Available online at www.sciencedirect.com
SCIENCE DIRECT®
PERGAMON
Marine Pollution Bulletin 46 (2003) 556–561
MARINE POLLUTION BULLETIN
www.elsevier.com/locate/marpolbul

Focus

Taxonomic sufficiency and the increasing insufficiency of taxonomic expertise

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

Dipartimento di Scienze e Tecnologie Biologiche e Ambientali, Università di Lecce, CoNISMa, 73100 Lecce, Italy

Abstract

Taxonomic sufficiency (TS) involves the identification of taxa only to a level of taxonomic resolution sufficient to permit the detection of changes in stressed assemblages. Recently, however, TS has been proposed also for conservation issues as a tool to estimate biodiversity over large areas and in poorly known environments. This paper briefly reviews the use of TS in environmental impact studies and the effects of TS on sampling procedures and data analyses. The risk of possible loss of information depending on TS and the studied environment are discussed. Concluding remarks deal with the dangers of loss of taxonomic expertise in marine biological studies and assess critically the proposal of TS as a tool to describe biodiversity at a taxonomic level higher than species.
© 2003 Elsevier Science Ltd. All rights reserved.

Keywords: Taxonomic sufficiency; Taxonomy; Environmental impact assessment; Biological conservation

1. Taxonomic sufficiency: a comfortable shortcut

Taxonomic sufficiency (TS) (Ellis, 1985) is the identification of taxa to taxonomic levels higher than species without significant loss of information in detecting changes in assemblages exposed to environmental stress. TS, thus, is an expedient to estimate the effects of perturbation on community structure, reducing costs associated with precise taxonomic analyses while allowing more resources for spatial and temporal replication of experiments (Williams and Gaston, 1994; Balmford et al., 1996a).

The need of TS, furthermore, stems from the widespread demise of taxonomy (Boero, 2001): even groups that are widely used in environmental impact studies (e.g. nematodes, Bongers and Ferris, 1999) are far from being taxonomically well known. Moreover, the knowledge of the species diversity of many habitats (e.g. deep sea) is inadequate. TS, thus, should allow impact studies also in poorly known environments by considering taxonomically difficult groups (Beattie and Oliver, 1994).

Some evidence is available that species diversity can be appreciated by the richness of taxa higher than species (Gaston and Williams, 1993; Roy et al., 1996). Accordingly, low taxonomic resolution has been proposed not only to detect community stress but also to estimate biodiversity in conservation biology, when detailed routine surveys are unfeasible (Vane-Wright et al., 1991; Harper and Hawksworth, 1994; Cabeza and Moilanen, 2001).

In environmental impact assessment, a low taxonomic resolution could reflect more clearly environmental pollution gradients because species are more affected than higher taxa by both natural variability and seasonal cycles (Warwick, 1988a,b). Further, TS (e.g. the use of morphological groups) is often unavoidable when sampling procedures involve non-destructive sampling techniques (Roberts et al., 1994). Finally, TS offers the possibility of comparing data from different habitats or geographical regions. Communities, in fact, are much more comparable at high taxonomical levels (e.g. phylum and class) by aggregating information through meta-analyses (Warwick and Clarke, 1993).

2. TS in environmental studies

In the last two decades many studies tested TS in the assessment of environmental impact (Heip et al., 1988;

* Corresponding author. Address: Laboratory of Zoology and Marine Biology, Department of Biological and Environmental Sciences and Technology, University of Lecce, Lecce 73100, Italy. Tel.: +39-0832-320-853; fax: +39-0832-320-702.
E-mail address: antonio.terlizzi@unile.it (A. Terlizzi).

0025-326X/03/$ - see front matter © 2003 Elsevier Science Ltd. All rights reserved.
doi:10.1016/S0025-326X(03)00066-3

Herman and Heip, 1988; Warwick, 1988c; Ferraro and Cole, 1992). Fewer attempts have been made to explore the use of TS in biodiversity and conservation issues (Andersen, 1995; Balmford et al., 1996b).

Most studies have been done in cold-temperate marine environments (e.g. North Sea), focusing on soft bottom macro- and meiobenthic communities (Bayne et al., 1988; Heip et al., 1988; Herman and Heip, 1988; Gray et al., 1990; Olsgard et al., 1998) in relation to oil pollution gradients (Warwick, 1988a,b). Fewer studies (mainly focusing on the effects of sewage, heavy metals or organic enrichment) were made in warm temperate (Warwick et al., 1990; Wright et al., 1995; Vanderklift et al., 1996; Mistri and Rossi, 2001; Roach et al., 2001) or tropical areas (Guzman and Garcia, 1996). The use of TS in quantifying the effects of impact on both hard marine bottoms (Mistri and Rossi, 2000; Pagola-Carte et al., 2002) and freshwater benthic assemblages (Bowman and Bailey, 1997; MacFarlane and Booth, 2001) is still poorly explored.

TS is not widely applied in terrestrial habitats, but it recently received increasing interest also in this type of environment (Pik et al., 1999; Balmford et al., 2000).

3. Effects of TS on sampling procedures and data analyses

Coarser mesh sizes and low taxonomic resolution allow the processing of more samples per unit time. James et al. (1995) found that the use of different mesh size (0.5 vs. 1 mm) and taxonomic resolution (species vs. family) made little difference to the soft-bottom macrofauna spatial patterns detected by multivariate analyses. Ferraro and Cole (1992) found that, when organisms were collected by sample units with 1-mm-mesh size, the sufficient taxonomic level to detect impact was family whilst, for 0.5-mm-mesh size, the level was that of species. The use of larger mesh samples is likely to avoid the "noise" of small sized organisms and might reduce the taxonomic resolution needed to detect impacts. Nevertheless, the loss of information might not be negligible if impact affected just small species.

Somerfield and Clarke (1995) considered the response of TS to multivariate analyses, comparing data with different transformations (row data, $\surd$, $\surd\surd$, presence/absence) and aggregation levels (from species to phylum and functional groups). They found, in both intertidal and subtidal environments, that data ordination (nMDS, non-metric multidimensional scaling ordinations) of nematode communities was consistent by aggregating data at genus level. The aggregation at family level had little effects on ordinations of macrofaunal data but at the phylum level the perception of impact was severely altered. Thus, ordination plots suffer the aggregation of data to higher levels showing, at low taxonomic resolution, a decreasing capacity to represent correctly distances between samples (Vanderklift et al., 1996).

Olsgard and Somerfield (2000) argued that the family level might represent the most suitable compromise between the need of time-costs saving and the necessity of statistical vigour of information. The level of family also provides a better agreement when multivariate data have been related to environmental variables (through BIO-ENV procedure; Clarke and Ainsworth, 1993).

However, at least for strong pollution gradients, nMDS can depict changes in assemblages also at phylum level (Ferraro and Cole, 1990; Gray et al., 1990; Warwick et al., 1990). The phylum level leads to clear results also in the meta-analysis of Warwick and Clarke (1993).

Mathematical transformations of data and low taxonomic accuracy can interact in decreasing the potential of multivariate tools to perceive changes in assemblages. Effects of transformations become more severe as taxonomic resolution decreases and, therefore, both factors affect the outcome of analyses (Olsgard et al., 1997). Also in terrestrial habitats, ordinations of aggregated data (e.g. functional groups rather than species) discriminated sampling sites but, when data were transformed to balance the contribution of rare and common taxa, differences among sites were less clear (Pik et al., 1999).

Ordination models are not the only multivariate statistical procedures that suffer of taxonomic aggregation. Non-parametric multivariate tests like the Analysis of Similarities (ANOSIM) might lead to contrasting outcomes at different taxonomic levels. Aggregation of data at levels higher than genus, in fact, decreases the ability of ANOSIM to separate sampling sites and smoothes out possible differences between the putatively impacted areas and controls (Somerfield and Clarke, 1995; Lardicci and Rossi, 1998; Pagola-Carte et al., 2002). The different responses of data to taxonomic aggregation depend on the circumstances of each study because the relationships between abundance, biomass or cover might vary depending upon habitats and/or the degree of taxonomic redundancy. This requires care in generalizing outcomes and emphasizes the need of pilot studies to distinguish, case by case, the most suitable procedure (Chapman, 1998; Pagola-Carte and Saiz-Salinas, 2000).

4. TS and marine hard substrates

Some degree of taxonomic inaccuracy is not a novelty in impact studies on hard substrates. In some cases, taxonomic resolution must stop at low levels due to specific constraints. When the study site is inside marine protected areas, for example, the use of non-destructive sampling methods (e.g. photographic methods or visual censuses) is mandatory. In such contexts, at least for some groups (e.g. encrusting calcified red algae, sponges, hydroids, bryozoans, etc.), identifying all organisms at species level is simply impractical, representing an intrinsic limit of sampling procedures. This does not mean, however, that the application of TS allows a sufficient appreciation of the diversity of hard bottom communities per se.

One of the first attempts to explore TS on marine hard substrates has been carried out in Mediterranean Sea (Mistri and Rossi, 2000) where changes in community structure due to sewage pollution were clearly detectable already at the family level.

In the same basin, Terlizzi et al. (2002), in an attempt to quantify the effects of sewage pollution on subtidal hard substrate sessile assemblages, based their analysis on a multivariate data set of 57 taxa. For some organisms, identification stopped at taxonomic levels higher than species, due to the sampling technique (photographic samples). Nevertheless, over 57 taxa, 41 were identified at species level. ANOSIM and nMDS clearly separated sites from the impacted location from those of controls (Fig. 1a). Here we analysed the same data set at different taxonomic levels of aggregation: separation of impacted sites from controls' sites is still evident at family level and less clear at both class and phylum level (Fig. 1b–d). Obviously, this is not enough to prove the efficiency of TS on hard substrates. It could be argued, for instance, that the original data set was not entirely at

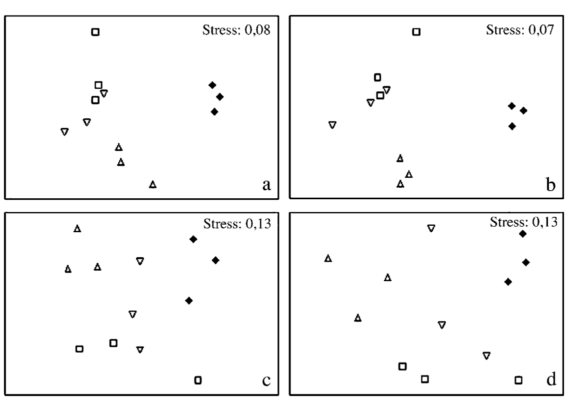

Fig. 1. Non-metric multidimensional scaling ordinations based on Bray–Curtis dissimilarities on square root transformed data. There are four locations, one impacted by a sewage outfall and three controls. Three sites are sampled at each location by 10 photographic records. Each point represents the centroid (average) of assemblage from the 10 replicates. ◆ = sites from the impacted location; △, ▽, □ = sites from the first, second and third control, respectively. Percentage cover of macroalgae and sessile animals have been aggregated at different taxonomic levels to represent differences among and within locations: (a) original data set based on 57 taxa; 41 identified as species, 6 as genus, 2 as family and 8 as morphological groups (e.g. filamentous green algae, encrusting calcified red algae) (Terlizzi et al., 2002); (b)–(d) aggregation to family, class, and phylum level, respectively. At class and phylum levels of aggregation goodness-of-fit of samples in the plot are reduced, as indicated by the increasing value of stress.

species level and, therefore, comparisons are not stringent. Further research on effects of TS on hard substrate is needed before extending the higher taxon concept to these habitats.

5. TS and loss of information

The time spent to identify organisms at the family level, as compared to identification to species, will depend on the number of species within the various families, whether the numerically dominant species belong to several taxonomically complicated families or to a few taxonomically trouble-free families, and on the availability of taxonomic expertise (Ferraro and Cole, 1990). The choice of taxonomic level, to optimise cost/efficiency rate in environmental studies, might be related to the groups of organisms involved and to their distribution in the studied area.

In subtidal soft bottom macrobenthic assemblages, there is evidence that little information is lost when specimens are identified at phylum level, whilst, for meiofauna, heavy losses of information occurred over family level (Gray et al., 1990; Warwick et al., 1990). Vanderklift et al. (1998), working with fish, algal and invertebrate assemblages, found that genus richness highly reflected species richness, but families described well species richness only for fishes assemblages, whilst class richness always gave scant results. Also in terrestrial habitats, a correlation between species and genus data has been found (Pik et al., 1999, 2002).

The response of different taxonomic levels might change according to biogeographical features and internal diversity of taxa (Roy et al., 1996). In other words, if the family richness is a good surrogate of species diversity in the North Sea, it might not be the same for the Mediterranean Sea (Bianchi and Morri, 2000). Moreover, in the same basin (or region), the efficiency of a taxonomic surrogate of species richness might not be constant for different biological groups. Family diversity might not properly reflect species richness. The use of low taxonomic resolution must be cautious in megadiverse groups of organisms (Balmford et al., 2000). The risk, using higher taxon richness as surrogate of biodiversity, in fact, is to consider in the same way both taxonomic groups poor in species and very speciose ones (May, 1990). Thus, low taxonomic resolution in estimating species richness might hide diversity centres (Prance, 1994). Each source of variability might lead to dangerous loss of information when taxonomic accuracy decreases, especially if evidences that justify TS in precise circumstances are superficially extended to other contexts.

In polluted environments the average degree to which individuals in assemblages are phylogenetically related to each other (i.e. taxonomic distinctness, Clarke and

Warwick, 2001) might decrease. In such situations, it might be less expensive to investigate the presence and abundance of some families or orders "indicators" of disturbance rather than identify the species that belong to them. Nevertheless, before the use of indicators is effective, accurate taxonomic analyses must be available (Grant et al., 1995). Species, in fact, might be not so structurally and functionally redundant as they are implied to be by the application of TS. Moreover, taxa including many abundant species might hide also rare species with key roles in communities' structure that only fine taxonomic analyses and manipulative experiments might reveal (Mistri et al., 2001).

It is widely recognized that the addiction or the loss of non-keystone species has only little effects on communities and ecosystems (Frost et al., 1995). When species are similar in their ecological features, the loss (or addiction) of one of them has relevance for community structure, but lower effects on community function, due to the compensative response of other species (Piraino et al., 2002). In such a case, the use of species or higher taxonomic levels makes little difference to understand patterns of assemblages but, if a species has a relevant functional role, TS might blur its importance. This might occur in endemism-rich faunas (Samways et al., 1996), as sensitive endemic species might be affected without a noticeable effect at higher taxon levels (Cagnolo et al., 2002).

6. Final remarks

The knowledge of species, and their biology and ecology, is an indispensable prerogative also to define the possible sufficient taxonomical level in routine monitoring studies. The use of TS is likely to be most advantageous if species level baseline studies have already been completed (Olsgard and Somerfield, 2000). In poorly known environments, the use of rough taxonomic resolution is still premature (Gage, 2001), and there is an urgent need to acquire detailed information before applying TS. Approximation must not be made a priori: the profound knowledge of systems and their species is the first, crucial, step.

The advantages of TS and related investigation methods are the lighted face of the medal. The dark side is that biological surveys are in increasing demand while taxonomic resources continue to decline (Maurer, 2000) and the crisis of taxonomy just in the "age of biodiversity" is more and more evident (Feldmann and Manning, 1992; Pimm and Lawton, 1998). Application of methods that involve low taxonomic resolution, even supported by rigorous statistics, might lead, on the long term, to great losses in knowledge heritage as a consequence of the scant replacement of taxonomists (Scheltema, 1996; Boero, 2001).

Finding a compromise between the profound knowledge of the single components of a system and the need of costs-effective methods is not an easy task. TS could have an acceptable role only when environmental features allow implementing taxonomic analyses less expensive than species identification. In some cases, TS represent a valid tool in routine monitoring but poorly known systems or baseline biodiversity study and TS are simply incompatible.

Current evidence suggests that family is a sufficient taxonomic level, but this statement stems from too a limited number of case studies. Relations among TS and sampling procedures, data analyses, spatial scale, habitat features and assemblages structure are still far to be generalized.

TS may be tolerated only when difficulties in sampling, data analysis and identification of some particular organisms make this procedure strictly necessary, not merely to save costs whatever the aim of the study is. TS, thus, is only a compromise, not a universally recognized practice. Such compromise, furthermore, is only acceptable to detect impacts, but it conflicts with the very definition of biodiversity. If species loss is the main concern of conservation biology (together with habitat loss), it is simply absurd to pretend to perform conservation studies without considering species. This radical (but nevertheless logical) view is incompatible with the current availability of taxonomic expertise for most groups. The lists of endangered marine animals comprise mainly charismatic and commercial species because, for the inconspicuous ones, very little is known (Piraino et al., 2002). It is evident that a current policy of marine conservation not only considering whales, dolphins, seals, turtles and (some) molluscs and corals must focus on biodiversity at community level, forcedly disregarding species diversity. This is not an alibi to continue with a policy of indifference for taxonomic expertise. In this case, taxonomic sufficiency might be used as a proof of the uselessness of taxonomists in both ecological and conservation studies, conflicting with the aims of conservation biology.

Acknowledgements

Financial support by PEET (Partnerships for Enhancing Expertise in Taxonomy) and MURST (COFIN project).

References

Andersen, A.N., 1995. Measuring more of biodiversity: genus richness as a surrogate for species richness in Australian ant faunas. Biological Conservation 73, 39–43.

Balmford, A., Jayasuriya, A.H.M., Green, M.J.B., 1996a. Using higher-taxon richness as a surrogate for species richness: II. Local applications. Proceedings of the Royal Society, London B 263, 1571–1575.

Balmford, A., Green, M.J.B., Murray, M.G., 1996b. Using higher taxon richness as a surrogate for species richness: I. Regional tests. Proceedings of the Royal Society, London B 263, 1267–1274.

Balmford, A., Lyon, A.J.E., Lang, R.M., 2000. Testing the higher-taxon approach to conservation planning in a megadiverse group: the macrofungi. Biological Conservation 93, 209–217.

Bayne, B.L., Clarke, K.R., Gray, J.S., 1988. Biological effects of pollution: results of a practical workshop. Marine Ecology Progress Series 46, 1–278.

Beattie, A.J., Oliver, I., 1994. Taxonomic minimalism. Trends in Ecology and Evolution 9, 488–490.

Bianchi, C.N., Morri, C., 2000. Marine biodiversity of the Mediterranean Sea: situation, problems and prospects for future research. Marine Pollution Bulletin 40, 367–376.

Boero, F., 2001. Light after dark: the partnership for enhancing expertise in taxonomy. Trends in Ecology and Evolution 16, 266.

Bongers, T., Ferris, H., 1999. Nematode community structure as a bioindicator in environmental monitoring. Trends in Ecology and Evolution 14, 224–228.

Bowman, M.F., Bailey, R.C., 1997. Does taxonomic resolution affect the multivariate description of the structure of freshwater benthic macroinvertebrate communities. Canadian Journal of Fisheries and Aquatic Sciences 54, 1802–1807.

Cabeza, M., Moilanen, A., 2001. Design of reserve networks and the persistence of biodiversity. Trends in Ecology and Evolution 16, 242–248.

Cagnolo, L., Molina, S.I., Valladares, G.R., 2002. Diversity and guild structure of insect assemblages under grazing and exclusion regimes in a montane grassland from Central Argentina. Biodiversity and Conservation 11, 407–420.

Chapman, M.G., 1998. Relationships between spatial patterns of benthic assemblages in a mangrove forest using different levels of taxonomic resolution. Marine Ecology Progress Series 162, 71–78.

Clarke, K.R., Ainsworth, M., 1993. A method of linking multivariate community structure to environmental variables. Marine Ecology Progress Series 92, 205–219.

Clarke, K.R., Warwick, R.M., 2001. A further biodiversity index applicable to species lists: variation in taxonomic distinctness. Marine Ecology Progress Series 216, 265–278.

Ellis, D., 1985. Taxonomic sufficiency in pollution assessment. Marine Pollution Bulletin 16, 459.

Feldmann, R.M., Manning, R.B., 1992. Crisis in systematic biology in the 'Age of Biodiversity'. Journal of Paleontology 66, 157–158.

Ferraro, S.P., Cole, F.A., 1990. Taxonomic level and sample size sufficient for assessing pollution impacts on the Southern California bight macrobenthos. Marine Ecology Progress Series 67, 251–262.

Ferraro, S.P., Cole, F.A., 1992. Taxonomic level sufficient for assessing a moderate impact on macrobenthic communities in Puget-Sound Washington, USA. Canadian Journal of Fisheries and Aquatic Sciences 49, 1184–1188.

Frost, T.M., Carpenter, S.R., Ives, F., Krats, T.K., 1995. Species compensation and complementarity in ecosystem function. In: Jones, C.G., Lawton, J.H. (Eds.), Linking Species and Ecosystems. Chapman and Hall, New York, pp. 224–239.

Gage, J.D., 2001. Deep-sea benthic community and environmental impact assessment at the Atlantic Frontier. Continental Shelf Research 21, 957–986.

Gaston, K.J., Williams, P.H., 1993. Mapping the world's species the higher taxon approach. Biodiversity Letters 1, 2–8.

Grant, J., Hatcher, A., Scott, D.B., Pocklinngton, P., Schafer, C.T., Winters, G.V., 1995. A multidisciplinary approach to evaluating impacts of shellfish aquaculture on benthic communities. Estuaries 18, 124–144.

Gray, J.S., Clarke, K.R., Warwick, R.M., Hobbs, G., 1990. Detection of initial effects of marine pollution on marine benthos: an example from the Ekofisk and Eldfisk oilfields, North Sea. Marine Ecology Progress Series 66, 285–299.

Guzman, A., Garcia, C.B., 1996. Taxonomic aggregation and the detection of patterns in a tropical marine benthos data set. Revista de Biologia Tropical 44, 907–910.

Harper, J.L., Hawksworth, D.L., 1994. Biodiversity: measurement and estimation. Philosophical Transaction Royal Society London B Biological Sciences 345, 45–58.

Heip, C., Warwick, R.M., Carr, M.R., Herman, P.M.J., Huys, R., Smol, M., Holsbeke, K., 1988. Analysis of community attributes of benthic meiofauna of Frierfjiord/Langesundfjiord. Marine Ecology Progress Series 46, 171–180.

Herman, P.M.J., Heip, C., 1988. On the use of meiofauna in ecological monitoring: who needs taxonomy? Marine Pollution Bulletin 19, 45–60.

James, R.J., Smith, M.P., Fairweather, P.G., 1995. Sieve mesh-size and taxonomic resolution needed to describe natural spatial variation of marine macrofauna. Marine Ecology Progress Series 118, 187–198.

Lardicci, C., Rossi, F., 1998. Detection of stress on macrozoobenthos: evaluation of some methods in a coastal Mediterranean lagoon. Marine Environmental Research 45, 367–386.

MacFarlane, G.R., Booth, D.J., 2001. Estuarine macrobenthic community structure in the Hawkesbury river, Australia: relationships with sediment physicochemical and anthropogenic parameters. Environmental Monitoring and Assessment 72, 51–78.

Maurer, D., 2000. The dark side of the taxonomic sufficiency (TS). Marine Pollution Bulletin 40, 98–101.

May, R.M., 1990. Taxonomy as destiny. Nature 347, 129–130.

Mistri, M., Rossi, R., 2000. Levels of taxonomic resolution and choice of transformation sufficient to detect community gradients: an approach to hard-substrata benthic studies. Italian Journal of Zoology 67, 163–167.

Mistri, M., Rossi, R., 2001. Taxonomic sufficiency in lagoonal ecosystems. Journal of the Marine Biological Association of the United Kingdom 81, 339–340.

Mistri, M., Fano, E.A., Rossi, R., 2001. Redundancy of macrobenthos from lagoonal habitats in the Adriatic Sea. Marine Ecology Progress Series 215, 289–296.

Olsgard, F., Somerfield, P.J., Carr, M.R., 1997. Relationship between taxonomic resolution and transformations in analyses of a macrobenthic community along an established pollution gradient. Marine Ecology Progress Series 149, 173–181.

Olsgard, F., Somerfield, P.J., Carr, M.R., 1998. Relationship between taxonomic resolution, macrobenthic community patterns and disturbance. Marine Ecology Progress Series 127, 25–36.

Olsgard, F., Somerfield, P.J., 2000. Surrogates in marine benthic investigations—which taxonomic unit to target? Journal of Aquatic Ecosystem Stress and Recovery 7, 25–42.

Pagola-Carte, S., Saiz-Salinas, J.I., 2000. A pilot study for monitoring the zoobenthic communities on the rocky shores of Abra de Bilbao (N. Spain). Journal of the Marine Biological Association of the United Kingdom 80, 395–406.

Pagola-Carte, S., Urkiaga-Alberdi, J., Bustamante, M., Saiz-Salinas, J.I., 2002. Concordance degrees in macrozoobenthic monitoring programmes using different sampling methods and taxonomic resolution levels. Marine Pollution Bulletin 44, 63–70.

Pik, A.J., Oliver, I., Beattie, A.J., 1999. Taxonomic sufficiency in ecological studies of terrestrial invertebrates. Australian Journal of Ecology 24, 555–562.

Pik, A.J., Dangerfield, J.M., Bramble, R.A., Angus, C., Nipperess, D.A., 2002. The use of invertebrates to detect small-scale habitat heterogeneity and its application to restoration practices. Environmental Monitoring and Assessment 75, 179–199.

Pimm, S.L., Lawton, J.H., 1998. Planning for biodiversity. Science 279, 2068–2069.

Piraino, S., Fanelli, S., Boero, F., 2002. Variability of species' roles in marine communities: change of paradigms for conservation priorities. Marine Biology 140, 1067–1074.

Prance, G.T., 1994. A comparison of the efficacy of higher taxa and species numbers in the assessment of biodiversity in the neotropics. Philosophical Transaction Royal Society London B Biological Sciences 345, 89–99.

Roach, A.C., Jones, A.R., Murray, A., 2001. Using benthic recruitment to assess the significance of contaminated sediments: the influence of taxonomic resolution. Environmental Pollution 112, 131–143.

Roberts, D.E., Fritzhenry, S.R., Kennelly, S.J., 1994. Quantifying subtidal macrobenthic assemblages on hard substrata using a jump camera method. Journal Experimental Marine Biology and Ecology 1, 157–170.

Roy, K., Jablonski, D., Valentine, J.W., 1996. Higher taxa in biodiversity studies: patterns from eastern Pacific molluscs. Philosophical Transactions of the Royal Society, London B 351, 1605–1613.

Samways, M.J., Caldwell, P.M., Osborn, R., 1996. Ground-living invertebrate assemblages in native, planted and invasive vegetation in South Africa. Agriculture, Ecosystems and Environment 59, 19–32.

Scheltema, R.S., 1996. Describing diversity: too many new species, too few taxonomists. Oceanus 39, 16–18.

Somerfield, P.J., Clarke, K.R., 1995. Taxonomic levels, in marine community studies revisited. Marine Ecology Progress Series 127, 113–119.

Terlizzi, A., Fraschetti, S., Guidetti, P., Boero, F., 2002. The effects of sewage discharge on shallow hard substrata sessile assemblages. Marine Pollution Bulletin 44, 544–550.

Vanderklift, M.A., Ward, T.J., Jacoby, C.A., 1996. Effect of reducing taxonomic resolution on ordinations to detect pollution-induced gradients in macrobenthic infaunal assemblages. Marine Ecology Progress Series 136, 137–145.

Vanderklift, M.A., Ward, T.J., Phillips, J.C., 1998. Use of assemblages derived from different taxonomic levels to select areas for conserving marine biodiversity. Biological Conservation 86, 307–315.

Vane-Wright, R.I., Humphries, C.J., Williams, P.H., 1991. What to protect? Systematics and the agony of choice. Biological Conservation 55, 235–254.

Warwick, R.M., 1988a. Analysis of community attributes of macrobenthos of Frierfjiord/Langesundfjiord at taxonomic levels higher than species. Marine Ecology Progress Series 46, 167–170.

Warwick, R.M., 1988b. Effects on community structure of a pollutant gradient—summary. Marine Ecology Progress Series 46, 207–211.

Warwick, R.M., 1988c. The level of taxonomic discrimination required to detect pollution effects on marine benthic communities. Marine Pollution Bulletin 19, 259–268.

Warwick, R.M., Platt, H.M., Clarke, K.R., Agard, J., Gobin, J., 1990. Analysis of macrobenthic and meiobenthic community structure in relation to pollution and disturbance in Hamilton Harbour, Bermuda. Journal of Experimental Marine Biology and Ecology 198, 119–142.

Warwick, R.M., Clarke, K.R., 1993. Comparing the severity of disturbance: a meta-analysis of marine macrobenthic community data. Marine Ecology Progress Series 92, 221–231.

Williams, P.H., Gaston, K.J., 1994. Measuring more of biodiversity: can higher-taxon richness predict wholesale species richness? Biological Conservation 67, 211–217.

Wright, I.A., Chessman, B.C., Fairwheather, P.G., Benson, L.J., 1995. Measuring the impact of sewage effluent on the macroinvertebrate community of an upland stream—The effect of different levels of taxonomic resolution and quantification. Australian Journal of Ecology 20, 142–149.