Journal of Arid Environments 124 (2016) 180–188

Contents lists available at ScienceDirect

Journal of Arid Environments

journal homepage: www.elsevier.com/locate/jaridenv

Growth and survival of thornscrub forest seedlings in response to restoration strategies aimed at alleviating abiotic and biotic stressors

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ARTICLE INFO

Article history:
Received 7 November 2014
Received in revised form
20 April 2015
Accepted 29 June 2015
Available online 25 August 2015

Keywords:
Thornscrub forest
Semi-arid
Revegetation
Seedling
Fire
Herbicide
Mowing
Shelter tube

ABSTRACT

Semi-arid thornscrub forests occur throughout South Texas and northeastern Mexico and provide habitat for numerous fauna, including the Federally-endangered ocelot. However, <2% of original thornscrub remains due to land conversion for human use. One attempt underway to restore thornscrub habitat around core ocelot populations in South Texas is the planting of thornscrub seedlings in old agricultural fields. However, growth and survival post-planting and effectiveness of restoration strategies to overcome common stressors (e.g., competition, herbivory, and drought) have not been evaluated. In March 2011, we initiated a pilot study to assess seedling growth and survival in response to pre-planting prescribed fire, mowing, herbicide, and shelter tubes aimed at alleviating stressors including invasive grass cover and herbivore browse. We found that a single pre-planting prescribed fire promoted invasive grass cover; mowing had no effect. Glyphosate reduced invasive grass cover, but acetic acid/orange oil was ineffective. Seedlings in fire plots were tallest with the largest basal diameters despite greater invasive grass cover. Shelter tubes promoted height growth, reduced browse, and increased survival. This research will help managers decide which restoration techniques most effectively reduce thornscrub seedling stressors and promote growth and survival.

1. Introduction

Habitat loss and fragmentation are the largest threats to wildlife populations in the United States (National Wildlife Federation 2014), and combined, are one of the four greatest threats to effective management of National Lands (United States Department of Agriculture Forest Service 2014). Globally, these factors have caused a ~22% reduction in land area of native ecosystems (Hoekstra et al., 2005) and are key drivers of species loss and a global biodiversity crisis (Balmford et al., 2003; Fahrig, 2003; Sax and Gaines, 2003). Habitat loss and fragmentation interact with habitat degradation through increased abundance of invasive species and altered disturbance regimes (Didham et al., 2007). Consequently, ecosystem processes like carbon, nutrient, and water cycling and trophic interactions are disrupted, and ecosystem function declines (Chapin et al., 1992; Suding et al., 2004).

The Tamaulipan ecoregion of southern Texas and northeastern Mexico encompasses ~140,000 km^2 and contains a diverse assemblage (~50 species; (Shindle and Tewes, 1998)) of dense shrublands interspersed with grasslands (Ricketts, 1999). Shrubland plants are characterized by adaptations to arid environments, including deep tap roots, small leaves, drought-deciduousness, and physical defenses such thorns and spines. Land conversion for agriculture and invasion by exotic species have caused substantial loss, fragmentation, and degradation of this ecosystem (Ricketts, 1999). Only 2% of the original ecosystem remains intact, with no habitat blocks >250 km^2 (Ricketts, 1999).

This ecoregion has been identified as a 'hotspot' for conservation priority because of high biodiversity coincident with high human land use (Ricketts et al., 2003). Thornscrub forest ecosystems are critically important habitat for the Federally and state-endangered ocelot (*Leopardus pardalis albescens*), which depends upon closed-canopy thornscrub forests of >95% cover (Harveson et al., 2004; Jackson et al., 2005). Thornscrub forests are habitat for the state-threatened Texas tortoise (*Gopherus berlandieri*) (Kazmaier et al., 2001), Texas horned lizard (*Phrynosoma*

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http://dx.doi.org/10.1016/j.jaridenv.2015.06.014
0140-1963/

cornutum) (Hellgren et al., 2010), a variety of birds, especially raptors like the Swainson's hawk (*Buteo swainsoni*) and broad-winged hawk (*Buteo platypterus*), small mammals, and reptiles (Jahrsdoerfer and Leslie, 1988). Thornscrub forests also support a high plant species diversity, which is especially important in early succession for facilitating the growth and development of mature thornscrub forests (Návar et al., 2014). At maturity, diverse thornscrub forests store ~20 Mg ha^{-1} of carbon in above- and belowground biomass; consequently, at current deforestation rates, thornscrub loss can cause substantial carbon emissions into the atmosphere (Návar-Chaidez et al, 2008). The link between thornscrub forests, biodiversity, productivity, and critical habitat has generated great interest in restoring these ecosystems to their prior state (Návar-Chaidez et al, 2008; Haines et al., 2005; Harveson et al., 2004).

One approach underway to restore thornscrub habitat around core ocelot populations in South Texas is the planting of native seedlings in previous agricultural fields. Over the last 5 yr, ~120,000 seedlings have been hand-planted across 36 ha at Laguna Atascosa National Wildlife Refuge (LANWR), location of one of two remaining breeding populations of ocelots in the U.S. (Haines et al., 2005). However, seedling success following planting is unknown. Furthermore, seedlings often experience a suite of abiotic and biotic stressors, and restoration strategies to overcome these stressors have rarely been investigated (Young and Tewes, 1994).

Invasive grasses, herbivory, and extreme drought are major threats to restoring thornscrub forests. Invasive grasses brought to the southwest in the mid-twentieth century for cattle forage and to reduce soil erosion have aggressively spread throughout the region (Ruffner et al., 2012). They are prolific seed producers, occupy newly-disturbed space rapidly, and their shallow, dense fine roots efficiently uptake water and nutrients (Schmidt et al., 2008), which is especially beneficial in semi-arid environments (McIvor et al, 2003). While herbivory is natural, the introduction of nilgai (*Boselaphus tragocamelus*) to South Texas in the 1930's, a big game exotic from India (Sheffield et al., 1971), combined with depletion of natural predators via hunting and other human activities (Guthery and Beasom, 1977), has increased abundance of native herbivores, including white-tailed deer (*Odocoileus virginianus*) and eastern cottontail rabbits (*Sylvalagus floridanus*), who rely on browse as a major portion of their diet (Davis, 1952; Davis and Winkler, 1968; Varner et al., 1987). Further complicating thornscrub restoration, the South Texas semi-arid climate, with high evaporation, low precipitation, and a net water deficit, is a difficult growth environment, and becoming increasingly more extreme with climate warming (Norwine and John, 2007).

In this study, we monitored thornscrub seedling success over a 2-yr period following planting under different restoration strategies aimed at reducing the abiotic and biotic stressors mentioned above. We used ground-layer treatments, including a single application of pre-planting prescribed fire or mowing to reduce invasive grass cover. We also applied two herbicide treatments, glyphosate, a common broad-spectrum synthetic herbicide and acetic acid/orange oil application, a natural, organic herbicide (Webber and Shrefler, 2007) to further reduce grass cover. To limit herbivory and modify seedling microclimate during early seedling establishment, we installed seedling shelter tubes. Each treatment was used singly and in combination. By addressing essential questions related to the ability of revegetation efforts to effectively restore critical thornscrub habitat for wildlife, this study aims to identify restoration strategies for alleviating seedling stressors and provide much needed data for an important yet understudied ecosystem.

2. Methods

2.1. Study area

This study took place in the 182-km^2 LANWR (26.21855N, 97.36666W), located ~20 km west of the Gulf of Mexico in Cameron Country, Texas, and 40 km north of Brownsville, Texas. Climate is semi-arid, sub-tropical, and characterized by hot summers and mild winters (Lonard and Judd, 1985). During this study, LANWR received 25 cm (2012) to 48 cm (2013) of precipitation annually, with 5–6 mo of >32 °C weather (NOAA National Climatic Data Center, Stations USR0000TLAG and USW00012957; Fig. 1). Soils are 90% clay and loam (Williams et al., 1977). Topography is flat, and elevation is ~5 m above MSL. Common thornscrub plants include Texas ebony (*Ebenopsis ebano* (Berl.) Barneby & Grimes), spiny hackberry (*Celtis pallida* Torr.), brasil (*Condalia hookeri* M.C. Johnst. var. *hookeri*), elbowbush (*Forestiera angustifolia* Torr.), Texas persimmon (*Diospyros texana* Scheele), and lotebush (*Ziziphus obtusifolia* Hook. ex Torr. & A. Gray) (A. Gray).

2.2. Study design

To investigate the effects of pre-planting prescribed fire, mowing, herbicide application, and seedling shelter tubes, used singly or in combination, on the growth and survival of thornscrub seedlings, a seedling study was initiated in 2011 in the Scum Pond South Unit at LANWR. Pre-treatment, woody shrubs (3–4 m tall) of honey mesquite (*Prosopis glandulosa* Torr.) and huisache (*Acacia farnesiana* (L.) Willd.) dominated the overstory; invasive grasses, including buffelgrass (*Cenchrus ciliaris* L.) and Kleberg bluestem (*Dicanthium annulatum (*Forssk.) Stapf), comprised the understory. These woody species are fast growers that can take over disturbed areas (e.g., Bontrager et al., 1979; Whitson and Scifres, 1981). Based on our observations at LANWR, the understory of these two woody shrubs rarely support native thornscrub species, and are thus, considered undesired species when growing in monospecific stands.

The study site consisted of three 384-m^2 areas subdivided into six 8-m × 8-m plots. These areas were adjacent to each other and ~50–100 m apart, and randomly assigned to ground-level treatments of pre-planting prescribed fire, mowing, or neither. Plots were then randomly assigned to a herbicide treatment, either acetic acid/orange oil (referred to as AA), glyphosate, or neither, and then to a shelter tube or no tube treatment. Prescribed fire was ignited March 2011 using handheld drip torches. Mowing occurred in July 2011 using a tractor and rotary mower (John Deere model 2155) with blade set to 15 cm. AA (20% vinegar with 59 mL orange oil per 4 L) and glyphosate herbicide (3% solution; MadDog PLUS, Loveland Products, Loveland, CO) were applied in July 2011 with backpack sprayers.

Seedlings, grown from native seeds at a nursery at Santa Ana National Wildlife Refuge or by local growers (Ewing and Best, 2004), were planted in a 2-m × 2-m grid in March 2012 within each plot (10–18 seedlings plot^{-1}). Seedlings were planted by hand after soils were ripped to a depth of 25–30 cm using a motor grader (Caterpillar model 140H). Seedlings were tagged with a unique identification number and flagged to facilitate re-location.

Seedlings were 1–2 yr old and included a random mixture of 25 species, for a total of 250 seedlings (Table 1). Species in the 'Other' category represented <2% of seedlings planted, and included huisache, coma (*Sideroxylon celastrinum* (Kunth) T.D. Penn), Chile piquin (*Capsicum annuum* L.), Texas senna (*Chamaecrista flexuosa* (L.) Greene var. *texana* (Buckley), blue mistflower (*Chromolaena odorata* (L.) King & H.E. Robins), guayacan (*Guaiacum angustifolium Engelm.*), tenaza (*Havardia pallens* (Benth.) Britton & Rose), Berlandier's Wolfberry (*Lycium berlandieri* Dun var. Berlandieri),