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SUMMARIZING REMARKS: SAMPLING DESIGN

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Strictly speaking, experimental design is concerned with treatments and controls, so this session should probably have been called "Sampling Design." The five papers are an interesting mix of approaches to designing bird census work. The overall message is that we need more validation of the accuracy of the methods, further standardization so that results can be compared, and more attention paid to variance in both the planning and analysis stages. In fact, variance is a biologically interesting statistic in itself. Progress could be made by concentrating on variance as the parameter of interest, thereby getting away from a typological emphasis on total or average species richness and substituting within- and between-habitat patterns in variance. Of course the biologically interesting variance would have to be separated from that attributable to error or bias inherent in the method. Another message in this set of papers is that we should pay more attention to the distribution of the data. Consider whether transformations are in order before making statistical comparisons that have underlying normality assumptions, or else use nonparametric methods of analysis. The field methods discussed in the first four papers are appropriate for broad-scale or long-term studies, and in that sense they are similar to the atlas projects or the Finnish line transects. The last paper, by Kenneth Pollock (1981), focuses on methods of studying a single population of one species over a long period. I think each paper is an excellent contribution towards the goal of characterizing avian populations in terms of species-individual, individuals-area, and species-area patterns.

The first paper, by David Dawson (1981b), discusses some limitations of point counts and transect methods. Nevertheless, he concludes that both are more suitable than territory mapping for broad surveys. I was surprised that after discussing the importance of understanding the underlying distribution of the data, he was willing to extrapolate the number of species observed, with different amounts of field effort, to obtain estimates of the total species richness of the habitat. The empirical observation of a generally linear increase in species with the logarithm of the field effort expended by the observer is interesting, but extrapolations of basically curvilinear phenomena make mathematicians uneasy. I think it is unwise to predict the species richness of an area beyond the data at hand. A preferable alternative exists for comparing the species richnesses of samples having different numbers of individuals. The procedure, rarefaction, is a distribution-free method of estimating the number of species that would have been present if fewer individuals had been observed (Heck et al. 1975). It is suitable for comparisons based on any field method. If density estimates are available, one can compare the species richnesses of areas of different size by first estimating the number of individuals that would have been present on equal-sized areas, and then, by rarefaction, finding how many species would have been present in samples of that size (Engstrom and James 1981).

One does not need density estimates to calculate the equitability or evenness of a community of birds. That requires only a list of the species and their relative abundances. Personally, I prefer graphs of the relative abundance patterns to calculations of indices such as J'. This index is usually close to 1 for bird communities and its value depends on the number of species in the list. This in turn depends on the sampling effort. So J' is not very sensitive to the evenness of the numbers of each species. Nevertheless, Dawson (1981b) is correct when he reminds us that the accuracy of density estimates made from point and transect samples is very difficult to determine.

Charles Gates (1981) discusses ways to plan the length of a transect survey, how many stations there should be along it, and how long the observer should stop at each station. The decisions are based on estimates of the variance in the results of a sample survey in the habitat in question. These estimates can be made in several ways. For instance, they could be based on the variation among transects replicated in either space or time. Or one long transect could be examined by "interpenetrating sampling," that is, estimating the variance of subsamples formed by selecting groups of individuals randomly from the larger sample. The optimal length of a transect will be the one for which the ratio of the variance in density to the density estimate itself is minimal. The author expands this problem to include estimates of the optimal number of stations, and the time to be spent at each. These procedures could save wasted effort spent either undersampling or oversampling an avifauna. I think that the variance estimates are

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probably of biological significance in themselves. If partitioned by habitat and season, they could be used to study the patchiness or heterogeneity of bird distribution. If analyzed along with quantitative data on the structure of the vegetation, they could be used to account for within-habitat patterns of distribution as well.

The paper by Jacques Blondel et al. (1981) describes two sampling procedures. They are being used to characterize broad-scale patterns of bird distribution in France, including analyses of correlates with quantitative vegetation data and implications for biogeographic theory. Both are based on point counts with unlimited distance to the birds. With the "Indice Ponctuel d'Abondance" (IPA), one visits several randomly selected points twice in a 30-day period in the habitat (biotope) in question, recording the birds heard or seen in 20 min at each point. Means and standard deviations are calculated for the higher of the two counts by species, and these values give an index to the abundance and variation in abundance of the species in that habitat. Also the average number of species per point and its standard deviation permit calculations of mean species richness ($\bar{s}$) for the habitat. On the basis of separate data obtained by spot-mapping, detection coefficients can be calculated for each species and each observer. These coefficients can then be used as weights to calculate densities from the IPA counts. With the second method, the "Echantillonage Frequentiel Progressif" (EFP) the observer visits a point only once and records only the presence or absence of the species. The frequency of each species (percentage of points at which the species was recorded) is considered to be an adequate index to its general abundance, except at very high densities. Clearly, comparisons of data from point counts should be based on nonparametric methods. I think the authors should consider whether median species richness might be a more appropriate statistic than mean species richness.

Michael Morrison et al. (1981) discuss a new method called the variable circular plot. They find that the number of stations required to obtain stable estimates of the density of birds varies with habitat, but that reasonably stable estimates can be obtained with only four stops. Of course the variation in the effective detection distance is bound to be a serious source of bias in the results, so the density estimates may be stable by being consistently inaccurate and this varies by species. The authors are aware of these problems, but they feel that the method is useful for inventories, especially in areas of rough terrain. The variable circular plot technique is reminiscent of the IPA technique described above. If it were validated by comparisons with spot-mapping, and standardized with the IPA method, comparisons between Old World and New World bird populations could be made.

If it were possible to make exact counts of the birds in an area, biologists would not need to wrestle with all these sampling problems. But given the complex multivariate nature of the sources of error and bias, plus the fact that the populations are open systems with no fixed boundaries, the problems will probably be with us into the indefinite future. It is good to know that we now have the attention of statisticians interested in applications of their theoretical work to the area of sampling. For a thorough treatment of this subject see Comak et al. (1979). This important book contains major articles on line transect and mark-recapture methods. If we can develop standardized, probabilistic methods that are of practical use considering the special nature of bird populations, then all that remains is to ask insightful questions and develop experimental tests.