

Increased drought frequency alters the optimal management strategy of an endangered plant



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ABSTRACT

Many rare plant and animal species require frequent habitat disturbance to ensure population persistence, but humans often suppress or modify natural disturbance regimes, such as floods and fires, which harms disturbance-adapted species. To manage these populations, demographic models are often used to quantify the optimal disturbance frequency of the habitat. Increasing drought frequency due to climate change could alter optimal management strategies by decreasing the benefit of a recently disturbed habitat. We ask whether disturbance and drought interactively affect population dynamics and optimal management of *Astragalus bibullatus*, a Federally endangered legume endemic to limestone cedar glades in Tennessee. We used matrix population models to determine the independent and interactive effects of drought and management of woody canopy cover on *A. bibullatus*' probability of extinction, time to extinction and future population size. Under current drought frequencies, *A. bibullatus*' probability of extinction was minimized with the most frequent management, since open habitats promote recruitment. However, as drought frequency increases, the probability of extinction was minimized with less frequent management, since canopy cover decreased mortality of older plants during droughts. We recommend managing disturbance-dependent habitats by maintaining two types of environments; those that promote high survivorship during climatically unfavorable years, and those that promote increased reproduction and recruitment during climatically favorable years. Varying management goals across the landscape will decrease species-wide risk by preventing a single drought from harming all populations.

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1. Introduction

Determining optimal management strategies is critical for maintaining or restoring populations of rare or endemic species (Lindenmayer et al., 2008). Many endemic plant species are adapted to environments with periodic natural disturbances, such as fire, floods or high winds, and require post-disturbance conditions (e.g., more light), to stimulate reproduction (McConnell and Menges, 2002; Pascarella et al., 2007; Pascarella and Horvitz, 1998) or seedling recruitment (Bowles et al., 2015; Jongejans et al., 2008; Menges and Quintana-Ascencio, 2004; Pardini et al., 2015; Pascarella et al., 2007; Smith et al., 2005). Human land use often suppresses or modifies natural disturbance regimes (Selwood et al., 2015). Demographic modeling of disturbance-dependent species can link plant vital rates to environments at different times since disturbance, and can be used to quantify the optimal management strategy for a disturbance-dependent habitat (Crone and Gehring, 1998; Menges and Quintana-Ascencio, 2004; Pascarella and

Horvitz, 1998). For example, demographic modeling of endemic plants in Florida scrub revealed that an every 15–30 year fire management strategy would allow persistence of these species (Menges, 2007; Menges et al., 2006; Menges and Quintana-Ascencio, 2004; Quintana-Ascencio et al., 2003).

Climate change has the potential to alter optimal management strategies for disturbance-dependent or early-successional species (Lindenmayer et al., 2010; Maalouf et al., 2012; Morris et al., 2006), because climate factors are often linked to plant population dynamics (Maschinski et al., 2006; Molano-Flores and Bell, 2012; Nicolè et al., 2011). For example, drought frequency in the southeast USA (focal region to our study system) is expected to double or triple due to climate change (Sheffield and Wood, 2008). This could negatively affect plants in exposed, recently disturbed environments, because reductions in water availability are related to lower rates of survivorship (Lendvay and Kalapos, 2014; Toräng et al., 2010), fecundity (Lendvay and Kalapos, 2014), recruitment (Maschinski et al., 2006; Toräng et al., 2010), and lower population growth rates (Maschinski et al., 2006; Matesanz et al., 2009; Phillips-Mao et al., 2016; Selwood et al., 2015; Smith et al., 2005; Toräng et al., 2010). In our system, we expect open,

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post-disturbance patches to promote high fitness (Albrecht et al., 2016). However, the same disturbance could have negative effects if it coincides with a drought event, and as drought frequency increases, they will coincide with the post-disturbance environment more often. Our study explicitly examines the interactive effects of drought and disturbance on plant population dynamics to ask whether the optimal frequency of disturbance will change with climate change.

Limestone cedar glade ecosystems (LCG) are an excellent system to quantify the interactive effects of disturbance and drought. LCG's are edaphic grasslands characterized by a high concentration of endemic forbs restricted to the Central Tennessee Basin (Estill and Cruzan, 1999). They include rocky outcrops with thin, infertile soil dominated by annual endemic forbs, and areas with slightly deeper soil dominated by perennial endemic forbs, perennial grasses, shrubs, and trees which were likely kept open by disturbance (Noss, 2013; Quarterman et al., 1993). They also experience extreme seasonal variation in microclimate; wet winters and dry summers (Baskin et al., 2007; Baskin and Baskin, 1999; Quarterman, 1950; Sutter et al., 2011), which could become even more extreme with climate change (Sheffield and Wood, 2008). Similar to other grasslands, reduced fire frequency has resulted in higher woody canopy cover in LCG's, which has resulted in a decline of endemic forbs (Albrecht et al., 2016; Sutter et al., 2011), presumably because less stress tolerant species can compete with endemics under the canopy (Lavergne et al., 2003). In the modern landscape, mowing, prescribed fire or selective tree thinning are needed to manage woody encroachment in LCG's (Albrecht et al., 2016).

We determined how the increase in drought frequency expected with climate change affects the optimal habitat management strategy for *Astragalus bibullatus*, a disturbance-dependent, Federally endangered legume endemic to LCG's by: 1) quantifying the effects of drought, woody canopy cover and their interaction on *A. bibullatus*' vital rates, and 2) quantifying the future probability of extinction, longevity, and size of *A. bibullatus* populations subjected to varying frequencies of drought and management of woody canopy cover.

2. Methods

2.1. Study system

Astragalus bibullatus Barneby & Briggs (Fabaceae) is known from eight naturally occurring sites in a single county (Rutherford County, TN) and is one of several endangered endemic forbs restricted to LCG's (Barneby and Bridges, 1987; Baskin and Baskin, 2005). It is an edaphic specialist that occurs on the margins of the rocky outcrops in LCG's where the soil is slightly deeper and there is partial shade (Barneby and Bridges, 1987). *Astragalus bibullatus* is a spring flowering, prostrate, perennial that produces mature legumes in early summer and is likely an obligate out-croser with no apparent dispersal mechanism (Albrecht and Penagos, 2012; Baskauf and Burke, 2009). Canopy cover exhibited the strongest effect on *A. bibullatus*' demographic structure among 15 microhabitat variables measured (Albrecht et al., 2016). Plants perform well (growth, flowering and seed production) in open, early successional habitats, and can persist in later successional habitats via a long-lived seed bank and a non-reproductive adult phase (Albrecht et al., 2016; Morris et al., 2002).

2.2. Overview of modeling approach

To determine how the increase in drought frequency expected with climate change affects the optimal habitat management strategy for *A. bibullatus*, we first parameterized matrix population models using field data collected in drought and non-drought years within sites that had either semi-open or closed woody canopy cover. We compared vital rates and population growth rates between each drought and canopy cover condition, and used life table response experiments to determine the contribution of each matrix element (or underlying vital rate)

to observed differences in population growth rates between each interactive drought and canopy cover environment. Next, we expanded the matrix population models to create simulation models that examine how drought frequency and the management interval of woody canopy removal interactively influence extinction risk, time to extinction and future population size. While matrix population models are not expected to accurately predict future population sizes, these are robust tools for examining the relative effects of different treatments on populations (Crone et al., 2013). Thus, these tools are ideal for addressing how drought influences optional management intervals for rare plant populations.

2.3. Demographic monitoring

We used data from a long-term demographic monitoring program (U.S. Fish and Wildlife Service, 2011) from three sites that represent two successional stages, in both drought (2012–2013) and non-drought years (2010–2011). Two sites had woody canopy cover estimates of 46–47% and were pooled to increase sample sizes. They represent a 'semi-open' canopy condition. The other site had a woody canopy cover estimate of 87% and represents a 'closed' canopy condition (Albrecht et al., 2016).

Astragalus bibullatus' life cycle consists of three above ground stages, seedlings, juveniles and adults, and a seed stage (Fig. 1). Seedlings are first-year plants identified by the presence of cotyledons and a single leaf. Juveniles are non-reproductive, one-stem plants. Adults are either reproductive or non-reproductive, multi-stemmed plants. At one semi-open site and the closed site the populations were small enough that every individual was tagged and monitored and the entirety of each site was searched for new seedlings every year. In the other semi-open site, individuals were tagged along a transect in 2010, up to 30 per stage class, and up to 30 new seedlings were marked every year. Vegetative and reproductive adults were tagged as separate stages at peak flowering (late April to early May). Reproductive adults were monitored again at peak fruiting (late May to early June) to quantify fruit production.

Survival of above ground stages (P_s , P_j & P_a) was calculated as the number of individuals still alive in a given stage divided by the total number of individuals originally tagged in that stage (at time t ; Fig. 1). Growth and stasis probabilities (G_s , S_j & S_a) were conditional on survival and calculated as the number of individuals that transitioned from a given stage to another (from time t to time $t + 1$). The average number of seeds in the seed bank and seedlings produced per reproductive plant in each year were the product of several vital rates: the proportion of adult plants that reproduced (R_p), the number of fruits per reproducing adult (F_p), the number of seeds per fruit (F_s), annual seed survivorship (V_i), and the proportion of viable seeds that germinate in a single year (E_m). For the semi-open canopy condition, R_p was assessed only in the fully surveyed, semi-open site. F_s was estimated at three sites over

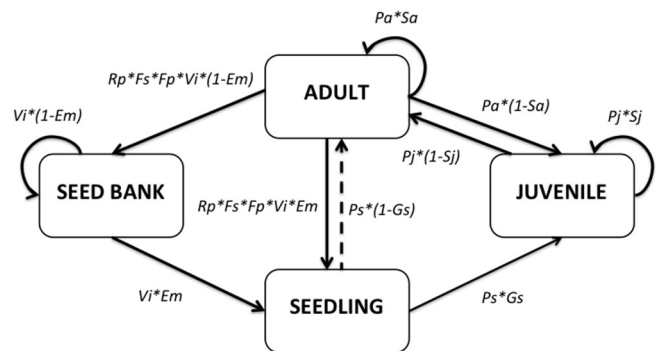


Fig. 1. Life cycle diagram for *Astragalus bibullatus* with vital rate equation for each transition. Transitions not shown do not occur. Dashed lines indicate rare transitions. Abbreviations describe in text.

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