Structure and Function of Chihuahuan Desert Ecosystem
The Jornada Basin Long-Term Ecological Research Site
Edited by: Kris Havstad, Laura F. Huenneke, William H. Schlesinger
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Chapter 1

Introduction

Kris M. Havstad and William H. Schlesinger

Arid lands throughout the world are often degraded or increasingly at risk of degradation. These lands, including those at the border of arid regions, commonly exhibit accelerated soil erosion, losses of productivity, and impaired economic potential to support human populations. Human history is replete with the collapse of great civilizations of the hot and dry subtropics that suffered severe soil resource depletions in their midst or on their margins. Given that over 1 billion people currently inhabit the arid lands of the world, it is critical that we have the knowledge and resulting technologies to mitigate our impacts and improve environmental conditions of these lands and their resources. This book describes our understanding of basic processes of arid ecosystems resulting from nearly a century of research in one desert locale, the Jornada Basin of southern New Mexico. Much of our understanding comes from both extensive and intensive studies in a landscape that has drastically changed over that time.

The loss of ecological, economic, and social capital is called "desertification" (Dregne et al. 1991). The 1992 United Nations Desertification Convention defined *desertification* as "land degradation in arid, semiarid and dry subhumid areas resulting from various factors, including climatic variations and human activities." In the future, we can expect that the shifting border between arid and semiarid lands will be one of the most sensitive indicators of global change.

Desertification involves human and environmental drivers of change but is a regional symptom that emerges from degradation at finer spatial scales (Reynolds and Stafford Smith 2002). Desertification does not describe cyclic phenomena, as when decadal variations of precipitation lead to periods of drought and to losses of vegetation cover that are fully restored when rains return (Tucker et al. 1994). An updated and revised desertification paradigm has been developed by Reynolds et al. (2003; table 1-1).

Table 1-1. The nine assertions of the Dahlem Desertification Paradigm, and some of their implications (Reynolds et al. 2003). These assertions are not all-encompassing but provide the framework for a new paradigm.

Assertion 1. Desertification Always Involves Human and Environmental Drivers	Always expect to include both socio-economic and biophysical variables in any monitoring or intervention scheme
Assertion 2. 'Slow' Variables are Critical Determinants of System Dynamics	Identify and manage forth small set of 'slow' variables that drive the 'fast' ecological goods and services that matter at any given scale
Assertion 3. Thresholds are Crucial, and May Change Over Time	Identify thresholds in the change variables at which there are significant increases in the costs of recovery, and quantify these costs, seeking ways to manage the thresholds to increase resilience
Assertion 4. The Costs of Intervention Rises Non-linearly with Increasing Degradation	Intervene early where possible, and invest to reduce the transaction costs of increasing scales of intervention
Assertion 5. Desertification is a Regionally Emergent Property of Local Degradation	Take care to define precisely the spatial and temporal extent of and processes resulting in any given measure of local degradation. But don't try to probe desertification beyond a measure of generalized impact at higher scales
Assertion 6. Coupled Human-Environment Systems Change over Time	Understand and manage the circumstances in which the human and environmental sub-systems become 'de-coupled'
Assertion 7. The Development of Appropriate Local Environmental Knowledge (LEK) must be Accelerated	Create better partnerships between LEK and conventional scientific research, employing good experimental design, effective adaptive feedback and monitoring
Assertion 8. Systems are Hierarchically Nested (Manage the Hierarchy!)	Recognize and manage the fact that changes at one level affect others; create flexible but linked institutions across the hierarchical levels, and ensure processes are managed through scale-matched institutions
Assertion 9. Limited Suite of Processes and Variables at Any Scale Makes the Problem Tractable	Analyze the types of syndromes at different scales, and seek the investment levers which will best control their effects – Awareness and regulation where the drivers are natural, changed policy and institutions where the drivers are social

An important feature of this conceptual model is that both biophysical and socioeconomic factors are jointly involved in desertification. This paradigm clearly recognizes critical points, or thresholds, in system dynamics, yet these points may be manageable for increasing system resilience. Central to the model is the recognition that managing degradation is possible if drivers of change for a particular region are properly understood and actions are geared to those drivers.

This book is about our understanding of a particular arid ecosystem and its recent changes. We draw on a long history of research by U.S. Department of Agriculture (USDA) scientists working in the Jornada Basin since 1912. In 1981, a group of scientists based in Las Cruces, New Mexico, and associated with New Mexico State University proposed an expanded program of long-term ecological research in the Jornada Basin of southern New Mexico to gain a better understanding of processes that determine the structure and function of arid land ecosystems. Given its existing history of research, the Jornada Basin was a natural candidate as an initial site for the Long-Term Ecological Research (LTER) program being organized by the National Science Foundation. Today, it is one of the 26 site network located throughout the United States and elsewhere (figure 1-1).

The Jornada Basin group hoped that this expansion would translate into more ecologically-based knowledge, strategies, and practices for effectively managing these increasingly human-affected environments and restoring degraded areas. To an extent, this book represents both a synthesis of that effort and a benchmark of our progress since the early 20th Century. The history behind this long-term presence of scientists in this basin is an important part of our synthesis.

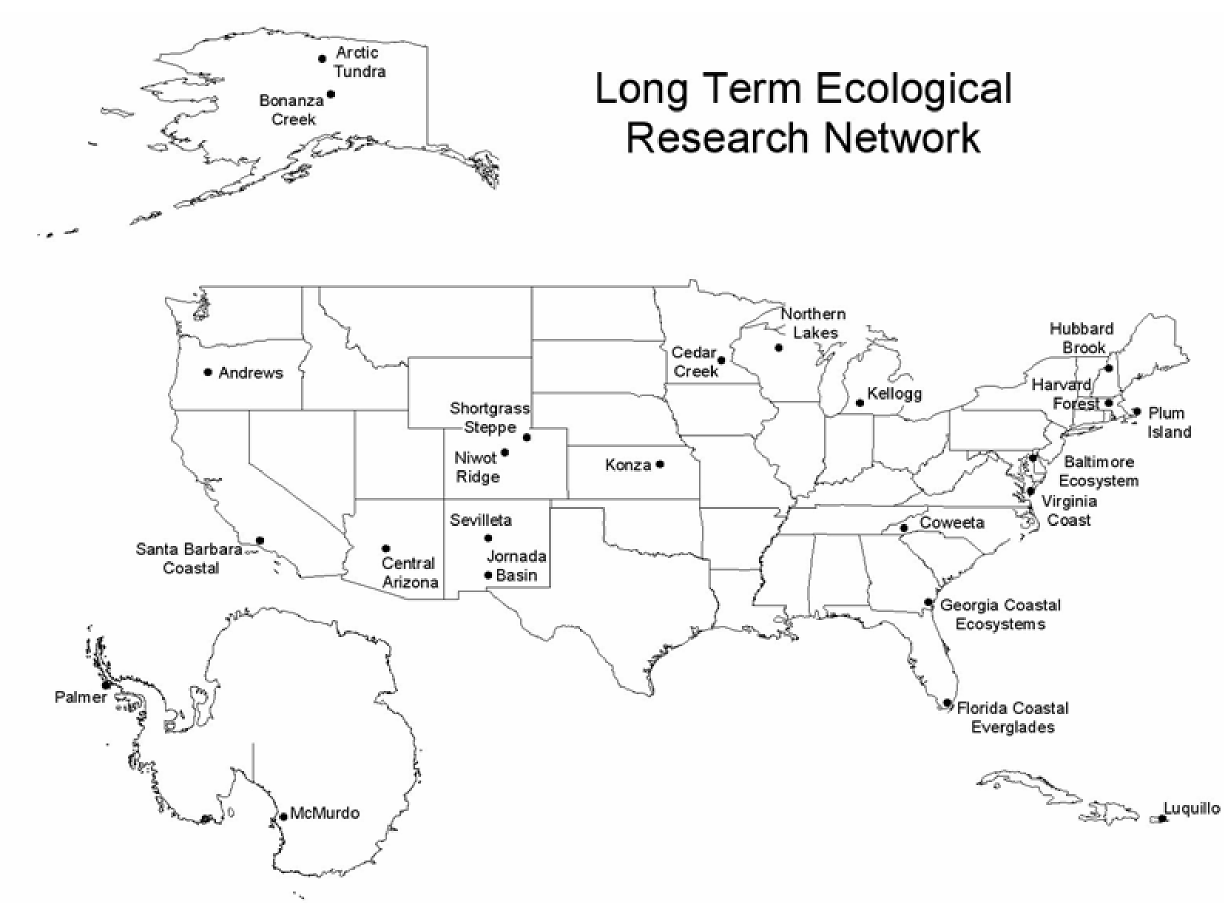

Fig. 1-1. The network of National Science Foundation's Long-Term Ecological Research sites in North America. There are two additional sites in Antarctica.

Early Ranching in the Jornada Basin

Though livestock were introduced from Mexico into southern New Mexico during the early part of the sixteenth century (Hastings and Turner 1965; see also chapter 13), for over 250 years grazing was limited to the Rio Grande Valley and adjacent slopes because of lack of surface water in the surrounding basins, including the Jornada Basin (see figure 2-1 in chapter 2 for general features of the Jornada Basin). Some water could be found in springs and seeps in the mountains away from the Rio Grande Valley, but supplies were ephemeral and livestock use was sporadic.

The Jornada Plain began to be settled following passage of the Homestead Act of 1862 and the end of the American Civil War in 1865. The first well on the plain was dug in 1867 at the Aleman ranch along the southern portion of the Santa Fe Trail north of the Dona Ana Mountains. Yet it was not until 1888 that the Detroit and Rio Grande Livestock Company pumped water from the river to a tank on the mesa and piped it to troughs 10 km inside the Jornada Basin so that cattle *(Bos taurus)*could graze these upland grasslands. Originally owned by former U.S. Army cavalry officers from Michigan, the Detroit Company began to assemble grazing rights across the Jornada Plain during this period, and grazing use increased. In the 1880s, it was estimated that the Bar Cross brand (and the 20 or so other purchased brands) of the Detroit Company could be found on 20,000 cattle, including 1,000 bulls on the Jornada Plain. The number of other stock, especially horses *(Equus caballus)*, is unknown but assumed to have been substantial.

This level of stocking (approximately 50 head of cattle per section of land) may have resulted in an annual forage consumption of 30–60 g/m^2 (see chapter 13). With the tremendous spatial and temporal variability of aboveground net primary productivity (see chapter 11) in this environment, this amount of forage consumption during drought years would have greatly exceeded any reasonable concept of carrying capacity. In addition, this amount of forage consumption would have been spatially heterogeneous, and even in productive years some areas would have been heavily grazed. The impacts of this level of use over several years would have been substantial and long lasting (see chapters 13 and 17).

Grazing was more limited on the intermittently distributed homesteads located at springs on the far eastern side of the Jornada Basin. At Goldenburg Springs on the east side of the basin, the three Goldenburg brothers reportedly watered 1,800 cows in the very early 1900s. Henry Summerford was reported to water 1,400 cows at a well at the base of the northern side of the Doña Ana Mountains (Mount Summerford) in 1905 (Lohmiller 1963). Lack of developed watering systems in the central regions of the plain limited livestock distribution in the area. The first wells at the current site of the Jornada Experimental Range were drilled in 1903 by Harvey Ringer. Ringer had begun to purchase portions of the Bar Cross ranch from the Detroit Company as it was dissolved, following the severe drought of the 1890–93 period.

One of the key people involved in expanding cattle grazing onto the Jornada Basin was Charles Travis Turney. Born in 1857 in Sutton County, Texas, and on his own from the age of eight, Turney spent his life working as a cowboy. Like some of his fellow Texans, he had decided that land had become too expensive in Texas at the end of the nineteenth century and viewed the New Mexico territory as a land of opportunity. In 1902, he began moving a herd of cattle from Texas to southern New Mexico. He was delayed in the Pecos area for a year due to animal quarantine restrictions but eventually arrived in Doña Ana County in 1904. In January, Turney purchased three 16-ha water lots in the Jornada Basin and $4,000 worth of cattle from Harvey Ringer. During the following eight years, Turney purchased additional wells from other homesteaders, including Joe Taylor and Hugo Seaburg, and shipped or trailed to Jornada an additional 3,000 cattle. By 1912, Turney held deed to 120 ha and nine wells that provided grazing rights to over 80,000 ha on the Jornada Plain for his 4,000–5,000 head of cattle. In fact, by 1912, he had already constructed fence around a portion of his ranch.

Concurrent with expansion of livestock grazing in the late 1800s throughout the Southwest region was a noticeable decline in rangeland conditions (Smith 1899). In 1908, E. O. Wooton documented deteriorated rangeland conditions in New Mexico. Wooton, a professor at New Mexico Agriculture and Mechanical Arts College in Las Cruces, spent years evaluating and characterizing rangeland conditions throughout the state (Allred 1990). In a thorough report on the subject, Wooton (1908) included the results of a survey questioning Southwestern cattlemen on the condition of regional rangelands. Of the 118 responses, 16 stockmen felt that rangeland conditions had improved in recent years, and 102 responded there had been significant declines in grazing capacities. Of these 102 responses, 69 attributed the declines to overgrazing and 33 blamed drought conditions. Earlier observations with similar results led to the first organized research efforts in the Texas Panhandle seeking to develop range management principles and improvement practices (Smith 1899). Wooton initiated his own experiments in cooperation with ranchers such as Turney by 1904, but he was frustrated by the lack of a suitably large area for research that would have application to the large ranches typical in the Southwest. Wooton, Turney, and L. B. Foster, president of the New Mexico

Agricultural and Mechanical College, developed a plan to withdraw from the public domain Turney's water lot holdings and the surrounding 72,000 ha as a land base for rangeland research (Ares 1974). In May 1912, five months after New Mexico was granted statehood, the Jornada Range Reserve was created by presidential Executive Order with Turney as the first livestock cooperator.

In 1919, Turney expanded his personal holdings outside the Jornada when he purchased several ranches that gave him control over all of the rangeland in northeastern Doña Ana County. These purchases included the Henry Summerford ranch. Later, financial problems forced Turney to sell some of these holdings to his children. His daughter, Maude, and her husband, Max Vander Stucken, bought the Summerford ranch in 1919, but unfortunately, this ranch went into foreclosure by 1926. In 1927, the New Mexico College of Agriculture and Mechanic Arts purchased 70 ha associated with water rights at three locations and the rights to about 2,430 ha of New Mexico state land grazing leases that comprised the holdings of the Vander Stucken ranch. Also in 1927, Congress deeded approximately 23,490 ha of public land associated with these water rights to New Mexico A&M for the purpose of conducting range livestock research. This holding provided a 25,920-ha facility adjacent to but separate from the federally operated Jornada Experimental Range (JER) for the university to pursue its research objectives. Using cattle purchased from area ranchers, including Turney, the Chihuahuan Desert Rangeland Research Center (CDRRC) was immediately used for livestock nutrition research, particularly studies on supplemental feeds (New Mexico Agricultural Experiment Station 1949, 1950). By the early 1930s rangeland research was being actively conducted by university and federal scientists on over 100,000 ha of desert rangeland within the Jornada Basin (see figure 2-1, chapter 2).

Our Setting

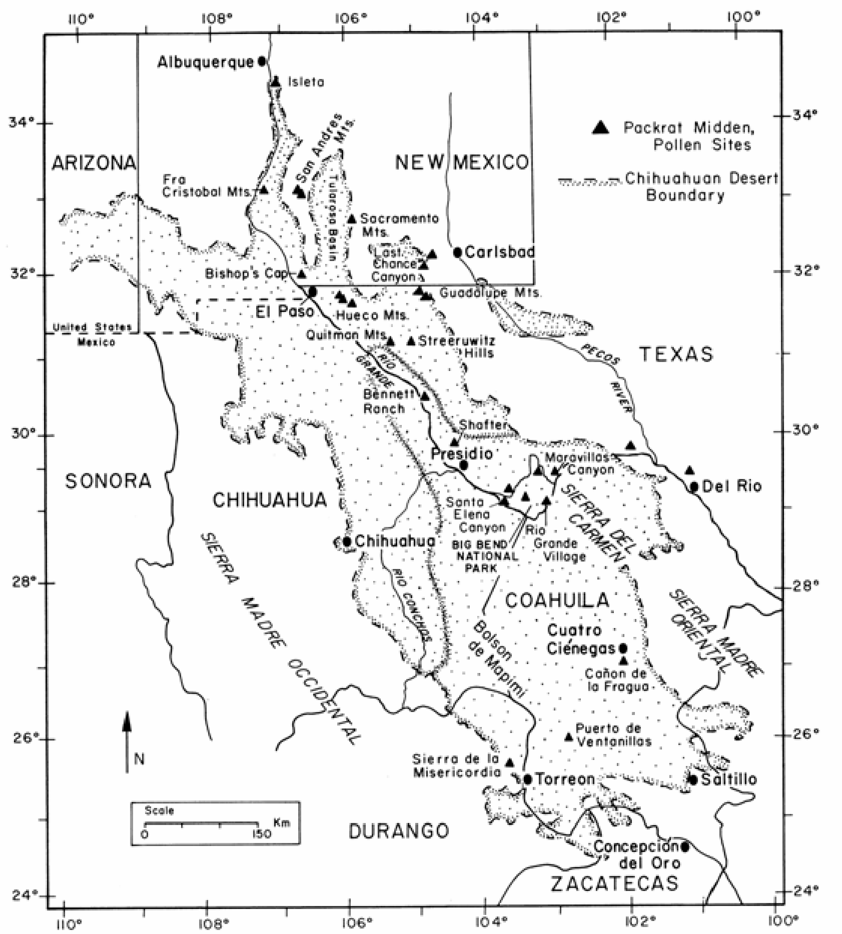

Fig. 1-2. Map of the full extent of the Chihuahuan Desert, showing the location of the Jornada Basin. From VanDevender (l990).

The Chihuahuan Desert is the largest desert in North America (figure 1-2).

The habitats of the Jornada Basin are representative of the northern Chihuahuan Desert (the Trans-Pecos region) and the Mexican Highland region of the Basin and Range Physiographic Province. The only North American desert located east of the Continental Divide, this region is a transition between the short-grass prairies of the central United States and the shrub dominated ecosystems of the Sonoran and Mojave Deserts to the west.

The Chihuahuan Desert dates to about 9,000 years ago. It has been hypothesized that during the past 3,000 years there have been three transitions from grasslands to shrublands, each followed by a return of grasslands in southern New Mexico (Van Devender 1995). Today, perennial grasses, such as black grama, may represent a relict community from more mesic climatic conditions in the mid-Holocene. Some modern plant species endemic to the desert were certainly present when large herbivores, such as ground sloths *(Megalonyx)* and mammoths*(Mammuthus)* grazed the Chihuahuan Desert, but apparently this region has not been subject to high levels of herbivory by bison *(Bison)* and other native ungulates for the past 10,000 years (Mack and Thompson 1982; Bock and Bock 1993).

The Jornada Basin receives an average of 245 mm/year of precipitation, about half in monsoonal storms that derive from the Gulf of Mexico during the late summer and the remainder in synoptic weather systems stemming from the Pacific Ocean during the winter months. Rainfall shows large interannual variability that controls the relative growth of C_3 shrubs during the spring and C_4 grasses in summer. Measured evaporation is about 220 cm/year (chapter 3), so the Bowen ratio—the dissipation of sensible versus latent heat—is very high (chapter 8). During the summer, the mean maximum temperature is 36°C, and often little or no precipitation is recorded in the months of May and June.

The Jornada Basin is typical of the closed-basin topography found in many arid regions of the Southwestern United States (chapter 2). Parallel, north–south, block-faulted mountains separate individual valleys, which have a predominance of internal drainage ways terminating in intermittently flooded lakes, known as playas. In the Jornada Basin, soils are largely derived from alluvial deposits from the mountains, as well as from floodplain deposits laid down by an ancient watercourse of the Rio Grande through the Jornada Valley (chapter 4). The entire surface is subject to wind erosion and eolian redistribution of soil materials (chapter 9).

Recent changes in ecosystem structure and function in southern New Mexico may represent a degradation process that is driven by both environmental and human impacts in combination with climatic stress, particularly prolonged drought. Anthropogenetic factors have contributed to local degradation (Fredrickson et al. 1998; see also chapter 13). Grassland sites of low resistance to grazing disturbance to have shifted to alternate, stable state in which shrubs dominate (Bestelmeyer et al. 2003a). The shift is likely to have been accelerated by a decline in the proportion of summer precipitation (which favors C_4 perennial grasses), and an increase in the proportion of precipitation during the winter, which favors C_3 shrubs (Neilson 1986). This shift may reflect an increasing frequency of Pacific El Niño events, which enhance wintertime synoptic rainfall in the Southwestern United States.

High rates of human population growth, low per capita income, and land-use changes driven by an increasing globalization of the world's economy impact natural ecosystems in most desert environments throughout the world. The ecosystems of the Chihuahuan Desert are no exception. In southern New Mexico, for example, the population of Doña Ana County (which includes much of the Jornada Basin) grew by nearly 81% in the decades of the 1980s and 1990s as population density went from 65 people per km^2 to nearly 120 people per km^2 (U.S. Census Bureau 2000). These population densities may pale in comparison to the urban centers of the world, but their relative impacts are substantial in these harsh water- and nutrient- limited environments. Similar high rates of population growth are found throughout much of the Chihuahuan Desert of Mexico and across the Southwestern United States. In addition to the direct space needed for human occupancy, the infrastructure needed to support this population is rapidly expanding. The region is increasingly traversed by roads, power lines, and aqueducts, and construction activities leave barren soils subject to wind erosion, reroute and linearize natural drainage ways, and replace native arid land vegetation with more profligate users of water. This desert area, like others, is in flux as the various pressures to increase economic production to support a growing human population are applied in a region of sparse and unevenly distributed resources.

Prior Research Themes

The history of research in the Jornada Basin consisted of several main themes over the first five to six decades: community ecology, rangeland management, animal husbandry, rangeland improvement, ecosystem sciences, and interdisciplinary studies (Havstad and Schlesinger 1996). An initial motivation for many studies was the expansive vegetation change within the Jornada Basin. These changes, now well recorded (Gibbens et al. 2005), were dramatic, progressive losses of desert grasslands dominated by black grama (*Bouteloua eriopoda*) and an invasion of desert shrubland species, predominately creosotebush (*Larrea tridentata*) and mesquite (*Prosopis glandulosa*) (Buffington and Herbel 1965; see figures 10-1 and 10-2, chapter 10).

Though the impacts of the nineteenth-century cattle industry and associated developments in southern New Mexico were severe, in reality, there was little formal, mechanistic understanding of what might have caused the complete reconfiguration of vegetation and soil resources on the Jornada landscape. It was equally possible that numerous factors, including fire suppression, rising concentrations of atmospheric carbon dioxide, and changes in the seasonal distribution of rainfall, had contributed to large changes in ecosystem structure and function. It is also quite possible that shrub encroachment was a result of a series of events occurring over centuries and less of a response to recent livestock overgrazing (Fredrickson et al. 2005). Current vegetation patterns may more broadly reflect historical legacies, dynamic patterns of ecological variables, various transport processes (fluvial, eolian, animal), resource redistributions across landscapes, and different cross-scale interactions (Peters and Havstad 2005).

Irrespective of our theories on causes and effects, an unequivocal answer would likely not derive from traditional short-term research studies. The simple facts that many of the plants in question require well over 10 years to be established in new areas and changes in the seasonal distribution of precipitation (which might lead to changes in vegetation) occur on time scales of decades and longer would require a research perspective with a more expansive temporal scale.

Like all LTER sites, the LTER studies in the Jornada Basin were initially organized into the following five core areas (Callahan 1984):

1. Pattern and control of primary production.

2. Spatial and temporal distribution of populations selected to represent trophic structure.

3. Pattern and control of organic matter accumulation in surface layers and sediments.

4. Patterns of inorganic input and movements through soils, ground water, and surface water.

5. Pattern and frequency of disturbance to the research site.

Over recent decades, we have developed a long-term monitoring program and archival data sets in each of these areas to provide a baseline of information regarding the response of this Chihuahuan Desert ecosystem to climatic fluctuations and regional changes in climate (chapter 3). Research on disturbance is of particular interest: Any insight gained into roles of environmental and human drivers would surely aid the ongoing national effort for the management of rangelands, public and private, throughout the United States (chapter 13). In addition, development of remediation technologies for degraded landscapes requires a thorough understanding of the processes associated with disturbance (chapter 14).

Prior studies of plant growth had shown little difference in the annual aboveground net primary production (ANPP) between black grama grasslands and the various shrubland habitats of the Jornada Basin. Rather, plant production seemed determined by landscape position, with greater plant growth in areas where runoff water accumulated and lower plant production in areas of limited soil moisture (Noy-Meir 1985; Ludwig 1986). The similarity of ANPP between grassland and shrubland habitats suggested that plant production per se was not a good index of desertification, to the extent that this term is appropriate to the historical loss of productive desert grassland in southern New Mexico (chapters 10 and 11).

This research group has also focused on changes in the distribution of essential soil resources during the transition from grassland to shrubland habitats. For example, sampling shrublands at a scale of 10- to 100-cm intervals, we found enormous variation in the content of nitrogen among soil samples. When we sampled grasslands at the same spatial scale, the soil samples seemed rather homogenous in basic soil characteristics (Schlesinger et al. 1990, 1996). Of course, ecologists have long recognized patches, or "islands," of fertility from under shrub vegetation, which leads to a heterogeneous distribution of soil resources in deserts. What was new to our work was that we hypothesized that desertification of semiarid grasslands may not be so much associated with a change in vegetation production as with an increase in the spatial heterogeneity of soil resources (Schlesinger et al. 1990) (see figure 1-3).

The heterogeneity of soil resources created by invading shrubs is followed by a further localization of soil resources under shrub canopies promoting further invasion,

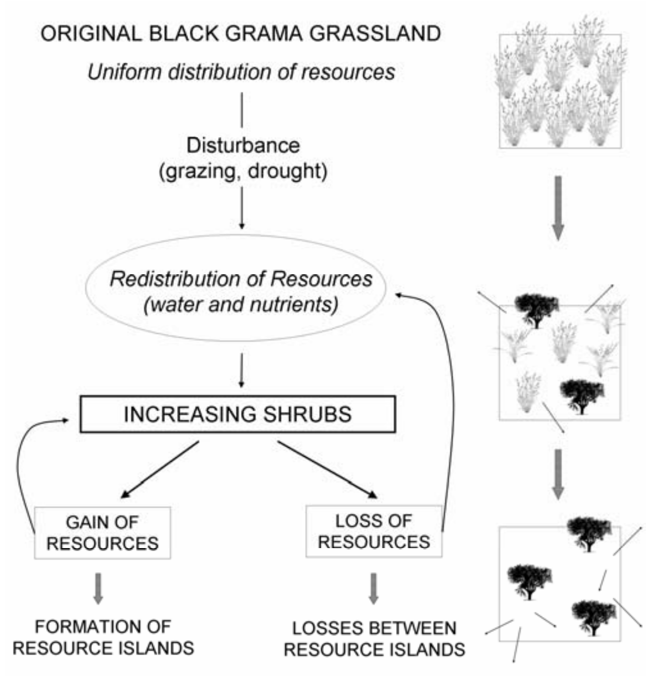

Fig. 1-3. A model of autogenic factors that lead to the development of soil resource heterogeneity and to desertification of desert grasslands.

increase, and persistence of shrubs. In this teeter-totter model, the patchy distribution of soil resources leads to heterogeneity in the distribution of soil microbial biomass (Herman et al. 1995), nematodes (Freckman and Mankau 1986), and microarthropods (Santos et al. 1978). The patches of soil fertility created by plants and animals are preferred sites for the establishment of shrubs (Chew and Whitford 1992; Silvertown and Wilson 1994; see also chapter 12). Barren areas between shrubs are increasingly subject to the physical removal of soil resources by water and wind erosion and the potential for long-term depletion or loss of soil nutrients (Ritchie et al. 2003).

Beyond our studies of the causes of degradation in southern New Mexico, we were also interested in its regional effects. Using the Jornada as an example, we have postulated the role of deserts in determining regional to global characteristics of the Earth's climate and biogeochemistry (Schlesinger et al. 1990; see also chapter 7). Loss of vegetation raises regional albedo as well as regional air temperatures (Bryant et al. 1990). Barren soils are a source of windborne dust, which can affect the radiative balance of the planet, depending on the mineralogy of dust and its persistence in the atmosphere (Tegen and Fung 1995; Sokolik and Toon 1996; Okin 2002; see also chapter 9). Loss of vegetation lowers the infiltration of rainfall, leading to higher runoff losses of rain water, greater losses of soil nutrients, and the persistence of regional desertification (Abrahams et al. 1995; see also chapters 5, 6, and 7). Thus studies in the Jornada Basin treated both cause and effect relationships associated with the shrub invasion of desert grassland habitats. Now in the twenty-first century, our research group and its collective missions have continued to evolve.

Our general research objectives now are (1) to understand and explain historic landscape scale dynamics characteristic of arid lands, (2) to understand current landscape structure and function, and (3) to predict future dynamics, including those of managed landscapes (Peters and Havstad 2005). All of these objectives still provide a base from which to develop strategies to manage arid lands and restore degraded areas, and our work has been providing these strategies and practices (Bestelmeyer et al. 2005; Herrick et al. 2005).

Conclusions

This book describes many of the basic processes operating over time and within and among the communities of the Jornada Basin. These descriptions and understandings should translate to other arid ecosystems around the world. Yet,these desert systems actually are intricate, interactive, and connected sets of patches within communities within sites within landscapes and within regions that are dynamic over time (chapters 16, 17, and 18). Our research group understands that we need to now focus on describing the linkages among these units and identifying important influences on emerging ecosystem dynamics and biotic patterns. We are concentrating on questions of temporal scale and spatial patterns. (Chapter 18). Over recent years, we have effectively linked the research efforts of the LTER and the USDA Agricultural Research Service (which has operated the JER since 1954 as part of the USDA research network) programs into a synergistic set of scientific objectives. This maturation and melding is a logical outcome because these groups share similar goals. This book, with its many coauthored chapters, is evidence of this collaboration. In reading this volume it often may not be evident what research is USDA-, university-, or LTER-based, because there is no longer a distinction in our minds. Given the enormity of arid landscapes not only in this region but around the world, working together to understand how resources are distributed and redistributed across these landscapes and among landscape units is crucial to developing a process-based understanding of the causes and consequences of degradation. Perhaps more important, this understanding will create a basis for both predictions of landscape dynamics and technologies for remediating or restoring degraded conditions.

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