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Chapter 8:

Tools for Management for Grassland Ecosystem Sustainability: Thinking "Outside the Box"

Introduction

Grassland ecosystem management is dynamic and has adapted to the development of new tools and ideas. Our ancestors were indirectly managing grasslands when they learned to move livestock to take advantage of better water and greener forage. One could argue that even their hunting of grassland wildlife, especially the use of fire to drive animals to waiting hunters, had an influence on local grassland ecology.

The science of range management is relatively new and is linked to the realization that land is limited and that managers must do their best to make the available resources last forever (Stoddart and Smith 1955). Poor land stewardship degrades the land's multiple resources and results in poor livestock production, while good management will provide healthy grassland ecosystems so that managers and landowners will have high livestock production and the potential for a viable economic livelihood. Owners, especially private owners, probably have different goals for their lands; traditional livestock production is not always the primary or even a secondary objective, but proper land stewardship should be the ultimate goal regardless of other objectives.

New challenges are impacting the management and health of all natural ecosystems, including Southwestern grasslands, and these forces are affecting land stewardship efforts. One of the greatest challenges is the result of the phenomenal growth of the region's human population, primarily urban and suburban—people with few direct connections to the land. Large expanses of privately owned grassland, such as some near Sonoita, AZ, have been subdivided into small units, fragmenting a relatively homogeneous landscape with potentially adverse impacts on many wildlife species, on regional hydrology, and on the traditional social fabric of the area. The new residents often introduce nonnative plants through their landscaping activities, miles of fences and new roads, and concentrations of predatory pets and domestic livestock. Even without fragmentation, the pursuit of recreational opportunities by this growing population is putting pressure on all open landscapes, impacting the vegetation, wildlife populations, and watershed condition. Other challenges are the growing concerns about the loss of native plant and animal species because of habitat loss, human disturbances, and the introduction of numerous nonnative species that successfully occupy areas of bare soil or out-compete native plants. Many grasslands have been adversely affected by past land management and need to be restored to a more functional ecological condition. But how can this be accomplished ecologically and economically?

Ecological and range management sciences continue to provide managers with new information and tools. Descriptions of many of the common techniques are found in standard range management textbooks dating from the historical coverage by Stoddart and Smith (1955), and from books such as Savory (1988), Holechek and others (1998), and Jemison and Raish (2000) that describe more recent developments. Important information has been gathered and disseminated by Federal, university, and State research, management, and extension agencies.

This chapter covers some new and current tools, issues, and approaches to grassland management. It does not attempt to be all inclusive but does reflect the opinions and expertise of the contributors. The first section includes some programs and tools and principles related to grassland management and restoration, and the second section covers new remote sensing technologies to evaluate grasslands and assist in management planning at a landscape level. The adaptation and use of remote sensing technologies and geographical information system databases to grassland management are just developing. The third section deals with education, a vital aspect of range management if current and future grassland managers are to do their best and if the general public is to be a true shareholder in these efforts.

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Grassland Resources Management

New Programs to Sustain Southwestern Grasslands

Attitudes and philosophies toward grassland management have shifted over time since the first herds of livestock were introduced into the Southwest. However, many changes have occurred more recently in response to the growing pressure on grasslands and their resources from traditional producers, conservation and environmental organizations, government entities, and especially from the growing regional population. Ranchers, conservation groups, and many members of the general public have a common interest in maintaining open landscapes because of the ecological importance of these systems, recreational and aesthetic concerns, and the desire to preserve the rural livelihood and life style (Raish, this volume). These groups, often working together, have developed innovative approaches to achieve their goals.

Grassbanks—Grassbanks are becoming popular methods for allowing land and grass resources to rest and recover during dry periods while continuing to provide the rancher with an economic return. The Malpai Borderlands Group (MBG), located in southeastern Arizona and southwestern New Mexico, was the first organization to initiate the Grassbank system to restore native grasslands and protect the open spaces of the region. "Grassbank" is a legally registered trademark. Basically, a Grassbank is grass made available from one ranch to another rancher's cattle in return for conservation value equal to the value of the grass (McDonald 1995). The MBG is a nonprofit organization, composed mainly of ranchers, that works to encourage profitable ranching and traditional livelihoods that sustain the region's open spaces (McDonald 1995). A specific goal is: "…to restore and maintain the natural processes, including fire, that create and protect a healthy, unfragmented landscape to support a diverse, flourishing community of human, plant and animal life in our Borderlands Region" (McDonald 1995: 483). Drum Hadley, of the Animas Foundation is credited with the idea of a Grassbank as a method of creating more grass, grass seed, and protection of open spaces. The Animas Foundation's Gray Ranch (also known as the Diamond A Ranch) provided the first Grassbank.

Grassbankers receive access for their cattle to the Grassbank in return for conveying a conservation easement to the MBG. The MBG pays the owner of the Grassbank for the use of the grass. The value of the easement is determined by an appraisal of the development rights on the Grassbanker's ranch. The Grassbanker gets access to the grass for a term that monetarily equals the value of the easement. A conservation easement prevents the sale of land for subdivisions and, thus, prevents landscape fragmentation. Easements can be released back to the landowner under two conditions. The first condition is the dissolution of the MBG, when no acceptable alternatives are available. This condition is grandfathered into original Grassbank agreements but is no longer part of easements now being offered. The second condition is the loss of access to grazing on nonprivate lands that are part of the landowner's ranch when this occurs through no fault of the rancher. Resting grasslands is a recognized method of improving range conditions and ultimately to improve the economics of ranching. The MBG and some government agencies, notably, the USDA Natural Resources Conservation Service, also may cooperate with Grassbankers to conduct improvement projects and monitoring to help the land return to a more productive condition before cattle are returned to the rested ranges. Fencing projects are one example of range improvements. Ranchers on the rested ranges agree to maintain their water systems for wildlife use during periods of rest. Stocking rates have to be maintained at lower levels than normal within the Grassbank so that the land will be able to provide sufficient forage for the additional cattle. Some lands within the Grassbank may be rested or deferred in anticipation of receiving a Grassbanker's livestock. Grassbank strategies need to be flexible to allow for variable climatic conditions.

Grassbanking also is being practiced in the Valle Grande Grass Bank Demonstration Program in northern New Mexico (Valle Grande Grass Bank Briefing Information, Anonymous, undated). The area is east of Santa Fe at the east end of Glorieta Mesa. The program is a cooperative effort involving the USDA Forest Service, the grazing permittees, the Conservation Fund, and the New Mexico State University Cooperative Extension Service. The basic goals of creating sustainable ranching are similar to those of the Malpai Borderlands Group, but this association consists of Forest Service permittees rather than private landowners. The Conservation Fund, a nonprofit organization, which holds the Valle Grande allotment and owns associated private lands, also hopes to reduce conflicts between grazing and other land uses and to demonstrate positive livestock and range management. Education for permittees and the public are important aspects of the program. Grassbankers under the program join the Valle Grande Grazing Association and are assessed a fee to cover operations; however, the Conservation Fund could provide supplemental funding. While their ranges are being rested, members are expected to conduct range improvements, such as riparian fencing and brush removal operations, which the Forest Service will fund. Grassbank arrangements can extend from 3 months to 3 years.

Other ranching organizations that foster proper land stewardship, such as the Quivira Coalition of Santa Fe, NM, also indicate that grassbanks are one tool for fostering ecological, economic, and social health of Western landscapes (Quivira Coalition undated). The USDA Forest Service is using a similar system in a coordinated and cooperative approach with forest partners when opportunities arise following a range assessment. The Tonto National Forest in central Arizona has policies and procedures in place that consider allowing one rancher to use another's unused allotment if all parties are in agreement (B. McKinney 2004, personal communication).

Conservation Easements—Conservation easements are voluntary legal instruments by which development rights or the rights to conduct other activities are conveyed to a qualified conservation entity (Society of American Foresters 2001, Stein and others 2001). The Malpai Borderlands Group requires conservation easements for ranchers to participate in its Grassbank program. Ranchers, conservation organizations, and many government agencies are concerned about the subdivision of large areas of private agricultural, forest, or range lands to create parcels of land for "40-acre ranchettes" or other small home site ownerships. Subdivision can create a personal loss to the original owner because many generations of effort are lost and the land will not be passed to heirs, even though the land sale may be financially profitable. Some landowners may consider selling their ranches for subdivision to provide for retirement or inheritance for their children. Society then loses valuable, scenic open spaces and the viability of local rural economies that depend on traditional agricultural activities (Rosan and others 1997). Subdivided landscapes can threaten the viability of dynamic ecosystems by obstructing traditional migration routes, destroying wildlife habitat, introducing nonnative plant and animal species, and increasing the demands on limited water supplies. Many wildlife species are sensitive to disturbances attributed to increased human activities (Mitchell and others 2002). One study in Colorado compared subdivided and intact ranches and found that subdivision resulted in an eightfold increase in road densities and, on one ranch, in a fourfold increase in number of landscape patches (Mitchell and others 2002). Another Colorado study found native plant communities were maintained better with less bare soil on ranches than in subdivided lands or in nature reserves (Maestas and others 2002). Maestas and his associates (2002) also cite evidence that there is change in animal biological diversity as lands are subdivided, with an increase of human-adapted species and a decrease in sensitive species. The alternative of conservation easements can be an effective tool for maintaining working landscapes, preserving environmental values, and protecting communities from excessive development (Society of American Foresters 2001).

Among the several approaches to conservation easements is the purchase of development rights (PDR). This allows the landowner to conserve working landscapes using market and incentive based, non-regulatory techniques (Stein and others 2001). PDR programs began in the Eastern United States in the 1970s to protect open spaces from suburban sprawl. Currently, more than 1,200 nonprofit land trusts in the United States (Hocker 2002) have protected about 2.6 million acres from future development through conservation easements (Maestas and others 2002). A local government or private organization, such as The Nature Conservancy and various nonprofit land trusts, purchases the real estate development rights from the landowner; however, the owner still owns the land and can use it for range, forestry, or agriculture and still obtains a financial benefit from the management of these resources. However, the activities may not affect the land's conservation value (Rosan and others 1997). The owner may sell the rights to all or part of the land and still retain part for limited development, for example for future home sites for children or to meet cash needs. These lots should not interfere with the ranching operation or detract from the scenery or natural resources (Rosan and others 1997). The land remains in the family and can be passed on to the owner's heirs, and a PDR may reduce inheritance taxes because the land's value has been reduced by 40 to 75 percent (Stein and others 2001). The purchaser of an easement is responsible for monitoring to ensure that the terms of the agreement are followed. The easement usually stays with the land for perpetuity and cannot be cancelled if the property is sold. However, some easements specify shorter durations (Society of American Foresters 2001). The PDR is a particularly important tool in the West because few governments or private organizations can afford to directly purchase large tracts of land. State governments have raised money for PDR programs, for example, by using parts of sales tax levies or by State lottery profits. Funding also can come from programs administered by Federal agencies such as the USDA Forest Service and USDI Bureau of Land Management.

There often are more requests by landowners to enter into a conservation easement than there is funding available. A landowner may sell the easement at less than its full value as a "bargain sale" and use the difference as a tax-deductible charitable donation.

The landowner may donate the entire easement to a nonprofit land trust or government entity. The amount of the charitable deduction is based on the impact of the easement on the value of the property (Rosan and others 1997). The value of an easement of more than $5,000 must be verified by a qualified appraisal if a contribution is claimed against Federal taxes.

Grassland Restoration—Grassland restoration is needed to return the ecosystems to productive and healthy states by enhancing the herbaceous cover that will increase productivity and biological diversity and also contribute to reduced erosion and to the reintroduction of fire into grassland ecosystems. Box (2002) says that land has been abused by people, the economy, and the weather. Many grasslands in the Southwest are in need of restoration because of past heavy grazing by herds owned by early ranchers and corporations who were trying to make a profit or just trying to make a living, combined with periodic drought that often extended for several consecutive years. This resulted in declines in herbaceous cover and species diversity, and increases in woody species. The changes in vegetation characteristics produced modifications of the hydrologic cycle, in particular, less infiltration of precipitation and increased surface runoff, and accelerated soil erosion and sedimentation.

Southwestern grasslands have been used and often abused for more than a century in parts of New Mexico. Sheep were an important exportable item during the Spanish Colonial Period in New Mexico, and large bands were maintained and herded down the Rio Grande Valley to Mexico (Gottfried and Pieper 2000). Large herds of cattle were imported into New Mexico and Arizona Territories after the suppression of the Apache Indians in the 1880s and the construction of the transcontinental railroad (Schickendanz 1980). In the early 1880s, three large cattle companies ran more than 60,000 head of cattle in Cochise County, Arizona, and Hidalgo County, New Mexico (Hadley and others 1999). Grazing continued in the area through the droughts of 1885, 1892 to 1893, and 1902 to 1903, when up to half of the cattle died of starvation and range resources were rapidly depleted (Hadley and others 1999). Heavy grazing also occurred in northern Arizona, and probably in other areas of the Southwest, during World War I to meet the demand for meat (Schubert 1974). Grazing during these earlier periods exceeded the carrying capacity of the land and resulted in a rapid decline in range vegetation resources, and in accelerated erosion, and channel downcutting. This combination of factors initiated desertification along the United States/Mexican border region (Hadley and others 1999) and throughout the Southwest. The impacts on watershed condition during this time still are apparent and can be identified by erosion rates, gully erosion, and soil compaction (USDA Forest Service 1993).

Two primary impacts of the loss of the herbaceous cover have been accelerated erosion and the encroachment of woody species, such as mesquite (*Prosopis* spp.) or juniper species (*Juniperus* spp.). The increased density of woody species has been linked to past heavy overgrazing by livestock and the consequential removal of fuels for wildfires as a natural control mechanism in many grassland communities (see the review by McPherson and Weltzin 2000). Exceptions are some drier desert grasslands where a continuous cover of fine fuels that would support large-scale fires did not occur (Buffington and Herbel 1965). Heavy overgrazing reduced grasses and fine fuels that were ignited by lightning during the late spring and early summer. Past fires eliminated or reduced the population of small trees and shrubs, maintaining low tree densities. Species that sprout after fires were kept in a subdominant position by repeated fires even if the plant survived. Under current conditions, many grasslands do not have the continuity of fuels to allow the uninhibited spread of fires. Without fire, trees that are adapted to a site will become established and regenerate successfully. However, the continued spread of invasive species such as Lehmann's lovegrass (*Eragrostis lehmanniana*), which is adapted to fire, may alter the present fire frequencies (McPherson 1995), and because of competition, these invasive species will impede the establishment of preferred native perennial grasses. The loss of ground cover and the concentrations of livestock in stream channels and wet meadows also resulted in severe erosion and loss of watershed condition on many grassland ranges.

The increase in woody species also has been linked to increased changes in the atmosphere or in the proportion of summer and winter precipitation. McPherson and Weltzin (2000) linked the increase in woody species to increased concentrations of carbon dioxide and other greenhouse gases in the atmosphere. Ranchers and researchers in southeastern Arizona, where most vegetation is dependent on summer rains, indicate that the proportion of annual precipitation has shifted to more winter precipitation when compared to the century-long average (Brown 1999, Valone and others 1998). This would favor the C_3 plants such as mesquite over the native C_4 grasses (Brown 1999); it also has been linked to declines in some key small mammal populations and increases in other species (Valone and others 1998). Aggressive fire suppression policies of Federal and State land management agencies have contributed to the situation by preventing potentially beneficial fires from burning. However, Allen (1998) indicates that fire suppression was not as effective as some maintain.

Many range restoration techniques call for the removal of trees. Restoration aims can range from complete removal of trees, although this is difficult, to the creation of savannas that retain a proportion of the trees as groups or individuals, to the creation of mosaics of grass openings and tree-covered zones. The retention of some residual trees and groups of trees would be beneficial for certain guilds of birds and as hiding and thermal cover for larger wildlife and livestock. Some prescriptions hope to establish a continuous and relatively dense stand of grasses and forbs so that prescribed fire eventually can be used to maintain the tree component in a less dominant position relative to the herbaceous species (Gottfried and others 1999).

Restoration efforts must be conducted with caution; one treatment will not be appropriate for all sites. Grasslands are complex ecosystems with different mixes of herbaceous and nonherbaceous species, site characteristics, and climatic conditions. Historical land uses have altered most areas, and the amount of change will affect present conditions and management options. Many areas that are perceived as grasslands are actually woodlands and never supported the grass communities that are projected to have been present. This includes areas adjacent to prehistorical and historical American Indian population centers where woodlands were heavily cut for domestic and agricultural purposes, and to areas surrounding Spanish-Mexican settlements and United States military posts in New Mexico. Many of the grasslands were actually savannas that contained scattered trees that provided the seed sources for an increase in tree density once fire events became less frequent. The presence of old or large trees would be a sign that caution is warranted. Some sites also have been so eroded and changed since the grasses were lost, that it may not be ecologically or economically possible to return to the original grassland communities. The introduction of invasive nonnative species, such as Lehmann's lovegrass and buffelgrass (*Cenchrus ciliaris*), has made restoration of native grasses more difficult (Weltzin and McPherson 1995). Long-term changes in greenhouse gases may make restoration difficult. Managers should recognize that even the best planned and executed treatments will not produce the desired results if weather conditions are not favorable. Except for ecologically critical areas, economical considerations may be the ultimate factor determining if, when, and what techniques should be employed to restore a grassland in a given location.

A wide variety of mechanical methods and prescriptions exist for use in reducing the woody species cover on grasslands (Vallentine 1971). The successes of these treatments depend on the characteristics of the woody species, including age, reproductive strategies, and stand densities; site characteristics such as slope, rockiness, terrain, and soil conditions; desired replacement vegetation; and soil seed bank availability. Herbicides also have been applied to mesquite and other woody species, but primarily on private lands. Climatic conditions before, during, and after an operation may determine if even the best planned and executed restoration treatment is successful. Forage increases after mesquite control, for example, will only occur if work is done during years of average or above average precipitation (Scifres and Polk 1974). It is recommended that livestock grazing be deferred from a site for a prescribed time after treatment so that new grasses can become established. Grazing by large and small wildlife species is more difficult to control. Deferral for 2 to 4 years has been recommended for many pinyon-juniper ranges (Gottfried and Severson 1993), but the amount of time will depend on the amount and condition of residual species, site potential, and weather conditions (Gottfried and Pieper 2000). Many of the failures of past pinyon-juniper treatments can be linked to premature grazing by livestock.

Unless satisfactory seed from residual grasses and forbs or from the soil seed bank are present, restoration will require seeding of native species. Forbs and shrub species could be seeded on some locations depending on site conditions and management objectives. It may be necessary and desirable to reestablish some shrubs, such as *Purshia* spp., which are important browse species. Although seed is usually not collected locally before a treatment, seed should come from a source as near to the project site as possible. The same principles that apply to tree seed provenance should apply to

Weather stations, such as this one on the Cascabel Watershed Area of southwestern New Mexico, provide data that are used to plan and evaluate grassland management and restoration treatments. (Photo by John Yazzie)

grass and associated species seed. Grassland species seed should, as closely as possible, be adapted to the site—for example, elevation and soils. Some desirable native species, such as black grama (*Bouteloua eriopoda*), may not be available from commercial seed companies, and adapted species may have to be substituted. The seeding of adapted nonnative species such as Lehmann lovegrass was common at one time but currently is discouraged.

Managers must consider the proper method of applying seed, whether seed should be drilled into the soil surface with a rangeland drill or if seed can be broadcast directly on the ground without cover. The creation of depressions in the soil surface in conjunction with seeding will enhance grass stand establishment in semidesert grasslands (Gottfried and others 1999). Each species has specific requirements. Timing of a treatment is important and should be done prior to or during the precipitation season for which the species is adapted. Optimum season for seeding will vary by site. Obviously, unprotected seed would be subject to granivory by insects and rodents or be blown or washed from the site. An established tree or shrub canopy that creates a moderate microclimate or reduces herbivore activity could result in reduced losses of viable seed and new seedlings. Restoration prescriptions should include monitoring before and for a period after treatment to ascertain if satisfactory results were achieved or if procedures should be modified for future success.

Research on the value of inoculating restoration sites with appropriate arbuscular mycorrhizal fungi to promote the survival and growth of the grasses could

A grassland restoration treatment designed to crush mesquite and seed native perennial grasses at the George Wright Pasture of the Diamond A Ranch Central Division in southwestern New Mexico. The crusher created depressions in the soil that enhance seeding success. (Photo by Ronald Bemis)

The sediment dam at Cascabel Watershed, New Mexico, is used to measure sediment production related to land management activities. (Photo by Gerald Gottfried)

enhance restoration successes. At present, there are no practical and affordable methods of reintroducing mycorrhizal plants to disturbed grasslands (Caplan and others 1999). Some work has been started on the relation between giant sacaton (*Sporobolus wrightii*) and mycorrhizae from a southeastern Arizona site (Elliott and others 1998). Seedballs consisting of clay, soil humus, grass seed, water, and a source of mycorrhizae may be an excellent way to disperse seed in disturbed areas (Caplan and others 1999). The ball should contain root segments of the native culture host plant with hyphae.

Watershed Condition—Many degraded grasslands have severe erosion problems; surface soils have been lost, and gullies and degraded stream channels are present. Most Southwestern grasslands are influenced by convectional, high-intensity thunderstorms during the summer monsoon. These thunderstorms have been linked to most surface runoff and erosion events, especially on degraded watersheds (Rich 1961). A change in surface conditions that increases infiltration capacity, whether by increasing the plant cover or by mechanical stabilization, should result in decreased surface runoff and soil erosion (Rich 1961). Increasing the herbaceous cover, especially in interspace areas between tree-influence zones will protect the soil surface from raindrop compaction and consequential soil pore sealing. Plant roots, especially the fibrous roots of monocotyledons, help buffer the soil from sealing, hold soil particles in place, improve the soil porosity and, thus, water movement in and through the soil, and increase water holding capacity because of organic additions to the soil. Plants also act as microbarriers to the free movement of surface runoff, allowing for greater infiltration and less soil movement within and from the larger watershed and the resulting losses in stream water quality. Increased infiltration provides more water for plant survival and growth. In many cases, changes in grazing season and intensities can reduce sediment loads from some grassland sites (Holechek and others 1998). Vegetation manipulations, by themselves, will not work on all sites; more expensive mechanical methods also may be necessary to prepare a site for restoration. Contour furrowing and trenching, ripping, or pitting has been used to retain water and reduce sedimentation (Brooks and others 2002). An early study in central Arizona found that surface runoff and erosion were reduced by a treatment that combined brush control, sloping of steep gully sides, placing cut brush in gully channels, and grass seeding (Rich 1961). Gullies develop when surface runoff is concentrated at a point where there is an abrupt change in elevation and slope and a lack of vegetative cover (Brooks and others 2002). Check dams and other barriers may be needed to retard head and down cutting and stabilize gullies until vegetation becomes established. Ranchers in Arizona's San Bernardino Valley are using local rocks to construct dams and structures to limit headcutting and to create meanders in relatively straight gullies. The meanders slow streamflow velocities, reducing potential bank cutting and increasing sediment deposition creating sites for the reestablishment of vegetation. Engineered structures may be necessary on larger streams to raise their base levels, thus reducing channel gradients and cross sections and streamflow velocities (Brooks and others 2002). Practices should not result in increased water pollution and should be conducted under existing Best Management Practice guidelines.

Prescribed Fire—The introduction of prescribed fire and the management of natural fire in grassland ecosystems are of major interest today. There is wide acceptance of fire as a paramount factor in maintaining native grass plant communities by reducing woody plants and removing the buildup of grass litter prior to Euro-American settlement. Landscape-level prescribed fires are usually designed to create mosaics of wooded and grass areas in addition to reducing general tree densities. In addition to reducing the cover of woody species, periodic fires may keep ungrazed grasslands vigorous by killing forbs and removing grass litter (Robinett and Barker 1996). However, some forbs may be desirable because they are high in the protein and moisture that are important for a number of animals (C.H. Sieg 2002, personal correspondence).

The prescribed burn at Baker Canyon in the Peloncillo Mountains, which straddle the border between Arizona and New Mexico, June 1995. The objective was to reduce tree densities and to create mosaics of grassland and tree dominated areas. (Photo by Gerald Gottfried)

Fire must be used judiciously after a thorough analysis of benefits and risks. A single prescribed fire may not achieve all of the ecosystem objectives for an area, and multiple burns may be necessary. Information is often lacking concerning pretreatment fuel loadings on an area dominated by trees. The Fuel Characteristic Classification System (FCC) (Ottmar and others 2003) has coverage for many pinyon-juniper sites and is currently being expanded to cover oak and juniper woodlands and savannas that are common in the Southwest. Several fire prediction models and systems may be appropriate in planning prescribed burns on sites with significant tree cover. A version of BEHAVE (BEHAVE PLUS), which was originally developed by Burgan and Rothermel (1984), was used in preparation for the 46,000-acre Baker II Burn in the southern Peloncillo Mountains of Arizona and New Mexico in June 2003 (P.A. Gordon 2004, personal correspondence). FCC information eventually will be linked to models such as BEHAVE and FARSITE (Ottmar and others 2003). Monitoring of fire effects is needed if a program is to be biologically and economically successful. Monitoring should be designed to include soil and hydrological responses as well as the common vegetation and wildlife inventories. The Revised Universal Soil Loss Equation (RUSLE) has been used to evaluate soil erosion from grasslands, but it tends to underestimate soil losses (Spaeth and others 2003). There is a shift to the Water Erosion Prediction Program (WEPP), especially for postfire predictions. A current effort in southeastern Arizona is attempting to define parameters for the Disturbed WEPP that could be used to predict soil losses following fires in semiarid grasslands (Paige and others 2003).

Wildfires can be beneficial, and each ignition should be evaluated prior to suppression actions. Fires obviously can be attacked if they are a potential danger to structures and improvements or if the landowner favors suppression; they can be monitored before a decision is made, or they can be allowed to burn. However, the last option must be taken with an understanding of the characteristics and needs of the specific area and of the actual and perceived impacts on encroaching population areas (Allen 1998). The Peloncillo Programmatic Fire Plan is an attempt to identify the prescribed fire and wildfire suppression philosophies of ranchers and landowners in this mountain range so that land managers may anticipate the appropriate actions (Allen 1999). Potential fire intensities may have changed since settlement times because of local buildups of larger woody fuels in savannas and riparian corridors. Current and desired fuel loadings are considerations, as are the habitat requirements of threatened, endangered, and sensitive (TES) species. The U.S. Fish and Wildlife Service and appropriate State agencies must be consulted on these issues.

Understanding the role of fire in maintaining habitats for rare species and the dynamics of fire in riparian areas will lead to more informed decisions (C.H. Sieg 2002, personal correspondence). The proper time to ignite prescribed fires is a concern where TES species habitats are present or where riparian areas could be adversely impacted. In semidesert grasslands, species are more influenced by fire season and frequency than by fire behavior (Steuter and McPherson 1995). Most wildfires in southeastern Arizona and southwestern New Mexico occur in the warm period as the annual monsoon develops, and most species are adapted to the relatively hot fires that occur prior to the growing season. Some authorities prefer cool season fires in the fall, winter, or early spring because they feel that less damage is done to the ecosystem. Others believe that cool season burning will cause a shift in species composition to favor shrubs and half-shrubs or will leave the soil surface open to accelerated erosion for a longer period. However, scientific data and documented observations are unavailable, and research is needed to determine if one season is better than the other. The research must address the impacts of the two burning prescriptions on other physical and biological ecosystem components, such as hydrology, sedimentation, arthropod populations, common animal species, and vegetation, as well as TES species. Ford and McPherson (1998) and Gottfried and others (2000) are studying some of these questions on the shortgrass prairies in eastern New Mexico and the oak (*Quercus emoryi)* savannas of southwestern New Mexico, respectively.

Fire frequency is a consideration in any prescribed burning program because frequent repeated fires may not allow for the recovery of many grass species. Pase and Granfelt (1977) recommended that at least 5 years separate fires so that herbaceous plants have an adequate period to recover and set seed. Kaib and others (1999) indicate that the grasslands of southeastern Arizona had low intensity fires every 4 to 8 years prior to the introduction of large herds of livestock. Research in southern Arizona has shown that grasslands in good condition can sustain a fire interval of between 5 and 10 years without a loss of productivity (Robinett and Barker 1996). Grass recovery depends on precipitation after treatment and the amount of herbivory (McPherson 1995).

Many prescribed fires in the Southwest occur in the early summer prior to the monsoon period. This also is a period when fire suppression and control resources for prescribed fires may be scarce because of wildfires. Prescribed fires are cancelled because of the lack of personnel and equipment during this period even when fuel and weather conditions are satisfactory and the risks to control are low. One suggestion is that the land management agencies consider creating a fire management organization, including personnel and equipment, to plan and conduct prescribed fires that is separate from the fire suppression organization (Bemis 2003).

Improving Soil Fertility—Heavy grazing and accelerated soil erosion have been linked to reductions in soil organic matter and soil fertility on many rangelands (Aguilar 1993). Any attempt to improve site potential and grass productivity must restore soil organic matter and associated nutrients; one recent method is to apply treated municipal sewage sludge to the soil surface. The Rocky Mountain Forest and Range Experiment Station conducted several experiments on grasslands in the Albuquerque area. Aguilar (1993), citing a number of studies by Fresquez and his associates, indicates that a one-time sludge application of 10 to 20 tons per acre increased plant production and ground cover without producing unsatisfactory levels of potentially hazardous constituents, such as heavy metals, in either soils or plant tissue. Blue grama (*Bouteloua gracilis*) yielded 1.5 to 2.7 times more production on treated compared to control plots. Total nitrogen, phosphorus, potassium, and electrical conductivity increased during the first year, and soil organic matter increased by the fifth year after application. Aguilar (1993) concluded that many areas with depleted soil nutrients would benefit from prescribed amendments of sewage sludge. A pot study in Texas found that applications of biosolids increased shoot growth of blue grama and tobosagrass (*Hilaria mutica*) because of increased soil NO_3-N (Mata-Gonzalez and others 2002). Low levels of biosolids and irrigation (40 percent of field capacity) resulted in increased root biomass, while high levels of both (80 percent of field capacity) resulted in a greater allocation of resources to the grass shoots. High applications of biosolids in the spring (34 and 90 $Mgha^{-1}$) produced greater soil nitrogen concentrations and shoot growth than did summer applications.

Another alternative is to use local materials as mulch. A recent study in the semidesert grasslands on the Santa Rita Experimental Range in Arizona examined the effects of combined mesquite overstory treatments and soil surface mulch treatments on herbaceous production (Pease 2000, Pease and others 2003). Overstory treatments consisted of removing the mesquite with or without sprout control and leaving the mesquite trees. These were combined with soil surface treatments consisting of mulches of lopped and scattered mesquite slash, commercial compost,

Prefabricated steel flumes, which can be assembled in the field, have been used to measure streamflow in remote, relatively inaccessible areas. (Photo by Gerald Gottfried)

A forestry technician downloads hydrologic data to a laptop computer from a Parshall flume installation at the Cascabel Watersheds, New Mexico. The small flume measures typical low streamflow events and the larger flume measures higher events. The 12 small instrumented watersheds will be used to evaluate the effects of warm and cool season prescribed burning and unburned conditions on the physical, chemical, and biological compenents of the oak savanna ecosystem. (Photo by John Yazzie)

and mesquite wood chips. The mesquite control treatment with no sprout controls resulted in a 79 percent increase in annual and fall herbaceous production of native species relative to the control plots; Lehmann lovegrass was not affected by the treatments. The mulching treatments had no effect on total annual, spring, or fall herbaceous production. The lack of response was attributed to low precipitation during the 4-year study, and to levels of mulch that were too low to impede evaporation (Pease 2000, Pease and others 2003). The lopped and scattered treatment did improve total soil nitrogen, plant available phosphorus, and soil pH relative to the controls.

Holistic Resource Management (HRM)—Savory (1988) introduced the idea of HRM into the United States from Zimbabwe. HRM is a grassland system or planning model that considers social, economic, and biological needs. However, it basically uses livestock to accomplish its goals. It involves a high-intensity, short-duration, time-controlled grazing system based on the phenological and physiological needs of the plant and animal species being managed, followed by periods of nonuse. The number of paddocks in the system is a function of the length of the deferment period that the plants require to maintain good health and high vigor; this usually is between 45 to 90 days, depending on the timing and amount of precipitation. Paddock use is scheduled to utilize both warm and cool season plants. Livestock are moved on a fast rotation during the growing season and are only allowed to remove 5 percent of the forage crop on each visit to a paddock before it is deferred. HRM requires a high degree of balance between annual forage consumption and annual forage production, the latter of which depends on annual climatic conditions, and HRM requires intensive herd management to achieve the desired effects.

High stocking densities are projected to improve water infiltration into the soil, increase mineral cycling, increase the number of plants consumed, improve the leaf area index, improve the distribution of grazing, increase the period when green forage is available, and reduce the percentage of ungrazed plants. However, Savory's system is controversial (Holechek and others 2000, Sayre 2001), and some of the claimed benefits have not been proven—for example, increased water infiltration has not been found, and sedimentation is higher under this system than under more moderate grazing systems. Holechek and his associates (1998, 2000) and Sayre (2001) provide a more complete analysis of HRM. They indicate that it may not be appropriate for arid grassland ecosystems because short growing seasons minimize the value of repeated periods of defoliation and nonuse. HRM may be best suited for monocultures of extremely grazing-tolerant grasses in subhumid environments, but it may not be suitable for lands where the goal is to manage for plant species diversity and variation in residual covers (C.H. Sieg 2002, personal correspondence). Nevertheless, some ranchers have adopted the short-duration grazing and have been satisfied with the results (Sayre 2001).

It is usually accepted that short-duration grazing is not the same as Savory's HRM, but many researchers have related their findings to HRM (Holechek and others 2000). Several studies have compared short-duration grazing to continuous grazing systems. A review of results indicates that the two systems produce similar results when stocking rates are equivalent with respect to forage production, plant succession and range condition, livestock productivity, and harvest efficiency (Holechek and others 2000). Short-duration/high-intensity grazing without the pasture rotation system has been used on some difficult restoration sites. For example, cattle have been grazed to rehabilitate mine tailing sites in central Arizona. Hay is often spread to encourage the cattle movements around the tailing site where they break up the tailing material by hoof action, fertilize and mix organic material into the substrate, and create small depressions to catch precipitation (Wheeler 1998). Hay also serves as mulch, reducing soil evaporation and soil surface temperatures. Wheeler (1998) claims that feeding also stimulates new growth on existing plants, and microorganisms associated with the hay and cattle droppings improve soil fertility and help buffer the soil pH of the tailings. Irrigation systems are available on many tailing sites. Short-duration/high-intensity grazing has been tried on a severely eroded site in the San Bernardino Valley of southeastern Arizona (Gottfried and others 1999). Mechanical restorations could not be used on the site because of valuable archeological resources. Native hay was spread on the fenced site before cattle were introduced for less than 3 days, and the site was seeded with a mixture of native grasses. Most of the resulting grass seedlings—cane beardgrass (*Bothriochloa barbinoides*) and, Arizona cottontop (*Digitorial californica*)—were from the hay. Initial results have not been as good as expected and were similar to the control area because of summer droughts and insect herbivory, both of which are common problems in the Southwest.

Watershed Management: Best Management Practices

Author: Penny Luehring, Southwestern Region

The Clean Water Act of 1972 (Federal Water Pollution Control Act, amendments of 1972; PL 92-500, 33U.S.C. 1311-1313, 1315-1317) defines a Best Management Practice (BMP) as: "a practice or a combination of practices, that is determined by a State (or designated area-wide planning agency) after problem assessment, examination of alternative practices and appropriate public participation, to be the most effective, practicable (including technological, economic, and institutional considerations) means of preventing or reducing the amount of pollution generated by non-point sources to a level compatible with water quality goals."

Nonpoint source pollution is water pollution that originates from many indefinable sources. Nonpoint source pollutants are generally carried over, or through, the soil and ground cover via streamflow processes. Resource management activities likely to occur in grassland ecosystems that may be considered nonpoint sources include runoff from grazing, construction, revegetation, restoration, prescribed burning, wildfire suppression, pest or invasive-plant control, developed recreation sites, mining, road construction, and road maintenance.

Best Management Practices must be designed on site-specific basis for planned activities, taking into consideration the degree of surface disturbance anticipated, drainage patterns, climate, slope, soil erodibility, and proximity to stream channels. BMPs may be operational or administrative. *Operational BMP* examples include putting drainage dips in roads, leaving untreated buffer strips between an activity and the stream channel, or applying mulch. Examples of *administrative BMPs* include controlling livestock numbers and season of use, timing of construction activities, and designing roads to minimize stream crossings. Most State water quality regulatory agencies and Federal land management agencies maintain handbooks of water quality protection techniques and tools that can be used to prescribe BMPs.

Monitoring of BMPs is a critical part of the process. Monitoring should be done first to see if the BMPs were implemented as prescribed. Then, BMPs should be evaluated as to their effectiveness so that prescribed protection measures can be continually improved and BMP knowledge can be recycled to benefit future projects.

Road Management

Author: Bill Woodward, Southwestern Region

Grassland roads provide legal access necessary for administration and use of Federal, State, and private lands. Federal grasslands are often fragmented, and as a result, grassland roads are generally branches of State, County, and other road systems that serve as primary access roads to these areas. Land fragmentation usually results in significant increases in road densities across previously undivided landscapes (Mitchell and others 2002).

Most grassland roads are for use by high clearance vehicles. Road densities on Federal lands are often less than 2 miles per square mile (equivalent to having a road around each section of land). For most grassland activities, such as cattle grazing and hunting, this is adequate to meet management objectives. However, in areas where oil and gas operations are a primary activity, road densities as high as 6 miles per square mile may be necessary to maintain wells and related equipment. One study in eastern Colorado found road densities for subdivided grasslands were between these two values. Road densities on two subdivided ranches were 3.4 to 5.7 miles per section compared to between 0.6 and 1.5 miles per section on two neighboring intact ranches (Mitchell and others 2002).

Existing roads and road construction and maintenance traditionally have been a concern in forest and grassland management. Older roads were often constructed along riparian corridors and across sensitive meadows and wetlands. Most of these roads were poorly designed, if designed at all, and had inadequate drainage. Poorly designed or constructed roads, properly designed roads that are not maintained, and roads with inadequate drainage and poor culvert design contribute significantly to erosion and sedimentation. Efforts to correct these problems through construction and maintenance have been hindered by budgets, priority safety items, and environmental considerations.

Today's emphasis for grassland roads on Federal lands is to locate, design, construct, maintain, and manage to minimize erosion and sedimentation effects and to reestablish wetland and riparian areas. Offroad use is often prohibited or restricted to minimize creation of unneeded travelways and the spread of noxious and invasive vegetation species. Unneeded roads are to be decommissioned or converted to other nonroad uses. Road conditions and management emphasis on private lands, which often have heavy use, are variable.

Standard USDA Forest Service manuals are available to ensure proper design, construction, and maintenance of roads and for implementation of soil

An illegal four-wheel drive vehicle road on steep slopes in the SP Crater area north of Flagstaff, Arizona. Such activities degrade vegetation, soil, water, and esthetic resources. (Photo by John Yazzie) and water conservation practices within grassland communities. Similar manuals also are available from other government agencies and from educational institutions.

Recreation Management

Author: Rick Atwell, Southwestern Region

Pressures for increased recreational opportunities are increasing throughout the West as the region's primarily urban populations continue to grow. While forests and associated lakes and streams are the primary recreational focus for many in the arid Southwest, grasslands also are being impacted by increased road traffic and offroad travel. Certain grasslands, especially mountain meadows, receive heavy use by the recreating public, and sometimes these sensitive areas must be protected from overuse.

One example: the measures used to protect the Kiwanis Meadow on the Sandia Ranger District of the Cibola National Forest. The meadow is used by hundreds of thousands of visitors who are traveling along the 1.5 mile trail between the Sandia Mountain Aerial Tramway and the Sandia Crest observation point. These two destinations receive the highest visitor counts for National Forests in northern New Mexico. The District employed a three-part plan. The first part was to reroute the popular Crest Trail from the meadow to its east side, and a second step was to build a buck and pole fence around the meadow. This provided a physical barrier to encourage visitors to stay on the established trails and not use the meadow for lounging or picnicking. The materials for the fence came from other areas of the District, often resulting in the creation of beneficial small wildlife openings. The third step was to place directional and informational signs around the area.

Integrated Weed Management

Author: Gene Onken, Southwestern Region

The introduction, adaptation, and spread of nonnative invasive plant species have become a serious threat to native grassland ecosystems of the Southwestern United States. Significant spread of invasive weeds in the Southwest has occurred relatively recently, especially during the past 15 years. Because of more xeric climate, harsh sites, and marginal soil productivity, the invasive weed problem reached serious dimension in the Southwest later than in other parts of the country. In the Southwestern Region of the USDA Forest Service, remoteness may also be a factor because the Region has a less dense road system than more highly developed agricultural production areas in other parts of the Southwest. These factors translate to a somewhat slower initial rate of weed introduction and spread.

Some of the most invasive of species evolved in Eurasia where the climate is similar to that of the Southwestern United States. Once these species were introduced here, the infestations spread rapidly. The weeds were and are often able to outcompete the native species for available moisture and space on the landscape. The overall problem is now highly significant both from an ecological and an economic perspective. To sustain the native grassland species, both *integrated* and *adaptive* management actions are now required for managing the invasive species threat.

Integrated weed management (IWM) is a systems approach to managing undesirable plants. It is defined in the Federal Noxious Weed Act of 1974 (PL 93-626, January 1975, U.S.C. 2801-2814) as:

> [A] system for the planning and implementation of a program, using an interdisciplinary approach, to select a method for containing or controlling an undesirable plant species or group of species using all available methods, including…education; prevention; physical or mechanical methods; biological control agents; herbicide methods; cultural methods; and general land management practices.

The concept of integrated weed management has already been adopted by most of the Federal and State agencies in the Southwest.

IWM involves using the best control techniques available for the target weed species. IWM requires a planned and coordinated program to limit the impact and spread of the weed. Control methods should be determined by: management objectives for the land, effectiveness of the control technique on the target species, environmental factors, land use, economics, policy and legal restrictions, safety to humans and the environment, and the extent and nature of the infestation.

An IWM approach for addressing invasive plant problems is particularly suited for an *adaptive management strategy*, which provides a way to describe and evaluate the consequences of dynamic and rapidly changing invasive plant populations on the landscape. Within a rather short time, invasive weeds spread rapidly from existing infestations into new locations. New species also may become established in any given locality. New technologies for weed control are continually being developed as new biological agents and herbicides become available.

An adaptive management strategy requires site-specific explanations of what actions the land managing agency or landowner will take under various conditions and what the environmental effects will be for those weed control actions. Weed management actions are continually reevaluated by land managers as monitoring indicates changes on the landscape and as new control options are developed. This reevaluation is done within the framework of the original integrated weed management plan. Then the next control actions are appropriately adjusted or adapted

Table 8-1. Map scale, vegetation, and appropriate imaging technology.

	Vegetation		Example			
Map scale	Potential	Existing	Potential	Existing	Image data type	
1:1,000,0001	Class	Lifeform	Close forest	Coniferous forest	AVHRR	
	Subclass	Lifeform	Mainly evergreen	Coniferous forest		
1:500,000	Group	Lifeform	Temp. evergreen needleleaf	Coniferous forest		
1:250,000	Formation	Structural stage	Pine forest	Seedling/sapling	Landsat MSS	
1:126,720						
1:100,000	Series	Cover type	Ponderosa pine		Landsat TM	
1:50,000	Subseries	Domance type	Ponderosa pine/ gambel oak		SPOT XS SPOT Pan	Air photos
	Association	Community type	Ponderosa pine/ Arizona fescue/ gambel oak phase	Ponderosa pine/ mutton bluegrass	Digital camera videography	

to the new and changing conditions and technologies. Thus, an adaptive management strategy is a continuing process of:

- Management action
- Monitor the results
- Evaluate the changes
- Adapt the treatment plan
- Implement the next (adapted) management action
- Monitor the results

An adaptive management approach shows how weeds will be treated without listing individual species or individual sites. Managers should specify an approximate number and/or percentage of treatment acres across a geographic area. This estimate forms the basis for predicting the environmental consequences and for defining the various weed management strategies.

Now that nonnative invasive species have become firmly established within the native grassland ecosystems of the Southwestern Region, aggressive and continuing eradication or control of new or existing nonnative invasive populations or infestations must be part of management to prevent spread or to restrict unacceptable impacts on existing native plant communities. Economic, environmental, or legal constraints may prevent eradication or the desired degree of invasive weed control. Therefore, implementing integrated weed management practices under an adaptive management strategy provides the most practical approach toward addressing this problem.

In summary, invasive plant species will continue to impact our landscapes and place our natural grassland ecosystems at risk. A perpetual expenditure of effort and resources will be required to sustain the grasslands.

Remote Sensing, GIS Applications, and Database Management

Remote Sensing

Author: Bill Krausmann, Southwestern Region

Remote sensing has a demonstrated potential to aid grassland managers in maintaining long-term viability of the resource. Remote sensing can be defined, in this context, as the analysis of grassland responses to electromagnetic radiation as collected and recorded in an image format. Examples of applications in remote sensing that deal with range management aspects of grassland ecosystems date back well into the 1930s (Tueller 1989).

The types of imagery and imagery-based analytical processes that can be applied to grassland management have grown exponentially over the past 25 years. Several forms of satellite imagery are currently available for analysis, in addition to various forms of aerial photography—a standard tool for managers. New satellite imaging systems are being brought on line each year, further increasing the potential value of remote sensing as a management tool. The marked increase in available imagery and the development of new techniques are fortuitous because of a need to augment standard inventory and monitoring methods to meet current requirements placed on resource management agencies.

Vegetation Mapping—Managers are interested in the type, distribution, and condition of grassland vegetation, and for grazing analysis, the forage base as it occurs across space and time. While remote sensing techniques have been utilized since the 1960s to map parameters of vegetation, the number of useful and fully applied procedures or techniques is quite low (Tueller 1989).

The level of detail that can be mapped within vegetation communities is directly related to the scale of a given project. Selecting an image data source that is appropriate for the scale of the mapping project is a critical element in the successful application of remote sensing in grassland management (table 8-1).

Aerial photography has long been a proven tool for mapping vegetation. Research has shown that photography acquired at a scale of 1:10,000 is optimum for mapping vegetation at the ecological site level (Tueller 1979). As photo scale becomes smaller, the range of vegetation units that can be detected becomes more general, as indicated in table 8-1. It is inappropriate, for example, to use Landsat Thematic Mapper imagery for a project where mapping at a species association level is of interest. On the other hand, mapping series level vegetation across an entire National Forest using aerial photography could be done but would be extremely laborious and expensive.

Computer mapping of vegetation types revolves around the processes of supervised and/or unsupervised image classification. In the supervised approach, areas of homogeneous training sites of known vegetation type are identified on the imagery. There are typically several training sites per class of vegetation. Statistics derived from the spectral response of the pixels within the training sites are used by one of several classification algorithms to separate the image into specified vegetation classes.

Generally, unsupervised classification seems to work best on grasslands (Tueller 1989). The analyst provides the computer with the number of clusters to be derived and parameters that drive cluster merging and splitting in the unsupervised process. Pixels in the image are then clustered into groups with similar spectral response by the computer. The groupings that are generated in this process are called spectral classes. They represent areas with similar spectral response. It is the analyst's responsibility to develop information classes from the spectral classes. The classes are developed by building relationships between the spectral classes and areas of the surface with known vegetation cover. Information classes can represent, among other things, plant communities, grazing allotments, or range improvements.

Mapping vegetation in rangelands, including grasslands, using satellite data is a difficult process in the Southwest. Several problems combine to reduce classification accuracies. Some of these problems include high soil background response, spatially heterogeneous precipitation patterns, spatially heterogeneous grazing patterns, and timber-covered range allotments. On average, for classifications produced at the vegetation series/sub-series level (table 8-1), overall classification accuracies between 65 and 75 percent could be expected.

Change Detection—The detection of change over time in grasslands and other rangelands is perhaps the most significant application of remote sensing to range management. Remote sensing instruments can produce imagery at scales from the site level to subcontinental areas that can be used to detect fluctuations in productivity.

Digital change detection involves using a computer to compare the spectral response of two or more images acquired on different dates. The comparison is performed at the pixel level and requires that the imagery data sets be accurately coregistered. There are several examples of change detection methods applied to range management issues (Chavez and MacKinnon 1994, Knight 1995, Pickup and others 1993, Ringrose and others 1999, Wallace and others 2003). Several algorithms have been developed for change detection, and a review of methodologies exists (Singh 1989), as does an assessment of Landsat Thematic Mapper imagery for change detection (Fung 1990). The most common change detection methodology is image differencing. In image differencing, change between two images is highlighted by subtracting one image's pixel values from the other.

Other Applications—Remote sensing has been used to monitor and evaluate grazing management. Pickup and Chewings (1988) used Landsat imagery and animal distribution models to estimate the distribution and grazing pattern of cattle on large pastures in Australia. Utilization levels of 25 to 40 percent are recommended in the semiarid Southwest (under 300 mm of precipitation annually) (Holechek and others 1998). Acquiring information on utilization levels requires considerable fieldwork. Repetitive aerial photography, videography, and digital camera imagery can provide baseline data on range readiness, utilization, livestock distribution, or other parameters that may reduce the amount of field work required to support management decisions.

Soil loss from gullying, overland flow, or eolian processes is a significant concern of grassland managers. Researchers have mapped soils, assessed soil loss, and measured gully erosion (Pickup and Nelson 1984, Westin and Lemme 1978) primarily using various forms of aerial photography.

Conclusion—In 1989, Tueller described the future of remote sensing applications in range management as "hazy" (Tueller 1989). The same could probably be said today. While research continues on applications of remote sensing to rangeland management, much of it relates to satellite monitoring of large, semiarid regions, and the questions being addressed are subcontinental in nature. This work does not address the needs of range managers working with several allotments on a USDA Forest Service Ranger District. If remote sensing is to become a standard management tool, procedures that directly address range readiness and utilization in a cost-effective manner at large scales must be developed.

New tools such as MODIS (a 36 band imaging radiometer) and the digital camera, combined with Landsat Thematic Mapper imagery and aerial photography, may provide opportunities to better monitor rangelands, including grasslands, at both the macro and micro scales. It is hoped that within 20 years much of the data required by managers may be derived from imagery.

Geographic Information System as a Tool for Managing Grasslands

Author: Pat Frieberg, Southwestern Region

The emergence of Geographic Information System (GIS) technology in the past few years has provided the grasslands manager with a decision support system that facilitates the decisionmaking process when addressing management issues. GIS provides the analytical capabilities for spatial data mapping, management, and modeling.

GIS is defined as a collection of computer hardware, software, geographic data, and personnel that are designed to hold, manipulate, analyze, and display all forms of geographically referenced information (Environmental Systems Research Institute 1995). GIS can address the impacts of multiple variables simultaneously—for example, to determine the capability of a grassland to sustain livestock grazing. Using basic layers of slope, aspect, vegetation, and water sources, along with certain known habits of livestock, one can model the grazing pattern and subsequent ability of the grassland to sustain grazing. Once the forage production and utilization information is measured and collected in the field, it can be entered into the model. The model then calculates the carrying capacity based upon actual use, and the criteria are entered into the model. The Apache-Sitgreaves National Forest in east-central Arizona is an example of a Forest that has used GIS for this purpose. The Range Management Staff developed a model using forage production, soil stability, distance from water, and steepness of slope to determine grazing capacities for allotments scheduled for new or revised allotment management plans.

Using the relationship between forage production and forest overstory density, a GIS map depicting herbaceous forage production classes for each allotment was developed and field checked. The result was an estimate of forage production in pounds per acre for each class. A percentage of allowable use for each of these forage production classes was established based upon range condition and management strategy. GIS maps showing limitations for soil stability, distance from water, and slope gradient were generated and used to further refine the percent allowable use in each forage production class. When the refined allowable use percentage was multiplied by the forage production in pounds per acre, the result was the pounds of forage available for consumption. This was multiplied by the GIS acres in each forage production class, then the total pounds of forage available for consumption by wildlife and livestock were computed for each pasture, allowing the range manager to estimate the livestock capacity for each pasture. The capacity of all pastures in the allotment was added to establish a capacity for the allotment.

GIS can be used for virtually every facet of resource management. Providing a spatial inventory of different aspects of the grassland resource, such as the location of noxious weeds, vegetation types, roads, and so forth, is a common use. Combining the database and mapping capabilities within the GIS system permits a variety of analyses to be performed, for example, analyzing counties and communities by economic characteristics. A study in the Sevilleta Long Term Ecological Research Program (LTER) is examining prehistoric and historic land use and exotic plant invasion by overlaying vegetation maps with archaeological site maps. Typically, GIS data are linked to large databases for decision support, such as the Forest Service's NRIS and INFRA databases and the Bureau of Land Management's Rangeland Information System (RIS). Remote sensing data can also be incorporated into GIS layers for analysis and for change detection purposes.

GIS data are increasingly being linked with modeling programs to create management applications. Some examples of the variety of applications:

- FRAGSTATS, a computer software program designed to compute a wide variety of landscape metrics for map patterns.
- The Agricultural Research Service's Arid Basin (ARDBSN) model to predict the amount of runoff resulting from rainstorm events.
- Predictive wildlife habitat models for current management or for potential reintroduction—for example, mountain lion (*Felis concolor*), black-tailed prairie dog (*Cynomys ludovicainus arizonensis*), and aplomado falcon (*Falco femoralis septentrionalis*).
- Texas A&M's PHYGROW, a hydrologic based plant growth simulation model using soil

characteristics, plant community characteristics, and weather data for a particular location to predict forage production.

GIS can also be an important tool in monitoring, not only to provide a spatial context to the monitoring effort but also to select sampling sites based on specific criteria, analyze changes in parameters over time, and for additional modeling to assess the temporal and spatial variability of ecosystem processes in an area.

Forest Service Corporate Databases That Cover Grasslands

Author: Reuben Weisz, Southwestern Region

The USDA Forest Service is currently investing in four major database projects that may be useful for grassland assessments:

- The Geographic Information System (GIS) Core Data Project
- The Automated Lands Project (ALP)
- The INFRASTRUCTURE (INFRA) Project
- The Natural Resources Information System (NRIS) Project

These database projects provide a set of interrelated databases and computer applications containing spatial (map) and tabular (numbers) data, collected and recorded in a consistent manner. The GIS Coordinator for a particular grassland area will be able to provide more details about applications of these databases.

Briefly described, the GIS Core Data Project is putting into place, "wall to wall" across all Forest and Grasslands boundaries, 15 standard GIS layers. These contain the minimum data required to do business everywhere in the Forest Service. Broadly speaking there are three categories of GIS layers:

1. **Land Information Layer—**The ALP database manages the spatial and tabular data associated with information about ownership, jurisdiction, land surveys, and restrictions and rights. Examples of ALP data include information about who owns a grassland area and what restrictions and rights apply to it.
2. **Constructed Features Layers—**The INFRA database manages spatial and tabular data describing those things in the ecosystem that are constructed or created by people. Examples of INFRA data include information about roads, trails, allotment and pasture boundaries, allotment and permit management information, and range improvements.
3. **Natural Resource Layers—**The NRIS database manages the spatial and tabular data about those parts of ecosystems that occur naturally such as air, water, terrestrial ecologic units, existing vegetation, threatened and endangered species occurrences, topography, water and watersheds, and the human dimension. In a given grassland area, this might contain useful information about water quality, water uses and water rights, threatened and endangered species, and watershed condition.

GIS Applications for Wildlife Management

Author: Bryce Rickel, Southwestern Region

GIS applications have been expanded to provide land managers with tools specific to wildlife management. Two examples are the Southwest Wildlife Information System and the Habitat Quality Index.

Southwest Wildlife Information System (SWIS)—This is an ArcView application that has been developed to provide field personnel with an easy way to search, query, and analyze basic wildlife species habitat relationships across landscapes. SWIS allows the user to perform species/habitat tabular and/or spatial searches and queries using ArcView. The focus of the current application is providing information at the Forest and project levels. SWIS also allows the user to display Arizona and New Mexico Natural Heritage data.

Habitat Quality Index (HQI)—This model is an ArcView application that allows Forest and District biologists to develop their own species habitat quality models. The primary modeling approach employed is simple and has been used for almost two decades. The idea behind the model is that a particular habitat type, per season, has certain cover and forage values for a particular wildlife species. An HQI model for a species will produce a GIS map with habitat qualities for each habitat type (or polygon) across a landscape.

Database Use to Assess Effects of Grazing on Southwestern Biodiversity: An Example

Authors: Curtis Flather and Patrick Zwartjes, Rocky Mountain Research Station

The decisions the Forest Service has made regarding the use of public lands for livestock grazing have become a contentious issue in the Southwest, resulting in many of these decisions being challenged (particularly through litigation) by a variety of parties with competing interests (for example, environmentalists and cattle ranchers). The Forest Service has recognized that National Forest managers and biologists have little information on the impact of grazing (both by permitted livestock and by native ungulates) on the various animal and plant species, as well as the overall biodiversity, found on National Forest System lands. To improve management decisions regarding species that may be at risk from permitted and/or native ungulate grazing, the Forest Service's Washington Office entered into a cooperative project with the Forest Service Southwestern Region (Region 3) and the Rocky Mountain Research Station (RMRS). The objectives of this project are to:

- Describe and classify habitat types on grazed lands in the Southwest.
- Determine species that are sensitive to grazing.
- Determine source habitats for sensitive species.
- Develop distributional maps and ecological/life history summaries for each species.
- Describe the effects of specific grazing management regimes on these species and their habitats.

Scope, Organization, Goals—Data acquisition for this project is focused on the compilation of existing information, both at a landscape level (including species distributions and general habitat associations), and at the individual species level (which includes data on specific habitat requirements and other pertinent ecological information). The geographic scope includes all land areas (not just National Forest System lands) in Arizona and New Mexico, with a taxonomic scope that includes select species of terrestrial vertebrates, aquatic vertebrates, and plants.

The responsibilities for the different objectives have been assigned to three units within the RMRS:

- **Fort Collins:** Characterize regional biodiversity patterns; develop models of species occupancy.
- **Albuquerque:** Identify species sensitive to grazing; develop species accounts for each with detailed habitat, ecology, and life history information.
- **Flagstaff:** Identify broad vegetative zones in the region; assess impacts of grazing on these zones as well as on select individual plant species.

In general, the goals of this project are to provide fundamental information on species distribution, occurrence, ecology, and life history for use by range and forest managers. It is important to note that this study is not intended to be a regional viability assessment, nor is it an assessment of Region 3's grazing program; rather, it is a tool to assess the habitat needs and vulnerabilities of individual species.

Geospatial Analyses—The objectives of this segment of the project are based on a geographic approach, one that will develop a geospatial database of species occurrence information as well as geographic information on land cover and land use throughout the Southwestern Region.

The format for this database is an ArcInfo 8/Microsoft SQL relational database, distributed as ArcInfo coverages. The content is divided into three map types:

- **Species Occurrence Maps—**Two general categories: (1) maps using species point observation data, collected from museum collection records, survey data (for example, USFWS Breeding Bird Survey), and biological atlases; and (2) predicted occurrence range maps, based on habitat associations, and produced by the National Gap Analysis Program. Of particular importance will be the capacity to generate species lists by spatial queries, such as within a particular National Forest or grazing allotment.
- **Biodiversity Maps—**Overlays geographic information for different species within a broad grouping (for example, birds, reptiles) to estimate species richness and relative biodiversity among geographical areas. Potential applications include identifying areas with the greatest number of species, and ranking different areas with respect to species richness.
- **Base Layer Maps—**Includes maps of topography/digital terrain, land use, land cover/vegetation, administrative boundaries, and so forth.

The main product for this project will be a Rocky Mountain Research Station General Technical Report (GTR) that will detail the methods and procedures utilized for this analysis, as well as the results of an analysis of biodiversity patterns in the Southwestern Region. The GTR will include a CD-ROM containing software and map files for analysis by the users. This CD-ROM will contain more than 30 GIS coverages, range maps for more than 800 species, more than 500,000 point locations for individual species, analysis algorithms, and a simple user interface.

Vertebrate Species Accounts—The project was designed to examine all terrestrial and aquatic vertebrate species in the Southwestern Region, and (1) identify those species with the greatest potential to be negatively impacted by grazing, and (2) collect detailed habitat and life history information into individual accounts based on information from both the published literature and the expertise of vertebrate zoologists working in Arizona and New Mexico.

Panels of zoological experts were assembled according to several broad categories of vertebrate taxa:

- reptiles and amphibians
- grassland-desert scrub birds
- woodland birds
- riparian birds
- small mammals
- carnivorous and ungulate mammals

The complete list of participants will include more than 40 zoological experts from Arizona and New Mexico, including university scientists, Federal and State scientists, wildlife experts, and private experts and consultants.

The panel process was organized into two stages, with an intervening period during which the Albuquerque RMRS developed draft species accounts based on the published literature:

- **Stage I—**The panel of experts considers and discusses the ecological and habitat needs of each species, followed by each panelist recording their assessment of the direction, magnitude, and likelihood of grazing impacts on this species. Species were selected for further consideration if at least one of the panelists determined the species had at least the *potential* to be severely negatively impacted (regardless of likelihood), or that the species is known to be negatively impacted (but of unknown magnitude).
- **Stage II—**Draft species accounts, developed for all species selected in stage I, are reviewed by panel members, who fill in gaps in information from the published literature, suggest additional sources of information, and make selections from a series of menus that contain habitat and life history descriptors that serve to characterize the ecological needs of each species. In addition, the stage II panel has the authority to either remove species from the database that were selected in stage I, or to add species, which they consider to be erroneously excluded.

The final version of the species accounts will be based on the inputs of the panelists in combination with the information from the published literature. The database of accounts will be contained on a CD-ROM in Microsoft Access format, with a user interface that allows for searches based on species names, or queries that will generate a species list based on shared habitat descriptors in the menu selections, such as general habitat association, specific attributes of habitat (tree heights, grass densities, and so forth), season of use, grazing effects, and others. Individual accounts will be able to be viewed on screen, or printed out individually according to the needs of each user. In addition, the CD-ROM will contain a ProCite file of all literature cited, and the Albuquerque RMRS will deliver to Region 3 the complete collection of literature used to develop all species accounts. We anticipate the final product to contain more than 300 terrestrial vertebrate and more than 50 aquatic vertebrate species, with a literature database of more than 2,000 entries. As of publication of this Assessment (2004), the species accounts database is well under construction, with a large percentage of accounts completed.

Progress and Schedules— The geospatial analyses and the panel process were largely completed by the start of Federal government fiscal year 2003. Development of the GTR, user interfaces for the CD-ROMs, and editing and completion of the individual species accounts are continuing as of the publication of this Assessment. The complete package should be available to forest managers and biologists as a new management tool by 2006.

Grasslands Education and Communication in the Southwestern Region

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Education for public and private land managers and for the interested public is vital for sound grassland management in the Southwest. Managers need the knowledge to be good stewards of their lands and to conduct ecologically and, especially for private landowners, financially sound treatments. Educated ranchers and land managers can help with many activities on their own or on leased grasslands. One example would be public agency managers who understand how to monitor grassland conditions, thus allowing educated decisions on livestock stocking levels and rotations and providing a basis for discussions on permits with the public, who may question their management decisions. Education of teachers, especially at the high school and university level, often pays large dividends.

The Coconino National Forest has a session on rangelands as part of the Arizona Natural Resource Conservation Workshop for Educators program. In this session, participants lay out transects to measure plant composition and amount of ground cover. The emphasis in this program is on rangelands as a type of landscape with many uses, not just grazing.

The Cuba Soil and Water Conservation District is the lead sponsor of the New Mexico Forestry Camp; the Forest Service is one of the many co-sponsors, with involvement from the Regional Office and the Santa Fe, Cibola, and Carson National Forests. Two sessions on grasslands are conducted at this weeklong camp for New Mexico youth (13 through 18 years old). One session focuses on identification of forbs and grasses, and the other focuses on grazing studies, soils, noxious weeds, and weed control methods.

The Malpai Borderlands Group conducts three "Ranching Today" workshops on the Borderlands near Douglas, AZ. These workshops are 3 to 5 days long and attended by ranchers, the public, and Nature Conservancy members. People from throughout the Western United States often attend these workshops to learn if the Malpai model would work in their areas. The workshops discuss examples of grassbanking, private land conservation easements, ongoing research, and endangered species. The Coronado National Forest participates in these activities. The Malpai Borderlands Group also supports activities at Douglas High School related to the supervised breeding of endangered Chiricahua leopard frogs (*Rana chiricahuensis*), and supports local students who serve as summer interns on sponsored research studies.

Most of the Western State sections of the Society for Range Management hold weeklong summer camps for high school students to learn about rangeland management. The Arizona Section has conducted camps in the State since the 1960s. Camps have been held at the Sierra Ancha Experimental Forest or at Mormon Lake.

The Cibola National Forest, as a partner with the Playa Lakes Joint Venture, has access to several Grassland Education "trunks" to use as a teaching tool. The trunks contain books, tools, and videos to aid in educating about grasslands. The Kiowa National Grasslands has been involved in outdoor education days, where countywide third graders are brought out to the National Grassland and given environmental instruction about vegetation. The National Grassland also serves as a site for workshops for landowners on grazing management and riparian enhancement.

The Washington Office of the USDA Forest Service is producing a series of posters, similar to the Smokey Bear poster series, that relate to grassland ecology and management. These posters will be distributed throughout the country. Some topics are:

- Grassland fire ecologies
- Rainfall in grasslands
- Noxious weeds
- What keeps a prairie a prairie?
- State grasses
- The cycle of life on a grassland
- The anatomy of grass
- The function of grass roots

Other Federal agencies have education programs related to grassland and general range management. The USDA Agricultural Research Service in Boise, ID, incorporates students in its watershed program to provide an educational experience and to broaden their awareness of the biological and physical processes, landscape attributes, and social and economic factors that affect viability of range management (Northwest Watershed Research Center, USDA ARS, undated).

Educational activities also include measures designed to inform the public about grassland ecology and management decisions. The Kiwanis Meadow near the Sandia Crest, north of Albuquerque on the Cibola National Forest, receives heavy recreational use because of its proximity to the Sandia Tram. Recent efforts to protect the alpine meadow by rerouting the trail have included the placement of directional and informational signs. The directional signs show visitors the new routes and where traffic is prohibited, and the informational signs explain why the Forest undertook the project. Signs that explained that meadow protection benefited wildlife were especially effective.

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References

Aguilar, R. 1993. Rehabilitation of Southwestern rangelands using sewage sludge: technology applicable to piñon-juniper ecosystems? In: Aldon, E.F.; Shaw, D.W., tech. coords. Managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30, Santa Fe, NM. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Allen, L. 1998. Grazing and fire management. In: Tellman, B., Finch D.M.; Edminster, C.B.; Hamre, R.H., eds. The future of arid grasslands: identifying issues, seeking solutions; 1996 October 9-13; Tucson, AZ. Proceedings RMRS-P-3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 97-100.

Allen, L.S. 1999. Fire management in the Borderlands: The Peloncillo Programmatic Fire Plan. In: Gottfried, G.J.; Eskew, L.G.; Curtin, C.G.; Edminster, C.B. compilers. Toward integrated research, land management, and ecosystem protection in the Malpai Borderlands: conference summary; 1999 January 6-8; Douglas, AZ. Proceedings RMRS-P-10. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 74-76.

Anonymous. Undated. Valle Grande Grass Bank briefing document. Unpublished report. 11 p.

Bemis, R.J. 2003. Barriers to burning. Unpublished report on file with the USDA Natural Resources Conservation Service, Douglas, AZ. 4 p.

Box, T. 2002. Listening to the land: speaking from the heart. Rangelands. 24: 21.

Brooks, K.N.; Ffolliott, P.F.; Gregerson, H,M.; DeBano, L.F. 2002. Hydrology and the Management of Watersheds. Ames: Iowa State Press.

Brown, J.H. 1999. Recent environmental changes in the Malpai Borderlands. In: Gottfried, G.J.; Eskew, L.G.; Curtin, C.G.; Edminster, C.B. compilers. Toward integrated research, land management, and ecosystem protection in the Malpai Borderlands: conference summary; 1999 January 6-8; Douglas, AZ. Proceedings RMRS-P-10. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 73.

Buffington, L.C.; Herbel, C.H. 1965. Vegetational changes on a semidesert grassland range from 1858 to 1963. Ecological Monographs. 35: 139-164.

Burgan, R.E.; Rothermel, R.C. 1984. BEHAVE: Fire prediction and fuel modeling system-FUEL subsystem. Gen. Tech. Rep. INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. 126 p.

Caplan, T.R.; Pratt, H.A.; Loftin, S.R. 1999. Influence of mycorrhizal source and seeding methods on native grass species grown in soils from a disturbed site. In: Finch, D.M.; Whitney, J.C.; Kelly, J.F.; Loftin, S.R., tech. coords. Rio Grande ecosystems: linking land, water and people toward a sustainable future for the Middle Rio Grande Basin. 1998 June 2-5, Albuquerque, NM. Proceedings RMRS-P-7. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 170-174.

Chavez, P.S.; MacKinnon, D.J. 1994. Automatic Detection of Vegetation Changes in the Southwestern United States Using Remotely Sensed Images. Photogrammetric Engineering and Remote Sensing. 60: 571-583.

Elliott, L.K.; Stutz, J.C.; Tiller, R.L.; Stromberg, J.C. 1998. Arbuscular mycorrhizal fungi, a possible tool for restoration of giant Sacaton grasslands. In: Tellman, B., Finch D.M.; Edminster, C.B.; Hamre, R.H., eds. The future of arid grasslands: identifying issues, seeking solutions; 1996 October 9-13; Tucson, AZ. Proceedings RMRS-P-3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 319-322.

Environmental Systems Research Institute. 1995. Understanding GIS: the ARC/INFO Method. New York: John Wiley and Sons.

Ford, P.L.; McPherson, G.R. 1998. Experimental fire research in semi-arid shortgrass prairie. In: Tellman, B., Finch D.M.; Edminster, C.B.; Hamre, R.H., eds. The future of arid grasslands: identifying issues, seeking solutions; 1996 October 9-13; Tucson, AZ. Proceedings RMRS-P-3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 107-116.

Fung, T. 1990. An Assessment of TM Imagery For Land-Cover Change Detection. IEEE Transactions on Geoscience and Remote Sensing. 28: 681-684.

Gottfried, G.J.; Edminster, C.B.; Bemis, R.J. 1999. Range restoration studies in the Southwestern Borderlands of southeastern Arizona and southwestern New Mexico. In: Gottfried, G.J.; Eskew, L.G.; Curtin, C.G.; Edminster, C.B. compilers. Toward integrated research, land management, and ecosystem protection in the Malpai Borderlands: conference summary; 1999 January 6-8; Douglas, AZ. Proceedings RMRS-P-10. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 95-99.

Gottfried, G.J.; Neary, D.G.; Bemis, R.J. 2000. Watershed characteristics of oak savanna in the Southwestern Borderlands. Hydrology and Water Resources in Arizona and the Southwest. 30: 21-28.

Gottfried, G.J.; Pieper, R.D. 2000. Pinyon-juniper rangelands. In: Jemison, R.; Raish, C., eds. Livestock Management in the American Southwest: Ecology, Society, and Economics. New York: Elsevier Science: 153-211.

Gottfried, G.J.; Severson, K.E. 1993. Distribution and multiresource management of piñon-juniper woodlands in the Southwestern United States. In: Aldon, E.F.; Shaw, D.W., tech. cords. Managing piñon-juniper ecosystems for sustainability and social needs; 1993 April 26-30, Santa Fe, NM. Gen. Tech. Rep. RM-236. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 108-116.

Hadley, D.; Sheridan, T.E.; Warshall, P. 1999. Human occupation and ecological changes in the Borderlands Region of Arizona/New Mexico/Sonora/Chihuahua: an analysis of causes and consequences. In: Gottfried, G.J.; Eskew, L.G.; Curtin, C.G.; Edminster, C.B. compilers. Toward integrated research, land management, and ecosystem protection in the Malpai Borderlands: conference summary; 1999 January 6-8; Douglas, AZ. Proceedings RMRS-P-10. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 51-56.

Hocker, J. 2002. Land is a gift for all time. *East Valley Tribune*, Wednesday, January 2, 2002. Mesa, AZ: 13A.

Holechek, J.L.; Gomes, H.; Molinar, F.; Galt, D.; Valdez, R. 2000. Short-duration grazing: the facts in 1999. Rangelands. 21: 18-22.

Holechek, J.L.; Pieper, R.D.; Herbel, C.H. 1998. Range Management, Principles and Practices. Upper Saddle River, NJ: Prentice Hall. 542 p..

Jemison, R.; Raish, C., eds. 2000. Livestock Management in the American Southwest: Ecology, Society, and Economics. New York: Elsevier Science. 612 p.

Kaib, M.; Swetnam, T.W.; Baisan, C.H. 1999. Fire history in canyon pine-oak forests, intervening desert grasslands, and higher-elevation mixed conifer forests of the Southwest Borderlands. In: Gottfried, G.J.; Eskew, L.G.; Curtin, C.G.; Edminster, C.B. compilers. Toward integrated research, land management, and ecosystem protection in the Malpai Borderlands: conference summary; 1999 January 6-8; Douglas, AZ. Proceedings RMRS-P-10. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 57-64.

Knight, A.W. 1995. REMA: A Neutral Model to Reveal Pattern and Processes of Cover Change in Wooded Rangelands. Remote Sensing of Environment. 52: 1-14.

Maestas, J.D.; Knight, R.L.; Gilgert, W.C. 2002. Cows, condos or neither: what's best for rangeland ecosystems? Rangelands. 24: 36-42.

Mata-Gonzalez, R.; Sosebee, R.B.; Wan, C. 2002. Shoot and root biomass of desert grasses as affected by biosolid application. Journal of Arid Environments. 50: 477-488.

McDonald, B. 1995. The formation and history of the Malpai Borderlands. In: DeBano, L.F.; Ffolliott, P.F.; Ortego-Rubio, A.;Gottfried, G.J.; Hamre, R.H.; Edminster, C.B., tech. coords. Biodiversity and management of the Madrean Archpelago: the Sky Islands of Southwestern United States and Northwestern Mexico, 1994 Sept. 19-23, Tucson, AZ. Gen. Tech. Rep. RM-GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 483-486.

McPherson, G.R. 1995. The role of fire in desert grasslands. In: McClaran, M.P.; Van Devender, T.R., eds. The Desert Grassland. Tucson: University of Arizona Press: 130-151.

McPherson, G.R.; Weltzin, J.F. 2000. Disturbance and climate change in United States/Mexico Borderland plant communities: a state-of-the-knowledge review. Gen. Tech. Rep. RMRS-GTR-50. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 24 p.

Mitchell, J.E.; Knight, R.L.; Camp, R.J. 2002. Landscape attitudes of subdivided ranches. Rangelands. 24: 3-9.

Moik, J.G. 1980. Digital Processing of Remotely Sensed Images. NASA Special Publication SP-431. Washington, DC: National Aeronautics and Space Administration. 329 p.

Ottmar, R.D.; Sandberg, D.V.; Prichard, S.J.; Riccardi, C.L. 2003. Fuel Characteristic Classification System. In: Second International Wildland Fire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology; 2003 November 16-20; Orlando, FL. Boston, MA: American Meteorology Society. 6 p. [CD-ROM].

Paige, G.B.; Stone, J.J.; Guertin, D.P.; McGee, R.; Blumenfeld, H. 2003. Runoff and erosion on a semi-arid grassland after a wildfire. In: Second International Wildland Fire Ecology and Fire Management Congress and Fifth Symposium on Fire and Forest Meteorology; 2003 November 16-20; Orlando, FL. Boston, MA: American Meteorology Society. 7 p. [CD-ROM].

Pase, C.P.; Granfelt, C.E., tech. coords. 1977. The use of fire on Arizona rangelands. Arizona Interagency Range Committee Publication No. 4. 15 p.

Pease, S. 2000. Effects of mesquite control and mulching treatments on herbaceous productivity and soil properties. MS Thesis. Tucson: University of Arizona. 82 p.

Pease, S.; Ffolliott, P.F.; DeBano, L.F.; Gottfried, G.J. 2003. Mesquite removal and mulching treatment impacts on herbage production and selected soil chemical properties. In: McClaran, M.P.; Ffolliott, P.F.; Edminster, C.B., tech. coords. Santa Rita Experimental Range: 100 years (1903 to 2003) of accomplishments and contributions; 2003 October 30- November 1; Tucson, AZ. Proceedings RMRS-P-30. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station:130-132.

Pickup, G.; Chewings, V.H. 1988. Estimating the distribution of grazing and cattle movement in a large arid zone paddock: an approach using animal distribution models and Landsat imagery. International Journal of Remote Sensing. 9: 1469-1490.

Pickup, G.; Chewings, V. H.; D.J. Nelson. 1993. Estimating Changes in Vegetation Cover Over Time in Arid Rangelands Using Landsat MSS Data. Remote Sensing of Environment. 42: 243-263.

Pickup, G.; Nelson, D.J.1984. Use of Landsat radiance parameters to distinguish soil erosion, stability, and deposition in arid central Australia. Remote Sensing of Environment. 16: 195-209.

Public Law 92-500, Federal Water Pollution Control Act (Clean Water Act) Amendments of 1972, 33 U.S.C. 1311-1313, 1315-1317.

Public Law 93-626, Federal Noxious Weed Act of 1974, (1975) U.S.C. 2801-2814.

Quivira Coalition. Undated. The Quivira Coalition: Innovation, Collaboration, Restoration. Santa Fe, NM. 8 p.

Rich, L.R. 1961. Surface runoff and erosion in the lower chaparral zone-Arizona. Station Paper No. 66. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 34 p.

Ringrose, S.; Musisi-Nkambwe, S.; Coleman, T.; Nellis, D.; Bussing, C. 1999. Use of Landsat Thematic Mapper Data to Assess Seasonal Rangeland Changes in the Southeast Kalahari, Botswana. Environmental Management. 23: 125-138.

Robinett, D.; Barker, S. 1996. Fire effects on Sonoran grasslands. In: Ffolliott, P.F.; DeBano, L.F.; Baker, M.B., Jr.; Gottfried, G.J.; Solis-Garza, G.; Edminster, C.B.; Neary, D.G.; Allen, L.S.; Hamre, R.H., tech. coords. Effects of fire on Madrean Province ecosystems-a symposium proceedings; 1996 March 11-15; Tucson, AZ. General Technical Report RM-GTR-289. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 64-68.

Rosan, L.; Cupell, M.; Daggert, D.; Elmendorf, C.; Van Cleve, B. 1997. Preserving Working ranches in the West. Tucson, AZ: The Sonoran Institute, 53 p.

Savory, A. 1988. Holistic Resource Management. Washington, DC: Island Press. 564 p.

Sayre, N.F. 2001. The New Ranch Handbook: A Guide to restoring Western rangelands. Santa Fe: NM: The Quivera Coalition. 102 p.

Schickendanz, J.G. 1980. History of grazing in the Southwest. In: K.C. McDaniel and C. Allison, eds. Grazing management systems for the Southwestern rangelands. Albuquerque, NM: The Range Improvement Task Force: 1-9.

Schubert, G.H. 1974. Silviculture of Southwestern ponderosa pine: the status of our knowledge. Research Report RM-123. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 71 p.

Scifres, C.J.; Polk, D.B., Jr. 1974. Vegetation response following spraying a light infestation of honey mesquite. Journal of Range Management. 27: 462-465.

Singh, A. 1989. Digital Change Detection Techniques Using Remotely Sensed Data. International Journal of Remote Sensing. 10: 989-1003.

Society of American Foresters. 2001. Conservation easements: a position of the Society of American Foresters. Bethesda, MD. 4 p.

Spaeth, K.E., Jr.; Pierson, F.B., Jr.; Weltz, M.A.; Blackburn, W.H. 2003. Evaluation of USLE and RUSLE estimated soil loss on rangelands. Journal of Range Management. 56: 234-246.

Stein, E.R.; McLeod, A.H.; Hyde, M. 2001. Purchase of development rights: conserving lands, preserving Western livelihoods. Western Governor's Association, Trust for Public Land, and National Cattlemen's Beef Association. 26 p.

Steuter, A.A.; McPherson, G.R. 1995. Fire as a physical stress. In: Sosebee, R.E.; Bedunah, D.J., eds. Wildland plants: physiological ecology and developmental morphology. Denver, CO: Society for Range Management: 550-579.

Stoddart, L.A.; Smith, A.D. 1955. Range Management. McGraw-Hill, New York. 433 p.

Tueller, P.T. 1979. Some Aspects of the Use of Dichotomous Keys to Aid in the Interpretation of Color Aerial Photographs for Vegetation Mapping. 7th Biennial Workshop of Color Aerial Photography in the Plant Sciences. Davis, CA: American Society of Photogrammetry: 189-200.

Tueller, P.T. 1982. Remote Sensing for Range Management, in Remote Sensing For Resource Management. Edited by Johannsen, C.J. and J. L. Sanders. Ankeny, IW: Soil Conservation Society of America: 125-140.

Tueller, P.T. 1989. Remote Sensing Technology For Rangeland Management Applications. Journal of Range Management. 42: 442-453.

USDA Agricultural Research Service. Undated. Partnerships incorporating students in rangeland watershed research. Boise, ID: U.S. Department of Agriculture, Agricultural Research Service, Northwest Watershed Research Center. 1 p.

USDA Forest Service. 1993. Watershed management practices for piñon-juniper ecosystems. Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Southwestern Region. 41 p.

Vallentine, J.F. 1971. Range Development and Improvements. Provo, UT: Brigham Young University Press. 516 p.

Valone, T.J.; Brown, J.H.; Curtin, C.C. 1998. Climatic causes and biotic consequences of recent shrub increase in the San Simon Valley. In: Tellman, B., Finch D.M.; Edminster, C.B.; Hamre, R.H., eds. The future of arid grasslands: identifying issues, seeking solutions; 1996 October 9-13; Tucson, AZ. Proceedings RMRS-P-3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 245.

Wallace, O.C.; Qi, J.; Heilma, P.; Marsett, R.C. 2003. Remote sensing for cover change assessment in southeast Arizona. Journal of Range Management. 56:402-409.

Weltzin, J.F.; McPherson, G.R. 1995. Potential effects of climate change on lower treelines in the Southwestern United States. In: DeBano, L.F.; Ffolliott, P.F.; Ortega-Rubio, A.; Gottfried, G.J.; Hamre, R.H.; Edminster, C.B., tech. coords. 1995. Biodiversity and management of the Madrean archipelago: the sky islands of Southwestern United States and northwestern Mexico. 1994 September 19-23; Tucson, AZ. Gen. Tech. Rep. RM-GTR-264. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 180-193.

Westin, F.C.; Lemme, G.D. 1978. Landsat Spectral Signatures: studies with soil associations and vegetation. Photogrammetric Engineering and Remote Sensing. 44: 314-325.

Wheeler, T.O. 1998. Holistic reclamation, a natural remediation process using cattle and other natural tools. In: Tellman, B., Finch D.M.; Edminster, C.B.; Hamre, R.H., eds. The future of arid grasslands: identifying issues, seeking solutions; 1996 October 9-13; Tucson, AZ. Proceedings RMRS-P-3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 312-315.