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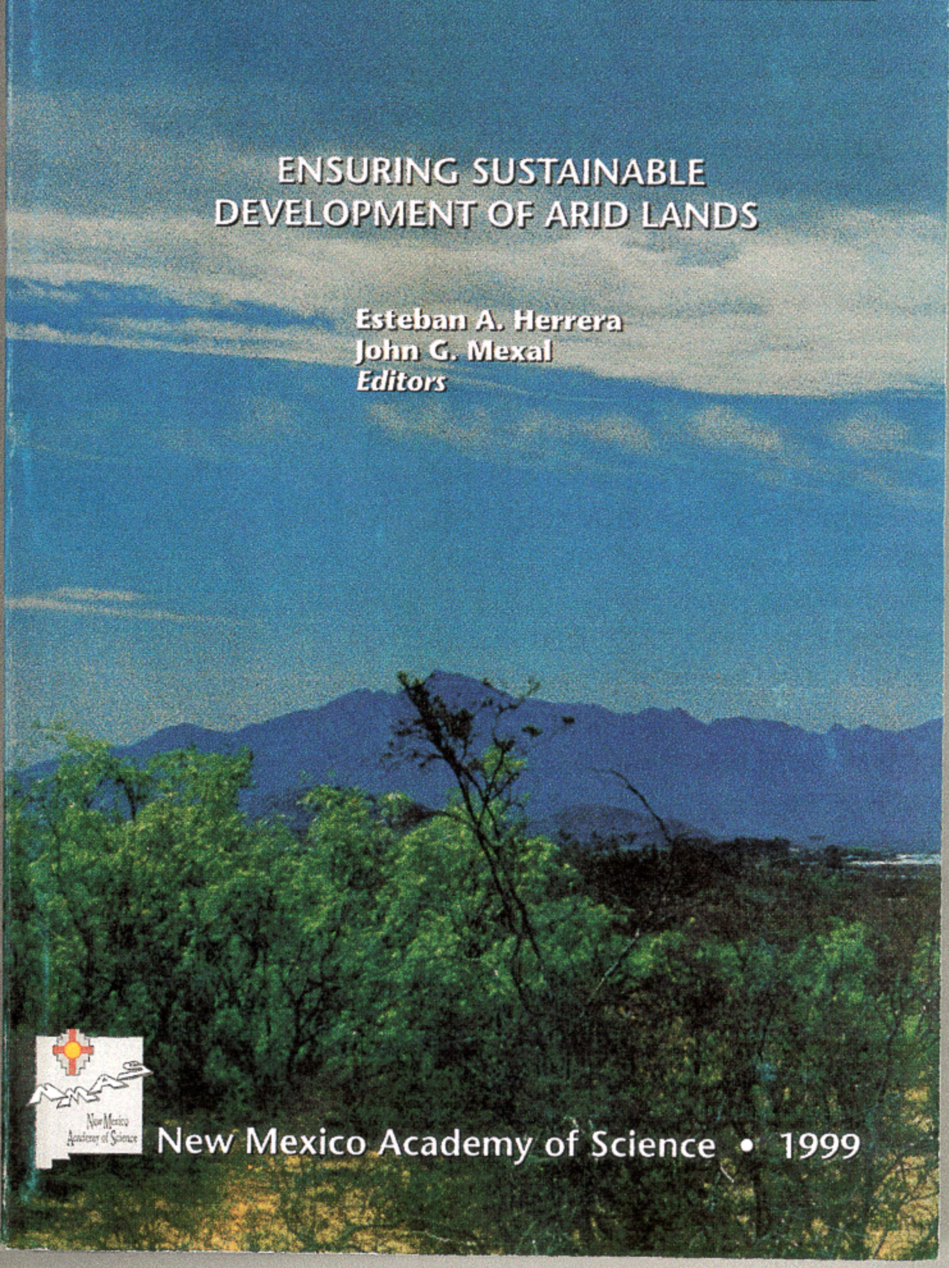
ENSURING SUSTAINABLE DEVELOPMENT OF ARID LANDS

Esteban A. Herrera
John G. Mexal
Editors



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Additional papers examine the future of agriculture in two contexts: the use of irrigation water, and the future of biotechnology in arid land agriculture. Finally, the renowned Dr. Gerald Thomas, President Emeritus of NMSU, looks ahead by discussing our history of use, abuse, and restoration of agriculture lands.

This issue of the *New Mexico Journal of Science* focuses on sustainable development with an emphasis on the Chihuahuan Desert. The desert is shared by two nations that realize ecosystems know no geopolitical boundaries. Thus, the environment, people, plants, and wildlife share an interdependent future. Sustainable development requires that the region's people work together to find long-term solutions that protect the regional economy, environment, and quality of life of all inhabitants.

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Contents

Improving Sustainability of Arid Rangelands

K.M. Havstad[21]

Abstract

Deserts are defined by their climate, and arid regions within deserts are usually identified using a combination of average precipitation, evaporation, and temperature. More generally though, arid regions are defined as areas receiving less than 250 mm (10 inches) of annual precipitation on a long-term average. In New Mexico, 10% of the state is classified as arid, but this region supports 77% of its population and nearly 30% of its agricultural lands. However, the arid zone is classified primarily as rangeland. Improving the sustainability of these arid rangelands will require employing technologies that exploit or augment natural processes and that are effective at relatively small, affordable spatial scales. Many of these technologies have been identified, but land managers need to revise their use of these technologies to comply with these two requirements. Implementing adaptive management in this arid zone will require flexibility; active collaborations among users, stewards, and public interests; and increased efforts in monitoring the effects of management on ecological conditions of arid lands.

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Introduction

Deserts often are described as arid, barren tracts of land incapable of supporting considerable populations. The term "arid" clearly imparts to this definition considerations of climate (primarily precipitation) and location (Nicholson 1999). Arid climates reflect not only low precipitation, but also moisture deficiency created by high evaporation rates. However, arid regions are commonly defined as those with long-term annual rainfall of between 100 and 250 mm (4 and 10 inches), while hyperarid regions are defined as those with <100 mm (4 inches) (Walter 1985). Generally, these arid regions occur in the subtropics between 20° and 40° latitude, occur on all continents, and occur on approximately 30% of the world's land surface.

Globally, arid climates are caused by insufficient atmospheric moisture, stable air masses, descending air masses, divergent air stream flows, and long distances from the routine tracks of major weather systems (Nicholson 1999). Stable, descending, divergent air flows caused by orographic effects of the southern Rocky Mountains are the principle causes of arid regions in New Mexico. There are six general characteristics of the resulting dry climate of these arid lands: 1) low rainfall of a highly variable nature, 2) extended periods of moisture deficits, 3) localized precipitation of short duration and often high intensity, 4) thermal duration extremes, 5) low humidity with high potential evaporation rates, and 6) extended periods of relatively high winds. Approaches to improving the sustainability of arid lands need to be developed with a complete understanding of the constraints imposed by these characteristics.

In New Mexico, arid lands comprise approximately 10% of the land area, or about 3.2 million ha (8 million acres) (fig. 1). The area depicted in this figure is taken from a map developed by Beck and Haase (1969), and is slightly different than the general area described as arid by the New Mexico State Planning Office (Tuan et al. 1973). Figure 1 was selected because it simply represents areas receiving less than 250 mm (10 inches) of annual precipitation on a long-term average, and does not

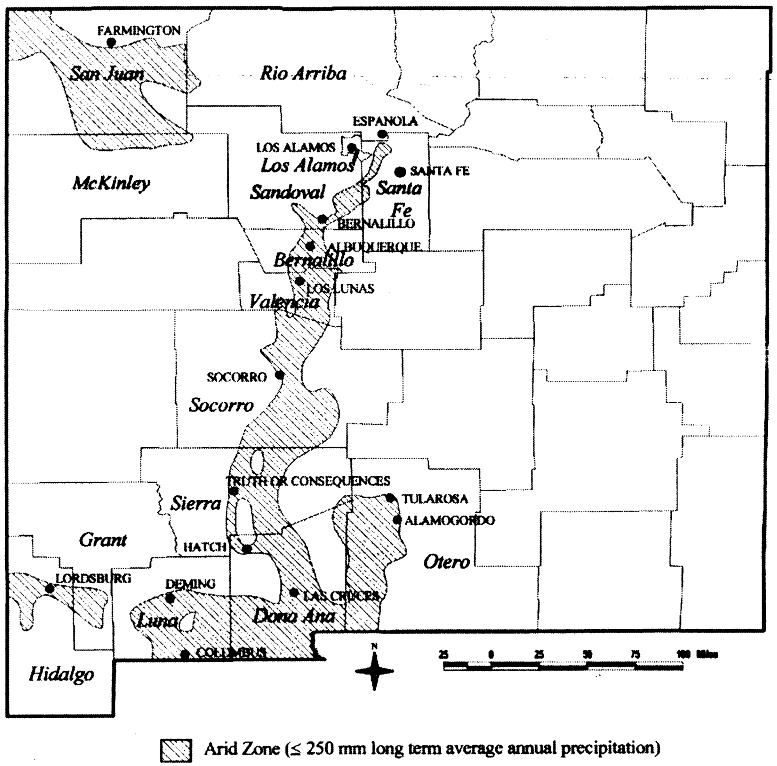

Figure 1. Counties and major cities in New Mexico within or adjacent to the state's arid zone.

consider annual ambient temperatures or potential evaporation rates. There are no areas in New Mexico classified as hyperarid.

The arid regions of New Mexico can hardly be described as barren, uninhabited tracts of land. Arid lands occur in 14 of New Mexico's 33 counties and are a major climatic type in eight counties: San Juan, Bernalillo, Valencia, Socorro, Sierra, Doña Ana, Luna, and Otero. These lands are primarily within either the San Juan and Chaco River Basins of the northwest region of the state or the Rio Grande Valley Basin below Española. The eight counties that are primarily arid land contain 30% of the farms and ranches in New Mexico, and these agricultural operations generate about 30% of annual agricultural cash receipts in New Mexico (USDA, New Mexico Agricultural Statistics Service 1997). However, 95% of the farm land in these eight counties is irrigated, compared to a state average of 56%.

This region is defined not only by its aridity but also by the **diversity of land ownership (fig. 2). Federal- and state-owned** public lands comprise 47% of the arid region under the auspices of agencies such as the US Department of Interior's Bureau of Land Management, the US Department of Agriculture's Agricultural Research Service, the Department of Defense's Departments of Army and Air Force, and the New Mexico Department of State Lands. Native Americans own approximately 24% of this region, while 29% is in private ownership. Efforts to sustainably manage landscapes within this region will require collaboration among this diverse group of landowners.

Globally, about 15% of the world's population live within the 30% of the land that is classified as arid. However, in New Mexico, 77% of the population resides within its arid zone. Obviously, the unusual occurrence of surface waters for rural irrigation and urban industrial uses in these arid lands has greatly increased our reliance upon the driest 10% of New Mexico's lands. This paper outlines some general considerations regarding continued use of the rangelands within this arid region.

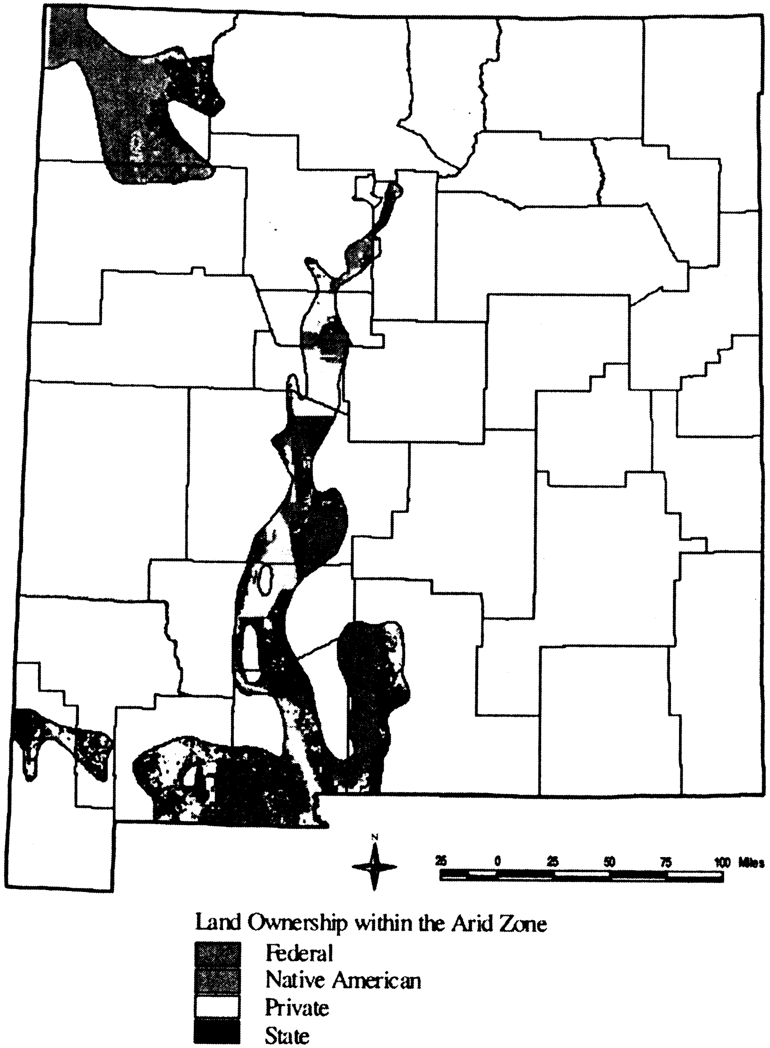

Figure 2. Land ownership within New Mexico's arid zone [250 mm (10 inches) of annual precipitation].

Sustainability

In general, *sustainability* refers to the maintenance of ecological integrity over time. However, an exact definition has been elusive (Lubchenco et al. 1991). It has been argued that the application of the concept of sustainability to natural ecosystems, including arid rangelands, is somewhat nonsensical for two reasons. First, natural systems are dynamic and subject to change, defying the notion of long-term stability. For example, the Chihuahuan Desert is only about 9,000 years old and vegetative states within the northern region of this desert have been highly dynamic (Van Devender 1995; Allred 1996; see also Beck and Gibbens, this volume). Secondly, ecosystems are by definition communities of organisms and their environment. On some spatial and temporal scales an ecosystem sustains use by these organisms; otherwise, it would cease to exist. Therefore, in one sense the concept of sustainability is unachievable because systems change. In another sense, the concept is a misnomer because systems by definition sustain use.

Yet if human interaction and activities within natural ecosystems are considered, and some economically based use is involved, the concept of sustainable use as a direction or goal has functional value (Safriel 1999). In this context, *sustainable use* can be defined as an appropriation of production (such as biomass) that allows for natural processes to replace appropriated materials (Safriel 1999). This definition parallels that of Lubchenco et al. (1991), who described sustainability as implying management practices that do not degrade used (exploited) systems or any adjacent ecosystems. These definitions also imply that standards of use or consumption are, in some fashion, gauged to the natural limits of an ecosystem. Interestingly, determining the capacities of systems and developing practices based on recognition of capacities have been long-term tenets of rangeland management. Though sustainability can be viewed as an inexact or even a nonsensical term, the use of a concept of acknowledged limits of an ecological system is a cardinal principle for management of arid lands. These general principles are well described in the central textbooks on range management (see Holechek et al. 1998a).

Livestock Grazing and Sustainability

Paulsen and Ares (1961) wrote the following statement in summarizing 45 years of grazing research in the arid region of southcentral New Mexico: "Sustained grazing capacity does not exist on the semi-desert ranges ... stocking may be high in some periods and in others there is virtually no capacity."

Our knowledge of various effects of livestock grazing in arid environments has been well synthesized (Pieper 1994). We have a general understanding of the importance of controlling timing, intensity, and frequency of grazing (Holechek et al. 1998b). It is also well recognized that livestock grazing can have various negative effects with poor management or excessive use. Proper use of forage species has long been recognized as a key component of livestock grazing management (Canfield 1939). Jardine and Forsling (1922) established early guidelines for carrying capacities of desert grasslands. These authors and others have repeatedly concluded that proper use of arid grasslands should be less than 40% of current year's growth (Campbell and Crafts 1938; Paulsen and Ares 1962; Holechek et al. 1994; Holechek et al. 1999).

There have been a few long-term studies of the effects on arid rangelands of extended rest periods with no livestock grazing. Atwood (1987) examined four exclosures in black grama (*Bouteloua eriopoda*)-dominated grasslands of the southcentral New Mexico desert after 17, 22, 32, and 48 years of rest. Basal cover of black grama was greater in the 32- and 48-year exclosures compared with adjacent grazed areas. However, no differences between grazed and rested areas were noted after 17 years of rest, and basal cover of black grama was actually greater in the grazed area compared to the exclosure receiving 22 years of rest. Obviously, black grama is slow to respond to protection and responses can be highly variable. Gardner

(1950) reported responses of grassland on the upland semi-arid (250–400 mm, or 10 to 16 inches, of annual precipitation) areas of southwestern New Mexico to 30 years of rest. Protected areas had 9.6% basal cover of perennial grasses [primarily blue grama (Bouteloua gracilis)] compared with 4.6% basal cover in the grazed area. Following drought, the differences between rested and grazed were considerably less: 2.3 and 1.0% respectively. Drought reduced grassland basal cover by 75%, irrespective of rest or livestock grazing. Other studies on the effects of prolonged rest in Southwest grasslands have reported some vegetation effects, but these effects have been only partially explained by the influences of livestock grazing (Brady et al. 1989; Bock and Bock 1993).

Our primary problems related to management of livestock grazing are those we have continually dealt with throughout the 20th century: 1) coping with variations (spatial and temporal) in forage production, 2) manipulating an animal behavioral process (grazing) that is plant species specific, and 3) managing grazing across landscapes with limited (if any) measurements to monitor or assess impacts.

The most persistent problems are the annual and seasonal deficits in available forage due to the natural, recurrent disturbance of drought in this environment. Forage production on upland desert rangelands can average between 300 and 400 kg/ha (268 and 357 lb/acre) during years of normal precipitation, but may be as low as 30 to 40 kg/ha (27 to 36 lb/acre) to during drought years (Herbel and Gibbens 1996). Almost any grazing during severe drought years would exceed proper utilization guidelines. Thus, Paulsen and Ares (1961) concluded that grazing could not be viewed as sustainable.

However, reasonable guidelines that allow for excessive use in selected areas during a particular year to accommodate disturbances such as drought have been recommended (Holechek et al. 1998b). Conservative stocking at 10 to 30% below capacity also has been recommended as both a strategy to cope with drought and as a means to improve vegetation conditions on some ranges (Holechek et al. 1999). Conservative stocking is probably the most important practice to improve rangeland conditions and approach sustained livestock use of New Mexico's arid rangelands.

Though most complex grazing systems have not been shown to improve rangeland conditions in the Desert Southwest (Martin 1975), some specialized grazing systems have demonstrated merit. In Arizona deserts, rotation grazing did not improve ranges that were in good condition, but it was suggested that a rotational seasonal rest and grazing system may accelerate recovery of ranges in poor condition (Martin and Severson 1988). For blue grama rangeland in southcentral New Mexico (land adjacent to the arid zone), a one herd/four pasture best pasture system was shown to be superior to continuous grazing (Pieper et al. 1991). Research results regarding the benefits of more intensive grazing systems, such as short-duration grazing, generally have been negative (Bryant et al. 1989). A few examples of good rangeland conditions under intensive grazing management in the arid zone exist, but these examples are undocumented in the scientific literature. The success of these specific situations is probably due to a unique combination of progressive management and a thorough understanding by the ranchers of the ecological characteristics of their specific rangeland.

Another creative approach for improving sustainability of grazed desert rangeland is the use of "grassbanks" (Page 1997). These reserve "banks" are specific areas selected to provide forage during drought or to allow rest following management action such as prescribed burning. Areas set aside for reserve grazing are becoming more common in New Mexico as federal stewardship agency personnel promote this practice in certain areas. An important factor in the establishment of grassbanks is the availability of a suitable area that can be set aside in reserve. The grassbank approach usually requires a collective action among landowners, both private and public.

Remediation

Generally, management actions to improve degraded or undesirable resource conditions are referred to as revegetation, rehabilitation, restoration, or reclamation. These terms imply improving a particular value of the land such as production of forage for livestock grazing or re-establishment of a prior vegetation state. Improving the sustainability of arid rangelands may or may not be related to specific values such as improving forage or historic vegetative conditions. It is becoming increasingly common to attempt to manage for sustained integrity of soil and ecological processes irrespective of how those rangeland resources may be used (National Research Council 1994).

The concept of "rangeland health" has been defined as the degree to which the integrity of the soil and ecological processes of rangeland ecosystems are sustained. A healthy rangeland is one in which erosion occurs at natural rates, water is retained at the inherent capacity of the soil and associated site features, and the plant community has the capacity to resist and recover from disturbances. Sites that are unhealthy would require management actions to correct deficiencies. We define these corrective actions as *remediation*, to distinguish them as activities intended to address deficiencies in fundamental functions of rangelands. A particular action, such as reseeding rangeland with a grass species that has forage value for livestock, would be evaluated primarily as a corrective action to improve perennial ground cover for reducing soil erosion or increasing water retention. The use of prescribed burning to improve plant species diversity might also reduce dominance of a woody species with limited value for wildlife.

The key concept is that remediation improves the capacity of rangelands to function rather than to address improvement of specific values. Remediation is oriented to sustain functions that would permit developing the potential of rangeland to support a variety of values and uses.

A General Strategy

Milton et al. (1994) outlined a general strategy for addressing remediation of degraded rangelands (table 1). This matrix strategy is based on the extent of degradation. For sites in satisfactory condition, management strategies are based on manipulating secondary consumers (typically livestock) for the grazed rangelands in New Mexico. Management goals should be achievable through adaptive strategies and proper stocking rates (Holechek and Pieper 1992). Methods for calculating stocking rates for New Mexico rangelands are well established and primarily require recognition of appropriate use levels for different rangeland types. Holechek and Pieper (1992) have summarized both recommended use levels and computation procedures.

For rangelands that are not in satisfactory condition because biomass resources have been reduced or soil erosion has been accelerated, the required management inputs are different. Management of primary producers is required in situations when desired plant species are not being regenerated. Management of the physical environment is required when perennial species have been lost from the system. The philosophy represented in table 1 illustrates the increased management inputs and costs associated with increased levels of degradation in order to recreate sustainable systems. This information also illustrates that radically different approaches are required for different existing conditions.

Developed Technologies

The first articles describing classical revegetation techniques for improving desert rangelands in New Mexico were published in the 1940s (Cassady and Glendening 1940; Parker 1943). These research efforts focused primarily on reseeding practices and a variety of brush control methods. With the development of appropriate machinery (such as the rangeland drill) and herbicides, examinations of intensive improvement practices were a significant focus of research for the next 45 years (Parker 1949; Herbel and Ares 1961; Herbel and Gould 1970; Herbel

et al. 1985). The principles of these intensive improvements have been well articulated (Herbel 1983); however, more recent economic assessments of these practices have not been wholly favorable. For example, Ethridge et al. (1997) concluded that more than 95% of the possible reseeding practices suitable for the arid rangelands in southcentral New Mexico would result in a negative economic return. Similar doubts have been raised regarding the cost effectiveness of chemical methods for brush control in arid regions (Herbel and Gould 1995). In addition to economic concerns, erratic and low precipitation and high evaporative losses characteristic of arid rangelands are principle causes of low success rates of these agronomic approaches. Cox et al. (1982) estimated that half to three-quarters of reseedings attempted in the Southwestern deserts fail. Even with favorable climatic conditions and inexpensive inputs, the use of many of these practices at large spatial scales is restricted in an increasingly regulated environment.

Fire is a relatively well-developed technology for rangeland remediation in many environments and has been studied in the desert Southwest (Wright 1980). Humans have affected fire regimes by reducing fire frequencies in this region for several centuries (Baisan and Swetnam 1997). Naturally occurring fires in the arid zone are generally small (Schmid and Rogers 1988) with relatively short intervals (<10 years) for desert grasslands, to relatively long (>100 years) for desert shrublands (Thomas and Goodson 1992). Fire is episodic in this environment and becomes more frequent after successive wet years (Rogers and Vint 1987). Fire can strongly influence vegetative structure, including woody vegetation and broad expanses of perennial grasslands (Cable 1965). Prescribed burns in the spring can reduce shrub cover, while summer burns can devastate perennial grasses (Cable 1965; Gosz and Gosz 1996). Response to natural or prescribed fires depends greatly upon the amount of precipitation after a fire. There is very little existing information on the use of fire as a management tool in the arid zone and few

Table 1. Stepwise degradation of arid or semi-arid rangelands. Symptoms describe the state of plant and animal assemblages, management options refer to actions that a manager could take to improve the condition of the range, and management level refers to the system (level of the food chain) on which management should be focused.[a]

Step number	Description	Symptoms	Management option	Management level
0	Biomass and composition of vegetation varies with climatic cycles and stochastic events	Perennial vegetation varies with weather	Adaptive management	Secondary producers
1	Herbivory reduces recruitment of palatable plants, allowing populations of unpalatable species to grow	Demography of plant population changes	Strict grazing controls	Secondary producers
2	Plant species that fail to recruit are lost, as are their specialized predators and symbionts	Plant and animal losses, reduced secondary productivity	Manage vegetation (e.g., add seed, remove plants)	Primary producers
3	Biomass and productivity of vegetation fluctuates as ephemerals benefit from loss of perennial cover	Perennial biomass reduced (short-lived plants and instability increase), resident birds decrease, nomads increase	Manage soil cover (e.g., mulching, erosion barriers, roughen soil surface)	Physical environment
4	Denudation and desertification involve changes in soil function and detritivore activity	Bare ground, erosion, aridification	?	?

[a] *From Milton et al. 1994*

guidelines for management of other uses (especially grazing) following fire.

Especially for publicly owned lands, conservation requirements for nonagricultural resources (such as cultural resources, wildlife habitat, water, aesthetic qualities, and threatened or endangered species) can effectively halt the use of many traditional technologies at pasture or allotment scales. Many of these practices are not environmentally benign, and their use can conflict with the missions of federal and state stewardship agencies. Many regulations also apply to private lands. A key question is, "Are these developed technologies no longer useful, or do they need to be adapted and applied with a greater understanding of the ecological conditions of arid lands?"

A Scaled Approach

Given the degraded conditions of some of New Mexico's arid lands, sustainable use requires both economically and ecologically effective techniques for remediation. Whisenant (1995) has argued for strategies that "jump start" natural repair processes as a viable alternative for either land abandonment or the classical rangeland improvement practices. Herrick et al. (1997) proposed sustainable approaches based on four premises: 1) maintenance or remediation of both above- and below-ground systems is necessary to buffer against disturbances (a key component of sustainability), 2) resource redistribution over time and across the landscape plays a role in both degradation and remediation, 3) restoration or remediation goals should focus on the most fertile sites in the system, and 4) employed technologies should exploit or augment natural processes.

The actual technologies that can be employed within this sustainability framework can be both classic methods, such as prescribed burning or reseeding of desired species, or more novel approaches. The latter may include nontraditional approaches for revegetation that use natural mechanisms of seed dispersal (Fredrickson et al. 1996), or nontraditional sources of soil amendments. Development and testing of nontraditional or novel techniques are active areas of research (Herrick et al. 1997).

Of more importance though, is the understanding that the sustainability of these management practices is strongly a function of the spatial scales of their application and resulting effects. In general, applying these technologies at large spatial scales (macro scales >100 ha, or >250 acres) cannot be economically sustained for remediating degraded rangelands (Noble et al. 1997). However, micro (<1 ha, or <2.5 acres) and meso (>1 and <100 ha, or >2.5 and <250 acres) scales are extremely important to the biotic and abiotic processes that structure ecosystems (Holling 1992). Sustainable rangeland management should be directed toward influencing mesoscale processes with the understanding that microscale processes are the underlying structure (Noble and Brown 1997).

These small spatial scales can be effectively used to characterize landscape patterns and rangeland conditions. In terms of patterns, it is now recognized that rangelands can be viewed as a heterogeneous mix of patches with a high degree of spatial organization and integration. Rather than being viewed as a haphazard, amorphous assemblage of species, rangelands (including deserts) are actually a nested set of plant, population, landscape, and biome scales that reflect connected mosaic patterns (Gosz 1993; Peters-Coffin and Goslee 1999). This overall spatial pattern of bounded elements in a background matrix is referred to as patchiness (Wiens 1995). It is recognized that the patchiness of arid landscapes 1) reflects ecological functions, 2) has implications for management, and 3) impacts strategies for remediation (Ludwig et al. 1997). These three key elements are the basis for sustainable use of arid lands.

Noble et al. (1997) have recommended a strategy of rebuilding landscape patchiness as a means of remediating degraded rangelands. These authors state three general economic principles for rangeland remediation: 1) invest to prevent degradation rather than incur costs of remediation, 2) employ technologies with relatively low capital costs and a low margin of risk, and 3) apply technologies to small areas.

In reality, a considerable amount of arid rangeland has either not been treated with special improvement practices or has failed to respond to these treatments. The confounding factors of economic costs, ecological risks, and regulatory constraints have prevented the widespread use of these practices, and/or severely restricted their effectiveness (Havstad and Schlesinger 1996). The specific effects of these technologies, though, still have application. However, they must be employed in a manner that minimizes external inputs, comply with a myriad of environmental regulations, and be cost-effective (Herrick et al. 1997).

Monitoring

Obviously, a discussion of improving resource conditions implies that standards for evaluating existing conditions are in place and in use. Classically, these evaluations have been measured in terms of degree of success in recreating potential natural plant communities. This assessment was based on the theory that original stable plant communities existing prior to a disturbance, such as fire or overgrazing, will be naturally regenerated following removal or termination of the disturbance (Heady 1975). This theory was synthesized for management applications through the concepts of range condition and trend, initially developed for rangelands in the Great Plains (Dyksterhuis 1949), and these attributes have served as a barometer of rangeland management for nearly half a century. In the context of this condition and trend model, rangelands have been monitored based on presumed departure or convergence with potential vegetation communities existing prior to the grazing disturbances of the late 1800s and early 1900s.

In recent years it has become increasingly apparent that this model for evaluating conditions and trends does not apply to all rangelands. For many areas, prior vegetative conditions will not be recreated even with sufficient time and removal of disturbances such as overgrazing. Not only have there been broad changes during this century in the global environment, but on a local scale there have been substantial changes in biotic and abiotic components of these ecosystems. The environments that shaped the plant communities of our arid deserts existing in the 19th century have, to varying extent, been altered (Fredrickson et al. 1998). For example, in southern New Mexico stable desert shrub communities have existed for more than 50 years after removal of the disturbance that impacted these former desert grasslands (Havstad et al. 1999). These shrublands are viewed as self-augmenting states that neither represent former conditions nor represent a short-term, intermediate vegetation state preceding an eventual return to grassland communities (Schlesinger et al. 1990). Models of state and transition are now being used to describe many rangelands (Westoby et al. 1989; Friedel 1991; Laycock 1991; Lockwood and Lockwood 1993). A common thread to these theories is that rangeland vegetation dynamics can be unpredictable. In many cases, vegetation states influenced by disturbances can be stable for long periods with little resemblance to prior states (Milton et al. 1994).

Approaches for evaluating improvement or monitoring the effects of resource management should rely on standards other than prior vegetation states. Monitoring should be based on qualitative and quantitative evaluations of indicators that are related to the capacity of rangelands to retain soil, capture and store water, and support a viable plant community. There are many systems and methods for monitoring rangelands, but there is a need for standardization (National Research Council 1994). Recently, monitoring methods for New Mexico's arid lands have been assembled into a manual for general use (USDA and EPA 1999). However, rangelands are complex ecosystems. Identifying indicators that can be easily and repeatedly monitored to reflect important properties of managed systems, which in turn are related to key ecological processes related to important functions, is extremely difficult. Identify

ing and testing indicators for use in monitoring rangelands is a needed area of research.

Irrespective of the state-of-the-art of rangeland monitoring, some level of monitoring is required. An established program, even at a cursory level, for monitoring the effects of management must be viewed as mandatory if we are going to achieve sustained use of the arid rangelands of New Mexico.

Conclusions

From a range management standpoint, we need to recognize two overriding factors that govern our capacity to manage arid lands in New Mexico. First, we have two primary management options: 1) we can manipulate vegetation structure in direct and indirect ways, and 2) we can affect plant and animal production by adjusting our controls over livestock (Stafford-Smith 1996). Secondly, we need to recognize that these arid systems respond weakly to management controls. The driving forces in these arid lands often are interactions between management practices and environmental stresses, especially drought (Tainton et al. 1996). Operationally, management and remediation actions need to be structured on spatial scales that can be observed and manipulated. Thus, spatial scales will generally be relatively small, regardless of whether observations will be relatively simple or more elaborate. It is unlikely that site-specific information will be available for each ecological site. Selected practices will need to be based on current ecological principles modified by knowledge of existing, local environmental conditions. Management would then be adjusted based on subsequent responses verified through monitoring. This model of applying principles, modifying to local conditions, monitoring responses, and adjusting actions is defined as adaptive management (Hoekstra and Joyce 1999) and is becoming the standard for conservation management in the western United States (Callicott et al. 1999).

Improving the sustainability of New Mexico's arid rangelands will rely upon four general management criteria: 1) understanding the ecological principles pertaining to arid lands, 2) knowing local environments and their natural variabilities, 3) using monitoring methods in a programmatic manner to evaluate management effects, and 4) flexibility in applying remediation technologies. The implementation of these criteria requires strong collaboration among land owners, stewards, management agencies, the scientific community, and the public to integrate and apply our knowledge to sustained use of these arid lands. These collaborations are developing in some areas within the arid zone and are working due to cooperation, scientific objectivity, and advocacy of good management practices (Brown and McDonald 1995). Any applications of technologies, new or old, will have to be based on these criteria.

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