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An approach to measuring biodiversity and its use in analysing the effect of nitrogen deposition on woodland butterfly populations in the Netherlands

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The current use of the term biodiversity is problematic in that it is frequently reduced to a paradigm of species richness through the interpretation of the CBD definition that identifies variability as the operative factor. Species richness actually conveys the least amount of information of all of the possible indices that could be used so a data treatment process has been established whereby taxonomic groups that have been sampled in a well-structured way can yield data that can be far more informative. An example using "biodiversity quality" indices for macrofungi following entry into a bespoke computer programme (FUNGIB) shows that these data can be established and they are capable of being assessed for statistical difference either between sites or over time. A case study showing how this approach can provide information on the mechanism whereby nitrogen deposition affects butterflies is given. It is clear that this approach can be of considerable use in establishing progress towards achieving the 2010 target of reducing the rate of loss of biodiversity by 2010 established by the CBD.

Keywords: Biodiversity quality, Butterflies, Macrofungi, Nitrogen critical load

Introduction

The definition of biodiversity given by the Convention on Biological Diversity 1992 (CBD) is as follows: "Biological diversity means the *variability* (our emphasis) among living organisms from all sources including *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

It is clear that this definition was one arrived at after much negotiation and as such represents a compromise in positions. For those researchers working on biodiversity the definition does not work well as the operative word is "variability" and this word is undefined. Consequently biodiversity has come to mean whatever the researcher considered to be variability. The easiest and most frequently used interpretation is to equate biodiversity with Species Richness (the number of species in a unit area/sample), *e.g.,* Billeter et al. 2008, Maiorano et al. 2007. This is patently not true as under this interpretation all species have the same properties and values.

We have developed a different approach to this problem by considering biodiversity to be a multi-faceted quality described by numerical indices that represent each of these facets. In this way the character of the biodiversity examined is represented by the balance of these indices. This concurs with the reports by Hooper et al. (2005), Petchey & Gaston (2002) and Petchey et al. (2004) where they considered that biodiversity had a variety of "functional components". Hooper et al. (2005) continue to add that these could be properties such as: species composition, species richness, species evenness and species interactions. It is important to also consider that the usual measure of biodiversity, species richness, is considered by these authors to convey the least amount of information. The list of "properties" of biodiversity given by these authors matches very closely those derived by Feest (2006) independently.

Materials and Methods

The components of biodiversity quality

Feest (2006, 2007) describes how well surveyed organism biodiversity data can be converted into the following indices:

1. *Species richness*: The number of species per unit area or per unit sample.
2. *Biodiversity index*: These are measures of evenness of different species or dominance by a single species. The normally used versions are: Shannon-Wiener, Simpson and Berger-Parker. These can be calculated by numbers of individuals or by biomass.
3. *Population density*: The number of individuals per species and per total sample or frequency of occurrence for those species without determinate form.
4. *Biomass*: Calculated from the measured individuals that have definitive form so for example the biomass of macrofungi is proportional to the cap area (Toth & Feest 2007). For insects biomass is a function of body length or wing width (Brady & Noske 2006).
5. *Species Conservation Value Index* (SCVI): This is an arbitrary value allocated to each species based on its conservation value. This value is normally a function of its commonness or rarity but it could be based on an intrinsic value according to human valuation or ecosystem functional importance. The coding is based on a skewed set of values to allow the rarer species to be registered by the calculations. Normally the SCVI is expressed as a mean and standard deviation; the latter of these highlights the presence of rare species. For the examples used in this paper the following scoring system was used: Abundant = 2; Common = 3; Frequent = 4; Occasional/ Local = 5; Rare = 10; Really Rare = 20; Red Data Book Species = 100.

Indices (1)-(4) above are the ones that match those suggested by Hooper et al. (2005) and only the SCVI is a freshly created index. For butterflies a second version of this index was calculated which recorded the nitrophilic/nitrophobic tendencies of the species: the Species Nitrogen Value Index (SNVI).

For the calculation of these biodiversity indices the data was entered into a bespoke

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East End Wood
26/10/01

Species name	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Sum	SVI	BI
GPS easting	36389	36370	36385	36374	36359	36375	36394	36394	36406	36408	36409	36422	36450	36458	36463	36465	36445	36438	36445	36443			
GPS northing	97602	97619	97636	97630	97654	97661	97671	97697	97713	97728	97750	97767	97772	97803	97801	97822	97836	97850	97864	97884			
0: Cortinarius decipiens	6	3																			9	4	113.097
1: Mycena galopus	2	2				1									5	1			1		12	2	37.699
2: Xerocomus subtomentosus	1																				1	3	78.54
3: Cortinarius umbrinolens		4																			4	5	28
4: Lactarius chrysorrheus		1		1	1	2	4	1	1	2							1				14	3	703.717
5: Russula velenovskyi		1																			1	3	38.484
6: Amanita pantherina			3	5	5	3	2		1	1	6										26	4	2,042.035
7: Collybia fusipes			12																		12	4	1,357.168
8: Cortinarius telamonia agg.			1	1										2	16	13	3		7		43	3	540.08
9: Lactarius mitissimus			8		7	1		1			4										21	3	593.761
10: Lactarius subdulcis			3			9	3	3	3												21	3	593.761
11: Mycena galericulata			1							1											2	2	56.549
12: Russula loteotacta			1												1						2	4	100.531
13: Russula xerampelina			1																		1	2	176.714
14: Boletus edulis				1													1				2	2	628.316
15: Cortinarius flexipes var. flexipes				1																1	2	5	14
16: Entoloma nidorosum				3																	3	2	339.292
17: Lactarius camphoratus				1	2																3	3	84.823
18: Lactarius cimicarius				8	1												4				13	4	500.299
19: Lactarius fuliginosus var albipes				1			2		1												4	4	314.159
20: Lactarius quietus				1	2	2	2	2			24										33	2	3,732.212
21: Psathyrella gracilis				1	4																5	3	35.343
22: Russula fragilis				3		2				1								1	1		8	3	226.195
23: Russula krombholzii				1													1		1		3	2	235.619
24: Russula pseudointegra				2							1						6				9	4	1,017.876
25: Russula risigallina				1																	1	2	19.635
26: Russula violacea				2			1														3	4	58.905
27: Tricholoma ustaloides				1					1		8						12				22	5	2,488.141
28: Cortinarius hinnuleus					3												11				14	3	703.717
29: Inocybe petiginosa					1																1	4	0.785
30: Mycena sanguinolenta					3			2	4			1			1						11	3	8.639
31: Aureoboletus gentilis						1											1				2	5	56.549
32: Cortinarius stillatitius						3								2					1		6	4	471.239
33: Xerocomus badius						1															1	2	176.714
34: Amanita citrina							1	1		2	2			1	1		1				9	2	706.858
35: Cortinarius torvus							3							1		1					5	4	392.699
36: Hebeloma pumilum							3	62		25	4	46		2		44	1	1			188	5	590.619
37: Mycena vitilis							1		1		3					1			1		7	3	21.991
38: Clitocybe nebularis								1													1	2	254.469
39: Cortinarius basililacina								21													21	10	267.54
40: Laccaria amethystina								9		3	1										13	2	367.566
41: Marasmiellus vaillantii								21													21	5	37.11
42: Amanita rubescens									1	3											4	2	706.858
43: Clitocybe gibba									14						1						15	2	424.115
44: Cortinarius anthracinus									3					5						1	9	5	63.617
45: Lactarius rubrocinctus									3		1										4	10	314.159
46: Amanita vaginata											1										1	4	113.097
47: Collybia butyracea											4										4	3	113.097
48: Tricholoma sulfureum												1									1	2	50.265
49: Cortinarius casimiri													4								4	5	38
50: Hydropus floccipes													19								19	10	59.69
51: Hebeloma radicosum														6							6	4	678.584
52: Hydnellum spongiosipes														4							4	10	283
53: Hydnum repandum														1							1	2	176.666
54: Russula vesca														2						1	3	3	235.619
55: Cortinarius duracinus															1						1	4	78.54
56: Mycena olida															8						8	5	14.137
57: Amanita fulva																1				1	2	3	76.969
58: Collybia maculata																3					3	4	339.292
59: Cortinarius alboviolaceus																1					1	3	50.265
60: Hebeloma sinapizans																8					8	4	904.779
61: Stropharia semiglobata																1					1	3	19.635
62: Cortinarius purpurascens																	9				9	4	1,017.876
63: Tricholoma viridifucatum																	1				1	5	50.265
Summary	9	11	30	34	29	25	22	124	33	38	59	48	23	26	34	74	52	2	12	4	689	3.766	26,019.981

Species Richness = 64
Shannon-Wiener Index = 3.2549(3.4217)
Simpson Index = 10.8129(19.254)
Berger-Parker Dominance Index = 0.2728(0.1434)
Density = 0.689 per sq.m.
Species Value Index = 3.7656+/-1.9018
Biomass Index = 26019.981

Fig. 1 - The biodiversity quality indices and species accumulation curve for the macrofungi of a woodland site in the UK. Specimen of the printout from the computer programme FUNGIB (see text for more details).

computer programme (FUNGIB) and specimen of the printout is shown in Fig. 1.

Sampling

Macrofungi were sampled following the scheme given by Feest (2006) where a transect route was followed and at each stop point all of the macrofungi in a 4 m radius circle (50m^2) were counted until 20 subsamples had been made. For the butterflies survey data for a 17 year period was supplied by Dr. Chris van Swaay from the Dutch *Der Vlinderstichting* butterfly recording scheme which follows a version of the Pollard and Yates transect sampling process.

Research hypotheses

Two hypotheses were tested:

1. It is possible to create a series of biodiversity quality indices for macrofungi and that these can be compared between sites.
2. It is possible to convert butterfly survey data to biodiversity indices and these can be tested for environment effects.

In this latter hypothesis we have created a sub-hypothesis that butterfly biodiversity quality is affected by nitrogen deposition.

Data

Data for macrofungal biodiversity quality index calculation was compiled by one of the authors (AF) and Mr J. Smith on two sites in the West of England, UK. Butterfly data was supplied by Dr. Chris van Swaay from the Dutch *Der Vlinderstichting* butterfly monitoring programme and the nitrogen deposition data was supplied as Critical Load Exceedence (CLE) data (the amount by which nitrogen deposition exceeds the capacity of the habitat to absorb it without ecological effect) by Dr. Arjen van Hinsberg of the Netherlands Environmental Assessment Agency.

Tab. 1 - Biodiversity quality indices of two macrofungal woodland sites. See text for explanation.

Parameter	East End Wood 29/10/01	Weston Big Wood 24/09/00
Species richness	64	44
Shannon-Wiener	3.255 (3.422)	2.538 (2.4)
Simpson's	10.813 (19.254)	7.419 (6.435)
Berger-Parker	0.273 (1.143)	0.246 (0.301)
Fruit body density (m^{-2})	0.689	0.731
Species value index (± STD)	3.766 ± 1.901	4.682 ± 3.785
Cap area index (Biomass)	26019	15285

Statistical methods

The macrofungal mean data was tested for comparison of two sites by *t*-Tests and F Tests on the mean and standard deviations of the compiled indices and the effect of nitrogen deposition (CLE) effect on butterfly populations in Dutch woodland was tested by Principle Component Analysis (PCA) due to the need to view the combined interactive changes in the biodiversity. In PCA the results are presented as a number of eigenfactors for a series of artificial axes where the power of each index is shown in relation to the others.

Results

Fungi

Fig. 1 presents an ample of a site where macrofungi have been sampled and the indices calculated by FUNGIB printed in the left hand corner. A useful adjunct of this type of data presentation is that it shows the species accumulation curve and the curve appears to be flattening off at sub-sample 17 indicating

Tab. 2 - The *t*-Test and F test results comparing the two woodland sites in Tab. 1 for biodiversity quality differences.

Parameter	*t*-Test	F Test
Fruit body density	p=0.353	p=0.002
SCVI	p=0.135	p=0.001
Biomass	p=0.710	p=0.028

that the surveyed species richness of 64 is approximately that present on the whole site at the time of the survey.

Tab. 1 presents the calculated indices for the macrofungi of two sites. A review of the data shows that the two sites have similar indices but reference to Tab. 2 where the results of the *t*-Tests and F Tests are presented show that whilst the mean and total values do not differ significantly (*t*-Test) the range of values (F Test) does differ for Fruit body density, SCVI and biomass showing that in particular the site with the rarest species has a significantly higher SCVI range of values despite there being fewer species present.

Tab. 3 - Principle component analysis of Woodland butterfly data from the Der Vlinderstichting survey over a 17 year period. SNVI = Species Nitrogen Value Index; SCVI = Species Value Index; CLE = Nitrogen Critical Load Exceedence. PC1 = 66.6% of variation; PC2= 16.5% of variation and PC3 = 8.3% of variation. Figures labelled with (*) in PC2 are for emphasis.

Variable	PC1	PC2	PC3
SNVI	0.395	0.154	-0.591
Species richness	-0.451	-0.013	0.002
Simpson	-0.294	-0.497(*)	-0.43
SCVI	-0.417	-0.017	0.467
Population	-0.381	0.486(*)	-0.279
Biomass	-0.381	0.488(*)	-0.274
CLE	-0.299	-0.505(*)	-0.307

Butterflies

The PCA data presented in Tab. 3 shows that all indices are very similar in component 1 (representing 66.6% of variation) except for the SNVI. This would be interpreted as all indices declining except for the SNVI which is increasing and the butterflies species are becoming more nitrophilic. The second component (16.5% of variation) is far more informative showing width (*): a) that species richness and SCVI have low values and are not important in this component; b) population and biomass are similar (An expected outcome given that butterflies do not differ greatly in size) and c. that Simpson index and critical load exceedence (CLE) are similar and opposite to population/biomass which would be interpreted as with decreasing CLE populations of butterflies decline as the sites become less populated by nitrophilic species and the nitrophobic species increase (evenness declines). The third component accounts for only a small proportion of the variation (0.083/1.0) and this will not be considered although in other datasets it may have greater relevance.

Conclusions

We have shown that further assessment (metadata analysis) of well surveyed data can yield more information and that this information can be assessed statistically for probability of importance. The first hypothesis is shown to be supported and that when such a difficult group of organisms as macrofungi are surveyed in a standardized way biodiversity quality indices can be created leaving analysis for difference between sites and over time. Since macrofungi either as decomposers and/or as mycorrhizae have a prominent place in forest/woodland ecosystems this will be of considerable utility in deciding on such things as the impact of global climate change or the effect of management activities.

The second hypothesis is supported by the calculation of indices (not presented) which have then been tested by PCA against a physical input: CLE. Is interesting to note that the CLE was declining rapidly throughout the period of surveyed data although it was still positive and therefore theoretically still having an effect. The principle component analysis has shown that if the usually measured element of biodiversity: species richness, had been used then no effect could have been detected that was not similar to all the other indices (in other words it might be more a result of interaction of factors that a direct effect). The second component in particular lends support to the arguments of Saint-Germain et al. (2007) for biomass to be taken much more seriously in biodiversity analysis.

In summary we conclude that adding further data treatment of biodiversity survey data by the creation of a range of biodiversity quality indices can provide far more information for the ecologist at no extra survey cost. Indeed the structured surveying advocated by Feest (2006, 2007) could be used to reduce field sampling effort without the loss of information. The use of biodiversity quality indices could be of considerable importance in setting baselines for judging progress towards the 2010 target of reducing the rate of loss of biodiversity by 2010.

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