

Artificial Populations for Teaching and Testing Range Techniques

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Originally, we planned for this paper the alliterative and euphonic title "Simple samples and plastic plants" but decided in favor of the more starkly definitive one given above. While the chosen title may scare away many readers who are addicts of catchy slogans and non-technical placebos, it should still attract those confronted with the serious problem of how to teach sampling theory, the methodology of ecology, and range man-

agement technique—all in the same course, or separately, as the case may be. It should also have some attraction for that conscientious group of technicians who are continuously looking for better ways of sampling and measuring the range.

The ideas presented here deal with artificial populations and a collection of devices enabling the measurement of certain attributes of those populations. The senior author has found this

combination to be a happy medium between the clouds of mosquitos or rain encountered during field sampling exercises and the clouds of profundity encountered in the Department of Statistics. We wish to describe in some detail the conception and the physical aspects of the populations and sampling devices.

If not for intellectual reasons, our present model, which is artistic and colorful, has incited enthusiastic interest by everyone who has seen it. In fact, it has a salivating-of-ideas reaction on most people, so that its effective usefulness is being enhanced continuously. Consequently many of the ideas expressed in

this paper are not originally those of the authors. We cannot begin to acknowledge them all, even if we remembered by whom they were volunteered. However, we wish to thank everyone who herein recognizes his own contribution.

Conception of the Populations

A population is an aggregation of items with some common property. A *natural* population, in the narrowest sense, would be one in which man has had *nothing* to do with the occurrence, quantity, or arrangement of the items. The common concept of a natural population includes animals or plants, which are natural to be sure, but certainly their abundance and distribution may have been modified by man. The often sampled grasses of the nearby college pasture constitute such a population. An *artificial* population, again in the narrowest sense, would be an aggregation of items generated and arranged by man, presumably but not necessarily with purpose in mind.

In our case, the purpose was definite. We wanted a population with stable attributes and one in which the exact values of the attributes were known. These exact values are called population parameters. With natural populations the parameters are seldom, if ever, known. Not even the experiment station director knows how many plants are in the college pasture or how much ground they cover. Then too, plant populations change from year to year and on a windy day cover changes from one moment to the next.

The model shown in Figure 1 is an artificial population. It has an artificial field—a square piece of plexiglas; artificial items—Mystic tape discs; arbitrarily decided abundance—a certain size and number of discs; and a pre-selected distribution pattern—random. These attributes will vary on other models to be dis-

cussed but the decisions concerning their construction were always made for our own convenience, without any natural population, concrete stand, or even abstract community in mind. It simulates nothing but a bunch of discs on a square-meter area. As will be seen, this lack of similarity to a plant population is an important characteristic of the model.

Construction of a Model with Randomly Distributed Discs

This population model has a field made of $\frac{1}{8}$ inch plexiglas, 42 inches on a side. A square meter area was marked off equidistant from the sides and subdivided by scribed lines into 1 centimeter squares. Plexiglas was selected over materials such as aluminum, stainless steel, masonite, and formica largely because of its transparency and durability. The transparent nature permits underlays of various kinds for stratification and

for improving visibility of the discs while sampling. The plexiglas field is mounted on a masonite board and surrounded by aluminum angles which serve as rails for various sampling devices.

The population items consist of circular discs cut from Mystic adhesive tape of various colors. Tape, originally selected so discs could be removed, proved to be a poor choice of material. The time involved in placing them is worth far more than the cost of materials to make additional models, so the discs may as well be permanent. Also, tape stretches slightly, the edges fray, and it gets dirty fast.

Nine disc sizes ranging from .550 to 1.756 centimeters in diameter were used for this population. Sizes were selected on the basis of available punches. The size classes followed a binomial distribution.

For positioning the discs on

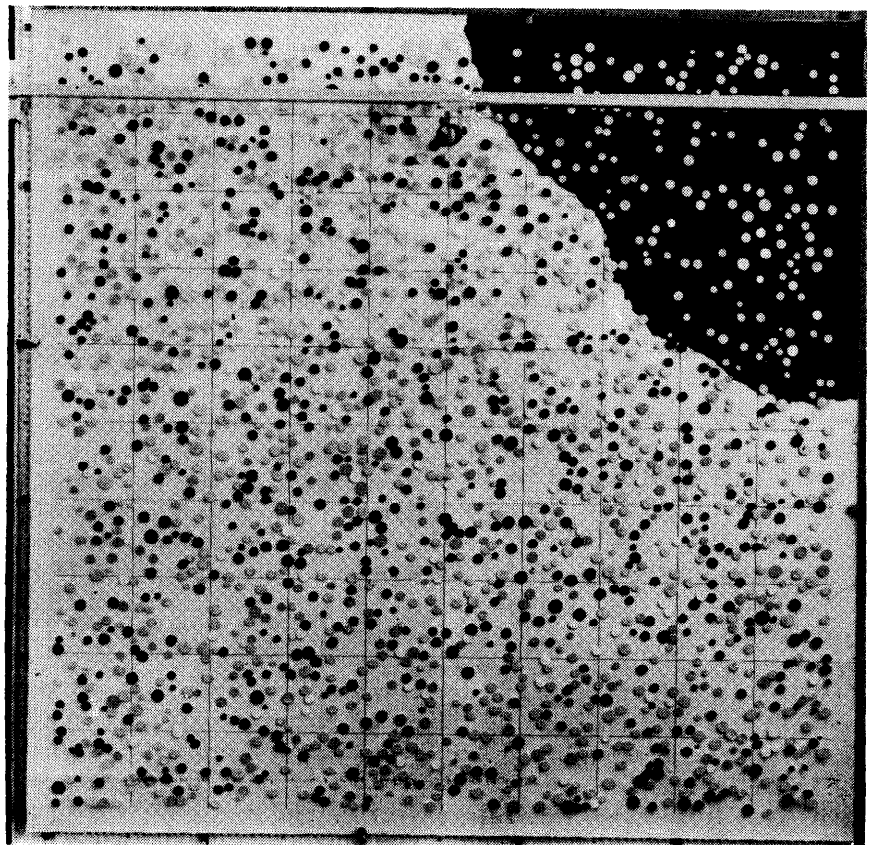


FIGURE 1. Artificial population with randomly placed discs.

the field, 0.01 of a square centimeter was considered as a point, making 1,000,000 points available at the beginning of the operation. To locate a point, pairs of three-digit random numbers were drawn from a table as coordinates. It had been predetermined, arbitrarily, that the population should consist of 2,036 discs with a definite color and size distribution. Selection was accomplished by randomly drawing slips of paper representing each disc. Marbles would have been better for mixing but how do you justify the purchase of 2,000 marbles at an institution of higher learning? After each drawing the slips were discarded until all were used up. The center of the selected disc was placed on the randomly located point. Combinations of numbers which caused discs to overlap were discarded to preserve the two-dimensional aspect. Some non-randomness was imposed at the edges of the field as discs were not allowed to extend beyond the borders. Thus, technically we do not have a randomly distributed population. As the board filled up, less than 1 out of 10 combinations of numbers were usable; we used up all the random numbers reading across the table in Snedecor's "Statistical Methods" and started to read down. An illuminating class exercise for students is to have them do some point-sampling, using for coordinates Snedecor's table, starting on page 1 and reading across. This is sure to shake their faith in chance, because all of their "random" points will fall on discs.

Equipment for Sampling

Auxiliary to the population are the sampling or measuring devices (Figure 2), gadgets which are unique to range ecology and forestry. They are miniature replicas or adaptations of the instruments developed and used by Clements, Canfield, Levy, Parker, and Bitterlich. They can be used to measure

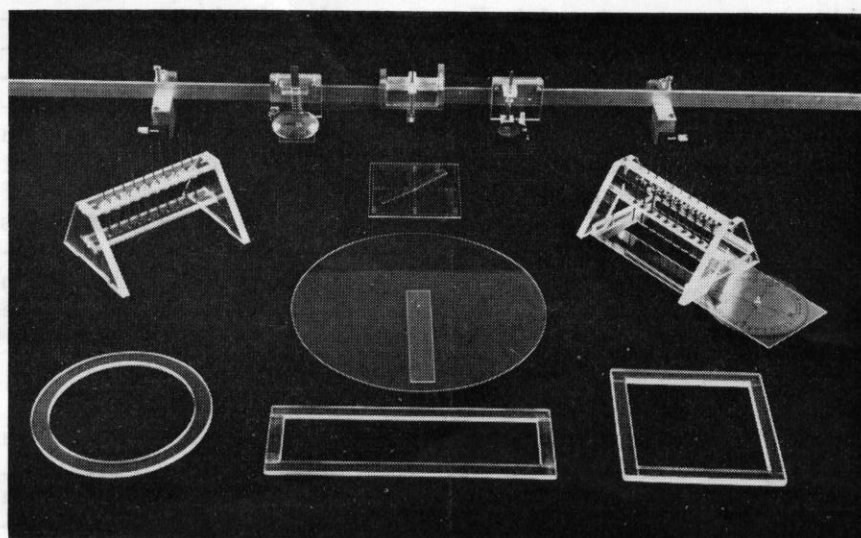


FIGURE 2. Sampling devices.

the usual attributes of cover, density, frequency, and "floristic" composition but in their present form cannot be used for weight, height, or volume. Most of our subsequent discussion deals with the attribute *cover*.

The simplest of the gadgets are the square-decimeter quadrats, used for ocular estimates. Circular, rectangular, and square quadrat frames are for testing the theorem that shape of plot affects density and cover estimates. Would shape of plot be important where population items are randomly distributed?

The line-intercept device (top left) is merely a segment of a plastic rule marked in millimeters, attached under a magnifier.

The ten-point frames are familiar to most range technicians. Our points are spring-loaded to prevent marring the discs and field. The compass gadget attached to the right-hand frame in the figure permits random selection of first point and direction. The individual point (top center) slides along the aluminum bar and can be used on random lines but only in two directions.

Our loop (top right) has a 1.5 mm. diameter. We had no particular ratio of average disc size

to loop size in mind. However, with the same ratio, Parker's $\frac{3}{4}$ -inch circle would be used for, say, bunch grasses averaging $5\frac{1}{4}$ inches in diameter. The loop gadget is spring-loaded so that the loop wall can make contact with the field, and it is outfitted with a magnifying lens to facilitate more accurate reading.

The variable-plot device, originated by Bitterlich, consists of a circular plastic base with a $11^{\circ}25'$ angle pivoted from its center. The sides of the angle extend only as far as needed for the largest disc to be included. The ratio of the distance to width of angle is 5 : 1; thus any disc which is not more than five times its own diameter from the sampling point is subtended by the angle and represents one percent cover at that point (Cooper '57). Of course, among trees a prism is used, not a flat gadget like this one.

A pivoted ruler mounted on a square base is designed for "point-to-plant" distance measurements. Random points can be located by coordinates and either the periphery or center of the nearest or next nearest, *ad infinitum*, disc measured. Modifications are simple for nearest neighbor, point-centered quarter methods, and others.

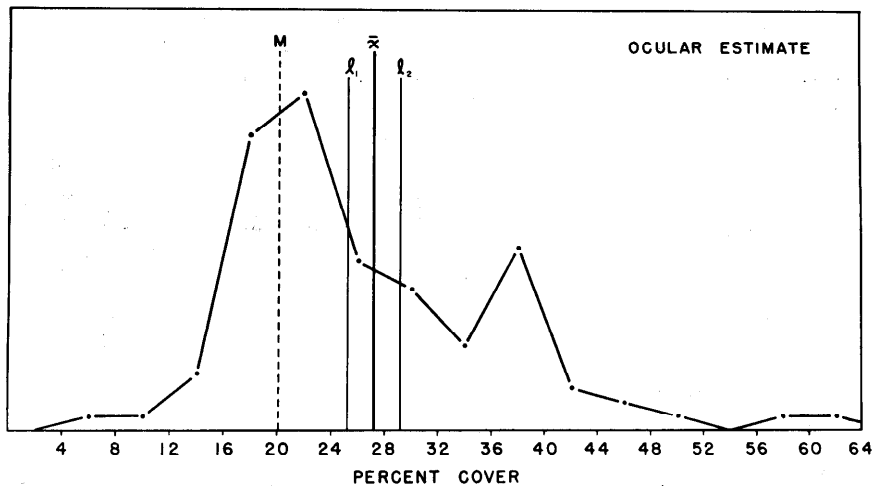


FIGURE 3. Frequency distribution of ocular estimate data from 100 range technicians.

Teaching Sampling Concepts and Range Techniques

Our present curricula in Range Management in the western colleges and universities are not strong for statistics. This was deduced from a recent meeting of the Range Management Education Council¹ where a decision was made not to require a course in statistics for a bachelor of science degree in range. The sudden evolution of state agricultural colleges into universities hasn't helped much at all in evolving the emphasis from vocational training to a more fundamental education. Whatever the reason, it is safe to say that not many sharp mathematicians major in range science. Where a techniques course is required, a basic knowledge of statistics and the concepts of sampling are essential. If these have not been mastered, they have to be reviewed or first learned during the techniques course. When a high proportion of the class is not mathematically adept, this kind of instruction is difficult to put across.

There is little education value in explaining how to divide number of pins by number of hits. One thing is to go out in the field with students and show them how to stab grass; another

is to teach them the concept of sampling and the principles of measurement.

Here is a list of concepts that every range technician should understand: *population* (already defined), *sample* and *observation*, *parameter* and *statistic*, *estimate* and *measurement*, *accuracy* and *precision*, *bias* and *error*, *level of accuracy* and *probability*, *randomness* and *non-randomness*. Any device of pedagogy which makes these concepts easy to understand would be priceless. The artificial population comes close to this characterization.

Let us consider one pair of the concepts listed above: *accuracy* and *precision*. By accuracy is meant what a beef steak really weighs, not what the butcher's scales read. By precision is meant the closeness of repeated readings of the scales. To go back to grass, if a technician takes a large number (n) of samples (of N observations) on a range and each sample comes out as 13.7 percent cover, his sampling is very precise. He does not know how accurate he is. By logic and not by statistics he has designed his method to be accurate. The measured mean value of 13.7, ($\bar{x}$) is an estimate of the population parameter (m), the latter being unknown in most natural populations. A measure of the difference be-

tween the two, $\bar{x} - m$, is called *bias*; a measure of the difference between the values of the individual observations is called *variance* or *error*.

The lesson above is not as naively simple as it may seem. While it should be expected that some students and technicians are not cognizant of the essential characteristics of samples and populations, some authors are not either and that is far worse. There are too many papers in the recent range literature referring to "best" methods inferring most accurate, using one favorite method as a standard (usually charting or line intercept), and confusing accuracy with preci-

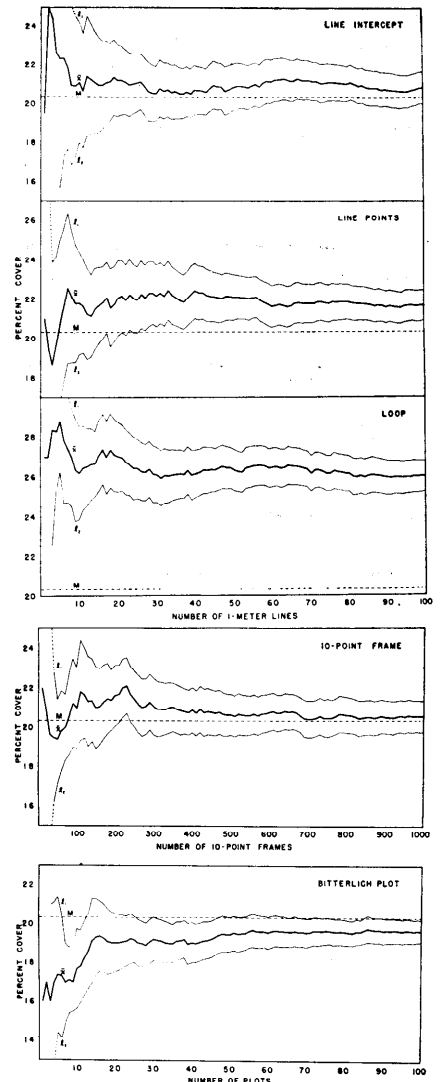


FIGURE 4. Sample statistics taken from artificial population, when sampled with five different methods.

¹Minutes of second annual meeting, Range Management Education Council, January 30, 1961, New-house Hotel, Salt Lake City, Utah.

sion. As has been pointed out, the only reason the parameters of the artificial populations are known is that they are built that way. Sampling procedures and methods of measuring should be compared with the known values. How this can be done is shown in the next section of the paper.

The artificial population concept lies somewhere between the droll field exercise of charting vegetation and the cold, formal, numerical equations and notations which generalize sampling theory. The items are "abstract" enough to prevent automatic identification of method with kind of population, yet realistic enough to induce quick analogy to range situations whenever that step is necessary in the learning process.

Students can draw their own samples, knowing them to be from exactly the same population used by their classmates. Over the years the instructor can build up a useful collection of sample statistics. Students who do not yet know that a large standard error is a measure of low precision rather than a big mistake will find themselves becoming intrigued with their own sample data. Such statistical rapport is hard to develop from exercises in a textbook or from the field.

Professor Harold F. Heady has used this and other known populations for several years in Range Management 102, School of Forestry, Univ. of California, Berkeley. His appraisal is well worth reading (Heady 1961). No doubt additional advantages of the artificial population in teaching sampling concepts, statistics, and range techniques will be apparent as the idea is further developed.

Testing Methods

Of late, "larrupping the loop" has been a very popular game played by plant ecologists. The Journal of Range Management and countless post-graduate

theses have carried the tales of such empirically founded evaluations. But with characteristic faith, as in other sciences, the sampler likes to see for himself. This attitude led us to do some extensive sampling on the random model, not only with the loop but with the other methods applicable for determining cover. Some of the results of this endeavor are shown in Figure 3 and Figure 4.

One important thing to look for in each graph is the proximity of the sample means to the population parameter, $m = 20.33$ percent cover. Another is the width of the band, l_1-l_2 , which measures the precision of the method at the 95 percent level.

Ocular Estimate

Conventioneers at the "Homecoming" meeting of the ASRM at Salt Lake City, January 1961, were asked to estimate the cover of the population. This was done with varying degrees of effort by 100 Society members who had varying degrees of "eyeballing" experience. Considering each estimate as made from a 100 percent sample, the frequency distribution is seen to be bimodal and skewed, with a longer tail toward overestimation (Figure 3). The bias is $27.17-20.33=6.84$, which is $\frac{1}{3}$ more than the true cover value.

There was no correlation between experience of the estimator and amount of bias, possibly due to modesty or facetiousness in the self-classification of experience. Given the same assignment, a group of 20 high I.Q. high school students², with no previous sampling experience whatever, had a bias of +3.55, which is half that of the Range Society members. The distribution of estimates for this group had the same shape as in Figure 3.

Line Intercept

Estimates of cover were obtained by measuring the length of chords of discs intercepted by

randomly selected 1-meter lines. Sample statistics were accumulated as each line was added. Thus, the first sample consisting of one line had a cover value of 19.50. The second sample consisted of the first line plus the second, and so on until 100 random lines were measured. The graph (Figure 4) shows a wildly fluctuating mean when sample size (number of lines) is low; it gradually settles down and undulates gently, approximately parallel to but just above the population parameter m . The fiducial limits, l_1 and l_2 , likewise settle down and reach a narrow range after about 50 lines have been included. After 100 lines, the sample mean of 20.85 showed this method to have a very low positive bias.

Of the 100 lines, 50 were taken in a direction perpendicular to the other 50. As would be expected in a near-randomly distributed population, it was easily demonstrated that samples from both strata were randomly distributed about the same mean. Cover estimates by color (equivalent to "floristic" composition) were taken but these data will not be presented for any of the methods.

It is possible to make density estimates—density is number of items per unit area—from line intercept data. By using the

$$\text{equation mean chord} = \frac{\pi d}{4},$$

the mean diameter and area for given color class or all discs together can be calculated. Once the mean area of discs is determined, number of discs is computed by dividing mean area into cover obtained from the same lines by the intercept method. Using 50 random lines, we estimated 1,948 discs, compared to the actual number 2,036.

Line Points

An individual point reading was taken at 1 cm. intervals

²Advanced Science Seminar, Miramonte High School, Orinda, California.

along random lines. Again, each sample on the graph (Figure 4) is cumulative. After 60 lines, fluctuations were minor, with a positive bias never exceeding 7½ percent of the true mean.

The point used was much sharper than points usually used in field sampling. Nevertheless, it was still blunt enough to overestimate cover. We are planning to build a more sophisticated model in which an infinitely small, hard point will be electrically charged, as well as the discs. Then the decision of a "hit" or "miss" will not depend on eyesight.

Loop

The loop is a blunt point; thus, its bias is expected to be large. It can also be viewed as a very small plot. Hutchings and Holmgren (1959) have pointed out that, as the loop is commonly used, not cover but frequency data are recorded. By frequency is meant presence or absence of vegetation in the plot.

Our loop, .15 cm. in diameter, was employed exactly as the line points, but not on the same 100 lines. After 10,000 loop readings, the loop-density index, estimating cover, was 25.99 percent. Since number of discs, their exact areas and loop sizes are known, we can use Hutchings and Holmgren's equation (2)

$$x = \frac{\sum_{i=1}^n 100 \pi (r_p + r_i)^2}{A} = 1$$

where r_p = disc radius, r_i = loop radius, and A = area. Working this out for all 2,036 discs in the population, we get $x = 26.04$ which is as close to 25.99 as you can get without cheating. Thus, for some methods like this one the bias can be calculated theoretically. In this case it is $26.04 - 20.33 = +5.71$.

Complementary use of the artificial population and the article referred to above makes an ideal classroom exercise for students who wish to understand the relationships between plant size,

density and distribution and size of plot. Other publications such as Grieg-Smith (1957) can be used the same way.

Ten-point Frame

Groups of 10 frames were used as a sample unit. Thus, the final cumulative sample included 10,000 points. The final sample mean of 20.57 was the most accurate estimate of the parameter obtained by any method. A good term project for a student would be to find out why the line points gave higher estimates than the 10-point frames.

It should be remembered that only one point of each frame is randomly placed, and the rest are systematic. This was also true of the line points: the line and first point, random; the remaining 99, systematic. We are now thinking of designing a little remote-control vehicle, appended with a point, that can be moved over the electrical model in such a way that all points can be randomly taken.

Bitterlich or Variable Plot

This method underestimated the population. Could it be the bias of range men using the foresters' technique? Actually a slight mechanical error of drawing the angle too large or a consistent rejection of discs which just subtend the angle would account for it. It will be seen in Table 1 that there is far less variation in this method from one sample to the next than, say, in

the several line methods, that is, from one line to the next.

Distance Measures

Of a wide variety of distance measures available, the only one we tested was the random-point-to nearest- "plant" or closest individual method. This is ordinarily used for density estimates. The shortest distance d (measured to nearest .01 cm.) from a randomly selected point to the periphery of the closest disc was measured and the radius of the disc noted. The appropriate equation for calculating cover is $y = \pi r^2 / 4 (d + r)^2$. A total of 200 distance measurements gave a cover of 30.71 percent. This rather extreme overestimation reflects, more than any of the other methods, the actual non-randomness of the population. It points toward the value of distribution of plants as an important attribute of the population, in addition to cover.

The potentialities of using the synthetic population for point-centered quadrants, nearest neighbor, paired individuals, and other modifications of distance measures are enormous. New methods can be developed and old ones checked for accuracy and precision. Range technicians are just beginning to use this concept in their survey work.

Summary of methods

This paper was not intended to give the pros and cons of the conventional sampling methods.

Table 1. Statistics of samples using 7 different methods in order of increasing coefficient of variation.

Method	Sample Unit	Sample Size	Final Sample Mean $\bar{X}$	Bias: $\bar{X} - m$	Coef. of Variation in percent
Variable plot	1 point	100 points	19.66	-.033	14.44
Loop	1-meter line with 100 loops	100 lines	25.99	+.278	15.24
Line Points	1-meter line with 100 pts.	100 lines	21.69	+.067	18.17
10-pt. frame	Group of 10 frames	100 groups	20.57	+.012	19.25
Line intercept	1-meter line	100 lines	20.85	+.025	20.05
Ocular estimate	100% estimate made by 1 person	100 persons	27.17	+.336	37.30
Closest Individual	1 point	200 points	30.96	+.523	69.06

Rather, we wanted to give some examples of the types of information that can be gotten from artificial populations. The table below brings together some of the statistics which are not evident in Figure 3 and 4.

In table 1, the final sample cover values, column 4, can be considered as means of 100 samples, although for Figure 4 the final values (of the heavy lines) are total cover for one big sample. The estimates of bias, column 5, are based on the assumption that this one big sample is so large that its difference from the average of all possible samples of that size is negligible.

Besides testing the methods listed above, many other "see for yourself" or "don't take the word of your teacher" tests can be made. Are 100 samples each with 10 observations better than 10 samples of 100 observations? How random or non-random is a population distribution? What is an adequate sample? What is the relationship between frequency and density? What are the various sources of bias? Students, teachers, and researchers should be straight on these things.

Potential Developments of Artificial Population Concept

It takes very little imagination to dream up improvements on the model which has been described. There are some features that need changing badly. The matter of non-randomness at the edge of the field, the restriction of no overlap, the constancy of

shape; these were compromised for the sake of accuracy on total disc area. There are other features which seem to be all right. For teaching purposes we like the idea of interchanging an entire plexiglas field with its fixed population rather than changing the number and distribution of items from time to time. For solving a particular sampling problem, a simulated plant population can be constructed and studied, then discarded or changed when other problems arise.

Future developments of the synthetic population concept fall into several categories: (1) variations in item distribution, shape and size; (2) use of different materials in construction; (3) greater preciseness of instrumentation for the sampling devices; (4) new concepts of sampling; and (5) additional uses of the model besides teaching and testing of techniques.

From the standpoint of testing useful ecological methods, populations with varying degrees of aggregation will be far more valuable than those with random distributions. Regular (underdispersed) and gradient distributions would be instructive also. For teaching one might have segmented square-meter fields which can be put together in various combinations for exercises in design of experiments and analysis of variance. The possibilities are endless.

Not many more than 50 years ago the chart quadrat was the only objective technique is meas-

uring vegetation. Pantographs were the vogue. Distance between plants, to the early ecologists, was merely an unfortunate deterrent to moving from one plant to the next. Today, we have plotless points and pointless plots, and both have their points. Would it not be presumptuous to think that all conceivable break-throughs in sampling methodology have now been made, that all we must do is refine the known techniques and standardize their use? If as much effort is put into this field of inquiry in the next decade as has gone into measuring the atom in the last, we should expect the proposed range inventory to be quite accurate. The truths we can promulgate about samples and populations will outlast all our ephemeral methods of practice. These truths which we now use to boost synthetic populations, will still be with us long after all our food comes from synthetic pills and long after range management is as dead as alchemy.

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