Background and measurement protocols for cover, density, and basal diameter data associated with livestock exclosures

Background

This protocol refers to measurements for cover, density, and basal diameter in 96 permanent 1x100-ft. belt transects corresponding to 22 livestock exclosures.

Ecological site mapping within each fenced exclosure area determined the location for the permanent transects. In 2011, for each ecological site represented within an exclosure, four 100-ft. transects were established: two within the exclosure and two just outside of the exclosure on the same ecological site. Only one exclosure (1A) contained more than one ecological site distinction, for a total of 6 transects on 3 different ecological sites. Transects that were within the exclosures were labeled numerically and with the letter "U" to indicate that the vegetation along the transect had been "Ungrazed" by livestock since the exclosure was established. Transects located outside of the exclosure were labeled numerically and with the letter "G" to indicate that the vegetation along the transect had been "Grazed" by livestock. Transects for each exclosure were therefore labeled G1, G2, U1, and U2. The exclosures' names and the corresponding pastures and Ecological Sites on the Santa Rita Experimental Range are reported in **Table 1**.

Table 1: Pastures and Ecological Sites of the 22 Livestock Exclosures on the Santa Rita Experimental Range.

Exclosure	Pasture	Number of Transects	Ecological Site
1A	2S	4 (G1, G2, U1, U2)	SLU 12-16" Pz, Baboquivari Soil
1A	2S	4 (G3, G4, U3, U4)	SLU 12-16" Pz, Diaspar Soil
1A	2S	4 (G5, G6, U5, U6)	SLD 12-16" Pz, Combate Soil
2B	2N	4	SLU 12-16" Pz, Diaspar Soil
4	2N	4	SLU 12-16" Pz, Diaspar Soil
5	2N	4	SLU 12-16" Pz, Sasabe Soil
6	6E	4	SLU 12-16" Pz, Baboquivari Soil
7	Huerfano Trap (G1, G2), 6A Corral (U1, U2)	4	SLU 12-16" Pz, Diaspar Soil
8	6A	4	SLD 12-16" Pz, Combate Soil
9	4	4	LU 12-16" Pz, Eloma Soil
11	4	4	LU 12-16" Pz, Whitehouse Soil
12	5 Mid	4	SLU 10-13" Pz, Tubac Soil
13	8	4	LU 16-20" Pz Terrarose Soil
15	8	4	LU 12-16" Pz, Whitehouse Soil
19	3	4	SLD 10-13" Pz, Hayhook Soil
22	6D	4	SLD 12-16" Pz, Combate Soil
23	UA Cell D	4	SLU 12-16" Pz, Baboquivari Soil
28	UA Cell D	4	SLU 12-16" Pz, Diaspar Soil
31	1	4	SLD 16-20" Pz, Lanque Soil
35A	2S	4	SLU 12-16" Pz, Baboquivari Soil
35B	2S	4	SLU 12-16" Pz, Baboquivari Soil
40	6A	4	SLU 12-16" Pz, Diaspar Soil
41	12C	4	LU 12-16" Pz, Whitehouse Soil
42	UA Cell B (G1, G2), UA Cell A (U1, U2)	4	SLU 12-16" Pz, Diaspar Soil
	Total Number of Transects	**96**	

Since their establishment in 2011, the exclosure transects have been measured every three years in the winter-spring season, from the beginning of January to the end of April. For each livestock exclosure, perennial grass, shrubs, and cacti cover and density, and perennial grass basal diameters, have been measured on the 1x100-ft transects. In most cases, taxa have been recorded separately to the species level and sometimes to the genus level only. Afterward, measurements have been entered in three datasets available for download at https://cales.arizona.edu/srer/content/exclosure-transect-data:

- Cover data from transects repeatedly measured since 2011;
- Density data from transects repeatedly measured since 2011;
- Grass basal diameter and biomass data from transects repeatedly measured since 2011.

On the website, each dataset is provided with a "Notes" and "Layout" file detailing the measurements and the dataset structure, respectively. The following protocol lists the sequence of operations necessary to perform the measurements in each exclosure transect. For more information about data entering and datasets, see the files associated with each dataset.

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 exclosure transects + extra batteries
- Blank Cover, Density, and Basal Diameter datasheets (see **Appendices 1, 2, and 3**)
- Photocopies of the datasheets with the original Cover, Density, and Basal Diameter measurements of the transects from three years earlier
- Map with the exclosure 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 exclosures
- Replacements for stationary, tools, and instruments (e.g. extra calipers, tapes, pencils, blank datasheets, etc.)

Transect Set-Up

The GPS coordinates of each exclosure transects are available for download on the Santa Rita Experimental Range website (https://cales.arizona.edu/srer/content/utm-coordinates-and-ecological-site-designations-exclosure-transects). 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://cales.arizona.edu/srer/content/photographs-exclosure-transects-2011-viewing-and-downloading) and check the transect orientation on the original Eco-Site maps (https://cales.arizona.edu/srer/content/maps-exclosures-transect-locations-and-ecological-sites). 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 (**Appendix 2**).

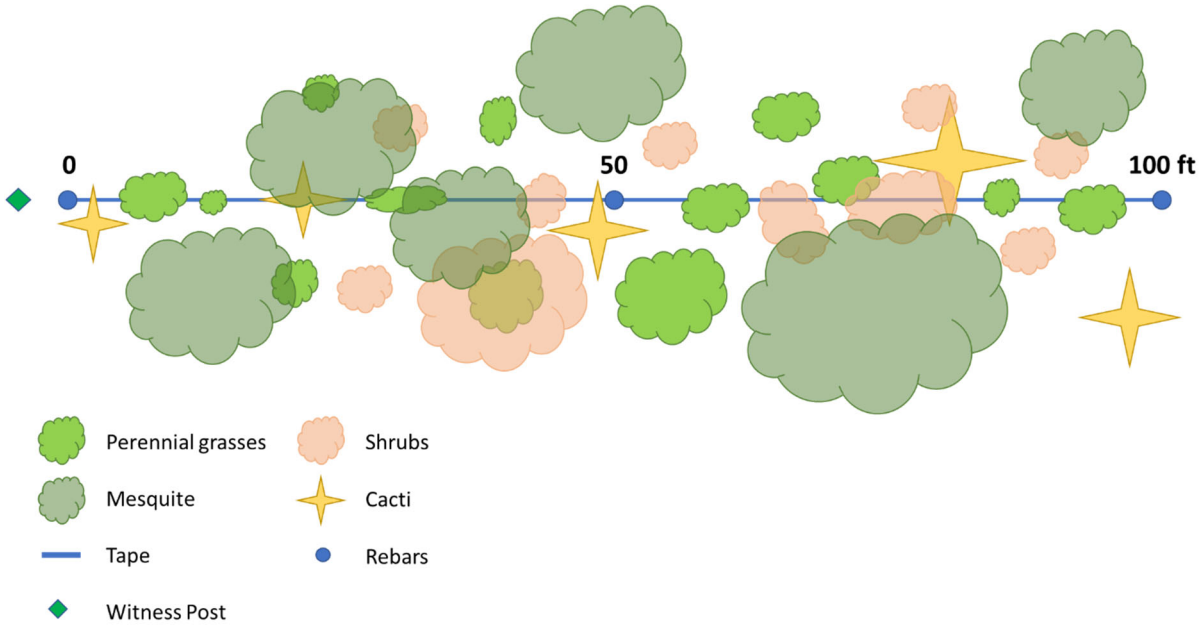

Figure 1. Example of 100-ft. permanent exclosure transect, with witness post and rebars.

Sequence of measurements for the exclosures' transects

Plant Cover (according to Canfield 1941)

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 openings 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 (**Appendix 1**), report: Pasture #, Exclosure #, Transect #, if Grazed/Ungrazed, 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., mimosa spp., burroweed), and cacti (e.g. ocotillo, prickly pear, cholla):
        i. the canopy intercept is the projection of plants, 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 (see **Appendix 1**).

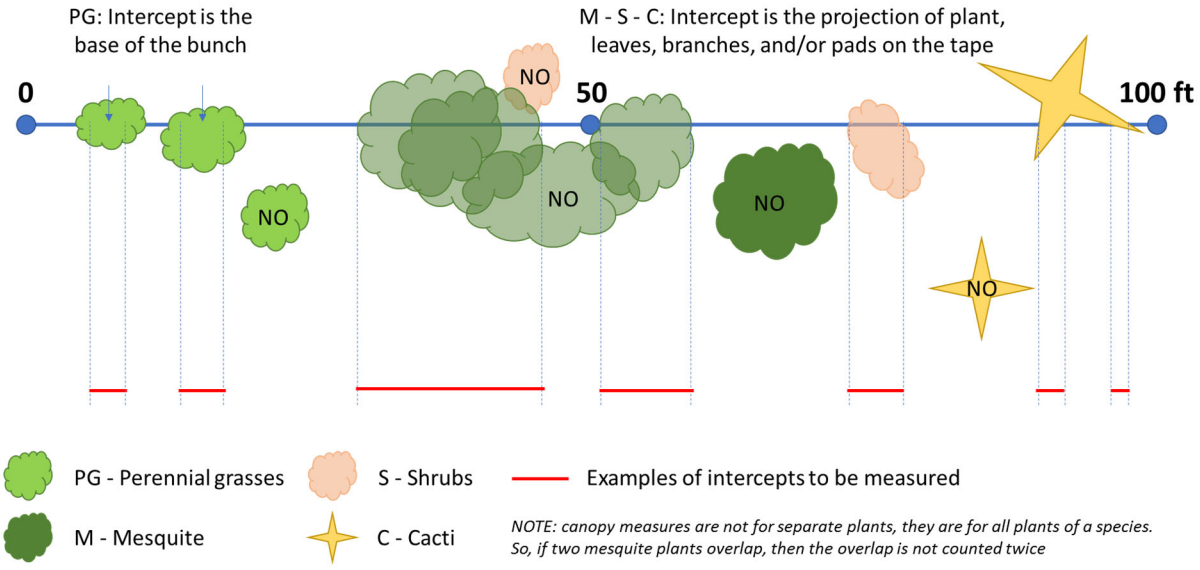

Figure 2. Example of plant cover intercept measurement.

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 density datasheet (**Appendix 2**), report: Pasture #, Exclosure #, Transect #, if Grazed/Ungrazed, 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.

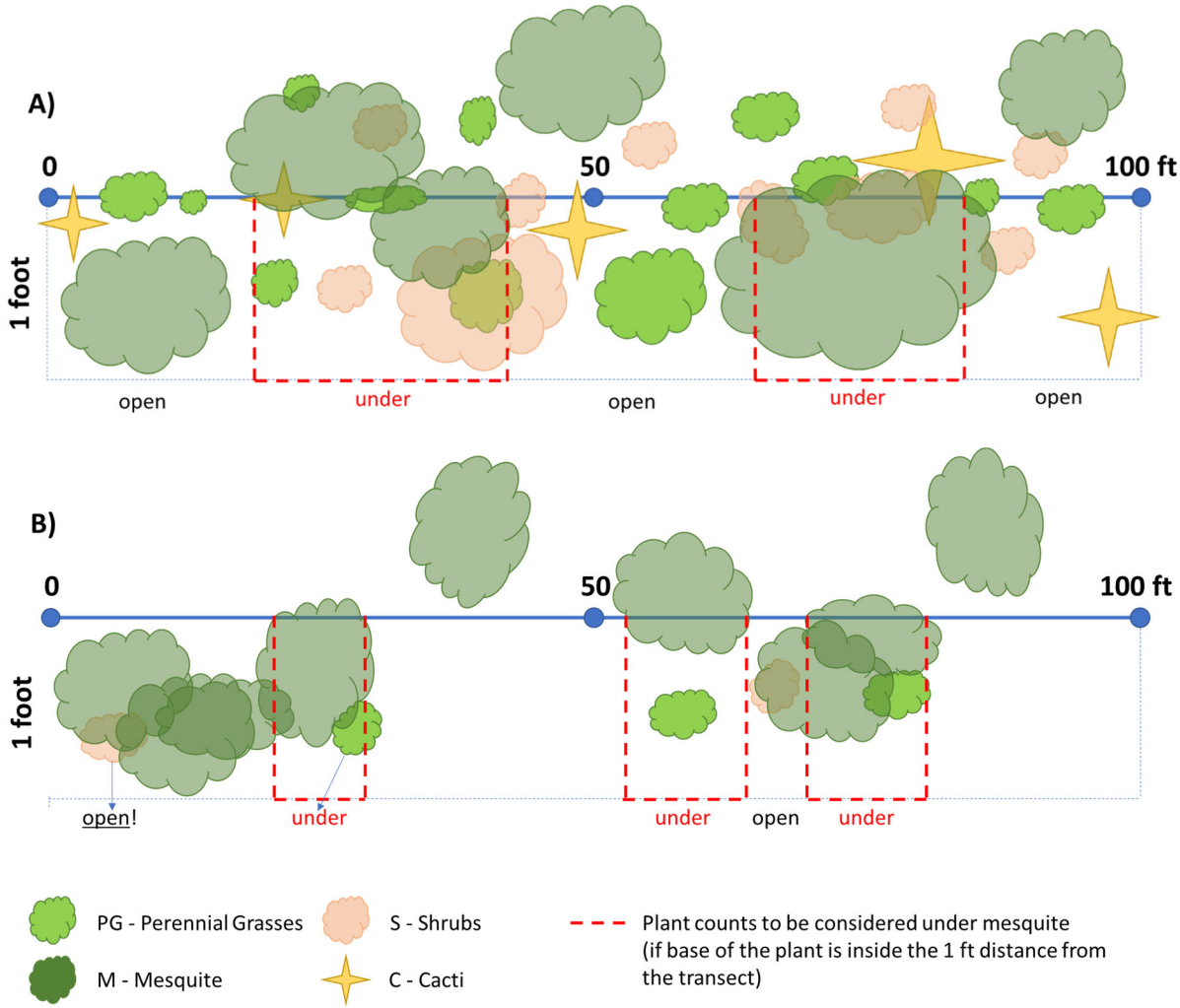

Figure 3. Examples of plant density measurement and assignation to the OPEN/UNDER mesquite canopy category.

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 a 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 (see **Appendix 2**).
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). 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 perennial grass basal diameter datasheet (**Appendix 3**), report: Pasture #, Exclosure #, Transect #, if Grazed/Ungrazed, 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 (**Appendix 2**) 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 datasheets (**Appendices 2 and 3**).

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.

References

Canfield, Roy H. 1941. Application of the Line Interception Method in Sampling Range Vegetation. Journal of Forestry, 39(4), 388–394. https://doi.org/10.1093/jof/39.4.388

Nafus, Aleta M.; McClaran, Mitchel P.; Archer, Steven R.; Throop, Heather L. 2009. Multispecies Allometric Models Predict Grass Biomass in Semidesert Rangeland. Rangeland Ecology & Management, 62(1), 68–72. https://doi.org/10.2111/08-003

Appendices

Appendix 1 - Blank Datasheet for Line Intercept (Plant Cover)

Appendix 2 - Blank Datasheet for Density (Plant Count)

Appendix 3 - Blank Datasheet for Basal Diameter of Perennial Grasses

Note for Users

Santa Rita Experimental Range website: https://cales.arizona.edu/srer/
All contents about the Exclosure Transects that are available on the SRER website through the pages linked above are accessible to public. Data users are requested to acknowledge their use of this database in publications, research proposals, websites, and other outlets by following the Instructions for Use, Citations, and Acknowledgement at https://cales.arizona.edu/srer/content/instructions-use-citations-and-acknowledgment.

Background and measurement protocols for exclosure transects
5 September 2023

SANTA RITA EXPERIMENTAL RANGE

Pasture: _____ Line Intercept (Plant Cover) Date: _____

Exclosure: _____ Observer: _____

Transect: _____ Grazed: _____

Intercept Total	Grass Species	Intercept of Individual Plants (tenths of feet)
	Anba (Boba)	
	ARIS	
	Boch	
	Bocu	
	Boer	
	Bofi	
	Bohi	
	Boro	
	Erin 1	
	Erle	
	Heco 1	
	Hibe	
	Leco	
	Ledu	
	Lyph	
	Mupo	
	Sema	
	Spor	
	Trca 1 (Dica)	
Intercept Total	Shrubs	Intercept of Individual Plants (tenths of feet)
	Apte (Hate)	
	Acgr	
	Babr	
	Caer	
	Cepa	
	Erwr	
	Fosp	
	Krpa	
	Mibi	
	Open	
	Opfu	
	Opsp	
	Prjuv	
	Zipy	

SANTA RITA EXPERIMENTAL RANGE
Density (Plant Count)

Pasture: _____ Date: _____
Exclosure: _____ Observer: _____
Transect: _____ Grazed: _____

UTM X: _____ Y: _____ Photo numbers from 0: _____ 100: _____

Total # /100 sq. ft.			Perennial Grasses	Number of Individual Plants	
Open	Under	Total		Open	Under
			Anba (Boba)		
			ARIS		
			Boch		
			Bocu		
			Boer		
			Bofi		
			Bohi		
			Boro		
			Erin 1		
			Erle		
			Heco 1		
			Hibe		
			Leco		
			Ledu		
			Lyph		
			Mupo		
			Sema		
			Trca 1 (Dica)		

Total # /100 sq. ft.			Shrubs	Number of Individual Plants	
Open	Under	Total		Open	Under
			Apte (Hate)		
			Acgr		
			Babr		
			Caer		
			Cepa		
			Erwr		
			Fosp		
			Krpa		
			Mibi 3		
			Open		
			Opfu		
			Opsp		
			Prjuv		
			Zipu		

SANTA RITA EXPERIMENTAL RANGE
Basal Diameter of Perennial Grasses

Pasture: _____ Date: _____
Exclosure: _____ Observer: _____
Transect: _____ Grazed: _____ Page: _____ of _____

If A_{basal} > 3.5 cm use diameter tape (cm). If A_{basal} < 3.5 cm use caliper (mm) and take two orthogonal measurements. Increments 0.1cm. U = under mesquite canopy; O = open.				1.2 U 1.0 1.1	
Species	Basal Diameter				