From:

Measuring & Monitoring Plant Populations BLM/RS/ST-98/005+1730 (5.1 MB)

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F. Density

Density is the number of counting units per unit area. To define density as the number of individuals per unit area is suitable for animals, for which an individual is a readily recognized entity. For plants, however, the above-ground expression can be of individuals (genets) or it can be an intermixing of a few individuals with many above-ground members (ramets). An aspen clone, for example, is an individual, but most people would consider each stem an individual, in spite of the fact that stems are interconnected underground and are technically ramets.

Thus, a critical question in the measure of density, just as it is in censusing, is to define the counting unit. A counting unit has to be consistently recognized by all observers for density to be used as a monitoring method (Appendix 11).

1. Advantages and disadvantages

Density is most effective when the change expected is recruitment or loss of individuals (or of the counting unit). Estimated density (in terms of number per unit area) is theoretically the same for all quadrat shapes and sizes, although the precision of the estimate will vary (sometimes dramatically) among sampling units of different shapes and sizes. The fact that density is reported as a per area measure allows comparison between sites even if the quadrat shape used for sampling differs. This is in contrast to another measure described below, frequency, which is dependent on plot size and shape.

In practice, the density estimate may vary with plot size because of the effects of boundary decisions, which are most pronounced in small quadrats or long narrow ones (see more on this in Section 2, below). Because most observers will consistently include boundary plants, estimates of density in small quadrats or in long, narrow ones (high perimeter to area ratio) are usually higher than estimates from larger or square quadrats. A key monitoring design decision when using density is to select a quadrat size and shape that will efficiently estimate density with acceptable precision (see Chapter 7), while controlling these boundary errors (see Section 2, below, for ways of reducing boundary errors).

Density is most sensitive to changes caused by mortality or recruitment. It is less sensitive to changes that are vigor-related, especially those that are sub-lethal (e.g., a reduction in production that is not accompanied by an increase in mortality or a decrease in recruitment). Figure 8.2 shows that a population can change dramatically without a large change in density. In this example, cover and the ratio of reproductive individuals compared to non-reproductive have declined dramatically, but simple counts would have detected a decline of only two individuals. Density may be an especially poor monitoring measure when

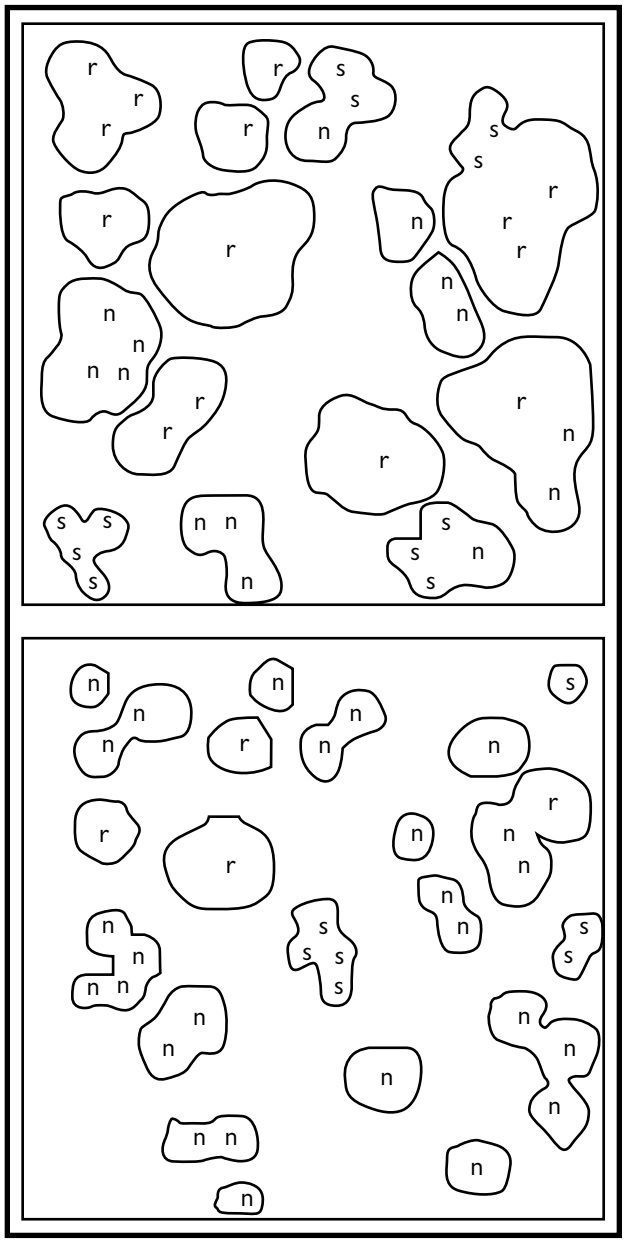

FIGURE 8.2. Two views of the same quadrat, the top measured in 1995 and the bottom in 1996. Outlined polygons denote canopy cover; letters represent individuals. Note that density declined from 39 individuals to 37 individuals. In 1995, there were 14 reproducing individuals (r), 14 non-reproducing individuals (n) and 11 seedlings (s) in the plot. In 1996, there were 4 reproductive individuals, 26 non-reproducing individuals and 7 seedlings. Note also the dramatic decline in cover from 1995 to 1996. The changes illustrated in this plot are not well captured by density measures of total individuals. Even a count of seedlings versus adults would not have captured the dramatic change in reproductive fraction.

individuals are long-lived, and respond to stress with reduced biomass or cover, rather than mortality. Density may also be a poor measure for plants that fluctuate dramatically in numbers from year to year, such as annuals.

Observer bias is generally low if the counting units are few and easily recognized, but errors are common when quadrats contain cryptic individuals or numerous plants. The most common non-sampling errors originate in "high speed" counts that overlook small individuals. Establishing a minimum search time per quadrat can reduce the temptation to hurry the measurements, although the actual time required per quadrat will vary depending on the number of counting units occurring within it.

2. Design and field considerations: quadrats

a. Quadrat design

The density of herbaceous plants is usually counted within the boundaries of a quadrat, each of which is a sampling unit. Quadrat design is discussed at length in Chapter 7. A few of the points are reiterated here:

1. The size of the quadrat should not be impractical, i.e., the quadrat should not be too large either in terms of number of individuals to be counted or search time required.

2. Size and shape of the quadrat must be tailored to the specific plant distribution observed in the field. For most situations, the most efficient quadrat shape will be a rectangle.

3. You should attempt to include at least some "clumps" of the target species in your initial trial quadrat sizes and shapes. The most efficient plot shape and size in terms of number of quadrats needed will be one in which the density in each quadrat is very similar (little variability between quadrats). Good guesses on size and shape can be made by first observing the distribution of the plants in the field. Pin flags can be placed throughout the population in areas of concentration to get a better picture of the distribution of the species at the site. You want to design a plot size and shape that intersects those areas of concentration. Appendix 17 describes a procedure to compare the efficiency of different quadrat sizes and shapes based on pilot sampling.

b. Counting unit

Density is usually based on a count of plants rooted within a quadrat. It works best with plants with distinct and fairly small diameter stems. As the size of the area of the plant intersecting the ground increases (such as trees with larger diameter trunks or bunchgrasses with large basal areas), deciding whether a plant along the boundary is in or out of the quadrat becomes more complicated. For some species, using a "rooted density only" rule is also problematic. For example, if the counting unit is a shoot of grass, individual tillers are sometimes not clearly rooted, but are clearly individual shoots. For many matted plants, trying to determine the rooted zone requires lifting and pulling at the top mat, possibly causing injury to the plant; thus, for these matted plants using the canopy outline for boundary decisions may be better than the rooted area. (A more appropriate technique for matted plants may be cover.) For most species, however, avoid using the outline of the canopy as the boundary to determine whether a plant is in or out of the quadrat (Figure 8.3), because changes in canopy (vigor) will affect the density measure and increase the complexity of the interpretation. For

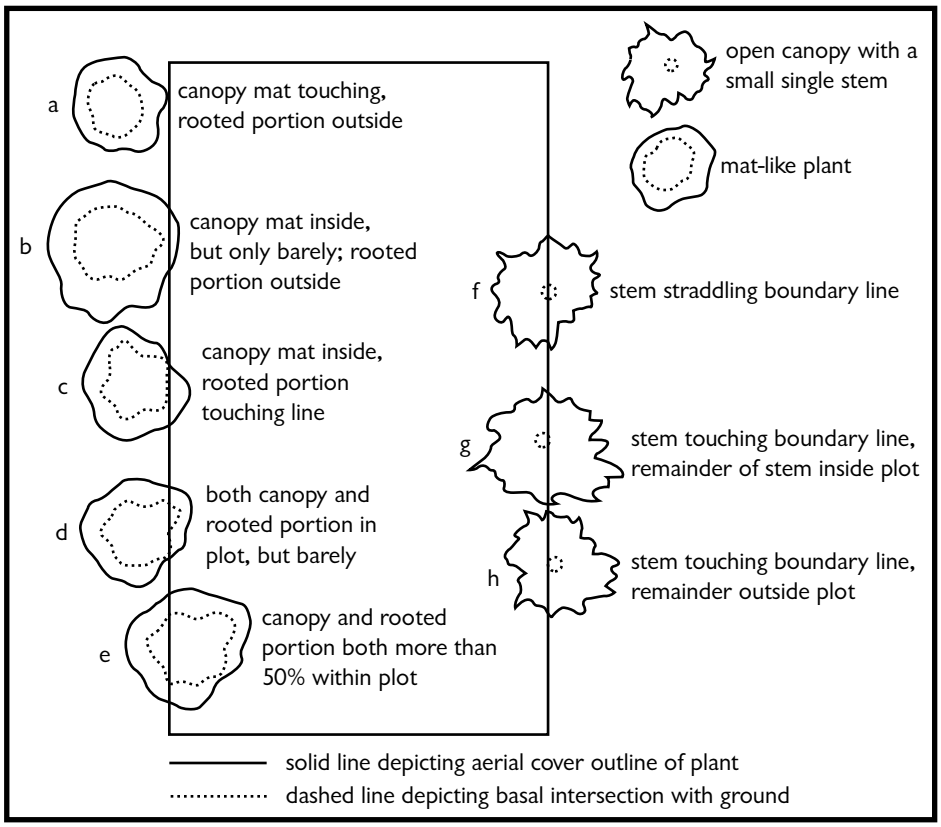

FIGURE 8.3. Boundary decisions. Which plants should be considered within the plot? Most investigators use one of two rules: (1) all boundary plants are counted in on two contiguous sides and out on the other two sides; or (2) every other boundary plant is counted. Plants c-h would be considered by most observers to be boundary plants. Plants a and b would generally not be considered boundary plants (because only the canopy intersects the plot), although occasionally a specific situation may require that the canopy boundary be used rather than the basal boundary (see text for additional discussion).

most species the best counting unit is a rooted individual, but for some species other rules may have to be developed (and documented).

In addition to identifying the counting unit, you should consider the value of using stage classes such as seedling, non-reproductive, and reproductive. Doing counts by stage class requires more time, but in many situations the additional information warrants the extra effort. Figure 8.2 clearly shows that measuring density in stage classes can rectify the insensitivity of density as a measure of some kinds of change. In this example, the number of plants in the quadrat only declines by two—from 39 plants the first year to 37 the second—but demographic structure displays a dramatic change, declining from 14 reproducing plants the first year to 4 the second year. Dividing the population into seedlings and non-seedlings can provide additional information for interpreting changes in density, although in this example adults increased by 2 individuals and seedlings declined by 4.

c. Boundary decisions

Boundary decisions are important in density measures, since a plant must be counted in or out (Figure 8.3). You must establish boundary rules and apply them consistently each time the monitoring is done. Plants with a single thin stem are fairly easy to determine if they are in

or out of a quadrat, but plants with a large basal diameter (e.g., bunchgrasses and tree), may be half in and half out. How will these be addressed?

Some viable alternatives are as follows:

1. Plants are considered in if any part of the plant boundary is touching the plot boundary along two adjacent sides of a rectangular plot, and considered out if any portion of the plant boundary is touching the other two sides of the plot. This provides an accurate estimate of density and is the recommended approach for reducing boundary bias. For monitoring in permanent plots, you must specify which sides are interpreted in which way (compass direction works well), and measure along those sides the same way consistently. The sides must be split so an equal portion of the perimeter is treated as the "in" sides compared with those considered the "out" sides. In other words, if the plot is rectangular, you would consider straddler plants "in" along one long side and one short side of the rectangle, and "out" along one long side and one short side (adjacent sides).

2. Plants are counted as in or out alternately along the boundary. This provides an unbiased estimate of density, but in a very large or long quadrat, you may have trouble keeping track of whether you last counted an "in" or an "out" plant.

3. Plants are considered in if more than 50% of the plant boundary (canopy or basal) is within the plot. This is illustrated by plants e and f in Figure 8.3. While this method will give an accurate measure of density, we do not recommend it because additional subjective observer decisions are required. Observers may have consistent bias in their estimates of 50% (over-inclusion is the most common), introducing an unknown observer error. Plants with irregular basal outlines are especially difficult to consistently determine if they are to be counted "in" or "out".

Some non-viable alternatives:

1. Count all plants that touch the line, even if most of the plant boundary is outside of the plot. This is illustrated in Figure 8.3, plants c and h. If you use this approach, you will overestimate density (number of individuals per unit area) because the length and width of the plot are essentially increased by the average diameter of the boundary of the plant. This is easiest to visualize with the matted plant in Figure 8.3.

2. Include only plants that are completely within the plot, including those that just touch the line. This is illustrated by plant g in Figure 8.3. This gives the opposite result as approach (1), above—an underestimation of true density.

Both approaches have been used in monitoring studies, and if you have a current study using one of these designs, it is not a fatal error. If the purpose of the study is to measure change over time, and the boundary rule resulting in over or under estimation has been consistently applied, you may still be able to interpret changes in terms of trend in the population. One problem in interpretation that may arise however, is that as plant boundaries change due to changes in vigor, the impact of that change on density estimated using either of these boundary rules will be much larger than if boundary decisions were made using an unbiased approach. Thus, interpreting changes in density measured in a monitoring project using one of these boundary rules will be partially obscured by changes in vigor. Another problem is that both methods create difficulties in comparing density estimates at different sites since the estimate of density is partially a function of plant diameter, which can vary from site to site.

3. Design and field considerations: distance measures

An alternative to estimating density in quadrats is a suite of techniques called distance measures. Several variations on the theme have been developed, but they all involve the measure of the distance of an individual from a point or from another individual, and estimating density from the average distance measure. Figure 8.4 shows the four most commonly used distance measures in vegetation sampling. These measures are most often used for large or scattered individuals such as trees, for which the use of quadrats is not practical. They have, however, occasionally been used in grasslands on common herbaceous plants (Becker and Crockett 1973). Distance measures are based on the concept of a mean area per plant. Once this is known, the value can be used to calculate a density per unit area.

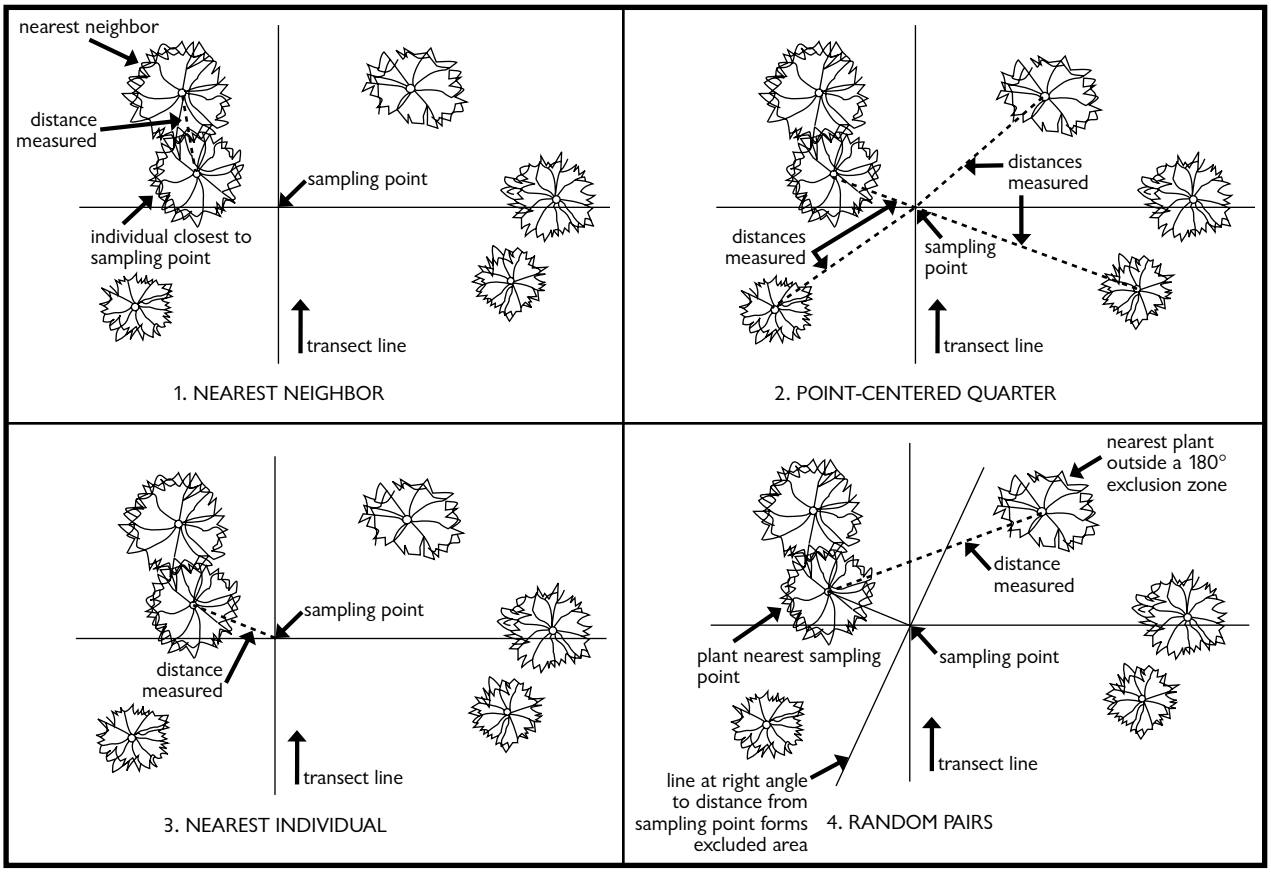

FIGURE 8.4. Four distance methods used for measuring density in plant populations with randomly distributed individuals: (1) nearest neighbor; (2) point center quarter; (3) nearest individual; and (4) random pairs. None of these methods are appropriate for species that have contagious (clumped) distributions.

These techniques, however, are only suitable for use on plants with random distributions. Most plants do not grow randomly in space, but occur in clumps, the result of short-distance dispersal of propagules or micro-variation in habitat. One technique, the wandering quarter method (Figure 8.5), was designed for individuals with non-random aggregated distributions (Catana 1963). A similar approach, the T-square method, was proposed by Diggle (1975) and by Blyth (1982).

Field tests of the latter two methods give mixed results. Lyon (1968) found that the wandering quarter method gave an accurate estimate of density in a shrub community in which all individuals had been enumerated. To achieve a reasonably precise estimate of density, however, actual counts were quicker than sampling with points and distance measures.

McNeill et al. (1977) sampled an area in which all individuals had been marked and mapped. They found that quadrats were superior in terms of the accuracy of the estimate and field efficiency compared to several distance measures. Becker and Crockett (1973) concluded that the wandering quarter method underestimated a clumped species and overestimated a single-stalked, well-dispersed species.

In a simulation study of 24 distance-based density estimators, Engeman et al. (1994) determined that the approach proposed by Diggle (1975) did not provide unbiased estimates of the mean when sampling clumped distributions. They also argued that the method is relatively inefficient in the field because of the difficulty in defining the area of exclusion (see Figure 8.5). They concluded that the best estimators were those that measured three distances per point (point to nearest individual, nearest individual to nearest neighbor, and nearest neighbor to its nearest neighbor), and estimators that measured from the point to the third nearest individual.

The value and performance of distance measures depends on the field situation. The best estimators for clumped distributions are complex, either requiring three measures per sampling point, or determining which individual is the third farthest from the sampling point. This complexity dramatically reduces the field efficiency of these methods. Distance measures may be appropriate when the individuals are so widely spaced that using quadrats is not practical (as for some trees), but for most monitoring situations involving rare plants, quadrat-based density estimates are more efficient and free from the potential biases of distance methods.

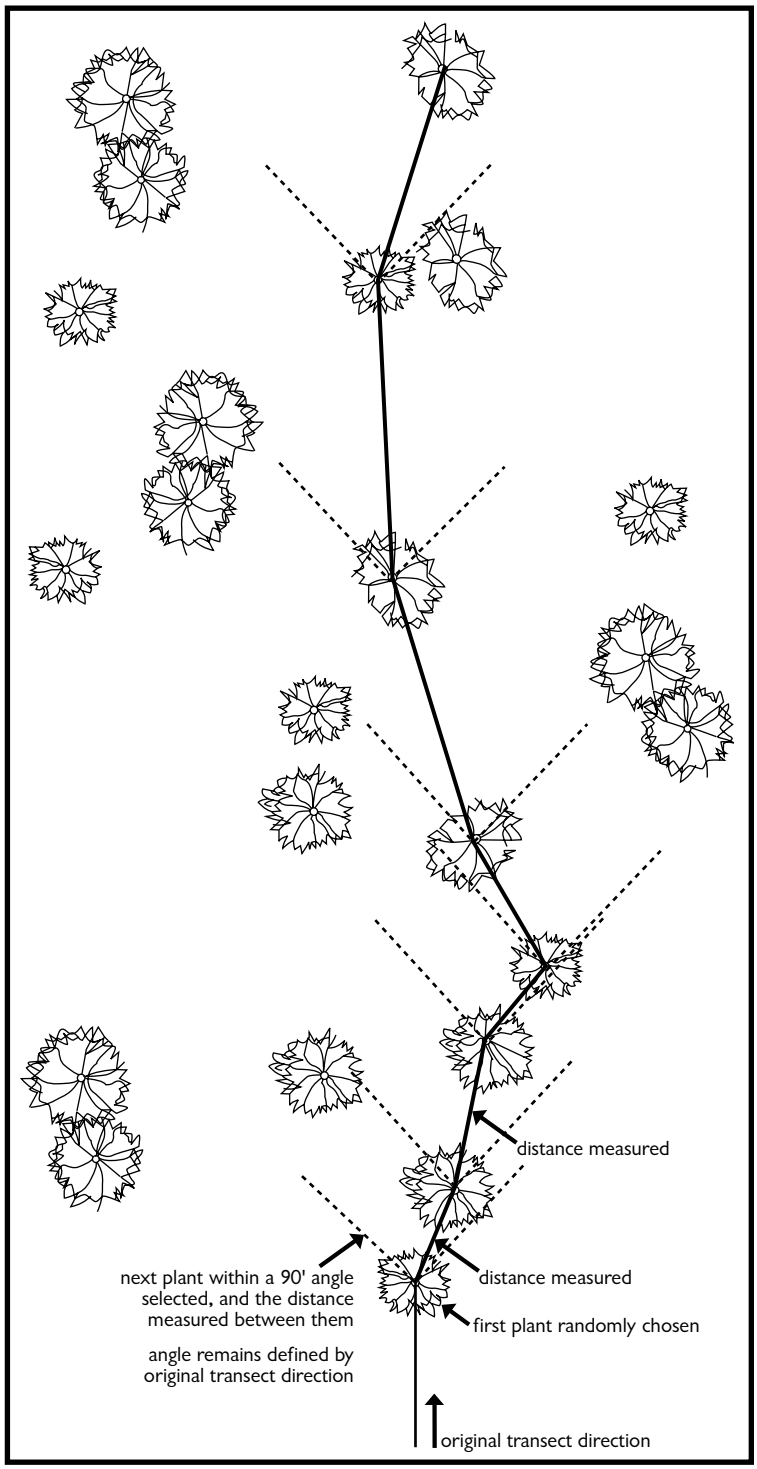

FIGURE 8.5. Wandering quarter distance measure, which can be used in plant populations with individuals contagiously distributed. This is the only distance measure recommended for general use since few plant populations are randomly distributed.