I. Density Method

1. *General Description* Density is the number of individuals of a species in a given unit of area. For rhizomatous and other species for which the delineation of separate individual plants is difficult, density can also mean the number of stems, inflorescences, culm groups, or other plant parts per unit area.

2. *Areas of Use* This method has wide applicability and is suited for use with grasses, forbs, shrubs, and trees.

3. *Advantages and Limitations*

   a Generally, the density of mature perennial plants is not affected as much by annual variations in precipitation as are other vegetation attributes such as canopy cover or herbage production.

   b Density is a quantifiable and absolute attribute.

   c Density is sensitive to changes in the adult population caused by long-term climatic conditions or resource uses.

   d Density provides useful information on seedling emergence, survival, and mortality.

   e Sampling is often quick and easy with certain life forms (e.g., trees, shrubs, bunchgrasses).

   f Plant communities on the same ecological sites can be compared using density estimates on specific species or lifeforms.

   g Density can be useful in estimating plant responses to management actions.

   h It can often be difficult to delineate an individual, especially when sampling sod forming plants (stoloniferous, or rhizomatous plants) and multi-stemmed grasses or closely spaced shrubs. Although in these cases a surrogate plant part (e.g., upright stems, inflorescences, culm groups) can be counted, the usefulness of such estimates is limited to the biological significance of changes in these surrogates.

   i Sampling may be slow and tedious in dense populations; this also raises the risk of non-sampling errors.

   j There is no single quadrat size and shape that will efficiently and adequately sample all species and life forms. For this reason, density estimations are usually limited to one or a few key species.

4. *Equipment* The following equipment is needed (see also the equipment listed in Section V.A, page 31, for the establishment of the photo plot):

   - Study Location and Documentation Data form (see Appendix A)
   - Density form (see Illustration 21)
   - Tapes: 50-, 100-, 150-, or 200-meter delineated in centimeters. (Tapes in

English measurements can be substituted but metric tapes are preferred.) At least three tapes are required (one, to be used for constructing quadrats, need only be as long as the long side of the quadrat; a rope of the desired length can be substituted for this tape); four are better.

- Meter sticks (or yard sticks if using English measurements). Two are required.
- Four stakes: 3/4- or 1-inch angle iron not less than 16 inches long
- Hammer
- Permanent yellow or orange spray paint
- Tally counter (optional)
- Compass
- Steel post and driver

5. *Training* As with any monitoring method, adequate training is essential to minimize nonsampling errors.

   a Examiners must be able to identify the target plant species.

   b For sod-forming grasses and other species for which individual plants might be hard to distinguish, written guidelines should be provided on what constitutes an individual unit to be counted.[6] This will help to ensure consistency among examiners. To assess consistency prior to the study, several examiners should be asked to independently count these units in the same set of quadrats and the results compared. If relatively consistent results cannot be achieved a different species should be chosen for estimation or a different method selected.

6. *Establishing Studies* Careful establishment of studies is a critical element in obtaining meaningful data.

   a **Site Selection** The most important factor in obtaining usable data is selecting representative areas (critical or key areas) in which to run the study (see Section II.D). Study sites should be located within a single plant community within a single ecological site. Transects and sampling points need to be randomly located within the critical or key areas (see Section III).

   b **Pilot Studies** Collect data on several pilot studies to determine the number of samples (transects or observation points) and the number and size of quadrats needed to collect a statistically valid sample (see Section III.B.8).

   (1) ***Quadrat size and shape*** It is vital to choose the quadrat size and shape that will give the highest statistical precision for the area and key species being sampled. As a general rule of thumb long, thin quadrats are better

[6] Determination of what constitutes a unit to be counted is somewhat arbitrary. For rhizomatous grasses such as western wheatgrass (*Pascopyrum smithii*), each culm group can be visualized as an actual or potential plant unit, as can rooted stoloniferous units of such species as vine mesquite (*Panicum obtusum*). Mat or sod-forming plants such as blue grama (*Bouteloua gracilis*) or alkali sacaton (*Sporobolus airoides*) usually start growth as small, distinct clumps, but may spread to plants a meter or more in diameter. As this occurs they tend to fragment into more-or-less separate units, and it is these separate units that should be counted as actual or potential individuals. For rhizomatous or mat-forming forbs, flowering stems may be the units counted. The examiner should ensure, however, that a change in the unit chosen is of biological significance, i.e., reflects a real change in the vegetation community. If it has no such significance, then another unit or a different species should be chosen. (Alternatively, an attribute other than density can be selected for monitoring.)

(often very much better) than circles, squares, or shorter and wider quadrats (Krebs 1989). How narrow the quadrats can be depends upon consideration of measurement errors due to edge effect, but these problems can be largely overcome by incorporating rules for determining whether a plant falls inside or outside a quadrat (discussed in more detail under Sampling Process below).

(a) Subjectively place quadrats[7] of a certain size and shape in areas with large numbers of the target plant species. See how many plants fall into the quadrat and ask if this is too many to count. See what kind of problems there might be with edge effect: when individuals fall on or near one of the long edges of the quadrat, will it be difficult for examiners to make consistent calls as to whether these individuals are in or out of the quadrat? See if there is a tendency to get more plants in rectangular quadrats when they are run one way as opposed to another.

(b) Determine the standard deviations of those quadrat sizes and shapes deemed to be practical from the subjective examination described above (see Section III.B.8.b).

(c) Choose the quadrat size and shape with the smallest standard deviation.

(2) ***Direction of quadrats*** Determine if there is an environmental gradient affecting the density of the target species in the key area. Examples of such gradients are elevation and moisture. If there is a gradient, the study should be set up so that the long side of each quadrat is placed *perpendicular* to this gradient. This ensures that there is more variability *within* each quadrat than there is *between* quadrats.

Subjectively placing quadrats in different directions as described under 6.b.(1)(a) above can assist in making this determination. For example, if quadrats laid out with the long side going north-south tend to have no or fewer plants of the key species than quadrats with the long side going east-west, the east-west position should be selected.

c **Study Layout** Data can be collected using the baseline, macroplot or linear study designs described in Section III.A.2 beginning on page 8. The macroplot technique is the recommended procedure.

d **Reference Post or Point** Permanently mark the location of each study with a reference post and a study location stake (see beginning of Section III).

e **Study Identification** Number macroplots for proper identification to ensure

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[7] Note that it is not necessary to construct an actual frame for the quadrats used. It is sufficient to delineate quadrats using a combination of tape measures and meter (or yard) sticks. For example, a 5 m x 0.25 m quadrat can be constructed by selecting a 5 m interval along a meter tape, placing two 1-meter sticks perpendicular to the tape at both ends of the interval (with their zero points at the tape), and laying another tape or rope across these two sticks at their 0.25 m points. This then circumscribes a quadrat of the desired size and shape. Alternately place a meter stick perpendicular to the tape at one end of the interval. The meter stick is then moved slowly up the interval and all plants of the species occurring within the first 0.25 m of the meter stick recorded until the end of the interval is reached.

that the data collected can be positively associated with specific sites on the ground (see Appendix B).

f **Study Documentation** Document pertinent information concerning the study on the Study Location and Documentation Data form (see beginning of Section III and Appendix A).

7. *Taking Photographs* The directions for establishing photo plots and for taking close-up and general view photographs are given in Section V.A.

8. *Sampling Process* In addition to collecting the specific studies data, general observations should be made of the study sites (see Section II.F).

a **Selecting Random Pairs of Coordinates** Using the technique described in Section III.A.2.b.(2) on page 10 and Appendix D, select coordinates to mark the points at which quadrats will be positioned.

b **Sampling** Assuming that the x-axis is on the "bottom" and the y-axis is at the "left," each pair of coordinates represents the lower left corner of each quadrat. Thus, if one random set of coordinates is 0,0, the quadrat is positioned with its lower left corner at the origin.

(1) Place the quadrats at each of the random pairs of coordinates and continue reading them until the number of quadrats previously determined to be required has been read.

Make a quadrat of the desired size and shape by running a tape in the direction of the long side of each quadrat from the appropriate axis and using two 1-meter sticks and another tape or rope. In the example in Section III.A.2.b.(2)(e) on page 11, it has been decided that the quadrats should be placed with their long sides parallel to the x-axis and that the quadrats should be 1 m x 16 m. Based on the random coordinates chosen, the first quadrat is to be placed at the 28 m point on the y-axis and the 16 m point on the x-axis. A tape is run parallel to the x-axis beginning at the 28 m point on the y-axis. At the 16 m mark on this tape, a meter stick is positioned perpendicular to the tape with its 0 point at the tape. Another meter stick is similarly placed at the 32 m mark. Another tape or a rope of 16 m in length is placed across the two 1-meter sticks at their 1 m points. The number of plants is counted in this quadrat and sampling continues. If the short side of each quadrat exceeds 1.0 m, more than one 1-meter stick or additional tapes or ropes may need to be used.

(2) Count the number of individuals (or other counting unit) of the key species in each quadrat and record this on the Density form (Illustration 21). Count only those plants that are rooted in the quadrat. Often it is desir-

able to make separate counts for different size or age classes of the key species. This is particularly true for seedlings, many of which may not survive to the next sampling period.

(a) To eliminate measurement error due to edge effects, it is helpful to have rules for determining whether an individual plant that falls exactly on the edge of a quadrat is considered inside or outside the quadrat.

(b) A good rule to follow is to count those individuals falling on the left and top edges of the quadrat as being inside the quadrat and those individuals falling on the right and bottom edges of the quadrat as being outside the quadrat. Make sure that all observers follow the same set of rules.

9. *Calculations* Make the calculations and record the results on the Density form (see Illustration 21).

a **Average Density per Quadrat** Calculate the estimated average density per quadrat for each size/age class by dividing the total number of plants counted in the sample for each size/age class by the number of quadrats in the sample. If more than one key species is counted, this process is done separately for each species. For example, a sample of 40 quadrats yields a total of 177 individual mature plants of key species Y. The estimated average density of mature plants per quadrat is therefore 177/40 = 4.4 plants/quadrat.

b **Total Density of Macroplot** Calculate the estimated total density of the macroplot by multiplying the average density per quadrat by the total number of possible quadrats in the macroplot. If more than one key species is counted, this process is done separately for each key species. Say the macroplot in the example given in 9.a above is 40 m x 80 m and the quadrat size is 1.0 m x 16 m. There are 200 possible nonoverlapping quadrat placements in a macroplot of this size (40/1 = 40 along one axis and 80/16 = 5 along the other; 40 x 5 = 200 possible quadrats). The estimate of the total density of the macroplot is therefore 4.4 mature plants/quadrat x 200 quadrats = 880 mature plants.

10. *Data Analysis and Interpretation* Data analysis is straightforward. Confidence intervals should be constructed around each of the estimates of average density per quadrat (hereafter referred to simply as "average") and total macroplot density for each year. The averages of two years should be compared by using a *t* test (for independent samples). Averages of three or more years can be compared by an analysis of variance. See Technical Reference, *Measuring & Monitoring Plant Populations.*

11. *References*

Krebs, C.J. 1989. Ecological methodology. Harper & Row, New York. This book discusses the superiority of long, thin quadrats over circular and square quadrats, as well as the potential problems of edge effect.

Salzer, D. 1994. An introduction to sampling and sampling design for vegetation monitoring. Unpublished papers prepared for Bureau of Land Management Training Course 1730-5. BLM Training Center, Phoenix, Arizona. These papers, together with material prepared for a class exercise, present the basic concepts of the Density Method. The Density Method is in rather widespread use in The Nature Conservancy and, increasingly, by the Bureau of Land Management and the Forest Service, particularly as a means of estimating numbers of special status plant species.

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Density

Study Number	Date	Examiner	Allotment Name & Number	Pasture	Plot Size

Study Location

Plot	1		2		3		4		5		6		7		8		9		10		Total	
Coordinates																						
Plant Species	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling

Density

Study Number	Date	Examiner	Allotment Name & Number	Pasture	Plot Size
Empire #4	9/6/96	Cindy Cone	Empire - 21206	South	16 m^2

Study Location: Study is 2 mi. south of Antelope fence on the EAST side of the road.

Plot	1		2		3		4		5		6		7		8		9		10		Total	
Coordinates	0	3	0	4	16	7	16	48	32	21	32	27	32	38	48	8	48	27	64	34		
Plant Species	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling	Mature	Seedling
HIBE	6		5	2	6	3			6	6	11	6			7					6	41	23
BOHI	4				3								10		4						21	
BOER 4	1								3				1								5	
HATE	3						3										4	1			10	1
LYPH	10		4				2	6					4								20	6
AAFF	3				1															8	4	8
Lupine															4		2			5	6	5
BOCU															1						1	
BOGR																	13				13	