

TRANSPIRATION OF OAK TREES IN THE OAK SAVANNAS OF THE SOUTHWESTERN BORDERLANDS REGION

Peter F. Ffolliott,¹ Cody L. Stropki,¹ Aaron T. Kauffman,¹ and Gerald J. Gottfried²

Transpiration of oak trees on the Cascabel watersheds in the savannas on the eastern slope of the Peloncillo Mountains in southwestern New Mexico has been estimated by the sap-flow method. Transpiration represents the largest loss of gross precipitation falling on a watershed in approximations of water budgets for the more densely stocked oak woodlands of the Southwestern Borderlands region (Ffolliott 2000, 2004, Shipek et al. 2004). Knowledge of transpiration is also important, therefore, in developing a general water budget for this more open ecosystem. An initial estimate of the transpiration of oak trees in the oak savannas of the Southwestern Borderlands region is presented in this paper.

STUDY AREA

Twelve small watersheds have been instrumented and sampled in the Peloncillo Mountains to study the effects of cool season (November-April) and warm-season (May-October) prescribed burning on the multiple resources of oak savannas in the Southwestern Borderlands. The watersheds are located near the Cascabel Ranch in the eastern part of the Coronado National Forest near the Animas Valley of southwestern New Mexico. The watersheds are 5,380 to 5,590 feet in elevation. The weather station at the Cascabel Ranch headquarters indicates that annual precipitation in the vicinity of the watersheds averages 21.8 " 1.2 inches, with more than one-half falling in the summer monsoon from late June through early September. However, a prolonged drought impacted the Southwestern Borderlands region from the middle 1990s to the present time. Annual precipitation during this drought period has averaged 14.9 inches. Geological, edaphic, hydrologic, and vegetative characteristics of the

Cascabel Watersheds have been described by Gottfried et al. (2007) and, therefore, are not included in this paper.

STUDY METHODS

Instantaneous transpiration of 16 Emory oak (*Quercus emoryi*) trees, the dominant oak species on the Cascabel Watersheds, was measured with a sap-flow meter (Swanson and Whitfield 1981, Swanson 1994, Schaeffer et al. 2000) in the late spring, summer, and early fall of 2004. The measured trees were located on two transects oriented perpendicular to the main stream channel on each of two Cascabel Watersheds, specifically, Watersheds E and I (Gottfried et al. 2007). Two of the trees were situated on the southerly aspect and two trees on the northerly aspect of each transect for a total of 16 measured trees. The trees ranged in diameter (root collar) from 6 to 14 inches. Parenthetically, errors of 5 to 15 percent are commonly associated with the measurement of instantaneous transpiration of individual plants with a sap-flow meter (Shuttleworth 2008).

The instantaneous measurements of transpiration of the Emory oak trees measured were transformed into approximations of daily transpiration by applying the equations of Barret et al. (1995) and Schaeffer et al. (2000). The resulting estimates of daily transpiration were considered to be a proxy for other oak species on the Cascabel Watersheds. Emory oak represented 75.5 percent of the oak trees on these watersheds, with Arizona white oak (*Q. arizonica*) and Toumey oak (*Q. toumeyii*) comprising 14.3 and 10.2 percent, respectively.

Earlier studies of transpiration in the oak woodlands on the southern slope of the Huachuca Mountains indicated that values of daily transpiration of oak trees cycled through time on an annual basis, ranged from relatively high values of transpiration following the summer monsoons and winter rains to intervening low values (Ffolliott and Gottfried 1999). It was hypothesized by the authors of this paper that this cycle of annual transpiration

¹School of Natural Resources, University of Arizona, Tucson, Arizona

²Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona

rates also applies in the oak savannas. To test this hypothesis, the estimates of daily transpiration rates obtained for the oak trees on the Cascabel Watersheds were plotted on a figure representing this cycle in the oak woodlands of the Huachuca Mountains (Figure 1).

and their respective drc values was coupled with the Cascabel stand table, which presented tree frequency per acre, to obtain the estimate of annual transpiration in area-inches. Information on the frequency of oak trees was obtained from an earlier inventory of the tree overstories on the watersheds (Gottfried et al. 2007).

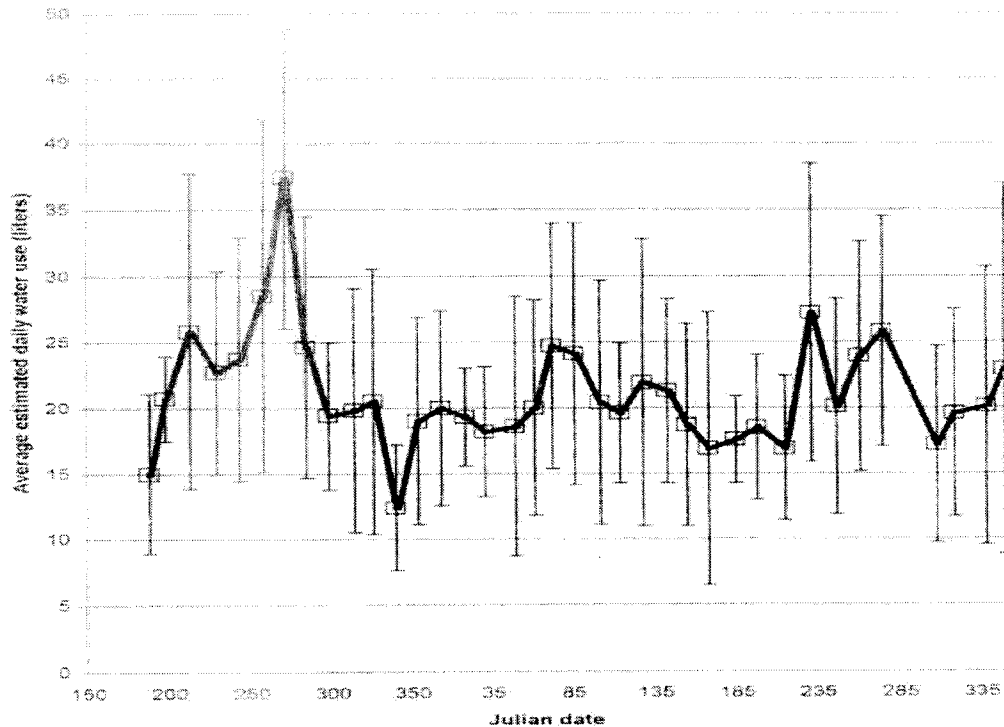


Figure 1. Average daily transpiration rates (with standard deviations) by oak trees in the woodlands of the Huachuca Mountains. (Source Ffolliott and Gottfried 1999.)

All of these plotted estimates fell within the confidence intervals in this figure. It was concluded, therefore, that the cycle illustrated in the figure is applicable to the oak savannas. It was further concluded that the relationship between annual transpiration and the drc of oak trees in the oak woodlands on the Huachuca Mountains (Figure 2) is also representative of the oak savannas on the Cascabel Watersheds. Relationship illustrated in figure 2 became a basis for obtaining an estimate of annual transpiration of the oak trees in the oak savannas in terms of area-inches. The relationship between estimated annual transpiration of oak trees

RESULTS AND DISCUSSION

The estimated annual transpiration of the oak trees in the oak savannas on the Cascabel Watersheds is nearly 4.8 area-inches. This estimate is about 60 percent of the annual transpiration of mature oak trees (60 years and older) in a stand on the Huachuca Mountains (Ffolliott and Gottfried 1999, Ffolliott et al. 2003). The last (known) harvest in the Huachuca stand selectively removed larger oak trees for mining timbers in 1895, and, therefore, the stand appeared to be largely representative of structure of uncut stands in the region when sap-flow measurements to estimate transpiration were made in 1997-1998. The lower value for annual transpiration in the oak

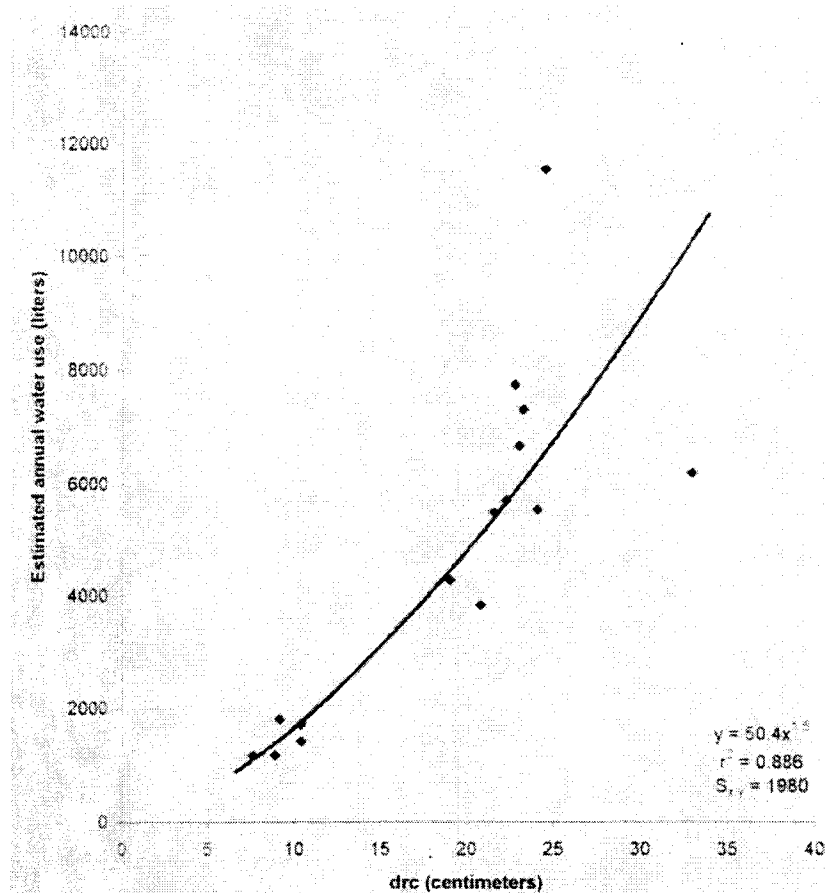


Figure 2. Relationship between annual transpiration and drc (diameter root collar) of oak trees in the woodlands of the Huachuca Mountains.

savannas is attributed largely to the smaller number of oak trees in the oak savannas compared to the oak woodlands. The average number of oak trees on the Cascabel Watershed is 42.6 stems per acre (Ffolliott and Gottfried 2005), while that in the sampled stand in the oak woodlands on the Huachuca Mountains was 183.1 stems per acre (Ffolliott et al. 2003).

Annual transpiration of oak trees can also be expressed as a percent of annual precipitation. An arbitrary annual precipitation value of 450 millimeters (about 17.7 inches) had been selected earlier as a basis to present this percentage for varying stand conditions and silvicultural treatments in the oak woodlands on the Huachuca Mountains in earlier studies (see Table 1 in Ffolliott 2004). This precipitation value is within a range of the variable annual precipitation amounts occurring in the oak

ecosystems in the region. Accepting this value as a basis for developing a similar expression for the transpiration of oak trees in the oak savannas indicated that the annual transpiration of the oak trees on the Cascabel Watersheds is approximately 30 percent of annual precipitation. Comparisons of this value with the relationships obtained for the different stand conditions and silvicultural treatments in the oak woodlands are shown in figure 3.

The most valid comparison presented in figure 3 is that between the annual transpiration of oak trees in the oak savannas on the Cascabel Watersheds and the oak trees in the uncut stand of mature oak trees in the oak woodlands of the Huachuca Mountains (Ffolliott and Gottfried 1999, Ffolliott et al. 2003). These two sites are generally similar in the past and present land-use practices imposed on them. The

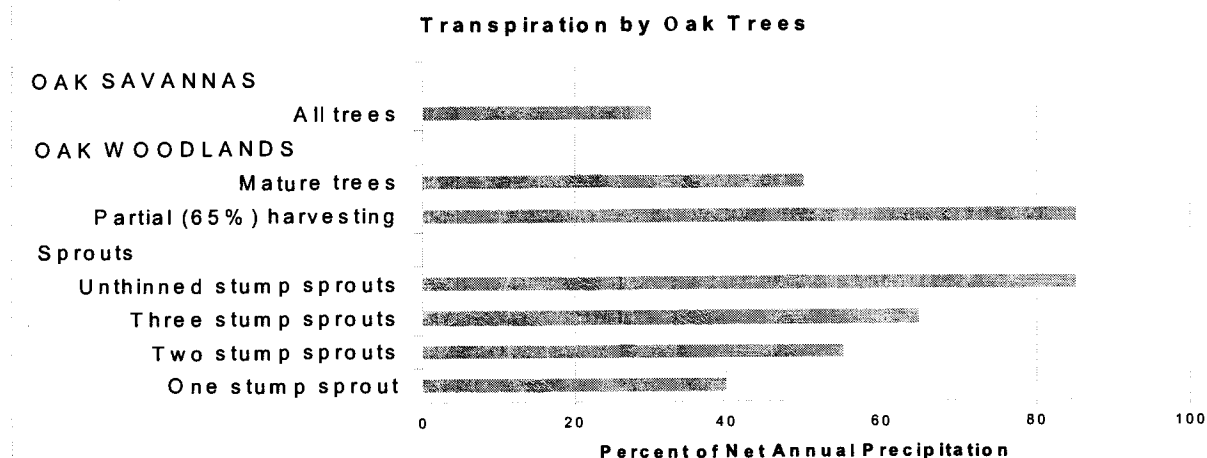


Figure 3. Annual transpiration of oak trees in the oak savannas as a percent of the (arbitrarily) selected annual precipitation value of 450 millimeters (about 17.7 inches) and varying stand conditions and silvicultural treatments in the oak woodlands on the Huachuca Mountains. Percentages for the oak woodlands were obtained from the studies reported by Ffolliott and Gottfried (1999), Ffolliott et al. (2003), Ffolliott (2004), and Shipek et al. (2004).

other comparisons presented in the figure are offered for information only.

The partial firewood harvest removed 65 percent of the mature oak trees in the oak woodlands of the Huachuca Mountains in 1981. Transpiration of the residual mature oak trees and the resulting stump sprouts (combined) was measured with a sap flow meter in 1997-1998 approximately 16 years after the firewood harvest. One factor contributing to the greater estimated transpiration in this stand was the large number of stump sprouts (Ffolliott and Gottfried 1999). Although the number of residual mature oak trees in this stand was (statistically) similar to the number of trees in the uncut stand of mature oak trees, there was a (very) large number of post-harvest stump sprouts. Even though the estimated transpiration of an individual stump sprout was comparatively small, the large number of sprouts in the stand translated into the greater annual transpiration value (Figure 3). There were 370.2 stump sprouts per acre in the stand when the measurements of transpiration were made (Ffolliott and Gottfried, Ffolliott et al. 2003). This number of sprouts was considerably larger than that normally found in the oak woodlands (Touchan 1988).

The stump-sprouts on rootstocks of some of the

trees in the harvested stand were thinned to one, two, and three of the dominant sprouts in 1984 to evaluate the effects of coppice thinning treatments on residual growth and volume (Bennett 1988, Touchan and Ffolliott 1999, Farah et al. 2003). Transpiration was measured with a sap-flow meter on 16 of these rootstocks representing each of these thinning treatments and an unthinned control in 2000, approximately 20 years following the firewood harvest (Shipek et al. 2004). Expressions of these annual transpiration values as a percent of the annual precipitation amount selected in the earlier studies are also shown in figure 3. Note that the transpiration of stump sprouts on the unthinned root-stocks is similar to the transpiration of stump sprouts in the partially harvested site, because of the overwhelming dominance of stump sprouts.

CONCLUSIONS

Annual transpiration of oak trees in the oak savannas is about 60 percent of the annual transpiration in a stand of mature oak trees in the oak woodlands. The lower value estimated for the oak savannas was likely due to differences in the densities of oak trees in the two ecosystems. The number of oak trees in the oak savannas is less than

that in the oak woodlands. Further study is necessary, however, to verify or refine this initial estimate. Also, other tree species including alligator juniper, border pinyon, and the tree-form of mesquite are often present in the oak savannas, and, therefore, an estimate of the transpiration for these trees species is required to obtain a comprehensive estimate of transpiration in this ecosystem.

Knowledge of the transpiration by herbaceous plants on the Cascabel Watersheds would strengthen our understanding of water use by most components of the vegetative community. These data combined with existing measurements of precipitation and streamflow would then facilitate more accurate estimates of the water balance of the Southwestern Borderlands Region.

ACKNOWLEDGMENT

This study and the preparation of this paper was supported by the Southwestern Borderlands Ecosystem Management Project of the Rocky Mountain Research Station, U.S. Forest Service, Phoenix, Arizona, and the Arizona Agricultural Experiment Station, University of Arizona, Tucson, Arizona.

REFERENCES

- Barret, D. J., T. J. Hatton, J. E. Ash, and M. C. Ball. 1995. Evaluation of the heat pulse velocity technique for measurement of sapflow in rainforest and eucalypt forest species of southeastern Australia. *Plant, Cell and Environment* 18:463-469.
- Bennett, D. A. 1988. Effects of coppice treatment on Emory oak. In: Ffolliott, P. F., and J. D. Hasbrouck, editors. *Oak woodland management: Proceedings of the workshop*. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, pp. 31-37.
- Farah, M. H., P. F. Ffolliott, and G. J. Gottfried. 2003. Growth and volume of Emory oak coppice 10 years after thinning. *Western Journal of Applied Forestry* 18:77-80.
- Ffolliott, P. F. 2000. An annual water budget for Emory oak woodlands: An initial approximation. *Hydrology and Water Resources in Arizona and the Southwest* 30:37-41.
- Ffolliott, P. F. 2004. A water budget for Emory oak woodlands of southeastern Arizona: An expansion of the initial approximation. *Hydrology and Water Resources in Arizona and the Southwest* 34:11-14.
- Ffolliott, P. F., and G. J. Gottfried. 1999. Water use by Emory oak in southeastern Arizona. *Hydrology and Water Resources in Arizona and the Southwest* 29:43-48.
- Ffolliott, P. F., and G. J. Gottfried. 2005. Vegetative characteristics of oak savannas in the Southwestern United States: A comparative analysis with oak woodlands in the region. In: Gottfried, G. J., B. S. Gebow, L. G. Eskew, and C. B. Edminster, compilers. *Connecting mountain islands and desert seas: Biodiversity and management of the Madrean Archipelago*. U.S. Forest Service, Proceedings RMRS-P-36, 399-402.
- Ffolliott, P. F., G. J. Gottfried, Y. Cohen, and G. Schiller. 2003. Transpiration by dryland oaks: Studies in the south-western United States and northern Israel. *Journal of Arid Environments* 55 (2003):595-605.
- Gottfried, G. J., D. G. Neary, and P. F. Ffolliott. 2007. An ecosystem approach to determining the effects of prescribed fire on Southwestern Borderlands oak savannas: A baseline study. In: Masters, R. E., and K. E. M. Galley, editors. *Fire in grassland and shrubland ecosystems. Proceedings of the 23rd Tall Timber Fire Ecology Workshop*, Tall Timbers Research Station, Tallahassee, Florida, pp. 140-146.
- Shipek, D. C., P. F. Ffolliott, G. J. Gottfried, and L. F. DeBano. 2004. Transpiration and multiple use management of thinned Emory oak coppice. U.S. Forest Service, Research Paper RMRP-RP-48, 8 p.
- Schaeffer, S. M., D. G. Williams, and D. C. Goodrich. 2000. Transpiration of cottonwood/willow forest estimated from sap flux. *Agriculture and Forest Meteorology* 105(2000):257-270.
- Shuttleworth, W. J. 2008. Evapotranspiration measurement methods. *Southwest Hydrology* 7(1):22-23.

- Swanson, R. H. 1994. Significant historical developments in thermal methods for measuring sap flow in trees. *Agriculture and Forest Meteorology* 72:113-132.
- Swanson, R. H., D. W. A. Whitfield. 1981. A numerical analysis of heat pulse velocity theory and practice. *Journal of Experimental Botany* 32(126):221-239.
- Touchan, R. 1988. Growth and yield of Emory oak. In: Ffolliott, P. F., and J. D. Hasbrouck, editors. *Oak woodland management: Proceedings of the workshop*. School of Renewable Natural Resources, University of Arizona, Tucson, Arizona, pp. 11-18.
- Touchan, R., and P. F. Ffolliott. 1999. Thinning of Emory oak coppice: Effects on growth, yield, and harvesting cycles. *The Southwestern Naturalist* 44:1-5.