SEED BANKS OF RARE *PHYSOSTEGIA CORRELLII* (LAMIACEAE) IN LADY BIRD LAKE, AUSTIN, TEXAS, U.S.A.

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ABSTRACT

Rare species threatened by climate and land-use change may harbor seeds in soil seed banks for periods of time even if adults have disappeared from the site. Soil samples were collected from sites with current *Physostegia correllii* populations and from sites with former populations in Lady Bird Lake (a reservoir of the Colorado River, Austin, Texas. A seedling emergence study was conducted under greenhouse conditions, and the presence/absence of seedling emergence was recorded for two years. Seeds germinated from the seed banks of all current and former colonies tested. The presence of seed banks in a historical site (Blunn Creek) of *Physostegia correllii* suggests that management to encourage the germination of seeds might help to encourage the establishment of populations of this species. The re-establishment of disturbance fugitives might be facilitated by removing overhanging ground vegetation or imposing water management regimes that mimic natural floodplain dynamics.

Key Words: bottomland hardwood forest; climate change; disturbance fugitive; floodplain; land-use change; rare species; seed bank; shading; wet grassland

RESUMEN

Las especies raras amenazadas por el cambio climático y el uso de la tierra pueden albergar semillas en bancos de semillas del suelo durante períodos de tiempo, incluso si los adultos han desaparecido del sitio. Se recolectaron muestras de suelo de sitios con poblaciones actuales de *Physostegia correllii* y de sitios con poblaciones anteriores en Lady Bird Lake (un embalse del río Colorado, Austin, Texas). Se realizó un estudio de emergencia de plántulas en condiciones de invernadero, y la presencia/ausencia de emergencia de plántulas se registró durante dos años. Las semillas germinaron de los bancos de semillas de todas las colonias actuales y anteriores probadas. La presencia de bancos de semillas en un sitio histórico (Blunn Creek) de *Phyostegia correllii* sugiere que el manejo para fomentar la germinación de semillas podría ayudar a fomentar el establecimiento de poblaciones de esta especie. El restablecimiento de los fugitivos de perturbación podría facilitarse mediante la eliminación de la vegetación del suelo que sobresale o la imposición de regímenes de gestión del agua que imiten la dinámica natural de las llanuras aluviales.

INTRODUCTION

Rare plant species are declining as shifts in land use alter the character of the natural disturbances that drive seed germination and establishment (Mettler et al. 2001). Disturbance fugitives depend on recurring natural disturbances to provide suitable early successional habitats (Mettler et al. 2001). A natural disturbance may reduce shading (e.g , fire: Fowler et al. 2012; Leonard & Van Auken 2013), and increase re-establishment via seed banks (Lavorel et al. 1994). In situations where the species requires high light levels for growth, a disturbance may be critical for regeneration.

Disturbance can increase gaps in thick masses of live and dead leaves/stems (thatch) and thus facilitate the short-term establishment of fugitive species, which in turn may increase biodiversity (Lavorel et al. 1994). In wetlands, gap-creating disturbances include fire (Anderson & Menges 1997), shoreline elevation changes, shading by wrack (Elsey-Quirk et al. 2019), soil digging by crayfish (e.g., *Cambarus batchi*) or other species (Brewer 1998; Krupa et al. 2021), flood pulsing (Middleton 1999; Mettler et al. 2001), and disturbance interactions (Brewer et al. 1998; Kirkman & Sharitz 1994). In rare floodplain habitats of high light but usually unflooded environments, seeds from the seed banks of disturbance fugitives may germinate and recruit seedlings (Brown & Cahill 2020) after a disturbance knocks down tall shrubs and grasses, thereby reinvigorating populations along floodplains with modified flood environments (Mettler et al. 2001).

J. Bot. Res. Inst. Texas 17(1): 363–368. 2023
https://doi.org/10.17348/jbrit.v17.i1.1301

Our objective was to observe whether seed banks of *Physostegia correllii* populations existed in current and former locations (previous populations but with no above-ground plants) in Lady Bird Lake in Austin Texas. *Physostegia correllii* is a rare species of southern Louisiana, Texas, and northern Mexico (Fig. 1; Cantino 1982). The lack of germination from these seed banks could either indicate the absence of viable seeds or that the environment did not meet the requirements of the species for germination. However, seed germination from seed banks of *P. correllii* would indicate that the seeds are maintained in both former and current populations in the soil. If so, maintaining more suitable natural disturbances and environments for seed germination and establishment might help in the conservation of this species.

MATERIAL AND METHODS

Study species background.—*Physostegia correllii* is considered a rare species by NatureServe (2021). The Federal Register (2011) states the reasons petitioners requested its inclusion as a federally protected species as: "Present or threatened destruction, modification or curtailment of its habitat or range," and "Inadequacy of existing regulatory mechanisms."

This species has indeterminate growth with secondary and tertiary horizontal rhizomes to 50 cm long (Cantino 1982). Rosettes can be generated either from the rhizomes or stolons (B. Middleton, U.S. Geological Survey, per. obs.). As a species with indeterminate growth, the flowers mature from the base toward the tip of the spike (B. Middleton, U.S. Geological Survey, per. obs.) and are attractive to a wide variety of pollinators, especially native bees, e.g., *Xylocarpa* spp. (Cantino 1982; B. Middleton, U.S. Geological Survey, per. obs., and Casey Williams, U.S. Geological Survey Volunteer, per. obs.).

A few relict populations of *P. correllii* have been documented in Louisiana, Texas, and northern Mexico (Cantino 1980) with populations along the Rio Grande (Owens et al. 2005), and an iNaturalist report on the Mexico side of the Rio Grande near Ciudad Acuña on August 8, 2022 (Eric Keith, email communication, December 31, 2022). In a detailed survey of colonies along the shoreline of Lady Bird Lake along the Colorado River, Austin, Texas, twenty-two colonies were found in 2014 (Williams & Manning 2020). In July 2021, the number of colonies had decreased to eleven along this lake (B. Middleton, U.S. Geological Survey, per. obs., and C. Williams and J. David, U.S. Geological Survey Volunteers, per. obs.). In 2019, colonies in Gillespie County Texas (C. Williams, U.S. Geological Survey Volunteer, per. obs.) and Cameron Parish Louisiana (B. Middleton, U.S. Geological Survey, per. obs.) could not be located and were presumed extirpated. In 2021, historical colonies along the Rio Grande in Del Rio TX, Val Verde County could not be verified because of lack of property access (C. Williams, U.S. Geological Survey, per. obs.). It is likely that only a few populations remain in Louisiana and Texas (USDA 2021).

Physostegia correllii is likely a disturbance fugitive (following Mettler et al. 2001) because it tends to emerge periodically after flood events on river floodplains, and along irrigation ditches, roadsides, and creek beds, especially at the edge of forested wetlands (NatureServe 2021), typically in isolated populations with either natural or human disturbance (Cantino 1982). After germination, the plant forms a rosette, which bolts and then flowers during the second year. The flowering stalks die back in late summer, and new rosettes emerge from rhizomes and stolons by October (B. Middleton, U.S. Geological Survey, and C. Williams, U.S. Geological Survey Volunteer, per. obs.). The overwintering stalks are capable of regrowing after ice storms and multi-day hard freezes to form new flowering stalks in the following summer (e.g., January 2020 and 2021; B. Middleton, U.S. Geological Survey, per. obs.).

The species grows in the saturated soil of open floodplains along streambanks or in the high-canopy shade of *Taxodium distichum* (B. Middleton, U.S. Geological Survey, per. obs , and C. Williams and J. David, U.S. Geological Survey Volunteers, per. obs.). Under dense vegetation, *P. correllii* appears unhealthy with yellowing leaves, insect damage, and decreased flowering (Williams & Manning 2020).

On Lady Bird Lake, *P. correllii* grows along open shorelines in alluvial moist to saturated sediment with associates such as *Alternanthera philoxeroides*, *Colocasia esculenta* (Williams & Manning 2000), *Elymus virginicus*, and *Mikania scandens*. Very short individuals may arise from horizontal rhizomes in the partial

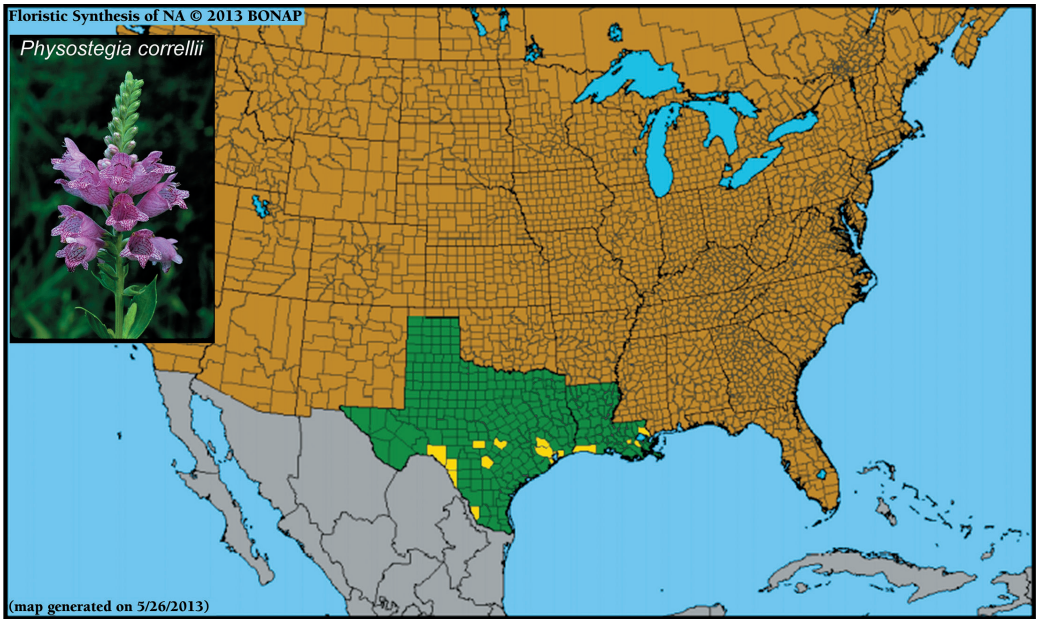

Fig. 1. *Physostegia correllii* distribution in North America with counties/parishes of historical and current locations shown in yellow (from Kartesz 2015). Inset photo from USDA Plants Database (2021).

shade of advancing shrubs (B. Middleton, U.S. Geological Survey, per. obs., and C. Williams and J. David, U.S. Geological Survey Volunteers, per. obs.).

Seed banks.—Soil seed bank samples were collected from the soil surface with a small garden shovel (~2.5 cm depth, soil volume <1375 cm^3) at Lady Bird Lake, Austin, Texas on August 22, 2019. The collected soil was placed into marked resealable bags. At current sites with *P. correllii*, which were directly adjacent to the lake (Waller Creek and Lakeside Apartments), seed banks were collected in three positions including 1) adjacent to the plant near enough to the plant that seeds might have fallen there by gravity taking care not to disturb the roots (B), 2) 1 m inland from the sampled plant (C), and 3) in the channel or lakebed closest to the plant (D). At Blunn Creek (directly adjacent to the lake and with no above-ground plants), sampling was conducted where adult plants had been observed and mapped in 2014 and 2018 (Williams & Manning 2020) but were not visible in 2019. During the 2019 sample, an arbitrary location on the bank was chosen to represent the position where *P. correllii* may have grown in the previous years, and the same procedure was followed for soil collection as in the current sites. Interestingly, over 200 stems of the species were observed at the mouth of Blunn Creek in 2022 (Eric Keith, email communication, December 31, 2022). GPS coordinates were recorded for all sample points either adjacent to a plant at current sites or representing that position in former sites with no above-ground *P. correllii*.

To prepare the seed banks for the experiment, the soil was sieved to remove coarse debris (mesh size = 2 mm). The collected soil was transferred to trays (16.5 × 11.4 × 2 cm depth; surface area of 188.1 cm^2) with one tray for each plot by site and placed in a tank (91 × 91 cm) in a greenhouse of the U.S. Geological Survey, Wetland, and Aquatic Research Center, Lafayette, LA. The trays were elevated on bricks to minimize shading in the tanks (30 cm depth) and the water was filled to the base of the soil in the trays in the tank; the soil in the trays was never flooded during the experiment. The average temperature inside the greenhouse was 26.40°C, and outside was 30.17°C during the experiment. Humidity was not recorded in the greenhouse; instead, humidity data from the Lafayette Louisiana airport were acquired and a mean of 77.7% during the experiment.

Table 1. Seed bank collection locations, GPS coordinates, *Physostegia correllii* seed germination in greenhouse seed bank study (seeds present/absent) in the seed banks. Former vs. current adult population status, and water depth (cm) are given. The seed banks were collected from Lady Bird Lake, Austin Texas on August 22, 2019. Germinated seedlings were observed from August 2019 to August 2021.

Location	Population status	Latitude/ Longitude	Germination present/absent	Date seedlings observed in greenhouse	Habitat notes
Blunn Creek 1B	Former	30.2526°N, 97.7405°W	absent	Not observed 2019–2021	Lakeside bank of the creek; moist, not flooded
Blunn Creek 1C	Former	30.2526°N, 97.7405°W	present	9/13/2019	Lakeside 1 m from bank in shrubs; moist, not flooded
Blunn Creek 1D	Former	30.2526°N, 97.7405°W	present	9/13/2019	Underwater near bank; >2 m water
Blunn Creek 2B	Former	30.25274°N, 97.7403°W	absent	Not observed 2019–2021	Bank of creek; moist, not flooded
Blunn Creek 2C	Former	30.25274°N, 97.7403°W	present	9/13/2019	Lakeside 1 m from bank in shrubs; moist, not flooded
Blunn Creek 2D	Former	30.25274°N, 97.7403°W	present	9/13/2019	Underwater near bank; >2 m water
Waller Creek 1B	Current	30.25879°N, 97.7415°W	present	9/20/2019	Bank of creek next to *Physostegia;* moist, not flooded
Waller Creek 1C	Current	30.25879°N, 97.7415°W	present	9/13/2019	Lakeside 1 m from bank in shrubs; moist, not flooded
Waller Creek 1D	Current	30.25879°N, 97.7415°W	present	9/13/2019	Underwater near bank; >1 m water
Lakeside Apartments 1B	Current	30.25879°N, 97.7415°W	present	9/20/2019	Between broken cement on lake embankment near *Physostegia;* moist, not flooded
Lakeside Apartments 1C	Current	30.25879°N, 97.7415°W	present	9/13/2019	Between broken cement on lake embankment 1 m from *Physostegia:* moist, not flooded
Lakeside Apartments 1D	Current	30.25879°N, 97.7415°W	present	9/13/2019	Between broken cement on lake embankment in the water of the lake; ~10 cm water

The presence or absence of *P. correllii* seedlings germinating from the seed bank was recorded at least once per month from August 2019 to August 2021 and recorded by site and plot. None of the seedlings flowered or set seed during the experiment, and all of the germinated seedlings survived during the study. Other species germinated from the seed banks but none were removed during the study because of the limited access to the greenhouse during the pandemic. Seed contamination from *P. correllii* was not possible because none of the seedlings in the seed bank produced flowers. No statistical comparison of current and former sites was possible because of the observational nature of the work.

RESULTS

Seedling emergence was noted for two years, and *P. correllii* seeds germinated from the seed banks of all current and former sites (Waller Creek and Lakeside Apartments vs. Blunn Creek, respectively) at Lady Bird Lake (Table 1; Middleton & Williams 2023). None of the *P. correllii* seedlings flowered or set seed during the experiment, and all of the germinated seedlings survived during the study. Other species germinated from the seed banks but none were removed or recorded during the study because of the limited access to the greenhouse during the pandemic.

DISCUSSION

Ultimately, the long-term success of disturbance-dependent species may depend on the presence of viable seeds via dispersal and/or seed bank storage. After the seeds enter the seed bank, seed longevity, germination, and recruitment depend on the presence of specific environments (Middleton 1999; Baskin & Baskin 2014).

For example, while the federally threatened *Boltonia decurrens* was uncommon along the Illinois River, the species expanded temporarily following the Great Flood of 1993 because the flood removed dominant vegetation, and seedlings were able to germinate from the seed bank. Also, the timing of disturbance events can be important; the persistence of disturbance fugitives depends on temporary adult occupation and seed bank replenishment (Lavorel et al. 1994; Mettler et al. 2001). The dispersal mechanism of *P. correllii* is not known; however, the majority of floodplain species are water-dispersed (Middleton 1999).

Seeds in the seed banks at Lady Bird Lake along the Colorado River in Austin Texas were widespread and found in both the extant and former colonies of *P. correllii*. Management approaches to remove low vegetation and support *P. correllii* germination from seed banks or hand-seeded sources might be effective. Stabilizing alluvial banks from erosion may protect accumulated seed banks. Future studies of *P. correllii* can better elucidate its seed longevity and germination requirements. Studies to better understand environments that support seedlings, adults, and seed production would also be helpful. Some species, including *Physostegia angustifolia* and *Physostegia virginiana,* have low germination rates without stratification or pretreatment (Cantino 1982). Seeds of species in the family Lamiaceae often need sunlight to germinate (Baskin & Baskin 2014), and this may also be true of *P. correllii*. A better knowledge of the constraints of seed germination and seedling recruitment in disturbance fugitives such as *P. correllii* can help in the design of strategies to encourage the establishment of these populations.

CONCLUSIONS

Viable seed banks of *P. correllii* occur in both current and former populations of the species in Lady Bird Lake in Austin Texas, and might well occur in similar environments along the Colorado, Mississippi, and Rio Grande Rivers. Management to restore natural disturbances to lakeside environments including hand-cutting and removal of tall vegetation may support the seed germination, seedling recruitment, and adult survival of *P. correllii*.

ACKNOWLEDGMENTS

Funding came from the U.S. Geological Survey Ecosystem Mission Area and the U.S. Fish and Wildlife Service (Interagency Agreement #4500146370). Special thanks to Minnette Marr of the Lady Bird Johnson Wildflower Center in Austin, Texas. We thank Norma Fowler, Wendy Leonard, and anonymous reviewers for comments on earlier drafts of this manuscript, and John David for help with experiments. Special thanks to Phil Cantino for his insights on *P. correllii* and related Lamiaceae throughout this project. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. We thank Eric Keith and an anonymous reviewer for their helpful comments.

Conflicts of interest

The authors declare no conflict of interest with any data or information provided in this manuscript.

Author Contributions

B.A.M. and C.W. conceived and planned the study. BAM wrote the first draft of the paper.

Data Availability Statement

Data for this study are available in Middleton and Williams 2023.

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