

Chapter 1

Introduction: Exotic Annual *Bromus* in the Western USA

Matthew J. Germino, Jeanne C. Chambers, and Cynthia S. Brown

Abstract The spread and impacts of exotic species are unambiguous, global threats to many ecosystems. A prominent example is the suite of annual grasses in the *Bromus* genus (*Bromus* hereafter) that originate from Europe and Eurasia but have invaded or are invading large areas of the Western USA. This book brings a diverse, multidisciplinary group of authors together to synthesize current knowledge, research needs, and management implications for *Bromus*. Exotic plant invasions are multifaceted problems, and understanding and managing them requires the biological, ecological, sociological, and economic perspectives that are integrated in this book. Knowing how well information from one geographic or environmental setting can transfer to another is a key need for broadly distributed *Bromus* species especially given ongoing climate change. Thus, the chapters in the book compare and contrast invasibility of different ecoregions and invasiveness of different *Bromus* species. A universal theme is managing for ecosystems that are resilient to disturbance and resistant to invasion which will be essential for adaptation to the human-caused problem of *Bromus* in the Western USA.

Keywords Resistance • Resilience • Exotic annual *Bromus* grasses • Western USA

M.J. Germino (✉)

US Geological Survey, Forest and Rangeland Ecosystem Science Center,

Boise, ID 83706, USA

e-mail: mgermino@usgs.gov

J.C. Chambers

USDA Forest Service, Rocky Mountain Research Station,

Reno, NV 89512, USA

e-mail: jchambers@fs.fed.us

C.S. Brown

Department of Bioagricultural Sciences and Pest Management, Colorado State University,

Fort Collins, CO 80523-1177, USA

e-mail: cynthia.s.brown@colostate.edu

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1.1 The Spectrum of Exotic Annual *Bromus*

Exotic annual grass invasions are transforming arid and semiarid landscapes worldwide. Mediterranean annual grasses have become the dominant species following European settlement in areas as widely separated as Chile, Australia (Rossiter et al. 2003; Gulmon 1977), and the Western USA (Mack 1981; D’Antonio and Vitousek 1992). The problem is particularly acute for arid and semiarid uplands of the Western USA, which are being invaded by several exotic annual species in the genus *Bromus* (*Bromus* hereafter) that originated from Europe or Eurasia. Settlement of these semiarid landscapes occurred over a century ago, and since then, urban, agronomic, and energy development have led to open, disturbed habitat, and land use practices such as overgrazing by livestock have depleted native perennial herbaceous species—which are the best competitors with *Bromus* (Mack 1981; Billings 1990). Not only are the *Bromus* species readily invading these disturbed areas, but because they are highly adapted to the relatively wet winters and drier summers that characterize much of the area, they also are expanding into native ecosystems with favorable climatic regimes. In many cases, increases in the abundance and continuity of fine fuels caused by these annual grasses are decreasing fire return intervals and resulting in the progressive conversion of native ecosystems to *Bromus* dominance.

The life history and ecophysiological traits of *Bromus*, such as fall or early spring germination, rapid growth, and high reproduction, make them highly competitive with native species and greatly increase the difficulty of management and restoration. *Bromus* now dominate millions of acres and are present as co- or subdominant species in many low- to mid-elevation ecosystems in the Western USA. Although traditional land uses facilitated initial invasion, expanding land uses, climate change, rising atmospheric carbon dioxide, and nitrogen (N) deposition have accelerated the process.

In contemporary terminology, many of the affected ecosystems have lost or are losing “resistance” to invasive *Bromus* grasses and “resilience” to disturbances, such as altered fire and climatic regimes (Chambers et al. 2014). Conversion of native ecosystems to annual grass dominance can change soil physical and chemical properties and alter ecosystem processes like nutrient cycling and soil water flux and storage (Wilcox et al. 2012). The progressive invasion of *Bromus* species and the global change process that facilitate invasion act at large spatial scales and cross conventional boundaries for land planning and management.

The risks and problems associated with *Bromus* have been known in the USA for at least a century. There has been as much or more research and management attention on *Bromus* species, such as *B. tectorum* L. (cheatgrass or downy brome), as on other exotic invasive plant species in the USA and elsewhere. A Google Scholar search of literature on the *Bromus* genus reveals more than 10,000 primary research publications in the last century. Moreover, many thousands of seeding, fencing, and rangeland “weed” treatments at scales ranging from a few to over 10,000 acres each and collectively covering millions of acres are on record for the decades leading up to 2015 in the Western USA (US Geological Survey’s Land Treatment Digital Library). Despite this relatively high number of studies and publications on *Bromus*

and the many attempts by managers to control them, their spread and impacts continue. It is noteworthy that much of the ecological research on *Bromus* has focused on a limited number of explanatory variables and been conducted at local or site scales, while most of the management-oriented research has emphasized treatments targeting control of these species.

1.2 Synthesis of Patterns, Challenges, and Opportunities

A critical need exists for research, planning, and management that focuses on ecoregional and larger scales. Scientists, policy specialists, and land managers would like to understand:

- Effects of environmental factors on *Bromus* species distributions
- Ecosystem attributes and processes that influence resistance to invasion
- Traits of *Bromus* species that contribute to invasiveness
- Impacts of *Bromus* invasions on ecosystems
- Effects of pathogens on *Bromus* invasions and their potential for biocontrol
- Effects of land uses on *Bromus* invasions
- Management options for exotic annual *Bromus* and their application
- Socioeconomic drivers and patterns of human response to *Bromus* invasion

This book addresses these points for the Western USA. The book is timely because concern for the *Bromus* problem and efforts to address it at broad spatial scales have increased to unprecedented levels. For example, annual grasses and *B. tectorum* specifically are major aspects of the US Department of Interior (DOI) Secretarial Order #3336 issued in 2015, which mandates one of the largest conservation efforts in US history on behalf of *Centrocercus urophasianus* Bonaparte (greater sage-grouse). New efforts to evaluate *Bromus* and prioritize areas for protection or restoration are now occurring at ecoregional and larger scales, such as in the DOI's Rapid Ecological Assessments (released in the last 2 years) and the Fire and Invasive Assessment Tool (2015; http://www.blm.gov/wo/st/en/prog/more/sagegrouse/documents_and_resources.html).

Herein, the available literature is synthesized to develop a more complete picture of the factors that influence invasibility, invasiveness, impacts, and management of annual *Bromus* invaders. A framework is used that is based on ecosystem resilience to disturbance and resistance to invasion. Resilience is defined as the capacity of an ecosystem to *regain* its fundamental structure, processes, and functioning when altered by stressors like drought and disturbances like overgrazing by livestock and altered fire regimes (Holling 1973; Walker et al. 2004). Resistance is defined as the capacity of an ecosystem to *retain* its fundamental structure, processes, and functioning despite stresses, disturbances, or invasive species (Folke et al. 2004). Resistance to invasion by exotic annual grasses is a subset of resistance and is a function of the abiotic and biotic attributes and ecological processes of an ecosystem that limit the population growth of an invading species (D'Antonio and

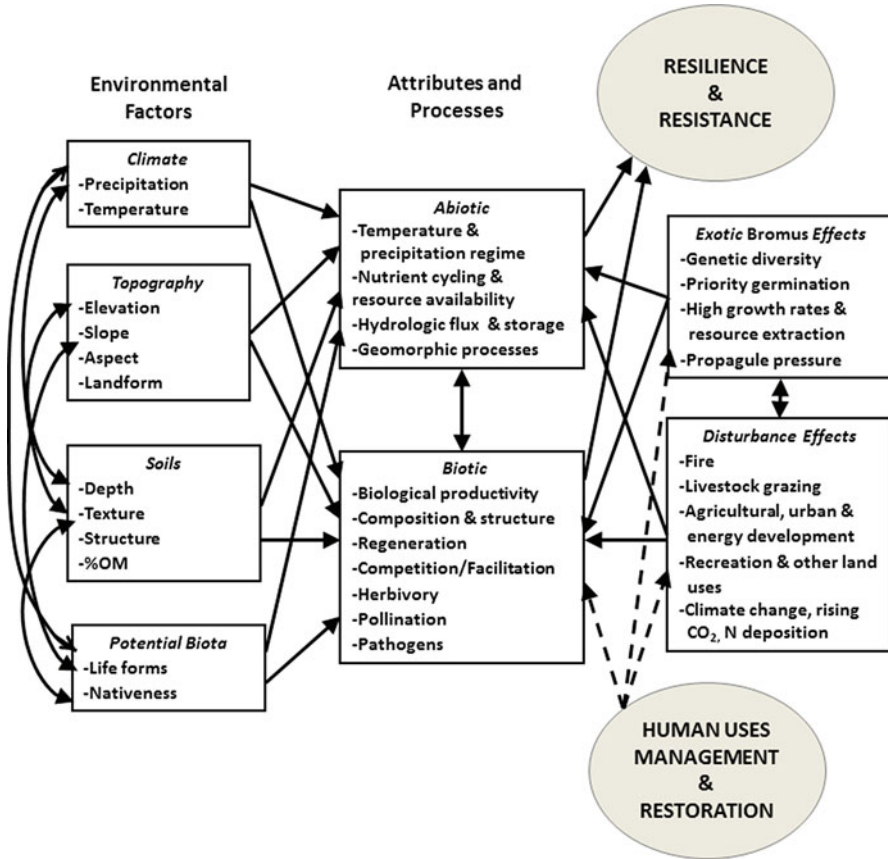


Fig. 1.1 Conceptual model of the environmental factors and ecosystem attributes and processes that affect resilience and resistance. Human activities including land uses and management actions influence invasion by exotic annual *Bromus* and the type and magnitude of disturbance which in turn can affect ecosystem attributes and processes and, ultimately, resilience and resistance (Adapted from Chambers et al. 2014)

Thomsen 2004). The environmental factors and ecosystem attributes that determine resilience of native ecosystems to stress and disturbance and resistance to invasion can be illustrated with a simple conceptual model (Fig. 1.1). The model shows that environmental factors, including climate, topography, and soils, determine the abiotic and biotic attributes of ecosystems. *Bromus* and other invaders, disturbance and stress, and global change factors act on the abiotic and biotic attributes of an ecosystem and influence its relative resilience and resistance over time. Management actions usually target the biotic attributes and processes of ecosystems and can influence the effects of *Bromus* and disturbance. This model contains those ecosystem attributes and processes suggested for evaluating ecosystem sustainability (Chapin et al. 1996). It also includes both the environmental factors and ecosystem

attributes used to develop the ecological site descriptions and state-and-transition models that are increasingly used by managers to evaluate options for managing *Bromus* (Briske et al. 2008; Caudle et al. 2013). All chapters in this book relate to key attributes of the model (Fig. 1.1).

There are nearly 150 species in the *Bromus* genus globally, and they vary considerably in their invasiveness and impacts across the vast Western USA. Chapters in this book range from incorporating all *Bromus* species (Chap. 6) to only one species (Chap. 5). Where chapters focus on fewer species, it is generally because the chapters have a relatively thorough treatment of better-studied species like *Bromus rubens* L. (red brome) and especially *B. tectorum* which is a widespread invader in the floristic Great Basin and one of the most studied invasive species globally. Several chapters also incorporate *B. diandrus* Roth (ripgut brome) and *B. hordeaceus* L. (soft brome) of California, the next most invasive and impactful exotic annual *Bromus*. Several chapters evaluate these species across regional and local gradients. The invasion of California grasslands is widespread, and *Bromus* was considered entrenched there nearly a century ago. Moving eastward, extensive invasion of the floristic Great Basin was underway over a century ago but is still occurring. Farther east in areas like the Front Range of Colorado, *Bromus* invasions are considered a relatively new occurrence. This east-to-west gradient of invasion is overlaid onto a gradient of increasing summer precipitation, changes in land use, and changes in plant community composition. *Bromus* invasions also tend to exhibit strong elevation patterns. Chapters that compare and contrast *Bromus* invasions among ecoregions (Chap. 2) or aim to explain evolutionary aspects or invasiveness in the genus (Chaps. 4 and 6) have the greatest taxonomic breadth. By comparing and contrasting *Bromus* species and regions, we hope that the book will produce generalized, transferable concepts and information or illustrate the limits of transferability by highlighting unique aspects of invasiveness or invader impacts.

Chapters in this book parse into four themes, organized as sections. The first section addresses patterns and impacts of invasion, generating a “35,000 foot view” of where, when, and how invasion by the dominant exotic annual *Bromus* species has varied among ecoregions in the Western USA (Chap. 2, Brooks et al.). This analysis reveals that *Bromus* has had very different impacts in different ecoregions. Germino et al. (Chap. 3) then examine ecosystem effects of *Bromus* in further detail, focusing most on *B. tectorum* and providing a basis for why *Bromus* is a concern.

The second section explores some of the organismal traits that contribute to invasiveness of the dominant annual *Bromus* species in the USA. The broad evolutionary, reproductive, and biogeographic traits and patterns affecting the genetic diversification and colonization of the Western USA by *Bromus*, particularly *B. tectorum*, are reviewed next with an emphasis on evidence from allozyme variation (Chap. 4, Novak and Mack). Many recent studies show that a capacity for rapid evolution or ability to withstand a wide range of environmental conditions through phenotypic plasticity has favored many invasive species. Ecological-genetics issues are explored for *B. tectorum* in Chap. 5 with an emphasis on molecular markers and common garden evidence (Hufft and Zelikova). Shifting back to the entire *Bromus* genus, Atkinson and Brown (Chap. 6) compare and contrast organismal and eco-

logical traits conferring invasiveness among all *Bromus* species using a database approach that incorporates many types of information. Theories about “natural enemies” are often invoked to explain invasiveness of species, and Meyer et al. (Chap. 7) evaluate fungal pathogen systems involving *Bromus*, with a focus on *B. tectorum* because it is the subject of current microbial biocontrol research and thus the most is known about its relations to pathogens.

The third section evaluates soil, climate, and plant community controls on *Bromus* to characterize key aspects of invasibility of sites, plant communities, or regions. Belnap et al. (Chap. 8) evaluate how the interaction of soils, nutrients, and climate variability influences invasion patterns, focusing on the greater information available for *B. tectorum* primarily and also *B. rubens*. In Chap. 9, Bradley et al. evaluate large-scale climate controls on *B. tectorum* and *B. rubens* in the Western USA using the species distribution modeling approach. Next, the interactive effects of climate, plant community attributes, and *Bromus* traits on plant community resistance to *Bromus* invasions are evaluated in Chap. 10 by Chambers et al.

The last section explores human and economic dimensions and management options related to both spread and management of *Bromus*. Chapters in this section generate concepts from relatively well-studied *Bromus* species but have some broader applicability to other exotic annual grasses and even to invasive plants in general. Pyke et al. (Chap. 11) evaluate humans as a driver and responder to *Bromus*, focusing on interactions among key land uses such as grazing and other drivers such as fire. A comprehensive review of management treatments directed at *Bromus* and their effectiveness is then provided by Monaco et al. (Chap. 12). The focus is on restoring and maintaining sustainable ecosystems, and a case study is provided on *B. tectorum* in the Great Basin. The vast scale of invasions and size of western landscapes has posed a major challenge to land managers, and modeling frameworks are increasingly important for allowing land managers to evaluate options and future invasion risks, such as with the state-and-transition simulation models that are described next by Provencher et al. (Chap. 13). Management actions are outcomes of the social context, and Brunson and Karcher (Chap. 14) describe how human perceptions, education, and regulatory aspects of *Bromus* and other invasive grasses have changed over the course of the invasion in the USA. Economics are a major driver of efforts to address the causes of *Bromus* invasion, and Chap. 15 by Eiswerth et al. explores how economic models can help inform management.

A few other points need to be noted about the book and the project underlying it. First, the book is an outcome of the US Department of Agriculture’s *Bromus* REENet (Research, Extension, and Education Network) which granted funding to bring a diverse range of agency and university specialists from around the USA together to generate the ideas and direction for this book. Second, readers will notice some uniqueness in reporting conventions as well as some overlap in content. Because each chapter will be available as a separate article, we wished to find a balance between interdependence and uniformity among chapters while also enabling each chapter to stand alone. In several cases, chapters cover aspects of the same theme from slightly different perspectives. We believe that bringing these perspectives from different science disciplines and geographic backgrounds together is an

essential part of solving the ever-growing problem of *Bromus* invasions and the spread of annual grasses globally.

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References

- Billings WD (1990) *Bromus tectorum*, a biotic cause of ecosystem impoverishment in the Great Basin. *The Earth in Transition*. Cambridge University Press, New York, NY, pp 301–322
- Briske DD, Bestelmeyer BT, Stringham TK et al (2008) Recommendations for development of resilience-based state-and-transition models. *Rangel Ecol Manag* 61:359–367
- Caudle D, DiBenedetto J, Karl M et al (2013) Interagency ecological site handbook for rangelands. <http://jornada.nmsu.edu/files/InteragencyEcolSiteHandbook.pdf>. Accessed 2 Jun 2015
- Chambers JC, Bradley BA, Brown CS et al (2014) Resilience to stress and disturbance, and resistance to *Bromus tectorum* L. invasion in cold desert shrublands of western North America. *Ecosystems* 17:360–375
- Chapin FS III, Torn SE, Tateno M (1996) Principles of ecosystem sustainability. *Am Nat* 148:1016–1037
- D’Antonio CM, Thomsen M (2004) Ecological resistance in theory and practice. *Weed Technol* 18:1572–1577
- D’Antonio CM, Vitousek PM (1992) Biological invasions by exotic annual grasses, the grass/fire cycle, and global change. *Ann Rev Ecol Syst* 23:63–87
- Folke C, Carpenter S, Walker B et al (2004) Regime shifts, resilience, and biodiversity in ecosystem management. *Ann Rev Ecol Syst* 35:557–581
- Gulmon SL (1977) A comparative study of the grassland of California and Chile. *Flora* 166:261–278
- Holling CS (1973) Resilience and stability of ecological systems. *Ann Rev Ecol Syst* 4:1–2
- Mack RN (1981) Invasion of *Bromus tectorum* L. into Western North America: an ecological chronicle. *Agro-Ecosystems* 7:145–165
- Rossiter NA, Setterfield SA, Douglas MM et al (2003) Testing the grass–fire cycle: alien grass invasion in the tropical savannas of northern Australia. *Divers Distrib* 9:169–176
- Walker BH, Holling CS, Carpenter SR et al (2004) Resilience, adaptability and transformability in social-ecological systems. *Ecol Soc* 9:5
- Wilcox BP, Turnbull L, Young MH et al (2012) Invasion of shrublands by exotic grasses: ecohydrological consequences in cold versus warm deserts. *Ecology* 5:160–173