

“INDICATOR” TAXA IN INVERTEBRATE BIODIVERSITY ASSESSMENT

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Abstract

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The concept of indicator taxa, widely used in environmental monitoring, has been adopted in the biodiversity assessment literature. Such a transfer can be misleading: such surrogate measures for biodiversity are referred to better as “predictors” — taxa proposed as correlates of wider biodiversity. Using survey data from a sampling protocol applied to five sites in north-east Tasmania, species diversity of terrestrial arthropods were investigated to assess the prospects for ranking sites in systems that are rich in species with poorly known taxonomy, and that change seasonally and erratically. No significant species-richness correlates were found, suggesting that there can be no generalised application of the concept of indicators of biodiversity.

Introduction

Most biodiversity estimates for terrestrial sites have been based on species counts or estimates of abundance in angiosperms (flowering plants) and vertebrates (mostly birds and mammals, although to a lesser extent reptiles and amphibians). Although conspicuous and relevant in terms of human amenity value, these taxa account for a very small percentage of all the world’s species. Site biodiversity estimates that do not consider invertebrates, not only omit the greatest part of what they purport to measure, but also ignore the major contributors to essential ecosystem processes — “the little things that run the world” (Wilson, 1987).

Whilst there is substantial agreement on their significance, precisely how to include invertebrate taxa in biodiversity estimation and conservation is far from evident. Given the huge diversity, and the variable, but usually poor, taxonomic knowledge of so many invertebrates, Australians particularly have advocated certain rapid biodiversity assessment methods (e.g., Oliver, 1993; Oliver and Beattie, 1994; Beattie and Oliver, 1994). Some aspects of this “pseudotaxonomy” have been critically addressed (e.g. Brower, 1995; Campbell, 1995; Cranston and Hillman, 1992; Hammond, 1994; Trueman and Cranston, this volume). Another suggestion for more rapid assessment might be to identify one or a suite of taxa, amenable to easy sampling and identification, whose diversity predicts the diversity of others. This concept has been referred to as “surrogacy” (e.g., RAC, 1993) or as “indication” (e.g., Noss, 1990; Brown, 1991;

Kremen, 1992; Pearson and Cassola, 1992; Williams and Gaston, 1994; Beccaloni and Gaston, 1994; Weaver, 1995) of biodiversity. However, the poorly tested concept of biodiversity “indication” frequently is conflated (*inter alia* by Kremen et al., 1993; Pearson, 1994) with the firmly-established environmental “indication” (e.g., Holloway and Stork, 1991; Cranston and Hillman, 1992; Johnson, 1995). We adopt Kitching’s (1993) terminology of “predictor set” for any subset which is postulated to act as a “surrogate” for the wider, unsampled, complete set.

If the diversity (taxon richness) of traditionally-measured taxa (angiosperms, vertebrates) were to correlate strongly with invertebrate diversity, then it would be valid to assume that conservation of taxon-rich areas for conventionally-surveyed “predictor sets” would provide an “umbrella” to protect the unsurveyed invertebrates. However, the strength of any correlations has, until recently, rarely been addressed directly, and the few results seem contradictory. Thus, Abbott (1974) found 73% of the variation in insect species was accounted for by the number of plant species but no statistical relationship between insect and bird species of remote southern hemisphere islands. The lepidopteran subfamily Ithomiinae correlated well with total neotropical butterfly diversity (Beccaloni and Gaston, 1994) although correlates of butterflies against other prospective indicators were not tested. In contrast, the studies of Yen (1987), on plant/vertebrate/bird relationships across 32 sites in Victoria, Australia, and in U.K. of Disney (1986) on insect / plants and of

Prendergast et al. (1993) on certain insect/plant/bird relationships, demonstrated little or no correlations. Problems of scale dependence have been identified by Williams and Gaston (1994), who argued that for vertebrate data the few local correlates fail to coincide at global scale, and Weaver (1995), who sampled higher taxonomic groups of invertebrates.

Following the advocacy of Landres et al. (1988), Noss (1990), Longino (1994) and DEST (1995), amongst others, for verification of biodiversity indicator relationships, we specifically test whether:

1. diversity measures obtained from a single arthropod taxonomic group or groups ("predictors" *sensu* Kitching, 1993) predict the diversity of other diversity measures obtained from a single arthropod taxonomic group or arthropod taxa at the same site; and

2. measures of arthropod diversity are congruent with measures based on a conventional diversity estimator, namely diversity of flowering plants.

Methods

Sites

Five sites (A-E), representing the range of natural vegetation types along a 40 km transect in NE Tasmania, were selected to traverse four major terrestrial ecosystems of the ERIN 30-group regionalisation (Thackway and Cresswell, 1992). Sites established were in wet sclerophyll forest (Site A, 3 km N of Weldborough, 41°10' S, 147°54' E) dry sclerophyll forest (Site B, 20 km E of above, 41°09' S, 148°08' E); coastal heathland (Site C, Eddystone Point, Mount William National Park, 41°00' S, 148°19' E.); periodically inundated heath (Site D, Mount William National Park, 41°02' S, 148°15' E.); buttongrass swamp (Site E, Rattrays Marshes, 41°12' S, 148°10' E.). Three of the sites had associated aquatic systems, streams at A and B, swamp at E; site C had an impermanent dune slack (pool) whilst site D was dry. The five sites are such that any reasonable sampling protocol or biodiversity index should be capable of indicating that there are gross differences amongst them, although this should not be taken to mean the respective conservation values necessarily differ widely.

Sampling design

Ten pitfall traps and two yellow pan traps of standard design were set at each site in each of February, May and August, 1993 (Trueman and Cranston, 1994). Pitfalls were opened for 1 week

and yellow pans for 24 hours on each sampling occasion. In February only, ten small pitfall traps of different design were set and equal-effort vacuum samples were taken. Yellow-pan traps on a black background were set in August for comparison against conventional traps. Leaf litter samples were taken at two forested sites on each sampling occasion, and arthropods extracted from the samples over a 1 week period in Tullgren funnels.

All animals from each sample were extracted and identified to ordinal level (insects) or to phylum or other appropriate category (other arthropods). Specimens were counted, identified to Recognisable Taxonomic Unit (RTU) by project personnel inexperienced in the taxonomic group, prepared as necessary for formal identification, and identified by consultant expert taxonomists where available (see *Acknowledgements*). Specimens are deposited in the Australian National Insect Collection, excepting where provided to taxonomists for their ongoing studies.

Results

The observed numbers of species at each site are listed in Table 1. Odonata, Coleoptera and Diptera comprise only adult insects; Diptera is of observed families, not species. Totals are accumulated over all trapping methods, and therefore are not directly comparable as between the two forested sites (A, B), where leaf litter samples were taken, and the others.

It is immediately apparent from Table 1 that there is no correlation amongst site rankings for these 11 taxa based on these data. Each row of the table places the five sites in a different rank order. If the numbers of identifiable species per site can be taken as estimates of species richness it is clear that the answer to the question "Which site is most diverse?" depends entirely upon which taxa are chosen to represent diversity.

There are few points of agreement within Table 2 except that both Amphipoda and Coleoptera give site ranking ABCDE, both Acari and Diptera give CBADE, and both Chilopoda and Diplopoda repeat the CBA — signal. Each other taxon gives a different site ranking. Of the taxa identified to species level (and listed in Table 1), only Coleoptera gives the same site ranking (ABCDE) on both the species-number and ordinal-abundance measure.

Table 3 demonstrates that site rankings vary according to taxonomic expertise, with RTUs (Trueman and Cranston, this volume), sometimes providing different site rankings to

Table 1. Numbers of identified* species by site; abundance and ranking of sites for each group. (Pooled observations; three sampling periods and all trapping methods)

Taxon	Site					Total	Rank
	A	B	C	D	E		
Diplopoda	7	5	4	0	0	10	ABC —
Chilopoda	3	7	3	0	0	9	BAC —
Araneae (Feb. + May)	19	28	17	7	6	54	BACDE
Collembola (Feb. only)	46	34	25	16	19	78	ABCED
Thysanoptera	2	11	6	4	4	17	BCDEA
Odonata	1	1	6	2	9	14	ECDAB
Coleoptera (Feb. + May)	63	46	18	13	10	132	ABCDE
Diptera?	13	18	25	18	20	32	CEBDA
Chironomidae: Feb only	18	12	5	-	7	35	ABEC -
Formicidae	7	15	21	11	9	36	CBDEA
Other Hymenoptera	42	47	10	7	10	113	BACED
TOTALS: all taxa	221	225	140	78	94	530	BACED

*NB: The category "identified" does not equate to "Fully Named". Up to one-half the specimens in most taxa could be identified only to a species number, a voucher collection number or some similar code.

? Terrestrial taxa, family level

Table 2. Numbers of specimens by site and "order". Large pitfall traps, combined totals for February, May and August

	Site					Rank
	A	B	C	D	E	
Amphipoda	194	149	44	13	11	ABCDE
Aeari	233	248	290	156	101	CBADE
Araneae	63	107	88	28	13	BCADE
Opilionida	16	11	97	4	1	CABDE
Chilopoda	1	2	14	-	-	CBA —
Diplopoda	7	11	20	-	-	CBA —
Collembola	563	694	414	238	375	BACED
Orthoptera	7	5	771	9	-	CDAB -
Hemiptera	43	7	38	11	12	ACEDB
Thysanoptera	1	-	16	2	13	CEDA -
Coleoptera	106	103	61	22	19	ABCDE
Diptera	137	152	194	84	63	CBADE
Lepidoptera	4	6	6	5	14	CDBA -
Formicidae	20	37	370	162	22	CDBEA
Other Hymenoptera	15	42	42	9	4	CBADE

Table 3. Site rank orders for species numbers against RTU for representative taxa and samples.

		A	B	C	Site D	E	Rank
Araneae (Feb)	RTU	30	10	12	6	4	ACBDE
	Spp.	14	24	11	5	4	BACDE
Araneae (May)	RTU	10	15	1	9	5	BACDE
	Spp.	16	21	16	5	4	BACDE
Chilopoda (all)	RTU	2	4	3	-	-	BCA —
	Spp.	3	7	3	-	-	BCA —
Diplopoda (all)	RTU	11	5	7	-	-	ACB —
	Spp.	7	5	4	-	-	ABC —
Collembola (Feb)	RTU	23	16	11	10	11	ABCD
	Spp.	51	31	24	15	18	ABCD
Thysanura (Feb)	RTU	-	6	5	3	6	BECD -
	Spp.	-	7	3	3	4	BECD -
Thysanura (May)	RTU	-	12	3	1	1	BCDE -
	Spp.	-	7	4	1	1	BCDE -
Formicidae (Feb)	RTU	8	12	16	9	7	CBDAE
	Spp.	5	12	17	11	6	CBDEA
Coleoptera (May)	RTU	37	17	9	5	3	ABCDE
	Spp.	36	17	9	5	3	ABCDE

taxonomist's species (e.g., spiders, Collembola). Furthermore, site rankings change with season (e.g., spiders in February and May).

Plants

The lists of plant species can be summarised as follows:

Site A: Four tree species present (*Eucalyptus regnans*, *Nothofagus cunninghamii*, *Atherosperma moschatum*, *Acacia dealbata*), and eight understorey vascular plants. Several mosses, lichens and fungi (i.e., a relatively large non-vascular component). Total: 12 species of vascular plants within the area from which the invertebrate samples were taken.

Site B: One species of large tree (*Eucalyptus sieberi*), nine identified understorey and ground plants and a number of other small vascular plants lacking fruiting bodies, etc. and so not fully identifiable to species level at this time of year. Total: 10 identified (to species) and approximately 15 species of vascular plants within the sampling area.

Site C: One tree species (*Eucalyptus amygdalina*) plus 35 shrub and ground-cover species, plus six other shrubs and ground covers. Total: at least 42 species of vascular plants within the sampling area.

Site D: One tree species (*Eucalyptus amygdalina*) located just outside the sampling area, plus six shrubs and 23 other plants identifiable to

species level and several other not fully identifiable sedges, pea-flowering genera and orchids. Total: at least 35 species of vascular plants within the sampling area.

Site E: One dominant plant (buttongrass: *Gymnoschoenus sphaerocephalus*), four identifiable trees or shrubs plus some unidentified sedges. Total: 6–8 species of vascular plants within the sampling area.

We took the absolute number of vascular plant species at sites A–E as being 12, 15, 42, 35 and 7 species, respectively, giving site rank order CDBAE.

Discussion

Specific hypotheses

We set out to test two specific hypotheses, namely:

1. there exist predictor set(s), defined as one or more groups of taxa the diversity of which predicts the diversity of other taxa;

2. there is a relationship between arthropod diversity and the diversity of conventionally surveyed taxa.

Table 1 demonstrates the virtually complete lack of correlation in rank order of sites as measured by the numbers of species (or, for Diptera, families) in different orders or other higher categories. Table 2 shows the lack of correlation in rank order of sites measured by the numbers

of specimens observed by pitfall trapping. Table 3 showed, *inter alia*, that species site rankings and RTU site rankings each vary considerably across sampling occasions, at least for some taxonomic groups. We also noted seasonal differences in the patchiness (clumping) of some taxa, and patterns related to trapping method.

Exploratory statistical analyses, conducted to investigate these hypotheses in greater depth, confirm and further quantify these general findings. That is:

1. although the possibility of biodiversity predictors cannot be denied, as yet we have failed to discover any taxon or subset of taxa which could be used to predict the diversity of other taxa across our sample of five sites;

2. there is no close correlation between arthropod diversity and diversity as measured by a count of the vascular plant species at each of our sites (at least for the majority of arthropod taxa).

Predictor sets

In relation to the search for indicators, New (1993) has suggested an "ecological" approach to defining which subsets of taxa are most suitable in biodiversity assessment and monitoring. The best suite would give "sound and subtle ecological information: concentrating on the groups of invertebrates sensitive to environmental change and whose incidence and abundance can thereby be used to assess and ensure the well-being of Earth's major ecosystems" (New, 1993: 626). Further important qualities for the selected taxa would include having a well-established taxonomy, being geographically widespread and abundant, being habitat-specific and being amenable to sampling. Other authors (e.g., Kremen et al., 1993; Pearson, 1994; Stork, 1994) have offered similar lists of desirable and/or required attributes, usually adding "ecological" or "trophic" diversity to the attributes listed in New (1993). To date, no author has suggested a specific "basket" of taxa which would have the attributes being sought.

Others have taken a single-taxon approach, giving reasons why their own specialist group is a good indicator, either of diversity or else environmental change. The most commonly studied taxa worldwide include butterflies, selected beetle families, spiders, bees and ants. In Australia, the use of ants as an indicator of terrestrial invertebrate diversity has been suggested (Greenslade, 1985; Andersen, 1987, 1990), as has use of *Collembola* (e.g., Greenslade, 1993). Ubiquity, ease of sampling, high

intra-group diversity and high ecological importance have been among the arguments used to justify these choices. However, although the diversity in each taxon shows undoubted relationships with ecological variables that may themselves be important in land management decisions, in no case is the capacity to predict meaningful components of the diversity of other taxa more than an untested assertion.

None of the authors cited above has distinguished between environmental indication and biodiversity prediction, as alluded to in our introduction. None-the-less it is instructive to examine the performance of the commended groups as predictors. The results presented in Tables 1-3 indicate that, for our five study sites, neither ant nor collembolan species richness predicts anything. Further, the discrepancies amongst site rankings for different taxa are such that no taxon or subset of taxa from amongst those which we were able to evaluate gives site rankings which predict the rankings obtained from other taxa. There is no evidence here for taxa which could be used as a predictor set.

Congruence with conventional estimators

Comparing site rank order for plants and invertebrate animals, there is little congruence. A test of statistical significance for rank order correlation among sites is available (e.g., Southwood, 1978: 280-282), but owing to the small sample size (five sites) requires complete agreement in rank order, without ties, to achieve the 95% confidence level. The site rank order for plant species (CDBAE) exactly matches that for ants (Formicidae), as shown in Table 1. We can conclude that ant species diversity and plant species diversity are well correlated. The ordinal signal for ants in large pitfall traps (site rank order based on numbers of specimens rather than species: Table 2; CDBEA) almost matches this pattern, and the RTU estimate from the February samples (all trapping methods, RTU count: Table 3; CBDAE) again is close, disagreeing only in the relative positions of sites B and D although the corresponding count of actual species (Table 3: CBDEA) differs at both DB and AE. Thus, sampling by more than one trapping method and across more than one sampling period may be necessary in order to recover the plant species diversity signal using ants as a surrogate.

Conclusions

It is imperative that for Australia's considerable biological diversity to be properly assessed,

managed and conserved, the major components of that biodiversity must be measured in relevant ways and within an acceptably short time frame. Current biodiversity assessment practice, in Australia as elsewhere, has focussed on vertebrates and flowering plants to the virtual exclusion of the more abundant, diverse, and in many cases ecologically more important invertebrate animals. A grossly insufficient "species richness" signal is obtained from the vertebrates and angiosperms alone.

Concentration on a narrow set of large and charismatic organisms stems from a perceived lack of knowledge of, and appropriate methods for assessing, the contribution of invertebrate richness to biodiversity value, although this is refuted by Coddington et al., (1991), Longino (1994) and Hammond (1994), amongst others. An additional misconception is the belief that actions designed to protect charismatic taxa will also protect invertebrates.

It is an attractive concept that there may exist certain taxonomic groups that can act as predictors of biodiversity in general. Indeed, we might expect such taxa if the historical factors that lead to differential and concerted patterns of survival and extinction between areas, operating across a range of unrelated taxa, lead to congruent patterns of species richness across taxonomic groups. Thus, high speciosity might be expected in areas (sites) where sustained benevolent conditions have promoted long-term survival and allowed complex mutualistic associations to develop (areas that may be termed refugia). Relatively low species richness across many taxa might be expected where adverse or fluctuating conditions have promoted community instability, causing high rates of species turnover and extinction and providing reduced opportunities for the development of coevolutionary complexity. The fact that we were unable to identify any predictor sets is no guarantee that such sets cannot be found. Undoubtedly, some patterns of correlation exist and they may well be useful in biodiversity assessment, at least in some biological systems, and further study is warranted.

We concur with recent advocacy of practical approaches to species richness assay (e.g., Hammond, 1994; Longino, 1994; Colwell and Coddington, 1995), but are not of the view that species richness, *per se*, is sufficient indicator of conservation value. Since assessment of invertebrate species richness remains fraught with difficulties caused by seasonality, cryptic behaviour, and stochasticity in invertebrate assemblages, measures of the class we have been

investigating may never, of themselves, give sufficient information on which conservation decisions can be based.

Why should a modern "snapshot" of a constantly shifting equilibrium between processes of continuity and change, species formation and extinction, be expected to provide a firm basis for the allocation of conservation resources? Is a species-poor community from an extreme environment (or, for example, from an island with naturally limited diversity) worthy of less conservation effort than is a highly diverse community? Inevitably, decisions on relative values of richness will be partially subjective, leading to development of more objective ideas, such as those concerning complementarity and phylogenetic measures of taxonomic diversity (e.g., Vane-Wright et al., 1991; Faith, 1992; Crozier, 1992; Margules, 1992).

Assessments of biological diversity need not necessarily be based solely on new survey data. A considerable physical database, including invertebrate taxa, exists in the form of museum and herbarium collections, and significant information on distributions, etc, is available in electronic form. Modelling tools (such as BIOCLIM, Busby, 1990) can be used to make site or area diversity predictions from such data, and at least for some taxonomic groups may substitute partially for new survey work. The current disadvantages of scattered repositories and shortage of electronically-stored data are being addressed for many taxa, although invertebrates lag behind vertebrates and angiosperms in coverage. A rapid field survey by way of testing (ground-truthing) the predictions of the models will, of course, still be necessary in all cases, first to correct for any mis-prediction and second to allow for anthropogenic or other changes in local conditions since the time at which data on which the prediction is based were collected.

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