

The Role of Landscape Anomalies in Regional Plant Conservation

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Abstract: Landscape anomalies are regionally restricted habitats created by unusual geologic, edaphic, or hydrologic factors. Barrens, cliff faces, canyons, hanging gardens, and playas are all examples of landscape anomalies in the arid Southwest. Such sites often harbor an unusual and rich flora, including endemic, disjunct, or relictual plant species. Using examples from our studies on the chalk barrens and riparian canyons of southeast Colorado, we show how regional diversity can be enriched by the biota of habitats that are small in extent but biologically distinctive. Landscape anomalies are relatively easily surveyed and monitored, provide opportunities for comparative studies, and can serve as flagship habitats for capturing public interest. Because of their small size, however, they may be easily destroyed by development or overlooked in regional planning. Although coarse filter conservation approaches can be effective for the protection of regional ecosystems, a focus on small landscape anomalies as specific conservation targets may also be desirable to protect biota with low prominence but high biogeographic significance.

The geological term “anomaly” refers to a local feature distinguished by its unusual geophysical, geochemical, or geobotanical aspects (American Geological Institute 1976). The term “landscape anomaly” is used here in a similar sense: a regionally restricted habitat with unusual geologic, edaphic, microclimatic, or hydrologic factors. Examples of landscape anomalies in the arid Southwest include such habitats as shale barrens, riparian canyons, hanging gardens, and playas. In other regions, habitats such as coastal plain pond margins, dunes, prairie potholes, vernal pools, or cliff faces may fit the criteria for landscape anomalies.

Regional conservation efforts today often focus on different scales of protection. “Ecoregional” protection (Nature Conservancy 2000), sometimes called a “coarse filter” approach, typically addresses widescale communities or ecosystems and large tracts of land. A fine filter approach specifically protects rare species that might be missed in a larger ecological context. Somewhat in between the coarse and fine filters lies the keystone or focal species approach, which targets species whose individual ecology makes their protection an effective and inclusive umbrella for other species (Soulé and Kohm 1989, Lambeck 1997). All of these approaches have considerable merit in conservation but may be costly to implement.

We highlight landscape anomalies that provide another scale between ecosystem and species approaches and additional targets for regional conservation planning. Because of their relatively

small physical size, landscape anomalies may be overlooked in planning for broad ecosystem conservation, or, because of their typically restricted biotas, they may not include species with a sufficiently high ecological profile to warrant recognition as critical habitat for keystone species. However, we suggest that these habitats can be valuable conservation targets on the basis of three important attributes: significance for regional biodiversity, research potential, and practical application for community-based conservation. We use two examples of southeastern Colorado landscape anomalies, chalk barrens and riparian canyons, to illustrate their importance in our regional biodiversity, their potential heuristic value as research sites, and their practicality for local conservation efforts.

Landscape Anomalies of Southeastern Colorado

The Pikes Peak region, which extends from about 30 miles south of Denver, Colorado to the Arkansas River Valley near the cities of Pueblo and Cañon City, is one of the country’s fastest growing areas. Development pressures continue to climb here as the region sees a dramatic growth in population, housing development, urban infrastructure, and industry, with additional growth predicted for the coming decades.

For the past 5 years, we have been studying the botany of two landscape anomalies in this region: the chalk barrens of the Arkansas River Valley and the riparian canyons in the lower Front

Range foothills. They provide unusual edaphic conditions and microclimate in a regional landscape that transitions from dry plains grassland through pinyon pine woodlands to ponderosa pine forests in the upper foothills. Both of these study habitat types occupy limited areas, contain unusual and rich floras, and can succumb readily to the impacts of development or recreational use.

The Chalk Barrens

The Niobrara Formation contains the stratigraphic remains of a Cretaceous mid-continental interior seaway. It underlies much of eastern Colorado and Kansas (Scott and Cobban 1964) as a calcareous bedrock of shale, limestone, and chalk. The Middle and Upper Chalk layers of the Smoky Hills unit in the formation occur as a more geographically limited subset of the Niobrara, and form the Niobrara barrens. Here thinly bedded, fissile chalk layers erode easily and form moderate slopes with a surface covering of rock fragments over a shallow mineral soil (Scott 1969, Kelso et al. 1999). The chalk barrens occur only in areas with topographic relief, particularly where rivers or tilted uplift have provided erosion-prone slopes. Although they may reach several kilometers in length, Niobrara chalk barrens often cover as little as 10 m, with short vertical slopes 3–10 m from base to summit. These patches form small islands of exposed calcareous bedrock within a surrounding grassland or pinyon pine–juniper community. Although a few chalk barrens occur around the Comanche National Grasslands in southeastern Colorado, they appear mostly in a narrow belt along the Arkansas River between Pueblo and Cañon City. These barrens contain a number of plant species of concern (Colorado Natural Heritage Program 1999). Because of their small size and primary occurrence in a region with spreading development, they are viewed as highly vulnerable habitats. None of the barrens, however, has gained formal protection, though several occur on state or federal lands under the jurisdiction of Colorado State Parks, the Colorado Division of Wildlife, and the Department of the Army.

In previous studies we have examined numerous aspects of the barrens, including soil geochemistry, plant endemism, and autoecology of selected species of concern (Kelso et al. 1995a, 1995b, 1996, 1997, 1999). We found that the endemism here is not related to any unusual geochemistry of the soils; in fact, the barrens plant taxa also grow extremely well in “normal” transplant garden soils if sufficient water is supplied. The restricted nature

of these species in the wild is probably due to their lack of ability to compete for water in sandy soils with other native species, especially grasses. However, on the barrens with a very shallow, fine soil on top of shallow, layered bedrock, they can occupy moisture-retentive bedrock cracks via extensive rhizomes and other belowground organs, and exploit a habitat that is inhospitable for more competitive species. This flora, though less than 100 species, contains an unusual association of plants, including rare, endemic, and disjunct species, as well as a high concentration of the Southwestern phytogeographic element at the northern periphery of its range. A comparison with the flora of Fort Carson, a U.S. Army base located just south of Colorado Springs, highlights the differences between the barrens flora and a typical regional shortgrass prairie flora (Table 1).

The data shown in Table 1 illustrate how the barrens flora is rich despite its small size: Rare endemics and geographically anomalous species show an unusually high profile here. In particular, the Southwestern phytogeographic element plays a prominent role. This element surfaces more frequently on the barrens than in the surrounding regional shortgrass prairie flora, approaching or perhaps exceeding its representation in the Mesa de Maya flora on the Colorado–New Mexico border, which predictably favors the warm climate, Southwestern species. For that region, Clark (1996) has shown that in a flora of approximately 570 vascular plant species, 17 percent have Southwestern phytogeographic affinities. Although most of the Southwestern species found on the barrens are not state or globally rare, they are nonetheless locally significant in our regional biodiversity profile. These northward or disjunct species are probably relictual elements from a previous climatic regime, such as in the early Holocene when the regional climate was periodically hotter, drier, or both than it is now (Dick-Peddie 1993, Thompson et al. 1993, Vierling 1998).

The Foothills Riparian Canyons

Unlike the foothills in the northern Front Range where continual moisture is available from mountain chains such as the Indian Peaks, the Pikes Peak massif and Rampart Range foothills are very dry. Not only are moisture-bearing weather systems less common here, but also water catchment areas on Pikes Peak now channel precipitation and snowmelt into reservoirs that were previously a system of natural lakes and streams. These larger reservoirs now curtail and direct the

Table 1. Comparative floras of Fort Carson and the chalk barrens of southeast Colorado. Fort Carson data from the Directorate of Environmental Compliance and Management, Fort Carson, CO (unpublished). Chalk barrens data from Kelso et al. (1999).

Attributes	Fort Carson	Barrens	
		Total Flora ^a	Core Flora ^b
Total flora	457	95	40
Number of high S-rated plant species ^c	8 (1.7%)	7 (7.4%)	5 (12.5%)
Southwestern element ^d	13.8%	15.6%	24.3%
Adventive element	18.6%	1%	< 1%

^aTotal flora found on 29 study sites in a 240 km transect across southeast Colorado.

^bCore flora defined as species found in at least 25 percent of the study sites.

^cHigh S-rated species are given the highest priority for conservation by the Colorado Natural Heritage Program. They carry an S1 or S2 rating under the ranking system used nationally by Heritage Programs (Colorado Natural Heritage Program 1999).

^dSouthwestern (or Chihuahuan) elements are species distributed primarily in Arizona, Colorado, New Mexico, Utah, and Mexico (Clark 1996).

water flow into just a few drainages in the region. In the approximately 100 km of foothills bordering Colorado Springs, there are several hundred topographic canyons, but few of these have permanent or semipermanent water. Prior to reservoir construction, these canyons, and perhaps others as well, were part of a hydrologic system fed by snowmelt and alpine lakes on Pikes Peak. Their perennial flows currently attract recreational use from the growing urban population here, and housing developments proliferate in the nearby foothills. None of these riparian canyons has explicit conservation protection thus far; ownership lies primarily with the City of Colorado Springs, the Pike National Forest, and private landowners.

The arid climate limits vegetation diversity in the foothills. The dominant species here are drought tolerant, many showing Southwestern phytogeographic affinities. A shrub community composed of *Quercus gambelii* Nuttall (Gambel oak), *Cercocarpus montanus* Rafinesque (mountain mahogany) and *Rhus aromatica* Aiton ssp. *trilobata* (Nutt.) Gray (skunkbrush) covers the lower elevations of Pikes Peak. In the middle elevations, montane forests of *Pinus ponderosa* Douglas (ponderosa pine) predominate, but on north-facing slopes the forests typically include *Abies concolor* (Gordon) Lindley (white fir) and *Pseudotsuga menziesii* (Mirbel) Franco (Douglas fir).

The riparian canyons, however, offer specialized habitats within the dominant foothills shrub or pine communities. We found that these landscape anomalies, like the chalk barrens, contain a rich flora that includes endemic, disjunct, and rare

species as well as a regionally unusual phytogeographic profile (Hall 2000). This diversity arises from the cooler temperatures and more humid conditions found in the canyons than in adjacent areas of comparable elevation and topography.

Riparian canyons occur on a larger scale than the chalk barrens: They typically extend ca 10 km in length, and therefore can encompass a diversity of plant communities. Several of these, such as the *Alnus incana* (L.) Moench-Cornus sericea L. (thinleaf alder-red osier dogwood) and the *Corylus cornuta* Marshall (hazelnut) communities are recognized by the Colorado Natural Heritage Program (1999) as rare. Riparian canyons also provide critical wildlife habitat as corridors and nesting sites for bird species, including Mexican spotted owls, ovenbirds, and peregrine falcons, which are also

Table 2. Biological diversity in riparian canyons of the Pikes Peak region. Primary study sites included Queen's Canyon, Bear Creek Canyon, North Cheyenne Canyon, and Little Fountain Creek Canyon in El Paso County, Colorado.

Total vascular flora: 262 spp.
High S-rated plant community types: 10
S-rated plant species: 8
S-rated nesting bird species: 3
Phytogeography
Southwestern: 10%
Eastern-Boreal: 18%
Adventive: 14%

Data from Hall (2000). High S-rated community types are those recognized by the Colorado Natural Heritage Program to have high conservation priority for the state of Colorado (Colorado Natural Heritage Program 1999).

considered as rare at the state or global level. Table 2 summarizes this biological diversity.

Along with a significant number of rare species occurring in these wet canyons, the presence of the disjunct cool-climate species (the Eastern-Boreal element) stands out. For comparison, this element provides a barely visible signal at 3.5 percent of the regional shortgrass prairie flora present at the base of the canyons (unpublished data from the Directorate of Environmental Compliance and Management, Fort Carson). As the Southwestern element may be relictual from a previous warm climate and now prevails on the chalk barrens, the Eastern and Boreal elements may be relictual from the late Pleistocene (Weber 1965, Kaul et al. 1988, Hogan 1993). Although these species were probably more regionally widespread 12,000–15,000 years ago, they can now persist only under the cool moist conditions found in isolated canyon habitats.

Biological Richness of Landscape Anomalies

Although very different with respect to their specific biology, both the chalk barrens and the riparian canyons share the general characteristics typical of landscape anomalies. They contain rare or sensitive species that are habitat specialists, a low adventive component, and a high disjunct component that creates a biogeographic profile strikingly different from the regional one and suggests a relictual aspect to the biota occurring there. These qualities are important attributes of overall biological richness, which too often carries the connotation of mere species richness defined purely on a numerical basis. Species numbers alone may not do justice to the significance of certain individual species or phytogeographic suite of species in the local landscape.

Finally, although the biological community is the obvious focal point for botanists to assess, the abiotic core of these communities should also be considered. Because landscape anomalies are defined geologically through their bedrock, hydrology, or topography, protection of their biotic communities needs to incorporate consideration of the structure and process critical to habitat maintenance. This may be particularly important if the supporting system is not directly *sub situ*, a situation common in complex hydrologic regimes that maintain habitat anomalies like vernal pools, playas, or pond margins.

Research Potential of Landscape Anomalies

As discrete landscape units, regional anomalies like chalk barrens and canyons provide opportunities for comparative, temporal, and autecological studies of their signature organisms. Because these floras (or more broadly, the total resident biotas) are typically small, they can be surveyed completely or almost completely on a yearly basis, providing the breadth of biodiversity information that is rarely available for large-scale landscape units. Complete floras can be useful for comparative studies across a geographic transect or for monitoring change through time. They also facilitate comparisons of species richness and analysis of the ecological or human factors that promote or diminish richness.

The value of continuing studies of ecosystems and ecosystem change has been recognized by the National Science Foundation with its Long-Term Ecological Reserves (LTER) network located in major terrestrial biomes. Long-term studies of small ecological units will also be critical for understanding local and regional changes, especially at the population level. As corridors or islands in increasingly fragmented regional terrain, landscape anomalies provide venues for this scale of monitoring, and their rich biotas suggest multiple research topics relevant for conservation biology. Multiyear analyses of population size, dormancy, pollination systems, herbivory, seed set, granivory, and other biological processes are critical for understanding rare plant biology (Schemske et al. 1994, Pavlik 1997). In the Southwest, where erratic weather cycles have brought both moisture excess and severe drought in recent years, it will be especially important to monitor dormancy and reproductive responses in sensitive species, especially in ecologically constrained populations.

Our continuing studies on the chalk barrens and the riparian canyons have provided a number of ecological insights about communities and species in these landscape anomalies. We have found, for example, that inter-annual drought and moisture regimes profoundly influence the appearance and reproductive output of certain rare plant species on the chalk barrens and thus can skew assessments of apparent population health in surveys conducted on a single-year basis. Chalk barrens species are not pollinator limited, nor do they require pristine conditions to thrive (Kelso et al. 1995a, 1995b, 1996, Heckmann 1997). We have

found that moderate disturbance may enhance the abundance of certain endemic species on the barrens, a result that enabled us to make management recommendations to accommodate current grazing, recreation, and military use practices for sites under state and federal ownership. Despite their small size and island nature, chalk barren communities appear to be composed of species that are well adapted to climatic vicissitudes by having opportunistic reproductive systems that tolerate or perhaps require some degree of disturbance, and that appear to function well with relative isolation and fragmentation. In these respects, they may be typical of anomaly communities that have evolved as constrained systems, and thus perhaps instructive for us to understand what life history attributes are adaptive for success under conditions of isolation, small size, and disturbance.

Practical Considerations

The financial and political costs of both ecosystem and species level conservation can be enormous, particularly if large tracts of land must be purchased at development-inflated prices, or if economic activities need to be curtailed to protect critical habitat of focal or keystone species. In contrast, landscape anomalies may be small enough that outright purchase by communities or conservation trusts may be feasible, or they may be taken out of high-impact use without major economic consequences. A third avenue of conservation may be the most viable of all: using private landowners and conservation easements to protect small habitats with biological interest.

Conservation easements held by local land trusts are a rapidly growing phenomenon in the United States. Private landowners seeking preservation of family land coupled with tax relief are providing increasingly substantial protection for open space and native habitat across the country, particularly in Colorado where development is explosively changing the landscape. Preserving land through easements that restrict development while maintaining private ownership is an attractive option for landowners because easements can reduce taxes substantially; easements are also an attractive option for nonprofit conservation organizations because they can maintain open space and habitat at a low cost. Well-funded land trusts may actively seek land parcels on which to purchase development rights. Attributes of landscape anomalies such as high biological values encompassing overall diversity, presence of rare species, or intact habitats can be useful criteria for identi-

fying conservation targets.

Unlike large ecosystems that may loom as too distant and complex for personal connection or a sense of stewardship responsibilities, landscape anomalies may be a perfect size for communities and private landowners to recognize and appreciate, or to identify as a special feature of their personal sense of place. In working with private landowners of riparian canyons, we found a biological interest and sense of connection to them, as well as appreciation for what we could tell them about the unusual biota found there. Such sensitivity to land attributes and appreciation for landscape features enhances the likelihood of responsible private stewardship; this can be extremely effective in land conservation without the costs inherent in public ownership of land. Rare plants need not necessarily be seen by landowners as a threat to their autonomy; if viewed as an asset, an archive of biological history, or a statement of land quality, unusual species can encourage landowners to be valuable allies in protection, monitoring, and providing access for ongoing scientific studies.

Although small landscape parcels may be problematic with respect to maintaining the long-term population viability of some species (e.g., Franklin 1980, Barrett and Kohn 1991, Primack 1998), small size also confers some positive attributes for conservation, such as the feasibility of relatively complete biodiversity surveys and the ease of monitoring change, as noted earlier, as well as the relative ease of controlling the incursion of undesirable species. Both the canyon habitats and the chalk barrens we surveyed contained a remarkably low component of nonnative plants, even in sites that had considerable human use. A similar situation has been found on other barrens in the eastern United States (Braunschweig et al. 1999), and may reflect a general tendency for ecologically or edaphically extreme sites to be at least somewhat protected against noxious weed invasions. Sites with a predominantly or exclusively native biota are highly desirable conservation targets, and a small size makes control or eradication of noxious weeds a much more manageable task than it is in large-scale conservation units.

Summary and Conclusions

Landscape anomalies are valuable targets for conservation efforts for a number of reasons. They typically contain a rich and regionally unusual biota that enhances local biodiversity with endem-

ic, rare, or disjunct species. Their small size offers the opportunity for relatively complete biodiversity assessments and for geographic or temporal comparisons. Their phylogeographic profile is often very different than the regional one, especially if they provide microclimatic conditions that allow relictual species to persist. In that context, landscape anomalies can act as biological archives. As islands or corridors with a constrained biota of small populations, landscape anomalies offer multiple research opportunities for monitoring population and species responses to climatic patterns, and autecological studies of rare species. If isolation has been in effect for a long time, these biotas can demonstrate life history strategies or adaptations that enable populations to successfully persist under conditions of ecological constraint, perhaps of increasing interest for our understanding or management of other fragmented communities.

In addition to being biologically valuable targets, landscape anomalies are also practical targets for conservation by local communities or private landowners. Small size makes them affordable for outright purchase or appropriate to include under the umbrella of conservation easements on larger pieces of land. Although many negative aspects of rapid growth affect communities like those of the Pikes Peak region, one positive result of growth may be heightened awareness of the need for open space conservation and increased resources to do so. As sensitivity to land issues rises, funding opportunities for land preservation may concomitantly rise as well through venues such as local sales taxes or state lottery funds. Communities may begin actively searching for locally significant conservation targets. In this context, landscape anomalies, with their concrete, often charismatic and biologically distinctive profiles, may provide significant reference points for connection to the local landscape.

Perhaps the most important message left for us in our contemporary landscape quilt of communities and ecosystems is the remaining importance of small places. Our small dune, wetland, canyon, and crevice niches contain some of our richest habitats with diverse biological stories. If, in the face of perhaps unstoppable change, we intend to keep our biological archives, then even small landscape patches may be important. Although large reserves play an undeniably valuable role in the preservation of ecosystems and wide-ranging species, smaller reserves forming an archipelago of mesas, sand dunes, canyons, or playa

basins may also provide critical leverage and space for species, if only as a temporary resting point in time or place. Conservation is composed of theory, knowledge and appreciation, effort, and expense. Success lies as much, or more, in the hands of the average citizen as in those of the politicians or biologists. Landscape anomalies offer rich opportunities as conservation targets that are locally or personally meaningful for communities and landowners and often biologically significant in a regional context.

Acknowledgments

Funds for the studies described here were provided by the Colorado Natural Areas Program and the Howard Hughes Medical Institute Undergraduate Research Program. We would also like to thank the personnel at the Natural Areas Program, the Heritage Program, Colorado State Parks, Fort Carson, and Pinyon Canyon Maneuver Site for their assistance in various aspects of these studies. Additional assistance was provided by the City of Colorado Springs, the Palmer Foundation, the Douglas County Land Conservancy, and many private landowners in El Paso, Douglas, Pueblo, Teller, and Fremont Counties, Colorado. Special thanks to Janet Coles and Kathy Carsey of the Colorado Natural Areas Program for their comments on a draft of this manuscript, and to Caron Rifici of the Division of Environmental Compliance for information about the Fort Carson flora.

Literature Cited

- American Geological Institute. 1976. Dictionary of geological terms. Anchor Press, Garden City, New York.
- Barrett, S. C. H., and J. R. Kohn. 1991. Genetic and evolutionary consequences of small population size in plants: Implications for conservation. In D. A. Falk and K. E. Holsinger, eds. *Genetics and conservation of rare plants*, pp. 3–30. Oxford University Press, New York.
- Braunschweig, S. H., E. T. Nilsen, and T. T. Wiebolt. 1999. The mid-Appalachian shale barrens. In R. C. Anderson, J. S. Fralish, and J. M. Baskin, eds. *Savannahs, barrens, and rock outcrop communities of North America*, pp. 83–98. Cambridge University Press, New York.
- Clark, D. A. 1996. A floristic survey of the Mesa de Maya region, Las Animas County, Colorado. *Natural History Inventory of Colorado* 17. University of Colorado Museum, Boulder.
- Colorado Natural Heritage Program. 1999. *Conservation status handbook* 3(2). Colorado Natural Heritage Program, Colorado State University, Fort Collins.
- Dick-Peddie, W. A. 1993. *New Mexico vegetation: Past, present, and future*. University of New Mexico Press, Albuquerque.
- Franklin, I. R. 1980. Evolutionary change in small populations. In M. E. Soulé and B. A. Wilcox, eds. *Conservation biology: An evolutionary-ecological perspective*, pp. 135–149. Sinauer, Sunderland, Mass.

- Hall, C. 2000. Botany of the riparian foothills canyons, El Paso County, Colorado. Senior thesis, Department of Biology, Colorado College.
- Heckmann, K. 1997. The ecology and distribution of *Oxybaphus rotundifolius*. Senior thesis, Department of Biology, Colorado College.
- Hogan, T. 1993. A floristic survey of the Boulder Mountain Park, Boulder, Colorado. Natural History Inventory of Colorado 13. University of Colorado Museum, Boulder.
- Kaul, R. B., G. E. Kantak, and S. P. Churchill. 1988. The Niobrara River valley, a postglacial migration corridor and refugium of forest plants and animals in the grasslands of central North America. *Botanical Review* 54:44–81.
- Kelso, S., G. W. Maentz, and C. Hall. 1999. A comparative study of the shale barrens on the Niobrara Formation in southeastern Colorado. A report to the Colorado Natural Areas Program, Denver.
- Kelso, S., N. Bower, D. Greve, P. Beardsley, and G. Maentz. 1997. Use of the ICP-OES and sequential soil extractions for assessment of edaphic endemism in plants. Society for Conservation Biology, Victoria, B.C. (abstract)
- Kelso, S., K. Heckmann, J. Lawton, and G. Maentz. 1996. Botanical notes from the Arkansas Valley II: The ecology of *Oxybaphus rotundifolius*. *Aquilegia* 20(1).
- Kelso, S., K. Heckmann, J. Lawton, and G. Maentz. 1995a. Endemic calciphiles of the Middle Arkansas Valley, Colorado. In J. Maschinski, H. D. Hammond, and L. Holter, eds. *Proceedings of the 2nd Southwestern Rare Plant Conference*, Flagstaff, Arizona, pp. 270–280. USDA Forest Service General Technical Report RM-GTR-283.
- Kelso, S., K. Heckmann, J. Lawton, and G. Maentz. 1995b. The ecology and distribution of *Oxybaphus rotundifolius* and *Penstemon versicolor*: Geobotany and endemism in the Arkansas Valley, Colorado. Report to the Colorado Natural Areas Program, Denver.
- Lambeck, R. 1997. Focal species: A multi-species umbrella for nature conservation. *Conservation Biology* 11:849–856.
- Nature Conservancy, 2000. *Designing a geography of hope: A practitioner's handbook to ecoregional conservation planning*. Vol. 1.
- Pavlik, B. 1997. Perspectives, tools, and institutions for conserving rare plants. *Southwestern Naturalist* 42:375–383.
- Primack, R. B. 1998. *Essentials of conservation biology*. Sinauer Associates, Boston.
- Schemske, D. W., B. C. Husband, M. H. Ruckelshaus, C. Goodwillie, I. M. Parker, and J. G. Bishop. 1994. Evaluating approaches to the conservation of rare and endangered plants. *Ecology* 75:584–606.
- Scott, G. R. 1969. Geology of the Northwest and Northeast Pueblo quadrangles, Colorado. U.S. Geological Survey Bulletin 1262.
- Scott, G. R., and W. A. Cobban. 1964. Stratigraphy of the Niobrara Formation at Pueblo, Colorado. U.S. Geological Survey Prof. Paper 454-L.
- Soulé, M., and K. A. Kohm, eds. 1989. *Research priorities for conservation biology*. Island Press, Washington, D.C.
- Thompson, R., S. C. Whitlock, P. J. Bartlein, S. P. Harrison, and W. G. Spaulding. 1993. Climatic changes in the western United States since 18,000 BP. In H. E. Wright, J. E. Kutzbach, T. Webb III, W. F. Ruddiman, F. A. Street-Perrott, and P. J. Bartlein, eds. *Global climates*, pp. 468–513. University of Minnesota Press, Minneapolis.
- Vierling, L. A. 1998. Palynological evidence for late and postglacial environmental change in central Colorado. *Quaternary Research* 49:222–232.
- Weber, W. A. 1965. Plant geography in the southern Rocky Mountains. In H. G. Wright and D. G. Frey, eds. *The Quaternary of the United States*, pp. 453–468. Princeton University Press, Princeton, New Jersey.