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Source: Madroño, 70(2) : 90-96

Published By: California Botanical Society

URL: https://doi.org/10.3120/0024-9637-70.2.90

MADROÑO, Vol. 70, No. 2, pp. 90–96, 2023

EFFECTS OF PRESCRIBED FIRE ON *CIRSIUM WRIGHTII* (ASTERACEAE) AT BITTER LAKE NATIONAL WILDLIFE REFUGE, NEW MEXICO, USA

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ABSTRACT

Cirsium wrightii A.Gray (Wright's Marsh Thistle) occurs in boggy soils, closely associated with the rare ciénegas (wet meadows) of New Mexico and often co-occurring with the federally threatened *Helianthus paradoxus* Heiser (Pecos Sunflower). Both species require full sun in order to mature, but can be shaded and outcompeted by invasive plants. Bitter Lake National Wildlife Refuge (BLNWR), located within the Northern Chihuahuan desert ecoregion, hosts one of the largest populations of *C. wrightii* and *H. paradoxus*. Currently, prescribed fire is a management tool used on BLNWR to improve habitat conditions for *H. paradoxus*, although little is known about how *C. wrightii* responds to prescribed fire. We conducted a prescribed fire at one of three wetland units populated by *C. wrightii* to study the effects of fire on growth and survival. We randomly selected 30 plants from the burned unit and five plants from unburned areas to monitor. We used generalized linear mixed effect modeling and Akaike information criterion (AIC_c) model selection to examine the effects of prescribed fire on the weekly growth of plant height and width. We found all plants survived the fire initially and differences in survival at 35 weeks were undetectable between burned and unburned plants. Individual plants within the fire boundary, and those that showed signs of damage due to the fire, grew taller and wider than plants that were not burned or showed no signs of damage. The results from our study will allow managers to improve habitat conditions for two rare and protected species by reducing competition with adjacent plants (including highly invasive species) and increasing the nutrient load in the system.

Key Words: ciénegas, *Cirsium wrightii*, land management, National Wildlife Refuge, Northern Chihuahuan desert, prescribed fire, Wright's marsh thistle.

Cirsium wrightii A.Gray (Wright's Marsh Thistle) is a wetland obligate species that grows in ciénegas (wet meadows), springs, seeps, and wetlands that have saturated soils with surface or subsurface waterflow and between 1150–2390 m in elevation (Hendrickson and Minckley 1985; Sivinski 2012; U.S. Fish and Wildlife Service [USFWS] 2017; Sánchez Escalante et al. 2019). The historic and current range is limited to these habitats within the Basin and Range Province of the American Southwest and northern Mexico (WEG 2008; Sivinski 2012). The majority of extant *C. wrightii* populations occur within New Mexico although recent studies verified occupied habitat at one site in Texas and one in northern Mexico (Sánchez Escalante et al. 2019); all previously documented sites of *C. wrightii* in Arizona are now considered extirpated (Sivinski 2012; USFWS 2017; Nesom 2018; Roth 2019). Within New Mexico, there are eight extant locations of *C. wrightii*, covering approximately 0.43 km^2 (106 acres), which are considered distinct populations or metapopulations (Sivinski 2012; USFWS 2017). Due mostly to the lack of known populations and existing habitat, the state of New Mexico lists *C. wrightii* as an endangered species (Roth 2019), and the U.S. Fish and Wildlife Service proposed to list this species as threatened under the Endangered Species Act in September 2020 (Federal Register 2020).

One of the largest populations of *C. wrightii* is located on Bitter Lake National Wildlife Refuge (BLNWR) (Sivinski 2012; USFWS 2017). Peterson and David (1998) first documented *C. wrightii* at BLNWR in 1998 at locations that were previously surveyed in the 1980s without documenting presence of the species. Surveyors concluded the 1998 location of the species must be due to recent arrival and establishment. A 2012 survey estimated the BLNWR population to be the largest known population, composed of 14,000–18,000 individuals, and occupying approximately 0.09 km^2 (22.6 acres) of habitat predominately around three refuge units (Sivinski 2012; USFWS 2017). At BLNWR, *C. wrightii* patches range in size from 50 individuals to thousands; despite an approximate 1 km separation between units, the BLNWR thistle locations are considered to be one population (Sivinski 2012; USFWS 2017). Most of the occupied areas are open ciénega, boggy margins of open water, or along excavated drains (Sivinski 2012).

Ciénegas are considered one of the most endangered habitats in New Mexico, as these formerly widespread habitats have dwindled to a scattered distribution due to increased demands on groundwater in the region (Hendrickson and Minckley 1985; Minckley et al. 2013; Sivinski 2016). Ciénegas typically have high endemism and habitat diversity and serve roles as migratory rest-stops for a host of different wildlife taxa, and as biodiversity centers within arid regions (Minckley et al. 2013). Plant species that occur in ciénagas on BLNWR are dominated by *Distichlis stricta* (Torr.) Rydb., *Muhlenbergia asperifolia* (Nees & Meyen ex Trin.) Matthei, bulrushes (*Scirpus* spp. L.), reeds (*Phragmites* spp. Adans.), cattails (*Typha* spp. L.), and spikerushes (*Eleocharis* spp. R.Br.).

Although the exact role of fire within ciénegas remains poorly understood, we do know plant community composition and vegetation structure can be easily affected through desiccation or fire (Minckley et al. 2013). Overall, the reduction of fuel loads and fire suppression efforts in the early 1900s reduced fire as a driving factor in the ecosystem (Gebow et al. 2004; Schussman et al. 2006; USFWS 2017). Prior to Euro-American settlement, wildfire frequency was high yet less intense than the fires that burn today (Schussman et al. 2006). The fire return interval within this region occurred within 5–10 years. (Drewa and Havstad 2001; Schussman et al. 2006). However, the number of fires and area burned increased as the era of fire suppression ended, during the 1970s and early 1980s, and where fuel levels increased (Gebow et al. 2004). Ciénegas have been further diminished due to both human activities and natural disturbances (Sivinski 2016). For example, *C. wrightii* habitat is threatened by aquifer and surface water depletion, effects of climate change, urbanization, agriculture, oil and gas development, livestock grazing, weed control, and establishment of non-native species (Sivinski 2016; USFWS 2017; Federal Register 2020).

One management method used to decrease fuel loads and invasive plants is prescribed fire. The National Wildlife Refuge System (NWRS) develops and implements scientifically based prescribed fire plans and has used fire as a management tool since the 1920s (USFWS 2002). On lands managed by the NWRS, prescribed fire is used to manage vegetation height and density plus enhance or alter nutrient cycling, which allows plant communities to support species that depend on fire-adapted ecosystems. Proper management requires knowledge of the role of fire within the ecosystem (USFWS 2002; Gebow et al. 2004; USFWS 2014). BLNWR is located within the northern Chihuahuan Desert natural fire regime where the fire season corresponds with the rainy season and lightning strikes generally start fires (Gebow et al. 2004). At BLNWR, prescribed fire is used to remove vegetation, to reduce the risk of large uncontrolled wildfires, and, followed with an herbicide application, to remove dense stands of invasive species (*Typha* spp. and *Phragmites* spp.) that can outcompete native species like *C. wrightii* and *Helianthus paradoxus* Heiser (USFWS 2017). Numbers of flowering *C. wrightii* have been monitored after prescribed fire (Roth 2019, 2020, 2021). However, plants can survive, but not flower after a prescribed fire. Our study monitored individual plant survival and growth through time independent of flowering status.

The objectives of our study were to: (1) determine effects of fire on *C. wrightii* survivorship and growth; (2) determine if there is a significant difference in *C. wrightii* plants and their growth over time between plants with and without signs of fire damage and stress.

Methods

Study Area

Bitter Lake National Wildlife Refuge is located within Chaves County, approximately 9.7 km northeast of Roswell, New Mexico. The refuge encompasses 99.3 km^2 (24,536 acres) at the transition of the Chihuahuan Desert and Southern Plains ecosystems and includes a biologically significant wetland area within the Pecos River watershed system (USFWS 1998; USFWS 2013). The wetlands at BLNWR are part of the Roswell Artesian Wetlands Ramsar Site, a designation for wetlands of international importance. This ecosystem supports several endangered endemic invertebrates, migratory birds, dragonflies, damselflies, and ciénega-dependent plants (RCS 2014). Wetland habitats on the refuge include springs, seeps, spring runs, ciénegas, spring ditches, sinkholes, a large playa, and nine managed wetland impoundments (Peterson and David 2001; Sivinski 2012). The spring ditches were constructed at BLNWR in the early 2000s to protect important spring habitat from the impoundments due to their fluctuation in salinity and other environmental parameters (Land 2005). The predominant source of water supplying the spring system is an artesian aquifer system in the San Andres limestone underlying the regional hydrologic system known as the Roswell Artesian Basin. The mineral content of the spring waters is influenced by discharged water passing through subsurface layers of gypsum and halite that overly the aquifer and results in water discharging from the springs that is brackish to saline, high in sulfate, chloride, and total ion concentrations (Land and Huff 2008). Most precipitation is rainfall occurring May through August and averages 250 mm (10 in) per year (Peterson and David 2001).

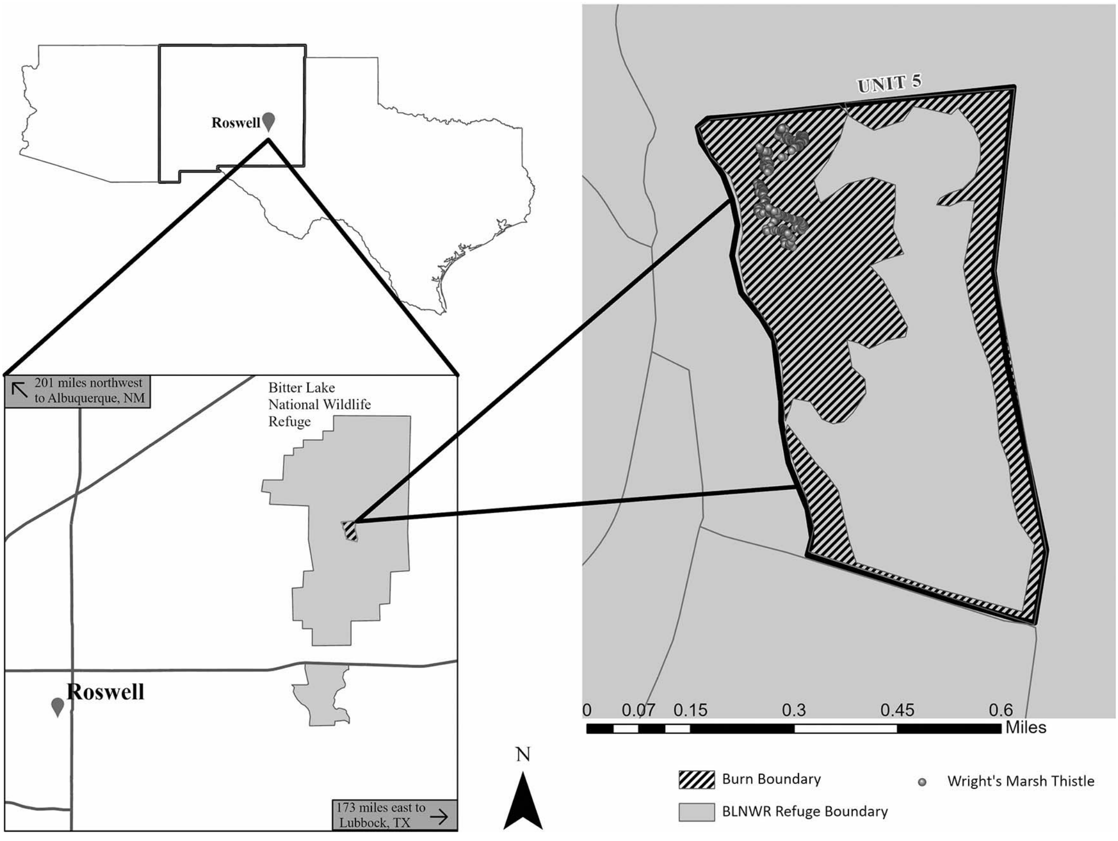

FIG. 1. Location of Bitter Lake National Wildlife Refuge, the prescribed burn and monitored individual plants of *C. wrightii*.

Vegetation associated with ciénegas at BLNWR include bulrushes (*Scirpus* spp.), reeds (*Phragmites* spp.), cattail (*Typha* spp.), spikerushes (*Eleocharis* spp.), Alkali Bulrush (*Bolboschoenus maritimus* (L.) Palla), Three-Square Bulrush (*Schoenoplectus americanus* (Pers.) Volkart ex Schinz & R.Keller), Scratchgrass (*Muhlenbergia asperifolia* (Nees & Meyen ex Trin.) Matthei), Saltgrass (*Distichlis stricta* (Torr.) Rydb.), Alkali Sacaton (*Sporobolus airoides* (Torr.) Torr.), Hairy Fimbry (*Fimbristylis puberula* (Michx.) Vahl), Heath Aster (*Symphyotrichum ericoides* (L.) G.L.Nesom), Sweet Scent (*Pluchea odorata*, (L.) Cass.), Seaside Arrowgrass (*Triglochin maritima* L.), Eastern Annual Saltmarsh Aster (*Symphyotrichum subulatum* (Michx.) G.L.Nesom), and Prairie Gentian (*Eustoma exaltatum* (L.) Salisb. ex G. Don) (Peterson and David 2001; Sivinski 2012). Rare plants include *C. wrightii, Agalinis calycina* Pennell (Leoncita False-Foxglove), and the federally threatened *H. paradoxus*; these three species co-occur together at this ciénega site (Sivinski 2012). Soils of BLNWR ciénegas are wet, alkaline with gypsum and other salts, with a large organic component (Sivinski 2012; Cantu de Leija 2021). *Cirsium wrightii* occupies ciénega habitat typically on the western edge of refuge management impoundments (Fig. 1). Patches of *C. wrightii* range in size from small (less than 50 individuals) to large (thousands of individuals; USFWS 2017).

We selected Unit 5, one of the managed wetland impoundments occupied by *C. wrightii*, for a prescribed fire in winter due to the presence of invasive plant vegetation targeted for removal. Prior to the burn, we identified and mapped 476 individual *C. wrightii* rosettes. On February 21, 2019, the U.S. Fish and Wildlife Service's New Mexico Fire District burned approximately 60 percent of Unit 5 on BLNWR, which covered almost the entire area containing *C. wrightii* in the northwest corner of Unit 5 (USFWS 2019, Fig. 1). On February 25, 2019, we randomly selected 30 of the 476 plants to locate and record plant status (alive/dead, burned/unburned, and extent of damage), height and width. If the plant showed some signs of damage, mostly indicated by singed leaves, we recorded that as damage present. We randomly selected an additional five plants from the unburned portion of Unit 5 to record width and height. Due to staffing constraints, we were only able to collected measurements from these 35 plants on a weekly basis through the growing and flowering seasons, March–September, which is when plants began to senesce. Each week we determined if the plant survived and estimated the proportion surviving at week 35.

TABLE 1. Summary of Model Selection Results Based on Akaike's Information Criterion (AIC_c) for Models Testing Effects of Time Post-burn (Weeks) on *Cirsium wrightii* Growth as Represented by Height (cm) and Width (cm).

Variable	Model	df	AIC_c	ΔAIC_c	Weight
Height	Burned + Weeks + Burned*Weeks	8	5768.5	0.00	0.454
	Damaged + Weeks + Damaged*Weeks	8	5768.9	0.44	0.364
	Weeks	6	5770.3	1.82	0.183
	Burned	6	5806.4	37.95	0.000
	Null	5	5807.5	39.03	0.000
	Damaged	6	5808.1	39.58	0.000
Width	Burned + Weeks + Burned*Weeks	8	5159.8	0.00	0.615
	Damaged + Weeks + Damaged*Weeks	8	5161.6	1.75	0.257
	Weeks	6	5163.0	3.14	0.128
	Burned	6	5195.7	35.85	0.000
	Damaged	6	5196.5	36.73	0.000
	Null	5	5197.3	37.48	0.000

Statistical Modeling

We used generalized linear mixed effect modeling to characterize the weekly growth of plant height (cm; through 29 weeks) and the diameter of the rosette or width (cm; through 25 weeks). These two timescales were chosen because this is when the plants began to show signs of senescing. We used the packages *lme4*, *MuMIn*, and *lmerTest* in the software program R (R, R Core Team, R Foundation for Statistical Computing, Vienna, Austria). Fixed effects included the number of weeks since the prescribed fire, if the plant was burned or unburned (burned), and if the plant showed signs of fire damage due to the prescribed fire (damaged). The variables burned and damaged were not included in the same model because of multi-collinearity. Random effects included both time and individual plant where individual plants vary randomly in terms of their intercept and their slope over time. We examined the interaction between weeks and whether plants were burned or damaged. We used Akaike information criterion for small sample sizes (AIC_c, Burnham and Anderson 1998) for model comparison and determined competitive models with $\Delta AIC_c < 2$.

RESULTS

All 30 randomly selected *C. wrightii* plants survived the prescribed burn with 21 (70%; exact binomial 90% CI = 53.5–83.4%) plants showing some signs of stress or damage (typically indicated by having singed leaves). We took initial observations five days after the prescribed burn, and then we monitored the plants weekly thereafter. After 35 weeks, 25 of the 30 (83.3%, exact binomial 90% CI = 68.1–93.2%) plants in the burn footprint, and 3 of the 5 (60%, exact binomial 90% CI = 18.9–92.4%) unburned plants survived.

For both thistle height and width, we found 2-3 models were competitive ($\Delta AIC_c < 2.0$, Table 1). The best model indicated that burn status interacted with time since burn and the second-best model indicated that plant damage status interacted with time since burn. Specifically, thistles that were burned increased in height by 0.60 cm more per week than unburned thistles ($t = 1.83$, $p = 0.076$, Fig. 2A). Damaged thistles increased in height by 0.52 cm per week more than thistles that did not show any signs of stress or damage due to the burn ($t = 2.31$, $p = 0.028$, Fig. 2B). Models also indicated burned thistles widened by 0.83 cm per week more than unburned thistles ($t = 1.84$, $p = 0.075$, Fig. 2C), and thistles that were damaged widened by 0.57 cm per week faster than undamaged plants ($t = 1.77$, $p = 0.086$, Fig. 2D).

DISCUSSION

Prior to our study and a concurrent study at Blue Hole Ciénega Nature Preserve (BHCNP) and Ballpark Ciénega near Santa Rosa, New Mexico, little was known about effects of prescribed fire on *C. wrightii*. Our study showed that a late winter to early spring prescribed burn may be beneficial to *C. wrightii* growth and have negligible effects on survival. However, drawing conclusions about similarities and differences in survival between burned and unburned plants should be done with caution since this study's sample size was small. Power analysis (>80% power) suggested 80 individual *C. wrightii* plants per treatment would be required to detect a difference in survival similar to what was observed in our study. However, differences in *C. wrightii* growth between the treatments were of sufficient magnitude to allow for detection of differences despite the small sample size. Research conducted at BHCNP and Ballpark Ciénega investigated the number of flowering *C. wrightii* plants along established transects and examined annual counts of flowing plants (Roth 2019, 2020, 2021). It is difficult to compare that study to ours since it was measuring different attributes. Furthermore, that research had no controls and conducted no statistical comparisons. In fact, without control transects, it is difficult to determine if observed changes in the number of plants flowering is due to prescribed fire or other environmental factors like drought. As a result, Roth (2021) hypothesized there may have been some direct impacts to seedlings and rosettes after a prescribed fire resulting in an initial reduction in flowering plants, but

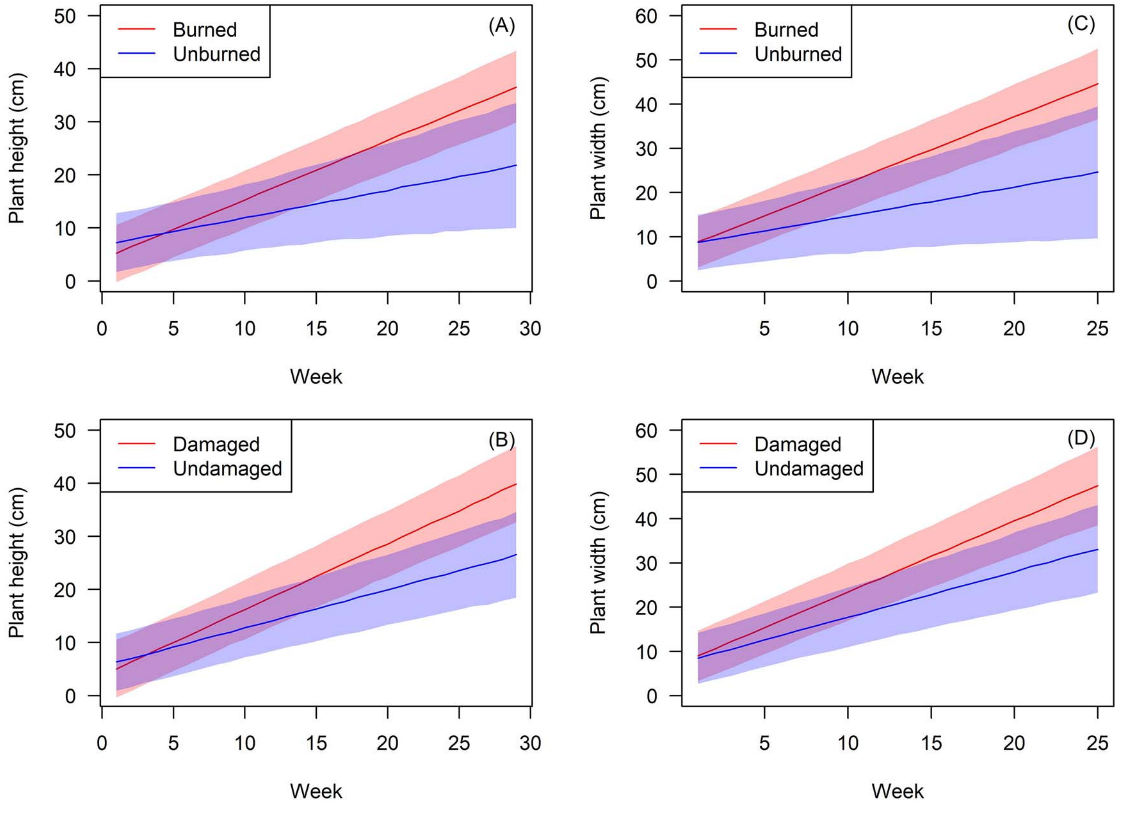

FIG. 2. The best models (based on AIC_c) demonstrate changes in *C. wrightii* height and width in the weeks following prescribed burn. They indicated an interaction between burn status (burned or unburned) time since burn (A & C). The second best model (based on AIC_c) indicates plant damage status (damaged vs undamaged) interacted with time since burn (weeks) (B & D).

the number of flowering *C. wrightii* ultimately recovered within a few years after fire.

In our study, only six (five burned and one unburned) of the monitored plants flowered during the growing season, and we did not have the resources to continue monitoring the rosettes into the following year's growing season. *Cirsium wrightii* requires full, direct, or nearly full sunlight for rosettes to develop into mature plants (USFWS 2017), therefore maturation and flowering can be suppressed by shade produced by dense patches of *Phragmites* (Sivinski 2012). Additionally, dense stands of invasive Phragmites and Cattails increase fuel loads and increase the threat of wildfire (USFWS 2017). Although fires are naturally occurring ecological phenomena within the ciénega habitat where these species co-occur, the specific effects of fire on wetland obligate biennials or monocarpic perennials, like *C. wrightii*, were unknown prior to our study.

There are few studies that look at the direct effects of fire on individual wetland plant species (USFWS 2017), but variation in responses is expected among species (McWilliams et al. 2007). At BLNWR, fire is used as a management tool to improve habitat conditions for *H. paradoxus* because this species responds favorably to well-timed prescribed fire. *Helianthus paradoxus* is an annual that sets seed in late fall and germinates in early spring; therefore, prescribed fires conducted in late winter to early spring provide benefits through reducing competition with invasive plants, increasing available nutrients, and breaking seed dormancy (Roth 2019). All *C. wrightii* populations on BLNWR occur within designated critical habitat for *H. paradoxus*, and some *C. wrightii* occur within stands of invasive Phragmites (*Phragmites* spp.) or Cattail (*Typha* spp.; Sivinski 2012; USFWS 2017; Roth 2019).

Our results indicate that survival of *C. wrightii* was not detrimentally impacted by late winter to early spring prescribed fire, if suitable conditions exist (e.g., soil moisture content), and support previous observations that some plant species respond to fire by increasing their vegetative growth (Gebow et al. 2004). Overall, our results showed that burned or damaged *C. wrightii* grew taller and wider, than unburned or undamaged *C. wrightii*. We hypothesize a reduction in competition from adjacent plants (e.g., more sunlight and decreased thatch) and an increase in nutrients may be what is driving the improved growth and those plants that were damaged by the fire had a higher intensity burn resulting in greater decreases in competition. This is an important finding for improving USFWS's management practices, following the Endangered Species Act (ESA) objective of increasing species' viability through increases to population size and occupied habitat. Although *C. wrightii* is currently proposed for listing under the ESA, USFWS is still required to manage *C. wrightii* on BLNWR as though it were listed using the best available management techniques. The use of prescribed fire to enhance habitat combined with seed collection, seed dispersal, and transplanting plants will enable managers to improve the viability of *C. wrightii* by increasing the population size, removing invasive species, and increasing occupied habitat.

Continued monitoring and evaluating the effects of prescribed fire on rare wetland plants is important to allow managers to understand species' responses to management actions and the factors that influence *C. wrightii* rosette persistence to flowering stage. At BLNWR, a well-timed prescribed fire appears to benefit both *C. wrightii* and *H. paradoxus*, but effects on a third rare wetland plant, *A. calycina*, are still unknown. Understanding the ecological requirements, population responses, and individual plant effects to habitat alteration is crucial to implementation of suitable habitat management for all three co-occurring species.

Acknowledgments

We thank David Weber for assistance in the field and the staff at Bitter Lake National Wildlife refuge for support during the data collection. The findings and conclusions in this article are those of the authors and do not necessarily represent the views of the USFWS. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the United States Government.

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