INVASIVE RANGELAND PLANTS

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Contents

Summary

Invasive plants, often referred to as weeds, have been defined and described in several

ways. Usage of the term invasive species in this chapter will include both native and non-native species. In this chapter we will attempt to describe this successional change and its associated ecological and economic impacts, provide some theoretical explanation for the change, present a theoretical framework for integrating weed management tools, and discuss some categories of invasive rangeland plants and how each may be effectively managed by addressing physiological status and environmental conditions. Finally, we will discuss the future of rangeland successional dynamics as influenced by atmospheric carbon dioxide concentrations and varying environmental conditions. We will attempt to present this material in the context of successional management which is a process-orientated framework for understanding and manipulating plant community dynamics.

1. Introduction

Rangelands are one of the earth's major land types, yet also one of the hardest ecosystems to define due to the variation of plant cover types encompassed by rangelands. Generally, rangeland is a term used to describe land that supports a variety of vegetation types including desert shrublands and chaparral, grasslands, steppes, heathlands, tundras, and open woodlands (<10% tree cover), with grasses and shrubs typically dominating. Rangeland is often found where growing of commercial crops or timber harvest is precluded by dry, sandy, rocky, saline, or wet soil conditions or steep topography. Rangeland was historically used for grazing, both by livestock and wildlife. However, in more recent years rangelands are often defined by multiple uses including mineral extraction, construction materials, wildlife habitat, medicines, preservation of endangered species, anthropological sites, recreation, and wilderness, in addition to traditional grazing use.

Comprising about 50% of the world's land surface, rangelands are an important ecological and economic resource. The World Resources Institute identified rangeland as a ecological reservoir of genetic diversity making up 15% of the Centers of Plant Diversity, 11% of Endemic Bird Areas, and 29% of ecoregions considered outstanding for biological distinctiveness. In the U.S.A. alone rangelands provide forage and habitat for millions of deer, sheep, pronghorn antelope, elk, and many other animals. Healthy rangelands prevent soil loss, promote soil development, store carbon, and contribute to proper nutrient and water cycling. From an economic perspective, the Food and Agriculture Organization of the United Nations (FAO) states that rangelands support billions of livestock, and an estimated 40 million nomadic and pastoral people. Rangeland provides food, fuel, and building materials for many rural communities as well as supporting tourism associated with hunting and wildlife viewing.

Rangeland plant communities are changing. Even though the composition of plant communities in rangeland changes continually through the process of succession (i.e. change in plant community composition and structure through time), in more recent years this change has included invasive, often non-native, species. Invasive plants are one of the greatest threats to rangeland integrity. In fact, rangelands have been identified as being among the global ecosystems that are most affected by weeds. Invasive plants, often referred to as weeds, have been defined and described in several ways. Two of the most common definitions of a weed are a "plant growing where it is not desired" or a "plant out of place" (Klingman 1966). In the U.S.A. a Presidential Executive Order (13112, February 3, 1999) defined invasive species as ". . .*an alien species whose introduction does or is likely to cause economic or environmental harm or harm to human health*." Usage of invasive species in this chapter will include both native and non-native species. In this chapter we will attempt to describe this successional change and its associated ecological and economic impacts, provide some theoretical explanation for the change, present a theoretical framework for integrating weed management tools, and discuss some categories of invasive rangeland plants and how each may be effectively managed by addressing physiological status and environmental conditions. Finally, we will discuss the future of rangeland successional dynamics as influenced by atmospheric carbon dioxide concentrations and varying environmental conditions. We will attempt to present this material in the context of successional management which is a process-orientated framework for understanding and manipulating plant community dynamics.

2. Extent of Invasion and Impacts on Ecological and Economic Systems

Accurate estimates of the extent of rangeland infested by invasive plants on a global scale are very difficult to obtain because many rangelands are sparsely populated and monitoring is relatively poor compared to more human-influenced systems like agricultural crop land. Even quantifying the extent of rangeland on a global scale is difficult! Nonetheless, the area of weed-infested rangeland is increasing. For example, around 2700 non-native plants have become naturalized on Australian rangeland, and South Africa now has 161 invasive species that impact 10 million hectares (8%) of the country. The increase in weed-infested rangeland is partly due to limited economically viable solutions to their management, and the fact that invasive plants on rangelands are often long-lived perennials that form self-perpetuating populations.

Ecological impacts of invasive rangeland plants are complex and poorly understood. However, it is generally assumed that invasive plants are impacting the structure, organization, and function of rangeland plant communities. Invasive plants are a primary threat to biodiversity and may displace native plants. For example, *Bromus tectorum* (cheatgrass) is an annual grass that is displacing native bunchgrasses and shrubs of the Great Basin in the western U.S.A. and now occupies over 40 million hectares in this region. There are several cases in which a native Australian rangeland species is reported to be threatened by either a single or multiple invasive species.

Soils in rangeland dominated by invasive plants may have lower amounts of organic matter and available nitrogen than areas supporting native grasses typical of rangeland. In a study by Evans and colleagues, rangeland invaded by *B. tectorum* increased the amount of litter by 125% compared to native non-invaded rangeland. The [carbon]:[nitrogen] ratio of *B. tectorum* was 100-200% greater as well, primarily due to *B. tectorum* tissue having significantly lower nitrogen content. Increases in bare ground and changes in rooting structure and depth associated with invasive plants may further compromise soil integrity through increased erosion. Because most of the organic matter is concentrated in the upper 3-10 cm of topsoil, any amount of erosion can have long-term implications on productivity and slope stability. Some invasive plants produce secondary compounds that may hinder soil microbiota from feeding on living roots, thus slowing decomposition and mineralization.

As rangeland plant community structure is altered by invasive plants, faunal community structure may be altered as well. Animal species typically co-evolved with particular assemblages of plant species that provided the appropriate habitat. Because plant community structure is altered relatively rapidly during invasion, faunal populations may not be able to respond quickly enough to remain viable. The fauna may reproduce less, reduce population growth, or simply leave or avoid infested rangeland. For example, on rangeland in Texas, U.S.A., that was dominated by the invasive exotic grasses *Eragrostis lehmanniana* (Lehmann lovegrass) and *Cencrhus ciliaris* (buffelgrass), bird and arthropod abundance was significantly reduced compared to rangeland dominated by native grasses. In Theodore Roosevelt National Park (North Dakota, U.S.A.), bison, deer, and elk used areas infested with *Euphorbia esula* (leafy spurge) significantly less than uninfested areas, because the desired forage species were less productive and the animals simply avoided infested areas.

Invasive rangeland plants can influence disturbance regimes to provide a positive feedback that enhances their spread. In most cases the invasive plant enhances either the frequency or intensity of fires by providing additional fuel for fires and/or by providing a continuous source of fuel. One of the best examples of this comes from the Great Basin where *B. tectorum* has reduced the fire return interval from about 70 years to less than 10 years. As disturbance intervals are altered, successional dynamics and nutrient cycling may be altered as well.

Economic impacts of invasive rangeland plants are slightly easier to understand and quantify than ecological impacts. However, because rangelands are used for such diverse purposes, some economic impacts are easier (e.g. forage for livestock production) to quantify than others (habitat for wildlife that supports hunting/tourism). Direct costs are typically easier to quantify because they can be associated with a specific activity. Two examples of direct costs are herbicide applications or loss of forage for livestock grazing. Indirect costs are harder to quantify because they are not directly linked to any specific control activity or agricultural production. Indirect costs include such things as loss of wildlife habitat or a reduction in some aspect of environmental quality.

Invasive plants cause more economic loss in rangeland in the U.S.A. than all other pests combined. Carrying capacity for domestic livestock is greatly reduced when unpalatable weeds invade. Cattle grazing capacities of rangeland infested with *E. esula* in North Dakota, U.S.A., and *Centaurea* (knapweed)-infested rangeland in Montana, U.S.A., have been reduced by up to 75%. Such costs can carry huge ramifications for rural communities and pastoral people who may already by living at subsistence levels. The costs associated with invasive plant control are staggering. For example, ranchers in the U.S.A. spend approximately $5 billion each year to control invasive plants in pastures and rangelands. Because rangeland is typically of lower value compared to crop land or land slated for development, invasive plant control may not provide a very high return. Productive lands infested with weeds provide a better return than low producing lands because the response of the forage species will be greater on productive lands. An alternative approach would be to consider some weeds as a forage resource for certain grazing animals like sheep and goats. Very few attempts have been made to assess indirect costs because it is extremely difficult. However, evidence suggests that indirect costs are about equal to direct costs, suggesting that the public at large stands to gain a great deal from preventing further invasion and controlling current infestations.

3. Successional Theory

There is a long scientific history associated with plant succession, or change in plant community composition and structure over time. Although rangeland ecosystems can achieve steady states, they dynamically change, especially as direct and indirect human activities transform and domesticate the terrestrial surfaces of the earth. Consequently, today more than ever, there is need to understand the causes of plant community change and how they influence invasion by exotic plants. Successional theory provides an understanding of the natural processes and human disturbances that influence vegetation change. Ecologically-based invasive plant management for rangelands has combined successional theory on the causes of succession (site availability, species availability, and species performance) with a management framework that modifies factors underlying the processes and components of succession: designed disturbance, controlled colonization, and controlled species performance. We will discuss successional management in more detail later in the chapter. Here we give a brief description of the invasion process, evaluate two salient ecological theories of plant community invasibility, and relate them to potential opportunities for using ecologically-based rangeland invasive plant management to improve whole plant community resistance to invasive plants. This approach is necessary because each individual component of invasion ecology is interlinked, much like a plant community and all its interacting components.

3.1. Invasion Process

Invasive plants are distinguished from transient weeds because they successfully establish, become naturalized, and spread without further assistance from humans. The invasion process of such species is characterized as having distinct phases, including introduction, colonization, and naturalization, as plants overcome geographic, biotic, and abiotic barriers. The invasion process has also been described with a slightly different sequence: introduction, establishment, spread, and impact. Clarifying the phases of the invasion process is important because whether a species becomes invasive is associated with distinct mechanisms operating at different phases of the invasion process. For example, it is unlikely that the same mechanisms are responsible for successful colonization, spread, and dominance within a community because species are generally considered incapable of simultaneously maximizing important traits (i.e., growth rate, competitive ability, and seed production) to tolerate, inhibit, or facilitate themselves or other species during succession. Instead, species experience unavoidable trade-offs for these important traits.

Another necessary distinction before embarking on a discussion of the complex mechanisms responsible for community invasibility is differentiating between the terms *invasiveness* and *invasibility*, and their relative contribution to predicting invasion. Invasiveness describes physiological, morphological, and life-history traits of the invading plant species and will be the focus of later sections of this chapter; however, we will briefly contrast challenges associated with independently evaluating invasiveness. In contrast, invasibility is the ease with which non-native species become established. Characterizing traits correlated with invasiveness has yielded few generalizations and poor predictive power. Consequently, the success of invaders can hardly be predicted, but only the probability of outcomes for invasions. To overcome this limitation, many have encouraged adopting a common framework that considers relationships between prevailing environmental conditions, traits of potentially invading species, and traits of resident species (invasibility) to predict invasive plant success within ecosystems. Because invasion success depends on complex interactions between species and the ecosystem, these relationships should be evaluated simultaneously.

A common framework that integrates characteristics of invasiveness and invasibility is needed because, while most invaders fail, some have large impacts following invasion, i.e., "transformer species", which make it difficult to indicate cause and effect. Thus, here we focus on two promising ecological theories capable of relating susceptibility of the various phases of invasion to structural and functional relationships between the invading species and the plant community.

3.2. Theory of Biotic Resistance to Invasion

Biotic resistance to exotic plant invasion stems from the long-held idea that interactions among resident species may resist invasion. For example, the theory that species-rich communities are more resistant to invasions by non-native species, has been extensively studied and reviewed. The underlying hypothesis of this relationship implies that species diversity provides stability to plant communities as co-occurring species compensate for environmental and biotic fluctuations. This hypothesis is controversial because models and field studies have not universally demonstrated direct causal relationships. In our attempt to establish a unifying and broadly applicable framework to describe why rangelands are invaded by non-native and how successional theory can facilitate restorative managerial actions, we focus on theoretical and empirical content related to the well-studied relationship between species diversity and community resistance to invasion.

3.2.1. Mechanisms of Biotic Resistance to Invasion

The relationship between biotic resistance and invasibility currently lacks consensus because variation in species diversity covaries with numerous and different factors when evaluated over ecological scales. At small scales, i.e., plot or neighborhood, and in the absence of covarying factors, resident species diversity increases the competitive environment through resource reduction and leads to greater invasion resistance in assembled communities and microcosms, even when a limiting soil resource is supplied. In small-scale studies, high species diversity increases invasion resistance if 1) resident species are functionally similar to invaders (i.e., similar resource use patterns), 2) a highly competitive species is present, and 3) if resident species have complementary resource use. However, at the scale of plant community, invasion often increases with diversity because of the overwhelming effects of ecological factors that spatially covary with diversity.

Positive relationships between species diversity and invasion are associated with unavoidable inclusion of extrinsic factors and processes that covary with diversity at large-scales. Although less mechanistic because they do not explicitly measure invasibility, large-scale studies show a rather consistent positive relationship between species diversity and invader abundance. Potential extrinsic factors that covary with species diversity and potentially cause conflicting responses at small and large scales are beginning to emerge. Modeling and large-scale studies indicate that changes in the number of available resources and propagule pressure across communities could cause invasion success to become positively correlated with native species diversity. Prominent ecologists have consequently surmised that invasibility and species diversity are regulated in a similar way by the same set of factors. Thus, the biotic resistance theory is highly scale-dependent because plant species diversity decreases invasibility at small scales, whereas at large scales, this relationship diminishes.

Although a simple general theory for the relationship between diversity and invasibility is probably unrealistic, a recent in-depth analysis by Jonathan Levine (University of California, Santa Barbara) and his colleagues indicate that resident species diversity functions as a barrier during the establishment phase, constraining the spread and impact phase more than the introduction phase. This is encouraging because one of the primary causes of succession, species availability, can be potentially managed to improve community resistance to invasive plants during the introduction and establishment stage by minimizing propagule pools and dispersal. Because invasions are a result of interplay between habitat compatibility and propagule pressure, if propagule supply of the invasive species can be maintained below a species-specific threshold, later phases of invasion may be prevented.

3.2.2. Theory of Fluctuating Resources

In a seminal paper by Mark Davis (University of Macalester) and his colleagues, they theorized that plant communities become more susceptible to exotic plant invasion as resource availability increases due to both declines in species uptake and resource enrichment. This theory is important to successional management because it relates to additional causes of succession not discussed for the theory of biotic resistance, i.e., site availability and species performance. Additionally the theory merges the key processes of disturbance and resource supply that are known to directly impact plant invasion.

Disturbance creates bare ground (i.e., “safe sites” or site availability) for propagules and increases resource availability, which may facilitate growth of invasive plants more than resident species. Field studies robustly indicate that disturbance has direct impacts on resource availability, and in turn, resource availability strongly controls species performance through competitive interactions. In both natural grasslands and old-field settings, the addition of resources increases invasibility. Similarly, addition of soil-macronutrients increases productivity of invasive species and decreases productivity of native species. The differential response of species to increased soil-nutrients is attributed to greater capacity of invasive species to respond to fluctuating resources than native species.

The theory of fluctuating resources also claims plant communities become more susceptible to invasion with reduced resource uptake by resident species and the resultant increase in unused resources. This aspect of the theory is supported by neighbor removal experiments in field settings that demonstrate that removing competition increases soil resources and leads to greater productivity of invasive species. Thus, ecophysiological and life history traits of species determine their capacity to respond to fluctuating resources, and successional management of species performance at strategic periods could be used to produce desirable plant community changes.

3.2.3. Synthesis of Community Invasibility Theories

The theories of biotic resistance and fluctuating resources appear to be compatible with the current successional management framework. While both theories may not always accurately predict invasibility, they can be used in developing strategic plant community manipulations. The biotic resistance theory emphasizes how management activities that modify species availability should develop ways to minimize propagule supply of invasive plants, because invasion resistance associated with species diversity has low potential to prevent introduction and establishment, but can influence spread and impact. The fluctuating resource theory applies to successional management by emphasizing how site availability and species performance are both directly impacted by fluctuating resources. The theory also indicates that timing of management activities is important to insure that disturbance favors desirable species and that resource availability coincides with the phenology of desirable species. In essence, successional management strategies benefit from both theories as they are developed for specific ecological sites. This approach emphasizes that predictions about the impacts of invasive plants on ecosystems can only emerge from focused studies on particular potential invaders and target communities.

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Biographical Sketches

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Rangeland Invasive Plant Specialist at Montana State University. She received a B.S. in biology from Iowa State University and an M.S. in Abused Land Rehabilitation and Ph.D. in Land Resources and Environmental Sciences from Montana State University. She has worked in the field of invasive plant ecology and management since 1998. Her research interests include revegetation of invasive plant-infested range and wild land, competition between native and invasive plant species, and ecologically-based integrated invasive plant management.

Tom Monaco is an Ecologist with the Forage and Range Research Laboratory (USDA-ARS) in Logan, Utah. His research emphasizes the ecological mechanisms and ecophysiological traits of invasive plants and how they impact semi-arid plant communities. He also seeks to development management strategies to control invasive plants and restore key ecological processes. Tom is from Washington State (USA) and earned a PhD in Rangeland Ecology from Texas A&M University.

Ron Sosebee is an Emeritus Professor from the Department of Natural Resources Management Texas Tech University in Lubbock, Texas. He completed graduate studies at New Mexico State University, Las Cruces and has a PhD from Plant Physiology from Utah State University. His research interest is on brush and weed control with an emphasis on plant physiology. Ron is active in the Society for Range Management and is Certified Professional in Range Management. Ron has worked in many overseas countries from South America to North Africa and Asia.

Tony Svejcar is the Research Leader for the USDA-Agricultural Research Service unit in Burns, Oregon. He received a B.S. and M.S. from Colorado State University and a Ph.D. from Oregon State University. His research focuses on the ecology and physiology of sagebrush steppe rangelands, with an emphasis on understanding how management actions influence processes and long-term trends.

Roger Sheley received his Bachelors and Masters of Science from Washington State University in Rangeland Management and Improvements. Roger received is Ph.D. in Rangeland Weed Ecology from Oregon State University. Dr. Sheley has been associate professor and Extension Noxious Weed Specialist in the Department of Land Resources and Environmental Science for 10 years. He has taught courses in Invasive Plant Ecology and Management, published over 45 refereed research articles on the topic, and edited the book “Biology and Management of Noxious Rangeland Weeds”. Roger has conducted a comprehensive educational and outreach program by developing a Noxious Weed Education and Awareness Program, Noxious Weed Managers Certification Program, and the Master’s Invasive Plant Managers Program in Montana. Dr. Sheley has been the impetus behind the Center for Invasive Plant Management. He is currently a Rangeland Weed Ecologist with the USDA-ARS located at Burns, Oregon working on the Medusahead Challenge. The Challenge is a partnership trying to do something about the serious medusahead problem in eastern Oregon.