# Chapter 1
# Rangeland Systems: Foundation for a Conceptual Framework

**David D. Briske**

**Abstract** This book describes the conceptual advances in scientific and management knowledge regarding global rangelands in the past 25 years. This knowledge originated from a substantial shift in underlying ecological theory and a gradual progression of natural resource management models. The progression of management models reflects a shift from humans as resource users to humans as resource stewards and it represents the backdrop against which this book has been written. The most influential scientific and sociopolitical events contributing to transformation of the rangeland profession in the past quarter century were recognition of nonlinear vegetation dynamics that solidified dissatisfaction with the traditional rangeland assessment procedure, the introduction of resilience theory and state-and-transition models that provided a conceptual framework for development of an alternative assessment procedure, and the National Research Council's report on Rangeland Health that provided the political support to implement these changes in federal agencies. The knowledge created by this series of interrelated events challenged the traditional concepts developed decades earlier and provided the space and creativity necessary for development of alternative concepts. In retrospect, these conceptual advances originated from the ability of the rangeland profession to progress beyond the assumptions of equilibrium ecology and steady-state management that directly contributed to its inception 100 years ago. A more comprehensive framework of rangeland systems may enable management agencies and educational, research, and policy-making institutions to more effectively develop the capacity to address the challenges confronting global rangelands in the twenty-first century.

**Keywords** Drylands • Natural resource management • Rangelands • Range science • Resilience-based management • Steady-state management

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## 1.1 Introduction

This book summarizes the current state of scientific and management knowledge regarding global rangelands and the major challenges that confront them. Current knowledge is assessed relative to changes that have occurred within rangeland ecology, management applications, and, more broadly, global events that have influenced rangelands. A widely accepted philosophical interpretation of scientific advancement notes that progress is often gradual and incremental as prevailing theories are explored and refined (Kuhn 1996). These periods of incremental progress, however, are periodically interrupted by major changes in underpinning theories that are termed scientific revolutions. This proved to be the case for range ecology and the discipline of ecology in the 1970s and 1980s when the prevailing theory of ecological equilibrium was challenged by a more dynamic nonequilibrium interpretation (Briske et al. 2003). Whether or not this represented a scientific revolution remains in dispute, but there is no question that it introduced a period of rapid conceptual change for the rangeland profession.

Perhaps more pertinent to the goal of this book is that the development of this new knowledge broadly paralleled the progression of natural resource management models based on human–natural resource interactions. These models are envisioned to sequentially progress with time following human settlement and societal development from humans as natural resource users to humans as natural resource stewards (Chapin et al. 2009). Consequently, changes in the perception of how humans interact with nature contribute to different knowledge needs and management strategies to maintain the supply of desired natural resources.

Natural resource exploitation is an anticipated outcome following a long period of low-impact preindustrial human use (Fig. 1.1). Exploitation of US rangelands, prompted by the perception of limitless open-access resources, did occur in response to excessive livestock grazing in the late nineteenth and early twentieth centuries. This period of exploitation and subsequent natural resource degradation was termed the “range problem” in the southwest USA, and it directly contributed to development of the rangeland profession (Sayre et al. 2012; Sayre 2017). Exploitation was followed by development of steady-state management that attempts to maximize sustainable yield of specific goods that are most highly valued. This model is implemented through the control of ecosystem variation—fire suppression, predator control, and fencing—to optimize production of desired goods, on the basis of broad ecological principles that are administered through command and control management by various state or national agencies (Table 1.1).

Recognition that effective management needed to consider entire ecosystems, including their inherent variation, and a societal demand for more diverse ecosystem services promoted development of the ecosystem management model. The ecosystem management model—focused on planning for integrated ecosystems as well as solicitation of more diverse stakeholder feedback—originated in the 1970s and was

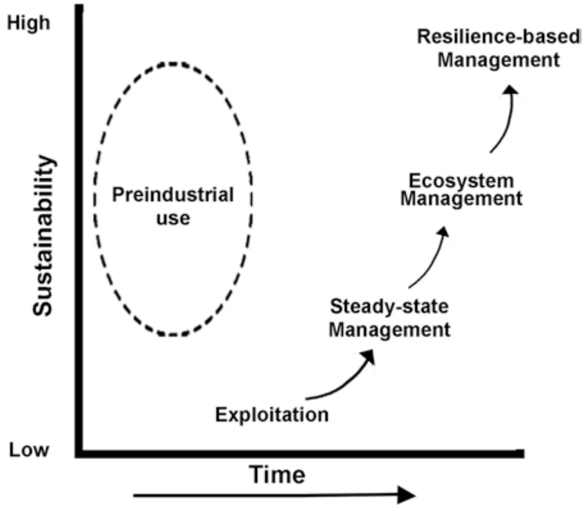


**Fig. 1.1** Progression of natural resource management models following human settlement (redrawn from Chapin et al. 2009)

**Table 1.1** Seven distinguishing attributes of steady-state, ecosystem, and resilience-based natural resource management models[a]

| Attribute | Steady-state management | Ecosystem management | Resilience-based management |
|---|---|---|---|
| Ecological models | Succession-retrogression | State-and-transition, rangeland health | Multiple social–ecological systems/ novel ecosystems |
| Reference condition | Historic climax plant community | Historic climax plant community, including historical range of variation | Landscapes with maximum options for ecosystem services |
| Role of humans | Use ecosystems | Part of ecosystems | Direct trajectories of ecosystem change |
| Ecosystem services | Meat and fiber products | Several ecosystem services | Options for diverse ecosystem services |
| Management goals | Sustain maximum yield of commodities | Sustain multiple uses | Sustain capacity of social–ecological systems to support human well-being |
| Science-management linkages | Top-down from management agencies | Top-down from management agencies | Multi-scaled social learning institutions |
| Knowledge systems | Management experience and agricultural experiments | Multidisciplinary science and ecological experiments | Collaborative groups, spatially referenced, updatable databases |

[a]From Bestelmeyer and Briske (2012)

widely adopted in the 1990s, especially by natural resource management agencies in the USA (Quigley 2005). Subsequently, ecosystem management has introduced associated concepts that include adaptive management and ecosystem services (Nie 2013). A more recent model—resilience-based management—is currently being developed and explored to provide a more effective means for managing natural resources (Chapin et al. 2009, 2010). This model recognizes the inevitability of change and seeks to guide change to sustainably provide multiple ecosystem services for society. Successive development and implementation of steady-state management, ecosystem management, and, most recently, resilience-based management represent the backdrop against which this book has been written.

## 1.2 Extent, Distribution, and Societal Value

Rangelands represent the most extensive land cover type on Earth. Many definitions of rangelands exist, but most address both a land cover type, associated with vegetation or biome, and a land use that primarily emphasizes grazing or pastoralism (Lund 2007) (Text Box 1.1). Although varying definitions of rangelands are presented in the following chapters, they all contain one or both of these characteristics. Rangelands were placed within the drylands category of the Millennium Ecosystem Assessment that includes cultivated land, scrublands, shrublands, grasslands, savannas, semideserts, and true deserts (MA 2005). Drylands are defined as being limited by soil water, the result of low rainfall and high evaporation, and show a gradient of increasing primary productivity, ranging from hyperarid, arid, and semiarid to dry subhumid areas (Fig. 1.2). The ratio of annual precipitation to annual potential evapotranspiration is termed the aridity index and it is less than 0.65 for drylands. Although the majority of rangelands exist within the dryland category, a portion also occur in wetter regions, and high-latitude and high-elevation grasslands and tundra.

Drylands are estimated to occupy 41 % of the Earth's land area (6 billion hectares), 69 % of which are rangelands, and support 2 billion humans and 50 % of global livestock (MA 2005). This is an area 1.5 times larger than all forests combined and nearly three times greater than cropland (Reid et al. 2008). Given their expansiveness and heterogeneity, rangelands provide numerous ecosystem services including biodiversity, carbon sequestration, and cultural values, in addition to the provisioning services of food, fiber, and fuel. Limited and highly variable resource availability, both ecological and socioeconomic, makes these systems and their human inhabitants highly vulnerable to both ecological and social disruption. Approximately 73 % of drylands are affected by accelerated soil degradation and 10–20 % of drylands are currently degraded (MA 2005). Human populations inhabiting drylands lag far behind the rest of the world in terms of human well-being and development indicators; 90 % of the inhabitants reside in developing countries (MA 2005; Chapter 17, this volume).

**Text Box 1.1: Chronology of Major Rangeland Definitions**

"From the 100th meridian to the Pacific," "one of the most important economic uses is the grazing of livestock," and "climatic conditions do not, in most localities, favor the production of farm crops" are the phrases that A.W. Sampson used to refer to rangelands in his book entitled "Range and Pasture Management," 1923, p. 4.

Rangelands are those areas of the world, which by reason of physical limitations—low and erratic precipitation, rough topography, poor drainage, or cold temperatures—are unsuited to cultivation and which are a source of forage for free-ranging native and domestic animals, as well as a source of wood products, water, and wildlife. Range Management, Stoddard et al. (1975, p. 3).

All territories presently used as grazing lands, which are accounted for in yearly FAO statistics as well as other nonagricultural, largely unoccupied, drylands which are used only occasionally by nomadic pastoralists or are presently unused at all. United Nations Environment Program 1991 (cited in Lund 2007).

Rangeland is a type of land that supports different vegetation types including shrublands such as deserts and chaparral, grasslands, steppes, woodlands, temporarily treeless areas in forests, and wherever dry, sandy, rocky, saline, or wet soils; and steep topography precludes the growing of commercial farm and timber crops. Rangeland Ecology and Management, Heady and Child (1994, p. 1).

An area where wild and domestic animals graze or browse on uncultivated vegetation. FAO (2000).

Rangeland is defined as "uncultivated land that provides the necessities of life for grazing and browsing animals." Range Management: Principles and Practices. Holechek et al. (2011, p. 1).

Rangelands are a type of land (not just land grazed by livestock) on which natural vegetation is dominated by grasses and shrubs and the land is managed as a natural ecosystem. UNCCD (2011).

"Land supporting indigenous vegetation that either is grazed or that has the potential to be grazed, and is managed as a natural ecosystem. Range includes grassland, grazable forestland, shrubland and pastureland." SRM Glossary of Terms 1998, updated 2015.

## 1.3 Events Contributing to Rapid Conceptual Advancement

A large number of conceptual advances began to occur in the late 1980s, after a 50-year period of minimal conceptual change, to markedly transform the rangeland profession. These advances originated from scientific events both internal and external to the profession, as well as sociopolitical events motivated by dissatisfaction with the prevailing method of rangeland assessment. These major events and conceptual advances, along with their contribution to the

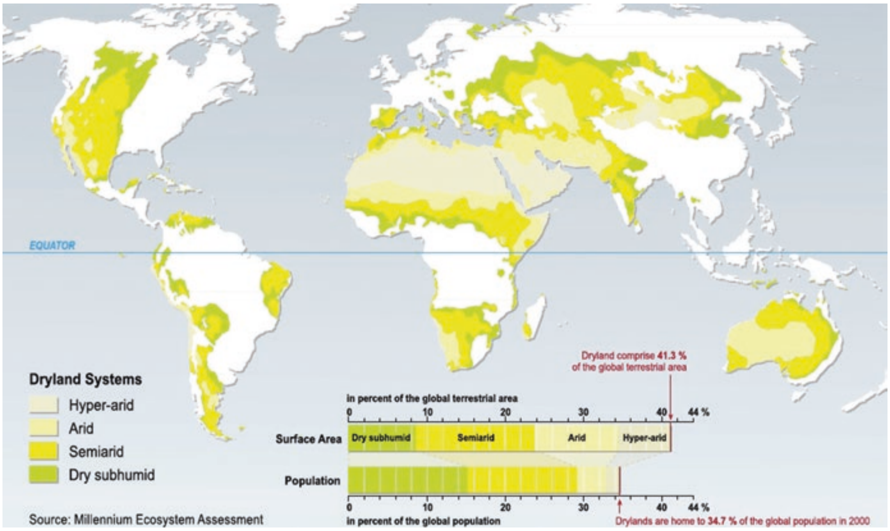


**Fig. 1.2** Distribution of global drylands as classified by the UNCCD (Millennium Ecosystem Assessment (2005))

progression of natural resource management models previously described, are summarized in the following sections (Table 1.1, Fig. 1.3). This section examines the professional legacies that have influenced our current, and potentially our future, perceptions of rangelands.

### *1.3.1 Internal to the Profession*

*Scientific*—A foundational concept of the US rangeland profession in the twentieth century was range condition and trend analysis (the range model). It was founded on plant successional theory developed by the influential early American ecologist Fredric E. Clements in 1916. The range model broadly assumed that livestock grazing counteracted plant succession to establish the species composition of plant communities in a linear response to the severity of livestock grazing (Briske et al. 2005). Arthur Sampson, a former student of Clements at the University of Nebraska, introduced succession as a conceptual framework for rangeland assessment in 1917. The adoption of successional theory—an equilibrium concept—was considered a major conceptual advance by rangeland professionals in the early twentieth century. It had a profound influence on the rangeland profession by directly linking it to equilibrium ecology and by indirectly contributing to the steady-state management model of natural resource management. Dyksterhuis (1949) further secured succession in the foundation of rangeland science by operationalizing the range model on a quantitative basis. The range model provided the standard assessment procedure for approximately 50 years (Fig. 1.3).

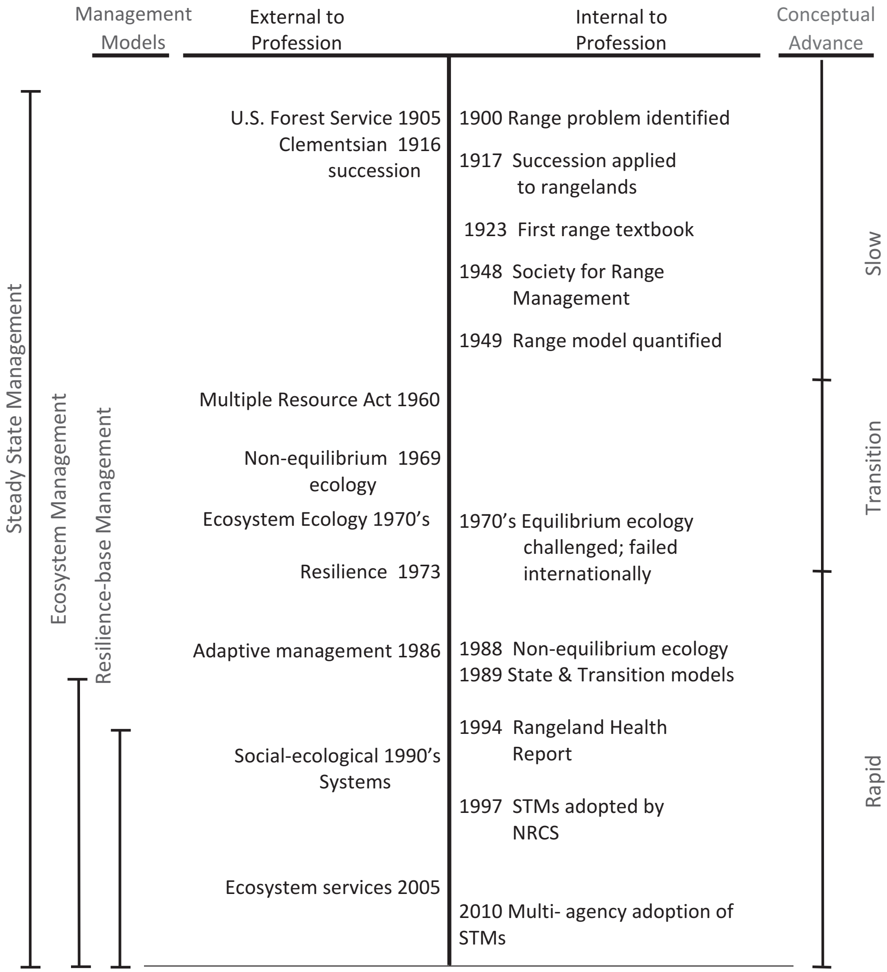


**Fig. 1.3** Timeline of major events and conceptual advances that have contributed to development of the rangeland system framework described in this chapter and throughout the entire book. The relative rate of conceptual advances is shown on the *right* and the successive emergence of natural resource management models on the *left*

However, both the range model and successional theory encountered severe criticism by both Australian and US rangeland scientists in the 1970s and 1980s. This criticism was primarily founded on recognition that the rate and extent of woody plant expansion was not solely a consequence of grazing intensity and that removal of grazing did not necessarily prevent or reverse woody plant encroachment (Westoby et al. 1989; Laycock 1991). This ecological outcome was inconsistent with the assumptions of the range model and it provided a strong justification for development of an alternative model to more accurately interpret observed vegetation dynamics and to more effectively support rangeland management.

A second source of criticism occurred when the concepts of range science that had been developed in the USA, including the range model, were applied to pastoral systems on other continents. International development programs recognized that these Western concepts had limited application to pastoral systems in the late 1970s (Sayre 2017). The international scope of this knowledge proved to be extremely valuable by assessing range science through the lens of pastoral societies where private lands and market-oriented goals were of limited relevance (Reid et al. 2014). Research in arid pastoral systems indicated that plant production and livestock numbers were seldom in equilibrium because periodic multiyear drought prevented livestock numbers from attaining the maximum carrying capacity established by plant production (Ellis and Swift 1988). This also contributed to management and policy recommendations that rejected the equilibrium-based concepts on which Western range science was founded.

*Sociopolitical*—Growing dissatisfaction with the range model, as well as inconsistent rangeland assessment procedures among the major US federal agencies, contributed to the development of political pressure to devise a more ecologically relevant and consistent assessment procedure. The National Research Council (NRC) published the "Rangeland Health Report" in 1994 that broadly outlined an alternative rangeland assessment to replace the highly criticized range model. Shortly following the publication of this influential report, a group of rangeland specialists within the NRCS made the bold decision to adopt this alternative assessment procedure and began development of state-and-transition models within the framework of Ecological Site Descriptions.

A memorandum of agreement was signed by the NRCS, US Forest Service (USFS), and Bureau of Land Management (BLM) in 2010 to use Ecological Site Descriptions as the major procedure for rangeland assessment to successfully fulfill the recommendation of the NRC report. The NRC Report provided political motivation for change, especially within the federal agencies. However, the conceptual framework for development of an alternative assessment procedure was based on the influential paper of Westoby, Walker, and Noy-Meir entitled "Opportunistic Management for Rangelands not at Equilibrium" that was published in the Journal of Range Management in 1989. It is this series of events that propelled nonequilibrium ecology beyond equilibrium ecology as the dominant theory underpinning the rangeland profession.

Interest in range science educational programs in Western universities of the USA began to wane during this period and student enrollment declined drastically in some cases. Greater societal demands from rangelands and increasing complexity of natural resource management had exceeded the capacity of the traditional range science curriculum to effectively address them. This trend was also occurring in other natural resource disciplines that had originated with the assumptions of simplicity, predictability, and manageability that characterized steady-state management last century (Holling and Meffe 1996; Thurow et al. 2007).

The close association of range science with livestock grazing, both real and perceived, further minimized the value of range science as multiple resource use and ecosystem management began to develop. Declining student enrollment in many natural resource management disciplines led to consolidation of academic programs, including many range science departments that were merged with those of related disciplines (Abbott et al. 2012). However, these events contributed to the integration and broadening of academic curricula and research programs that were more inclusive of multiple disciplines. Although the rangeland profession was multidisciplinary from its inception, the contributions of the allied disciplines were often narrowly confined by prevailing perceptions within the rangeland profession.

Development of a more diverse multidisciplinary range science curriculum that included systems ecology, landscape ecology, spatial sciences, and biogeochemistry contributed to a knowledge base that has brought range science into closer alignment with the concepts and theories of its related disciplines. The Grassland Biome Project of the International Biological Program promoted ecosystem ecology as a research focus in the late 1960s and early 1970s and introduced subsequent generations of US and Canadian grassland and rangeland ecologists to this systems-oriented approach (Smith 1968). The past 25 years have witnessed an important generational turnover of researchers and managers that has introduced broader, multidisciplinary perspectives, and new scientific, technological, and communication skills that extend far beyond the traditional perspectives of the twentieth-century rangeland profession.

In some cases, professionals with degrees in disciplines other than range science were employed to further expand this knowledge base. It was also during this period that social scientists who had been studying pastoral societies and peoples began to interact with biophysical scientists to create a more comprehensive interdisciplinary framework for investigating rangeland systems (Reid et al. 2014). This provided necessary knowledge of the people that inhabit rangelands, including their culture, social structure, and livelihoods. These events collectively created both the scientific capacity and creative space for reassessment and exploration of alternative perspectives, interpretations, and concepts that contributed to this period of rapid change (Fig. 1.3).

### *1.3.2 External to Profession*

*Scientific*—Resilience is undoubtedly the major scientific theory that contributed to the transformation of range science. Resilience was introduced in 1973 by C.S. Holling in an attempt to reconcile ecosystem dynamics with the prevailing concept of ecological stability. Resilience recognizes that ecosystems can exhibit dynamic behavior, and yet retain their general structure and function, and that alternative stable ecosystems may be formed in cases where resilience of the initial ecosystem has been exceeded. However, it took another 16 years before resilience was introduced to the rangeland profession (Westoby et al. 1989) and nearly another 10 years before it was incorporated into rangeland assessment. It continues to be developed as a central component of the rangeland profession (Bestelmeyer and Briske 2012; Herrick et al. 2012). Resilience theory is currently replacing nonequilibrium ecology as the dominant theoretical concept because what was previously considered nonequilibrium is now more appropriately interpreted as multiple equilibria in many cases (Petraitis 2013; Chapter 6, this volume). Resilience is also used to describe “a way of thinking,” in addition to a property of ecological systems, especially in reference to social–ecological systems.

Recognition of the importance of spatial scales to ecological processes and ecosystem dynamics also had a profound influence by shifting emphasis from small plots to a broader landscape perspective (Turner 1989). The concept of social–ecological systems emerged in the 1990s to emphasize the strong linkage that existed among ecological and social components (Berkes and Folke 1992). This goes beyond simply stating that humans are dependent upon nature to emphasize that ecological and social systems are tightly integrated with many complex and poorly understood interactions that directly influence natural resource management.

Rangeland research priorities were further modified by major changes in funding sources beginning in the early 1990s. Research programs shifted from single-scientist projects funded by land-grant institutions and agricultural experimental stations to much larger, multidisciplinary programs that emphasized broader and more contemporary natural resource management issues identified by federal funding agencies (Thurow et al. 2007). A portion of these federal grant programs required that research include extension or education personnel, and some required direct stakeholder engagement to further ensure that research outcomes had practical application. This provided a strong incentive that moved range science toward more effectively integrated, multidisciplinary research programs that ultimately contributed to a portion of the conceptual advances summarized in this book.

Although this shift in research funding has enhanced the scientific capacity of the rangeland profession, concern has been expressed that it may have reduced management emphasis and expertise (Abbott et al. 2012). However, the rangeland CEAP assessment that was organized by the NRCS to evaluate the effectiveness of rangeland conservation practices indicated that the benefits of these practices that had been developed decades earlier were largely undocumented (Briske 2011). This was primarily a consequence of minimal monitoring of practice outcomes and the assessment further concluded that previous research had provided only modest support for management and policy recommendations. Consequently, this shift in research emphasis driven by research funding may potentially introduce greater, rather than less, management-relevant science, especially when federal grant programs require stakeholder involvement and demonstration of research application. This indicates that the management model in which knowledge is implemented is as important as the knowledge itself.

*Sociopolitical*—The steady-state model of natural resource management was developed early last century and it is still widely implemented today (Table 1.1, Fig. 1.3). This model attempts to maintain ecosystems in a single state through the implementation of management practices and policies that are applied in a command and control manner to efficiently optimize production of one or a few select ecosystem services

(Holling and Meffe 1996). The steady-state model began to be challenged in response to an increasing incidence of natural resource management failures and societal demand for more diverse ecosystem services. The publication of academic papers entitled "The pathology of natural resource management" (Holling and Meffe 1996) and "The era of management is over" (Ludwig 2001) was a direct challenge to steady-state management that has continued to the present. In many respects the major conceptual advances that range science has made in the past 25 years are a consequence of its ability to progress beyond the assumptions of equilibrium ecology and steady-state management that directly contributed to its inception 100 years ago.

Expanding societal awareness of the value of rangelands and greater demands for diverse services from them, especially those held in the public domain, required that federal land management agencies develop more comprehensive objectives following passage of the Multiple Use Act in 1960 (Holechek et al. 2011). The ecosystem management model emerged in the late 1970s in response to recognition that entire ecosystems, including their inherent variation, were appropriate units for natural resource management (Koontz and Bodine 2008; Nie 2013) (Table 1.1). By the mid-1990s all four of the major federal natural resource management agencies in the USA had adopted this model. This raised a new set of social, as well as ecological, questions and challenges regarding natural resource management that had not previously been considered. Consider that the initial definitions of range management provided by Stoddart and Smith in the first (1943) and second (1955) editions of the text book "Range Management" make reference to "obtaining maximum livestock production" which is consistent with steady-state management previously described (Text Box 1.2). It wasn't until the third edition in 1975 that this definition was modified to "optimize returns from rangelands in those combinations most desired and suitable to society." Heady (1975) introduced a similar definition in the text "Rangeland Management" that same year. These expanded definitions are indicative of a shift from the steady-state management to the ecosystem management model.

Use of the term ecosystem management rapidly declined in the early 2000s likely in response to its ambiguous definition, multiple interpretations, and numerous barriers encountered in its implementation (Nie 2013). However, several of its major components—stakeholder engagement, adaptive management, and restoration—continue to shape natural resource management and planning. Resilience-based management appears to have adopted some of the most effective components of the ecosystem management model (Table 1.1). This management model embraces the inevitability of ecological and social change and emphasizes that management should anticipate and guide change, rather than minimize it, to sustainably provide society with desired ecosystem services (Chapin et al. 2009, 2010; Bestelmeyer and Briske 2012). It seeks to address uncertainty and incomplete knowledge through the involvement of diverse stakeholders to develop adaptive capacity, rather than static management prescriptions and regulations, to maintain resilient systems.

**Text Box 1.2: Chronology of Major Range Management Definitions**

"The science and art of planning and directing range use so as to obtain the maximum livestock production consistent with conservation of the range resource"—Range Management. Stoddart and Smith (1943, p. 2).

"The science and art of obtaining maximum livestock production from range land consistent with the conservation of the land resources"—Range Management. Stoddart and Smith (1955, p. 1).

"The science and art of optimizing the returns from rangelands in those combinations most desired by and suitable to society through the manipulation of range ecosystems"—Range Management. Stoddard et al. (1975, p. 3).

"Land management discipline that skillfully applies an organized body of knowledge know as range science to renewable natural resource systems for two purposes: (1) protection, improvement, ad continued welfare of the basic range resource, which may include soils, vegetation, and animals; and (2) optimum production of goods and services in combinations needed by mankind"—Rangeland Management, Heady (1975, p. 4).

"The manipulation of rangeland components to obtain optimum combination of goods and services for society on a sustained basis"—Holechek et al. (1989, p. 5). This definition has been retained in all subsequent editions.

"A distinct discipline founded on ecological principles and dealing with the use of rangelands and range resources for a variety of purposes. These purposes include use as watersheds, wildlife habitat, grazing by livestock, recreation, and aesthetics, as well as other associated uses." SRM Glossary of Terms 1998, updated 2015.

## 1.4 Section Perspectives

All three sections of this book—processes, management, and challenges—summarize concepts that did not exist 25 years ago, and those few that did have been greatly modified and refined, which is indicative of the rate at which science and global events have advanced. This rapid change also parallels the progression of natural resource models previously described through greater understanding of human dependence and impact on natural resources (Table 1.1, Fig. 1.3).

### *1.4.1 Processes Section*

The processes section outlines a comprehensive and in-depth understanding of ecological knowledge that has challenged and, in some cases, replaced traditional assumptions and concepts. The chapters in this section reflect the global significance of rangeland processes and indicate that accelerating global change will further amplify the inherent variability and uncertainty inherent to rangelands. Ecological processes are the source of multiple ecosystem services that society demands from rangelands, including the provisioning services of food, fiber, and fuel.

A greater understanding of belowground processes, including the structure and function of microbial communities, has increased insight into the contribution of soils in rangeland systems, and their significance in global biogeochemical cycles. Hydrological processes are central to the function of arid and semiarid rangelands and their close coupling with vegetation makes them very sensitive to natural disturbances and human activities. Woody plant encroachment has occurred in many rangelands throughout the globe to modify not only vegetation structure, but also ecological processes that create trade-offs among important ecosystem services. Heterogeneity, diversity, and variability are envisioned to possess inherent value and the occurrence of ecological processes over diverse spatial and temporal scales has been recognized to produce important ecological outcomes. Resilience theory has provided an interpretation of how ecosystems can be dynamic, but persist as self-organized systems, and climate change science provides valuable projections of how ecosystems may be impacted by these changes in the future.

### *1.4.2 Management Section*

The management section emphasizes the transition of humans from users to stewards of natural resources within the context of social–ecological systems. Management is used in a broad context to reference landscape and regional scales, in addition to smaller "pasture" scales, to optimize land-use decisions for both landowners and society at large. The content of these chapters cautions that we must learn from past professional experiences, but stand ready to move beyond them to explore alternative approaches and to create innovative solutions. For example, rapidly increasing global demand for animal protein requires development of more efficient livestock production systems while minimizing their adverse ecological consequences. State-and-transition models are widely used to support rangeland management and they continue to undergo further refinement to increase their management utility.

Management decisions are often made under conditions of inherent uncertainty and risk that require systematic approaches to inform decision-making processes under these circumstances. Adaptive management has been developed to address these challenges, but its application has been limited by both insufficient management-relevant science and the inability of institutions to support its implementation. A consensus is emerging that collaborative learning and collective action are required among diverse stakeholders to produce useable knowledge, increase adaptive capacity, and maintain resilience of rangeland systems.

### *1.4.3 Challenges Section*

The challenges section emphasizes that future events may surpass previous human experience regarding adaptation to changing climatic, ecological, and socioeconomic conditions. Surprises occur when unanticipated outcomes originate from threshold conditions, extreme events, and unrecognized drivers external to the system. A primary challenge will be to determine the types of changes that are desirable and beneficial and to implement them in a manner that does not create other problems or degrade rangeland resources. Invasive species continue to alter the structure and function of rangeland systems and ecosystem services supplied, and in some cases these transformations may be irreversible. Invasive plant management has adopted an ecosystem perspective to contend with this accelerating biotic challenge. Ecosystem services, including those that do not currently possess economic market value, are being explored as a means to recognize and evaluate trade-offs and create win-win outcomes regarding land-use decisions.

Changing socioeconomic conditions have required that pastoralists throughout the world become more sedentary which undermines the traditional risk aversion strategy of livestock mobility. Knowledge of rangelands and their human inhabitants in developing countries has rapidly increased, but numerous barriers exist to its implementation to improve rangeland resources and human well-being. The development of cost-effective, large-scale monitoring of rangeland resources will be a considerable challenge for implementing effective management and policy decisions.

## 1.5 Foundation for a Rangeland Systems Framework

Range management has focused on prescribed management practices to a much greater extent than management approaches or strategies to achieving desired outcomes (Text Box 1.2). The limited development of management approaches has been highlighted by the introduction of adaptive management—an approach to management that emphasizes structured learning through decision making for situations where knowledge is incomplete and managers must act despite uncertainty (Chapter 11, this volume). Limited management strategies may be a consequence of the heterogeneous environmental and managerial conditions encountered on rangelands that necessitates development of broad principles. However, the application of prescribed practices appears to be more consistent with administrative regulation than it does with an effective approach for addressing heterogeneity.

Limited development of well-defined management strategies may have partially resulted from the regulatory origins of the profession to minimize rangeland exploitation, initially by the US Forest Service (Sayre 2017). Emphasis on “prescribed” management practices—stocking rates, fencing of pastures, and grazing seasons—by land management agencies enabled them to retain authority over users of public land in a manner that is consistent with command and control management.

These practices were initially designed to minimize livestock impacts based on the assumption that they were the key variable influencing rangeland—controlling livestock equated to controlling ecosystems. In addition, the economic benefits that fencing and predator control provided by reducing labor costs for herders may have also reinforced "management by practice" (Sayre 2015). Consequently, the need for management to control rangeland exploitation, support agency authority, and produce economic value directly contributed to the development of range science—not the other way around (Sayre 2017).

The occurrence of these events early in the rangeland profession may partially explain why "management practices" have to some extent become synonymous with range management. This perspective is evident in the phrase "manipulation of rangeland components" that is used to define range management in a widely used textbook (Holechek et al. 2011). Even though it is obvious that practices do not equate to management—the process of *deciding* how to allocate finite resources—consider how prevalent practices are in a management context. For example, the USDA-NRCS Environmental Quality Assessment Program (EQIP)—a voluntary cost share program to enhance conservation on private rangelands—is primarily organized around the selection and implementation of practices in the context of broader conservation planning (Briske 2011). The implementation of prescribed practices and their management have made major contributions to rangeland conservation in the twentieth century, but the Rangeland CEAP Assessment indicated that documentation of these outcomes was extremely limited (Briske 2011). Another important constraint of "practice-based" management is that it enforces a small-scale "pasture" focus that precludes assessment within landscapes and regions where many of the most pressing challenges exist.

Provenza (1991) cautioned that range *science* was dominated by managerial issues that limited progression of the science in an editorial written 40 years after the profession had been formally founded. This is consistent with the interpretation that the rangeland profession originated from the need for management action to resolve immediate practical problems, rather than from the establishment of sound scientific principles (Sayre 2017). However, the conceptual advances that have occurred in the past 25 years may have differentiated management and science to the greatest extent in the history of the profession. Ironically, these concepts have also provided the approaches and justification—social–ecological systems, adaptive management, and resilience-based management—for integrating these two important knowledge sources. This represents a pressing challenge for which no solution or approach has yet emerged.

Collectively, these considerations make a compelling case for development of a more comprehensive framework to assess rangelands and to implement management. Definitions emphasizing land cover type and land use are narrowly focused on biophysical systems and do not recognize the social component of these systems (Reid et al. 2014; Chapter 17, this volume). The content of these chapters collectively indicates that neither ecological nor social knowledge alone is sufficient to effectively assess or manage rangeland systems because of the highly integrated nature of the social and ecological subsystems (Chapter 8, this volume). A new management framework is required to place greater emphasis on social components, including cultural values, land tenure, governance systems, and markets, that interact with ecological systems to influence the value, availability, and use of rangeland resources. Adaptive management and collaborative adaptive management—adaptive management among multiple stakeholder groups—represent essential approaches to a more comprehensive management framework.

The inability of the rangeland profession to resolve debates concerning intensive rotational grazing, shrub removal versus water yield, and wild horse and burro dilemma on public lands in the western USA is symptomatic of a narrow management framework that does not possess the capacity to effectively address the social components of these systems (Briske et al. 2011; Boyd et al. 2014). Similarly, the implementation of well-intended, but inappropriate, policy throughout the world has contributed to rangeland fragmentation, degradation, and conversion (MA 2003). These adverse consequences occur for numerous reasons, but they often result because the potential trade-offs and consequences were not recognized prior to policy implementation.

This questions whether current management approaches possess sufficient capacity to contend with future challenges confronting global rangelands. These seemingly intractable management dilemmas demonstrate that a framework is required that can keep pace with the increasing scope and complexity of natural resource management. In contrast to "practice-based" management, the comprehensive approach to collaborative adaptive management that was used to address the proposed listing of the greater sage grouse (*Centrocercus urophasianus*) as a threatened species in the western USA has been viewed as being highly successful (Boyd et al. 2014). A successful outcome to this complex, regional natural resource concern lends credibility to the emerging natural resource management model of resilience-based management.

Resilience-based management involves the development and implementation of strategies that support human well-being via adaptation and transformation of social–ecological systems to sustain the supply of ecosystem services in changing environments (Chapin et al. 2010; Chapter 6, this volume). This management model acknowledges both the dependence and impact that humans can have on natural resources and the ecosystem services they provided. It also cautions managers and scientists to exhibit greater humility regarding the management of natural resources, than that conveyed by the linear and predictable outcomes inherent to the steady-state management model. The emerging reality of natural resource management is one of increasing management complexity, disputed values, and incomplete knowledge (Benson and Craig 2014).

Incorporation of the concepts presented in this book—namely, ecosystem services, structural heterogeneity, and social–ecological systems—into a management context has been slow—although resilience is a clear exception. The primary challenge may reside in the fact that these concepts are more consistent with resilience-based management than they are with the steady-state management model. Therefore, management must learn to not only adopt new concepts, but also transition between natural resource management models to effectively incorporate new knowledge. However, concepts and experience with the ecosystem management model may serve to bridge this transition in some cases (Nie 2013). In addition, resilience-based management empowers diverse stakeholders to bring unique knowledge, goals, and values to decision-making processes. Integrating human dimensions into natural resource management will require expertise and methodology from the social sciences, which is currently underrepresented in the rangeland profession, and this has likely slowed concept adoption as well.

The Drylands Development Paradigm describes a set of management and policy recommendations that are consistent with resilience-based management (Reynolds et al. 2007). Five principles of this paradigm follow: (1) social–ecological systems are coupled, dynamic, and co-adapting with no single target equilibrium point; (2) critical system dynamics are determined by several slow or controlling variables; (3) controlling variables possess thresholds that, if crossed, cause the system to reorganize as a new state; (4) stakeholders are networked across multiple organizational levels in social–ecological systems to produce cross-scale interactions; and (5) "hybrid" knowledge that integrates management and policy experience with scientific knowledge must be developed and legitimized by relevant social institutions. Collectively, these principles are in direct contrast to those of the steady-state management model that is interwoven with the origins of the rangeland profession (Table 1.1). This provides further insight into the magnitude of the challenge associated with the transition from the steady-state management to the resilience-based management model.

This compilation of major conceptual advances provides an opportunity to envision a more comprehensive framework for rangeland systems that is capable of designing and implementing management strategies for landscape and regional applications. The following definitions of rangeland systems and management could provide the foundation for an alternative framework. *Rangeland systems* represent ecological systems supporting native or naturalized vegetation characterized as grasslands, shrub steppe, shrublands, savannas, and deserts that are managed as adaptive social–ecological systems to provision multiple ecosystem services to benefit human well-being. These systems function through complex interactions among social and ecological subsystems, at multiple scales, to influence supply, demand, and preferences for ecosystem services (Chapters 8 and 14, this volume). *Rangeland system management* is based on the iterative development of management strategies through collaborative adaptive management among diverse stakeholders, representing management and scientific knowledge, to provision multiple ecosystem services required by society. The outcomes of management strategies are collaboratively monitored and evaluated to provide information feedbacks to enhance subsequent management effectiveness and to promote adaptive capacity of multiple stakeholder groups to support resilient rangeland systems (Chapters 6 and 11, this volume). Development of a framework that can accommodate the concepts that have emerged in the past 25 years to support rangeland systems in the twenty-first century may be the primary challenge confronting the global rangeland community.

## 1.6 Summary

This book describes the advances that have occurred in scientific and management concepts regarding global rangelands in the past 25 years. This knowledge originated from two interwoven themes—a substantial shift in underlying ecological theory and a gradual progression of natural resource management models—the former appears to have been most influential, but the latter may prove most significant over the longer term. The conceptual advances that occurred in the 1980s and 1990s were a reaction to what can be considered the initial conceptual advance in the rangeland profession—the introduction of Clementsian successions as a conceptual framework for rangeland assessment. This had a profound influence on the rangeland profession by directly linking it to equilibrium ecology and by indirectly contributing to the steady-state management model of natural resource management.

However, both the initial procedure for rangeland assessment and successional theory, on which it was founded, encountered two broad categories of criticism in the 1970s and 1980s. The first was recognition of nonlinear vegetation dynamics which was inconsistent with both concepts. The second category of criticism occurred in response to the failure of range science concepts that had been applied to pastoral systems on other continents. These criticisms provided a strong justification for development of an alternative ecological theory to more accurately interpret the dynamics of rangeland vegetation and to more effectively support rangeland management. Two alternative models emerged simultaneously, but independently, in the late 1980s—the nonequilibrium and state-and-transition models.

The state-and-transition framework was adopted by the rangeland profession in the late 1990s and it has become an important management tool replacing the range model that had been introduced 80 years earlier. However, resilience theory is currently replacing nonequilibrium as the dominant theory because what was previously considered nonequilibrium is more appropriately interpreted as multiple equilibria. It is somewhat ironic that rangeland systems are now considered to have an equilibrial component after the severe criticism that the concept had previously received.

The conceptual advances described above were broadly paralleled by the progression of natural resource management models that reflected a shift from humans as resource users to humans as resource stewards. Although these models are not always obvious—they have a pronounced influence by shaping the perception of human interactions with nature. A major objective of range science in the twentieth century was to develop knowledge in support of the steady-state management model that emphasized the maximum sustainable production of forage and livestock. Recognition that management needed to consider entire ecosystems, including their inherent variation, promoted development of the ecosystem management model. The most recent management model—resilience-based management—is currently being developed and investigated as an extension of resilience theory. Currently, elements of all three management models are in operation to varying degrees.

The conceptual advances presented in this book make a compelling case for development of a more comprehensive framework to assess rangelands and to implement more effective management strategies. This framework could be organized around the following definitions of rangeland systems and rangeland management. *Rangeland systems* represent ecological systems supporting native or naturalized vegetation characterized as grasslands, shrub steppe, shrublands, savannas, and deserts that are managed as adaptive social–ecological systems to provision multiple ecosystem services to benefit human well-being. These systems function through complex interactions among social and ecological subsystems, at multiple scales, to influence supply, demand, and preferences for ecosystem services. *Rangeland system management* is based on the iterative development of management strategies through collaborative adaptive management among diverse stakeholders representing management and scientific knowledge to provision multiple ecosystem services required by society. Development of a framework that is capable of incorporating the concepts that have emerged in the past 25 years to support rangeland systems in the twenty-first century may represent the major challenge confronting the global rangeland community.

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