Exercise 3C
Estimating Population Size & Distribution

Parts of this lab adapted from *General Ecology Labs*, Dr. Chris Brown, Tennessee Technological University and *Ecology on Campus*, Dr. Robert Kingsolver, Bellarmine University.

Introduction

One of the goals of population ecologists is to explain patterns of species distribution and abundance. In today's lab we will learn some methods for estimating population size and for determining the distribution of organisms.

Measuring Abundance: Quadrats

One of the first questions an ecologist asks about a population is, "How many individuals are here?" This question is trickier than it appears. First, defining an individual is easier for some organisms than others. In Canada geese, a "head count" of geese captured on the ground during their summer molt gives a clear indication of adult numbers, but should eggs be counted as members of the population or not? In plants, reproduction may occur sexually by seed, or asexually by offshoots that can remain connected to the parent plant. This reproductive strategy, called clonal reproduction, makes it difficult to say where one individual stops and the next one begins.

Once the individual is defined, ecologists working with stationary organisms such as trees or corals can use spatial samples, called **quadrats**, to estimate the number of individuals in a larger area. Quadrats are small plots, of uniform shape and size, placed in randomly selected sites for sampling purposes. By counting the number of individuals within each sampling plot, we can see how the density of individuals changes from one part of the habitat to another. The word "quadrat" implies a rectangular shape, like a "quad" bounded by four campus buildings. Any shape will work, however, as long as quadrats are all alike and sized appropriately for the species under investigation. For creatures as small as barnacles, an ecologist may construct a sampling frame a few centimeters across, and simply drop it repeatedly along the rocky shore, counting numbers of individuals within the quadrat frame each time. For larger organisms such as trees, global positioning equipment and survey stakes may be needed to create quadrats of appropriate scale.

The number of individuals counted within each quadrat is recorded and averaged. The mean ($\bar{x}$) of all those quadrat counts yields the **population density**, expressed in numbers of individuals per quadrat area (barnacles per square meter, for example, or pine trees per hectare).

Population size can then be estimated using the formula:

$N = (A/a) * n$ where:
N = the estimated total population size
A = the total study area
a = the area of the quadrat
n = the number of organisms per quadrat

Note: this formula can be used with one quardat or an average of all the quadrats as long as the area (a) matches the number of organisms/quadrat (n).

An alternative approach is to measure **ecological density**, expressed in numbers of individuals per resource unit (numbers of ticks per deer, for example, or numbers of maggots per apple).

Determining Distribution

Members of a population constantly interact with physical features of their environment, one another, and other species in the community. Distinctive spatial patterns, describing the distribution of individuals within their habitat, result from these interactions. Movements, family groupings, and differential survival create spatial patterns that vary from one population to another. A population can also change the way it is scattered through space as seasons or conditions change. As an example, monarch butterflies spread out to feed and reproduce during the summer, but congregate in dense assemblies during fall migration and winter dormancy. The physical arrangement of organisms is of interest to ecologists because it provides evidence of interactions that have occurred in the past, and because it can significantly affect the population's fate in the future. Analyzing spatial distributions can reveal a lot more about the organism's natural history than we could ever know from estimates of population size alone.

Since it is often impossible to map the location of every individual, ecologists measure features of spatial pattern that are of particular biological interest. One such feature is the dispersion of the population. **Dispersion** refers to the evenness of the population's distribution through space. (Dispersion should not be confused with dispersal, which describes movement rather than pattern.) A completely uniform distribution has maximal dispersion, a randomly scattered population has intermediate dispersion, and an aggregated population with clumps of individuals surrounded by empty space has minimal dispersion (Figure 3.1).

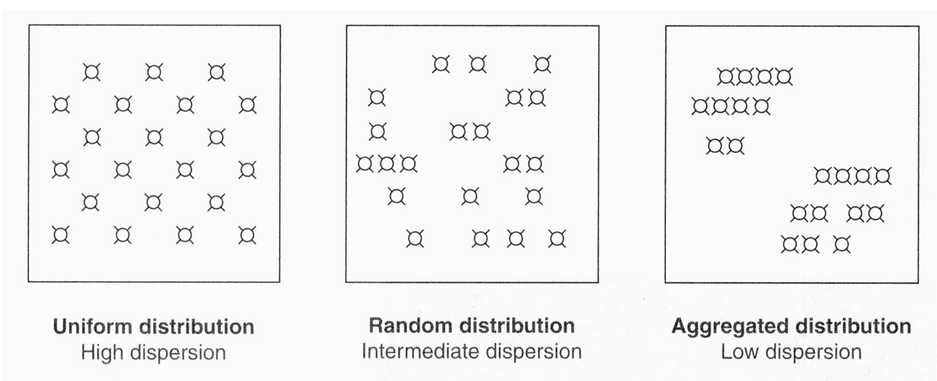

Figure 3.1 Three types of spatial distribution. Individuals spread evenly through the environment are highly dispersed, individuals clumped together exhibit low dispersion.

How can we measure dispersion in populations? A typical approach again involves quadrat sampling. By counting the number of individuals within each sampling plot, we can see how the density of individuals changes from one part of the habitat to another. To get a measure of dispersion in our population, we need to know how much variation exists among the samples. In other words, how much do the numbers of individuals per sampling unit vary from one sample to the next? The sample variance (s^2) gives us a good measure of the evenness of our distribution.

Consider our three hypothetical populations, now sampled with randomly placed quadrats (Figure 3.2). Notice that the more aggregated the distribution, the greater the variance among quadrat counts. To standardize our measurements for different populations, we can divide the variance by the mean number of individuals per quadrat. This gives us a reliable way to measure aggregation. Statisticians have demonstrated that the variance/mean ratio, $s^2/\bar{x}$, yields a value close to 1 in a randomly dispersed population, because in samples from a random distribution the variance is equal to the mean. Any ratio significantly greater than 1 indicates aggregation, and a ratio less than 1 indicates a trend toward uniformity. We could therefore call the variance/mean ratio an index of aggregation, because it is positively related to the "clumping" of individuals in the population. The variance/mean ratio is also called an **index of dispersion**, even though dispersion is inversely related to $s^2/\bar{x}$. It is good to remember: a high value of $s^2/\bar{x}$ means high aggregation, but low dispersion.

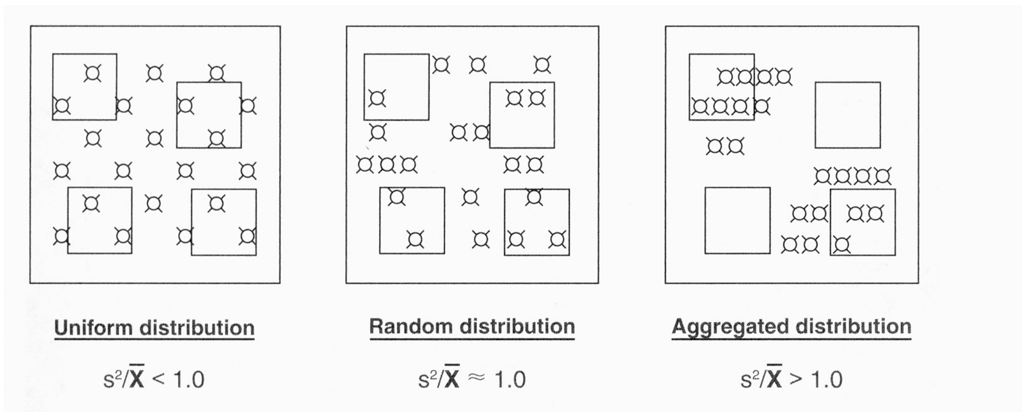

Figure 3.2 Quadrat sampling allows measurement of dispersion by counting numbers of individuals within each sampling frame, and then comparing the variance to the mean. Note that the mean number per frame is the same for all three patterns, but variance increases with aggregation.

Bear in mind that the size of the sampling frame can significantly influence the results of this kind of analysis. A population may be clumped at one scale of measurement, but uniform at another. For example, ant colonies represent dense aggregations of insects, but the colonies themselves can be uniformly distributed in space. Whether we consider the distribution of ants to be patchy or uniform depends on the scale of our investigation. Figure 3.3 illustrates a population that would be considered uniformly distributed if sampled with large quadrats, but aggregated if sampled with smaller quadrats. For organisms distributed in clusters, the $s^2/\bar{x}$ ratio will be maximized when the size of the sampling frame is equal to the size of the clusters.

Check your progress:
If densities are equal, which would yield a higher variance in numbers of individuals per quadrat: a highly aggregated population or a highly dispersed population?

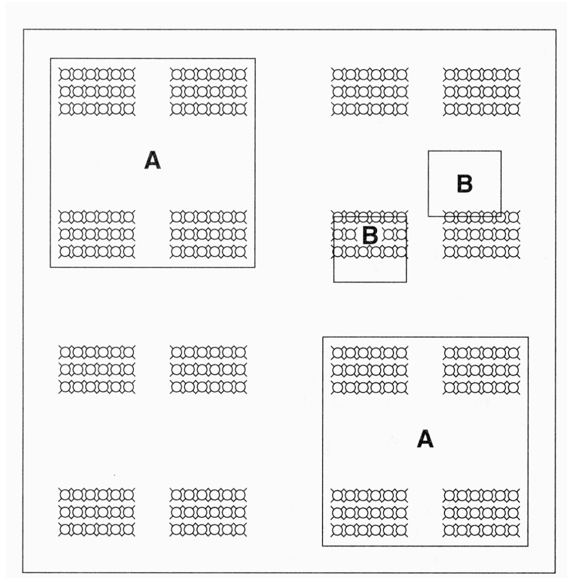

Figure 3.3 The calculated index of dispersion depends on the size of the quadrats used to sample the population. This hypothetical spatial pattern would exhibit a uniform dispersion index if sampled with large quadrats (A), but a clumped dispersion index if sampled with small quadrats (B).

The significance of aggregation or dispersion of populations has been demonstrated in many kinds of animal and plant populations. Intraspecific competition, for example, tends to separate individuals and create higher dispersion. Territorial animals, such as male robins on campus lawns in the spring, provide an excellent example. As each male defends a plot of lawn large enough to secure food for his nestlings, spaces between competitors increase, and the population becomes less aggregated. Competition can also create uniform plant distributions. In arid habitats, trees and shrubs become uniformly distributed if competition for soil moisture eliminates plants growing too close together.

If organisms are attracted to one another, their population shows increased aggregation. Schooling fish may limit the chance that any individual within the group is attacked by a predator. Bats in temperate climates conserve energy by roosting in tightly packed groups. Cloning plants and animals with large litter sizes create aggregation as they reproduce clusters of offspring. For example, the Eastern wildflower called mayapple generates large clusters of shoots topped by characteristic umbrella-like leaves as it spreads vegetatively across the forest floor. By setting up quadrats, and calculating the variance/mean ratio of the quadrat counts, you can gain significant insights about the biology of your organism.

Check your progress:
Give an animal example of high dispersion; of low dispersion. Give a plant example of high aggregation; of low aggregation.

Exercise 3C: Population Size Estimate and Dispersion of Plants in a Lawn Community

Research Question
What is the population size of the lawn species of interest? What can we infer about the natural history of a lawn species from its spatial distribution?

Preparation
Before laboratory, carefully examine lawns on campus. Regardless of maintenance efforts, few lawns are actually monocultures. Almost all lawn communities include some broad-leaved plants such as dandelions, plantain, or clover growing among the grasses.

Materials (per laboratory team)
1 large nail
1 meter stick
1 piece of nylon string, about 1-1/2 m long

Procedure

1. Make quadrat sampler by tying one end of the string around the nail, tightly enough to stay on, but loosely enough to swivel around the head (Figure 3.4). Then using the meter stick, mark a point on the string 56 cm from the nail by tying an overhand knot at that position. Repeat the procedure to make a second knot 80 cm from the nail, then a third knot 98 cm from the nail, and a fourth knot 113 cm from the nail. The distance to the first knot represents the radius of a circle of area 1 m2. (Try verifying this calculation using the formula Area = πr^2 for a radius of .56m.) The knots further along the string will be used to sample circles of areas 2 m2, 3m2 and 4m2, respectively. Take your sampler to a lawn area.

2. Choose one lawn species exhibiting an interesting spatial pattern and common enough to find some specimens growing less than a meter apart. Decide what vegetative unit of this plant you will designate as an individual for the purpose of counting plots. For non-cloning plants such as dandelions, one rosette of leaves constitutes one individual. For cloning plants such as violets, choose a unit of plant growth, such as a shoot, as an arbitrary unit of population size.

3. Choose an area of lawn for sampling in which this species is relatively common. Before taking any samples, observe physical features of the habitat such as shade, soils, or small dips or mounds affecting water runoff that might help you interpret the pattern you see. Develop hypotheses relating the reproductive history of your species and habitat features with the distribution you are measuring.

4. Next, you must select sites for quadrat samples within your study area. You can obtain a fairly unbiased sample by tossing the nail within the sample area without aiming for any particular spot, and then pushing it into the soil wherever it lands. Hold the string at the first knot and stretch it out taut from the nail.

5. Now move the string in a circle (Figure 3.4). The length marked by your closest knot becomes a radius of a circular quadrat with area 1 m^2• If this circle is too small to include several individuals, move out to the second knot for a 2-m^2 quadrat, the third knot for a 3-m^2 quadrat, or the fourth knot for a 4-m^2 quadrat, as needed. After you decide on the appropriate scale, use the same size quadrat for all your samples.

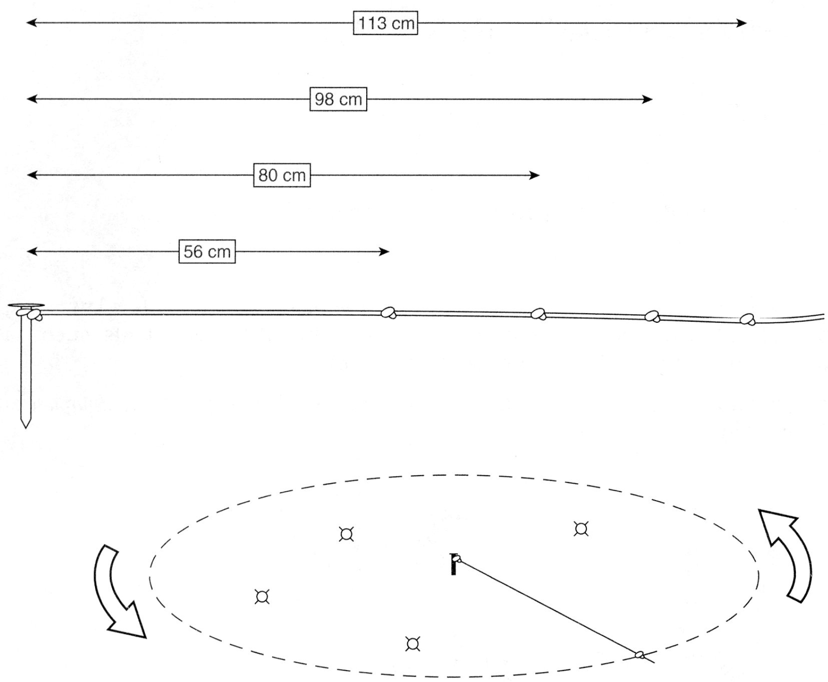

Figure 3.4 A string tied to a large nail, with knots tied at specified distances, can be used to sample a fixed area of lawn. Put the nail in the ground and pull the string taut. Moving the knot around the nail, count how many of your organisms fall within the circle.

6. As you move the string in a circle, count how many individuals fall within this quadrat. When the circle is complete, record this number in Table 3.1. Pull out the nail, make another toss to relocate your circular plot, and repeat for a total of 20 samples. Your sampling is complete when you have recorded 20 quadrat counts.

Data Analysis: Population Size Estimate

Calculate N for the quadrat data using the formula:

$N = (A/a) * n$ where:

- N = the estimated total population size
- A = the total study area
- a = the area of one quadrat
- n = the mean number of organisms/quadrat

Data Analysis: Determination of Dispersion

1. Enter your 20 counts of organisms per sampling unit (x_i) in the second column of Table 3.1.
2. Calculate a mean ($\bar{x}$) by summing all the counts and dividing by the sample size (n = 20).
3. Subtract the mean from each data value to obtain the deviation from the average (d_j).
4. Square each deviation $(d^2)_i$. (Note that this step takes care of the negative signs.)
5. Add up all the squared deviations (□d^2).
6. Divide the sum of d^2 values by (sample size - 1) to calculate the sample variance (S^2).
7. Finally, divide the variance by the mean ($\bar{x}$) to compute the variance/mean ratio ($S^2/\bar{x}$).
8. By comparing the variance of your 20 quadrat counts with the mean, you will determine whether the plants you sampled are aggregated, random, or uniformly dispersed. Refer to the Introduction, and to the methods section you used, to interpret this ratio.

Table 3.1 Quadrat Sampling of Lawn Species: ______________________________

Sample number (i)	No. of organisms in sample i (x_i)		Deviations (d_i)		Squared deviations $(d^2)_i$
1		$- \bar{x}$ =		^2 =	
2		$- \bar{x}$ =		^2 =	
3		$- \bar{x}$ =		^2 =	
4		$- \bar{x}$ =		^2 =	
5		$- \bar{x}$ =		^2 =	
6		$- \bar{x}$ =		^2 =	
7		$- \bar{x}$ =		^2 =	
8		$- \bar{x}$ =		^2 =	
9		$- \bar{x}$ =		^2 =	
10		$- \bar{x}$ =		^2 =	
11		$- \bar{x}$ =		^2 =	
12		$- \bar{x}$ =		^2 =	
13		$- \bar{x}$ =		^2 =	
14		$- \bar{x}$ =		^2 =	
15		$- \bar{x}$ =		^2 =	
16		$- \bar{x}$ =		^2 =	
17		$- \bar{x}$ =		^2 =	
18		$- \bar{x}$ =		^2 =	
19		$- \bar{x}$ =		^2 =	
n = 20		$- \bar{x}$ =		^2 =	
Total # organisms $\Sigma (x_i) =$		**Sum of Squared Deviations** $\Sigma (d^2)_i =$			
Mean $\Sigma (x_i)/n =$		**Sample Variance** $s^2 = \Sigma (d^2)_i/(n-1) =$			
	Variance/Mean $(s^2/\bar{x}) =$				

Discussion

1. Based on the variance/mean ratio, what can you conclude about the spatial pattern of your population? How might you explain this pattern, given observations you made as you were sampling?

2. Random sampling is very important if the data you collected are meant to represent a larger population. In retrospect, do you have any questions or concerns about the validity of the sampling method? If bias exists, how might you alter your method to randomize your samples?

3. An index of aggregation is maximized in patchy distributions if the size of the quadrat is the same as the size of the organism's aggregations. Might a larger or smaller sampling unit (or a different sized resource unit) have affected your results?

4. Would you expect another organism from the same biological community to exhibit a similar index of dispersion? Is spatial pattern a property of the organism, or of its habitat?