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Application of Self-Thinning in Mesquite (*Prosopis glandulosa* var. *glandulosa*) to Range Management and Lumber Production

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ABSTRACT

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To gain a better understanding of the relationships between stand density and tree volume in mesquite, seven native stands were examined. Stand densities ranged from 6 to 19 000 stems ha^{-1}, and estimated biomass ranged from 0.65 to 1300 kg stem^{-1}. Regression equations were used to estimate biomass from basal diameters. A plot of estimated tree biomass vs. stand density was defined by the estimated self-thinning line: $\log W = -1.17 \log d + 5.22$ ($r^2 = 0.95$), where: W is stem fresh weight (kg); and d stand density (stems ha^{-1}). Regressions of stand density on basal diameter, lumber volume stem^{-1} and total biomass ha^{-1} were also examined. When plots deemed to not be at full stand occupancy were excluded from the data set, a regression predicted that densities of 100 stems ha^{-1} would produce 35-cm-basal-diameter stems. This density also gave the highest lumber yield.

INTRODUCTION

Mesquite (*Prosopis glandulosa* var. *glandulosa*) trees can occur at densities of 10 000 stems ha^{-1}, with basal diameters of 3–4 cm, about ten years after land-clearing. These dense stands are a problem on rangelands, where they compete with forage species for light, water and nutrients (Fisher, 1950). Larger mesquite trees give shade to livestock and produce abundant beans, useful for animal feed in dry years (Felker, 1979). Furthermore, mesquite trees improve soil fertility through nitrogen fixation (Rundel et al., 1982). Large trees can provide timber with properties suitable for quality hardwood furniture and flooring (Weldon, 1986).

Formerly, where dense stands of mesquite existed, eradication was attempted (Fisher et al., 1972), usually without success. If 'self-thinning' oc-

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curred in mesquite stands, the livestock problems caused by small trees could be eliminated. Large mesquite trees, grown at wide spacings, might compete against seedlings and maintain a savannah. In search of economical and self-sustaining techniques for rangeland management, we evaluated self-thinning in mesquite. Could large trees prevent dense stands of mesquite from becoming established? If self-thinning occurred in mesquite, what would be the ultimate tree size and stand-density for lumber production?

The natural thinning of other forest communities has been described by a plot of stand density (stems ha^{-1}) vs. plant diameter or weight (Long and Smith, 1984). Research with other species has examined density/diameter relationships at full-stand occupancy. In mesic areas, this can be assumed to occur at crown closure.

Mesquite trees grow in semi-arid and arid regions, where self-thinning might occur at low stand densities. The root: shoot biomass ratio of arid-land trees could exceed 1, with lateral roots extending beyond the canopies. Indeed, Cable (1977), using neutron access tubes, found that mesquite trees used water at 10–15 m beyond their canopy zones. In arid-land forests there is seldom canopy closure; the spacing of trees increases as annual rainfall decreases. Thus, full-stand occupancy in mesquite trees may depend more on root competition than canopy competition. This could complicate the estimation of a self-thinning line.

MATERIALS AND METHODS

Since mesquite stands seldom have closed canopies, it is difficult to know when 'full-site occupancy' occurs. We measured large trees, at spacings several times the canopy diameter, to obtain an upper limit for tree size with minimal competition. Mesquite plantations do not exist, except for research plots. Hence, it was impossible to measure density/volume relationships of trees at known ages. Instead, sites with contrasting density: volume ratios were chosen. Native mesquite stands between Kingsville and Nixon, Texas, were measured for basal diameters, tree heights, and canopy diameters. The mean annual rainfall in both locations was about 650 mm. Selection criteria were based on absence of irrigation and fertilization. The first, second, and fourth locations were near Kingsville; the other four encompassed a 15-km distance near Nixon, Texas. Plot sizes varied according to stand density, with smaller plots used in denser stands (Table 1).

A regression from the harvest of 194 young South American *Prosopis alba* trees in Kingsville, Texas (Felker, unpublished data, 1986) was used for estimating the biomass of small stems at sites 1 through 3. The equation was:

$$\log W = 2.70 \log d_b - 1.11 \quad (r^2 = 0.957, \text{SE} = 0.041)$$

where: W is stem fresh weight (kg); and d_b, stem basal diameter (cm). The

TABLE 1

Weights and densities of stems in surveyed mesquite (*Prosopis glandulosa* var. *glandulosa*) stands

Site	Plot (m^2)	Diameter ($cm\ stem^{-1}$)	Biomass ($kg\ stem^{-1}$)	Density ($stems\ ha^{-1}$)
1	50	1.88	0.72	18 800
1	50	1.85	0.60	13 800
1	50	3.61	4.16	10 200
1	50	3.40	3.20	10 000
2	144	4.87	9.36	7180
2	144	6.08	13.67	5110
2	144	5.76	16.6	4760
2	144	5.96	12.3	3590
3	100	5.67	11.2	5800
3	100	6.18	15.0	4900
3	100	7.04	19.3	2900
4	900	20.7	183	280
4	900	18.8	148	320
4	900	18.0	137	350
4	900	15.5	95	470
5	900	22.0	213	311
5	900	24.7	281	244
5	900	25.8	298	222
6	900	30.6	452	167
6	900	31.2	467	122
6	900	42.4	885	111
7	11800	43.7	943	13.9
7	7100	49.2	1190	9.92
7	6500	50.9	1290	5.93

biomass of stems at the other four sites was estimated by a regression on 10 large mesquite (*P. glandulosa* var. *glandulosa*) trees that were weighed and measured in South Texas (El Fadl et al., 1989):

$$\log W = 1.05 \log A_b + 3.83 \quad (r^2 = 0.800, \text{SE} = 0.187)$$

where: A_b is stem basal area (cm^2).

Logarithms of fresh weight ($kg\ stem^{-1}$) were estimated with these regression equations, and plotted on the logarithms of stand density ($stems\ ha^{-1}$). A regression describing this 'self-thinning' relationship was plotted over the points.

A study conducted by Rogers (1984) in Lufkin, Texas regressed sawn lumber, grade 2 lumber, and grade 1 lumber yields on the lengths and diameters of 105 mesquite logs. Boards with a clear surface of 5.1 cm × 15.2 cm were classified as grade-2 lumber; boards with a clear surface of at least 5.1×by 60 cm were considered grade-1 lumber. The metric conversions of these regressions were used to predict lumber volumes:

$$\text{SL} = 1.86\ D_{se} + 0.170\,L - 36.0 \quad (r^2 = 0.71)$$

$$G2 = 1.16\ D_{se} + 0.085\,L - 20.0 \quad (r^2 = 0.53)$$

$$G1 = 0.482\,D_{se} + 0.023\,L - 9.21 \quad (r^2 = 0.45)$$

where: D_{se} is small-end diameter of a mesquite log (cm); L, mesquite log length (cm); SL, sawn lumber (m^3); $G2$, grade-2 lumber (m^3); and $G1$, grade-1 lumber (m^3).

In estimating tree volumes, El Fadl et al. (1989) equated branch sections to cylinders, with diameters equal to the mean of 'small-end' and 'large-end' thicknesses. Lumber volumes, predicted from Rogers (1982), were regressed on the basal areas (m^2) of these trees to obtain:

$$\log V = 1.27 \log A_b + 0.718 \quad (r^2 = 0.91, \text{SE} = 0.141)$$

$$\log \text{SL} = 1.37 \log A_b + 0.453 \quad (r^2 = 0.93, \text{SE} = 0.139)$$

$$\log G2 = 1.35 \log A_b + 0.228 \quad (r^2 = 0.93, \text{SE} = 0.136)$$

$$\log G1 = 1.65 \log A_b - 0.202 \quad (r^2 = 0.90, \text{SE} = 0.197)$$

where: V is tree volume (m^3); and r^2, correlation for the regressions of predicted lumber volumes on stem basal area.

Rogers' lumber grades were below common grades for other hardwoods, due to defects in mesquite wood. Both Rogers (1984) and El Fadl et al. (1989) used regressions based on logs greater than 10 cm at the small end. Since it is difficult to process small logs, we considered the lumber volume to be nil in trees with diameters less than 15 cm.

RESULTS

Density statistics of trees in the survey areas (Table 1) are useful for predicting the biomass of native mesquite stands. Biomass stem^{-1} ranged from 0.65 kg at a stand density of over 10 000 stems ha^{-1}, to 1300 kg at a stand density of 10 stems ha^{-1}. Stem volume can be obtained by dividing mass by a mesquite wood density of 700 kg m^{-3} (Weldon, 1986).

Several regressions were examined for predicting stem biomass from stand density. We assumed that full-stand occupancy did not exist at site 7, and computed a regression that excluded these trees. The equation, shown graphically in Fig. 1, is:

$$\log W = -1.17 \log N + 5.22 \quad (r^2 = 0.95, \text{SE} = 0.064)$$

where: N is stand density (stems ha^{-1}).

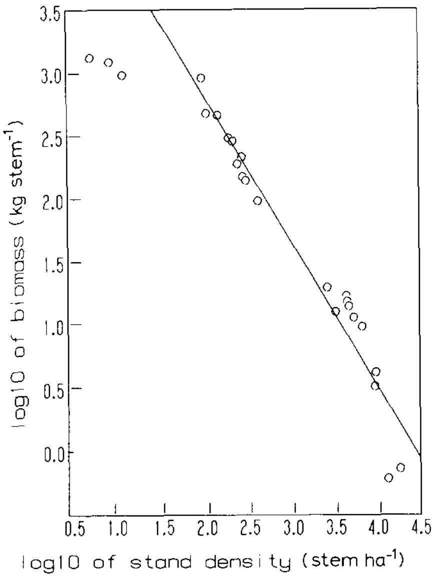

Fig. 1. Self-thinning line for honey mesquite (*Prosopis glandulosa* var. *glandulosa*) stands. (The regression line: $\log_{10}$ fresh weight (kg stem^{-1}) $= -1.17 \times \log_{10}$ stand density (stems ha^{-1}) $+5.22$ does not include the three sites in the upper-left corner of this graph.)

Reducing stand density is beneficial for cattle grazing and lumber production. A regression of basal diameter (cm) on stand density (stems ha^{-1}) indicated what thinning regime would produce a given-size log. When the largest trees at site 7, with densities below full-site occupancy, were excluded, the equation was:

$$\log D_b = -0.51 \log N + 2.59 \quad (r^2 = 0.96, \text{SE} = 0.022)$$

where: D_b is basal diameter (cm).

This regression equation predicts that 30-cm and 40-cm-basal-diameter logs could be grown at spacings of 8.3 m and 10.9 m respectively (Fig. 2). However, the slope is different from the -1.5 frequently reported (Harper 1977; Long and Smith, 1984). The 'minus 3/2 law' shows that "biomass ha^{-1} increases in proportion to the reciprocal of the square root of stand density". For example, if stand density decreases from 1000 to 100 stems ha^{-1}, then biomass ha^{-1} increases by a factor of 3.16. The substitutions are as follows:

$$\log W = -3/2 \log N + \log K_0$$

$$\log (WN^{3/2}) = \log K_0$$

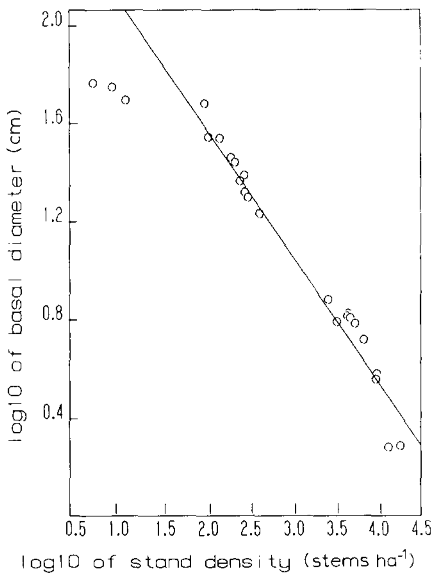

Fig. 2. Self-thinning line for honey mesquite (*Prosopis glandulosa* var. *glandulosa*) stands. (The regression line: $\log_{10}$ basal diameter (cm) $= -0.51 \times \log_{10}$ stand density (stems ha^{-1}) $+2.59$ does not include the three sites in the upper-left corner of this graph.)

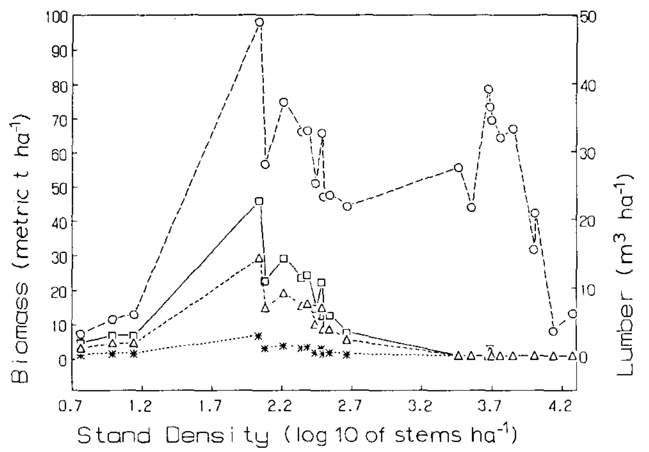

Fig. 3. Green mesquite biomass (○, t ha^{-1}) and lumber volumes ($m^3\ ha^{-1}$) as influenced by stand density ($\log_{10}$ stems ha^{-1}). *, grade-1 lumber; △, grade-2 lumber; □, total sawn lumber.

Since $WN = B$,

$$K_0 = BN^{0.5}$$

and $B \quad = W_0/N^{(m-1)}$

where: B is biomass ha^{-1}; and m, slope of a self-thinning line.

This implies that when the absolute value of the slope is greater than 1, biomass ha^{-1} increases with decreasing stand density, as in mesquite stands. When the slope is 1, biomass ha^{-1} does not change with stand density; when the slope is less than 1, biomass ha^{-1} declines with decreasing stand density. Maximum biomass ha^{-1} occurred at densities of about 100 stems ha^{-1}. Large trees at low stand density, and small trees at high stand density, had lower biomass ha^{-1}. The sawn lumber (grade 1 and grade 2 lumber) for stems larger than 15 cm diameter is presented in Fig. 3. At densities above 3000 stems ha^{-1}, no lumber was produced. But, as stand density decreased to 470 stems ha^{-1}, lumber increased rapidly. The volume/density relationship was described by the following regression:

$$\log \text{SL} = -0.77 \log N + 2.84 \quad (r^2 = 0.70, \text{SE} = 0.180)$$

The largest stems, and stems below 15 cm in diameter, were excluded from this regression. Sawn lumber was maximized (23 m^3 ha^{-1}) at densities of about 111 stems ha^{-1}, or stem spacings of 9.5 m. At retail prices of US\$425 m^{-3}, non-select lumber from these trees would be worth US\$9775.

DISCUSSION

Plotting mesquite biomass ha^{-1} on stand density indicated maximum biomass at about 100 stems ha^{-1}. The self-thinning line developed for mesquite had a slope that was different from the $-3/2$ often reported in literature. Recently, Weller (1987) stated that the $-3/2$ slope is not applicable to all tree species. The difference between mesquite trees, and other species with different thinning slopes, may relate to the extensive root system in mesquite; full site occupancy may occur without canopy closure in mesquite.

The number of mesquite stems ha^{-1} shortly after seedling establishment has exceeded 10 000. In this condition, mesquite is a threat to grass production on rangeland. The minimum density we observed was 6 stems ha^{-1}, but these trees were not at full-site occupancy. Under this condition, seedlings become established in open areas. Medium stand densities (100–150 stems ha^{-1}) could prevent this problem.

Controlled thinnnings may increase the quality of mesquite lumber. Most hardwoods are phototropic and develop misshapen boles when grown under the crowns of other trees. Thus, it is beneficial to establish hardwoods in dense and uniform stands (Smith, 1962). Although full-stand occupancy should be maintained to prevent seedling establishment, tree spacings in mechanical-thinning operations should be based on desired tree-size. Regression equations predict that 100 stems ha^{-1} would achieve basal diameters of 36.5 cm, and sawn-lumber volumes of about 19.8 m^3 (8391 fbm[1]). It is questionable whether the same density/volume relationships would hold in regions with different rainfall, but stem spacings of about 10 m would be a good management objective for this study area.

CONCLUSIONS

Regressions of stand density on stem volume, biomass ha^{-1}, basal diameter and three grades of sawn lumber were estimated for mesquite stands. The regression of stem volume on stand density had a slope slightly less than -1, indicating that mesquite biomass increased little with lower stand density. Yet, decreasing stand densities for mesquite lumber production was compatible with lumber production and land management for cattle grazing. Maximum predicted lumber volume (22 m^3 ha^{-1}) occurred in 42-cm-diameter stems at spacings of 9.5 m.

Mesquite lumber is superior to most oaks, walnut, and Philippine mahogany in hardness and shrink/swell characteristics; cultivating it could enhance land revenues, which, from cattle alone, are currently only about \$6 ha^{-1} $year^{-1}$.

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[1]fbm, foot board measure, ≈ 2.360 dm.