INTEGRATING RESEARCH INTO BIOLOGICAL AND CULTURAL RESOURCES MANAGEMENT ON THE COLORADO PLATEAU—A SYNTHESIS

Charles van Riper III

In his book review of the Sixth Colorado Plateau Biennial Conference Proceedings: "The Colorado Plateau: Cultural, Biological and Physical Research," Fleming (2006) closes with the following statement: "A synthesis chapter by the editors on the issue of human impacts would have been a welcome addition to this potentially useful book." The following synthesis chapter provides that addition to this book, summarizing and integrating material from all previous chapters and also utilizing information from previous books published in the Colorado Plateau series. In addition to providing a synthesis, another goal of this chapter is to demonstrate how aspects of research have been used to enhance biological and cultural resource management.

This book is the eighth (and the third volume published by the University of Arizona Press) in a series of compilations that focus on the Colorado Plateau. These books highlight the integration of research into resource management efforts, as related to cultural, natural, and physical resources within the biogeographic province. The mix of chapters addresses management issues from many diverse resources and from disparate regions of the Colorado Plateau, specifically focusing on aspects of vegetation and wildlife research, combined with a series of chapters explaining integrative and collaborative tools that can be used to better manage natural and cultural resources on smaller and larger scales.

The 20 previous chapters in this book were selected from scientific presentations at the Eighth Biennial Conference of Research on the Colorado Plateau. The conference was held 7–10 November 2005 in Flagstaff, Arizona, hosted by the U.S. Geological Survey Southwest Biological Science Center's Colorado Plateau Research Station and the Center for Sustainable Environments at Northern Arizona University. The meeting theme revolved around research, inventory, and monitoring of lands over the Colorado Plateau, with a focus on the integration of research into resources management actions. Material presented in this book represents original research that has not been previously published, and every chapter contains a section on how that research can be best implemented by managers. Each paper selected for publication has been anonymously peer reviewed by at least two scientists from that specific research discipline. These contributed scientific studies each constitute a separate chapter, with the material subdivided into sections: Collaborating to Achieve Conservation, Assessing Large-scale Land-use Issues, Addressing Wildlife Issues, Addressing Vegetation Issues, Gaining Insights from the Past, and Synthesis.

The scientific works published in this Biennial Conference Series contribute significantly to presenting peer-reviewed results of collaborative efforts among scientists and land managers. The U.S. Geological Survey Southwest Biological Science Center's staff, university, and other partner agency scientists have worked closely with Colorado Plateau land managers from a variety of state and federal agencies, as well as from the private sector to achieve remarkable management results. Many of the protocols and techniques presently being utilized in land management units over the Colorado Plateau are a result of previous collaborative works published in this series of books. It has been clearly demonstrated that, because of similarities across the Colorado Plateau, techniques that work in one management unit can be applicable to many other areas. This is due primarily to the similarity of habitat and climatological conditions over the Colorado Plateau.

COLLABORATING TO ACHIEVE CONSERVATION

Collaboration is a critical component of almost every successful large-scale conservation effort. The opening chapter by Tilt et al. highlights the importance of collaborative efforts, a theme that is carried throughout this section of the book. The authors structure this opening chapter under the 11 lessons that they feel are critical for successful collaboration to occur: (1) Understand what collaboration is and is not, (2) Recognize challenge and time involved, (3) Exhaust traditional approaches (ripeness), (4) Build a common vision (passion for place, a community of purpose), (5) Create an open, inclusive, and transparent process, (6) Ensure stakeholders are representative of the community, (7) Provide facilitation and process, (8) Develop a common factual base, (9) Secure operational funding, (10) Achieve and communicate results, and (11) Meet or exceed applicable laws and be accountable. They illustrate aspects of successful partnerships with a series of stories from throughout the western United States, focusing on the successes of community-based collaboratives (CBCs). The one CBC that they feel has created a benchmark, and is the present standard for the Colorado Plateau, is the Diablo Trust. A background on this collaborative can be found in previous chapters of the Colorado Plateau book series (e.g., Sisk et al. 1999; Loeser et al. 2001). Initially founded in 1993 by two ranches, the Bar-T-Bar and Flying M, the Diablo Trust CBC was created to link private and public values under one holistic goal: "to create sustainable rangeland management that maintains the tradition of working ranches and provides for economic viability while managing for ecosystem health." The focus area of this CBC is east of Flagstaff, Arizona, encompassing checker-boarded private and state lands, augmented with U.S. Forest Service summer grazing allotments. Collaborators of the Diablo Trust now include local ranchers, state and federal agencies, scientists, environmentalists, and other interested stakeholders.

Working with researchers at Northern Arizona University and Prescott College, and with the many products that have been produced in this biennial conference series (van Riper 1995: van Riper and Deshler 1997; van Riper and Stuart 1999; van Riper et al. 2001; van Riper and Cole 2004; van Riper and Mattson 2005), the Diablo Trust is one of the premier examples of a CBC that incorporates research and monitoring into rangeland conservation. One aspect that has led to the success of the Diablo Trust is the recognition that good land stewardship incorporates the integration of research into monitoring projects. Working with scientists in a collaborative environment has helped the Diablo Trust develop appropriate research questions that are relevant to the ranchers, while addressing perceived conflicts among stakeholders and the outside public (Sisk et al. 1999). In addition, integrated collaborative research and sound monitoring protocols can generate clear measures of effectiveness and progress from which to evaluate the success of any collaboration (Muñoz-Erickson and Aguilar-Gonzalez 2003).

As Tilt et al. clearly point out, the Diablo Trust CBC has yielded several benefits to scientists. This collaboration provides scientists with a landscape of resources at multiple scales that allow their studies to go from small plots to whole landscapes. In addition, the ability to collaborate with the people who manage the land results in more meaningful, insightful, and useful science (Sisk and Palumbo 2005). It must be recognized by scientists that, in order to continue this fruitful relationship among stakeholders, they must be willing to invest significant time into the collaborative process and anticipate a multi-decadal relationship. On the other hand, stakeholders and land owners must share a goal of sustaining research and monitoring over long time periods in order to generate information that is relevant to an ecological system that is often typified by slow responses interrupted by periodic bouts of dramatic change.

Although collaborations have their challenges and critics, Tilt et al. present outcomes and experiences of numerous CBC efforts, reaffirming that a collaborative process can be successful in developing long-term solutions for natural resource issues. Drawing from the experiences of these collaborations, the authors highlight several criteria that have contributed to the CBC success. First, all collaborative processes face issues where the problem and its solution are poorly understood, where there are few scientific data and little understanding of what that information means, and where personnel and financial resources are few or nonexistent. Next, they point out that conflicting values confuse the process and innovation is often viewed as risky and expensive. Not only must collaborations bring together a diverse and representative group of stakeholders, but they must also recognize the amount of time, effort, and funding that is necessary for creating and sustaining a successful collaborative process. Finally, the authors point out the importance of gaining the trust of the stakeholders and outside interest groups, which is accomplished by maintaining an open and transparent process that incorporates research and monitoring protocols that will properly evaluate the CBC goals. It is evident from the findings presented in this chapter that the spectacular natural resources of the Colorado Plateau will continue to serve as a focal draw for new CBCs being formed in the region, thus ultimately influencing all facets of collaborative efforts from which management policies will be developed.

The collaborative theme in this first portion of the book is continued in Chapter 2, where Turner et al. present the results of an effort between researchers and resource managers at Mesa Verde National Park. This collaborative modeling approach, called FRAME, details impacts of forest restoration policy at the park. The overall strategy of the FRAME Project was to combine the principles of collaboration with the adaptive capabilities of the U.S. Geological Survey modular modeling system (MMS), in order to develop a transportable, collaborative modeling approach to adaptive, multi-objective natural resource management. The group first collaboratively identified key system components, critical pathways, and associated conceptual models of pinyon-juniper ecosystem dynamics. They found that the recent invasion and rapid spread of cheatgrass in the park had the potential to significantly alter the fire regime by increasing fire frequency and impacting long-term vegetation successional patterns. This concern led the authors to focus on cheatgrass for their first modeling simulations. They modified the SIMPPLLE landscape model to capture key ecosystem components and dynamics of the conceptual models, which were then further refined through an iterative process in which project scientific experts helped define probabilities.

Model results presented by Turner et al. indicated the potential for frequent reburning in the park, at intervals as short as a few years. These simulations suggested a fire rotation of approximately 45 years for the park as a whole, a dramatic change from the historic fire rotation that has previously been measured in centuries. The authors argue that such a disturbance regime would be far outside the historical range of variability for the ecosystem, and would likely lead to a substantial reduction and even local extirpation of many native plant species. They also showed that the projected changes in Mesa Verde's fire regime would bring an increased risk of significant debris-flow events, with the potential for substantial damage to water and cultural resources. The FRAME case study at Mesa Verde National Park provided an ideal opportunity to implement and refine the principles and components of a collaborative modeling approach. By coupling the principles of collaboration with integrated modeling approaches, the authors developed a collaborative modeling framework to facilitate adaptive, multi-objective resource management that would be applicable across a wide range of ecosystems.

We now see, across the Colorado Plateau, trends in public and private lands management toward integrated science approaches, with co-management of public lands, adaptive management in the face of uncertainty, and public engagement in land-use decision making, developed primarily in response to a greater appreciation of the inherent complexity and uncertainty in natural systems. We are also seeing an increased public scrutiny of decisions on public lands. The authors have developed their FRAME collaborative modeling approach to address the challenges faced by natural resource managers, and to provide those managers with mechanisms to effectively link integrated science to natural resource management needs. The FRAME approach can also readily be adapted to engage the public in participatory natural resource management efforts, and the authors demonstrate that this collaborative process could easily be applied to most management units over the entire Colorado Plateau.

ADDRESSING LARGE-SCALE LAND-USE ISSUES

At this point, the book departs from the arena of citizen-based collaboratives and moves into large-scale land management issues. The next three chapters focus on aspects of the GAP program, a computer-based Geographic Information System (GIS) tool initially developed by J. Michael Scott (Scott et al. 1993), a U.S. Geological Survey scientist at the University of Idaho. A number of research studies utilizing GAP have been published in chapters of previous books within the Colorado Plateau series (see especially the volumes of van Riper et al. 2001; van Riper and Cole 2004; van Riper and Mattson 2005). The GAP program provides information on ecosystem representation by creating digital maps of conservation networks, providing an account of the representation of elements of biodiversity within a region (Crist and Scott 1999). Gap analysis uses the distribution of vegetation types and vertebrate species as indicators of biodiversity. Digital map overlays in GIS are used to identify individual species, species-rich areas, and vegetation types that are absent or underrepresented in existing management areas (Scott et al. 1993). These products are used to develop conservation strategies and to predict contributions of new management areas for biodiversity maintenance at landscape scales (Scott et al. 1991).

In Chapter 3, Ernst and Prior-McGee argue that the conservation of biological diversity is important for the maintenance of naturally functioning ecosystems, and to ensure preservation of species and communities as well as functional diversity of plant and animal populations. The Colorado Plateau, which is perhaps one of the most diverse ecoregions in North America, is characterized by unique geology and landform features that create an environment that results in high endemism. Ernst and Prior-McGee demonstrate that the vulnerability and conservation of these unique Colorado Plateau resources can be adequately evaluated using the Southwest Regional Gap Analysis Project (SWReGAP) stewardship data set, and that the information provided can effectively assess general patterns of biodiversity protection within this ecoregion. They point out that this evaluation is important because federal agencies and tribal land stewards manage the majority (more than 75%) of the Colorado Plateau (the Bureau of Land Management manages 31% of the ecoregion, the National Park Service 7%, and the Forest Service 4% of the ecoregion), and maintenance of biodiversity with federal land management is easier to accomplish when compared to working with a mosaic of land-ownership patterns.

In examining degrees of protection, Ernst and Prior-McGee identified land management categorization schemes relative to the purported degree of management for biodiversity maintenance for each managed area. They listed four biodiversity management status categories as defined by Scott et al. (1993), Edwards et al. (1994), and Crist et al. (2000):

Status 1: An area having permanent protection from conversion of natural land cover and mandated management plan in operation to maintain a natural state within which disturbance events (of natural type, frequency, intensity, and legacy) are allowed to proceed without interference or are mimicked through management.

Status 2: An area having permanent protection from conversion of natural land cover and a mandated management plan in operation to maintain a primarily natural state, but which may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.

Status 3: An area having permanent protection from conversion of natural land cover for the majority of the area, but subject to extractive uses of either a broad, low-intensity type (e.g. logging) or localized type (e.g. mining). It also confers protection to federally listed endangered and threatened species throughout the area.

Status 4: There are no known public or private institutional mandates or legally recognized easements or deed restrictions held by the managing entity to prevent conversion of natural habitat types to anthropogenic habitat types. The area generally allows conversion to unnatural land cover throughout.

The authors found that approximately 5 percent of the Colorado Plateau ecoregion has permanent protection (GAP Status 1) from conversion of natural land cover to anthropogenic land cover types. The National Park Service manages 90 percent of the Status 1 lands, with the largest parcels including Grand Canyon, Canyonlands, Zion, and Arches National Parks. The BLM manages 7 percent of the Status 1 lands, with most occurring as small and isolated parcels in the form of administratively designated Areas of Critical Environmental Concern and Outstanding Natural Areas. The U.S. Forest Service manages 3 percent of the Status 1 lands, the largest being the Kanab Creek Wilderness, and The Nature Conservancy manages 1 percent. On the Colorado Plateau, the state of Arizona manages 63 percent of the Status 1 lands and Utah manages 33 percent.

Status 2 lands constitute 12 percent of the Colorado Plateau with 85 percent of those lands managed by the BLM. About 60 percent of the Colorado Plateau is managed as Status 3 lands (primarily multiple-use lands), with 57 percent being tribal lands and 33 percent BLM. Additionally, 23 percent of the Colorado Plateau is managed as Status 4 lands, which are primarily privately owned lands (62%) with no known mandates that limit natural land cover conversion to anthropogenic land uses. The information provided by this chapter will be effective in identifying land areas that are presently being managed for biodiversity and their levels of protection over the Colorado Plateau. By helping managers identify locations of conservation lands, and the stewards of those lands, the GAP program allows the managers to better place their parcels into a regional perspective. When the land stewardship data are combined with information on vegetation and species richness, land stewards can then evaluate how well their areas are contributing to protecting biodiversity over the Colorado Plateau.

The interface between conservation and aspects of resource management, utilizing the GAP program, is further developed in Chapter 4 by Langs et al. These authors build upon the framework of the previous chapter, providing the reader with the first mapping of natural land cover across the Colorado Plateau using ecological systems. They conducted a gap analysis for the Colorado Plateau ecoregion through a geospatial union of key environmental and management data layers using ESRI ArcGIS Desktop 9 software and Spatial Analyst extension. Their input data consisted of three spatial databases developed by SWReGAP: land cover, land stewardship, and biodiversity management status categories. The stated goal of this chapter was to provide land managers and policy makers with information needed to make better-informed decisions when identifying priority areas for conservation.

Langs et al. documented 77 different land cover types that occur within the Colorado Plateau ecoregion, 62 of which they determined to be ecological systems. Only 7 of the 62 ecological systems had more than 5 percent of their mapped distribution within the Colorado Plateau ecoregion, which when combined represent approximately 75 percent of the total area. They also found that 48 of the ecological systems had 1 percent or less distribution within this ecoregion and 40 of these have 5 percent or less of their regional distribution on the Colorado Plateau. These ecological systems have either naturally restricted ranges, or although common, are considered peripheral to the Colorado Plateau.

The seven most abundant ecological systems on the Colorado Plateau were the Colorado Plateau Pinyon-Juniper Woodland (23% of the ecoregion), Inter-Mountain Basins Semi-Desert Shrub-Steppe (11%), Colorado Plateau Mixed Bedrock Canyon & Tableland (11%), Inter-Mountain Basins Semi-Desert Grassland (8%), Inter-Mountain Basins Mixed Salt Desert Scrub (7%), Colorado Plateau Blackbrush–Mormon tea Shrubland (7%), and Inter-Mountain Basins Big Sagebrush Shrubland (6%). There were five ecological systems they considered "nearly endemic" to the Colorado Plateau: Southern Colorado Plateau Sand Shrubland (99.7% of its mapped distribution falls the ecoregion), Colorado Plateau Blackbrush-Mormon-tea Shrubland (99.6%), Colorado Plateau Mixed Bedrock Canyon and Tableland (86%), Inter-Mountain Basins Mat Saltbush Shrubland (82%), and Inter-Mountain Basins Shale Badland (82%).

The use of conservation thresholds allowed Langs et al. to identify ecological systems with low representation in Status 1 and 2 lands (explained by Ernst and Prior-McGee in the previous chapter). Langs et al. also identified six ecological systems with minimal protection within the ecoregion. On the other hand, they point out that there are many ecological systems within the Colorado Plateau that are either barren, sparsely vegetated, or have open-canopied scrubby vegetation (West and Young 2000). These systems occur on soils that are easily erodible such as sand sheets, dunes, and shale badlands. Wind and water degradation of the soil leads to degradation of the vegetation supported in these substrates. The presence of cryptogamic crusts plays an important role for many of these systems by facilitating the infiltration of water, increasing fertility, and reducing erosion of the soil (Belnap et al. 2001). The authors also point out that drought and increasing temperatures pose a near-future threat to the ecological systems of the Colorado Plateau.

In carrying through the earlier CBC theme of this book, Langs et al. point out that conservation at ecoregional (larger) scales requires the involvement of multiple partners and cooperative management among diverse land stewards. Partnerships with federal land management agencies, tribal entities, private land owners, academic institutions, and non-government organizations all play a vital role for ensuring successful, long-term conservation on the Colorado Plateau (Tuhy et al. 2002). One collaboration highlighted by the authors as an example of a CBC partnership that includes the Colorado Plateau is the Utah Partners for Conservation & Development. This CBC is composed of state, federal, and natural resource agencies, universities, county and local governments, private land owners, conservation organizations, and other vested stakeholders, who are working cooperatively to manage and restore rangelands in Utah (Utah Division of Wildlife Resources 2005). By having CBC groups utilizing regional GAP data, and by analyzing land-cover over the entire Colorado Plateau, land managers can strike a balance between biodiversity management with anthropogenic impacts, including development potential.

The next chapter serves as a summary of the large-scale land management section, as well as a transition into the Biological portion of this book. Boykin et al. incorporate protocols from the GAP program to create GIS models that map the distributions of wildlife over the Colorado Plateau. The authors use seven foundation GIS layers, ranging from dominant overstory vegetation through slope and aspect, to tree density and basal area to develop their models. From a survey of 40 academic institutions, they also provide a list of sensitive species that is incorporated into their model as a separate data layer. They then developed habitat models from literature reviews for each species using specific associations of available GIS environmental variables. Specific variables that they used included land cover, elevation, slope, aspect, distance to hydrological features, landform (after Manis et al. 2001), soils, and mountains. Models were constrained to the known range of the species using state, regional, and national references. Range data were converted to sub-basin watershed units (8-digit hydrologic units) using the National Hydrography Dataset (Boykin et al. 2006; see http://nhd.usgs.gov/).

Throughout Chapter 5 Boykin et al. point out that GAP analysis for vertebrate species is a process of intersecting habitat models with a data set of land stewardship that identifies levels of long-term conservation management. They provide spatial habitat models for 817 vertebrate species for the region comprising Arizona, New Mexico, Colorado, Utah, and Nevada, finding that total species richness was highest in areas of the Colorado and San Juan River drainages. They also demonstrate that patterns of richness vary among different vertebrate groups and subgroups, for example between the herpetofauna, bats, and large mammals. The information in this chapter was collected from the entire biogeographic province of the Colorado Plateau, from along the Mogollon Rim in the south to the White Mountains in eastern Arizona, up to the Green River in northern Utah, and west to the Mojave Desert, so land managers over the entire biogeographic region will find this information useful.

The authors then provide an in-depth example of how their habitat model might be used, taking 19 amphibians with predicted habitat on the Colorado Plateau (51% of all amphibians modeled in the region), 341 birds (78%), 143 mammals (67%), and 78 reptiles (60%). They provide full results for the vertebrate models, including references, habitat data, modeling process, and textual and spatial models. The authors also calculated total species richness from the SWRe GAP data for the Colorado Plateau, and found an average of 354–390 animal species per drainage sub-basin. Species richness was higher in the eastern portion of the Colorado Plateau, with animals associated with the San Juan Mountains and the San Juan River, and on the western side of the plateau along the Colorado and Virgin Rivers. Compared to the entire SWReGAP region, Boykin et al. found that species richness on the Colorado Plateau was intermediate, with higher richness than more northern areas but lower richness than southern Arizona, much of New Mexico, and the Colorado Rocky Mountain Front Range. The information contained in Chapter 5 provides baseline information for conservation of animals over the entire Colorado Plateau, particularly when combined with other current inventory efforts. This chapter provides another useful tool for managers to better assess large-scale land-use issues over the Colorado Plateau, and this sound scientific tool can be used to enhance our understanding of vertebrate distributions on the plateau, and within the context of those species' habitats throughout southwestern North America.

ADDRESSING WILDLIFE ISSUES

This section of the book brings a focus to wildlife issues, and to addressing management concerns within this group of organisms over the Colorado Plateau. Chapter 6 serves as an introduction to wildlife issues, providing a historical account of the pronghorn antelope in Arizona, with a focus on Anderson Mesa. No area in Arizona is more frequently associated with pronghorn than the Anderson Mesa Game Management Unit. More than 25 percent of all of the pronghorn in the "Millennium" edition of the Arizona Wildlife Trophy Book came from this unit or from areas restocked with animals from Anderson Mesa (Lewis 2000). Three of the top five pronghorn trophies in the Boone and Crockett Club's North American Record Book are from Coconino County, where Anderson Mesa is located (Byers and Bettas 1999). Anderson Mesa was the site of Arizona's first legal pronghorn hunt and has been a focal point for pronghorn studies since the early 1930s. Pronghorn studies on Anderson Mesa have ranged from developing survey and capture methodologies (Wilkins and Welles 1944; Edwards 1947; Wallmo 1951), to determining seasonal food habits (Gay 1984), to evaluating reproductive performance (Erling 1956a, 1956b) to evaluating the effects of coyote control and other factors on fawn recruitment (Arrington 1947; Arrington and Edwards 1951; Neff and Woolsey 1980; Neff et al. 1985).

Brown provides a detailed history of the increases and declines in pronghorn recruitment rates and of the population sizes on Anderson Mesa. He documents that in the 1970s, declining pronghorn numbers resulted in an intensive study to determine if aerial gunning of coyotes could improve pronghorn numbers on Anderson Mesa. Although aerial gunning was expensive and politically unpopular, Brown concluded that these studies indicated pronghorn fawn recruitment could be improved by applying such control practices, as did Neff and Woolsey (1980) and Neff et al. (1985). When pronghorn recruitment and population numbers again declined in the 1990s, however, coyote reduction efforts were no longer deemed an effective solution, and since that time pronghorn recruitment on Anderson Mesa has been below herd maintenance levels (Yoakum 2003). Since the early 1900s pronghorn populations on Anderson Mesa have declined several times and then rebounded, demonstrating that the species is highly adaptable. But whether pronghorn on Anderson Mesa can again attain their former numbers is problematic, and Brown argues that these animals are now subsisting on a declining forage base due to excessive elk and livestock use. He concludes this chapter by saying that sportsmen, ranchers, and the general public will have to press management agencies to reduce ungulate pressures and improve forage quality if mean annual pronghorn recruitment rates are to again exceed maintenance levels.

In Chapter 7, pronghorn antelope home range and the effects of Interstate 40 and the Burlington-Northern and Santa Fe railroad is examined at Petrified Forest National Park. The impact of transportation corridors on pronghorn in northern Arizona was first identified in the Colorado Plateau book series (Ockenfels at al. 1997), and later further detailed by van Riper and Ockenfels (1998) and then Bright and van Riper (2000). Hart et al. build upon these earlier studies by establishing an experimental study that examines the potential, non-lethal effects of transportation corridors on the basic ecology of pronghorn. The authors looked specifically at the one pronghorn herd that Ockenfels at al. (1997) documented as isolated, under comparatively unique conditions where Interstate 40 and the BNSF railroad constituted near impenetrable barriers. Hart et al. designed a manipulative study where fences were modified in an attempt to see if pronghorn would expand their home range, with the hope that by removing fences the confined animals would move across the railroad tracks and mix genetically with other pronghorn in the park.

After 2 years of manipulative studies, the authors' efforts were not successful in changing the movement patterns of the targeted pronghorn herd. Even after fence modification, they found consistent pronghorn avoidance of the I-40 freeway and the railroad, diminishing the odds that exploratory behavior would result in chance crossings. The isolated pronghorn at the park appear likely to remain so for the foresee-able future given the frequency of the train traffic and its inherent disturbance, as well as the other potential physical and psycho-logical deterrents associated with the right-of-way. The authors state that it may ultimately be necessary to use over-passes or underpasses to enable pronghorn to negotiate these two transportation corridor barriers. However, they still believe that efforts to modify the right-of-way to enhance the potential for pronghorn crossings, such as those employed in this study, may have merit if the scope of the effort can be expanded both spatially and temporally. Given the high costs associated with creating structures to span or tunnel beneath the railroad, the authors recommend further investigation of the potential to enhance direct crossings of the right-of-way before more complicated and costly measures are pursued.

In Chapter 8 Wakeling and Riddering examine bighorn sheep being released in habitats based on a priority ranking system, and the possibility of differential mountain lion predation on those sheep. The authors agree that it seemed logical to assume that releases in lower-quality habitats would have lower survival and higher cause-specific mortality, but their analyses failed to support that assumption. They argue that a possible reason for the lack of a relationship to survival and the presently utilized priority ranking system is that habitat quality must fall below a critical threshold before bighorn survival is directly affected. The authors also point out that all past bighorn sheep releases have occurred primarily within the range of suitable habitats that are all above this critical threshold. Cunningham's (1989) original speculation that habitat must score higher than 50 to be suitable must be incorrect, because they found that bighorn sheep were capable of sustaining themselves in habitats that score as low as 40.

An alternate explanation that the authors explore in this chapter is that habitat quality scores that the Arizona Game and Fish Department presently use to identify bighorn sheep translocation sites are not good predictors of true bighorn habitat suitability. This latter rationale, however, seems unlikely because several studies have tested the suitability ranking method and found that these techniques are fairly reliable in selecting suitable bighorn habitats (e.g., Wakeling and Miller 1990). Most of the habitats where bighorn sheep releases have occurred scored over 40 points using the Cunningham-Brown criteria, and the highest-quality habitat in this evaluation received a score of 55. Moreover, habitats that received a numerical score in excess of 34 were not correlated with survival or mortality. Further, Wakeling and Riddering question the use of translocated animals as an effective surrogate for survival of resident bighorn sheep populations. The chapter also provides an analysis of data that examines the question "Do increases in mountain lion predation cause declines in bighorn sheep numbers?" Based on measured survival rates for translocated bighorn sheep populations, the authors point out that their analysis on survival and habitat quality did not support the hypothesis that translocations into lower-ranking habitats influenced mountain lion predation on, or survival of, bighorn sheep.

The next two chapters cover management aspects of avian resources on the Colorado Plateau. Chapter 9 by John Spence and Chapter 10 by Hurteau and her collaborators deal with birds in Grand Canyon National Park and on U.S. Forest Service lands in northern Arizona, respectively. Spence, who works as a resource manager in Glen Canyon National Recreation Area, has spent many years monitoring bird activities along the Colorado River. In Chapter 9 he analyzes 5 years of breeding bird survey data from the Colorado River between Glen Canyon Dam and upper Lake Mead. The principal emphasis of that program was to develop a baseline data set on relative abundance of riparian species, in order to develop a standardized methodology to monitor birds in riparian vegetation, and to examine aspects of statistical power in those data. Spence uses data from selected species to illustrate the relationships between relative abundance measures, abundance variability over time, and statistical power. He provides a quantitative model of avian community structure along the Colorado River in two national parks, and a power analysis related to the ability to accurately count birds, given differing avian guild assemblages and existing habitat structures associated with the Colorado River corridor.

Avian communities along the Colorado River have changed substantially since completion of Glen Canyon Dam in 1963, as predam vegetation along the river consisted of a thin riparian strip controlled primarily by spring flooding (Carothers and Brown 1991). Extensive stands of riparian habitat have become established on silt terraces where the Colorado River drains into Lake Mead. These recent habitat modifications have caused changes in the avian community (Brown et al. 1987). The monitoring program that Spence details in this chapter was established to provide data necessary to adaptively manage dam operations in order to minimize impacts to selected resources (National Resource Council 1999). He points out that various monitoring programs had been established as part of the environmental impact studies since 1982, under management of the Glen Canyon Environmental Studies Program (National Resource Council 1987, 1996), and a number of these studies have appeared as chapters in this Colorado Plateau book series (e.g., Felley and Sogge 1997). The avifauna, principally riparian breeding birds, bald eagles (*Haliaeetus leucocephalus*), and the endangered southwestern willow flycatcher (*Empidonax traillii extimus*), have been an integral part of past and ongoing monitoring studies along the river corridor (van Riper and Sogge 2004).

Spence points out that many birds are considered to be good indicators of ecosystem change because of their quick response. Such changes could be caused by climatic variation, invasion of the ecosystem by a new exotic species, recreational-based disturbances, changes in prey-base, differing management practices, or some combination of these factors. Due to the strong tendency of passerine birds to exhibit pronounced habitat selection (Hilden 1965; Cody 1985), Spence suggests that birds can be a useful group of organisms for monitoring habitat effects in a dynamic system such as the Colorado River. Two of the major forcing variables presently controlling the Colorado River riparian system are quantity and timing of dam releases, so it is likely that most breeding birds are responding to changes in vegetation rather than to fluctuating river flows. By monitoring avian populations, changes in other components of the riparian ecosystem may be detected, and management practices can be developed to address any potential problems.

The principal goal of the study that Spence details in Chapter 9 was to determine whether a long-term monitoring program with adequate statistical power could be developed to detect trends in the riparian breeding bird community along the Colorado River. Power analysis is a necessary and important tool in the establishment of any monitoring program and it is particularly critical in the case of endangered species monitoring, as the failure to detect a decline may have disastrous consequences (Taylor and Gerrodette 1993). Most natural wildlife populations vary from year to year in abundance and this variation can result from numerous complex and interacting factors. In this study, Spence found that the power to detect change in less than 10 years only existed for a few species, such as Lucy's warbler and Bewick's wren, and only for very large effect sizes. Hence, long-term commitment of substantial financial and human resources would be needed to detect statistically defensible trends in the riparian bird community along the Colorado River. Such long-term commitments of time and resources are still rare in bird monitoring programs.

Spence also points out that it is important to understand that bird abundance within the study area is affected by numerous other variables outside the Colorado River corridor. The most important among these are winter and migration habitat changes and winter habitat climate variability, both of which strongly influence bird survivorship. Glen Canyon Dam operations affect birds primarily through impacts on breeding habitat, but under normal operations these impacts are likely to be fairly minor compared with climate and habitat changes outside the Colorado River corridor. The major impacts of dam operations are the planned or unplanned floods, including those in 1983 and 1996. These floods can potentially scour out much of the riparian vegetation along the river corridor. Past flooding, particularly that in 1983, may explain many of the present differences found in the breeding bird communities between the mid-1980s and Spence's study, as the extent of riparian vegetation was much reduced after the 1983 event (Spence 2004; Holmes et al. 2005).

In summary, Spence demonstrates that in more temporally variable avian species it is often difficult to detect subtle long-term trends because of the natural variability in bird populations. His power analysis provides a measure of how well the monitoring program could detect a trend through variability in the monitoring data. In the absence of an estimate of the power of a monitoring program, resource managers and scientists cannot always know if change in a population (or species of interest) is statistically significant. Furthermore, without adequate power, managers may not be able to detect a significant change in a rare species that may be of management importance. This study used the approach of "prospective" power analysis (cf. Steidl et al. 1997), in which preliminary baseline data on population numbers and variability are gathered over a period of time and then, in turn, used to design an effective long-term monitoring program, examining factors like sample size considerations, sampling protocols, and duration of data collection. Although this model of predicted bird occurrence was developed along the Colorado River corridor, the technique would be widely applicable to other areas over the Colorado Plateau.

In the second bird chapter, Hurteau et al. document that in the past century forest management practices have significantly altered the function and structure of ecosystems in the Southwest that are dominated by ponderosa pine (*Pinus ponderosa*). There have been significant portions of earlier books in the Colorado Plateau series devoted to this subject (e.g., Garret et al. 1997; Garret and Soulen 1999; Bailey et al. 2001), all pointing out that fire suppression, grazing, and logging have resulted in a dense, closed-canopy forest with an increased susceptibility to stand-replacing wildfire. Mechanical thinning and prescribed fire, which are important tools in fuel reduction treatments, can mitigate the threat of stand-replacing wildfire, but the effects of these practices on wildlife communities are poorly understood. The authors explain that the Fire and Fire Surrogates (FFS) Program is a national study that seeks to quantify the effects of prescribed fire and mechanical thinning on numerous response variables, including wildlife. On three FFS Southwestern Plateau sites in northern Arizona, Hurteau et al. examined the short-term (3-year) avian community response to experimental thinning and prescribed fire treatments. For a suite of focal species selected from the total avian community, they evaluated changes in abundance and density resulting from different treatment types. Their results suggest that patterns in ranked avian abundance among treatments were significantly correlated, and that overall community structure was generally not affected by fuel reduction treatments, regardless of treatment type.

Among a suite of focal species, the authors found that response to specific treatment types was more variable. For example, western bluebird (*Sialia mexicana*) and dark-eyed junco (*Junco hyemalis*) densities increased in response to thinning and fire, alone and in combination. Mountain chickadee (*Poecile gambeli*) density decreased dramatically in all treatment types in the post-treatment period, while the pygmy nuthatch (*Sitta pygmaea*) exhibited a decrease in density during this same period. They also found that the yellow-rumped warbler (*Dendroica coronata*) exhibited a negative response to the thin-only treatment but a positive response to the burn-only treatment. Considering the wide spectrum of avian community attributes that the authors measured, their results provide essential baseline information for project-level planning. Moreover, their research provides evidence that perhaps the avian community may not be responding to fuel reduction treatments as previously believed. The authors' overarching conclusion was a recommendation that forest managers implement a mosaic of treatment types so as to best preserve avian habitats in ponderosa pine forests on the Colorado Plateau.

The next two chapters focus on other groups of vertebrates on the Colorado Plateau—herpetofauna and native fish. In Chapter 11 Trevor Persons and his colleagues provide a summary of the present status and historic changes of all reptiles and amphibians (herpetofauna) in national parks over the southern Colorado Plateau. This chapter provides a much-needed summary of numerous years of a biological inventory that has been undertaken at National Park Service sites. Although many national park areas on the Colorado Plateau were created primarily to protect remarkable deposits of cultural resources, the authors point out that these parks also preserve a diverse assemblage of vertebrate species. The inventory work outlined in this chapter began in 2000 when the National Park Service (NPS) initiated a nationwide program to inventory vertebrates and vascular plants within the parks. As part of this new inventory effort, 265 National Park units (e.g. parks, monuments, recreation areas, historic sites) were identified as having significant natural resources, and these were divided into 32 groups or "networks" based on geographical proximity and similar habitat types. The many NPS areas on the Colorado Plateau of Utah, northern Arizona, northwestern New Mexico, and western Colorado were divided into Northern and Southern Colorado Plateau networks. In this chapter Persons et al. summarize the results of their amphibian and reptile inventories at 19 parks within the Southern Colorado Plateau Inventory and Monitoring Network. They synthesize distribution and habitat information for all amphibian and reptile species across that network; the primary goal of their complete species inventory is to document at least 90 percent of the species present at each park. To evaluate their progress toward that goal, they provide an estimated level of inventory completeness for each park. This chapter also provides an exhaustive checklist of all possible herpetofauna found over the southern Colorado Plateau, with an estimated level of inventory completeness for each species. The authors close the chapter with a list of considerations for future inventory work.

Chapter 12 details a unique application of inventory techniques, documenting fish species assemblages along drainages that have been disturbed by fire. Jonathan Long examines the potential impact that a forest fire in KP and Grant Creeks, within the White Mountain Apache Reservation, had on native Apache trout. These streams extend into mixed conifer forests where mixed-severity wildfires such as the KP and Steeple fires are typical. The two drainages are similar in geology, topography, and vegetation, and are similar to the majority of streams planned for recovery of Apache trout. Fish extirpations have been reported from streams in drier, lower-elevation forest types where wildfires have been more severe; however, long-term fire history studies suggest that high-severity wildfires do occur in high-elevation forest types during extended dry periods.

Long, with his colleagues at the U.S. Forest Service Rocky Mountain Research Station, sampled fish populations and habitat conditions at seven 50-m long sampling sites in KP and Grant Creeks in June 2004 after the KP fire was contained. Fish populations were resampled at six of the sites one year later. They also attempted to relocate sites that had been previously sampled for fish in September of 1995 by the Arizona Game and Fish Department, as part of their General Aquatic Wildlife Surveys program. Fish populations were sampled using backpack-mounted electro-shocking gear. Each reach was blocked off with nets to prevent fish from escaping during sampling, and each was sampled three times using the depletion method. They found that trout populations persisted following the mixed-severity wildfires in KP and Grant Creeks. These findings indicate that evacuation of populations, which is now standard procedure, may not be necessary at the higher elevations when a watershed is not severely burned. While many factors can influence the likelihood of fish persistence, Long suggests that burn severity can be determined through the use of satellite imagery, and until more confirmatory studies are conducted, the satellite imagery metric may help managers to quickly evaluate whether to evacuate Apache trout populations that are threatened by wildfire.

The final chapter that addresses wildlife issues deals with managing invertebrates within caves on the Colorado Plateau. Wynne et al. point out that cave environments are among the most fragile and understudied ecosystems on earth. From what scant information they can find, only limited research seems to have been conducted on caves in Grand Canyon National Park and over the southern Colorado Plateau. The authors reviewed all available literature and park cave trip reports, representing nine studies of 15 caves at Grand Canyon National Park. Chapter 13 lists approximately 37 cave-dwelling invertebrates that are known to occur in Grand Canyon caves (3 troglobites, 6 trogloxenes, 14 troglophiles, 1 stygobite, 10 unknown cavernicoles, and 3 "special case" species). Currently, only four cave-adapted taxa are known to occur in the Grand Canyon. The authors also provide an annotated checklist of all known invertebrates from caves over the Colorado Plateau. Because this information represents data on only about 5 percent of the known caves in Grand Canyon National Park, the authors suggest that more endemic cave-adapted invertebrates are expected to be discovered in the future.

ADDRESSING VEGETATION ISSUES

Vegetation studies are introduced into this book with Chapter 14, where Thomas et al. provide an analysis of plant community composition and structure at Petrified Forest National Park (PEFO); this is the first complete survey of all vegetation types to be published for PEFO. The vegetation at PEFO is complex and varied, containing many dominant plants of low stature, with a rich mosaic of grasslands, steppe, and shrubland types that have different species dominating at different locations. In their description of PEFO vegetation associations, alliances, and park specials, the authors emphasize how the topography and soil types within the park are correlated with the vegetation distribution patterns that they documented. Other factors that influenced the expression of the park vegetation were drought and invasive plant species distributions. Precipitation in this area of the Colorado Plateau is biseasonal, with winter precipitation and a summer monsoon period. The authors found that grasses in the park responded particularly strongly to the seasonality of precipitation. Some of the PEFO grasses showed the most growth in the spring warmup (these were cool season grasses) and others showed the most growth in response to the summer monsoons (warm season grasses). Climatic events that reduce precipitation during the winter, summer, or both seasons inhibit plant growth and reproduction, and may ultimately kill plants. For example, the authors point out that the drought in the U.S. Southwest in the early 2000s greatly reduced vegetation cover at the park, as plants responded with reduced vegetative growth and dieback. Climate change, especially warmer temperatures and decreases in precipitation and/or changes in the monsoon pattern, can be expected to dramatically change the characteristics of plant distribution in the park.

Thomas et al. also provide a thorough inventory of invasive non-native plants within Headquarters Mesa, the Puerco River corridor, and portions of the southern park. The authors found more than 25 different invasive (non-native) plants, with the most prolific being Russian thistle, which occurred in more than 75 percent of the sampled area. Many of the earlier book chapters in the Colorado Plateau series (e.g., Floyd et al. 2001; Falzarano et al. 2005; Nabhan et al. 2005) have demonstrated that invasive plants are increasingly threatening ecosystems over the Colorado Plateau. The invasive plants not only interact with native plants and animals, but can also increase the frequency and magnitude of fires (Floyd-Hanna et al. 1999). In the event of a prolonged drought, invasive species can magnify the effects of reduced water on native species by sprouting earlier, thus removing soil moisture that would have been available for native plants.

Chapter 15 moves west, from the short-grass prairie at PEFO to the higher elevation ponderosa pine forests of northern Arizona. Speer and Bailey provide forest managers with information on under-story vegetation responses to tree harvesting and prescribed fire in overly dense ponderosa pine forest stands. Throughout the past century, ponderosa pine forests over the Colorado Plateau have become increasingly dense; this change was brought about by Euro-American settler land-use practices beginning in the late 1800s (Covington and Moore 1994; Covington et al. 1997; Moore et al. 1999). The current high density of ponderosa pine forests allows little sunlight for understory vegetation development (Naumburg and DeWald 1999). Continuous heavy grazing by domestic livestock and by recently expanding elk populations has further depleted the rich understory of grasses and forbs that once out-competed pine seedlings. The pre-historic understory once enabled frequent surface fires that further prohibited extensive pine regeneration (Korb and Springer 2003). In addition to supporting a natural fire regime (Laughlin et al. 2004), the earlier understory enhanced net primary productivity, nutrient cycling, and forage for wildlife communities, in addition to promoting a number of ecosystem functions such as hydrology and soil stabilization (Korb and Springer 2003). Of particular interest to the authors, in regards to harvesting, burning, and general soil disturbance, was the introduction and spread of introduced (alien) grass species (Crawford et al. 2001; Sieg et al. 2003; Korb et al. 2004). These alien species are of importance to ecosystem function and health because they alter successional pathways by out-competing native pioneer species, thereby altering the ecosystem functions normally performed by native species (Fornwalt et al. 2003). Speer and Bailey, as also documented in the chapter by Hurteau et al., conducted their research on one of 13 sites in the national Fire and Fire Surrogate (FFS) Program. Their goal was to learn more about how perennial and annual understory plants respond to increasing intensities of management (burn only, harvest only, harvest and burn), with a focus on species richness and ground cover of native and exotic vegetation in ponderosa pine forests.

Speer and Bailey examined harvesting and burning, alone and in combination, focusing on any increases or decreases in native and alien species richness and abundance. They found that as management intensities increased (burn only, harvest only, harvest and burn), understory responses increased. In areas that were treated mechanically, understory showed significant but small increases in native species ground cover (2–3%) and native richness (~5 species, a 20% increase). Tree harvesting also resulted in smaller increases in alien species richness and ground cover that were significantly greater than that of their controls. Both native and alien species richness and cover responded most strongly to the combination of harvesting and burning treatments, yielding levels significantly higher than in the controls, where alien cover and native richness and cover stayed relatively consistent during the 4 years of their study. Burning alone stimulated insignificant increases in native species richness and cover, given only minor changes in overstory condition and relatively little site disturbance.

On their control plots, Speer and Bailey observed 9 of the 15 total alien species found in this study. Occurrences of field bindweed (*Convolvulus arvensis*), lambsquaters (*Chenopodium album*), prickly lettuce (*Lactuca serriola*), and the common dandelion (*Taraxacum officinale*) all declined across sites during the 4 study years. They felt that this decrease in alien species richness and frequency was due to species-specific natural germination cycles of annual and biennial plants relative to their limited 2-year sampling period. Alien species richness decreased (0.15) with time in their control areas. Several recent studies (see Chapter 16) clearly document that management disturbance provides a vector for alien species to colonize (Crawford et al. 2001; Sieg et al. 2003; Korb et al. 2004), but there is little documentation of a decrease in alien species richness when left undisturbed.

In response to harvesting and burning treatments in their study design, Speer and Bailey found that more intensive management regimes yield higher understory vegetation cover and richness for both native and alien species. This general trend has been documented repeatedly (e.g., Crawford et al. 2001; Laughlin et al. 2004), particularly in ponderosa pine forests. The authors suggest that if promoting a more robust understory is a desired management objective for enhancing grazing and foraging, promoting soil stabilization and nutrient cycling, influencing fire behavior, ecological restoration, or simply for aesthetics, then these goals can be achieved at different levels by changing intensities of management activities. However, the risk of invasive alien species colonizing after treatment should be weighed carefully, as any of the management activities presented here provide a vector for colonization in this Colorado Plateau landscape. They conclude this chapter by suggesting that managers continue to monitor these permanent plots to adequately document whether the trends that the authors found will continue over time, or will differ as time from disturbance passes.

The response of Colorado Plateau vegetation communities to fire is further explored in Chapter 16, where the 2000 Outlet fire in Grand Canyon National Park is examined. In this chapter, Julie Crawford brings to light the need to investigate high-severity fire and the effects of fire-fighting activity on vegetation and understory recovery in mixed conifer forests. The Outlet fire burned more than 13,000 acres (5261 ha) of mostly mixed conifer forest on the North Rim of Grand Canyon National Park and Kaibab National Forest. This chapter documents a study that examined post-fire vegetation change in relation to three types of disturbance: high-severity burned areas, fire-fighting staging areas, and fire-fighting handlines. Crawford employed an indicator species analysis, nonmetric multidimensional scaling, and ANOSIM to determine indicator species and trends among disturbance types and across years. She found statistically significant differences in floristic composition, cover, and diversity over time and among disturbance types. Burned sites had the highest vegetation cover in all years through 2004. Diversity in the burned areas decreased following dieback of the initial invasion and by 2004 had become largely floristically homogeneous with high cover of two native rhizomatous species. Few exotic species were present in high-severity burn transects, although by 2004, cheatgrass (*Bromus tectorum* L.) had become an indicator species. Staging areas used in fire-fighting contained the greatest number of exotic species in all years of study, but this may be related to continued use of these roadside areas by park visitors. Areas of handlines showed no statistically significant differences between 2000 and 2004, indicating that no vegetation recovery had occurred.

Several studies have found that the damage associated with fire control activities is a legitimate concern that should be examined carefully (see also Chapter 15). Crawford found that following handline construction, the current methods of site rehabilitation do not improve vegetation recovery. In addition, she suggests that managers should (1) require mitigation for fire fighters and their equipment to eliminate the spread of exotic plants, (2) continue and expand this study to investigate vegetation responses at additional sites of fire and fire-fighting activity, (3) conduct experiments on the effectiveness and efficiency of restorative seeding using locally collected native species, and (4) encourage the local collection and storage of native seed for post-disturbance management. The author also states that continued monitoring is essential for understanding long-term changes in vegetation due to high-intensity fires and fire-suppression crews operating in high-elevation forests on the Colorado Plateau.

Chapter 17 by Crall et al. evaluated relationships between native and non-native plant species richness and cover within and across 15 vegetation types in the Grand Staircase–Escalante National Monument in Utah. This chapter extends the vegetation portion of this book into the Colorado Plateau region of southern Utah, focusing on a Bureau of Land Management area. The authors discuss how various theories have been proposed to explain patterns of species richness using measures of productivity, with the most widely accepted theory suggesting that this relationship results in a hump-shaped/unimodal curve, with species richness increasing and then decreasing as productivity increases (e.g., Grime 1973a, 1979; Huston 1979, 1994; Tilman 1982; Rosenzweig 1992; Grace 1999). However, some authors have suggested that surveys of species richness conducted over limited productivity ranges are less likely to detect a hump-shaped relationship than are studies conducted over a broad productivity range (Begon et al. 1990; Rosenzweig 1992, 1995; Huston 1994; Grace 1999). Therefore, data are clearly lacking to establish only one relationship between native species richness and productivity, and the authors examine this perceived need throughout the chapter.

The authors develop four hypotheses: (1) That the common unimodal relationship between species richness and total cover would be found for native and non-native species when looking across all vegetation types, and that this relationship should only show a monotonic increase for xeric and a monotonic decrease for mesic vegetation types; (2) that native and non-native species richness and cover would be greatest in the mesic vegetation types (when compared to the xeric vegetation) because of greater resource availability; (3) that non-native species richness and cover would be positively correlated with native species richness and cover within and across vegetation types at the plot scale, but that the reverse would be found at smaller spatial scales due to competitive interactions; and (4) that disturbance would increase non-native species richness and cover because disturbance is known to facilitate the establishment and potential dominance of non-native plant species. The objectives of their study were to evaluate the relationships between native and non-native plant species richness and cover in the Grand Staircase–Escalante National Monument, and to provide some insight into how these relationships might be affected by productivity and disturbance across vegetation types at different spatial scales. In addition, to help guide and direct future BLM management efforts they determined where non-native species have successfully established and gained dominance in the monument.

The authors discuss the various mechanisms that can make species-rich vegetation types (e.g., riparian vegetation communities) more easily invaded than species-poor vegetation types. Species richness tends to be low in stressful environments as a result of few species being able to survive under harsh conditions (Grime 1973a, 1973b). If species-poor vegetation types are a result of limited resources, the authors argue that non-natives are also unlikely to establish and succeed in those areas. Stohlgren et al. (1998, 1999) also suggest that non-natives would more likely be found in areas of greater species richness and resource availability. Natural and anthropogenic disturbances are also correlated with the vulnerability of habitats to invasion (Fox and Fox 1986; Hobbs 1989; Hobbs and Huenneke 1992). As niche space in a vegetation type becomes available through disturbance, the establishment of a non-native species may be possible because of open space and increased nutrient availability (Robinson et al. 1995). However, establishment of non-native species into these areas may still be limited by dispersal or seed availability (Rosentreter 1994).

To add to this complexity, it is not known which factors make a vegetation type vulnerable to plant invasion. But a long-held theory of invasion asserts that disturbed, species-poor communities are more susceptible to invasion by non-natives due to a lack of biotic resistance from such factors as competition or predation (Elton 1958; Simberloff 1986). The authors point out that all of these theories are confounded by studies being conducted at multiple spatial and temporal scales (Levine and D'Antonio 1999; Stohlgren 2002). Several multi-scale observational studies have shown both a negative and a positive relationship between native and non-native species richness at small spatial scales (Brown and Peet 2003; Fridley et al. 2004), whereas a positive relationship was seen at larger spatial scales in most cases (Stohlgren et al. 1998, 1999). This may be a consequence of differences in primary controls on diversity. At smaller spatial scales (plant neighborhoods), native and non-native species richness may be negatively correlated because of competitive exclusion, while at larger spatial scales the effects of competition might be reduced or reversed because most competitors have similar habitat requirements (Levine and D'Antonio 1999). Nevertheless, differences at multiple scales have made it difficult for researchers to develop broad generalizations related to non-native species invasions.

In addition, the authors point out that research findings are dependent on the vegetation type's stage of invasion at a particular point in time (i.e., on a temporal scale). Positive relationships between native and non-native species richness may occur only in the early stages of invasion, while later in the invasion process certain non-native invaders might have the capability to drastically alter an ecosystem (e.g., Vitousek et al. 1987; D'Antonio 2000). In such cases, native species richness is likely to be reduced as a result of the non-native species' ability to gain dominance under these new conditions. Thus, it remains unclear as to what role productivity and disturbance may play in determining native and non-native species richness.

Crall et al. did find that, at all scales, regressions across all vegetation types showed an increase in species richness as total cover increased. They also demonstrated a monotonic increase in total cover for the xeric vegetation types, at both large and smaller scales on this BLM monument. Thus, they suggest that the hump-shaped model (see Grime 1973a, 1979; Huston 1979, 1994; Tilman 1982; Rosenzweig 1992; Grace 1999) may not be applicable to less-productive landscapes such as occur in the monument. This may be an indication that productivity should be used in multivariate analyses, along with the other factors, in order to better explain patterns of species richness over the Colorado Plateau.

Chapter 18, which concludes the group of chapters that address vegetation issues, examines techniques of ecological restoration on forest roads. Across many landscapes, and especially on the Colorado Plateau, forest roads are a common component of the environment. Nearly half of all ponderosa pine forest lies within 0.25 miles of a road. The impacts of roads and trails in forests of the Colorado Plateau are of particular concern to people who deal with ecological restoration (Covington 2003). Forest-road removal is increasingly being used as a method of restoring pre-disturbance hydrology, ecosystem processes, and habitat continuity. The physical aspects of road rehabilitation are well studied (e.g. Luce 1997), but little research has been done to assess the effectiveness of these procedures in restoring critical ecosystem attributes and processes. When forest roads are constructed, the organic soil layers are removed, leaving a surface that is primarily mineral soil, which lacks symbiotic and other fungi that assist with essential processes in the soil food web, such as nutrient cycling and plant community support (Harvey et al. 1979).

The purpose of the study by Joseph Trudeau was to examine one possible method for increasing the effectiveness of road restoration through the utilization of fungal inoculum that would assist plant and microbial communities to achieve pre-disturbance conditions. He investigated the effects on plant establishment using ground waste-wood (mulch) and fungal inoculum, and then evaluated the effectiveness of inoculated saprophytic fungi in colonizing ponderosa pine mulch. This experiment was conducted on areas that had formerly been forest roads, with three experimental roads selected at Northern Arizona University's Centennial Forest near Flagstaff. Each road was divided into five experimental blocks containing four identical treatments. Treatments were (1) control, (2) mycorrhizal inoculum, (3) mulch, saprophytic fungal inoculum, and mycorrhizal inoculum, and (4) mulch only. All plots were seeded with the same mix of native plants. Trudeau collected data at 2 and 14 months after application of treatments, and found that mycorrhizal inoculum had no effect on grass seedling establishment, species richness, or abundance, while mulch was found to significantly suppress plant establishment. The author also found that mulched plots had lower species richness and abundance. However, he did discover that Gambel oak seedlings were frequent on mulched plots but not common on non-mulched plots. Saprophytic inoculum showed poor survivorship; after 14 months, only 34 percent of the inoculated sites were colonized, while most mulched plots were naturally colonized by resident soil fungi. Trudeau concludes this chapter by suggesting that inoculation is less effective than natural colonization, and that until sources of inoculum that are adapted to local conditions are developed, the methods that he examined are less effective than natural revegetation processes.

GAINING INSIGHTS FROM THE PAST

The final two chapters of this book focus on research that provides managers with insights from the past. In Chapter 19, Cole et al. provide readers with a compelling argument that climate change will have a dramatic effect on plant species distributions over the Colorado Plateau. They describe new techniques for paleo-botany modeling, using the widespread Southwest tree species Colorado pinyon pine (*Pinus edulis*). Their model requires knowledge of the plant's current distribution, climate tolerances, and migratory response to change, as well as the geography of future climates, and it incorporates all of the climate-modulated physical and biological variables occurring near the continental range of the species during the twentieth century. The authors developed models of future potential geographic ranges by applying this climatic envelope to future climate predictions from general circulation model (GCM) results. Finally, to distinguish between this future potential climate range and the species' likely future range, they apply a spatial model of the species' observed migration rate in response to past and ongoing climate warming. Through the compilation of spatially detailed data for the twentieth century climate model, the GCM modeling, and current pinyon distribution data, their results are projected to a landscape grid scale of ~1 km^2.

The modeling results of Cole et al. for pinyon pine suggest that over the next 100 years, the range of pinyon pine will continue to profoundly contract throughout Arizona, Utah, and southern New Mexico, but will expand in Colorado and northernmost New Mexico. The results from this one GCM scenario imply a large magnitude of change for this species, and delineate useful areas in which managers can focus future monitoring efforts. This detailed projection allows their results to be easily applied by individual land managers as well as providing specific predictions of future distributions that would assist land-management agencies with future monitoring efforts.

In the final chapter of the book, Draut and Rubin examine the role of wind-blown (aeolian) sediment on the preservation of archaeological sites along the Colorado River corridor in Grand Canyon National Park. They document that aeolian deposits in the river corridor fall broadly into two categories: (1) modern fluvial sourced (MFS) deposits, which form as the wind transports sand inland from < 1270 m^3/s (45,000 ft^3/s)-stage sandbars, creating aeolian dunes directly downwind, and (2) relict fluvial sourced (RFS) deposits, which formed as wind eroded and redistributed sediment of extensive pre-dam fluvial terraces. Archaeological material is known to occur in aeolian deposits of both types. The authors then describe how Glen Canyon Dam operations have caused a reduction in sandbar size, thereby reducing the supply of sand available for transport from upwind sources to provide cover to some archaeological sites. They also show how past and present sedimentary processes can be evaluated, along with modern wind and sand-transport rates, to assess the sensitivity to dam operations of specific areas and associated cultural sites along the Colorado River corridor in the Grand Canyon.

The authors found that some archaeological sites in MFS dunes have been negatively affected by the loss of aeolian sand caused by decreased sand supply on upwind sandbars, a process attributable to dam operations. They suggest that these sites could benefit from aeolian redistribution of new sand deposited on fluvial sandbars by sediment-rich controlled floods. The November 2004 Colorado River high flow resulted in major deposition of new sand in many areas that are sediment sources for MFS aeolian deposits, and wind reworking of 2004 flood sand has also been observed to fill in small eroded gullies. The authors document that 3 months of high daily flow fluctuations in 2004 removed much of the new sand prior to the start of the first post-flood windy season in April 2005. Draut and Rubin conclude their chapter by suggesting that the restoration potential for cultural sites in aeolian deposits can be maximized by using dam operations (controlled floods and post-flood flows) that maximize the exposed sand area on fluvial sandbars from April through early June, when wind-borne sediment transport is greatest in the Grand Canyon.

SUMMARY

The 20 chapters of this book have brought together much of the current research on the Colorado Plateau, particularly that which is applicable to land managers. More and more we see people from diverse backgrounds coming together on the Colorado Plateau to achieve common conservation goals. The beginning portion of the book provides examples of collaborative processes that have worked; these chapters also provide recipes of the "ingredients" necessary to assure fruitful collaborations. If the public and private land stewards in Arizona, Utah, Colorado, and New Mexico—and in particular managers of our national parks, the U.S. Forest Service, Fish and Wildlife Service, Bureau of Reclamation, tribal lands, and the many new BLM national monuments—utilize the ideas and concepts presented within this portion of the book, they will be better able to launch efforts toward enhanced management and stewardship of their lands. Along with the collaborative tools, these groups will also find useful some of the large-scale land-use tools that are presented in the second section of the book. GAP programs have now reached a level of development that makes them powerful tools for addressing large-scale questions and issues over the Colorado Plateau.

The chapters on assessing wildlife and vegetation issues, like many of the chapters in this series' previous books, provide species- and location-specific information that managers can use to better preserve their wildlife and vegetation resources. From looking at the history and movement patterns of pronghorn, and responses of that species to fenced transportation corridors, to relocation of bighorn sheep, wildlife managers have new information and tools that will better enable them to properly manage wildlife. Land managers who are concerned with the monitoring and preservation of birds will find current information on monitoring and the responses of avian communities to forest management; in particular, the power analysis provided by Spence in Chapter 9 should serve as an example that all managers should follow in the analyses of their monitoring information. For the first time, the Colorado Plateau manager is supplied with a complete inventory of all herpetofauna that they should expect to occur on their managed lands. There is also valuable information provided on the potential impacts of fire on native trout populations. Scientists and managers are also provided with insight into potential cave invertebrate resources over the Colorado Plateau.

As in previous books of this Colorado Plateau series, a number of chapters examine the impact of fire on vegetation communities. This is the first time that fire and restoration ecology are examined together in the same context, within the ponderosa pine ecosystem. Finally, there are sections in the book that provide the reader who is interested in natural and cultural resources, with a glimpse into the past and some predictions about the future state of the Colorado Plateau. It truly is our hope that the material in this volume will provide land managers with useful information and tools, and that this information can in some way act as a stimulus of future research support for cultural, natural, and physical resources over the Colorado Plateau.

LITERATURE CITED

Arrington, O. N. 1947. Predator control as a management factor in antelope reproduction. Project 22-R, August 20, 1947. Arizona Game and Fish Commission.

Arrington, O. N., and A. E. Edwards. 1951. Predator control as a factor in antelope management. Transactions North American Wildlife Resource Conference. 16: 179–193.

Bailey, J. D., M. R. Wagner, and J. J. Smith. 2001. Stand treatment impacts on forest health (STIFH): Structural responses associated with silvicultural treatment. In Proceedings of the Fifth Conference of Research on the Colorado Plateau, edited by C. van Riper III, K. A. Thomas, and M. A. Stuart, pp. 137–145. U.S. Geological Survey/Forest and Rangeland Ecosystem Science Center USGSFRESC/COPL/2001/21 Rep. Ser., Flagstaff, Arizona.

Begon, M., J. L. Harper, and C. R. Townsend. 1990. Ecology: Individuals, Populations and Communities. Blackwell Scientific Publications, Cambridge, Massachusetts.

Belnap, J., J. H. Kaltenecker, R. Rosentreter, J. Williams, S. Leonard, and D. Eldridge. 2001. Biological soil crusts: Ecology and management. In BLM Technical Reference 1730-2, edited by P. Peterson, p. 110. USDI Bureau of Land Management, USGS Forest and Rangeland Ecosystem Science Center, Denver, Colorado.

Boykin, K. G., B. C. Thompson, R. A. Deitner, D. Schrupp, D. Bradford, L. O'Brien, C. Drost, S. Propeck-Gray, W. Rieth, K. Thomas, W. Kepner, J. Lowry, C. Cross, B. Jones, T. Hamer, C. Mettenbrink, K. J. Oakes, J. Prior-Magee, K. Schulz, J. J. Wynne, C. King, J. Puttere, S. Schrader, and Z. Schwenke. 2006. Predicted animal habitat distributions and species richness. In Southwest Regional Gap Analysis Final Report, edited by J. S. Prior-Magee. USGS Gap Analysis Program, Moscow, Idaho. Available at http: //fws-nmcfwru.nmsu.edu/swregap/ (see also http: //nhd.usgs.gov/).

Bright, J. L., and C. van Riper III. 2000. Pronghorn home ranges, habitat selection and distribution around water sources in northern Arizona. USGS, Forest and Rangeland Ecosystem Science Center, Colorado Plateau Field Station Technical Report USGSFRESC/COPL/2000/.

Brown, B. T., S. W. Carothers, and R. R. Johnson. 1987. Grand Canyon Birds. University of Arizona Press, Tucson.

Brown, R. L., and R. K. Peet. 2003. Diversity and invasibility of southern Appalachian plant communities. Ecology 84: 32–39.

Byers, C. R., and G. A. Bettas, editors. 1999. Records of North American big game, 11th ed. Boone and Crockett Club, Missoula, Montana.

Carothers, S. W., and B. T. Brown. 1991. The Colorado River through Grand Canyon. University of Arizona Press, Tucson.

Cody, M. L. 1985. An introduction to habitat selection in birds. In Habitat Selection in Birds, edited by M. L. Cody, pp. 3–56. Academic Press, San Diego, California.

Covington, W. W. 2003. The evolutionary and historical context. In Ecological Restoration of Ponderosa Pine Forests, edited by P. Friederici, pp. 26–47. Island Press, Washington, D.C.

Covington, W. W., and M. M. Moore. 1994. Southwestern ponderosa pine forest structure and resource conditions: Changes since Euro-American settlement. Journal of Forestry 92: 39–47.

Covington, W. W., P. Z. Fulé, M. M.Moore, S. C. Hart, T. E. Kolb, J. N. Mast, S. S. Sackett, and M. R. Wagner. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. Journal of Forestry 95: 23–29.

Crawford, J. A., C. H. A. Wahren, S. Kyle, and W. H Moir. 2001. Responses of exotic plant species to fires in *Pinus ponderosa* forests in northern Arizona. Journal of Vegetation Science 12: 261–268.

Crist, P. J., and J. M. Scott. 1999. Identifying the gaps, locating the reserves: Some thoughts on getting gap analysis into conservation practice. Gap Analysis Bulletin 8: 14–16.

Crist, P. J., T. C. Edwards Jr., C. G. Homer, S. D. Bassett, and B. C. Thompson. 2000. Mapping and categorizing land stewardship. A Handbook for Gap Analysis, Version 2.1.0. Gap Analysis Program, Moscow, Idaho.

Cunningham, S. 1989. Evaluation of bighorn sheep habitat. In The Desert Bighorn Sheep in Arizona, edited by R. M. Lee, pp. 135–160. Arizona Game and Fish Department, Phoenix.

D'Antonio, C. M. 2000. Fire, plant invasions, and global changes. In Invasive Species in a Changing World, edited by H. A. Mooney and R. J. Hobbs, pp. 65–93. Island Press, Washington, D.C.

Edwards, A. C. 1947. Antelope airplane survey. Project 26-R-1, Job 1. Arizona Game and Fish Commission, Phoenix.

Edwards, T. C., C. Homer, and S. Bassett. 1994. Land management categorization: A user's guide. A Handbook for Gap Analysis, Version 1. Gap Analysis Program, Moscow, Idaho.

Elton, C. S. 1958. The Ecology of Invasions by Animals and Plants. Methuen, London.

Erling, H. G. 1956a. Report on a study of reproduction in antelope. Special Report, January 1956. Project W-53-R-5, WP2, J1.

Erling, H. G. 1956b. Report on a study of reproduction in antelope. Project W-53R-6,WP2, J1. Special Report, April 1956.

Falzarano, S., K. Thomas, and J. Lowry. 2005. Using decision tree modeling in gap analysis land cover mapping: Preliminary results from northeastern Arizona. In The Colorado Plateau II: Biophysical, Socioeconomic, and Cultural Resources, edited by C. van Riper III and D. J. Mattson, pp. 87–100. University of Arizona Press, Tucson.

Felley, D. L., and M. K. Sogge. 1997. Comparison of techniques for monitoring riparian birds in Grand Canyon National Park. In Proceedings of the Third Biennial Conference of Research on the Colorado Plateau, edited by C. van Riper III and E. Deshler, pp. 73–83. U.S. Department of the Interior National Park Service Transactions and Proceedings Series NPS/NRNAU/NRTP-97/12.

Fleming, B. 2006. Review of: The Colorado Plateau: Cultural, Biological, and Physical Research. New Mexico Historical Review 81(1): 115–117.

Floyd-Hanna M. L., A. DaVega, D. Hanna, and W. H. Romme. 1999. Fire vegetation monitorin and mitigation. In Proceedings of the Fourth Biennial Conference of Research on the Colorado Plateau, edited by C. van Riper III and M. A. Stuart, pp. 61–75. USGS Forest and Rangeland Ecosystem Science Center CPFS Rep. Ser., 99/16. Flagstaff, Arizona.

Floyd, M. L., D. D. Hanna, and G. Salamacha. 2001. Post-fire treatment of noxious weeds in Mesa Verde National Park, Colorado. In Proceedings of the Fifth Conference of Research on the Colorado Plateau, edited by C. van Riper III, K. A. Thomas, and M. A. Stuart, pp. 147–157. U.S. Geological Survey/ Forest and Rangeland Ecosystem Science Center USGSFRESC/COPL/2001/21 Rep. Ser., Flagstaff, Arizona.

Fornwalt, P. J., M. R. Kaufmann, L. S. Huckaby, J. M. Stoker, and T. J. Stohlgren. 2003. Non-native plant invasions in managed and protected ponderosa pine/Douglas-fir forests of the Colorado Front Range. Forest Ecology and Management 177: 515–527.

Fox, M. D., and B. J. Fox. 1986. The susceptibility of natural communities to invasion. In Ecology of Biological Invasions: An Australian Perspective, edited by R. H. Groves and J. J. Burdon, pp. 57–66. Australian Academy of Sciences, Canberra.

Fridley, J. D., R. L. Brown, and J. E. Bruno. 2004. Null models of exotic invasion and scale-dependent patterns of native and exotic species richness. Ecology 85: 3215–3222.

Garret L. D., and M. H. Soulen. 1999. Changes in character and structure of Apache/Sitgreaves forest ecology: 1850–1990. In Proceedings of the Fourth Biennial Conference of Research on the Colorado Plateau, edited by C. van Riper III and M. A. Stuart, pp. 25–29. USGS Forest and Rangeland Ecosystem Science Center CPFS Rep. Ser., 99/16, Flagstaff, Arizona.

Garret L. D., M. H. Soulen, and J. R. Ellenwood. 1997. After 100 years of forest management: "The north Kaibab." Proceedings of the Third Biennial Conference of Research on the Colorado Plateau, edited by C. van Riper III and E. Deshler, pp. 129–149. U.S. Department of the Interior National Park Service Transactions and Proceedings Series NPS/NRNAU/NRTP-97/12.

Gay, S. M. 1984. Winter range forage availability and utilization of range forage by pronghorn (*Antilocapra americana*) near Anderson Mesa. Master's thesis, Northern Arizona University, Flagstaff.

Grace, J. B. 1999. The factors controlling species density in herbaceous plant communities: An assessment. Perspectives in Plant Ecology, Evolution, and Systematics 2: 1–28.

Grime, J. P. 1973a. Competitive exclusion in herbaceous vegetation. Nature 242: 344–347.

Grime, J. P. 1973b. Control of species diversity in herbaceous vegetation. Journal of Environmental Management 1: 151–167.

Grime, J. P. 1979. Plant Strategies and Vegetation Processes. John Wiley and Sons, New York.

Harvey, A. E., M. J. Larsen, and M. F. Jurgensen. 1979. Comparative distribution of ectomycorrhizae in soils of three western Montana forest habitat types. Forest Science 25 (2): 350–358.

Hilden, O. 1965. Habitat selection in birds: A review. Ann. Zool. Fenn. 2: 53–75.

Hobbs, R. J. 1989. The nature and effects of disturbance relative to invasions. In Biological Invasions: A Global Perspective, edited by J. A. Drake, H. A. Mooney, F. di Castri, R. H. Groves, F. J. Kruger, M. Rejmanek, and M. Williamson, pp. 389–405. Wiley and Sons, New York.

Hobbs, R. J., and L. F. Huenneke. 1992. Disturbance, diversity, and invasion: Implications for conservation. Conservation Biology 6: 324–337.

Holmes, J., J. R. Spence, and M. K. Sogge. 2005. Birds of the Colorado River in Grand Canyon: A synthesis of status, trends and dam operation effects. In The State of the Colorado River Ecosystem, edited by S. P. Gloss, J. E. Lovich, and T. E. Melis, pp. 123–138. U.S. Geological Survey Circular 128.

Huston, M. A. 1979. A general hypothesis of species diversity. American Naturalist 113: 81–101.

Huston, M. A. 1994. Biological Diversity: The Coexistence of Species in Changing Landscapes. Cambridge University Press, Cambridge, UK.

Korb, J. E., and J. D. Springer. 2003. Understory vegetation. In Ecological Restoration of Southwestern Ponderosa Pine Forests, edited by P. Friederici, pp. 251–267. Island Press, Washington, D.C.

Korb, J. E., N. C. Johnson, and W. W. Covington. 2004. Slash pile burning effects on soil biotic and chemical properties and plant establishment: Recommendations for amelioration. Restoration Ecology 12 (1): 52–62.
Laughlin, D. C., J. D. Bakker, M. T. Stoddard, M. L. Daniels, J. D. Springer, C. N. Gildar, A. M. Green, and W. W. Covington. 2004. Toward reference conditions: Wildfire effects on flora in an old-growth ponderosa pine forest. Forest Ecology and Management 199: 137–152.
Levine, J. M., and C. M. D'Antonio. 1999. Elton revisited: A review of evidence linking diversity and invasibility. Oikos 87: 1–11.
Lewis, N. L. 2000. Arizona Wildlife Trophies. Arizona Wildlife Federation, Mesa.
Loeser, M. R., T. D. Sisk, T. E. Crews, K. Olsen, C. Moran, and C. Hudenko. 2001. Reframing the grazing debate: Evaluating ecological sustainability and bioregional food production. In Proceedings of the Fifth Conference of Research on the Colorado Plateau, edited by C. van Riper III, K. A. Thomas, and M. A. Stuart, pp. 3–18. U. S. Geological Survey/ Forest and Rangeland Ecosystem Science Center USGS FRESC/COPL/2001/21 Rep. Ser., Flagstaff, Arizona.
Luce, C. H. 1997. Effectiveness of road ripping in restoring infiltration capacity of forest roads. Restoration Ecology 5 (3): 265–270.
Manis, G., J. Lowry, and R. D. Ramsey. 2001. Preclassification: An ecologically predictive landform model. GAP Analysis Bulletin 10. U.S. Geological Survey, Biological Resources Division. Available at http: //www.gap.uidaho .edu/Bulletins/10/preclassification.htm.
Moore, M. M., W. W. Covington, and P. Z. Fulé. 1999. Reference conditions and ecological restoration: A Southwestern ponderosa pine perspective. Ecological Applications 9 (4): 1266.
Muñoz-Erickson, T. A., and B. J. Aguilar-Gonzalez. 2003. The use of ecosystem health indicators for evaluating ecological and social outcomes of the collaborative approach to management: The case study of the Diablo Trust. Prepared for the National Workshop on "Evaluating Methods and Environmental Outcomes of Community-based Collaborative Processes." Online Journal of the Community-based Collaborative Research Consortium (www.cbcrc).
Nabhan, G. P., S. Smith, M. Coder, and Z. Kovacs. 2005. Land-use history of three Colorado Plateau landscapes: Implications for restoration goal-setting. In The Colorado Plateau II: Biophysical, Socioeconomic, and Cultural Resources, edited by C. van Riper III and D. J. Mattson, pp. 101–119. University of Arizona Press, Tucson.
National Research Council. 1987. River and Dam Management: A Review of the Bureau of Reclamation's Glen Canyon Environmental Studies. National Academy Press, Washington, D.C.
National Research Council. 1996. River Resource Management in the Grand Canyon. National Academy Press, Washington, D.C.
National Research Council. 1999. Downstream. Adaptive Management of Glen Canyon Dam and the Colorado River Ecosystem. National Academy Press, Washington, D.C.
Naumburg, E., and L. E. DeWald. 1999. Relationships between *Pinus ponderosa* forest structure, light characteristics, and understory graminoid species presence and abundance. Forest Ecology and Management 124 (2-3): 205–215.
Neff, D. J., and N. G. Woolsey. 1980. Coyote predation on neonatal fawns on Anderson Mesa, Arizona. Proceedings Pronghorn Antelope Workshop 9: 80–93. Rio Rico, Arizona.
Neff, D. J., R. H. Smith, and N. G. Woolsey. 1985. Pronghorn antelope mortality study. Arizona Game and Fish Department Project W-78-R Final Report 1-22. Phoenix.
Ockenfels, R. A., C. van Riper III, and W. K. Carrel. 1997. Home ranges and movements of pronghorn in Northern Arizona. In Proceedings of the Third Biennial Conference of Research on the Colorado Plateau, edited by C. Van Riper III and E. T. Deshler, pp. 45–62. 97/12, 2 NPS Transactions and Proceedings Series NPS/NRNAU/NRTP-56.
Robinson, G. R., J. F. Quinn, and M. L. Stanton. 1995. Invasibility of experimental habitat islands in a California winter annual grassland. Ecology 76: 786–794.
Rosentreter, R. 1994. Displacement of rare plants by exotic grasses. In Proceedings, Ecology and Management of Annual Rangelands, edited by S. B. Monsen and S. G. Kitchen, pp. 170–175. General Technical Report INT-GTR-313. USDA-USFS, Intermountain Research Station, Ogden, Utah.
Rosenzweig, M. L. 1992. Species diversity gradients: We know more and less than we thought. Journal of Mammalogy 73: 715–730.
Rosenzweig, M. L. 1995. Species diversity in space and time. Cambridge University Press, Cambridge, UK.
Scott, J. M., B. Csuti, K. Smith, J. E. Estes, and S. Caicco. 1991. Gap analysis of species richness and vegetation cover: An integrated biodiversity conservation strategy. In Balancing on the Brink of Extinction: The Endangered Species Act and Lessons for the Future, edited by K. Kohm, pp. 282–297. Island Press, Washington D.C.
Scott, J. M., F. Davis, B. Csuti, R. Noss, B. Butterfield, C. Groves, H. Anderson, S. Caicco, F. D'Erchia, T. C. Edwards Jr., J. Ulliman, and R. G. Wright. 1993. Gap analysis: A geographic approach to protection of biological diversity. Wildlife Monographs 123: 1–41
Sieg, C. H., B. G. Phillips, and L. P. Moser. 2003. Exotic invasive plants. In Ecological Restoration of Southwestern Ponderosa Pine Forests, edited by P. Friederici, pp. 251–267. Island Press, Washington, D.C.
Simberloff, D. 1986. Introduced insects: A biogeographic and systematic perspective. In Ecology of Biological Invasions of North America and Hawaii, edited by H. A. Mooney and J. A. Drake, pp. 3–26. Springer-Verlag, New York.

Sisk, T. D., and J. Palumbo. 2005. Collaborative science: Making research a participatory endeavor for solving environmental challenges. The Quivira Coalition 7 (3).

Sisk, T. D., T. E. Crews, R. T. Eisfeldt, M. King, and E. Stanley. 1999. Assessing impacts of alternative livestock management practices: Raging debates and a role for science. In Proceedings of the Fourth Biennial Conference of Research on the Colorado Plateau, edited by C. van Riper III and M. A. Stuart, pp. 89–103. USGS Forest and Rangeland Ecosystem Science Center CPFS Rep. Ser., 99/16, Flagstaff, Arizona.

Spence, J. R. 2004. The riparian and aquatic bird communities along the Colorado River from Glen Canyon Dam to Lake Mead, 1996–2000. Final report to the U.S. Geological Survey Grand Canyon Monitoring and Research Center, Flagstaff. Resource Management Division, Glen Canyon NRA.

Steidl, R. J., J. P. Hayes, and E. Schauber. 1997. Statistical power analysis in wildlife research. Journal of Wildlife Management 61: 270–279.

Stohlgren, T. J. 2002. Beyond theories of plant invasions: Lessons from natural landscapes. Comments on Theoretical Biology 7: 355–379.

Stohlgren, T. J., K. A. Bull, Y. Otsuki, C. A. Villa, and M. Lee. 1998. Riparian zones as havens for exotic plant species in the central grasslands. Plant Ecology 138: 113–125.

Stohlgren, T. J., D. Binkley, G. W. Chong, M. A. Kalkhan, L. D. Schell, K. A. Bull, Y. Otsuki, G. Newman, M. Bashkin, and Y. Son. 1999. Exotic plant species invade hot spots of native plant diversity. Ecological Monographs 69: 25–46.

Taylor, B. L., and T. Gerrodette. 1993. The uses of statistical power in conservation biology: The vaquita and northern spotted owl. Conservation Biology 7: 489–500.

Tilman, D. 1982. Resource competition and community structure. Princeton University Press, Princeton, New Jersey.

Tuhy, J. S., P. Comer, D. Dorfman, M. Lammert, J. Humke, B. Cholvin, G. Bell, B. Neely, S. Silbert, L. Whitham, and B. Baker. 2002. A Conservation Assessment of the Colorado Plateau Ecoregion. The Nature Conservancy, Moab Project Office, Moab, Utah.

Utah Division of Wildlife Resources. 2005. Utah's Watershed Restoration Initiative: Coming together to help rangelands. Available at http://www.wildlife.utah.gov/watersheds/upcd.php.

van Riper, C. III, editor. 1995. Proceedings of the Second Biennial Conference on Research in Colorado Plateau National Parks. NPS Transaction and Proceedings Series NPS/NRNAU/NRTP-95/11.

van Riper, C. III., and K. A. Cole, editors. 2004. The Colorado Plateau: Cultural, Biological, and Physical Research. University of Arizona Press, Tucson.

van Riper, C. III, and E. T. Deshler, editors. 1997. Proceedings of the Third Biennial Conference of Research on the Colorado Plateau. NPS Transactions and Proceedings Series NPS/NRNAU/NRTP-97/12. Denver, Colorado.

van Riper, C. III., and D. J. Mattson, editors. 2005. The Colorado Plateau II: Biophysical, Socioeconomic and Cultural Research. University of Arizona Press, Tucson.

van Riper, C. III, and R. A. Ockenfels. 1998. The influence of transportation corridors on the movement of pronghorn antelope over a fragmented landscape in northern Arizona. In Proceedings of the Second International Conference on Transportation and Wildlife Ecology, edited by D. Zeigler, pp. 241–248. Ft. Meyers, Florida.

van Riper, C. III, and M. K. Sogge. 2004. Bald eagle abundance and relationships to prey base and human activity along the Colorado River in Grand Canyon National Park. In The Colorado Plateau: Cultural, Biological, and Physical Research, edited by C. van Riper III and K. A. Cole, pp. 163–185. University of Arizona Press, Tucson.

van Riper, C. III, and M. A. Stuart, editors. 1999. Proceedings of the Fourth Biennial Conference of Research on the Colorado Plateau. USGS Forest and Rangeland Ecosystem Science Center CPFS Rep. Ser., 99/16, Flagstaff, Arizona.

van Riper, C. III, K. A. Thomas, and M. A. Stuart, editors. 2001. Proceedings of the Fifth Conference of Research on the Colorado Plateau. U.S. Geological Survey/ Forest and Rangeland Ecosystem Science Center USGSFRESC/COPL/2001/21 Rep. Ser. Flagstaff, Arizona.

Vitousek, P. M., L. R. Walker, L. D. Whiteaker, D. Mueller-Dombois, and P. A. Matson. 1987. Biological invasion by *Myrica faya* alters ecosystem development in Hawaii. Science 238: 802–804.

Wakeling, B. F., and W. H. Miller. 1990. A modified habitat suitability index for desert bighorn sheep. In Managing Wildlife in the Southwest, edited by P. R. Krausman and N. S. Smith, pp. 58–66. Arizona Chapter of the Wildlife Society, Phoenix.

Wallmo, O. C. 1951. Antelope range preference study. Completion Report, July 24, 1951. Project 46-R-2, J-5, Arizona Game and Fish Commission, Phoenix.

West, N. E., and J. A. Young. 2000. Intermountain Valleys and Lower Mountain Slopes. In North American Terrestrial Vegetation, 2nd ed., edited by M. G. Barbour and W. D. Billings. Cambridge University Press, New York.

Wilkins, A. S., and P. Welles. 1944. Antelope survey—1944. Project 9-R, Special Report. May 22 through June 1, 1944. Arizona Game and Fish Commission, Phoenix.

Yoakum, J. D. 2003. An assessment of pronghorn populations and habitat conditions on Anderson Mesa, Arizona: 2001–2002. Report prepared for Arizona Wildlife Federation, Mesa. Western Wildlife, Verdi, Nevada.