GLOBAL CHANGE ECOLOGY AND SUSTAINABILITY
a.a. 2022-2023

Conservation and Management of Marine Ecosystems

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 individuals of the *i* species

N = The total number of individuals

$p_i = n_i/N$

Evenness

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

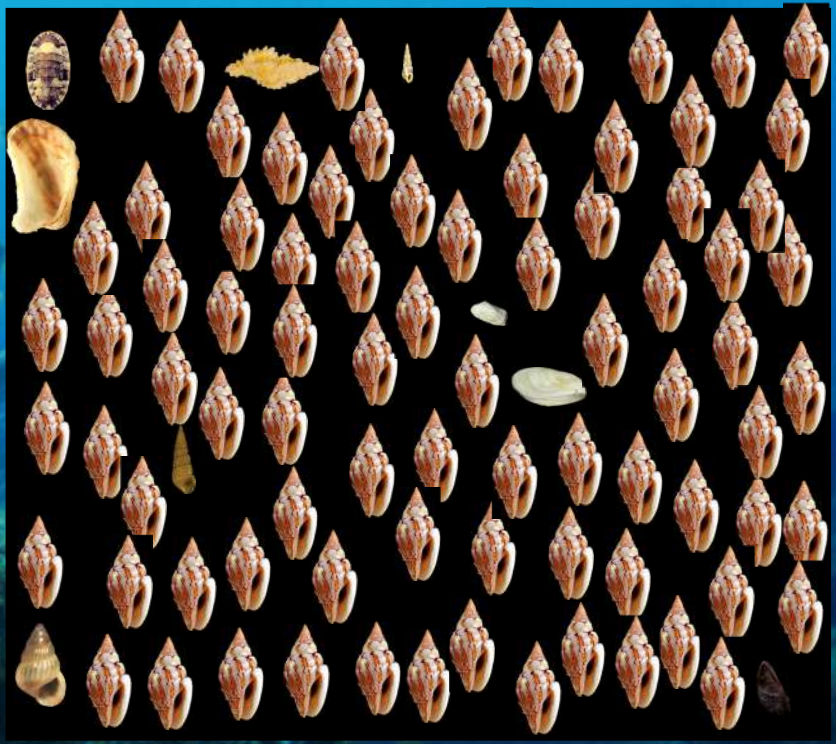
1st assemblage:
10 species and 100 individuals

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

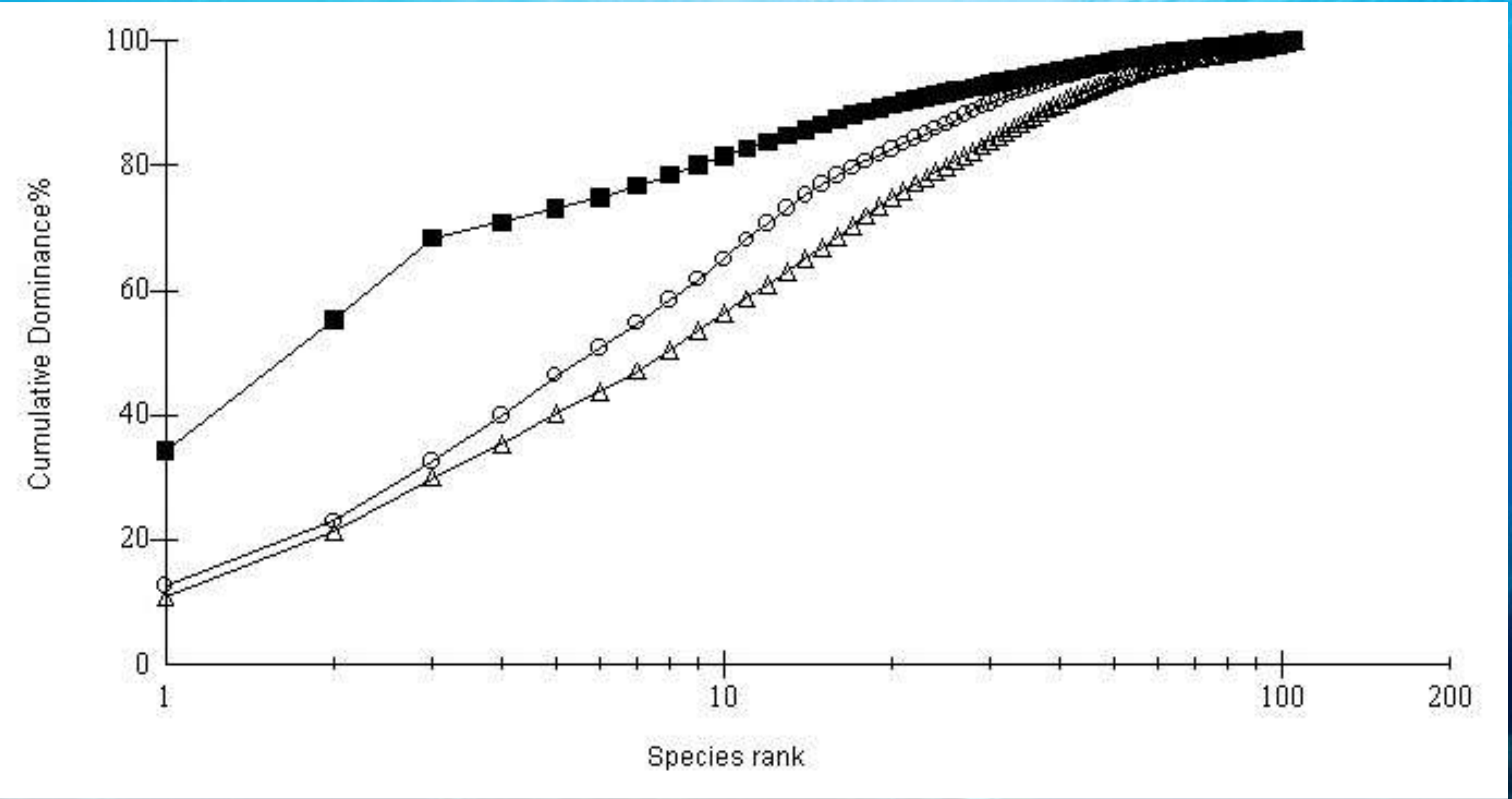
H' =2,30 J' =1

2nd assemblage:
10 species e 100 individuals

S=10 N=100

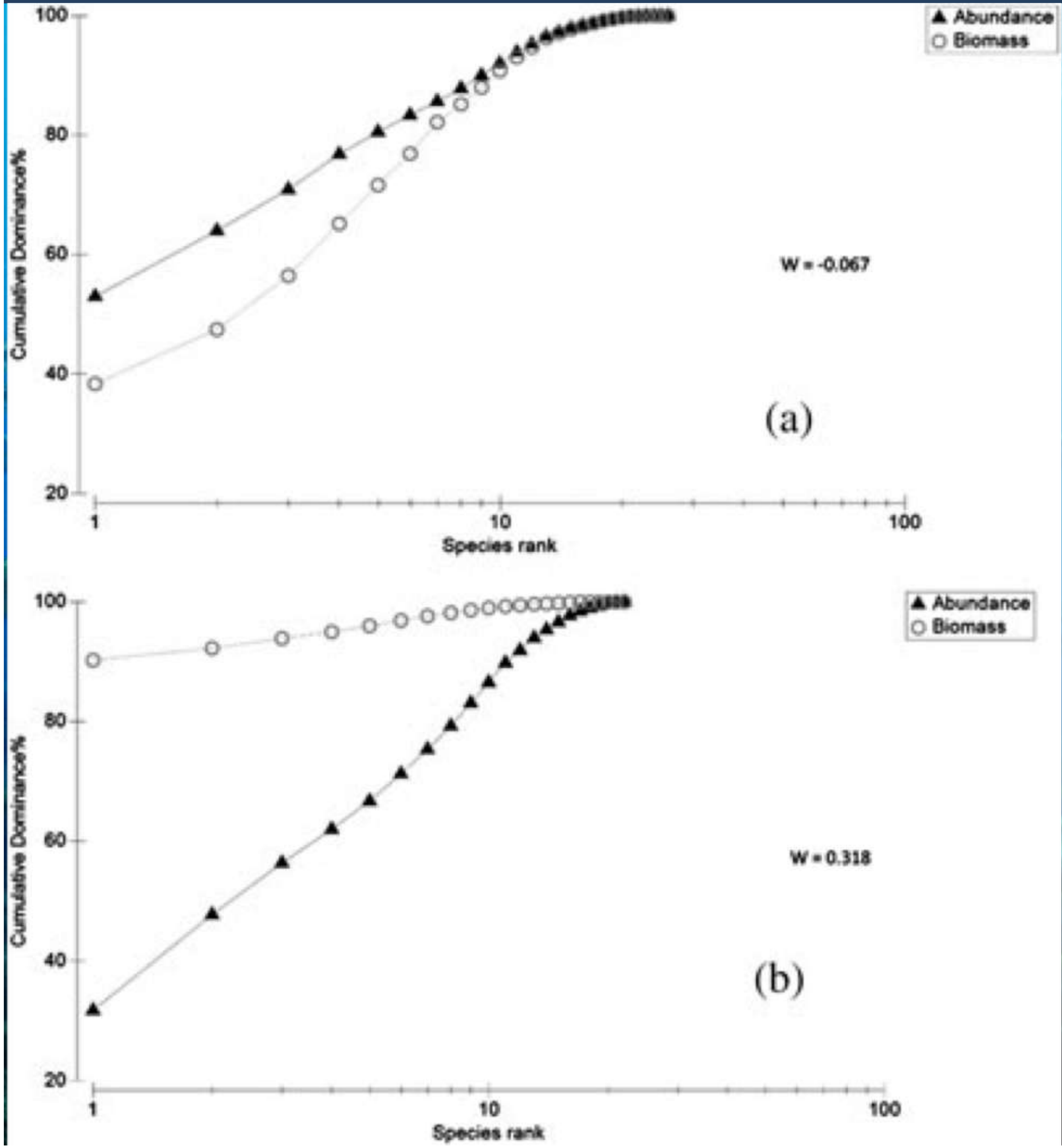
H' =0,50 J' =0,22

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

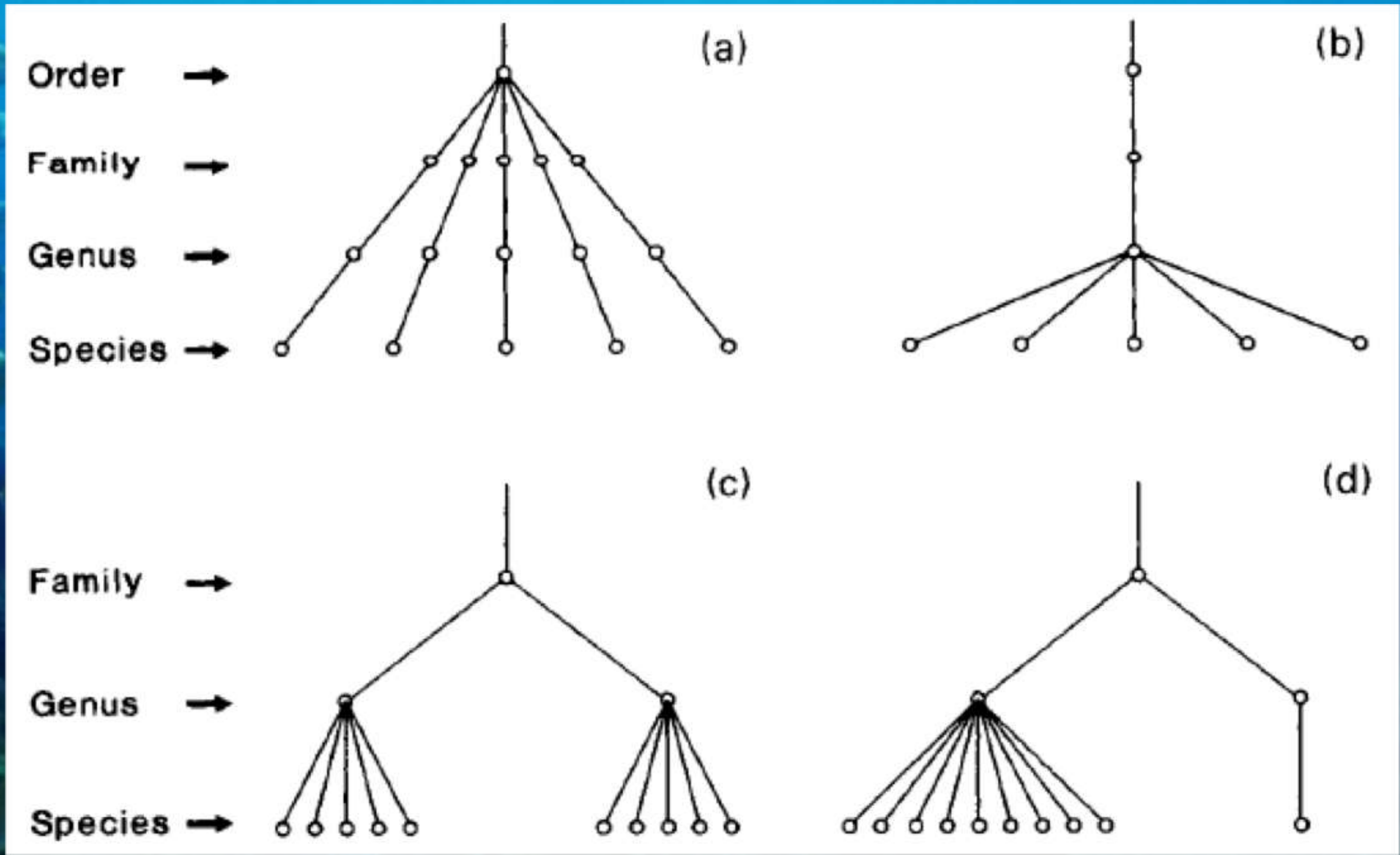
Taxonomic diversity indices

This assemblages has more species

Which is more “biodiverse”

Taxonomic diversity indices

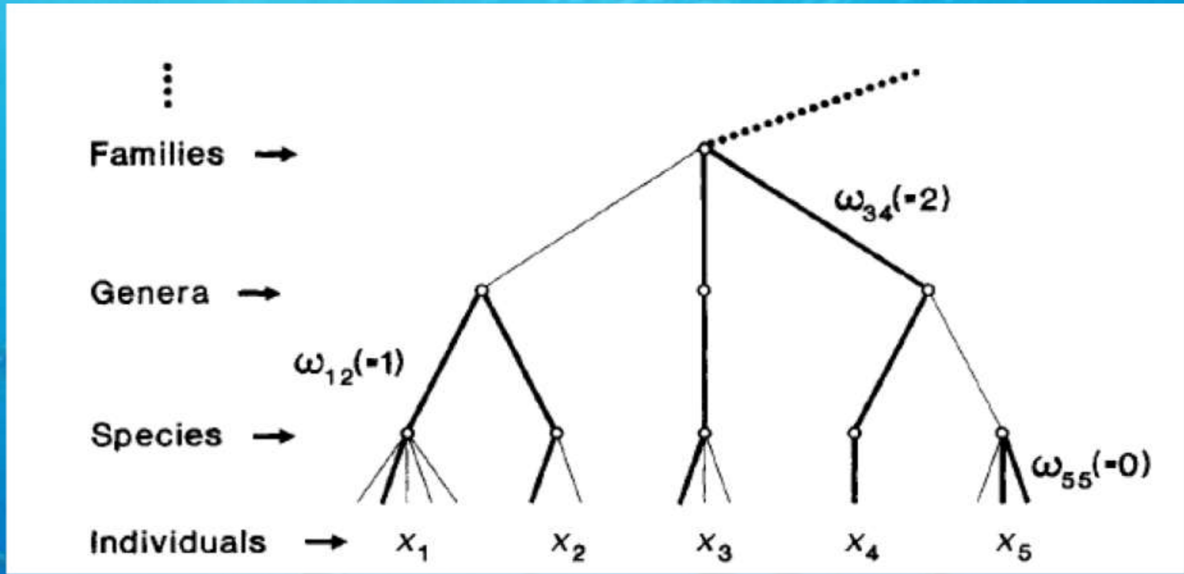
Many traditional diversity indices are based on species richness and abundance, overlooking other aspects of diversity. To capture taxonomic diversity Clarke & Warwick (1995, 1998) conveived a set of new indices which included in their formulation species richeness and abundance, but also the taxonomic relations among speceis.



Taxonomic diversity indices

These indices are: the Taxonomic Diversity (Δ) and the Taxonomic Distinctness (Δ*), which derive from the Simpson's index but adding taxonomic distance in their formula.

Abundance of the two species are weighted by a coefficient which reflect the lenght of the path between two species in the taxonomic tree.



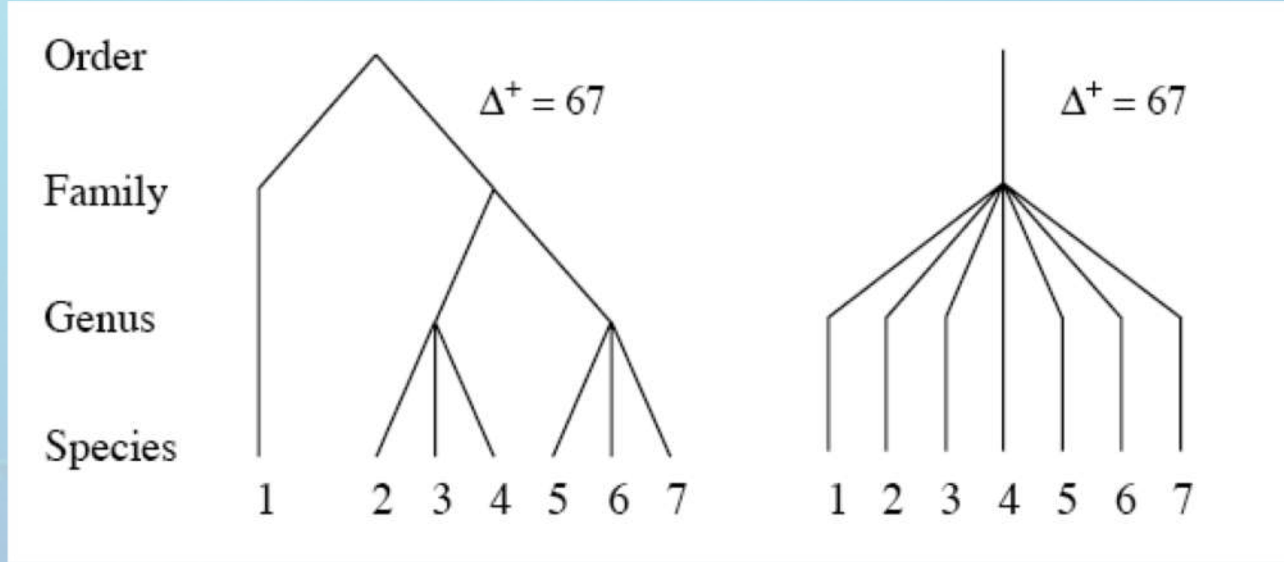
Taxonomic Diversity (Δ): The expected distance in between two randomly-chosen individuals from the sample

Taxonomic Distinctness (Δ*): The expected distance between two randomly-chosen individuals from the sample conditional to belong to the same species

Taxonomic distinctness

With presence/absence data Δ e Δ^* both converge to Δ^+ (Average Taxonomic Distinctness), the average distance between two randomly-chosen species in the sampled community

The average distinctness alone, however, cannot characterize all aspects in the taxonomic tree. For instance, the variation around this average value can be important

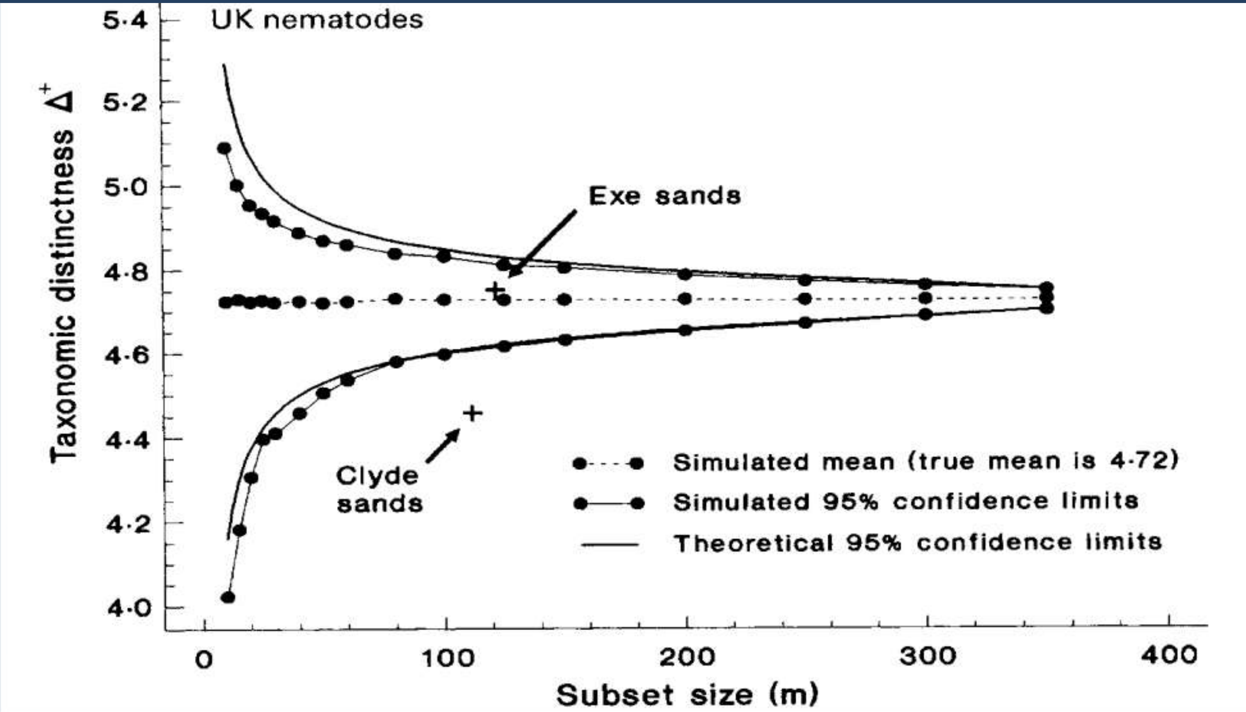


To capture this aspect Clarke & Warwick (2001) proposed another index to complement Avg D.

Λ^+ (Variation in Taxonomic Distinctness)

Represents variation of delta+ and, reflects the distribution of taxa in the taxonomic tree.

Pros



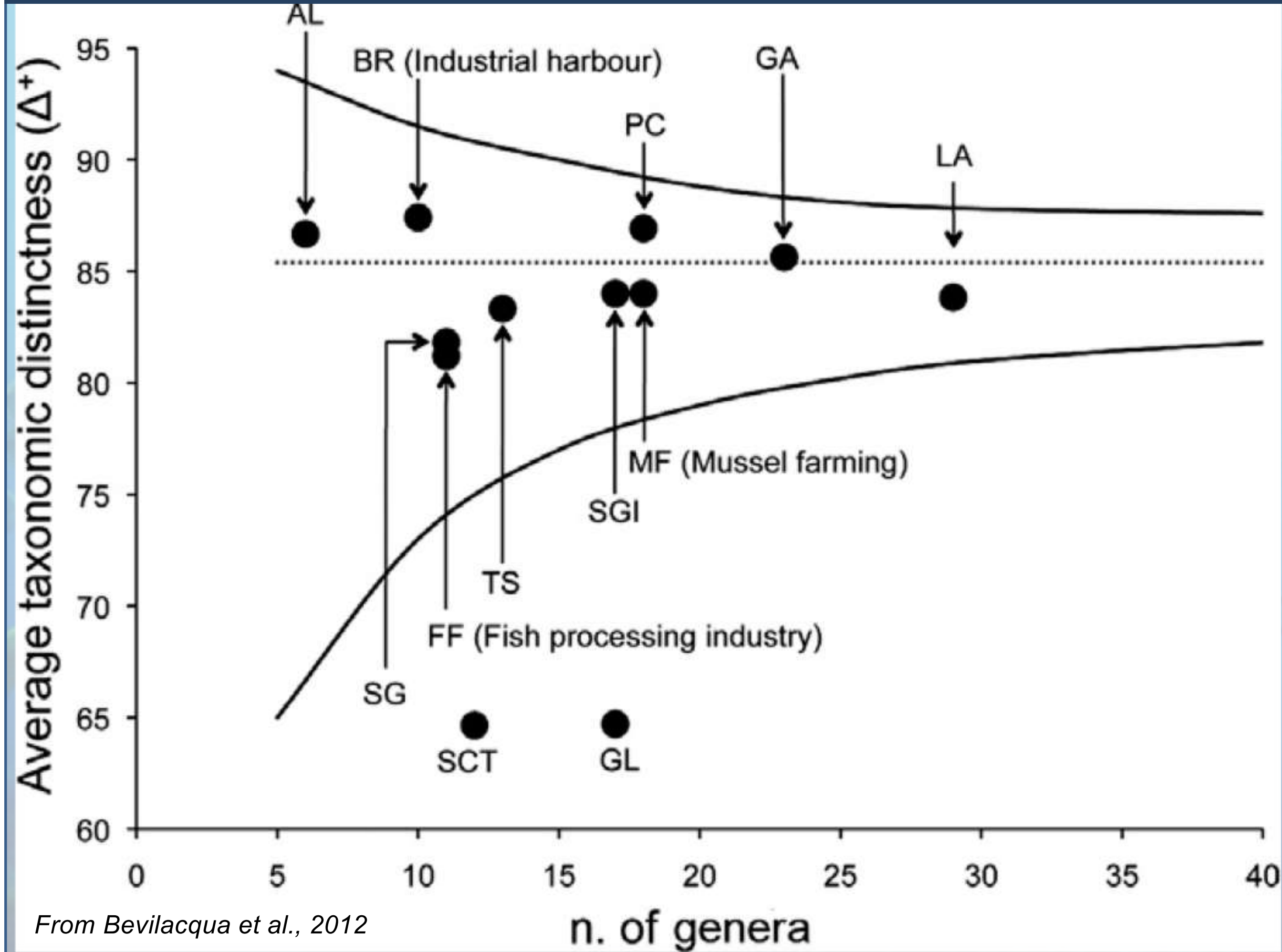
Main advantages:

- Independent from sampling efforts and methods
- Statistical test
- Comparison among areas
- Historical analysis based on P/A
- Sensitive to changes otherwise unnoticed

Simulation test

A statistical test is available based on a list of species representative of the region or habitat under study. Index value calculated on a random subset of species from the list. Procedure repeated many times to construct a confidence interval of Δ^+ for each subset to contrast against real values

Problems

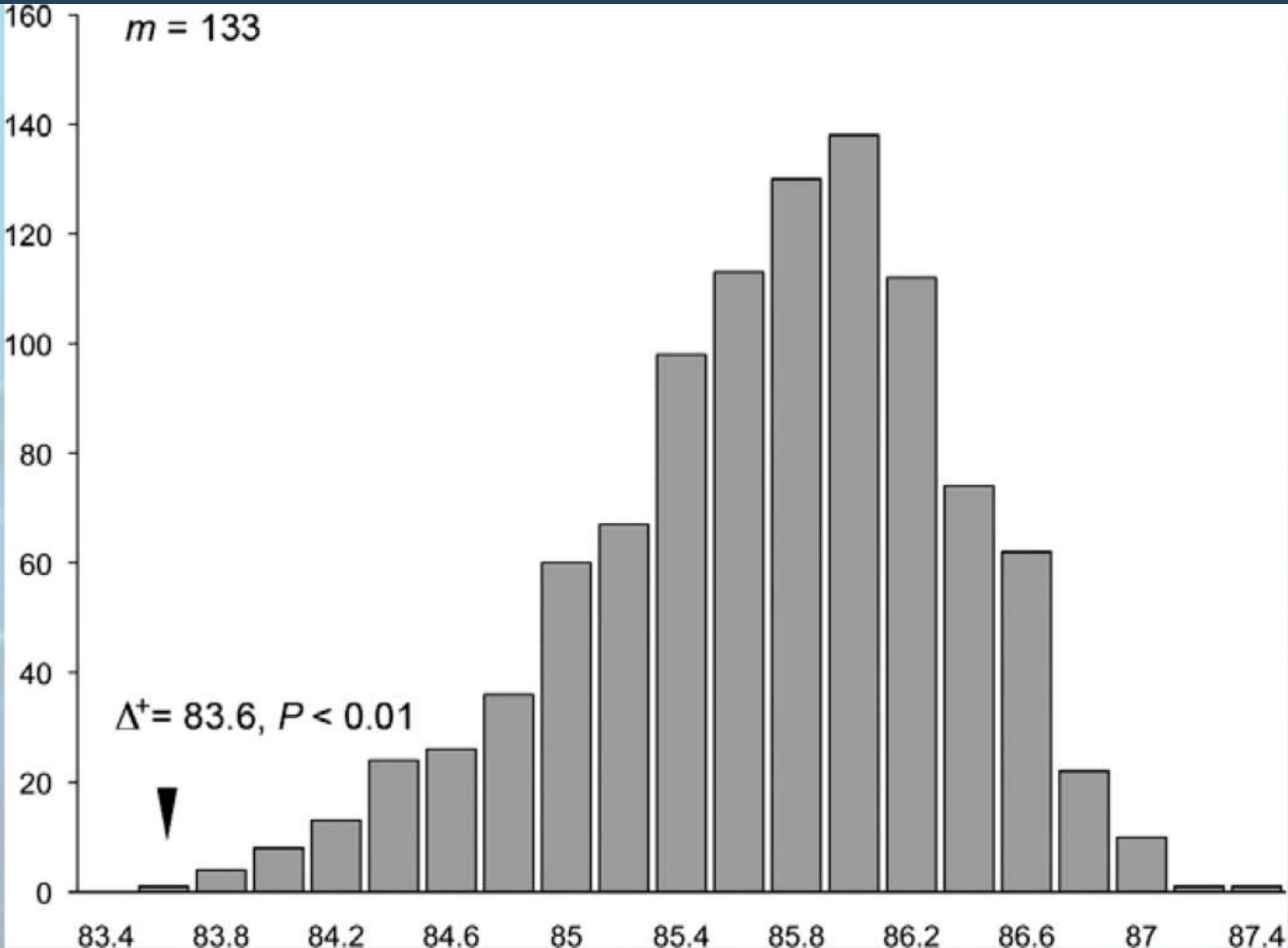


From Bevilacqua et al., 2012

The assemption is that natural disturbance causes only species replacement within taxa, so not cange the taxonomic structure. In constrast, human disturbance change the taxonomic structure. This could be not true in many cases.

Taxonomic structure of marine communites can be affected by natural changes or habitat features. Also, if disturbance in not selctive, or affect abundance of species, these indices coul have problems in detecting changes.

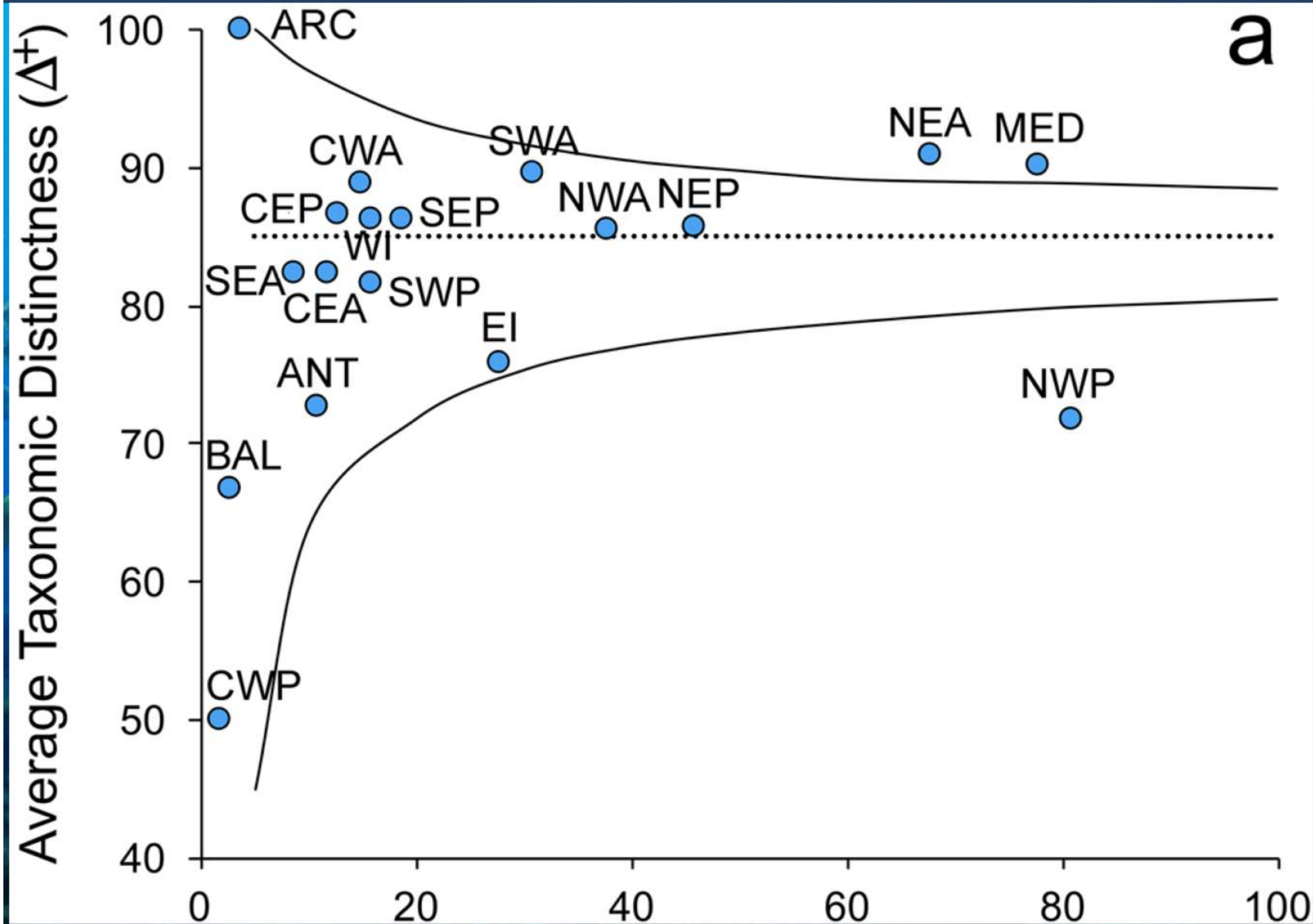
Reference list



The index and statistical tests rely on the reference list, which in turn could affect the results.

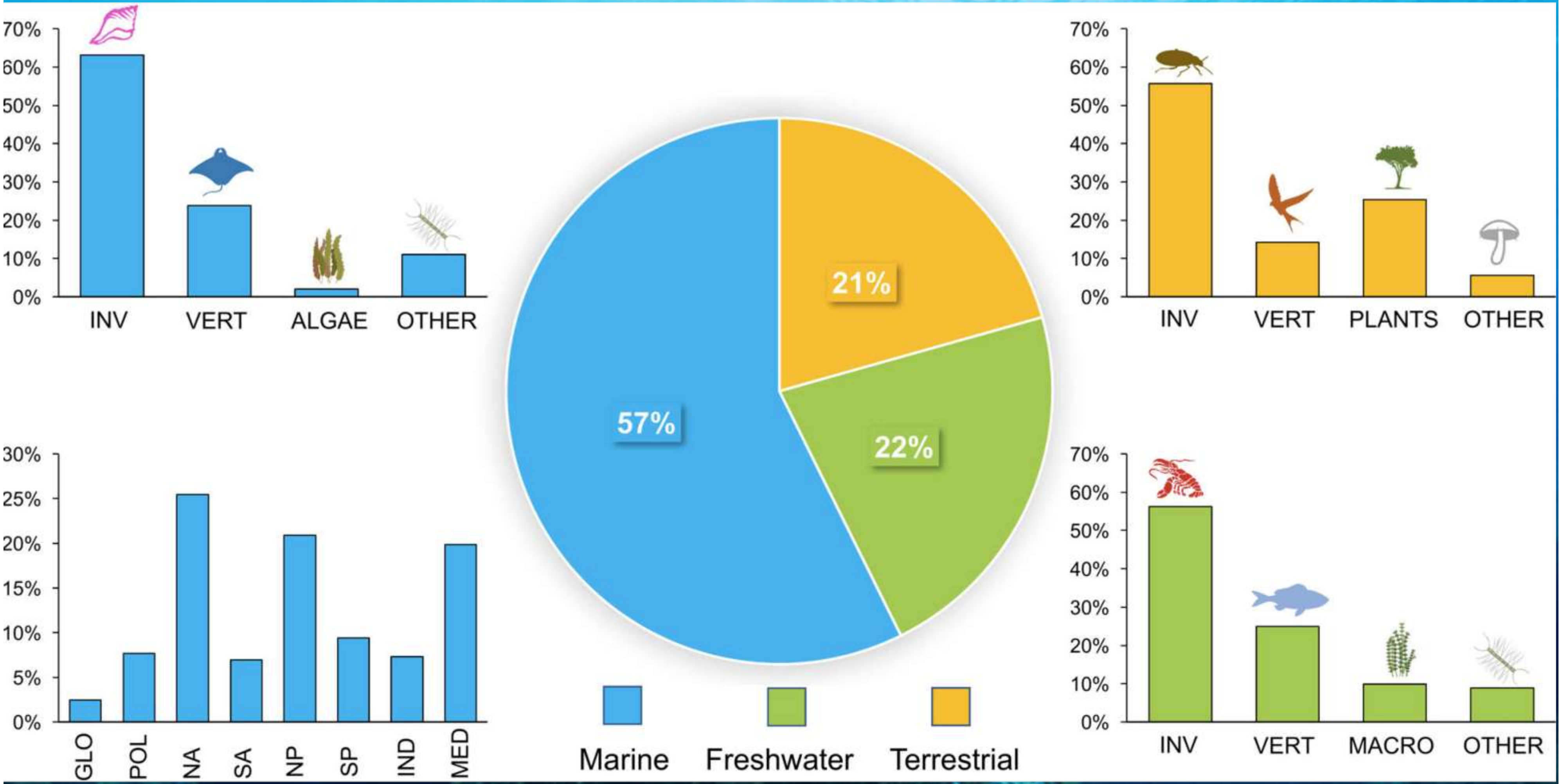
For example, if the taxonomic structure of the community depends on habitat features then a common list of species across habitats could confound the effects of impact with the effects of habitat. Also, if a given group of organism has different structure among different bioregions, the effect of disturbance can be confounded by these biogeographic differences. Reference list. Therefore should be carefully constructed, for example limiting the list of species to spatially coherent units.

Taxonomic diversity indices



Tedesco et al. 2020

Taxonomic diversity indices



Bevilacqua et al. 2021

Taxonomic diversity indices

Table 1. Summary of main fields of application of taxonomic distinctness indices from the scientific literature

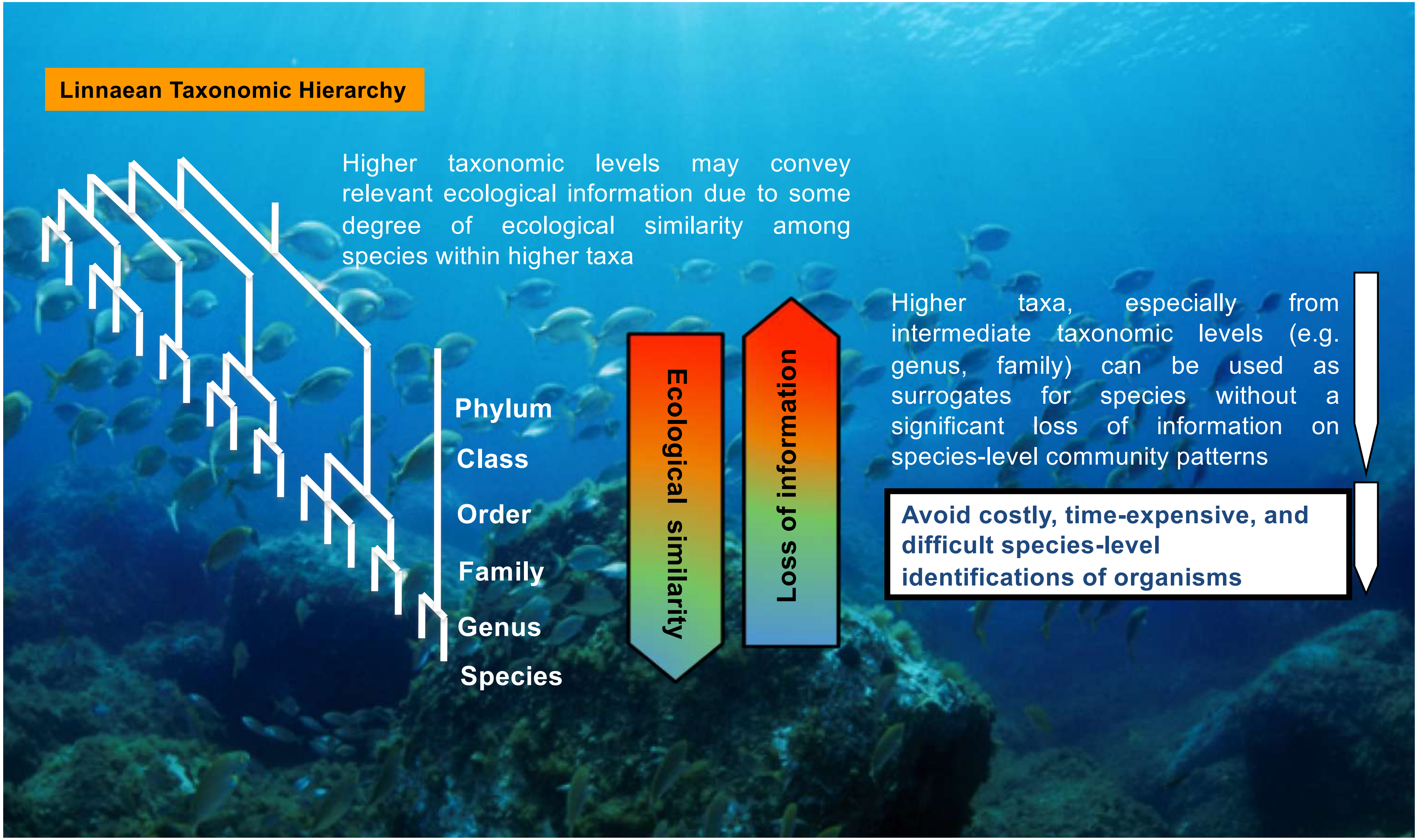
Environmental assessment and monitoring	
Local-scale human impacts (Somerfield *et al.* 1997)	Habitat-dependent changes in biodiversity (Diaz 2012)
Natural disturbance (Ronowicz *et al.* 2018)	Seasonal changes (Alvarez-Filip *et al.* 2006)
Indicators of ecological quality (Arvanitidis *et al.* 2005)	Historical changes in biodiversity (Gravili *et al.* 2015)
Effect of climate change (Rizvanovic *et al.* 2019)	Diversity patterns in fossil assemblages (Sun *et al.* 2020)
Effect of natural extreme events (Sathianandan *et al.* 2012)	Diversity patterns in death assemblages (Warwick & Light 2002)
Effectiveness of conservation measures (Stobart *et al.* 2009)	***Basic ecology***
Assessing restoration success (DeNicola & Stapleton 2016)	Ecological successions (Yang *et al.* 2016)
Correlating environmental and biological changes (Jiang *et al.* 2014)	Diet-specificity (Stringell *et al.* 2016)
Complementing other diversity indices (Barzoki *et al.* 2020)	Relationships among different aspects of biodiversity (von Eulen & Svesson 2001)
Effects of invasion/extinction (Floerl *et al.* 2009)	Effects of interspecific interactions (Griffin *et al.* 2013)
Biodiversity patterns	Biodiversity-productivity relationships (Conlan *et al.* 2015)
Local to regional patterns of biodiversity (Ellingsen *et al.* 2005)	Habitat specificity (Bevilacqua *et al.* 2009)
Spatial-temporal patterns (Barjau-Gonzalez *et al.* 2012)	Processes of community assembly (Martínez *et al.* 2019)
Biogeographic patterns of biodiversity (Price *et al.* 1999)	Parasite–host associations and diversity (Tedesco *et al.* 2020)
Gradients of biodiversity (Li *et al.* 2019)	***Methods in ecology***
Identifying biodiversity hotspots and endemism (Moir *et al.* 2009)	Effects of sampling procedures (Wang *et al.* 2019)
Global patterns of biodiversity (Fritz & Rahbek 2012)	Deriving further diversity indices (Somerfield *et al.* 2008)

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

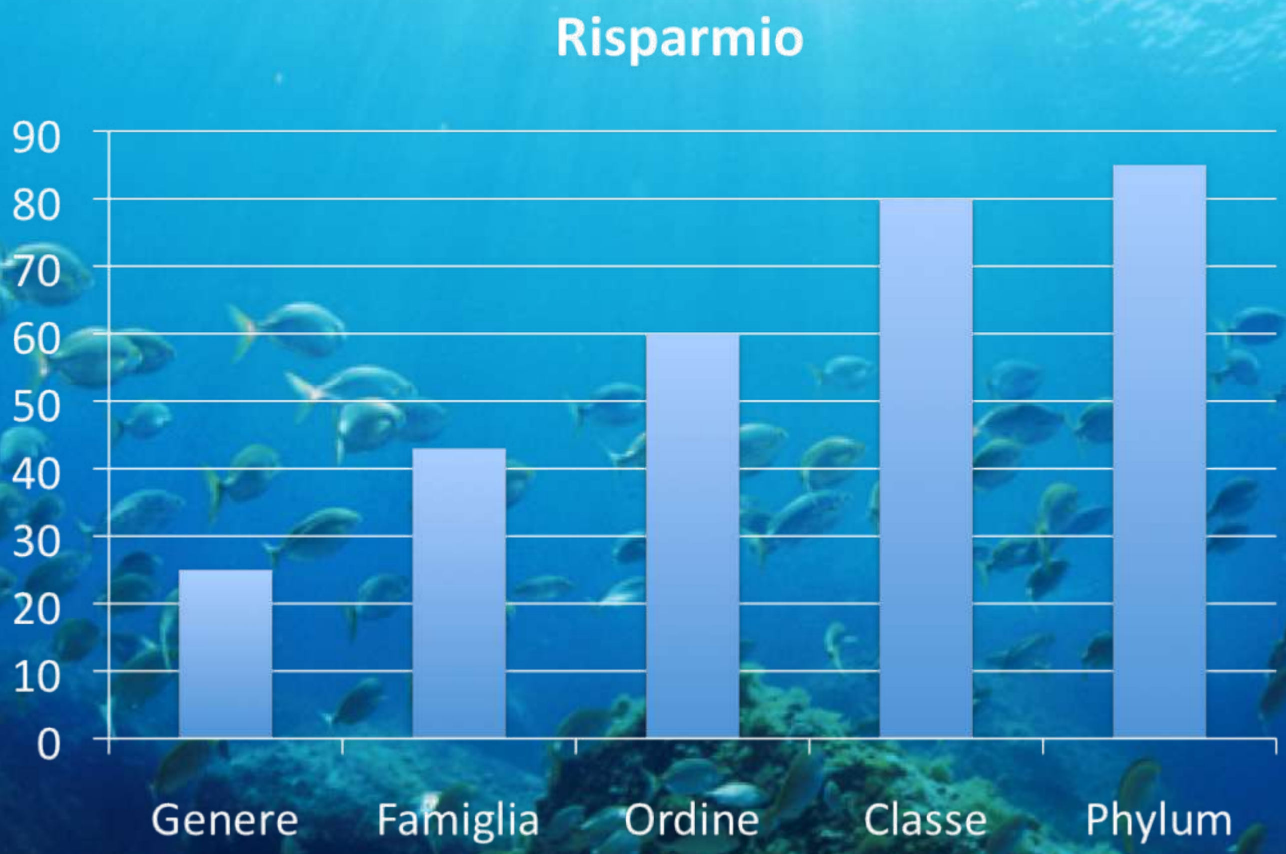
USING HIGHER TAXA AS SURROGATES FOR SPECIES



Convenienza

Convenienza

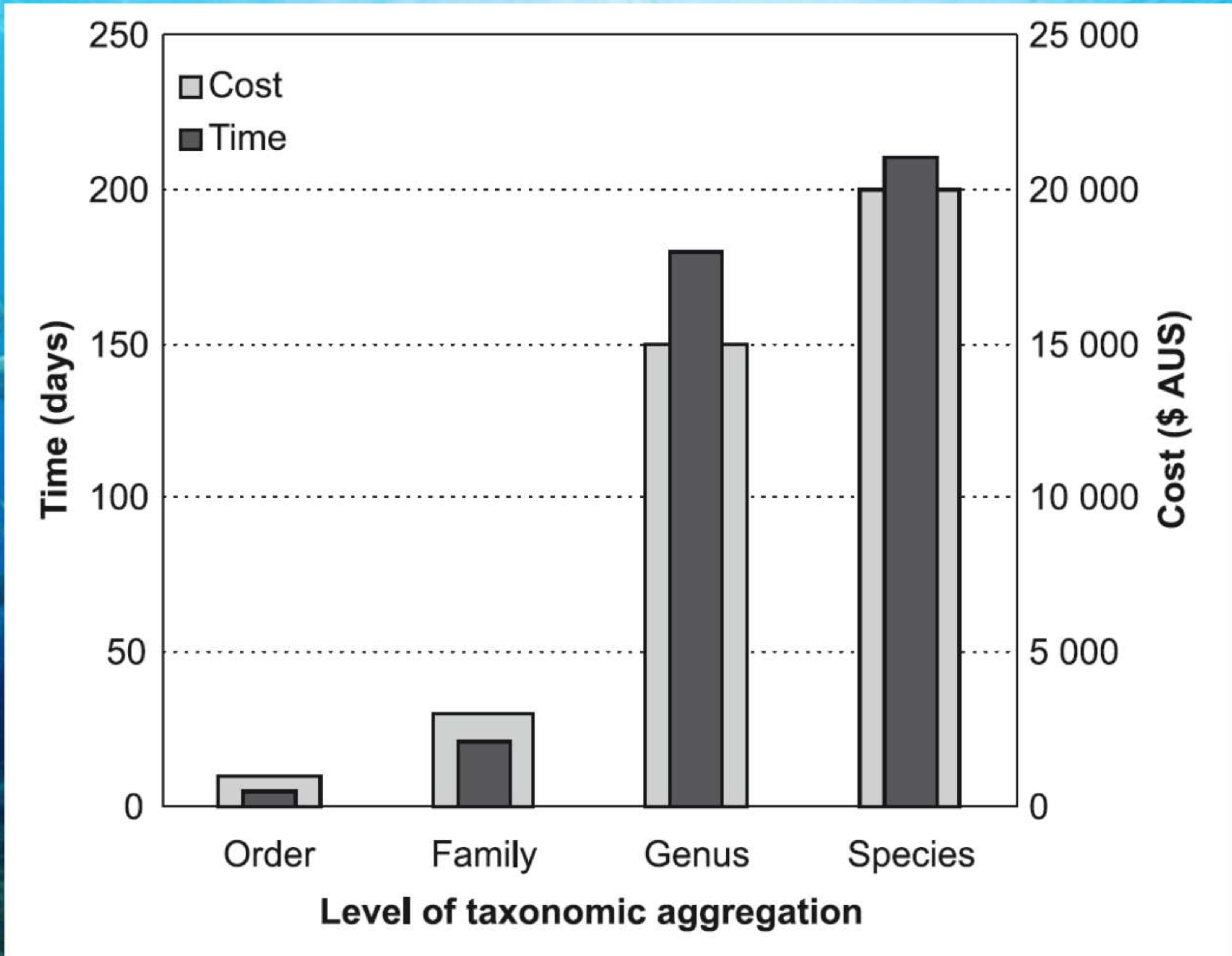
Investimento elevato in termini di tempo per identificare gli organismi a livello di specie



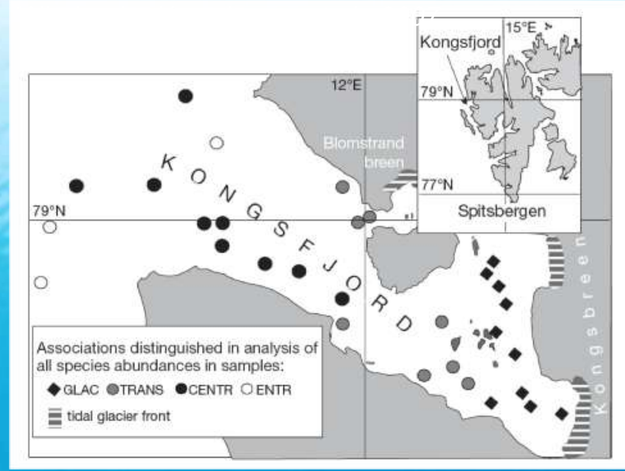
da *Ferraro & Cole, 1995 Env Tox Chem*
Thompson et al., 2003 Mar Pollut Bull
Lampadariou et al., 2005 Mar Pollut Bull

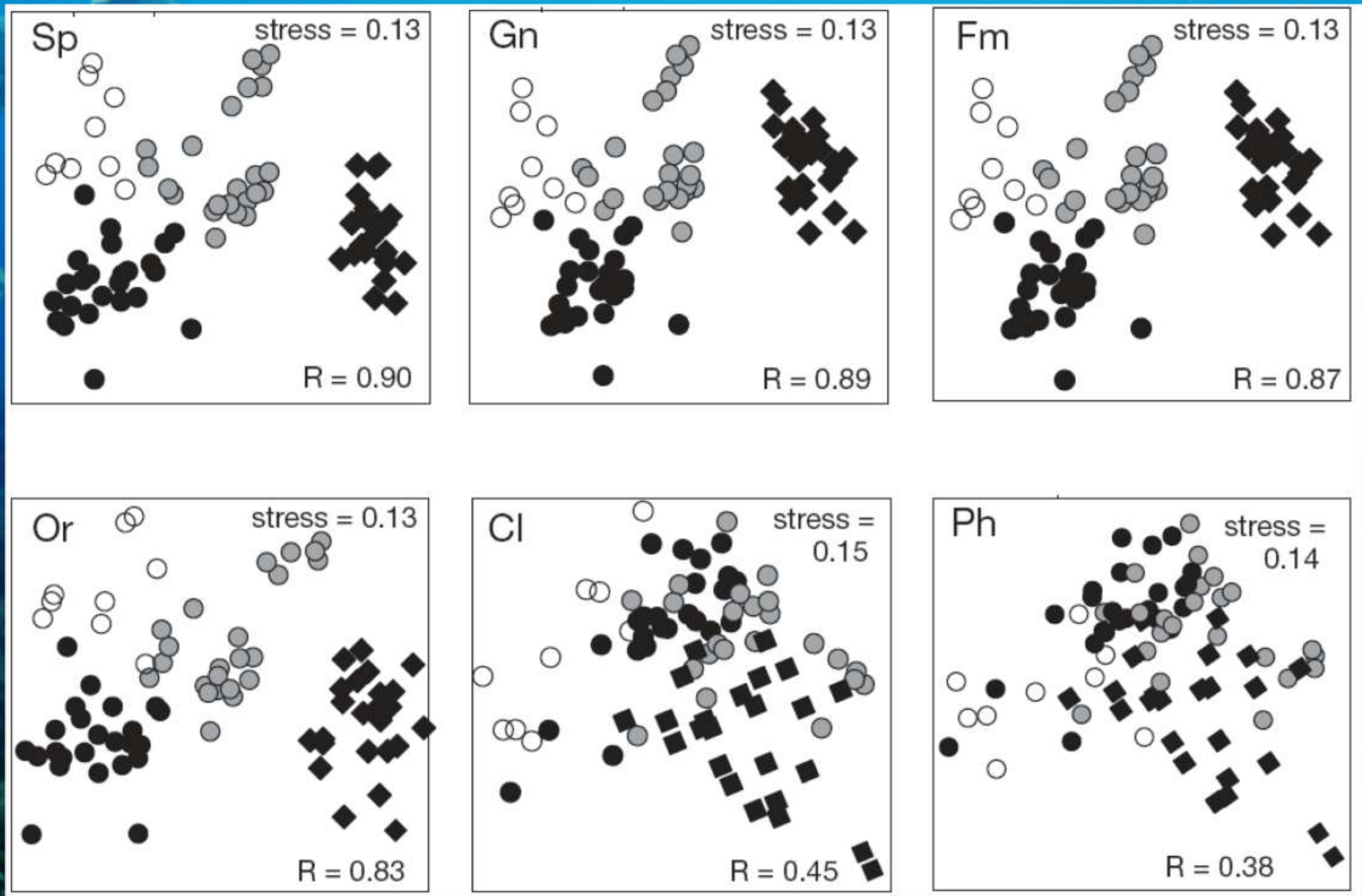
Più risorse per estendere il campionamento nello spazio e nel tempo

! Strettamente dipendente dalla preparazione tassonomica


Cost
Time
Time (days)
Cost ($ AUS)
250
200
150
100
50
0
25 000
20 000
15 000
10 000
5 000
0
Order
Family
Genus
Species
Level of taxonomic aggregation

Gradienti di disturbo naturale





Alta risoluzione tassonomica

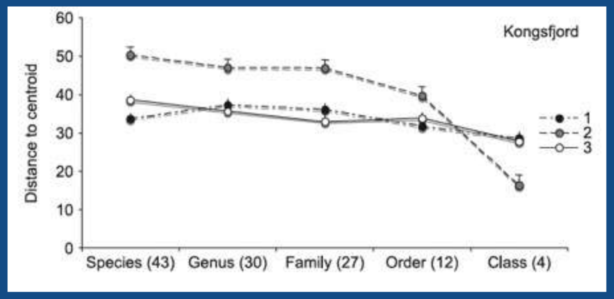
Alta informazione

Bassa risoluzione tassonomica

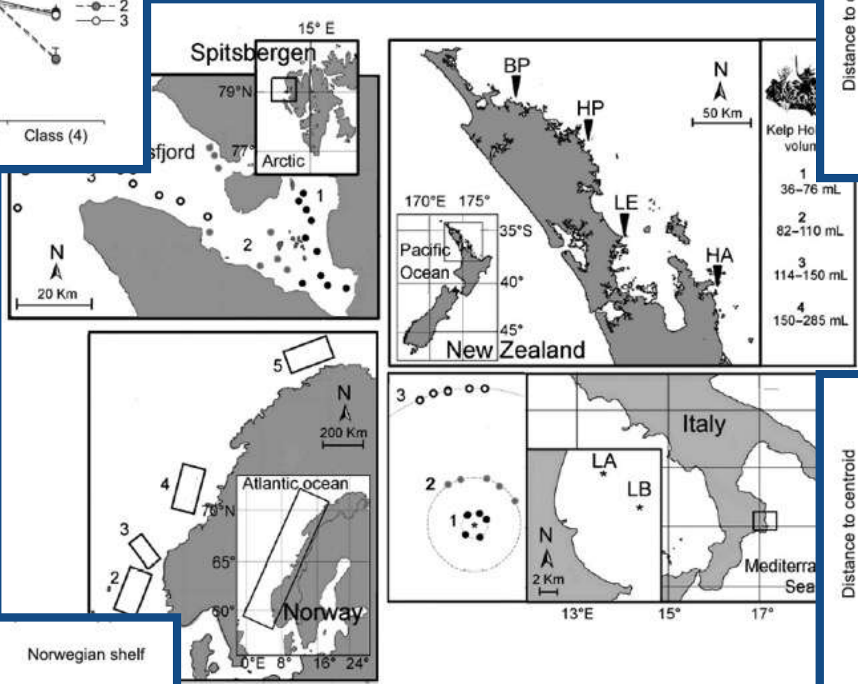
Bassa informazione

Beta-diversity

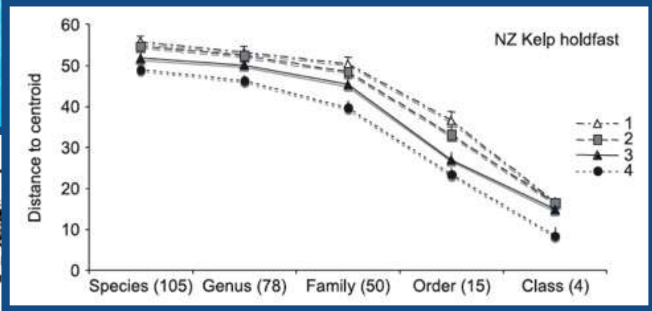
MOLLUSK ASSEMBLAGES



Glacial sedimentation gradient



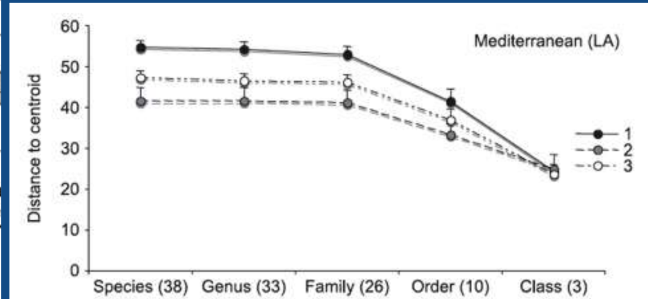
Terlizzi et al. 2009 Divers Distrib

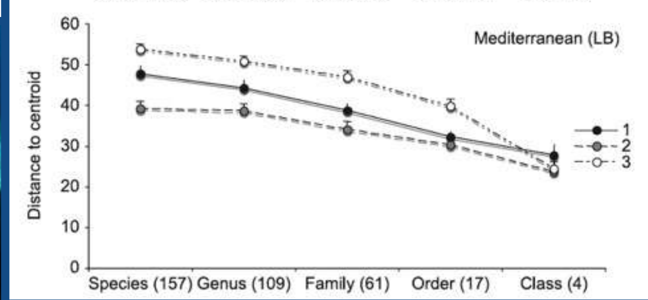


Kelp holdfast size

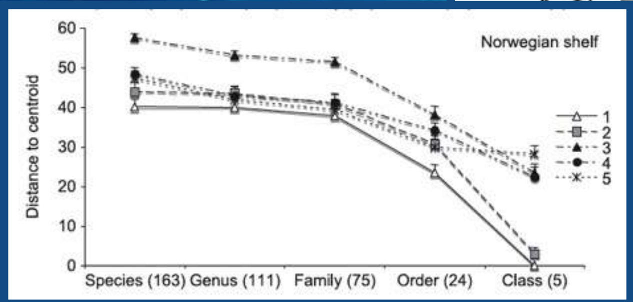
From Terlizzi et al., 2009

Distance from offshore platform

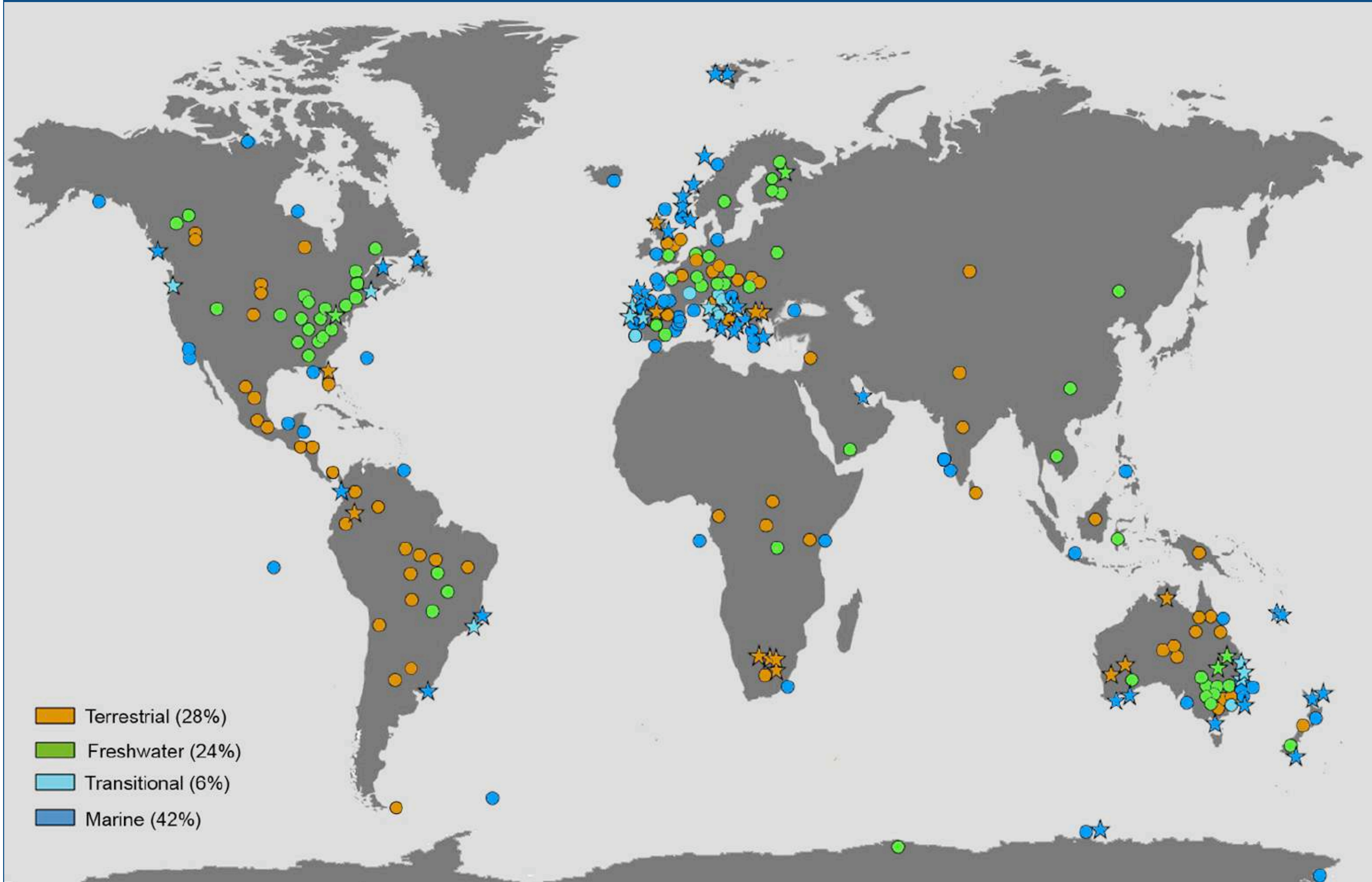




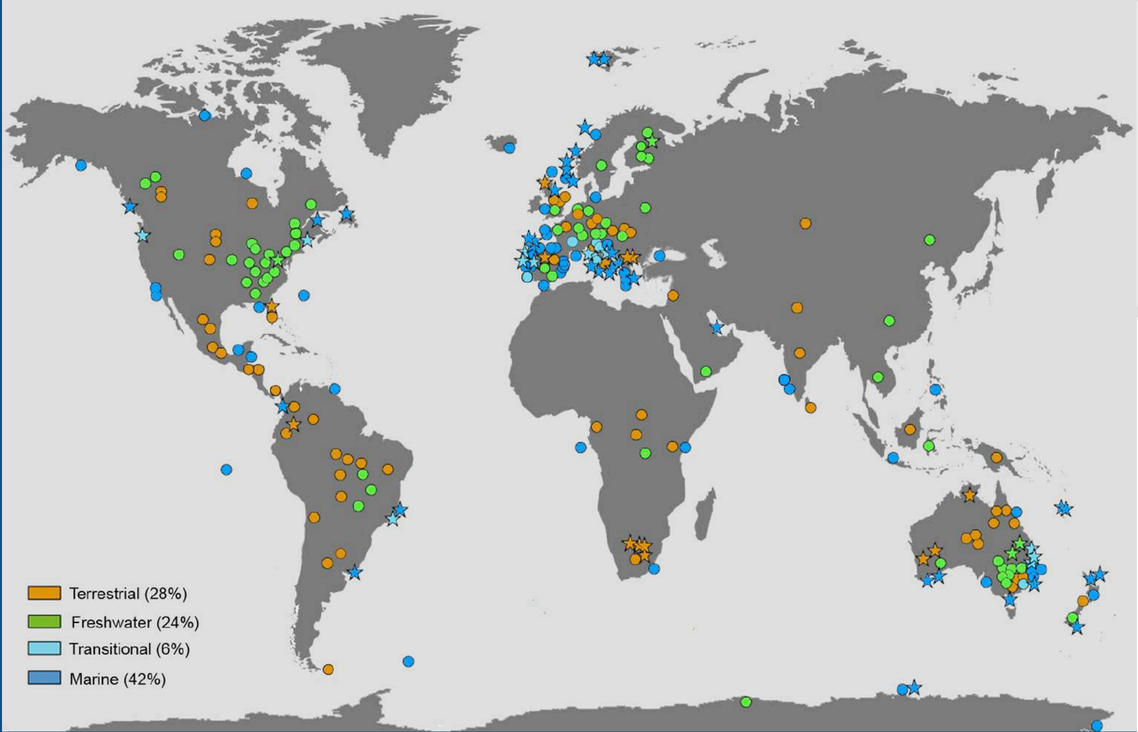
Latitudinal gradient



Species level beta-diversity patterns retained up to family level



Terrestrial (28%)
Freshwater (24%)
Transitional (6%)
Marine (42%)




Contents lists available at ScienceDirect

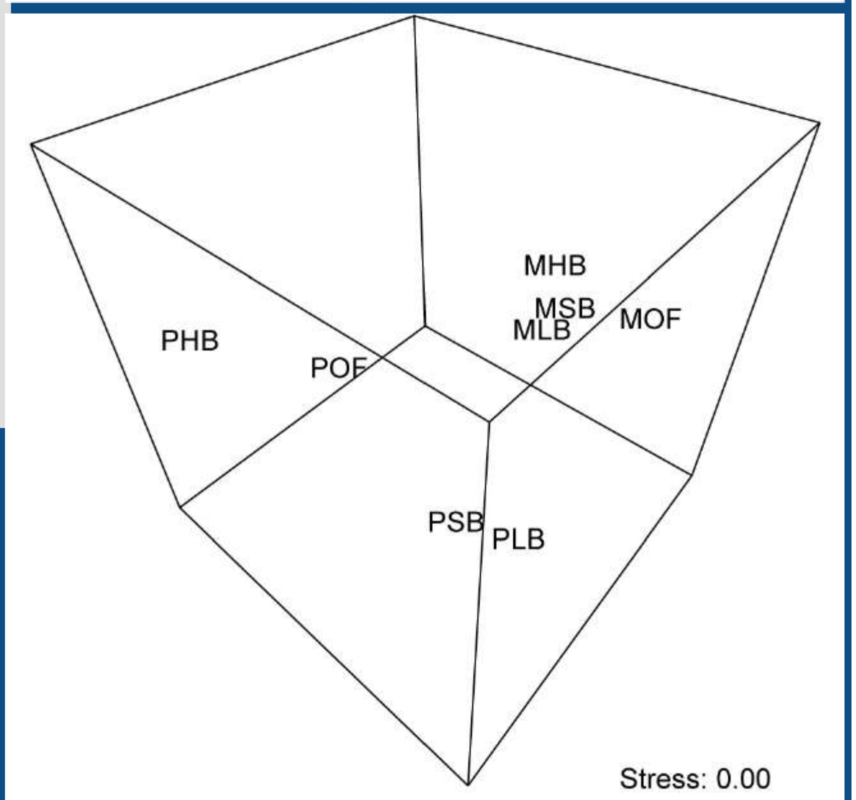
Marine Pollution Bulletin

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

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

Dipartimento di Scienze e Tecnologie Biologiche ed Ambientali, Università del Salento, Lecce, CoNISMa, I-73100 Lecce, Italy



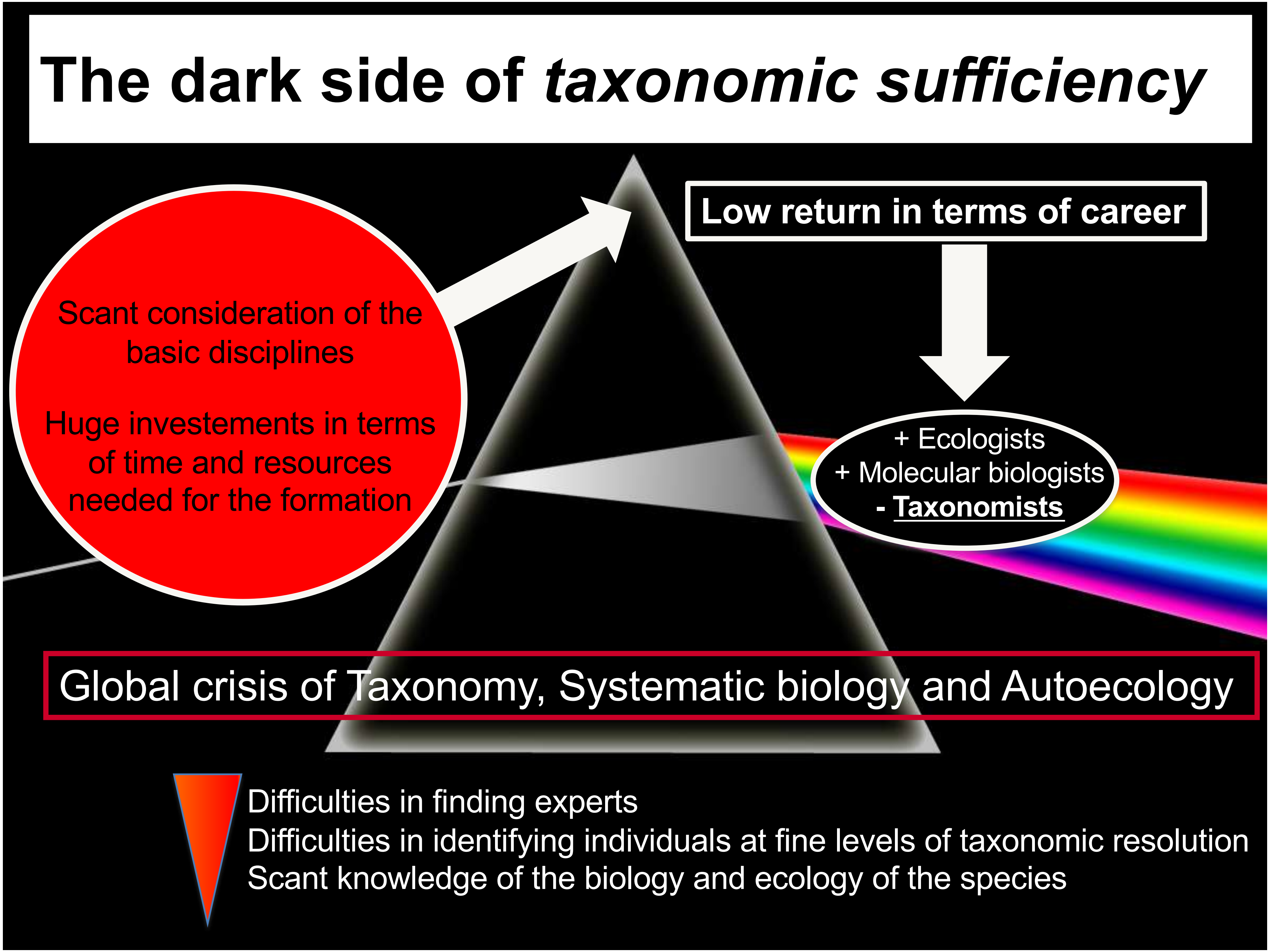
Lack of an ecological theory

Risk of loss of ecological information

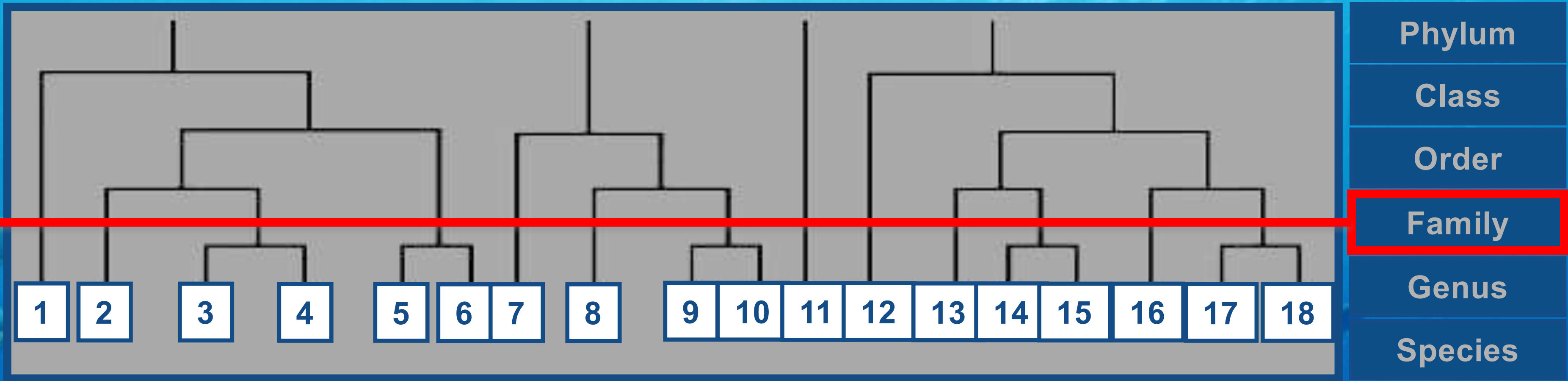
Potentially affected by taxonomic revisions

Performances changes among groups

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


The dark side of *taxonomic sufficiency*
Scant consideration of the basic disciplines
Huge investements in terms of time and resources needed for the formation
Low return in terms of career
+ 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

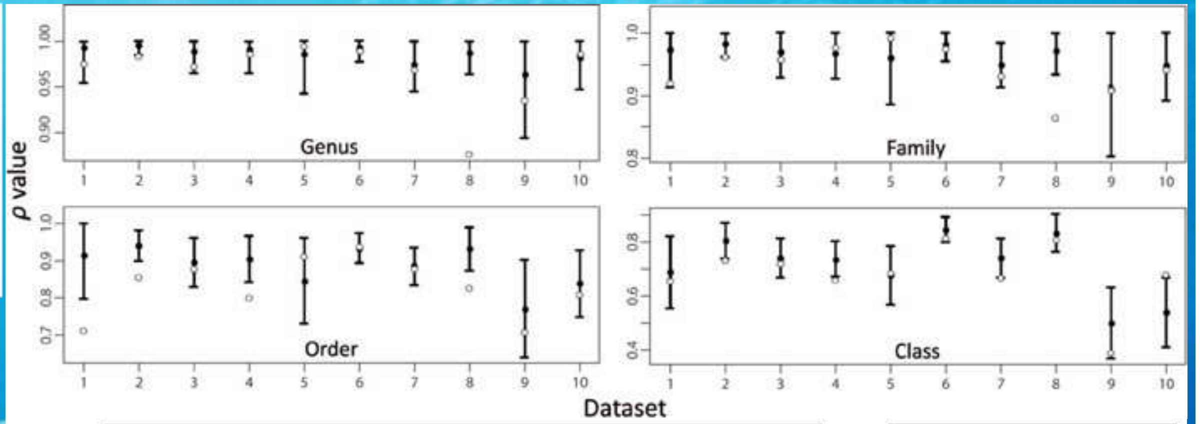
Taxonomic relatedness does not matter for species surrogacy in the assessment of community responses to environmental drivers

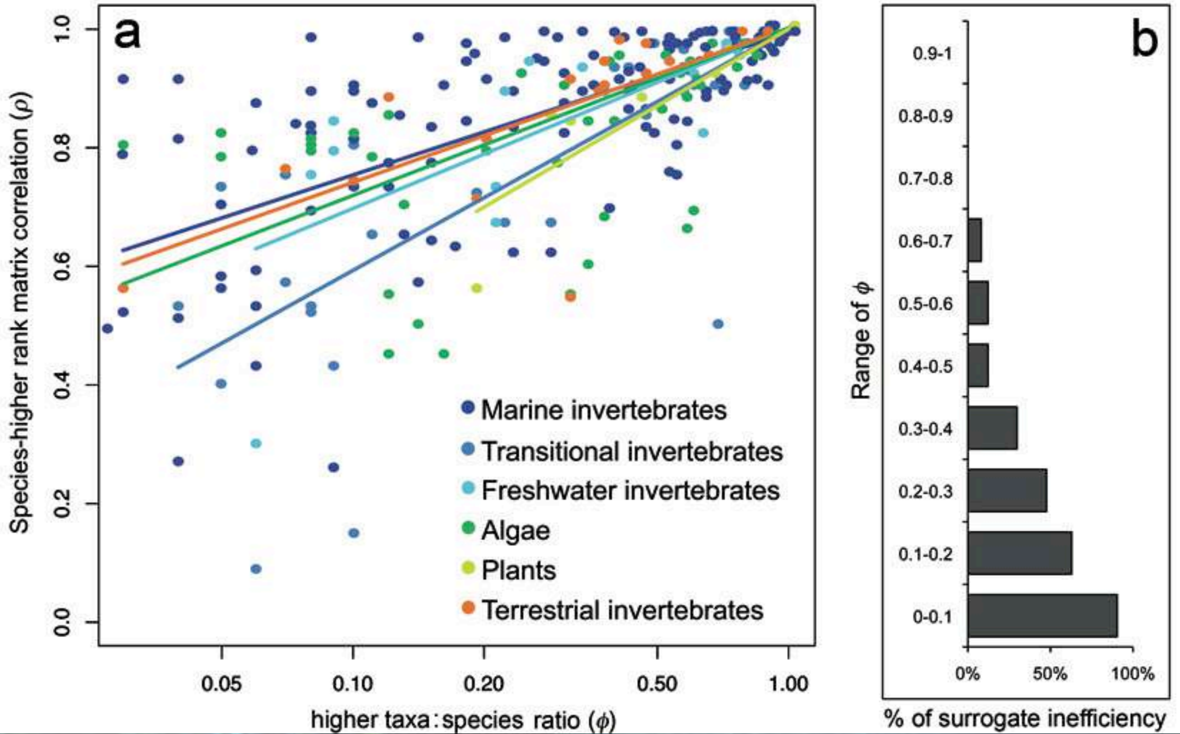
Stanislao Bevilacqua[1], Antonio Terlizzi[1*], Joachim Claudet[2,3], Simonetta Fraschetti[1] and Ferdinando Boero[1]

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



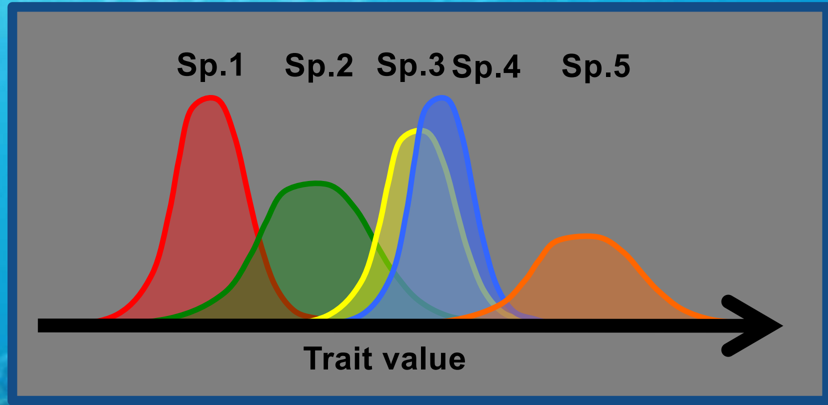


INTRATAXON ECOLOGICAL SIMILARITY?

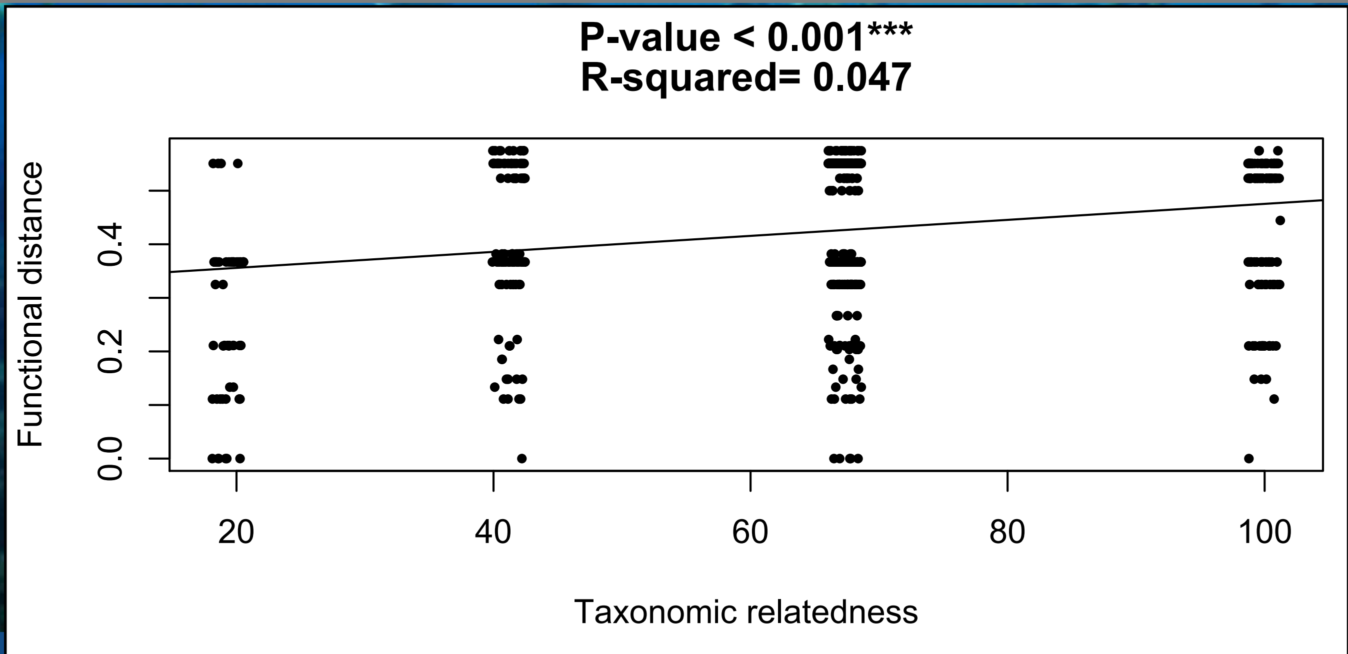
Phylogenetic/taxonomic relatedness often unrelated to ecological traits

Similarity not necessarily extends to the whole functional trait spectrum

Similarity not necessarily concerns functional traits involved in the response



NEUTRAL RESPONSE



Contents lists available at ScienceDirect

Biological Conservation

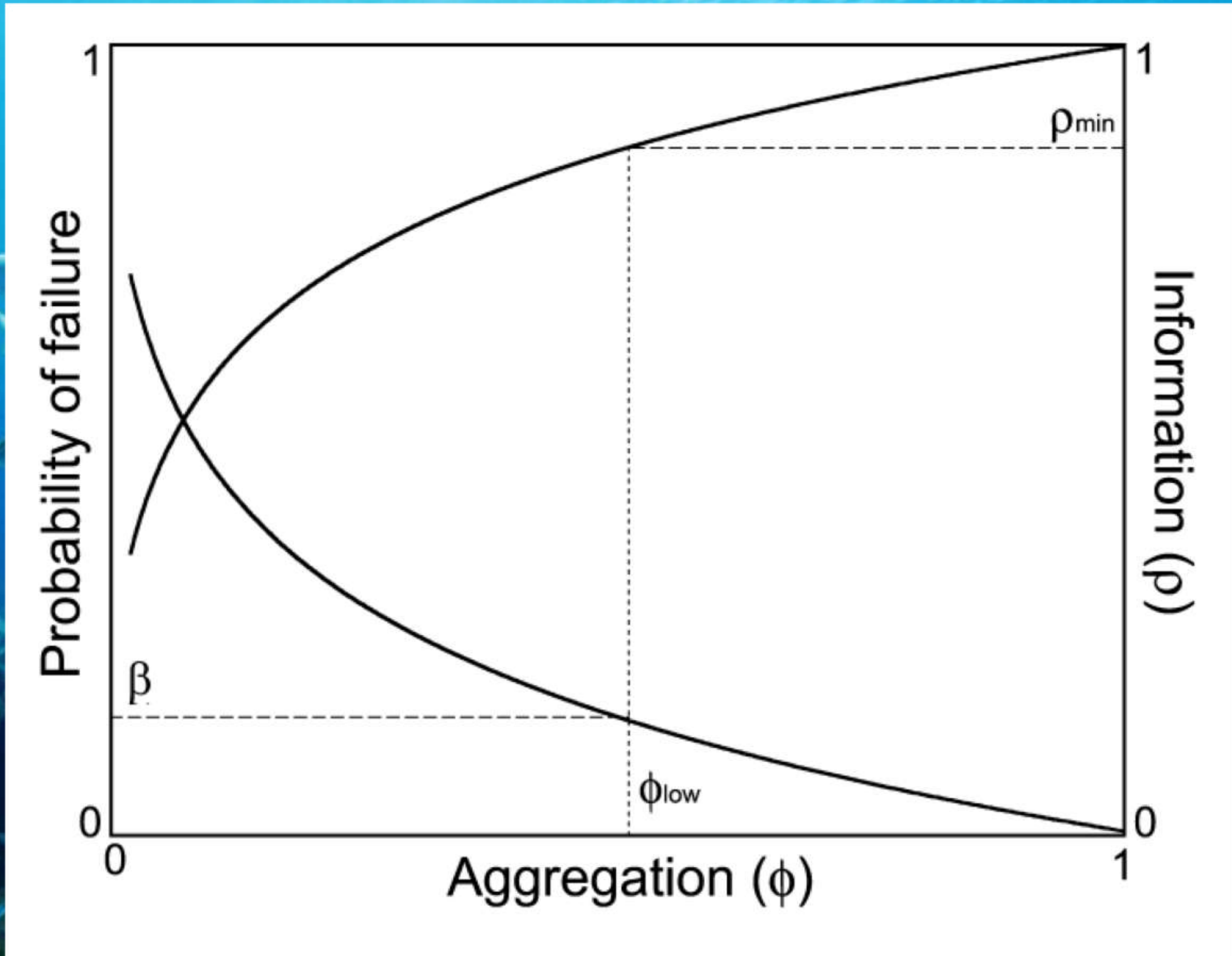
journal homepage: www.elsevier.com/locate/biocon

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

Lauric Thiault[a,b,*], Stanislao Bevilacqua[c], Antonio Terlizzi[c], Joachim Claudet[a,b]

[a] National Center for Scientific Research, CRIOBE, USR 3278 CNRS-EPHE-UPVD, 66860 Perpignan, France
[b] Laboratoire d'Excellence CORAIL, France
[c] Laboratory of Zoology and Marine Biology, Department of Biological and Environmental Sciences and Technologies, University of Salento, 73100 Lecce, Italy

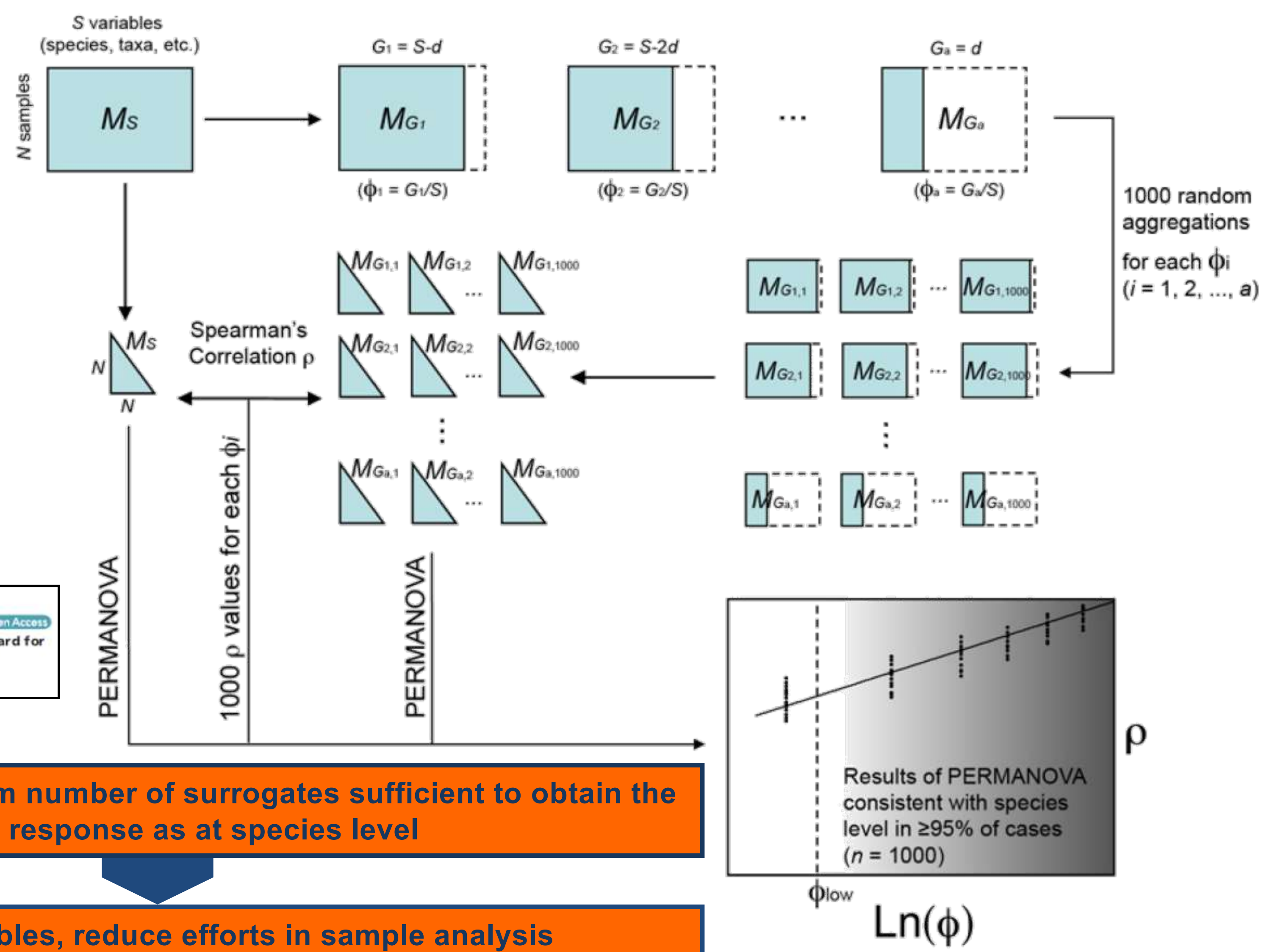
…OR THE EFFECT OF VARIABLE AGGREGATION?



THE BESTAGG APPROACH

1

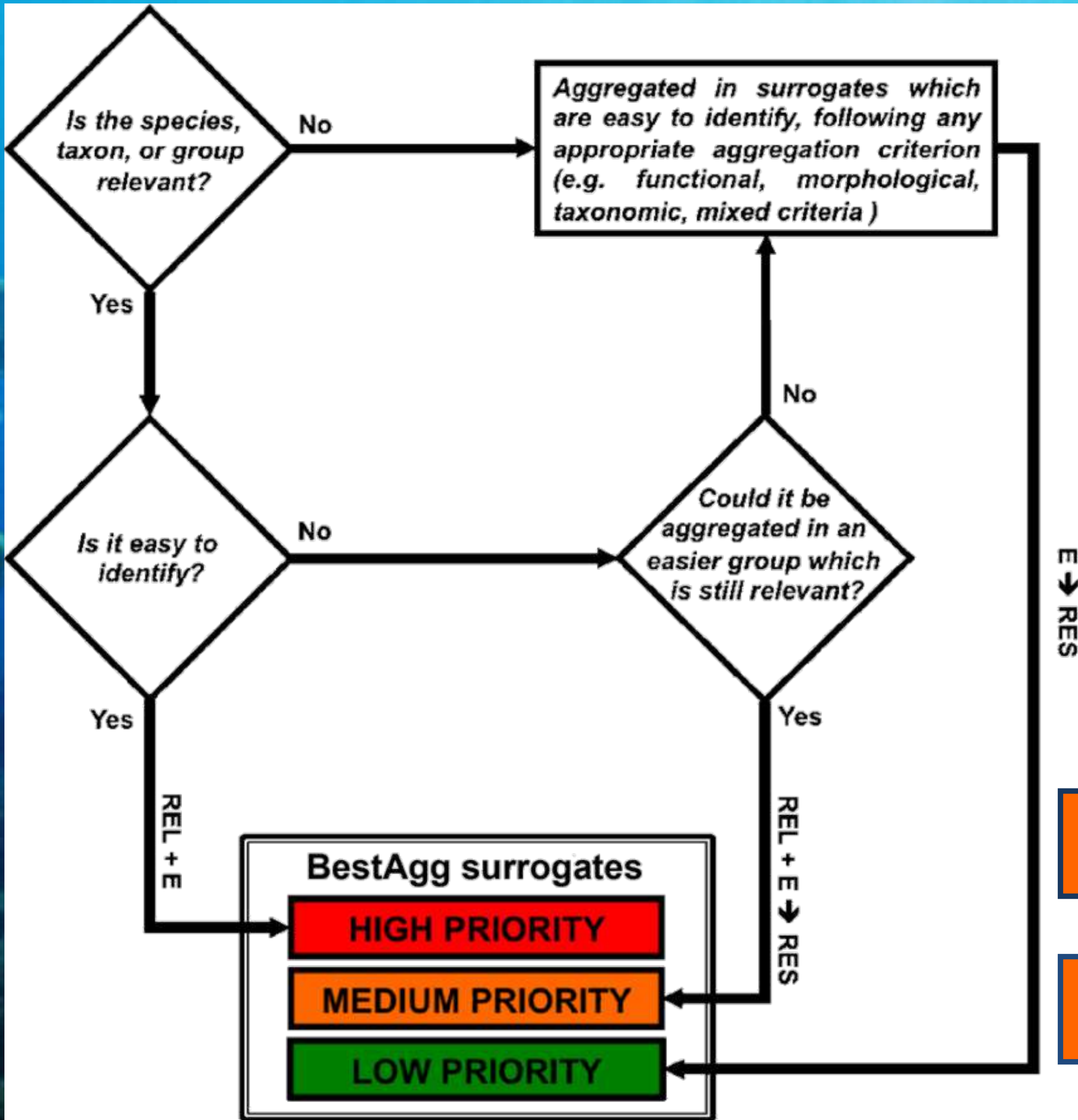

Ecology and Evolution
Open Access
Best Practicable Aggregation of Species: a step forward for species surrogacy in environmental assessment and monitoring
Stanislao Bevilacqua[1], Joachim Claudet[2,3] & Antonio Terlizzi[1]



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



Relevance
(ecological importance)

Easiness
(low difficulty of taxonomic identification)

Resemblance
(shared characteristics among organisms)

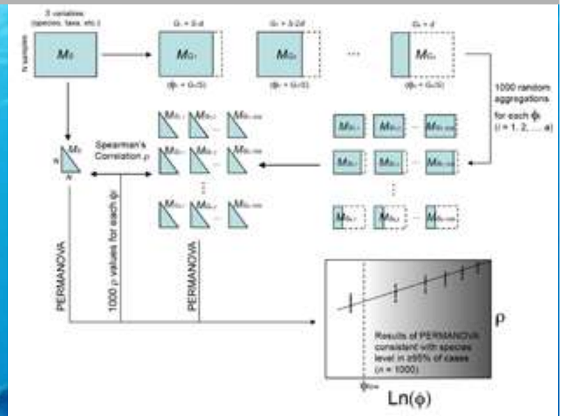
2

Identifying surrogates types based on relevance, easiness, and resemblance

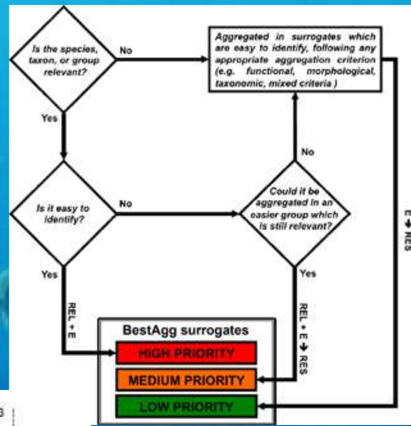
Minimize difficulties of identifications and maximize ecological information

THE BESTAGG APPROACH

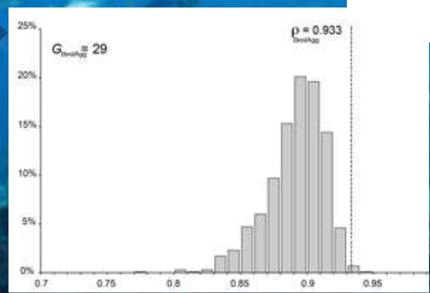
Identifying the highest level of aggregation based on null models of random assembly of species variables



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



Validating surrogate selection using randomization tests



Controlling for uncertainty in applications

Obtaining the minimum set of surrogates irrespective of aggregation criterion

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

THE BEST PRACTICABLE AGGREGATION OF SPECIES

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

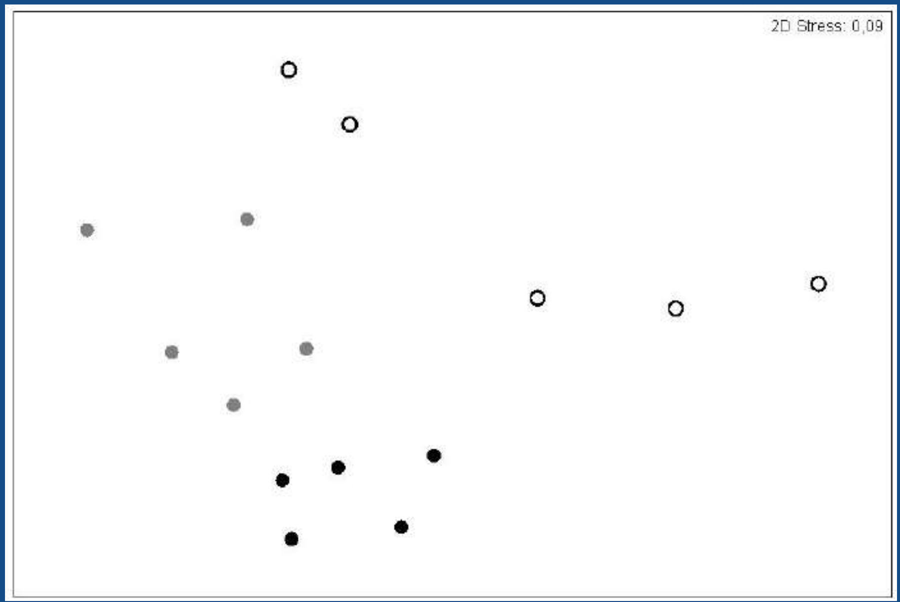
Unleash the investigator from static surrogacy schemes strictly relying on taxonomic relatedness

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

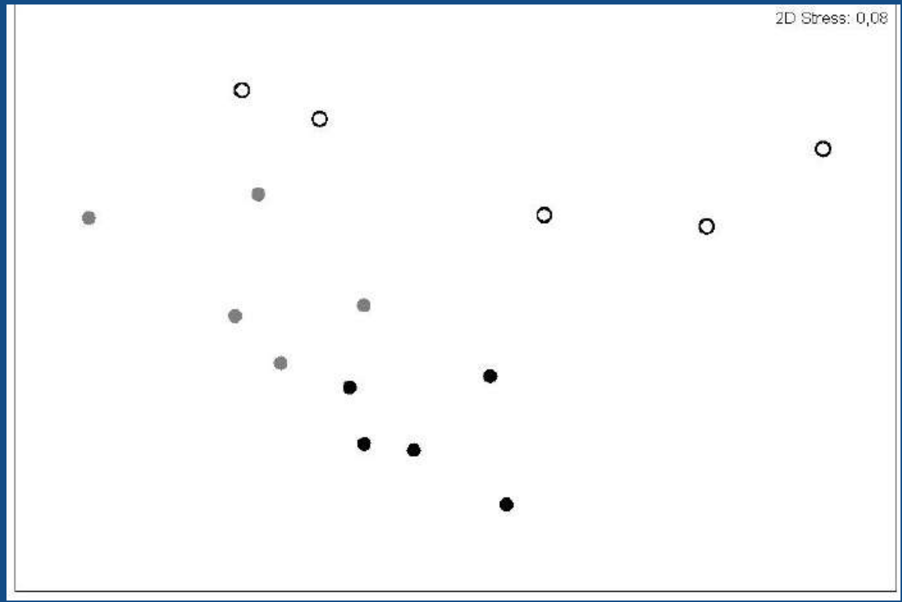
Lead to ecologically meaningful surrogates that, while cost effective in reflecting community patterns, may also contribute to unveil underlying processes

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

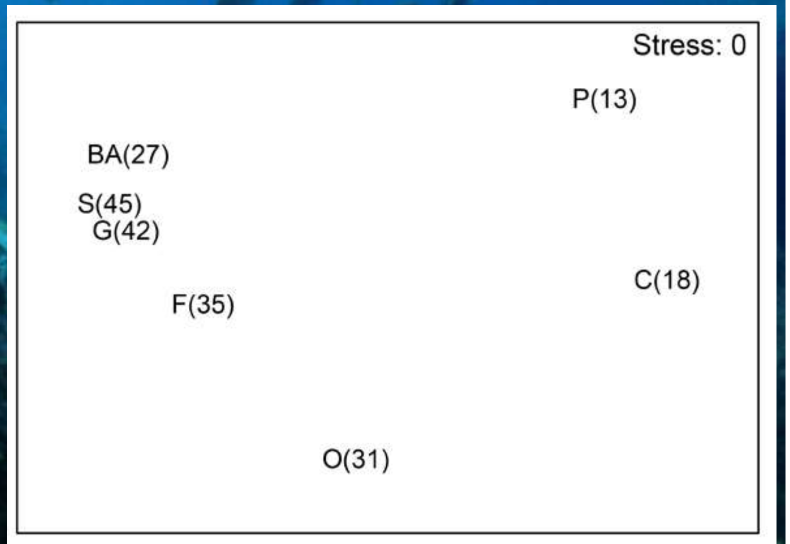
Freshwater invertebrates
Continental river basin
River gradient
Variables' reduction: 88%
Relative savings: 45%

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



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