BIOMONITORING AND INVERTEBRATE TAXONOMY

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Abstract. Biological monitoring requires identification of the fauna of the environment under study. Three prevalent methods have been used to alleviate the need for universal species-level identification: selection of indicator taxa, taxonomic reduction, and allocation to functional groups. Each method is discussed in relation to species recognition. It is suggested that the validity of all attempts to reduce data should be tested in the light of phylogenetic hypotheses.

Introduction

Biological communities reflect their environmental conditions and respond, in an often predictable manner, to disturbance. Quantification of community composition allows recognition of temporal and spatial variations in the biota that may be used to demonstrate the magnitude of detected changes. On the other hand, physico-chemical assessment of environmental conditions alone cannot detect intermittent pollution. Furthermore, even if continuous physico-chemical monitoring is undertaken it isn't yet possible to predict reliably the biological effects. The widespread and increasing use of fauna and flora in the description and classification of ecosystems, and subsequent detection of anthropogenic impacts, requires no further justification.

Species and their populations respond to altered environmental conditions. The nature of response of taxonomically higher categories (genus, tribe, family etc) is poorly understood, yet many attempts have been, and continue to be made, to circumscribe species identification. Even when species are recognised, biological understanding may be limited. Resh and Unzicker (1975), in berating the prevalence of uninterpreted lists of taxa in environmental impact assessment, stressed the need not only for good taxonomy but for more autecological studies.

Aquatic invertebrates, particularly insects, are very significant in environmental impact assessment (eg. Hellawell, 1977; Rosenberg et al., 1986). For example, in the northern hemisphere, chironomid midge community structure is the most important indicator of lake typology (Saether, 1979). Interaction between taxonomists studying invertebrates and aquatic ecologists has been and remains extensive and intensive, involving more than the taxonomists acting solely as purveyors of identifications. Thus, the following observations relate predominantly, but not exclusively, to taxonomy and aquatic ecology and to those scientists investigating both.

Those involved in surveillance and analysis of the biota have taken three
approaches, namely selection of indicator taxa, taxonomic reduction of the total data and allocation of biotic components to functional groups. These are not mutually exclusive categories, but since they combine different philosophical bases with pragmatism, they can be conveniently segregated.

**Recognition of Key Taxa**

Analysis of all but the simplest ecosystems reveals a complexity of communities requiring taxonomic expertise across many orders and several phyla. The attempt to achieve species-level identification for all taxa is hindered by differences in taxonomic refinement, by problems in co-ordinating the input of different specialists, and by the frequent inability to identify the particular life-history stage revealed in the survey. These problems can be resolved most readily by the selection of critical taxa for detailed study — the indicator concept. The choice of taxa generally is pragmatic, being based on ease of identification, availability of taxonomic expertise, and on species-richness and ecological diversity.

A major attempt to assess the indicator organism(s) approach came from studies at the Freshwater Biological Association, in England, with a team led by John Wright. This research programme, known as the Rivers Classification Project, attempted to develop a biological classification of unpolluted running waters in the U.K. and then to assess whether the macroinvertebrate community could be predicted from physico-chemical features of that site. Further predictions then could be made, based upon the occurrence of indicator groups (Wright et al., 1984; Furse et al., 1984). Deviations of community structure from that predicted could be taken as indications of abnormality in the system, such as that caused by anthropogenic disturbance.

In all these investigations there was a prior need to know the complete fauna, before assessment of the value of indicator taxa could be made. In the United Kingdom, given the manpower to handle samples, most groups of aquatic organisms encountered can be identified to a quite refined level. There are few other parts of the world where this is true, and in Australia it is not yet possible.

A different aspect of the indicator concept is the concentration on a taxonomically selected group, to the exclusion of all others. The *a priori* criteria suggested by Greenslade and Greenslade (1984) for selection of manageable groups of invertebrates for restricted study are appropriate and are quoted here in a slightly modified form. The group should be:

1. exposed by its ecology to the environmental parameters to be monitored,
2. be functionally important in ecosystems,
3. be ubiquitous and/or widely distributed within a continental area,
4. not dominate any locality by an excessive (i.e., unmanageable) number of species,
5. be identifiable, or at least recognisable at species level,
6. be easily sampled, and
(7) be responsive to environmental perturbation at a convenient and detectable scale.

The taxonomist specialist may see this as a justification to advocate any particular group as a potential indicator of environmental conditions, but personal advocacy is to be avoided. However, assessment of these criteria should be an essential prerequisite in the allocation of the limited funding for taxonomic research in Australia. In Britain, more than a decade ago the National Environment Research Council (1976) applied somewhat similar criteria in its assessment of priorities to taxonomic research in relation to the perceived needs of ecological users. Australia needs to set such priorities.

**Taxonomic Penetration**

Attempts to reduce the level of identification of samples, referred to as ‘taxonomic penetration’ by Morris and Brooker (1980), have been attempted often. Certain groups are identified to species, others to genera, while some are determined to family or higher category. The justification for such treatments rarely, if ever, have been made explicit. In most cases it is a purely pragmatic approach, i.e. species determinations are made only if specialist expertise is not required at any stage; other levels of identification are made according to availability and ease of use of identification keys. Probably in all cases, the handling time to sort and identify samples is a major criterion in determining the level of identification, Clearly this is a somewhat arbitrary criterion and is of unknown value in assessing and comparing communities.

A further development is the delimiting of Recognisable Taxonomic Units (R.T.U.s) – another tempting short cut in the provision of data for inclusion in summary statistics, indices of relative abundance and diversity which may then be used in inter-ecosystem comparisons. The number of species present and the abundance of each taxon is assessed with no attempt to name the taxa. In circumstances where ecological (including biomonitoring) study precedes the taxonomy – for example in much of Australian freshwater biota – the use of R.T.U.s may be the only practical solution possible. Clearly, there are drawbacks: the differences in taxonomic penetration alluded to above and the inability to communicate R.T.U.'s accurately to other scientists other than by reference to voucher material. In aquatic entomology, an R.T.U. may be equivalent to anything from order (e.g., Oligochaeta), family (Chironomidae), genus (*Procladius, Tasmanocoenis*) to species (*Chironomus tepperi*) according to the expertise of the taxonomic input. The effect of variable taxonomic input on the summary statistics used in the abbreviated description of the system is loss of comparability.

In the absence of good taxonomic guides, the voucher system can succeed – it is the only means by which future workers will know the identity of the organisms studied and can add to that database of autecological knowledge. However, a plethora of incompatible voucher numbers can result if ecological studies greatly out-distance the taxonomy. It is essential that voucher material be deposited in safe
housing on completion of all ecological studies, whether species are referred to as vouchers, or even if reliably named.

Taxonomy and Functional Group Approaches

Another approach to detection of biological patterns and their responsiveness to environmental stress is derived from recognition of guilds (or functional groups to most aquatic biologists). If variation in the proportions of basic functional components reflect degrees of environmental perturbation, then identification might be circumvented.

Naturally, the taxonomist with a vested interest in maintaining interaction between ecological users of taxonomic information, may be seen as a partisan commentator on these approaches. Nevertheless, a spectrum of functional approaches may be noted and assessed. At one extreme, identification of organisms is taken as far as is possible, and allocation to guild made by reference to the known biology of each species, an approach exemplified by Moran and Southwood (1982) in their comparisons of arthropod communities in trees. Similarly, Greenslade and Greenslade (1985) stress the requirement for species level identification of Collembola (soil invertebrates) before allocating them to ecological groupings.

An intermediate approach occurs where taxonomic groupings other than species are allocated to a feeding guild. Broad taxonomic ranges of organisms have been placed, often uncritically, into feeding groups, and subsequent correlations of functional group proportions with environmental parameters has been detected. This method perhaps reached its (aquatic) zenith with some uncritical adherents, although not necessarily the original authors, of the river continuum concept (Vannote et al., 1980). One, amongst many, warnings of the fallibility of assigning even well known taxa to functional feeding groups comes from Hildrew et al. (1985) who demonstrated both instar and seasonal variation in the proportions of prey to detritus in the diet of 3 co-occurring species in the supposedly exclusively predatory chironomid subfamily Tanypodinae. This problem of species functioning at different trophic levels seems to be quite prevalent. Furthermore, in the southern hemisphere, Winterbourne et al. (e.g. 1981) have questioned the universality of theories based upon functional groupings, noting the absence of major taxonomic groupings from New Zealand, for reasons that are presumed to be historic. Once again, geographic imbalances in functional groups also may be prevalent.

Perhaps the ultimate approach could be envisaged where, frustrated by taxonomic impediments in the selected environmental indicator taxa, simple recognition of ecological groupings could allow elimination of the taxonomic stage. Before such a method can attain credibility, it is necessary to distinguish between different categories, be they evolutionary, ecological or simply operational. In his presentation at this symposium, Faith (1989) addresses these questions and suggests methods for validating functional group responses.

In summary, advocates of the elimination of the taxonomic stage in monitoring
provide a tempting but, as yet, scientifically unjustified substitution for species level assessment.

Taxonomy

At the heart of the differing approaches exemplified above is the recognition that taxonomy predominantly lags behind the demands of the users of the taxonomy. Is this correct, and if so, are there any solutions available?

The role of taxonomy in biological science has become, at best, taken for granted, but is more often dismissed as an archaic and legalistic irrelevance. Mound’s (1983) observations entitled ‘For a taxonomist you seem to know a lot about biology!’ are a witty but apposite exposure of the problem. The view that taxonomy is integrally linked to virtually all spheres of biological endeavour is so fundamental that the practitioners take it for granted that the rest of the scientific community also recognises this. However, the continuous decline in support indicates that advocacy of the pivotal role of taxonomy in biological science is not widely understood. Thus, it is pertinent to examine the relationship between the discipline and its’ users, with particular reference to aquatic biology.

Many, if not most, users of taxonomic information wish to communicate natural history (‘autecological’) information, such as response to particular pollutants or more generally to response to environmental perturbation such as eutrophication. Other users may be investigating, for example, the specificity of allergic response to inhalation of nuisance midges, or of DNA sequence in haemoglobin producing genes. These observations concern species or populations – broader taxonomic categories have no intrinsic value for conveying these data.

A distinction may be made between taxonomy and systematics, whilst recognising the inter-relationship. Taxonomists recognise species and higher categories, describe them and provide illustrations and identification keys so that others may use the identity (the names) to communicate multifarious biological information. The taxonomist often may be viewed uncharitably as little more than a biological philatelist, describing the biological world based upon morphological discontinuities between preserved Museum specimens. This approach should not be denigrated, for with specimens bearing little or no biological information it may be the only one possible and is basic to many current classifications. That the basis of modern classification preceded the modern evolutionary synthesis, the discovery of the rules of heredity and the demonstration of the mechanism of inheritance, does not necessarily negate earlier, apparently ‘theory-free’, classifications.

Biological systematics takes taxonomy further, to a more rigorous and integrative discipline, attempting to utilise all biological data attached to the taxon. This data is then reconciled with evolutionary and earth history explanations for the underlying patterns revealed in classifications. As a discipline, systematics has become a contentious area of philosophical conflict, but this is not an appropriate place to refer further to these matters. Suffice it to say that cladistic methods seek to reveal a pattern of
relationships between taxa through a hierarchical structure (a cladogram) representing the sharing of homologous derived characters, as opposed to overall similarity. The number of theorised evolutionary changes in these characters is minimised (the criterion of parsimony). Lineages recognised should be monophyletic, containing all the descendants of a single postulated common ancestor. A further corollary is that cladists attempt to restrict the interpretation of evolutionary and biogeographic scenarios (process) until after detection of the taxonomic distribution of characters (pattern). These views are discussed in Nelson and Platnick (1981).

A simplistic view of taxonomic input into environmental programmes such as biological monitoring would be that the provision of full identification is all that is required. Given the identity (names) of the organisms involved, the ecologist is free to assess community structure with any of the multiplicity of summary statistics available. Has systematics anything to contribute to biological monitoring?

**Systematics and Biological Monitoring**

The diverse approaches to biological monitoring all reveal some recognition of the requirement for an initial species level separation. If species are not identified for any reason, three solutions can be identified:

1. species recognition as far as is practical: a biologically arbitrary procedure;
2. recognition of unnamed taxonomic units postulated as representing species, retained as voucher specimens and referred to by voucher number: may suffer from lack of comparability between investigators, and hence loss of communicability of results;
3. recognition of guild/functional group: suffers from lack of theoretical basis for group response to given perturbation.

Few attempts have been made to quantify the differences between these and other approaches. The important criteria are efficacy in detecting perturbation in ecosystems, and, conversely, imperviousness to natural variation. A poorly investigated solution might be the systematic reduction in the level (‘penetration’) of identification on phylogenetic grounds. The widespread generic level determinations of the freshwater biota in North America, encouraged by the excellent keys to genus in Merritt and Cummins (1978), may be seen as an unconscious case, although lacking any overt phylogenetic justification. Another example, again probably unconscious, is given in Moran & Southwood (1982), where, because they lacked feeding information to allocate some species to guilds, they based allocation on better known taxonomically related species.

The implicit, but unstated and untested, assumption made in these two cases is that related taxa are ecologically similar and therefore convey identical information in summary statistics used in biological monitoring. Common descent implies common ecology.

What evidence, if any, do we have for this? If the primary mode of speciation is allopatric (i.e. by vicariant division of the range of an ancestral taxon, for example,
by a geological or climatic event) then there is no a priori expectation of ecological difference between the two resultant daughter taxa. In contrast mechanisms that suggest speciation by life history alteration infer ecological differentiation between sister taxa. Clearly these will have quite different effects when taxonomic data are reduced. If speciation is predominantly allopatric, with little ecological differentiation, then the environmental patterns and responses to perturbation detected at the species level, ought also to be detectable at higher levels. If allopatry is not the predominant mode of speciation, and ecological differentiation between sister taxa is rife, then reducing the data (to, for example, groupings of sister species or monophyletic genera) would destroy any species-level pattern of response.

In a study on pollution-related changes in chironomid communities, Waterhouse and Farrell (1985) examined the effect of taxonomic rank, contrasting species with generic level. The high correlation found between similarity values at species and genus level was ascribed to the ability of distribution patterns of the robust species to withstand the random information loss from data reduction rather than to any inherent similarity of congeners. This explanation would seem to weigh against taxonomic reduction. However, as Waterhouse and Farrell (loc. cit.) recognised, the generic concept utilised was much broader than most chironomid systematists would recognise. The use of more subdivided (homogeneous) genera obviously would have resulted in less information loss when species data were collapsed to generic level. In studies of the marine macrobenthos, Warwick (1988a,b) found no loss of information when species abundance and biomass was aggregated to family level and agreement was found even at phylum level. Warwick (1988b) suggested that anthropogenic effects modified community composition at a higher taxonomic level compared with the species level replacements associated with natural environmental variation. Such detailed studies have not yet been undertaken in freshwater ecosystems, although Morris and Brooker's (1982) observations may be considered comparable.

The observation that members of a genus of Chironomidae, when believed to be monophyletic, predominantly do reflect rather similar ecologies is an indication that the process of speciation in the family probably did not involve extensive ecological differentiation. However, there may be an element of circularity here. Although higher taxonomic categories are purported to be monophyletic, based upon un-weighted character state distributions alone, this is not universally the case. For example, it has been difficult to avoid incorporation into the classification of pre-existing evolutionary ideas. Thus the movement of a group of animals into a new ecological niche often results in corresponding morphological differentiation ('adaptation'). If systematists emphasise these characters more than others, then evolutionary grades, not clades, are recognised. It is vital that the cladogram, the portrayal of pattern, to be tested against ecology (and therefore 'evolution') is constructed without undue emphasis of elements pertaining to process.

Once again, it is fundamental that species be recognised first and their phylogenetic relationship assessed before attempts are made to introduce rigour into the reduction
of the level of taxonomic determination. Such studies are underway, but results will not be rapid – there are no instant answers.

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References

