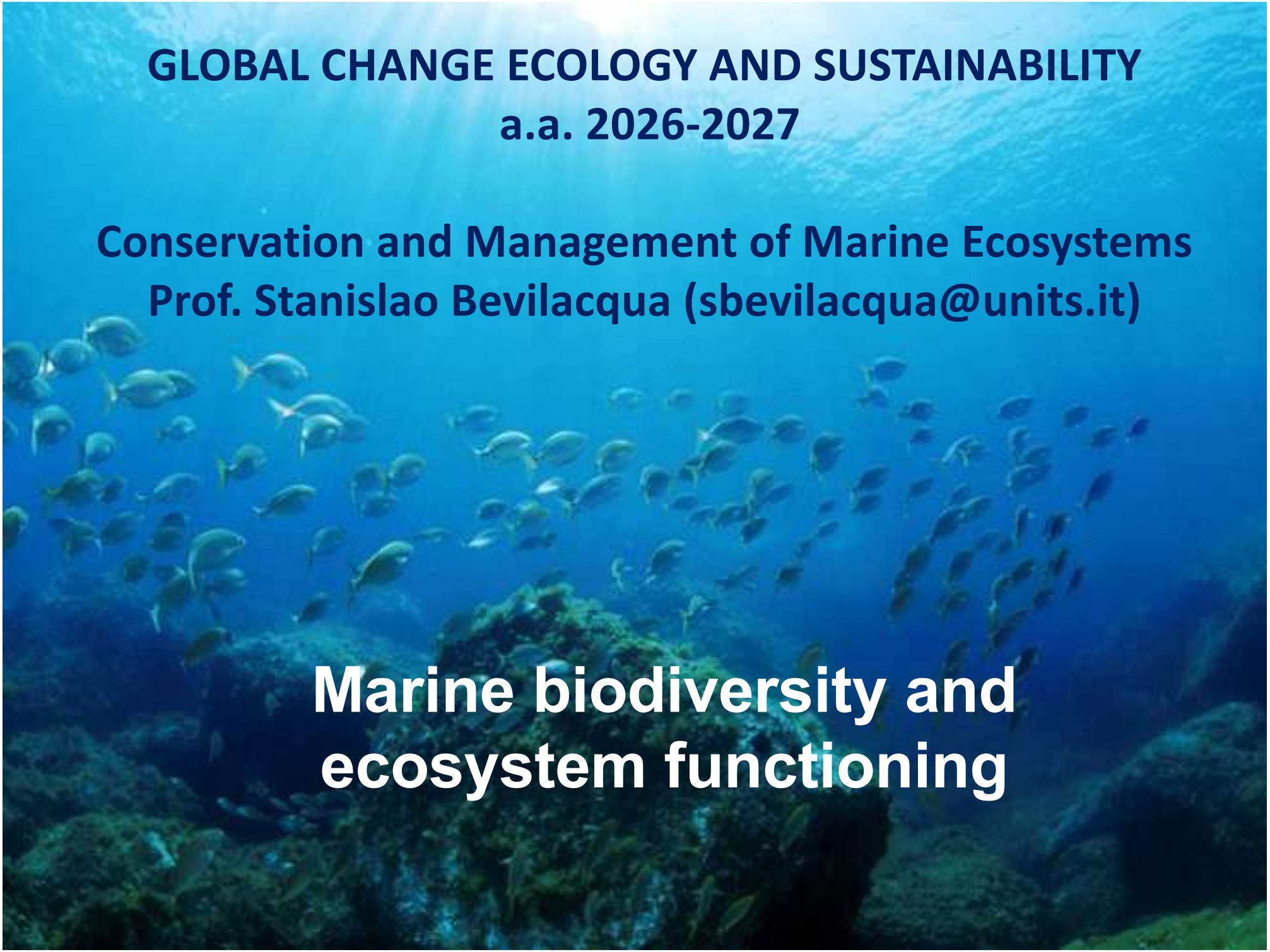
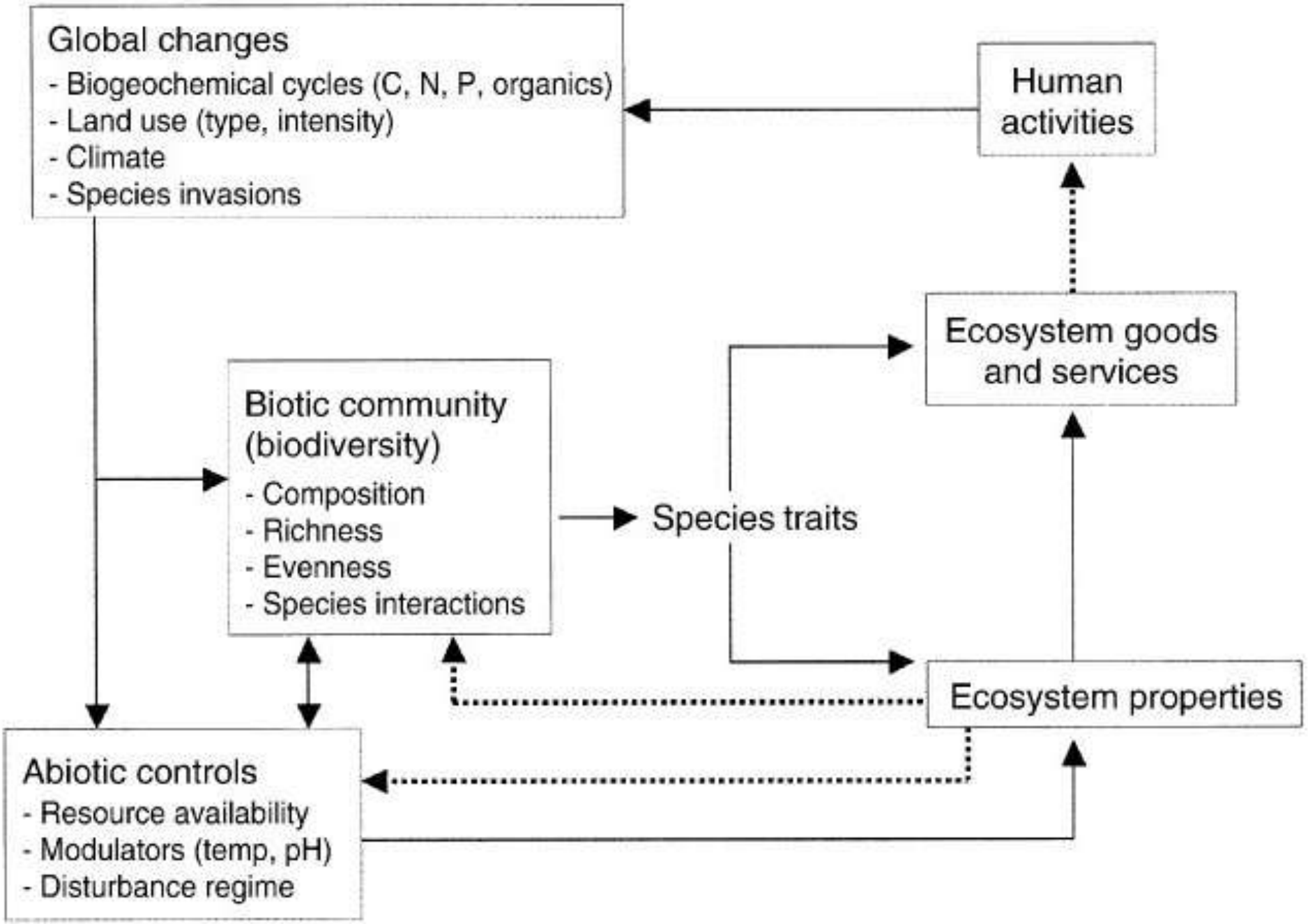


GLOBAL CHANGE ECOLOGY AND SUSTAINABILITY
a.a. 2026-2027

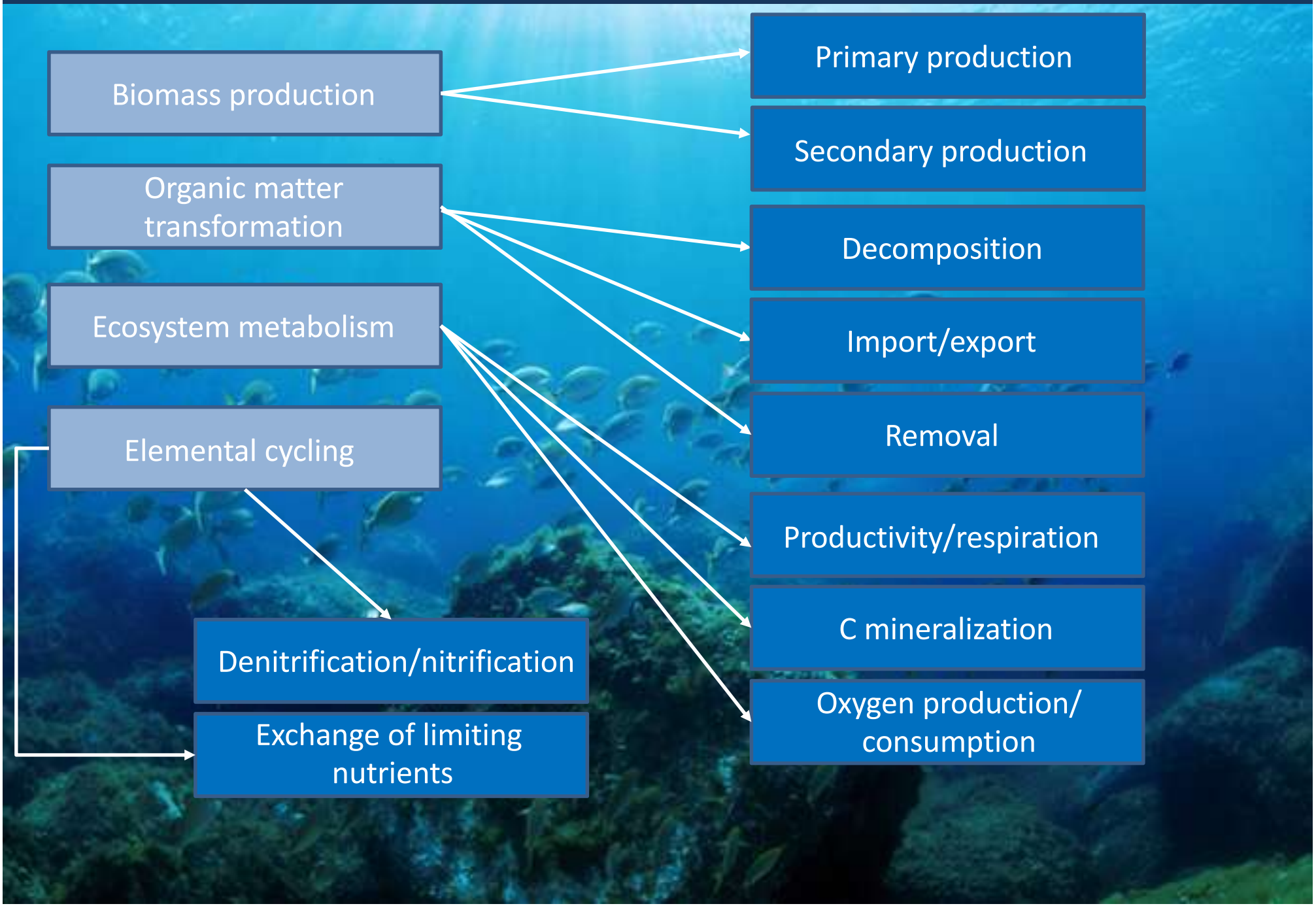
Conservation and Management of Marine Ecosystems
Prof. Stanislao Bevilacqua (sbevilacqua@units.it)

Marine biodiversity and ecosystem functioning

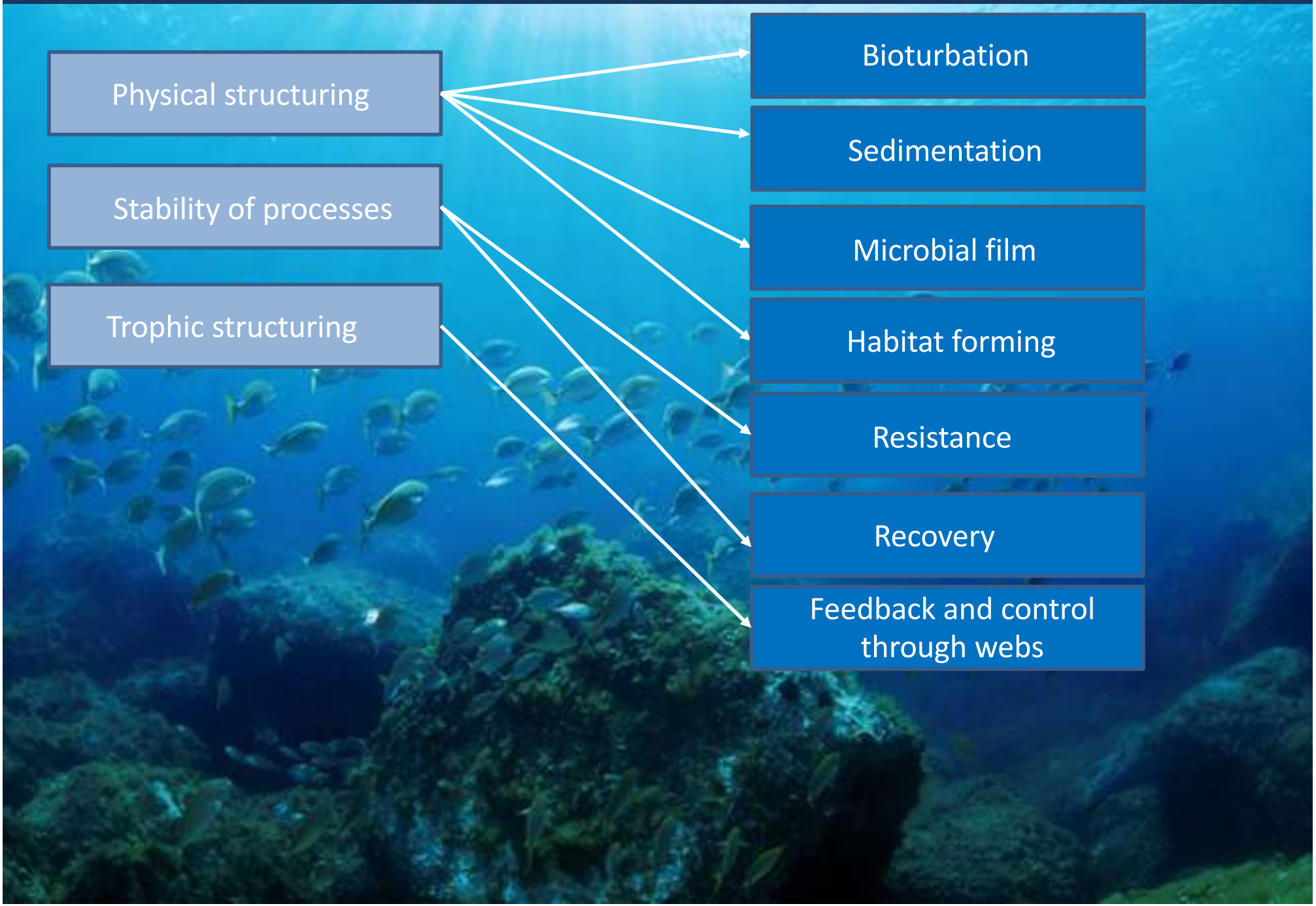
Ecosystem functions: mechanisms



Ecosystem functions



Ecosystem functions



Functional traits, functional roles

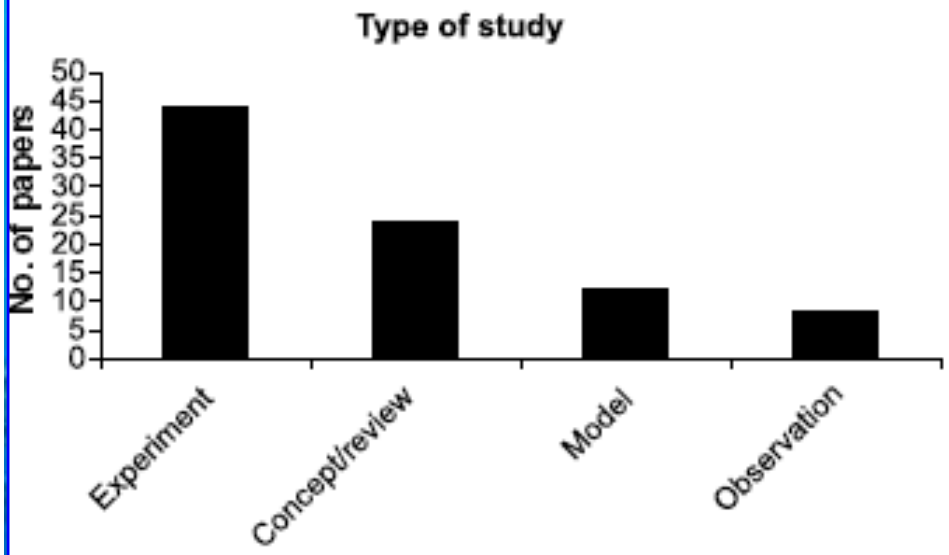
- Ecosystem functioning depends on the interplay between environmental processes and biological components. This last part is regulated by species features (phenotype, behaviour, life cycles, biochemical pathways, trophic role and all others traits identifying species).

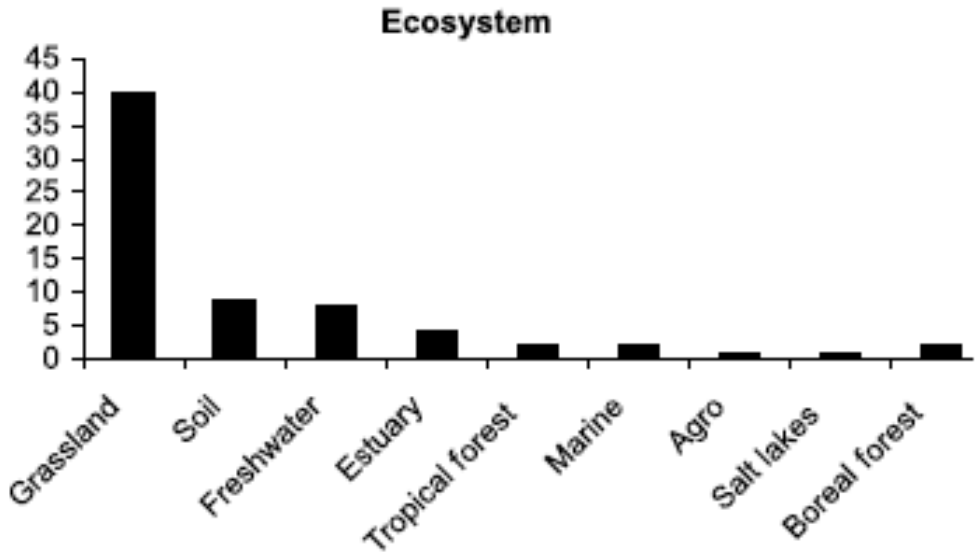
- All functions are mediated by species abundance, so that the magnitude of related functional processes may be proportional to abundance. However, for some species, important processes may be exerted even at low abundance (ex. keystone predators)

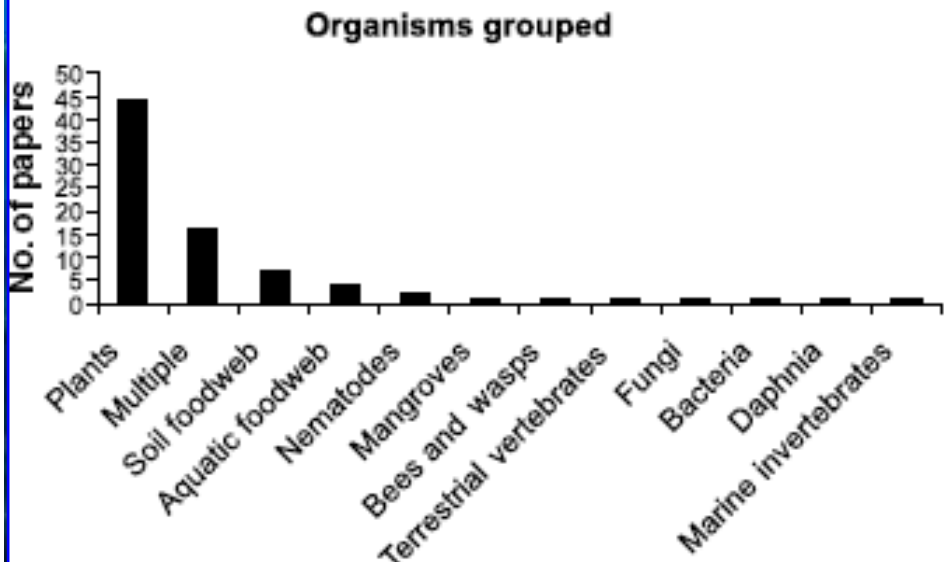
- Functional traits may vary among individuals, and also depending on the life stage, or environmental or geographic contingencies.

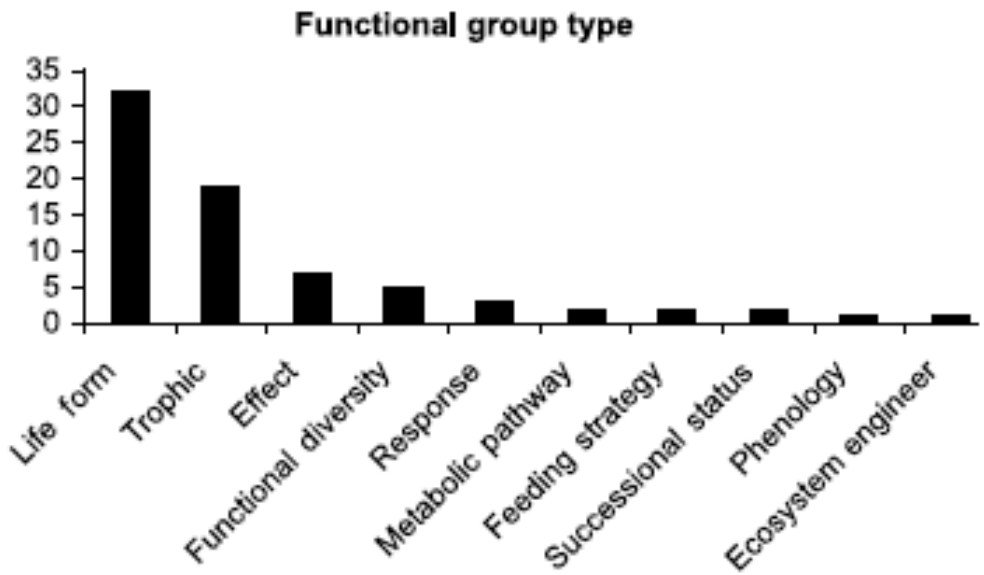
All these factors complicate our understanding of functioning. In the marine realm, moreover, the limited knowledge of species, and particularly of invertebrates, further hampers our ability to study how species affect functioning of marine systems.

Limited studies in the marine environment



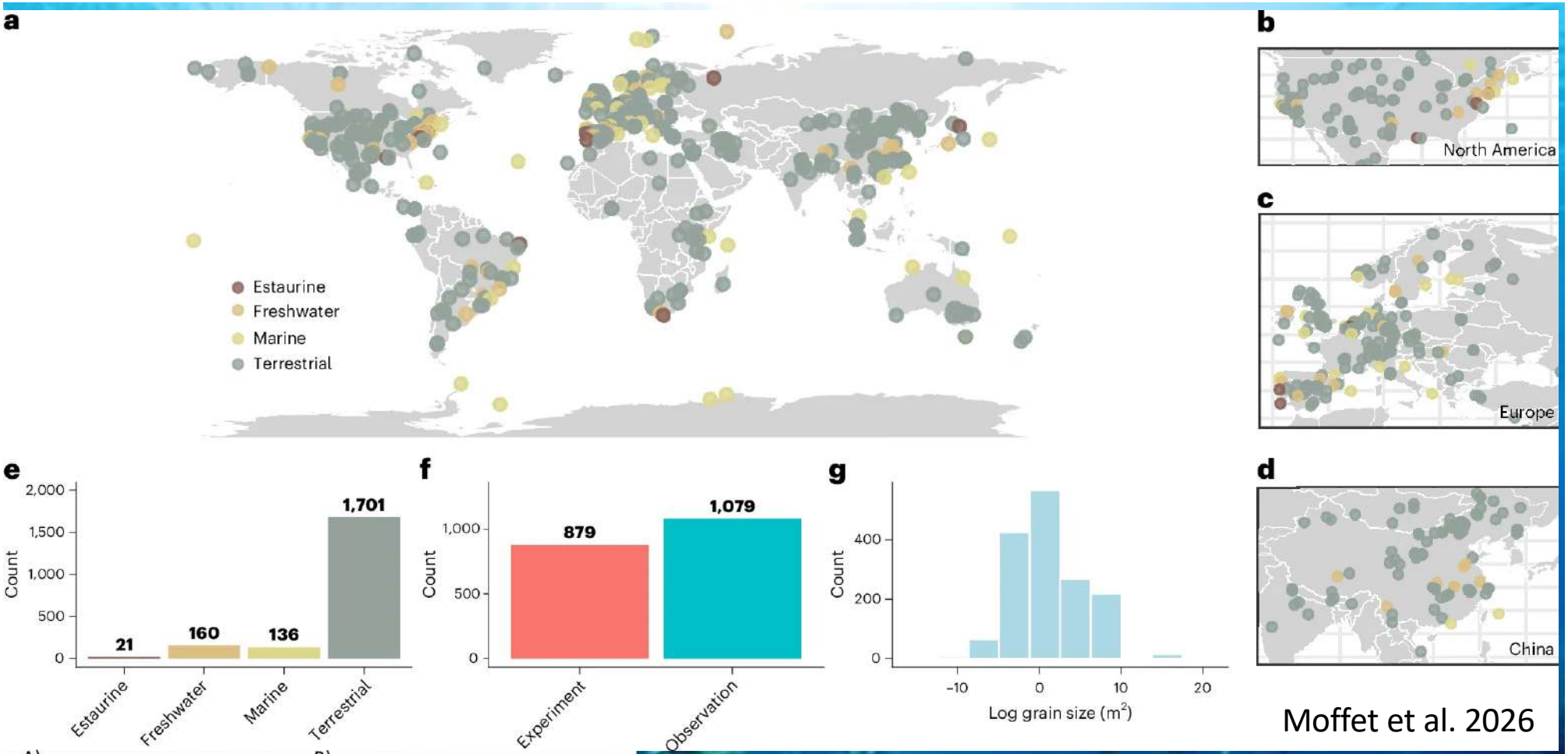




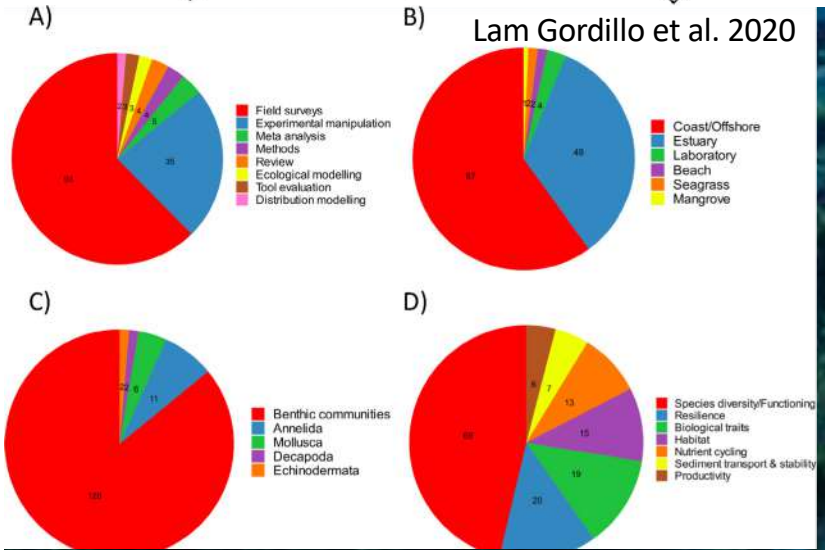


Naeem and Wright 2003





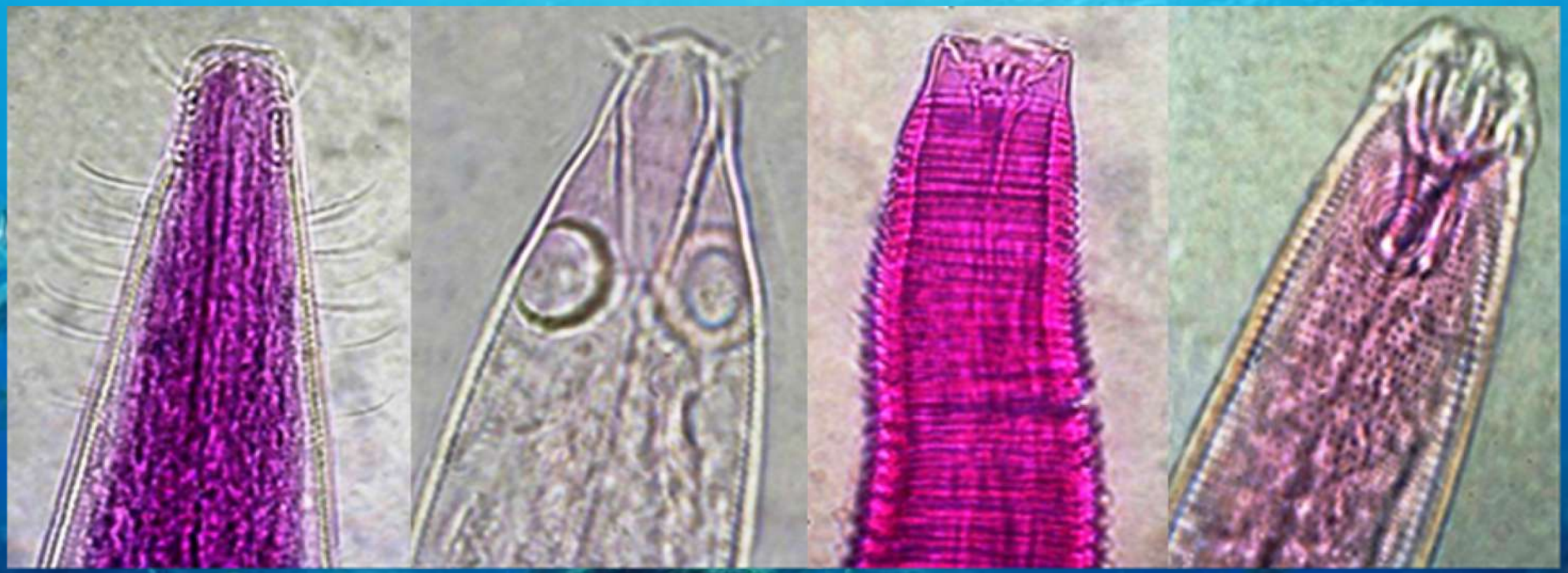
Moffet et al. 2026



Lam Gordillo et al. 2020

Studies in the marine realm are still limited if compare to terrestrial ecosystems, with most case studies being observational or correlative rather than manipulative

Functional diversity



Bacteriovorus Deposit-feeder Grazer Predator

Biodiversity expressed as functional groups: an example with nematodes

Functional diversity

	Trait 1	Trait 2	Trait 3	…	Trait n
Species 1	…	…	…	…	…
Species 2	…	…	…	…	…
Species 3	…	…	…	…	…

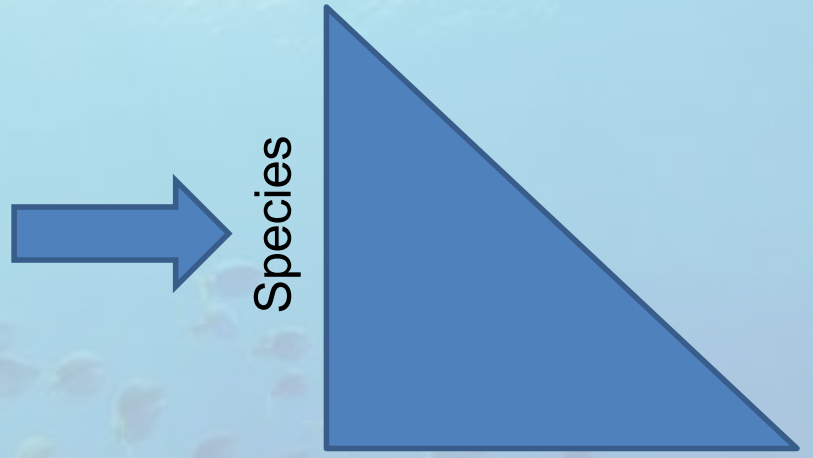


	Species 1	Species 2	Species 3
Species 1	0		
Species 2	20	0	
Species 3	80	70	0

FAD (functional attribute diversity) = sum ($d_{i,j}$)

Functional diversity

	Trait 1	Trait 2	Trait 3	…	Trait n
Species 1	…	…	…	…	…
Species 2	…	…	…	…	…
Species 3	…	…	…	…	…
Species 4	…	…	…	…	…
Species 5	…	…	…	…	…
Species 6	…	…	…	…	…
Species 7	…	…	…	…	…
Species 8	…	…	…	…	…
Species 9	…	…	…	…	…
Species 10	…	…	…	…	…



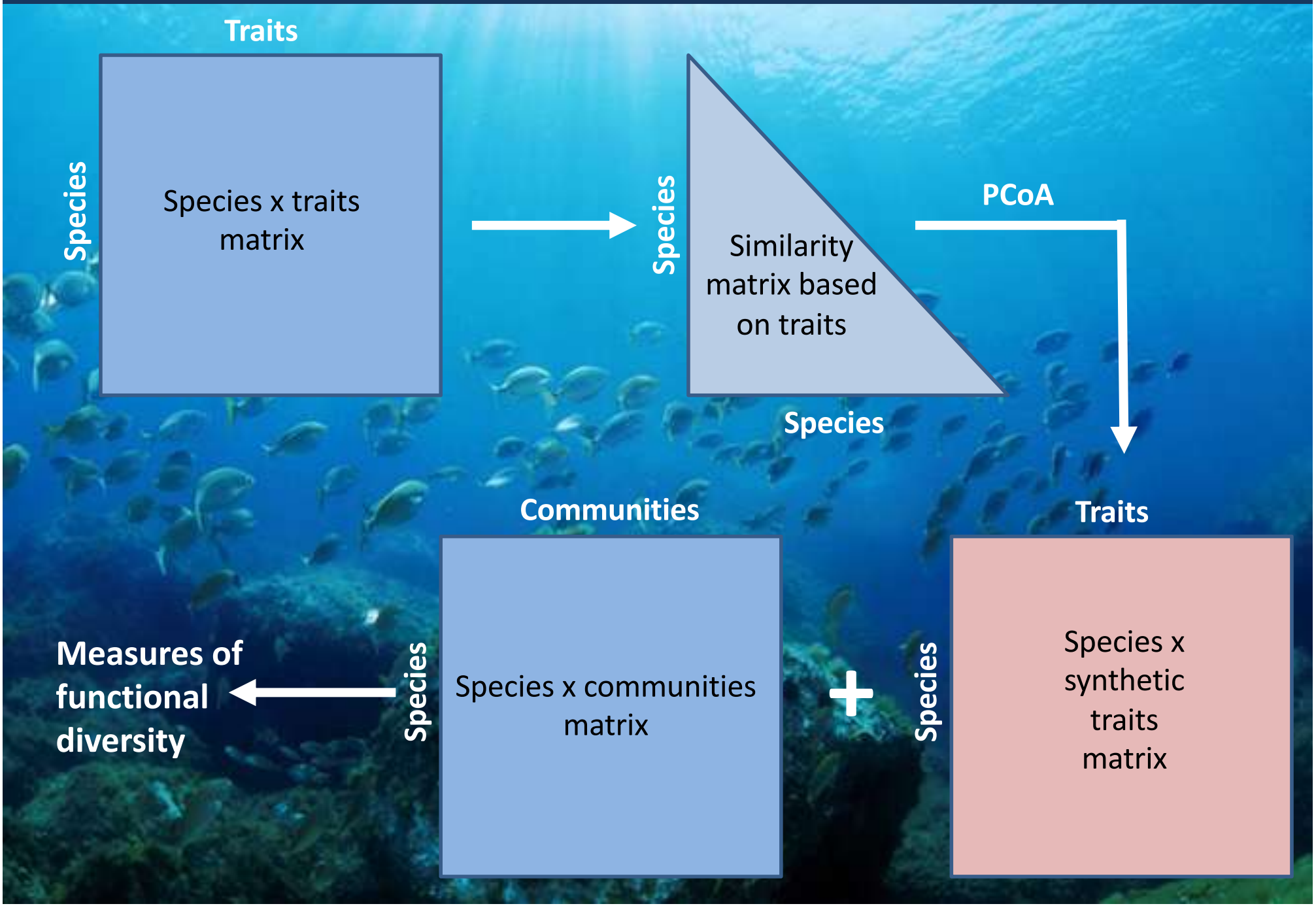


dendrogram

1-5 Community 1 FR = 2

1-10 Community 2 FR = 6

Analysis of functional diversity



Functional diversity

	Trait 1	Trait 2	Trait 3	…	Trait n
Species 1	…	…	…	…	…
Species 2	…	…	…	…	…
Species 3	…	…	…	…	…
Species 4	…	…	…	…	…
Species 5	…	…	…	…	…
Species 6	…	…	…	…	…
Species 7	…	…	…	…	…
Species 8	…	…	…	…	…
Species 9	…	…	…	…	…
Species 10	…	…	…	…	…



Fric = multidimensiona
space volume

Species

Traits

PCoA

Species

Functional traits: an example

Category	Trait	Description
Morphology	*Body complexity*	Body shape and three-dimensional structure
	Body size	Dimension of the body/colony (cm)
	Flexibility	Quality of bending without breaking (angle)
	Fragility	Likelihood to break as a result of physical impact
Life cycle and growth	*Growth form*	Individual or modular life form
	Life cycle	Type of life cycle: haplontic (multicellular haploid stage, unicellular diploid stage), diplontic (the opposite of haplontic), or haplo-diplontic (presence of multicellular haploid and diploid stages)
	Developmental mechanism	Development of the organism through spores, planktotrophic larvae, or lecitotrophic larvae
	Growth rate	Rate of increasing in size (mm mo^{-1})
	Life span	Approximate duration of life (years)
Reproduction	*Reproductive type (sexual)*	Type of sexual reproduction
	Gamete type	Morphology of male and female gametes
	Reproductive season	Range of months or season(s) for reproduction
	Reproductive strategy	Type of life strategy encompassing a single (semelparous) or multiple (iteroparous) reproductive events during life
	Generation time	Time between two generations (years)
	Time to maturity	Time to sexual maturity (years)
	Fecundity-Egg size	Size of eggs
	Fecundity-Number of eggs	Number of eggs
	Fertilization type	External or internal fertilization

Functional traits: an example

Interactions with the environment	*Living habit/environmental position*	Position with respect to the substrate
	Strength of attachment to substrate	Difficulty of being detached from the substrate
	Min depth	Approximate upper limit of depth distribution range (m)
	Max depth	Approximate lower limit of depth distribution range (m)
	Min salinity	Approximate lower limit of the salinity range
	Max temperature	Approximate upper limit of temperature range
	Max N	Approximate upper limit of nitrogen range
	Max P	Approximate upper limit of phosphorous range
	Min O% saturation	Approximate lower limit of oxygen saturation range
	Degree of attachment to substrate	Quality of being permanently or temporary attached to the substrate
	Substratum preferences	Type of typical substrate



Functional traits: an example

Dispersal and colonization	*Spatial distribution*	Distribution range at basin scale (Mediterranean Sea)
	Duration of larval stage (pelagic)	Time spent by larval stages in the water column before settelment (days)
	Asexual reproduction	Presence or absence of any type of asexual reproduction
	Recruitment success	Rate of post-settlement survival
	Migration	Capacity to migrate
	Mobility	Movement features
	Regeneration potential	Potential to survive to injury or damage through regenaration of lost tissues
	Dispersal potential (larval)	Distance of larval dispersal
	Dispersal potential (adult)	Distance of adult dispersal



Matter and energy flow	*Biomass*	Biomass
	Caloric content	Energy content of tissues
	$CaCO_3$ content	Amount $CaCO_3$ in tissues (% per g dry weight)

Functional traits: an example

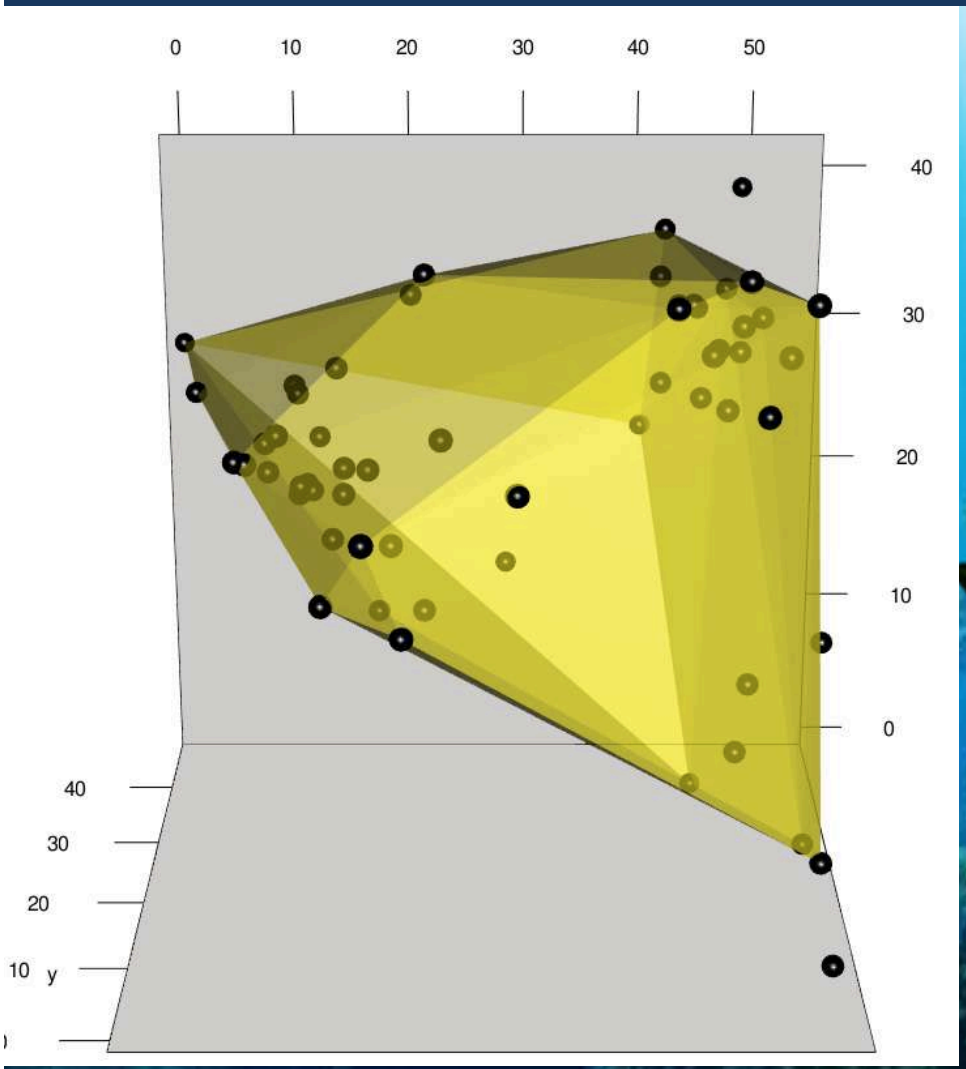
Biological interactions	*Sociability*	Aptitude to live with conspecific or to form colonies
	Defence	Presence of defence against predators, competitors
	Biogenic habitat provision	Quality of providing shelter or secondary substrate for other organisms
	Scale of habitat provision	Persistence in providing shelter, secondary substrate or forming biogenic habitat
	Food type/diet	Type of food ingested
	Dependency	Presence of symbiotic interactions





Matter and energy flow	*Feeding habit*	Strategy employed for food collection/production
	Biomass	Biomass
	Caloric content	Energy content of tissues
	$CaCO_3$ content	Amount $CaCO_3$ in tissues (% per g dry weight)

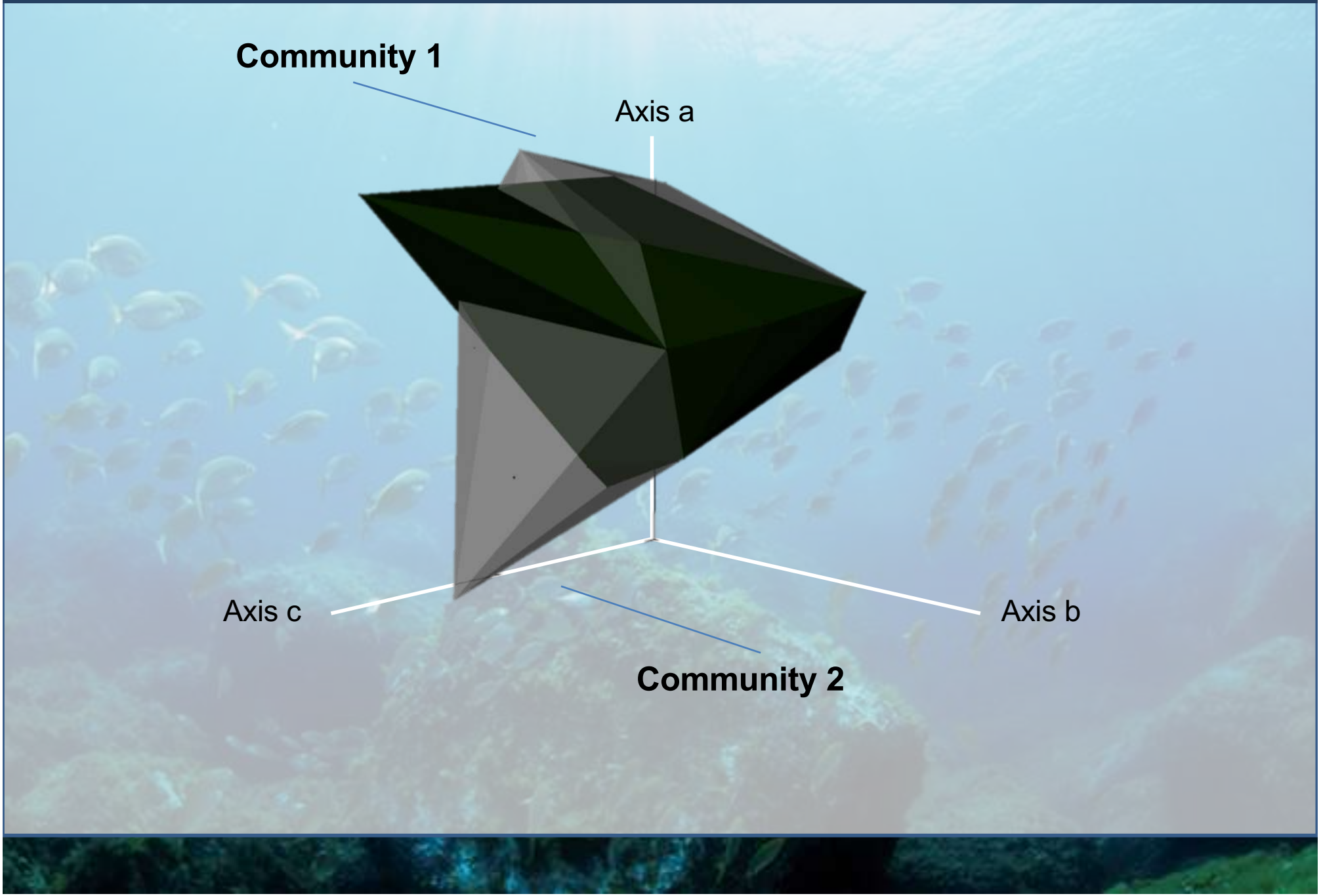
Measures of functional diversity



Functional richness

Functional beta-diversity

Functional diversity



Redundancy (?)

Are all species unique in term of their contribution to the overall functioning? Or are there "replicated" functions (redundancy)?

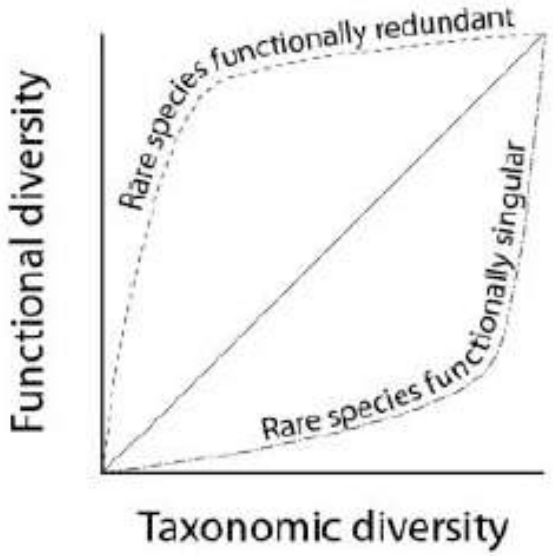
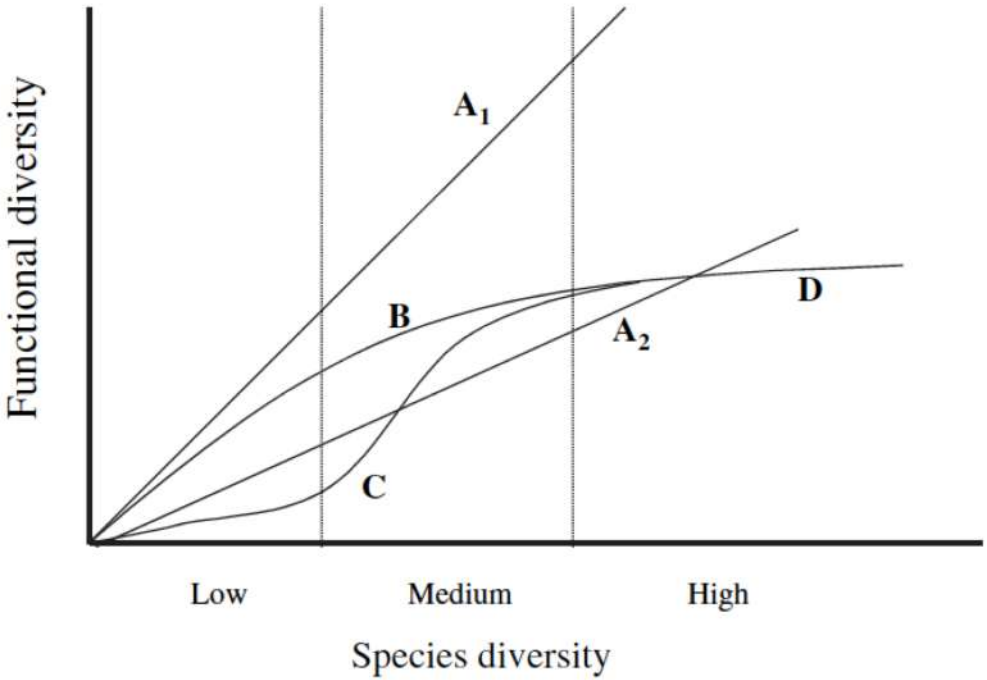
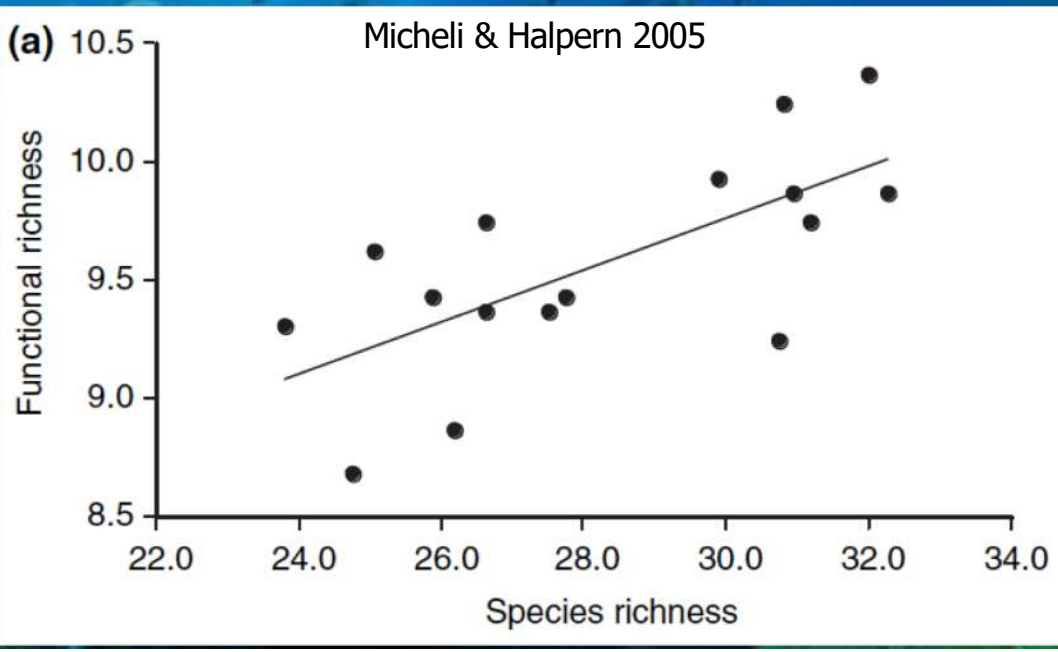


Figure 2 The relationship between taxonomic and functional diversity. Three possible relationships are shown. The top (dashed) line shows the relationship when rare species are functionally redundant. The middle, straight line (continuous) shows the relationship when every species contributes to functioning and is equally abundant. The third relationship (bottom, dash-dot) shows the relationship when rare species carry unique functional traits.



Micheli & Halpern 2005



However, redundancy strongly depends on the approach used to group species, or to define traits

Biodiversity and ecosystem functions

- **Facilitation**

Facilitative interactions among species could lead to increases in ecosystem pools or process rates as species or functional richness increase. Such facilitation could occur if certain species alleviate harsh environmental conditions or provide a critical resource for other species (improve functioning and enhance biodiversity)

- **Complementarity**

Complementarity results from reduced interspecific competition through niche partitioning. If species use different resources, or the same resources but at different times or different points in space, more of the total available resources are expected to be used by the community

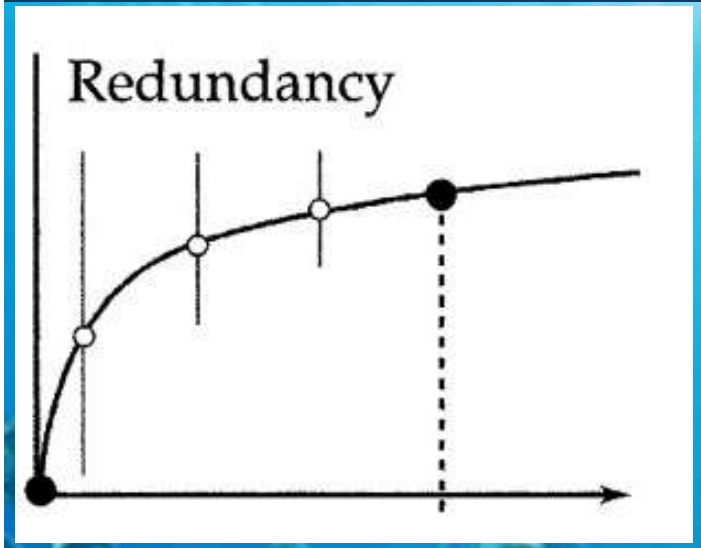
- **Sampling effect**

Increased probability of including species that best perform at a given condition

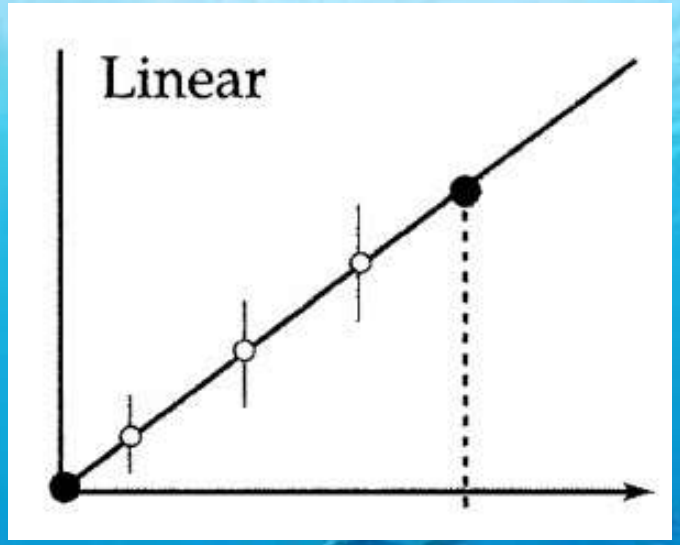
- **Portfolio effect on stability**

Portfolio effects derive from statistical averaging across the dynamics of system components. Increased ability to face perturbation, or compensating functional loss avoiding collapse.

Models of BEF relationships

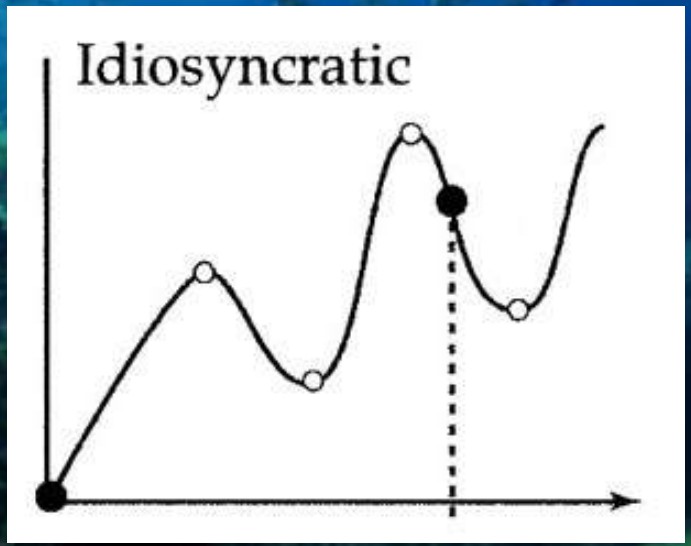


Species are primarily redundant: loss of species is compensated for by other species with a similar function. Conversely, the addition of such species adds nothing new to the system.

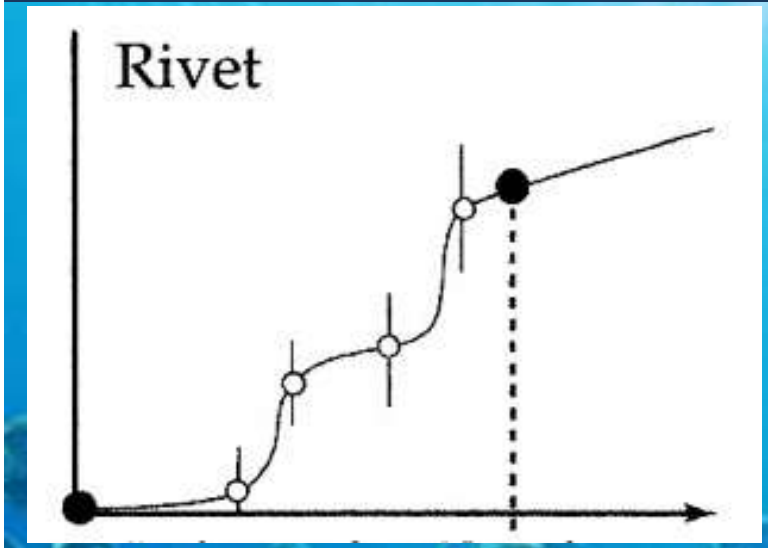


Species are primarily singular: loss or addition of species causes detectable changes in ecosystem process rates, i.e. species make unique contributions to ecosystem functioning.

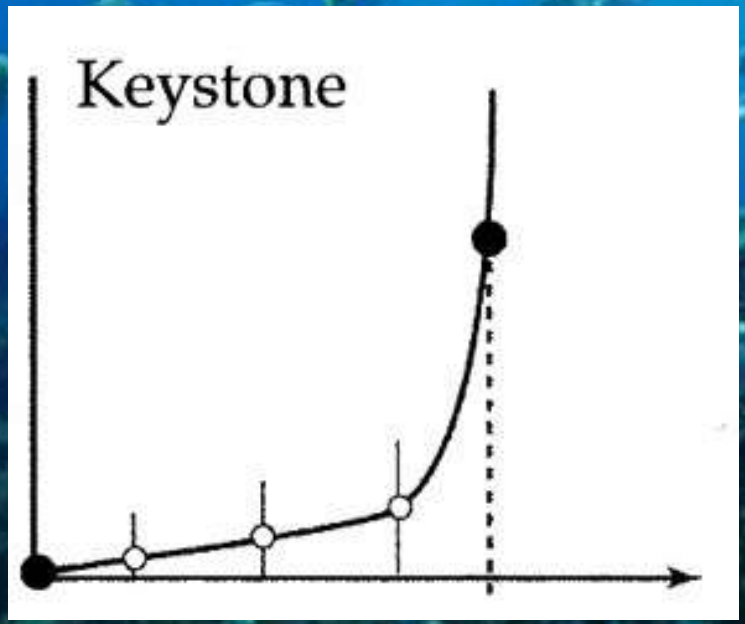
Species impacts are context-dependent and therefore idiosyncratic: the impact of loss or addition of species depends on environmental conditions and the species, and its interaction with the others (Lawton 1994)



Models of BEF relationships

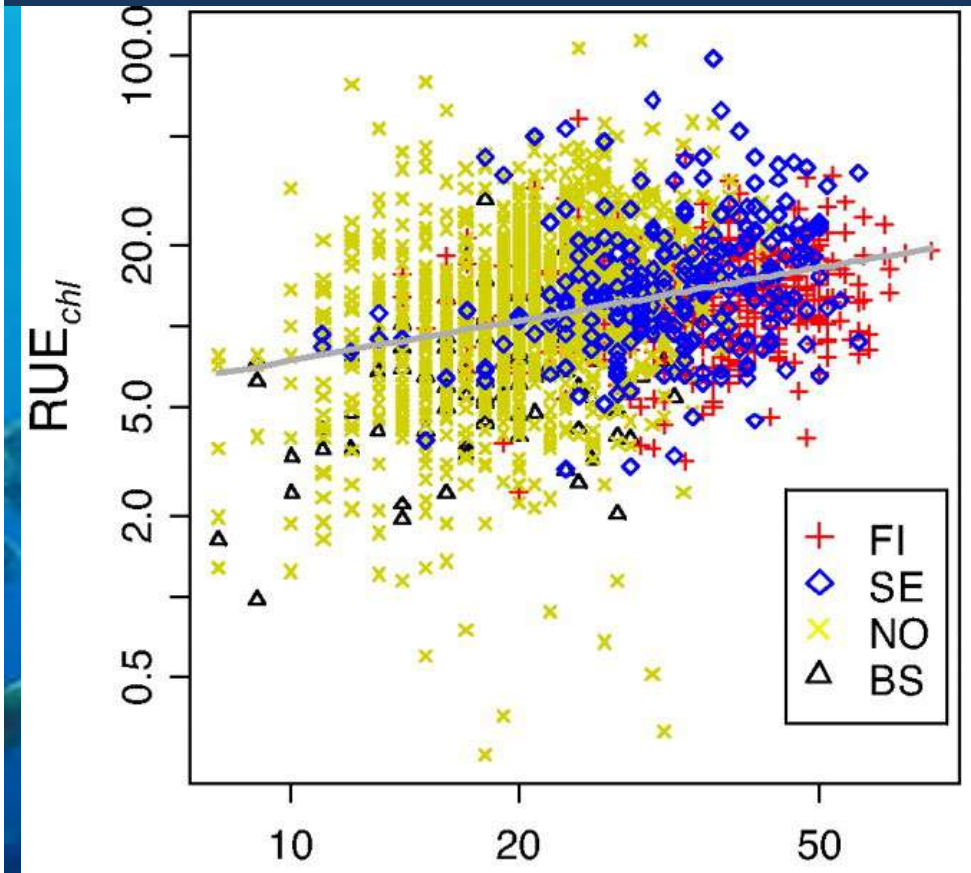


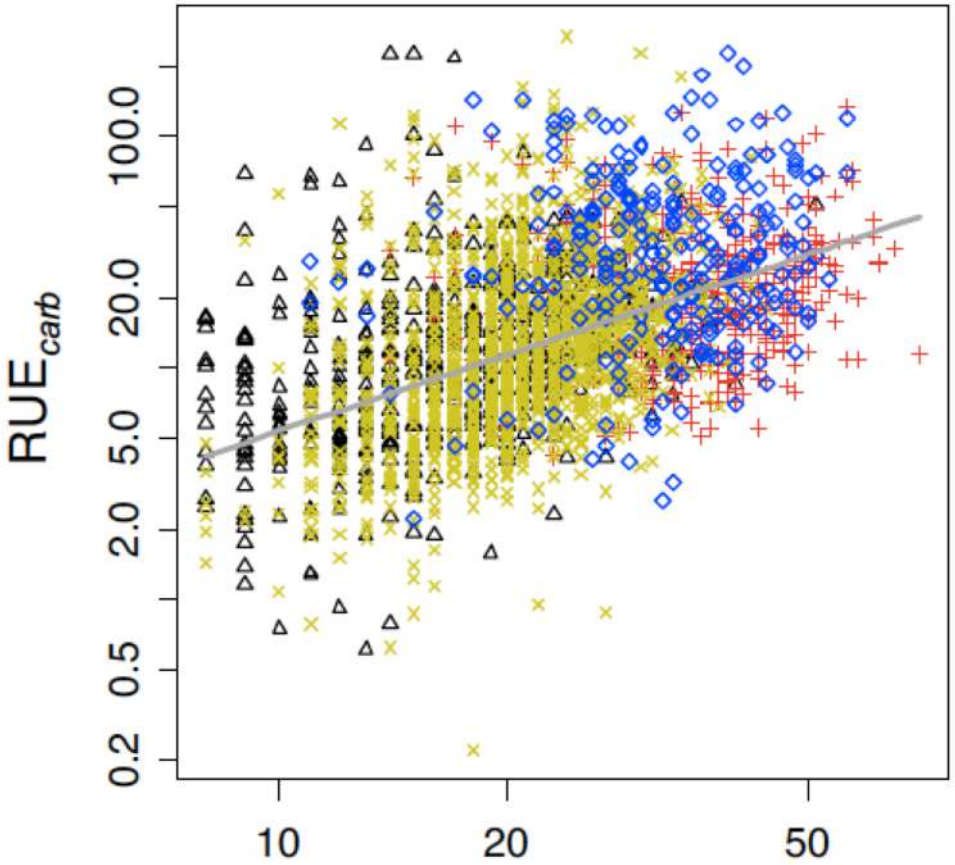
Loss of species could or could not have an impact on ecosystem processes. Species loss can be compensated for by other species with a similar function (redundancy). However, when all species with the same role are removed this causes a change in the system (Ehrlich & Ehrlich, 1981)



Some species is more important than others in causing changes in ecosystem processes, exerting a keystone role

Diversity and primary productivity





PNAS

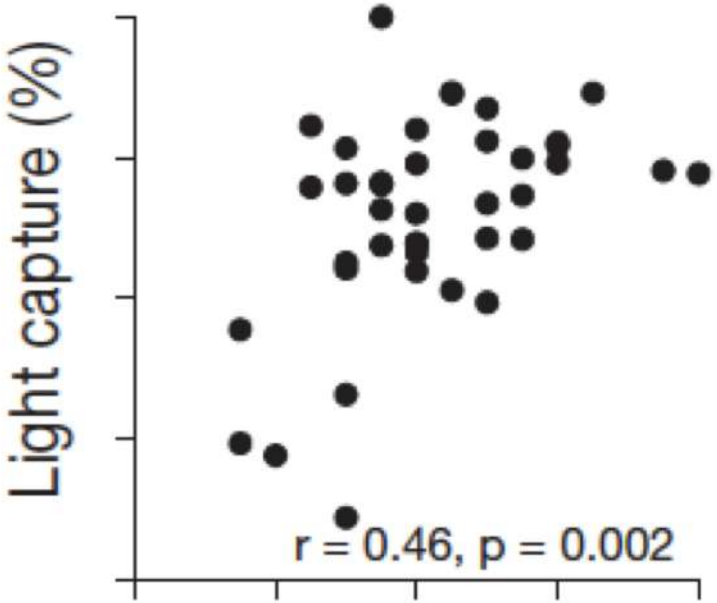
Diversity predicts stability and resource use efficiency in natural phytoplankton communities

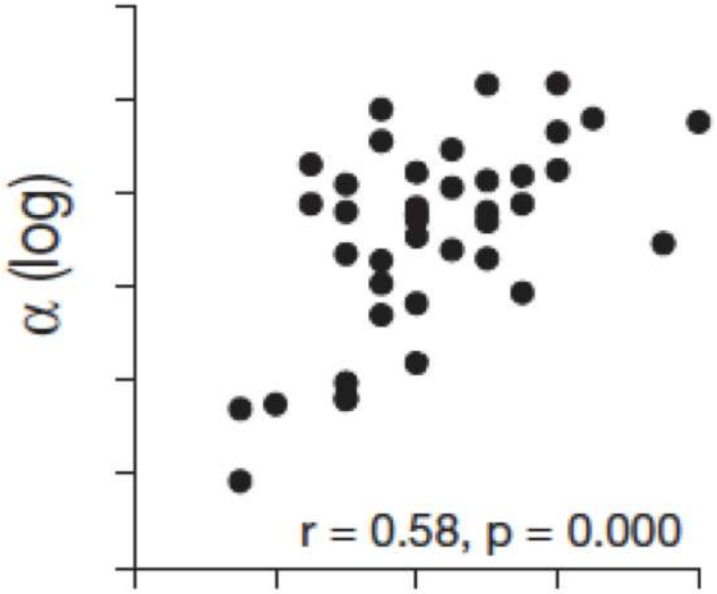
Robert Ptacnik*†, Angelo G. Solimini‡, Tom Andersen*§, Timo Tamminen¶, Pål Brettum*, Liisa Lepistö¶, Eva Willén‖, and Seppo Rekolainen¶

*Norwegian Institute for Water Research, Gaustadalléen 21, 0349 Oslo, Norway; ‡European Commission, Joint Research Centre, Institute for Environment and Sustainability, I-21020 Ispra, Italy; §Department of Biology, University of Oslo, P.O. Box 1066, Blindern, 0316 Oslo, Norway; ¶Finnish Environment Institute, P.O. Box 140, FIN-00251, Helsinki, Finland; and ‖Swedish University of Agricultural Sciences, P.O. Box 7070, SE-750 07 Uppsala, Sweden

Edited by Paul G. Falkowski, Rutgers, The State University of New Jersey, New Brunswick, NJ, and approved February 5, 2008 (received for review September 3, 2007)

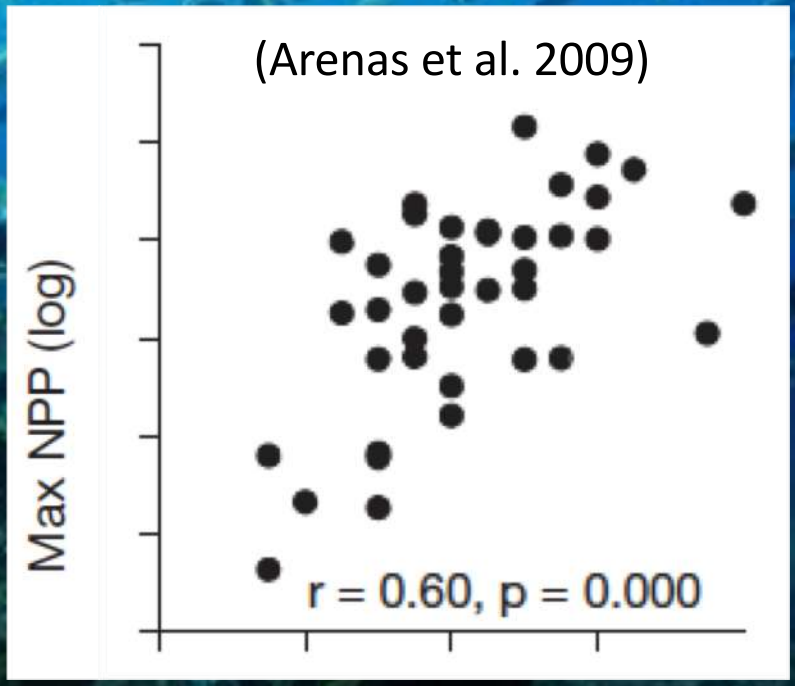
Diversity and primary productivity



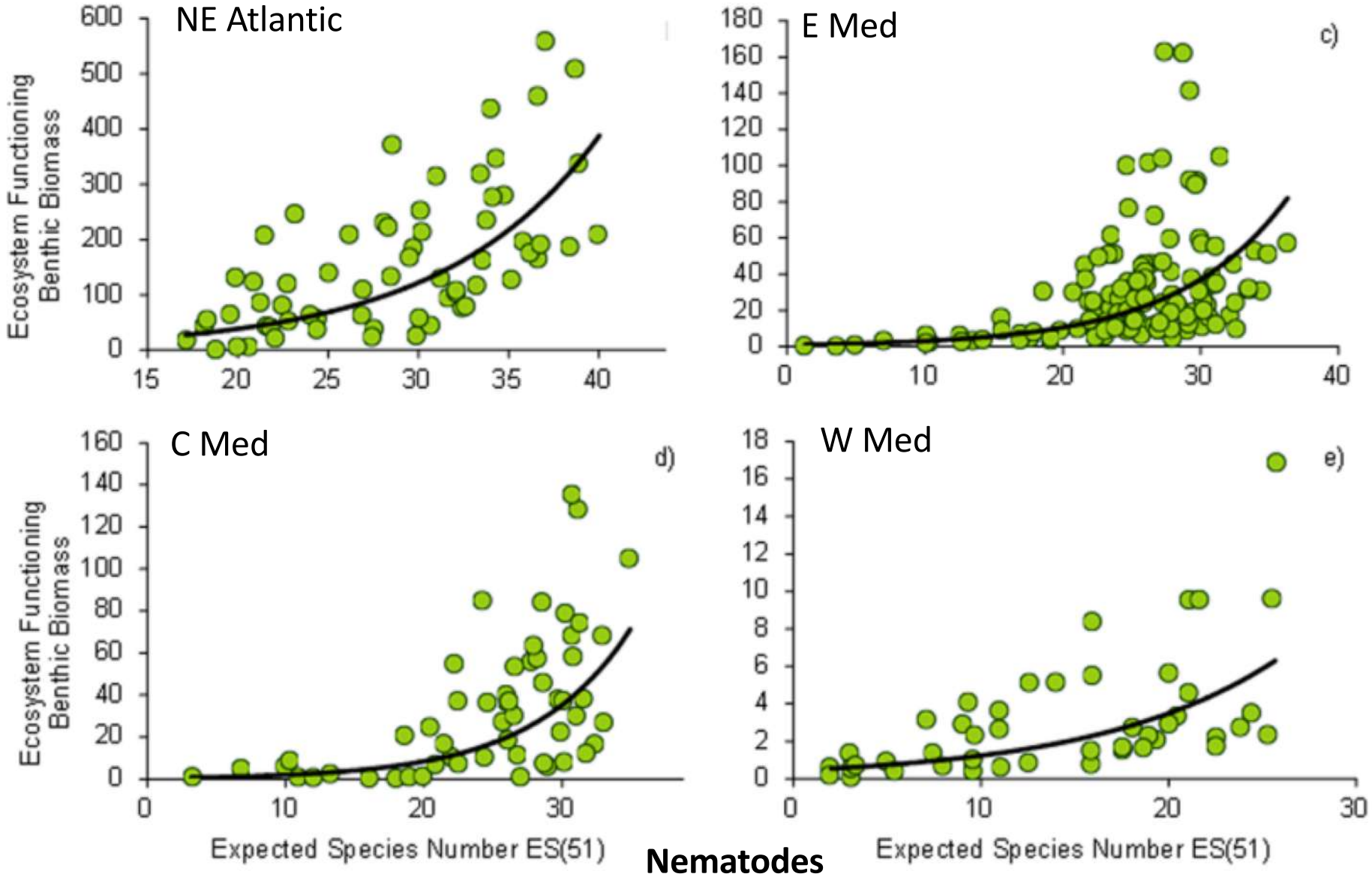


Positive relationships between species richness and light capture, photosynthetic efficiency and maximum net primary production in intertidal macroalgal assemblages

(Arenas et al. 2009)

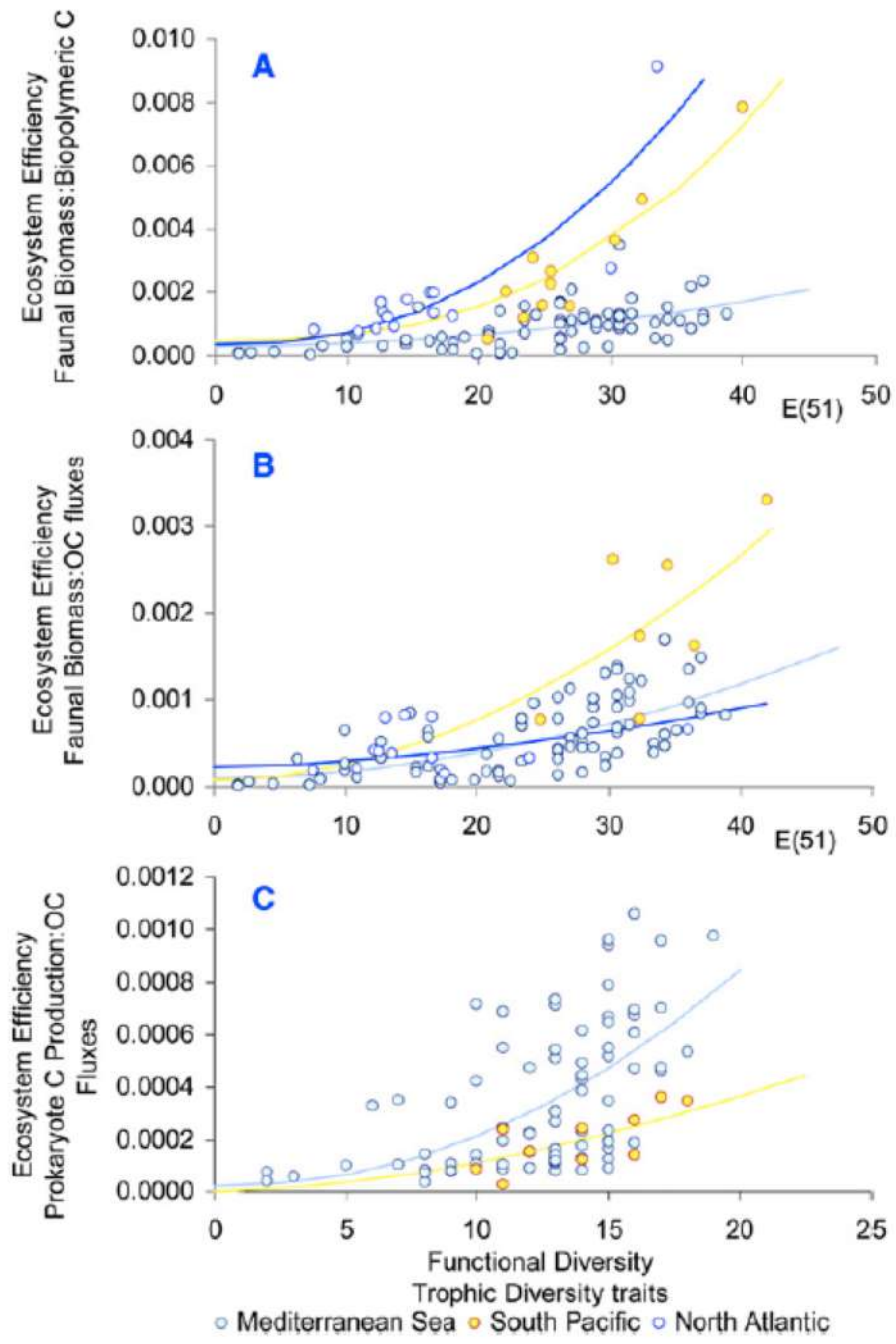


Diversity and secondary productivity



Narayanaswamy et al. 2013

Diversity and carbon flux



Danovaro et al. 2008

Deep-sea ecosystem functioning is exponentially related to deep-sea biodiversity and that ecosystem efficiency is also exponentially linked to functional diversity. These results suggest that a higher biodiversity supports higher rates of ecosystem processes and an increased efficiency with which these processes are performed. The exponential relationships presented here, being consistent across a wide range of deep-sea ecosystems, suggest that mutually positive functional interactions (ecological facilitation) can be common in the largest biome of our biosphere.

A) Faunal biomass/biopolymeric C (detritus) in sediments vs FD

B) Faunal biomass/organic C flux (increase C in sediments) vs FD

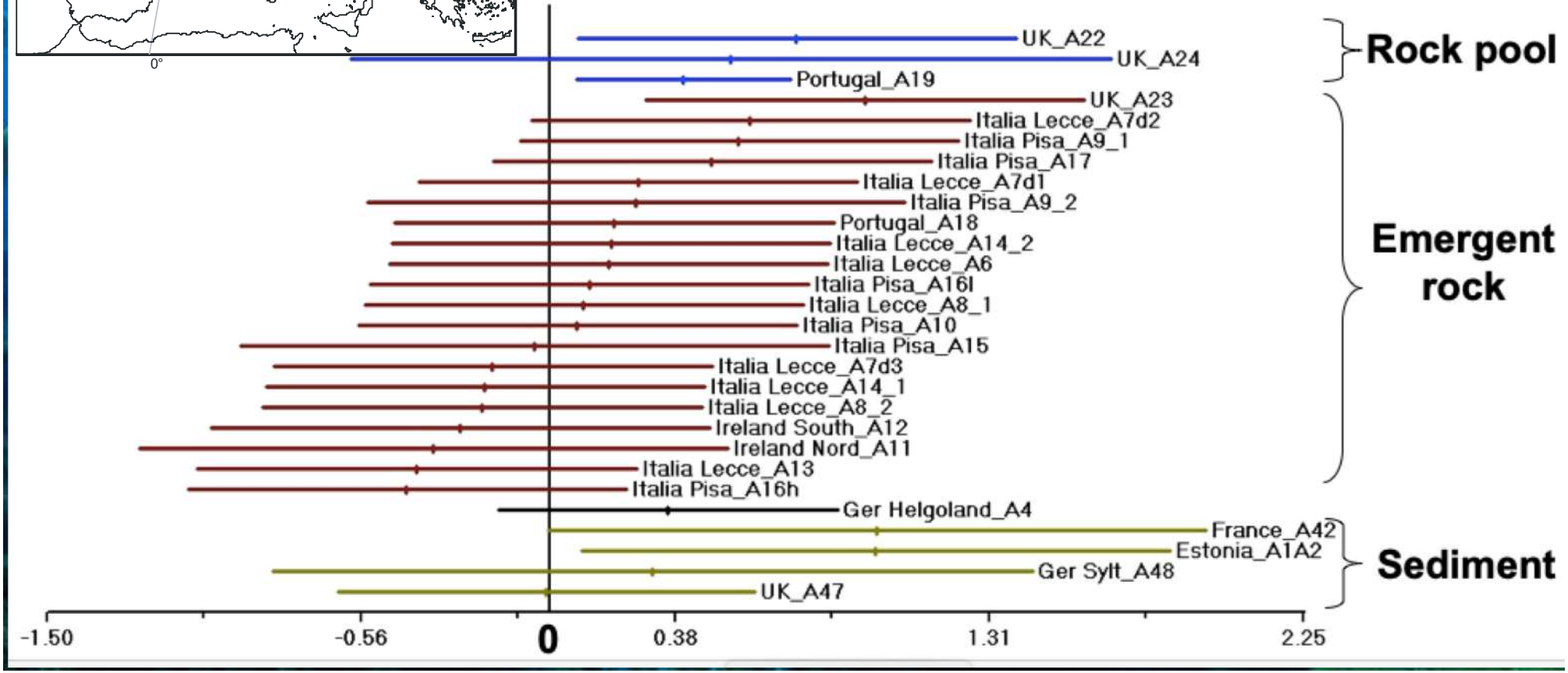
C) Bacterial C production/organic C flux vs FD

Diversity and stability



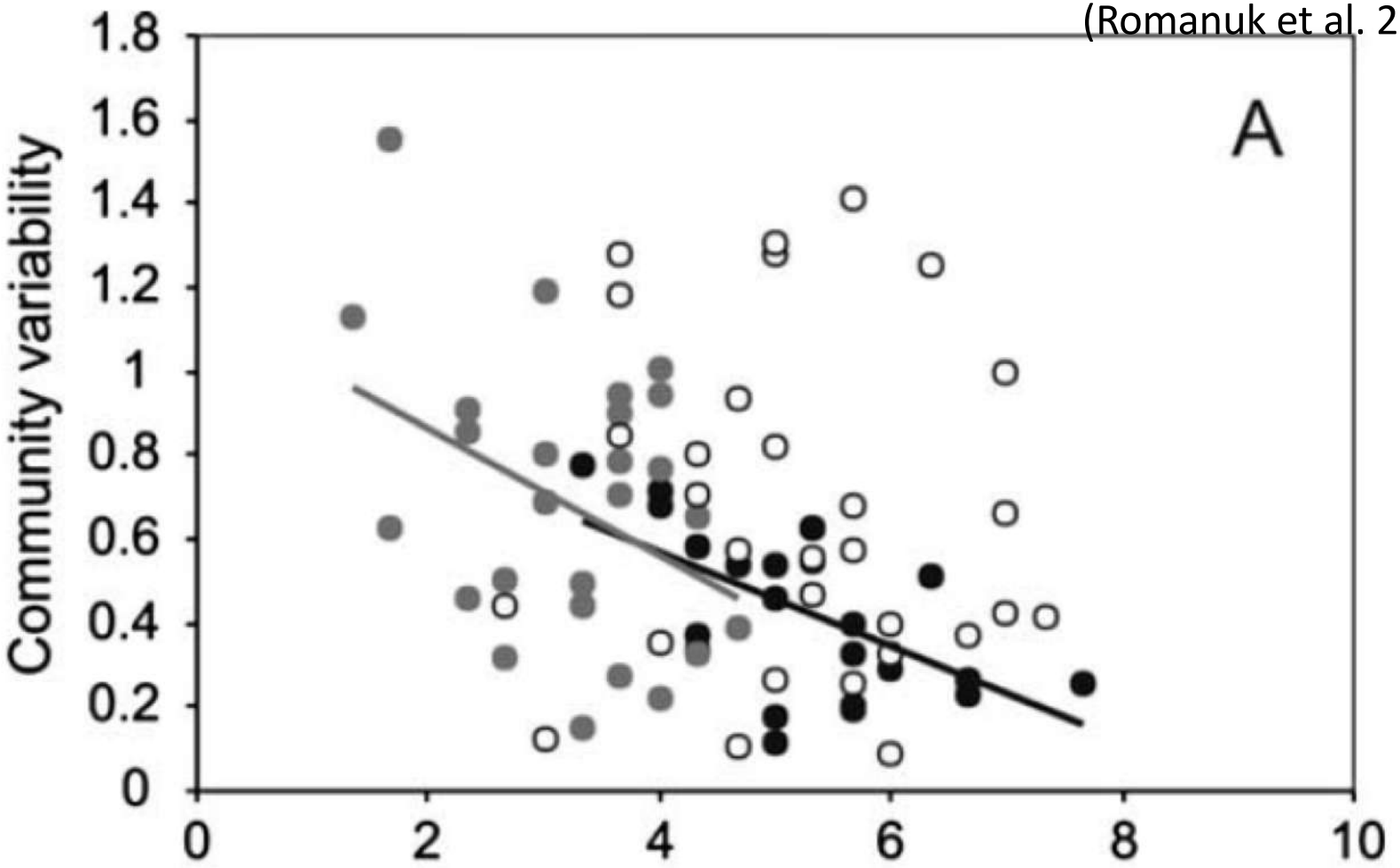
Negative or positive, or no correlation between species richness and temporal variability in benthic assemblages

(Cusson et al. 2014)



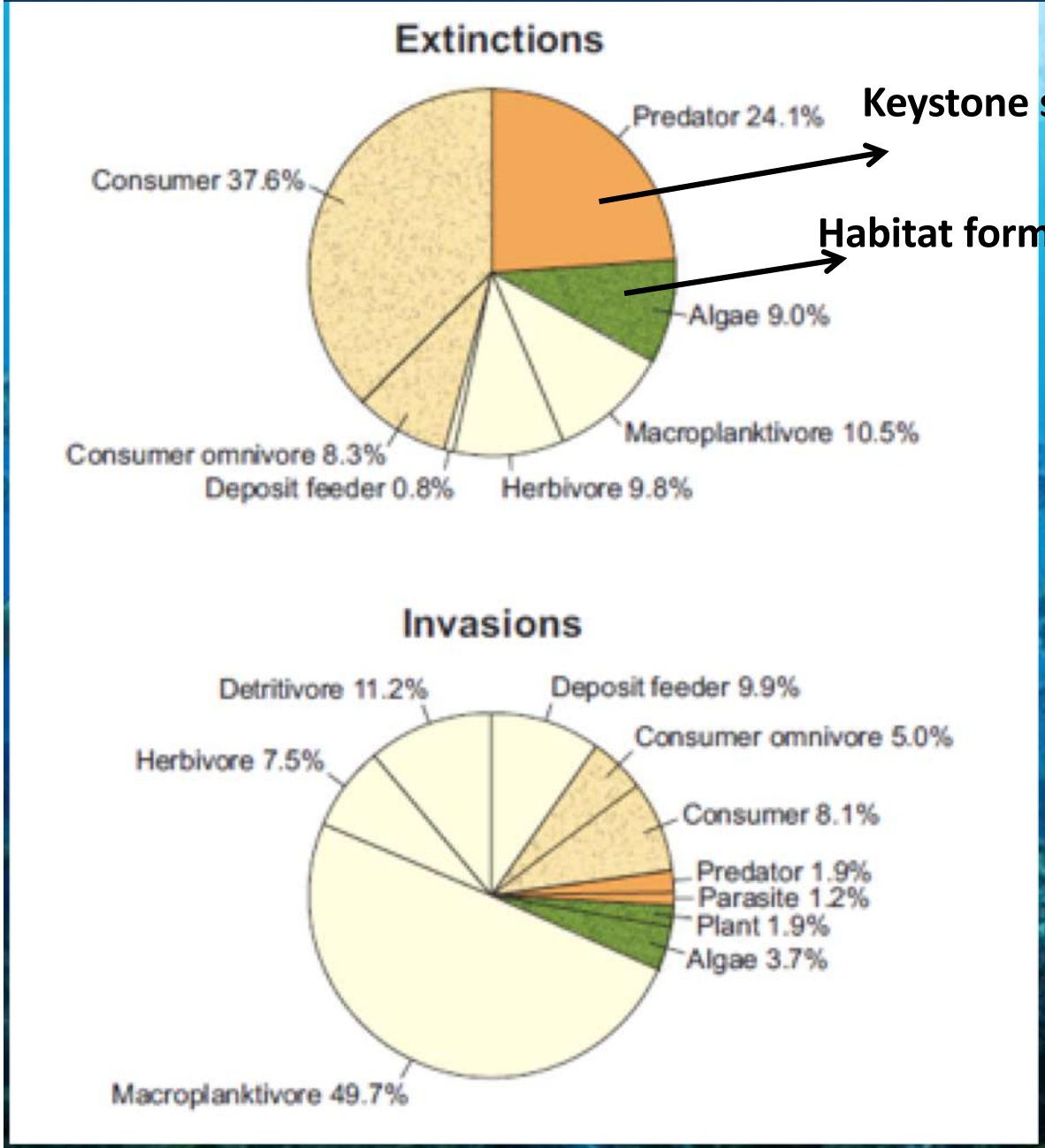
Diversity and stability

(Romanuk et al. 2009)



Effect of species richness on community variability for laboratory microcosms (black circles), artificial rock pools (grey circles) and natural pools (open circles).

Diversity and invasion



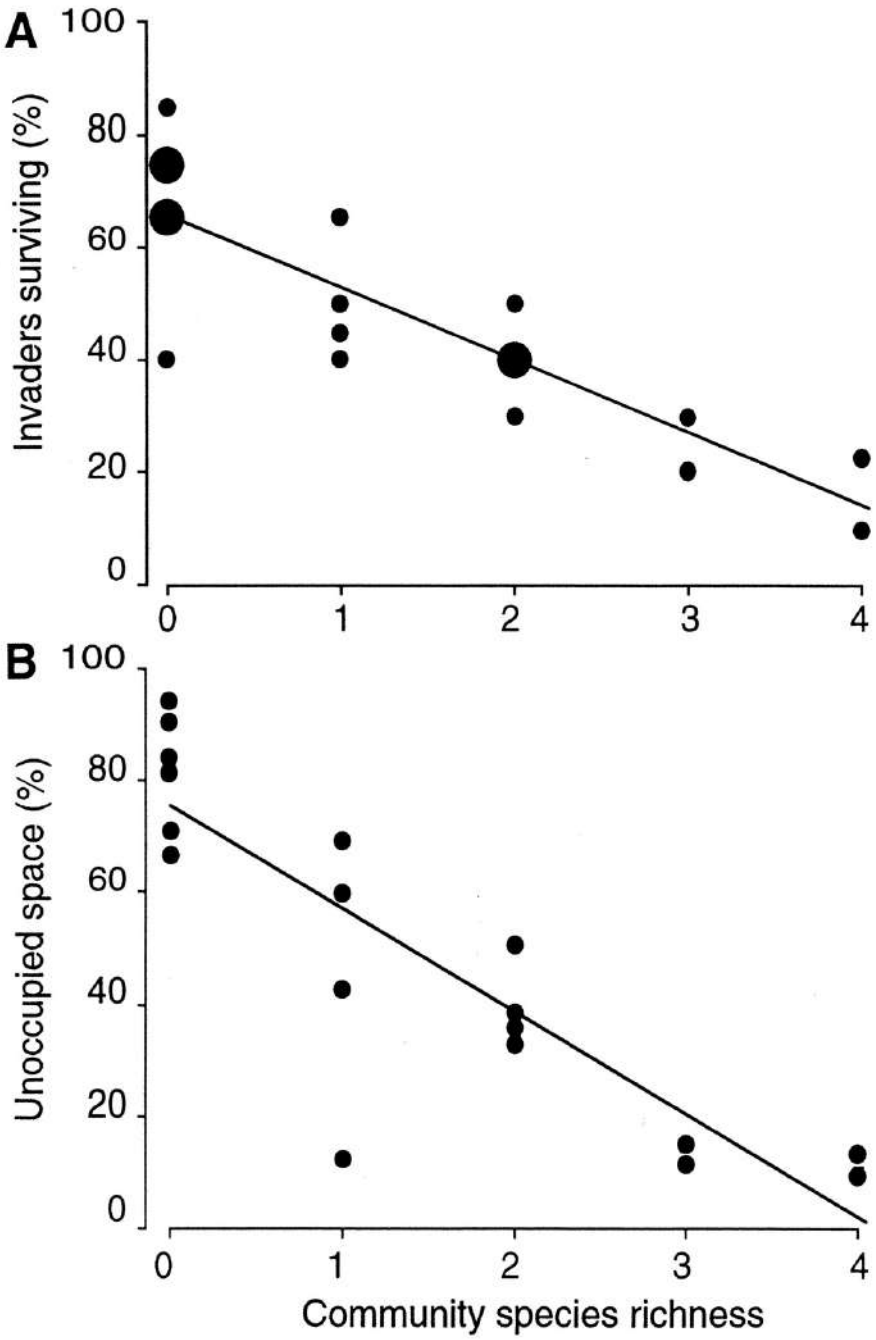
Keystone species

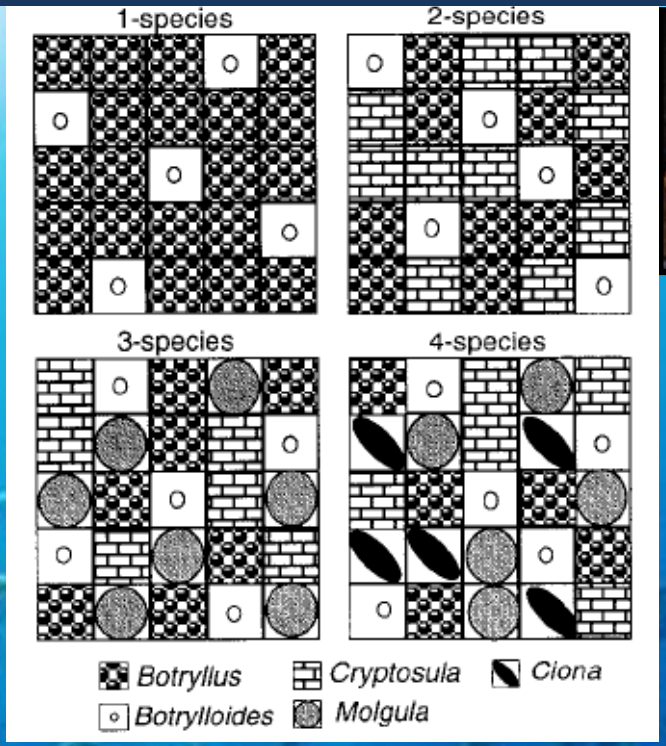
Habitat formers

Changing patterns of trophic skew in coastal/estuarine marine ecosystems as the combined result of species introductions and local extinctions. Data replotted from Byrnes et al. (2007). Species loss is biased toward higher trophic levels, whereas species gain is biased toward lower levels (primary consumers). The functional groups most responsible for this skew were top predators (24.1% of extinctions but 6.1% of invasions on average), secondary consumers (37.6% of extinctions but 8.1% of invasions), and suspension feeding macroplanktivores (10.5% of extinctions but 44.6% of invasions).

Stachowicz et al. (2007)

Diversity and invasion





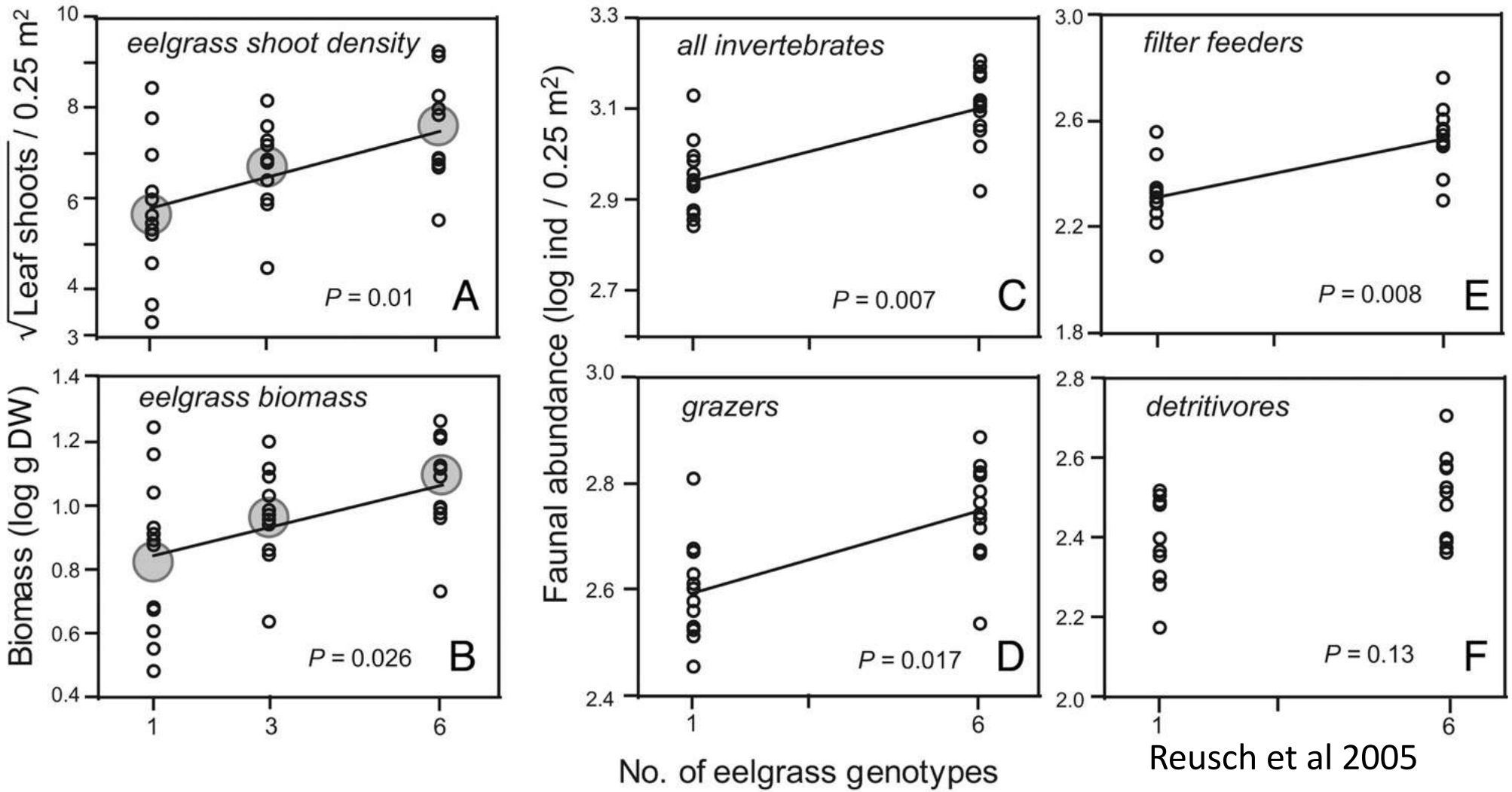
Stachowicz et al. (1999)



The exotic ascidian *Botrylloides diegensis*

Increased species richness significantly decreased invasion success, apparently because species-rich communities more completely and efficiently use available space, the limiting resource in this system.

Diversity and climate change



Reusch et al 2005

The seagrass *Zostera marina* (dominant macrophyte species of shallow sedimentary shorelines in the northern hemisphere)

Ecosystem recovery after climatic extremes enhanced by genotypic diversity

Summary of evidence

Response	Positive	Negative	No effect
Stability, disturbance, resistance, or resilience[b]	9	1	0
Plant biomass or production	7	0	6
Decomposition	0	0	2
Associated species diversity	0	0	3
Associated species abundance	2	0	1
Resource use[b]	6	0	3
Resource regeneration[c]	4	4	9
Invader abundance or survival	0	6	1
Invader settlement	2	0	1
Secondary production	6	0	1

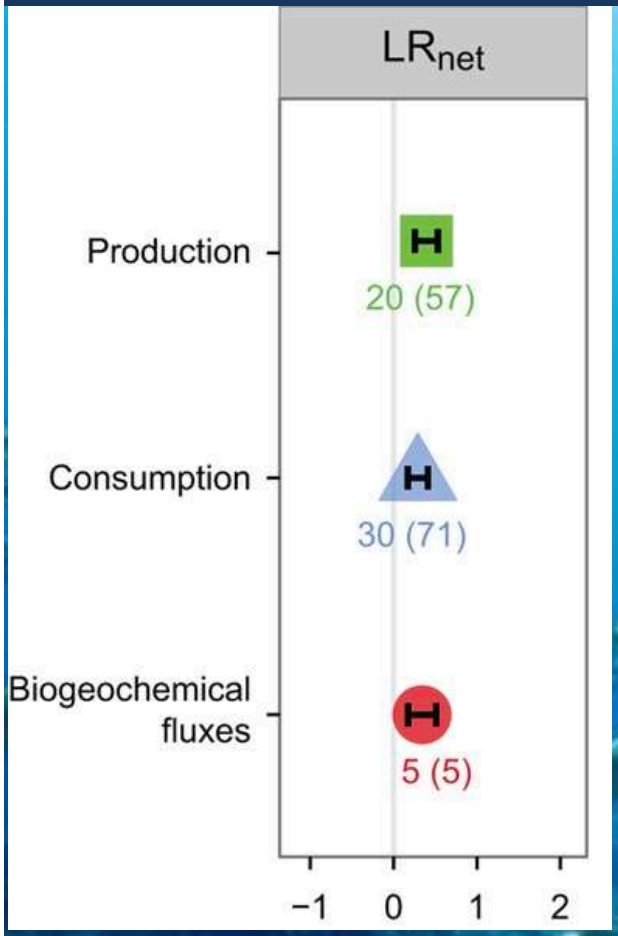
Manipulation of species richness within single trophic levels

Taxon manipulated	Response	Positive	Negative	No effect
Algal prey	Consumer growth	6	0	0
	Consumer survival	5	0	2
	Consumer reproduction	5	0	3
	Integrated production or population growth	6	0	1
Consumer	Prey biomass	3	8	4
Predator	Plant biomass (two trophic levels away)	3	2	1

Manipulation of species richness within a trophic level and effects on other trophic levels

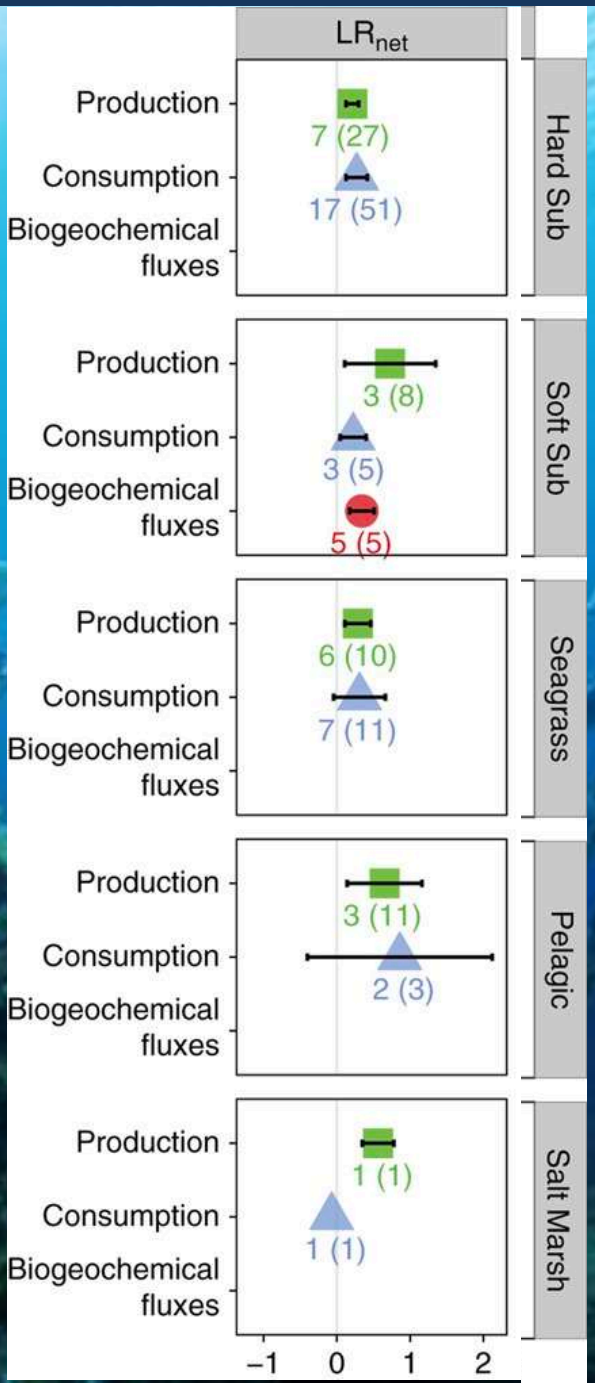
Stachowicz et al. (2007)

Summary of evidence



Meta-analysis of available studies comparing multispecies and average monospecific systems suggest a positive effect of biodiversity on production, consumption and cycles

Gamfeldt et al. (2015)



This pattern is common to different marine ecosystems