DISTRIBUTION OF *HELIANTHUS PARADOXUS* (ASTERACEAE) AND *AGALINIS CALYCINA* (OROBANCHACEAE) ON BITTER LAKE NATIONAL WILDLIFE REFUGE, NEW MEXICO, U.S.A.

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ABSTRACT

Helianthus paradoxus (Asteraceae) is listed as threatened under the U.S. Endangered Species Act (ESA), and *Agalinis calycina* (Orobanchaceae) is currently being considered for listing under the ESA. We surveyed *H. paradoxus* in 2018 and *A. calycina* from 2018 to 2020 in order to document their distribution and abundance on Bitter Lake National Wildlife Refuge (BLNWR), New Mexico. In 2018, *H. paradoxus* coverage was estimated to total 41.32 ha, with approximately 12,691,116 plants, and *A. calycina* coverage was estimated to total 1.45 ha, with approximately 107,338 plants. Approximately 0.56 ha of *A. calycina* coverage, totaling about 105,073 plants, fell in areas also mapped as *H. paradoxus* polygons. This accounted for about 39% of the *A. calycina* area in 2018. No *A. calycina* plants were detected in 2019, and in 2020 detections were limited to individual plants. BLNWR is one of only two areas where both plants occur, but *A. calycina* has a far more restricted distribution on BLNWR than *H. paradoxus*, occurring only in wetland management units. As with prior surveys, *A. calycina* abundance is highly variable from year-to-year. Periodic comprehensive surveys (once every 5 years) are needed in order to access status and trends. Further, we suggest that an index be developed that can characterize germination and establishment conditions for *A. calycina* into good, average, and poor conditions in order to meaningfully assess long-term trends.

RESUMEN

Helianthus paradoxus (Asteraceae) está incluida en la lista de especies amenazada en la Ley de especies amenazadas (ESA), mientras que *Agalinis calycina* (Orobanchaceae) está actualmente en consideración para ser incluida. Para documentar su distribución y abundancia en Bitter Lake National Wildlife Refuge (BLNWR), Nuevo México, llevamos a cabo un censo de *H. paradoxus* en 2018 y de *A. calycina* de 2018 a 2020. En 2018, *H. paradoxus* tenía una cobertura estimada de 41.32 ha, y aproximadamente 12,691,116 plantas, mientras que *A. calycina* tenia una cobertura de 1.45 ha, y aproximadamente 107,338 plantas. Aproximadamente 0.56 ha de la cobertura de *A. calycina*, con alrededor de 105,073 plantas, convergían con áreas ocupadas por *H. paradoxus*. Esto representó alrededor del 39% del área ocupada por *A. calycina* en 2018. En el 2019, no se encontró ningún individuo de *A. calycina*, y en 2020 los registros estuvieron limitados a algunos individuos. BLNWR es uno de los dos únicos sitios donde ambas plantas coexisten, pero la distribución de *A. calycina* en BLNWR es mucho más restringida que la de *H. paradoxus*, encontrándose solamente en unidades de humedal manejado. De acuerdo con censos anteriores, la abundancia de *A. calycina* varia mucho de año a año. Esfuerzos de monitoreo periódicos y exhaustivos (cada 5 años) son necesarios para evaluar su estatus y tendencia. Además, sugerimos el desarrollo de un índice que pueda caracterizar las condiciones de germinación y establecimiento de *A. calycina* como buenas, promedio, o condiciones pobres para evaluar efectivamente sus tendencias poblaciones a largo plazo.

Key Words: *Agalinis calycina*, Bitter Lake National Wildlife Refuge, *Helianthus paradoxus*, Leoncita false-foxglove, New Mexico, Pecos sunflower

INTRODUCTION

Helianthus paradoxus Heiser (common name: Pecos sunflower) occurs in seven locations across New Mexico and western Texas (USFWS 2005). In 1999, it was listed as threatened under the U.S. Endangered Species Act (ESA) due to its limited distribution, and the potential for loss of habitat due to groundwater pumping, surface water diversion, changes in land management, and invasive plant competition (for additional justification, see Federal Register 1999). *Agalinis calycina* Pennell (common name: Leoncita false-foxglove) is known from only two sites in the United States, one in New Mexico and one in Texas (Sivinski 2011). It may also occur at two sites in Coahuila, Mexico, although the status of these populations are unknown (Sivinski 2011; Roth 2019). *Agalinis calycina* is currently being evaluated for potential listing under the ESA (Federal Register 2016).

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Helianthus paradoxus is an annual plant that prefers moist, alkaline soils and predominantly occurs in association with spring-influenced areas, such as inland salt marshes (or ciénegas), and the margins of spring-runs, spring creeks, and spring pools (Van Auken & Bush 1998; USFWS 2005; Van Auken et al. 2007). Soils associated with *H. paradoxus* may experience seasonal drying near the surface or be perennially saturated (Cantu de Leija 2021); likewise, groundwater salinities vary seasonally (Van Auken & Bush 1995; Grunstra & Van Auken 2007; Cantu de Leija et al. 2022). Although *H. paradoxus* grows over a range of soil moisture and salinity conditions (Cantu de Leija 2021; Cantu de Leija et al. 2022), establishment is best when spring germination coincides with a reduction in salinities near the soil surface due to elevated water tables or precipitation (Van Auken & Bush 1995). Flowering is conspicuous, and typically occurs from September into early October (USFWS 2005). Although it sometimes grows adjacent to *H. paradoxus*, *A. calycina* has a far narrower distribution, and is restricted to alkaline, spring influenced salt marshes with perennially saturated soils (Sivinski 2011; Sivinski & Tonne 2011). More so than *H. paradoxus*, spring germination requires the reduction of surface salinities associated with precipitation or elevated high-water tables (Cantu de Leija et al. 2022). Flowering occurs in August and September (Sivinski 2011).

In the late 1990s, a comprehensive mapping effort to document the extent of *H. paradoxus* at Bitter Lake National Wildlife Refuge (BLNWR), New Mexico, was undertaken (Wells 1998; Warrick & Linnell 1999). *Helianthus paradoxus* were concentrated along the perimeters of the refuge's managed wetland units, but also occurred along spring creeks and other spring influenced areas. The survey efforts in the 1990's were carried out by writing notes and sketching polygons on topographic maps. Estimates of coverage and plant abundance were not provided with these maps. Since these initial surveys, *H. paradoxus* survey efforts on the refuge have been limited to monitoring the localized effects of restoration actions.

In 2009 and 2010, Sivinski (2011) documented four patches (mapped as polygons) of *A. calycina* and an additional three locations that consisted of only a few plants each on BLNWR. This survey effort was included in the 2012 petition to list *A. calycina* as an endangered species (McGrath 2012). Since this initial survey effort, there has been little effort to monitor *A. calycina* at BLNWR, although disturbance of known areas has been avoided.

We attempted to survey all *H. paradoxus* and *A. calycina* growing on BLWNR in 2018. In 2019 and 2020, surveys were focused on *A. calycina* only. The effort included creating geospatial files of plant locations and estimating plant abundance. We also mapped areas of overlap between the two species in order to incorporate the information into future habitat management scenarios.

MATERIALS AND METHODS

Study area.—BLNWR is located along the Pecos River floodplain in Chaves County, New Mexico (Fig. 1). The Refuge's vegetation is characteristic of Chihuahuan desert shrublands and grasslands (Griffith et al. 2006). Its wetlands include riparian areas as well as spring-influenced systems, such as sinkholes, spring-creeks, spring runs, salt marshes and managed wetlands. Spring-influenced wetlands derive water almost entirely from the San Andres artesian aquifer system (Land 2005; Land & Huff 2008). Infrastructure (e.g., levees, water control structures) associated with managed wetlands was constructed by the Civilian Conservation Corps between 1937 and 1942. From the time of construction until 1994, wetland units were managed as permanently inundated lakes in order to maintain both a recreational fishery and waterfowl roosting areas (USFWS 1998). In 1994, additional levees were constructed on the west side of some wetland units to ensure impounded water within units did not back up into areas of springs known to harbor rare invertebrates. Concurrent with levee construction, management of wetland units transitioned to a seasonal water management regime in order to alleviate extreme salinities created by perpetual flooding and to encourage the germination and growth of moist-soil plants (Fredrickson and Taylor 1982; USFWS 1998), including *H. paradoxus* (Cantu de Leija 2021). Current management utilizes seasonal fluctuations in springflow and precipitation to create conditions where wetland units are partially flooded during fall, winter and early spring, and allowed to experience drying during late spring and summer.

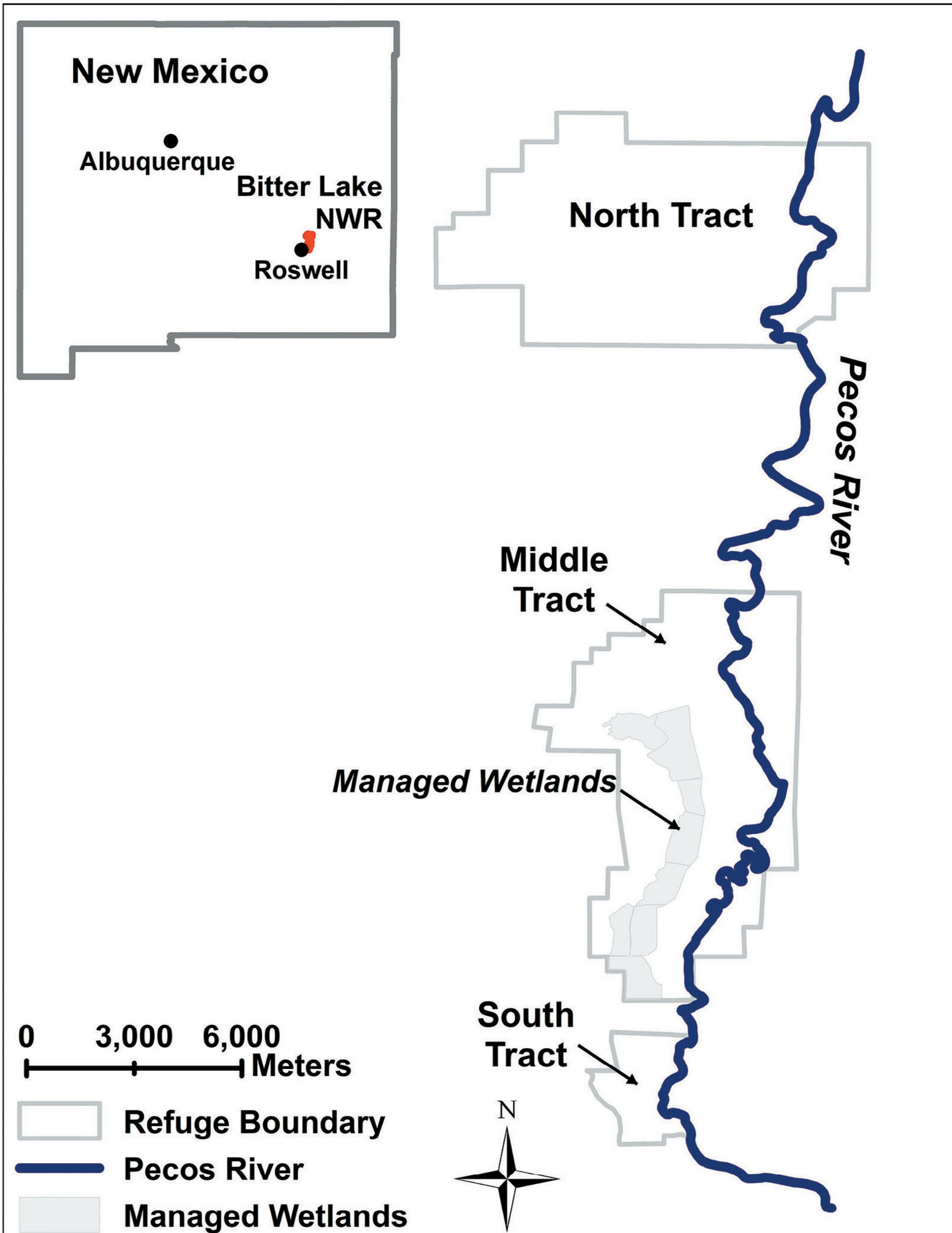

Fig. 1. The North, Middle, and South Tracts of Bitter Lake National Wildlife Refuge, Chaves County, New Mexico. Location of wetland management units, which are important areas for both *Helianthus paradoxus* and *Agalinis calycina*, are indicated.

The many spring systems at BLNWR differ with respect to water characteristics, including salinity, which contributes to the refuge's high biological diversity (Gallo 2013). The refuge has six spring-associated species that are listed as federally threatened or endangered, including *Gammarus desperatus* (Noel's amphipod), *Pyrgulopsis roswellensis* (Roswell springsnail), *Juturnia kosteri* (Koster's springsnail), *Assiminea pecos* (Pecos assiminea), *Gambusia nobilis* (Pecos gambusia) and *H. paradoxus*. The refuge also has multiple state-listed species that are associated with its spring systems, including *Agalinis calycina*, *Assiminea pecos*, *Astyanax mexicanus* (Mexican tetra), *Cirsium wrightii* A. Gray (Wright's marsh thistle), *Cyprinodon pecosensis* (Pecos pupfish), *Gambusia nobilis*, *Gammarus desperatus*, *H. paradoxus*, *J. kosteri,* and *P. roswellensis* (NMDGF 2020; EMNRD 2021). In 2010, BLNWR was designated a Ramsar site due to the importance of its wetlands to narrow range endemics, endangered species, and migratory birds (Ramsar.org 2010).

BLNWR consists of three tracts: North, Middle, and South. The North Tract is a Wilderness Area and its wetlands primarily consist of sinkholes and riparian areas along the Pecos River. The Middle Tract has abundant spring-influenced wetlands, including sinkholes, spring-creeks, spring runs, seasonally flooded marshes, and managed wetlands. The largest stands of *H. paradoxus* and all known *A. calycina* come from this tract (Sivinski & Tonne 2011). The South Tract includes farmland, riparian areas, and a large spring-creek.

Field surveys.—*Helianthus paradoxus* surveys began on August 13, 2018 and ended on September 17, 2018. *Agalinis calycina* surveys were conducted on September 11, 2018. *Agalinis calycina* was also surveyed in September 2019 and on September 22, 2020. All known potential *H. paradoxus* and *A. calycina* habitat on the Middle and South Tracts of BLNWR were surveyed. Additionally, the southern portion of the North Tract near the Pecos River was surveyed.

We used the mobile mapping app Collector for ArcGIS (Collector is now ArcGIS Field Maps, Esri 2019a; Nowak et al. 2020) on cell phones and tablets (iPad) to collect geospatial information and attributes (e.g., date, abundance). Geospatial features collected included polypoints, polylines, and polygons. Polypoints were created by recording coordinates (i.e., waypoints) of individual plants or small groups of plants. Polylines were created by recording coordinates to create a path (line) when plants were growing in a narrow strip, such as along a spring-run. Creation of polygons involved using Collector while mapping the perimeter of a stand or large cluster of plants; surveyors held the mobile device along the outer edge of the patch while walking around it. The numbers of plants associated with each polypoint, polyline and polygon were visually estimated and entered into the mobile app while in the field. Survey information contained on mobile devices was synced/uploaded to ArcGIS Online (Esri 2019b) periodically during each survey day, and effort was made to sync/upload data at the end of each survey day as well.

Data processing.—Data were downloaded from ArcGIS Online and the areas of polygons were calculated in ArcGIS Desktop (Esri 2019c). Both polypoints and polylines were buffered (0.5 m) in order to account for some spatial variation and area coverage of plants; the buffered data were used in the estimate of total plant coverage and in calculating plant density.

Spatial records were quality assessed by 1) looking for overlapping geometry of polygons, 2) making sure all field entered dates reflected actual survey dates (for archival purposes), and 3) by looking for untenable estimates of abundance. When overlapping polygons were found they were merged, and the plant abundance estimate of the larger polygon was kept; there were two overlapping *A. calycina* polygons. Incorrect field survey dates (one instance) were corrected after consultation with the field surveyor. Unlikely abundance estimates were addressed by changing the estimate to zero but keeping the associated geometry; these edits were noted in the comments column of the attribute file (or table) associated with the spatial data. There were two relatively small *A. calycina* polygons with estimates of 100,000. These estimates were extremely high relative to other estimates and were likely the result of a field surveyor adding an extra zero; one of these instances was addressed when overlapping polygons were merged, so a zero is not reflected in the attribute table for this polygon. The remaining untenable estimate involved a *H. paradoxus* polypoint that had an estimate of 500 plants; comments recorded by the field observer indicated a polypoint was recorded instead of polygon because water made a nearby cluster of *H. paradoxus* inaccessible. The comment and geometry were kept, but the abundance estimate was changed to zero and the change was noted in comments.

After quality assessment of geospatial attributes, abundance estimates were summed across all geospatial features to get an estimated total plant abundance. Coverage estimates (hectares) were based on polygons, buffered polylines, and buffered polypoints. All summary statistics were calculated using tools available in ArcGIS Desktop.

RESULTS

In 2018, the estimated number of *H. paradoxus* on BLNWR was 12,691,116 plants. The area occupied by *H. paradoxus* was 41.32 ha. The population density within the occupied area was 30.71 plants/m^2. In total, 616 stands (or polygons) of *H. paradoxus* were mapped. The average number of *H. paradoxus* per stand was 20,146 ± 138,785 SD (median = 60 plants/stand). Average stand area was 652.72 m^2 ± 2,627.91 SD (median = 99.11 m^2) (Fig. 2). In addition to the mapped stands of *H. paradoxus*, 976 polypoints were recorded ranging in size from 1–30 plants (average of 1.42 plants/polypoint ± 1.82 SD), and 377 polylines were taken ranging in size from 3–100,000 plants (average 741.72 plants/polyline ± 5,906.58 SD) (Fig. 2). No *H. paradoxus* were identified on the North Tract. Spatial files pertaining to the 2018 *H. paradoxus* survey and subsequent surveys discussed in this manuscript are available to US Fish and Wildlife staff at https://doi.org/10.7944/P9FIHZ6Q, and to cooperators (e.g., state conservation agencies, universities) upon request.

The estimated number of *A. calycina* on BLNWR in 2018 was 107,338 plants. The area occupied by *A. calycina* was 1.45 ha. The population density within the occupied area was 7.40 plants/m^2. In total, 36 stands were mapped. The average number of *A. calycina* per stand was 2,981.19 ± 8,630.44 SD (median = 100 plants/stand). Average stand area was 402.16 m^2 ± 678.68 SD (median = 146.33). In addition to the mapped stands of *A. calycina*, 13 polypoints were taken that had 1 to 3 plants each (Fig. 3). These estimates are likely conservative, as many polygons contained expansive amounts of cattail (*Typha* spp.) and many *A. calycina* plants growing within such areas were likely missed. No *A. calycina* plants were documented in either the North or South Tracts of the refuge. Our *A. calycina* data from 2018 were included in Roth's (2019) unpublished status report, but our geospatial data had not been proofed at this point and contained overlapping polygons and probable attribute entry mistakes.

In 2018, approximately 0.56 ha of *A. calycina* coverage, totaling about 105,073 plants, fell in areas also mapped as *H. paradoxus* (Fig. 3). This accounted for about 39% of the *A. calycina* area, but only about 1.4% of *H. paradoxus* area. In addition, 13 of the 15 *A. calycina* polypoints fell within areas mapped as *H. paradoxus* polygons.

In 2019, no *A. calycina* were detected during surveys. In 2020, 420 polypoints were recorded for scattered individual plants (Fig. 4), but no stands of *A. calycina* were found. After buffering each point by 0.5 m, the estimated coverage was 0.03 ha. Of the 420 polypoints, 116 fell within the 36 polygons mapped in 2018, 39 fell within 2 m of 2018 polygons, and an additional 13 were within 2 m of the buffered (0.5 m) point layer from 2018. The remaining 62% of *A. calycina* documented in 2020 were greater than 2 m away from 2018 locations.

DISCUSSION

Our estimate of *H. paradoxus* abundance on the refuge, which is likely conservative, suggests there are over 12 million plants. Recovery Plan (USFWS 2005) criteria for "core conservation areas" requires at least one good population (>5,000 plants in 7 of 10 years) or one "excellent" population (several hundred thousand plants). Although there is no coordinated range-wide survey of *H. paradoxus*, our data along with recent assessments (Roth 2020) from an additional "core conservation area" suggest the species is doing well in several key locations. *Helianthus paradoxus* was distributed along spring-creeks, spring-seeps, salt marshes and other spring-influenced areas; however, it was particularly abundant along the interior margins of wetland management

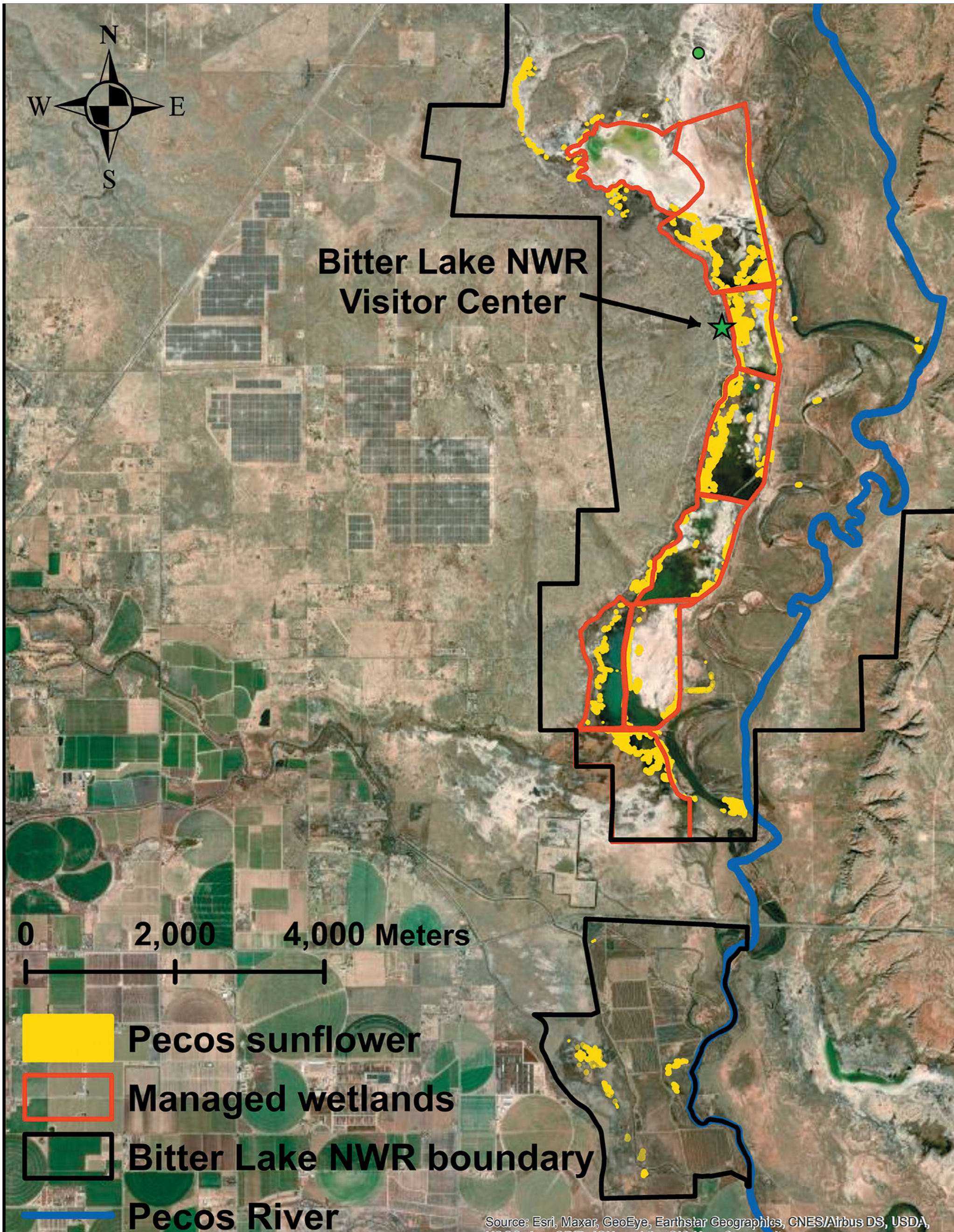

Fig. 2. Distribution of *Helianthus paradoxus* on Bitter Lake National Wildlife Refuge in 2018. All mapped geospatial features (polygons, polylines, and polypoints) are depicted.

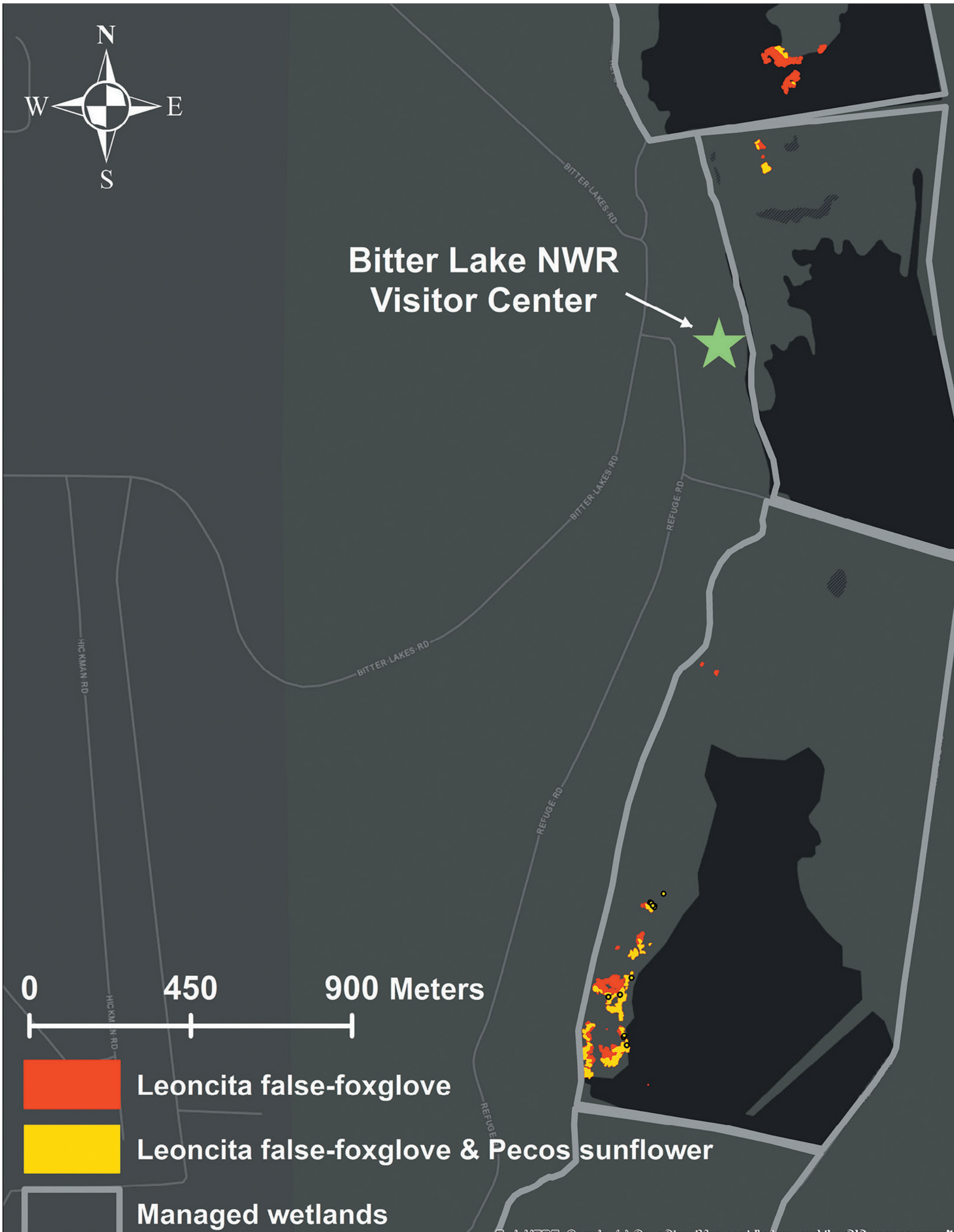

Fig. 3. Distribution of *Agalinis calycina* (red) on Bitter Lake National Wildlife Refuge in 2018, and areas of *A. calycina* and *Helianthus paradoxus* overlap (yellow). All geospatial features (polygons and polypoints) are depicted. Mapping of the two species took place on separate survey days. *Agalinis calycina* features were "clipped" (ArcDesktop) by *H. paradoxus* polygons to obtain areas of overlap. Black areas within managed wetlands (or wetland management units) are sparsely vegetated, seasonally flooded areas.

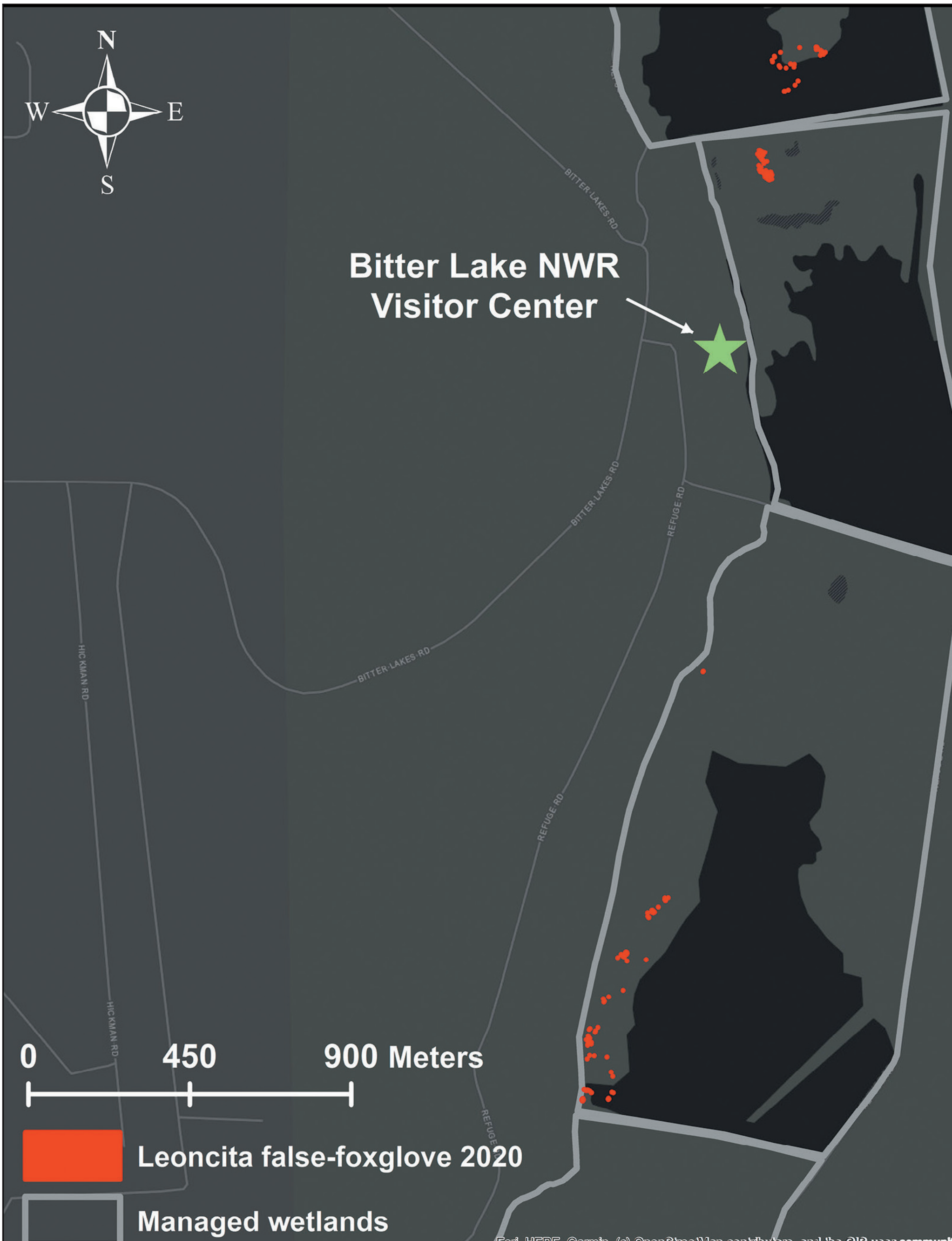

Fig. 4. Distribution of *Agalinis calycina* (red) on Bitter Lake National Wildlife Refuge in 2020. Polypoints were the only geospatial feature collected due to the dispersed nature of plants detected. Black areas within managed wetlands are sparsely vegetated, seasonally flooded areas.

units, similar to surveys from the late 1990s (Wells 1998; Warrick & Linnell 1999). Water management within these units typically allows for increases in soil moisture during winter and early spring, which may reduce salinity and create conditions favorable for the germination and growth of *H. paradoxus* (Van Auken & Bush 1995; Cantu de Leija 2021).

We found *A. calycina* in the same wetland management units, and in the same general locations within those units, as did the initial survey efforts in 2009 and 2010 (Sivinski 2011). Although we documented no plants in 2019, the spatial distribution of *A. calycina* within units was larger in both 2018 and 2020 than in initial surveys (Sivinski 2011). Likewise, far more plants were documented in 2018 than in the 2009 and 2010 surveys (> 100,000 compared to a max estimate of a few thousand, Sivinski 2011). However, we cannot say that *A. calycina* status has improved due to the potential for large year-to-year variation (Sivinski 2011; Sivinski & Tonne 2011; this study). Indeed, additional surveys will be required to understand the status of *A. calycina*. Development of an index of factors that drive germination and growth (e.g., soil salinity, soil moisture, water table elevation, precipitation) would be extremely useful in making annual predictions about *A. calycina* abundance; such an index would allow survey results to be calibrated against germination and establishment expectations. Trends pertaining to abundance and coverage could then be developed for "good", "average" and "poor" years to allow for meaningful comparisons in status through time.

Because of its growth habit, *A. calycina* is much less conspicuous than *H. paradoxus* and more difficult to detect during surveys. *Agalinis calycina* are often shielded by taller, more robust species that also occur in perennially moist areas (e.g., *Typha* spp.). Although our estimates for both species are likely conservative, it is likely that *A. calycina*, in particular, were underestimated.

All *A. calycina* documented on the refuge occurred within wetland management units, and about 37% of the mapped *A. calycina* stands co-occurred with *H. paradoxus*. Soils in areas where *A. calycina* occurs on BLNWR tend to be perennially saturated, and the water table is near the surface (Cantu de Leija 2021). Cantu de Leija et al. (2022) concluded, based on germination experiments, that reduced salinities during spring are necessary for *A. calycina* germination, and that *A. calycina* has a much lower salinity tolerance during germination than *H. paradoxus* (which may explain the much broader distribution of *H. paradoxus* on the refuge). Interestingly, *H. paradoxus* growing in these saturated areas typically appeared less robust and stunted but occurred in very high densities. Since 1994, wetland management units at BLNWR have been managed as seasonal wetlands with an attempt to mimic the natural, seasonal inundation patterns of the Pecos River floodplain (USFWS 1998). Water management within these units typically allows for increased soil moisture during winter and early spring, which should reduce salinity and create conditions favorable for the germination of both *A. calycina* and *H. paradoxus* (Van Auken & Bush 1995; Cantu de Leija 2021). However, water management capacity is variable from year-to-year, as it is dependent on increased spring flows during the non-growing season (agriculture) and/or precipitation.

Although the intent of this monitoring effort was not to examine the role of environmental conditions with respect to plant abundance or coverage, total precipitation during February–May in both 2018 and 2019 was only about 2.8 cm, which is approximately 3.8 cm below average (NOAA 2022). February–May precipitation in 2020 was about 7.9 cm, or 1.3 cm above average (NOAA 2022). Precipitation likely plays an important role in reducing salinities near the soil's surface, but *A. calycina* estimates were greatest in 2018, a year of low late-winter and spring rainfall. Field investigations are needed to understand the relative contributions that spring flows and precipitation have in reducing surface salinities and encouraging the germination and establishment of *A. calycina* and *H. paradoxus*. If the primary driver contributing to plant germination and establishment is springflows, then aquifer decline and loss of spring viability may negatively impact the status of these species.

The impact of managing wetland units as lakes for 50+ years was likely negative for *A. calycina* and *H. paradoxus*, as managed wetlands became hypersaline (USFWS 1998) and high surface salinities negatively impact germination and establishment of both species (Cantu de Leija et al. 2022). The construction of additional levees in 1994, including two units where *A. calycina* is found, likely altered spring-influenced salt marsh areas. However, speculation about the potential impacts of these levees on *A. calycina* and *H. paradoxes* is problematic owing to the shift away from managing wetland units as permanently flooded lakes, and because of the minimal knowledge of rare plants prior to this transition in management. Indeed, *A. calycina* had not been documented on the refuge in 1994 (USFWS 1998; Peterson 2000), and *H. paradoxus* was not regularly monitored. A seasonal water management regime should help alleviate extreme salinities (USFWS 1998), which should benefit *A. calycina* and *H. paradoxus* (Cantu de Leija et al. 2022), as should a water management strategy that strives to create conditions suitable for germination and growth of these two plants.

Because of the rare nature of these species (Sivinski & Tonne 2011), as well as the refuge's role in conservation, we suggest annual monitoring (e.g., transects) within areas where *A. calycina* occurs in order to better understand populations trends. We also advise implementing a refuge wide survey effort for both species once every 5-years. Data should be made available in geospatial files that can be directly incorporated into formal status assessments. Further, the refuge should consider targeted mapping of selected areas for use in assessing management actions, such as prescribed fire or Pecos River floodplain restoration (oxbow restoration).

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