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Comments on Transect Methodology

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One of the more obvious outcomes of the recent spate of attention to environmental problems is the realization that we do not have suitable methods to census "non-game" species. It can, of course, be remarked that we don't have very many useful techniques for harvested species, either. However, in those cases, there are at least some kill statistics and other data to serve as indicators of trends. Since marking is expensive and time-consuming, investigators have tended to look for methods that involve only visual techniques. One of the leading candidates thus becomes the line transect method. The purpose here is to briefly describe some of the available transect methods, and to comment on some aspects that may be of particular interest and importance.

Perhaps the main objective to be kept in mind in considering transect methods is that of determining the probability that a given individual or group of individuals will be observed in the course of the survey. In this respect, the transect methods have a common limitation shared also by the capture-recapture approach. This is simply that the "trick" in getting a good estimate is to obtain suitable measures of the probability that a given individual will be included in the sample. The main shortcoming in the capture-recapture methodology is the requirement that the capture probability be the same for every member of the population on any particular sampling occasion. With the transect methods, this need is also present, but can usually be met by locating transect lines at random, although that is clearly not the whole story. However, the main apparent problem in transect methods at the moment is that of finding a way to estimate the probability of sighting (more accurately, of finding its mean value).

TRANSECT METHODS

A classification (Fig.1) will be useful in identifying the differences in the several transect methods. The classification is based on several aspects of the process leading to detection, and thus provides a framework for models of the methods. An alternative way to consider the different methods is by describing what is done in the field. Fig.2 may help in distinguishing methods on the basis of the mechanics of what actually is done in the field. In the _line intercept_ methods, only those individuals somehow "intercepted" by the transect line are tallied. The best-known use is for measuring canopy coverage in botanical studies. The _line transect_ method is based on corrections for "effective width" of the strip covered that are derived from distances to the animal or object from the transect line at the time it is first sighted. Various names for these distances have been used; it will be convenient here to speak of the right-angle distance (that from the line to the object at a right-angle to the line) and the radial distance (that from the observer to the object when it is first sighted). _Strip_ trammpdtyslong, narrow evidence that not all of the animals or objects on these plots are tallied. It may then be possible to utilize line transect methodology to correct for the missed individuals. However, it seems best to simply call this a line transect. We will here use "strip transect" to mean either plots on which complete counts are made, or on which the corrections differ from those of the usual line transect. In what follows, such corrections will be denoted by "modified" strip transects. Table 1 provides a list of the methods, which are then discussed under the appropriate headings below.

Table 1

A List of Transect Methods

MODIFIED STRIP TRANSECTS	
Submerged marine mammals	Eberhardt et al.(1979)
Highly mobile animals	Skellam(1958)
Aerial surveys	Jolly and Watson(1979)
LINE INTERCEPTS	
Length of interception(l_i)	McIntyre(1953)
Needle-sampling	DeVries(1979)
Width of interception(w_i)	Eberhardt(1978a)
Bitterlich transect	Strand(1958)
LINE TRANSECTS-RADIAL DISTANCE	
Hayne's(1949) method	Eberhardt(1978a)
LINE TRANSECTS-RIGHT-ANGLE METHODS	
(1)Probability distribution models	
Exponential	Gates et al.(1968)
Half-normal	Hemingway(1971)
Log-linear	Anderson et al.(1978)
Exponential power series	Pollock(1978)
Logistic	Eberhardt(1978a)
Power series	Eberhardt(1968)
(2)Curve-fitting	
Quadratic(polynomial)	Anderson and Pospahala(1970)
Fourier series	Crain et al.(1978)
Splining	Gates(1979)
(3) Histograms	
Kelker's method	Eberhardt(1978a)
Cox's method	Eberhardt(1978a)

Modified strip transects

There are at least three kinds of modified strip transect. One concerns searches for marine mammals from shipboard. A major source of bias arises due to the fact that the animals may be submerged when the vessel comes into visual range. The corrections proposed thus far are reviewed in Eberhardt et al. (1979), and will not be discussed here. A second modification arises when very mobile animals must be dealt with. In this situation, individuals may move into and out of the observer's field of view as he traverses the transect line, making the width of strip censused difficult to define. Efforts were made to deal with this problem by Yapp(1955), and a firmer mathematical basis was established by Skellam(1958). The chief difficulty has to do with the need to obtain some measurement of the average velocity of the animals, and this seems to have prevented much further action on this front. Yet a third class of modification may be typified by aerial surveys for large animals, as done extensively in Africa. The methodology was described by Norton-Griffiths(1975). Experience has shown that quite narrow strips are essential, but even so appreciable numbers of individuals may be missed. Caughley(1974:Table 1) reported some estimates of fractions counted and Caughley and Goddard(1975:Fig.2) showed an impressive decline in number of elephants counted as strip width was increased. Where groups of varying sizes are present, it may be possible to obtain some approximate corrections on the basis of group size. These will be discussed below.

Line Intercepts

There are several variants of the line intercept method, and these are most effectively classified by the basis for estimating the probability of interception. One method uses the length of the interception of the object by the transect line(l_i). In the original use of line intercepts, the sum of these values divided by the length of line traversed gives an unbiased estimate of coverage of, for example, shrub canopies. However, the measurements can also be used to estimate the density of objects, using an equation developed by McIntyre(1953). Unless the objects are circular in form, the method will have some degree of bias, which may be quite severe if the objects have sharp protusions, giving small intercepts. This point is discussed by McIntyre(1953) and Eberhardt(1978a). Another method is known as "needle" sampling, and is described in detail by DeVries(1979). This method was developed for assessing the abundance of long, narrow objects ("needles"), such as tree-trunks in a recently logged area. It depends on a random orientation of the objects, and may thus be seriously biased if there is some pattern in the arrangement of the objects. A third method depends on measuring the width (w_i) of the objects measured at right-angles to the transect line. It was suggested by Strong(1966) as an improvement on McIntyre's method. Strong's definition of "width" seems a little ambiguous. It should be measured between the extreme right- and left-hand parts of the object, when viewed from the transect line, or as the projection of the object onto a baseline. The rationale for using the width of the objects can readily be seen by reference to

Fig.3. The probability of intercepting an object is simply its "width"(w_i) relative to a baseline on which the transect lines are randomly located. On this basis, only the width(w_i) provides an unbiased estimate of density, without further assumptions. McIntyre's method may be useful if the main purpose of the survey is to measure coverage, since a second measurement is not needed. Somewhat the same argument holds for needle-sampling, in that the applications in forestry mostly have to do with estimating the volume of "slash" left after logging(but see DeVries,1979, for other uses). Several measurements may thus be required (e.g., length and diameter), so that width relative to the baseline calls for an additional measurement. However, this cost should be judged relative to the risk of a pattern in the orientation of the objects, and the corresponding risk of biased estimates.

A fourth kind of interception can be defined through use of an "angle-gauge", as used in forestry in Bitterlich's method for estimating basal area. This technique is normally used as a "point" method, i.e., the observations are taken from a sampling point. However, it can also be utilized from a transect line, as suggested by Strand(1958). The objects are then viewed at right-angles from the transect line, and the angle-gauge is used to determine whether or not a given object has or has not been "intercepted". This is decided by determining whether or not the gauge covers the object(holding one's fist out with extended thumb at eye-level provides a convenient angle-gauge). The width of those objects not covered by the gauge must be measured, and a little trigonometry is required to determine the effective width of the objects.

The four intercept methods suggested above have more or less specialized applications, but it seems likely that a variety of further applications may turn up in time. Thus Strand's use of the Bitterlich method on a transect line might be handy in estimating the density of some rather rare objects, such as "den trees". Auxiliary measurements, such as size, can be incorporated through ratio estimation (discussed below). J.H. Hunt(personal communication) has suggested an application of McIntyre's method in furbearer censusing. Trails or logging roads serve as the transect, and l_i is measured between crossings of a given animal , after a snowfall(several assumptions are evidently necessary, such as a roughly circular course of an animal during the night, and that both crossings of the same animal are observed, etc.). Seber and Pemberton(1979) discuss use of line intercepts for studying plant cuticles in rumen and fecal samples.

Line Transects

A long list of methods of estimating density from line transect data is now possible, and a good deal of theoretical work is being done on these and additional estimators. Undoubtedly it will be some time before a few methods can be singled out as being "best", and it isn't feasible to do more here than to list some of the methods and mention some points that need consideration. Two groups of methods can be defined on the basis of whether the radial or the right-angle distance is used. At present it seems that an important feature in the choice between these two approaches is the method of detection. When detection depends on reaction by the animal being censused(flushing), then it seems likely that the radial distance method may be preferred. Some reasons for this belief are suggested in Eberhardt(1978a), and some tests to check on the necessary assumptions are suggested below. When detection depends on the observer locating the object or animal, then it seems that the underlying model for use of radial distances may not hold, and that it may be necessary to go to use of right-angle distances. However, it may well turn out that either an improvement in field techniques or a new model (some suggestions have been made by Burnham and Anderson, 1976) will permit use of radial distances. Some of the methods either used or recently proposed will be suggested in the remainder of this section.

Radial distance methods

The main method for estimation is now that of Hayne(1949). Those suggested by King(described by Leopold,1933) and Webb(1942) have now largely been shown to be of questionable validity (see Gates,1979, for a discussion). Hayne's original derivation assumed a fixed flushing radius to be associated with each animal at the time of the observer's approach. As soon as the observer crosses the boundary of a circle defined by that radius, the animal flushes. With this model, one can immediately see that the arguments underlying unbiased intercept sampling apply, with the width now being the diameter of the circle. The method could thus be listed as an "intercept" method, above. However, an alternative "probability-of-flushing" model can also be defined(Eberhardt 1978a), and used to obtain the same estimator. It doesn't seem to be possible to distinguish between the two models on the basis of field observations.

Right-angle distance methods

The right-angle distance methods are all based on the notion of a "visibility" or "detection" curve. This is based on the apparent decline in numbers of individuals seen with increasing distance from the transect line. It is assumed,with reason, that all animals or objects directly on the transect line are observed, and that the probability of seeing an individual decreases with its distance from the line. A general theory based on this model for line transects was proposed by Burnham and Anderson(1976), although the concept was reported earlier by Cox(1969), in a very different context. The goal of all of the estimation schemes is to estimate the relative frequency of sightings on the transect line. This value can be considered as being the reciprocal of the "effective width" of the transect , i.e., width of a comparable strip transect on which all animals are seen.

Schemes for estimating this parameter can conveniently be described as having three general forms, as follows(Table 2 gives equations for the models.)

(1) Probability distribution models. These models take the form of several well-known probability density functions for the relative frequencies of right-angle distances. The first such model reported is that of the negative exponential distribution (Gates et al. 1968). This model assumes that sightings fall off at a constant rate from the transect line,i.e., exponentially. While this model seemed to fit the data from which it was derived (flushing data on ruffed grouse), it has the drawback that a more general view of field observations is that the frequency of sightings does not seem to drop off in this fashion. Instead, there is a fairly constant frequency of sightings near the transect line, followed by a rather sharp drop-off, and then a more gradual decrease associated with a small frequency of more distant sightings, or "distant flushes". A model more nearly in accord with this notion is the half-normal suggested by Hemingway(1971). Both the exponential and the half-normal share the advantage of having only one parameter to estimate, along with the consequent disadvantage of a lack of flexibility. A general model with more parameters can be obtained from the exponential power series (Pollack 1978). Such a model, with two parameters, can be considered to encompass either the exponential or the half-normal. Another candidate with two parameters is a modified logistic curve (Eberhardt 1978a). This model has the exponential as a limiting form, and will also fit the half-normal very closely. Among other models proposed are a log-linear exponential model(Anderson,Burnham, and Crain 1978) and an ordinary power series (Eberhardt 1968). The latter was proposed mainly as a way of illustrating the effect of the shape of the model on number of individuals seen, and not as a basis for an estimation scheme.

(2) Curve-fitting schemes. Since it is the relative frequency of the observations at the transect line that is sought, it is not necessary to posulate probability density functions. One can instead, just fit curves to the observed data and use the value of these fitted curves at x=0 to provide the requisite estimate. One such procedure is to fit a quadratic curve to the data, as was done by Anderson and Pospahala(1970). More flexibility can, of course, be achieved by using more terms of a polynomial. Another very flexible scheme was proposed by Crain et al. (1978), who derived a "Fourier series" model. Gates(1979) provides further discussion of these and other models, including "splining" techniques.

(3) Histograms. A very simple way to estimate the relative frequency of the observations near the transect line is to use only those observations near the line. Doing so amounts to using the "Kelker" estimate, which is indistinguishable from a strip transect estimate. The main difference is that Kelker's approach amounted to "looking at the data" after the survey was completed to determine how wide a transect might reasonably be used, instead of making that decision in advance. It can be argued that Emlen's(1971) technique for censusing

small birds is essentially that of Kelker(Eberhardt 1978a). These methods use only the first bar of a histogram representing the observed right-angle distances. A way to use the first two bars was suggested by Cox(1969), but for another purpose. Any number of bars can be used(Eberhardt 1979), and increasing the number of bars (or "belts" out from the transect line) reduces the bias in the estimates. Unfortunately, the variance appears to increase with the number used, so that there is a need to balance bias against variance.

Table 2

Models for Right Angle Distance Methods

(1) Probability distribution models	
Exponential	$g(x)=e^{-ax}$
Half-normal	$g(x)=e^{-ax^2}$
Log-linear	$g(x)=e^{-ax-bx^2}$
Exponential power series	$g(x)=e^{-ax^b}$
Logistic	$g(x)=(1+b)e^{-ax}/(1+be^{-ax})$
Power series	$g(x)=1-(x/w)^a$
(2) Curve-fitting	
Quadratic	$y=a-bx^2$
Fourier series	$y=1/W+\sum_{j=1}^{m} b_j \cos(j\pi x/W)$
Splining	$y=a \quad (x\leq W) \; ; \quad y=a-b(x-W) \quad (x>w)$
(3) Histograms	
Kelker	$y=n_1/W$
Cox	$y=an_1-bn_2$

SAMPLING DESIGN AND ANALYSIS

Much of the recent and current activity concerning transect methods has been concerned with the development and fitting of new models. Without denying that this is a subject in need of investigation, it may nonetheless be remarked that there needs to be more done on the problems of designing, executing, and carrying out an analysis of the data from such surveys. About all that can be done here is to offer some rather general suggestions. These are set out under a number of topics under the following headings. Caughley(1977) discussed sampling in aerial survey, and Anderson et al.(1979) offered some guidelines for line transect sampling.

Randomization

This issue always is a problem in designing a survey. Most of the available theoretical knowledge depends on the assumption of random sampling, but many practical circumstances are better served by taking a systematic sample. Cochran (1977) gives a good deal of material that is pertinent here. Among the major objections to systematic sampling are those of the prospect of a pattern in the density of the objects being sampled. One can see this as a good possibility in areas that have been logged, fenced, etc. If there is a pattern, then successive observations may be correlated, leading to a bias in the estimates. However, when one comes to sampling very large areas, with baselines that may be in the hundreds or thousands of miles long, it is difficult to suppose that a pattern may need to be considered. On the other hand, if the lines are laid out randomly, there will be cases where two lines lie quite closely together. One may then expect two possible problems. One is that two closely associated lines may indeed sample much the same densities, and thus give about the same results. The other prospect is that mobile animals may move onto or off of an adjacent line while one is being censused. If the lines are run in the order in which they are drawn, this problem is disposed of, but it is usually not feasible to follow such a schedule. Instead, a random selection of lines is made, and the searching starts at one end of the baseline and proceeds across to the other end.

Although the practical approach in most cases is clearly to take a systematic sample, it should also be considered that the line transect estimators have largely been derived on the basis of random sampling. Some caution is thus in order, and further study of this aspect is needed.

Stratification and variance estimation

It is always wise to consider stratified sampling in any out-of-doors study, since the objects of interest are rarely evenly spread around the landscape. The investigator usually has some knowledge that there are "more here" and "fewer there", and this frequently can be taken into account in planning the survey. There are a couple of pitfalls in this approach for line transects, however. One is that it is ordinarily poor practice to have any sizable fraction of the sampling units come up with "zero" observations, and the other is that it is advisable to be able to get a variance from "replicate sampling" data. That is, the survey is designed to give a number of independent estimates of the overall population size (or density). A variance estimate is then calculated on the basis of these "replicate" estimates.

Another potential problem in transect work is that weather conditions tend to affect results. Wind has an important effect on many surveys, and others may differ appreciably between "wet" and "dry" days. It would thus be highly desirable to take time into account in designing the replication mentioned above. One way to approximate the requirements suggested above is indicated schematically by Fig. 4. One first delineates strata (3 are suggested in Fig. 4), and randomly located transect lines are run in each of the strata on each of a number of days. The independent estimates for each day are then averaged for the survey estimate, and a standard error is calculated from the same set of daily estimates. It is, of course, likely that more than one line may be required in a given stratum to avoid coming up with many zero observations. This can conveniently be done by using a systematic pattern of lines in each stratum, but locating each day's set by a "random start",i.e., by drawing a random distance from one end of the stratum along the baseline as a starting point, and then spacing the remaining lines uniformly along the baseline. The spacing can then reflect the subsampling intensity needed for the particular stratum. Most experience suggests that this can be roughly proportional to the square root of the expected density of the objects (cf. Eberhardt 1978b).

Sample size

Some rough guidance in determining sample size can be obtained from the approximation that, for line transects using radial distances, the coefficient of variation will be approximately :

$$C.V.=(2/n)^{1/2}$$

(Seber 1973, Eberhardt 1978a). A rough approximation for line transects utilizing right-angle distances is(Eberhardt 1978a):

$$C.V=(4/n)^{1/2}$$

In both cases, n is the number of individuals observed in the survey. For strip transect surveys, one might suppose a lower limit on the coefficient of variation can be obtained by assuming a wholly random distribution of individuals, and a resulting Poisson distribution of totals. This gives:

$$C.V.=(1/n)^{1/2}$$

This will almost always give an underestimate. (cf. Eberhardt 1978b for some observed coefficients of variation).

The three equations given above will also serve to give an indication of the likely efficiency of the three methods. All other things being equal, one would choose strip transects as the method of choice, followed by radial distance line transects, with right-angle line transects last in a listing of preference. A choice cannot,of course, always be made on the basis of variance formulas.

Errors in measurements

Very little has been done about assessing the importance of errors in measurements in line transect work, but it seems quite likely that such errors can have a substantial effect on the survey's value. One approach is suggested by Eberhardt (1978a:7). Since it is the radial or right-angle distance that is to be used in estimation in transect methods, these two values should be measured directly if at all possible. Some investigators have measured or estimated one of these distances and estimated the included angle as a means of obtaining the other distance.

In aerial surveys, there is evidence that such factors as airspeed, altitude, width of strip searched, type of aircraft, and observer experience have important effects on counts. These factors are described by Caughley et al.(1976),Frei et al.(1979), Norton-Griffiths(1975, 1976), Pennycuick and Western(1972), LeResche and Rausch(1974), and Erickson and Siniff(1963) for a variety of habitats and other circumstances.

<u>Tests of assumptions</u>

When radial distances are used for estimation, with Hayne's equation, there are two tests of validity of the underlying model that should be considered. One is to do a chi-square test to check whether the distribution of x/r is uniform, and the other is to test for independence of r and the included angle(Eberhardt 1978a). If it turns out that these two items are correlated, one might want to look into the prospect that the models postulated by Burnham(1979) and DeVries(1979) offer alternative possibilities. These authors have made the interesting suggestion that the flushing circle may instead be an ellipse, with the narrow end pointed towards the observer. One can suppose that this might be the case if the animal has good directional hearing and is able to anticipate that the observer is ultimately going to come very close to it, rather than passing by at some distance. If the flushing zone is indeed elliptical in shape, then the test for correlation of radial distance and angle should be significant, with the degree of correlation depending on the ratio of length to width of the ellipse.

An example of the chi-square test for uniformity of the distribution of x/r appears in Eberhardt (1978a:Table 3), based on data from an experimental transect survey of lizards. The angle and radial distance data appear in Fig. 5. A simple non-parametric test for independence is based on ranking the data (distances and angles), and calculating the ordinary correlation coefficient on the ranked data (Spearman's rank correlation coefficient, Snedecor and Cochran 1967:194). In this case, the sample correlation is -.225, while the 5% significance level is .217. From Fig. 5 it appears that there was a tendency for longer distances to be associated with the smaller angles, although the tendency is not very well defined.

<u>Ratio adjustments</u>

For convenience, most of the mathematical development of transect estimation schemes has proceeded as though the study area were a rectangle, and all of the transect lines were of the same length. In practice, the areas may be irregular in shape, so that the lengths of transect lines may vary considirably. In such cases, location of the transect lines can readily be accomplished by setting up a baseline, as shown in Fig. 4. Adjustments for the length of individual lines can be accomplished by using a ratio estimation scheme. Details are given by Jolly(1969a,Jolly and Watson 1979) for strip transects, and by Eberhardt(1978a) for line intercepts. The same procedure can be used for line transects.

Another ratio adjustment will be useful if something other than density or number of individuals is to be estimated. Examples might be the volume of timber slash left after logging, quantities of browse on a sample of shrubs, or the basal area of a stand of trees. When density alone is estimated, the procedures utilize sums of the reciprocals of widths of the objects (w_i). To shift to estimation of some other quantity, x_i, one simply substitutes x_i/w_i for $1/w_i$ in the estimating equations.

Group size effects

In line transects, animals or objects of interest may be encountered in groups. In the case where detection depends on flushing, an unresolved question is whether groups flush more or less readily than individuals. A test for association of group size and flushing distance might be made as suggested above for angles and distances. If there is no association, a ratio correction of the kind suggested above may be made to estimate the total number of individuals. If group size does affect flushing then it may be necessary to make separate calculations based on a stratification of the data by group size. When detection depends on the observer, then it seems clear that groups are usually more readily detected. This has been the experience in the as yet unpublished line transect estimates of porpoise abundance in the Eastern Tropical Pacific, carried out by personnel from the Southwest Fisheries Center of the National Marine Fisheries Service. In that work, an empirical correction has been made by weighting by the reciprocals of the natural logarithm of group size.

In aerial strip transect surveys, group size has been noted to have an important effect on visibility, and various corrections have been proposed. Jolly(1969b) and Jolly and Watson(1979) discuss the problem, and Cook and Martin(1974) and Cook and Jacobson(1979) give another approach.

DISCUSSION

Clearly there are presently many uncertainties about the results and application of transect methods. A number of these have been mentioned above. If field measurements are carefully made, the intercept methods seem to be on the soundest footing, so long as the "width" of the object is measured. Advances will probably take the direction of new applications, and ways to obtain greater efficiency.

The major need in strip transect work is undoubtedly one of finding more effective ways to correct for those animals or objects missed (not seen) in the surveys. There is an obvious need to find ways to check on the methods now available. One approach is through radiotelemetry, and a useful prospect has been developed by Floyd et al.(1979). Another approach is through what has been called "ground-truthing". If a subset of individuals can be kept under surveillance by ground observers when the aircraft passes over, then a ratio-type correction may be made for those missed from the air. A successful application has been made in counts of the sea otter off the California coast. This study has been described in the review by Eberhardt et al.(1979).

One of the big questions about line transect work is the use of right-angle distances. Not only is there a question of which of the techniques to use in a given application, but there is a more fundamental question whether any of the techniques are actually more effective than using a narrow strip transect.

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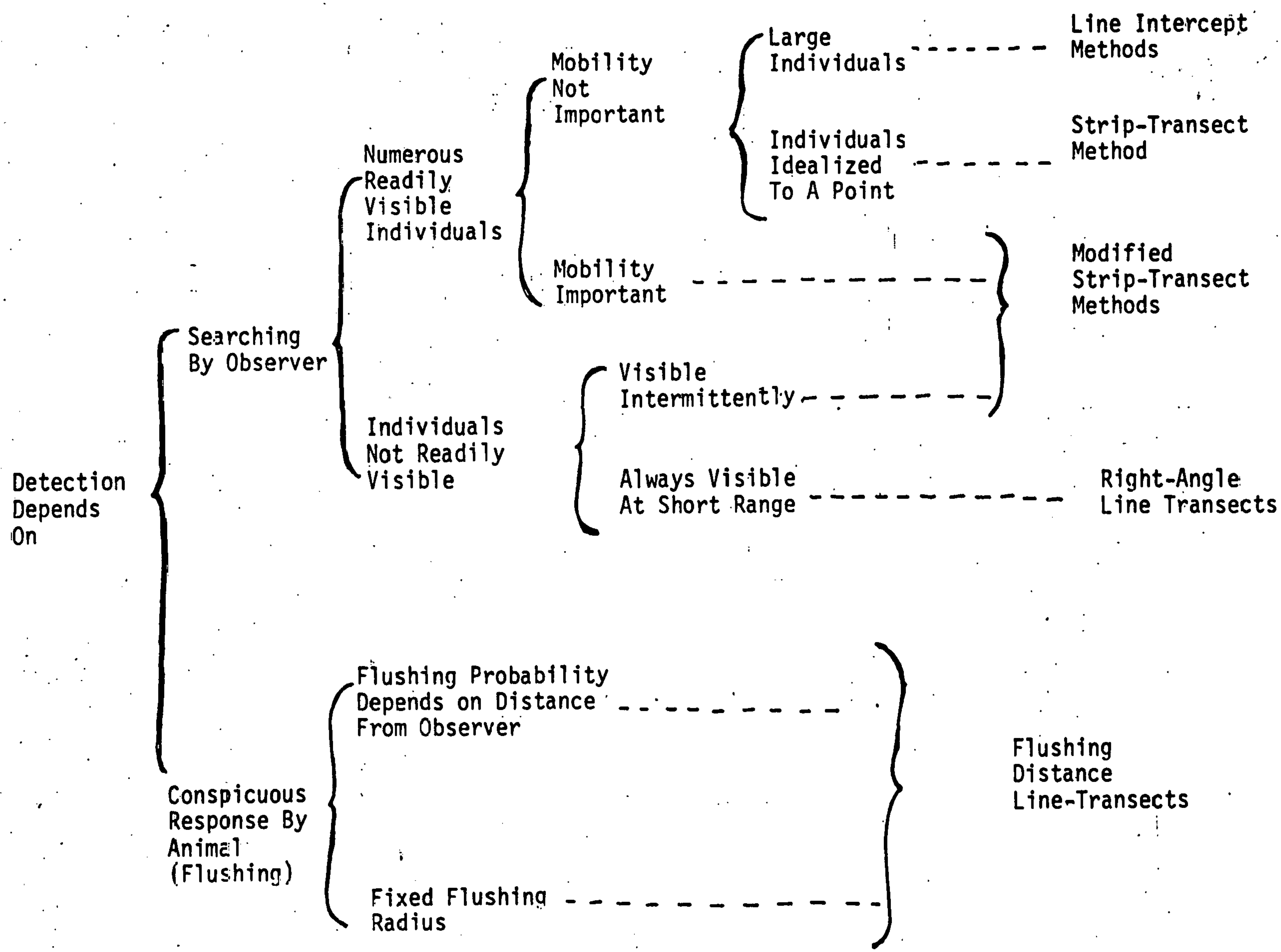
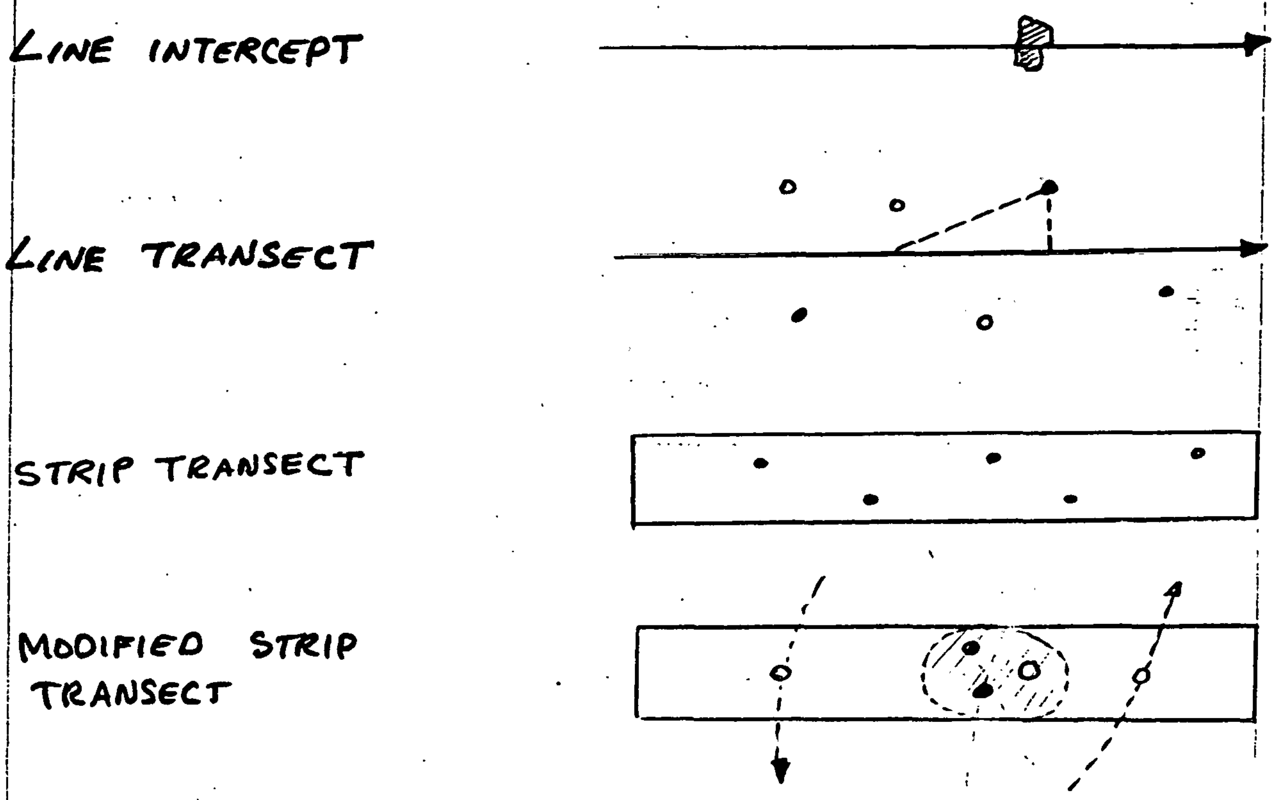


Fig. 1 A classification of transect methods



Solid circles = observed, open = not observed

Fig. 2. Basis for data collected in different transect methods

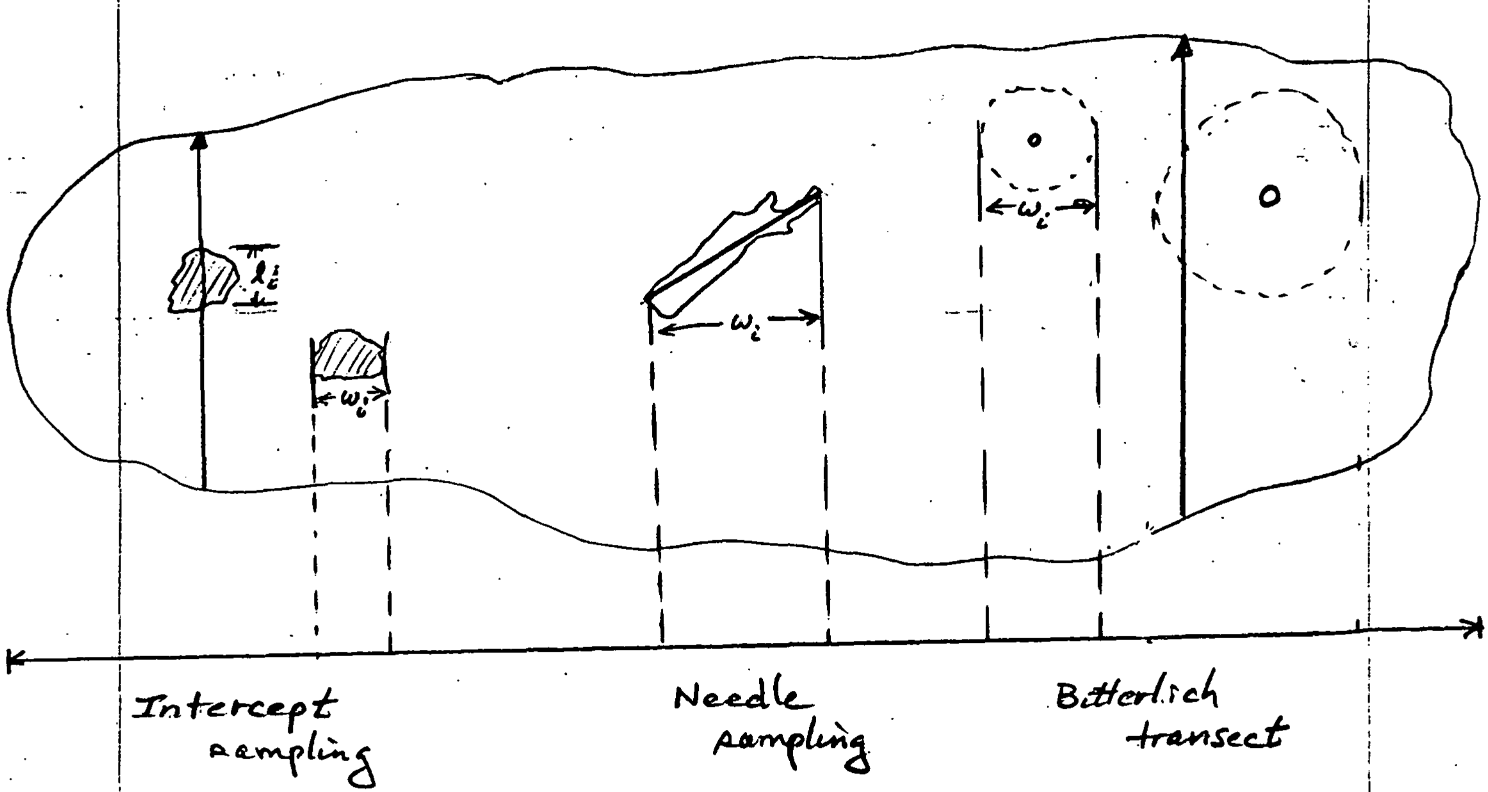


Fig. 3, Measurements used in various line intercept techniques.

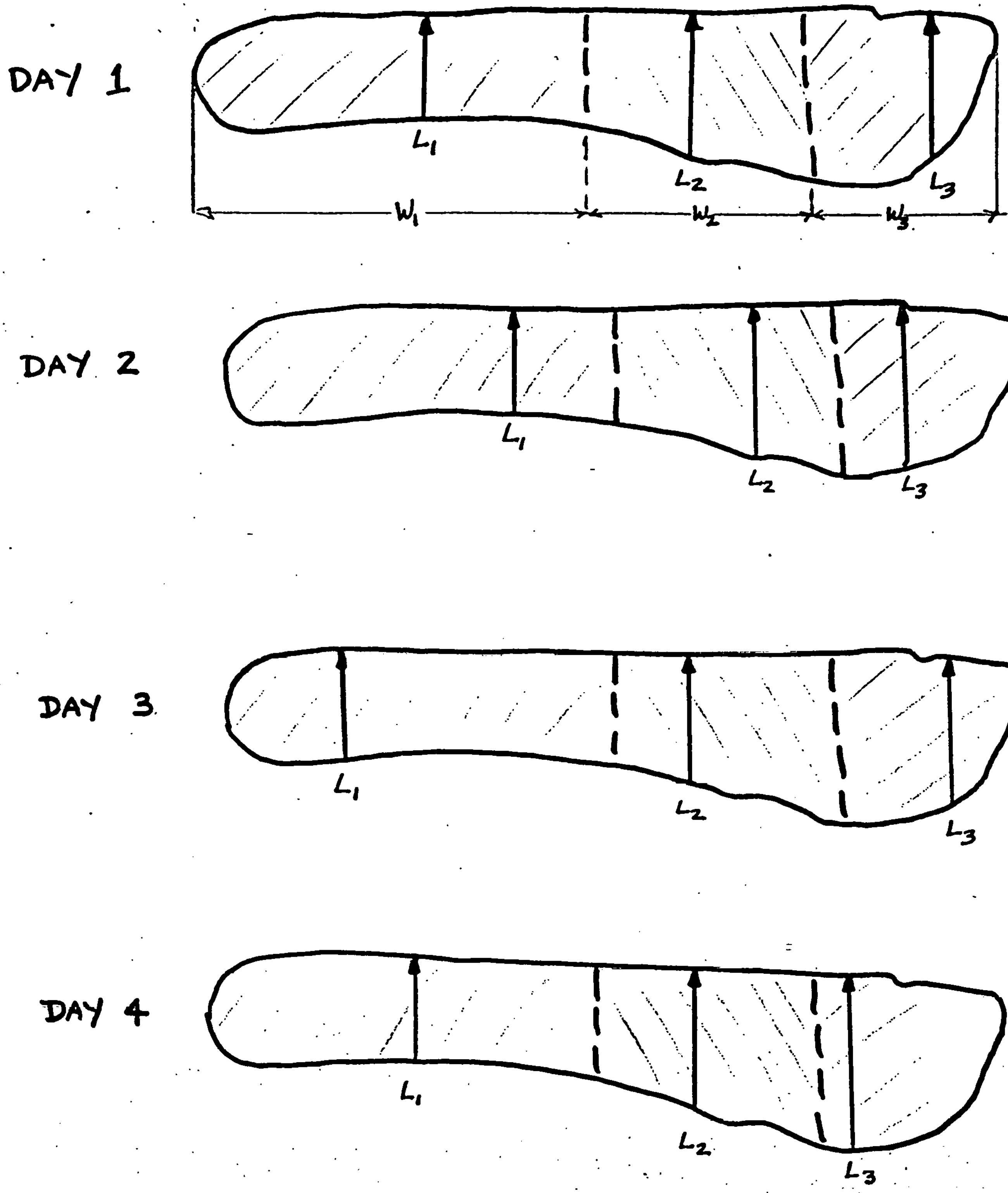


Fig. 4 Randomization of transect lines within sub-areas on successive census-days.

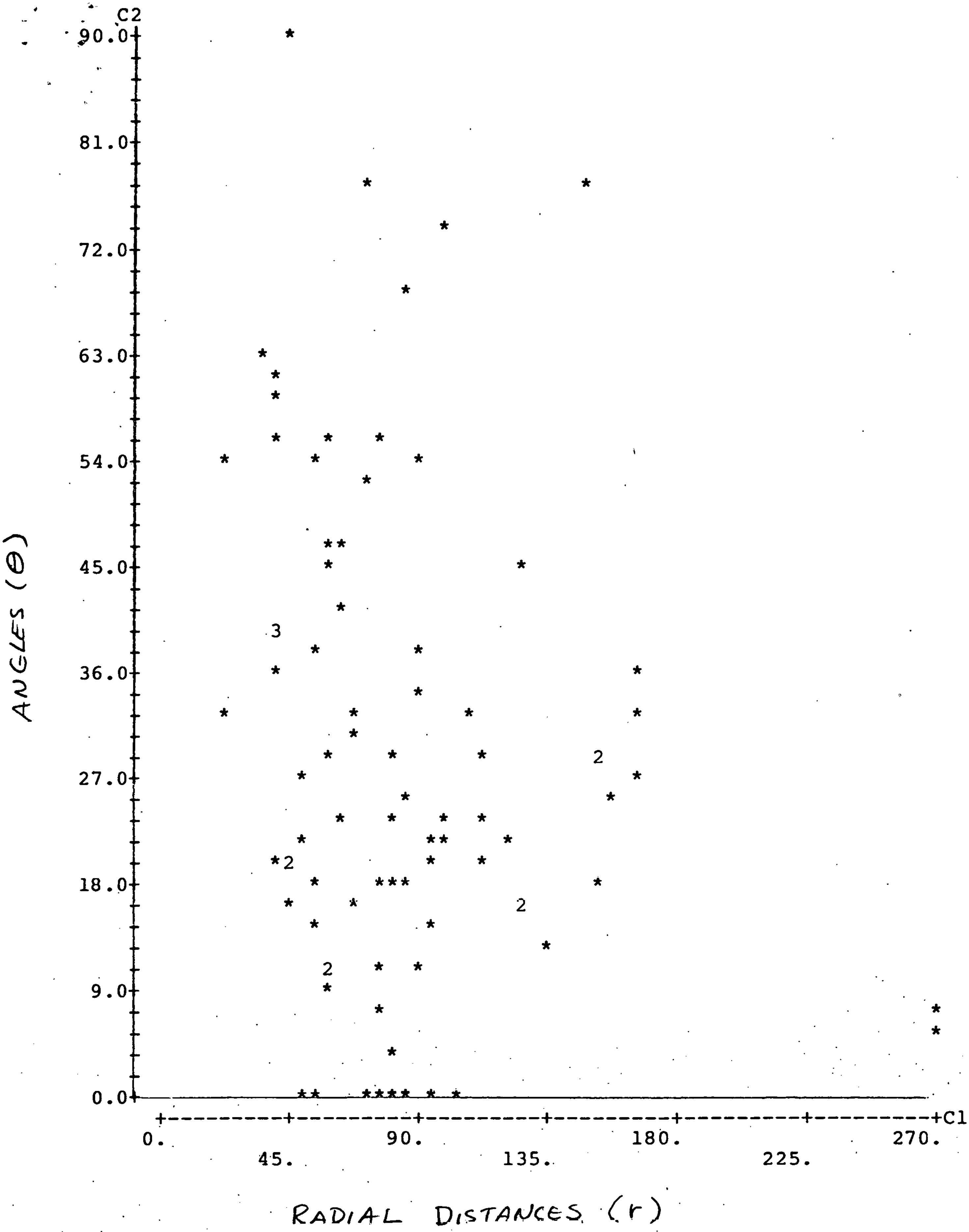


Fig. 5. Flushing angles and distances for a lizard census