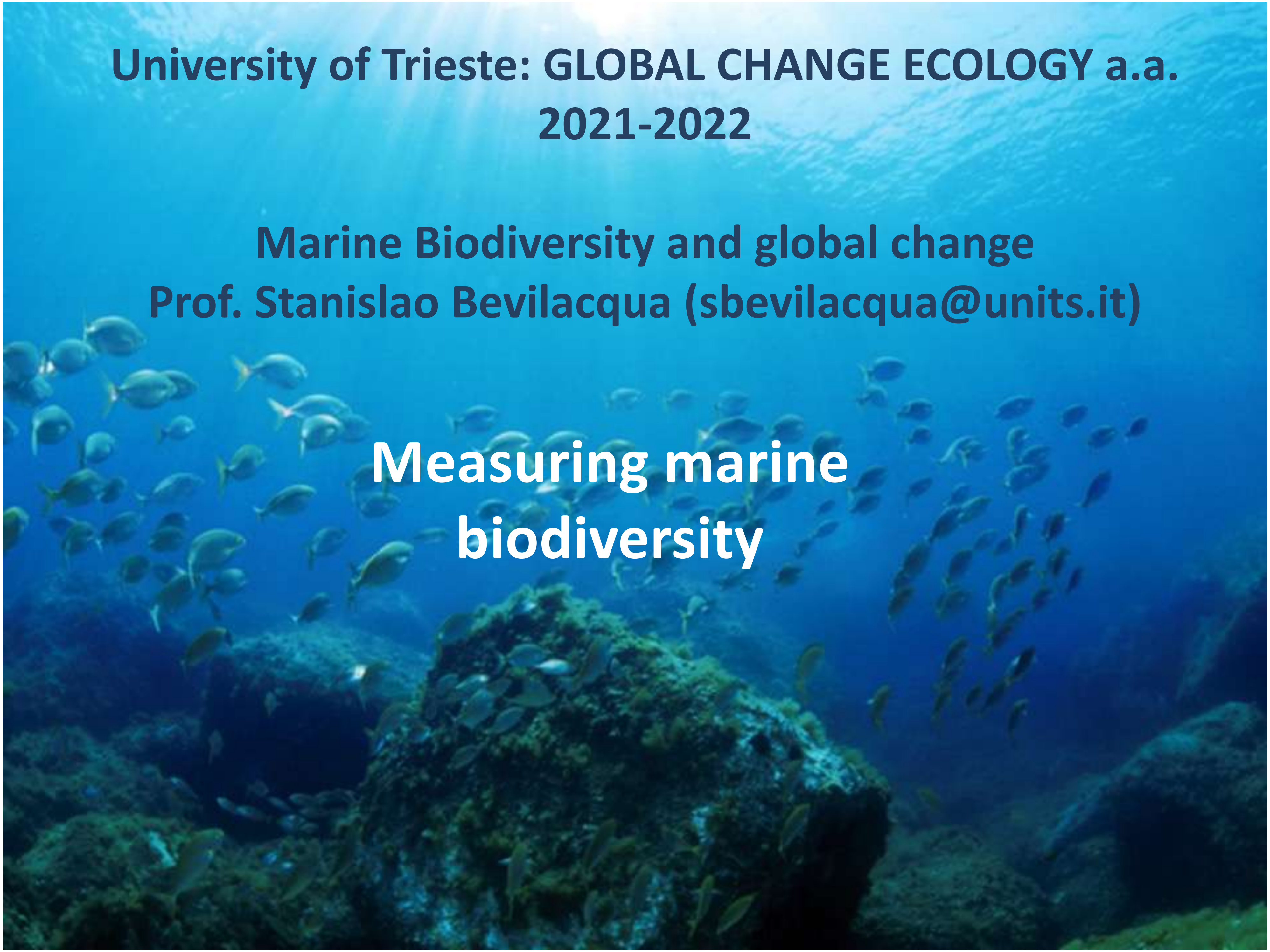


University of Trieste: GLOBAL CHANGE ECOLOGY a.a. 2021-2022

Marine Biodiversity and global change

Prof. Stanislao Bevilacqua (sbevilacqua@units.it)

Measuring marine biodiversity

Biodiversity

How to measure Biodiversity

Biodiversity encompasses many levels of organization including **genes, species, habitats, communities and ecosystems**. Although species diversity is the most commonly used measure of **taxonomic** diversity (or diversity between types of organisms), other measures of taxonomic diversity exist, the most common of which is **phylogenetic** diversity. Phylogenetic diversity is the variation in the working body plans (phyla) of organisms. It is also possible and very useful to measure diversity as the variation in the **functional** roles of species (rather than the number of species or gene types), within a community or ecosystem. Functional diversity is thought to be one of the main factors determining the long-term stability of an ecosystem and its ability to recover from major disturbances

Diversity indices

Indices of diversity: an example

✓Let’s consider an homogeneous habitat sampled in five replicate units

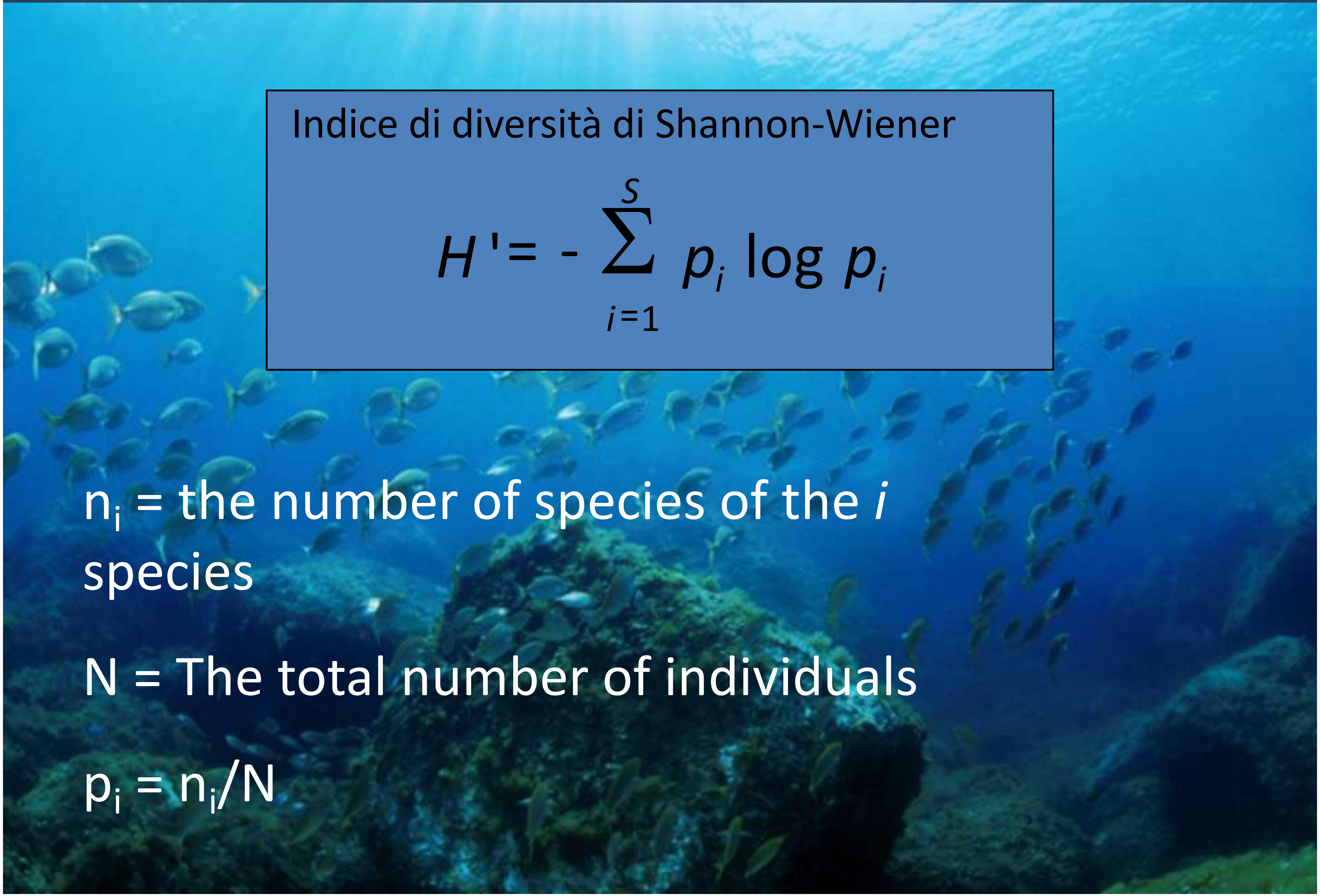
✓There are 60 specimens in each of the 5 units

✓ Specimens belongs to a variable number of species

✓Do biodiversity differ among units of observations?

Comm.	Sp. A	Sp. B	Sp. C	Sp. D	Sp. E	Sp. F	? n_i	# spp.
1	10	10	10	10	10	10	60	6
2	12	12		12	12	12	60	5
3	30		30				60	2
4		20		20		20	60	3
5	57	1	1	1			60	4

Indice di Shannon-Wiener



Indice di diversità di Shannon-Wiener

$$H' = -\sum_{i=1}^{S} p_i \log p_i$$

n_i = the number of species of the *i* species

N = The total number of individuals

$p_i = n_i/N$

Evenness

A component of diversity: the equitability (**evenness**)

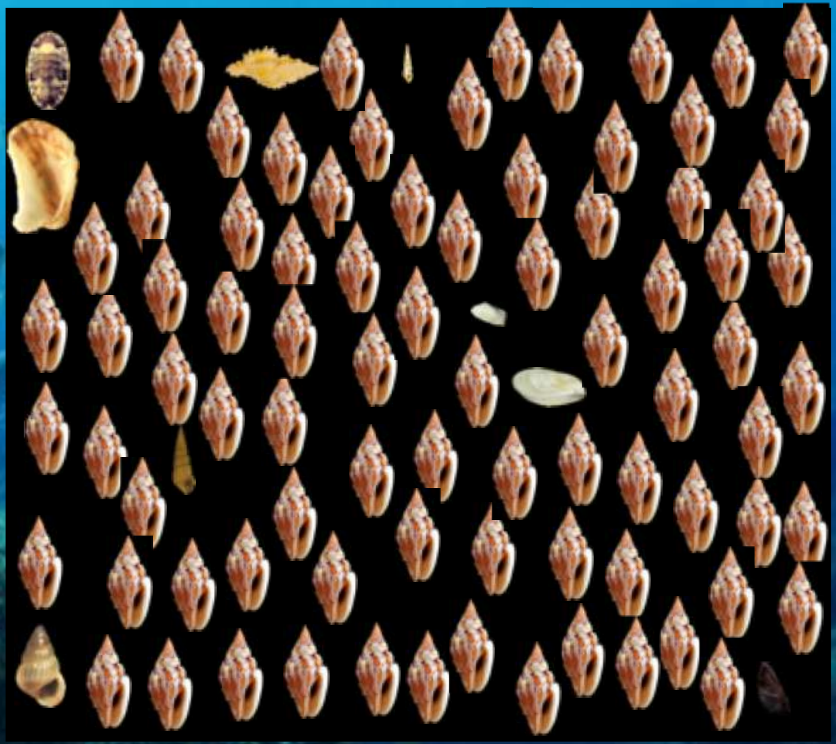
1st assemblage:
10 species and 100 individuals

S/N=10

10+10+10+10+10+10+10+10+10+10

2nd assemblage:
10 species e 100 individuals

S/N=10



91+1+1+1+1+1+1+1+1+1

Evenness

1st assemblage:
10 species and 100 individuals

S=10 N=100

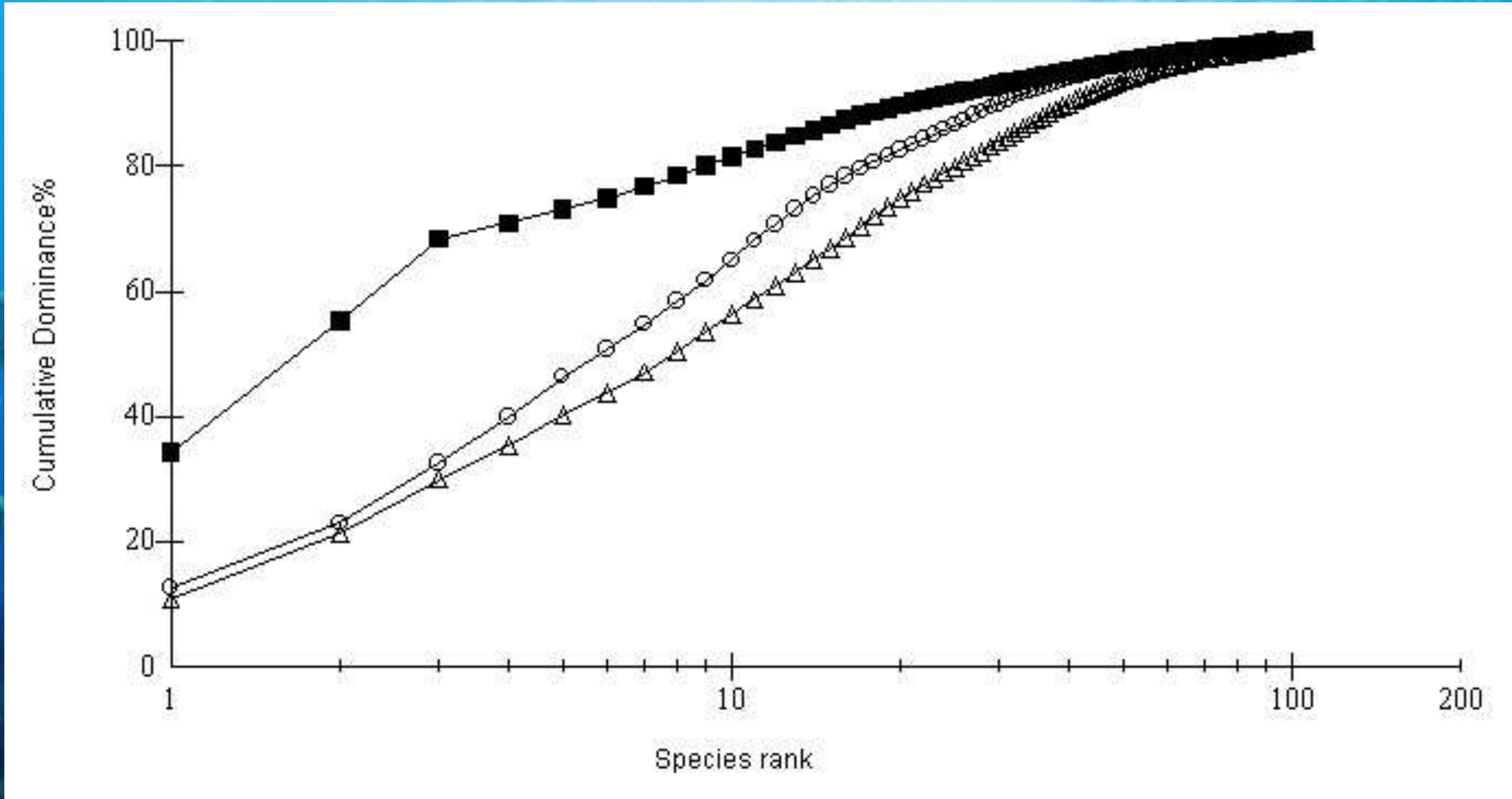
H' =2,30   J' =1

2nd assemblage:
10 species e 100 individuals

S=10 N=100

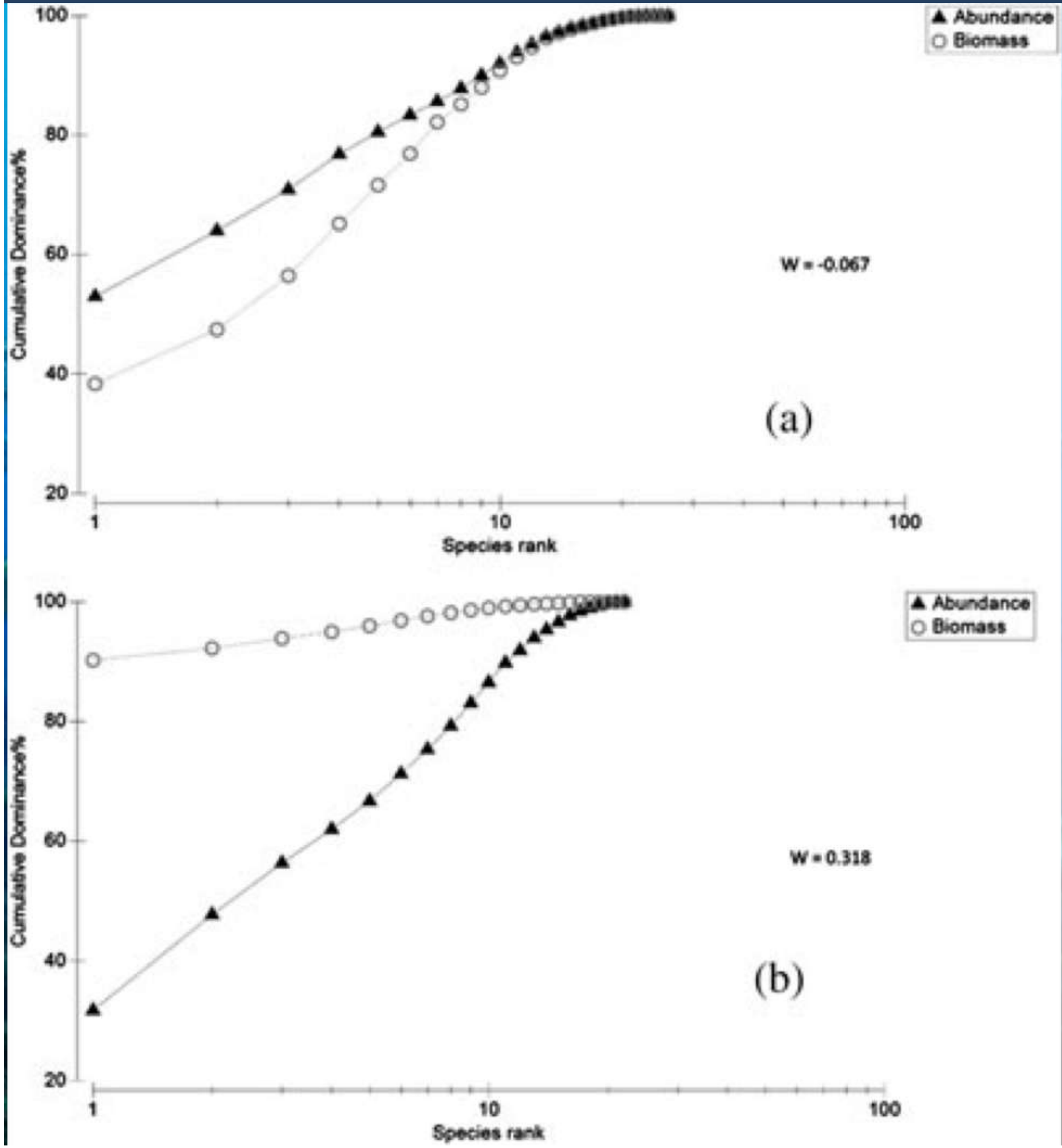
H' =0,50   J' =0,22

Dominance curves



Dominance curves depict the distribution of species abundance highlighting uneven distribution of the number of individuals (or biomass) through the species composing the community

ABC curves



Abundance-biomass curves compare the distribution of the number of individuals and biomass in the different species within a given community. In stable conditions, the biomass curve should lie above the abundance curve. Inverted patterns are typical of disturbed conditions

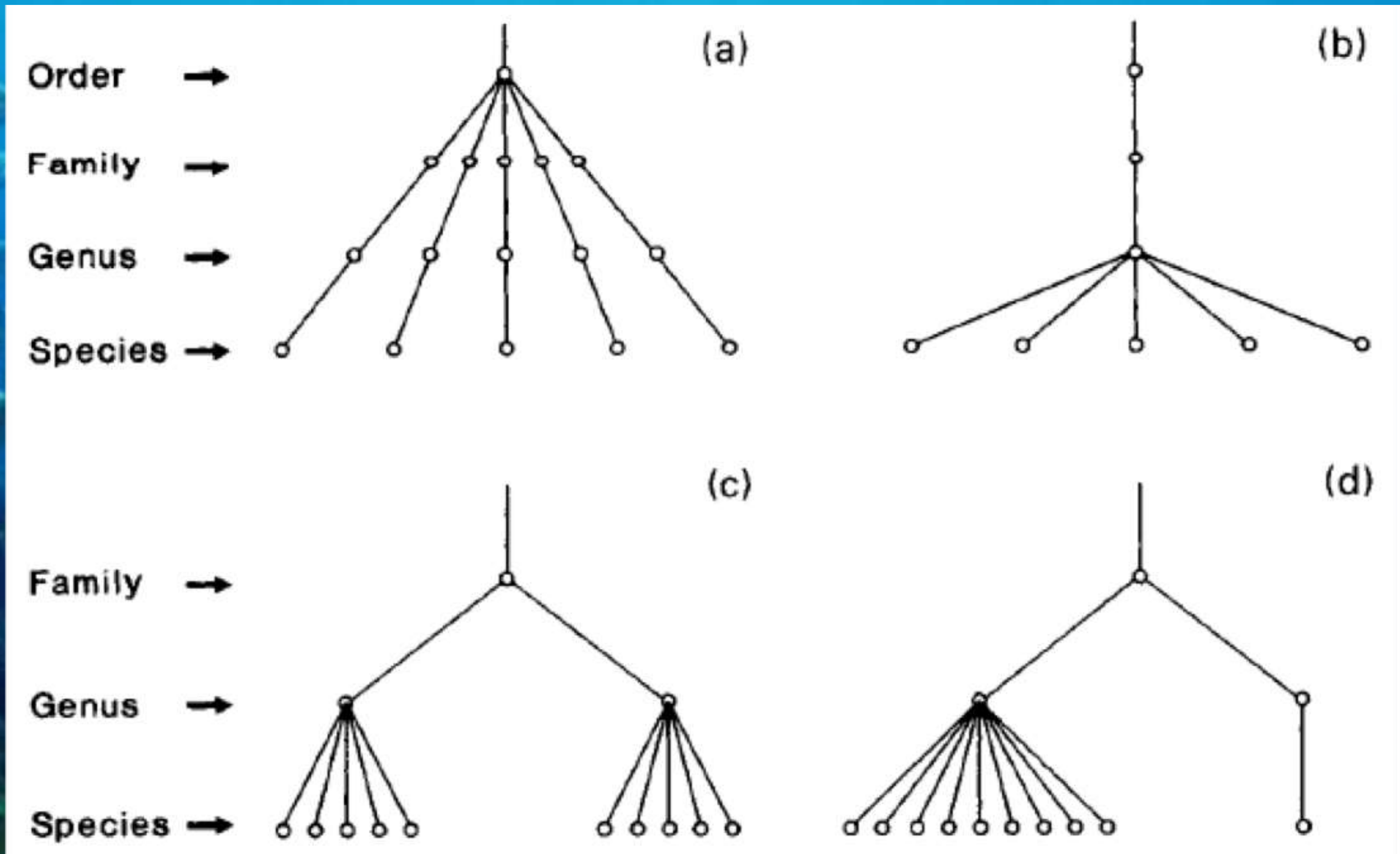
Taxonomic diversity indices

This assemblages has more species

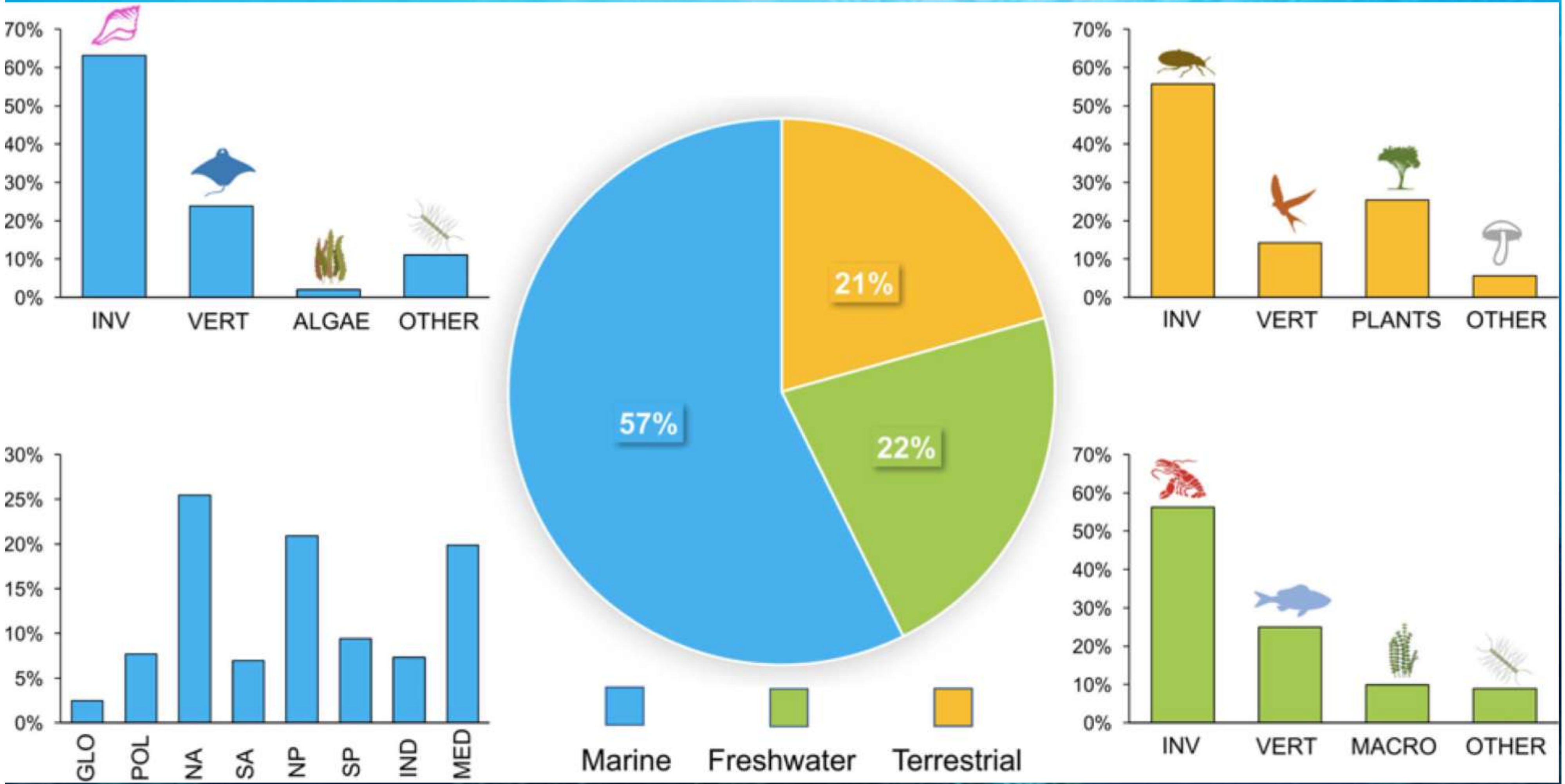
Which is more "biodiverse"

Taxonomic diversity indices

Molti indici di diversità tradizionali si basano sul numero di specie e l'evenness, trascurando completamente la diversità tassonomica. Per catturare anche questo aspetto della biodiversità, Clarke & Warwick (1995, 1998) proposero dei nuovi indici che includessero, oltre alla ricchezza in specie e le abbondanze relative, anche informazione sulle relazioni tassonomiche tra le specie.



Taxonomic diversity indices

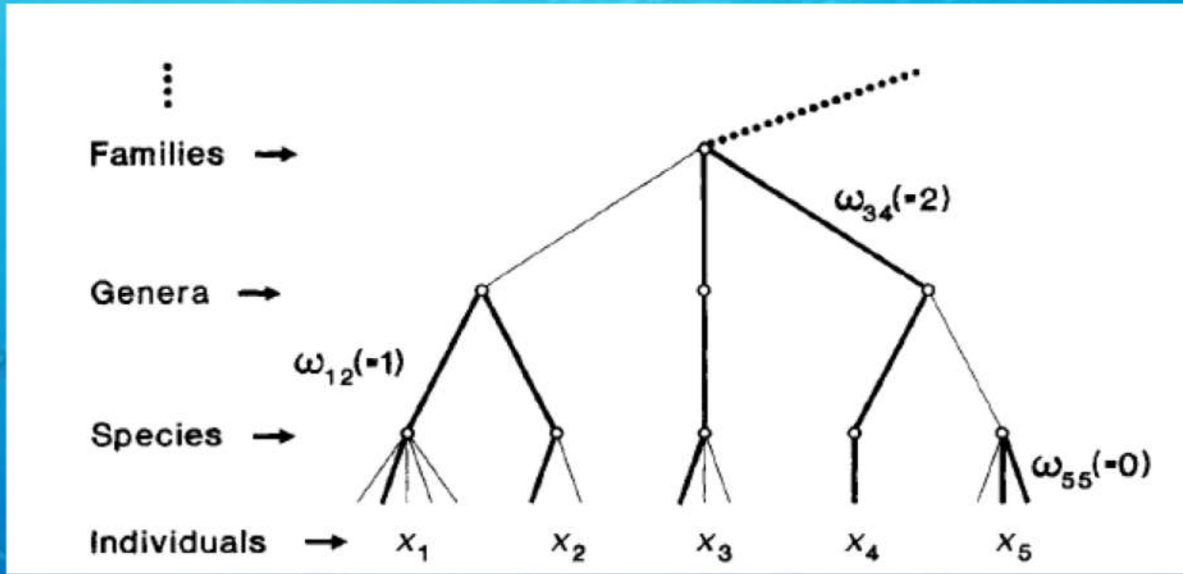


Bevilacqua et al. 2021

Taxonomic diversity indices

Questi indici, denominati Taxonomic Diversity (Δ) e Taxonomic Distinctness (Δ^*), sono una derivazione dell'indice di Simpson con l'aggiunta delle distanze tassonomiche tra le specie.

Le abbondanze delle due specie sono pesate (cioè moltiplicate) per un coefficiente che indica la lunghezza del percorso tra le due specie nella gerarchia tassonomica



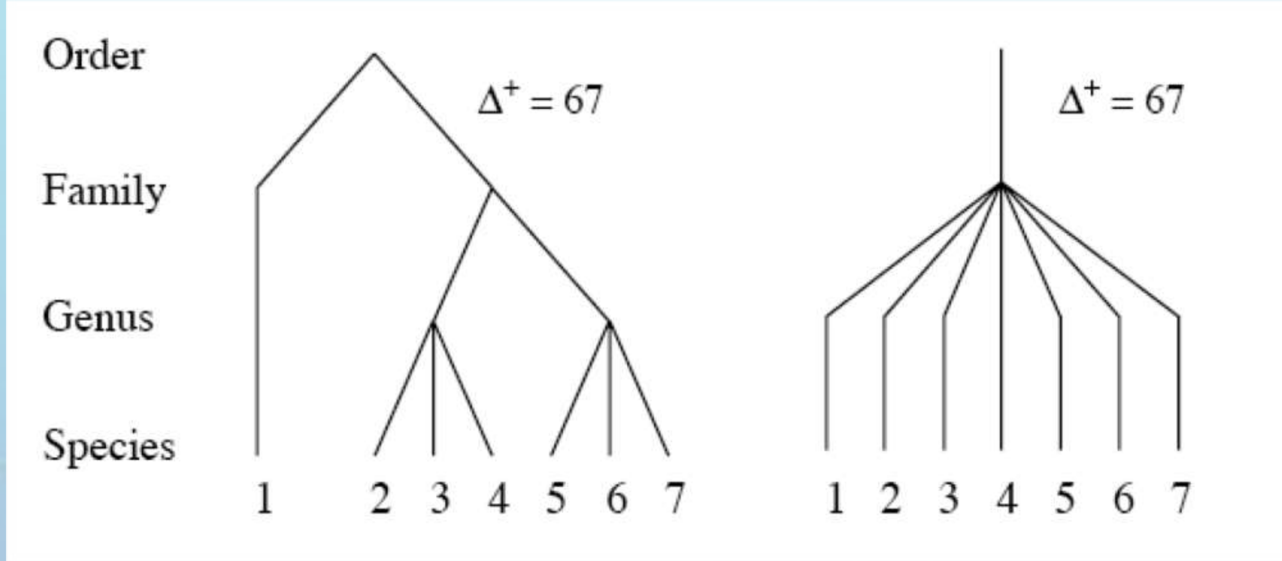
Taxonomic Diversity (Δ) Rappresenta la distanza attesa nella gerarchia tassonomica tra due individui scelti randomicamente dal campione.

Taxonomic Distinctness (Δ^*) Rappresenta la distanza attesa nella gerarchia tassonomica tra due individui appartenenti a specie diverse.

Taxonomic distinctness

Quando i dati sono espressi in termini di presenza assenza Δ e Δ^* convergono in Δ^+ (Average Taxonomic Distinctness), che rappresenta la distanza media tra due specie qualunque all'interno dell'albero tassonomico.

Da solo però, l'indice non identifica tutte le caratteristiche della diversità tassonomica. Ad esempio, per uno stesso valore di Avg Tax Distinctness, la distribuzione delle specie nell'albero tassonomico può presentare una diversa *variazione* attorno a questo valore.

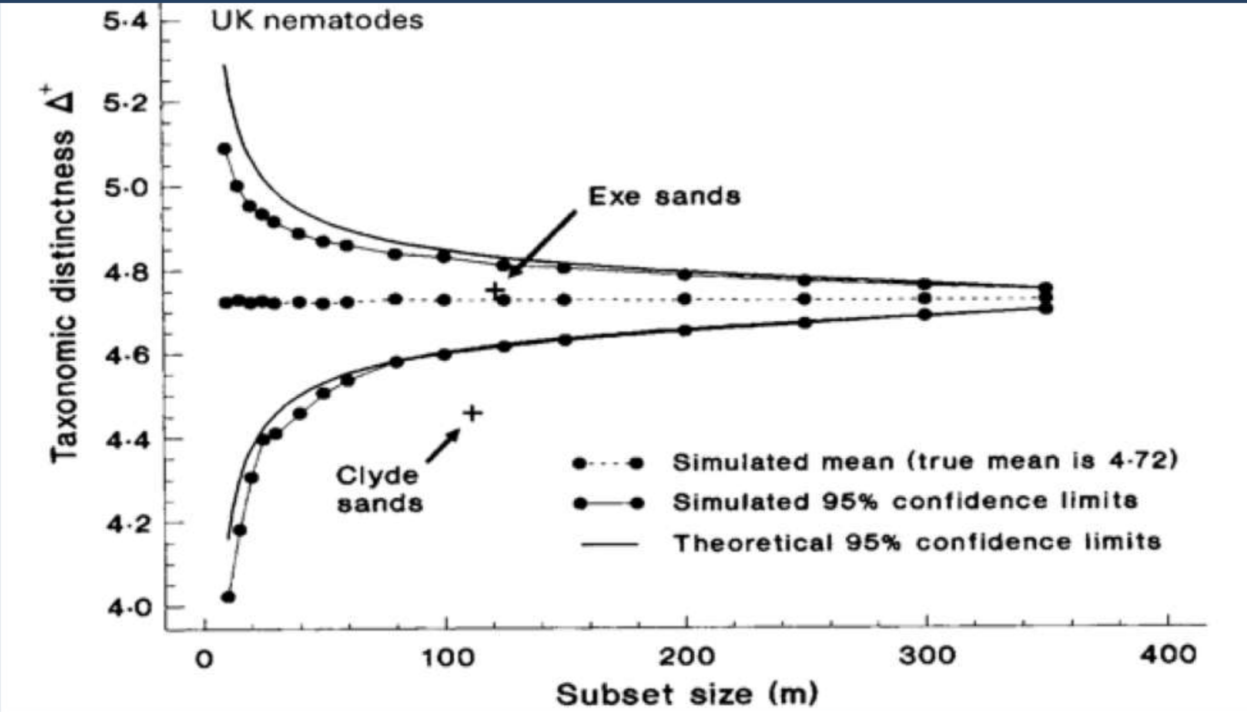


Per catturare anche quest'aspetto Clarke & Warwick (2001) crearono anche un secondo indice a complementare il precedente.

Λ^+ (Variation in Taxonomic Distinctness)

Esso rappresenta la variazione di delta+ e, in pratica, riflette la distribuzione delle specie all'interno dei taxa nell'albero tassonomico.

Pros



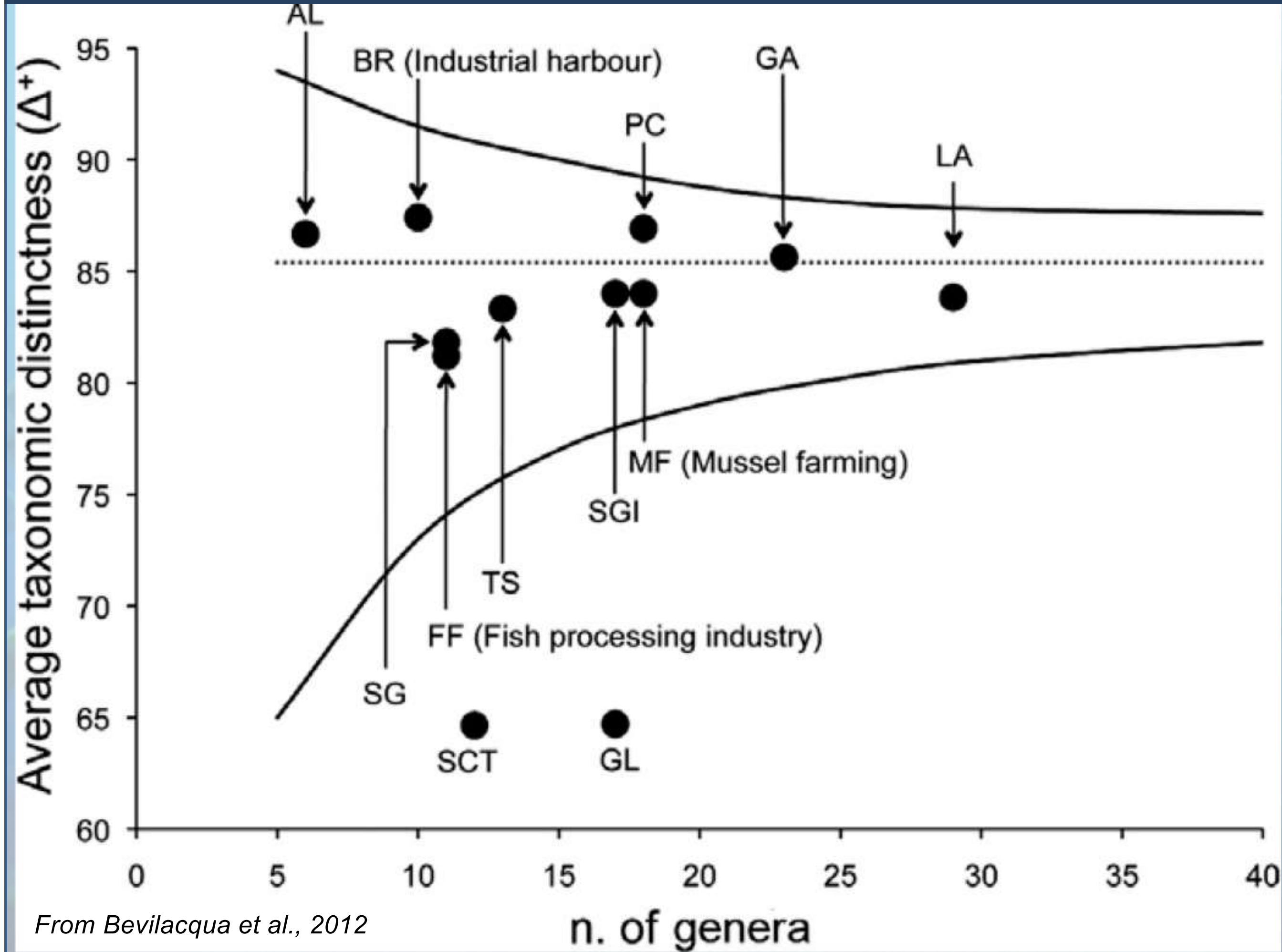
<u>Principali vantaggi:</u>

- Indipendenza dalle tecniche e dallo sforzo di campionamento
- Dotati di un test statistico basato sulle simulazioni
- Possibilità di confrontare dati da aree geografiche differenti
- Possibilità di analisi di dati storici, anche in forma di presenza/assenza
- Potenziale per identificare cambiamenti che possono passare inosservati

<u>Il test basato sulle simulazioni</u>

Il test si basa su una lista di specie rappresentativa della diversità regionale di un determinato tipo di organismi. L'indice viene calcolato su un gruppo di specie che viene estratto randomicamente dalla lista. La procedura viene ripetuta migliaia di volte, generando un intervallo di confidenza di valori simulati di Δ^+ su cui testare i valori reali di una determinata area.

Problems

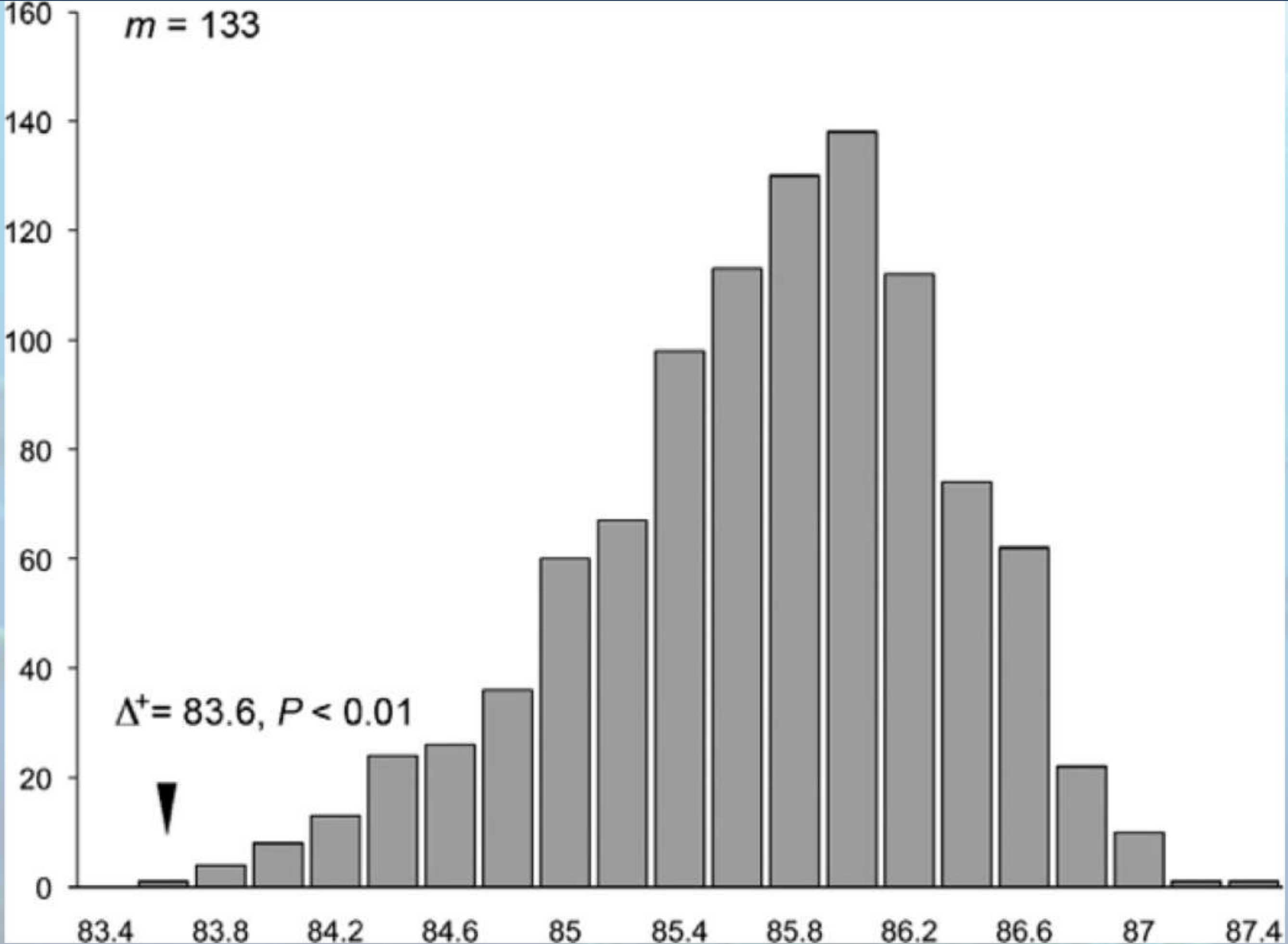


From Bevilacqua et al., 2012

L’assunzione alla base del cambiamento degli indici, per cui la naturale variabilità dovrebbe implicare solo un rimpiazzo tra specie all’interno dei taxa superiori, mentre un disturbo antropico causare dei cambiamenti nella struttura tassonomica potrebbe non essere così stringente.

Contrariamente a quanto atteso, questi indici possono essere influenzati significativamente dalle variazioni naturali nelle condizioni ambientali e dall’habitat, con un conseguente ridimensionamento delle loro potenzialità nell’identificazione degli impatti antropici. Se disturbo influenza evenness o se non selettivo riduzione di sensibilità.

Reference list



Il calcolo dell'indice e i test di simulazione si basano una lista di riferimento. Questa può influenzare il calcolo e l'esito dei test.

Ad esempio, se la struttura tassonomica della comunità è dipende dall'habitat, un lista unica può portare a confondere effetto del disturbo antropico con differenze tra habitat. Stesso discorso se esistono differenze biogeografiche nell'area in esame per il gruppo considerato. In questi casi ridurre la lista a unità spaziali coerenti dal punto di vista della struttura tassonomica può evitare confusioni, ma può ridurre la sensibilità dei test o impedire i confronti tra casi di studio simili.

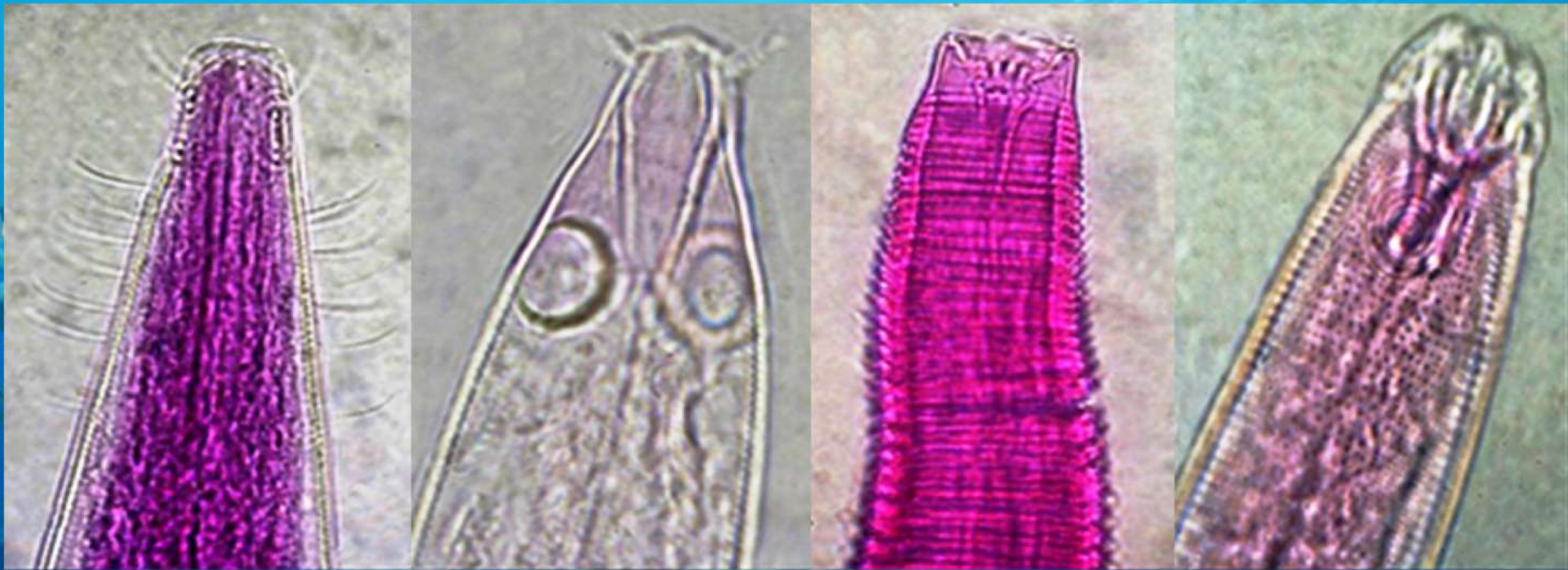
Functional diversity

	Tratto 1	Tratto 2	Tratto 3	…	Tratto n
Specie 1	…	…	…	…	…
Specie 2	…	…	…	…	…
Specie 3	…	…	…	…	…

	Specie 1	Specie 2	Specie 3
Specie 1	0		
Specie 2	20	0	
Specie 3	80	70	0

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

Functional diversity

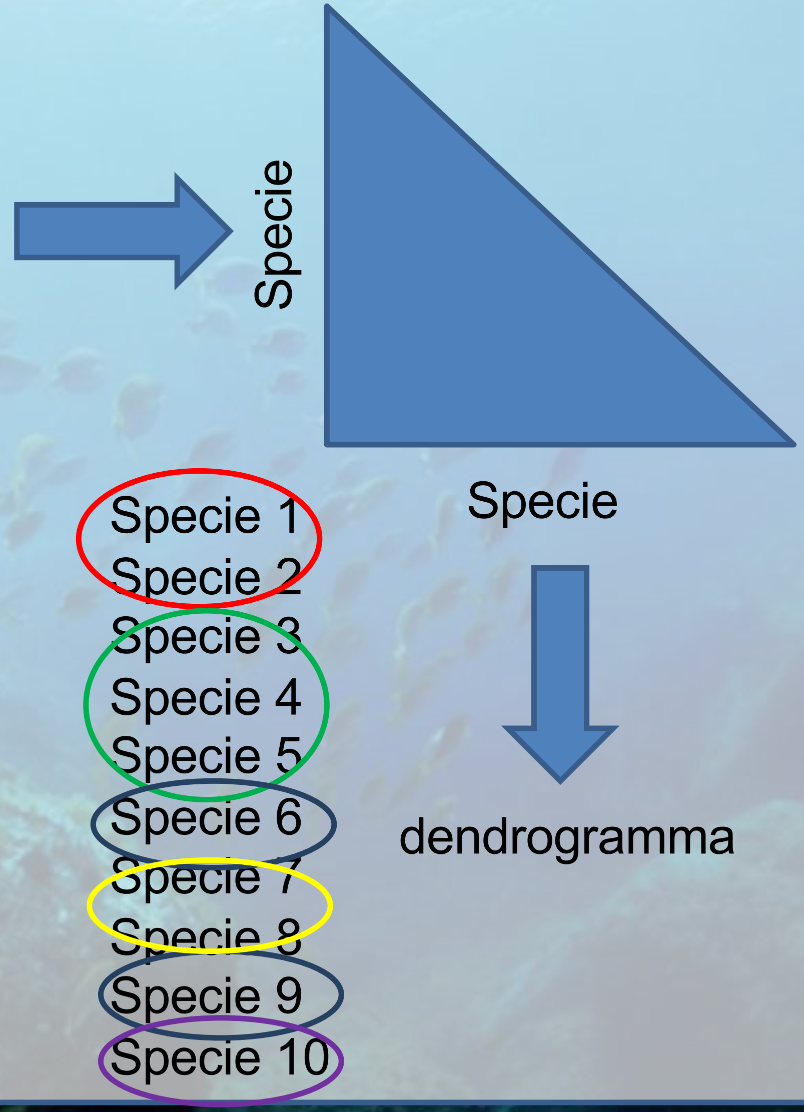


Bacteriovorus Deposit-feeder Grazer Predator

Biodiversity expressed as functional groups: an example with nematodes

Functional diversity

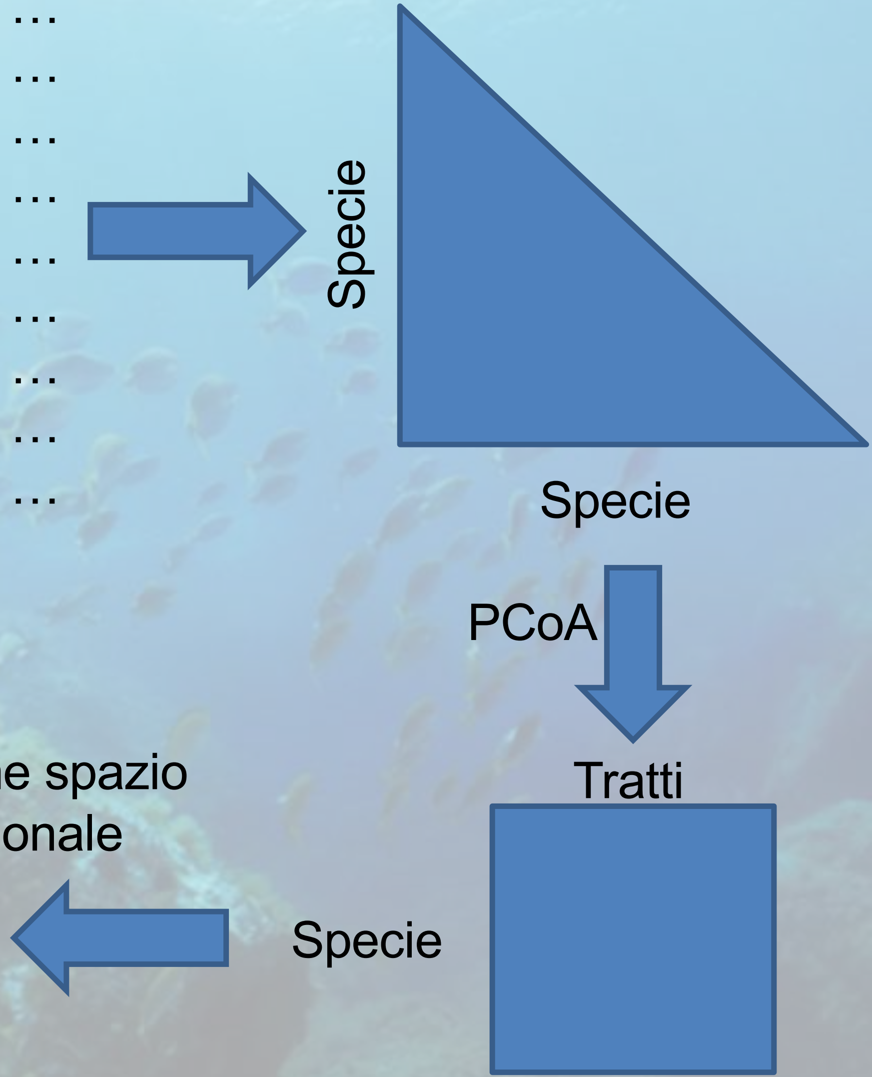
	Tratto 1	Tratto 2	Tratto 3	…	Tratto n
Specie 1	…	…	…	…	…
Specie 2	…	…	…	…	…
Specie 3	…	…	…	…	…
Specie 4	…	…	…	…	…
Specie 5	…	…	…	…	…
Specie 6	…	…	…	…	…
Specie 7	…	…	…	…	…
Specie 8	…	…	…	…	…
Specie 9	…	…	…	…	…
Specie 10	…	…	…	…	…



1-5	Comunità 1	FR = 2
1-10	Comunità 2	FR = 5

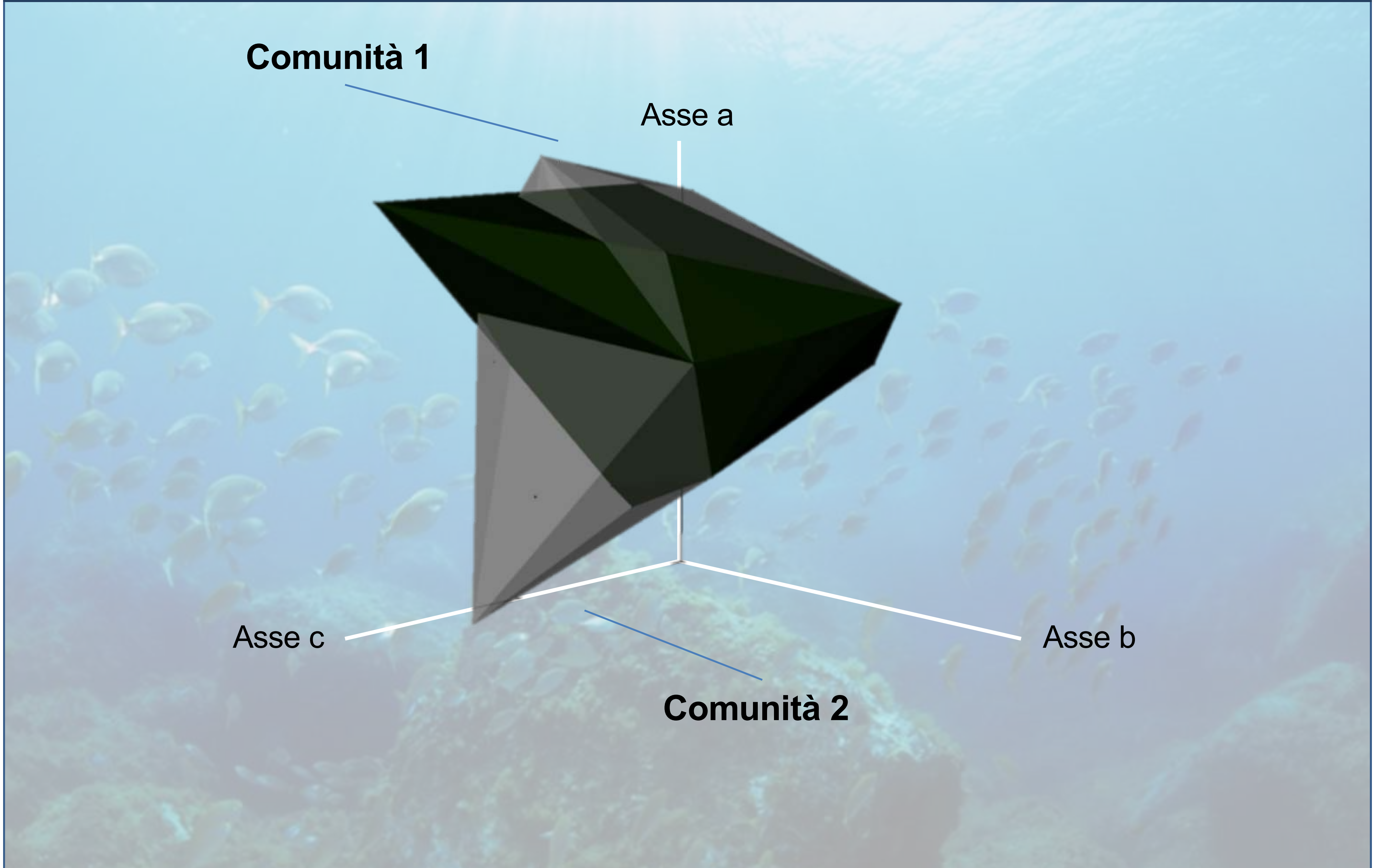
Functional diversity

	Tratto 1	Tratto 2	Tratto 3	…	Tratto n
Specie 1	…	…	…	…	…
Specie 2	…	…	…	…	…
Specie 3	…	…	…	…	…
Specie 4	…	…	…	…	…
Specie 5	…	…	…	…	…
Specie 6	…	…	…	…	…
Specie 7	…	…	…	…	…
Specie 8	…	…	…	…	…
Specie 9	…	…	…	…	…
Specie 10	…	…	…	…	…

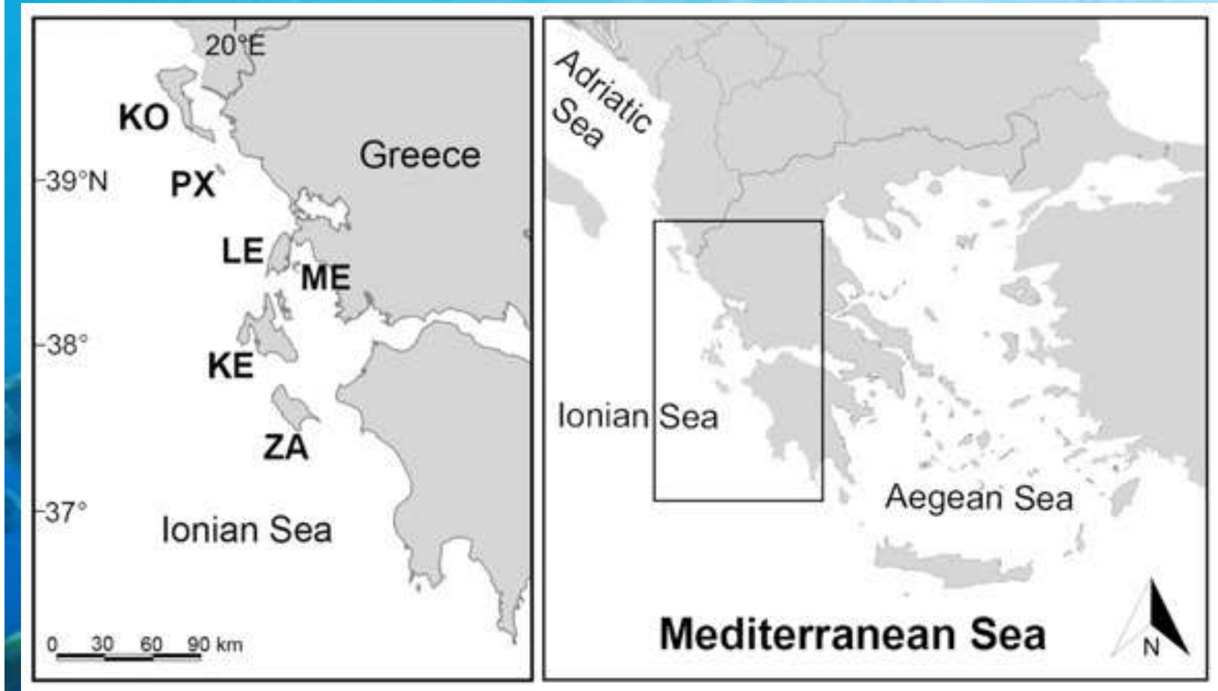


Fric = Volume spazio multidimensionale

Functional diversity



A case study in the Ionian Sea



Six islands, four sites in each islands. Sessile assembalges on subtidal reefs at 5 and 15 m depth. Photographic samples with 10 replicates in each sites. Identification of taxa at species level (genus or morphological groups in case of difficult organisms). Identification of funtional traits (48)

Traits related to functional aspects of organisms (shape, reproduction, dispersal, interaction with the environments, energy flow. Construction of multidimensional functional space for each assemblage in each islands and depth

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

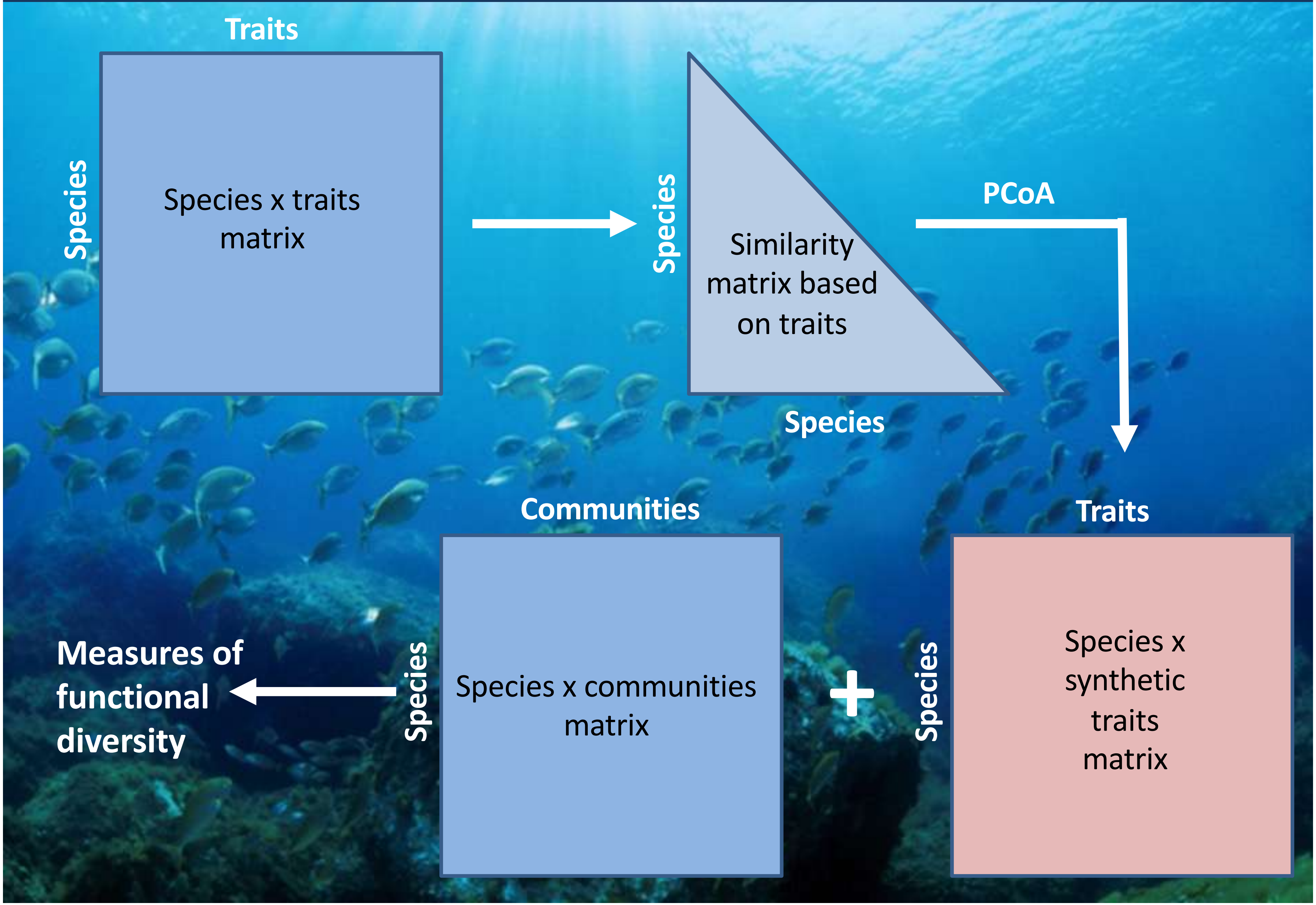
Dispersal and colonization	*Spatial distribution*	Distribution range at basin scale (Mediterranean Sea)
	Duration of larval stage (pelagic)	Time spent by larval stages in the water column before settelment (days)
	Asexual reproduction	Presence or absence of any type of asexual reproduction
	Recruitment 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)

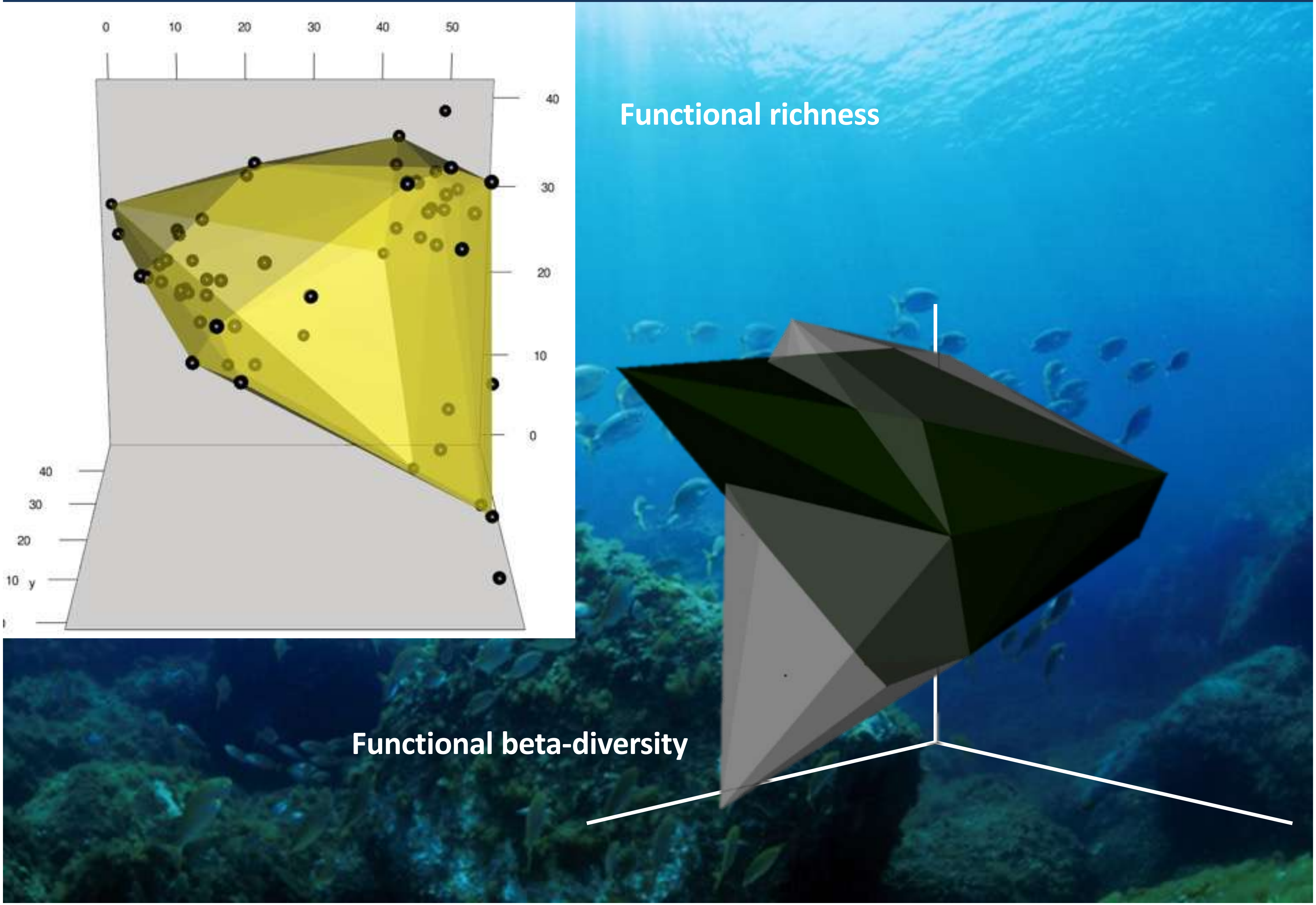
Functional traits: an example

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)

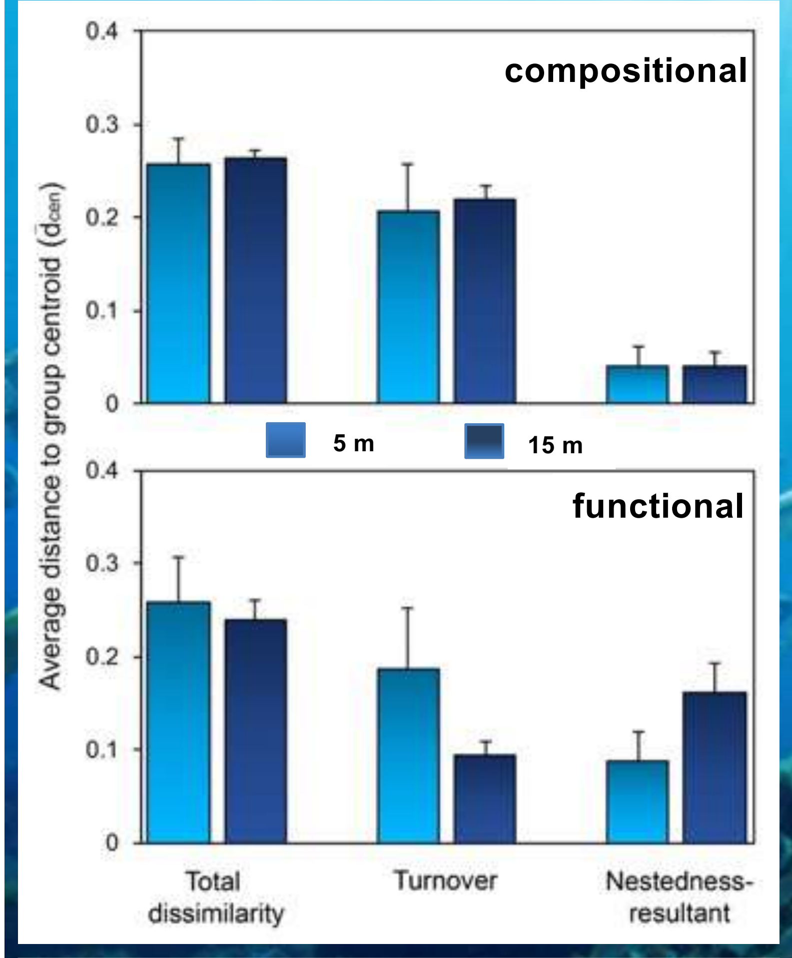
Analysis of functional diversity



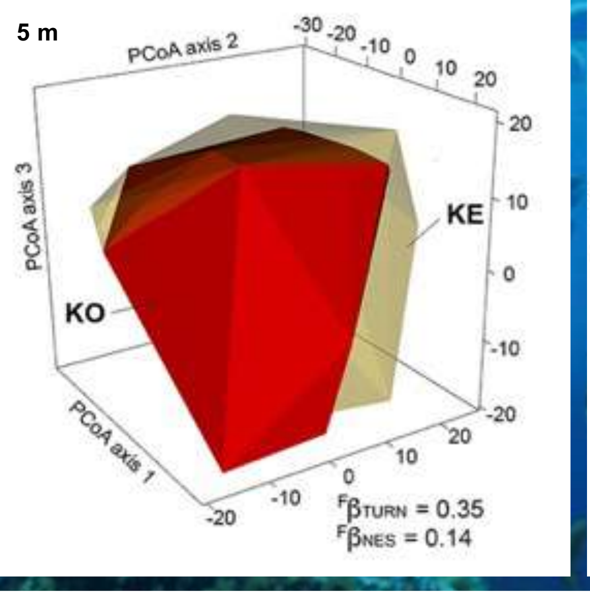
Measures of functional diversity

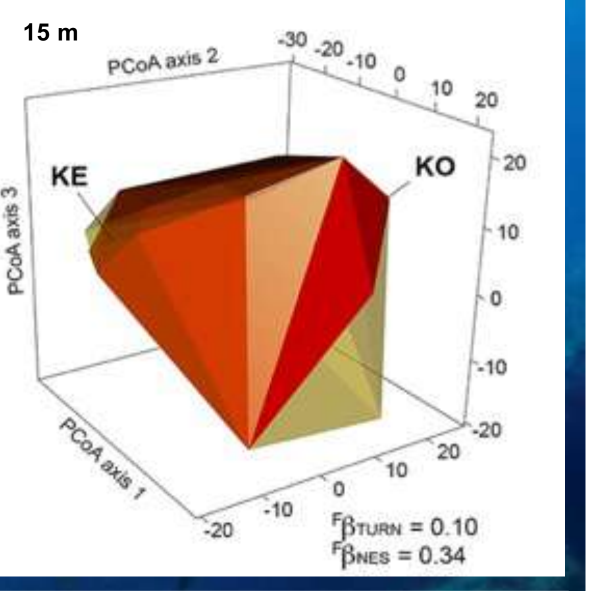


Results



Compositional beta-diversity of assemblages at both depths was mainly due to species turnover (replacement), whereas nestedness component was negligible.
However:
5 m: species turnover ⟹ functional turnover
15 m: species turnover ⟹ functional nestedness
This means that at 15 m there were islands representing hotspots of functional diversity, and islands that were functional subsets of these hotspots.





Partitioning nestedness and turnover unveils contrasting relationships between compositional and functional beta-diversity in subtidal rocky reef assemblages at varying depth.

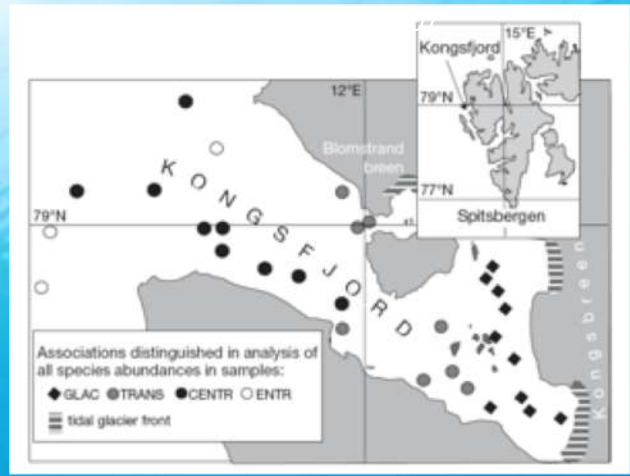
Understanding whether compositional diversity underlies functional diversity is crucial for conservation strategies.
Reserve networks based on taxonomic beta-diversity, although maximizing protection of species richness, do not necessarily ensure preserving functional representativeness.

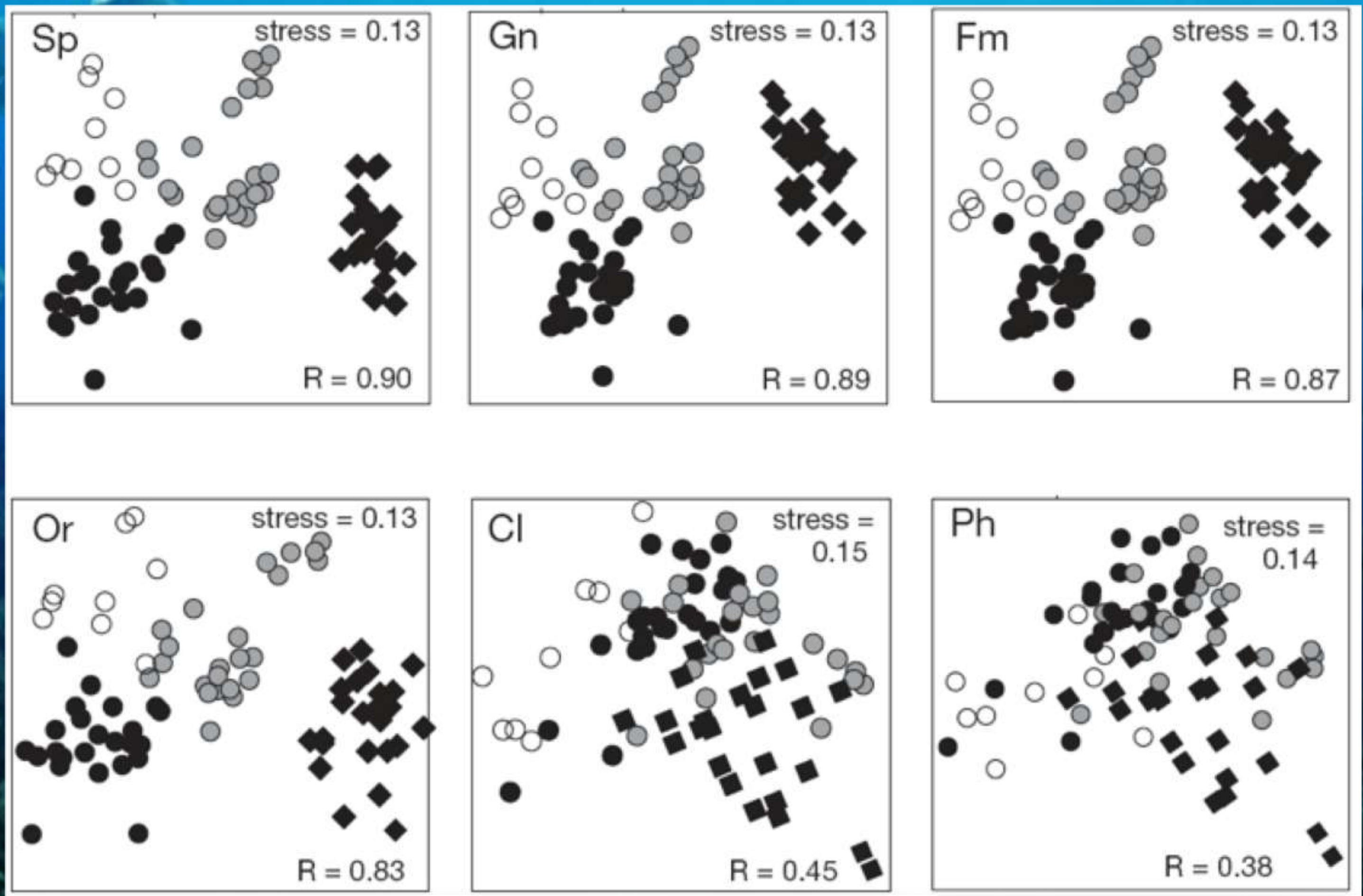
Taxonomic sufficiency

	1	2	3
Famiglia Arenicolidae			
Abarenicola affinis		X	
Abarenicola affinis africana			X
Abarenicola claparedii	X		
Arenicola cristata	X	X	X
Famiglia Capitellidae			
Capitella capitata	X	X	X
Capitella giardi			X
Capitomastus minimus	X	X	X
Dasybranchus caducus	X	X	X
Famiglia Cossuridae			
Cossura soyeri	X	X	X
Famiglia Maldanidae			
Axiothella constricta	X	X	X
Clymenura clypeata	X		X
Clymenura tricirrata		X	
Famiglia Opheliidae			
Ophelia amoureuxi	X		
Ophelia barquii	X	X	
Ophelia bicornis	X	X	X
Ophelia limacina			
Famiglia Orbiniidae			
Naineris laevigata	X	X	X
Schroederella laubieri	X	X	X
Famiglia Paraonidae			
Acmira assimilis	X	X	X
Acmira catherinae		X	X
Acmira cerrutii	X	X	X
Allia monicae	X	X	
Allia pseudannae			
Allia quadrilobata			
Famiglia Polygordiidae			
Polygordius neapolitanus			X
Polygordius triestinus	X		
Famiglia Questidae			
Questa caudicirra		X	
Famiglia Scalibregmatidae			
Scalibregma inflatum	X	X	
Sclerocheilus minutus			X

The use of higher-taxon diversity as a surrogate for species diversity

Gradienti di disturbo naturale





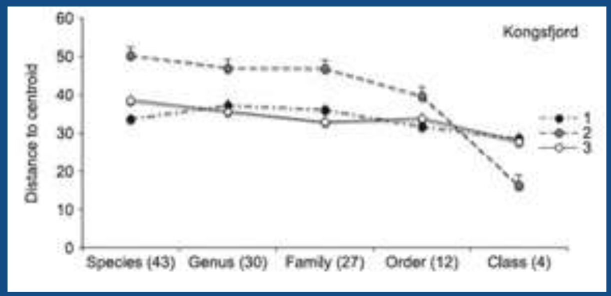
Alta risoluzione tassonomica

Alta informazione

Bassa risoluzione tassonomica

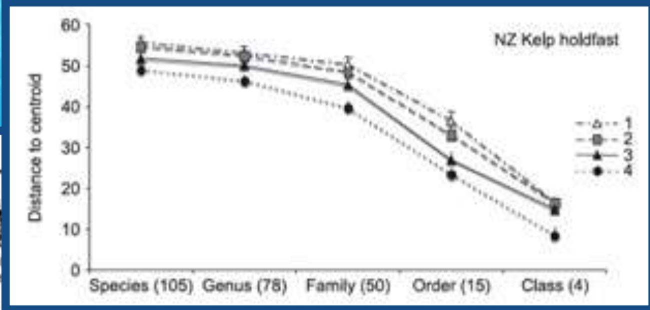
Bassa informazione

Beta-diversity

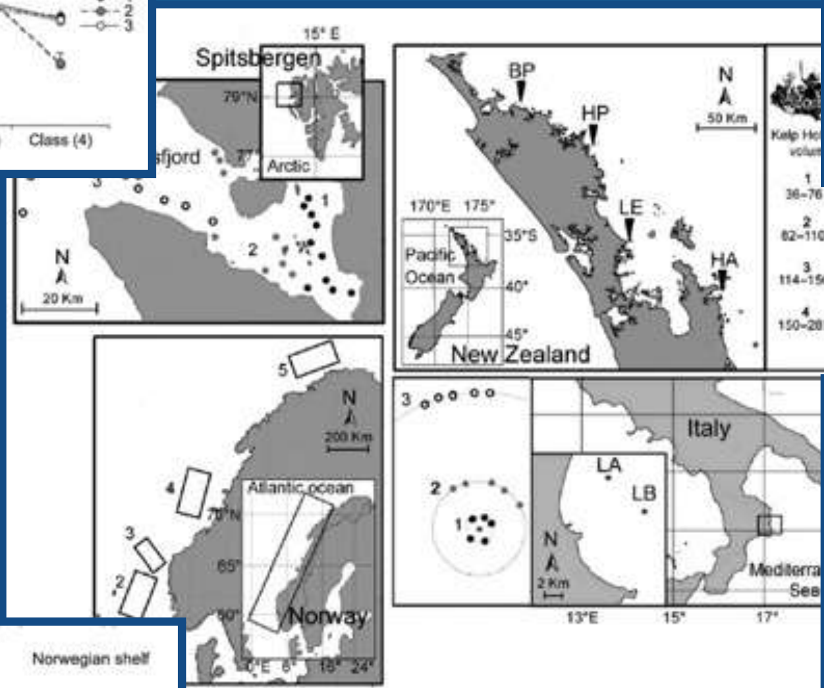


Glacial sedimentation gradient

MOLLUSK ASSEMBLAGES

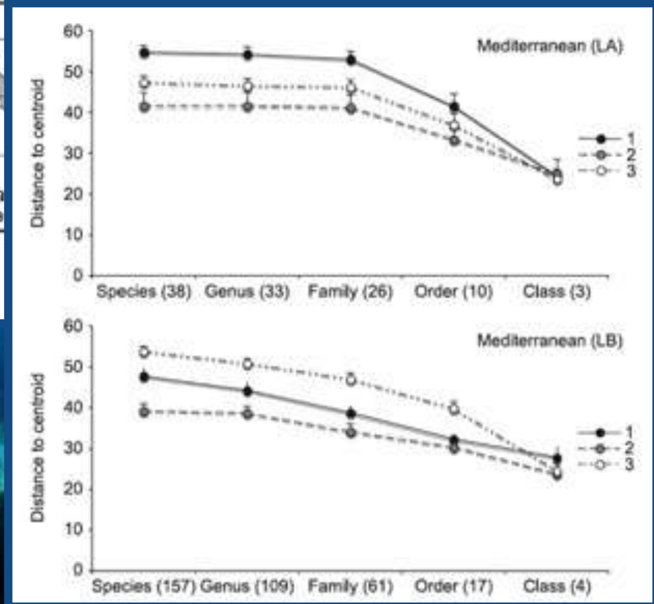


Kelp holdfast size

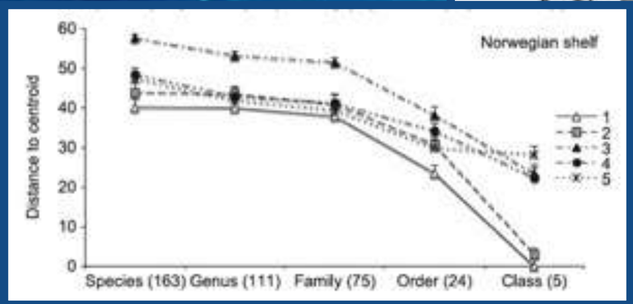


From Terlizzi et al., 2009

Distance from offshore platform



Latitudinal gradient



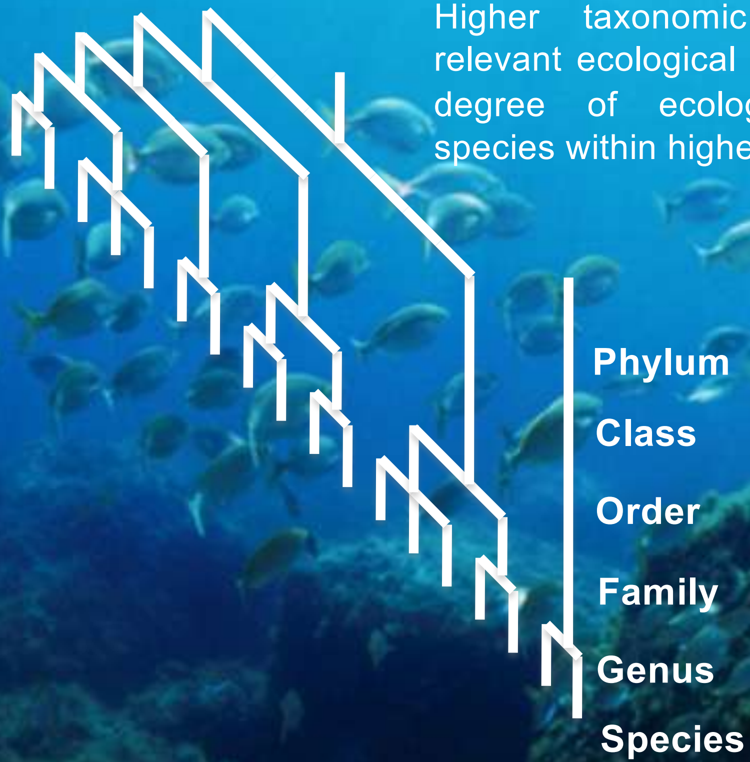
Terlizzi et al. 2009 Divers Distrib

Species level beta-diversity patterns retained up to family level

USING HIGHER TAXA AS SURROGATES FOR SPECIES

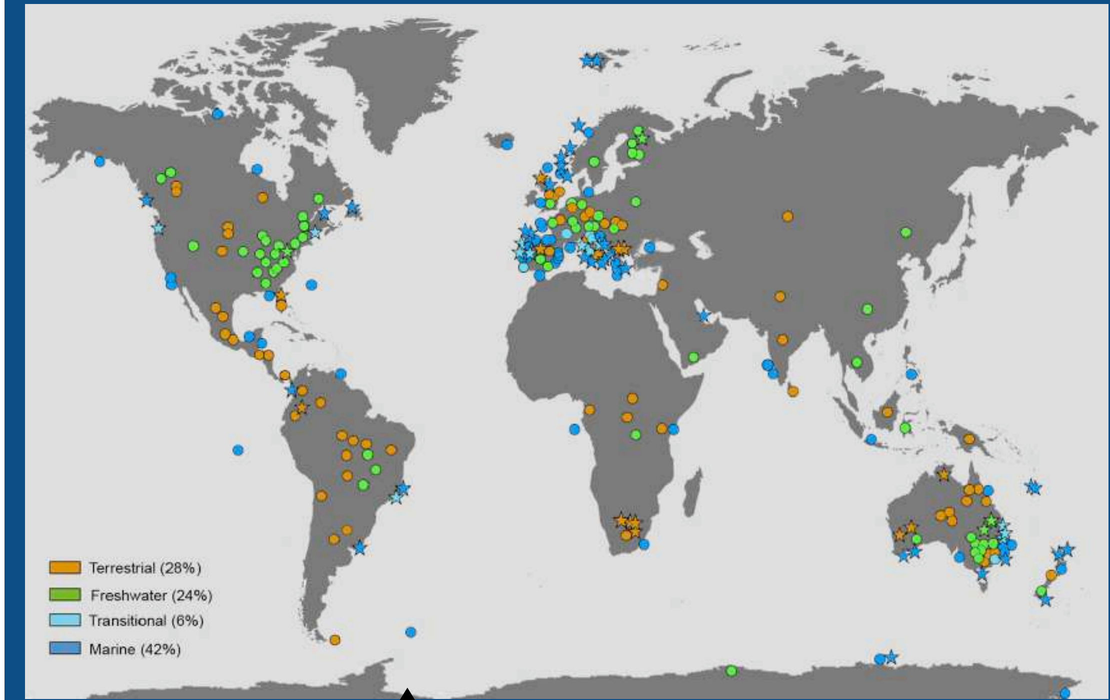
Linnaean Taxonomic Hierarchy

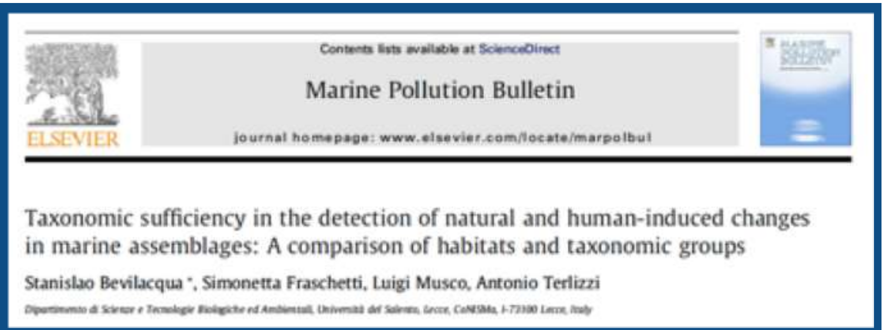
Higher taxonomic levels may convey relevant ecological information due to some degree of ecological similarity among species within higher taxa



Higher taxa, especially from intermediate taxonomic levels (e.g. genus, family) can be used as surrogates for species without a significant loss of information on species-level community patterns

Avoid costly, time-expensive, and difficult species-level identifications of organisms

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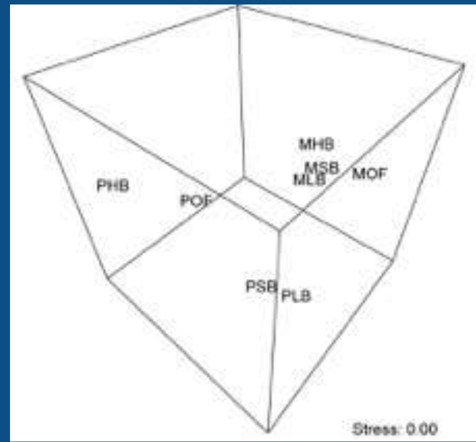
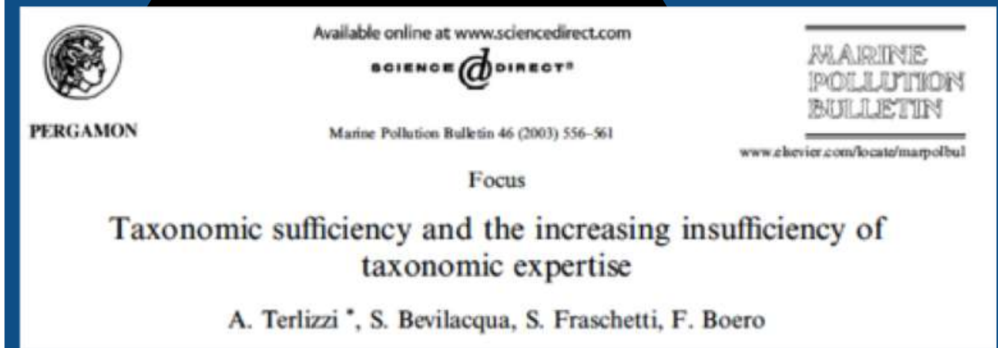
Taxonomic sufficiency in the detection of natural and human-induced changes in marine assemblages: A comparison of habitats and taxonomic groups

Stanislao Bevilacqua *, Simonetta Fraschetti, Luigi Musco, Antonio Terlizzi

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SCIENCE DIRECT

Marine Pollution Bulletin 46 (2003) 556–561

MARINE POLLUTION BULLETIN

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Focus

Taxonomic sufficiency and the increasing insufficiency of taxonomic expertise

A. Terlizzi *, S. Bevilacqua, S. Fraschetti, F. Boero

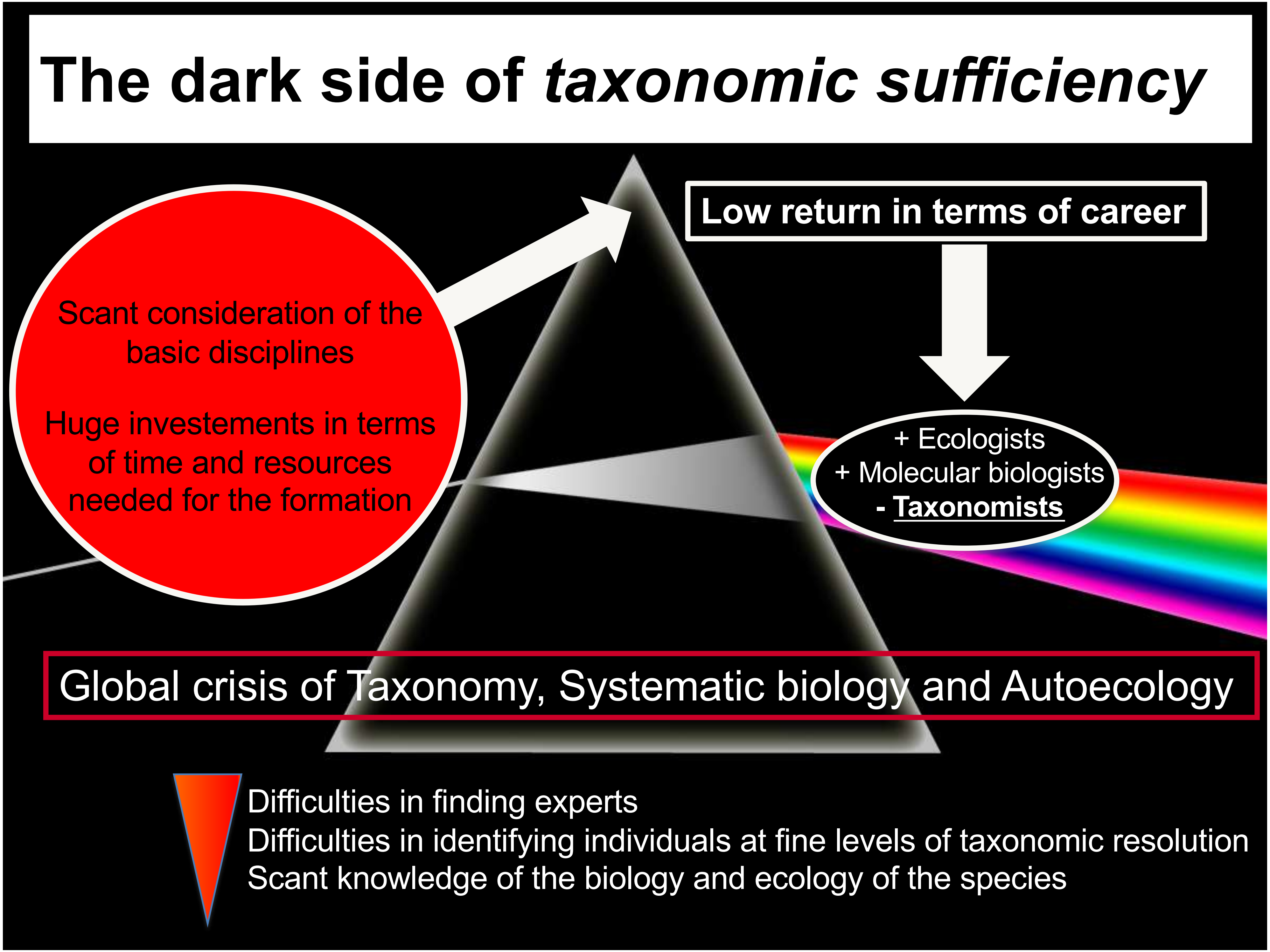
Lack of an ecological theory

Risk of loss of ecological information

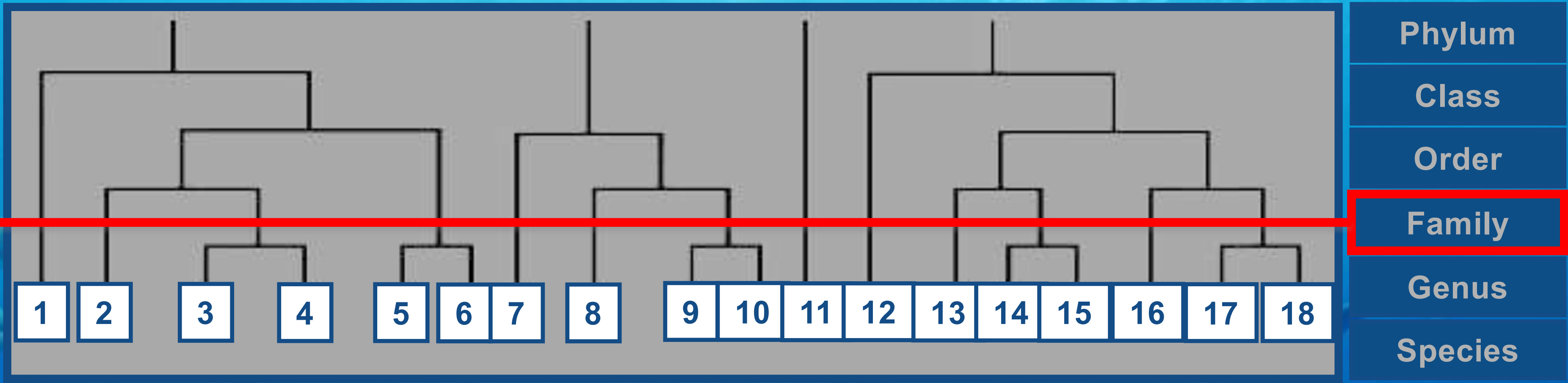
Potentially affected by taxonomic revisions

Performances changes among groups

Cannot be applied a priori but should be adopted following pilot studies


The dark side of *taxonomic sufficiency*
Low return in terms of career
Scant consideration of the basic disciplines
Huge investements in terms of time and resources needed for the formation
+ Ecologists
+ Molecular biologists
- Taxonomists
Global crisis of Taxonomy, Systematic biology and Autoecology
Difficulties in finding experts
Difficulties in identifying individuals at fine levels of taxonomic resolution
Scant knowledge of the biology and ecology of the species

USING HIGHER TAXA AS SURROGATES FOR SPECIES



Sufficient taxonomic level

- Difficult association of a clear ecological meaning to changes in community structure when it is codified through ranks of the Linnaean hierarchy higher than species
- Static grouping of organisms in taxa of a single taxonomic level irrespective of their ecological relevance or difficulty of taxonomic identification
- Lack of control for uncertainty in assuming a given level as sufficient

Loss of ecological information

AN ALTERNATIVE THEORETICAL FRAMEWORK

Journal of Applied Ecology

Journal of Applied Ecology 2012, 49, 357–366 doi: 10.1111/j.1365-2664.2011.02096.x

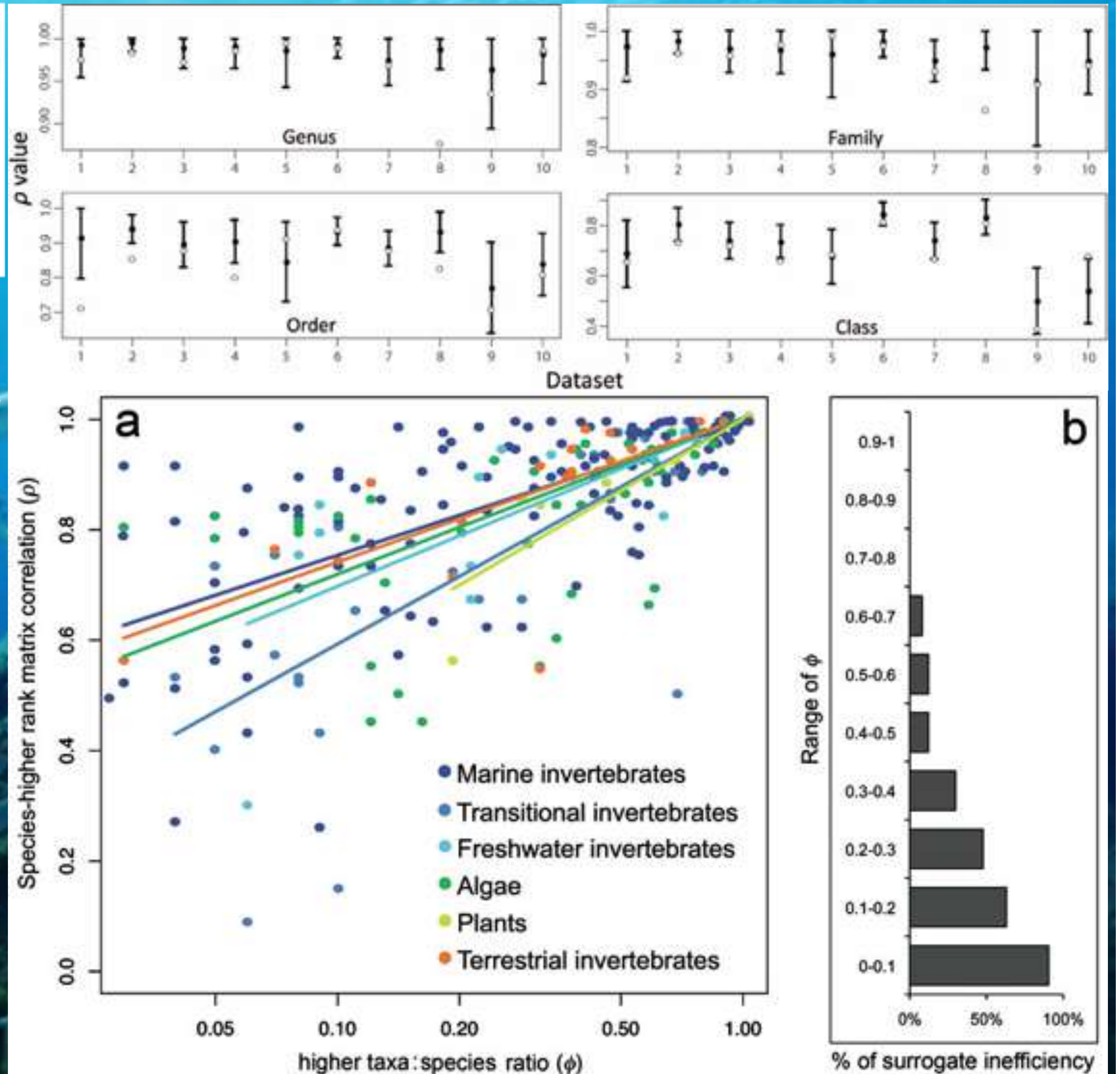
Taxonomic relatedness does not matter for species surrogacy in the assessment of community responses to environmental drivers

Stanislao Bevilacqua[1], Antonio Terlizzi[1*], Joachim Claudet[2,3], Simonetta Fraschetti[1] and Ferdinando Boero[1]

Higher taxa can behave as random groups of species unlikely to convey consistent responses to natural or human-driven environmental changes

The effectiveness of surrogates depends on the level of aggregation rather than on taxonomic relatedness

Results from 20 years of studies on taxonomic surrogates supports this dependence



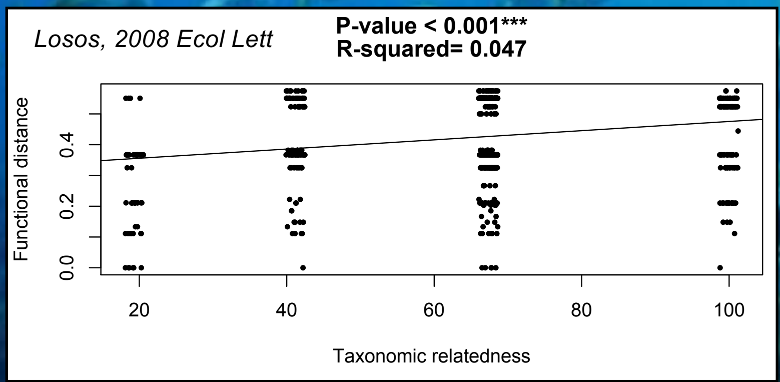
INTRATAXON ECOLOGICAL SIMILARITY?

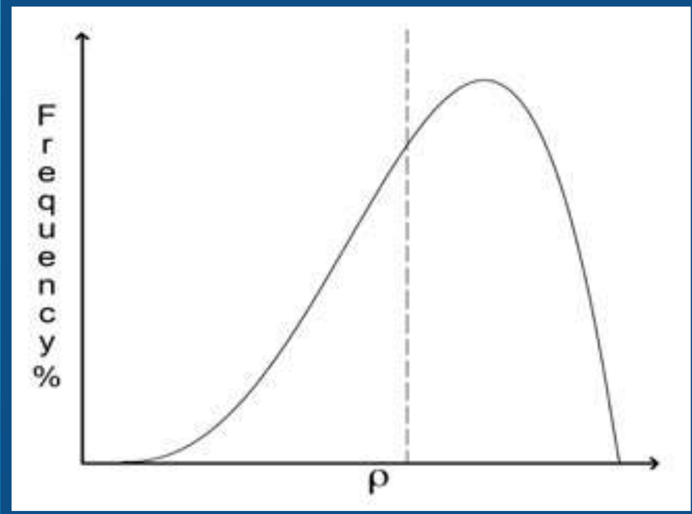
Phylogenetic/taxonomic relatedness often unrelated

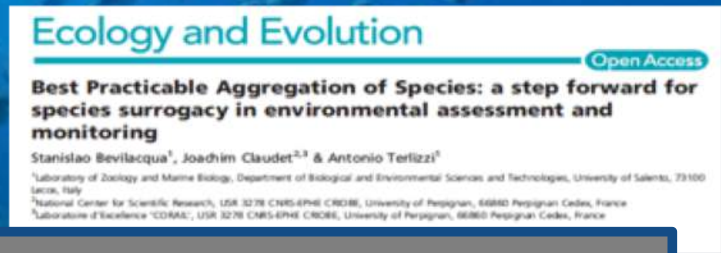
Similarity not necessarily extends to the whole functional trait spectrum

Similarity not necessarily concerns functional traits involved in the response

NEUTRAL RESPONSE







Ecology and Evolution

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Best Practicable Aggregation of Species: a step forward for species surrogacy in environmental assessment and monitoring

Stanislao Bevilacqua, Joachim Claudet & Antonio Terlizzi

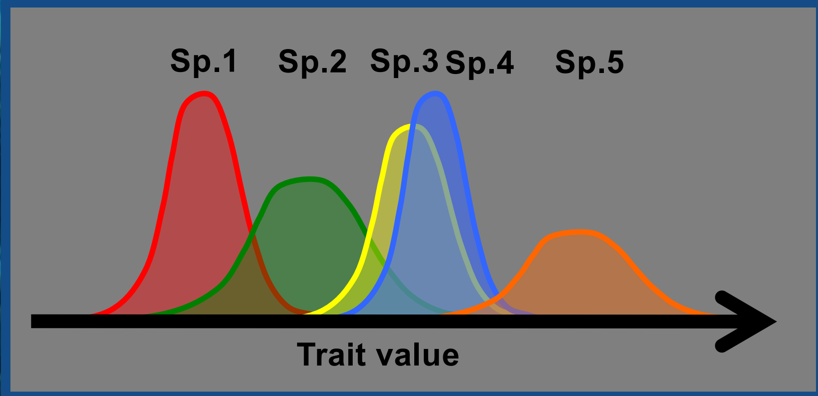
Contents lists available at ScienceDirect

Biological Conservation

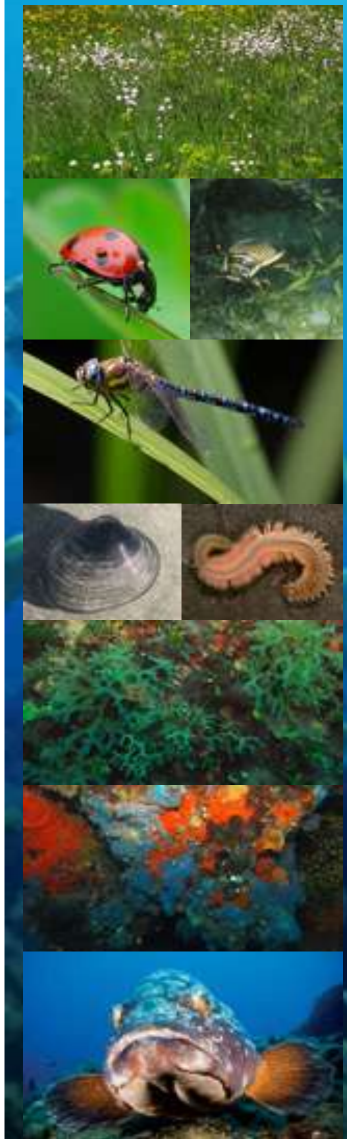
journal homepage: www.elsevier.com/locate/biocon

Taxonomic relatedness does not reflect coherent ecological response of fish to protection

Lauric Thiault, Stanislao Bevilacqua, Antonio Terlizzi, Joachim Claudet



…OR THE EFFECT OF VARIABLE AGGREGATION?



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Taxonomic relatedness does not matter for species surrogacy in the assessment of community responses to environmental drivers

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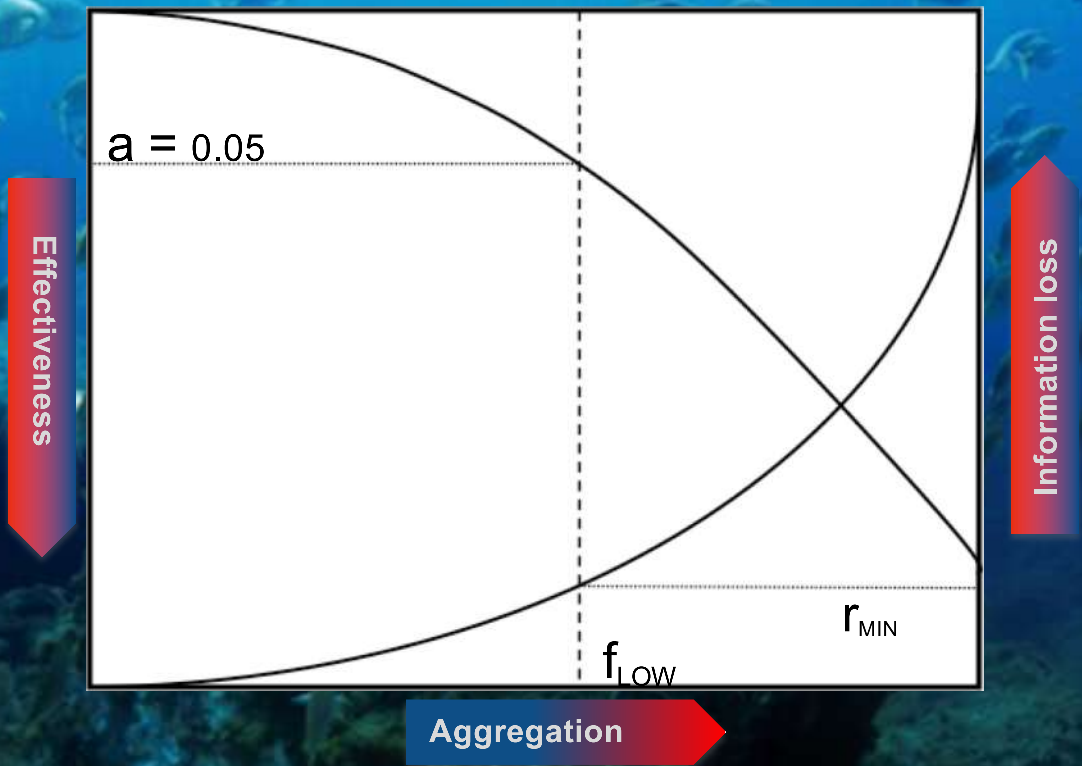
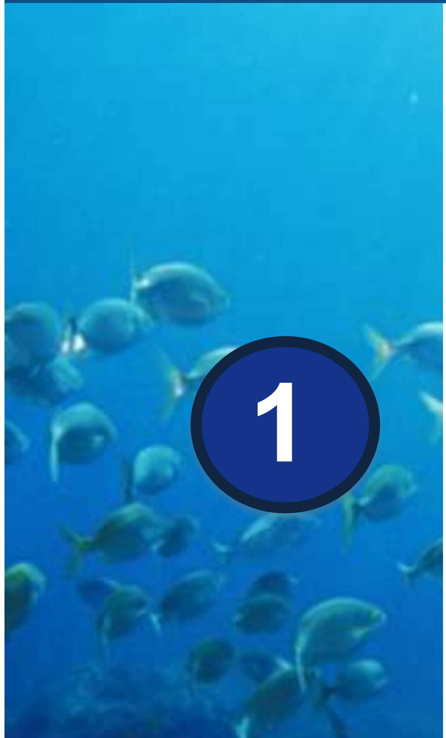
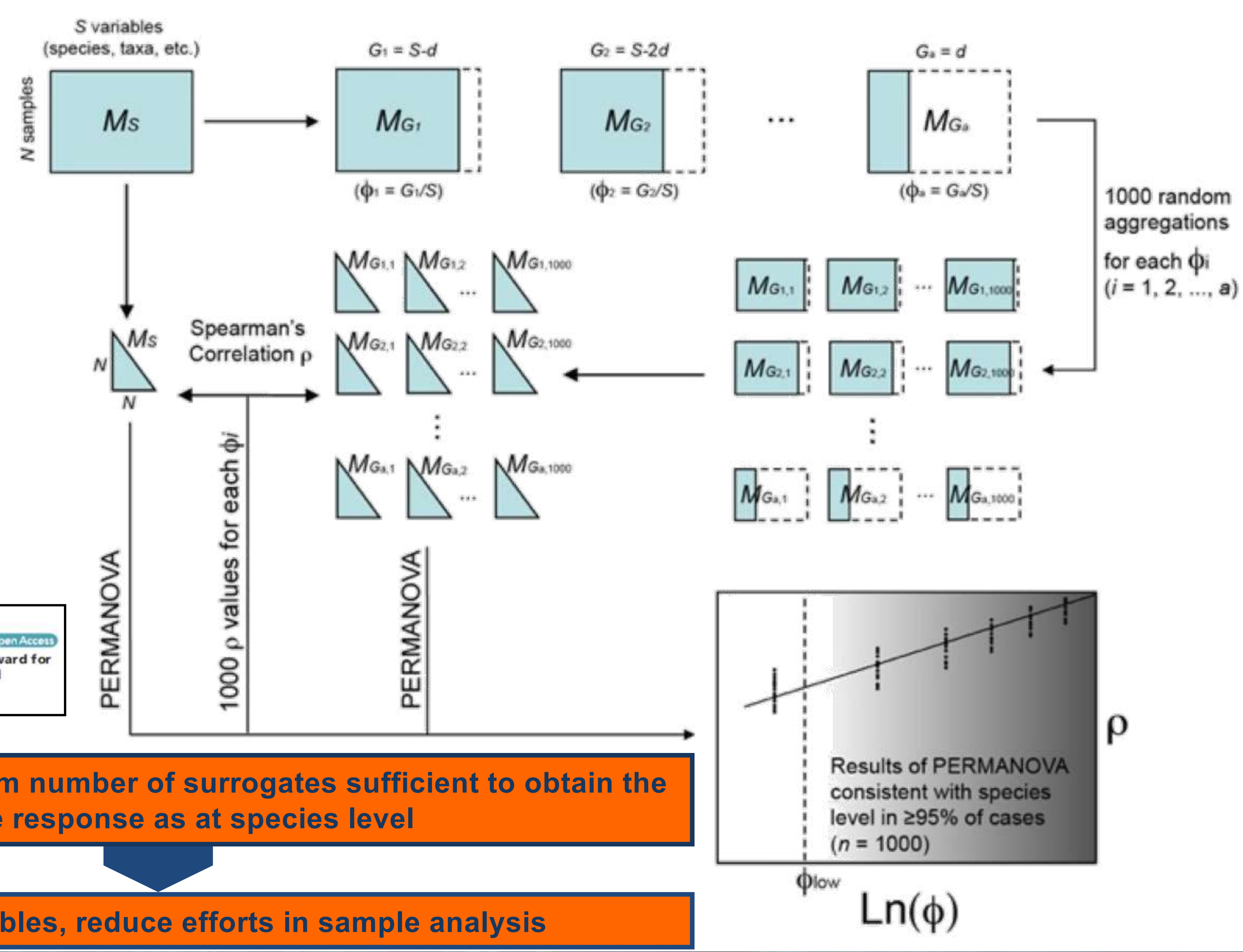


THE BESTAGG APPROACH





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Best Practicable Aggregation of Species: a step forward for species surrogacy in environmental assessment and monitoring

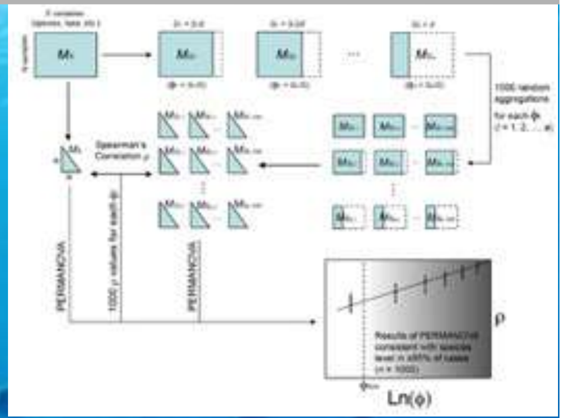
Stanislao Bevilacqua[1], Joachim Claudet[2,3] & Antonio Terlizzi[1]

Identifying the minimum number of surrogates sufficient to obtain the same response as at species level

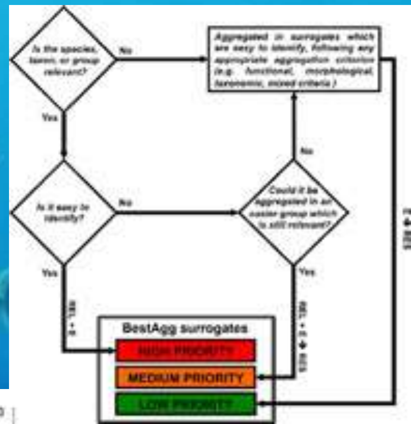
Minimize variables, reduce efforts in sample analysis

THE BESTAGG APPROACH

Identifying the highest level of aggregation based on null models of random assembly of species variables

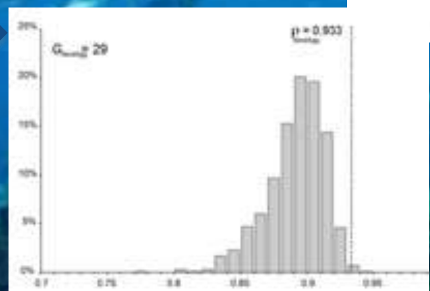


Selecting surrogates based on this threshold and ecological relevance, identification easiness, and resemblance of species



Controlling for uncertainty in applications

Validating surrogate selection using randomization tests

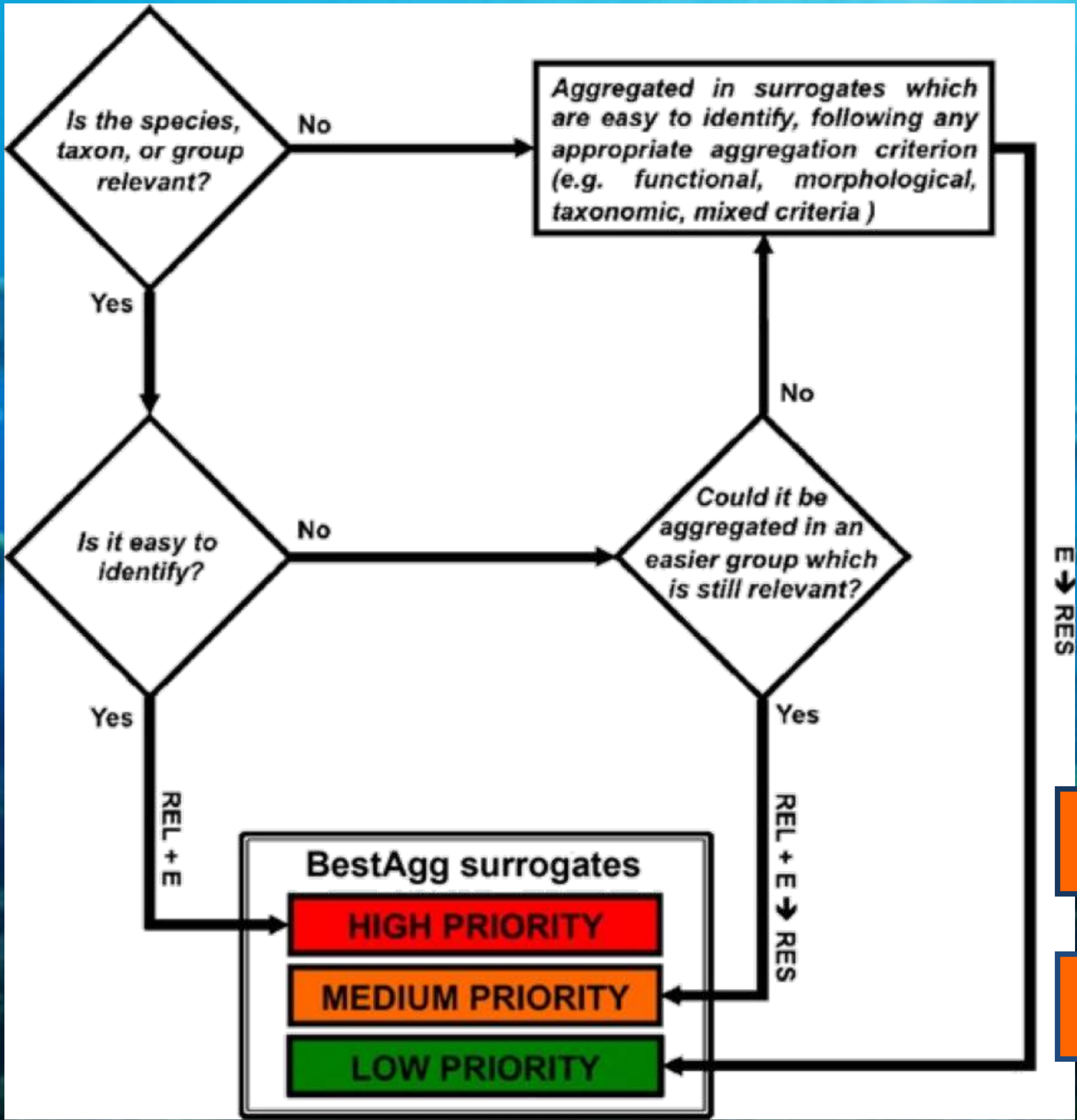


Obtaining the minimum set of surrogates irrespective of aggregation criterion

THE BEST PRACTICABLE AGGREGATION OF SPECIES

Maximizing ecological information while minimizing the number of variables to take into account

THE BESTAGG APPROACH



Relevance
(ecological importance)

Easiness
(low difficulty of taxonomic identification)

Resemblance
(shared characteristics among organisms)

2

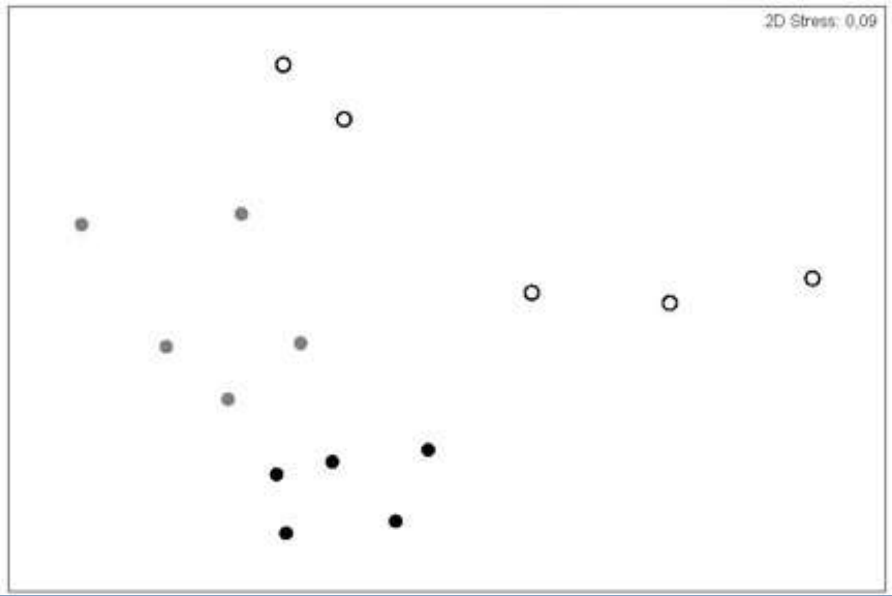
Identifying surrogates types based on relevance, easiness, and resemblance

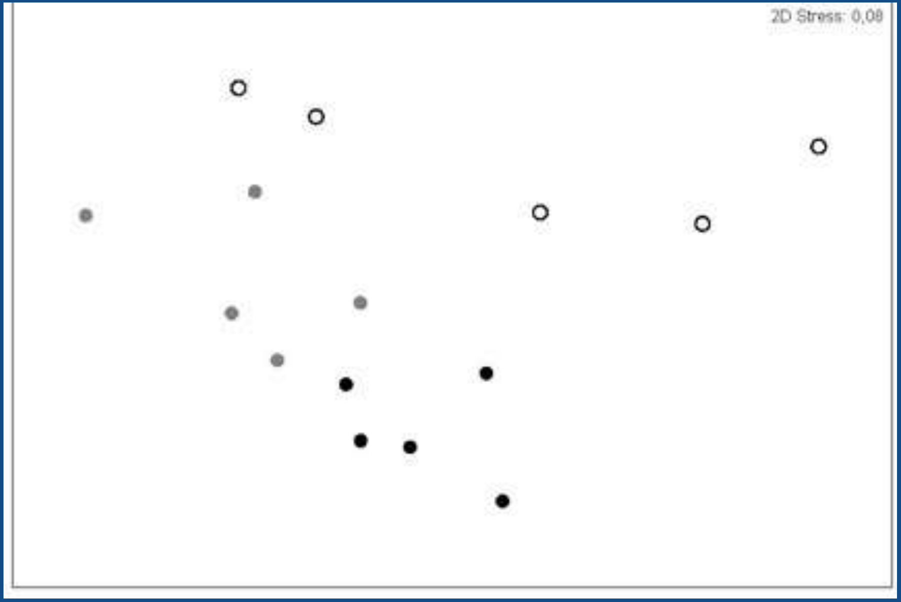
Minimize difficulties of identifications and maximize ecological information

THE BESTAGG APPROACH: CASE STUDIES

Species (S=259)

Best Agg (S=26)





APPLICATIONS

Soft bottom invertebrates
Continental shelf mud flats
Offshore gas fields
Variables' reduction: 90%
Relative savings: 5%

Sessile macrobenthos
Rocky reefs
Depth gradient
Variables' reduction: 80%
Relative savings: 26%

Bevilacqua, Claudet & Terlizzi, 2013 Ecology & Evolution

Sessile macrobenthos
Hard substrates
Harbour impact
Variables' reduction: 40%
Relative savings: 10%

Bevilacqua & Terlizzi 2016 Marine Ecology Progress Series

Trans. water invertebrates
Coastal lagoons
Natural variability
Variables' reduction: 71%
Relative savings: 45%

Bevilacqua, Terlizzi, Mistri, Munari, 2015 Ecological Indicators

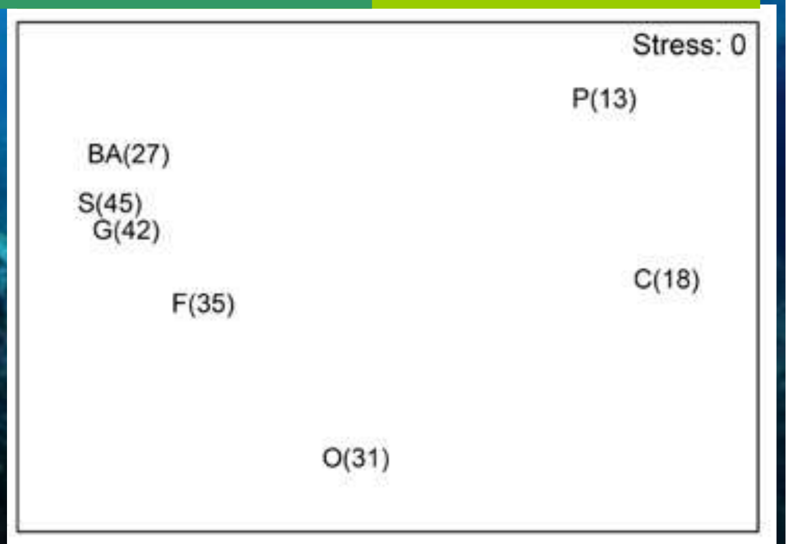
Freshwater invertebrates
Continental river basin
River gradient
Variables' reduction: 88%
Relative savings: 45%

Milosevic et al, 2014 Hydrobiologia

Reducing the set of variables from 40% up to 90% while still obtaining results consistent with species level analysis (statistical tests, ordinations, correlation with environmental variables, etc.)

Often retaining greater information than what expected by chance, and more than comparable sufficient taxonomic levels

Estimated timesaving from 5% up to 45% with respect to the sufficient taxonomic level identified using classical approach



ADVANTAGES

•Application to any type of data and organism

•Reduce as much as possible the number of surrogates needed

•Additional reduction of time in sample processing with respect to classic approaches based on taxonomy

•Minimize difficulties in identifying organisms

•Prioritize ecological information

•Provide control for uncertainty

Unleash the investigator from static surrogacy schemes strictly relying on taxonomic relatedness

Allow the selection of any surrogate type potentially leading to retain ecological information and/or to reduce efforts for the identification of organisms and sample processing

Lead to ecologically meaningful surrogates that, while cost effective in reflecting community patterns, may also contribute to unveil underlying processes

Final remarks

Human disturbances can “impact” biodiversity at different levels. How these impacts are perceived is strongly dependent by the notion of biodiversity, which is essentially based on the concept of Species

Although tests of hypotheses about the effects of human impacts on biodiversity may be continuously advanced by the development of innovative statistical procedures, the widespread demise of taxonomy yet prevent an adequate taxonomic definition of the variables

Changes in biodiversity can be detected even when the analysis is based on a taxonomic level higher than species but there are no ecological patterns underlying the aggregations through the Linnean ranks

Causal inferences about the effects of impacts on biodiversity are severely limited by poor taxonomy

Importantly, although the taxonomic efforts required can be reduced, the concept of BESTAgg does not disregard the importance of the identification of species and thus the role of taxonomy, a crucial discipline that lies at the heart of any knowledge or study of biodiversity

A plea for Taxonomist in the actual concept of Biodiversity

The emphasis given to the Biodiversity issue concerns our explicit recognition that its global pattern is changing as a consequence of human footprint

"Changes in Biodiversity" is therefore an "ecological problem" that, however, can't be faced without a precise definition of its components

The "precise definition of components" concerns taxonomy, a discipline which is not intended as limited to routine species identification but rather, to **the biology, behaviour and autoecology of any classified species**

Lack of awareness that taxonomy and ecology should strictly interact in approaching the biodiversity issue imply the risk of generating parataxonomists and paraecologists

The use of surrogates does not imply demise of taxonomy but, rather, a weighted reduction of variables managed by modern taxonomists and not by the taxonomy itself