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## VEGETATION–HYDROLOGY MODELS: IMPLICATIONS FOR MANAGEMENT OF *PROSOPIS VELUTINA* (VELVET MESQUITE) RIPARIAN ECOSYSTEMS<sup>1</sup>

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**Abstract.** *Prosopis velutina* (velvet mesquite) forests are one of many types of aridland riparian ecosystems that are threatened by groundwater pumping and other types of water development. Empirical models developed using both hydrological and vegetational data sets have potential uses in the management of these threatened ecosystems. To this end, we developed models for *Prosopis velutina* stands across a xeric-to-mesic moisture gradient. The models expressed canopy height, basal area, leaf area index, vegetation volume, and leaflet area as functions of plant water potential, and they expressed plant water potential and riparian stand structure as functions of water table depth. These data indicated that stand structure was strongly related to water availability. Management applications of the models include the ability (1) to identify minimum water-table depths for riparian stand maintenance and (2) to detect stressful hydrological conditions, via water potential measurements, before the onset of structural degradation.

**Key words:** *empirical models; groundwater; hydrology; Prosopis velutina; riparian vegetation; Sonoran Desert, Arizona; stem water potential; vegetation characteristics vs. water availability; water gradients; water table reduction.*

### INTRODUCTION

In the arid Southwest, <2% of the land surface supports forested vegetation. This forest occurs in riparian ecosystems that are under continual threat from water developments such as surface flow diversion, groundwater pumping, and river regulation. Many riparian plant species are dependent on shallow water tables (Jarrell and Virginia 1990, Busch et al. 1992), and reductions in water availability can reduce the extent of the riparian vegetation or cause compositional shifts from mesic to more xeric species (Rood and Mahoney 1990, Stromberg and Patten 1990, Smith et al. 1991). Impacts of such changes are great because of the disproportionate contribution of riparian ecosystems in the arid Southwest to biotic diversity.

*Prosopis velutina* (velvet mesquite) is a facultative riparian species native to the Sonoran biotic region. It survives in arid habitats, but attains maximum size and cover in riparian habitats (Campbell and Green 1968). Among the driest habitats occupied by *P. velutina* are Sonoran Desert uplands, vegetated by low densities of *Larrea tridentata*, *Ambrosia deltoidea*, and other desert scrub species that utilize precipitation and overland runoff. *Prosopis velutina* habitats with intermediate water availability include xeroriparian washes

with ephemeral surface or subsurface flow, sand dunes, and semidesert grassland savannas (Hennessy et al. 1985, Warren and Anderson 1985, Brown and Archer 1989). The wettest habitats include riverine floodplains with perennially available groundwater. In these habitats *P. velutina* forms closed-canopy forests, or bosques (Spanish for “woodland”), together with other riparian trees and shrubs including *Celtis reticulata*, *Juglans major*, and *Zizyphus obtusifolia* (Stromberg 1992). These riparian forests reach their greatest development along the higher floodplains of large, low-gradient desert rivers where they co-occur with riparian types such as *Populus fremontii*–*Salix gooddingii* forests. *Prosopis velutina* forests historically covered more land area than any other riparian type in the Southwest but have been reduced to remnant status largely because of water developments (Stromberg 1992).

Effects of water stress on *Prosopis* growth and biomass have received considerable attention from agricultural and harvestable-yield perspectives (Felker et al. 1983). Among natural ecosystems it has long been recognized that *P. velutina* growth form varies with water availability. Early researchers observed that *Prosopis* occurs as a tree rather than a shrub where groundwater is within about 15 m from the ground surface (Havard 1884, Cannon 1913) and that canopy height of riparian *Prosopis* varies with depth to groundwater (Meinzer 1927). Recent work has quantified differences

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in *Prosopis* biomass and productivity between riparian and upland stands (Sharifi et al. 1982), and described site-specific effects of groundwater decline on *P. velutina* stand structure (Stromberg et al. 1992). Recent work also has led to a thorough understanding of *Prosopis* water relations (Nilsen et al. 1983, 1984, 1986b, 1991).

Further quantification of relationships between *P. velutina* traits and water availability is important from several perspectives. As a riparian management tool, models that relate vegetation structure to water table depth could be used to predict effects of groundwater pumping on riparian ecosystems or to define minimum depths for maintenance of riparian ecosystems with a high degree of "biological integrity" (Karr 1991). From a basic ecological perspective, such information is important because it lends insight into the range of variability inherent in facultative riparian species, and the extent to which their size and productivity can be limited by water.

This study had the following objectives: (1) to quantify the structure of *P. velutina* stands as a function of water availability, as indirectly indicated by plant water potential, across an upland-to-riparian water gradient; and (2) to quantify water potential and structure of riparian *P. velutina* stands as functions of depth to groundwater.

#### STUDY SITES

Ten riparian sites (among four areas), five xeroriparian sites, and three upland sites were selected in the Sonoran Desert of south-central Arizona. Efforts were made to select undisturbed *Prosopis velutina* stands, but few of the riparian sites met this criterion because of past and present regional disturbance by livestock grazing, land-clearing, wood-cutting, and other human influences. *Prosopis velutina* trees were not aged because their dense wood is impenetrable by standard increment borers. Maximum stem diameter of *P. velutina* trees among habitat types was  $70 \pm 21$  cm (riparian),  $37 \pm 7$  cm (xeroriparian), and  $24 \pm 1$  cm (upland).

One of the riparian areas was 100 m from the edge of Cooks Lake (Pinal County, 700 m elevation,  $32^{\circ}52'$  N,  $110^{\circ}43'$  W). Two were along floodplains of perennial rivers at distances of  $\approx 100$  m from the channel (Hassayampa River in Maricopa County at 600 m elevation,  $33^{\circ}56'$  N,  $112^{\circ}41'$  W; and San Pedro River in Pinal County at 700 m,  $32^{\circ}45'$  N,  $110^{\circ}38'$  W). The fourth area was adjacent to the channel of Tanque Verde Creek (Pima County, 800 m,  $32^{\circ}15'$  N,  $110^{\circ}43'$  to  $110^{\circ}49'$  W), a river that has surface flow for an average of 195 d/yr. One site was sampled per area except along Tanque Verde Creek, where seven sites were selected in areas with differing depth to groundwater. The Tanque Verde Creek area had much spatial variation in groundwater depth because of local variation in subsurface geology and the operation of high-

capacity production wells that have been pumped in recent years to supply municipal water (Stromberg et al. 1992).

The xeroriparian sites were along ephemeral washes, including Waterman Wash (Maricopa County, 400 m elevation,  $33^{\circ}07'$  N,  $112^{\circ}22'$  W) and unnamed tributary washes to Hassayampa River, Cooks Lake, and Tanque Verde Creek. The desert upland sites were located on alluvial plains (bajadas) at the foothills of small desert mountains, within 10 km of the Hassayampa River, Cooks Lake, and Tanque Verde Creek areas.

*Prosopis velutina* was the dominant tree at all study sites. The riparian sites supported a canopy of *P. velutina*, *Sambucus mexicana*, and *Celtis reticulata*, with a shrub understory of *Zizyphus obtusifolia*, *Lycium* spp., and *Acacia greggii*. The xeroriparian washes were vegetated with a mixture of desert trees (*P. velutina*, *Cercidium floridum*, *Acacia constricta*) and shrubs (*Ambrosia deltoidea*, *Lycium* spp., *Thamnosma montana*, *Hymenoclea* spp.). The desert uplands contained mixtures of desert trees (*P. velutina*, *Cercidium microphyllum*), shrubs (*Larrea tridentata*, *Ambrosia deltoidea*), and cacti (*Ferocactus* spp.). Species names follow Lehr (1978).

#### METHODS

Vegetation variables were measured in the summer of 1990 or 1991. These included two indicators of stand biomass (leaf area index [LAI] and vegetation volume), two other indicators of stand structure (maximum canopy height and basal area of *Prosopis velutina*), and three *P. velutina* leaflet variables (primary leaflet area, primary leaflet length, and secondary leaflet number). *Prosopis velutina* in all stands contributed the majority of the canopy leaf area and vegetation volume. LAI was measured at 20 points per site (in the early morning shade) with a LICOR 2000 plant canopy analyzer (Welles 1990). Vegetation volume was measured at 20 points per site with a modified vertical line intercept technique (Mills et al. 1991). Canopy height was measured for the tallest *P. velutina* on site, and basal area of live *P. velutina* was calculated in one  $10 \times 50$  m plot per site. Leaflet variables were measured with a CID area meter (model CI-201; CID, Inc., Moscow, Idaho, USA), on ten leaflets from five *P. velutina* trees at each site.

Plant water potential was measured on three mature *P. velutina* trees per site with a Scholander-type pressure bomb (Kaufmann 1990, Koide et al. 1990). Three shoots per tree were randomly collected from the canopy with a tree trimmer. The shoots were placed on ice and measured within 5 min of harvest. Data were collected at predawn (time of least stress) and midday (greatest stress) (Stromberg et al. 1992), in May and June of 1991 (all sites) and 1990 (Tanque Verde sites only). May data represent intermediate-stress conditions for the Sonoran Desert, and June data represent high-stress conditions of low rainfall and high tem-

TABLE 1. Stand structure and leaflet size and number for *Prosopis velutina* in three habitat types in the Sonoran Desert (Arizona). Values are means  $\pm$  1SD. Values within rows followed by the same superscript letter are not significantly different at  $P < .05$  (Scheffé tests).

	Riparian	Xeroriparian	Upland
<b>Stand structure</b>			
Leaf area index (m <sup>2</sup> /m <sup>2</sup> )	1.9 $\pm$ 0.3 <sup>a</sup>	0.6 $\pm$ 0.2 <sup>b</sup>	0.1 $\pm$ 0.1 <sup>c</sup>
Vegetation volume (m <sup>3</sup> /m <sup>2</sup> )	1.8 $\pm$ 0.3 <sup>a</sup>	0.8 $\pm$ 0.1 <sup>b</sup>	0.5 $\pm$ 0.1 <sup>b</sup>
Canopy height (m)	10.3 $\pm$ 1.7 <sup>a</sup>	6.2 $\pm$ 0.8 <sup>b</sup>	4.1 $\pm$ 0.1 <sup>c</sup>
Mesquite basal area (m <sup>2</sup> /ha)	28.2 $\pm$ 5.1 <sup>a</sup>	7.5 $\pm$ 5.0 <sup>b</sup>	2.5 $\pm$ 0.6 <sup>b</sup>
<b>Leaflet characters</b>			
Primary leaflet area (cm <sup>2</sup> )	8.0 $\pm$ 1.0 <sup>a</sup>	7.4 $\pm$ 0.3 <sup>a</sup>	6.6 $\pm$ 1.3 <sup>a</sup>
Primary leaflet length (cm)	6.4 $\pm$ 0.6 <sup>a</sup>	6.2 $\pm$ 0.2 <sup>a</sup>	5.4 $\pm$ 0.7 <sup>a</sup>
Secondary leaflet number	36.5 $\pm$ 2.3 <sup>a</sup>	32.5 $\pm$ 1.6 <sup>b</sup>	31.3 $\pm$ 0.5 <sup>b</sup>

peratures. The May and June values were averaged to provide an index of average seasonal water potential. Soil salinity was assumed to be negligible, and plant water potential was assumed to be driven primarily by soil water content.

Site-specific data on depth to the water table as of summer 1991 (all sites) and 1990 (Tanque Verde sites) were obtained from several sources. At Cooks Lake a 5.1 cm diameter monitoring well with a steel drive point and 1.21-m lengths of steel pipe, was hand-driven to a depth of 6.8 m. Data for the Hassayampa and San Pedro River sites were obtained, respectively, from wells operated by the Arizona Nature Conservancy and Magma Copper Company. Data for Tanque Verde Creek sites were interpolated from groundwater depth contours developed from well data supplied by Tucson Water. A 20-yr record was obtained for one site along Tanque Verde Creek to determine whether the 1991 data were reflective of long-term means, and to determine the extent of annual fluctuation in water table depth.

To meet the first objective, empirical models were developed with nonlinear univariate regression between plant water potential (independent variable) and stand structural traits and leaflet variables (dependent variables). Plant water potential rather than soil water was measured as the independent variable because of the difficulty in measuring soil water availability across systems with multiple water sources that are used differentially (e.g., precipitation, ephemeral stream flow, and groundwater). The intent of developing models with several autocorrelated dependent variables was not to provide independent confirmation of the relationships between vegetation and water availability, but to quantify relationships with several vegetational attributes of interest. The data set for the stand-structure models excluded riparian sites with depressed water tables, because the structural traits may not have been in equilibrium. Mesquite leaflet size, in contrast, rapidly adjusts to environmental changes (Nilsen et al. 1986a).

For objective two, models for the riparian habitat type were developed between depth to groundwater

and plant water potential, canopy height, and the three leaflet variables. For the canopy height models, pre-drawdown groundwater depth values were used for the four depressed Tanque Verde sites, assuming that present-day canopy height was a function of antecedent water tables. Response curves were not developed for other structural variables that may not have been in equilibrium with either present-day or antecedent water tables, because of the small number (five) of riparian sites with stable water tables.

## RESULTS

All stand structural variables differed significantly between riparian and upland sites, based on one-way analysis of variance followed by the Scheffé test (Table 1). Leaf area index (LAI) and basal area had >10-fold differences, and vegetation volume and canopy height had 2- to 4-fold differences between riparian and upland sites. All stand structural variables also differed significantly between riparian and xeroriparian sites, but only LAI and canopy height were significantly higher at xeroriparian than upland sites. Among leaflet variables, the number of secondary leaflets per primary leaflet was significantly higher at riparian than at xeroriparian and upland sites. Primary leaflet area and length varied considerably within types and did not differ significantly between any habitat types.

Average seasonal predawn and midday water potential differed significantly among all habitat types (Table 2). Predawn and midday water potentials declined from May to June for xeroriparian and upland trees, but were constant over time for riparian trees. During May, predawn and midday values did not differ between riparian and xeroriparian trees. During June, midday values did not differ between xeroriparian and upland trees.

Water potential explained only from 8 to 13% of the variation in leaflet size or number across the xeric to mesic moisture gradient, and none of the regression models were significant at  $P < .05$  (Fig. 1, Table 3). Stand structural traits, in contrast, varied, with high significance as a function of plant water potential (Figs. 2 and 3, Table 3). Most structural traits were more

TABLE 2. Stem water potentials (in megapascals) for *Prosopis velutina* in three Sonoran Desert habitat types in 1991. Values are means  $\pm$  1 SD. Values within rows followed by the same superscript letter are not significantly different at  $P < .05$  (Scheffé tests).

		Riparian	Xeroriparian	Upland
May:	Predawn	$-0.78 \pm 0.04^a$	$-0.89 \pm 0.14^a$	$-1.87 \pm 0.23^b$
	Midday	$-2.36 \pm 0.18^a$	$-2.56 \pm 0.15^a$	$-3.57 \pm 0.12^b$
June:	Predawn	$-0.76 \pm 0.04^a$	$-1.22 \pm 0.26^b$	$-2.25 \pm 0.06^c$
	Midday	$-2.30 \pm 0.40^a$	$-3.22 \pm 0.24^b$	$-3.87 \pm 0.23^b$
Avg.:	Predawn	$-0.77 \pm 0.04^a$	$-1.06 \pm 0.19^b$	$-2.06 \pm 0.10^c$
	Midday	$-2.33 \pm 0.28^a$	$-2.89 \pm 0.18^b$	$-3.72 \pm 0.18^c$

significantly related to midday values ( $r^2$  values from 0.72 to 0.85) than to predawn values ( $r^2$  values from 0.65 to 0.68). Relationships between water potential and LAI, vegetation volume, canopy height, and basal area were curvilinear. Riparian sites with midday water potentials above  $-2.5$  MPa and predawn values above  $-0.7$  MPa had values for LAI  $> 1.0$ , vegetation volume  $> 1.2$  m<sup>3</sup>/m<sup>2</sup>, basal area  $> 20$  m<sup>2</sup>/ha, and canopy height  $> 8$  m. Upland sites had low water potentials ( $< -3.4$  MPa midday and  $< -1.9$  MPa predawn) and correspondingly low values for structural traits (e.g., LAI  $< 0.2$  and canopy height  $< 5$  m). Xeroriparian sites had values intermediate to upland and riparian sites.

Depth to groundwater in 1991 ranged from 3 to 7 m among riparian sites with stable water tables. Water table varied annually by 3.6 m at the Tanque Verde Creek site for which a 20-yr period of record was analyzed, from a maximum depth of 6.3 to a minimum of 2.7 m. Water depths at this site during 1991 (4.3 m) were within 0.1 m of the long-term average ( $4.2 \pm 1.1$  m [mean  $\pm$  1 SD]), so 1991 values probably are representative of long-term means. Depth to groundwater was substantially greater at the pumped Tanque Verde sites, ranging to 30 m below the surface in 1990 and 27 m in 1991.

Predawn and midday water potential of *P. velutina* varied significantly as a function of depth to ground-

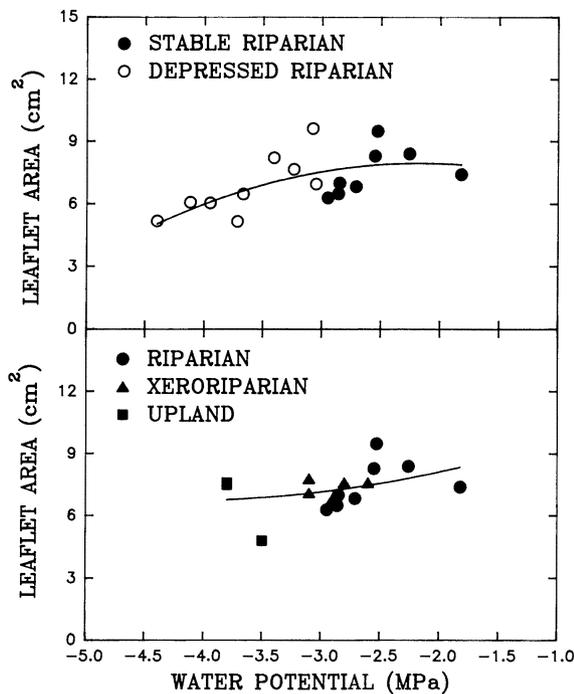


FIG. 1. Leaflet area ( $y$ ) as a function of average midday water potential ( $x$ ) for *Prosopis velutina* within riparian sites (above) and across habitat types (below) in the Sonoran Desert (Arizona). The riparian data points include sites with stable water tables as well as those recently depressed from groundwater pumping. The regression equation for the former is:  $y = 5.2 - 2.54x - 0.58x^2$ ;  $r^2 = 0.38$ ,  $df = 16$ ,  $P < .05$ . The equation was not significant at  $P < .05$  for the latter.

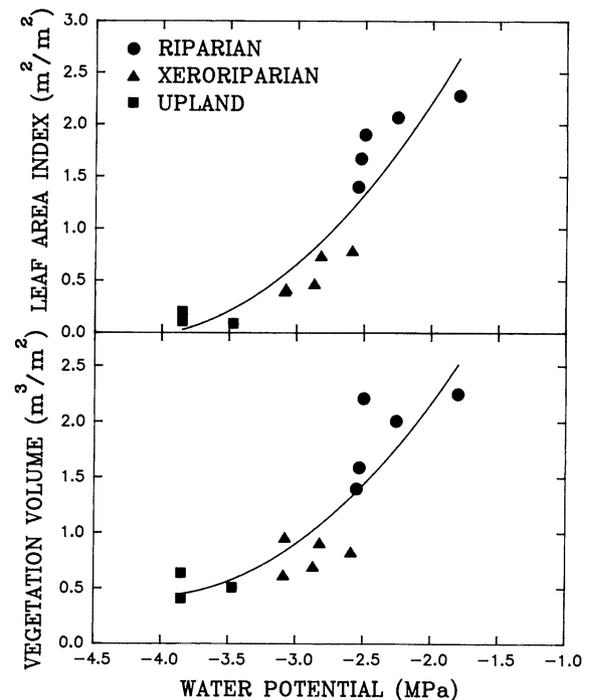


FIG. 2. Leaf area index and vegetation volume of stands dominated by *Prosopis velutina* ( $y$  variables), as functions of average midday seasonal plant water potential ( $x$ ). Respective regression equations are:  $y = 7.9 + 3.8x + 0.44x^2$ ;  $r^2 = 0.82$ ,  $df = 12$ ,  $P < .01$ ; and  $y = 7.3 + 3.4x + 0.42x^2$ ;  $r^2 = 0.76$ ,  $df = 12$ ,  $P < .01$ .

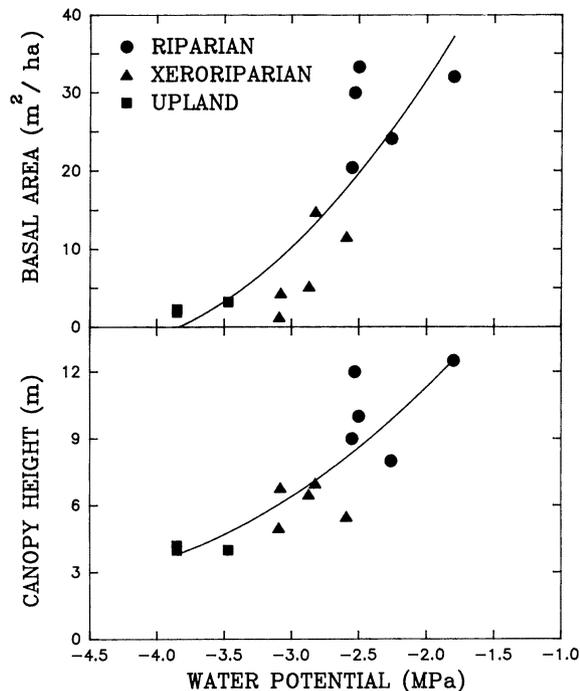


FIG. 3. Basal area and maximum canopy height of *Prosopis velutina* ( $y$  variables), as functions of average midday seasonal plant water potential ( $x$ ). Respective regression equations are:  $y = 105 + 46.6x + 5.0x^2$ ;  $r^2 = 0.72$ ,  $df = 12$ ,  $P < .01$ ; and  $y = 28 + 10x + 1.1x^2$ ;  $r^2 = 0.72$ ,  $df = 12$ ,  $P < .01$ .

water (Fig. 4). Predawn water potentials at shallow groundwater sites (e.g., <5 m depth) were above  $-1.0$  MPa, and corresponding midday values were above  $-3.0$  MPa. Predawn water potential values at sites with depressed water tables ( $\approx 30$  m depth) reached  $-2.5$  MPa, while some midday values were  $< -4.5$  MPa.

Maximum canopy height of riparian stands varied linearly as a function of depth to the water table (Fig. 5). Trees were no taller than 8 m at deep water-table sites (15 m), whereas trees attained heights greater than 12 m at sites with shallow water tables. Leaflet area, length, and number varied significantly as functions of depth to groundwater (data not shown), but relationships had relatively high scatter ( $r^2$  values from 0.16 to 0.19;  $P < .05$ ). Leaflet variables among riparian sites showed greater correspondence to plant water potential. Predawn water potential explained 29% of the variation in primary leaflet area, while midday water potential explained 38% (Fig. 1).

#### DISCUSSION

The data presented in this study indicate that upland, xeroriparian, and riparian *P. velutina* stands in the Sonoran Desert have large differences in stand structure (Table 1) and that water availability is strongly related to this variation in structural development. Canopy height, basal area, leaf area index, and vegetation volume all increased in curvilinear fashion with average

TABLE 3. Coefficients of determination ( $r^2$ ) for best-fit regression equations relating stand structure and leaflet variables to seasonal plant water potential for *Prosopis velutina*, across a xeric-to-mesic moisture gradient. All equations are second-order polynomials.

Dependent variable	Independent variable	
	Predawn water potential	Midday water potential
Stand structure		
Leaf area index	0.68**	0.85**
Vegetation volume	0.65**	0.73**
Canopy height	0.66**	0.72**
Basal area	0.65**	0.72**
Leaflet characters		
Primary leaflet length	0.08	0.08
Primary leaflet area	0.10	0.14
Secondary leaflet number	0.09	0.13

\*\* =  $P < .01$ .

seasonal plant water potential across a xeric-to-mesic moisture gradient (Figs. 2 and 3). In riparian forests, significant relationships were found between depth to groundwater and *P. velutina* plant water potential (Fig. 4) and stand structure (Fig. 5), and between water potential and leaflet area (Fig. 1).

The large range in structural characteristics between upland and riparian *P. velutina* stands contrasts sharply with findings for tree species that grow in upland and lowland sites in mesic regions (Briand et al. 1991). Factors other than water availability that may have contributed to the stand structure differences include soil nutrient contents. Soil nutrients under leguminous trees often vary with water availability (Virginia 1986), and may be more abundant in the deep, alluvial soils characteristic of riparian *P. velutina* sites than in the relatively shallow soils of upland sites that are often underlain by an impermeable layer of calcium carbonate (caliche).

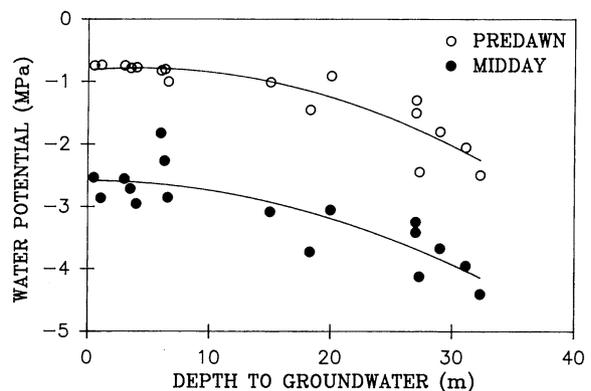


FIG. 4. Predawn and midday seasonal water potential of *Prosopis velutina* ( $y$  variables) as functions of depth to groundwater ( $x$ ). Water table depths  $> 10$  m were a result of groundwater pumping. Respective regression equations are:  $y = -0.81 + 0.015x - 0.0018x^2$ ;  $r^2 = 0.82$ ,  $df = 17$ ,  $P < .01$ ; and  $y = -2.57 + 0.0016x - 0.0014x^2$ ;  $r^2 = 0.73$ ,  $df = 17$ ,  $P < .01$ .

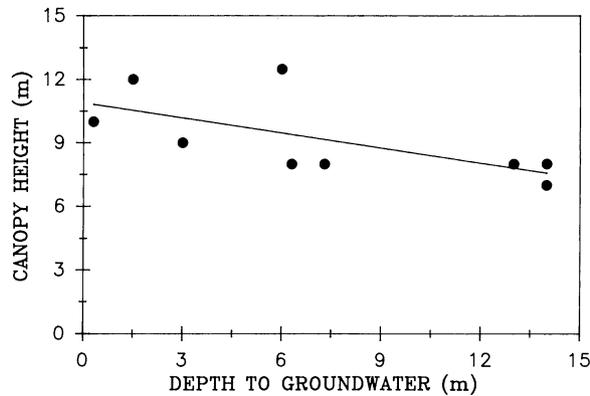


FIG. 5. Maximum canopy height ( $y$ ) of *Prosopis velutina* as a function of depth to groundwater ( $x$ ). The regression equation is:  $y = 10.9 - 0.24x$ ;  $r^2 = 0.43$ ,  $df = 8$ ,  $P < .05$ .

Genetic divergence or varying tree age between upland and riparian *P. velutina* may be other contributing factors. On the whole, populations of *P. velutina* from Sonoran Desert upland and riparian sites do not show significant measurable genetic divergence, although some allozyme systems do differ significantly (H. J. Spanglet, unpublished data). With respect to stand age, all efforts were made to select mature mesquite stands, and there is no reason to suspect that all upland sites were younger and less structurally developed than riparian sites. Whereas *Prosopis* has only recently invaded (or re-invaded) semidesert grasslands, the same is not true for stands in Sonoran desert scrub uplands (Brown and Archer 1989).

In contrast to stand structural variables, most of the leaflet variables did not vary significantly between habitat types, and were less strongly related to seasonal plant water potential across the xeric-to-mesic moisture gradient (Table 3). Within riparian sites, however, high correlations were observed between plant water potential and leaflet area in this study and in a prior study (Stromberg et al. 1992). Leaflet area of *P. velutina* may be more highly correlated with water potentials measured early in the season during the time of leaf formation, given that leaflet size of *Prosopis* adjusts seasonally to changing conditions of water availability (Nilsen et al. 1986a). During 1991, water potentials may have been high for upland and riparian trees alike because of above-average spring rainfalls. Other leaf parameters such as total leaf area per shoot or specific leaf mass may be more sensitive indicators of water stress across habitat-based water gradients.

#### MANAGEMENT APPLICATIONS

Many types of riparian ecosystems in the arid Southwest are endangered, largely because of threats to their water supply (Stromberg 1992). Thus, empirical models using both hydrologic data and vegetation structure have important management implications for riparian

ecosystems. Models integrating groundwater and stand structure of riparian *P. velutina*, for example, potentially allow a determination of groundwater requirements for riparian stand maintenance and a prediction of the effects of groundwater reduction on structural traits. The models in this study indicate, for example, that structurally rich *P. velutina* stands (e.g., those with heights >12 m) require groundwater at depths of  $\approx 6$  m or less, and that when the water table declines below this depth, continual and quantifiable decline in tree stature will occur. Similar relationships could be developed with parameters such as leaf area index and vegetation volume. Because some of these structural parameters also are used to measure avian habitat quality (Mills et al. 1991), the effects of water table decline on the density of breeding birds could be estimated by extension.

Empirical models developed with plant water-potential data also are useful for riparian management. Because plant water potential responds rapidly to changing hydrologic conditions, it is valuable as an early warning detector of change (Kelly and Harwell 1990). Thus, low water potential may indicate impending degradation of riparian *P. velutina* stands as a result of groundwater pumping before structural changes become apparent. For example, trees in sections of the Tanque Verde Creek riparian area that has been pumped for groundwater to depths of 30 m had midday water potential values below  $-4$  MPa while still retaining the appearance of a viable bosque to the casual observer. These low water-potential values are similar to those for *P. velutina* in Sonoran Desert uplands. The across-habitat models using both water potential and vegetation structure would lead one to predict that the structure of such riparian sites, if maintained at water potentials of about  $-4$  MPa, would degrade to a canopy structure typical of upland sites. Corroboration for such a prediction comes from a former riparian *P. velutina* stand along the Gila River, which underwent groundwater withdrawal to depths of >30 m in the 1930s to 1950s (Judd et al. 1971). The large, riparian *P. velutina* trees are now dead and the site is dominated by desert scrub species.

Constraints of such models must be recognized. First, the models must be considered as region-specific until shown otherwise. Riparian *P. velutina* stands in the Sonoran Desert may have different biomass and stature for a given water-table depth than do stands in semidesert grassland areas, because of regional differences in growing-season length, precipitation, temperature, and evaporation rate. Also, the vegetation-water table relationships may vary temporally with recent rainfall and aquifer recharge conditions. Data in this study indicated that water table depth can fluctuate annually by  $\approx 4$  m, and the extent of fluctuation can be greater in areas with local groundwater use (e.g., Schwalen and Shaw 1961). In addition, *P. velutina* in some riparian systems may obtain water from sources other than

groundwater. If so, water table models may sometimes be inappropriate. Other potential water sources include shallow soil water supplied by recent precipitation, floods, or lateral seepage of surface flow into floodplain soils. However, although periodic inputs of shallow soil moisture are an important water source for riparian stands undergoing groundwater withdrawal, groundwater is the primary water source for riparian *P. velutina* (Stromberg et al. 1992). Stable isotope studies (e.g., Flanagan and Ehleringer 1991) might help clarify the sources of water for riparian vegetation.

Caveats are also in order with respect to models based on plant water potential. First, pre-conditioning from prior water stress can alter plant water relations, by causing stomatal closure at higher water potentials (Clemens and Jones 1978). Second, stand thinning caused by water diversion may lead to reduced competition for water and thus to higher-than-expected water potentials for the remaining plants (Schlesinger et al. 1989). Finally, water potential values used to develop the models may vary with annual or seasonal climatic conditions, particularly for upland stands that grow in a highly stochastic rainfall environment. The accuracy of the curves would undoubtedly be improved by increasing the seasonal and annual frequency of water potential measurements and by exploring relationships between water potential and rising and falling water-table conditions, but are useful first approximations for predicting effects of water reduction on riparian habitat. Water potential models highlight the sensitivity of all *P. velutina* stands, including those in threatened riparian habitat, to even small reductions in water supply.

Further research is needed to determine whether the relationships described for *P. velutina* can be developed for other riparian species. Water potential is an appropriate indicator of internal water stress for *Prosopis*, in part because of the plant's capacity for extensive osmoregulation and large fluctuations (2.5 MPa) in diurnal water potential (Nilsen et al. 1984). Stomatal conductance measurements are a critical adjunct to water potential measurements for riparian species such as *Salix* or *Populus* that show confounding responses including incomplete nighttime stomatal closure (Kelliher et al. 1980, Williams 1989).

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#### LITERATURE CITED

- Briand, C. H., U. Posluszny, D. W. Larson, and U. Matthes-Sears. 1991. Patterns of architectural variation in *Thuja occidentalis* L. (eastern white cedar) from upland and lowland sites. *Botanical Gazette* 152:494-499.
- Brown, J. R., and S. Archer. 1989. Woody plant invasion of grasslands: establishment of mesquite *Prosopis glandulosa* var. *glandulosa* on sites differing in herbaceous biomass and grazing history. *Oecologia* (Berlin) 80:19-26.
- Busch, D. E., N. L. Ingraham, and S. S. Smith. 1992. Water uptake in woody riparian phreatophytes of the southwestern United States: a stable isotope study. *Ecological Applications* 2:450-459.
- Campbell, C. J., and W. Green. 1968. Perpetual succession of stream-channel vegetation in a semiarid region. *Journal of the Arizona Academy of Science* 5:86-98.
- Cannon, W. A. 1913. Some relations between root characters, ground water and species distribution. *Science* 37:420-423.
- Clemens, J., and P. G. Jones. 1978. Modification of drought resistance by water stress conditioning in *Acacia* and *Eucalyptus*. *Journal of Experimental Botany* 29:895-904.
- Felker, P., G. H. Cannell, P. R. Clark, J. F. Osborn, and P. Nash. 1983. Biomass production of *Prosopis* species (mesquite) and other leguminous species grown under heat/drought stress. *Forest Science* 29:592-606.
- Flanagan, L. B., and J. R. Ehleringer. 1991. Stable isotope composition of stem and leaf water: applications to the study of plant water use. *Functional Ecology* 5:270-277.
- Havard, V. 1884. The mezquit. *American Naturalist* 18:450-459.
- Hennessey, J. T., R. P. Gibbons, J. M. Tromble, and M. Cardenas. 1985. Mesquite (*Prosopis glandulosa* Torr.) dunes and interdunes in southern New Mexico: a study of soil properties and soil water relations. *Journal of Arid Environments* 9:27-38.
- Jarrell, W. M., and R. A. Virginia. 1990. Soil cation accumulation in a mesquite woodland: sustained production and long-term estimates of water use and nitrogen fixation. *Journal of Arid Environments* 18:51-58.
- Judd, I. B., J. M. Laughlin, H. R. Guenther, and R. Handergate. 1971. The lethal decline of mesquite on the Casa Grande National Monument. *Great Basin Naturalist* 31:153-159.
- Karr, J. R. 1991. Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications* 1:66-84.
- Kaufmann, M. R. 1990. Ecophysiological processes affecting tree growth: water relationships. Pages 64-80 in R. K. Dixon, R. S. Meldahl, G. A. Ruark, and W. G. Warren, editors. *Process modeling of forest growth responses to environmental stress*. Timber Press, Portland, Oregon, USA.
- Kelliher, F. M., M. B. Kirkham, and C. G. Tauer. 1980. Stomatal resistance, transpiration, and growth of drought-stressed eastern cottonwood. *Canadian Journal of Forest Research* 10:447-451.
- Kelly, J. R., and M. A. Harwell. 1990. Indicators of ecosystem recovery. *Environmental Management* 14:527-545.
- Koide, R. T., R. H. Robichaux, S. R. Morse, and C. M. Smith. 1990. Plant water status, hydraulic resistance and capacitance. Pages 161-183 in R. W. Pearcy, H. A. Ehleringer, H. A. Mooney, and P. W. Rundell, editors. *Plant physiological ecology—field methods and instrumentation*. Chapman and Hall, London, England.
- Lehr, J. H. 1978. A catalogue of the flora of Arizona. Desert Botanical Garden, Phoenix, Arizona, USA.
- Meinzer, O. E. 1927. Plants as indicators of ground water. U.S. Geological Survey Water Supply Paper 577. U.S. Government Printing Office, Washington, D.C., USA.
- Mills, G. S., J. B. Dunning, Jr., and J. M. Bates. 1991. The relationship between breeding bird density and vegetation volume. *Wilson Bulletin* 103:468-479.
- Nilsen, E. T., M. R. Sharifi, and P. W. Rundel. 1984. Comparative water relations of phreatophytes in the Sonoran Desert of California. *Ecology* 65:767-778.
- Nilsen, E. T., M. R. Sharifi, and P. W. Rundel. 1991. Quantitative phenology of warm desert legumes: seasonal growth

- of six *Prosopis* species at the same site. *Journal of Arid Environments* **20**:299–311.
- Nilsen, E. T., M. R. Sharifi, P. W. Rundel, W. M. Jarrell, and R. A. Virginia. 1983. Diurnal and seasonal water relations of the desert phreatophyte *Prosopis glandulosa* (honey mesquite) in the Sonoran Desert of California. *Ecology* **64**:1381–1393.
- Nilsen, E. T., M. R. Sharifi, P. W. Rundel, and R. A. Virginia. 1986a. Influences of microclimatic conditions and water relations on seasonal leaf dimorphism of *Prosopis glandulosa* var. *torreyana* in the Sonoran Desert, California. *Oecologia* (Berlin) **69**:95–100.
- Nilsen, E. T., R. A. Virginia, and W. M. Jarrell. 1986b. Water relations and growth characteristics of *Prosopis glandulosa* var. *torreyana* in a simulated phreatophytic environment. *American Journal of Botany* **73**:427–433.
- Rood, S. B., and J. M. Mahoney. 1990. Collapse of riparian poplar forests downstream from dams in western prairies: probable causes and prospects for mitigation. *Environmental Management* **14**:451–464.
- Schlesinger, W. H., P. J. Fonteyn, and W. A. Reiners. 1989. Effects of overland flow on plant water relations, erosion, and soil water percolation on a Mojave Desert landscape. *Soil Science Society of America Journal* **53**:1567–1572.
- Schwalen, H. C., and R. J. Shaw. 1961. Water in the Santa Cruz Valley. Report number 205. University of Arizona Agricultural Experiment Station, Tucson, Arizona, USA.
- Sharifi, M. R., E. T. Nilsen, and P. W. Rundel. 1982. Biomass and net primary production of *Prosopis glandulosa* (Fabaceae) in the Sonoran Desert of California. *American Journal of Botany* **69**:760–767.
- Smith, S. D., A. B. Wellington, J. L. Nachlinger, and C. A. Fox. 1991. Functional responses of riparian vegetation to streamflow diversion in the eastern Sierra Nevada. *Ecological Applications* **1**:89–97.
- Stromberg, J. C. 1992. Riparian mesquite forests: a review of their ecology, threats, and recovery potential. *Journal of the Arizona–Nevada Academy of Science*, *in press*.
- Stromberg, J. C., and D. T. Patten. 1990. Riparian vegetation instream flow requirements: a case study from a diverted stream in the eastern Sierra Nevada, California. *Environmental Management* **14**:185–194.
- Stromberg, J. C., J. A. Tress, S. D. Wilkins, and S. D. Clark. 1992. Response of velvet mesquite to groundwater decline. *Journal of Arid Environments* **23**:45–58.
- Virginia, R. A. 1986. Soil development under legume tree canopies. *Forest Ecology and Management* **16**:69–79.
- Warren, P. L., and L. S. Anderson. 1985. Gradient analysis of a Sonoran Desert wash. Pages 150–155 in R. R. Johnson, C. D. Ziebell, D. R. Patton, P. F. Ffolliott, and R. H. Hamre, technical coordinators. *Riparian ecosystems and their management: reconciling conflicting uses*. General Technical Report RM-120. USDA Forest Service, Fort Collins, Colorado, USA.
- Welles, J. M. 1990. Some indirect methods of estimating canopy structure. *Remote Sensing Reviews* **5**:31–43.
- Williams, J. G. 1989. Interpreting physiological data from riparian vegetation: cautions and complications. Pages 381–386 in D. L. Abell, technical coordinator. *Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990s*. General Technical Report PSW-110. USDA Forest Service, Berkeley, California, USA.