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Using indices to measure biodiversity change through time

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Abstract. *Biodiversity indices are widely used to measure diversity differences between areas or within the same area but through time. However, conclusions may be made about the study area based on the calculation of one value, with confidence intervals or standard errors of the index rarely reported. The overall aim of this study is to assess the use of biodiversity indices in detecting diversity change with time using a bootstrap technique; the concept and initial results are explained here. The abundance of beetle species at 12 terrestrial sites in the UK Environmental Change Network (ECN) from 1993-2008 were used to calculate 4 biodiversity indices: Shannon Weiner, Simpson's, Berger-Parker and Pielou's indices. 90% confidence intervals for each index per site per year were generated using a bootstrap technique. The size of the confidence interval for all indices varied across sites and time periods, however, the intervals did not always overlap. Preliminary results indicate that the biodiversity indices can be used to detect differences between habitat types and time periods. The effect of the sampling unit on the bootstrap technique will be investigated further.*

Keywords. *Biodiversity; bootstrap; ECN; beetles; Shannon Index*

1 Introduction

Assigning biodiversity values to specific sites has been widely used to describe community composition and structure or to prioritise conservation policy decisions. The biodiversity value will depend not only on the habitat studied and the species examined, but also on the measurement used. There are many different indices of biodiversity but they are all based on species abundance or richness. The properties and merits of each index and evaluation of the most appropriate one to use has been discussed intensively (Kempton 1979, Routledge 1979, Koeleff et al. 2003, Magurran 2004). Most conclude that a

combination of indices which measure aspects such as species richness, diversity and evenness are more satisfactory. Biodiversity indices and species richness data are commonly used to assess community variation across sites and at different time periods. However, even when several different indices are calculated for each site and time period, only summary index values without any error estimate are often reported making the comparison between sites and time periods difficult. By generating bootstrap confidence intervals for a range of biodiversity indices including species richness, this study aims to assess the usefulness of these measures in comparing diversity between sites and across time intervals.

2 Method

Data and Study Sites

The Environmental Change Network (ECN) is a long term monitoring programme in the UK which aims to document information on the effects of environmental change on physical, chemical and biological systems. The data analysed from the ECN in this paper is a 15 year-long dataset on Carabidae (Coleoptera) species diversity. There are 12 terrestrial sites throughout the UK in which a standard protocol is applied for sampling Carabidae (Woiwod and Coulson 1996, Scott and Anderson 2003). The pitfall trapping method was used to collect the Carabidae specimens and traps are placed along three transects. Each transect was ideally placed in a different habitat type and in areas where no cattle were grazed. Ten traps are placed along each transect with 10m spacing between traps. Each year trapping starts in March and ends in October, with traps collected fortnightly. The total number of beetles collected per trap per transect were identified to species level. The predominant habitat type at each site varies with environments such as high altitude bogs, peat, heath, permanent pasture, pine forests and mixed deciduous forests present. There are 15 years of data for 6 sites, 14 years of data for 4 sites and 9 years of data for 2 sites.

3 Biodiversity indices

The biodiversity index is a non-parametric tool used to describe the relationship between species number and abundance. Four derived biodiversity indices were calculated in this study, the Shannon Weiner Index, the Simpson's Index, the Berger-Parker Index and Pielou's Index (Table 1). Scott and Anderson (2003) calculated biodiversity indices for the Carabidae data at 10 of the UK ECN sites from 1993-1999. This study will add to the data discussed in that paper by using all of the sites, 9 years extra data and generating confidence intervals for the values across all of the years.

4 Statistical analysis

A non-parametric bootstrap with replacement was performed in R version 2.10.1 (R Development Core Team) using the package bootstrap. Firstly, total annual counts for each transect were sampled with replacement 1000 times and each index was calculated per repeat. The index value for the Carabidae at each site from the original sample was calculated in addition to the mean biodiversity index value from the bootstrapped samples. The difference between the original mean index value and the bootstrap

Diversity Index	Equation	Description
Shannon Weiner Index	$H' = -\sum p_{ii}$	If $H' = 0$, there is only one species in the sample, and H' is maximum only when all S species are represented by the same number of individuals.
Simpson's Index	$D = \sum p_i^2$	D ranges between 0 - 1, where 0 represents a community with infinite diversity and 1 is a community with no diversity. The reciprocal $(1/D)$ is bounded by 1 and the maximum number of species sampled.
Berger-Parker Index	$d = N_{max}/N$	The reciprocal of the Berger-parker Index is commonly used. An increase in $1/d$ corresponds to an increase in diversity and a decrease in dominance.
Pielou's Index	$J' = \frac{H'}{H_{max}} = \frac{H'}{\ln S}$	J' is bounded by 0 and 1 with a larger index value indicating a more even community.

Table 1: The biodiversity indices calculated for Carabidae data from the UK ECN sites. Where p_i is the proportion of individuals in the ith species, N_{max} is the proportion of individuals in the most abundant species and S is the number of species in the sample (Magurran 2004).

mean value is the bias introduced from the sampling process. The calculated bias is then added to the original estimate of the index. The bootstrapping method produces a range of possible indices calculated from the sample. The 90% confidence limits based on quantiles were calculated using the 5% and 95% intervals. The range of values from the bootstrap were then compared across transects, years, sites and habitat types.

5 Results

Preliminary analyses of the results indicate that variation exists in all diversity indices, but different factors may affect this. Similar results were obtained for all four derived indices but only the Shannon Weiner diversity index for four sites which highlight a range of outcomes is reported here. The Shannon Weiner values for Alice Holt, Drayton, Glensaugh and the Cairngorms sites are shown in Figure 1. The data at Alice Holt indicates that the index can be used to track changes over time, specifically a shift in index value after the year 2000. There are small confidence intervals at all transects and years. In contrast the data at the Cairngorms site (Figure 1B) shows a variation in index value possibly with both time and habitat type, but the confidence intervals are large for several index values. However, the confidence intervals do not overlap for the same transect at all time periods indicating the index could be used to detect changes in biodiversity. The Shannon Weiner indices suggest a distinct difference between habitat types at Drayton (Figure 1C), specifically between the habitats at transect 1 (in an area between a stream and pasture) and transects 2 and 3 (both grassland habitats). The Shannon Wiener index differs with time and habitat at Glensaugh (Figure 1D); however, the difference between transects alters after 1999. The value of the index for transects 2 and 3 is generally smaller than transect 1 before 1999, but after that the index values for transects 2 and 3 are greater. Species richness remained relatively constant for each site over time and the differences appear to be due to changing species abundance or dominance. The index values are similar to those in Scott and Anderson (2003) for the sites studied; however, the size of the confidence intervals generated from the bootstrap suggest that the values could differ depending on the year the measure is taken from. This will be investigated further to provide statistical comparison across time periods both within and across sites.

6 Conclusions

The value of a biodiversity index may vary with small changes in the species data that it is calculated from, but also with habitat type and time period. It is important to know the range of possible biodiversity values that may occur at any one site and the confidence intervals generated from this bootstrap technique provide this. This preliminary result demonstrates the potential use of biodiversity indices to compare across sites and time periods. Further developments will include modifying the bootstrap methods to improve the sampling of individuals from the original data. In addition, generalised linear models will be fitted to relate changes with environmental covariates and to provide empirical distributions of species richness and abundance at each site.

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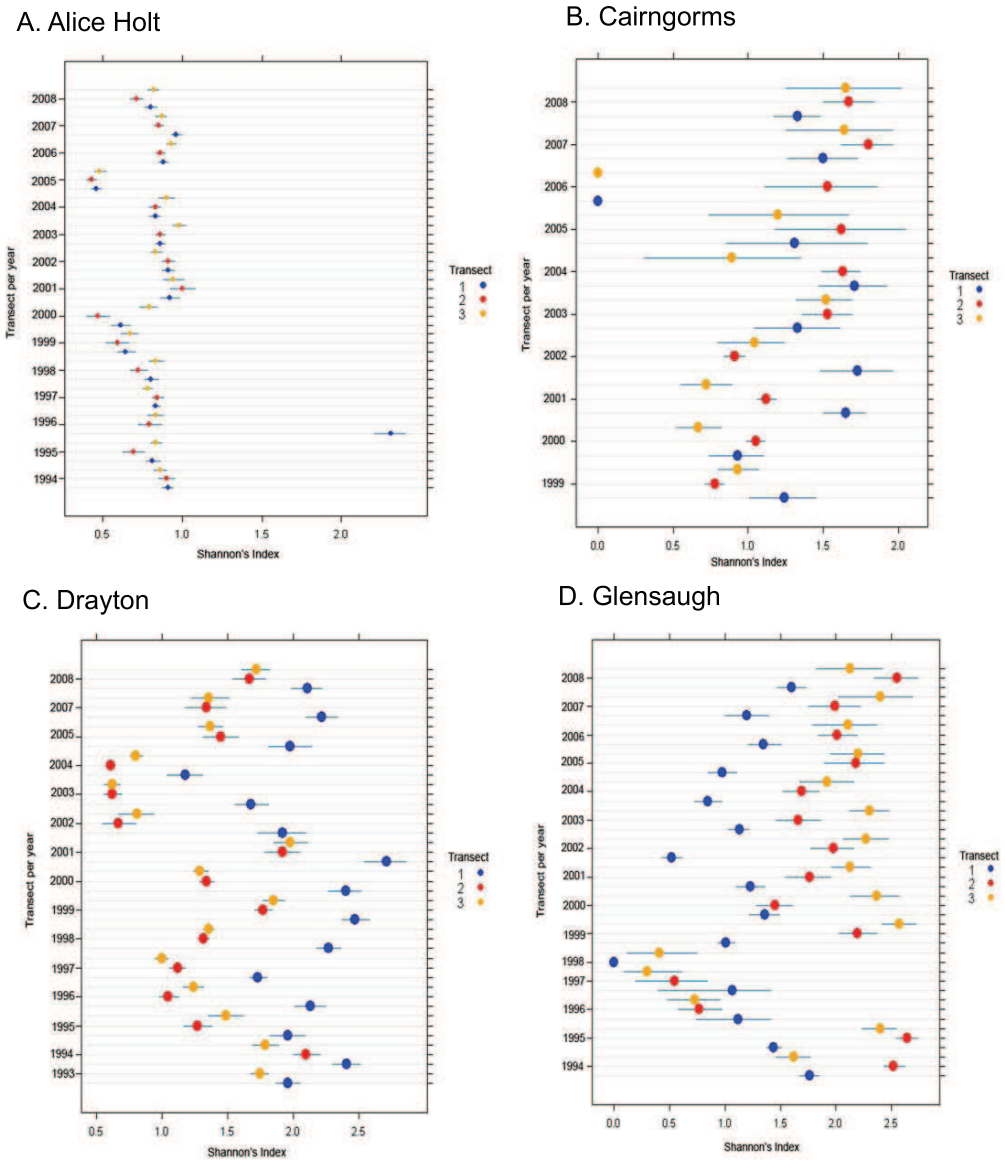

Figure 1: Mean Shannon Index values for total beetle count per transect per year at: A. Alice Holt, B. Cairngorms, C. Drayton, D. Glensaugh. 90% confidence intervals are shown after a 1000 replicate bootstrap with replacement was performed. Transects 1 - 3 represent different transects for each site.