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Selecting Indicator Taxa for the Quantitative Assessment of Biodiversity

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SUMMARY

Introducing greater objectivity to selection of indicator taxa produces results that are likely to reduce uncertainty, be more efficiently obtained and more clearly communicated. Seven criteria are presented that can be used to objectively test the claim that a given taxon is an ideal indicator: (i) well known and stable taxonomy; (ii) well known natural history; (iii) readily surveyed and manipulated; (iv) higher taxa broadly distributed geographically and over a breadth of habitat types; (v) lower taxa specialized and sensitive to habitat changes; (vi) patterns of biodiversity reflected in other related and unrelated taxa; and (vii) potential economic importance. These criteria have different priorities depending on which of two general categories of biodiversity the indicator taxon is to be used. Monitoring places an emphasis on sensitivity to habitat change, and inventory places an emphasis on systematics. An index is suggested by which the results of selecting an indicator taxon can be more accurately communicated. This index is based on the number of criteria that are successfully tested for the proposed indicator and their priority.

1. INTRODUCTION

Biodiversity as a focus for conservation efforts has received increasing attention (Wilson 1988; Noss 1990; Erwin 1991). To test for pertinent patterns of biodiversity, various levels of study have been proposed that include ecological communities (Hunter *et al.* 1988), cladistic classifications (Vane-Wright *et al.* 1991), a hierarchical composite of different levels of organization (Noss 1990) as well as groups of taxonomically related species (Holloway & Jardine 1968). Although the inherent complexity of such studies is not unique to biodiversity, the time limits and role in public and political decisions are (Maguire 1991).

Because of such pressures, studies of biodiversity have often relied on subjective approaches to understanding and resolving problems. At least three powerful reasons argue for changing this philosophy and relying on objective approaches (Platt 1964; Murphy & Noon 1991):

1. *Rigorous results are most likely to reduce uncertainty.* Uncertainty is an integral part of all science. The application of critical thinking and quantitative tests can be essential to reducing this uncertainty (Romesburg 1981; Murphy 1990). Among the scientific community, the strength of a field is judged generally by the degree to which this uncertainty has been reduced. Those studies or fields that do not use a critical approach are often termed 'soft' science. Conservation studies are not inherently soft, and conservation biology must come to rely on critical and rigorous scientific investigation whenever possible (Murphy 1990).

2. *Lack of funds and time demand the most efficient research method possible.* Developing predictions with focused quantitative tests dictate relatively narrowly those data that must be gathered. Alternatives to this model involve a generally less efficient method whereby broad data types are gathered and then patterns are sought (Platt 1964). The result is that a large proportion of the data are not utilized. Although it is possible to find useful results in this manner, a large proportion of the time and effort is used inefficiently. In conservation studies, lack of funds and time dictate that any inefficient effort must be avoided.

3. *Clarity of communication of results and generalizations to both the scientific and non-scientific communities are necessary.* Accurate communication of scientific results is essential. The development of clear operational definitions for terminology is key to communication.

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An objective approach is the least ambiguous way in which to present and comprehend results (Murphy & Noon 1991). It is more consistently structured than alternative subjective approaches, and once learned, it reduces the chances of misunderstanding and misinterpretation by fellow scientists and lay people (reporters, lawyers, politicians).

The goal of this paper is to establish rigorous guidelines for selecting indicator taxa based on objective tests, especially in developing standards of repeatability and reliability.

2. PROBLEMS AND SOLUTIONS

For conservation biologists normal scientific problems often are confounded by political pressures. Thus solutions often are innovative and unconventional (Murphy 1990). One innovative, albeit controversial, area of biodiversity that has received considerable attention is in the use of indicator taxa (Landres *et al.* 1988). By focusing studies on a small but representative subset of the habitat or ecosystem, patterns can be more quickly and clearly distinguished.

The vast majority of indicator taxa have been selected by two processes that rarely rely on criteria that deal with scientific issues. First, rare and endangered taxa have become indicators by default because of legal processes. Besides the problems of a taxon thrust into the category of indicator regardless of its appropriateness, these rare and endangered taxa are often divisive. Public pressure generally focuses virtually all efforts on the taxon itself and not what it is supposedly indicating: habitat degradation, ecosystem decline, species distribution patterns, etc. Second, some taxa have been defined by scientists as indicators solely on the basis of familiarity with them through research in other or related areas of interest. This type of choice is one of expedience, and rarely is any other consideration given as to how appropriate this taxon is in meeting the often distinct and unique features of an indicator (Pearson & Cassola 1992).

Although no single species or taxon can be expected to adequately represent or indicate patterns for all other species and taxa, logistical and biological criteria that are desirable to maximize the generality of indicator organisms include (Noss 1990, Pearson & Cassola 1992): (i) taxonomically well-known and stable so that populations can be reliably defined; (ii) biology and general life history well understood: limiting resources, enemies, physical tolerances, and all stages of the life cycle available to readily incorporate into hypotheses and experimental design; (iii) populations readily surveyed and manipulated such that tests are logistically simple and inexperienced students and non-professionals can be trained easily to help conduct studies; (iv) at higher taxonomic levels (order, family, tribe, genus), occurrence over a broad geographical range and breadth of habitat types so that results will be broadly applicable; (v) at lower taxonomic levels (species, subspecies), specialization of each population within a narrow habitat is likely to make them sensitive to habitat change; (vi) some evidence that patterns observed in the indicator taxon are reflected in other related and unrelated taxa; and (vii) potential economic importance of some populations so that scientists and politicians, especially in developing countries where pure or basic science is frequently considered a luxury, can be convinced that this taxon is worth dedicating local personnel and resources for studies.

The priority for these seven criteria, however, is not fixed. Although each situation is likely to be somewhat unique and demand its own prioritization of criteria, virtually all biodiversity studies can be placed into one of two distinct but interrelated categories. These two categories differ in their objectives and thus in the general priority of the criteria applied to potential indicator taxa (Kremen *et al.* 1993). First, *monitoring studies* evaluate changes in habitats or ecosystems over time, such as habitat degeneration (Noss 1990; Spellerberg 1991; Murphy & Noon 1992; Kremen 1992). Here high priority for potential indicators is placed on sensitivity to environmental changes. Second, *inventory studies* record the distributional patterns of taxa or ecological units over geographical space, generally for establishing conservation areas (McKenzie *et al.* 1989; Kremen 1994). Here high priority for potential indicators is placed on strong phylogenetic and biogeographical history such as endemism, co-occurrence, and centers of evolution (Erwin 1991). The priority position of the other criteria, or if some criteria can or must be ignored, is determined by the immediacy of the particular situation.

For instance, among animal taxa, the preponderance of studies using indicator taxa has relied on vertebrates, especially those 'species of high public interest' (USDI 1980). Vertebrates, however, tend to be relatively long-lived, have low rates of population increase, long generation times, and comparatively low habitat specificity (Murphy *et al.* 1990), all of which tax the time and finances for proper investigation. As a result there is a contemporary trend to use arthropod species, especially insects, instead of vertebrates as often more appropriate indicator taxa (Pyle *et al.* 1981; Samways 1990).

Recently in Manaus, Brazil, a meeting of many of the active biological researchers in the Amazon sought to establish the relatively simple distribution of pockets of high and low species numbers for various plant and animal taxa across the basin. With these data an initial list of priority areas for conservation could be established with those areas exhibiting high species numbers across many taxa of the highest priority. Some accord was found (Kuliopulos 1990), but for most taxa, high diversity was often associated with the presence of a biological field station. Whether many of the intervening areas with relatively low species numbers actually had few species or were simply understudied was unclear.

To adequately census diversity across the Amazon Basin in a relatively unbiased manner with most sufficiently well-known taxa, such as birds or butterflies, it would take decades. A group such as tiger beetles, however, could probably be surveyed in five to ten years (Pearson 1988, 1992).

Even though the primary function of indicator taxa is to simplify complex problems, in themselves the application of numerous criteria, different categories, and varying priorities does not simplify how indicator taxa are to be selected. To reduce uncertainty, increase efficiency and ensure clarity of communication, objectivity is essential for selecting appropriate indicators. Eventually all indicator studies should justify selection of a taxon based on quantitative tests of the claim that this taxon is an ideal indicator taxon. The minimum tests can be quantitative comparisons of the candidate taxon against each of the various criteria listed above. Failure to eliminate the taxon as ideal for all criteria is the goal. Only when a particular criterion can be shown as extremely low in priority for that particular situation, is there justification for ignoring weak results or a rejection of a test. To date remarkably few studies using indicator taxa have followed this procedure (Pearson & Cassola 1992).

As the data gathered by conservation biologists are scrutinized and used by a broader and broader spectrum of policy makers, expediency is no longer a sufficiently valid argument to continue haphazard choices. Choosing a single taxon as an indicator is complicated, but even more complicated is that in the future a single indicator taxon will likely be considered insufficient. Future action plans will demand a suite of indicators from unrelated taxa (plant, invertebrate, vertebrate) or representatives from each trophic level in the system under study. Each of these indicators needs to be chosen deliberately. To anticipate this increase in complexity some initial studies are needed to serve as models and to validate the criteria for choosing indicators within the context of various categories and priorities. For instance, are these seven criteria the only appropriate ones or should there be substitutes or additions? Without this minimal validation process, the frequently uncritical choice of indicators will have negative impact both politically and scientifically.

3. SUGGESTED TESTS FOR CRITERIA

Because of the breadth and complexity of potential factors involved in conservation problems, some degree of flexibility in applying criteria to the selection of indicators is necessary. However, for the sake of efficiency, comparison and communication some standardization of tests is also necessary. Following Pearson & Cassola (1992), tests of criteria that meet these requirements are:

1. *Taxonomically well-known and stable.* Regional and world-wide check lists and revisions of a taxon would serve as an initial test of how well known it was. A more quantitative comparison of the stability of the taxon is to determine the per cent of taxonomic synonymies in subsequent revisions. The most stable taxa, such as birds, butterflies and tiger beetles tend to have less than 10% synonymy.

2. *Biology and general life history well understood.* Although it is difficult to quantitatively establish which taxa have well-known biology and natural history, the breadth of studies on the taxon from around the world would serve as a demonstration of the level of this knowledge. Review articles, newsletters, and journals dedicated to the biology of a taxon are generally present for the best known groups.

3. *Populations are readily surveyed and manipulated.* Quantification of this criterion could include cumulative species numbers over hours or days of observation compared to total species lists for the area. If an asymptote cannot be reached within several weeks or months, it likely not to be an appropriate taxon. If the taxon is difficult or expensive to capture, mark or observe, it is unlikely to be useful as an indicator. If it takes years of training to learn to identify, observe or capture the taxon, it is unlikely to be a useful taxon, especially in developing countries.

4. *Higher taxa occupy a breadth of habitats and a broad geographical range.* Published data, label data from museum specimens and unpublished field notes can be used to test how widely the taxon occurs geographically and over what range of habitat types. Taxa that occupy only a narrow habitat type or occur in a limited geographical range may serve as appropriate indicators for small local conservation problems, but they are less likely to be appropriate for broader problems. The cost effectiveness of studying an indicator taxon for which the results are not applicable to other regions and habitats except by indirect extrapolation is generally less useful.

Numbers of species in biogeographical regions as well as the number of species and endemic species in each of the countries of the world has biological as well as political ramifications for potential indicator taxa (Collins & Morris 1985). Non-biologist decision makers are more likely to respond to taxa that are uniquely represented in their country; in disproportionate abundance or alternatively in only small remnants. These decisions are clearer when an obvious frame of reference is available by direct comparison to other countries.

5. *Specialization of each population within a narrow habitat.* The habitat specialization of populations and species can be quantified from published information. If habitat types are unambiguously defined, the breadth of habitat types occupied by each can usually be quickly determined. Among insects, this breadth is generally much less than among vertebrates. Regional revisions of tiger beetles, for instance, include habitat types for each species, and usually less than 1% occupy more than one obvious habitat type (Pearson & Cassola 1992).

6. *Patterns observed in the indicator taxon are reflected in other related and unrelated taxa.* Obviously if a taxon is going to be selected to reveal patterns for other taxa, any evidence that the potential indicator actually reflects significant patterns among other taxa is vital. For monitoring studies, an indicator taxon should show patterns of response to factors such as pollution and habitat degradation that presage those of other members of the community, habitat or ecosystem. For

inventory studies an indicator taxon will have patterns such as species richness and biogeographical dispersal that are common to many other taxa.

7. *Potential economic importance*. The sociological justification associated with indicator taxa is often one that requires mollification more than major economic impact. Without minimizing the significance of this criterion, even economic potential and minimal economic impact may be sufficient to rebut objections that might have eliminated an otherwise ideal indicator taxon.

4. CONCLUSIONS

The next logical step in making the selection and use of indicator taxa more useful is the introduction of an index. If the seven criteria above are accepted as pertinent, each potential indicator taxon could be tested and then given a rating calculated from the number of criteria which could not be rejected. Criteria could be weighted to take into account their differential importance. A simple number or letter could be applied to that taxon so that anyone reading a published article, a government report or a newspaper article could instantly recognize the reliability of the conclusions or recommendations based on this taxon.

As a preliminary step toward establishing a simple index, the seven criteria can be ranked with the least important criteria first and the most important last for each of the two biodiversity research categories:

Monitoring
1. Economic potential
2. Occurs over a broad geographical range
3. Patterns of response reflected in other taxa
4. Biology and natural history well known
5. Easily observed and manipulated
6. Well known and stable taxonomy
7. Specialization to habitat

Inventory
1. Economic potential
2. Specialization to habitat
3. Biology and natural history well known
4. Occurs over a broad geographical range
5. Patterns reflected in other taxa
6. Easily observed and manipulated
7. Well known and stable taxonomy

I present here one simple procedure by which a standardized but flexible index could be determined. The rank numbers are added for all criteria tested and not rejected. In this case the seven criteria would have a potential maximum number of twenty-eight. The percentage of this maximum for the taxon being tested as an indicator would then be used to place it into one of four classes. For example, greater than 90% = class A; 75–89% = class B; 55–74% = class C; and less than 55% = class D. This index is flexible in that criteria can be re-ranked before the testing to more accurately reflect the specific circumstances for that situation. These seven criteria can also be supplemented with other criteria and ranked as special circumstances dictate. A justification of the ranking and the addition of criteria will make the index open to critical evaluation.

Conservation scientists do not carry out their studies in a vacuum or only for the sake of colleagues conducting similar studies. Their primary goal is to anticipate public debate, sociological impact, economic balance, as well as management (Murphy & Noon 1991). To this end scientific robustness and efficiency of data gathering are only as useful as their ability to be communicated to non-scientists.

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