Background and measurement protocols for cover, density, and basal diameter data associated with the long-term vegetation transects

This protocol refers to measurements for cover and density of perennial grasses, shrubs, and cacti, and perennial grass basal diameters on 132 permanent 1x100-ft. belt transects located on the Santa Rita Experimental Range (SRER). These transects were established by S. Clark Martin during USFS Studies FSRM 1706-09, FSRM 1706-12, FSRM 1706-15, and FSRM 1706-25 (https://cals.arizona.edu/srer/data.html). The Forest Service began the measurements on three of those experiments as early as 1953 and proceeded for approximately 10 years, with annual measurements of cover and biomass on permanently established plots. The experiments were designed to compare vegetation responses to different seasons of livestock grazing, the removal of velvet mesquite, and the spatial distribution of water developments for livestock use. The fourth experiment was based on a subset of the permanent plots from the previous three experiments and 30 newly established permanent plots to compare, on a large scale, the vegetation responses to continuous-yearlong grazing versus a three-pasture rotation grazing system called the Santa Rita Grazing System. This experiment lasted from 1972 to 1984, with measurements made every 3 years. In 1991, the University of Arizona resumed the measurements for cover and density of perennial grasses, shrubs, and cacti, and perennial grass basal diameters on 132 1x100-ft selected transects used in the Santa Rita Grazing System experiment. These transects have subsequently been measured every three years, in the winter-spring season, from the beginning of January to the end of April. In most cases, taxa have been recorded separately to the species level and sometimes to the genus level only.

All data derived from the long-term vegetation transects are available for download on the SRER website (https://cals.arizona.edu/srer/data.html). Specifically, the website provides:

- The present measurement protocols;
- The datasets including all measurements of vegetation by species or species group made on the transects for cover (from 1953 to 2021), density (from 1972 to 2021), fetch data (from 2009 to 2012), grass basal diameter and biomass data (from 2009 to 2018, as in 2021 they were not recorded due to the 2020 drought). Each dataset also provides the fire and mesquite removal history of each transect. A "Notes" and "Layout" files detail the measurements and the structure of each dataset, respectively;
- The figures for cover, density, and perennial grass biomass;
- The Ecological Site Designations of each transect;
- The UTM coordinates for the study transects;
- The photographs of the long-term vegetation transects for viewing and downloading (from 1957 to 2021);
- The original Forest Service Studies FSRM 1706- 09, FSRM 1706-12, FSRM 1706-15, and FSRM 1706-25 which originated these measurements.

The transects' names and the corresponding pastures and Ecological Sites on the Santa Rita Experimental Range are reported in **Table 1**.

The following protocols list the sequence of operations necessary to perform the measurements in each vegetation transect. For more information about data entering and datasets, see the files associated with each dataset.

Table 1: Pastures and Ecological Sites of the 132 long-term vegetation transects on the Santa Rita Experimental Range.

Pasture	Transect	Ecological Site
2N	1E	Sandy loam Deep
	1W	Sandy loam Deep
	2E	Sandy loam Deep
	2W	Sandy Wash
	4E	Sandy loam Deep
	4W	Sandy loam Upland
	10E	Sandy loam Upland
	10W	Sandy loam Upland
	11E	Sandy loam Upland
	11W	Sandy loam Upland
2S	1	Sandy loam Upland
	2	Sandy loam Deep
	4	Sandy loam Upland
	5	Loamy Upland
	6	Sandy loam Upland
	7	Loamy Upland
	8	Sandy loam Deep
	9	Loamy Upland
3	1E	Sandy loam Upland
	1W	Sandy loam Upland
	4E	Sandy loam Deep
	4W	Sandy loam Deep
	7E	Sandy loam Deep
	7W	Sandy loam Deep
	8E	Sandy Upland
	8W	Sandy Upland
	10E	Loamy Upland
	10W	Loamy Upland
5N	1E	Sandy loam Upland
	1W	Sandy loam Upland
	2E	Sandy loam Deep
	2W	Sandy loam Deep
	8E	Sandy loam Upland
	8W	Sandy loam Upland
	10E	Clay loam Upland
	10W	Loamy Upland
	11E	Clay loam Upland
	11W	Clay loam Upland
5S	1E	Sandy loam Upland
	1W	Sandy loam Upland
	2E	Sandy loam Deep
	2W	Sandy loam Deep
	4E	Limy Upland Deep
	4W	Limy Upland Deep
	5E	Loamy Upland
	5W	Loamy Upland

Pasture	Transect	Ecological Site
6A	1	Sandy loam Upland
	2	Sandy loam Upland
	3	Sandy loam Upland
	4	Sandy loam Upland
	5	Sandy loam Upland
	11	Sandy loam Deep
	12	Sandy loam Deep
	13	Sandy loam Deep
	14	Sandy loam Deep
	15	Sandy loam Deep
	16	Sandy loam Upland
	17	Sandy loam Upland
	18	Sandy loam Upland
	19	Sandy loam Deep
	20	Sandy loam Deep
	36	Sandy loam Deep
	37	Sandy loam Deep
	38	Sandy loam Deep
	39	Sandy loam Deep
	40	Sandy loam Deep
	41	Sandy loam Deep
	42	Sandy loam Deep
	43	Loamy Upland
	44	Sandy loam Deep
	45	Sandy loam Deep
6B	1E	Sandy loam Deep
	1W	Sandy loam Deep
	2E	Sandy loam Deep
	2W	Sandy loam Deep
	3E	Sandy loam Upland
	3W	Sandy loam Deep
	4E	Sandy loam Upland
	4W	Sandy loam Upland
	5E	Sandy loam Upland
	5W	Sandy loam Upland
	51	Sandy loam Upland
	52	Sandy loam Deep
	53	Sandy loam Upland
	54	Sandy loam Upland
	55	Sandy loam Upland
	56	Sandy loam Upland
	57	Sandy loam Upland
	58	Sandy loam Upland
	59	Sandy loam Upland
	60	Sandy loam Deep

continue

Pasture	Transect	Ecological Site
8	2	Sandy loam Upland
	3	Loamy Upland
	4	Loamy Upland
	5	Sandy loam Upland
	7	Sandy loam Upland
	8	Loamy Slopes
	9	Loamy Upland
	12	Loamy Slopes
	13	Loamy Slopes
	14	Granitic Hills
12B	4E	Loamy Upland
	4W	Loamy Upland
	5E	Loamy Upland
	5W	Loamy Upland
	7E	Sandy loam Deep
	7W	Sandy loam Deep
	10E	Loamy Swale
	10W	Sandy loam Deep
	11E	Sandy loam Upland
	11W	Sandy loam Upland

Pasture	Transect	Ecological Site
21	1	Loamy Upland
	2	Sandy loam Deep
	3	Sandy loam Upland
	4	Sandy loam Deep
	5	Sandy loam Upland
	6	Sandy loam Upland
	7	Sandy loam Upland
	8	Sandy loam Upland
	9	Sandy loam Upland
	10	Loamy Hills
22	1	Loamy Upland
	2	Loamy Upland
	3	Loamy Upland
	4	Loamy Upland
	5	Sandy loam Deep
	6	Sandy loam Deep
	7	Sandy loam Upland
	8	Sandy loam Deep
	9	Sandy loam Upland
	10	Loamy Upland

Equipment List

The following list includes all the minimum equipment necessary for the daily fieldwork of a team of two people. Bringing replacements of each item is always advisable given the possibility of some equipment failure, loss, or breakage.

Daily equipment:

- GPS with the coordinates of the long-term vegetation transects + extra batteries
- Blank Cover, Density, and Basal Diameter datasheets
- Photocopies of the datasheets with the original Cover, Density, and Basal Diameter measurements of the transects from three years earlier
- Map with the transects' location and the nearest car stops
- Tablet with the transects' pictures from three years earlier
- 2 Storage clipboards, one for the datasheets, one for part of the equipment (calipers, pencils, eraser, diameter tapes, extra-batteries, etc.)
- Pencils and erasers
- Rubber bands and clips to secure the datasheets to the clipboard on windy days
- 2 Open reel fiberglass tapes, 200 feet, graduated 1/10-1/100 on one side (e.g. Tapes Keson® English Open Reel Fiberglass Tape, OTR-10-200, 200 feet)
- 2 Diameter tapes with graduated diameter in cm and mm on one side, and linear in cm and mm on the other side (e.g. Lufkin® Thinline Model W606PM, 64 cm diameter on one side, 200 cm linear on the other side)
- 2 Digital calipers 6"/150mm + batteries (e.g. Carbon Fiber Traceable® Digital Caliper, 6"/150mm)
- 2 Rulers 6 ft. x 5/8 in. (e.g. Lufkin® Red End Flat Reading Wood Ruler)
- 2-4 Rebars (3/8 * 1-2 feet) to replace missing rebars

- 1 Hammer
- 2 White paint spray cans for metals
- 2 C-Clamps for the two tapes
- 1 Pole + 1 C-Clamp to pass the tape through cacti and shrubs
- Extra batteries for GPS and calipers
- Sampling bags to collect specimens
- 2 Pairs of gloves
- 2 Camping chairs or stools

In the car:

- Extra fence posts in case some of the witness fence posts are missing in some transects
- Replacements for stationary, tools, and instruments (e.g. extra calipers, tapes, pencils, datasheets, etc.)

Transect Set-Up

The GPS coordinates of each vegetation transects are available for download on the Santa Rita Experimental Range website (https://cals.arizona.edu/srer/data.html). Coordinates refer to a witness fence post located nearby the starting point of each transect. Three rebars driven into the ground indicates the start, the middle, and the end of each transect at 0, 50, and 100-ft. distances, respectively. Witness posts are painted in green with horizontal white stripes while rebars are painted in white.

To set up the transect:

1) Through the GPS coordinates, find the witness fence post located at the beginning of each transect and the 0-50-100-ft. rebars.
2) To confirm the transect code/orientation, from the 0 and 100-ft. rebars, respectively, compare the current transect view with the view in the picture taken following measurements in previous years (https://cals.arizona.edu/srer/transects/index.html).
   In case one of the rebars is missing, replace it with new rebar: use the tape to confirm the transect length and the pictures from the previous years to adjust the transect orientation.
3) To set up the transect, stretch the graduated tape (units of tenths of feet 0.10 ft.) from the 0 to the 100-ft. rebars:
   a. use the C-clamp to fix the tape to the 0-ft. rebar;
   b. when necessary, use a pole with a carabiner to hook the tape and pass it under and through shrubs and cacti;
   c. roll the tape around the 50-ft. rebar (or pass over it when not accessible because of cacti or shrubs);
   d. tie the tape up at the 100-ft. rebar.

   The tape must be taut, placed as close to the ground as possible, and marks must face up as much as possible. An example of a transect is showed in **Figure 1**.
4) Take a picture of the transect from both ends, from the 0 and 100-ft. rebars, respectively, making sure to include the tape and the rebars in the view. Record the code numbers of each 0 and 100-ft. picture on the density datasheet.

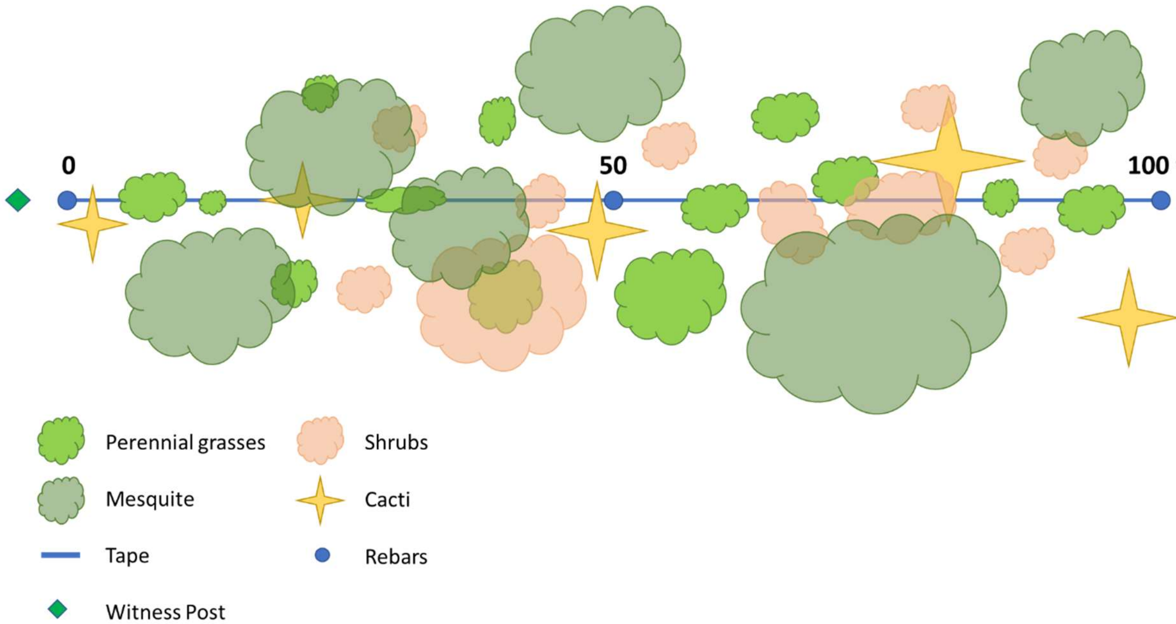

Figure 1. Example of 100-ft. long-term vegetation transect, with witness post and rebars.

Sequence of measurements for the long-term vegetation transects

Plant Cover

Perennial grass and shrub cover is estimated by species along the 100-ft. transect obtained by stretching the graduated tape between the 0 and 100-ft. rebars (**Figure 2**). Perennial grass is recorded as basal intercept, i.e. length of live root crown portion of the tuft at ground level. Shrub cover is recorded as the entire live crown intercept excluding conspicuous opening or areas of dead crown. Both basal intercept for perennial grasses and canopy intercept for shrubs and trees are reported in TENTHS of FEET (0.1-ft.) units.

Plant cover measurement protocol:

1) On the plant cover datasheet, report: Pasture #, Transect #, Observers, and Date.
2) Consult the list of plant species identified on the transect three years earlier.
3) Moving from 0 to 100-ft., report on the datasheet the intercept values for the live root crown portion of the tuft at the ground level of all perennial grasses, and for the canopy of shrubs, cacti, and trees. More particularly:
    a. Intercepts have to be recorded in tenths of feet (0.1-ft.). When the intercept of a plant is < 0.10 ft.:
        i. if several plants for that species occur in the transects, then merge plants into units of 0.10 ft. (maybe 2-3 plants sum to 0.10 ft.) to avoid overestimating the cover of that species;
        ii. if that is the only plant of that species that intercepts the tape, the intercept must be rounded up to 0.10 ft. to record the presence of that species.
    b. For perennial grasses: the intercept value refers to the base of the bunch (basal cover). The plant must NOT be recorded if its base does not intercept the tape.
    c. For trees (e.g. mesquite, palo verde), shrubs (e.g. acacia spp.), and cacti (e.g. ocotillo, prickly pear, cholla):
        i. the canopy intercept is the projection of plant, branches, and/or pads on the tape. Interspaces > 0.3 ft. between branches and pads must NOT be recorded;

ii. canopy measures do not account for separate plants, they are for all plants of a species. Therefore, if two plants of the same species overlap, then the overlap must NOT be counted twice;

iii. to determine the length of the canopy intercept in tenths of feet, it is possible to record, respectively:
   - ✓ the number of tenths, OR
   - ✓ the corresponding start and end intercept values as increments on the graduated tape (writing them into brackets). Afterward, these records will be converted to the total intercept by difference;

iv. mesquite and other large shrubs/trees must be considered as if leaves are present because these plants are deciduous during the winter and spring. Again, canopy measures are not for separate plants, they are for all plants of a species. So, if two plants of the same species overlap, then the overlap is not counted twice (**Figure 2**).

4) When all measures are completed, sum up all values recorded per species in the "Intercept Total" column of the datasheet.

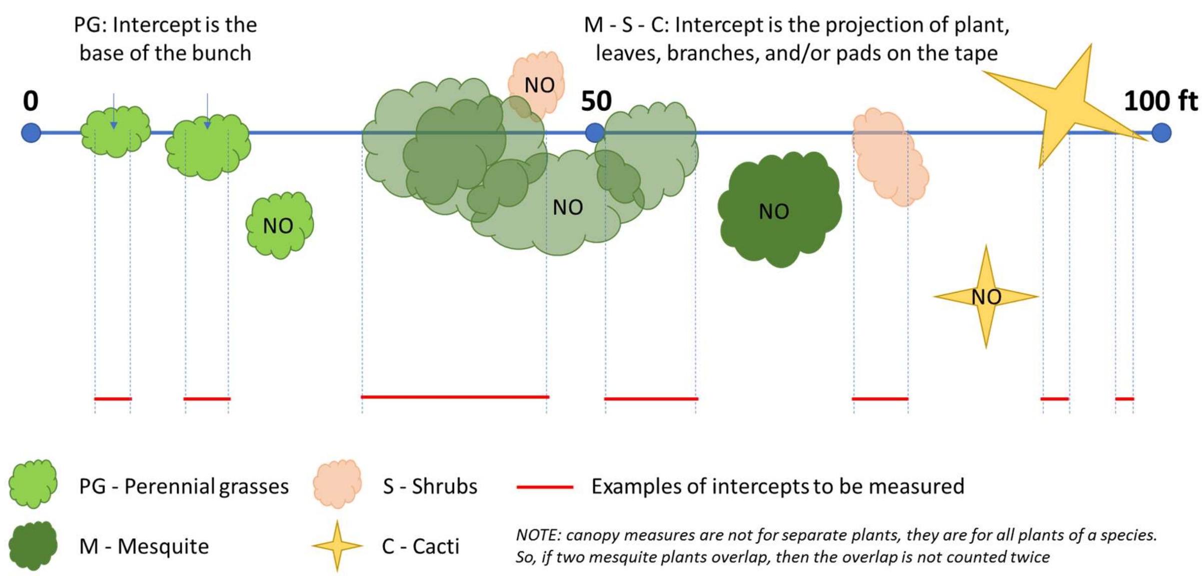

Figure 2. Example of plant cover intercept measurement.

Plant Density

Perennial plant density (grasses, shrubs, trees, and cacti) is recorded in 100x1-ft. belt transects, where the 100-ft. dimension is provided by the permanent line intercept transect location and the 1-ft. width is on the right side of the transect as viewed from the 0-ft. rebar (**Figure 3**). Therefore, density is estimated as the number of plants per 100 square ft. For each species, three values are recorded:

- the number of perennial grass or shrub plants found under mesquite canopy, recorded as "UNDER";
- the number of plants found outside mesquite canopy, recorded as "OPEN";
- the total number of plants found on the transect resulting from the sum of the "UNDER" and "OPEN" recorded plants.

The following sequence refers to the measurement of the density values for trees, shrubs, and cacti. The density of perennial grasses is calculated from the count of plants having basal diameter measurements (see “Basal Diameter of Perennial Grasses”).

Plant density measurement protocol:

1) On the plant cover datasheet, report: Pasture #, Transect #, Observers, and Date.
2) Consult the list of plant species identified on the transect three years earlier and their density values.
3) Moving from 0 to 100-ft., record on the datasheet the number of INDIVIDUAL PLANTS for SHRUBS, CACTI, and TREES growing on the 100x1-ft. belt transect on the RIGHT SIDE of the tape as viewed from 0-ft. Use the ruler to set the 1-ft. distance from the tape. Do not count plants whose base is more than 1 ft. away from the tape.
4) For each plant, indicate if it is OPEN or UNDER mesquite canopy by checking if the base of the plant is included in the intercept interval of a mesquite tree on the tape (**Figure 3**). Register the plant in the OPEN or UNDER columns of the datasheet accordingly.
5) When all measures are completed, sum up the values recorded for shrubs, cacti, and trees in the Open, Under, and Total columns of the datasheet, respectively.

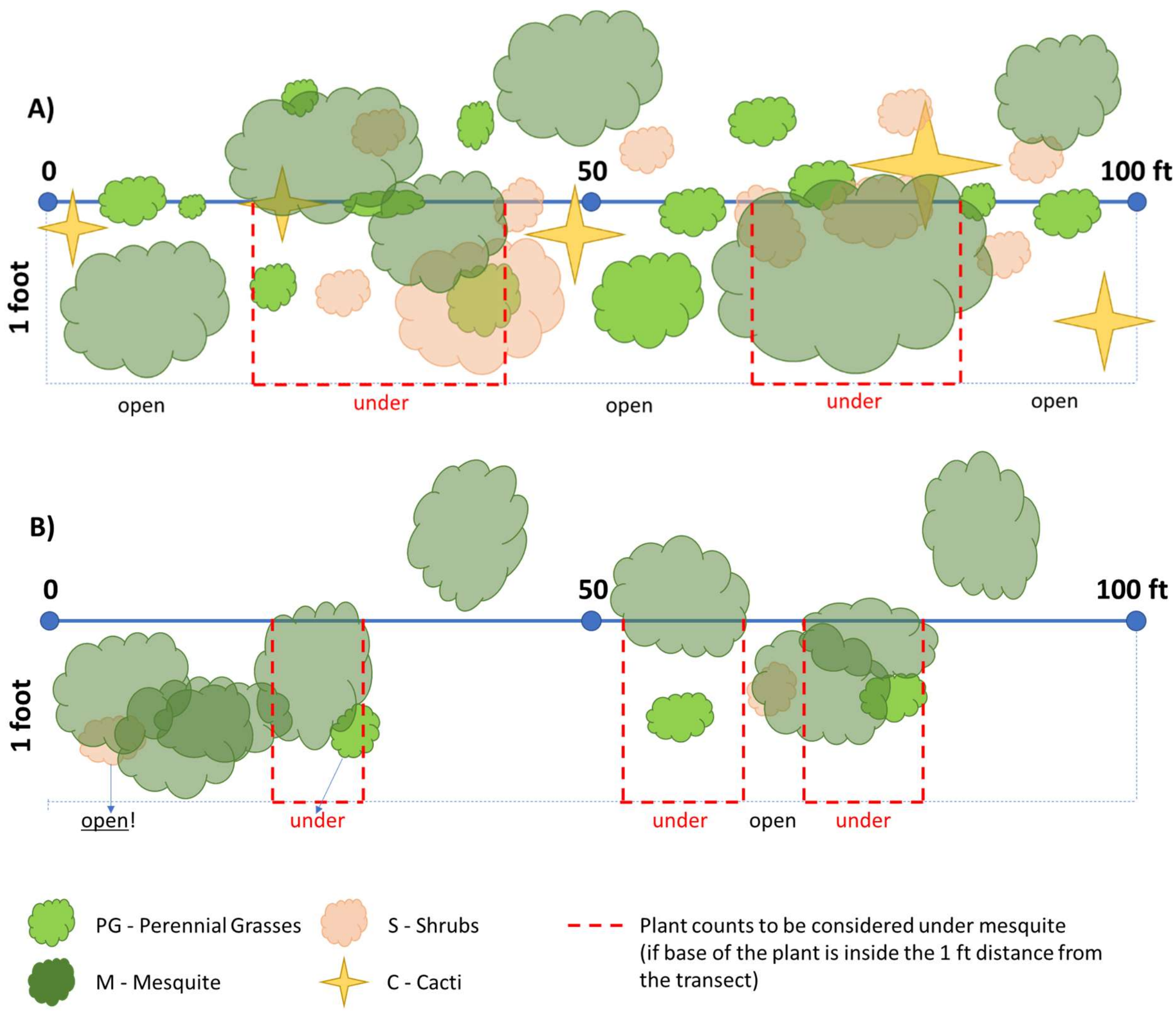

Figure 3. Examples of plant density measurement and assignation to the OPEN/UNDER mesquite canopy category.

Basal Diameter of Perennial Grasses

The basal diameter of perennial grasses is measured and recorded for all individual plants within the same 100x1-ft. belt transects of the density measurement (i.e. on a 100 square ft. area).

In all cases, measurements are made around the base of each plant as close to the soil surface as possible and recorded to the nearest tenth of a centimeter. A Diameter-Tape is used to estimate the basal diameter of individual plants that have a diameter greater than 3.5 cm. A digital caliper is used to estimate the basal diameter of individual plants that have a diameter of less than 3.5 cm. When using the digital caliper, two perpendicular readings of the basal diameter are measured and recorded. The average of those two values is recorded as the basal diameter for those individuals less than 3.5 cm in diameter. Each individual plant is then recorded as "UNDER" when found under mesquite canopy or "OPEN" when outside (see **Figure 2**).

In some cases, the number of individual plants along a transect can be too great to census in an efficient time frame. Therefore, plants are measured in areas 6-inches wide (or sometimes 4- or 3-inches wide) along the 100-ft. transect, making a 50 square foot area (or smaller). Afterward, these data are multiplied by 2 (or by 3 or 4, respectively, depending on the size of the measured transect) to represent the entire standard 100 square ft. area.

The basal diameter data are used to estimate perennial grass density, percent basal cover (this is the second measure of grass cover, the first being line intercept), and biomass.
Perennial grass density is estimated by counting all species measured within the 100 square ft. area and classified as OPEN or UNDER. Those plants are then reported in the OPEN, UNDER, and TOTAL columns of the density datasheet.
Grass biomass is estimated directly in the dataset from the basal diameter data by means of the allometric equation developed on the Santa Rita Experimental Range by Nafus et al. 2009. *Multispecies allometric models predict grass biomass in semidesert rangeland*. Rangeland Ecology and Management 62:68-72. The mass-size relationship is an exponential function. That equation is biomass (g) = e(raised to the 1.441 power) x diameter (cm)(raised to the 1.253 power). The values are expressed in grams and represent the mass produced at the end of the most recent summer growing season.

Perennial grass basal diameter measurement protocol:

1) On the plant cover datasheet, report: Pasture #, Transect #, Observers, and Date.
2) Consult the list of plant species identified on the transect three years earlier and their density values.
3) From 0 to 100-ft., for each species, measure the basal diameter of all plants included in the 100x1-ft. belt transect on the RIGHT SIDE of the transect as viewed from the 0-ft. rebar (the same belt transect used to measure plant density). For each plant:
    a. if basal diameter > 3.5 cm, use the diameter tape and register one measurement in cm;
    b. if basal diameter < 3.5 cm, use the caliper and register two orthogonal measurements in mm, with 1 mm increments. Afterward, on the datasheet, calculate the average value and convert it into cm;
    c. indicate if the plant is UNDER (U) mesquite canopy or OPEN (O) (see **Figure 2**).
4) Always record the size of the belt transect for each species, especially when plants are measured within a smaller area (e.g. 100 x 3, 4, or 6-inches). Smaller belt transect measurements must be multiplied respectively by 4, 3, or 2 to count the plant species density. This is especially important when transferring the data to the digital dataset.

5) Report on the plant density datasheet the number of Open and Under plants per species, and the Total number of plants. Remember to multiply by 2, 3, or 4 if that species was counted on a 6, 4, or 3-inches belt transect, respectively.
6) Before removing the tape from the transect, compare intercept, density, and basal diameter measurements of all perennial grasses to check for possible errors. All grass species recorded in the intercept should appear in both the density and basal diameter datasheet.

Transect Final Check and Steps

1) Before removing the tape from the transect, compare intercept, density, and basal diameter measurements with the measurements made three years earlier to compare the species composition and check for possible missing plants.
2) If not already done, take pictures from both ends of the transect (see section "Transect Set-Up").
3) Remove the tape from the 0, 50, and 100-ft. rebars and roll it up.
4) Apply white paint to all rebars, and re-paint white stripes on the witness fence post.

Background and measurement protocols for long-term vegetation transects
18 August 2021