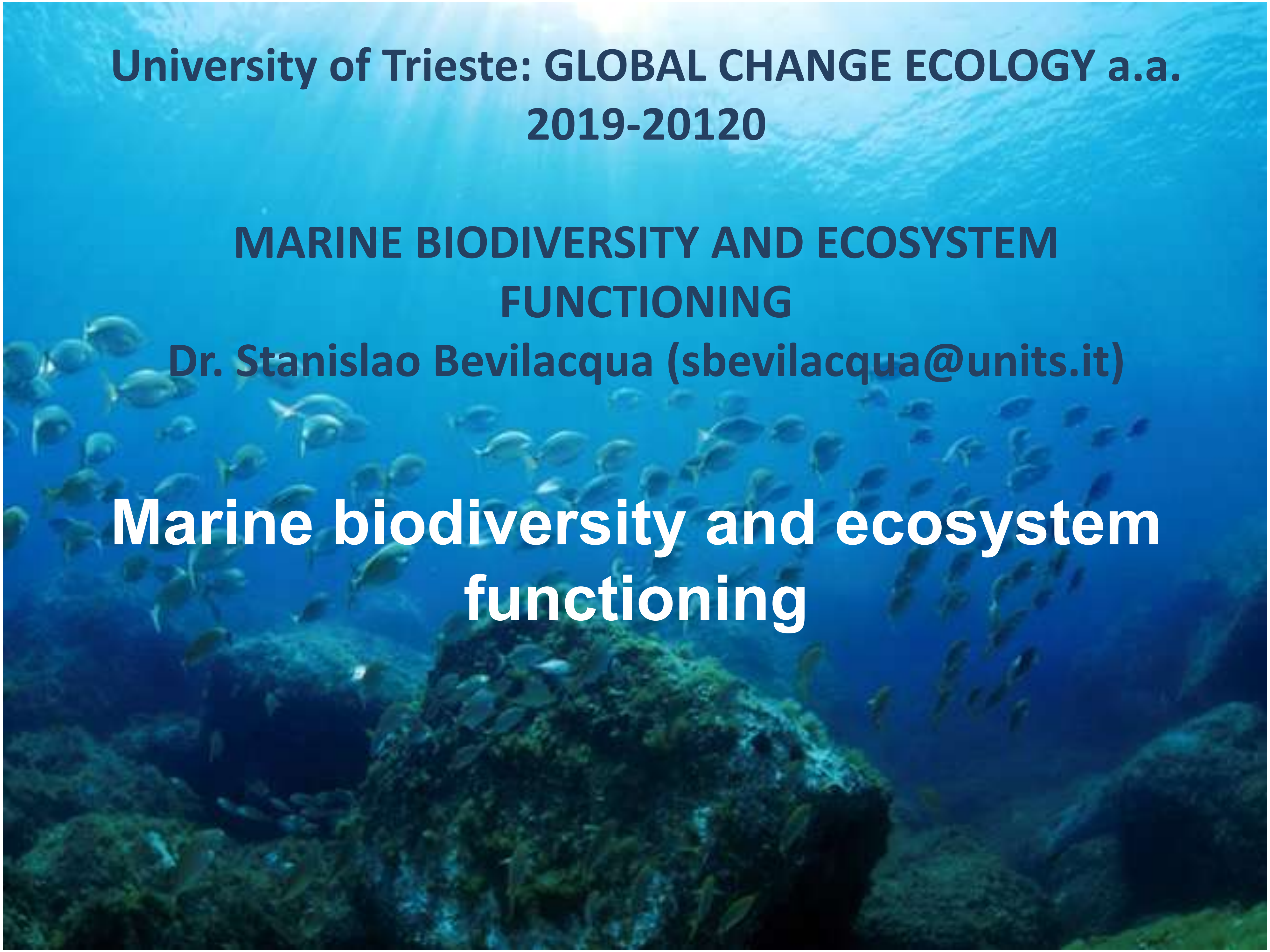


University of Trieste: GLOBAL CHANGE ECOLOGY a.a. 2019-20120

MARINE BIODIVERSITY AND ECOSYSTEM FUNCTIONING

Dr. Stanislao Bevilacqua (sbevilacqua@units.it)

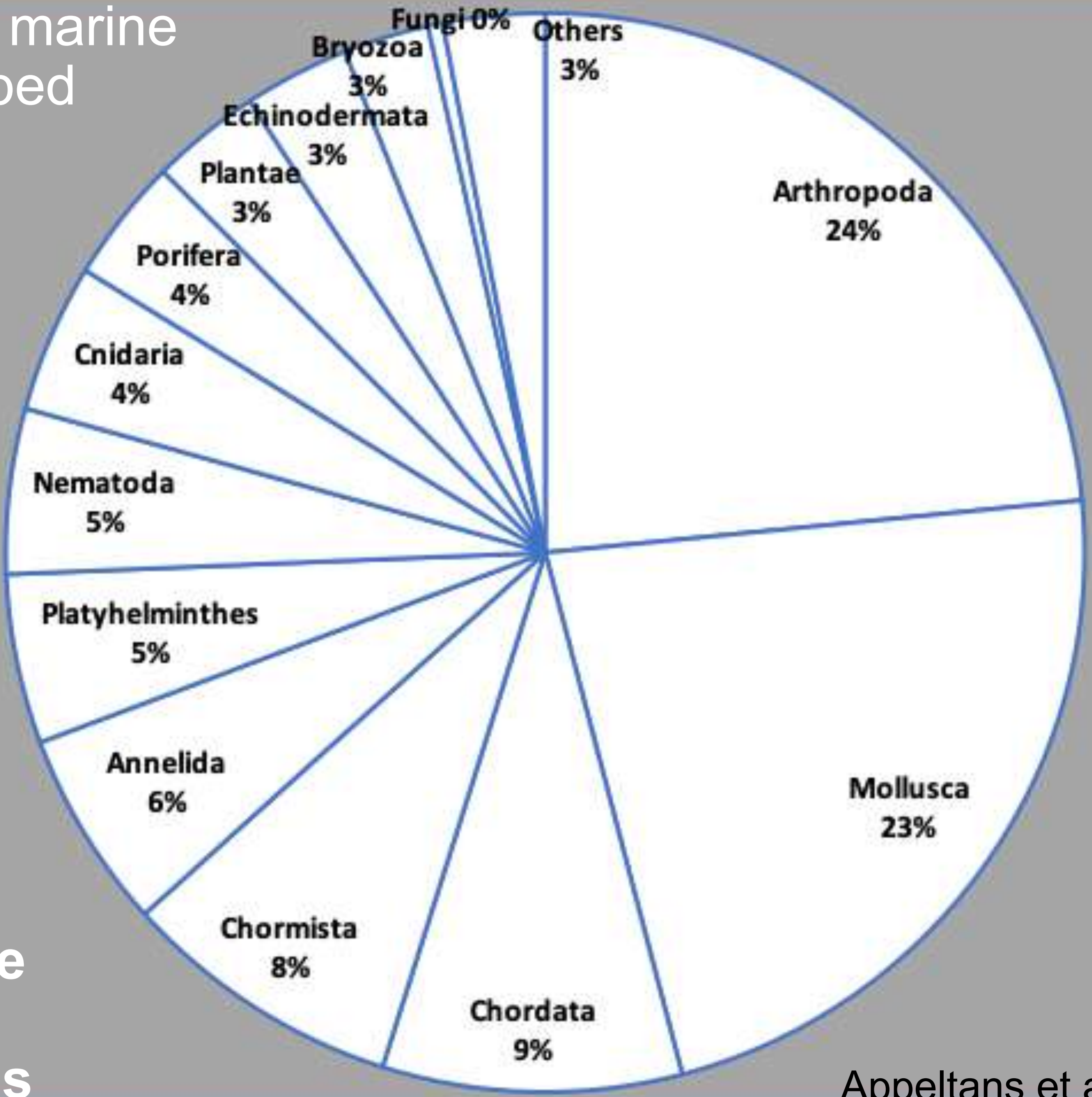
Marine biodiversity and ecosystem functioning

How many species

About 240,000 marine species described

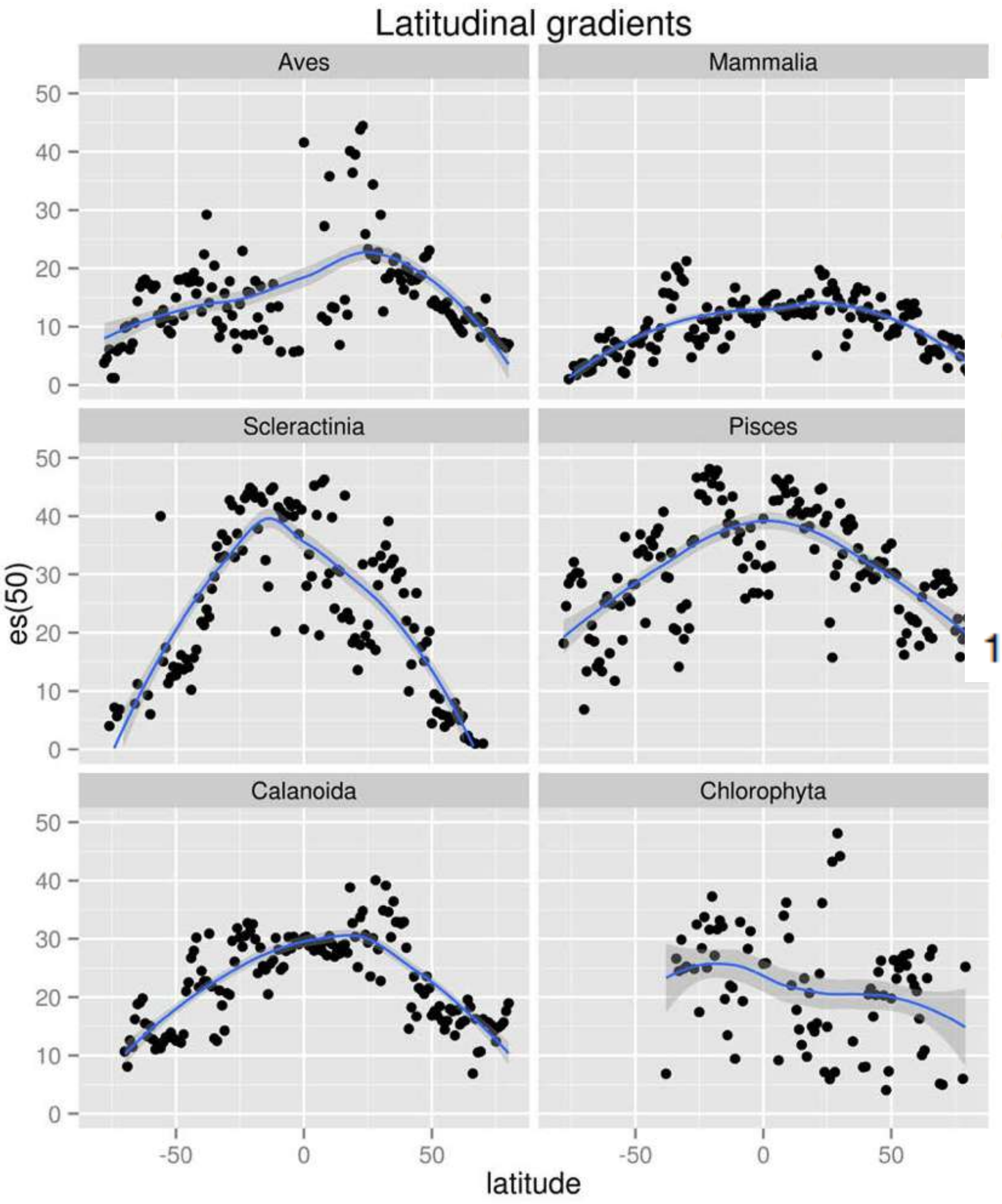
58,000-72,000 marine species sampled but still not described

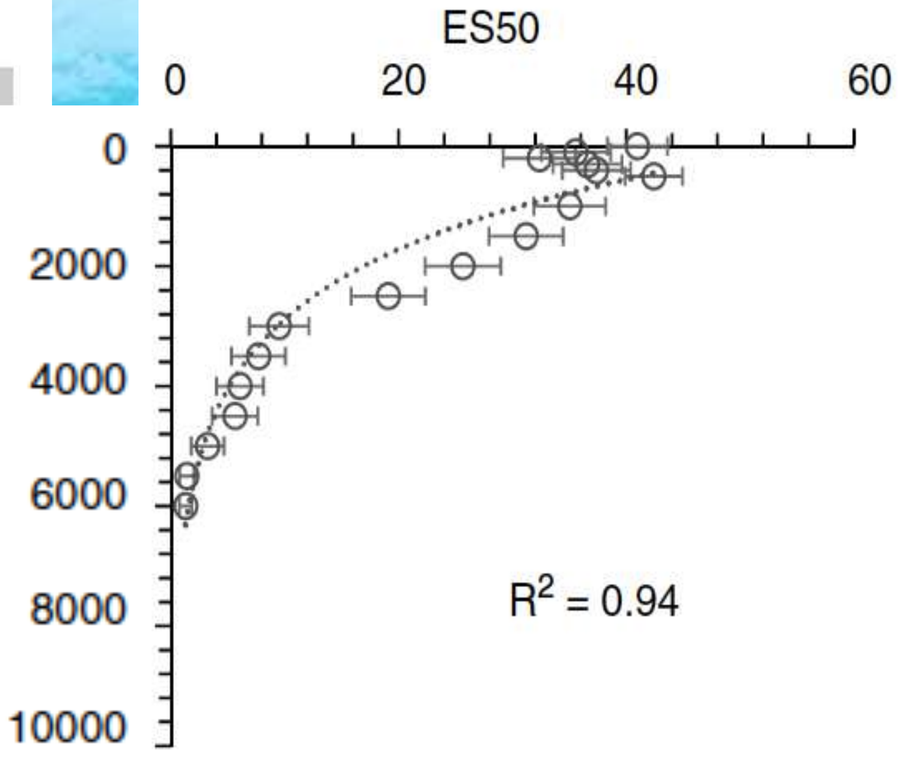
There could be 0.7-1.0 million marine species



Appeltans et al. 2012

Patterns

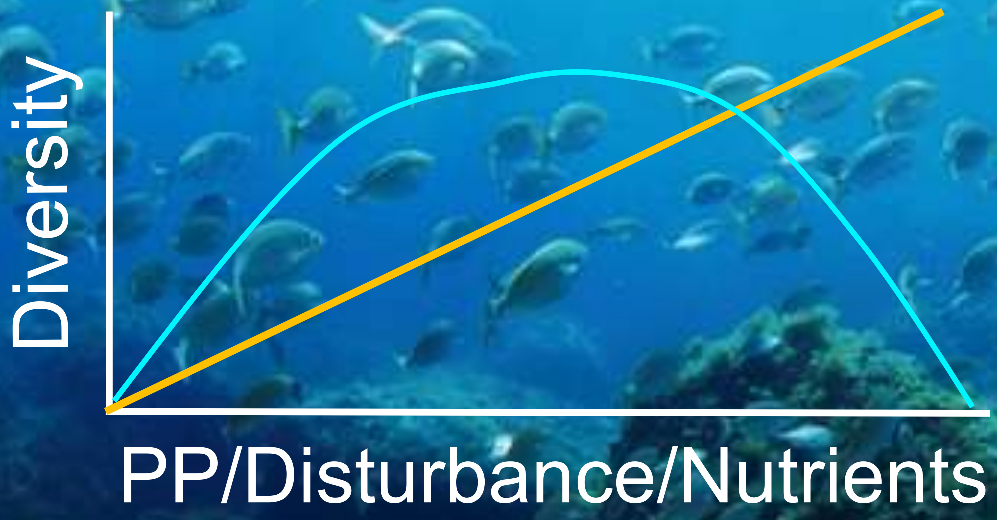




Marine biodiversity peaks at tropical latitude (Snelgrove et al. 2016) and at shallower depths (Costello & Chaudhary 2017)

Factors affecting biodiversity

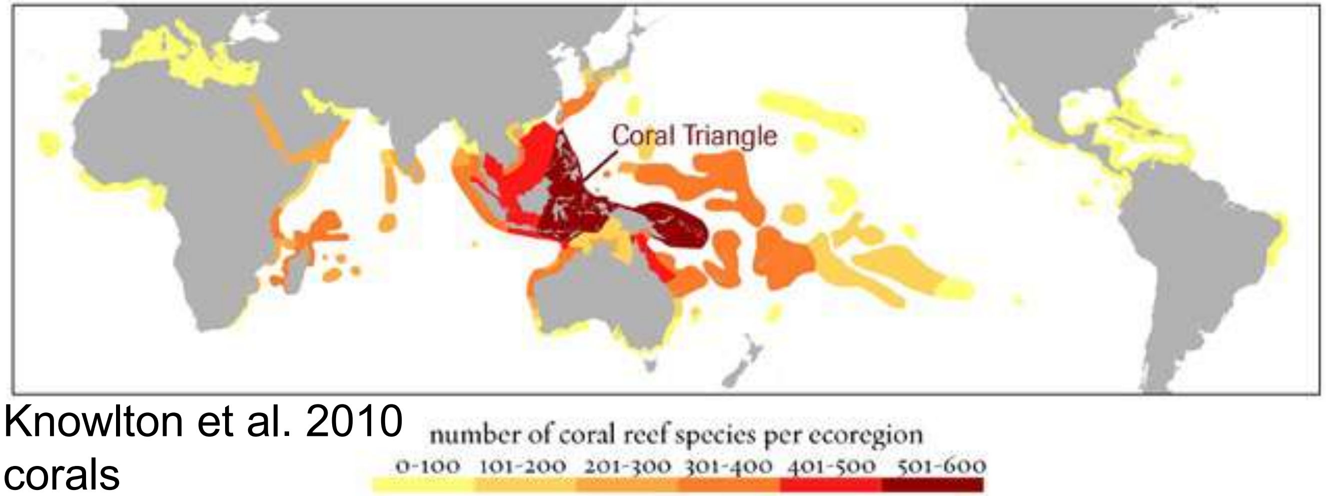
- Geographic factors (latitude, depth)
- Productivity, climatic factors, history
- Predation, competition
- Disturbance, isolation, heterogeneity



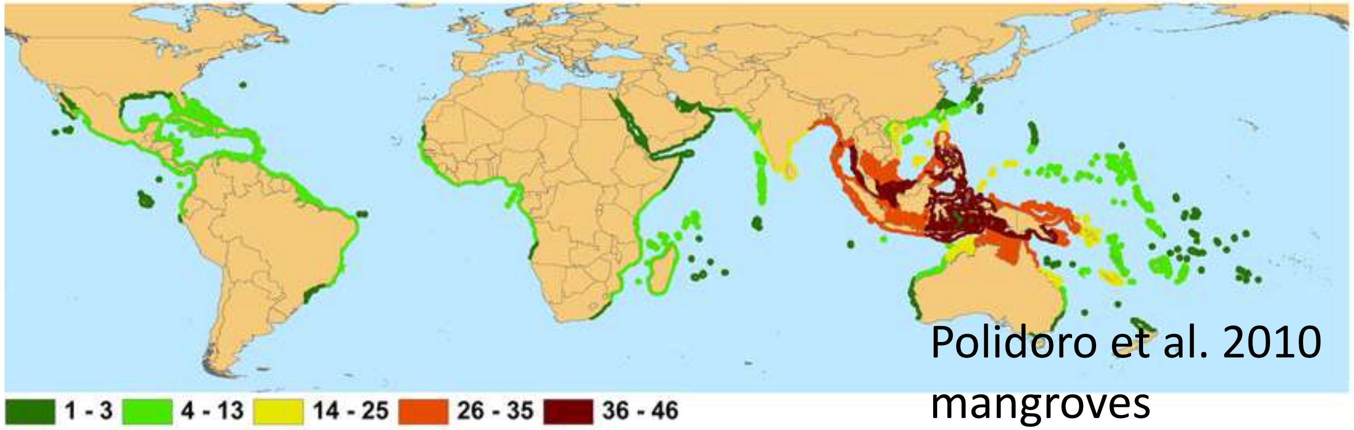
Stability-Time Hypothesis (Sanders 1968). This model says that physical instability in an environment prevents the establishment of diverse communities. However, if physically stable conditions persist for a long period of time, speciation and immigration will cause species diversity to increase gradually.

The intermediate disturbance hypothesis (Connell 1978). Small-infrequent or large-frequent disturbance could reduce diversity, which is maximum at intermedite levels of disturbance

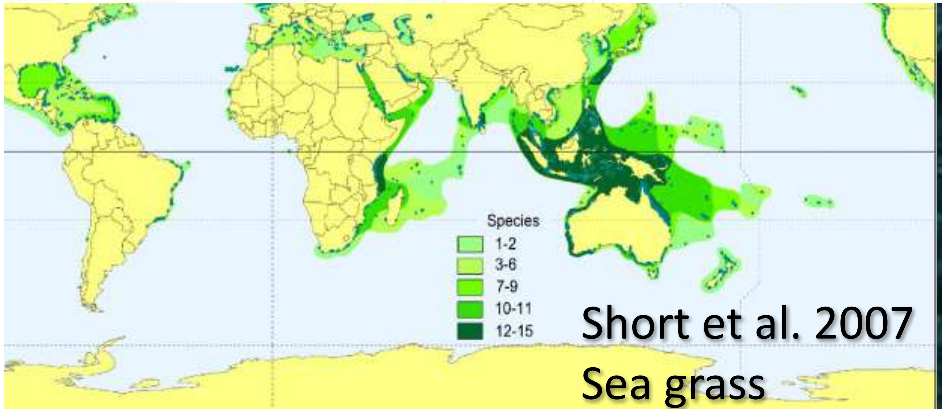
Biodiversity hotspots



Knowlton et al. 2010
corals



Polidoro et al. 2010
mangroves



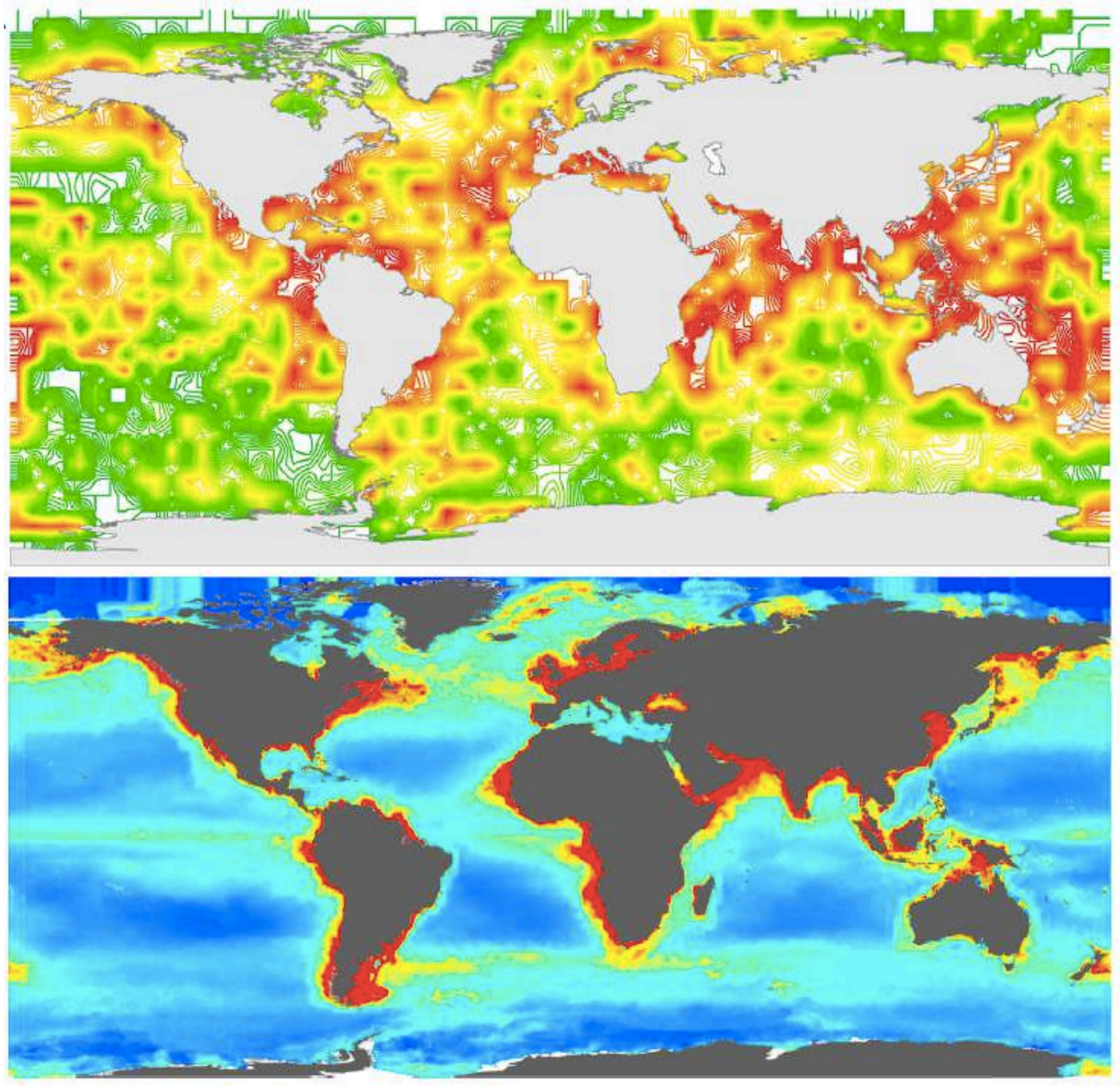
Short et al. 2007
Sea grass

Most groups shows peaks of diversity in the Indo-Pacific region

Sea level changes and tectonic processes regulated habitat availability and heterogeneity (Mihaljevic et al. 2017)

The high (fish) diversity of the Central Indo-Pacific was explained by its colonization by many lineages 5.3–34 million years ago. These relatively old colonizations allowed more time for richness to build up through *in situ* diversification compared to other warm-marine regions. (Miller et al. 2018)

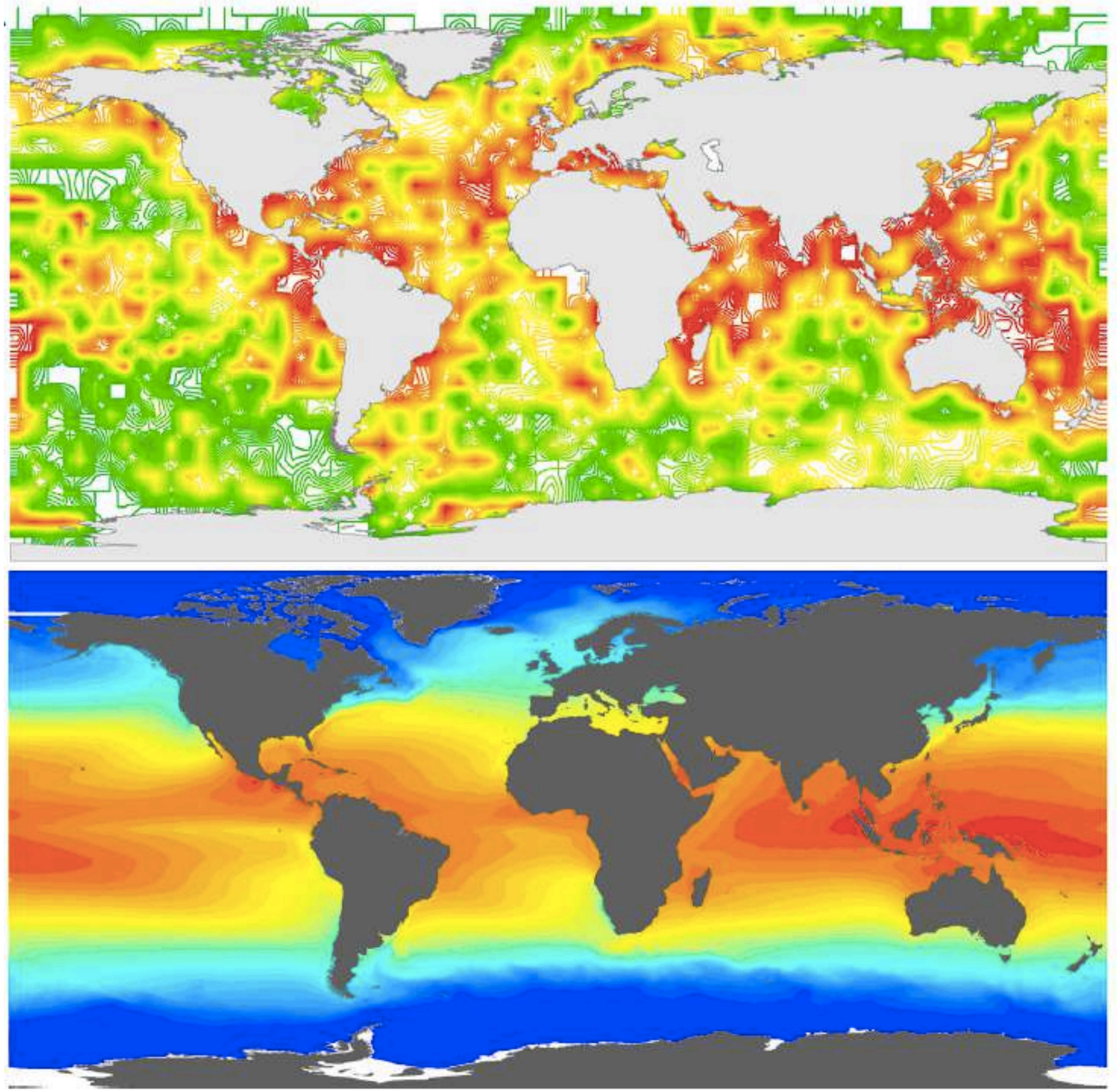
Productivity



Productivity and high energy flow could sustain higher number of species with respect to less productive areas

(maps from Costello & Chaudhary 2017)

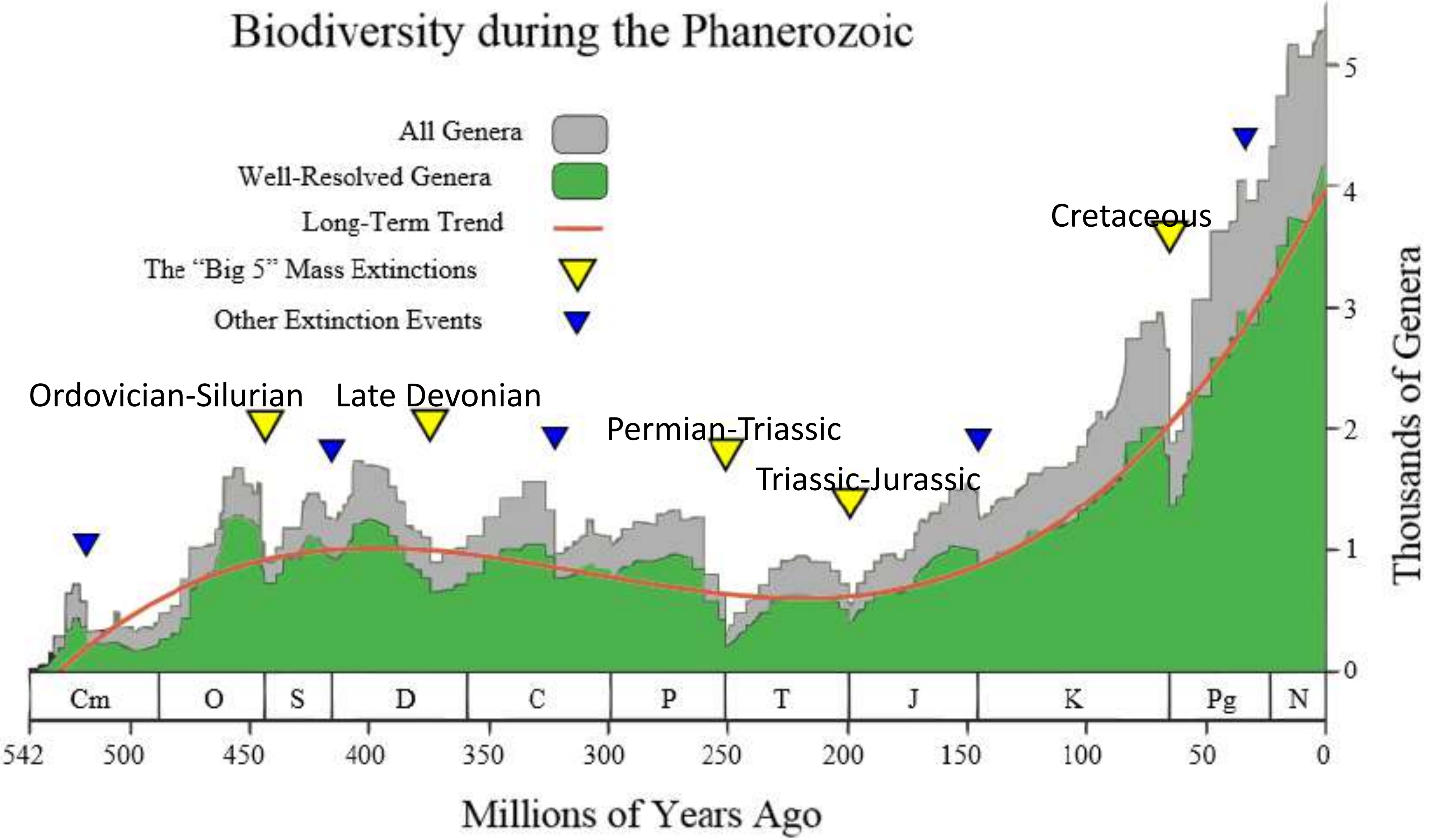
Temperature



(maps from Costello & Chaudhary 2017)

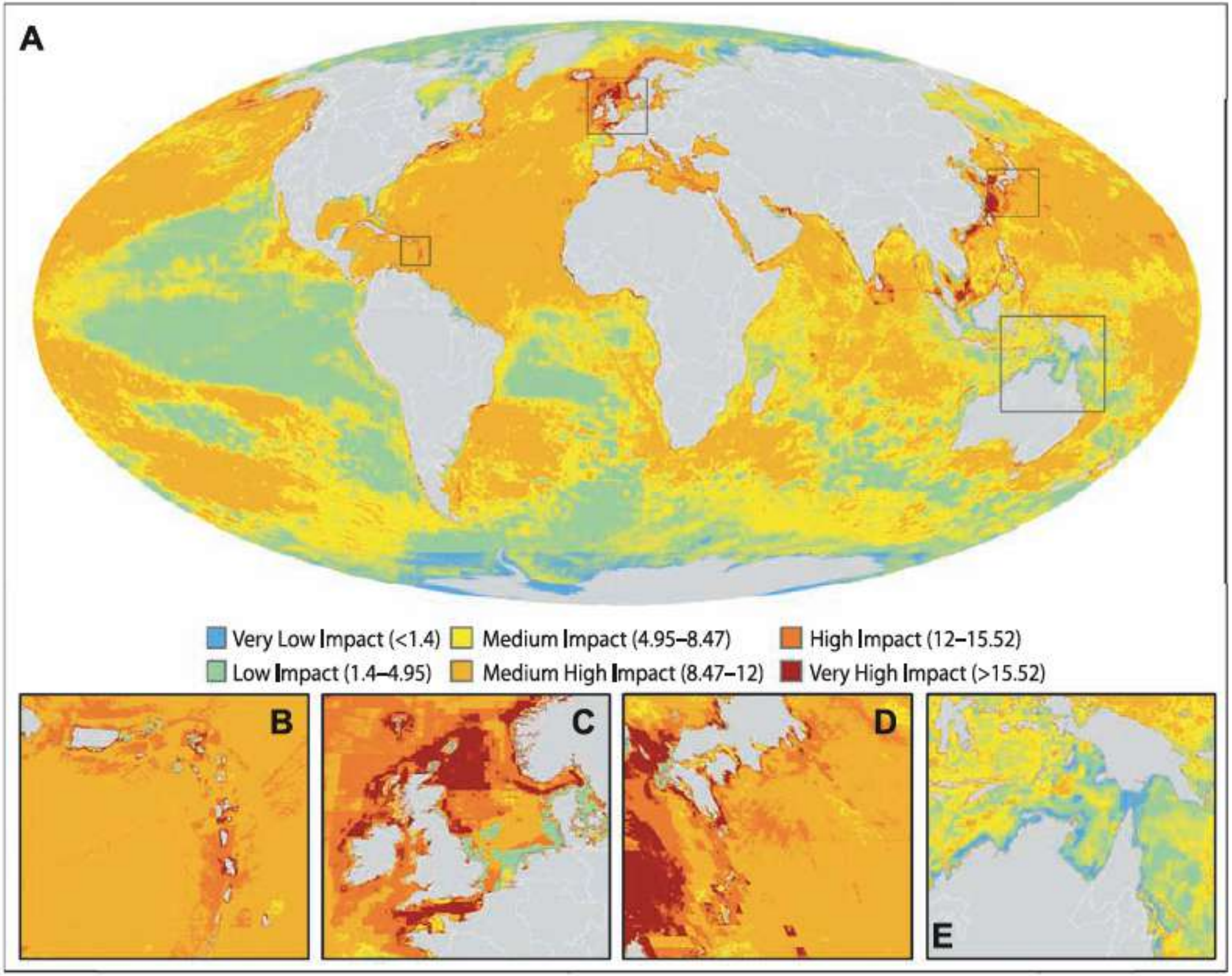
Rates of genetic divergence and speciation are both governed by metabolic rate and therefore show the same exponential temperature dependence. So, higher temperature increases speciation rates (Allen et al. 2006)

Biodiversity in the last eon



5 big mass extinctions. Biodiversity is increasing

Human impacts on world's oceans



A Global Map of Human Impact on Marine Ecosystems (Halpern et al. 2008)

Biodiversity loss

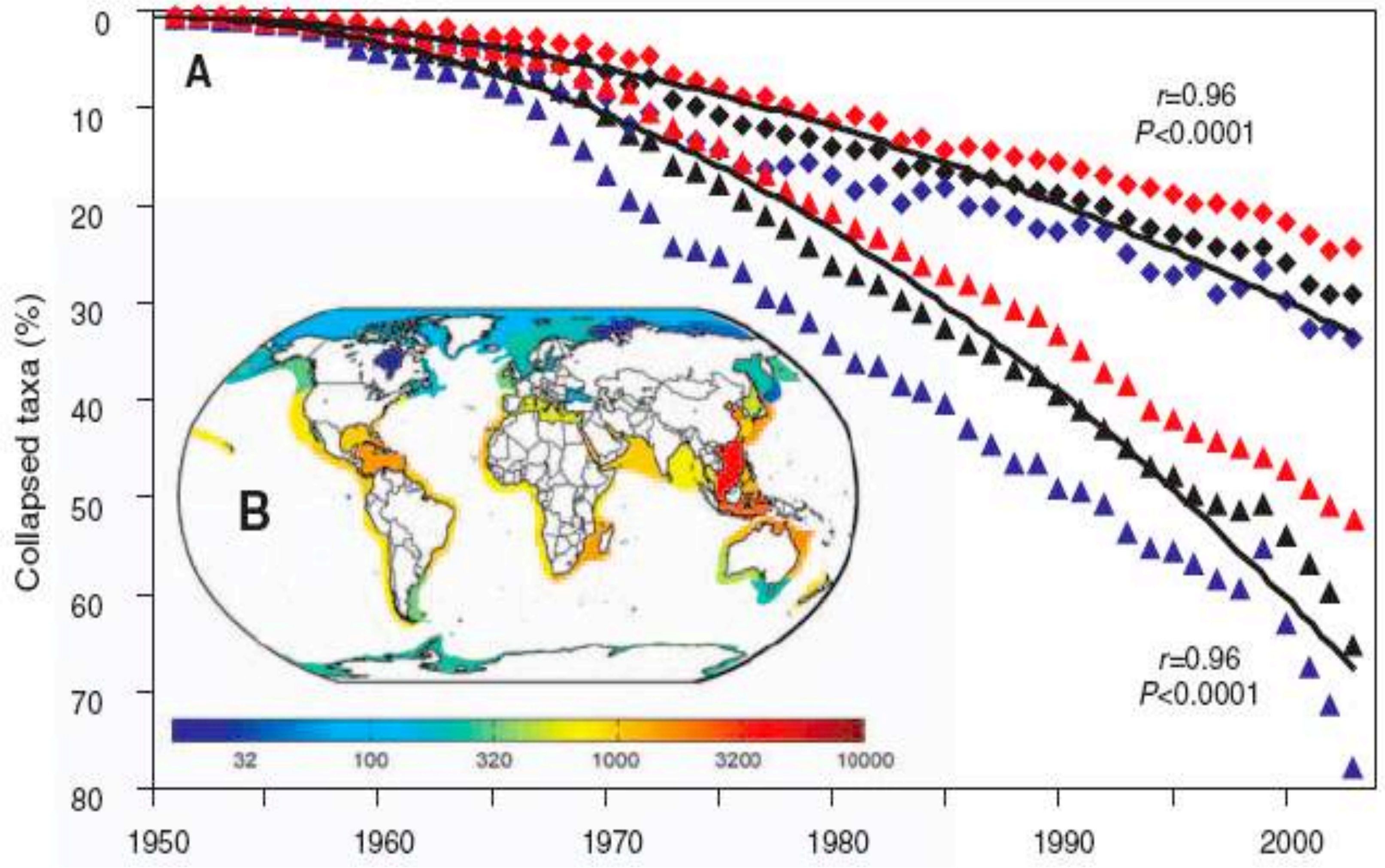
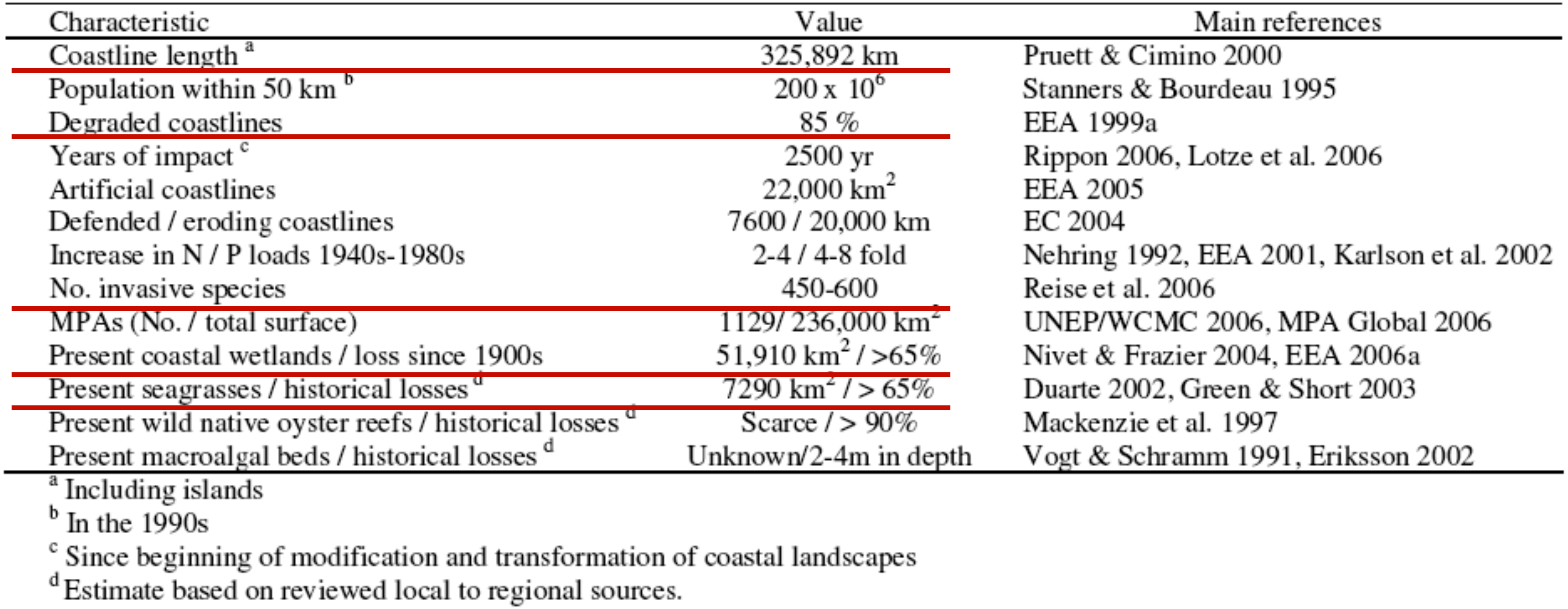


Fig. 3. Global loss of species from LMEs. (**A**) Trajectories of collapsed fish and invertebrate taxa over the past 50 years (diamonds, collapses by year; triangles, cumulative collapses). Data are shown for all (black), species-poor (<500 species, blue), and species-rich (>500 species, red) LMEs. Regression lines are best-fit power models corrected for temporal autocorrelation.

Worm et al. Science 2006

Habitat loss

85% of European coasts are degraded. Salt marshes and seagrass experienced about 50% loss over last decades. (Airoldi & Beck 2007)



Characteristic	Value	Main references
Coastline length [a]	325,892 km	Pruett & Cimino 2000
Population within 50 km [b]	200×10^6	Stanners & Bourdeau 1995
Degraded coastlines	85 %	EEA 1999a
Years of impact [c]	2500 yr	Rippon 2006, Lotze et al. 2006
Artificial coastlines	22,000 km^2	EEA 2005
Defended / eroding coastlines	7600 / 20,000 km	EC 2004
Increase in N / P loads 1940s-1980s	2-4 / 4-8 fold	Nehring 1992, EEA 2001, Karlson et al. 2002
No. invasive species	450-600	Reise et al. 2006
MPAs (No. / total surface)	1129/ 236,000 km^2	UNEP/WCMC 2006, MPA Global 2006
Present coastal wetlands / loss since 1900s	51,910 km^2 / >65%	Nivet & Frazier 2004, EEA 2006a
Present seagrasses / historical losses [d]	7290 km^2 / > 65%	Duarte 2002, Green & Short 2003
Present wild native oyster reefs / historical losses [d]	Scarce / > 90%	Mackenzie et al. 1997
Present macroalgal beds / historical losses [d]	Unknown/2-4m in depth	Vogt & Schramm 1991, Eriksson 2002

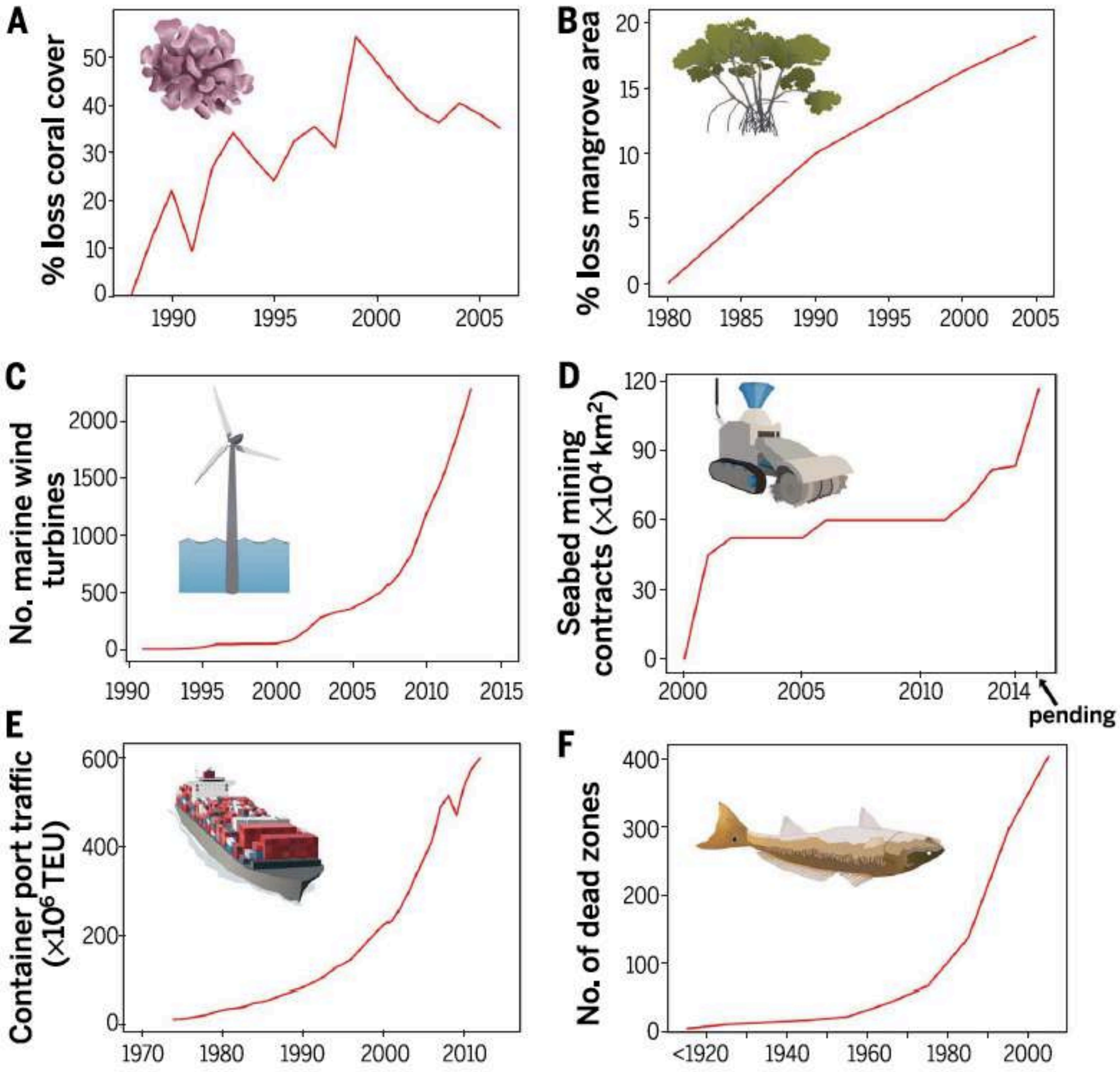
[a] Including islands

[b] In the 1990s

[c] Since beginning of modification and transformation of coastal landscapes

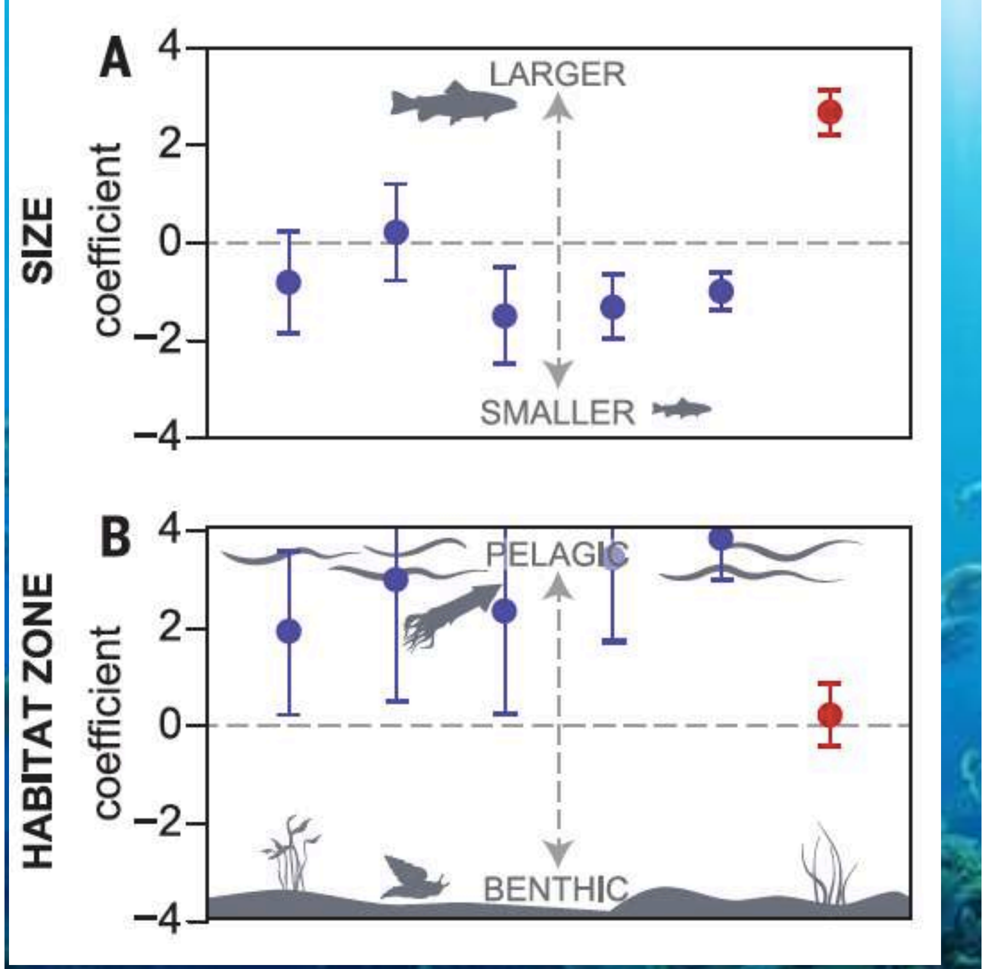
[d] Estimate based on reviewed local to regional sources.

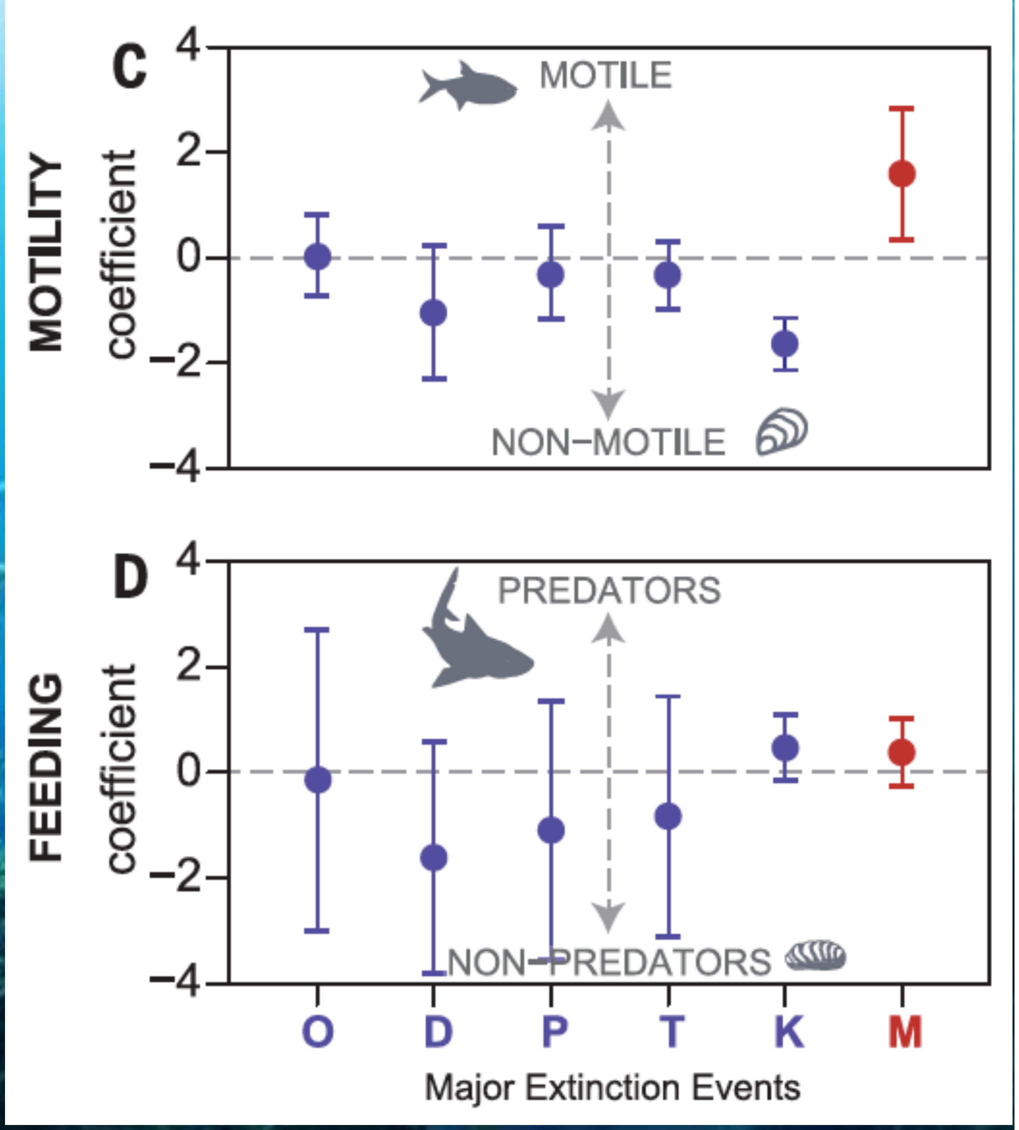
Habitat loss or alteration



McCauley et al. 2015

Modern extinction risk

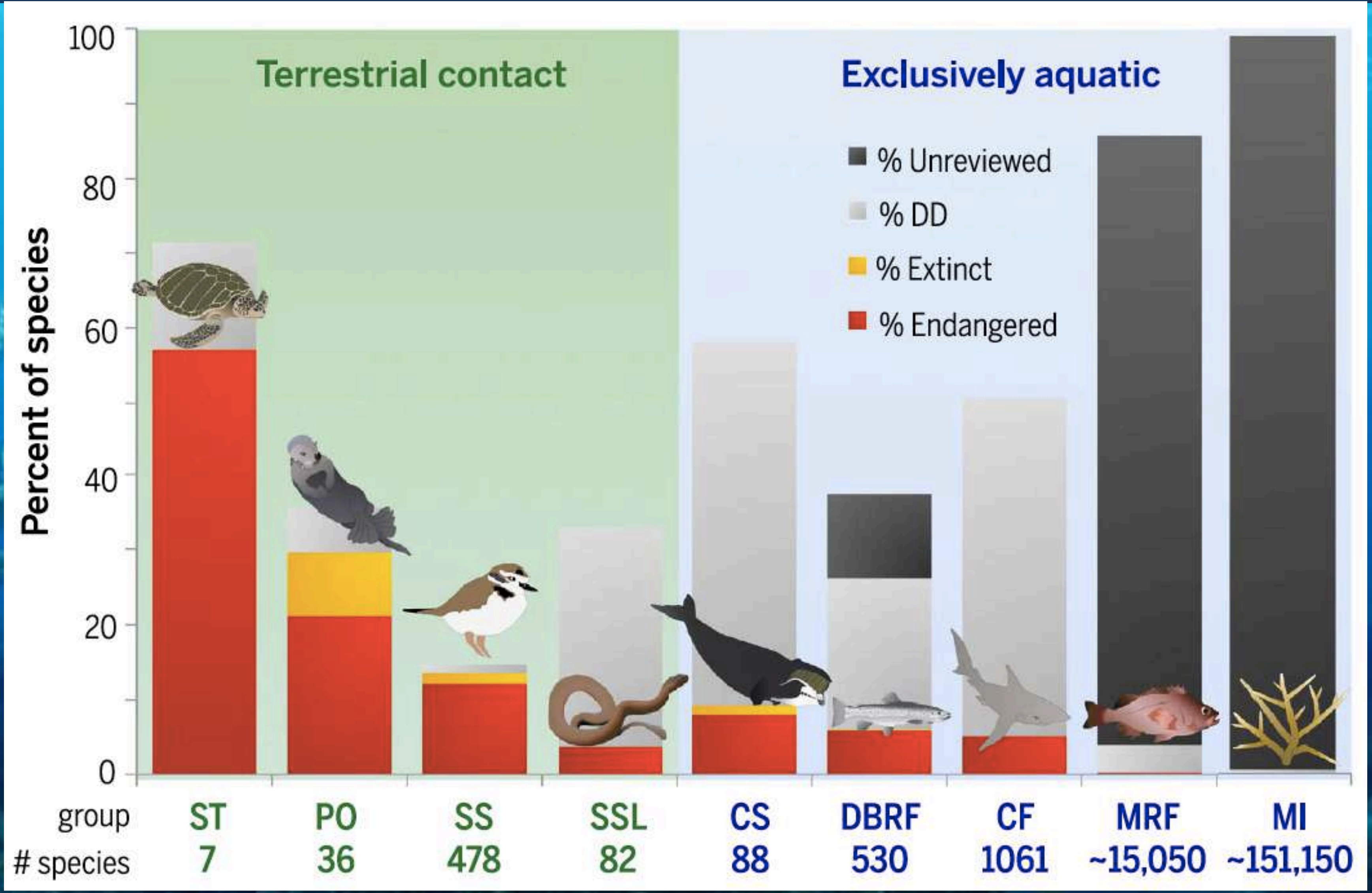




Payne et al. 2016

Ecological selectivity of extinction threat in the modern oceans is unlike any previous mass extinction. Previous mass extinction events (blue symbols) preferentially eliminated pelagic genera and, sometimes, smaller genera, whereas the modern extinction threat (red symbols) is strongly associated with larger body size and moderately associated with motility

Modern extinction risk

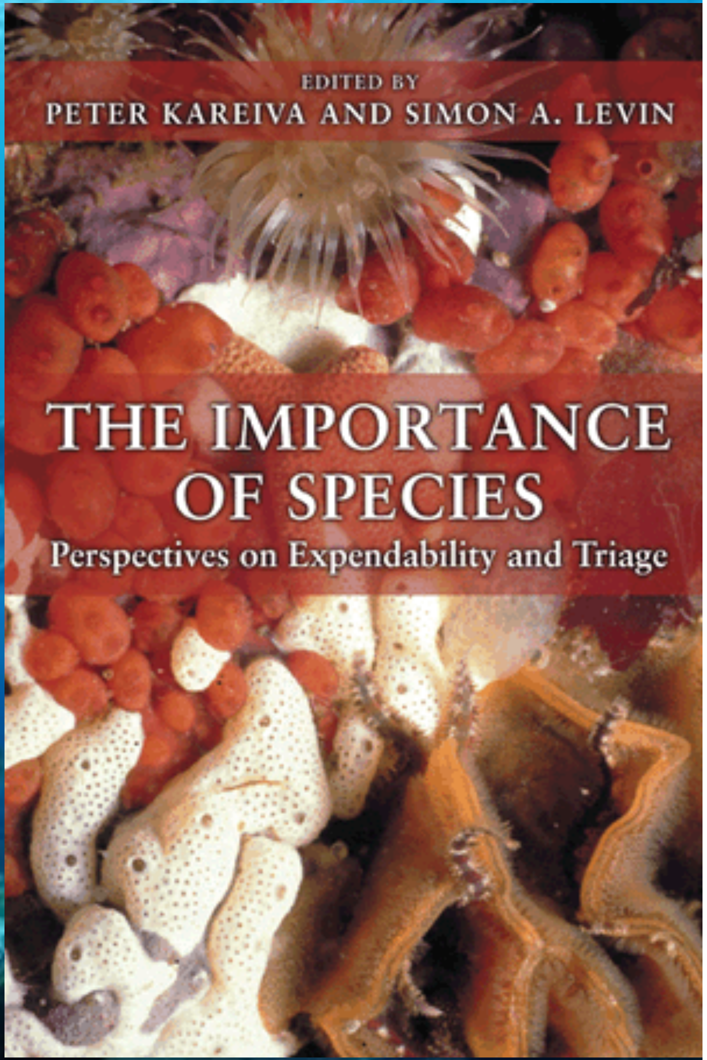


McCauley et al. 2015

Threat from defaunation is portrayed for different groups of marine fauna as chronicled by the IUCN Red List.Threat categories include “extinct” (orange), “endangered” (red; IUCN categories “critically endangered” + “endangered”), “data deficient” (light gray), and “unreviewed” (dark gray).

Consequences of this loss?

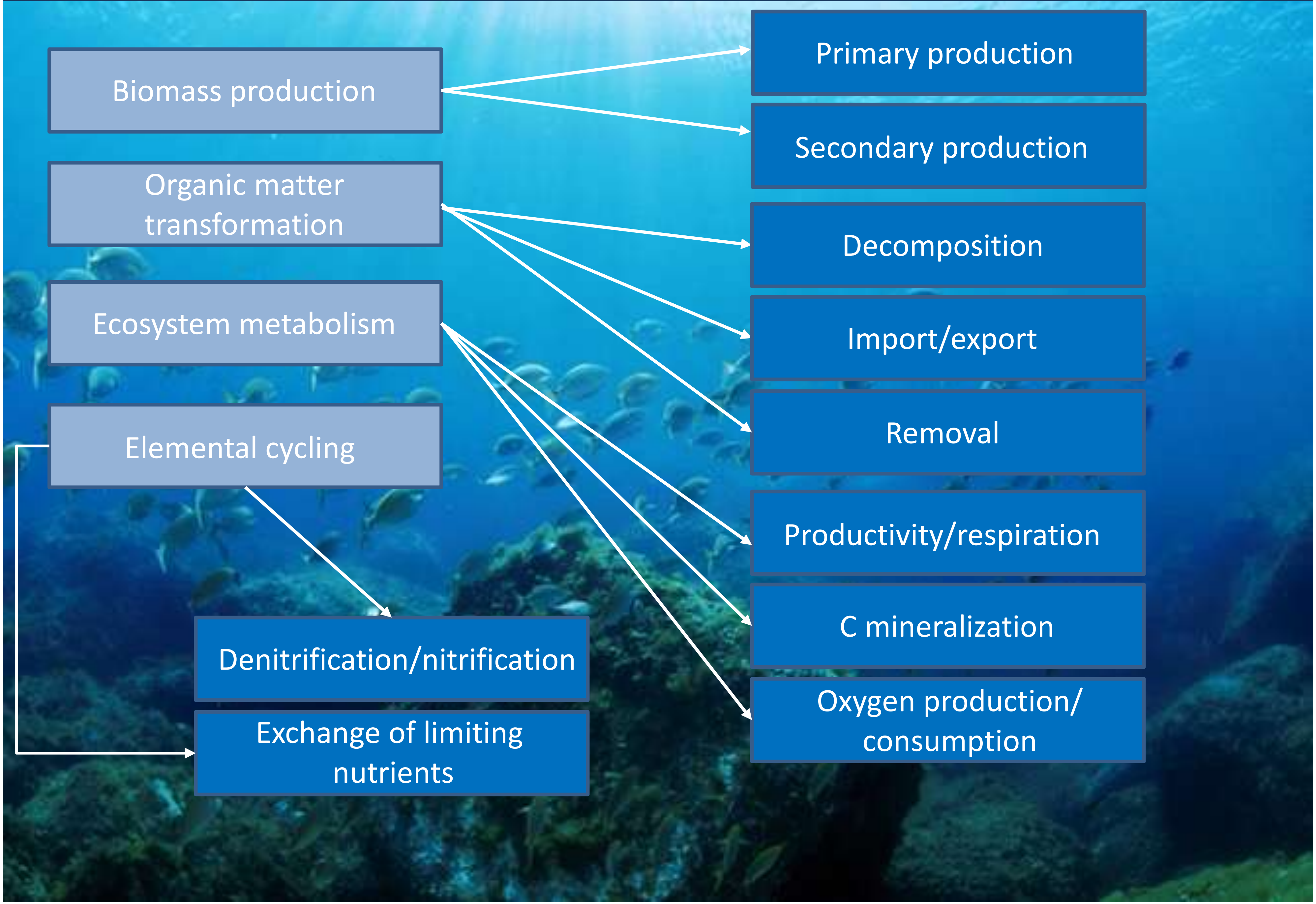
- What are the consequences of biodiversity loss (and invasions) at local and regional scale on the functioning of ecosystems?
- Although we know (more or less) the effects of productivity, disturbance, nutrients on diversity, the inverse relationships are still debated.
- The risk of ecosystem collapse fuelled an intense research on the potential effects of biodiversity loss



EDITED BY
PETER KAREIVA AND SIMON A. LEVIN

THE IMPORTANCE OF SPECIES
Perspectives on Expendability and Triage

Ecosystem functions



Biomass production

Organic matter transformation

Ecosystem metabolism

Elemental cycling

Primary production

Secondary production

Decomposition

Import/export

Removal

Productivity/respiration

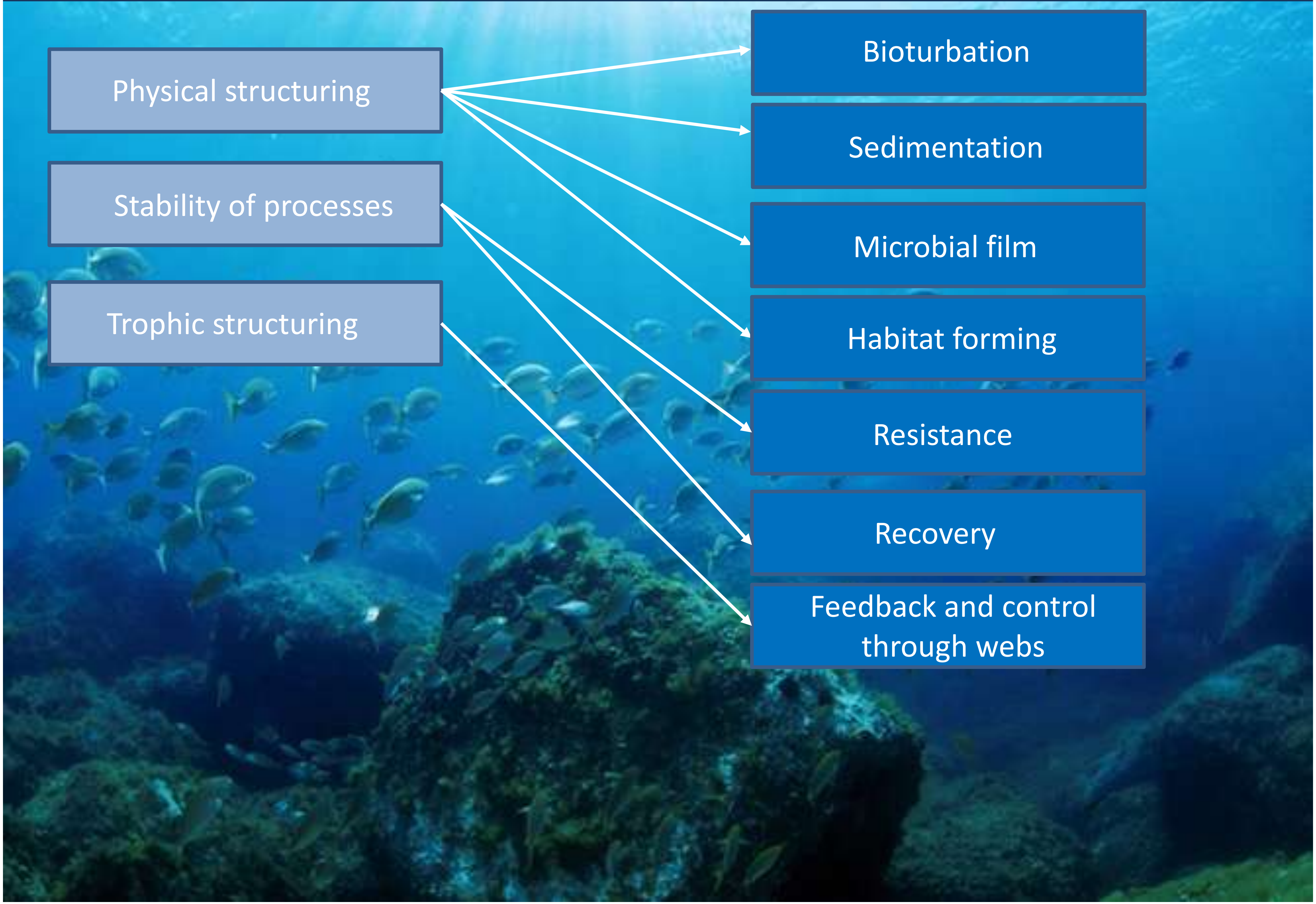
C mineralization

Oxygen production/ consumption

Denitrification/nitrification

Exchange of limiting nutrients

Ecosystem functions



Physical structuring

Stability of processes

Trophic structuring

Bioturbation

Sedimentation

Microbial film

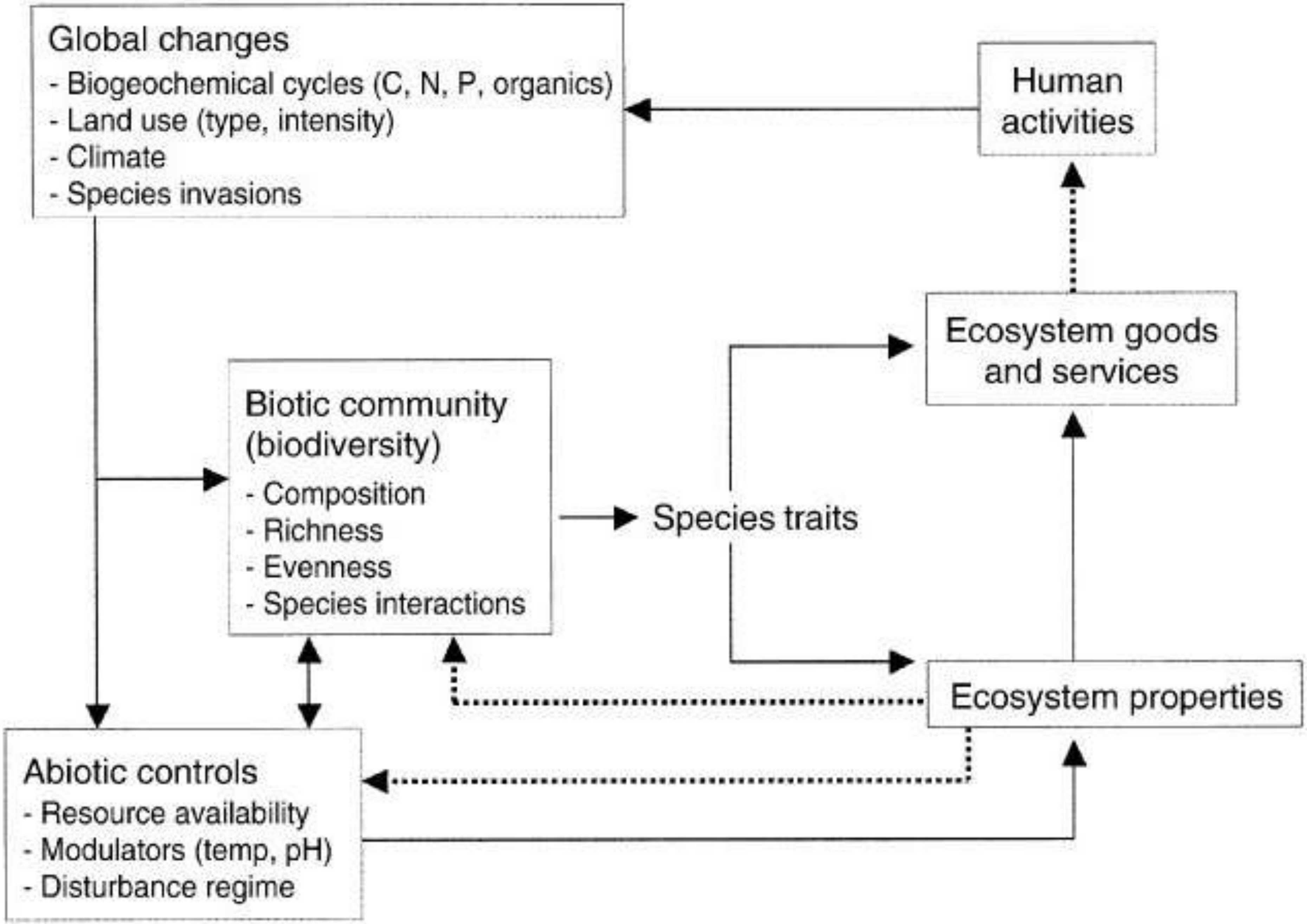
Habitat forming

Resistance

Recovery

Feedback and control through webs

Ecosystem functions: mechanisms



Global changes
- Biogeochemical cycles (C, N, P, organics)
- Land use (type, intensity)
- Climate
- Species invasions

Human activities

Ecosystem goods and services

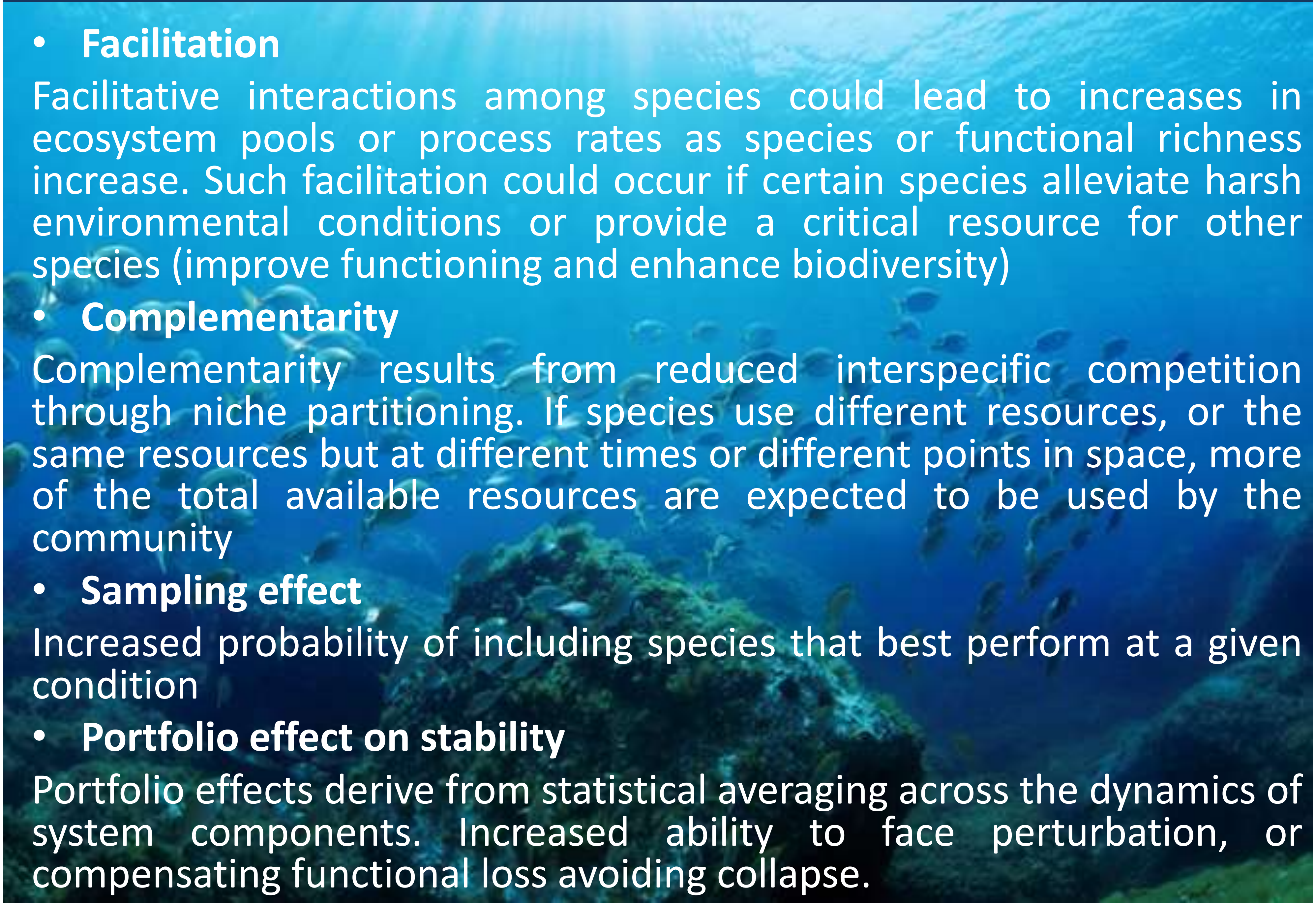
Biotic community (biodiversity)
- Composition
- Richness
- Evenness
- Species interactions

Species traits

Ecosystem properties

Abiotic controls
- Resource availability
- Modulators (temp, pH)
- Disturbance regime

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

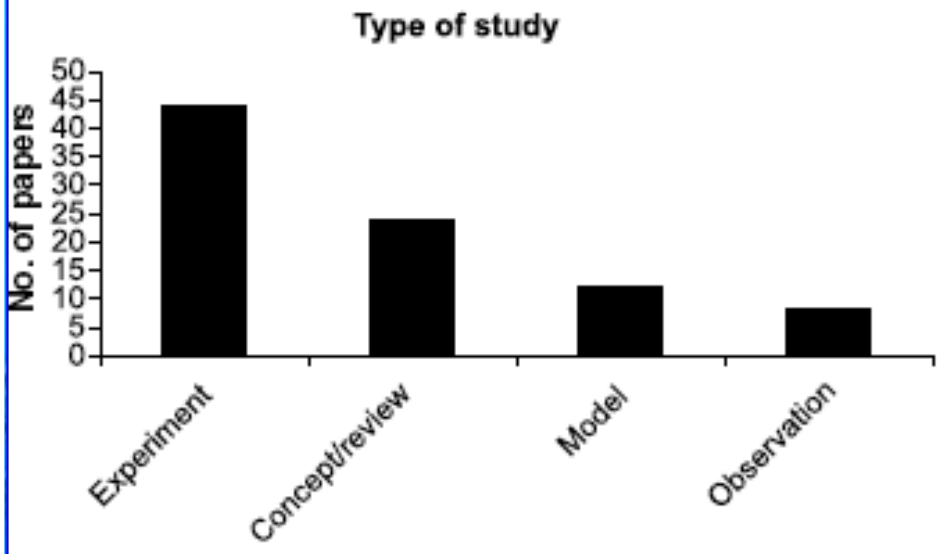
- **Sampling effect**

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

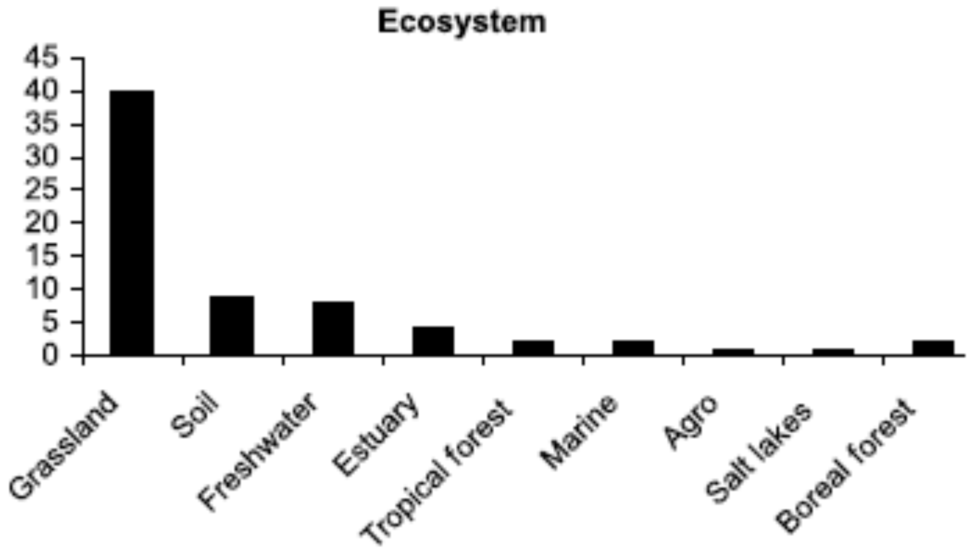
- **Portfolio effect on stability**

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

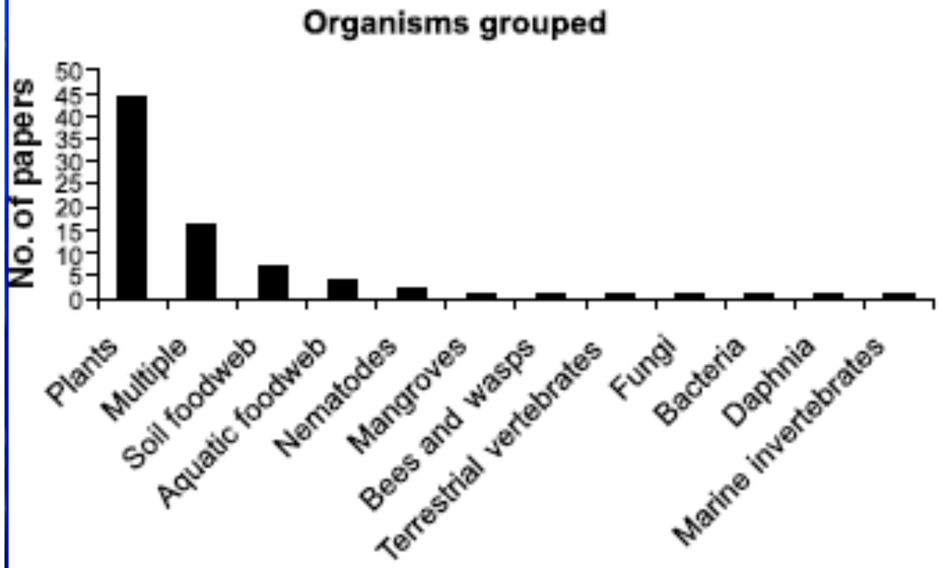
Limited studies in the marine environment



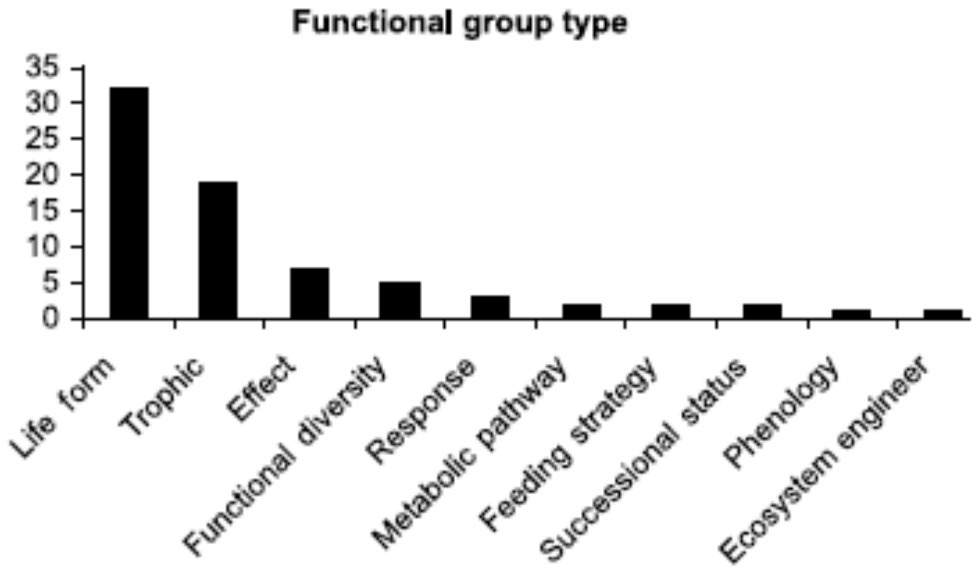
Type of study



Ecosystem

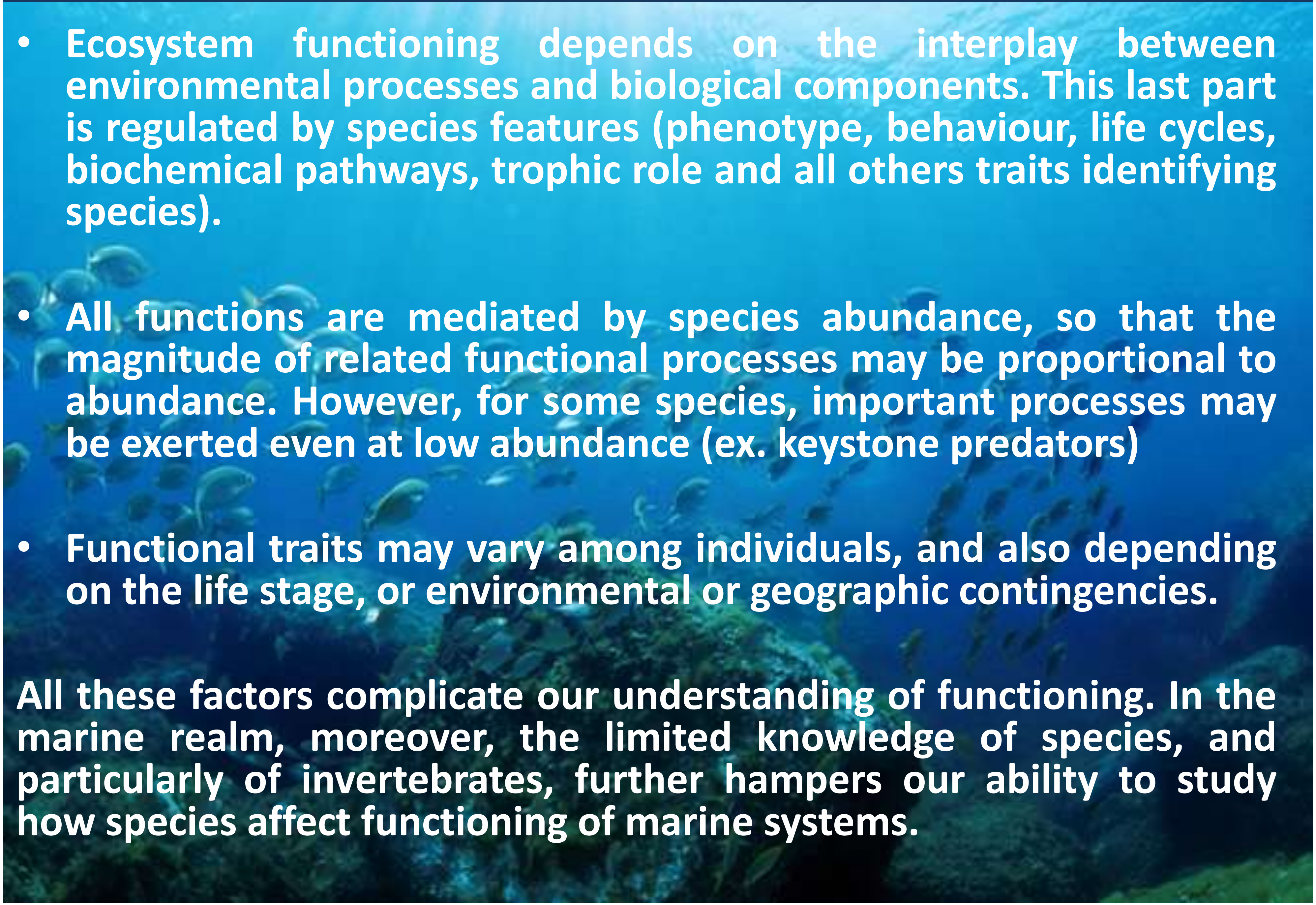


Organisms grouped



Functional group type

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.

Redundancy (?)

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

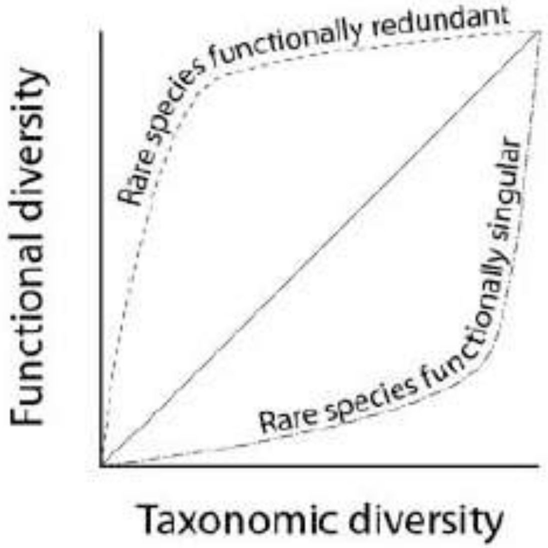
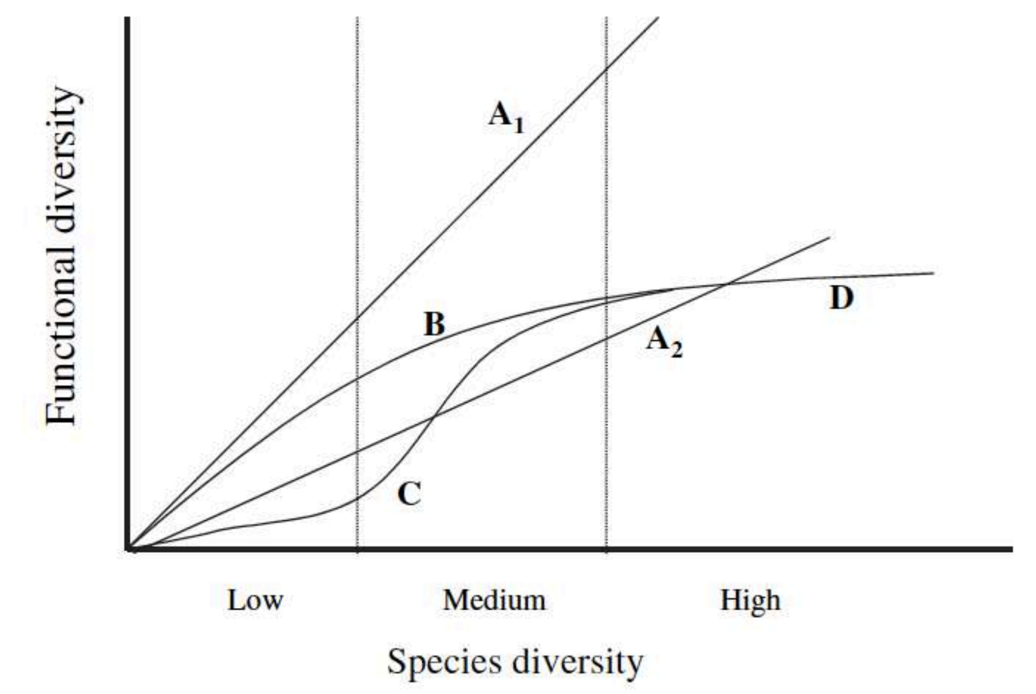
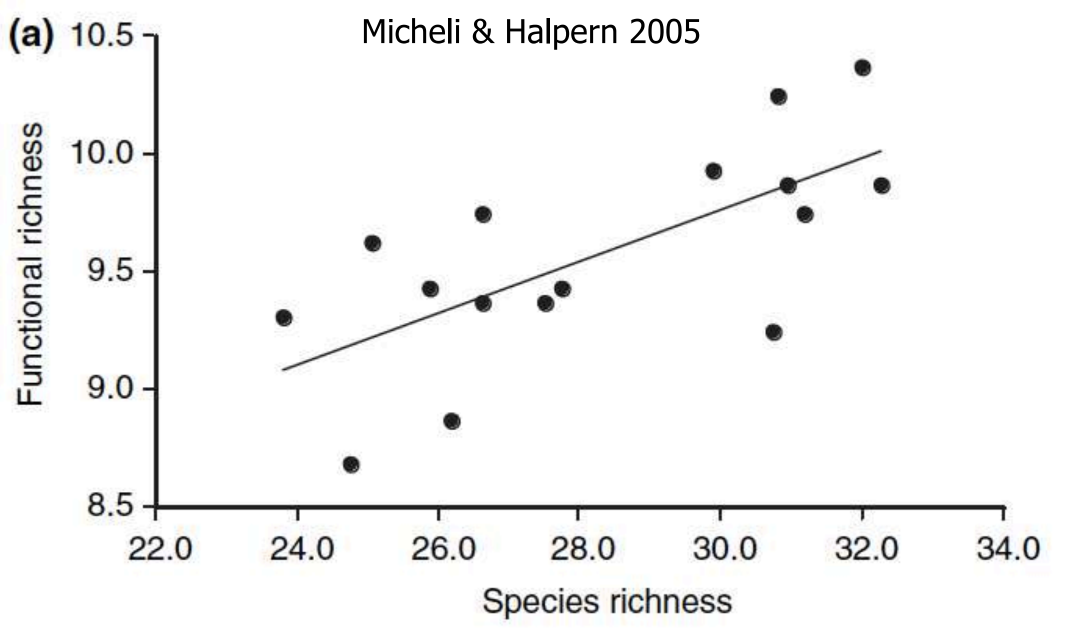


Figure 2 The relationship between taxonomic and functional diversity. Three possible relationships are shown. The top (dashed) line shows the relationship when rare species are functionally redundant. The middle, straight line (continuous) shows the relationship when every species contributes to functioning 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

Taxonomic, phylogenetic and functional diversity

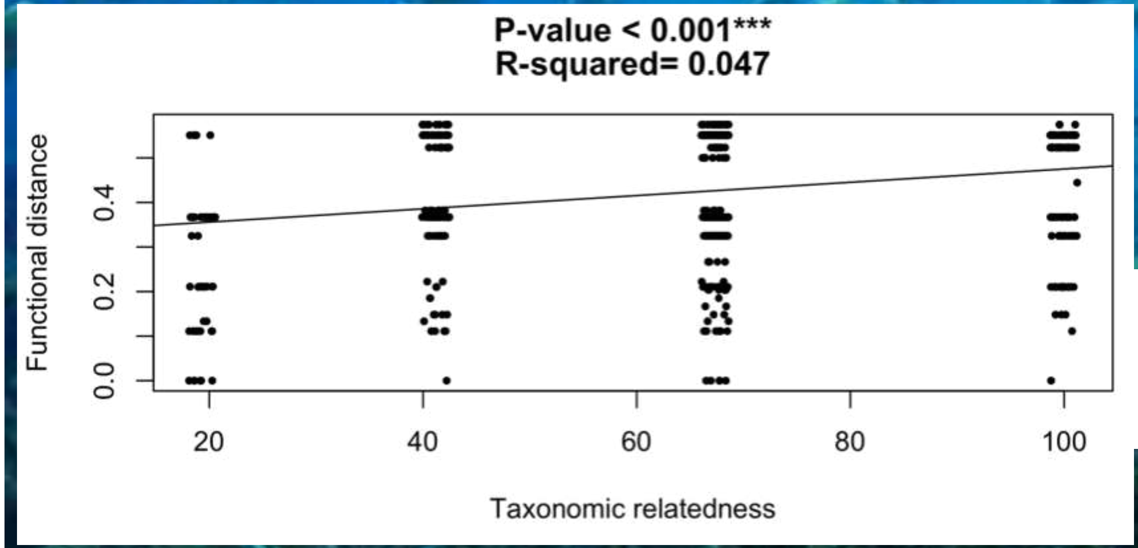
Phylogenetic/taxonomic relatedness often unrelated

Similarity not necessarily extends to the whole functional trait spectrum

Similarity not necessarily concerns functional traits involved in the response

NEUTRAL RESPONSE

Losos, 2008 Ecol Lett



Relationships among different facets of biodiversity are crucial for ecological application of BEF concept to the real world.

For instance, if taxonomic richness is correlated to functional richness, we could use the first as a proxy of the second, helping the understanding of link between diversity and functioning.

An example from aquatic vertebrates: fish assemblages from Mediterranean rocky coasts

Thiault L, Bevilacqua S, Terlizzi A, Claudet J, 2015.

However, these relationships are not so consistent

Implications for conservation

ECOLOGY LETTERS

Ecology Letters, (2010) 13: 1030–1040 doi: 10.1111/j.1461-0248.2010.01493.x

LETTER

Spatial mismatch and congruence between taxonomic, phylogenetic and functional diversity: the need for integrative conservation strategies in a changing world

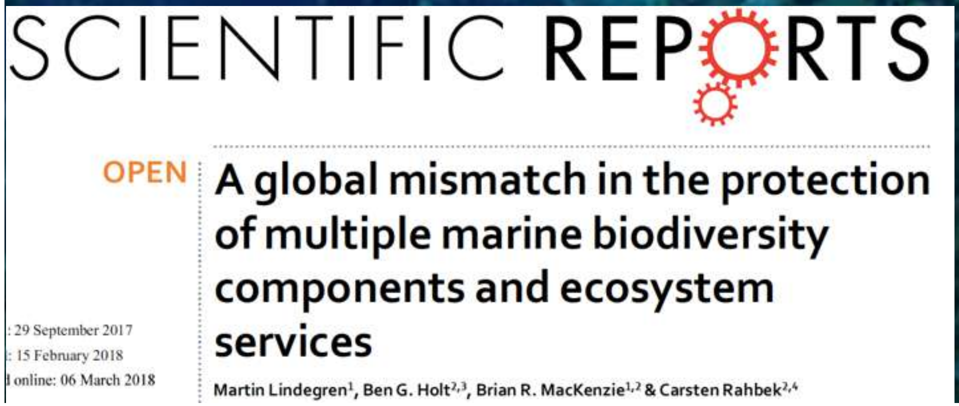
nature COMMUNICATIONS

ARTICLE

DOI: 10.1038/s41467-018-05126-3 OPEN

Prioritizing phylogenetic diversity captures functional diversity unreliably

Florent Mazel[1,2,3], Matthew W. Pennell[3,4], Marc W. Cadotte[5,6], Sandra Diaz[7], Giulio Valentino Dalla Riva[8], Richard Grenyer[9], Fabien Leprieur[10], Arne O. Mooers[1], David Mouillot[10,11], Caroline M. Tucker[12] & William D. Pearse[13]



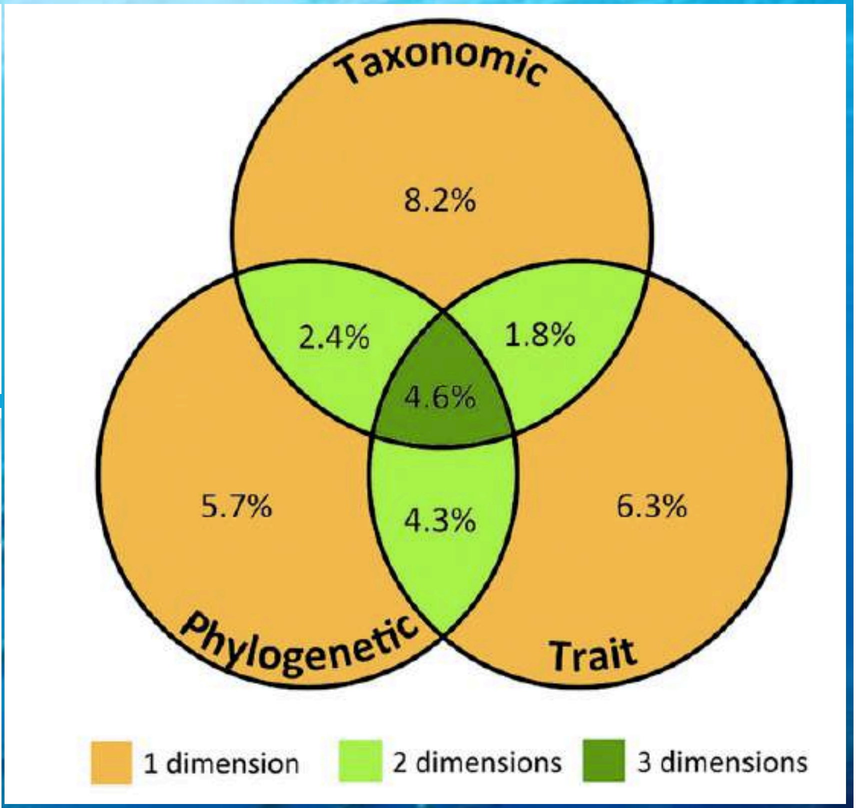
SCIENTIFIC REPORTS

OPEN

A global mismatch in the protection of multiple marine biodiversity components and ecosystem services

: 29 September 2017
: 15 February 2018
l online: 06 March 2018

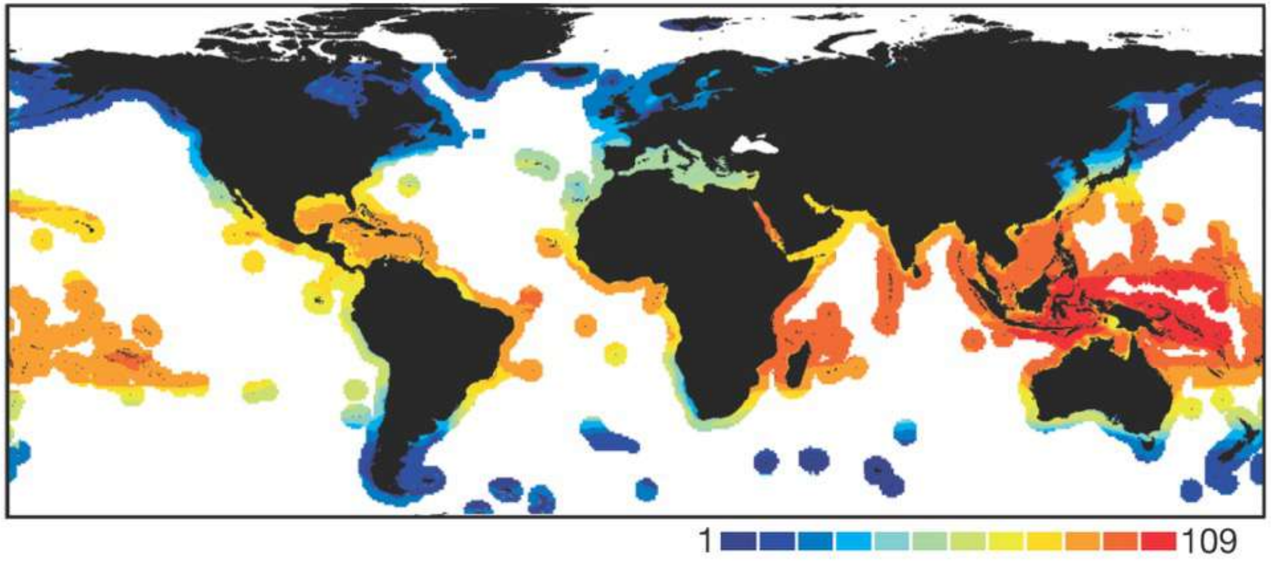
Martin Lindegren[1], Ben G. Holt[2,3], Brian R. MacKenzie[1,2] & Carsten Rahbek[2,4]



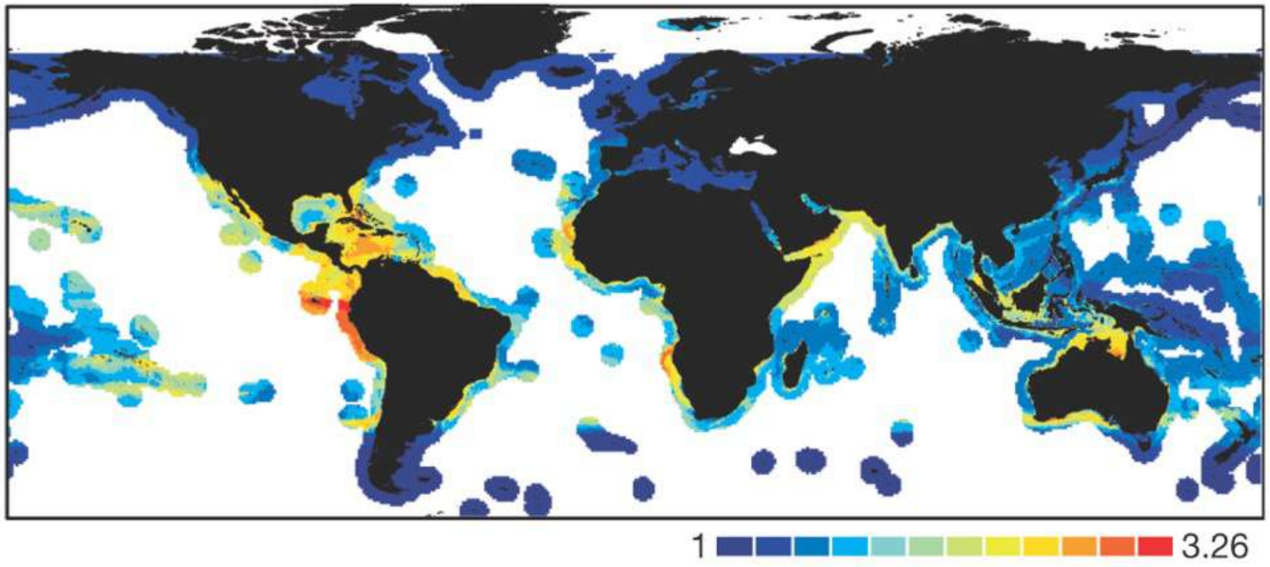
There is the need for integrative conservation strategies, which, beyond structure (taxonomic diversity) could allow the protection and maintenance of functions and evolutionary aspects

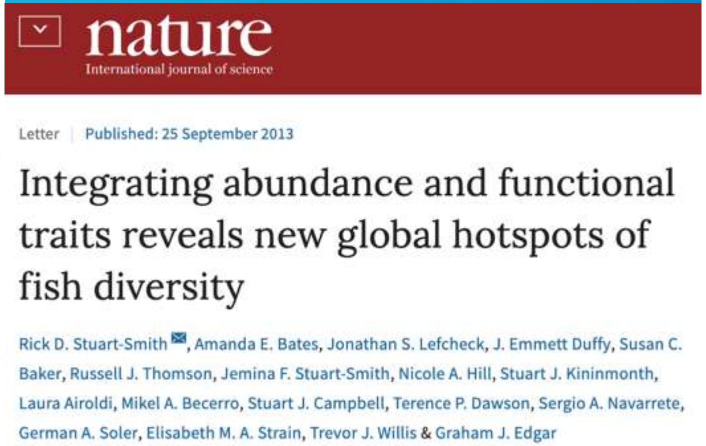
Spatial mismatch in diversities

a Species density



d Functional diversity





Letter | Published: 25 September 2013

Integrating abundance and functional traits reveals new global hotspots of fish diversity

Rick D. Stuart-Smith, Amanda E. Bates, Jonathan S. Lefcheck, J. Emmett Duffy, Susan C. Baker, Russell J. Thomson, Jemina F. Stuart-Smith, Nicole A. Hill, Stuart J. Kininmonth, Laura Airoldi, Mikel A. Becerro, Stuart J. Campbell, Terence P. Dawson, Sergio A. Navarrete, German A. Soler, Elisabeth M. A. Strain, Trevor J. Willis & Graham J. Edgar

Different patterns considering species richness and functional diversity of fish assemblages

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

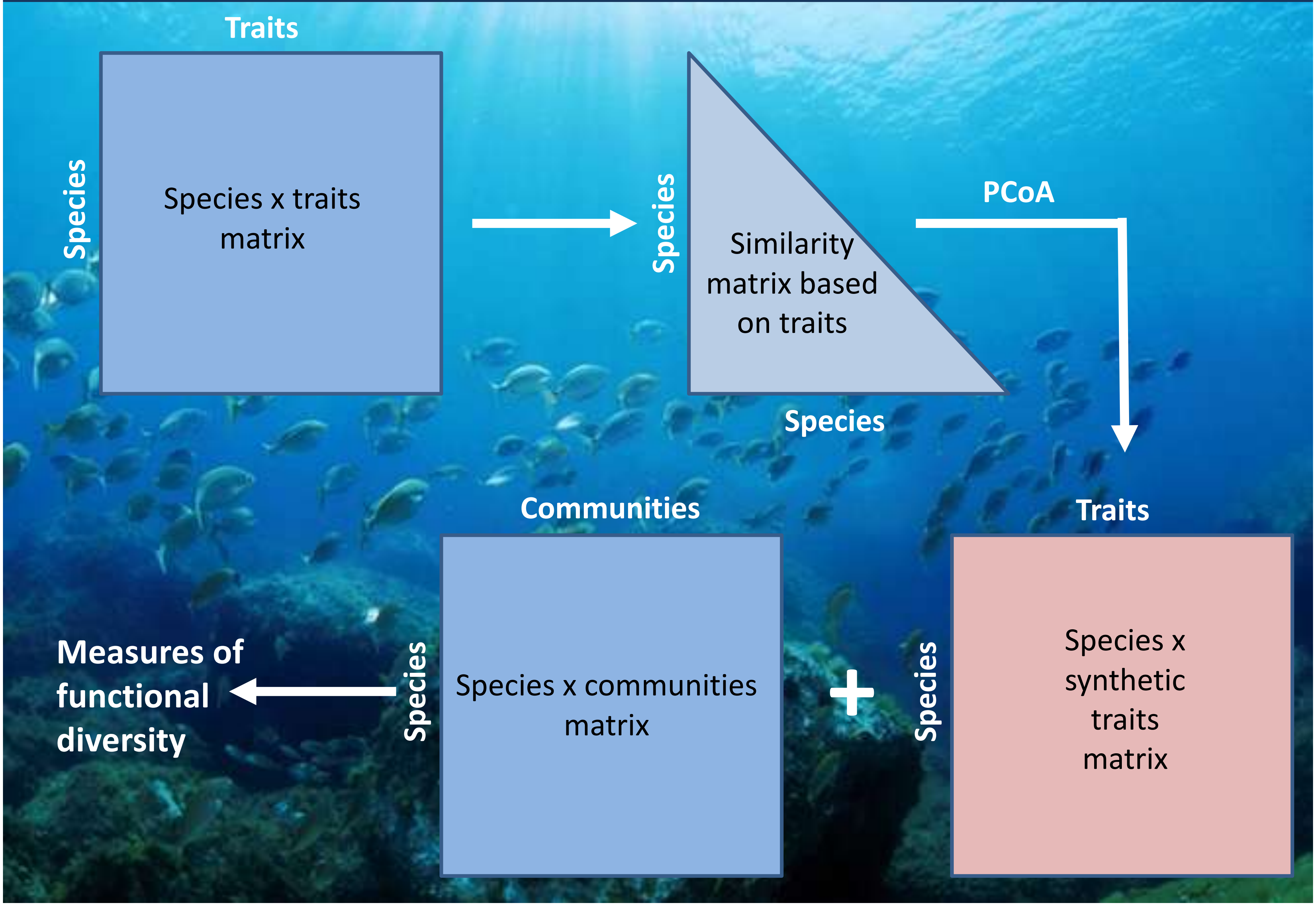
Matter and energy flow	*Biomass*	Biomass
	Caloric content	Energy content of tissues
	$CaCO_3$ content	Amount $CaCO_3$ in tissues (% per g dry weight)

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)

Analysis of functional diversity



Traits

Species

Species x traits matrix

Species

Similarity matrix based on traits

Species

PCoA

Traits

Species

Species x synthetic traits matrix

+

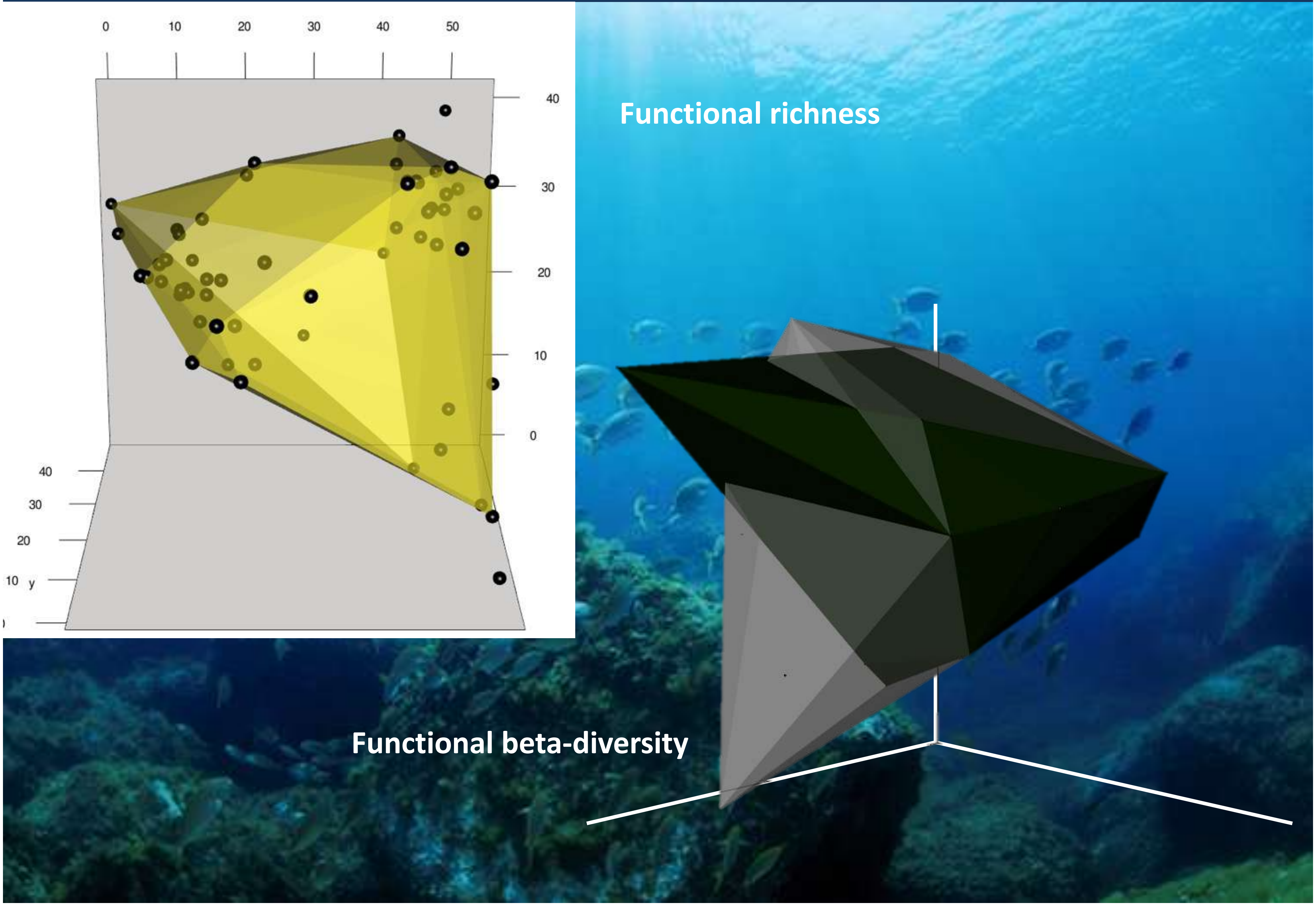
Communities

Species

Species x communities matrix

Measures of functional diversity

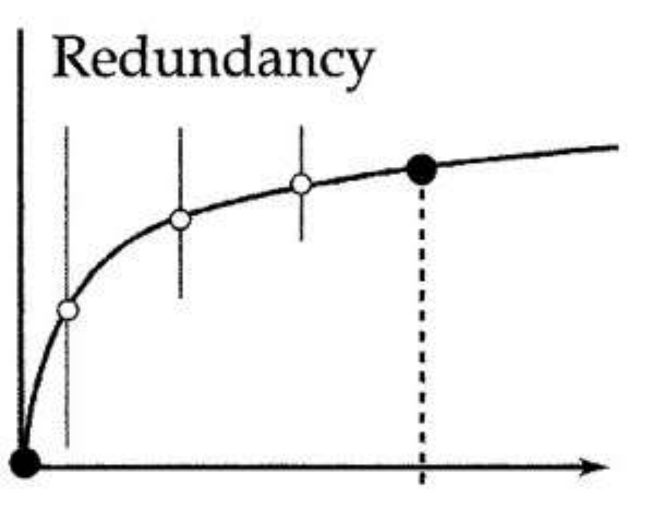
Measures of functional diversity

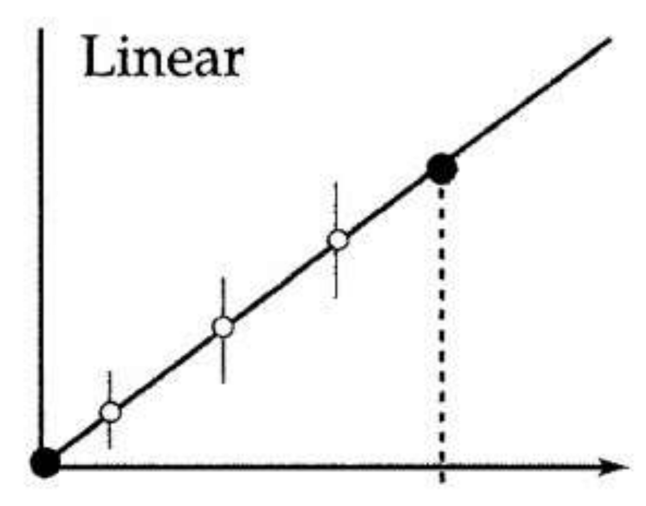


Functional richness

Functional beta-diversity

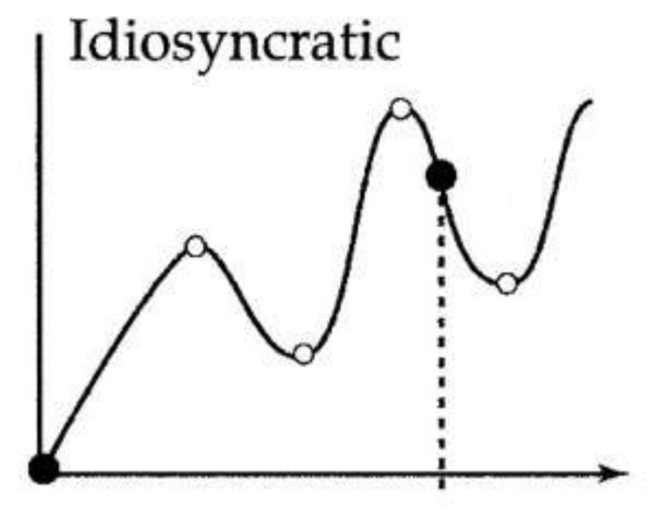
Models of BEF relationships





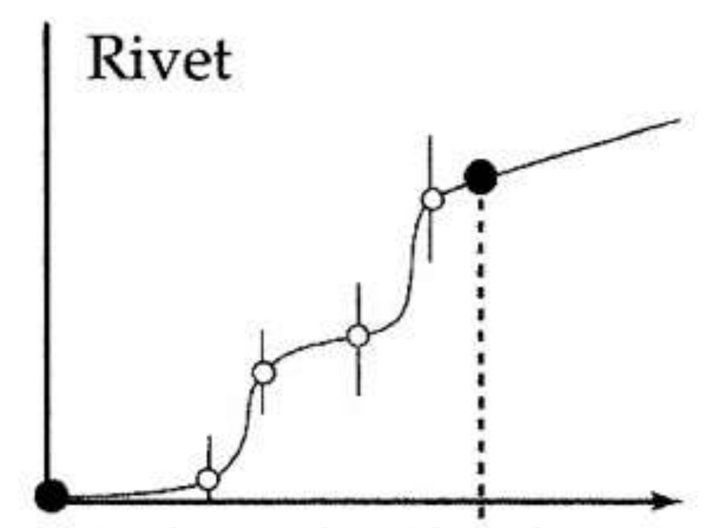
Species are primarily singular: loss or addition of species causes detectable changes in ecosystem process rates, i.e. species make unique contributions to ecosystem functioning.

Species 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.

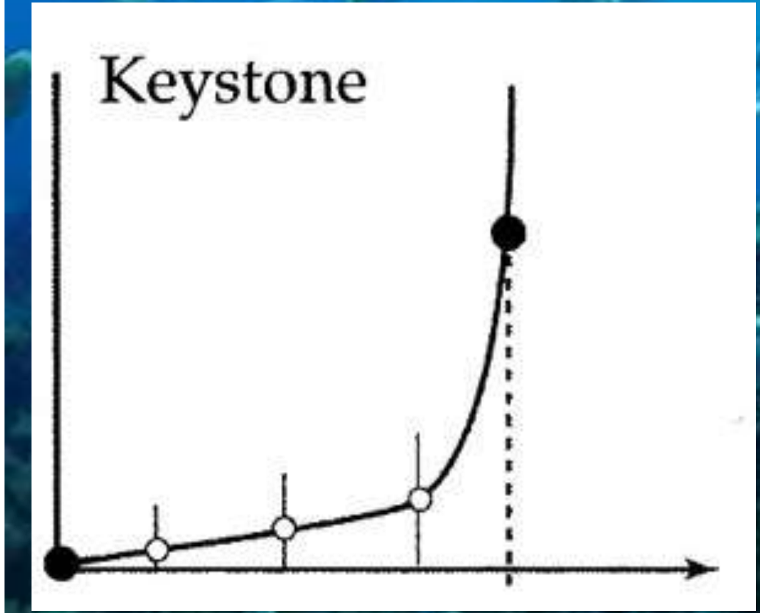


Species impacts are context-dependent and therefore idiosyncratic: the impact of loss or addition of species depends on environmental conditions and the species, and its interaction with the others (Lawton 1994)

Models of BEF relationships

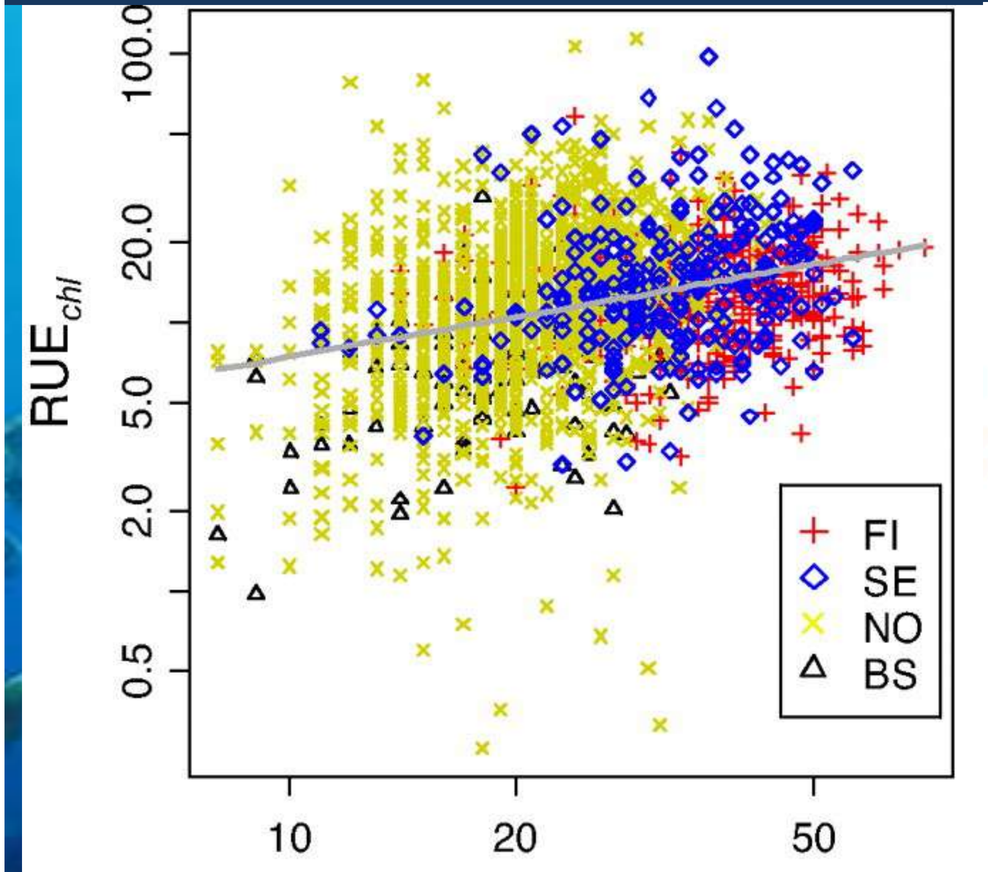


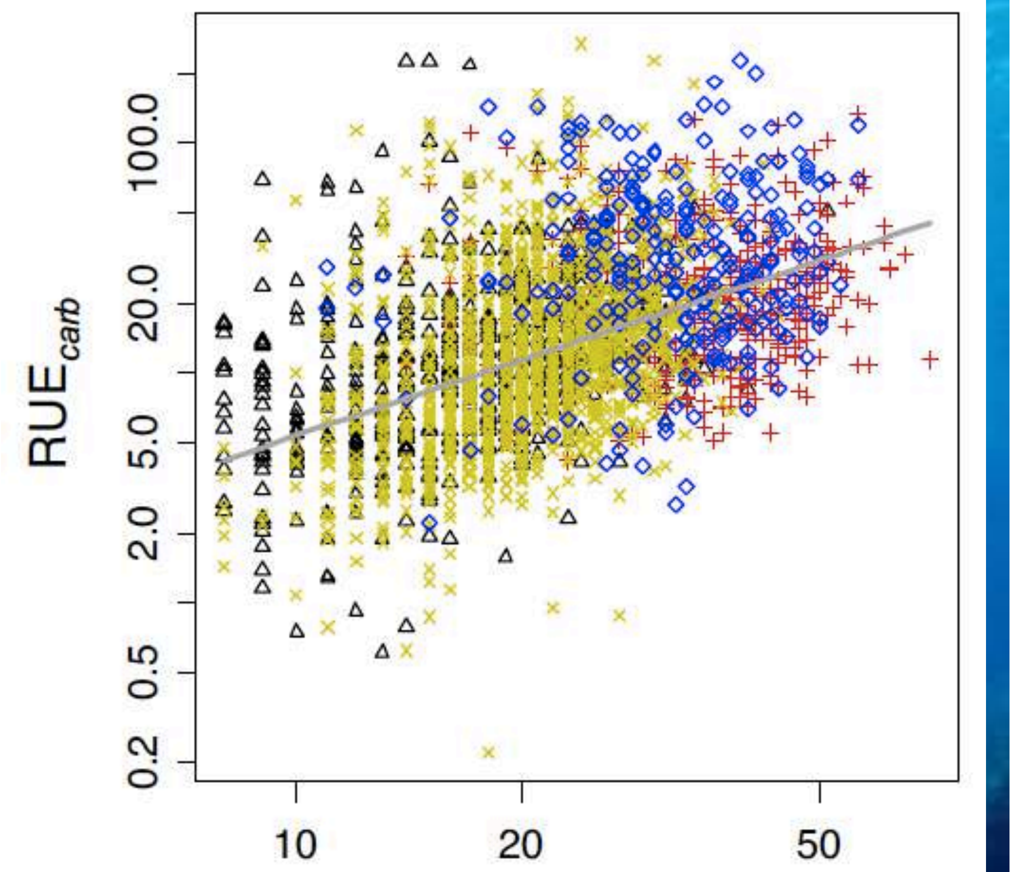
Loss of species could or could not have an impact on ecosystem processes. Species loss can be compensated for by other species with a similar function (redundancy). However, when all species with the same role are removed this causes a change in the system (Ehrlich & Ehrlich, 1981)

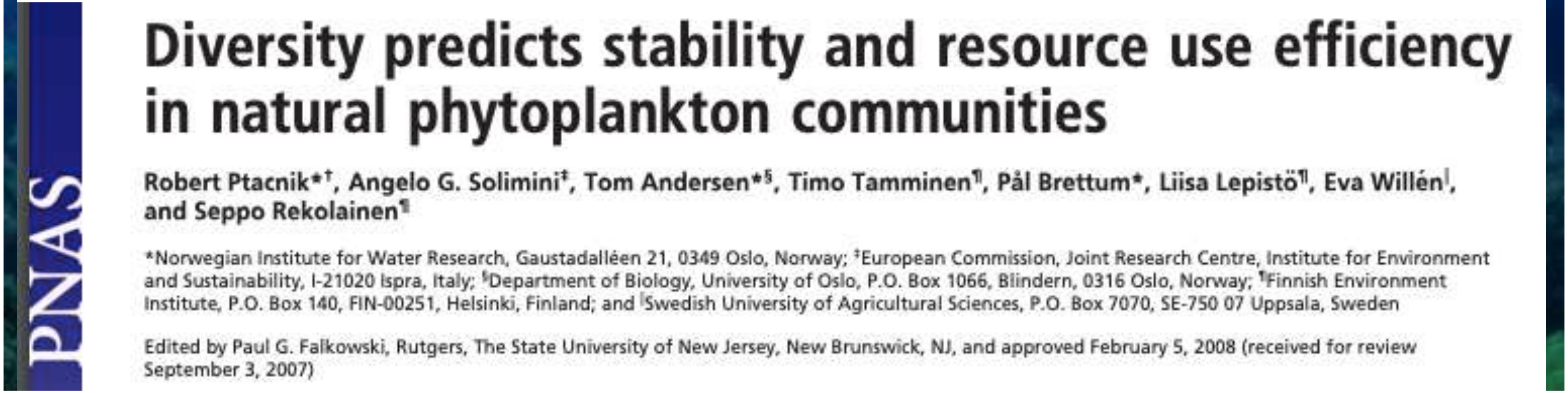


Some species is more important than others in causing changes in ecosystem processes, exerting a keystone role

Diversity and primary productivity







Diversity predicts stability and resource use efficiency in natural phytoplankton communities

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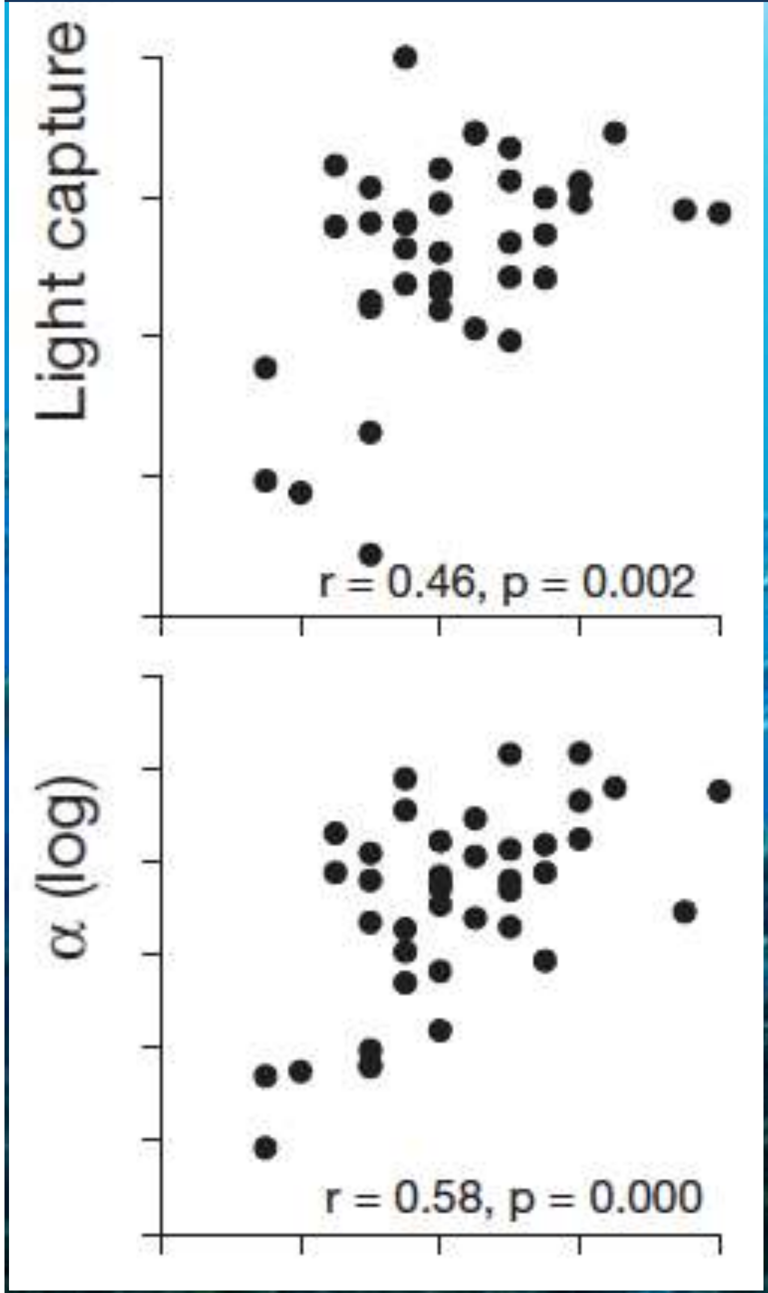
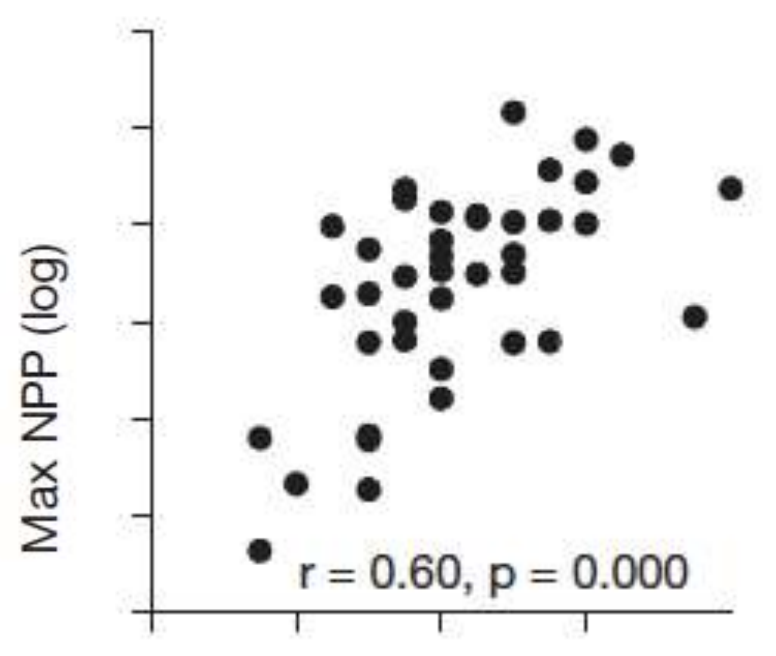
Edited by Paul G. Falkowski, Rutgers, The State University of New Jersey, New Brunswick, NJ, and approved February 5, 2008 (received for review September 3, 2007)

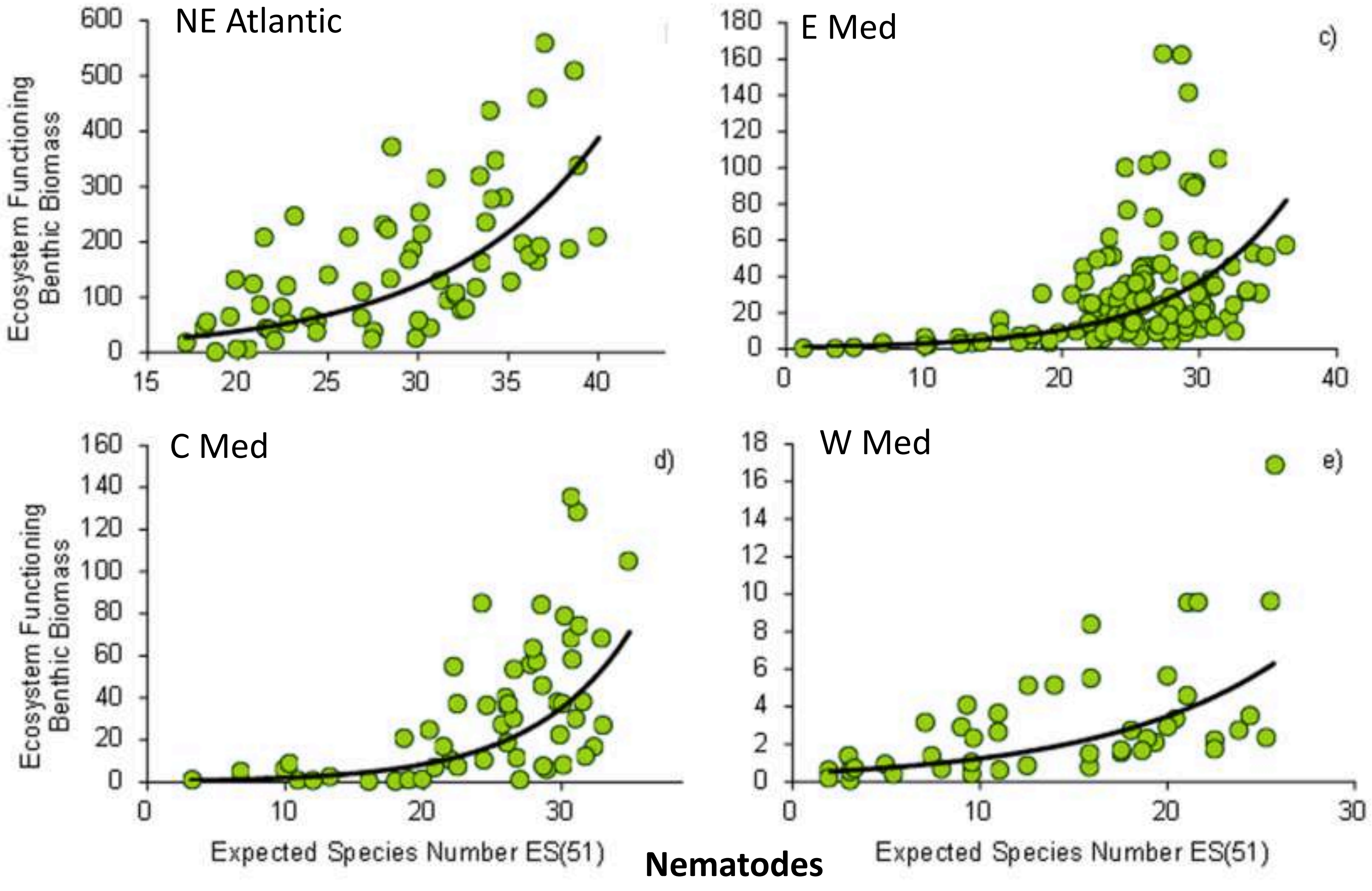
Diversity and primary productivity

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





Diversity and secondary productivity

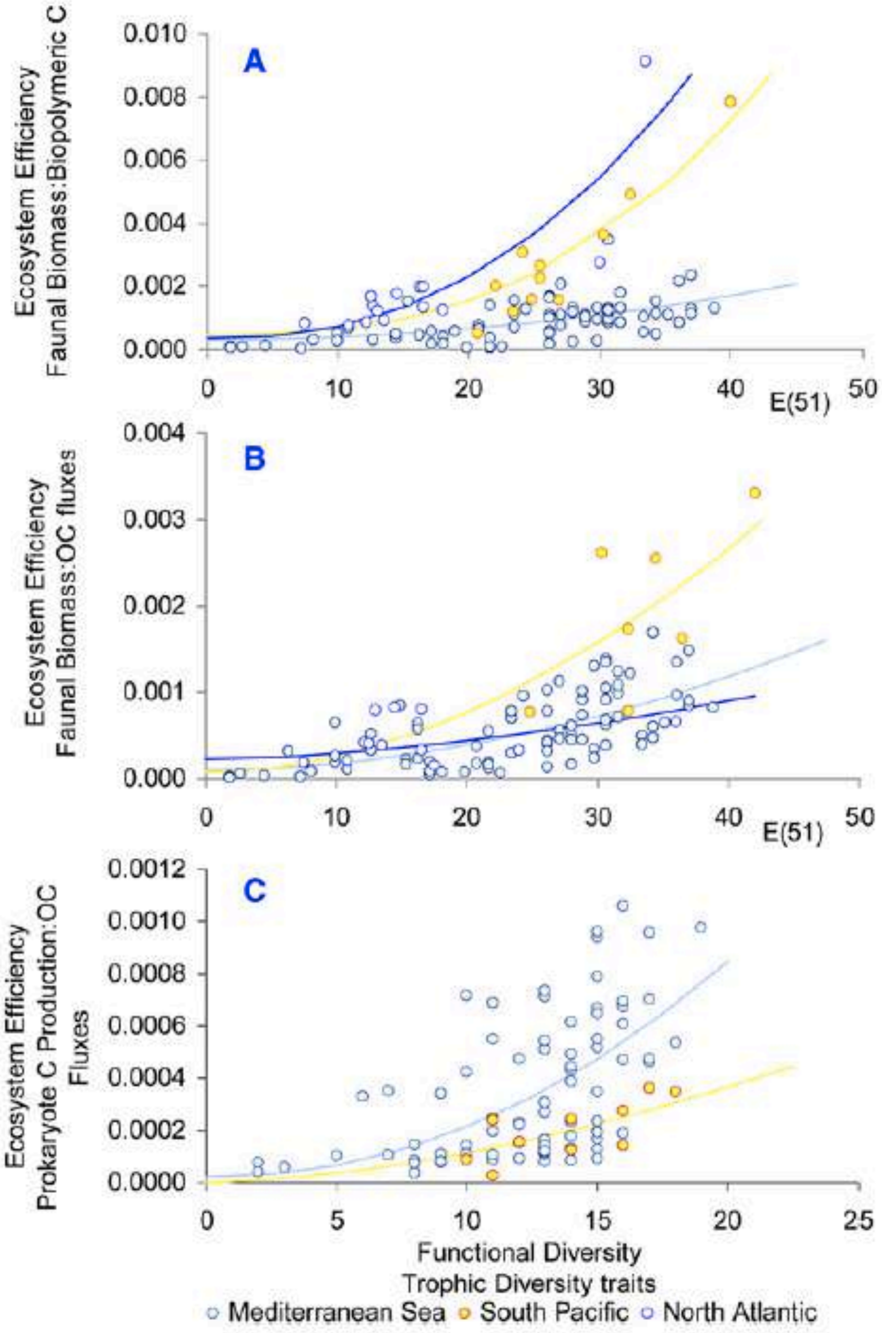


Nematodes

Narayanaswamy et al. 2013

idiosyncratic response when a limited number of species is considered

Diversity and carbon flux



Danovaro et al. 2008

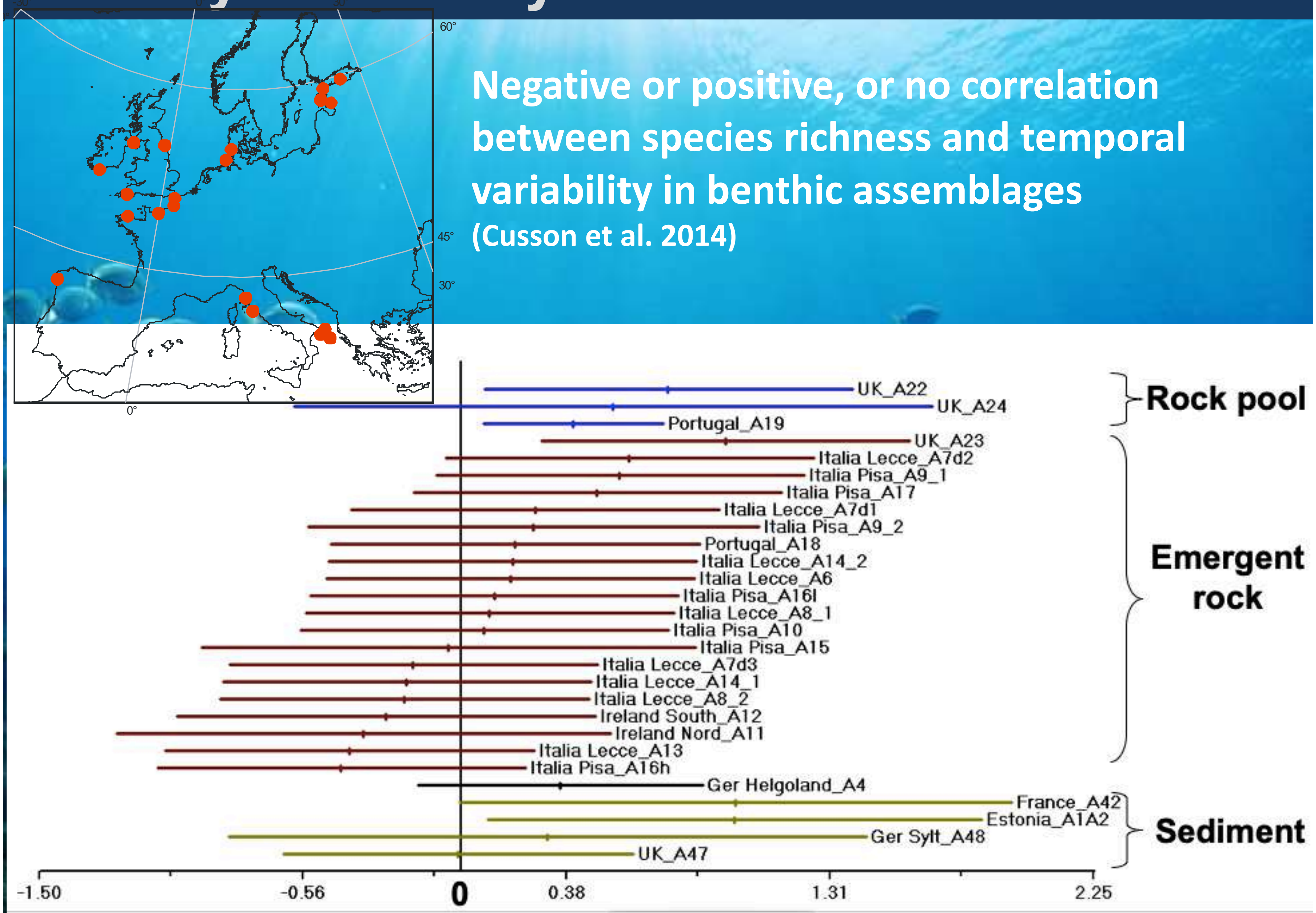
Deep-sea ecosystem functioning is exponentially related to deep-sea biodiversity and that ecosystem efficiency is also exponentially linked to functional biodiversity. These results suggest that a higher biodiversity supports higher rates of ecosystem processes and an increased efficiency with which 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 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

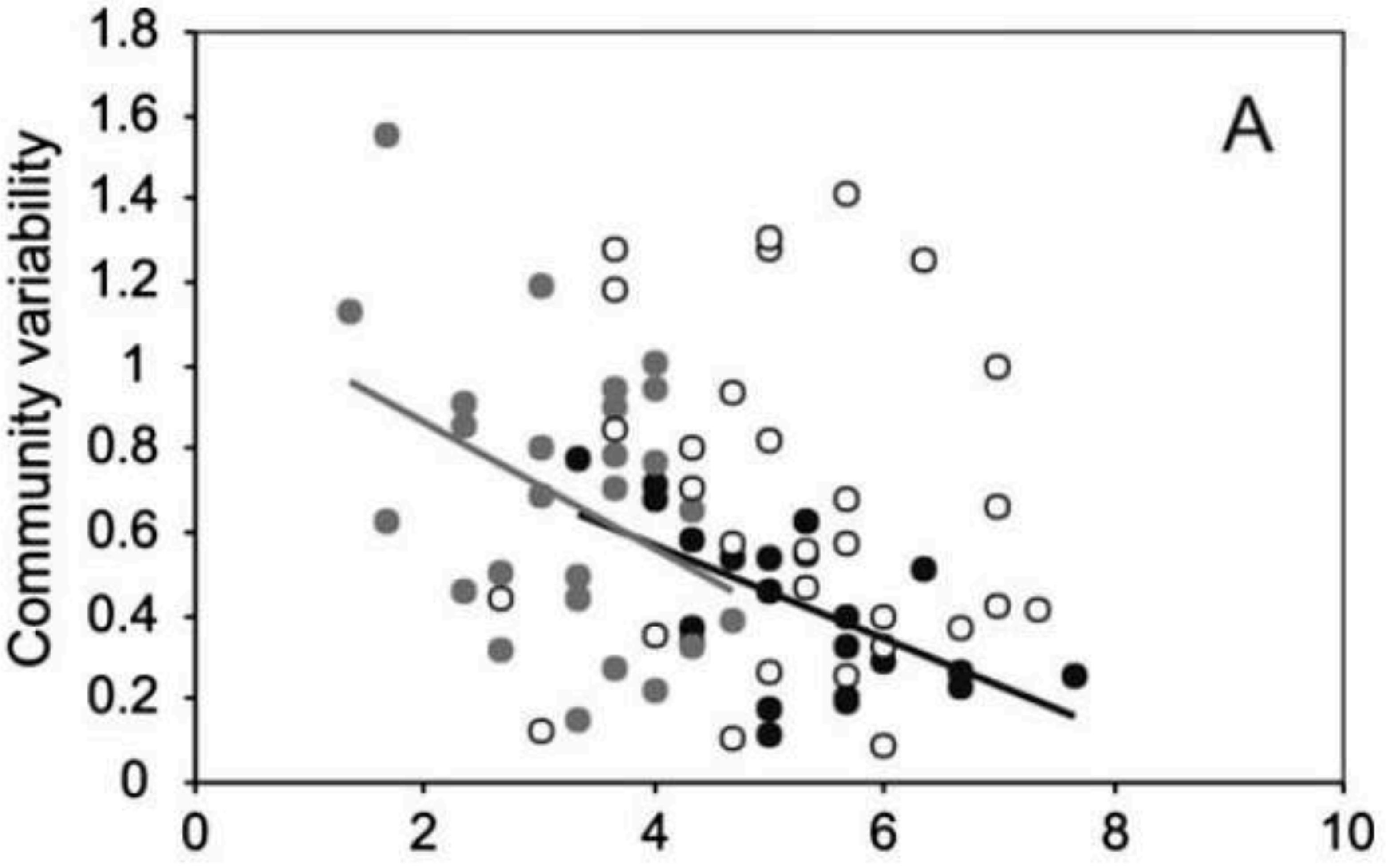
Diversity and stability

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

(Cusson et al. 2014)

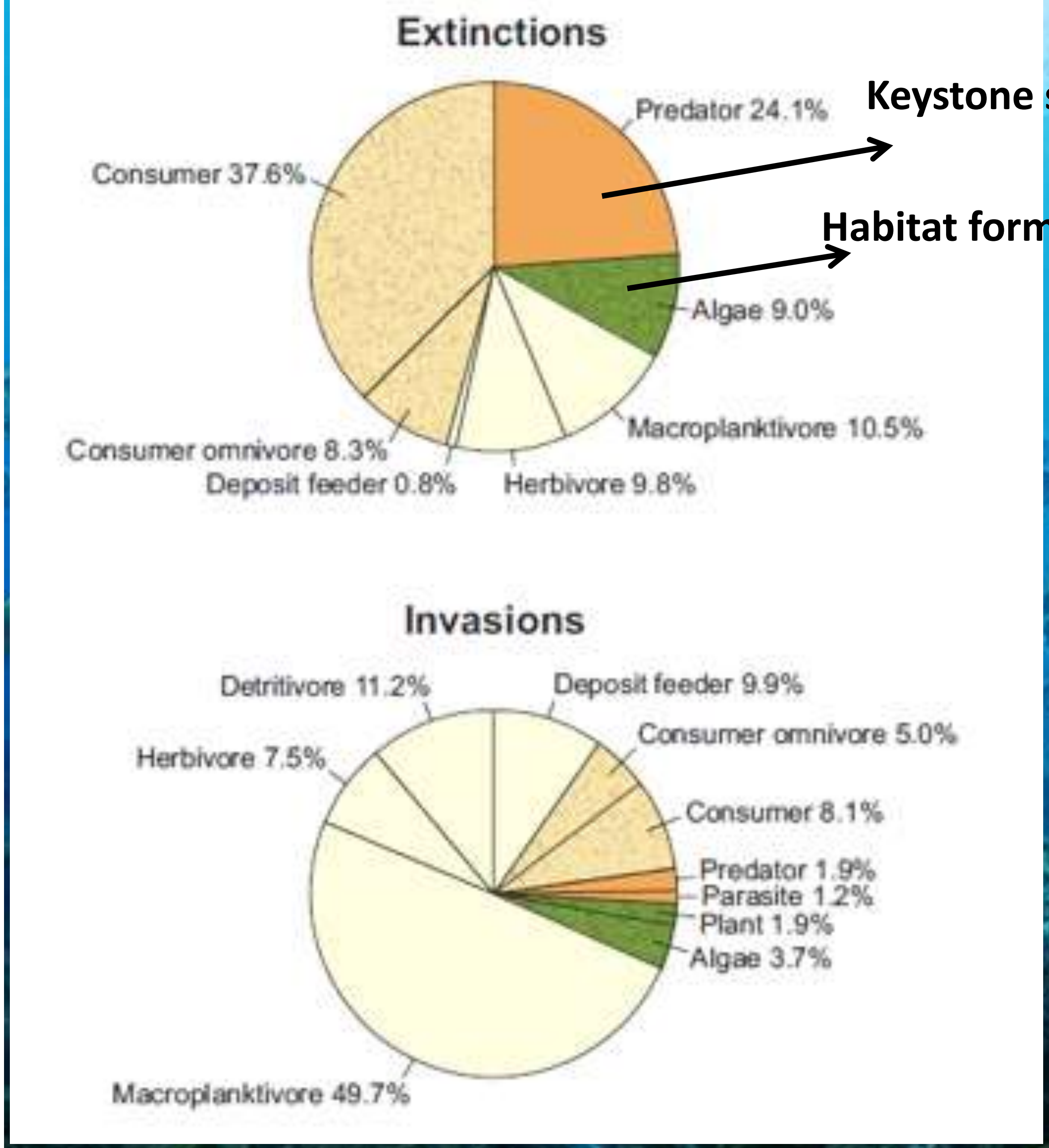


Diversity and stability



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



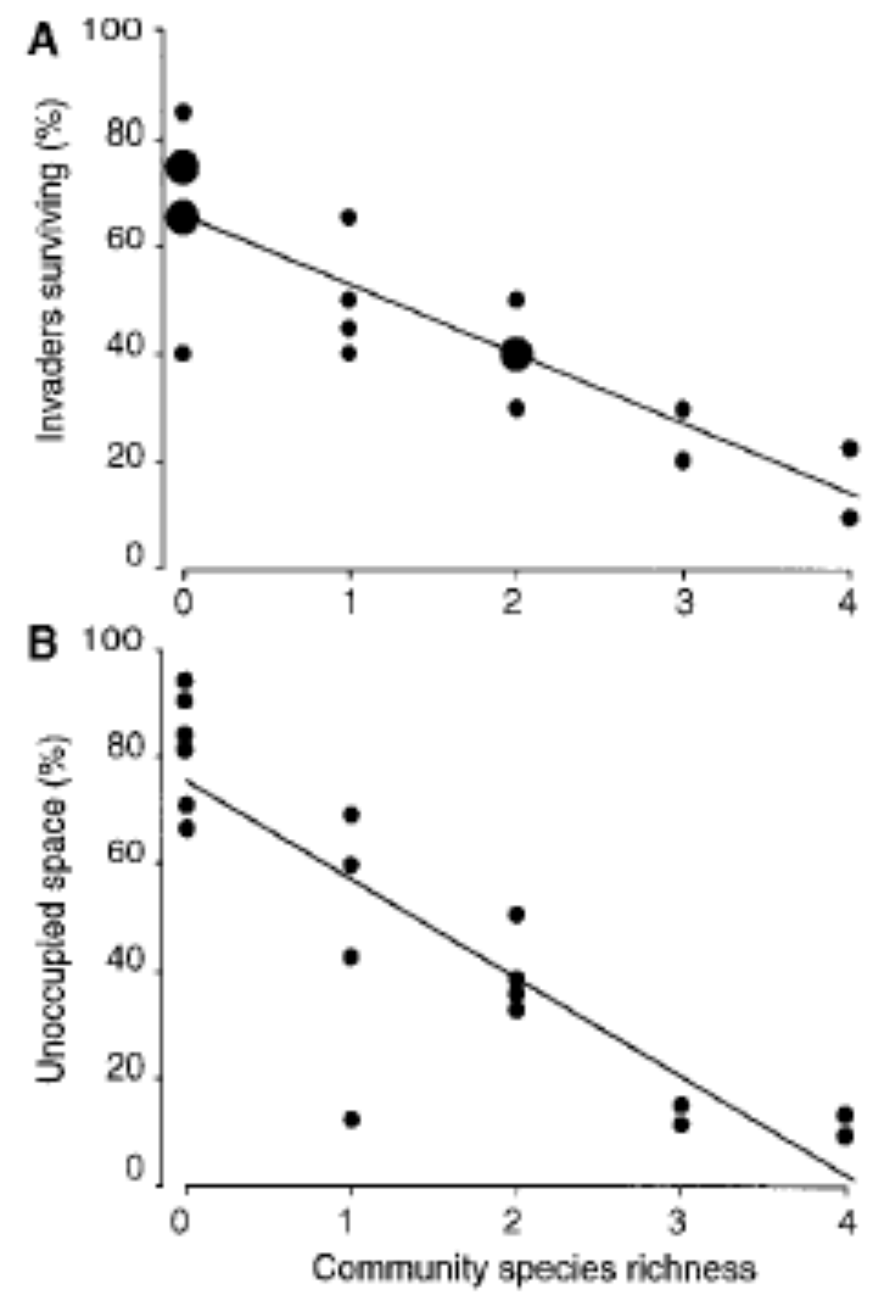
Keystone species

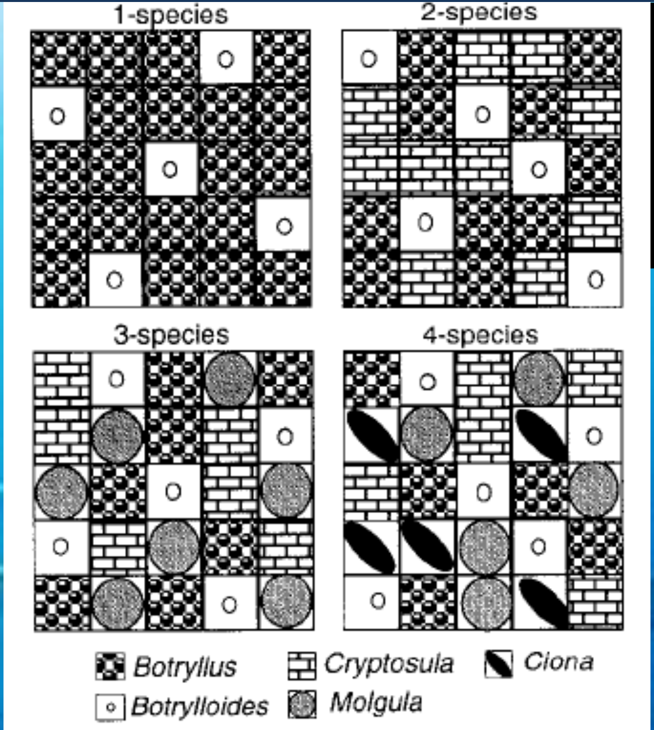
Habitat formers

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



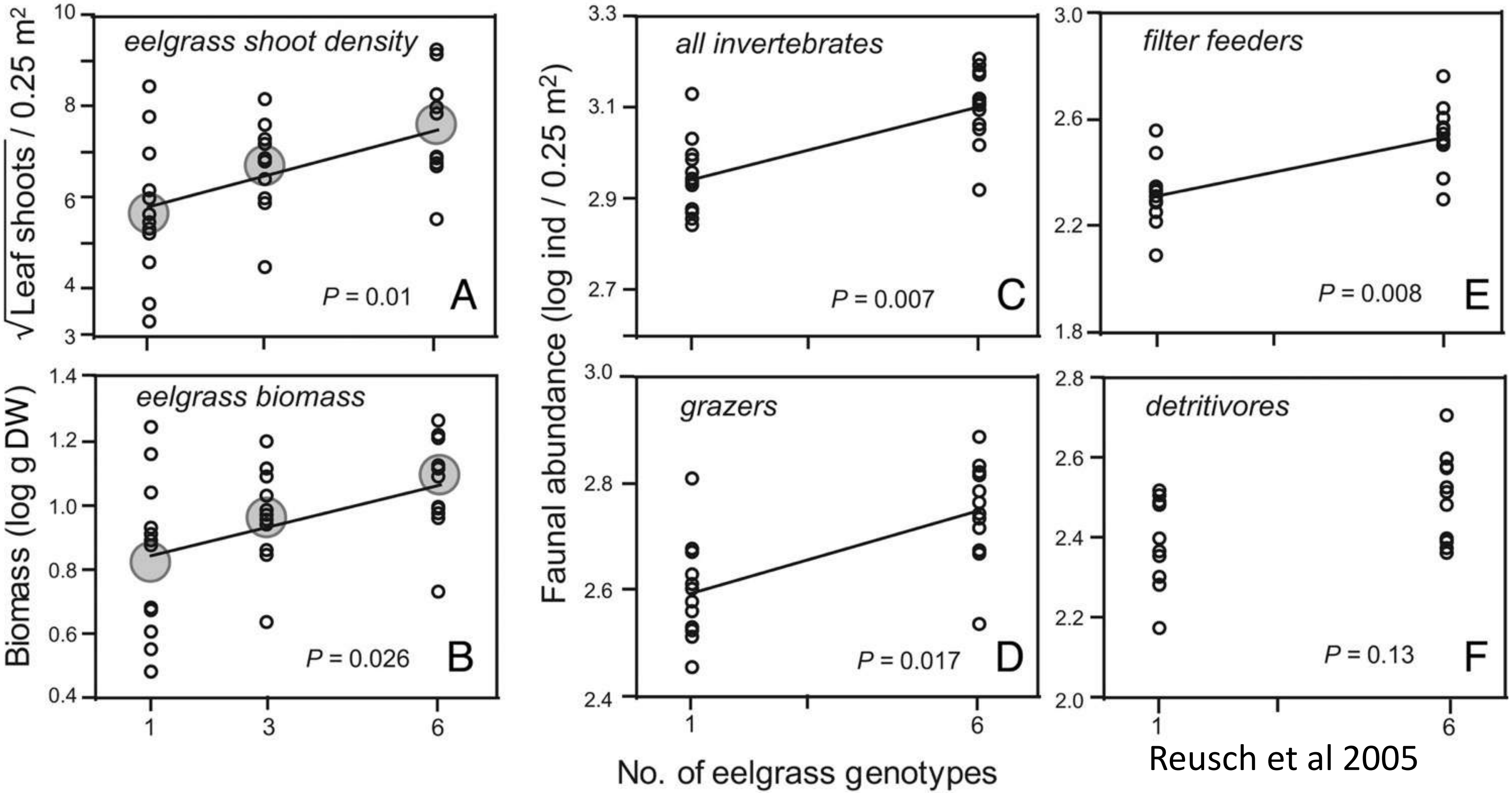


The exotic ascidian *Botrylloides diegensis*

Stachowicz et al. (1999)

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

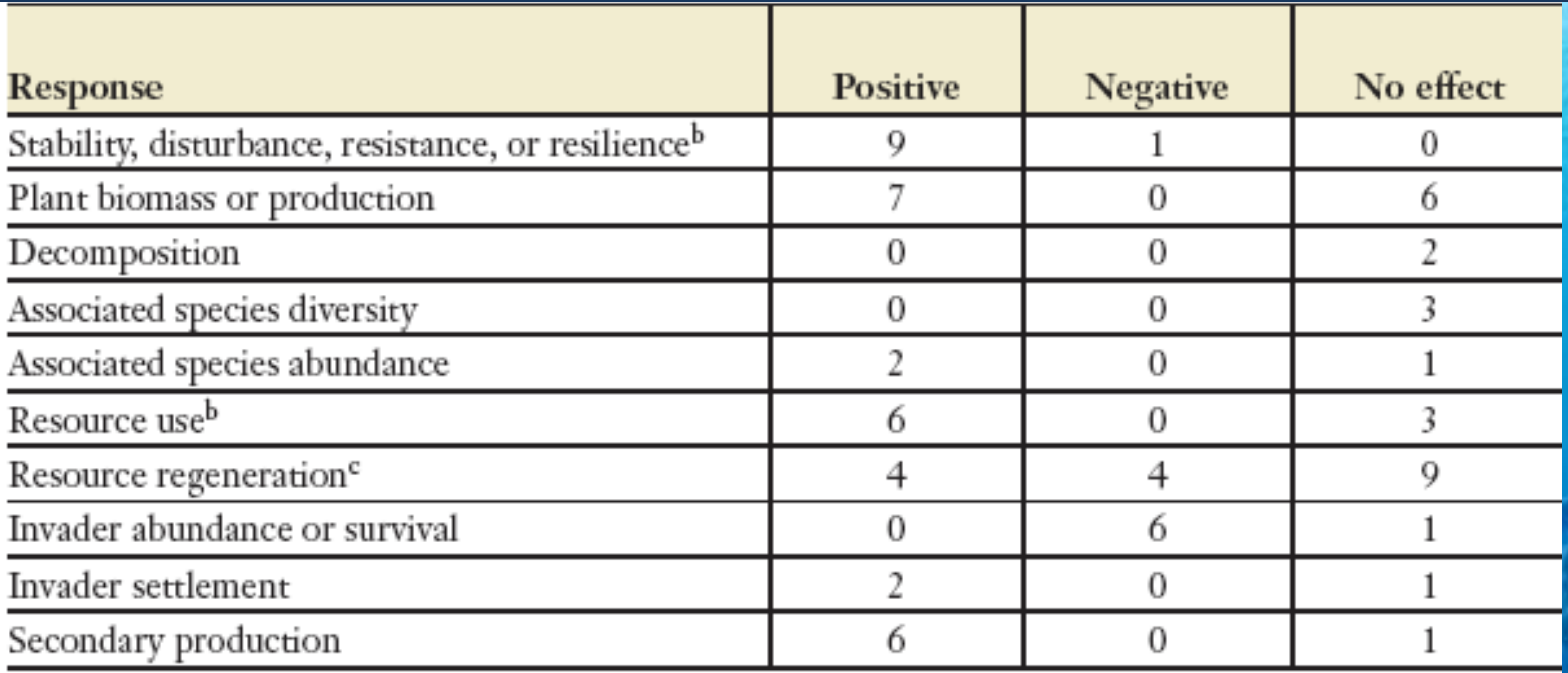


Reusch et al 2005

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

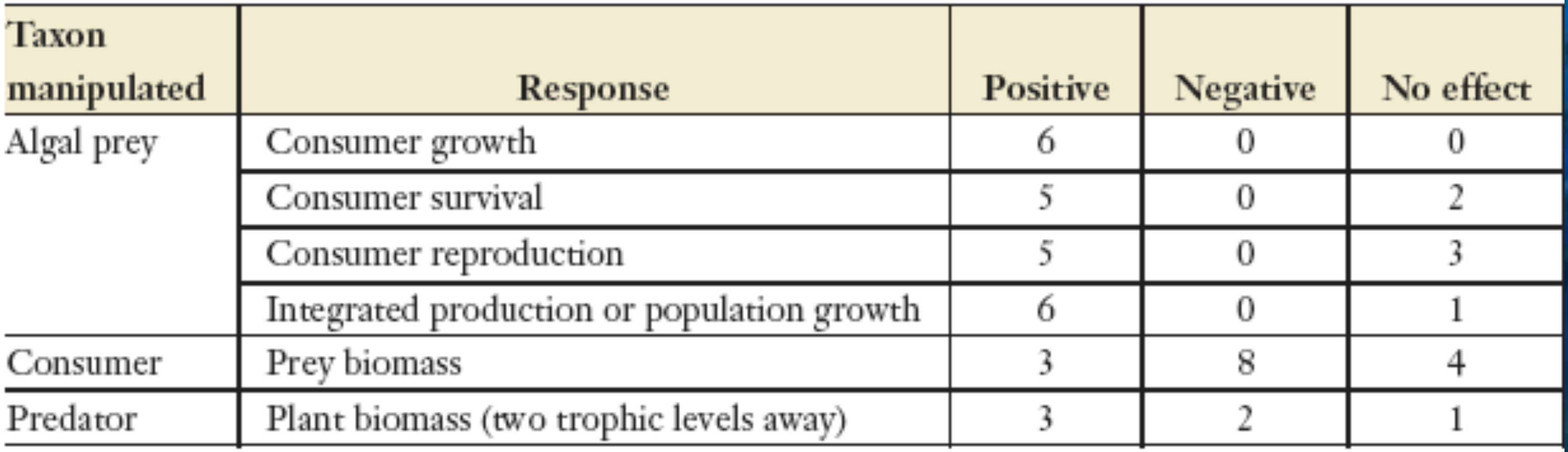
Ecosystem recovery after climatic extremes enhanced by genotypic diversity

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

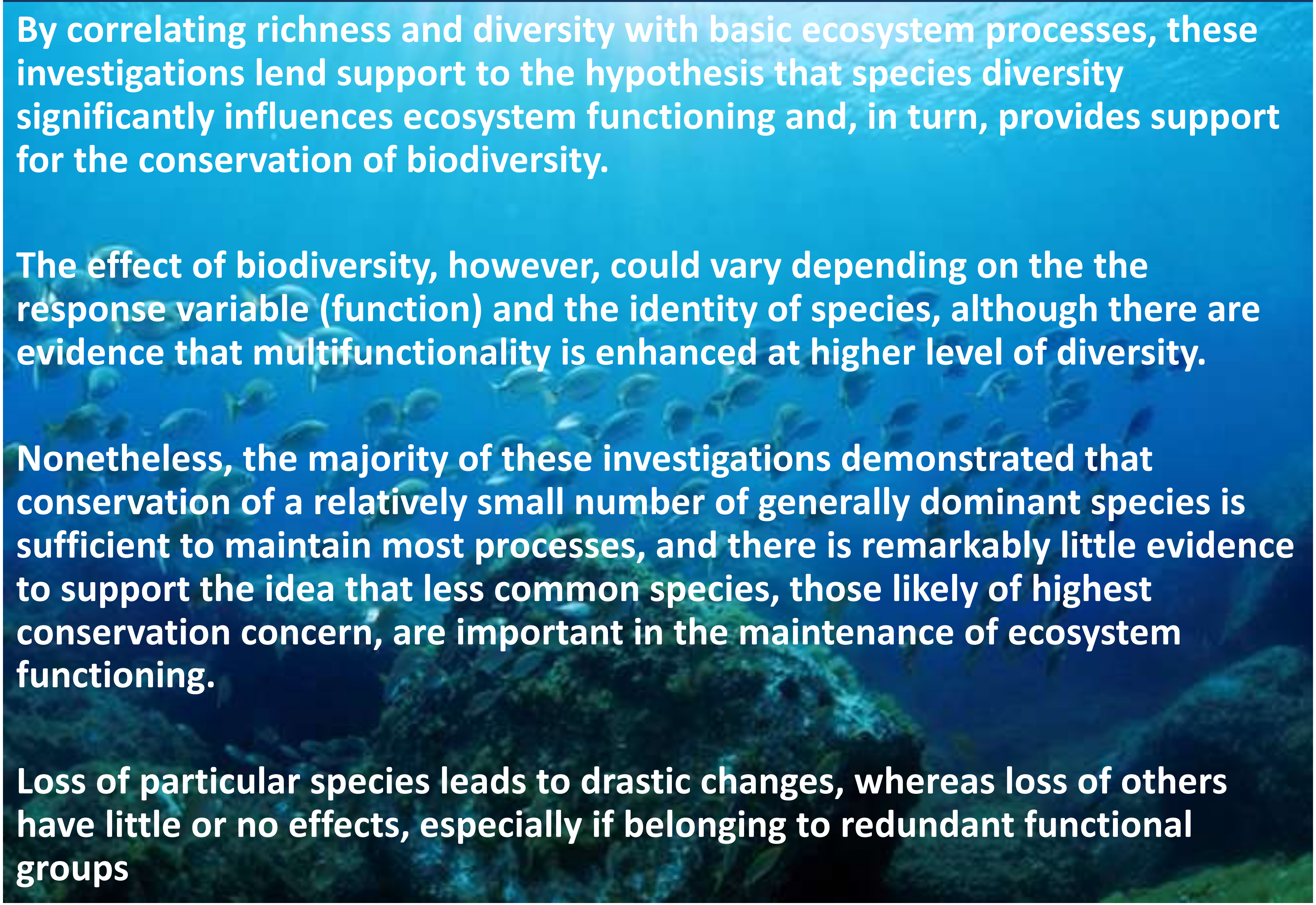


Taxon manipulated	Response	Positive	Negative	No effect
Algal prey	Consumer growth	6	0	0
	Consumer survival	5	0	2
	Consumer reproduction	5	0	3
	Integrated production or population growth	6	0	1
Consumer	Prey biomass	3	8	4
Predator	Plant biomass (two trophic levels away)	3	2	1

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

Stachowicz et al. (2007)

Are there ‘expendable species’?



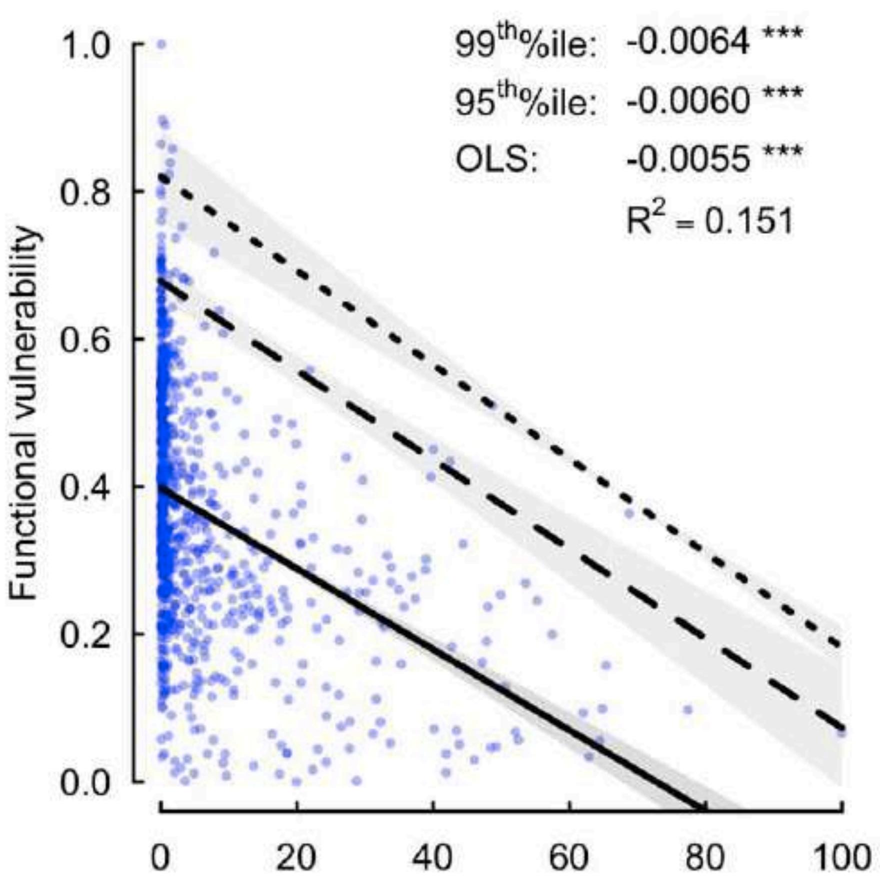
By correlating richness and diversity with basic ecosystem processes, these investigations lend support to the hypothesis that species diversity significantly influences ecosystem functioning and, in turn, provides support for the conservation of biodiversity.

The effect of biodiversity, however, could vary depending on the the response variable (function) and the identity of species, although there are evidence that multifunctionality is enhanced at higher level of diversity.

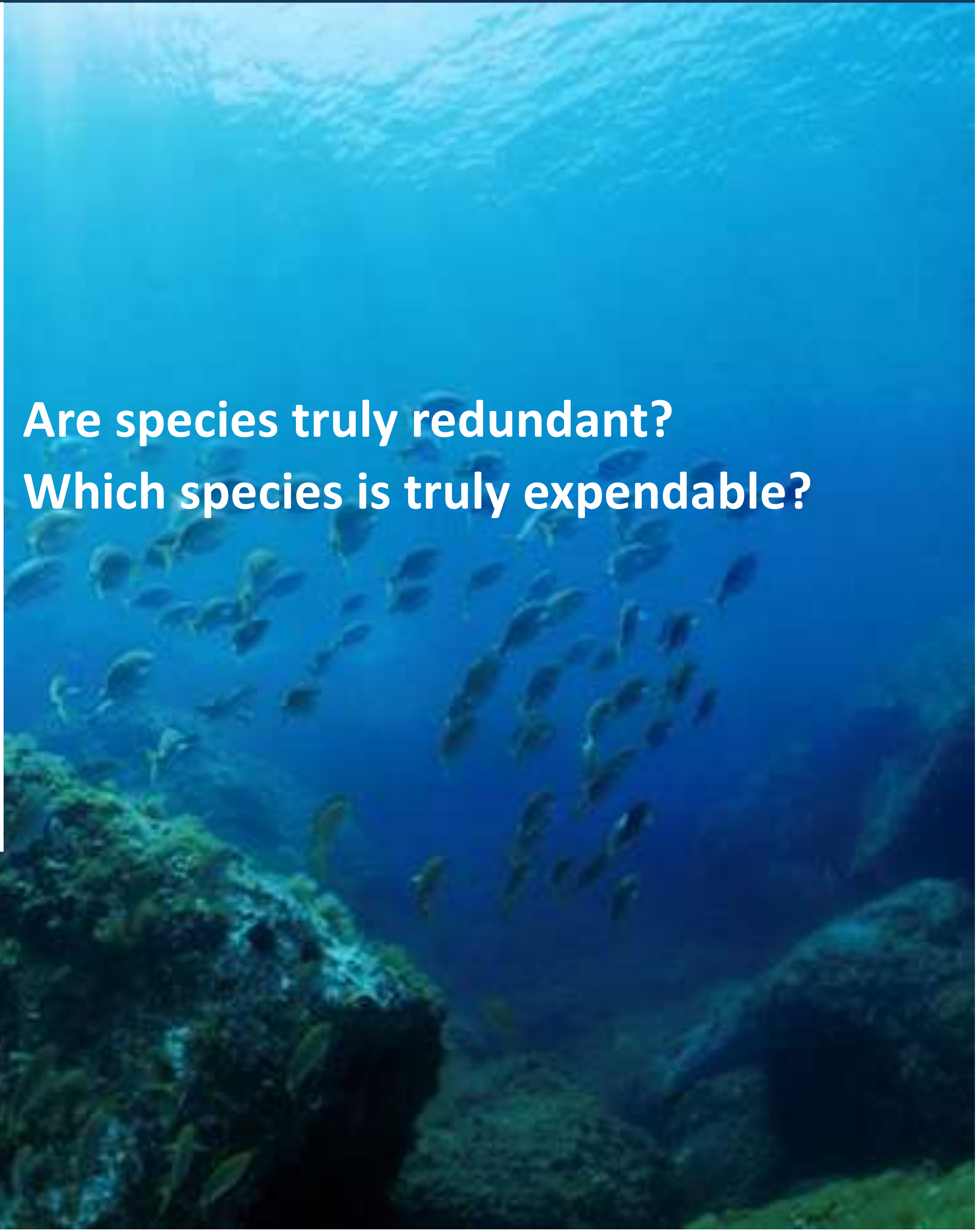
Nonetheless, the majority of these investigations demonstrated that conservation of a relatively small number of generally dominant species is sufficient to maintain most processes, and there is remarkably little evidence to support the idea that less common species, those likely of highest conservation concern, are important in the maintenance of ecosystem functioning.

Loss of particular species leads to drastic changes, whereas loss of others have little or no effects, especially if belonging to redundant functional groups

Are there ‘expendable’ species’



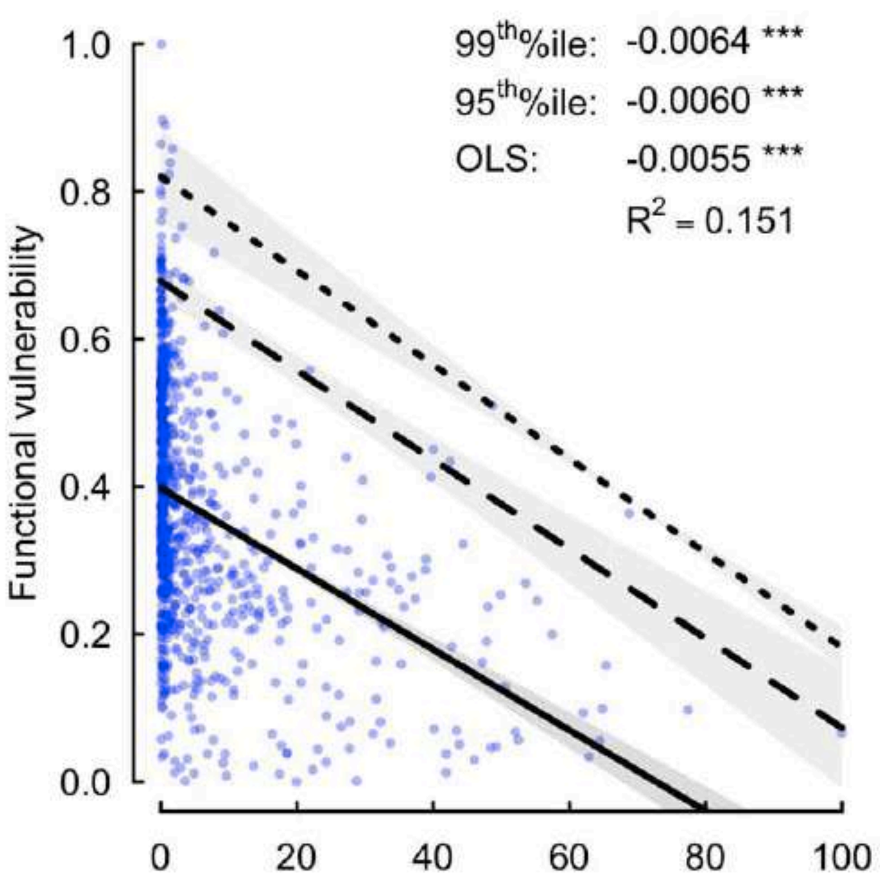
Functional vulnerability of coral fish species. Rarest species account for more vulnerable functional traits (i.e. traits poorly represented in other species (Mouilliot et al. 2013)



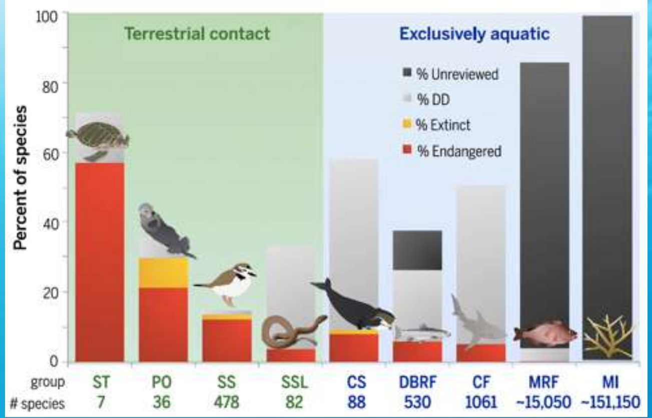
Are species truly redundant?

Which species is truly expendable?

Are there ‘expendable’ species’



Functional vulnerability of coral fish species. Rarest species account for more vulnerable functional traits (i.e. traits poorly represented in other species (Mouilliot et al. 2013)



A given species which is expendable now, could be considered expendable in the future?

Current species loss could cause changes, but it is difficult that an empty niche will stay empty for long time, but time is at evolutionary scale, so is truly important for life on Earth or for us?

What does we loose when a species is lost? Could we considered expendable or not what we don’t know yet?