Old School and High Tech: A Comparison of Methods to Quantify Ashe Juniper Biomass as Fuel or Forage

Article *in* Rangelands · June 2019

DOI: 10.1016/j.rala.2019.06.001

7 authors, including:

Doug Tolleson
Texas A&M University

Edward C. Rhodes
Texas A&M University

Lonesome Malambo
Texas A&M University

Jay Angerer
Agricultural Research Service

Old School and High Tech: A Comparison of Methods to Quantify Ashe Juniper Biomass as Fuel or Forage

By **Douglas R. Tolleson, Edward C. Rhodes, Lonesome Malambo, Jay P. Angerer, Reid R. Redden, Morgan L. Treadwell,** and **Sorin C. Popescu**

On the Ground

- Ashe juniper invasion is a widespread issue on Texas and Oklahoma rangelands. Increased densities of Ashe juniper trees increase the risk of wildfire and decrease herbaceous forage production.
- Browsing animals, such as goats, are one tool that can be used to effectively reduce juniper fuel.
- In order to estimate the available biomass, allometric measurements were compared against three-dimensional Light Detection and Ranging (LiDAR) scans of whole juniper plants.
- Accurate measurements of standing juniper browse and fuel load can be vital information for decision support of grazing management and wildland fire mitigation, especially in the ever-growing wildland-urban interface.

Keywords: goats, juniper, LiDAR, targeted grazing, browse, wildland-urban interface, fuel load.

Rangelands xx(x):1–2
doi 10.1016/j.rala.2019.06.001

"*What is a weed? A plant whose virtues have not yet been discovered.*" For some in the natural resource profession, this quote attributed to Ralph Waldo Emerson epitomizes the discussion concerning junipers. Perhaps this is nowhere more true than in the Edwards Plateau or "Hill Country" of central Texas, where ecology and sociology have interacted to create an interesting dichotomy of perceptions toward junipers. In particular, Ashe juniper (*Juniperus ashei*) has stimulated both a lively and long-lived debate. Should Ashe juniper be conserved or controlled? If conserved, for what benefits? And if controlled, by what methods?

On one side, proponents tout the beneficial qualities of the species.[1] Mature Ashe juniper trees provide nesting sites and material for an endangered migratory songbird, the golden-cheeked warbler (*Setophaga chrysoparia*), and are also a larval host and nectar source for the juniper hairstreak butterfly (*Callophrys gryneus*). In addition, juniper berries are consumed by many avian and mammalian wildlife species. Ashe juniper often serves as a nurse tree for other rare and less hardy tree species such as Texas madrone (*Arbutus xalapensis*). Urban sprawl has resulted in many homes built among the junipers in the Hill Country region west of the large metropolitan areas, Austin and San Antonio. These exurban homeowners often praise the evergreen juniper for providing an attractive natural privacy fence. Ashe juniper is a native plant and is thus considered to be part of the rural lifestyle there. Although acknowledging some of the positive aspects, those on the other side of the juniper issue highlight its negative aspects.[2] Most citizens would likely list the allergenic properties of "mountain cedar" as its' primary negative characteristic. Reduction in forage available to livestock or ungulate wildlife would be the largest drawback for ranchers. There is also much discussion over the impact Ashe juniper has on water resources.[3–5] Love them or hate them, no plant is entirely beneficial or detrimental, and learning more about them will increase our understanding. Increased understanding should lead to better management.

Historic accounts, photographs, and available data indicate that much of the Edwards Plateau was grassland with mottes of interspersed trees[6] in earlier times. These authors note that there were, however, also areas of dense juniper growth largely determined by soils and topography. Much of the Edwards Plateau is now classified as woodland[7] or savanna-woodland.[8] Post-settlement reduction in fire and improper grazing practices are often cited as reasons for the dramatic expansion of juniper in Texas. Aldo Leopold (1933) wrote in his classic book on game management that, "Game can be restored by the creative use of the same tools which have heretofore destroyed it; the axe, plow, cow, fire and gun."[9] Texas researchers have long sought ways to incorporate these tools into the management of Ashe juniper.

Grazing management, the "cow" mentioned by Leopold, in this part of the world often refers to using domestic goats (*Capra hircus*) as the tool. Goats are classified as browsers and can consume up to approximately 30% of juniper in their diet on rangelands.[10] Paired with prescribed fire, they can be effective in managing juniper.[11] The critical piece of information in any grazing management practice is stocking rate.[12] We use the term here as the number of animals placed on an entire management unit for a length of time. Proper stocking rate results from a balance between forage supply and demand to meet management objectives. Intelligent application of stocking rate will not only help determine the success of a grazing management system, but will also affect fuels management for prescribed fire. Thus, to effectively use grazing and fire together, quantitative monitoring of forage and fuel is imperative.

Because there is a need to inform fire and grazing management decisions with useable science, we wanted to quantify the amount of dry matter biomass in Ashe juniper for the purposes of having a data-based estimate of stocking rate for goats and to use in wildfire fuel and behavior models. Quantifying forage for browsers is more difficult than for grazers owing to both animal selectivity and the vertical distribution of forage. Quantifying vertically distributed woody plant fuel is also more difficult than quantifying horizontally distributed herbaceous or fine fuels. Tools to help fire and grazing managers making these decisions will facilitate better rangeland planning. Other scientists have used allometric measurements to accomplish biomass estimates in juniper species.[13,14]

Light Detection and Ranging, or LiDAR, is a remote sensing technology that employs a pulsed laser to measure distance and thus generate three-dimensional point clouds of objects or landscapes. Airborne LiDAR has been used to calculate forest[15] and one-seeded juniper (*J. monosperma)* biomass.[16] Airborne LiDAR has been used to evaluate an Edwards Plateau site for characterization of Ashe juniper for golden-cheeked warbler habitat,[17] but we find no literature reporting application of this technology for the quantification of Ashe juniper as fuel or forage. Therefore, we conducted a study at the Texas A&M AgriLife Research - Sonora Research Station (Fig. 1) to use terrestrial LiDAR to estimate biomass of Ashe juniper and compared this with established allometric techniques.

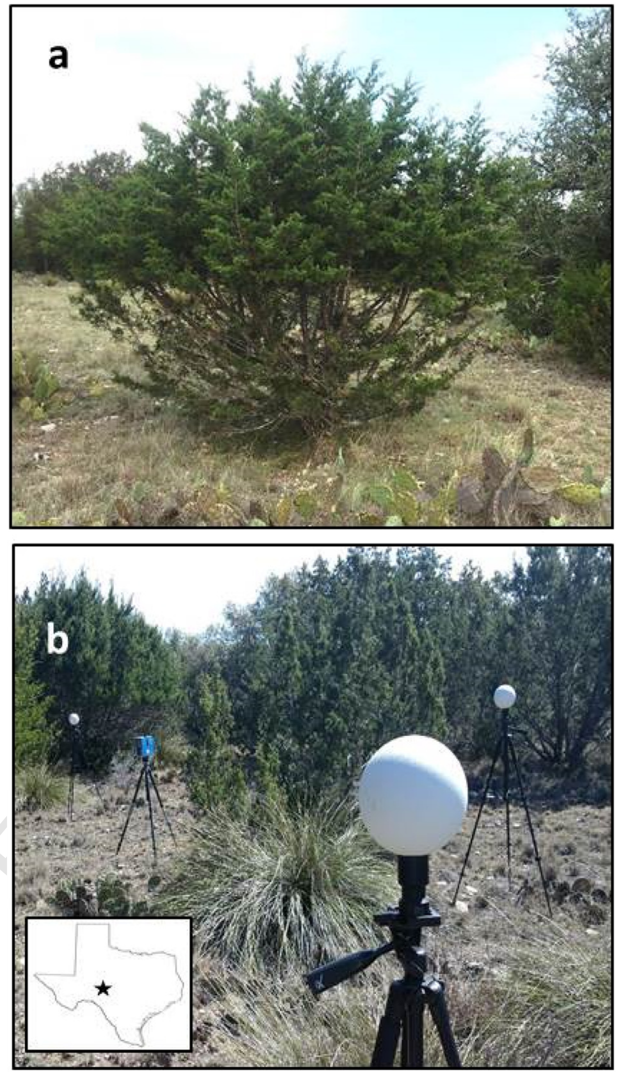

Figure 1. A, Example of browse line on Ashe juniper at approximately 1.83 m. **B,** LiDAR data collection setup including scanner and reference spheres. Inset illustrates the experimental location (Texas A&M AgriLife Sonora Research Station).

The Nuts and Bolts

We started by validating the allometric calculations of Reemts[13] using her methodology. Briefly, she measured 33 Ashe juniper trees for basal diameter, height, and canopy width, processed them into three size classes and separated the dry material into live and dead fractions. Similarly, in February of 2017, we measured nine individual Ashe juniper trees, three each in three size categories: 1) < 0.91 m, 2) between 0.91 and 1.83 m, and 3) > 1.83 m height. The 1.83-m threshold represents a typical browse line above which most small ruminant herbivores in the Edwards Plateau region could not reach even in a bipedal feeding stance (Fig. 1A). We collected basal diameter, maximum height, maximum canopy width, and canopy width perpendicular to the maximum. In addition to the allometric measurements, we harvested all plant material from each tree into five size classes based upon wildland fire fuel categories: 1-hour (leaves, twigs, and reproductive parts < 6 mm in diameter), 10-hour (branches 6-25 mm in diameter), 100-hour (branches 25-76 mm in diameter), 1,000-hour (branches 76-203 mm in diameter), and 10,000-hour (branches > 203 mm in diameter) fuel categories. Harvest was accomplished using small shears,

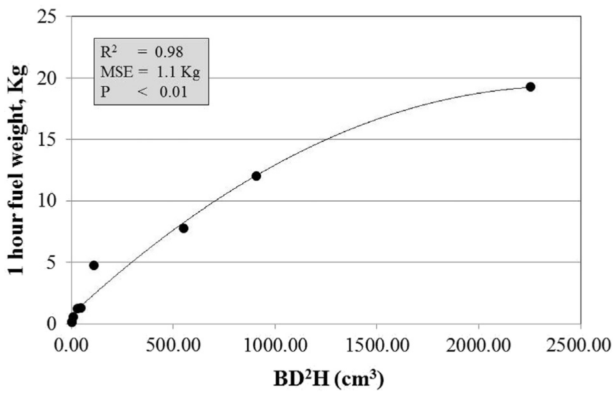

Figure 2. Basal diameter^2 x height (BD^2H) predicted less than 1.83 m 1-hour fuel weight in Ashe juniper. R^2 indicates coefficient of determination; and MSE, mean squared error.

Q1

pruners, or chainsaws as appropriate for the tree and fuel size class.

Allometric measurements were input to Reemts' predictions for total aboveground biomass and for 1-hour fuels (which we used as a proxy for browse-able forage). Harvested material was also categorized as being above or below the 1.83 m-threshold, and we obtained field weights on all described categories. Plant tissue was dried to constant weight at 60°C in a forced air oven. Leaf and stem separations were conducted on dry material from the 1-hour fuel category. Linear regression techniques were applied to determine relationships between allometric measurements and canopy diameter, canopy volume, and fuel category dry weights.

All trees were located in an approximately 60-ha pasture that had been mechanically cleared of juniper in 1985 and other than occasional stray animals, has received no livestock grazing since. In addition to the native ungulate herbivore, white-tailed deer, and other smaller animals, Axis deer (*Axis axis*) have become numerous on the Station in the last 10 years and are frequently observed in the study pasture. Most of the pasture is classified as a Low Stony Hill ecological site with Tarrant soils. In addition to Ashe juniper, trees such as redberry juniper (*J. pinchotii*), honey mesquite (*Prosopis glandulosa*), and liveoak (*Quercus fusiformis*) are found. Shrubs such as algerita (*Mahonia trifoliolata*), lotebush (*Ziziphus obtusifilia*), and elbowbush (*Foresteria pubescens*) are common, as are forbs such as orange zexmania (*Wedelia texana*), Engelmann's daisy (*Engelmannia peristenia*), and goat weed (*Croton spp.*). Dominant grasses include sideoats grama (*Bouteloua curtipendula*), Texas wintergrass (*Nasella leucotricha*), and King Ranch bluestem (*Bothriochloa ischaemum*). We collected LiDAR imagery before the tree harvest using a FARO Focus X330 terrestrial laser scanner. It has a scanning range of 0.6 to 330 m, a scan rate of up to 976,000 points/second and integrates a Global Positioning System (GPS) and high-resolution digital camera for collection of high-density three-dimensional point clouds with precise location and true color representation. Five tripod-mounted reference control targets (porcelain spheres) were arranged around the tree to be scanned and their positions measured with a Trimble GeoXH GPS system (Fig. 2A). The reference targets served as ground control and as auxiliary marks during later point cloud registration. The scanner was located 2 to 4 m from the target tree, positioned in such a way to include at least three reference targets. To ensure complete coverage, each tree was scanned from multiple scan locations. Smaller trees (<1.83 m) were scanned twice, and larger trees (≥ 1.83 m) were scanned from three separate positions.

The multiple scans collected for each tree were registered onto a single aligned coordinate system using FARO SCENE software. In registering the point clouds, each cloud

Table 1. Allometric measurements collected from nine individual Ashe juniper trees in three different size classes: small (<0.91 m), medium (between 0.91 and 1.83 m), and large (>1.83 m)

	Basal Diameter	Height	Basal Diameter^2 x Height	Canopy Area	Canopy Volume	Widest Canopy Diameter
Tree ID	cm	m	cm^3	m^2	m^3	m
Small 1	3.58	0.89	11.41	0.54	0.32	0.90
Small 2	2.42	0.63	3.69	0.15	0.06	0.47
Small 3	1.92	0.80	2.95	0.12	0.07	0.48
Medium 1	5.00	1.22	30.50	0.72	0.58	0.94
Medium 2	7.83	1.83	112.20	3.08	3.75	2.24
Medium 3	5.67	1.44	46.29	0.65	0.62	0.96
Large 1	26.10	3.31	2254.81	16.26	35.86	4.50
Large 2	18.14	2.76	908.20	10.95	20.14	3.83
Large 3	13.69	2.95	552.88	9.82	19.30	3.71

Table 2. Dry weights (kg) of fuel size categories.

Tree ID	Less than 1.83 m						Greater than 1.83 m						
	Total Weight	**1-hour fuels**	**10-hour fuels**	**100-hour fuels**	**1,000-hour fuels**	**10,000-hour fuels**	**Total Weight**	**1-hour fuels**	**10-hour fuels**	**100-hour fuels**	**1,000-hour fuels**	**10,000-hour fuels**	**Grand Total**
Small 1	0.73	0.55	0.09	-	-	-	-	-	-	-	-	-	0.73
Small 2	0.22	0.16	0.05	-	-	-	-	-	-	-	-	-	0.22
Small 3	0.15	0.11	0.03	0.05	-	-	-	-	-	-	-	-	0.15
Medium 1	1.66	1.19	0.22	0.18	-	-	-	-	-	-	-	-	1.66
Medium 2	7.02	4.74	0.93	1.17	-	-	-	-	-	-	-	-	7.02
Medium 3	2.08	1.27	0.52	0.21	-	-	-	-	-	-	-	-	2.08
Large 1	66.22	19.27	20.54	14.12	7.64	4.52	23.68	21.65	0.34	0.34	-	-	89.90
Large 2	41.31	12.02	12.81	8.81	4.77	2.82	7.79	7.12	0.11	0.11	-	-	49.10
Large 3	26.71	7.77	8.28	5.69	3.08	1.82	7.63	6.97	0.11	0.11	-	-	34.33

Note. Plant tissue collected from nine individual Ashe juniper trees above and below 1.83 m browsing threshold height in three different size classes: small (<0.91 m), medium (between 0.91 and 1.83 m), and large (>1.83 m).

Table 3. Proportion of leaf in the 1-hour fuel category for each Ashe juniper size and height class: small (<0.91 m), medium (between 0.91 and 1.83 m), and large (>1.83 m).

Tree Size Category	Mean	Standard Error
Small	0.71	0.02
Medium	0.70	0.02
Large biomass < 1.83 m	0.65	0.03
Large biomass > 1.83 m	0.74	0.03
Average	0.70	0.02

Note. 1.83 m indicates the browsing threshold height.

underwent a number of preprocessing steps including noise filtering and the automatic reference target (spheres) detection. A number of predefined filters were applied to remove stray and low intensity points. After the preprocessing steps, the locations of the reference spheres were updated with their measured GPS locations to enable creation of georectified point cloud and correspondences matched among the point clouds. Once the correspondences were established, the multiple scans were fused into one point cloud with a single and consistent coordinate system. Finally, a clipping step was carried out to limit the point cloud to the tree extent.

For each tree, we measured maximum height and maximum canopy width directly from the LiDAR data using Quick Terrain Modeler (QTM, http://appliedimagery.com—a software package for the processing and analysis of 3D point cloud data. For tree volume estimates, we converted the LiDAR data into a 3D voxel model through a 3D gridding process[7] and used the number of voxels (voxel count) as the volume estimate. Each voxel, which is the basic building block of the model, measured 10 cm in length, width, and height. A voxel size of 10 cm was adopted, after prior experimentation with other sizes (2.5 cm, 5 cm, 7.5 cm, 12.5 cm, and 15 cm), as a compromise between modelling accuracy (especially for small trees) and computational burden. As with the allometric measurements, linear regression techniques were applied to determine relationships between LiDAR-derived data and tree biomass characteristics.

Table 4. Statistical values of quadratic Ashe juniper allometric prediction equations.

y	x	a	b	c	R^2	MSE	*P*
Canopy area	BD	-0.003200	0.8064	-2.3828	0.9735	1.2922	0.01
Canopy volume	BD	0.014800	1.1497	-4.0079	0.9684	7.1381	0.01
Dry weight	BD	0.089800	1.3444	-5.3786	0.9927	9.6104	0.01
1-hour fuel weight	BD	0.048000	3.5050	-1.2169	0.9936	1.6248	0.01
Dry weight (LT 1.83 m only)	BD	0.046100	1.6023	-5.6449	0.9909	6.7799	0.01
1-hour fuel weight (LT 1.83 m only)	BD	0.008000	0.5863	-1.4604	0.9928	0.4271	0.01
Canopy area	BD^2H	-0.000004	0.0170	0.3525	0.9842	0.7685	0.01
Canopy volume	BD^2H	-0.000007	0.0318	0.0177	0.9819	4.0769	0.01
Dry weight	BD^2H	-0.000010	0.0660	-0.1832	0.9994	0.7301	0.01
1-hour fuel weight	BD^2H	-0.000003	0.0248	0.5275	0.9955	1.1383	0.01
Dry weight (LT 1.83 m only)	BD^2H	-0.000010	0.0557	0.0382	0.9997	0.2449	0.01
1-hour fuel weight (LT 1.83 m only)	BD^2H	-0.000003	0.0154	0.7300	0.9813	1.1061	0.01

Note. Large tree (LT) biomass above the browse line of 1.83 m is excluded.
BD indicates basal diameter; BD^2H, basal diameter squared times height; R^2, coefficient of determination; and MSE, mean squared error.

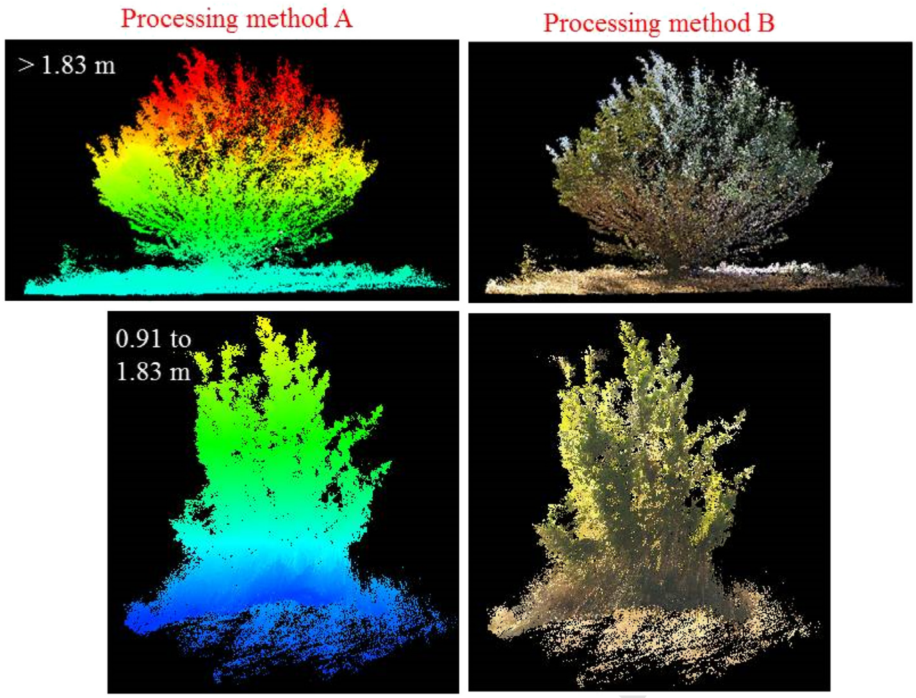

Figure 3. Example LiDAR imagery in a large- (>1.83 m) and medium-sized (>0.91 and <1.83 m) Ashe juniper tree.

What We Observed

Reemts' exponential equations using either basal diameter or basal diameter squared times height accurately predicted ($P < 0.01$) our observed values for total weight ($R^2 > 0.95$, SE < 7.0 kg) and 1-hour fuel ($R^2 > 0.98$, SE < 2.0 kg). Not surprisingly, our results from predictive equations developed in Excel with allometric measurements are similar to Reemts' and confirm that basal diameter and height, easily collected in the field, are useful measurements for estimating Ashe juniper biomass. Table 1 contains the allometric data from all size classes of Ashe juniper trees utilized in this study.

Table 2 contains dry weights of each fuel size category above and below the browsing threshold. One-hour fuel values below 1.83 m represent the potential forage available to browsers. Grand total weight represents the available biomass for burning. In Table 3 we present the proportion of leaf found in the 1-hour fuel class for the various tree size categories. Ashe juniper foliage averages approximately 7% crude protein.[19] The 1-hour fuel category, composed of 70% leaf, thus represents a potential maintenance forage source for browsers.

Results of the regression analyses correlating allometric measurements to canopy and biomass characteristics are found in Table 4. Quadratic equations were the most successful ($R^2 > 0.96$), and all relationships were highly predictive ($P < 0.01$). An example relationship between the basal diameter squared times height and 1-hour fuel less than 1.83 m is illustrated in Figure 2.

Examples of the processed LiDAR imagery for a large- and medium-sized tree as used in this study are presented in Figure 3. LiDAR was equally successful ($R^2 > 0.92$; $P < 0.01$) in predicting canopy and biomass in Ashe juniper. Table 5 contains results of the regression analyses correlating LiDAR measurements and these characteristics.

What We Learned

We evaluated two different methods of quantifying Ashe juniper biomass: physical measurements obtained with field-expedient methods and three dimensional point cloud imagery via LiDAR. Both were highly effective. Both will be useful to inform either stocking rate calculations for browsing animals or fire behavior models for juniper-occupied rangelands. LiDAR, whether ground-based, as applied here, or obtained on an aerial platform, will become more useful as instruments become more available and decrease in cost. Aerial imagery will especially be applicable for large landscapes and the creation of publically available data. In the interim, resource managers armed with little more than a tape measure and tablet can obtain readily usable information on juniper biomass for browsing or fire fuel planning.

The US Forest Service Fire Effects Information System[20] reports an estimated 0.25 million ha of rangeland containing Ashe juniper in southern Oklahoma and 3.5 million ha in Texas; much of this is on land formerly classified as grasslands. Increased juniper cover is generally viewed negatively by managers of livestock and ungulate wildlife. For instance, Dye et al.[21] reported that biomass of herbaceous understory increased from approximately 1,400 kg/ha to approximately 2,000 kg/ha in the year after chemical treatment of redberry juniper. These same authors projected approximately 500 kg/ha of herbaceous biomass under a closed canopy of redberry

Table 5. LiDAR Ashe juniper calibration results.

y	x	Slope	Intercept	R^2	SE	P
Canopy area	Voxel Count	0.000909	0.165200	0.99	0.540	0.01
Canopy volume	Voxel Count	0.001945	-0.731003	0.98	1.891	0.01
Dry weight	Voxel Count	0.004618	-2.446218	0.95	7.744	0.01
1-hour fuel weight	Voxel Count	0.001993	-0.732854	0.92	4.229	0.01
Dry weight (LT 1.83 m only)	Voxel Count	0.003504	-1.263396	0.96	4.975	0.01
1-hour fuel weight (LT 1.83 m only)	Voxel Count	0.000975	0.372700	0.94	1.767	0.01

Note. LT biomass above the browse line of 1.83 m is excluded.
R^2 indicates coefficient of determination; LT, large tree; and SE, standard error.

juniper. Yager and Smeins[22] report that sideoats grama and green sprangletop (*Leptochloa dubia*) increased when canopy cover of Ashe juniper was removed. As previously mentioned, however, some view Ashe juniper positively and conservation of the golden-cheeked warbler is highly dependent on mature stands of trees such as Ashe juniper. Another and more recent positive benefit of mechanically harvested Ashe juniper trees is that they can be used as livestock feed. George et al.[23] have explored the use of whole juniper biomass as a replacement for bulk ingredients such as cottonseed hulls. They have reported no detrimental effects on animal health or meat palatability.[24] Furthermore, ground redberry juniper added to a livestock diet may aid in control of internal parasites.[25]

The United States Department of Agriculture National Agricultural Statistics Service reports that there are 795,000 meat goats, 75,000 Angora (mohair producing) goats, and 26,000 dairy goats in the state of Texas.[26] Many of the meat and mohair goats are found in the Edwards Plateau. There is thus a great opportunity to use juniper as forage and to use these animals for juniper management. The combination of prescribed fire and goat browsing is an effective method for reducing juniper expansion after a mechanical treatment.[27] Goats have been used to reduce fuel loads near the wildland-urban interface.[27]

One practical example of using the biomass calculations derived here would be to determine the amount of juniper forage available on a given land area or management unit and then using this to calculate a stocking rate for goats. Tables 6 and 7 provide information collected on juniper density at the Sonora Research Station and calculations of goat intake.

Table 6. Example application of using estimated juniper biomass to allocate browsable forage allowance for goats on rangeland.

Juniper Composition Data				
	<0.91 m	**0.91–1.83 m**	**>1.83 m**	**Total**
Trees/ha	100	50	10	160
Juniper forage (kg/tree)	0.27	2.40	13.02	NA
Juniper forage (kg/ha)	27.0	120.0	130.2	277.2
Estimated Daily Juniper Intake Per Goat				
		Low Use	Moderate Use	High Use
Body Weight (kg)	Daily Intake (3% BW kg)	20% of Diet	35% of Diet	50% of Diet
22.7	0.68	0.14	0.24	0.34
34.0	1.02	0.20	0.36	0.51
45.4	1.36	0.27	0.48	0.68
56.7	1.70	0.34	0.60	0.85
68.0	2.04	0.41	0.71	1.02
79.4	2.38	0.48	0.83	1.19

* Intake of juniper will vary from low to high use based on availability of other forages, season, and individual goats, along with sex, size, and species of juniper.

Table 7. Estimated forage from Ashe juniper in 8 sample plots within pastures at the Texas A&M AgriLife Sonora Research Station.

Pasture	Juniper Tree Count in 0.1 ha			Trees/ha	Juniper Forage kg/0.1ha			Juniper Forage kg/ha
	<0.91 m	0.91–1.83 m	>1.83 m		<0.91 m	0.91–1.83 m	>1.83 m	
1	29	15	25	690	7.9	36.0	325.4	369.4
2	13	5	1	190	3.5	12.0	13.0	28.6
3	52	5	9	660	14.1	12.0	117.2	143.3
4	13	6	5	240	3.5	14.4	65.1	83.0
5	71	17	39	1270	19.3	40.8	507.7	567.8
6	83	23	40	1460	22.5	55.3	520.7	598.5
7	62	13	18	930	16.8	31.2	234.3	282.4
8	48	23	36	1070	13.0	55.3	468.6	536.9
Average				813.8				326.2
SE				161.6				80.4

SE indicates standard error.

Using this information we could estimate a beginning stocking rate for goats on typical Edwards Plateau rangeland. For instance, we could estimate that a 200-ha pasture with 326 kg of juniper and 560 kg herbaceous standing crop per ha (886 kg/ha total forage available) and a 25% utilization efficiency could provide grazing or browsing for 362, 45-kg goats for 90 days.

We should be able to use LiDAR to estimate harvested amount of material and further verify its use in setting stocking rates and in range monitoring for woody plants. LiDAR as we applied it here could be used to determine biomass for individual trees and would be a good research tool, but did not dramatically improve the prediction accuracy and was much slower and costly. LiDAR in an aerial platform, however, may produce accurate estimates of juniper biomass for forage or fuel across large landscapes in a relatively short time period and thus could be very useful in regional planning applications.

Accurate assessments of fuel from Ashe juniper biomass will allow managers to make more informed decisions and targeted efforts for thinning, pruning, piling, and broadcast burning in addition to assessments for canopy fuel characteristics for fire fuel planning. Consequently, Ashe juniper biomass estimates can be useful for planning fuel reduction treatments and estimating the effects of wildfire on canopy fuel characteristics. Adequately understanding how much biomass exists in Ashe juniper trees surrounding wildland-urban interface areas would also enable more accurate assessments of fire behavior in crown fuels to determine whether fuel accumulations have potential to burn or whether planned treatments may be dangerous to fire fighters or the public.

In light of the recent California fire season, a report from the California Department of Insurance emphasized that mitigation should be a primary objective because of a significant increase in insurer-initiated nonrenewals in the 3.6 million homes located in the California wildland-urban interface. One of the recommendations to legislators was to offer policies where the property meets specific mitigation and defensible space criteria or similarly make discounts available where such mitigation has been undertaken. Applying Ashe juniper biomass estimates would be key to improving community land-use planning, contingency planning, or to facilitate prescribed fires for ecological restoration or fuel treatment programs for juniper occupied rangelands. Informing fire management decisions with both physical measurements and LiDAR will facilitate better wildland-urban interface planning that is focused on mitigation and land-use planning strategies that reduce risk.

Statistical values of quadratic Ashe juniper allometric prediction equations, where "BD" is basal diameter, "BD^2H" is basal diameter squared times height, "R^2" is the coefficient of determination, and "MSE" is the mean squared error. Large tree (LT) biomass above the browse line of 1.83 m is excluded.

LiDAR Ashe juniper calibration results. "R^2" is the coefficient of determination and "SE" is the standard error. Large tree (LT) biomass above the browse line of 1.83 m is excluded.

Example application of using estimated juniper biomass to allocate browsable forage allowance for goats on rangeland.

Estimated forage from Ashe juniper in 8 sample plots within pastures at the Texas A&M AgriLife Sonora Research Station. "SE" is the standard error. Q6

Q7 Uncited reference

18

Acknowledgments

The authors wish to thank Nick Garza, Jesse Goplin, Robert Moen, and Emily Pecilunas for their assistance in data collection.

References

1. McAuliffe, J., and M. Dunn. 2015. Ashe juniper is really more good than bad. Available at: , http://npsot.org/wp/boerne/ashe-juniper-really-good-bad/. Accessed 6 May 2017.
2. Lyons, R.K., M.K. Owens, and R.V. Machen. 1998. Juniper biology and management in Texas. Texas A&M AgriLife Extension Publication B-6074. College Station, TX, USA: Texas A&M AgriLife Extension, The Texas A&M University System. Available at: , https://dspacepre1.library.tamu.edu/bitstream/handle/1969.1/87846/pdf_968.pdf. Accessed 23 October 2018.
3. Wilcox, B.P., and T.L. Thurow. 2006. Emerging issues in rangeland ecohydrology. *Hydrological Processes* 20:3155-3157.
4. Wu, X.B., E.J. Redeker, and T.L. Thurow. 2001. Vegetation and water yield dynamics in an Edwards Plateau watershed. *Journal of Range Management* 54:98-105.
5. Hibbert, A.R. 1983. Water yield improvement potential by vegetation management on western rangelands. *Water Resources Bulletin* 19:375-381.
6. Smeins, F.E., S.H. Fuhlendorf, and C.A. Taylor, Jr. 1997. Environmental and land use changes: a long-term perspective. *In:* C.A. Taylor, Jr. [Ed.] 1997 Juniper Symposium Proceedings. San Angelo, TX, USA; Texas A&M University Research & Extension Center. p. (1-3)–(1-21).
7. Conservancy, Nature 2004. A biodiversity and conservation assessment of the Edwards Plateau Ecoregion. Edwards Plateau Ecoregional Planning Team. San Antonio, TX, USA: The Nature Conservancy. Q8
8. Elliott, L.F., A. Treuer-Kuehn, C.F. Blodgett, C.D. True, D. German, and D.D. Diamond. 2009–2014. Ecological Systems of Texas: 391 Mapped Types. Phase 1–6, 10-meter resolution Geodatabase, Interpretive Guides, and Technical Type Descriptions. Austin, TX, USA: Texas Parks & Wildlife Department and Texas Water Development Board. Available at: , http://www.tpwd.state.tx.us/gis/data/downloads#EMS-T. Accessed 23 October 2018.
9. Xxxx.
10. Campbell, E.S., C.A. Taylor, J.W. Walker, C.J. Lupton, D. F. Waldron, and S.Y. Landau. 2007. Effects of supplementation on juniper intake by goats. *Rangeland Ecology and Management* 60:588-595.
11. Taylor, C.A. 2008. Ecological consequences of using prescribed fire and herbivory to manage Juniperus encroachment. In: & Van Auken OW, editor. Western North American Juniperus Communities. Ecological Studies. New York, NY, USA: Springer. Q9
12. Heitschmidt, R.K., and C.A. Taylor, Jr. 1991. Chapter 7. Livestock production. *In:* Heitschmidt, and Stuth [Eds.]. Grazing management: an ecological perspective. Q10
13. Reemts, C.M. 2013. Allometric equations for Ashe juniper (*Juniperus ashei*) of small diameter. *The Southwestern Naturalist* 58:359-363.
14. Hicks, R.A., and W.A. Dugas. 1998. Estimating ashe juniper leaf area from tree and stem characteristics. *Journal of Range Management* 51:633-637.
15. Sheridan, R.D., S.C. Popescu, D. Gatziolis, C.L.S. Morgan, and N. Ku. 2015. Modeling forest aboveground biomass and volume using airborne LiDAR metrics and forest inventory and analysis data in the Pacific Northwest. *Remote Sensing* 7:229-255.
16. Krofcheck, D.J., M.E. Litvak, C.D. Lippitt, and A. Neuenschwander. 2016. Woody biomass estimation in a southwestern U.S. Juniper savanna using LiDAR-derived clumped tree segmentation and existing allometries. *Remote Sensing* 8:453.
17. Sesnie, S.E., J.M. Mueller, S.E. Lehnen, S.M. Rowin, J.L. Reidy, and F.R. Thompson. 2016. Airborne laser altimetry and multispectral imagery for modeling Golden-cheeked Warbler (Setophaga chrysoparia) density. *Ecosphere* 7:1-19.
18. Putman, E.B., and S.C. Popescu. 2018. Automated estimation of standing dead tree volume using voxelized terrestrial Lidar data. *IEEE Transactions on Geoscience and Remote Sensing* 56:6484-6503.
19. Rollins, D., and B. Armstrong. 1997. Cedar through the eyes of wildlife. *In*: C.A. Taylor [Ed.]. 1997 Juniper Symposium Proceedings. San Angelo, TX, USA: Texas, Texas A&M University Center.
20. Sullivan, J. 1993. Juniperus ashei. *In:* Fire effects information system, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory. Available at; , https://www.fs.fed.us/database/feis/plants/tree/junash/all.html. Accessed 23 October 2018.
21. Dye, K.L., D.N. Ueckert, and S.G. Whisenant. 1995. Redberry juniper-herbaceous understory interactions. *Journal of Range Management* 48:100-107.
22. Yager, L.Y., and F.E. Smeins. 1999. Ashe juniper (Juniperus ashei: Cupressacea) canopy and litter effects on understory vegetation in a juniper-oak savanna. *The Southwestern Naturalist* 44:6-16.
23. George, C.H., C.B. Scott, T.R. Whitney, C.J. Owens, B.J. May, and R. Brantley. 2010. Supplements containing escape protein improve redberry juniper intake by goats. *Rangeland Ecology and Management* 63:655-661.
24. Whitney, T.R., and S.B. Smith. 2015. Substituting redberry juniper for oat hay in lamb feedlot diets: carcass characteristics, adipose tissue fatty acid composition, and sensory panel traits. *Meat Science* 104:1-7.
25. Whitney, T.R., S. Wildeus, and A.M. Zajac. 2013. The use of redberry juniper (*Juniperus pinchotii*) to reduce *Haemonchus contortus* fecal egg counts and increase ivermectin efficacy. *Veterinary Parasitology* 197:182-188.
26. USDA-NASS. 2018. United States Department of Agriculture National Agricultural Statistics Service sheep and goat report. (ISSN: 1949-1611). Available at: , http://usda.mannlib.cornell.edu/usda/current/SheeGoat/SheeGoat-01-31-2018.pdf. Accessed 25 October 2018.
27. Taylor, C.A., Jr. 2006. Targeted grazing to manage fire risk. *In:* K. Launchbaugh and J. Walker [Eds.]. Targeted grazing: a natural approach to vegetation management and landscape enhancement. Englewood, CO, USA: American Sheep Industry Association. Q12

Texas A&M University, Sonora, TX 76950, USA(douglas.tolleson@ag.tamu.edu, Tolleson); Texas A&M University, Sonora, TX 76950, USA (Rhodes, Malambo, Angerer, Redden, Treadwell, Popescu). Q3