AQUATIC CONSERVATION: MARINE AND FRESHWATER ECOSYSTEMS

Aquatic Conserv: Mar. Freshw. Ecosyst. **13**: 451–459 (2003)

Published online in Wiley InterScience
(www.interscience.wiley.com). DOI: 10.1002/aqc.584

VIEWPOINT

Biodiversity, conservation, and the 'Taxonomic impediment'

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ABSTRACT

1. This paper highlights the poor esteem in which taxonomy, as autonomous science, is held and the relative implications of this for conservation biology.

2. In recent times, taxonomy at the species level has tended to be neglected not just within ecological researches, but also in the identification and justification for the selection of the marine protected areas (MPA). A traditional criterion for choosing an MPA is the conservation of biodiversity, but most of the Italian MPA were chosen without initial detailed studies on their biodiversity, so that lists of species of the main invertebrate groups are not available.

3. The identification of organisms within communities to species level is one of the greatest constraints in terms of time and costs in ecological studies. Some studies have suggested that working at a taxonomic level higher than species does not result in an important loss of information (Taxonomic sufficiency). It does, however, lead to an inaccuracy of biodiversity evaluation which is, especially important when comparing different areas, and can lead to an '*a priori*' exclusion of some entities before understanding their role in ecology.

4. Taxonomy has always been considered a marginal science even during the pioneer descriptive period of ecology, and traditionally has received little financial support. The result was the production of many misidentifications and erroneous records. During recent years, the developing experimental ecological approach has led to an improvement in scientific methods, but concurrently to a reduction in the number of expert taxonomists for many invertebrate groups. Descriptive works, historically so common in the Mediterranean area, are now considered obsolete, despite having an intrinsic value.

5. Biodiversity, particularly 'species richness' has long been thought to influence temporal variability and it seems that efforts to clarify the biodiversity/temporal variability relationship or to demonstrate the lack of such a relationship should continue. Such information is essential in order to maintain the ecological function despite the loss of component species, an important topic not only to ecologists but also to policy makers. Many species appear to have overlapping niches, and as such it could be argued that it is not essential for all species to be present. In contrast the crucial role of keystone species has been embraced in conservation biology as a tool to help highlight species requiring priority for protection.

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Received 16 January 2002
Accepted 24 January 2003

6. Present knowledge of marine systems has led to the conclusion that, before developing theories and experimental design, we need an appropriate description of the system under investigation. A basic knowledge of the general biodiversity in term of species richness of a proposed MPA for example is essential, with a detailed survey providing the taxonomic lists necessary for biotope characterization and a reference data set for future comparisons.

KEY WORDS: taxonomy; biodiversity; species richness; monitoring; experimental ecology; descriptive ecology; conservation

INTRODUCTION

The aim of biological conservation is to understand and control human impact on the natural world, preventing habitat destruction with consequent species extinctions. The World Conservation Strategy in 1980 proposed that the main goal of protection was to maintain essential ecological processes and life support systems on which human survival depends, preserving genetic diversity, and finally, ensuring sustainable utilization of species and ecosystems (New, 1995).

Marine protected areas (MPA) are increasingly being used to protect marine resources and biodiversity, to optimize management, and to allow recovery of degraded areas. The basic information needed in designing, implementing and maintaining MPA are: (a) where and how to establish them; (b) how to regulate and manage them; (c) how to monitor the efficiency of the protection provided.

A traditional criterion for choosing an MPA may be the high biodiversity of an area, with the overall aim of its long-term conservation. Biodiversity 'hotspots' might be important source areas, for example, for the surrounding populations, a principle well documented for fish populations, and applied also in benthic ecology (Gaines and Roughgarden, 1985). Paradoxically, however, most of the Italian MPA were designated without a prior comprehensive survey of their biodiversity, with the consequent lack of any definitive lists of invertebrate species present in these areas. In part at least, this is due to the low scientific esteem in which such descriptive works are held.

At present, more and more research is stressing the need to document natural assemblages as a basis for the conservation and sustainability of natural systems (New, 1995). In this context, taxonomy should represent the core reference system and knowledge base for any discussion of biodiversity: the framework within which biodiversity is recognized and species diversity characterization occurs (Bisby, 1995).

There is a profound role for Systematics as the basis for functional ecology; this is not only through the conventional task of naming species, but also focusing on the importance of the taxonomic structure, which creates ecosystem function (Cousins, 1994). Differences between organisms are at the core of ecosystem interactions, and the task of Systematics is to describe and relate these differences between organisms. The general impression is, however, that nowadays taxonomy at the species level tends to be neglected within ecological works, especially in monitoring programmes, but also in conservation biology.

TAXONOMY AND BIODIVERSITY

Nowadays, there is a broad consensus of the need to protect biodiversity, even though it is less clear what this means in policy and practical terms. Biodiversity can be considered at the ecosystem, species, and/or genetic levels. A discussion on these different approaches is found in Heywood (1994), who also underlined the difficulty of measuring taxonomic diversity and its application to conservation.

Systematic conservation evaluation depends on the basic information about the number of taxa present in a given area, their distribution and their taxonomic relationships. The existence of reliable taxonomic and systematic survey data is of fundamental importance (Vane-Wright *et al*., 1994), together with well-maintained collections and catalogues (Nielsen and West, 1994; Stork, 1994).

The traditional focus of developing local, regional and global inventories for most groups has been at the level of species. Compiling lists of species is the common thread that links the formal catalogue of life's diversity to all studies of natural assemblages. However, the existing species record is deficient in several respects (Hammond, 1992), since the majority of species are still undescribed, or inaccurately described, although it is more complete for some groups and for some biomes than others. On the basis of extrapolations, it has been suggested that there may be 10 million or more marine macrofaunal species (Grassle and Maciolek, 1992), but despite the growing importance given to biodiversity in the last few years, we remain far from being able to produce biodiversity maps (Gaston and Spicer, 1998).

One of the most important questions in conservation is the choice of the target organisms and their relative taxonomic rank. Our knowledge of the taxonomy of most of the indicative invertebrate groups is so scanty that they cannot be used for detailed systematic evaluation. For this reason, well-known groups both taxonomically and geographically, are chosen as surrogates for the whole biodiversity (Vane-Wright *et al*., 1994).

According to Boero (1996), the main problem with biodiversity is with reference to particular poorly known groups. Some phyla are more or less completely neglected as they are of no economic importance or applied research value. Taxonomic expertise is restricted to a few, often, elderly workers, with no younger taxonomists being trained to take their place.

As a consequence, taxonomic specialists are lacking and many invertebrate organisms remain undescribed and do not even have scientific names. This situation is unlikely to be overcome without a massive renaissance in descriptive taxonomy and increase in the taxonomic workforce.

The progressive decrease in the number of taxonomists for a large number of invertebrate groups is a widespread phenomenon, particularly evident throughout Europe, despite the past tradition in this research field. By contrast, in the USA, this problem led The National Science Foundation (NSF) to enhance and stimulate taxonomic research to train and inspire future generations of morphological taxonomists. Competitively reviewed research projects that targeted poorly known groups, were supported by the Partnerships for Enhancing Expertise in Taxonomy (PEET). Unfortunately, despite these efforts, the benefits have been limited to only a few groups included in the project, in particular those for which American experts were lacking. Without a reversal in the current European trend, it is probable that in 20 years students of taxonomy will have to study in the USA (Boero, 2001).

During the last 20 years, the trend towards an experimental ecological approach in marine science has led to the decline in marine invertebrate taxonomists. The Mediterranean marine flora and fauna, for instance, are among the best described in the world, thanks to the tradition of descriptive studies dating back to the renaissance time (Bianchi and Morri, 2000). Descriptive ecological studies so common in the past also are now declining.

Taxonomy has always been considered as a marginal science, however, sitting within other more applied disciplines and without financial support directly devoted to it, so that most of the past taxonomists were not full Systematists. The bulk of scientists identifying polychaetes, for instance, were benthic ecologists doing identification work strictly for need! They could be considered 'parataxonomists', many carrying out high-level identifications, resulting in either inadequate or mis-identifications with all the related problems.

Distribution of taxonomic expertise is also highly uneven, both among taxa, where many large groups of invertebrates have very few specialists, and geographically, with the greatest concentrations of taxonomic expertise in temperate regions of the world (New, 1995). Most countries have rather poor inventories of their flora and fauna, and the pattern of growth in our knowledge often does not reflect the real distribution of biodiversity. While it is well known that most of the species occurs in the tropics, most insect species per unit area are described from temperate regions rather than from tropical ones (Gaston, 1994).

Therefore, although the most commonly used unit of biological diversity is the species, the number of people able to identify to this taxonomic level is becoming smaller, and the richness of several groups remain considerably underestimated. This difficulty in identifying organisms gave rise to a parataxonomy movement called 'Taxonomic sufficiency,' firstly proposed for practical use in monitoring studies (Ellis, 1985), and later became a philosophy also in conservation biology, with the use of the high taxon-richness as a surrogate for species richness (Faith, 1994; Balmford *et al*., 1996a, b; Vanderklift *et al.,* 1998). There is evidence, however, for an incorrect estimation of biodiversity following this approach, especially when comparing different areas on account of the loss of information due to the intertaxa variability. The same rank (e.g. genus or family) may be more-or-less appropriate as a descriptor in different groups, according to its intrinsic richness (Balmford *et al.,* 2000), moreover, some surrogates could be descriptive for some geographical areas, but not for others. The main criticism in utilizing taxonomic richness as a surrogate for biodiversity lies, however, in the different value that the same rank may have between groups. As an example, a recent analysis of mollusc and polychaete diversity, in the South Adriatic Sea, revealed a higher diversity of molluscs than polychaetes, at the family level, whilst when examined at the species level, polychaetes were more diverse than molluscs! (Terlizzi *et al*., 2003; Giangrande *et al*., submitted.) Only the use of the finest level of classification, e.g. the 'species' (LITU *sensu* Pleijel and Rouse, 2000) ensures a consistently comparable estimate of diversity.

BIODIVERSITY, MONITORING AND ECOLOGY

In the assessment of coastal environmental quality, the abundance, biomass and species richness of zoobenthos are widely utilized parameters (Eaton, 2001), especially in monitoring studies within marine soft-bottom environments (Clarke, 1993). As already mentioned, in these monitoring and environmental impact studies the identification of organisms at species level within communities appeared to be the greatest constraint in terms of both time and costs, and the use of a reliable reduced taxonomic resolution was an important improvement in the practical assessment of environmental changes. Some studies have shown that little information is lost by working at a taxonomic level higher than species (e.g. family or even phylum), and there are theoretical reasons and empirical evidence for supposing that community responses to human perturbations may be easily detected working at such high taxonomic levels (Warwick, 1988; Warwick and Clarke, 1995; Olsgard and Somerfield, 1998; Olsgard *et al.,* 1998; Mistri and Rossi, 2000; Olsgard and Somerfield, 2000; Mistri and Rossi, 2001).

The increase, during the last 20 years, in the number and complexity of field experiments towards the optimization of experimental design, analysis and interpretation of complex data, has contributed to the better determination of environmental impacts on habitats varying naturally in space and time (Underwood, 1993, 1996; Chapman *et al*., 1995). Recently it was suggested to utilize these procedures to assess the scale of variation in ecological diversity studies, and, in the field of conservation biology for the implementation and management of marine reserves (Underwood, 2000), as well as a tool to test their effectiveness (Fraschetti *et al.,* 2002).

Developing a correct experimental design involves a great number of replicates in space and time. The application of such experimental designs, considering taxa at the species level, becomes difficult especially within sublittoral rocky bottom environments. Monitoring is often carried out considering only macroscopic encrusting organisms, and involving non-destructive sampling of permanently marked quadrats or transects resurveyed visually or photographically (Fraschetti *et al.,* 2001). This implies that biodiversity can be measured by the examination of only macroscopic organisms ignoring small and/or inconspicuous species.

Many rocky shores, however, are characterized by an extremely diverse assemblage of small cryptic invertebrates (Kelaher *et al.,* 2001), whose response to changes in environmental conditions are largely unknown (Moore, 1972). The difficulties of reliable quantitative sampling and comparison between different substrates makes these vagile invertebrates unsuitable as indicator species in any monitoring programme. By contrast, vagile invertebrates have been shown to be good descriptors of cascade effects in rocky areas subjected to resource exploitation or protection (Chemello *et al*., 1999; Pinnegar *et al*., 2000; Licciano *et al*., 2002).

Ignoring small, vagile invertebrates in benthic ecological studies means that we exclude some species without even understanding their role. Within 400 cm^2 of rocky substrate, more than 2000 individuals belonging to more than 100 species of polychaetes may be found! (Giangrande, 1988). What is the significance of the high diversity observed in such a group of invertebrates on rocky shores? To what extent are many of the species found 'redundant'? This is not a new question (Hutchinson, 1959). Boero (1996) hypothesized that species richness could represent a sort of intrinsic capacity for the community to respond to temporal changes, but it is far from certain that this is the only or definitive answer.

The idea that similar species may overlap in their functional properties to a sufficient degree so that the loss of certain species may have a negligible effect on ecosystem function has been expressed in the redundancy hypothesis (Walker, 1992), functional compensation *sensu* Menge *et al*. (1986, 1994). This effect may be larger when many species are present in the same functional group. So species diversity is functionally important, providing insurance against changes in ecosystem processes. It is possible, therefore that the degree of ecological redundancy may be indicative of the sensitivity of the community to changes (Mistri *et al*., 2002). However, Underwood (1996) critically discussed the existence of a taxonomic redundancy in marine habitats. The apparent functional redundancy is not in accordance with the experimental evidence suggesting the existence of important specific roles for most of the components of the assemblage. The crucial role of keystone species has often lead to them receiving greater weighting within an assemblage in conservation biology when highlighting species for priority protection (Mills *et al.,* 1993; Underwood, 2000; Piraino *et al.,* 2002).

Schoener (1993) has pointed out the importance of indirect effects between species, different from the classic keystone concept. Lawton and Jones (1995) have identified organisms that modulate the resource availability to other species (i.e. ecosystem engineers or interaction modifiers; Wootton, 1993). Studies focused on the influence of nutrient cycling on the dynamic properties within food chains have begun to show the relationship between biodiversity and ecosystem functioning (De Angelis, 1992; Grover, 1994; Loreau, 1995). Ecosystem productivity seems to be positively correlated to biodiversity: Tilman *et al*. (1996) and Hooper and Vitousek (1998) found that within plant communities limiting resources were more completely exploited when the biodiversity was higher. This was also evident as a result of indirect mutualism among species in a multispecific context (Wootton, 1993).

Lastly, species richness has long been thought to influence temporal variability patterns in communities. The idea that communities with many interacting species fluctuate less than communities with fewer species has led to a large amount of literature (Goodman, 1975; Pimm, 1984; Haydon, 1994). Empirical studies tended to support the complexity–stability hypothesis, whereas theoretical ones indicated that a model with more interacting species was less stable than a model with fewer interacting species (May, 1974). Interest in complexity–stability relationships declined during the 1980s, in part due to difficulties in defining the concepts of complexity and stability (Hollings, 1973; Connell and Sousa, 1983). Recently, however, ecologists have renewed their interest in the effect of biodiversity on ecosystem processes including stability and a wide range of other ecosystem functions (Chapin *et al.,* 1995; Johnson *et al*., 1996; Chapin *et al*., 2000; McCann, 2000). However, it seems that the effort to clarify the nature of the relationship between biodiversity and ecosystem functioning, should continue (Cottingham *et al*., 2001). This information is essential in increasing our ability to maintain the continuity of ecological function despite the loss of component species, a topic that is important not only for ecologists but also for policy makers.

CONCLUSIONS

Biodiversity is the product of a long history of evolution, speciation and extinction in a complex and changing geographical/ecological theatre. Patterns of biodiversity are the product of evolutionary diversification interacting with local ecological processes, which are influenced by intrinsic characteristics of organisms, and by landscape and seascape structure (Wilson, 1993). The maintenance of diversity in natural and managed ecosystems depends on our understanding of these processes and the mechanisms producing diversity, and allowing its accumulation over evolutionary time.

Conservation management depends on knowledge of the biology and dynamics of the species and systems involved. Systematics and evolutionary studies could provide valuable knowledge about the origins and patterns of life, essential when planning conservation and the sustainable exploitation of natural resources.

At present, however, it seems that the major problems are in understanding what biodiversity is and in defining the best descriptor for it. The dichotomy between Ecology and Systematics is reflected in the different interpretations of diversity suggesting different conservation strategies (Cousins, 1994). Ecologists regard species diversity as an index of the richness of a particular area, and explain the functioning of the ecosystem on the basis of the complexity of the interactions of the different component species. Systematists take a genealogical view, and concentrate their efforts in trying to explain how the species within a particular taxon are related. Obviously the two topics are inter-related, but often ecologists and systematists work independently (Brooks and McLennan, 1991).

Different approaches to taxonomic diversity can therefore be taken for management and monitoring purposes, from the simple measure of species richness, to taxonomic and phylogenetic diversity through to the functional diversity. Emphasis has been given to the use of taxonomic and phylogenetic diversity in conservation options (Bisby, 1995). Increased biodiversity due to species linked by co-evolutionary processes could be the component that probably more than others may represent the backbone of the community. In this case species richness and species rarity could be less important in ecosystem functioning. However, Boero (1996) suggested that some of today's rare species, which often are considered as ecologically insignificant or irrelevant noise, could become key species of the future.

A serious limitation on all measures of species diversity is our inability to survey and identify all organisms at any site due to the lack of good taxonomists: only a few taxonomic groups are sufficiently known for complete field surveys. This 'taxonomic impediment' as coined by Taylor (1983) represents the main problem in the survey of the biodiversity of an area. The current situation is unlikely to be overcome without a massive renaissance in descriptive taxonomy and increase in the taxonomic workforce. By contrast, applied ecology is considered to not require taxonomy; zoology and botany are disappearing from university curricula and conservation biologists are drawn from other professions such as engineers or architects! (Boero, 2001).

Despite the importance of good experimental design in marine conservation (Castilla, 2000), a basic inventory of the biodiversity of an area proposed for protection is essential, with the production of taxonomic lists for the characterization of the different biotopes inside the area and also for the production of a data set for future comparison. Before developing theories and experimental designs, we need an adequate description of the system that is to be investigated. Underwood (1996) advocated the intrinsic value of descriptive work, and was critical of many journals' reluctance to publish purely descriptive studies.

At present, most of the investment is towards the development of analytical methods to create sophisticated computational methods to identify 'sets of nature reserves' that represent regional diversity. The successful application of these methods, however, is compromised by the poor data quality available on species distributions, and by the choice of using surrogates as a measure for biodiversity (Cabeza and Moilanen, 2001).

In conclusion, even though taxonomic sufficiency can simplify methods in monitoring approaches, its employment in understanding biodiversity patterns can lead to the wrong conclusions being reached, so that it is not applicable to understanding ecosystem function, and the effectiveness of conservation measures.

ACKNOWLEDGEMENTS

Financial support by M.U.R.S.T (PRIN). I wish to thank Dr Greg Rouse (South Australian Museum) for our useful discussion on the topic.

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