SILVOPASTORALISM AND WATERSHED MANAGEMENT IN THE SOUTHWESTERN UNITED STATES

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ABSTRACT

Concurrent with the continuing production of wood for fiber or other tree-based benefits, forage for livestock, and livestock products themselves in the southwestern United States is the increasing need to manage the region=s watersheds to insure sustainable flows of high quality water. It is fortunate, therefore, that the long-practiced silvopastoralism has been and continues to be embedded in most watershed management practices implemented for this purpose. The complementary nature of silvopastoralism with watershed management in the southwestern United States is presented in this paper. Past and present perspectives and future opportunities to blend silvopastoralism with ecosystem-based, multiple-use watershed management are highlighted.

Keywords: Silvopastoralism, watershed management, trees, forage, livestock, water

INTRODUCTION

Simultaneous production of wood for fiber or other tree-based benefits, forage for livestock, and livestock products themselves has been a historical land management objective in the southwestern United States. Concurrently with the continuing silvopastoralism is the increasing need to manage the region=s watersheds to insure sustainable flows of high quality water to downstream users in this drought-prone part of the country. It is fortunate, therefore, that silvopastoralism has been and continues to be embedded in most watershed management practices implemented for this purpose. An overview of the complementary nature of the tree and forage and livestock components of silvopastoralism with watershed management in the region is presented in this paper. Past and present perspectives and future opportunities to blend silvopastoralism with ecosystem-based, multiple-use watershed management are highlighted.

SOUTHERN ROCKY MOUNTAIN FORESTS

Southern Rocky Mountain Forests cover 10.1 million ha (24.9 million ac) of mountainous terrain in Colorado, New Mexico, Arizona, Utah, and parts of Nevada, ranging from 1,500 to 2,000 m (5,000 to 6,500 ft) in the lower elevations to 2,500 to almost 3.000 m (8,500 to 9,500 ft) in the higher elevations. The forests are found on a variety of soils developed from igneous, metamorphic, and sedimentary parent materials. Widely fluctuating seasonal and daily temperature patterns are common. Annual precipitation (rain and snow) ranges from 300 to 650 mm (12 to 26 in.). Spring is relatively wet in Colorado and northern New Mexico, while spring drought is the rule elsewhere in the four-corner states.

Ponderosa pine (*Pinus ponderosa*) forests are communities in which the species is climax and associated coniferous species largely absent and should not be confused with ponderosa pine forests where the species is seral. Douglas-fir (*Pseudotsuga menziesii*) is the climax species in the latter forests in which ponderosa pine and Engelmann (*Picea engelmannii*) and blue (*P. pungens*) spruce are common. Spruce-fir forests at higher elevations succeed to subalpine (*Abies lasiocarpa*), white (*A. concolor*), and corkbark *(A. lasiocarpa* var. *arizonica*) fir at the expense of Douglas-fir, spruce, and lodgepole pine *(P. contorta*). Aspen (*Populus tremuloides*) is an associate throughout. Arizona fescue-mountain muhly (*Festuca arizonica-Muhlenbergia montana*) is a prominent herbaceous community with Thurber fescue *(F. thurberii*) replacing Arizona fescue in western Colorado and northern New Mexico. Up to 35 species of grass and grass-like plants grow on sites in good to excellent condition including bluestem (*Andropogon scoparius*), blue grama (*Bouteloua gracilis*), Junegrass (*Koeleria cristata*), and bottlebrush squirreltail (*Sitanion hystrix*). Only a few forb genera such as the asters (*Aster* spp.), erigerons (*Erigeron* spp.), lupines (*Lupines* spp.), and yarrows (*Achillea* spp.) are abundant enough to warrant silvopastoralism consideration. Big (*Artemisia tridentana*) and black (*A. nova*), sagebrush, mountainmahogany (*Cercocarptus* spp.), cliffrose (*Cowania mexicana*), the brush-form of Gambel oak (*Quercus gambelii*), and buckbrush (*Ceanothus* spp.) are among the half-shrubs and shrubs.

Tree Component

Southern Rocky Mountain Forests are not managed as intensively for timber production as the case in the past, although earlier harvesting practices exert a controlling influence on the composition, structure, and condition of present-day forests. Individual stands consist of frequent deficiencies or surpluses in certain tree size classes. Silvicultural prescriptions leading to even-aged stands are based on clearcutting, shelterwood, and seed-tree methods, while natural regeneration of uneven-aged stands is achieved through selection cuttings. Planting of containerized tree seedlings is preferred in artificial regeneration.

Forage and Livestock Components

Forage increases as forest density decreases and visa versa. However, this relationship is affected by timber management. Forage production beneath thinned stands can be greater than that beneath unthinned stands at lower density levels (Clary and Ffolliott 1966). Production of forage and nonforage plants is similar for comparable undisturbed sites even though species compositions differ. Herbicides have been used in improving forage production by controlling undesirable plants in the past, but their application is limited at this time because of environmental concerns. Prescribing fire is also a tool to eliminate undesirable plants in some situations. Occasional seeding of forage plants is undertaken to restore sites where forage resources are scarce. Utilization of 30 to 40 percent of the forage growth provides a sustained level of forage resources for livestock on rangelands in good condition. Forage on higher elevation rangelands is ready for grazing by early June and can be grazed into late October in most years. Rangelands with a large proportion of the forage comprised of Arizona fescue, sedges (*Carex* spp.), or bluestem are grazed earlier because of the early development of these species. Rangelands with a dominance of mountain muhly are suitable for mid- to late-season grazing. Continuous yearlong grazing is practiced on lower-elevations in the southern part of the region. Rotation or deferred grazing including variations of the rest-rotation system is also common. Short-duration, high-intensity grazing is found on some ranges. Fencing, strategic placement of stock tanks and salt licks, and constructing driveways to move livestock from one allotment to another are used to improve livestock distribution, attain specified stocking levels, and obtain more uniform utilization of forage resources.

Watershed Management

Much of the emphasis placed on watershed management in Southern Rocky Mountain Forests in the past had been placed on modifying overstory structures for water yield improvement possibilities. While this purpose has regained importance more recently (Baker et al. 2003), managers are also presently concerned with implementing practices necessary to minimize adverse land use impacts on water and soil resources by preventing or mitigating landscape degrading processes. Among these practices are closing older roadways and seeding them with protective herbaceous plants; regulating the construction of new roads near stream channels and other sensitive areas; restricting the limited timber harvesting in periods of heavy rainfall to reduce soil losses; and monitoring livestock grazing to insure minimal impacts of impacted areas. Rehabilitation practices to bring watersheds from a poor, mismanaged condition to a more productive state include the construction of upstream check dams and other diversion structures to mitigate the formation of gullies; establishment of covers of protective vegetation on severely degraded sites, and, when necessary, curtailment of livestock grazing. All of these activities can be effectively and efficiently incorporated into integrated watershed management practices that are ecosystem-based, multiple-use in nature and, therefore, largely consistent with silvopastoralism.

SIERRA CONIFEROUS FORESTS

Sierra Coniferous Forests are found on 6.9 million ha (16.9 million ac) of mountain landscapes in California with minor occurrences in Nevada, occupying elevations between 1,075 and 2,300 m (3,500 and 7,000 ft.). They attain their best structural development on deep, well-drained soils. Marked variations in temperatures occur, particularly in the middle altitudes. Annual precipitation is less than 500 mm (20 in.) at lower altitudes increasing to more than 1,900 mm (75 in.), including heavy snowfall events on the northern Sierra Nevada and Coastal mountain ranges. Precipitation is relatively low in the summer months and high in winter.

Ponderosa pine dominates the lower and white fir the higher elevations. Intermediate are mixed conifer forests which additionally include Douglas-fir, incense-cedar (*Libocedrus decurrens*), and sugar pine (*P. lambertiana*). Above the ponderosa pine and white fir forests are red fir (*A. magnifica*), and lodgepole and Jeffrey (*P. jeffreyi*) pine forests, while subalpine forests consisting of mountain hemlock (*Tsuga mertensiana*), western juniper (*Juniperus occidentalis*), and western white pine (*P. monticola*) are below. More than 100 species of herbaceous plants contribute to the understory. Perennial grasses and sedges genera include *Calamagrostis*, *Carex*, *Festuca*, *Muhlenbergia*, *Poa*, and *Stipa*. Common forbs are Sierra iris (*Iris hartwegii*), milkwort (*Polygala cornuta*), starflower (*Trientalis* spp.), and violet (*Violet* spp.). Half-shrubs and shrubs include manzanita (*Arctostaphylos* spp), bush chinkapin (*Castanopsis* spp.), and several species of *Ribes*.

Tree Component

Management of the tree component of the Sierra Nevada Forests parallels that in the Southern Rocky Mountain Forests. Clearcutting with site preparation and planting of seedlings is frequently prescribed in ponderosa pine forests. Seed-tree and shelterwood cuttings are successful on better sites. Silvicultural prescriptions in mixed conifer forests are dictated by species compositions. Clearcutting, seed-tree, and shelterwood cuttings are implemented when even-aged stands are the objective and selection cuttings lead to uneven-aged stand structures. Satisfactory stocking of natural regeneration can be attained on sites where competing shrubs are controlled. Seedlings are planted in renewing many ponderosa pine forests, while artificial regeneration of other species is less certain. White fir, Douglas-fir, and sugar pine plantings have been successful on small clearcuts.

Forage and Livestock Components

Inverse relationships between forest density and forage production are affected by timber management in a manner that is similar to the Southern Rocky Mountain Forests. Forage production increases rapidly, slowly giving way to shrub species, and then to tree regeneration following harvesting of timber. Forage is almost nonexistent beneath old-growth forests but increases once overstory canopies open. Many herbicides used to control undesirable plants are presently limited. Prescribed fire has also been applied to increase forage production. Seeding of forage species is more common on privately than publicly owned rangelands. Utilization of 40 percent of the forage growth provides a sustained level of livestock production on rangelands in good condition. Forage on high elevation rangelands is grazed from June through late October with continuous yearlong livestock grazing on lower elevations. Rotational or deferred grazing is also common. Varying forms of seasonal grazing are found where cool-season grasses comprise most of the forage. Only limited short-duration, high-intensity grazing is practiced, mostly on private lands.

Watershed Management

Watershed management is carried out largely to minimize adverse land use impacts on water and soil resources by controlling landscape-degrading processes. Similar to many of the practices implemented in the Southern Rocky Mountain Forests, these efforts include the regulating construction of new roads near sensitive areas; restricting timber harvesting and the implementation of silvicultural practices when impacted sites become susceptible to increased soil erosion; and mitigating livestock grazing when necessary to eliminate consequent impacts detrimental to the site. Among the rehabilitation practices implemented to bring degraded watersheds to a more productive and hydrologic acceptable state are construction of upstream check dams and other structures to mitigate the formation of gullies; establishment of covers of protective vegetation on severely degraded sites, and rerouting of streams to achieve environmentally and hydrologically desired flow regimes. Of particular note are the intensive rehabilitation activities initiated by the public and private sectors in the Tahoe Basin to improve watersheds conditions and, in doing so, sustain the water quality of this highly valued lake system. All of these activities are effectively and efficiently incorporated into integrated watershed management practices that include appropriate silvopastoralism.

PINYON-JUNIPER WOODLANDS

Pinyon-Juniper Woodlands cover 26.3 million ha (65 million ac) from the eastern slopes of the Sierra Nevada Mountains, eastward throughout the Great Basin, through the Rocky Mountains of Colorado, and southward into New Mexico and Arizona. These woodlands are found from 1,000 to 2,500 m (3,500 to 8,000 ft) in elevation, attaining their best development from 1,400 to 2,300 m (4,500 to 7,500 ft). They merge with ponderosa pine forests at upper elevations and oak woodlands and desert shrub and grassland ecosystems at its lower limits. Pinyon-juniper woodlands grow on a variety of soil parent materials and types. Temperature regimes vary throughout the year. Annual precipitation ranges from 300 to 500 mm (12 to 20 in.). Most of the precipitation falls in the form of rain with occasional snowfall in the winter.

Overstories include common (*P. edulis*), singleleaf (*P. monophylla*), and Mexican (*P. cembroides*) pinyon and Utah *(J. osteosperma*), one-seed (*J. monosperma*), Rocky Mountain (*J. scopulorum*), and alligator *(J. deppeana*) juniper. Pinyon is more abundant than juniper at higher elevations. Common pinyon is replaced by singleleaf pinyon in northwestern Arizona and Nevada and Mexican pinyon in southern New Mexico and southeastern Arizona. Utah juniper spreads throughout northern Arizona, Utah, Nevada, and parts of California. One-seed juniper is scattered throughout New Mexico. Rocky Mountain juniper is common in northern New Mexico and throughout Colorado. Alligator juniper is common in southwestern New Mexico and southern Arizona. Sideoats grama (*B. curtipendula*), bottlebrush squirreltail, dropseed (*Sporobolus* spp.), and muttongrass (*Poa fendleriana*) are common grasses on high-producing rangelands, while forage plants on low-producing sites include blue grama and muttongrass. Common forbs are annual goldeneye (*Viguiera annua*), goosefoot ragleaf (*Chenopodium incisum*), pingue (*Hymenoxys richardsonii*), and sweetclover (*Melilotus officinalis*). Big and black sagebrush, cliffrose, shrub live oak (*Q. turbinella*), the brush-form of Gambel oak, and mountain mahogany are among the half-shrubs and shrubs.

Tree Component

A past activity has been to control the invasion of Pinyon-Juniper Woodlands onto lower elevation grasslands to reduce competition and improve forage production. More recently, people have begun to realize that the woodlands can be managed to sustained wood production for fuel, small poles, and posts at levels compatible with site productivity potentials.

Silvicultural treatments are primarily single-tree selection and shelterwood methods which are compatible with seed dispersal patterns, provide site protection for natural regeneration, and are aesthetically acceptable (Gottfried and Ffolliott 1993). Pinyon seeds germinate in the spring although germination is delayed until summer rains if the site conditions are not favorable. Juniper seeds also germinate in the spring but the timing of germination can be delayed because of embryo dormancy and impermeable seed coat.

Forage and Livestock Components

Forage declines rapidly as the woodlands increase in density. Therefore, large-scale efforts have been undertaken in the past to convert Pinyon-Juniper Woodlands to grasslands by mechanical and chemical methods and prescribed burning (Gottfried 1999). However, forage production has not always improved with tree removal and, furthermore, economic and environmental concerns have limited the implementation of conversion methods in recent years. Seeding efforts are most successful when seedbed preparation, species selection, and planting techniques are carefully prescribed. Many rangelands are only fair or poor in their condition. As a consequence, managers consider utilization of forage plants in excess of 40 percent to be detrimental to sustained forage production. Many of the lower elevations are grazed yearlong. Rotation or deferred grazing systems have been adopted on some higher sites. A lack of precipitation at critical times negates sustained livestock grazing on many woodlands regardless of the system.

Watershed Management

Early attempts at water augmentation through vegetation manipulations in Pinyon-Juniper Woodlands have been largely unsuccessful. Most of these woodlands do not receive sufficient annual precipitation for this watershed management objective to be realistic (Hibbert 1979). Nevertheless, watershed management is considered crucial in protecting flows of high quality water to downstream users because many of the streams and rivers that carry water from high elevation watersheds to downstream users pass through the woodlands. Watersheds must be managed, therefore, to retain their often limited vegetative cover. Watershed management as it relates to erosion control, improving plant covers, and retarding excessive surface runoff (overland flow) and soil loss are, therefore, important to the involved stakeholders and general public. Present management prescriptions are aimed at creating savanna-like situations by retaining a number of larger trees, reducing the density of smaller trees, and curtailing livestock grazing on sites supporting only sparse herbaceous cover (Gottfried 1999). Silvopastoralism continues at a lesser intensity than earlier within these prescriptions. Tree harvesting is eliminated unless it can be integrated into larger landscape mosaics.

OAK WOODLANDS

Oak Woodlands are found between montane forests and grasslands throughout California and scattered in western Colorado, Utah, and southwestern New Mexico and southeastern Arizona. These woodlands occupy 3.6 million ha (9 million ac) in California and 0.5 million ha (1.2 million ac) elsewhere in the region. Oak Woodlands of California occur at elevations from less than 150 to 925 m (500 to 3,000 ft), while those in the interior occupy elevations from 1,215 to 1,825 m (4,000 to 6,000 ft), occasionally reaching 2,450 m (8,000 ft). A variety of soils support the woodland communities. Annual precipitation ranges from less than 300 to 500 m (12 to over 20 in.). Winter rains dominate in California, while precipitation is split into summer and winter seasons in the interior.

Trees in the California foothills include blue (*Q. douglasii*), black (*Q. kelloggii*), valley (*Q. lobata*), and interior live (*Q. wislizenii*) oak, and digger pine (*P. sabiniana*) with Engelmann (*Q. engelmannii*) and coast live (*Q. agrifolia*) oak being common in southern California. The brush-form of Gambel oak dominates the woodlands in western Colorado and Utah. Emory (*Q. emoryi*), Arizona white (*Q. arizonica*), Mexican blue (*Q. oblongifolia*), and silverleaf (*Q. hypoleucoides*) oak, Mexican pinyon, and alligator juniper grow throughout southwestern New Mexico and southeastern Arizona. Annual grasses in California including blue grass *(Poa annua*), fescue (*Vulpia* spp.), and ryegrass (*Lolium multiforum*) are largely introduced. Native perennial grasses are pine bluegrass (*P. scabrella*), purple stipa (*Stipa pulchra*), and brome (*Bromus* spp.). Common forbs include fiddleneck (*Amsinckia* spp.), tarweed *(Hemizonia*, *Holocarpha*, *Madia* spp.), trefoils (*Lotus* spp.), and mullein (*Eremocarpus setigerus*). Half-shrubs and shrubs are buckbrush, scrub oak (*Q. dumosa*), and toyon (*Heteroomeles arbutifolia*). Among prominent grasses in the four-corner states are grama, bluestem, curly mesquite (*Filaria Bellinger*), threeawn, bottlebrush squirreltail, and bluegrass. Wright deervetch (*Lotus wrightii*) is a prominent forb.

Tree Component

Inherently low levels of growth, irregular stem forms, and a lack of markets constrain the intensive management of oak trees for wood production, although trees are cut locally for fuelwood, small poles, posts. Vegetative reproduction by stump sprouting is common in most of the Oak Woodlands, and, therefore, coppicing forms a potential basis to obtain natural regeneration with limited regeneration from seed is expected. Cutting cycles for local fuelwood harvesting are reduced through thinning of resulting coppice (Touchan and Ffolliott 1999). Seedling establishment is successful in California when site conditions are favorable for germination of acorns and initial growth. Artificial regeneration is limited in the interior.

Forage and Livestock Components

Forage production appears to be little influenced by the density of trees. As a result, there has been little effort to control overstory trees to sustain increase forage production elsewhere in the type, while there has been some conversion of Oak Woodlands to grasslands in California. Selected seeding of preferred species has improved forage production on some rangelands. Many of the rangelands are fair to poor in condition. Therefore, managers often prescribe a utilization level of forage plants that is less than 40 percent to sustained production. Yearlong and seasonal grazing have been the traditional livestock grazing practices. Rotating livestock among allotments on rangelands in better condition has been practiced to balance livestock distribution and forage utilization. Livestock management is more intensive on privately owned rangelands in California than in the interior. A lack of precipitation at critical times places almost any grazing system in jeopardy.

Watershed Management

People do not often think of the Oak Woodlands as watershed lands. However, water relationships in these generally water-deficient woodlands are likely to be of equal if not more importance as those in the higher elevation forests. Unfortunately, knowledge of the hydrology of the Oak Woodlands is incomplete, and, therefore, intensive studies have been initiated to obtain a better understanding of hydrologic processes and streamflow regimes. This information will become a prerequisite to prescribing and applying a watershed management approach to incorporate water and soil considerations and land use planning into a broader and more holistic framework for conservation and sustainable development (Shipek et al. 2004). More specifically, managing for optimal combinations of water, wood, livestock, and wildlife benefits becomes possible with this approach.

MESQUITE-DOMINATED ECOSYSTEMS

Mesquite-Dominated Ecosystems are scattered throughout the semidesert rangelands of the region on sites between 900 to 1,500 M (3,000 and 5,000 ft) in elevation, mostly in a strip 80 to 160 km (50 to 100 mi) wide along the southern boundaries of Arizona, New Mexico, and western Texas. Soils are typically those of the semideserts. Annual precipitation ranges from 8 inches in the western ecosystems to nearly 500 mm (20 in.) adjacent to the mountain ranges in southeastern Arizona and the eastern edge of western Texas. Half of these ecosystems receive less than 250 mm (10 in.) of precipitation each year.

Nearly pure stands of relatively large, straight-stemmed mesquite trees grow in riparian corridors while small, multiple-stemmed mesquite shrubs on upland savannas. Species of mesquite include *P. juliflora*, *P. velutina*, *P. glandulosa* var. *torreyana*, *P. glandulosa* var. *glandulosa*, and *P. pubescens*. Extensive stands on upland sites are intermingled with palo verde (*Cercidium floridum*), creosotebush (*Larrea tridentata*), tarbush (*Flourensia cernua*), and saltbush (*Atriplex canescens, A. hymenelytra, A. talacea*). A dominant herbaceous plant is Lehmann lovegrass (*Eragrostis lehmanniana*), an introduced species. Black grama (*Bouteloua eriopoda*) and cottontop (*Digitaria* spp.) are found intermixed. Occasional annuals, scattered forbs, and cacti are associated with mesquite-dominated ecosystems.

Tree Component

Mesquite is a source of fuelwood, poles and posts, and feed for ruminants. It also makes excellent charcoal. Small wood-producing (cottage) industries largely dependent on mesquite as the raw material have evolved into a number of profitable enterprises in the southwestern United States. Knowledge of effective silvicultural practices are limited, however, jeopardizing achieving sustainability of the wood resource (Ffolliott 1999). Vegetative reproduction is possible because of the ability of mesquite to resprout following cutting and, therefore, coppicing is feasible. Artificial regeneration is dependent on pretreated seeds.

Forage and Livestock Components

Invasion of mesquite has reduced the production of forage on many semidesert rangelands. While the fruit and leaves of mesquite make excellent forage, production by the plants themselves does not compensate for the decline in herbaceous forage as mesquite become denser. Controlling mesquite invasion by mechanical methods, applications of chemicals, and prescribed burning continues to be a focus of management with environmental considerations dictating selection of the method applied. Nevertheless, livestock production has declined from the boom-and-bust days of open rangelands to the more stable present-day situation of carefully controlled grazing systems. Continuous livestock grazing can result in a deterioration of forage production, although it is often less destructive than some of the alternatives. Rotation systems are successful when rest periods are long enough, frequent enough, and at the proper time to allow forage plants to recover.

Watershed Management

Surface runoff is normally limited in the Mesquite-Dominated Ecosystems and less erosive on landscapes with a protective cover of herbaceous plants than on those with a depleted cover, and, as a consequence, quality of the runoff water from the former is higher. These ecosystems, therefore, are managed to the protect watersheds in good condition and restore those in poor condition. Sustaining livestock production and enhancing wildlife habitats wherever feasible are often other watershed management objectives. When carefully planned, these management practices can also include the harvesting of selected mesquite trees for fuel, poles, or posts and controlling the encroachment of mesquite shrubs onto otherwise productive rangelands to sustain the historical silvopastoralism practices in these ecosystems.

CONCLUSIONS

Simultaneous production of fiber or other tree-based benefits, forage for livestock, and livestock products themselves continues to be an important management objective in the southwestern United States, although at levels that are less intense than in the past. Compatible with silvopastoralism is management of the regions=s fragile watershed landscapes in a manner that insures the flows of high quality water to downstream users. That these goals can often be simultaneously obtained is not surprising, however, because many of the management practices imposed for these purposes are common in their principle and application to management programs that are often implemented to benefit the full array of benefits that can be derived from the natural resources of the region.

REFERENCES

Baker, M. B., Jr., P. F. Ffolliott, D. G. Neary, and G. J. Gottfried. 2003. Contributions of watershed research to water supply in the Colorado River Basin. In *Watershed management for water supply systems: Proceedings of the 2003 international congress*, eds., Pfeffer, M. J., D. J. Van Abs, and K. N. Brooks. New York, NY: American Water Resources Association. [CD-ROM] Windows

Clary, W. P., and P. F. Ffolliott. 1966. Differences in herbage-timber relationships between thinned and unthinned ponderosa pine stands. Research Note RM-74. Fort Collins, CO: USDS Forest Service, Rocky Mountain Forest and Range Experiment Station.

Ffolliott, P. F. 1999. Mesquite ecosystems in the southwestern United States. In *Ecology and management of forests, woodlands, and shrublands in the dryland regions of the United States and Mexico: Perspectives for the 21st century*, eds., Ffolliott, P. F., and A. Ortega-Rubio, 95-106. La Paz, Baja California Sur, Mexico: Centro de Investigaciones Biologicas del Noroesta.

Gottfried, G. J. 1999. Pinyon-juniper woodlands in the southwestern United States. In *Ecology and management of forests, woodlands, and shrublands in the dryland regions of the United States and Mexico: Perspectives for the 21st century*, eds., Ffolliott, P. F., and A. Ortega-Rubio, 53-67. La Paz, Baja California Sur, Mexico: Centro de Investigaciones Biologicas del Noroesta.

Gottfried, G. J., and P. F. Ffolliott. 1993. Silvicultural prescriptions for sustained productivity of the southwestern pinyon-juniper and encinal woodlands. In: *Making sustainability operational: Fourth Mexico/U.S. symposium*, tech. coord., Manzanilla, H., D. Shaw, C. Aguirre-Bravo, L. Iglesias Gutierrez, and R. H. Hamre, 185-192. Gen. Tech. Rep. RM-240. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Hibbert, A. R. 1979. *Managing vegetation to increase flow in the Colorado River Basin.* Gen. Tech. Rep. RM-66. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

Shipek, D. C., P. F. Ffolliott, G. J. Gottfried, and L. F. DeBano. 2004. *Transpiration and multiple use management of thinned Emory oak coppice.* Research Paper RMRS-RP-48. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

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.