Assessing Impacts of Alternative Livestock Management Practices: Raging Debates and a Role for Science

Thomas D. Sisk
Center for Environmental Sciences and Education
Northern Arizona University
P.O. Box 5694
Flagstaff, AZ 86011

Timothy E. Crews
Environmental Studies Program
Prescott College
220 Grove Ave.
Prescott, AZ 86301

Ryan T. Eisfeldt
Matthew King
and
Elaine Stanley
Center for Environmental Sciences and Education
Northern Arizona University
P.O. Box 5694
Flagstaff, AZ 86011

Abstract. Grazing of domestic livestock is the most pervasive and persistent human impact on the grasslands and shrublands of the Colorado Plateau. Impacts on ecosystem function and biological diversity are thought to be great, but few studies have attempted to characterize such effects and compare the impacts of alternative livestock management practices. The dearth of pertinent, defensible information has contributed to the polarization of ranching and environmental interests, and has exacerbated what is one of the most contentious social issues in the southwestern USA. We discuss the role of ecological science in deriving and disseminating information that will help focus and perhaps resolve the impasse over grazing impacts and other natural resource issues. Specifically, we describe results of our involvement in "management teams" that include ranchers, environmentalists, public servants, and interested citizens, and how this collaborative process has helped shape an experimental research program that would be impossible to execute without the involvement of divergent interests in the grazing debate. Claims of various interest groups are reformulated as testable hypotheses, and a research design is presented.

Key words: arthropods, biological diversity, conflict resolution, cooperative research, plant communities, grazing, net primary productivity, ranching

Introduction

Grazing of domestic livestock is the most pervasive and persistent human impact on grasslands and shrublands of the arid Southwest (Fleischner 1994). The practice of livestock grazing affects approximately 70% of western states (Fleischner 1994), and 86% of the land surface in Arizona (Mayes and Archer 1982). Since the 1860's, the cattle industry has played a significant role in the social, cultural and political development of Arizona (Schlegel 1992) and, along with other factors, it has brought profound ecological change (Hastings and Turner 1965, Bahre 1991).

Today, the ubiquitous practice of cattle grazing in the arid West, in general, and Arizona, in particular, is an intensely contentious social issue (Dagget 1995). Widespread rangeland degradation has led public interest groups to challenge traditional grazing practices and demand a policy that will insure long-term productivity of public rangelands and the conservation of native biological diversity (e.g., Cooperrider and Wilcove 1995, Southwest Forest Alliance 1996). Meanwhile, ranchers facing weakening markets and declining profits, have fiercely resisted cutbacks in grazing allotments, increased fees, and greater regulation (Hecox and Ack 1996). Polarization of the policy debate has led to an impasse among ranchers, environmentalists, and resource managers regarding appropriate management of public lands (Brown and McDonnell 1995, Cooperrider and Wilcove 1995). Continuing debate, court actions, and pending lawsuits may have profound impacts on ranching and the future use of public lands in the Southwest. While it is clear that livestock grazing will remain an important economic activity and land use on the Colorado Plateau and throughout the region, it is also clear that grazing will be restricted or eliminated on some public lands. Which lands to graze, and how best to graze them, are pressing questions. How these questions are answered will greatly impact the ecological condition of the arid Southwest, as well as the future of one of the region's few significant food production systems.

A Role for Science

Like many environmental issues, the grazing debate is so polarized that it often seems that there is little room for science. Positions have been staked out for years, and scientific input often is reduced to a parade of "expert witnesses" presenting opposing interpretations of existing information. Yet many environmental issues rise to public prominence precisely because existing scientific information is equivocal or inadequate and, therefore, subject to misuse or misinterpretation (Ehrlich and Ehrlich 1996). Certainly there is no shortage of published research addressing many aspects of domestic livestock raising; however, much of this information fails to address directly the issues that have become pivotal to the grazing debate, namely the impacts of grazing on rangeland productivity and biological diversity. The impacts of domestic livestock on arid rangeland productivity and biological diversity are thought to be great, but quantitative information comparing different grazing approaches is scant. Furthermore, many studies comparing grazed and ungrazed areas have been criticized on methodological grounds because they rely on small exclosure areas for ungrazed sites (Bock et al. 1993), employ questionable photographic comparison techniques, or employ unreplicated designs in field comparisons (Brown and Waller 1986).

Objective evaluation of the many conflicting statements regarding the impacts of overgrazing or the benefits of certain range management techniques are further complicated by the failure of many advocates to clearly articulate specific claims and the response variables being discussed. Terms like "rangeland health," "biodiversity," "overgrazing," and "overrest" can mask the specifics and make it tempting to drown legitimate debate in arguments over vague generalities. The current grazing controversy, for example, often focuses on two distinct topics: ecosystem productivity and biological diversity. Unfortunately, references to these very different issues are often confused and muddled in discussions of "range condition" or "ecosystem health."

For these reasons, we have initiated a study of ecological factors that we believe undergird much of the controversy over grazing practices in the Southwest. Our first objective is to identify the points of conflict that emerge from differing claims regarding the ecological impacts of livestock grazing. We believe that if scientists are to contribute to solving real environmental problems they must strive to understand the issues that underlie and sustain conflict. By focusing research on these issues, we hope that it will be possible to engage a diverse group of landowners, public servants, and interested citizens to support and participate in efforts to improve our understanding of certain ecological factors that all agree are important determinants of environmental quality on arid rangelands (Table 1).

For the past three years we have participated in "management teams" – loosely organized groups of ranchers, environmentalists, agency officials, and interested citizens who are working collectively to improve management practices on private and public rangelands in Arizona. This experience has helped us to develop a research program that addresses questions of import to land managers and is broadly understood and appreciated by people on different sides of the grazing debate.

COMMON GROUND: SUSTAINABLE ECOSYSTEMS

One idea that is shared almost universally is the importance of managing grassland ecosystems for long-term, sustainable use. While the concept of sustainability has been widely embraced (e.g., Goodland 1995), inadequate definition combined with frequent use has diluted its meaning substantially. Nevertheless, sustainability is a central concept in the grazing debate and constitutes the common ground upon which any real resolution of the issue is likely to be founded. Clearly, for any type of agriculture to persist it must be both economically and ecologically sustainable (Crews et al. 1991). Across much of the arid West, economics

Table 1. Scientists, managers, landowners, and public interest groups often disagree on the role of science in land and resource management. Researchers attempting to illuminate controversial issues should strive to understand the conflict and assess the potential contributions of new research before launching investigations. Our experiences suggest the following sequence of steps for developing research projects that address scientific issues underlying conflict.

Steps for Turning Conflicting Claims Into Questions, and Then Into Testable Hypotheses:

- Study the controversy; understand the conflict.
- Restate contradictory claims as questions or hypotheses.
- Discuss questions/hypotheses with all parties.
- Get "buy-in" on research approach from the affected parties. If unsuccessful, repeat previous step, or change the approach.
- Design research through an open process, with opportunities for discussion and dialog.
- Initiate the study and guard scientific independence.
- Maintain channels of communication and provide regular updates.

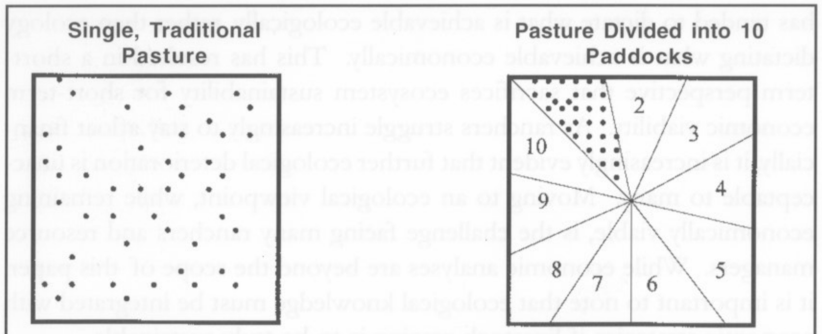
has tended to dictate what is achievable ecologically, rather than ecology dictating what is achievable economically. This has resulted in a short-term perspective that sacrifices ecosystem sustainability for short-term economic viability. As ranchers struggle increasingly to stay afloat financially, it is increasingly evident that further ecological deterioration is unacceptable to many. Moving to an ecological viewpoint, while remaining economically viable, is the challenge facing many ranchers and resource managers. While economic analyses are beyond the scope of this paper, it is important to note that ecological knowledge must be integrated with economic strategies if livestock grazing is to be truly sustainable.

In this paper we focus on two important aspects of ecological sustainability: ecosystem productivity and biological diversity. Ecological sustainability is concerned with the production of digestible plant material over the long term (decades to centuries), without significant external inputs, such as diverted water and fertilizers. Biological diversity reflects the ability of the land to support viable population of native species, from soil microorganisms to plants to the herbivores that consume them. These two issues lie at the heart of the grazing debate. Does grazing reduce or enhance the productivity of rangelands? Is the diversity of native organisms higher or lower on grazed lands? These are very different, though related questions, and the scientific approaches for answering them are also quite distinct. We are working with diverse management teams, on lands under active management, to investigate simultaneously these two aspects of ecosystem sustainability.

ALTERNATIVE APPROACHES TO RANGELAND MANAGEMENT

For the past 120 years, traditional cattle operations in Arizona have turned animals out onto large pastures for relatively long periods of time (Schlegel 1992). It is not unusual to see stocking densities of one animal per 100+ acres, with herds being moved between summer pastures at higher elevations and winter pastures in lower, desert grasslands. The result is relatively low grazing pressures over relatively long periods of time (Fig. 1). Stocking densities are manipulated in an attempt to maximize production without degrading range quality and the future ability of the system to produce forage. Hereafter, we will refer to this approach as "traditional grazing."

An alternative approach involves much higher stocking rates for relatively short periods of time (Fig. 1). Grazing episodes are followed by long periods of complete rest from the impacts of domesticated livestock, allowing time for the heavily impacted rangelands to recover prior



Example:

Single, Traditional Pasture	Pasture Divided into 10 Paddocks
50 head of cattle graze 5,000 acres of rangeland for 5 months, continuously.	50 head of cattle graze 500 acres of rangeland for 15 days, then move to a new paddock.
Low stocking rate, low animal impact, long-term disturbance, no rest.	High stocking rate, high animal impact, short-term disturbance, followed by $4^1/_2$ months of rest.

Figure 1. Alternative grazing practices employed in the arid Southwest include season-long grazing on large pastures, at relatively low stocking densities (referred to as "traditional grazing" in this paper), and relatively rapid rotation of cattle among multiple small pastures, followed by long periods of rest (we refer to this as "HRM-style grazing"). The diagram contrasts two hypothetical grazing strategies for the same herd.

to the next introduction of cattle (Savory 1978). Stocking densities and rotation times may vary, often in response to prevailing economic or ecological conditions, but in virtually all cases the stocking density is several times that of traditional grazing systems, and the cattle are left in a particular pasture for a period of several days to weeks, rather than several months (Fig. 1). High density, short duration grazing is frequently implemented as part of a system called Holistic Resource Management (HRM, see Savory 1988) that has gained many enthusiastic adherents among ranchers, some public range managers, and some members of the environmental community (Dagget 1995).

While there is a considerable body of work on the effects of livestock grazing on native species and ecosystem function (e.g., Jeffries and Klopatek 1987, Belsky 1987, Belsky and Blumenthal 1997), and on the removal of livestock from rangelands (e.g., Bock et al. 1984, Brady et al. 1989, Milchunas and Lauenroth 1993) few studies have examined the relative impacts of alternative strategies. This is unfortunate because the

actual policy decisions made by land managers seldom involve the introduction of livestock onto previously ungrazed lands, or the complete removal of livestock from current rangelands. Instead, development of sustainable grazing policy demands that ranchers and public lands managers choose an appropriate management strategy and stocking level to protect the integrity of the grazed ecosystem. The current project attempts to assist decision makers by providing information on grazing impacts on both ecosystem function and biological diversity, under alternative management strategies.

RESEARCH APPROACH

Involvement with ranchers, anti-grazing activists, and management teams has identified numerous conflicting claims regarding the ecological effects of grazing. Our first task was to turn these claims into clear questions that could be stated as testable hypotheses that are amenable to scientific inquiry. We include here three examples of the contradicting claims and the approaches that we have taken in addressing them through field research. For illustrative purposes, we have presented direct quotes from two published sources that are widely cited by activists on opposite sides of the grazing controversy.

Question 1. Do rates of organic matter decomposition and related nutrient cycling vary with grazing intensity?

- "In brittle environments...most dead plant material breaks down through slow oxidation and weathering. Large accumulations of unrecycled plant parts suppress plant growth and reduce uptake of those nutrients that eventually do get below the soil" (Savory 1988).
- "Grazing disrupts the fundamental ecosystem functions of nutrient cycling and succession....On the Colorado Plateau...a single footprint can bring a local nitrogen cycle almost to a halt" (Fleischner 1994).

Approaches:

1) Decomposition: Undertake a 3-year grass decomposition experiment using litter bags and grass stems to compare rates of decomposition (mass loss), as well nitrogen and phosphorus release rates (both immobilization and mineralization). Measure rates of soil respiration across a gradient of grazing intensity.

2) Nutrient availability: Over 3 years, measure the availability of important soil nutrients using buried anion and cation exchange resin bags, and analysis of leaf tissue nutrient concentrations and soil-extractable nutrients.
3) Nitrogen fixation: Using the natural abundance of ^{15}N, as well as acetylene reduction, determine whether grazed grasses support more or less rhizosphere-associated nitrogen fixation than ungrazed grasses.

Question 2. Do rates of water infiltration vary according to grazing intensity?

- "Tools that break up a sealed or "capped" surface, or increase the soil's organic content and crumb structure, speed penetration. A loosened, rough surface or one covered by old, prone plant material achieves this" (Savory 1988).
- "Microbiotic crusts in arid ecosystems have been correlated with…increased soil water infiltration.... Grazing has repeatedly been shown to decrease water infiltration" (Fleischner 1994).

Approach: Compare soil moisture in matched grazed and ungrazed plots immediately following rainfall events.

Question 3. How do native plant diversity and community composition vary with grazing intensity?

- "Periodic high animal impact...could remove old material, invigorate existing plants without exposing soil, create conditions for new plants to establish and move succession away from forbs and woody plants; …prolonged rest does not favor perennial grass plants" (Savory 1988).
- "Decreases in density of native plant species and diversity of native plant communities as a result of livestock grazing activity have been observed in a wide variety of western ecosystems" (Fleischner 1994).

Approach: Quantify plant community composition under different grazing practices; implement controlled, replicated experiments and document plant communities before and after treatments, over several years. Measure living/dead plant material, species composition, and plant abundances under a replicated, spatial sampling design.

Response Variables and Sampling Design

These examples illustrate an approach to research that is driven not only by the scientific questions but also by the context of the debate over grazing impacts and the management of arid rangelands. We believe that this approach offers an opportunity for doing sound science that will help illuminate real land use issues. Table 2 lists the response variables that we are monitoring and provides a brief reference to the methods that we will employ.

Our sampling design is based on the Modified-Whittaker plot, which

Table 2. Response variables measured and methods employed in integrated studies of rangeland productivity and biodiversity. All measurements are made contemporaneously on common research plots.

RESPONSE VARIABLE	METHODS EMPLOYED
Productivity Variables	
Net Primary Productivity	Aboveground annual productivity harvests. Soil respiration measurements after rainfall events.
N and P availability	Buried anion and cation resin bags. In-lab mineralization using KCl extracts. Grass leaf tissue analyses. Measurements of immobilization and mineralization throughout decomposition experiments.
Decomposition / Soil Organic Matter	Mass loss of tethered grass bundles and litter bags. Soil carbon fractionation analysis.
Nitrogen fixation	Measurement of rhizosphere N-fixation activity using acetylene reduction. Estimate of rhizosphere fixation using natural abundance of ^{15}N.
Soil Water Infiltration	Bulk density and water infiltration capacity throughout soil profiles. Soil water content by depth following rainfall events.
Biodiversity Variables	
Plant Species Richness, % Cover by species, % Native species.	Exhaustive survey of nested Modified-Whittaker subplots; frequency sampling in smallest subplots to estimate percent cover.
Plant Biomass, by growth form	Aboveground harvests and dry biomass of grasses, forbs, and woody perennial.
Arthropod Diversity and Abundance (at various taxonomic levels)	Pitfall trapping associated with smallest Modified-Whittaker subplots; sweep-net sampling along transects within Modified-Whittaker plot.
Arthropod Biomass, by taxon	Dry weight of sorted pitfall and sweep-net samples.

has been shown to capture spatial variability in grassland studies, and to more accurately estimate species richness (Stohlgren et al. 1995). The largest plot, 20m x 50m, contains subplots of differing sizes and varying amounts of replication (Fig. 2). The approach permits estimation of variance among subplots, providing a measure of spatial variability. Recent studies suggest that the Modified-Whittaker approach also is effective at detecting rare plants (Stohlgren et al. 1997) and the presence of exotic species. We have integrated measurements of a host of grazing response variables (Table 2) with the Modified-Whittaker design. For example, ion exchange bags, pitfall traps and sweep-net transects have been associated with vegetation subplots, permitting similar analytical approaches for ecosystem variables, vegetation, and arthropod data when comparing the effects of different grazing treatments. In some cases, we employ additional plots and/or transects to increase replication and/or spatial independence of sample points.

Study Sites

We have begun work at three sites in Arizona to test productivity and biodiversity response variables (Fig. 3).

Reed Lake Site

Located at 2190 m on the Colorado Plateau, and classified as Plains and Great Basin Grassland (Brown 1994), the Reed Lake site is com-

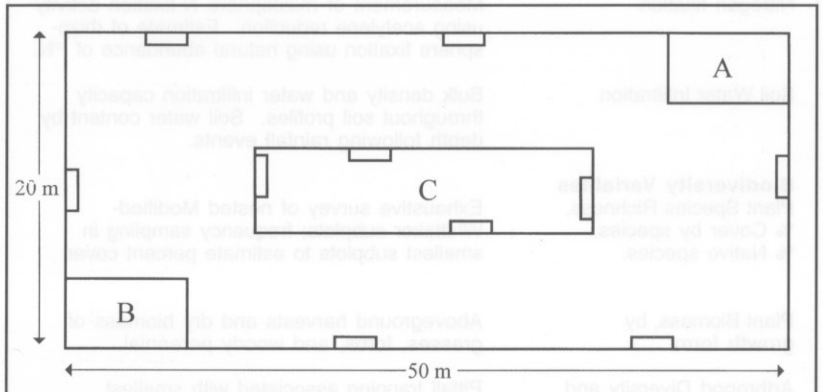


Figure 2. The Modified-Whittaker plot combines aspects of traditional plot and transect methods. Small subplots capture spatial variability; these and the larger subplots (A, B, C, and the 20m X 50m outer plot) permit estimates based on species:area relationships (Stohlgren et al. 1995). Modified-Whittaker plots are employed in each treatment type at all study sites.

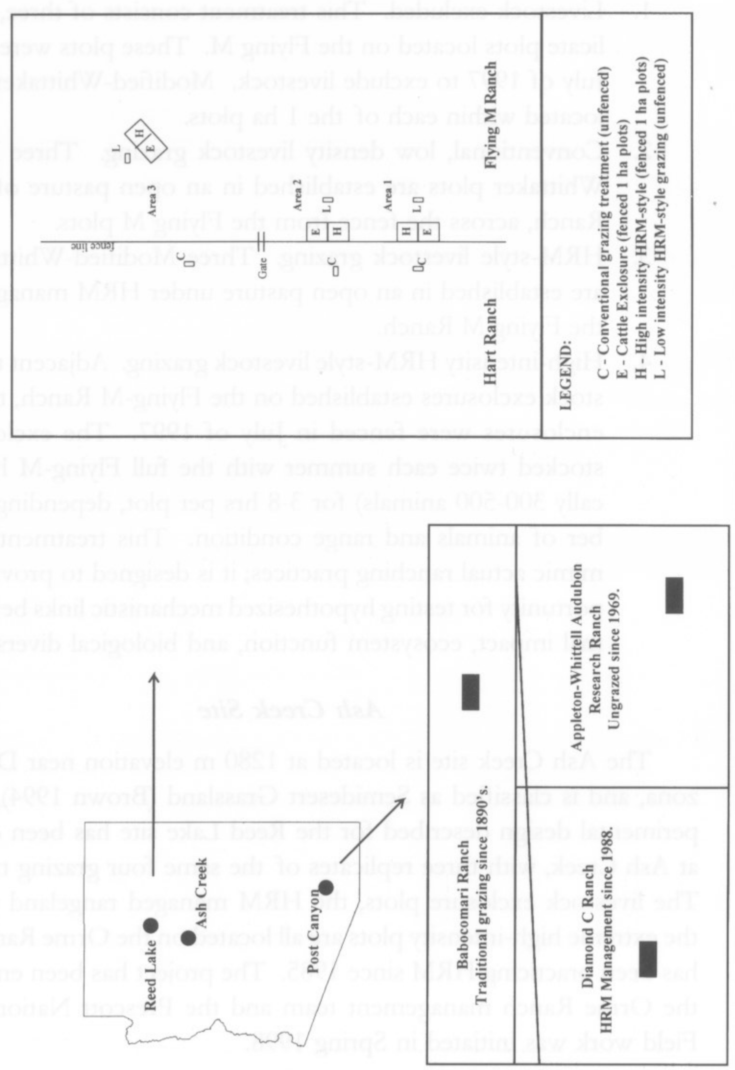


Figure 3. Research is underway at three study sites, one in a desert grassland in a monsoonal climate (Post Canyon), one in a mid-elevation high desert grassland (Ash Creek), and one in a high-elevation summer pasture on the Colorado Plateau (Reed Lake). At the Post Canyon site, comparison of three treatment types is made possible by the presence of the Appleton-Whittell Research Ranch which has not been grazed since 1969. At Reed Lake and Ash Creek, replicated experimental plots supplement sample plots on adjacent ranches employing different grazing strategies.

prised of two working ranches, the Flying M and the Hart Ranch. The Flying M Ranch has practiced Holistic Resource Management, including relatively high stocking rates with long periods of rest, beginning in 1988. The experimental design we are using at Reed Lake consists of plots that receive 4 levels of livestock grazing—

1. Livestock excluded. This treatment consists of three, 1 ha replicate plots located on the Flying M. These plots were fenced in July of 1997 to exclude livestock. Modified-Whittaker plots are located within each of the 1 ha plots.
2. Conventional, low density livestock grazing. Three Modified-Whittaker plots are established in an open pasture of the Hart Ranch, across the fence from the Flying M plots.
3. HRM-style livestock grazing. Three Modified-Whittaker plots are established in an open pasture under HRM management on the Flying M Ranch.
4. High-intensity HRM-style livestock grazing. Adjacent to the livestock exclosures established on the Flying-M Ranch, three, 1 ha enclosures were fenced in July of 1997. The exclosures are stocked twice each summer with the full Flying-M herd (typically 300-500 animals) for 3-8 hrs per plot, depending on number of animals and range condition. This treatment does not mimic actual ranching practices; it is designed to provide an opportunity for testing hypothesized mechanistic links between animal impact, ecosystem function, and biological diversity.

Ash Creek Site

The Ash Creek site is located at 1280 m elevation near Dugas, Arizona, and is classified as Semidesert Grassland (Brown 1994). The experimental design described for the Reed Lake site has been duplicated at Ash Creek, with three replicates of the same four grazing treatments. The livestock exclosure plots, the HRM managed rangeland plots, and the extreme high-intensity plots are all located on the Orme Ranch, which has been practicing HRM since 1985. The project has been endorsed by the Orme Ranch management team and the Prescott National Forest. Field work was initiated in Spring 1998.

Post Canyon Site

Located at 1520 m in the Sonoita Valley of SE Arizona, the vegetation of the Post Canyon site is classified as Plains and Great Basin Grassland (Brown 1994). The experimental design of the Post Canyon site differs from that of the Reed Lake and Ash Creek sites. At Post Canyon, the three land management treatments of interest converge at one point (Fig. 3) — The Diamond C Ranch has been managing livestock according to HRM principles since 1984; the Babocomori Ranch uses conventional, low intensity livestock management practices; and the Appleton-Whittell Audubon Research Ranch has excluded livestock from its premises since 1969. We have taken advantage of these three well established "treatments" by setting up Modified Whittaker plots, supplemented by stratified random samples on comparable land forms within 1 km of the convergence of the three ranches.

Conclusions

Environmental issues are often so polarized that there appears to be little room for objective scientific analysis. Yet few pressing environmental issues can be resolved without sufficient scientific understanding. The debate over grazing impacts and the proper use of public rangelands in the Southwest presents quite a "Catch 22" situation, with different interests advancing forceful arguments, each claiming that their position is based on sound science. Environmental scientists often find themselves called upon to bolster one side of the argument or the other, rather than doing what they are trained to do: identify important questions, design rigorous studies to address them, and analyze and interpret the results. If scientists wish to contribute to resolving real management issues, such as those posed by livestock grazing in the Southwest, they must understand (and target for research) the notions that underlie and sustain conflict. Developing an objective research approach that is broadly understood by all affected parties is a difficult task, but one that is essential to conducting relevant research that will be considered by decision makers.

We have worked with ranchers, environmentalists, agency scientists, and interested citizens to identify appropriate scientific questions and design approaches for field research. Exposure to a wide range of perspectives and interactions with many committed individuals have helped us develop a research effort that many agree is addressing key questions that are relevant to the future management of southwestern rangelands. While our geographic, taxonomic, and conceptual approaches are necessarily focused on particular issues and locations, the interactive process, which continues as our field work progresses, provides an encouraging indication that the results (whatever the outcome) will be considered by ranchers, public officials, and involved citizens – those individuals whose opinions and actions will determine future grazing policy.

ACKNOWLEDGMENTS

We wish to thank the owners, managers and employees of the Flying M, Orme, Diamond C, Babocomari, and Hart Ranches, and the Appleton-Whittell Audubon Research Ranch. We are also thankful for the hard work and dedication of the Diablo Trust, student researchers E. Baldwin, L. Golten, A. Keller, and numerous ranchers, agency officials, and interested citizens who have helped us develop and implement these ideas, and who continue to participate in this exciting research effort. This work was supported by an Organized Research award from Northern Arizona University, the U.S. Department of Energy and in-kind contributions from the Agroecology Program of Prescott College and the Flying M Ranch.

LITERATURE CITED

Bahre, C. J. 1991. A Legacy of Change: Historic impact on vegetation in the Arizona borderlands. Univ. of Arizona Press, Tucson, AZ.

Belsky, A. J. 1987. The effects of grazing: Confounding ecosystem, community, and organism scales. American Naturalist 127:870-892.

Belsky, A. J. and D. M. Blumenthal. 1997. Effects of livestock gazing on stand dynamics and soils in upland forests of the interior West. Conservation Biology 11:315-327.

Bock, C. E., J. H. Bock, W. R. Kenney, and V. M. Hawthorne. 1984. Responses of birds, rodents, and vegetation to livestock exclusion in a semidesert grassland site. Journal of Range Management 37:239-242.

Bock, C. E., J. H. Bock, and H. M. Smith. 1993. Proposal for a system of federal livestock exclosures on public rangelands in the western United States. Conservation Biology 7:731-733

Brady, W. W., M. R. Stromberg, E. F. Aldon, C. D. Bonham, and S. H. Henry. 1989. Response of a semidesert grassland to 16 years of rest from grazing. Journal of Range Management 42:284-288.

Brown, D. E., editor. 1994. Biotic communities: Southwestern United States and northwestern Mexico. Univ. of Utah Press, Salt Lake City, UT. 342 pp.

Brown, J. H., and W. McDonald. 1995. Livestock grazing and conservation on southwestern rangelands. Conservation Biology 9:1644-1647.

Brown, M. A. and S. S. Waller. 1986. The impact of experimental design on the application of grazing research results - an exposition. Journal of Range Management 39:197-200.

Cooperrider, A. Y. and D. S. Wilcove. 1995. Defending the desert: Conserving biodiversity on BLM lands in the Southwest. Environmental Defense Fund, New York.

Crews, T. E., C. L. Mohler, and A. G. Power. 1991. Energetics and ecosystem integrity: The defining principles of sustainable agriculture. American Journal of Alternative Agriculture 6:146-149.

Dagget, D. 1995. Beyond the rangeland conflict. Gibbs-Smith, Layton, UT.

Ehrlich, P. R. and A. H. Ehrlich. 1996. Betrayal of science and reason: How anti-environmental rhetoric threatens our future. Island Press, Washington, D.C. 338 pp.

Fleischner, T. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8:629-644.

Goodland, R. 1995. The concept of environmental sustainability. Annual Review of Ecology and Systematics 26:1-24.

Hastings, J. R. and R. M. Turner. 1965. The changing mile: An ecological study of vegetation change with time in the lower mile of an arid and semiarid region. Univ. of Arizona Press, Tucson, AZ.

Hecox, W. E. and B. L. Ack. 1996. Charting the Colorado Plateau: An economic and demographic exploration. Grand Canyon Trust, Flagstaff, AZ. 51 pp.

Jeffries, D. L. and J. M. Klopatek. 1987. Effects of grazing on the vegetation of the blackbrush association. Journal of Range Management 40:390-392.

Mayes, H. M. and T. F. Archer. 1982. Arizona cattle ranches on public land. College of Agriculture, Univ. of Arizona. Tucson, AZ. 12 pp.

Milchunas, D. G. and W. K. Lauenroth. 1993. Quantitative effects of grazing on vegetation and soils over a global range of environments. Ecological Monographs 63:327-366.

Savory, A. 1978. A holistic approach to ranch management using short duration grazing. Pages 555-557 *in* First International Rangeland Congress. Society for Range Management, Denver, CO.

Savory, A. 1988. Holistic resource management. Island Press, Washington, DC.

Schlegel, P. A. 1992. A history of the cattle industry in northern Arizona, 1863-1912. M.A. thesis, Northern Arizona University, Flagstaff, AZ.

Southwest Forest Alliance. 1996. Forests Forever. Southwest Forest Alliance, Flagstaff, AZ. 30 pp.

Stohlgren, T. J., F. W. Chong, M. A. Kalkhan, and L. D. Schell. 1997. Multiscale sampling of plant diversity: Effects of minimum mapping unit size. Ecological Applications 7:1064-1074.

Stohlgren, T. J., M. B. Falkner and L. D. Schell. 1995. A Modified-Whittaker nested vegetation sampling method. Vegetatio 117:113-121.