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Ants (Hymenoptera: Formicidae) pass the bioindicator scorecard

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Abstract

Invertebrates are increasingly being used as biological indicators of land restoration success, land degradation, the conservation value of tracts of land, and much more. They are either used as indicators of the health and functioning of the environment (ecological and environmental indicators) or as surrogate indicators of the overall diversity or assemblage composition of other groups within an area (biodiversity indicators). In both cases, the particular taxonomic group that is used tends to be related to the preference of the researcher or to currently favoured taxa. This paper summarises the findings from two field studies that evaluated how well a series of invertebrate taxa performed as environmental or biodiversity indicators in regard to each other, and also to vertebrates and plants. These studies were performed on restored bauxite and mineral sand mines in Western Australia. At the bauxite mine, assemblage composition of spiders, true bugs (Hemiptera) and beetles tracked biophysical changes in the environment more faithfully than did birds, although the performance of plants was the best, and terrestrial vertebrates and ants were intermediate. Assemblage composition of ants, and to a lesser extent true bugs, beetles, and spiders all reflected trends in the composition of other groups to a greater extent than did plants, terrestrial vertebrates and birds. In terms of data-yield per hour spent in field and laboratory, most invertebrate groups represented a better return for effort than did terrestrial vertebrates, but not plants. Trends were similar at the Iluka mineral sand mine. Overall, taking into account the data-yield per hour of effort, and the problem of dealing with immature forms in the case of spiders and true bugs, we conclude that ants perform moderately well as environmental, and extremely well as biodiversity indicators. The applicability of these results to other regions of the world and to other land-uses is discussed.

Key words: Ant, Formicidae, invertebrate, vertebrate, plant, bioindicator, cross-taxon congruence, mining, restoration.

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Introduction

Biological indicators, commonly abbreviated as "bioindicators", are species, groups of species, or other taxonomic units that can be used to measure some feature of the environment. In cases where they are used to measure the "health", "state" or "condition" of the environment they are termed environmental or ecological indicators (MCGEOCH 1998). In addition, certain groups may be used as surrogates for the diversity or assemblage composition of other taxa; these are referred to as biodiversity indicators (MCGEOCH 1998). Bioindicators are used to measure the conservation potential of areas, progress with minesite restoration, the degree of degradation of areas, rangeland condition and impacts of tourism, as well as impacts of many other land uses. Until recently, when considering terrestrial ecosystems, biologists have generally used plants as the primary source of bioindication, with a tendency to focus on the more charismatic birds, mammals, reptiles and amphibians if the fauna does happen to be considered (see BÜCHS 2003). Although invertebrates have long been used for the monitoring of the health of aquatic systems (HAWKINS & al. 2000), they were not formally proposed for use in terrestrial ecosystems until about 25 years ago (MAJER 1983).

The use of invertebrates has escalated since then, with examples being found in most regions of the world. Today, we see spiders, mites, collembolans (springtails), hemipterans (true bugs), beetles, ants, and many other groups all being advanced as excellent indicators of environmental features or of biodiversity. In Australia ants are by far the most commonly used group, and their value as bioindicators has recently been reviewed by ANDERSEN & MAJER (2004). The reader is referred to this paper, and references therein, for a full explanation of the justification of their role as bioindicators. In essence, their value stems from the fact that they are ubiquitous, highly abundant, diverse, of great functional importance, sensitive to environmental change, and are easily sampled. Although they are now commonly used throughout Australia, parts of Africa, North and South America, Europe and Asia, few data are available to test their effectiveness as bioindicators, particularly in relation to the potential value of other taxa.

The choice of taxon used as a bioindicator has tended to be influenced by personal interest in particular groups, availability of taxonomists, or simply which group has been "sold" most successfully for its potential as a bioindicator (see ANDERSEN 1999). But which taxa are the most effective, and which taxa are the most practical and inexpensive to handle? Several studies have endeavoured to answer these questions by drawing up lists of criteria for an ideal bioindicator and then considering the attributes of various taxa against this list (e.g., HOLLOWAY & STORK 1991, PEARSON & CASSOLA 1992, PEARSON 1994, BROWN 1997, HILTY & MERENLENDER 2000). There have been few convincing attempts to compare the effectiveness of plants, vertebrates and selected invertebrates in terms of their efficacy as bioindicators; some exceptions include OLIVER & al. (1998), DUELLI & OBRIST (1998), PALITZSCH LUND & RAHBEK (2002), SAUBERER & al. (2004), and ROHR & al. (2007).

Two recent studies in Western Australia have attempted to do this, using restored bauxite mines (ORABI 2006, MAJER & al. 2006) and mineral sand mines (BISEVAC 2003, BISEVAC & MAJER 1999, 2002) as the platform on which to make the comparisons. A comprehensive paper describing the outcome of the Worsley study is currently in preparation (G. Orabi & J.D. Majer, unpubl.; submission to Restoration Ecology intended), so it is not the intention of this paper to describe all of the results. Instead, we here summarise the main findings from these two studies, with particular attention being paid to the performance of ants in relation to plants, vertebrates, and other invertebrate taxa.

Methods

The studies were undertaken at the Worsley Alumina bauxite mine near Boddington, Western Australia (32° 48' S, 116° 28' E) (Figs. 1 - 3) and at the Iluka mineral sand mine near Eneabba (29° 49' S, 115° 16' E) (Figs. 4 - 6). At each minesite a chronosequence of 10 restored plots and four native vegetation controls was selected. The restored plots were stratified into five replicated time bands, referred to as "new", "young", "mid-age", "old" and "oldest" restoration, and were selected *a priori* to represent a clear maturation of the vegetation, the expectation being that the biota would track these visible changes in the vegetation. A 100 m transect was marked out in a representative part of each plot (Fig. 7).

At Worsley, but not at Iluka, a full set of environmental measurements was made along the transects. These included measurements on soil nutrients, plant stratification, floristic composition, and ground cover variables.

Along each transect, 10 plastic vials (43 mm diameter × 110 mm depth) were used as pitfall traps (Fig. 8). The traps were located at 10 m intervals and were left open for seven consecutive days and nights. Each pitfall-trap position was used as the starting point for vegetation suction samples (Fig. 9), which ran at right angles to the transect and into the core area of habitat being sampled. Each suction sample consisted of a 40 m walk away from the pitfall-trap position and a 40 m return walk, the latter aligned 2 m to the side of the original traverse. Invertebrates vacuumed off the plants were placed in containers of 70 % alcohol for sorting. Litter samples were also collected along transects and placed in large polyethylene bags for subsequent extraction of invertebrates using Tullgren funnels (Fig. 10). Sampling by each method was repeated five times at 3-month intervals These three sampling methods provided a relative estimation of the abundance and species richness of invertebrates on the ground (pitfall-traps), on the herb, small shrub and small tree strata (suction samples) and in the litter (Tullgren funnels).

Figs. 1 - 3: General views of (1) eucalypt forest vegetation, (2) young restoration (four yr.) and (3) older restoration (nineteen yr.) at the Worsley Alumina bauxite mine, near Boddington, Western Australia.

Figs. 4 - 6: General views of (4) heathland vegetation, (5) young restoration (three yr.) and (6) older restoration (nineteen yr.) at the Iluka mineral sand mine, Eneabba, Western Australia.

Invertebrate samples were sorted in the laboratory to broad taxonomic levels, with selected taxa further sorted to morpho-species level when represented by adult forms. The taxa involved were spiders (Araneae), "myriapods" (Chilopoda and Diplopoda), slaters (Isopoda), springtails (Collembola), true bugs (Hemiptera) (only at Worsley), ants (Formicidae), and beetles (Coleoptera). These taxa were then sent to taxonomists in the relevant areas for verification and allocation of generic and species names or morpho-species codes.

Plants and vertebrates were surveyed in the same plots, with the layout of quadrats and traps being integrated with the invertebrate sampling transects as shown in Figure 7. Plants were surveyed once by an independent consulting company and were mostly identified in the field; species

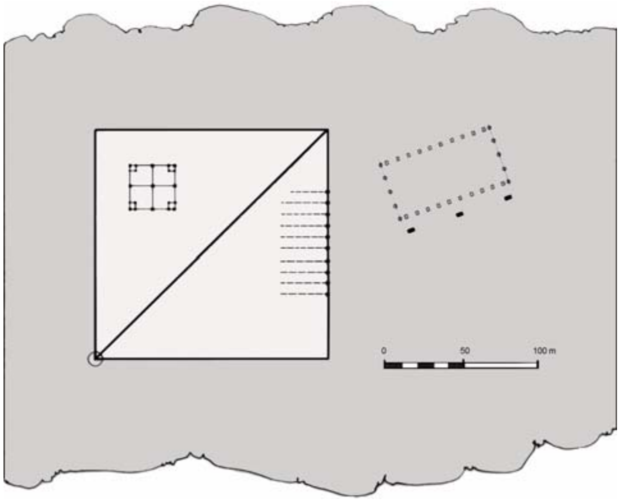

Fig. 7: Schematic diagram of sampling protocol of the type used in the flora and fauna surveys at Worsley and Iluka. The plants were surveyed in the large and smaller quadrats, the birds were surveyed by traverses around the large quadrat and across the diagonal, the terrestrial vertebrates were surveyed by pitfall trap, cage trap and box traps in the rectangle to the side of the large quadrat, and the invertebrates were surveyed by pitfall traps, suction sampling, and Tullgren funnels (see Figs. 8 - 10) along the transect on the right hand side of the large plant quadrat (adapted from ALLEN 1989).

that could not be identified in the field were collected for later identification. Vertebrate animals were also surveyed by local consulting companies, with most identifications being performed in the field. The data for birds were treated separately from the other vertebrates (amphibians, reptiles, and mammals), the latter being bulked together and referred to as terrestrial vertebrates.

All parts of the work, including those performed by consultants, were timed and expressed as time (in hours) per plot needed to perform each separate task. The cost involved in performing surveys using each of these taxa could then be estimated and related to the data-yield from each of these groups. Therefore, the possibility is created to set expectations on the quality of data that are going to be obtained for the planned budget.

The plant, vertebrate and invertebrate data were summarised for each plot using the commonly used species richness, species diversity and species evenness measures. In addition, the assemblage composition of the various taxa was compared between the various restored plots and controls by a detrended correspondence analysis (DCA) ordination procedure (HILL & GAUCH 1980) using the PC-ORD statistical package. A cross-taxon analysis was then performed to examine how the various taxa compared with each other in their ability to track changes in the characteristics of the environment. Cross-taxon congruence analysis involved the estimation of the relationship in assemblage composition of each taxon with each other taxon and with the overall combined environmental variables (MCKENZIE & al. 2000). Databases of plants, soil variables and plant structural variables in the Worsley plots were used and were combined to create the environmental variables matrix. Using Pearson product-moment correlation, the re-

Figs. 8 - 10: Methods used in the fauna surveys at Worsley and Iluka: (8) pitfall traps, (9) suction sampling, and (10) Tullgren funnels.

lationship between each pair of taxa was calculated. By doing this, it was possible to derive similarity matrices for each data sub-set, as well as for the combined environmental variables data-set. These matrices were represented as linear similarity vectors. This correlation matrix was converted to a dissimilarity matrix. Then, a minimum spanning tree was superimposed in order to indicate the nearest-

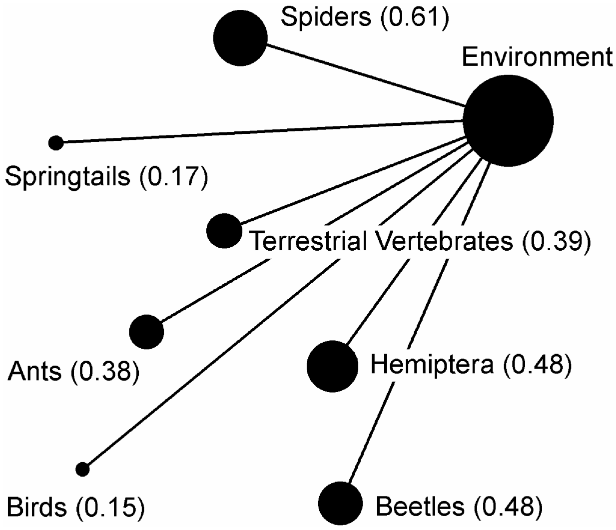

Fig. 11: Cross-taxon congruence analysis of the assemblage patterns derived from seven taxa with the environmental variables recorded in the ten restored and four forest control plots at the Worsley Alumina bauxite mine. A matrix of correlation coefficients was compiled from a pair-wise comparison of the relevant plot similarity matrices. The correlations of each taxon with the environment are shown in brackets and are also represented by the length of the lines and distance into the paper (shown by smaller dots).

neighbour in ordination space. This analysis was performed using the PATN statistical package (BELBIN 1995). The low species richness of Isopoda and the "myriapodous" groups precluded their inclusion in the ordination and cross-taxon analyses.

Since no environmental data were available for the Iluka study, a combined data-set of all plant, invertebrate, and vertebrate taxa was derived and used as a surrogate for the "environment" in the cross-taxon congruence analysis. This led to limitations on how well the environmental fidelity of each taxon in the Iluka study could be assessed, but it did enable an assessment of how well the changes in one taxon tracked the changes in the other taxa in the plots.

Results

The trends in species richness, diversity and evenness, and the seasonal patterns of the various taxa have been reported on elsewhere (BISEVAC & MAJER 1999, 2002, BISEVAC 2003, ORABI 2006, MAJER & al. 2006, G. Orabi & J.D. Majer, unpubl.), and are not the subject of this paper. Suffice to say that at both Worsley and Iluka the various invertebrate groups were highly seasonal, suggesting that sampling should be performed across a range of seasons so that the full complement of species is captured. Apart from the Isopoda and the "myriapodous" groups, most taxa exhibited interpretable trends across the chronosequence and between restoration and controls.

The plants, terrestrial vertebrates, birds, and most invertebrate groups all revealed patterns on the ordination diagrams (not shown here) that could be used to evaluate how the maturing restoration was beginning to resemble that of the controls in terms of the particular taxonomic group in question. However, evaluation of how well each taxon performed in relation to the others remains somewhat subjec-

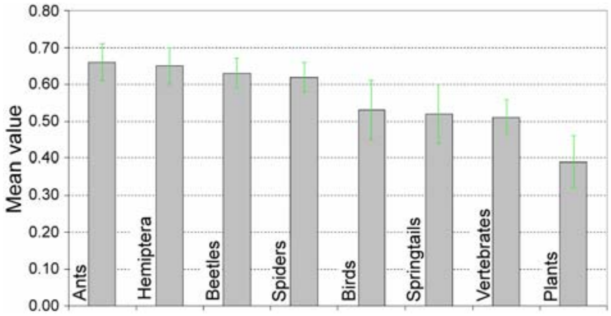

Fig. 12: Histograms of the mean (with error bars) of the correlation coefficients between assemblage composition of each taxonomic group with that of each other taxon that was sampled at the Worsley Alumina bauxite mine.

tive if the practitioner simply compares trends in one ordination diagram against those in another. It is here that the cross-taxon congruence analysis allows each taxon to be benchmarked against the rest.

Figure 11 shows the result for the Worsley study. Depiction of the relationships is difficult in two dimensions, so relationships with the environment are inversely related to the length of the lines and also to the size of the dots, with small dots indicating increasing distance into the page. The numbers in brackets indicate the correlations between the matrices of the various taxa with those of the environmental variables. At Worsley, spiders and true bugs were most highly correlated with the measured environmental variables (r = 0.61 and 0.58), followed by beetles (0.48), terrestrial vertebrates and ants (0.39 and 0.38), by springtails (0.17), and lastly by birds (0.15).

These correlations reflect the potential of each taxon to act as an environmental indicator. By contrast, the mean of the correlations between each taxon and each of the other taxa provides an indication of how much the variation in species composition of one group represents that of the others; in other words how well they act as taxonomic surrogates or, by extending the definition to include indicators of assemblage composition as well as diversity of other groups, as biodiversity indicators. Here, ants, true bugs, beetles and spiders all produced high correlations, followed by moderate but lower correlations for birds, springtails, and terrestrial vertebrates; plants had the lowest mean correlation with the other taxonomic groups (Fig. 12). At Iluka, ants and beetles were most highly correlated (both 0.90) with the combined biota data-set, followed by terrestrial vertebrates (0.82), springtails (0.79), birds (0.65), and spiders (0.59).

Table 1 shows the total species sampled within each taxon for the Worsley and Iluka studies and also the number of species that were obtained per plot per hour. The taxa are ranked on the basis of the number of species per plot per hour at the Worsley minesite. At Worsley, ranked in decreasing order of total species sampled, were plants, beetles, spiders, true bugs, ants, birds, terrestrial vertebrates, springtails, isopods and, finally, "myriapods". The richness values were lower in the Iluka heathland study, but values were significantly positively correlated with the values in the Worsley study (r = 0.98; df = 7; P < 0.001; true bugs excluded from analysis). In both studies, ants were ranked amongst the top five taxa in terms of species richness (Tab. 1).

Terrestrial vertebrates, birds and, to a lesser extent, plants were more time-consuming to sample / observe in the field than were the invertebrates. However, the laboratory time for terrestrial vertebrates and birds was generally zero, as identifications could be made in the field. By contrast, laboratory time for some invertebrate groups was often long, especially if specimens had to be slide-mounted (e.g., springtails) or if they were extremely diverse (e.g., beetles). By

Tab. 1: The number of species per study and number of species per plot per hour of sampling / sorting / identifying for a range of taxa sampled during the surveys of 10 restored and four native vegetation control plots at the Worsley Alumina bauxite mine and the Iluka mineral sand mine. ni: not identified to species level.

Taxon	**Worsley bauxite mine**		**Iluka sand mine**	
	Total species number	**Number of species per lot per ha**	**Total species number**	**Number of species per lot per ha**
Hemipterans	149 (4)	3.67 (1)	ni	–
Beetles	237 (2)	3.34 (2)	172 (2)	2.98 (3)
Plants	247 (1)	3.10 (3)	194 (1)	8.72 (1)
Spiders	182 (3)	2.99 (4)	95 (3)	1.47 (5)
Ants	117 (5)	2.94 (5)	86 (4)	1.98 (4)
Birds	55 (6)	2.42 (6)	47 (5)	5.10 (2)
Springtails	20 (8)	0.87 (7)	22 (6)	0.43 (6.5)
Isopods	10 (9)	0.43 (8)	3 (8.5)	0.28 (9)
Vertebrates	29 (7)	0.43 (9)	9 (7)	0.43 (6.5)
Myriapods	7 (10)	0.29 (10)	3 (8.5)	0.34 (8)

combining field and laboratory time together, invertebrate groups were found to be quicker to survey than plants, and terrestrial vertebrate surveys consumed considerably more time than any other group. When the data were expressed as number of species per hour (Tab. 1), trends at both minesites were correlated ($r = 0.65$; df = 7; $P < 0.05$; true bugs excluded from analysis) and taxa fell into three groups. In decreasing order, true bugs (at least at Worsley), beetles, plants, spiders, ants and birds were relatively time-effective, while isopods, terrestrial vertebrates and "myriapods" yielded very low returns; springtails fell between these two groupings due to their intermediate species richness level and the large amount of time required to identify such small animals.

Discussion

The findings presented here indicate that in the context of minesite restoration, certain groups of invertebrates perform extremely favourably as environmental or biodiversity indicators when compared with birds, terrestrial vertebrates or, in the case of biodiversity indicators, plants. Although ants are surpassed as environmental indicators by spiders, true bugs, and beetles (at least at Worsley), they are the best indicator of assemblage composition of other groups at both Worsley and Iluka. The results of these two extensive *post priori* investigations thus leads us to conclude that certain groups of invertebrates are practical, economic and effective environmental or biodiversity indicators. They performed favourably in relation to plants, better than or on a par with terrestrial vertebrates, and better than birds as environmental indicators. Ants, hemipterans (at Worsley), beetles and spiders all performed favourably in relation to terrestrial vertebrates, birds, and even plants, as biodiversity indicators. The fact that the two areas where these studies were performed are several hundred kilometres apart in widely different vegetation types is supportive of the fact that the trends in the taxa discussed here have general applicability to a wide range of regions in Australia. However, the superior performance of springtails and inferior performance of spiders as biodiversity indicators at Iluka when compared to the Worsley study is noteworthy and may be related to the structure of the vegetation, which is more two-dimensional in the Eneabba heathland than in the forested areas at Worsley. The poor performance of plants as biodiversity indicators (at least in the Worsley study) may be due to the fact that the natural succession of plants tends to be obscured by the mix of plants that were seeded or planted during the revegetation operations. Although a large number of species may be present at an early stage, they may not be mature or widespread, meaning that they contribute to the species list but not necessarily to the functioning of the ecosystem.

We conclude that in Australia, certain groups of invertebrates, notably true bugs, beetles, ants, and spiders are cost-effective to survey and potentially high in information content. True bugs and spiders suffer the disadvantage of being represented in samples by large numbers of immature forms that are often impossible to identify or to associate with the corresponding adult. This is not a problem with the endopterygote ants and beetles. Of the latter two groups, both have been shown to be good environmental indicators, but ants show slightly superior performance as biodiversity indicators. Ants also have the advantage that so much is known about their ecology, it is possible to consider their functional attributes during the bioindication process (HOFFMANN & ANDERSEN 2003). For instance, their richness is known to be correlated with microbial activity in rehabilitated minesites (ANDERSEN & SPARLING 1997). Thus, although there is great potential to use several of these taxonomic groups as bioindicators (and doubtlessly other taxa that we did not include in these investigations), ants have been shown to perform particularly well under the criteria of cost and ease of surveying, data yield per hour of effort, and efficacy as indicators of environmental conditions and of assemblage composition of other groups.

How applicable are these findings to other land uses and to other parts of the world? Perusal of the references in ANDERSEN & MAJER (2004) reveals that ants have been successfully used as bioindicators in minesites in all climatic regions of Australia, and as indicators of pollution, forest health, and rangeland condition. There is also a burgeoning literature on their use as bioindicators in South America (e.g., MAJER 1992, BESTELMEYER & WIENS 1996, OSBORN & al. 1999), southern Africa (e.g., MAJER & DE KOCK 1992, VAN HAMBURG & al. 2004), and elsewhere in the tropics. However, there are less examples from the more temperate regions of Europe and North America (but see PUSKAR 1978, KASPARI & MAJER 2000, GOMEZ & al. 2003). In cases where the utility of ants in Europe has been benchmarked against other taxa the results are conflicting, with papers by DUELLI & OBRIST (1998), EKSCHMITT & al. (2003), and SAUBERER & al. (2004) indicating significant but unspectacular correlations of ant richness with that of other taxa or of environmental variables. In part this may be associated with the lower richness of ants in most European sites, although this may also stem from most attempts to find the best bioindicator seeking correlations between richness, rather than assemblage composition of different groups. The fact that VESSBY & al. (2002) found more significant correlations between assemblage composition of different taxa than between corresponding species richness values reinforces this suggestion. It is therefore suggested that further investigations into the utility of ants as bioindicators in the more temperate regions of the world may also yield promising results.

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Zusammenfassung

Wirbellose Tiere werden zunehmend als biologische Indikatoren für Renaturierungserfolg, Landverbrauch, Naturschutzwert und vieles andere eingesetzt. Sie werden entweder als Zeiger für guten Erhaltungszustand und funkti-

onelle Aspekte der Umwelt (ökologische Indikatoren und Umweltindikatoren) oder als Zeiger für Gesamtdiversität oder Zusammensetzung von Gemeinschaften anderer Taxa in einem Gebiet (Biodiversitätsindikatoren) herangezogen. In allen Fällen ist es oft Ausdruck persönlicher Präferenzen des Bearbeiters oder einer Modeerscheinung, welche taxonomische Gruppe bearbeitet wird. Diese Arbeit fasst die Resultate von zwei Feldstudien zusammen, die bewertet haben, wie gut verschiedene Wirbellose als Umwelt- und Biodiversitätsindikatoren abschneiden, im Vergleich untereinander sowie zu Wirbeltieren und Pflanzen. Diese Studien wurden in einer renaturierten Bauxitmine und einer renaturierten Sandgrube in Westaustralien durchgeführt. Am Gelände der Bauxitmine zeichneten die Zusammensetzungen von Spinnen-, Wanzen- und Käfergemeinschaften die abiotischen Veränderungen besser nach als Vögel; Pflanzen aber stiegen am besten aus. Terrestrische Wirbeltiere sowie Ameisen lagen im Mittelfeld. Die Zusammensetzung der Ameisengemeinschaft und, in geringerem Ausmaß, auch jene der Wanzen, Käfer und Spinnen brachten jedoch jene der anderen Indikatorgruppen stärker zum Ausdruck als es Pflanzen und Wirbeltiere taten. Bezogen auf den Datenzuwachs pro Stunde Feld- und Laborarbeit waren Wirbellose effizienter als Wirbeltiere, aber nicht effizienter als Pflanzen. Alle diese Trends waren im Falle der Sandgrube ähnlich. Wenn wir die Effizienz im Datengewinn pro Zeiteinheit berücksichtigen sowie auch das Problem, welches das Bearbeiten von Jugendstadien bei Spinnen und Wanzen darstellt, schlussfolgern wir insgesamt, dass Ameisen mittelmäßig als Umweltindikatoren abschneiden, aber extrem gut als Biodiversitätsindikatoren. Wir diskutieren die Umsetzbarkeit dieser Ergebnisse auf andere Lebensräume und andere Regionen der Welt.

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