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INDICATOR GROUPS AND FAUNAL RICHNESS

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ABSTRACT. Species richness is a popular indicator of ecosystem vitality, but is difficult to assess. Many natural resource managers seek an efficient bioindicator, but the link between candidate indicators and the richness of other taxonomic groups remains elusive. A series of faunal surveys in the Mbalmayo Forest Reserve in Cameroon suggest that it may be possible to devise faunal bioindicators. The species richness of birds, of butterflies and of termites is significantly correlated with total faunal richness across eight species groups, suggesting that these groups may have potential as bioindicators, alone or in combination. Although expensive, further research is warranted because of the substantial potential benefits and implications of the use of indicator groups.

Keywords: alpha diversity, species richness, bioindicator, surrogate, butterflies, termites.

1 INTRODUCTION

Natural resource managers need a “canary” to draw attention to sites of special significance and to forewarn them of impending problems (cf. the coal miner’s canary to warn of fatal methane levels). It is impractical to comprehensively monitor every aspect of a resource; efficiency demands the use of indicators as proxies (or surrogates in the sense of Prendergast *et al.* 1993) for comprehensive assessment. The choice of indicator is critical, not only because of the inferences that may be drawn from it, but also because an efficient indicator may free funds from monitoring for more productive research, maintenance of the resource, and education of its constituency.

Researchers have considered many potential indicators (Brown 1991) or surrogates (Oliver and Beattie 1996), including plant genera (e.g., Prance 1994), vegetative morphology (e.g., Gillison *et al.* 1996), vegetative structure (e.g., Ferris-Kaan *et al.* 1998), sound patterns (e.g., Riede 1993), birds (Garson *et al.* 2003), insects (e.g., Halffer and Favila 1993, Kremen 1994) and rare species (Lawler *et al.* 2003). While morphology and structure-based assessments may eventually offer reliable and automated monitoring, many researchers resort to faunal indicators, assuming that their inter-relationships with other fauna and flora will also extend to species richness. The expectation is that species richness within a particular (often conspicuous) group should be correlated with the overall faunal richness (and presumably also with vegetative richness), and thus that the welfare of the selected indicator group should offer an insight into the state of the system as a whole. Unfortunately, there is little empirical evidence to support the contention (e.g., Lindenmayer 1999, Ricketts *et al.* 2002, Vessby *et al.* 2002).

Lawton *et al.* (1998) examined species richness (or alpha diversity as defined by Whittaker 1977) in several animal groups (birds, butterflies, beetles, ants, termites, nematodes) sampled in the Mbalmayo Forest Reserve, Cameroon (11°E, 3°N, 650 m above sea level) during 1992-94, and suggested that assessments of habitat change based on familiar groups (e.g., birds, butterflies) may mislead because of low pair-wise correlations between groups and weak trends with disturbance. Their conclusion may be unnecessarily pessimistic, because such indicators may not be used to infer the richness within other groups, but rather to gain an insight into overall species richness. An alternative interpretation of their data offers a more promising prognosis, and does not exclude the possibility that some species groups may indeed indicate overall faunal richness.

Lawton *et al.* (1998) found that 40 of 45 between-group correlations did not differ significantly from zero (i.e., $P > 0.05$), and thus found no reason to reject the null hypothesis that the species richness within any one group bore no relationship to the richness in any other group. This is not the question

usually posed by resource managers, who often want to make inferences about the total species richness. This question is explored below, using the Mbalmayo data kindly provided by Prof. John Lawton.

2 DATA

The Mbalmayo data involve counts of individual species or morphospecies within nine taxonomic groups sampled at six sites (Table 1). These observations have been adjusted to reflect an equal sampling effort (Lawton *et al.* 1998), so some of the reported counts are fractional. Forty-five of the 54 possible site-species combinations were sampled, in most cases with a single sample, although two samples were available in 15 instances. Nine site-species combinations remained unsampled. There are two problems with these missing data: the column representing partial mechanical clearance, where only 5 of the 9 species groups are sampled; and the row representing canopy ants, which were sampled at only half of the sites. Despite this weakness, there are few better data presently available to address this important and urgent question.

Table 1. Species counts from Mbalmayo Forest Reserve, Cameroon (Lawton *et al.* 1998).

Taxonomic group	Site and treatment †					
	NP	OS	PC _{man}	PC _{mech}	CC	FF
Birds	45	45	29		5	9
Butterflies	29, 33	51	30	28	30, 31	14
Malaise beetles ‡	27, 31.5	40.5	33.5		32, 36.5	48.7
Intercept beetles ‡	24, 47	113.5	41		59, 70.5	42.7
Canopy beetles	72	78	53, 80	91, 61	49, 46	
Leaf litter ants	62, 55.3	73.6	79	72.8	46, 58.6	
Termites	46	53	53		16	24
Soil nematodes	70.11	62.8	69.41	57.4	62.8, 67.36	54.05
Canopy ants			38.1, 28.8	35.7, 28.9	23.7, 31.8	

† NP = Near-Primary forest, OS = Old-growth Secondary forest, PC_{man} = Partly Cleared (manually) with *Terminalia ivorensis* plantation 10-15 m tall, PC_{mech} = Partly Cleared (mechanically) with *T. ivorensis* 10-15 m tall, CC = Completely Cleared and planted to *T. ivorensis* 1-2 m tall, FF = manually cleared Farm Fallow (Lawson *et al.* 1998). ‡ Malaise beetles = flying beetles caught in malaise traps; Intercept beetles = beetles caught in flight-interception traps.

There are three ways to deal with the incomplete column (Table 1) representing partial mechanical clearance: to omit the entire column, to pool it with the column representing partial manual clearance, or to try to infer the missing values. The first option (omit) discards scarce information, and the third option (infer missing values) involves making difficult and uncertain inferences, so the second option was adopted. The two treatments involving partial clearance by manual and mechanical means are similar in nature and in species counts (paired t-test, $t_6=0.6$, $P=0.6$), and were combined. The row representing canopy ants was omitted from the calculation of species totals (Table 2), but was included in the analysis of possible species indicators.

Table 2. Maximum number of species recorded within each group at each site.

Taxon	NP	OS	PC	CC	FF
Birds	45	45	29	5	9
Butterflies	33	51	30	31	14
Malaise beetles	31.5	40.5	33.5	36.5	48.7
Intercept beetles	47	113.5	41	70.5	42.7
Canopy beetles	72	78	91	49	0 †
Litter ants	62	73.6	79	58.6	60.5‡
Termites	46	53	53	16	24
Nematodes	70.1	62.8	69.4	67.4	54.1
Species total *	406.6	517.4	425.9	334	253

† Assumed to be zero, since no canopy. ‡ Interpolated from termite counts.

* Excludes canopy ants.

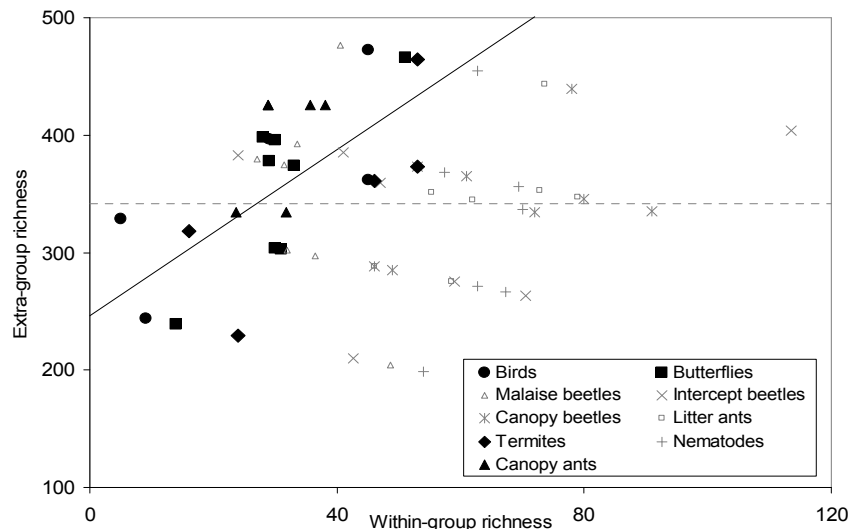
Multiple samples occur in 14 instances (after combining the two rows concerning partial clearing), so there was more than one possible way to compute the total number of species for a site. For instance, the total number of species at a site could be based on the average or the greatest of these multiple observations of a species group at the site. In most cases, the difference between alternative calculations was small, with the greatest discrepancy being canopy beetles on partially cleared sites where the average (of 4 counts) was 71 and the maximum was 91 species. The present study based the estimates of species totals on the greatest number of species observed, with the assumption that smaller numbers were incomplete counts, and that the largest observations did not include vagrants (or 'tourists' in the sense of Moran and Southwood 1982). The possibility that the same beetle species may occur in the malaise, flight interception and canopy data was dismissed, as these different trapping methods catch different components of the beetle fauna (Lawton *et al.* 1998).

Two cells in the Table 2, canopy beetles and litter ants, were not sampled on the farm fallow site and some assumptions were required to complete the table. Table 2 follows Lawton *et al.* (1998) in assuming that no canopy beetles were detected in farm fallow since no canopy was present at this site. The number of litter ants was estimated through regression. Because of their similar niche and reasonable correlation ($r_3=0.83$, $P=0.07$), the likely number of litter ant species was estimated using a simple linear regression of litter ants on termites ($n_{ants}=50.2+0.42n_{termites}$). These two inferred values were used only to estimate the total number of species present on each site, and were not used directly in further regression analyses.

3 ANALYSIS

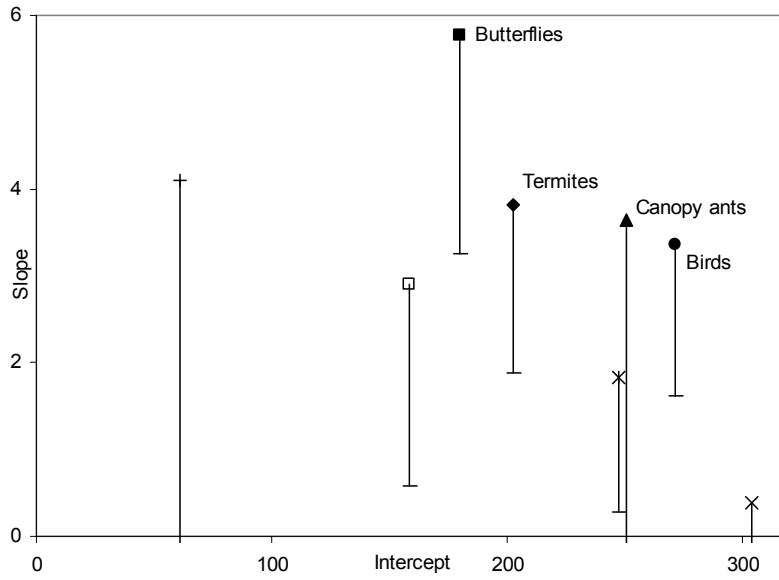
The relationship between within-group richness and total faunal richness was examined using regression analyses and permutation tests. Regression analyses were used to seek a predictor set of organisms such that changes in the biological status of the predictor set reflect similar changes in a wider group of organisms (Kitching 1993). Evidence of such qualities may be inferred from the relationship $N_i = \square n_i + e$, where e is a random error, n_i is the number of species within group i , N_i is the "extra-group" richness, the number of species in other groups $N_i = \sum_{j \neq i} n_j$, such that total surveyed species richness is $N = N_i + n_i$ for any i . Using total richness N as the response variable would artificially enhance the quality of the fit (e.g., since $N = n_i + N_i = n_i + e'$ even when no relationship between n_i and N_i exists). For the 14 site-species combinations where multiple samples were available, the individual samples were used in further analyses, providing a total of 60 data observations (including the observations on canopy ants, and excluding the presumed values for canopy beetles, canopy ants and leaf litter ants in the farm fallow, see Appendix).

Figure 1. Extra-group richness (N_i) versus within-group richness (n_i) in Mbalmayo Forest Reserve, Cameroon. The solid line is the relationship $N_i=246+3.5n_i$ and the dotted line represents the mean of the unfilled symbols, 342.



- Preliminary graphical analyses of these data (Figure 1) reveal that
1. the five sample sites are evident in these data as five bands, declining with slope -1 as within-group richness increases (i.e., the relationship extra-group richness N_i = site richness N_{site} minus within-group species count n_i),
 2. some species groups (birds, butterflies and termites, illustrated with filled symbols) exhibit a correlation between extra-group and within-group species numbers, and that
 3. for some species (e.g., beetles caught in flight interception traps), the number of extra- and within-group species appears uncorrelated.

Figure 2. Four species groups exhibit both large intercept and steep slope. Bars indicate one standard error and illustrate the significance of the estimated slope.



These trends were confirmed by preliminary statistical analyses, which revealed three taxonomic groups of interest (Table 3 and Figure 2): the birds, butterflies and termites, each of which has relatively steep slope (β_1), large intercept (β_0), high correlation with extra-group richness (r), and a low probability (P) that this is due to chance. Canopy ants exhibit a trend similar to these three groups (Figure 2), but were recorded only at two sites (partially and completely cleared), so estimates for this group are not significant (Table 3).

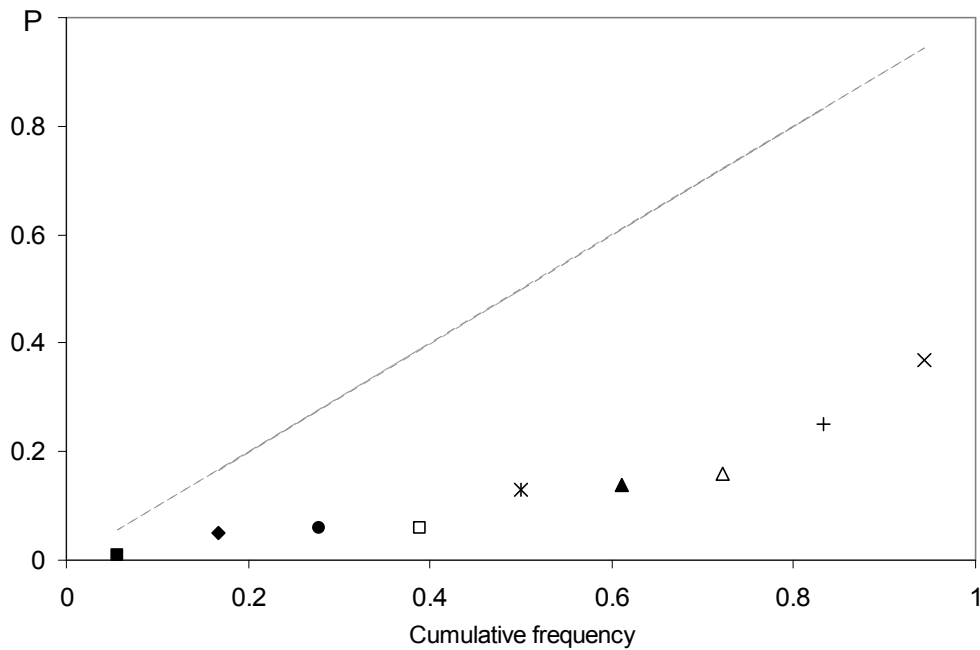
Table 3. Correlation coefficients for each species group.

Taxon	n	Sites	β_1	β_0	r	P	\hat{P}
Birds	5	5	3.4	271	0.76	0.06	0.06
Butterflies	8	5	5.8	180	0.81	0.006	0.006
Malaise beetles	7	5	-5.3	535	-0.43	0.16	0.17
Intercept beetles	7	5	0.4	303	0.15	0.37	0.40
Canopy beetles	8	4	1.3	257	0.44	0.13	0.15
Litter ants	7	4	2.9	158	0.62	0.06	0.07
Termites	5	5	3.8	203	0.77	0.05	0.07
Nematodes	7	5	4.1	61	0.3	0.25	0.23
Canopy ants	6	2	4.6	251	0.51	0.14	0.15

P is the probability derived from the correlation coefficient; \hat{P} is the estimated probability derived from a permutation test.

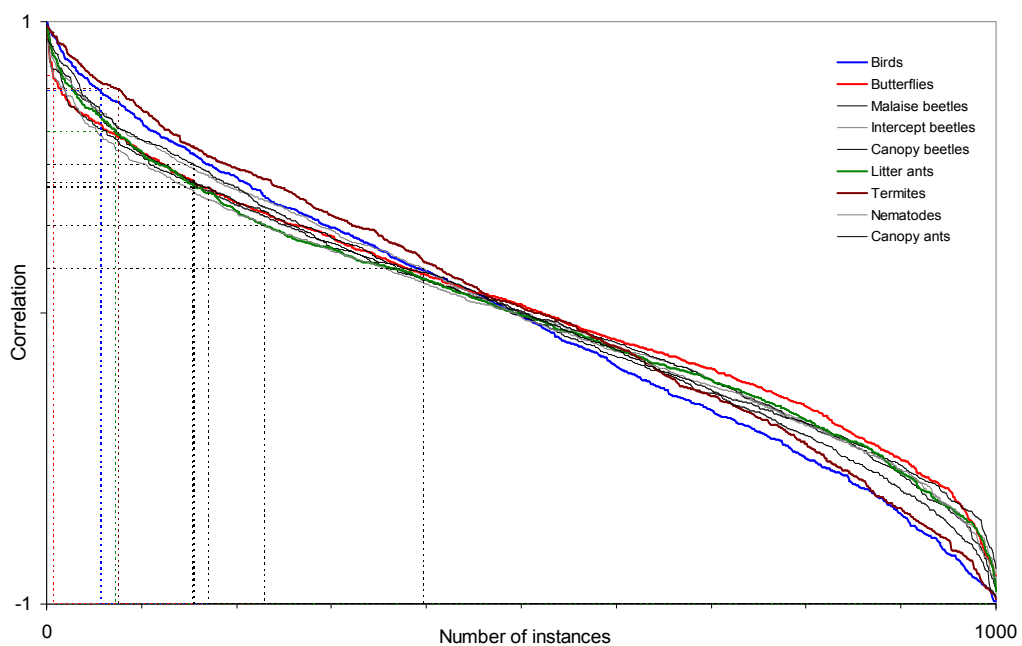
Tests of this kind may indicate a significant result purely due to chance. If the observed correlations are due to chance alone, the associated probabilities should be uniformly distributed on [0,1]. However, in this case, the probabilities observed remain small, suggesting that the correlation between within- and extra-group richness is real (Figure 3, where the slope of the observed probabilities is 0.29, significantly different from 1.0, $P < 0.001$).

Figure 3. Probabilities reported in Table 3 are not distributed uniformly on [0,1].



A further way to confirm the robustness of these findings is to resample (Good 2000). The permutation test (\hat{p}) reported in Table 3 results from shuffling the within- and between-group richness data (Appendix) 1000 times, and reporting the relative number of times that the observed correlation could have arisen by chance. The estimates from this test correspond closely to the conventional probability estimates obtained from the single-sided t-test (Cohen 1977). Results of these tests are illustrated in Figure 4. The curves indicate the correlations (in decreasing order) observed in the shuffled data; different curves arise because of different numbers of observations, numbers of sites, and random sequences for each species. There are only six instances (out of 1000) in the shuffled data that exhibit a correlation higher than that observed in the real data (0.81), so it is unlikely that this correlation is due to chance. In contrast, there are 397 instances in the shuffled data that exhibit a correlation higher than that observed for intercept beetles, illustrating that this correlation may simply be a chance occurrence.

Figure 4. Results of permutation tests



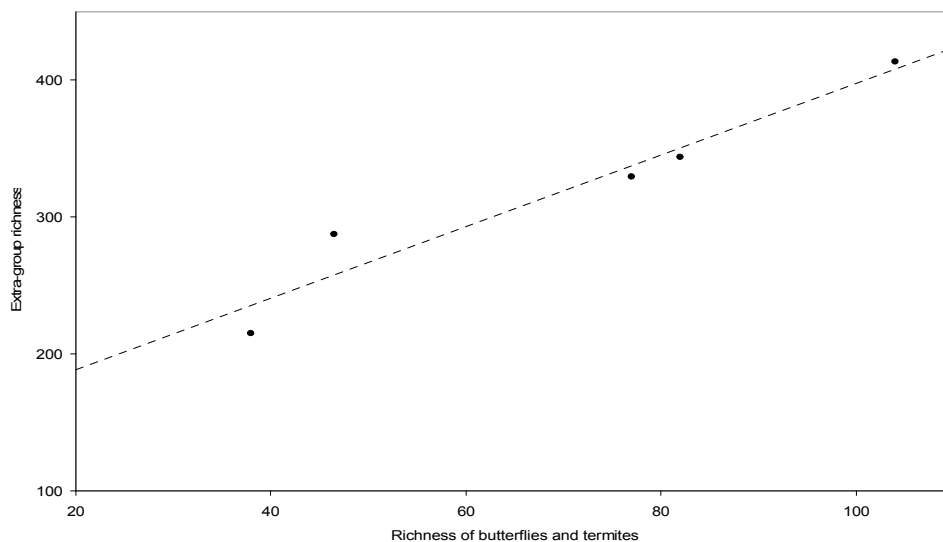
Regression analyses confirmed that it was appropriate to divide the data into two categories (evidence for two categories $F_{2,56}=5.78$, $P=0.005$; no evidence for additional categories $F_{14,42}=0.71$, $P=0.8$). One category contained four species groups, the birds, butterflies, termites, and canopy ants, each of which exhibited a relationship with a slope of about 3.5 (evidence for positive slope in pooled data: $r=0.8$, $t_{22}=3.5$, $P=0.0009$). A simple linear regression (i.e., $N_i=\beta_0+\beta_1n_i$) appeared adequate: a Box-Cox analysis (Box and Cox, 1964, 1982) revealed no need to transform the response variable, and an analysis of variance using six categories offered no evidence of a curvilinear relationship ($F_{4,20}=0.18$, $P=0.9$). The canopy ants were recorded on only two sites (PC and CC), so contribute little to the trend, but lead to smaller residuals when included within the bird-butterfly-termite group than with the remaining groups. The remaining category with five species groups exhibited no detectable trend (no evidence for non-zero slope $t_{34}=0.93$, $P=0.2$; and no evidence for a curvilinear relationship $F_{2,34}=1.05$, $P=0.4$). The resulting parameter estimates are given in Table 4.

Table 4. Parameter estimates to predict extra-group species richness from within-group richness, $N_i=\beta_0+\beta_1n_i$. Standard errors are shown in parentheses. All parameters significant at $P<0.01$.

Species group	Observations	Intercept (β_0)	Slope (β_1)
Birds, butterflies, termites, & canopy ants	24	246.4 (27.6)	3.53 (0.81)
Other species groups	36	341.9 (11.9)	–
Butterflies and termites in conjunction (Fig. 2)	5	133.8 (21.2)	2.20 (0.29)

Ideally, an indicator should have a high intercept (large and positive, because the “canary” should die before the miners) and a steep slope (rich information content). However, the present data offer no empirical way to discriminate between birds, butterflies and termites, as specific estimates of slope and intercept for these groups do not differ significantly.

Figure 5. Extra-group richness (numbers of bird, beetle, litter ant and nematode species) versus the number of butterfly plus termite species. The line represents the linear regression $N_i=133.8+2.2n_i$, where n_i is the sum of butterfly and termite richness.



A “shopping basket” of selected surrogate taxa may form a better predictor set than a single species group (e.g., di Castri *et al.* 1992, Kremen 1994, Oliver and Beattie 1996). Whilst the present data set is too small to adequately resolve this issue, there is some evidence to support this contention and to draw attention to the need for further research. For instance, butterflies and termites in conjunction provide a good estimate of extra-group species richness (Table 4 and Figure 5). These estimates are based on the regression of extra-group richness (total species minus the number of butterfly and termite species) versus the numbers of termites plus the average of the numbers of butterfly counts reported in Table 1. In this instance, there is a strong probability that the slope differs from zero ($t_3=7.59$, $P=0.002$), even

after allowing a Bonferroni adjustment (Neyman and Pearson 1928, Stewart-Oaten 1995) for the three possible pairwise combinations of birds, butterflies and termites ($P=0.007$), or the 36 possibilities of pairing any of the groups ($P=0.08$). A permutation test that shuffled the data 10,000 times indicated an estimated probability of 0.003.

4 DISCUSSION

The results reported in Table 3 and 4 obviously depend upon several assumptions, e.g., those involved in:

1. collapsing Table 1 (i.e., assuming partial clearance by manual and mechanical means are not significantly different),
2. completing missing cells in Table 2 (i.e., assuming no canopy beetles where there is no canopy, and predicting richness of litter ants from termite richness),
3. estimating total surveyed faunal richness (i.e., using maximum rather than the average richness in cells with multiple samples, omitting canopy ants from the total, assuming no beetle species occurs in both interception and malaise traps), and
4. assuming that the faunal richness across the eight groups surveyed is indicative of the total richness of all fauna (including fauna not sampled in the Mbalmayo study).

Fortunately, the findings appear to be relatively robust and hold when the first three of these assumptions are varied, at least for the three groups involving birds, butterflies, and termites. When the data were processed in other ways, consistent results were obtained for birds, butterflies and termites, but canopy ants seemed more closely aligned with the second category of organisms under some assumptions.

6 CONCLUSION

These findings support the contention (Garson *et al.* 2002) that some species groups (e.g., birds, butterflies, and termites, in the case of Mbalmayo) may be useful indicators of the overall species number. It seems that an even better indication of overall faunal richness may be obtained by using diverse groups in conjunction (e.g., butterflies plus termites).

This observation must be qualified since the findings of the present study depend on the validity of four assumptions made during the analyses (see above), and do not take into account the nature of these species (*viz.* exotic versus endemic). It seems possible to make inferences about total species richness, but one should not assume that all faunal groups follow the response of the chosen group (cf. Lawton *et al.* 1998). These findings are specific to disturbed forest near Mbalmayo Forest Reserve in Cameroon, and it should not be assumed that they are generally applicable. It seems feasible that butterflies and termites in combination may be good indicators for other humid forest environments, but it is possible that other species groups may be more effective indicators in other regions (e.g., arid or temperate regions).

Faunal richness may not be a good indicator of vegetative disturbance, as some disturbances (e.g., partial clearance) may actually increase species richness (Table 2, and Lawton *et al.* 1998), and disturbance can be gauged more easily and reliably in other ways (Watt 1998).

Because complete faunal inventories are difficult, time-consuming and expensive (Lawton 1998, Stork 1995), most natural resource managers cannot monitor the status of all species operationally. Many managers and researchers yearn for practical indicators that can be monitored efficiently and extrapolated reliably. Several surrogates have been suggested, but little empirical evidence has been tendered in support of these nominations. The present study offers some empirical evidence to support the notion that selected species groups may serve as indicators of a broader group of fauna, particularly when used in conjunction. If so, managers and researchers may be better served by reliable, comprehensive studies of selected groups, rather than superficial attempts to survey the whole fauna. However, the issue warrants further research (notably comprehensive faunal surveys for a range of sites) since the potential benefits and implications are considerable.

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APPENDIX 1. DATA USED IN ANALYSES

Datum	Site	Group	Within-group richness	Extra-group richness
1	NP	Birds	45	361.61
2	OS	Birds	45	472.4
3	PC _{man}	Birds	29	396.91
4	CC	Birds	5	328.96
5	FF	Birds	9	243.98
6	NP	Butterflies	29	377.61
7	NP	Butterflies	33	373.61
8	OS	Butterflies	51	466.4
9	PC _{man}	Butterflies	30	395.91
10	PC _{mech}	Butterflies	28	397.91
11	CC	Butterflies	30	303.96
12	CC	Butterflies	31	302.96
13	FF	Butterflies	14	238.98
14	NP	Malaise beetles	27	379.61
15	NP	Malaise beetles	31.5	375.11
16	OS	Malaise beetles	40.5	476.9
17	PC _{man}	Malaise beetles	33.5	392.41
18	CC	Malaise beetles	32	301.96
19	CC	Malaise beetles	36.5	297.46
20	FF	Malaise beetles	48.7	204.28
21	NP	Intercept beetles	24	382.61
22	NP	Intercept beetles	47	359.61
23	OS	Intercept beetles	113.5	403.9
24	PC _{man}	Intercept beetles	41	384.91
25	CC	Intercept beetles	59	274.96
26	CC	Intercept beetles	70.5	263.46
27	FF	Intercept beetles	42.7	210.28
28	NP	Canopy beetles	72	334.61
29	OS	Canopy beetles	78	439.4
30	PC _{man}	Canopy beetles	53	372.91
31	PC _{man}	Canopy beetles	80	345.91
32	PC _{mech}	Canopy beetles	91	334.91
33	PC _{mech}	Canopy beetles	61	364.91
34	CC	Canopy beetles	49	284.96
35	CC	Canopy beetles	46	287.96
36	NP	Litter ants	62	344.61
37	NP	Litter ants	55.3	351.31
38	OS	Litter ants	73.6	443.8
39	PC _{man}	Litter ants	79	346.91
40	PC _{mech}	Litter ants	72.8	353.11
41	CC	Litter ants	46	287.96
42	CC	Litter ants	58.6	275.36
43	NP	Termites	46	360.61
44	OS	Termites	53	464.4
45	PC _{man}	Termites	53	372.91
46	CC	Termites	16	317.96
47	FF	Termites	24	228.98
48	NP	Nematodes	70.11	336.5
49	OS	Nematodes	62.8	454.6
50	PC _{man}	Nematodes	69.41	356.5
51	PC _{mech}	Nematodes	57.4	368.51
52	CC	Nematodes	62.8	271.16
53	CC	Nematodes	67.36	266.6
54	FF	Nematodes	54.05	198.93
55	PC _{man}	Canopy ants	38.1	425.91
56	PC _{man}	Canopy ants	28.8	425.91
57	PC _{mech}	Canopy ants	35.7	425.91
58	PC _{mech}	Canopy ants	28.9	425.91
59	CC	Canopy ants	23.7	333.96
60	CC	Canopy ants	31.8	333.96