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Defoliation of *Flourensia cernua* (tarbush) with high-density mixed-species stocking

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Interest in shrub use by livestock is increasing along with the rising demands placed on rangelands worldwide. Historically, *Flourensia cernua* (tarbush) has increased in the Chihuahuan Desert but receives limited use by cattle. Cattle, sheep and goats co-grazed eight 0.6 ha tarbush-dominated paddocks during two periods for up to nine days during two consecutive years. Cumulative tarbush defoliation across periods and years averaged 75.6%, with a mean increase of 9.3%/day ($P < 0.0001$). Defoliation of individual shrubs varied from 5 to 99% in 1989 and 0–100% in 1990, indicating highly variable palatability among individual plants. Sheep lost 2.3–5.5 kg/hd ($P < 0.0001$) across periods and years when forced to browse tarbush. In 1989, goats gained ($P = 0.0345$) 0.6 kg/hd in period 1, but the gain in period 2 was not significant ($P = 0.2934$). During 1990, goats lost 3.1 kg/hd ($P = 0.0001$) across periods. High-density mixed-species stocking of small areas for short time periods resulted in extensive tarbush use, primarily due to browsing by sheep and goats. Targeted use of tarbush for short time intervals may increase use of this highly nutritious forage and potentially serve as a form of biocontrol for this shrub.

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1. Introduction

Multiple demands currently placed on rangelands globally have led to increased interest in the use of shrubs by livestock as a source of nutrients (Estell et al., 2012). Tarbush (*Flourensia cernua* DC.) is currently underutilized on rangelands in the Chihuahuan Desert stocked only with cattle. This shrub is the principal shrub species on the fertile clay loam soils of approximately 35 million ha of the Chihuahuan Desert (Schmidt, 1979). Tarbush occurs on about 21% (>6.75 million ha) of the southern and south-central portions of New Mexico; however, it is also found in Arizona, Texas and northern Mexico (O'Laughlin, 1975). Jornada Experimental Range (JER) historical records indicate essentially no dense tarbush stands in 1858; however, by 1963, over 9% of the 78,266 ha JER contained dense tarbush stands (Buffington and Herbel, 1965). Tarbush sites normally have a high inherent productive potential because soils are fertile and often receive additional run-on water (Paulsen and Ares, 1962); consequently, tarbush has been considered an undesirable encroaching shrub to be controlled by mechanical or chemical means (Herbel and Gould, 1980).

Although cattle (Nelson et al., 1970; Anderson and Holechek, 1983) and goats (Laribi et al., 1988; Mellado et al., 1991) have been documented to browse tarbush on native rangeland, it is usually not consumed in significant quantities even though its nutrient content approximates alfalfa (Estell et al., 1996). In a three year study of the nutritional profile of tarbush during the growing season, the crude protein content ranged from 16.4 to 24.7% (dry matter basis) and *in vitro* dry matter digestibility ranged from approximately 60 to 67% of the dry matter. Fiber concentrations ranged from about 19 to 22% (NDF) and 14–18% (ADF), while lignin (ADL) content ranged from approximately 5 to 7% of the dry matter. Condensed tannin concentration ranged from 0.3 to 0.4%, while total phenolics ranged from approximately 6 to 8% of the dry matter across the growing season (Estell et al., 1996). The total volatile concentration of tarbush was about 3.6% (dry matter basis; Fredrickson et al., 2007). Tarbush leaves in the pre-bloom state have the potential to supply crude protein to foraging livestock if animals can maintain adequate dry matter intake (King et al., 1996b).

Secondary compounds on the leaf surface of this resinous shrub may be responsible for differences in palatability observed among individual tarbush (Estell et al., 1994b, 1998, 2001). When chemical extracts from tarbush leaves were applied to alfalfa pellets, consumption of pellets by sheep decreased (Estell et al., 2001). Furthermore, sheep that have experienced negative feedback from

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tarbush ingestion may subsequently exhibit lower intake of tarbush under free-ranging conditions (Fredrickson et al., 2000). Though tarbush has been fed safely to sheep at up to 30% of the diet for four weeks (King et al., 1996a) and up to 90 days at 15% of the diet, lambs fed a 15% tarbush diet from birth through 120 days of age exhibited apoptotic liver damage and possible muscle damage (Fredrickson et al., 1994).

Tarbush intake is highly variable among individual animals (King et al., 1996a); thus, some animals within a species may consume significant amounts without being forced. However, because livestock species differ in preference for plant species and small ruminants are typically better browsers than cattle, mixed-species stocking may be a viable option to increase shrub utilization on arid rangeland landscapes compared to cattle alone (Anderson et al., 2010). The objective of this research was to determine if cattle, sheep and goats managed together under relatively high-density stocking for short intervals would defoliate tarbush without negative consequences on livestock production.

2. Materials and methods

2.1. Study area and vegetation

Eight 0.6 ha paddocks containing dense tarbush stands at two sites (four paddocks per site) separated by approximately 1.6 km on the JER (Dona Ana County, New Mexico, USA, 32.52,251 latitude; −106.74,693 longitude and 32.54,681 latitude; −106.72,423 longitude for sites 1 and 2, respectively) were used. Paddocks were stocked with cattle, sheep, and goats in 1989 and 1990. Long-term mean annual precipitation for the area is 237 mm. Study dates were as follows: 29 August to 7 September (1989, Period 1), 12 September to 21 September (1989, Period 2), 20 August to 29 August (1990, Period 1), and 4 September to 11 September (1990, Period 2). Period length was 7–9 days, depending on forage availability. After each period, livestock were moved to an adjacent 16.2 ha paddock with abundant herbaceous forage for 4 days.

Shrub canopy cover and species composition were estimated in each paddock from 10 randomly located, permanently marked, 30-m line transects each year. Shrub height and canopy diameter at ground level were measured on each transect prior to animal introduction and immediately following livestock removal from paddocks. Height and canopy diameter of two additional randomly selected tarbush were measured in each paddock each year and then harvested prior to animal introduction. Harvested shrubs were transported to the laboratory, air-dried, and manually separated into five categories: leaves, flowers, current year's twigs, live stems and dead stems. Current-year twigs and older stems were separated based on color (older stems were darker). After separation, each component was dried at 60 °C. Mean biomass (kg) of each component was determined and standing biomass (kg/ha) was calculated from the ratio of biomass and canopy cover of harvested tarbush plants (n = 16 tarbush per year) and the canopy cover estimates for each paddock (Table 1). Also, use of 10 randomly selected tarbush plants (identified with metal tags at ground level) was monitored daily in each paddock both years (same plants each year). Disappearance of the current year's growth (leaves and small twigs) was visually estimated each morning beginning 24 h after livestock exposure.

2.2. Livestock

This experiment was conducted before Animal Care and Use protocols were required. Each year, four randomly selected paddocks were stocked per period (Table 2). Each of the four livestock groups contained mature crossbred cows (≥4 years of age; n = 8), white-faced sheep (6–48 months of age; n = 20 and 23 in year 1 and 2, respectively), Spanish goats (8–20 months of age; n = 17 and 14 in year 1 and 2, respectively), and Angora goats (8–32 months of age; n = 2). In 1990, six cows had a nursing calf at their side. Groups remained intact for both periods each year, and were reconstructed with different animals in year 2. Groups were randomly assigned to the eight paddocks each year (Table 2). All animals had access to fresh water at all times and had been previously exposed to tarbush. Physiological stage of cattle varied slightly between years (late gestation vs. late gestation/early lactation in year 1 and 2, respectively), while small ruminants were in similar physiological stages both years (sheep were in last trimester of gestation and goats were castrated males and barren females).

The decision was made *a priori* to maintain constant livestock numbers and vary number of days in a paddock based on visual appraisal of available herbaceous vegetation, animal health, and tarbush foliage disappearance. Consequently, the number of days paddocks were stocked ranged from 5 to 9 days across years (Table 2). All livestock were removed from a paddock when tarbush defoliation within a paddock was ≥80%. A species was removed if one or more animals appeared lethargic or refused to eat tarbush after herbaceous material was removed.

Sheep and Spanish goats were weighed in the morning on a portable scale before entering paddocks (initial), upon removal from paddocks (final), and after four days in a larger adjacent paddock (a 16.2 ha paddock located next to treatment paddocks at each site). These large paddocks contained abundant grasses, forbs, and browse (including tarbush). The weight after four days in the large pasture following period 1 served as the initial weight for period 2 (Table 3). Cattle generally refused to eat tarbush and therefore were not weighed. Angora goats were not weighed due to limited sample size; thus, all references to goats hereafter refer to Spanish goats.

Livestock time budgets were assessed with a modified bite-count procedure (Bjugstad et al., 1970). Activity of individual animals was observed on day 3 in period 1 (1989) and on days 1, 3, and 7 in the latter three periods. Eighteen randomly selected animals (6 of each species, excluding Angora goats) in each paddock were observed at 1 min intervals for 16 consecutive minutes by trained observers to determine foraging activity during the morning foraging bout, beginning at 0630 h.

2.3. Statistical analyses

Mean daily tarbush defoliation of the 10 individual plants monitored each day was calculated for the level of experimental unit (paddock). A repeated measures linear mixed effects model (PROC MIXED; SAS V9.4; SAS Institute, Cary, NC) was then used to model effects of day, year and their interaction on paddock tarbush defoliation. Day was implemented as a repeated effect with paddock nested within year as the subject, using a heterogeneous first-order autoregressive temporal covariance matrix (determined by the minimum small-sample Akaike Information Criterion [AIC_c]). The model included a random paddock x period effect nested within year. The Kenward-Roger method was used to adjust denominator degrees of freedom. Goat and sheep weights were analyzed by year as a completely randomized design with data arranged as a split plot in time. For fixed effects with significant overall F tests ($P < 0.05$), means were separated using LSD.

Table 1
Mean *Flourensia cernua* standing biomass (kg/ha ± SD) from two randomly selected plants harvested from each of eight paddocks in August and September 1989 and 1990.

Year and Paddock	Standing biomass (kg/ha)							
	Live tissue						Dead stem	Entire plant
	Leaves (L)	Flowers (F)	Twigs (T)	L + F + T	Stems (S)	L + F + T + S		
1989								
A	186	53	64	303	1069	1372	390	1762
B	205	58	71	334	1180	1514	430	1945
C	285	81	99	465	1812	2315	661	2977
D	315	79	96	490	1602	2092	584	2677
E	224	63	77	364	1286	1650	469	2119
F	315	89	109	513	1812	2315	661	2977
G	156	44	54	253	895	1149	327	1476
H	246	70	85	400	1412	1812	515	2327
Mean ± SD	242 ± 59.5	67 ± 15.4	82 ± 18.8	390 ± 93.4	1384 ± 339.0	1777 ± 434.7	505 ± 123.5	2283 ± 558.6
Percent	10.6	2.9	3.6	17.1	60.6	77.8	22.1	99.9
1990								
A	135	0	18	153	1088	1242	399	1641
B	160	0	22	181	1286	1467	471	1938
C	166	0	22	189	1337	1526	490	2016
D	163	0	22	185	1315	1501	482	1983
E	181	0	24	205	1454	1659	533	2192
F	223	0	30	253	1797	2051	659	2710
G	97	0	13	110	781	892	286	1178
H	203	0	27	231	1636	1867	600	2467
Mean ± SD	166 ± 38.9	0	22 ± 5.2	188 ± 44.3	1337 ± 313.7	1526 ± 357.8	490 ± 115.2	2016 ± 473.0
Percent	8.2	0	1.1	9.3	66.3	75.7	24.3	100

Table 2
Number of days animals remained in paddocks (A-H) in 1989 and 1990. Paddock subscripts indicate randomized location of groups.

Year and livestock[a]	Dates the eight paddocks (A-H) were stocked							
	Period 1 - (29 August to 7 September)				Period 2 - (12–21 September)			
	A_1	B_2	C_3	D_4	E_3	F_1	G_4	H_2
1989								
Cows	8	8	6	6	6	6	4	4
Sheep	9	9	9	9	9	9	8	8
Goats	9	9	9	9	9	9	8	8
	Period 1 - (20–29 August)				Period 2 - (4–11 September)			
	B_1	C_3	D_4	H_2	A_2	E_4	F_3	G_1
1990								
Cows	4	3	3	3	3	3	3	3
Sheep	8	9	9	9	7	7	7	5
Goats	8	9	9	9	7	7	7	5

[a] Individual animals in livestock groups differed between years.

3. Results

3.1. Vegetation

Shrubs represented a large percentage of the vegetation in each paddock before stocking, ranging from 47.6 to 87.8% across years, with tarbush comprising 30.8–87.0% of the shrub component (Table 4). Tarbush canopy cover prior to stocking ranged from approximately 11 to 23% and 7–16% in 1989 and 1990, respectively (Table 5). Mean tarbush standing biomass in 1989 and 1990 was 390 and 188 kg/ha, respectively (Table 1). Mean standing biomass of tarbush components was approximately 11 and 8% leaves, 3 and 0% flowers, 4 and 1% twigs, and 61 and 66% live stems in 1989 and 1990, respectively (Table 1).

Mean percent canopy cover of tarbush was reduced 34% and 30% in 1989 and 1990, respectively, with large variations among paddocks (Table 5). Across periods and years, livestock removed 75.6%

Table 3
Least squares mean weights (±SD) for sheep and goats in 0.6 ha *Flourensia cernua* (tarbush) infested paddocks (Initial), after removal from paddocks (Final) and after four days in a larger paddock, 1989 and 1990.

Year, period and livestock	Body weight (kg/hd)			*P* Value
	Initial	Final	Large Paddock	
1989				
Period 1				
Goats	23.5 ± 0.2 ^{a}	24.1 ± 0.2 ^{b}	24.7 ± 0.2 ^{c}	0.0001
Sheep	51.4 ± 0.2 ^{a}	48.4 ± 0.2 ^{b}	51.0 ± 0.2 ^{a}	0.0001
Period 2				
Goats	24.7 ± 0.2 ^{a}	25.0 ± 0.2 ^{ab}	25.4 ± 0.2 ^{b}	0.049
Sheep	51.0 ± 0.1 ^{a}	48.7 ± 0.2 ^{b}	25.1 ± 0.2 ^{a}	0.0001
1990				
Period 1				
Goats	40.3 ± 0.1 ^{a}	37.2 ± 0.1 ^{b}	40.3 ± 0.1 ^{a}	0.0001
Sheep	62.5 ± 0.2 ^{a}	57.0 ± 0.2 ^{b}	61.3 ± 0.2 ^{c}	0.0001
Period 2				
Goats	40.3 ± 0.1 ^{a}	37.2 ± 0.1 ^{b}	40.3 ± 0.1 ^{a}	0.0001
Sheep	61.3 ± 0.1 ^{a}	56.9 ± 0.1 ^{b}	61.6 ± 0.1 ^{a}	0.0001

^{a,b,c}Means in the same row with the same superscript are not different ($P > 0.05$).

Table 4
Mean percentage (±SD) of shrubs and *Flourensia cernua* (tarbush) in each of eight 0.6 ha paddocks prior to stocking, August 1989 and 1990.

Paddock	Composition (%)			
	Shrubs		Tarbush[a]	
	1989	1990	1989	1990
A	50.7	59.8	34.2	42.3
B	47.6	51.7	30.8	37.7
C	71.0	72.9	68.8	72.6
D	61.5	58.9	54.5	54.2
E	58.5	62.7	37.3	43.7
F	65.8	81.8	49.6	63.3
G	76.0	79.5	72.6	78.1
H	79.4	87.8	77.2	87.0
Mean ± SD	63.8 ± 11.44	69.4 ± 12.91	53.1 ± 18.22	59.9 ± 18.27

[a] Percent of shrub component.

(±4.2 SEM) of tarbush foliage (Fig. 1). No year effect ($P = 0.3186$) or day × year interaction ($P = 0.1526$) was detected. However, a day main effect was observed ($P < 0.0001$) and mean comparisons indicated each day was significantly different from other days with an increasing linear trend over time (Fig. 1). The model-based estimate of this linear increase was 9.3% (±0.5 SEM) tarbush defoliation per day.

3.2. Livestock

In 1989, cattle were removed first from paddocks after herbaceous material had been depleted because they refused to eat tarbush. In contrast, sheep and goats remained for the entire nine days in 6 of 8 paddocks (removed on day 8 in paddocks G and H). In 1990, again cows were removed first, with sheep and goats remaining in paddocks for five to nine days (Table 2).

Spot evaluations of livestock activities revealed sheep and goats consistently browsed more tarbush than cows. Overall, sheep (58 and 25% in 1989 and 1990, respectively) and goats (55 and 35% in 1989 and 1990, respectively) spent about equal time defoliating tarbush. In the large paddocks, goats browsed tarbush about twice as frequently as sheep even though tarbush browsing accounted for <15% of total activities of either species (behavior in large paddocks was only monitored after period 2 in 1989). Goats also spent more time browsing tarbush in large paddocks than sheep after both periods in 1990.

3.3. Animal weight

Both goat and sheep weights varied between two or more weigh dates in all four periods (Table 3). Sheep and goats lost weight (2.3–5.5 kg/hd) ($P < 0.05$) in the small paddocks both years, with two exceptions. In 1989, goats gained 0.6 kg/hd ($P < 0.05$) while

Table 5
Mean (±SD) *Flourensia cernua* (tarbush) canopy cover before and after stocking eight 0.6 ha paddocks with cattle, sheep and goats in August and September in 1989 and 1990.

	Canopy cover (%)					
	1989			1990		
Paddock	Before	After	Reduction	Before	After	Reduction
A	13.5	8.0	40.7	9.9	7.4	25.2
B	14.9	10.1	32.2	11.7	7.2	38.5
C	20.7	10.5	49.3	12.2	7.9	35.3
D	20.3	10.5	48.3	12.0	9.1	24.2
E	16.3	12.3	24.5	13.3	10.3	22.6
F	22.9	17.6	23.1	16.4	12.1	26.2
G	11.3	7.4	34.5	7.1	4.9	31.0
H	17.9	14.7	17.9	14.9	9.3	37.6
Mean ± SD	17.2 ± 3.95	11.4 ± 3.40	33.8 ± 11.68	12.2 ± 2.87	8.5 ± 2.18	30.1 ± 6.38

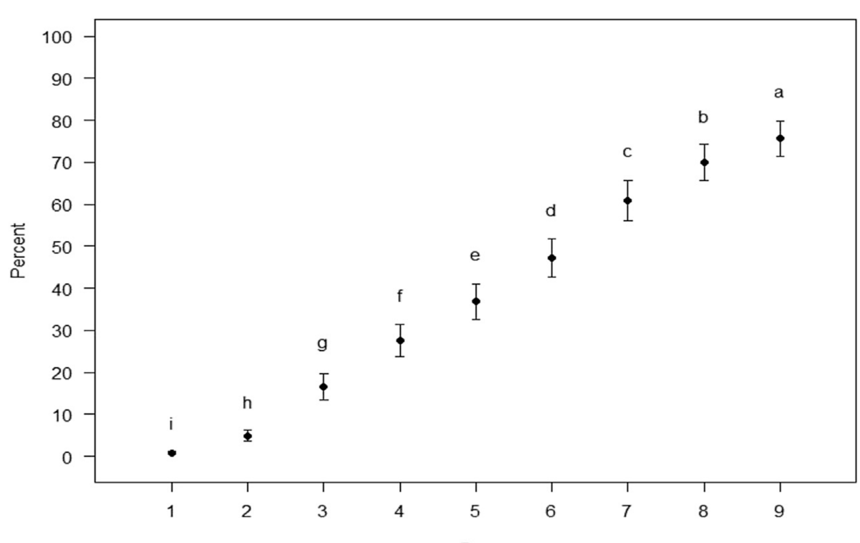

Fig. 1. Model-based least squares means of visually estimated cumulative *Flourensia cernua* defoliation (%) by day pooled across year and period. Means with the same letters are not different ($P < 0.05$). The same 10 shrubs in each of the eight 0.6 ha paddocks were observed both years.

confined to small paddocks during period 1, and their weight did not change while in the small paddocks in period 2 ($P > 0.05$).

Mean weights for both sheep and goats increased (0.6–4.7 kg/hd) between final and large paddock weighing (Table 3). Weight after four days in the large paddock exceeded ($P < 0.05$) initial weight for goats during both periods in 1989. Goats during period 1 of the first year were the only animals that gained weight ($P < 0.05$) on all three weigh dates (Table 3). Weight of goats after four days in the large paddock following period 2 of 1989 was not different than final weight ($P > 0.05$) but greater ($P < 0.05$) than initial weight (0.7 kg/hd). Mean weight of goats after four days in the large paddock did not differ from initial weight ($P > 0.05$) in either period in 1990. Weight of sheep after four days in the large paddock was less than initial weight (1.2 kg/hd) in period 1, 1990 ($P < 0.05$) and not different from initial weight in the other three periods.

4. Discussion

Domestic livestock, principally sheep and goats, managed together under high-density stocking defoliated 60–80% of the vegetative tarbush in 0.6 ha paddocks in ≤9 d without large reductions in livestock productivity (Fig. 1). Animal weight gains varied among species, period and year. Some of the difference between years may be due to different animal groups used to impose the treatments (i.e., different weights, ages, and physiological states). However, short-term weight changes must be viewed with caution. More importantly, no year effect was observed in rate or extent of tarbush defoliation with the two different animal groups.

Across both periods and years, sheep and goats spent about equal time browsing tarbush, while cattle typically refused to browse tarbush. Cattle were responsible for early and rapid removal of the herbaceous component of the standing crop. These observations are not surprising given the well documented propensity for small ruminants to browse compared to cattle (Estell, 2010). When animals were moved to larger paddocks, tarbush was not actively sought by livestock. Thus, under the constraints of this study, it does not appear that animals were conditioned to consume tarbush.

Typically, when livestock are confined to areas that contain tarbush, foraging (especially by cattle) on the herbaceous component is high until little remains except tarbush. However, in this study, some tarbush plants were browsed during the first two days before herbaceous material was depleted (Fig. 1). Thus, even during the early portion of the periods when herbaceous material was still present in the paddocks, tarbush was browsed by mixed livestock groups.

Tarbush plants were not browsed uniformly in either year in any paddock, with individual plant use ranging from 5 to 99% in 1989 and 0–100% in 1990. Although the variability in use among individual plants may have been due to palatability differences based on concentrations of secondary chemicals, chemical effects were not examined in this study. Subsequent research by the authors revealed surface compounds associated with tarbush leaves are related to differential use among plants (Estell et al., 1994a,b; 1998). Additional research will be required to completely elucidate the factors responsible for different use patterns among plants (e.g., concentrations of other classes of secondary compounds and interactions between nutrients and secondary compounds).

As traditional forage bases dwindle and producers are forced to find alternative forage sources, opportunities to alter management and capitalize on plant and animal traits must be identified to exploit shrubby landscapes (Estell et al., 2012). Increasing shrub use involves capitalizing on animal behavior and physiology as well as management strategies such as targeted grazing and appropriate timing of use (Estell, 2010). Identification of animal and plant characteristics related to tarbush consumption may allow their manipulation to enhance utilization of browse. Variation among animals within a species may be as important as variation among plants and animal species in terms of use. Animal traits might be exploited by identifying individuals and/or species with a propensity to browse tarbush or by genetically selecting for offspring more adept at browsing shrubs. Plant characteristics might be identified that provide opportunities to browse tarbush when nutrient concentrations are greatest and/or secondary compounds are lowest.

This study revealed that for short time periods, high-density mixed-species stocking resulted in heavy defoliation of tarbush, primarily by sheep and goats. The high concentration of crude protein and other nutrients in tarbush (Estell et al., 1996) suggests overall availability of nutrients might be increased by foraging systems that increase tarbush in the diet. Continued defoliation during subsequent years would be required to determine the effect of sequential defoliation on tarbush canopy cover and survival. However, high density targeted browsing of tarbush for short time periods by small ruminants holds promise as a mechanism for control and use of this nutrient-dense, poorly utilized shrub.

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