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A COMPARISON OF SOME SPECIES-INDIVIDUALS DIVERSITY INDICES APPLIED TO SAMPLES OF FIELD INSECTS

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Abstract. A comparison was made of several cumulative species/cumulative individuals indices using a statistical distribution corresponding to the species of insects in a sample from the herb stratum of a lespedeza field. Criteria used in comparison were that the indices be intensive for a given universe regardless of sample size and that the indices differentiate between universes having different numbers of species for a given number of individuals. Species/log individuals, species—1/natural log of individuals, log species/log individuals, and species/square root of individuals were examined. Only the index of species/square root of individuals met both of the criteria.

INTRODUCTION

Diversity is an important aspect of species structure in a community. Many attempts have been made to use particular functions to describe how species and individuals in a community are related (Hairston 1959). These relationships are often called diversity indices and are of value in comparing the species composition of different communities or in making comparisons of the same community at different times of the year. With a satisfactory diversity index, it might be possible to extrapolate from a set of data to determine the total number of species in a given "universe" (Preston 1948).

Species-area relationships have been particularly useful in the study of plant diversity (Gleason 1922). This is true because all plants in a given area can be examined quite easily. It is often difficult to determine the actual density of animals, however, and diversity of animals is more easily expressed in terms of the number of species per number of individuals in a sample collection. The total number of species is not usually related linearly to the total number of individuals, but rather, the chance of collecting a new species decreases as sampling increases. A ratio (index) of species to individuals was sought which would be constant for samples of different sizes taken from the same collection and which would differentiate among samples having different numbers of species for a given number of individuals. In this paper actual field data of insect populations are used to test the behavior of several cumulative species/cumulative individuals function as they relate to sample size.

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METHODS

The model (statistical distribution) used to compare various diversity indices was based upon the adult insects collected in ten samples of 250 sweep-strokes each, from a uniform stand of sericea lespedeza [*Lespedeza cuneata* (Dumont) G. Don] (see Menhinick 1963a for the original use of these data). The entire stand of lespedeza covered an area of 32 hectares along River Road at the Savannah River Plant, Aiken County, South Carolina. All adult insects except Microhymenoptera, Microdiptera, and Microlepidoptera were sorted to species and counted (Menhinick 1963a).

To determine whether a given diversity index varied with sample size, it was necessary to construct a distribution model, in which both the number of individuals and the number of species were known for samples of different sizes. To determine the number of species for several different numbers of individuals, the average number of species and individuals collected in one, two, four, eight, and ten samples of 250 sweep-strokes each was examined for two dates, July 1 and August 1. These samples were chosen because they were of moderate size and differed considerably in diversity. Mean number of species for one sample was an average of the number of species found in each of the ten samples considered separately. The mean number of species for two samples was an average of the number of species found in combined samples: 1 + 2, 3 + 4, 5 + 6, 7 + 8, and 9 + 10. For four samples the mean was an average of the number of different species found in combined samples 1–4, 4–7, and 7–10. For eight samples it was an average of 1–8, and 2–10.

A Monte Carlo analysis was made to determine the number of species present in samples smaller than those of 250 sweep-strokes. This consisted of drawing randomly from cards marked in the proportion that insects actually occurred in the sweeps. For July 1, 2,995 adult insects comprising 119 different species were collected, ranging from 858 individuals in one species to a large number of species containing but one individual (Table

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TABLE I. Numerical abundance and coefficient of variation (C.V. $= \frac{\sigma}{\bar{x}}$) of species collected in 2,500 sweep-strokes from sericea lespedeza

July 1, 1959				August 1, 1959			
No.	C. V.	Genus	Family	No.	C. V.	Genus	Family
858	.39	*Scaphytopius*	Cicadellidae	592	.35	*Dorymyrmex*	Formicidae
843	.60	*Dorymyrmex*	Formicidae	283	.17	*Acanalonia*	Fulgoridae
280	.51	*Maecolaspis*	Chrysomelidae	201	1.22	*Trachymyrmex*	Formicidae
204	.40	*Alydus*	Coreidae	148	.40	*Scaphytopius*	Cicadellidae
84	.67	*Vanduzea*	Membracidae	120	.35	*Psallus*	Miridae
54	.47	*Phthiria*	Empididae	93	.51	*Vanduzea*	Membracidae
52	.57	*Alydus*	Coreidae	76	.70	*Stictocephala*	Membracidae
50	.65	*Geocoris*	Lygaeidae	73	.21	*Bombus*	Apidae
50	.71	*Phyllobaenus*	Cleridae	48	.53	*Gyponana*	Cicadellidae
44	.38	*Stictocephala*	Membracidae	39	.49	*Phthiria*	Empididae
43	.50	*Melanoplus*	Acrididae	36	.67	*Alydus*	Coreidae
29	.80	*Psallus*	Miridae	36	1.01	*Apis*	Apidae
25	.93	*Asilus*	Asilidae	31	.74	*Bothrotes*	Tenebrionidae
21	.73	*Oecanthus*	Gryllidae	30	.42	*Maceoloaspis*	Chrysomelidae
20	.47	*Bombus*	Apidae	29	.55	*Asilus*	Asilidae
17	.85	*Epyris*	Bethylidae	28	.71	*Alydus*	Coreidae
16	1.27	*Stirellus*	Cicadellidae	23	.72	*Epyris*	Bethylidae
15	1.49	*Trachymyrmex*	Formicidae	20	.67	*Megachile*	Megachilidae
15	1.02	*Megachile*	Megachlidae	18	1.34	*Stirellus*	Cicadellidae
14	.63	*Sinea*	Reduviidae	18	1.17	*Conoderus*	Elateridae
13	1.52	*Conoderus*	Elateridae	16	.91	*Phyllobaenus*	Cleridae
12	1.04	*Cuerna*	Cicadellidae	14	.86	*Geocoris*	Lygaeidae
11	1.09	*Campylenchia*	Membracidae	10	1.05	*Deltocephalus*	Cicadellidae
10	1.15	*Furcifera*	Thereviidae	[b]			
[a]							

[a]Also 4 species of 9 individuals each, 2 of 7, 3 of 6, 4 of 5, 5 of 4, 5 of 3, 0 of 2, and 61 species represented by 1 individual each.

[b]Also 2 species of 9 individuals each, 2 of 8, 2 of 7, 3 of 6, 5 of 5, 6 of 4, 11 of 3, 20 of 2, and 50 species represented by 1 individual each.

I). A total of 2,995 cards 1 cm^2 were marked to duplicate the empirical distribution. These cards were mixed and selected at random to determine the average number of species for various numbers of individuals. In this procedure the problem was one of determining the chances of getting *at least* one of each card (i.e., the chances of getting one plus the chances of getting two plus the chances of getting three, etc.) rather than determining the *number of each* kind of card. For example, examination of 70 sets of ten cards each gave an average of 5.74 species for ten individuals. Table II gives the number of species for various numbers of individuals. The number of species for fewer than 512 individuals was determined by selection of cards. Those of 512 and more were from the average number collected in sweep-samples. The number of species calculated for 299 individuals in the July 1 sample and for 220 individuals in the August 1 sample closely approached the actual field results. Therefore this procedure is believed to be justified. However, the distribution of each species is often of a more orderly nature than predicted from randomness (Table I, Coefficient of variation).

Results and Discussion

Once the number of species for various numbers of individuals was established (Table II), it was possible to examine hypothetical mathematical relationships for closeness of fit to these data. Indices of diversity based on at least 64 individuals are considered in this discussion. Values for lower numbers are given in Table II.

Species/logarithm of individuals.—One of the most commonly used measures of diversity is the total number of species divided by the logarithm of the total number of individuals (or area; Gleason 1922). This index gave a value which varied from 9.4 for 64 individuals to 29.9 for 2,220 individuals within the less diverse July sample (Table II, Fig. 1). The ratios for the more diverse August sample varied from 11.6 to 37.1. Thus, the diversity index of cumulative species/logarithm of cumulative individuals varied greatly with sample size. The reason for this is that both numerator and denominator change, but not by a constant:

$$D = \frac{S/a}{\log (I/b)} \quad \text{or} \quad \frac{S}{a(\log I - \log b)}$$

where

D = diversity
S = number of species in whole distribution
a = a parameter by which number of species is reduced with reduced sample size
I = number of individuals in whole distribution
b = a parameter expressing reduction of sample size

For this reason and because of overlapping of values for the two samples of different diversity, this index could not be used to compare different samples of various sizes.

Species—1/log e of individuals.—This formula, used by Margalef (1958) to compare species diversity of plankton, was not a satisfactory measure of insect diversity because of wide variation with sample size and because of overlapping of diversity values from different samples (Table II). This variation with sample size was expected as this index was almost the same as species/logarithm of individuals.

Logarithm of species/logarithm of individuals.—When the logarithm of the species was graphed against the logarithm of the individuals, a nearly straight-line relationship was obtained (Fig. 1). However, this index

TABLE II. Comparison of diversity indices (S = species I = individuals)

Individuals	Species		$\frac{S}{\log I}$		$\frac{S-1}{\log_e I}$		$\frac{\log S}{\log I}$		$\frac{S}{\sqrt{I}}$	
	July 1	Aug. 1	July 1	Aug. 1	July 1	Aug. 1	July 1	Aug. 1	July 1	Aug. 1
1	1.0	1.0	—	—	0.00	0.00	—	—	1.00	1.00
2	1.8	1.9	6.08	6.31	1.15	1.30	.870	.926	1.29	1.33
4	3.1	3.4	5.15	5.65	1.51	1.73	.815	.882	1.56	1.70
8	5.0	5.8	5.54	6.42	1.92	2.31	.774	.844	1.76	2.08
16	7.3	9.4	6.06	7.81	2.27	3.03	.716	.808	1.82	2.36
32	11.5	14.2	7.64	9.30	3.03	3.81	.704	.761	2.03	2.51
64	17	21	9.41	11.63	3.85	4.81	.691	.732	2.12	2.74
128	24	31	11.39	14.71	4.74	6.18	.654	.707	2.12	2.74
256	34	44	14.11	18.27	5.95	7.75	.635	.682	2.12	2.75
512	49	63	18.08	23.26	7.69	9.94	.623	.664	2.14	2.78
1024	70	90	23.26	29.92	9.95	12.84	.612	.649	2.16	2.81
2048	96	120	28.99	36.56	12.46	15.61	.598	.631	2.12	2.66
2220	100	124	29.91	37.09	12.85	15.83	.598	.625	2.13	2.63
2995	119	—	34.23	—	14.74	—	.596	—	2.18	—

was unsatisfactory for comparing different sized samples because of overlapping of range of values. For 64 to 2,995 individuals these values varied from .681 to .598 in the July sample and from .732 to .625 in the August sample (Table II). This index would be intensive only where a = b in the formula:

$$D = \frac{\log S/a}{\log I/b}$$

The slope of the line between 64 and 3,000 individuals was practically identical for July 1 and August 1 (Fig. 1), and therefore would not serve to differentiate between the two distributions.

Species/square root of individuals.—Within the range of 64 to 3,000 individuals, species divided by the square root of the number of individuals gave a value which varied between 2.12 to 2.18 for the July 1 sample, and between 2.63 to 2.81 for the August 1 sample (Table II, Fig. 1). The values did not overlap, and the difference between samples was 2.5 times the greatest range within the samples. Thus the relation of species to the square root of individuals gave a nearly constant value which could be used to compare samples of different sizes.

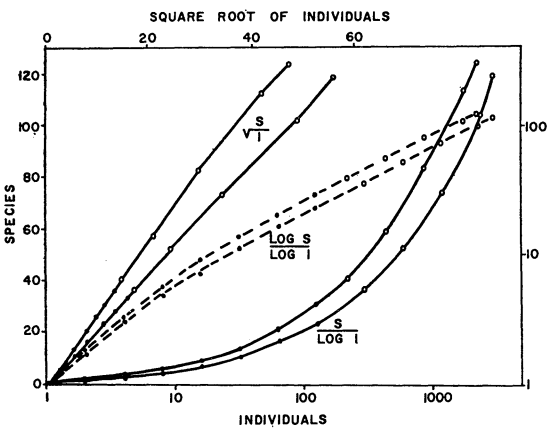

FIG. 1. Relationship of cumulative number of species/cumulative number of individuals functions as related to sample size. S = species, I ≈ individuals. Open circles represent field data, solid dots represent Monte Carlo data. Upper line in each case = August, lower line = July.

Calculation of the slope and power function from the data in Table II (64 and more individuals) by the method of least squares gives:

$$\text{July 1:}\quad S = 2.15\, I^{.500}$$
$$\text{Aug. 1:}\quad S = 2.77\, I^{.497}$$

These data show that the power function expressing the relationship of species and individuals is essentially a square root:

$$D = \frac{S/a}{\sqrt{(I/b)}}$$

In this case D would be constant only for $y = \sqrt{b}$. Since b changes faster than a would, taking the square root may have for a particular distribution the effect of keeping $a \approx \sqrt{b}$, and hence D would remain nearly constant as observed.

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