Proceedings—Fire Effects on Rare and Endangered Species and Habitats Conference, Nov. 13-16, 1995. Coeur d'Alene, Idaho.

Development and Management of Mesquite Savanna Using Low Intensity Prescribed Fires

R. J. Ansley, B.A. Kramp and T.R. Moore

Assistant Professor and Research Associates,
Texas A&M Agricultural Experiment Station, P.O. 1658, Vernon, TX 76384
Tel. (817) 552-9941; Fax (817) 553-4657; E-mail r-ansley@tamu.edu

Abstract. Density of honey mesquite (*Prosopis glandulosa*) has increased in the southwest USA during the last century. Mesquite in dense thickets reduce grass production and plant species diversity. Prescribed fire is currently the least environmentally challenged and most economically sustainable option to manage mesquite. However, few mesquite over 1 year old are completely killed by fire. Moreover, the current treatment of choice, high intensity winter fire, kills above-ground portions of mesquite (topkill) and stimulates sprouting from stem bases. Regrowth mesquite form a thicket within a few years. Our objective was to examine the potential of low intensity fires to convert mesquite thickets into savannas. Mean topkill (plants with complete above ground mortality) from single low intensity fires ranged from 7-17%. Topkill remained less than 28% with repeated low intensity fires. Most topkilled mesquite were < 1.5 m tall. Mean canopy foliage reduction from single low intensity fires ranged from 21 to 58%. In most taller mesquite (> 2 m) lower-positioned growing points were killed, but not main support stems, and foliage was retained in the upper canopy. The appearance was similar to a browse-line. Most mesquite which retained 40% or more of pre-burn foliage maintained apical dominance and did not basal sprout. Low fire intensity was maintained by burning under specific weather conditions and fuel loads. Intensities ranged from 164 to 1200 kW/m. We hypothesize that repeated low intensity fires have potential for low-cost, sustainable management of mesquite-dominated rangelands as savannas.

Introduction

Historical and current theories suggest encroachment of the arborescent legume, honey mesquite (*Prosopis glandulosa*), on southwest USA grasslands during the last century has been due in part to the reduction of naturally occurring fires and enhanced seed distribution via domestic livestock (Humphrey 1949, Smeins 1983, Archer 1989). Today most mesquite occur as multistemmed thickets which occur after repeated use of nonlethal chemical or mechanical treatments that kill above-ground tissue (topkill) but have little impact on root mortality (Fisher et al. 1959). This process, repeated over the years, stimulates regrowth from stem bases and increases stem number per plant and per land area. Mesquite in dense thickets reduce understory herbaceous production and impair wildlife habitat quality by reducing plant species diversity. Mesquite thickets also reduce visibility for livestock management. The option of repeated nonlethal treatments may decrease in the future because of costs, environmental concerns, and a greater appreciation of potential benefits of woody plants (Jacoby and Ansley 1991).

Prescribed fire is currently one of the the least environmentally challenged and most economically sustainable mesquite management options. However, the full potential of fire alone or in combination with other treatments has not been realized. Fire is not without limitations and very few mesquite over 1 year old are completely killed by fire (Wright et al. 1976, Ansley et al. 1994). Moreover, the current treatment of choice, high intensity winter fire, topkills mesquite and stimulates sprouting from stem bases (Wright and Bailey 1982). If left untreated, regrowth mesquite form a thicket within 10 to 15 years.

Historical accounts identified mesquite as a natural part of southwest rangelands (Bartlett 1854, Marcy 1866). If true, then it is necessary to better understand potential benefits of this species for soil fertility, wildlife habitat and subcanopy microclimate modification. A mesquite savanna, or a relatively low density of large trees, may offer a management alternative which maximizes benefits and minimizes negative impacts of this species.

Researchers have suggested fire as a fundamental process in mesquite savanna management, but specific technology for converting savannas from thickets is unknown (Trollope 1984, Jacoby 1985). Consideration must be given to landscape distribution as well as architecture of individual trees. Mesquite growth form is a fundamental consideration in savanna development because of the potential for rapid regrowth following topkill (Hamilton et al. 1981). We hypothesize that low intensity fires will reduce mesquite canopy foliage, thereby reducing competition with understory grasses, and simultaneously preserve apical dominance and the arborescent structure. Our objectives were to (1) quantify effects of low intensity fires on mesquite vertical structure, (2) develop a predictive capability for implementation of low intensity fires and (3) determine the potential of low intensity fires for conversion of mesquite woodlands to savannas.

Methods and Materials

Research was conducted from 1991 to 1995 on 2 fenced exclosures in the northern Rolling Plains ecological area of Texas: Ninemile pasture on the Waggoner Ranch south of Vernon (33° 51'N, 99° 26'W; elev. 381 m), and River pasture on the Y Ranch west of Crowell (33° 53'N, 100° 00'W; elev. 472 m). Mean annual rainfall at Ninemile is 665 mm. Soils are fine, mixed, thermic Typic Paleustolls of the Tillman series which are alluvial clay loams to 3-4 m depth, underlain by Permain sandstone/shale parent material (Koos et al. 1962). Mesquite at Ninemile were multistemmed, 1-6 m tall and at 200-500 trees ha^{-1}. Primary C3 grass species are Texas wintergrass (*Stipa Leucotricha*) and Texas bluegrass (*Poa arachnifera*), and C4 species are buffalograss (*Buchloe dactyloides*) and meadow dropseed (*Sporobolus asper* var. *drummondii*).

Mean annual rainfall at River Pasture is 450 mm. Soils are fine-silty, montmorillonitic, thermic Typic Haplusterts of the Hollister series. Mesquite occurred at densities similar to Ninemile but had more stems per plant and were shorter (1-4 m). Primary grass species are tobosagrass (*Hilaria mutica*) and buffalograss. A topkilling herbicide (2,4,5-T) was sprayed commercially on mesquite at Ninemile in 1965 and at River Pasture in 1983. Livestock grazing was excluded at Ninemile since 1986 and River pasture since 1994.

Nine 2-ha plots were established at Ninemile in 1991 to evaluate low intensity fires for savanna development. Treatments included 3 replicates each of low intensity fires in winter 1991 (W91), 1993 (W93) or 1995 (W95), repeated winter fires in 1991 and 1993 (W91+W93) and 1991, 1993 and 1995 (W91+W93+W95), and repeated fires in winter and summer 1993 (W93+S93). Savanna fire treatments were initiated at River pasture in 3 replicate 1-ha plots in the winter of 1995. Other fire treatments at both sites included repeated high intensity winter and summer fires designed to maximize topkill.

Low intensity fires were conducted as headfires under low to moderate fine fuel amounts, high humidity, and/or low air temperature. Understory herbaceous fine fuel amount (litter + standing crop) in interspaces between trees, fuel moisture content, wind speed and direction, air temperature, and relative humidity (RH) were measured prior to each fire. Fire temperatures were measured at 1-sec intervals using glass-insulated type K (Chromel-Alumel) thermocouple wire (20 AWG; 0.8 mm diam.) overbraided with stainless steel and a Campbell CR7 datalogger placed in a fireproof container (Jacoby et al. 1992). Temperature was measured at 0, 0.1, 0.3, 1, 2, and 3 m above ground at each of 3 to 6 locations per plot. Flame length was estimated with video tape and metered standards in each plot. Fire intensity was quantified using the flame length equation of Byram (1959), $I = 5.7L^{2.2}$, where I = fireline intensity (btu/ft/s) and L = flame length (ft). Intensity values were converted to kW/m. Fire temperature was also used to qualitatively assess fire intensity. Estimation of fire intensity from scorch height measurements (after Van Wagner 1973) was unreliable because in many trees, smaller branches at the top of the canopy with thinner bark were killed by the convection column, yet axillary meristems along the larger more insulated stems below were released from dormancy.

Fifty to 60 mesquite were evaluated along permanently marked line transects in each plot for topkill, canopy foliage reduction of non-topkilled (NTK) trees, and basal resprout growth during the growing season following each fire. Foliage reduction was estimated for individual plants by ocular estimate. Relationship between the amount of remaining tree foliage and basal regrowth was determined. Data were pooled within each treatment replicate prior to determination of treatment means.

Results

Winter low intensity fires were conducted at mean air temperatures between 13 and 20°C (52-68°F) and relative humidities near or above 30% (Table 1). Summer low intensity fires (W93+S93) were conducted at air temperatures near 32°C (90°F) and RH near 35% but fine fuel was low because these plots had been burned 8 months earlier. Mean fine fuel ranged from 1540to 2779 kg/ha at Ninemile and was 2585 kg/ha at River pasture. Mean wind speed ranged from 10.2 to 16.1 kph. Moderate wind was needed to move winter low intensity fires because fires were conducted under relatively high RH and low air temperatures.

Peak temperature of low intensity winter fires occurred at 0.1 or 0.3 m above ground and ranged from 408 to 690°C. Mean peak fire temperature usually did not exceed 500°C and duration above 300°C was no more than 20 sec (Table 1). In contrast, mean peak temperature in high intensity fires usually exceeded 600°C and duration over 300°C was 40-70 sec (data not shown). Greatest differences in peak temperature between high and low intensity fires occurred at 1, 2 and 3 m heights (Figure 1).

Average flame length per plot of low intensity fires ranged from 0.8 to 2.0 m and fireline intensity ranged from 164 to 1236 kW/m. Flame length and fire intensity of high intensity fires at both sites from 1991-1995 ranged from 2 to 5 m and 1236 to 9281 kW/m, respectively (data not shown).

Table 1. Weather, fuel and mesquite response data from low intensities fires conducted on 2 sites in north Texas from 1991 to 1995. Values are means of 3 treatment replicates with 1 standard error in parentheses. Foliage data are from non-topkilled (NTK) trees only.

Site	Treatment	Air Temp (C)	RH (%)	Wind (kph)	Fine Fuel (kg/ha)	Peak Fire Temp. (°C)	Mesq. Topkill (%)	Mesq. Foliage Remain. (%)	Mesq. Foliage Reduc. (%)
NM[1]	W91[2]	14.4	28	16.1	2450	408	7 (4)	79 (5)	21 (5)
	W91+W93	19.4	32	11.3	2339	660	23 (13)	49 (6)	51 (6)
	W91+W93+W95	18.1	30	11.3	2779	502	27 (8)	43 (3)	57 (3)
	W93	18.3	24	14.5	1540	443	14 (4)	59 (7)	41 (7)
	W93+S93	32.2	34	12.1	1643	472	14 (11)	46 (9)	54 (9)
	W95	13	37	15.3	3196	476	15 (8)	66 (4)	34 (4)
RV	W95	15	36	10.2	2585	690	17 (5)	42 (4)	58 (4)

[1] NM=Ninemile asture, Waggoner Ranch; RV=River Pasture, Y Ranch.

[2] Fire treatment replicates in 1991 or 1993 (W91, W91+W93, W93 and W93+S93) were burned simultaneously and therefore had identical weather data. Fine fuel and mesquite response data were unique to each replicate. Weather data on repeated fire treatments are from the most recent fire in each series.

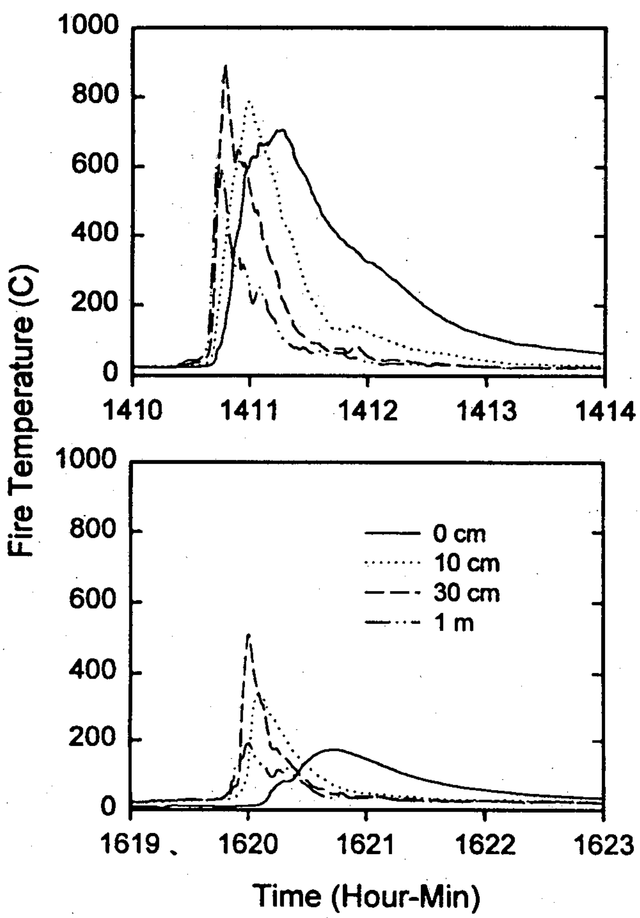

Figure 1. Temperature at 4 heights above ground of a high intensity (top) and low intensity fire (bottom) burned in adjacent pastures during the afternoon of 27 January 1993 in Ninemile pasture, Waggoner Ranch.

Mesquite Responses

Mean mesquite topkill from single low intensity fires (W91, W93, W95) ranged from 7-17% (Table 1). Topkill percent increased slightly from 7 to 23 and 27 with repeated winter fires, W91+W93 and W91+W93+W95, respectively. Topkill did not increase with a summer fire following a winter fire in the same year (W93+S93), probably because of low fine fuel. While trees of all heights were topkilled in adjacent high intensity fires, most trees topkilled by low intensity fires were <1.5 m tall. No trees in the low intensity fires were root-killed and all topkilled trees resprouted from stem bases.

Mean canopy foliage reduction of NTK trees from single low intensity fires ranged from 21 to 58%. Foliage reduction varied widely among trees within each treatment replicate and, as with topkill, was largely a function of tree size. Most trees that were partially defoliated by low intensity fires retained foliage in the upper portions of the canopy, but lower-positioned canopy growing points were killed. Primary support stems were not killed, however. The appearance was similar to a browse-line. Amount of living foliage following each fire had direct bearing on whether the trees basal sprouted or maintained apical dominance the following growing season. At Ninemile, over 80% of the mesquite plants had basal sprouting if 0 to 20% of preburn foliage amounts remained intact (Figure 2). In contrast, if at least 40% of pre-burn foliage remained intact, over 80% of the trees did not basal sprout and maintained apical dominance. The threshold foliage amount for determining apical dominance was between 20 and 40% of preburn levels. A similar relationship was found at River pasture after the winter 1995 fires although apical dominance was more prominant within the 10 to 30% remaining foliage categories than at Ninemile.

Maintenance of the savanna growth form was possible with repeated low intensity fires. While foliage was reduced with repeated winter fires (W91+W93 and

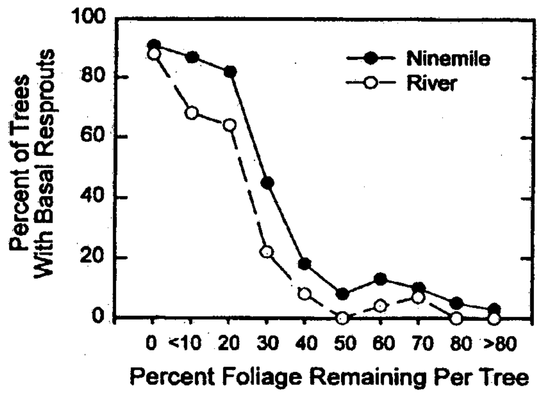

Figure 2. Relation between percent of preburn mesquite foliage remaining after low intensity fires and percent of trees that had basal sprouting at Ninemile and River pastures. Data from all treatments and replicates at a site were pooled. Over 480 and 140 trees were surveyed at Ninemile and River pasture, respectively.

W91+W93+W95) and a summer fire following a winter fire (W93+S93) (Table 1), remaining foliage was maintained above the 20-40% threshold level needed to maintain apical dominance (Figure 3).

Discussion

Historical accounts differ as to original density and distribution of mesquite in Texas. Bartlett (1854) described much of Texas rangeland as open grasslands with scattered large mesquite (i.e., a mesquite savanna). Marcy (1866) described some upland areas of central Texas as

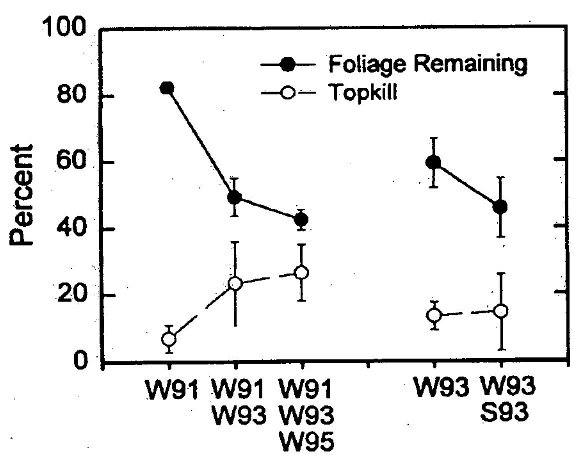

Figure 3. Effects of single and repeated low intensity fires (x-axis) on mesquite percent topkill and canopy foliage remaining of non-topkilled trees during the growing season after each fire. Vertical bars around each mean are ±1 standard error (n=3).

"covered with groves of mesquite trees", and an area in the lower Texas panhandle as "one continuous mesquite flat, dotted here and there with small patches of open prairie". These observations suggest honey mesquite was a natural part of the north Texas vegetation complex prior to white settlement and, apparently in some instances, occurred as dense stands. There is no indication as to the growth form of mesquite trees prior to white settlement. It is likely that most of the the multistemmed thickets that occur in Texas today have greater stem and foliage density because of anthropogenic perturbation of the canopy than what would have occurred naturally.

Occurrence of mesquite at densities less than that of regrowth thickets may enhance ecosystem stability when compared to open grassland by increasing soil fertility through nitrogen fixation and organic carbon additions (Johnson and Mayeux 1990). Low densities of woody plants have been observed to promote herbaceous production in south Texas (Scifries et al. 1982). Savanna mesquite may enhance species diversity via subcanopy microenvironment modification. Unquantified observations from the Ninemile site suggest that the cool-season (C3) Texas bluegrass, a desirable forage grass, has increased beneath mesquite canopies treated with frequent low intensity fires in a predominantly warm-season (C4) grassland. The physionomic diversity of a savanna or mosaic of mesquite thickets mixed with open areas may enhance wildlife habitat over open grassland.

High vs Low Intensity Fires

Response of mesquite to fire is variable and has been related to intensity, seasonality and frequency of fire or to age and condition of the plants (Cable 1965, Wright et al. 1976, Stinson and Wright 1969, Martin 1983). A single intense fire will likely destroy most above ground tissue in mesquite, but not kill the plant (Ansley et al. 1994). Single topkilling fires will stimulate resprouting and create the potential for a mesquite thicket if no maintenance practices are utilized (Hamilton et al. 1981, Hamilton and Scifries 1982). There is much evidence to indicate that a single, topkilling fire achieves no better results than a single topkilling herbicide treatment and is not the solution to long-term mesquite management (Ueckert 1975). Frequent use of high intensity fires will maintain suppression of mesquite regrowth but, without root mortality, it remains uncertain whether high-intensity fires are a sustainable option for converting mesquite shrublands to grasslands.

Variation in mesquite response to fire creates an opportunity to use fire for savanna development. Our results demonstrated that low intensity fires usually did not completely topkill mesquite but destroyed some lower canopy growing points. Upper foliage exerted apical dominance that inhibited sprouting from tree bases (Figure 4). With less leaf mass, these savanna mesquite will

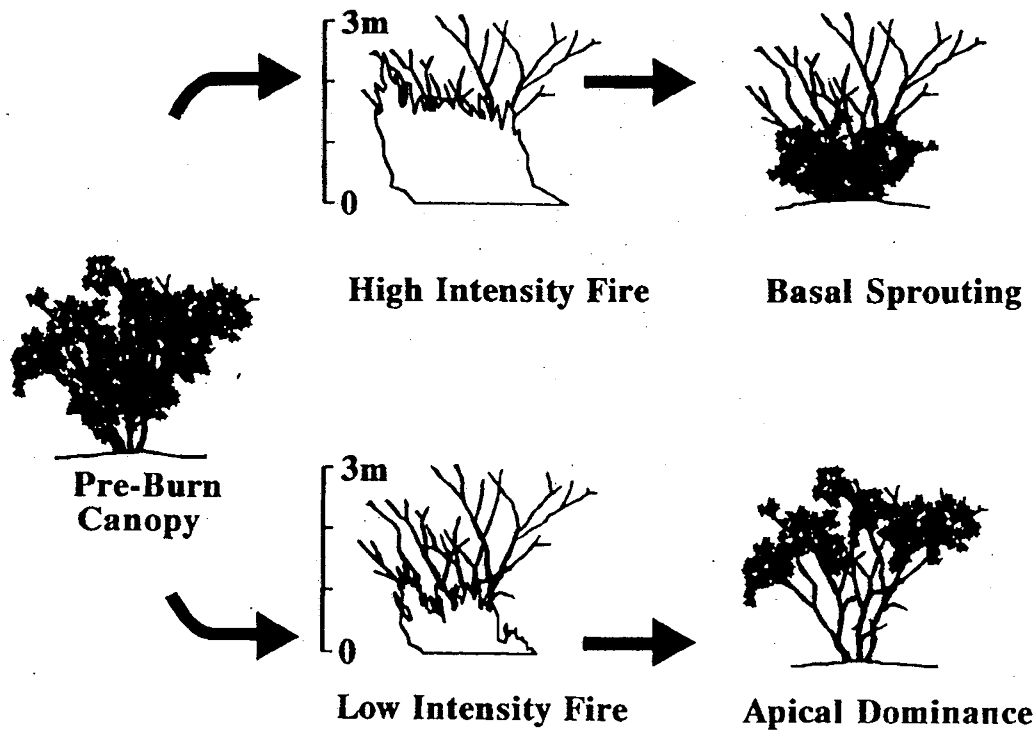

Figure 4. Illustration depicting effects of high and low intensity fires on mesquite canopy foliage and basal sprouting.

be transpirationally less competitive with grasses and should enhance herbaceous understory production when compared to mesquite thickets.

Economics of time and labor needed to gather livestock from mesquite thickets when compared to savanna or grassland have not been quantified, but poor visibility through thickets is often cited by livestock managers as a significant and costly problem. The data suggest that over time, an area frequently burned with low intensity fires will have mesquite foliage positioned high enough as to not impede vision for livestock management, yet provide shade for livestock. Moreover, because less fine fuel is needed to support a low than a high intensity fire, preburn livestock deferral time would likely be reduced. Preliminary data suggest grass recovery is faster following low than high intensity fires which would reduce post-fire deferral time as well.

Management Guidelines for Low Intensity Fires

Guidelines for prescribed fires include consideration of climatic and fuel variables as well as season of burning, time of day, fire type (headfire or backfire) and fire frequency. While Wright and Bailey (1982) identified the most desirable weather and fuel conditions to produce high intensity mesquite-topkilling fires during winter months, alternate guidelines are needed if savanna is the management goal. An intense fire could destroy the canopy, stimulate basal sprouting and create a thicket instead of the desired savanna. Such a fire could limit savanna development for 20-30 years. Conversely, extremely low intensity fires (60-270 kW/m; flame length 0.5 to 1 m) that have little or no effect on mesquite are not considered suitable for savanna development from thickets. The ideal goal for the low intensity fire prescription is to create a fire intense enough to reduce foliage but preserve apical dominance in taller (> 2 m) trees.

Most of our research has focused on guidelines for low intensity winter headfires (Table 2). We successfully conducted low intensity headfires within fine fuel levels of 1000 to 3200 kg/ha. Headfires were conducted in mornings (8-10:00 AM) or at night (7-9:00 PM) to exploit higher relative humidity (RH) and cooler air temperature. Under low fuels (1000 to 1500 kg/ha), savanna fires were conducted in afternoons. Fuels greater than 4000 kg/ha generated topkilling fires under most weather conditions. Fine fuel below 1000 kg/ha often burned completely, but there was no apparent damage to mesquite foliage. Similarly, winter backfires under higher fuel loads produced no effect on mesquite.

The occurrence of the annual cool-season grass, Japanese brome (*Bromus japonicus*), beneath mesquite canopies inhibited spread of winter fires within dense mesquite stands because it is green during February and March. We encountered this during the W91 and W95 fires at Ninemile. Where Japanese brome was green, there were extensive unburned patches and fire had minimal effects on mesquite. However, the W91 fires reduced annual brome enough to support more effective second fires in the winter of 1993. The W91+W93 treatment was more effective on mesquite topkill and foliage reduction than W91 or W93 alone (Table 1).

Low intensity summer fires may have greater potential than winter fires to reduce mesquite foliage to desired levels but the risk of topkill is greater. Preliminary results indicate that summer low intensity fires are possible if burned as headfires during the evening (6 to 10:00 PM) and at wind speeds not exceeding 10 kph. Daytime summer headfires under any fuel load appear to topkill most mesquite and are unsuitable for savanna development (Ansley et al. 1994). Areas heavily dominated with Japanese brome understories may need to be burned with a low intensity summer fire to kill the brome seed. This treatment could then be followed with low intensity winter fires.

Low intensity fires modified the vertical structure of mesquite but did not reduce stand density. Decreases in mesquite density may be facilitated by individual plant treatment with herbicides, or larger-scale chemical or mechanical treatments in strips or patches, but at a increased cost. Repeated low intensity fires should prevent increases in density by maintaining suppression of shorter, topkilled mesquite and killing some seedlings and seeds on the ground. Taller mesquite may limit recruitment of mesquite seedlings because of shading and competition for moisture (Haas et al. 1973, Ruthven et al. 1993).

Conclusions

Low intensity fires altered the vertical structure of honey mesquite by reducing foliage and preserving apical dominance. Behavior of low intensity fires was predictable and primarily a function of relative humidity, air temperature and fine fuel. Low intensity fires facilitated conversion of mesquite woodlands to savanna by modifying individual tree structure but did not reduce stand density. The mesquite savanna is a viable management option which allows the land manager to live with mesquite rather than attempt the more costly option of converting mesquite woodland to grassland. We hypothesize that a savanna provides sustainable ecological and economical productivity while minimizing management and maintenance costs.

References

Ansley, R.J., P.W. Jacoby, D.R. Lucia, and D. Jones. 1994. Effect of summer and winter fires and fire frequency on honey mesquite mortality. Abstr.act In: Proceedings. Society for Range Management, 47th Ann. Meet., Colorado Springs, CO (pg. 3).

Archer, S. 1989. Have Southern Texas savannas been converted to woodlands in recent history? The American Naturalist. 134: 545-561.

Bartlett, J.R. 1854. Personal narrative of explorations and incidents in Texas, New Mexico, California, Sonora and Chihuahua. D. Appleton & Co., NY.

Byram, G.M. 1959. Combustion of forest fuels. pages 61-89 In: K.P. Davis (ed), Forest Fire: Control and Use. McGraw-Hill Book Co., New York. 548 p.

Cable, D.R. 1965. Damage to mesquite, Lehmann lovegrass and black grama by a hot June fire. Journal of Range Management 18: 326-329.

Fisher, C.E., C.H. Meadors, R. Behrenns, E.D. Robison, P.T. Marion and H.L. Morton. 1959. Control of mesquite on grazing lands. Texas Agricultural Experiment Station Bulletin. 935, 24p.

Haas, R.H., R.E. Meyer, C.J. Scifres and J.H. Brock. 1973. Growth and development of mesquite. Chap. 2, pages 10-19 In: C.J. Scifries et al. (eds), Mesquite. Texas Agricultural Experiment Station Research Monograph 1, College Station, 84 pages.

Hamilton, W.T., L.M. Kitchen, and C.J. Scifries. 1981. Height replacement of selected woody plants following burning or shredding. Texas Agricultural Experiment Station Bulletin 1361, 9pages.

Hamilton, W.T., and C.J. Scifries. 1982. Acute effects of summer burns on south Texas mixed brush. PR-3990. In: Brush Management and Range Improvement Research 1980-81. Texas Agricultural Experiment Station CPR 3968-4014.

Humphrey, R.R. 1949. Fire as a means of controlling velvet mesquite, burroweed, and cholla on southern Arizona ranges. Journal of Range Management 2: 175-182.

Jacoby, P.W. 1985. Restoring mesquite savanna in western Texas, USA through brush and cacti management. pages 223-228 In: J.C. Tothill and J.J. Mott (eds), Ecology and Management of the World's Savannas. Australian Academy of Science, Canberra, ACT 2601. 384 pages

Jacoby, P.W. and R.J. Ansley. 1991. Mesquite: classification, distribution, ecology and control. Chap. 36, pages 364-376, In: L.F. James, J.O. Evans, M.H. Ralphs, D.R. Child (eds), Noxious Rangeland Weeds. Westview Press, Boulder, CO. 466 pages.

Jacoby, P.W., R.J. Ansley, and B. A. Trevino. 1992. An improved method for measuring temperatures during range fires. Journal of Range Management. 45: 216-219.

Johnson, H.B. and H.S. Mayeux, Jr. 1990. *Prosopis glandulosa* and the nitrogen balance of rangelands: extent and occurrence of nodulation. Oecologia 84: 176-185.

Koos, W. M., J. C. Williams, and M. L. Dixon. 1962. Soil survey of Wilbarger County, Texas. USDA Soil Conservation Service, Soil Survey Series 1959 No. 18, Fort Worth, TX.

Marcy, R.B. 1866. Thirty years of army life on the border. Harper and Bros, NY.

Martin, S.C. 1983. Responses of semidesert grassland shrubs to fall burning. Journal of Range Management 36: 604-610.

Ruthven, D.C., T.E. Fulbright, S.L. Beasom and E.C. Hellgren. 1993. Long-term effects of root plowing on vegetation in the eastern south Texas plains. Journal of Range Management. 46: 351-354.

Scifries, C.J., J.L. Mutz, R.E. Whitson, and D.L. Drawe. 1982. Interrelationships of huisache canopy cover with range forage on the Coastal Prairie. Journal of Range Management. 35: 558-562.

Smeins, F. 1983. Origin of the brush problem - a geological and ecological perspective of contemporary distributions. pages 5-16, In: K. McDaniel (ed), Proceedings - Brush Management Symposium, Texas Tech Univ. Press, Lubbock, TX, 105 p.

Stinson, K.J. and H.A. Wright. 1969. Temperatures of headfires on the southern mixed prairie. Journal of Range Management. 22: 169-174.

Trollope, W.S.W. 1984. Fire in Savanna. pp 149-175 In: P. de V Booysen and N.M. Tainton (eds), Ecological Effects of Fire in South African Ecosystems. Ecol. Studies 48. Springer-Verlag, Berlin-Heidleberg, 426 pages.

Ueckert, D.N. 1975. Response of honey mesquite to method of top removal. Journal of Range Management 28: 233-234.

Van Wagner, C.E. 1973. Height of crown scorch in forest fires. Canadian Journal of Forestry Research. 3: 373-378.

Wright, H.A., S.C. Bunting and L.F. Neuenschwander. 1976. Effect fire on honey mesquite. Journal of Range Management 29: 467-471.

Wright, H.A. and A.W. Bailey. 1982. Fire Ecology - United States and Southern Canada. John Wiley and Sons, New York. 501 p.