Effects of Long-term Livestock Exclusion in a Semiarid Grassland

Carl E. Bock
Jane H. Bock
Department of Biology
University of Colorado
Boulder, Colorado 80309

Abstract. Southwestern semiarid grasslands and those of the Colorado Plateau developed in the absence of large herds of native ungulates. The Appleton–Whittell Research Ranch is a 3,160-ha National Audubon Society sanctuary in southeastern Arizona where livestock have been excluded since 1968. By 1990, canopy cover of upland perennial grasses averaged 61% on the sanctuary, compared with 41% on adjacent cattle ranches. Among the 10 most common species, the tallest bunchgrasses (*Bothriochloa barbinodis*, *Bouteloua curtipendula*, and *Eragrostis intermedia*) responded most positively to release from grazing, while two short, stoloniferous grasses (*Bouteloua eriopoda* and *Hilaria belangeri*) were more abundant on grazed lands.

In general, common animals on the exclosure have been those requiring cover, while species preferring open habitat and bare ground dominated grazed areas. Peak fall densities of grasshoppers were over 3 times higher on grazed land. The bunchgrass lizard (*Sceloporus scalaris*) was the most abundant reptile on the sanctuary, but it was virtually absent from adjacent ranches. Cottonrats (*Sigmodon* spp.), harvest mice (*Reithrodontomys megalotis*), and hispid pocket mice (*Perognathus hispidus*) were the common rodents in ungrazed habitat, whereas deer mice (*Peromyscus* spp.) and kangaroo rats (*Dipodomys merriami*) predominated in grazed areas. Montezuma quail (*Cyrtonyx montezumae*), Cassin's sparrows (*Aimophila cassinii*), Botteri's sparrows (*A. botterii*), and grasshopper sparrows (*Ammodramus savannarum*) were common breeding birds on the sanctuary. The most abundant nesting birds on grazed lands were scaled quail (*Callipepla squamata*), horned larks (*Eremophila alpestris*), and lark sparrows (*Chondestes grammacus*).

We conclude that livestock, functioning as keystone species in grasslands of southeastern Arizona, can determine which components of the native flora and fauna persist or increase and which decline or disappear.

Key words: Arizona, birds, grasshoppers, grassland, grazing, livestock, rodents.

Grazing by large, hooved mammals is a major force influencing the structure, function, and evolution of grasses and grasslands, including those in western North America (Anderson 1982; Axelrod 1985; Sims 1988). Most grasslands potentially include mixtures of taller bunchgrasses and shorter

sod-forming species. The bunchgrasses are more vulnerable to damage by grazing mammals, and ecosystems with large numbers of grazers frequently are dominated by the shorter sod-forming species (Milchunas et al. 1988). A major predictor of the response of a grassland to livestock is its historic association with native ungulates. Grasslands of the Great Plains, for example, once supported millions of bison (*Bison bison*). Sodgrasses such as blue grama (*Bouteloua gracilis*) and buffalograss (*Buchloë dactyloides*) were common on the plains and were tolerant of the effects of livestock grazing (Detling 1988). By contrast, grasslands of the Intermountain West existed for at least the past 10,000 years in the virtual absence of bison. These grasslands were dominated by taller bunchgrasses, and they have been severely damaged by the activities of domestic grazers (Mack and Thompson 1982).

Grasslands of the Colorado Plateau and the American Southwest also had few bison present, at least since the Pleistocene (Hall 1981; McDonald 1981), and it is appropriate to regard intensive and extensive ungulate grazing as an exotic ecological force in these regions. Both areas include mixtures of sod and bunchgrasses, and both share strong floristic affinities with semiarid grasslands of north-central Mexico (Rzedowski 1975; Stebbins 1975). For these reasons, we believe that our studies comparing grazed and ungrazed grasslands in southeastern Arizona should be of interest to individuals facing management decisions about livestock on the Colorado Plateau.

The Appleton–Whittell Research Ranch is a 3,160-ha National Audubon Society sanctuary in the semiarid grasslands of southeastern Arizona. All livestock have been excluded from this former cattle ranch since 1968 (Bahre 1977). For the past decade, we have compared the flora and fauna of the sanctuary with those of adjacent grazed lands. Our detailed methods and tabular data supporting our general conclusions are published elsewhere (see Literature Cited). Our objective here is to review and synthesize results of those studies to reveal the long-term consequences of excluding exotic ungulates from a large semiarid grassland that previously had been subjected to livestock grazing.

Study Area

The Research Ranch lies on the Sonoita Plain, between the Huachuca and Santa Rita mountains, Santa Cruz County, Arizona. Sanctuary elevations vary from 1,400 to 1,560 m. Temperatures range from a mean daily January minimum of –3.0°C to a mean daily June maximum of 32.6°C. Twenty-year mean annual precipitation has been 43 cm; about 57% falls during July to early September, the period of maximum plant growth and animal reproduction.

Vegetation on the sanctuary is remarkably similar to grasslands of the Mexican High Plateau (Rzedowski 1975), where most of the dominant grass taxa probably evolved (Stebbins 1975). Level to rolling uplands on and adjacent to the sanctuary support a variety of native perennial grasses, especially threeawns (*Aristida* spp.), sideoats grama (*Bouteloua curtipendula*), blue grama, plains lovegrass (*Eragrostis intermedia*), curly mesquite (*Hilaria belangeri*), and wolftail (*Lycurus phleoides*; Bock and Bock 1986). An even greater variety of forbs is present, but none is abundant compared to the grasses. Scattered low shrubs include burro weed (*Haplopappus tenuisectus*) and yerbe de pasmo (*Baccharis pteronioides*). There are scattered mesquite trees (*Prosopis juliflora*) in these grasslands and, near the southern boundary of the sanctuary, increasingly broken terrain supports an oak savannah (mostly *Quercus emoryi* and *Q. arizonica*). Floodplains include broad stands of sacaton grass (*Sporobolus wrightii*), a species that reaches a height of 2 m.

Most of our studies have centered on upland mesas and, to a lesser degree, on sacaton floodplains. These were the largest topographically uniform areas transected by sanctuary boundary fences, where we could compare sites similar in all respects except the presence versus absence of livestock. Our methods have been standard field techniques of estimating plant canopy cover, rodent live-trapping, grasshopper hoop counts, and visual censuses of birds and lizards. A potential weakness of all our work is that no cross-fence comparisons were made before livestock removal in 1968. Previous land use of the sanctuary, however, did not differ from that of adjacent cattle ranches (Bahre 1977). The entire region has been devoted to livestock production since the 1890's at the latest (Bahre 1991). Furthermore, photographic and vegetation data revealed a marked increase in grass cover at two sites on the sanctuary itself between 1969 and 1984 (Brady et al. 1989). For these reasons, we are confident that differences across fencelines since 1980 can be attributed to continued presence versus absence of livestock.

It has not been possible to determine exact stocking rates on ranches adjacent to the sanctuary, which in any event would bear no necessary relationship to the numbers of livestock on our particular grazed plots over the preceding 22 years. Livestock grazing appears to have been moderate, insofar as substantial grass cover remained present. Qualitatively, no dramatic changes in grass cover have occurred on adjacent ranches since we began to work in the area.

Results

Vegetation

Cross-fence comparisons have revealed consistent differences in grass canopy cover and relative abundance of grassland species between the sanctuary and adjacent grazed lands. In 1981–82, we measured vegetation on a 300-ha mesa crossing the northern boundary fence of the sanctuary (Bock et al. 1984). Perennial grass canopy was 80% on ungrazed versus 56% on grazed land. Forb canopy was 12% on the sanctuary versus 5% on grazed land. One shrub, *Baccharis pteronioides*, was significantly more abundant

and individual plants larger where livestock were excluded. Cattle apparently browse this shrub in winter, and it was consistently more abundant and larger in ungrazed habitat on four cross-fence sites in 1982–83 (Kenney et al. 1986).

Brady et al. (1989) made cross-fence vegetation comparisons along the northeastern border of the sanctuary in 1984. Grass canopy was 68% in ungrazed versus 44% in grazed habitat, and most of this difference involved taller bunchgrasses. In their sites, forb canopy was nearly equal between treatments (17% grazed vs. 14% ungrazed).

In 1990, we compared grass canopy cover at eight additional cross-fence sites. The average was 61% on the sanctuary versus 41% on adjacent ranches (Bock and Bock 1993). There was a strong positive correlation ($R = 0.90$) between potential height of a grass species and the degree and direction of cross-fence differences in its average canopy cover. The three tallest bunchgrasses showed the greatest positive response to livestock exclusion—sideoats grama, cane beardgrass (*Bothriochloa barbinodis*), and plains lovegrass. Two native short-stature stoloniferous grasses were the only taxa significantly more abundant in grazed habitat—black grama (*Bouteloua eriopoda*) and curly mesquite. Three bunchgrasses of intermediate height were more evenly distributed across fencelines but generally were more abundant in the ungrazed condition—threeawns, blue grama, and wolftail.

Grass canopy cover has increased on the Research Ranch since livestock were excluded in 1968, and species' relative abundances have shifted in favor of taller bunchgrasses. These findings are consistent with observations elsewhere regarding the relative grazing tolerance of shorter sodgrasses and with observed increases of bunchgrasses under livestock exclosure, especially in areas where precipitation is sufficient to sustain the taller species (Anderson and Holte 1981; Mack and Thompson 1982; Detling 1988; Milchunas et al. 1988).

Grasshoppers

Grasshoppers (Orthoptera: Acrididae) are dominant insect herbivores in grassland ecosystems (Otte 1981), and they can significantly affect grasslands when their densities are high (Hewitt and Onsager 1983). We compared grasshopper abundance and species composition across a sanctuary fenceline in 1983–84 (Jepson-Innes and Bock 1989). In summer, grasshoppers were significantly more abundant on ungrazed plots where peak adult densities were about 2 animals/m^2. The pattern shifted in fall when grasshoppers became much more abundant in grazed habitat, and peak adult densities reached 5 animals/m^2. Dempster (1963) concluded that most grasshoppers thrive in habitat mosaics of sunny, bare ground interspersed with green vegetation. Nymphs and adults require vegetation for food, but neither they nor their eggs survive well in moist litter or shade. Grazing ungulates can create ideal grasshopper habitat by reducing litter and grass canopy and by stimulating plants to produce succulent new growth. Various studies indicate that grasshoppers do best in moderately-grazed sites compared with either heavily grazed or ungrazed areas (Holmes et al. 1979; Capinera and Sechrist 1982; O'Meilia et al. 1982). Our findings are consistent with this pattern (Jepson-Innes and Bock 1989). Taken together, the data strongly suggest that native and exotic grazers indirectly cause some grasshopper outbreaks.

Bunchgrass Lizard

Herpetofaunal responses to livestock grazing have received relatively little study, although lizard abundance and variety were reduced in grazed habitat in western Arizona (Jones 1981). The bunchgrass lizard (*Sceloporus scalaris*) is a grassland specialist presently found north of Mexico largely in isolated montane meadows of southern Arizona and New Mexico (Stebbins 1985). In 1989, we discovered that it was the common grassland lizard on the Research Ranch sanctuary, where it was over 10 times more abundant than on adjacent ranches (Bock et al. 1990). The observation that bunchgrass lizards can be common in semiarid grasslands is new, and it suggests that the apparent concentration of *Sceloporus scalaris* in montane meadows likely is an artifact of historic livestock grazing at lower elevations.

Rodents

Livestock grazing potentially can affect rodent populations by changing cover and food, although not all studies have revealed such effects (Samson et al. 1988; Heske and Campbell 1991). Between July 1981 and January 1983, we live-trapped rodents on the sanctuary and adjacent upland grazed sites (Bock et al. 1984). Total rodent captures were significantly higher in ungrazed grassland, and species dominance varied in ways consistent with what is known of habitat associations of the various taxa. Deer mice (*Peromyscus* spp.) are adaptable and generalized rodents (Phillips 1936; Baker 1968), and we found them about equally abundant on both sides of the boundary fence. Merriam's kangaroo rat (*Dipodomys merriami*) is an open-ground species (Reynolds 1950; Rosenzweig and Winakur 1969), and we found it 18 times more abundant in grazed habitat. Hispid pocket mice (*Perognathus hispidus*), western harvest mice (*Reithrodontomys megalotis*), and cotton rats (*Sigmodon* spp.) all were significantly more abundant on the sanctuary, and all are known to prefer areas of heavy ground cover (Rosenzweig and Winakur 1969; Cameron and Spencer 1981; Webster and Jones 1982; Randolph et al. 1991).

Birds

Grazing and haying can significantly alter habitat for upland birds (Kirsch et al. 1978). We recently reviewed our comparative studies of birds in ungrazed versus grazed uplands on and adjacent to the Research Ranch, and we quote here from that review (Bock and Bock 1988:54):

While total numbers of bird detections were very similar on grazed and ungrazed areas, relative abundances of individual species differed dramatically. Grasshopper (*Ammodramus savannarum*) and Cassin's sparrows (*Aimophila cassinii*) are grassland specialists (Wiens 1973; Hubbard 1977), and they dominated ungrazed uplands in both summer and winter (Bock et al. 1984; Bock and Webb 1984). Two sorts of birds were substantially more common in grazed areas. The first group includes species typical of lower elevations and relatively xeric habitats, such as the scaled quail (*Callipepla squamata*; Johnsgard 1973), and the Brewer's (*Spizella breweri*) and black-throated sparrows (*Amphispiza bilineata*; Phillips et al. 1964). Their abundance in grazed areas may be indicative of desertification. Second are species preferring relatively open ground for foraging, including the mourning dove (*Zenaida macroura*), horned lark (*Eremophila alpestris*), northern mockingbird (*Mimus polyglottos*), lark sparrow (*Chondestes grammacus*), and chestnut-collared longspur (*Calcarius ornatus*; Laskey 1962; Baepler 1968; Leopold 1972; Cannings and Threlfall 1981). Two additional species, the vesper sparrow (*Pooecetes gramineus*) and eastern meadowlark (*Sturnella magna*), appear sufficiently generalized to have used grazed and ungrazed areas about equally.

Two other birds are important components of grasslands on the sanctuary—Montezuma quail and Botteri's sparrow. Montezuma quail have been abundant on the sanctuary where they relied on heavy cover as protection from avian predators (Stromberg 1990). Although we have not compared populations across fencelines, this species is known to decline in grazed habitats in southeastern Arizona because of its vulnerability to predation (Brown 1982).

The Botteri's sparrow is a tallgrass specialist, most abundant in the Southwest in sacaton grassland floodplains. On and near the Research Ranch, Botteri's sparrows were maximally abundant in ungrazed sacaton stands adjacent to grassy slopes (Webb and Bock 1990). Birds nested at the bases of sacaton clumps and foraged for grasshoppers on the grassy hillsides. Botteri's sparrows were missing or less abundant in floodplains lacking either mature ungrazed and unburned sacaton or the adjacent undisturbed grassy hillsides. Botteri's sparrows also have increased in abundance in recent years on upland mesas on the sanctuary, because these mesas have developed taller grasslands (Bock and Bock 1992).

Discussion and Conclusions

Twenty-five years ago, R. T. Paine introduced to ecology the term *keystone species* (Paine 1966), defined as a taxon that exerts a controlling influence over the structure and function of an ecosystem to which it belongs. Paine demonstrated experimentally that biological communities have dramatically different compositions when keystone species are present than when they are absent (Brown and Heske 1990).

We believe that livestock function as keystone species in many grasslands, especially those in western North America that lacked large pre-Columbian herds of native ungulates. In a semiarid grassland in southeastern Arizona, release from the controlling influence of livestock has resulted in increased height and cover of grassland vegetation, and this in turn has resulted in major changes in the grassland's fauna. These changes have been gradual, and we have no reason to assume they are yet complete. However, the record of the Research Ranch speaks to the value of permanently protecting large tracts of grassland from domestic grazers to restore or maintain the diversity of plants and wildlife they will come to support.

The issue is not that livestock preclude vegetation and wildlife. Indeed, many species are favored by grazing, a fact shown by a variety of studies, including our own. The issue instead is that grazing favors certain kinds of plants and animals at the expense of others. Given the near ubiquity of domestic ungulates in the American West, those species favored by grazing today are abundant, while those negatively affected by grazing are greatly diminished or even rare. Near the Research Ranch, plants and animals favored by grazing have been those otherwise typical of lower elevations, especially those preferring open, more desertlike, habitats.

Much has been made recently about the value of certain intensive short-term livestock grazing systems, about the use of livestock as a habitat management tool, and about possible positive effects of livestock on grassland productivity (Savory 1988). A number of recent controlled studies dispute the presumed benefits of short-duration grazing relative either to livestock exclusion or to application of more traditional grazing systems (Weltz and Wood 1986; Heitschmidt et al. 1987; Hart et al. 1988; Reece et al. 1988; Thurow et al. 1988a, 1988b; Dormaar et al. 1989; Walker et al. 1989; Ralphs et al. 1990; Weigel et al. 1990). We have not worked with livestock, so we have little to contribute to this debate except to note that the grasslands of the Research Ranch continue to support an abundance and diversity of plants and wildlife in the absence of livestock.

It is important to distinguish the value of grassland as a crop from its value as habitat for indigenous flora and fauna. There is abundant evidence showing that moderate grazing can increase grassland productivity (Williamson et al. 1989), though more so in ecosystems that evolved with native grazers (McNaughton 1979; Mack and Thompson 1982). However, mature ungrazed grasslands with abundant litter and shade are not unhealthy in any ecological or evolutionary sense, and they can provide essential habitat for many species precluded from ecosystems under the influence of keystone ungulate grazers.

Acknowledgments

We thank the managers of the Appleton–Whittel Research Ranch (V. Hawthorne, E. Knoder, and M. Stromberg), the Appleton family, and many students for their advice and assistance. We are grateful to the following organizations, agencies, and individuals for their support: National Audubon Society, National Science Foundation, National Geographic Society, Earthwatch and the Center for Field Research, National Park Service, U.S. Forest Service, U.S. Bureau of Land Management, Research Ranch Foundation, Lindbergh Foundation, and Joseph and Helen Taylor.

Literature Cited

Anderson, J. E., and K. E. Holte. 1981. Vegetation development over 25 years without grazing on sagebrush dominated rangeland in southeastern Idaho. Journal of Range Management 34:25–29.

Anderson, R. C. 1982. An evolutionary model summarizing the roles of fire, climate, and grazing animals in the origin and maintenance of grasslands: an end paper. Pages 297–308 *in* J. R. Estes, R. J. Tyrl, and J. N. Brunken, editors. Grasses and grasslands: systematics and ecology. University of Oklahoma Press, Norman.

Axelrod, D. I. 1985. Rise of the grassland biome, central North America. Botanical Review 51:163–201.

Baepler, D. H. 1968. Lark sparrow. Pages 886–902 *in* A. C. Bent, editor. Life histories of North American cardinals, grosbeaks, buntings, towhees, finches, sparrows, and allies. U.S. National Museum, Bulletin 237. Washington, D.C.

Bahre, C. J. 1977. Land-use history of the Research Ranch, Elgin, Arizona. Journal of the Arizona Academy of Science 12:1–32.

Bahre, C. J. 1991. A legacy of change. University of Arizona Press, Tucson. 231 pp.

Baker, R. H. 1968. Habitats and distribution. Pages 98–126 *in* J. A. King, editor. Biology of *Peromyscus*. American Society of Mammalogists, Special Publication 72.

Bock, C. E., and J. H. Bock. 1988. Grassland birds in Arizona: impacts of fire, grazing, and alien vegetation. Pages 43–58 *in* P. D. Goriup, editor. Grassland birds. International Council for Bird Preservation Publication 7, Cambridge, England.

Bock, C. E., and J. H. Bock. 1992. Response of birds to wildfire in native versus exotic Arizona grassland. Southwestern Naturalist 37:73–81.

Bock, C. E., and J. H. Bock. 1993. Cover of perennial grasses in southeastern Arizona in relation to livestock grazing. Conservation Biology 7:371–377.

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

Bock, C. E., H. M. Smith, and J. H. Bock. 1990. The effect of livestock grazing upon abundance of the lizard, *Sceloporus scalaris*, in southeastern Arizona. Journal of Herpetology 24:445–446.

Bock, C. E., and B. Webb. 1984. Birds as grazing indicator species in southeastern Arizona. Journal of Wildlife Management 48:1045–1049.

Bock, J. H., and C. E. Bock. 1986. Habitat relationships of some native perennial grasses in southeastern Arizona. Desert Plants 8:3–14.

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, J. H., and E. J. Heske. 1990. Control of a desert–grassland transition by a keystone rodent guild. Science 250:1705–1707.

Brown, R. L. 1982. Effects of livestock grazing on Mearns quail in southeastern Arizona. Journal of Range Management 35:727–732.

Cameron, G. N., and S. R. Spencer. 1981. *Sigmodon hispidus*. Mammalian Species 158, American Society of Mammalogists. 7 pp.

Cannings, R. J., and W. Threlfall. 1981. Horned lark breeding biology at Cape St. Marys, Newfoundland. Wilson Bulletin 93:519–530.

Capinera, J. L., and T. S. Sechrist. 1982. Grasshopper (Acrididae)—host plant associations: response of grasshopper populations to cattle grazing intensity. Canadian Entomologist 114:1055–1062.

Dempster, J. P. 1963. The population dynamics of grasshoppers and locusts. Biological Review 38:490–529.

Detling, J. K. 1988. Grasslands and savannahs: regulation of energy flow and nutrient cycling by herbivores. Pages 131–148 *in* L. R. Pomeroy and J. J. Alberts, editors. Concepts of ecosystem ecology, a comparative view. Ecological Studies 67, Springer-Verlag, New York.

Dormaar, J. F., S. Smoliak, and W. D. Willms. 1989. Vegetation and soil responses to short-duration grazing on fescue grasslands. Journal of Range Management 42:252–256.

Hall, E. R. 1981. The mammals of North America, 2nd ed. John Wiley & Sons, New York. 1,181 pp.

Hart, R. H., M. J. Samuel, P. S. Test, and M. A. Smith. 1988. Cattle, vegetation, and economic response to grazing systems and grazing pressure. Journal of Range Management 41:282–286.

Heitschmidt, R. K., S. L. Dowhower, and J. W. Walker. 1987. 14- versus 42-paddock rotational grazing: aboveground biomass dynamics, forage production, and harvest efficiency. Journal of Range Management 40:216–223.

Heske, E. J., and M. Campbell. 1991. Effects of an 11-year livestock exclosure on rodent and ant numbers in the Chihuahuan desert, southeastern Arizona. Southwestern Naturalist 36:89–93.

Hewitt, G. B., and J. A. Onsager. 1983. Control of grasshoppers on rangeland in the United States—a perspective. Journal of Range Management 36:202–207.

Holmes, N. D., D. S. Smith, and A. Johnston. 1979. Effects of grazing by cattle on the abundance of grasshoppers on fescue grassland. Journal of Range Management 32:310–311.

Hubbard, J. P. 1977. The status of Cassin's sparrow in New Mexico and adjacent states. American Birds 31:933–941.

Jepson-Innes, K., and C. E. Bock. 1989. Response of grasshoppers (Orthoptera: Acrididae) to livestock grazing in southeastern Arizona: differences between seasons and subfamilies. Oecologia 78:430–431.

Johnsgard, P. A. 1973. Grouse and quails of North America. University of Nebraska Press, Lincoln. 553 pp.

Jones, K. B. 1981. Effects of grazing on lizard abundance and diversity in western Arizona. Southwestern Naturalist 26:107–115.

Kenney, W. R., J. H. Bock, and C. E. Bock. 1986. Responses of the shrub, *Baccharis pteronioides*, to livestock exclosure in southeastern Arizona. American Midland Naturalist 116:429–431.

Kirsch, L. M, H. F. Duebbert, and A. D. Kruse. 1978. Grazing and haying effects on habitats of upland nesting birds. Transactions of the North American Wildlife Conference 43:486–497.

Laskey, A. R. 1962. Breeding biology of mockingbirds. Auk 79.86–96.

Leopold, A. S. 1972. The wildlife of Mexico. University of California Press, Berkeley. 568 pp.

Mack, R. N., and J. N. Thompson. 1982. Evolution in steppe with few large, hooved mammals. American Naturalist 119:757–773.

McDonald, J. N. 1981. North American bison, their classification and evolution. University of California Press, Berkeley. 316 pp.
McNaughton, S. J. 1979. Grazing as an optimization process: grass–ungulate relationships in the Serengeti. American Naturalist 113:691–703.
Milchunas, D. G., O. E. Sala, and W. K. Lauenroth. 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. American Naturalist 132:87–106.
O'Meilia, M. E., F. L. Knopf, and J. C. Lewis. 1982. Some consequences of competition between prairie dogs and beef cattle. Journal of Range Management 35:580–585.
Otte, D. 1981. The North American grasshoppers. Volume I. Acrididae (Gomphocerinae and Acridinae). Harvard University Press, Cambridge, Mass. 275 pp.
Paine, R. T. 1966. Food web complexity and species diversity. American Naturalist 100:65–75.
Phillips, A., J. Marshall, and G. Monson. 1964. The birds of Arizona. University of Arizona Press, Tucson. 212 pp.
Phillips, P. 1936. The distribution of rodents in overgrazed and normal grasslands of central Oklahoma. Ecology 17:673–679.
Ralphs, M. H., M. M. Kothmann, and C. A. Taylor. 1990. Vegetation response to increased stocking rates in short-duration grazing. Journal of Range Management 43:104–108.
Randolph, J. C., G. N. Cameron, and J. A. Wrazen. 1991. Dietary choice of a generalist herbivore, *Sigmodon hispidus*. Journal of Mammalogy 72:300–313.
Reece, P. E., R. P. Bode, and S. S. Walker. 1988. Vigor of needleandthread and blue grama after short duration grazing. Journal of Range Management 41:287–291.
Reynolds, H. G. 1950. Relation of Merriam kangaroo rats to range vegetation in southern Arizona. Ecology 31:456–463.
Rosenzweig, M. I., and J. Winakur. 1969. Population ecology of desert rodent communities: habitats and environmental complexity. Ecology 50:558–572.
Rzedowski, J. 1975. An ecological and phytogeographical analysis of the grasslands of Mexico. Taxon 24:67–80.
Samson, F. B., F. L. Knopf, and L. B. Hass. 1988. Small mammal response to the introduction of cattle into a cottonwood floodplain. Pages 432–438 *in* R. C. Szaro, K. E. Severson, and D. R. Patton, technical coordinators. Management of amphibians, reptiles, and small mammals in North America. U.S. Forest Service General Technical Report RM-166. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo.
Savory, A. 1988. Holistic resource management. Island Press, Washington, D.C. 564 pp.
Sims, P. L. 1988. Grasslands. Pages 265–286 *in* M. G. Barbour and W. D. Billings, editors. North American terrestrial vegetation. Cambridge University Press, Cambridge, England.
Stebbins, G. L. 1975. The role of polyploid complexes in the evolution of North American grasslands. Taxon 24:91–106.
Stebbins, R. C. 1985. A field guide to western reptiles and amphibians, 2nd ed. Houghton–Mifflin Co., Boston, Mass. 279 pp.
Stromberg, M. R. 1990. Habitat, movements, and roost characteristics of Montezuma quail in southeastern Arizona. Condor 92:229–236.
Thurow, T. L., W. H. Blackburn, and C. A. Taylor, Jr. 1988a. Some vegetation responses to selected livestock grazing strategies, Edwards Plateau, Texas. Journal of Range Management 41:108–114.

Thurow, T. L., W. H. Blackburn, and C. A. Taylor, Jr. 1988b. Infiltration and interrill erosion responses to selected livestock grazing strategies, Edwards Plateau, Texas. Journal of Range Management 41:296–302.
Walker, J. W., R. K. Heitschmidt, and S. L. Dowhower. 1989. Some effects of a rotational grazing treatment on cattle preference for plant communities. Journal of Range Management 42:143–148.
Webb, E. A., and C. E. Bock. 1990. Relationship of the Botteri's sparrow to sacaton grassland in southeastern Arizona. Pages 199–209 *in* P. R. Krausman and N. S. Smith, editors. Managing wildlife in the Southwest. Arizona Chapter of The Wildlife Society, Phoenix.
Webster, W. D., and J. K. Jones, Jr. 1982. *Reithrodontomys megalotis*. Mammalian Species 167, American Society of Mammalogists. 5 pp.
Weigel, J. R., C. M. Britton, and G. R. McPherson. 1990. Trampling effects from short-duration grazing on tobosagrass range. Journal of Range Management 43:92–94.
Weltz, M., and M. K. Wood. 1986. Short duration grazing in central New Mexico: effects on infiltration rates. Journal of Range Management 39:365–368.
Wiens, J. A. 1973. Pattern and process in grassland bird communities. Ecological Monographs 43:237–270.
Williamson, S. C., J. K. Detling, J. L. Dodd, and M. I. Dyer. 1989. Experimental evaluation of the grazing optimization hypothesis. Journal of Range Management 42:149–152.