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Bird Census and Atlas Studies				

Part. I. Bird Census – Methodology

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3. SAMPLE SIZE AND EDGE EFFECT ON COMMUNITY MEASURES OF FARM BIRD POPULATIONS

Common Birds Census data is used to show sample size dependence of H', J, and $\log_2 S$ (measures of diversity from the Shannon's index). Sample size independence is seen as a hindrance to monitoring farm bird populations. The measurement of species density is preferred. Species density maps are given for two farms. Other farm data show edge effects which should be excluded for calculation of species density and species evenness measures.

Biologists are attracted by the use of diversity indices to condense species abundance distributions into one or perhaps two statistics which appear to characterise properties of the group or "community" sampled. Various authors (Tramer 1969, Goodman 1975, Hurlbert 1971) have questioned the ecological significance of these indices. Here I examine the assumption that certain diversity indices are independent of sample size and, more importantly, the assumption that diversity measures should be independent of sample size in order to provide valid measures of community properties.

Williams (1964) has amply documented the empirical observation that as the number of individuals (N) identified in a sample increase so does the number of species identified (S). There are upper limits to this relationship but these need not concern us here. Since the number of species in a sample is fundamental to the calculation of a diversity index, the index must be either independent of sample size or circumscribed by reference to the size of the sample.

The Shannon index (Pielou 1975) has been partitioned to give two measures of diversity: J, a measure of the evenness of distribution of individuals into species; and $\log_2 S$ a measure of species richness. H' is perceived as a composite index determined by species richness and species evenness, such that

$$H' = J \log_2 S \qquad (1)$$

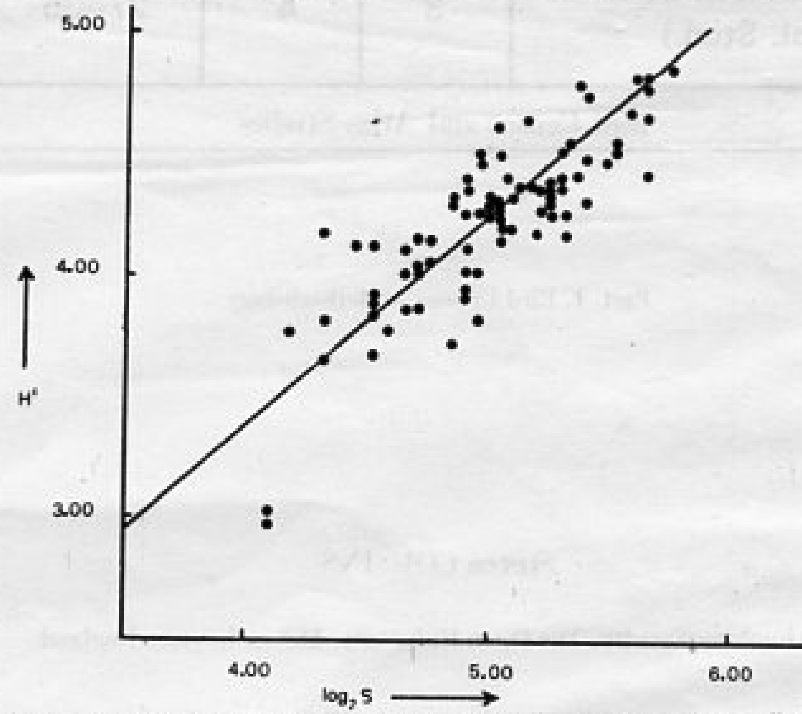

Fig. 1. The relationship between H' and $\log_2 S$; calculated on the data of Common Birds Census 1973 for the farmland

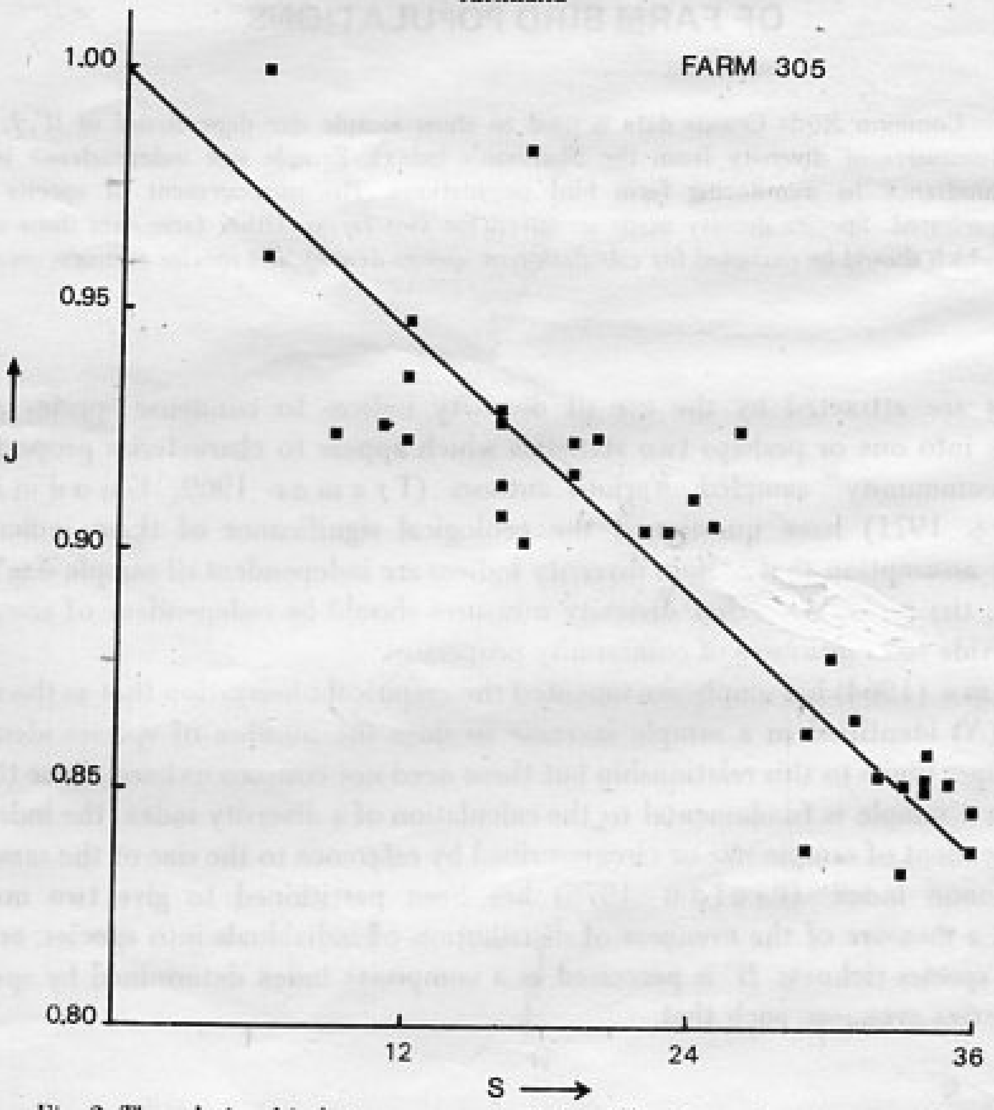

Fig. 2. The relationship between evenness index (J) and number of species (S)

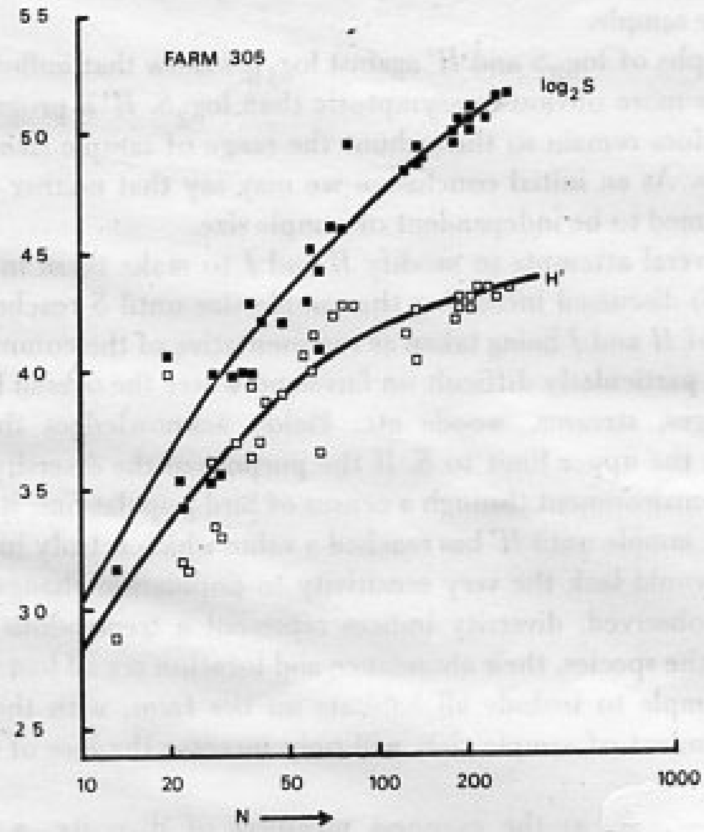

Fig. 3. The effect of sample size (N) on $\log_2 S$ and H'

The indices H' and J are widely used without reference to sample size. However, since S is known to increase with sample size, it follows from equation (1) that H' and J cannot both be constants, as would be required if H' and J were both independent of sample size. Figure 1 shows the relationship between H' and $\log_2 S$ for the farmland census plots of the 1973 Common Birds Census made by the British Trust for Ornithology. The census plots are distributed throughout the United Kingdom, although most plots are found in central and southern England. For details of the method see (Williamson and Homes 1964). The slope of the graph gives the value of average J, which equals 0.85 for the farmland plots studied. This is similar to Tramer's (1969) graph of H' against $\log_2 S$ for bird communities of different vegetational types at various latitudes, for which average J is 0.87. He concluded that since J varied only from 0.718 in tundra to 0.921 in rain forest it could be treated as a constant. Diversity could then be described by S alone without the trouble of calculating H'. One might reach the same conclusion from the farm data, except that we know S to be dependent on the sample size as well as on ecological causes.

In order to test how sample size affects the parameters of equation (1) the 1973 census data was re-extracted from the base maps. Each map was divided into approximately 10 ha sectors and the numbers of species and individuals in each sector were recorded. These sub-samples were added together at random to simulate increasing sample size. Futher details are given in the appendix.

The evenness measure J proved to be highly dependent on sample size. On plot 209, J had correlation coefficients of −0.74 and −0.72 with the number of species and number of individuals respectively. On plot 305 (Fig. 2) the correlations were stronger at −0.89 and −0.88

for S and N respectively. When S is less than about 10 species, J varies widely due to chance variation in making the sample.

In Figure 3 the graphs of $\log_2 S$ and H' against $\log_{10} N$ show that indices are affected by the size of sample N. H' is more obviously asymptotic than $\log_2 S$. H' is progressively less sensitive to sample size but it does remain so throughout the range of sample sizes encountered in the Common Birds Census. As an initial conclusion we may say that neither of the parameters in equation 1 can be assumed to be independent of sample size.

There have been several attempts to modify H and J to make them independent of sample size. Pielou (1975) discussed increasing the sample size until S reaches an upper limit, the corresponding values of H and J being taken as representative of the community sampled. Such an approach would be particularly difficult on farmland where the overall habitat is a mosaic of fields, meadows, hedges, streams, woods etc. Pielou acknowledges that it is intrinsically impossible to estimate the upper limit to S. If the purpose of the diversity index is to monitor change in the farming environment through a census of bird populations, it makes little sense to attempt to enlarge the sample until H' has reached a value which is truly independent of sample size. Such a measure would lack the very sensitivity to population change that is required. As Fager (1972) has observed, diversity indices represent a tremendous loss of information since the identities of the species, their abundance and location are all lost in a single value. The enlargement of the sample to include all habitats on the farm, with the aim of making the diversity index independent of sample size, will only increase the loss of information and the lack of sensitivity.

Returning to look briefly at the evenness measures of diversity, a general approach to attaining independence of sample size has taken the form

$$\frac{\text{observed index value} - \text{minimum index value}}{\text{maximum value} - \text{minimum value}} \quad (2)$$

The maximum value of an index when used to measure evenness of distribution is obtained when each species has exactly the same number of individuals, N/S. The minimum value, i.e. the most uneven distribution, is given when each species has only one individual except for a single species which has all the other individuals, $N-(S-1)$. For H' a measure of evenness, V, which is independent of sample size is given by

$$V = \frac{H_{obs} - H_{min}}{H_{max} - H_{min}} \quad (3)$$

One other measure Fager's (1972) ("Number of Moves") has been used in this paper. The basis of this is overtly non-biological. It is simply a count of the "Number of Moves" required to transform an observed distribution into a perfectly even one. The species are ranked so that the most abundant species has rank 1, the next most abundant rank 2 etc. Then since the even condition is one where N/S individuals are present in each species, individuals are "moved" from the most abundant species to species with less than N/S individuals. Each time an individual moves from one rank to another the value of NM is increased by one. A value of NM which is nationally independent of sample size is obtained from

$$NM = \frac{NM_{obs} - NM_{min}}{NM_{max} - NM_{min}} \quad (4)$$

One fundamental problem with measures of diversity which are truly independent of sample size is that the measures are unaltered by large increases or large decreases in the bird population. For example, using Williams (1964) α which is determined simply from the parameters S and N, the value of α is equal to 16 for each of the following pairs of (S, N) values: (33, 100); (46, 200); (51, 300). Therefore habitat changes which halved the bird population from 200 to 100 individuals would go unrecorded by the diversity index α, provided that 13 species were also lost. If less than 13 species were lost then α would record an increase in diversity.

COMMUNITY MEASURES PER UNIT AREA

Rather than attempting to construct indices which are independent of sample size, I believe it may be easier and biologically more realistic to concentrate on measuring community

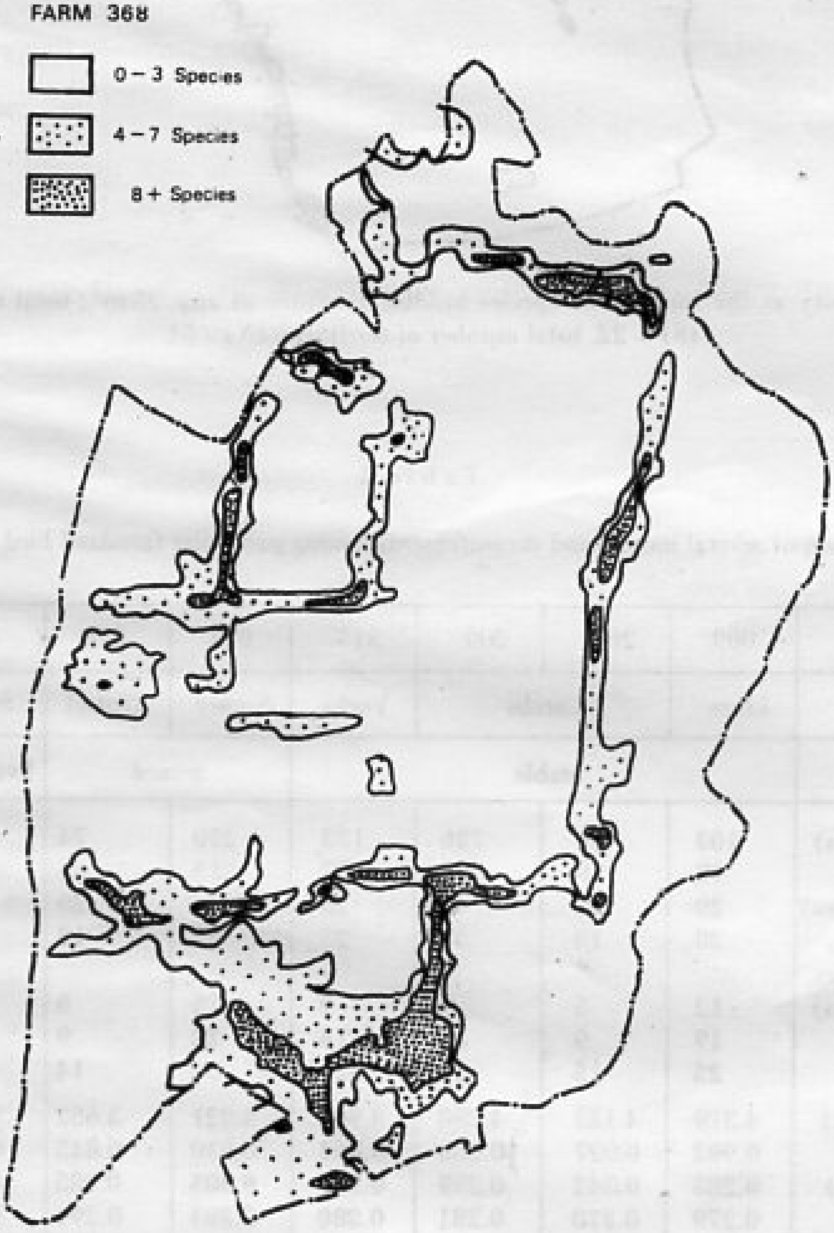

Fig. 4. Species density as the number of species holding territory at any 25 m^2: total number of species (S) equals 45, total number of territories (N) = 185

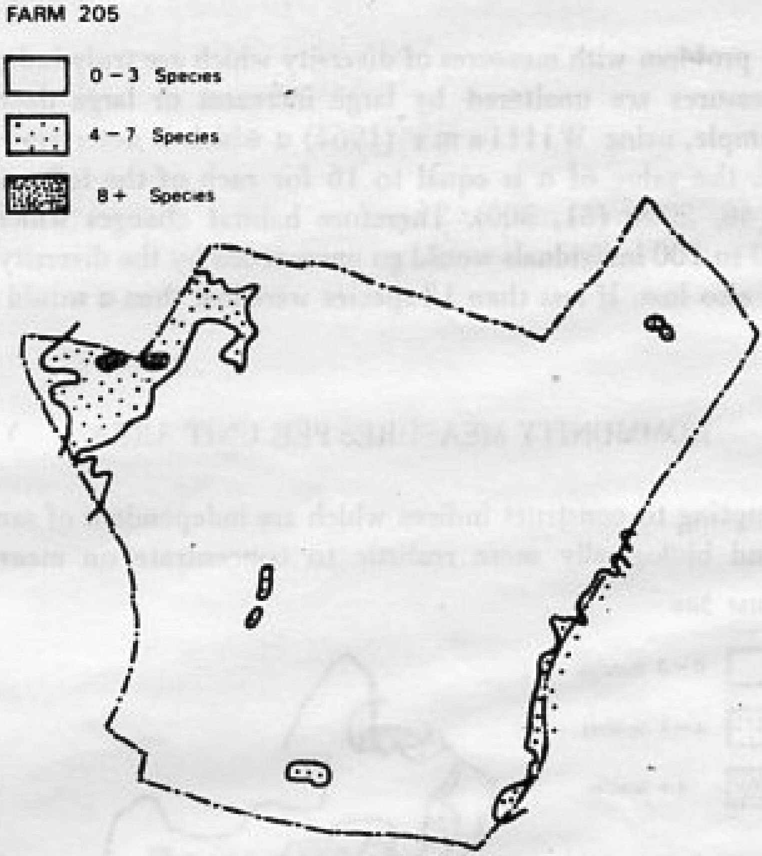

Fig. 5. Species density as the number of species holding territory at any 25 m^2: total number of species (S) = 22, total number of territories (N) = 51

Table 1

The comparison of several indices and measurements among particular farmland bird communities

Farm	009	205	209	315	072	078	259	372
County	Lincs	Cambs		Yorks	Somer	Dorset	Somer	Dorset
Farm type	arable				mixed		livestock	livestock
N (number of pairs)	103	51	736	133	250	74	187	305
N – edge	98	39	482	97	213	64	137	273
S (number of species)	29	22	41	23	34	20	30	38
S – edge	28	18	38	23	33	18	27	35
S_{10ha} (no. of species on the 10 ha)	12	5	9	9	15	6	11	19
S_{20ha}	19	9	15	14	22	9	16	27
S_{40ha}	25	15	22	21	30	14	22	33
H' (Shannon index)	4.379	4.133	4.288	3.900	4.221	3.652	4.102	4.251
J (eveness index)	0.902	0.927	0.800	0.861	0.830	0.845	0.836	0.810
NM (Fager's index)	0.285	0.342	0.299	0.358	0.305	0.285	0.303	0.276
NM – edge	0.279	0.370	0.281	0.280	0.393	0.294	0.306	0.307
V (evenness measure)	0.832	0.805	0.775	0.800	0.775	0.722	0.772	0.756
V – edge	0.822	0.805	0.757	0.743	0.831	0.715	0.775	0.777

attributes on an area basis. Area is a fundamental unit in ecology since the energy supply from sunlight is available per unit area. The numbers of individuals and species in an area determine the size and variety of pathways through which that energy is dissipated. Similarly the number of species present in a small area determines the contempory level of interaction between species.

I have used two area-based approaches. The first was to map the number of species present in each 25 m × 25 m square on plots 368 and 205. This was done by counting the number of territories which were present in each square. The maps of overlapping territories are shown in Figure 4. For the Dorset dairly farm (368) areas of low species density include all fields. Moderate species density (4–7 species) is found along the hedgerows.

Species densities of 8 or higher are associated with standard trees being present in the hedgerows. The large area of high species density at the foot of the figure is due to a 1.6 ha wood and a disused railway line running obliquely from the foot of the figure up to the left. Plot 205 in Figure 5 is on an arable farm where internal hedgerows have been removed. The remaining areas of moderate species density are found at the boundary hedges at the top left and bottom right of the figure and also at a pond at bottom centre.

The second approach was to calculate species richness on the basis of the number of species found on 10, 20 and 40 ha areas. The calculation of this definition of species density has been made by drawing curves of the number of species ($\log_2 S$) against sample size ($\log_{10} N$). From these curves the values of S can be found corresponding to the mean number of individuals occurring on 10, 20 and 40 ha. The results are given in Table 1 and are adjusted for edge effects. This adjustment is needed because boundary habitat features can be responsible for as much as 50% of the total numbers of birds found on some census areas. This is the case for plot 205 where 24 of the 51 territories were considered to be at the edge.

The table illustrates how the comparison of farms by the measurement of species density gives a very different picture to the comparison using H'. Plot 205 has 1/3 the bird density of plot 259, and far fewer species, yet it exhibits higher "diversity". as measured by H'. The measurement of species richness is relatively simple -- one counts the number of species. For species evenness, one is attempting to measure the inverse of species dominance: It is not clear that any of the evenness indices do this in a meaningful way. The indices have to be invested with meaning by comparison between samples, with the hope that particular ranges of index values are correlated with other properties which are directly measurable.

Lastly, how should one equate species richness with species evenness? It was stated that H' is a product of evenness and richness, but Hurlbert (1971) has noted that there is no empirical basis for the manner in which evenness should be combined with richness. Since from Table 1 it seems that the nonbiologically based index NM shows no better or worse performance than the other evenness indices, it would at least appear to have the advantage that it cannot be combined with species richness attributes. Using S per unit area and NM, the concepts of species richness and evenness can remain distinct.

The adjustment for edge effect resulted in marked changes in evenness for farms 315 and 072 only. Edge effect adjustments are important when measuring bird or species density.

CONCLUSION

I began by describing two options necessitated by the observation that the number of species in a sample increase with the size of sample. Either diversity measures must be independent of sample size, or they must be circumscribed by the size of the sample. To date diversity indices have been designed to be independent of sample size although for certain indices this aim has not been fully achieved. Sample size independence is convenient for the observer since, within broad limits, the index will not be affected by the amount of time spent in the field and the boundaries of the observation area need not be precise. However, the convenience of the observer is gained at great cost. The very sample size independence means that the index is designed not to detect changes in bird density. Hence the use of such indices to monitor environmental change is very limited. If instead of sample size independence, species richness is circumscribed by sample size in the form of species density, then changes in bird populations can be monitored directly. Fine-grained variation in species richness can be demonstrated easily. Also the species density approach does not lead to the presumption that there is a "community structure" which is measurable. Indeed, without the diversity "fog" things may become much clearer "down on the farm".

APPENDIX

SUBSAMPLE SELECTION AND EDGE TERRITORY COMPENSATION

The Common Birds Census species maps for the farm land plots were divided into sectors, which were then reaggregated, in the following manner.

1. The number of sectors required was chosen by dividing the farm area (in hectares) by 10.

2. For approximately square or round plots the sectors radiated out from a central point; for narrow or irregularly shaped areas the sectors radiated out from two or more points. Sector edges were not placed along linear habitats.

3. The number of territories and the identity of each species was recorded for each sector. A territory was taken as being inside a given sector if it had more registrations in that sector than in any other sector.

4. Where the sector edge was also the plot edge, the number of territories on the plot edge was halved for each species. Edge territories were defined as those which were likely to be recorded on the adjacent plot if it were also being censused. Thus an edge territory is one which has 3 or more registrations on the plot edge, or which has 2 on the edge and only 1 internal, or where the size of territory which includes the edge is small compared to those territories internal to the plot. The key arbiter in doubtful cases was the test, "would the territory be likely to be recorded on the adjacent plot"?

5. Aggregating the sectors was done by using a random number generator subject to the condition that each sector could not be included more than once in an aggregation. For each plot an increasing number of sectors was aggregated until the whole plot was reconstituted.

I would like to thank Tim Reed, Leo Batten, Janet Wingfield and Mike O'Carroll for their help with this project.

STRESZCZENIE

Autor na podstawie spostrzeżenia, że liczba gatunków wzrasta w miarę zwiększania badanej próbki, udowadnia, iż nie istnieją wskaźniki różnorodności zespołu (diversity) niezależne od wielkości próby. Wydaje się łatwiejsze i biologicznie bardziej uzasadnione skoncentrowanie się na pomiarach cech zespołu zwierzęcego odnoszonych do wielkości badanej powierzchni od prób konstruowania nowych wskaźników niezależnych lub mniej zależnych od wielkości próby. Obszar (powierzchnia) jest bowiem podstawową jednostką w ekologii, gdyż ilość energii słonecznej obliczana jest również na jednostkę powierzchni.

Zaleca się zatem, zamiast wskaźnika Shannona i tym podobnych, stosowanie obliczania zagęszczenia gatunków. Na przykładzie materiałów z liczeń ptaków na farmach angielskich dokonano obliczenia zagęszczenia gatunków i przedstawiono na mapkach (fig. 4–5). Możliwość uniknięcia zniekształcającego wpływu wielkości próby (powierzchni) autor widzi w stosowaniu podziału badanych obszarów na

drobniejsze jednostki o jednakowej wielkości, np. na 10 ha. Te części powierzchni oprócz zapewnienia porównywalności gęstości populacji i zagęszczenia gatunkowego zwiększyłyby również materiał (liczbę prób) umożliwiając statystyczne opracowanie danych.

Autor opowiada się za odrębnym wyrażaniem dwóch komponentów zróżnicowania gatunkowego zespołu, tj. bogactwa (liczby) gatunków (richness) i równomierności ich udziału ilościowego (evenness). Bogactwo gatunków autor zaleca badać za pomocą obliczeń zagęszczenia gatunków (liczba gatunków na jednostkę powierzchni), a równomierność udziału ilościowego ptaków wskaźnikiem Fagera (1972), tzw. *NM*, podanym w obecnej pracy.

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