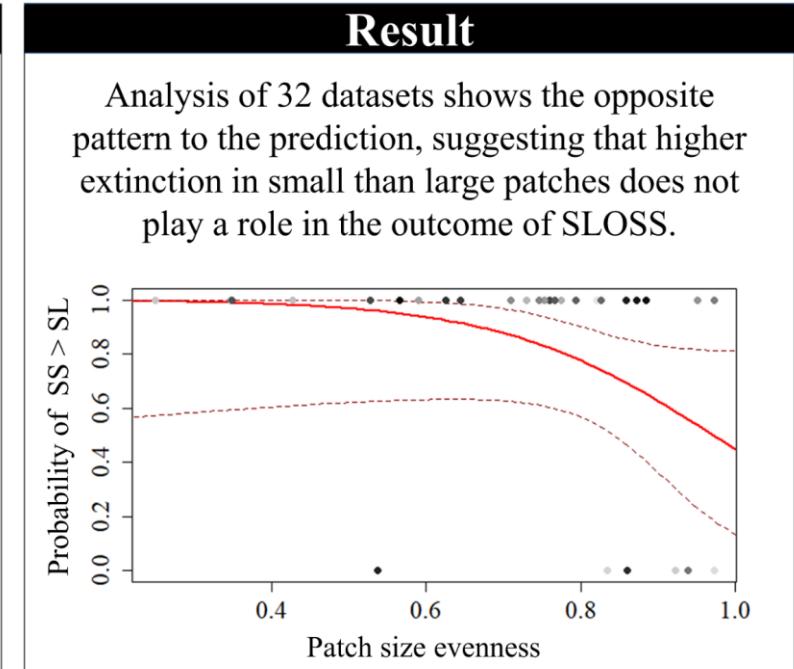
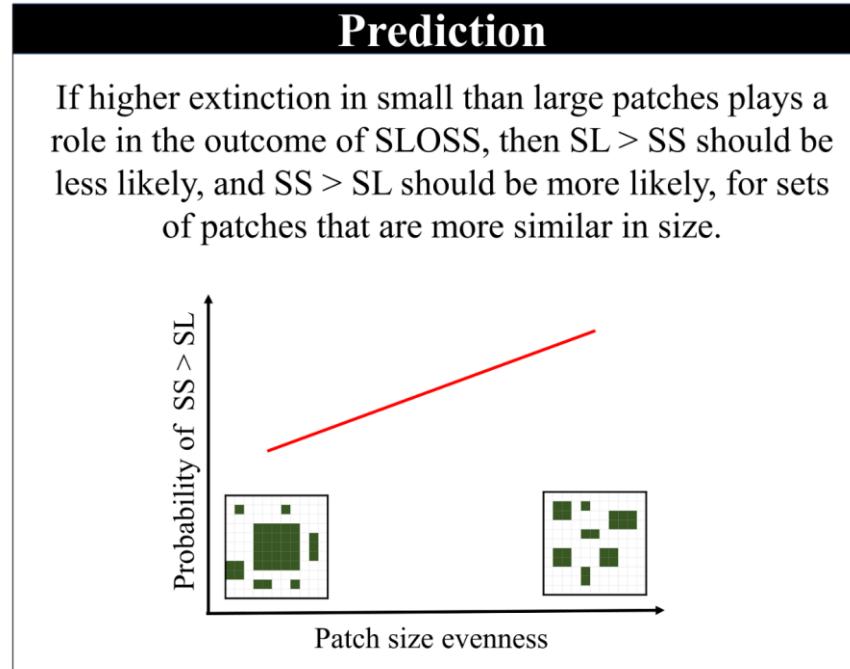
Landscape scale



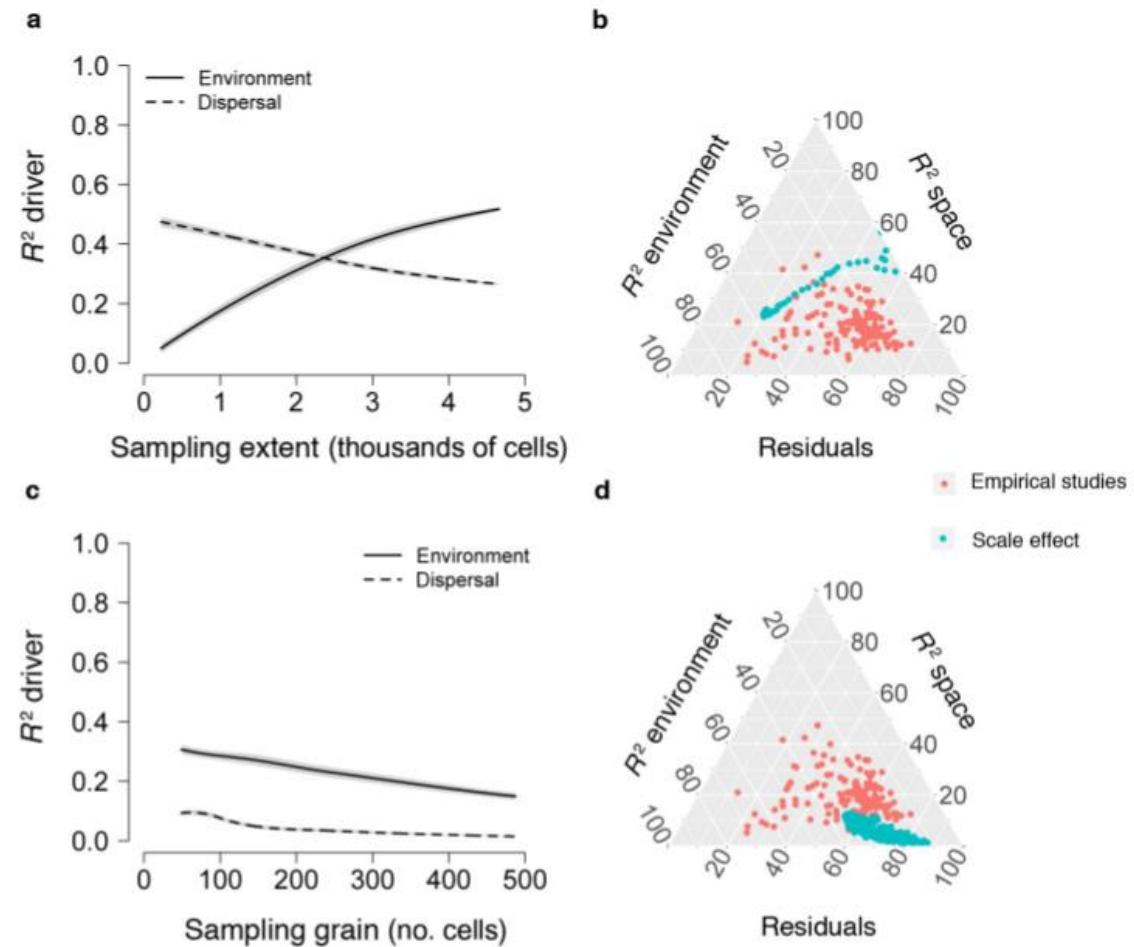
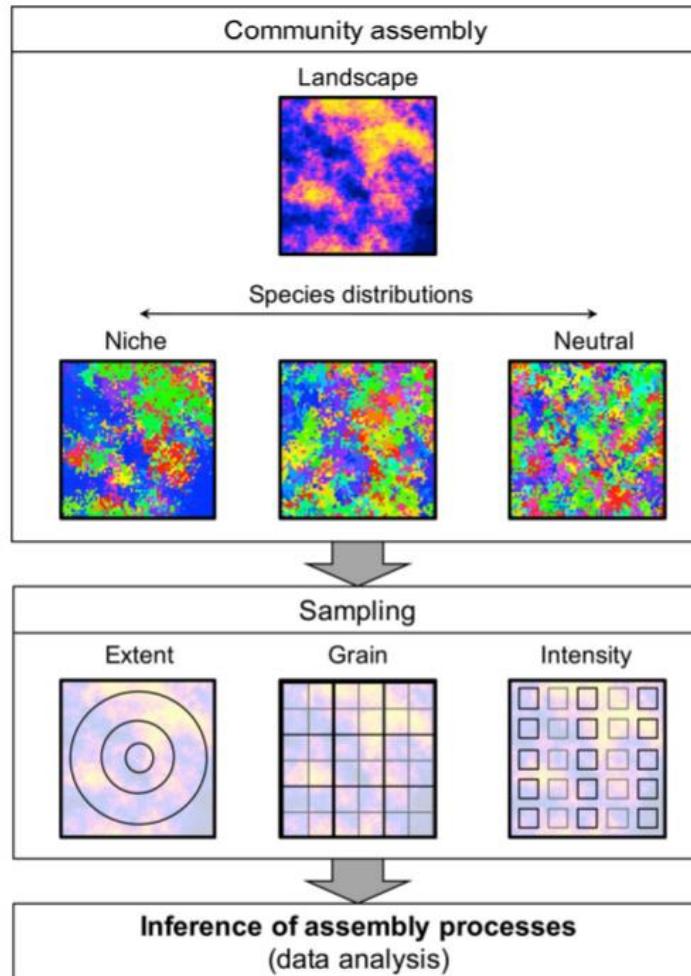
Patch scale



Landscape scale



Assembly processes in metacommunities



Scales explain different results observed when answering the same questions in different systems

Applications in ecology and conservation

Productivity-diversity relationship

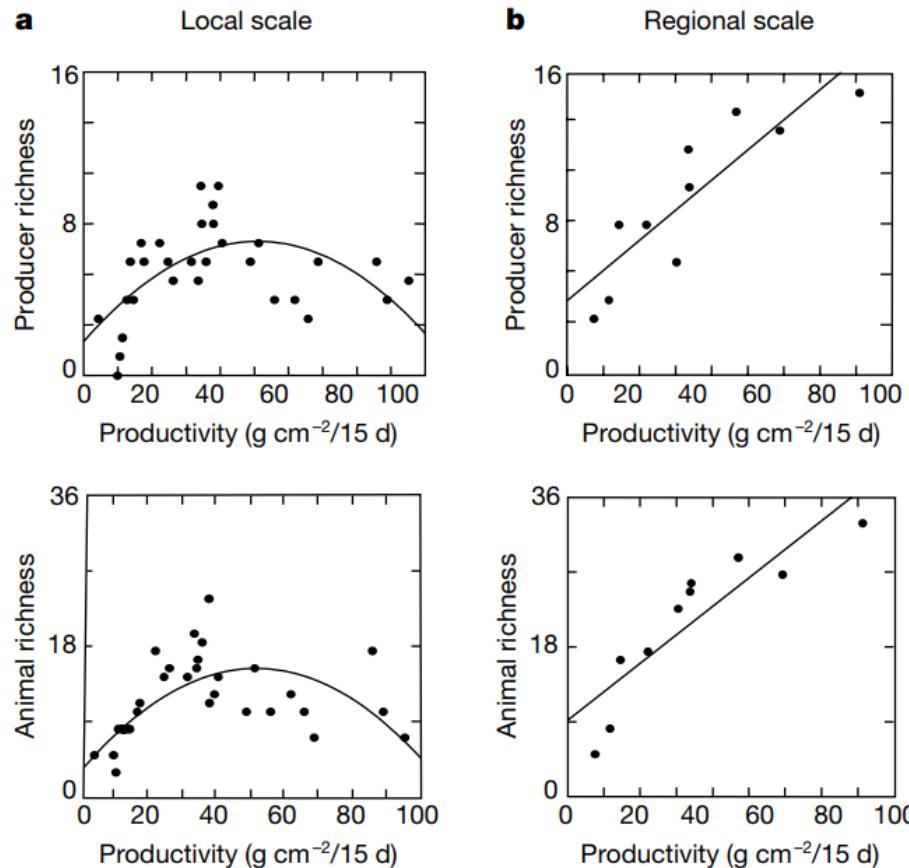
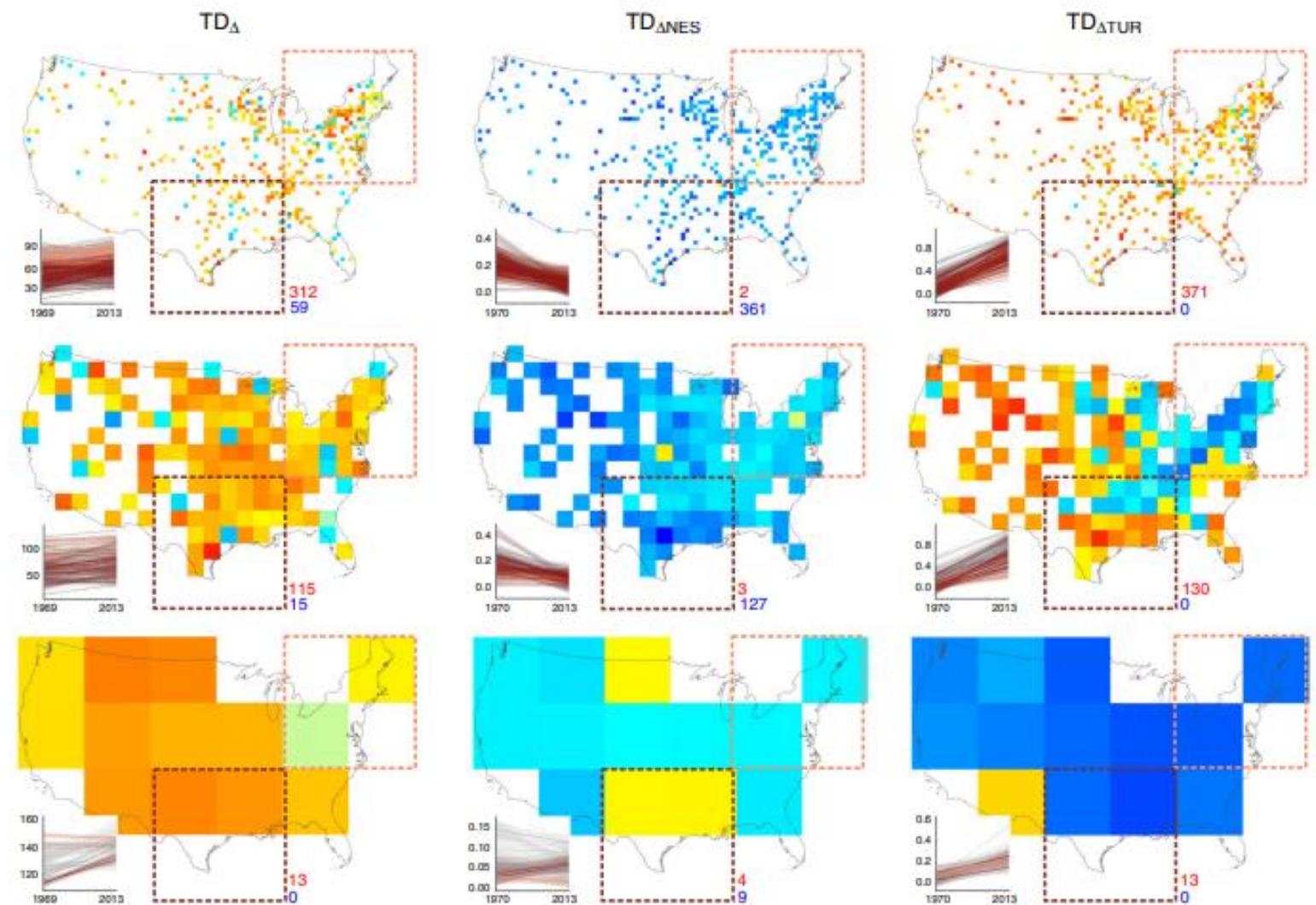


Figure 1 Results from the survey of pond species diversity relative to *in situ* primary productivity at local and regional scales. Top panels, producers (vascular plants and macroalgae); bottom panels, benthic animals (insects, crustaceans, amphibians, and so on). **a**, Local, within-pond, species diversity ($N = 30$). Both relationships are significantly unimodel ($P < 0.05$) (see text for explanation of statistical methodology). The line

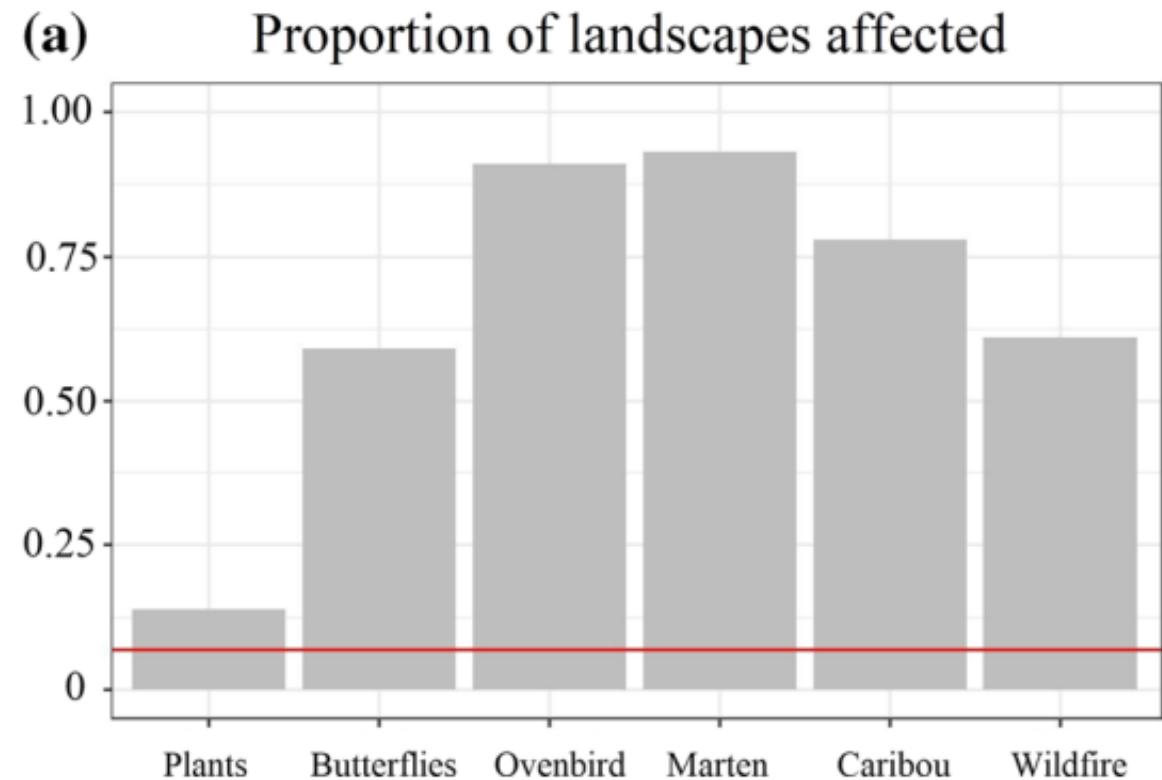
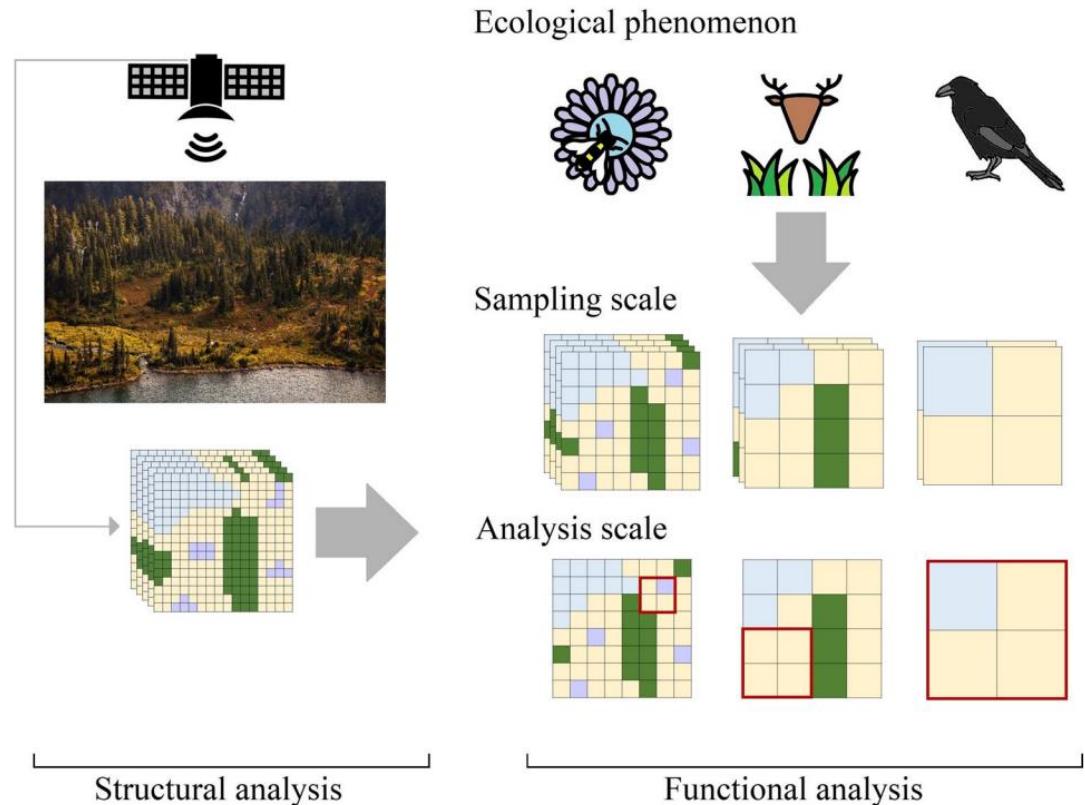
represents the estimated quadratic function. **b**, Regional, within-watershed, species diversity. For both producers (regression: $N = 10, R^2 = 0.74, P < 0.001$) and benthic animals (regression: $N = 10, R^2 = 0.75, P < 0.001$) regional species diversity was linearly related to primary productivity.

Trends in biodiversity change with spatial scales

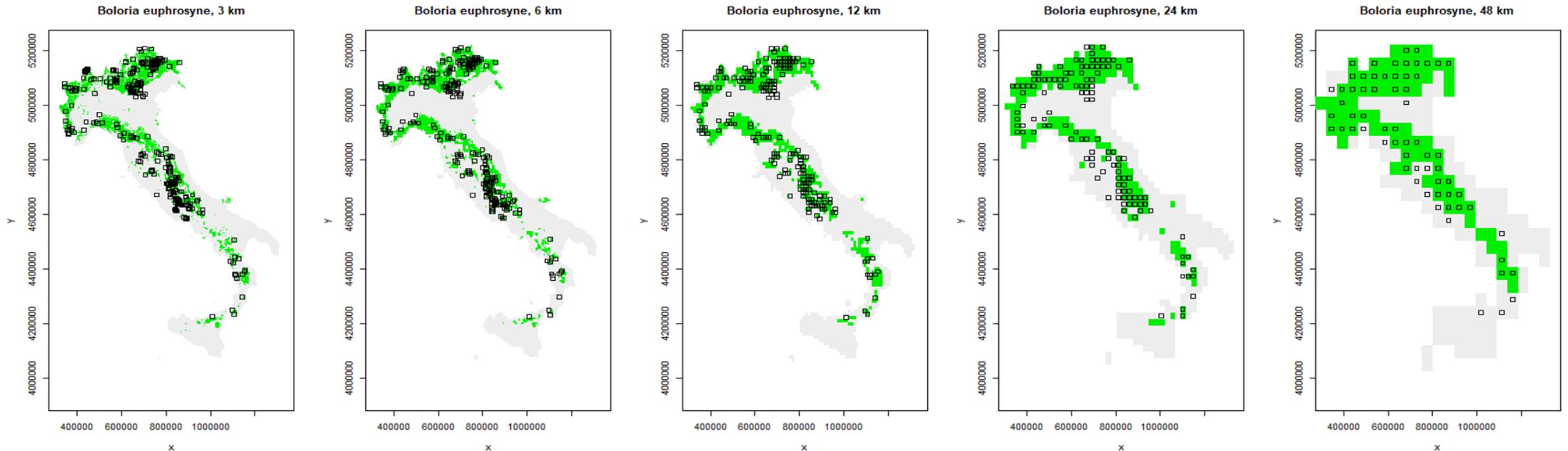
... Scales shown, from top to bottom, are 50 km, 200 km, 800 km. Fitted positive and negative slopes indicate increases and declines in taxonomic diversity ($\text{TD}\Delta$, left panel), temporal nestedness of taxonomic diversity ($\text{TD}\Delta\text{NES}$, middle panel), and temporal turnover of taxonomic diversity ($\text{TD}\Delta\text{TUR}$, right panel). Red and blue numbers indicate the number of grid cells for which these trends were positive and negative, respectively. Insets show the fitted slopes between the respective measure of change (y-axis) and time (x-axis; calendar year) for the cell inside the brown (brown lines) or beige (beige lines) quadratic regions.

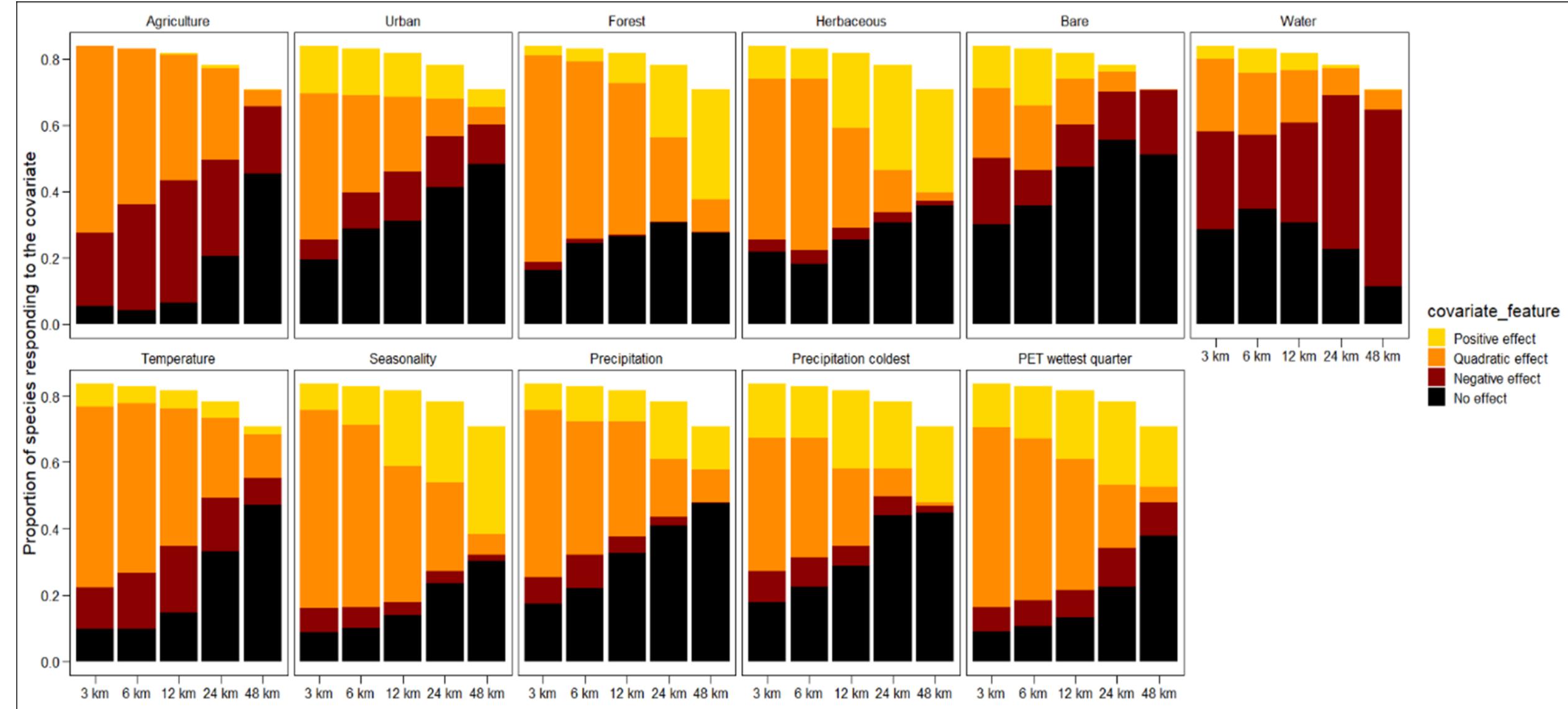


Thematic resolution affects habitat loss measures



Grain affects the relationship between species distribution and the environment





Conclusions

It does matter – what can we do?

- Always think about the ecological process of interest
 - E.g., for conservation, are you interested in large scale, regional patterns, or in *in situ* protection and management of species?
 - Why are you proposing an analysis at a given spatial scale, temporal scale?
 - Taxonomic scales, other scales?
- How can scales affect your conclusion, and why do you think that is?
- Are you interested in processes that are typically dynamics, or less so?
- Scaling itself remains a topic of interest after 50+ years

