Rangeland Ecology & Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Weather-Centric Rangeland Revegetation Planning☆

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A R T I C L E I N F O

Article history:
Received 25 January 2017
Received in revised form 24 May 2017
Accepted 10 July 2017
Available online xxxx

Key Words:
adaptive management
climate
forecasting
planning
rehabilitation
restoration
revegetation
weather

A B S T R A C T

Invasive annual weeds negatively impact ecosystem services and pose a major conservation threat on semiarid rangelands throughout the western United States. Rehabilitation of these rangelands is challenging due to interannual climate and subseasonal weather variability that impacts seed germination, seedling survival and establishment, annual weed dynamics, wildfire frequency, and soil stability. Rehabilitation and restoration outcomes could be improved by adopting a weather-centric approach that uses the full spectrum of available site-specific weather information from historical observations, seasonal climate forecasts, and climate-change projections. Climate data can be used retrospectively to interpret success or failure of past seedings by describing seasonal and longer-term patterns of environmental variability subsequent to planting. A more detailed evaluation of weather impacts on site conditions may yield more flexible adaptive-management strategies for rangeland restoration and rehabilitation, as well as provide estimates of transition probabilities between desirable and undesirable vegetation states. Skillful seasonal climate forecasts could greatly improve the cost efficiency of management treatments by limiting revegetation activities to time periods where forecasts suggest higher probabilities of successful seedling establishment. Climate-change projections are key to the application of current environmental models for development of mitigation and adaptation strategies and for management practices that require a multidecadal planning horizon. Adoption of new weather technology will require collaboration between land managers and revegetation specialists and modifications to the way we currently plan and conduct rangeland rehabilitation and restoration in the Intermountain West.

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Introduction

Millions of hectares of rangeland in the western United States are either currently degraded or under threat of degradation from the influence of invasive annual grasses (D'Antonio and Vitousek, 1992; Knapp, 1996; Bradley and Mustard, 2006; Davies, 2008, 2010; Bromberg et al., 2011; Brooks et al., 2016; Germino et al., 2016). These invasive species are particularly well adapted to western rangeland environments that experience high variability in annual and seasonal precipitation and temperature. Some useful weather-adaptive traits of these species include prolific seed production, rapid establishment response to short periods of site availability, rapid growth, preemptive utilization of site resources, and an annual life cycle that facilitates survival during seasonal drought (Harris, 1977; Melgoza et al., 1990; Reichenberger and Pyke, 1990; Arredondo et al., 1998; Humphrey and Schupp, 2001, 2004; Kulmatiski et al., 2006; Rimer and Evans, 2006; Hardegree et al., 2010, 2013; Mangla et al., 2011; Mazzola et al., 2011). Annual grass proliferation also results in significant and self-perpetuating changes to nutrient cycling, fire frequency, and vulnerability

☆ This work was supported by a grant from the USDA National Institute of Food and Agriculture (AFRI-60-5360-2-832). The USDA is an equal opportunity provider and employer. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the US government.

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http://dx.doi.org/10.1016/j.rama.2017.07.003
1550-7424/Published by Elsevier Inc. on behalf of The Society for Range Management.

Please cite this article as: Hardegree, S.P., et al., Weather-Centric Rangeland Revegetation Planning, Rangeland Ecology & Management (2017), http://dx.doi.org/10.1016/j.rama.2017.07.003

to postfire wind erosion that reinforce site dominance and prevent reestablishment of desirable perennial species (Norton et al., 2004; Bradley et al., 2006; Boxell and Drohan, 2009; Rau et al., 2011; Balch et al., 2013; Blank et al., 2013; Gasch et al., 2013; Owen et al., 2013; Germino et al., 2016). Landscape-level transitions to annual-weed dominated plant communities have had major negative environmental and economic impacts on natural resource values, land management costs, and societal benefits from western rangelands (Riggs et al., 2001; Duncan et al., 2004; Epanchin-Niell et al., 2009; Brunson and Tanaka, 2011; Maher et al., 2013).

Western rangelands are heterogeneous for a wide range of biophysical characteristics. The western United States generally has complex topography and soil variability at scales typically smaller than boundaries associated with management applications (Herrick et al., 2006; Bestelmeyer et al., 2011). Relatively detailed site information is now available, or under active development, from the Natural Resources Conservation Service (NRCS) as ecological site descriptions (ESDs) and associated state-and-transition models (STMs; Herrick et al., 2006; Caudle et al., 2013; NRCS, 2013). Site-specific information on potential weather effects on vegetation is usually limited to the identification of plant materials that are associated with broad climatic zones (Shiflet, 1994; Vogel et al., 2005; NRCS, 2006; Bower et al., 2014). Recent research, however, has identified climatic gradients of precipitation and temperature that are associated with both the relative difficulty of seedling establishment and the inherent resistance and resilience of mature plant communities (Chambers et al., 2014b; Knutson et al., 2014).

Historically, the predominant management response to invasive annual weeds has been postfire seeding under federal agency Emergency Stabilization and Rehabilitation (ESR) programs (Eiswerth and Shonkwiler, 2006; USDI BLM, 2007; Eiswerth et al., 2009; Pyke et al., 2013; Knutson et al., 2014). ESR plans are mandated for rapid implementation in the years immediately following the fire, emphasize site and soil stabilization, and have not been integrated with longer-term interventions necessary to sustain a positive trajectory toward an acceptable vegetation state (USDI BLM, 2007; USDI, 2015). Short-term, postfire rehabilitation management also restricts initial establishment success to the relatively low probability of favorable weather in the years immediately following disturbance. Pyke et al. (2013) conducted a meta-analysis to determine whether seeding after wildfires has reduced invasion or abundance of undesirable non-native plant species and found that the majority of postfire seedings (67%) had no effect. Overall success rates tend to be greater at higher elevation, where climatic conditions are generally more favorable for establishment (Davies et al., 2014; Knutson et al., 2014), but initial establishment success at drier sites is still possible with adequate precipitation in the winter and spring (Jessop and Anderson, 2007; Taylor et al., 2014).

The objective of this synthesis is to provide a framework for incorporating weather and climate information into rangeland revegetation planning: to reduce management uncertainty, to improve our understanding of the ecological processes driving succession, and to increase the efficiency of rangeland rehabilitation and restoration efforts.

Weather Variability and Plant Establishment

The microclimatic requirements for many successional processes and life-stage transitions are much more restrictive than those necessary for the persistence of mature plant communities, even in the absence of competitive annual weeds (Grubb, 1977; Call and Roundy, 1991; Peters, 2000; Hardegree et al., 2003, 2013, 2016; Cox and Anderson, 2004). In particular, transition pathways between undesirable and desirable plant-community states may require a series of specific, and, therefore, infrequent weather patterns to sustain a positive successional trajectory through multiple phases of plant community development (Fig. 1; Westoby et al., 1989; Call and Roundy, 1991; Hardegree et al., 2011; James et al., 2011, 2013; Svejcar et al., 2014).

Weather Impacts: Examples from the Literature

An example of the importance of weather in the phenological timing of germination and root growth comes from efforts to improve establishment of native grasses at the Santa Rita Experimental Range in southern Arizona. Average annual temperature in this area is 17.7°, and average precipitation is about 400 mm, with about half falling during the summer monsoon period. Warm season grasses have traditionally been sown during the spring before the onset of monsoonal moisture. Years of field research indicated that Lehmann lovegrass *(Eragrostis lehmanniana* Nees*)* and other introduced South African grasses establish more successfully than native grasses (Roundy and Biedenbender, 1995). In a comparative study, Abbott and Roundy (2003) found that the majority of native grass seeds germinate relatively quickly after the onset of summer thunderstorms, whereas a relatively small fraction of Lehmann lovegrass seeds germinate during any particular period of water availability (Hardegree and Emmerich, 1991, 1993; Roundy et al., 1992). Without a consistent period of subsequent water availability, seminal root growth cannot keep up with the soil drying front, adventitious roots do not develop, and seedlings become highly vulnerable to desiccation and detachment (Tischler and Voigt, 1987; Roundy et al., 1993, 1997; Abbott, 1999). The success of Lehmann lovegrass is partially attributed to reserving some seed cohorts to germinate later in the monsoon season when precipitation frequency and soil moisture increase (Roundy et al., 1996). Incorporating site-specific information on the seasonality of precipitation frequency as it pertains to establishment probability has led to the recommendation that establishment of native grasses could be improved by seeding later in the summer.

In another example of weather-dependent life-cycle transitions, studies have shown that germination is generally not limiting, regardless of planting date, but there is often a large discrepancy between germination and emergence in the field for fall-planted perennial grasses in the Great Basin (Hardegree and Van Vactor, 2000; Roundy et al., 2007; James et al., 2011; Boyd and Lemos, 2013). The relative timing of germination, however, can be extremely important as pre-emergent seedlings are vulnerable to relatively short periods of soil freezing and/or soil desiccation (James et al., 2011; Boyd and Lemos,

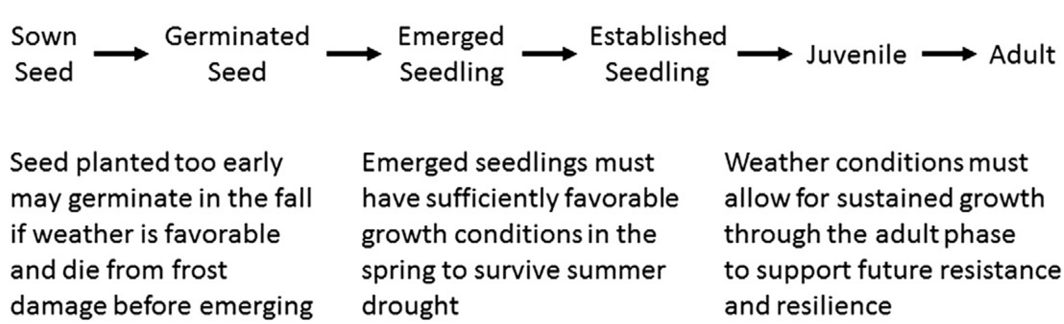

Figure 1. Life stage transitions (from James et al., 2011) and weather effects on growth and mortality of seeded grass and shrub species.

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