Riparian Plant-Pollinator Ecology Phase 2

Riparian Restoration Effectiveness to Improve Desert Riparian Bird and Pollinator Habitats

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

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FOR RIPARIAN PLANT-POLLINATOR ECOLOGY PHASE 2

between

CLARK COUNTY, NEVADA

DEPARTMENT OF ENVIRONMENT AND SUSTAINABILITY

DESERT CONSERVATION PROGRAM

and

BOARD of REGENTS, NSHE, obo UNIVERSITY OF NEVADA, LAS VEGAS

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EXECUTIVE SUMMARY

For the benefit of MSHCP covered riparian bird species, the Clark County Desert Conservation Program (DCP) manages a riparian reserve unit system with properties along the Virgin and Muddy Rivers. Within the Mormon Mesa Subunit (Riparian Subunit 1) in northeastern Clark County along the Virgin River, restoration of degraded riparian habitat occurred in 2014 and in 2020 – 2021. For the 2014 restoration, activities included strategically clearing nonnative tamarisk (*Tamarix*) patches within the extensive tamarisk monoculture and planting native plants that contribute to perennial structure and function, including providing pollinator-attracting species. For the 2020 – 2021 restoration, activities included large-scale removal of tamarisk from a portion of the subunit and implementing an experimental planting along channels to assess two different planting palettes. An important component of riparian restoration is whether restoration activities result in self-sustaining and persistent plant communities that are utilized by pollinators, even during drought conditions and when under herbivory pressure. Identifying native plant species that persist through drought and herbivory, contribute to a propagule bank, and encourage establishment of other native riparian plants, could lead to improved restoration efforts and habitat connectivity along the Virgin River corridor.

Project objectives

Project objectives for Phase 2 included:

- Conducting inventories of native patches planted in 2014 within the Mormon Mesa Subunit (Riparian Subunit 1) managed by Clark County, and inventorying plants in adjacent tamarisk-invaded areas.
- Conducting inventories of experimental native plant patches planted in 2021 in areas cleared of tamarisk in fall 2020 and comparing plant communities to non-planted controls.
- Conducting invertebrate or pollinator utilization assessments in the 2014 and 2021 restoration patches as a metric of habitat utilization of the restoration patches.
- Assessing soil properties within the 2021 experimental restoration patches to determine variation among the experimental units.
- Determining if and how soil water varies by depth within the 2021 experimental restoration patches.
- Establishing an experiment assessing wind and invertebrate pollination of willow species (*Salix*), which experienced difficulty due to limited flowering and is discussed in the report.

Significant results

- Restoration treatments reduced tamarisk and increased native perennial plant cover.
- Planted species within the restoration treatments persisted and contributed to vegetation structure and invertebrate habitat, although limitedly in the 2021 restoration due mortalities of shrub and tree species.
- Native plants naturally recruited into planted areas and contributed to native plant cover.
- Drought conditions and cattle impacted planted and naturally recruited native plants, reducing aboveground biomass, seed production, and flower resources for invertebrates.
- A diversity of invertebrates was detected suggesting development of invertebrate and pollinator habitat, though invertebrate utilization of restoration patches was limited, suggesting potential that dispersal through the tamarisk monoculture, the small areas of native patches, or ongoing disturbance may have limited utilization. The restored patches, however, could be starting points to expand broader potential pollinator habitat.

Conservation and Management Applications

- Native patches restored by Clark County through planting native species in 2014 remained dominated by native trees, shrubs, grasses, and forbs. Many of the planted species were observed and likely represent important floral resources and structural habitat to pollinators and other fauna.
- The native patches restored by Clark County in 2014 provide a sharp contrast with the surrounding matrix of primarily tamarisk monoculture, which had comparatively low plant diversity and few native species compared with the restored native patches.
- Native patches restored by Clark County through planting native species in 2021 contained planted species and contributed to native plant cover, although limitedly. A limited number of planted species were detected with active growth, although several individuals were observed resprouting after the onset of the 2022 monsoon rains. With sufficient precipitation and climate conditions, established species could provide important vegetation structure and floral resources for pollinators and other fauna.
- The project results suggest that the Clark County patch restoration efforts provided clear benefits accruing to native species overall but that benefits could be intermittent depending on the degree of disturbance at the site, particularly herbivory and drought. Based on the initially highly successful small-scale restoration effort achieved by Clark County, expanding native species restoration to provide diverse habitat structure for native wildlife is strongly supported by the project findings, as long as restoration patches are protected from nonnative herbivores. Results from the large-scale tamarisk removal and planting effort along channels suggest additional protection, supplemental treatments, or an incremental restoration implementation approach are likely necessary to further restoration efforts in this part of the unit.

- Continued monitoring of vegetation, including monitoring of planted species, and continued monitoring of invertebrate utilization will help inform the continued conservation and restoration of native vegetation at the sites and identify potential future threats to native species such as re-encroachment by tamarisk or seed dispersal by other nonnative species. Continued monitoring of restoration plant communities provides insight to the maturation processes. Continued monitoring of invertebrate utilization throughout this maturation process assists with identifying the longer-term trends of pollinator habitat restoration.

Table of Contents

Contents

Riparian Plant-Pollinator Ecology Phase 2

Riparian Restoration Effectiveness to Improve Desert Riparian Bird and Pollinator Habitats

INTRODUCTION

Description of the Project

We monitored ecosystem responses within two restoration efforts conducted by the Clark County Desert Conservation Program (DCP) in 2014 and 2021. The 2014 restoration effort included strategically clearing tamarisk in areas where groundwater was shallow and close to the surface, then planting cleared patches with native riparian plants. Within five native patches, we installed vegetation monitoring plots in 2020 as part of Phase 1 of this project. Additionally, per patch, we installed two plots 10 m and two plots 20 m from the edge of native patches into the untreated tamarisk stand to compare vegetation communities. During Phase 2 (this project), we resurveyed vegetation within all plots during spring 2022, fall 2022, and spring 2023 to monitor change of vegetation over time. The 2021 restoration effort included large-scale tamarisk clearing (fall 2020) adjacent to but not including the 2014 restoration patches, followed by installation of an experimental planting that included plots planted with overstory plants, with overstory and understory plants (mixed), and not planted to serve as controls. Plots were surveyed in spring and fall 2022. In the 2014 native patch restoration plots and the 2021 experimental planting plots, we conducted sweep netting in spring, summer, and fall 2022 to assess invertebrate utilization, including by potential pollinators. Among the 2021 restoration plots, we sampled soils from three depths to assess the uniformity of soils across the restoration site and to determine if soil properties varied by depth. Additionally, within these same plots, we sampled soils from three depths three times, spring, summer, and fall 2022, to determine if and how soil water varied among sites, depth, and across time.

Background

Tamarisk or saltcedar (*Tamarix* L., Tamaricaceae) was first introduced to the United States from Eurasia as ornamentals in the 1800s and used as erosion control agents throughout the early 1900s (Horton 1964; Stromberg & Chew 2002). Several species of tamarisk invaded floodplains throughout the American Southwest by the middle of the twentieth century, altering riparian habitat and corridors (Robinson 1965; Schulz & Hislope 1972). The *Tamarix* genus consists of over fifty shrub and tree species. In the United States the most encountered species include *T. aphylla*, *T. parviflora*, morphologically similar *T. canariensis* and *T. gallica*, and morphologically similar *T. chinensis* and *T. ramosissima*. The two most common species occurring in the Southwest include *Tamarix chinensis*, a native to China, Mongolia, and Japan, and *T. ramosissima*, a native to the region between eastern Turkey and Korea (Baum 1978; Friedman et al. 2005). Hybrids previously unidentified in tamarisk's native range have been discovered in the United States, and *T. chinensis* and *T. ramosissima* represent the most common hybrids in the United States (Gaskin & Schaal 2002, 2003; Friedman et al. 2005).

Tamarisk species are considered among the most widespread and influential invasions in North America, particularly in riparian habitats (see *Reviews* DiTomosa 1998; Smith et al. 1998; Stromberg 2001; Stromberg & Chew 2002; Zouhar 2003). Tamarisk invades disturbed and undisturbed streams, waterways or water basins, moist rangelands and pasturelands, and natural and artificial drainage washes (Carman & Brotherson 1982). Riparian zones along rivers of the desert Southwest are prime habitat for tamarisk (Everitt 1980; Brock 1994). Tamarisk spreads vegetatively by submerged stems producing adventitious roots and sexually by seed. Tamarisk are prolific seed producers. Tamarisk species have high salt and drought tolerance, are resistant to water stress, and have greater fire tolerance compared to many native mesic trees, such as cottonwood (*Populus*) species and willow (*Salix*) species, although the level of fire-adaptation in tamarisk species is unclear. With mostly windborne seeds, these facultative phreatophytes spread quickly (Robinson 1965; DiTomasa 1998) and can displace native mesic plants (Fraiser & Johnson 1991; Cleverly et al. 1997; DiTomasa 1998; Fleishman et al. 2003).

As a result of tamarisk colonization, native ecosystem functions, services, and wildlife utilization are altered (Hunter et al. 1988; Zavaleta 2000; Shafroth et al. 2005). These alterations change riparian habitat utilized by birds and invertebrates (Ellis et al. 2000; Shafroth et al. 2005; Wiesenborn et al. 2008), which are critical prey for many bird species (Hunter et al. 1988; Ellis 1995; Sherry & Holmes 1995; Walker 2006). In the Southwest, over 40% of bird species depend on river valleys and riparian vegetation for shelter or foraging (Carothers et al. 1974; Ohmart & Anderson 1982). Riparian corridors are migratory routes and nesting sites for many terrestrial species whose movements coincide with flowering and seed production of native species (Ohmart et al. 1998). Although birds utilize tamarisk stands (Sogge et al. 2008), including the endangered Southwestern willow flycatcher (*Empidonax traillii extimus*), invasions alter bird demographics and utilization in these previously native riparian ecosystems (Hunter et al. 1998; Ellis 1995; Fleishman et al. 2003).

Because of the characteristics of tamarisk, this group of species is a formidable barrier to native plant communities and native riparian community restoration. Under natural flow regimes, native trees have been shown to be competitive with tamarisk in germination and establishment (Merritt & Pott 2010). However, many river and reservoir systems in the Southwest have regulated flows, which benefit tamarisk (Everitt 1980, 1998; Shafroth et al. 2002; Stromberg & Chew 2002; Merritt & Pott 2010). Exposed banks with minimal vegetation cover adjacent to flowing water (rivers, side channels, lakes), sandbars, or areas disturbed by flooding, provide optimal habitat for rapid tamarisk establishment. Seedlings require several weeks of wet, mostly exposed soils for survival (Horton et al. 1960; Kerpez & Smith 1987). Once established, plants can form dense thickets or monocultures that displace or exclude natives and reduce opportunities for natives to establish (Fraiser & Johnson 1991; Cleverly et al. 1997; DiTomasa 1998).

To reduce or remove tamarisk, aggressive and persistent tactics are often required to deter a tamarisk reinvasion (Shafroth et al. 2005), including cutting and herbicide application, using mechanical equipment that rips into soil surfaces to remove root crowns, burning to remove plants and reduce resprouting, and planting native plants to reduce available area for reinvasion. Often additional management treatments such as cutting or herbicide spot treatments are necessary for several years to reduce the likelihood of tamarisk reinvasion. Few examples in the literature present evidence of natural recovery of native riparian ecosystems after tamarisk removal without substantial additional efforts (e.g., Dudley et al. 2000; Harms & Hiebert 2006). Native plant propagule reintroduction is commonly required to regain native riparian communities.

Large-scale plantings (transplanting, outplanting) are often difficult to implement due to landscape features, access to riparian sites, and the number of native individuals required to cover large areas and create habitat. Transplants and seedlings often require protection or supplemental treatments to offset antagonistic site conditions resulting from invasion and management activities. Site-level (e.g., fencing) or plant-specific (e.g., cages) protection can be expensive or difficult to install due to landscape features or access to the restoration site. However, without revegetation or reintroduction of native propagules, many sites are vulnerable to reinvasion after tamarisk has been removed (Shafroth et al. 1998). Tamarisk-invaded areas are utilized by resident and migratory birds for nesting and foraging. Removal of tamarisk without an immediate habitat replacement is a concern for some managers and scientists (Sogge et al. 2008; Stromberg et al. 2009; Hultine et al. 2010). Small, dense concentrations of native patches installed before or immediately after large-scale tamarisk removal may provide native habitat and point sources for native propagules during the restoration process (Holl et al. 2017; de Oliveira Bahia et al. 2023). These small, dense patches, or nucleation sites, could provide seed sources to build native seed banks, which are often depauperate on tamarisk-invaded sites (Vosse et al. 2008), or provide other propagule sources, such as those from rhizomatous or stoloniferous plants that spread into surrounding areas as tamarisk is removed. Dense native plant cover may reduce the risk of reinvasion by tamarisk. Seedlings of rapidly establishing species, such as *Populus* and *Salix*, have a greater chance at survival when they are present at higher densities, particularly when tamarisk seedlings are present (Sher et al. 2002). Other densely planted native species, particularly species that spread, may reduce the likelihood of reinvasion, while providing wildlife with forage and flower resources.

Restoration using nucleation is the process of planting specific sets of plants in dense clusters in the landscape to establish propagule banks that contribute to the spread of native plants through natural processes (Holl et al. 2004; Corbin & Holl 2012; Holl et al. 2017). Conditions created by nucleation sites may further native habitat restoration by contributing to depositing seed, providing microclimate conditions more conducive to seed germination and seedling establishment, and providing wildlife habitat and pollinator resources to reestablish food webs and species networks. Woody plants are often included when establishing nucleation sites (Holl et al. 2018; Piaia et al. 2020), as many woody plants form resource islands, creating microhabitats that benefit recruiting plants by mitigating surrounding adverse or antagonistic conditions (Yarranton & Morrison 1974; de Oliveira Bahia et al. 2023) and providing habitat for wildlife, including pollinators (Williams 2011; Frick et al. 2014). Tall shrub and tree canopies provide shade, reduce light irradiance, and slow soil-water evaporation (Potts et a. 2010; Piaia et al. 2020). Woody plant roots concentrate soil water and nutrients through hydraulic lift and nutrient cycling (Yoder & Nowak 1999; Hultine et al. 2004; Stubbs & Pyke 2005; Prieto et al. 2010). Plants with vegetative structures closer to the ground can slow wind speeds and surface water flows, allowing for soil particle and seed deposition.

As a part of Phase 2 of this joint project with Clark County DCP, we surveyed vegetation and invertebrate utilization within two riparian restoration efforts installed at the Mormon Mesa Subunit (Riparian Subunit 1) (Fig. 1). The 2014 restoration effort included strategically clearing small patches of tamarisk (Table 1) and planting native plants (Table 2) into these patches. During Phase 1 of this project, we installed monitoring plots within native patches and two plots 10 m and two plots 20 m from the edge of native patches into the remaining tamarisk. The 2021 restoration effort included installation of an experimental planting (Fig. 1) that included a no-planting control treatment, planting overstory plants only, and a mixture of overstory and understory plants (Table 4) within an area in which tamarisk was cleared in fall 2020. Planted species included a range of species and planting types (Table 5). All plots within both restoration areas were surveyed two or more times to capture variation throughout the growing season. Throughout the 2022 growing season, we additionally conducted sweep netting to capture invertebrate utilization. The intent of seasonal utilization surveys was to capture episodic flowering events and utilization by invertebrates, including pollinators, during these events throughout the active growing season.

Goals and Objectives of the Project

The goals of this project included:

i. Determine the success of the 2014 and 2021 restoration efforts, including identifying which planted species successfully established within planted patches.

ii. Determine pollinator resources in the 2014 and 2021 restoration patches and how resources vary over time.

iii. Assess invertebrate utilization of 2014 and 2021 restoration patches.

iv. Identify which planting palette in the 2021 restoration resulted in greater native plant establishment and invertebrate utilization.

v. Assess the relationships between invertebrates and plant communities as a metric of restoration success.

vi. Determine if soil properties, including soil moisture, vary among the 2021 experimental restoration units and at different depths.

vii. Determining the importance of invertebrate- and wind-pollination of *Salix* species to further delineate metrics for pollinator habitat restoration.

To meet our goals, the objectives for this project included:

i. Resurveying vegetation plots established in the 2014 restoration by UNLV at least twice during the 2022 growing season.

ii. Establish new vegetation survey plots in the 2021 restoration to assess planted and non-planted plant establishment and survey at least twice during the 2022 growing season.

iii. Conduct invertebrate utilization assessments (sweep netting and plant-pollinator observations) in the 2014 and 2021 restoration units at least three times during the 2022 growing season.

iv. Sample soils from three depths, surface (0 – 5 cm) and subsurface depths (15 – 20 cm and 35 – 40 cm) to assess soil properties; sample soils from three depths throughout the 2022 growing season to determine soil moisture content.

v. During flowering of female *Salix* individuals, isolate flowers using nonwoven synthetic fabrics to tent or cover willow flowers to reduce the likelihood of pollination by wildlife and compare successful seed development between isolated and non-isolated flowers.

METHODS AND MATERIALS

Restoration assessments and invertebrate utilization occurred at the Mormon Mesa Subunit (Riparian Subunit 1), 19.5 km (12 mi) south of Riverside, Nevada, along the eastern bank of the Virgin River, a tributary into Lake Mead reservoir and the Colorado River. The banks of the Virgin River have been invaded by tamarisk species, either *T. chinensis*, *T. ramosissima*, or a hybrid, for an unknown period but for at least the last three decades.

Restoration Treatment Assessments

2014 Native Plant Restoration Patches

In 2014, Clark County removed the mature tamarisk stand from five variable-sized small patches within this riparian subunit in strategic areas where groundwater was shallow and close to the surface during intermittent times of the year (Table 1). All five patches were planted with native plants, either as poles (1.5 cm in diameter, <1 m) or seedlings grown in 2.5-L (No. 1) nursery pots. Species and the number of individuals planted varied by native patch (Table 2). The survival of the specific planted individuals is unknown.

As a part of Phase I of this project, using coordinates provided by Clark County of the five planted native patches within the tamarisk stand, in 2020 we identified a central location within each native patch to install a 5.642-m radius survey plot (100-m^2 area) to assess vegetation (June 8, 2020), sample soils for seed bank analyses (May 25, 2020), and install seed rain traps (June 4, 2020). Additionally, we established four plots per native patch within the surrounding tamarisk stand in two directions 10 m and 20 m from the edge of the native patch (Table 3). Because of the high density of the tamarisk, these plots were placed adjacent to narrow access paths cut through the tamarisk. Paired tamarisk plots served at least two purposes. First, pairs provide a benchmark for comparison, especially for native seed banks and potential native seed rain conditions surrounding native patches. Second, measurements in the tamarisk plots serve as pre-treatment data of ecological conditions if the tamarisk surrounding the native patches is removed in the future. All annual and perennial native and exotic plant cover was estimated in each of the 25 plots using cover classes (Peet et al. 1998). Results from Phase 1 are presented in the December 20, 2020 report Riparian Plant-Pollinator Ecology Phase 1: *Plant-Pollinator Systems for Increasing Restoration Effectiveness for Desert Riparian Bird Habitats* (Project number: 2019-UNLV1992A). During the current Phase 2 project, plant communities in all 25 plots were reassessed in spring 2022 and 2023 and fall 2022 using the same survey methods. A list of species identified is provided in Supplement Table S1. These additional observations provide further evaluation of restoration activities, particularly during the recent severe drought conditions experienced regionally, information on which species persist in native patches, including planted and recruited species, and if native plants are recruiting into the surrounding tamarisk stands. Although severe drought conditions may have abated during the latter portion of the 2022 growing season, the legacy of drought conditions may have persisted into spring 2023.

2021 Native Plant Restoration Patches

Within the Mormon Mesa Subunit (Riparian Subunit 1) within the central and eastern portion of the property to the east and south of the original 2014 restoration plots, a continuous patch of tamarisk was cleared in fall 2020 using mechanical equipment. Following, in January 2021 along approximate north to south parallel channels, 11 experimental planting patches were installed. Five patches were planted on either side of the channel with native trees and understory plants (mixed treatment), and six patches were planted on either side of the channel with native tree species only (overstory treatment). An additional five channel patches were identified to act as unplanted, control treatments for comparison. In May 2022, we established one 10 m × 25 m plot per patch that spanned the channel on either side to conduct vegetation assessments. Planted species were counted and measured (height, width) to determine density and estimate growth within plots. Cover of all species, native and exotic annuals and perennials, was estimated using cover classes. Among the 2021 experimental restoration patches, we sampled surface (0 – 5 cm) and subsurface soils (15 – 20 cm and 35 – 40 cm) three times during the growing season (spring, summer, late summer) to capture field soil water conditions in the root zone of establishing plants. Soils were sampled at three points per plot and composited on a plot and depth basis. Soils sampled during the first sampling event were additionally used to determine soil texture, sand particle distribution, pH, and electric conductivity.

Invertebrate Utilization of Restoration Treatments

To attempt to synchronize pollinator utilization surveys with riparian plant flowering events, we conducted sweep netting within the 2014 restoration patches (5 patches) and the 2021 experimental planting patches (16 patches) three times during the 2022 growing season: (1) May/June 2022, (2) late July 2022, and (3) late September 2022. Sweep netting included using a standard invertebrate sampling fine-mesh sweep net and swinging the open net in a general figure eight pattern close to the soil surface to 1 m above the surface, while walking an even cadence. Sweep netting was conducted as a timed activity to allow for a relative comparison among restoration patches. All captured individuals were euthanized using 99% ethanol, then stored in a 4˚C environmental control room until processing. Individuals were rinsed, dried, and then examined under a stereoscope for identification. Specimens were identified using local and regional keys and online resources to identify to functional and mobility groups (e.g., butterfly, moth, fly, bee, and wasp; flying, crawling, jumping) or to a higher resolution where possible and resources were available. Specimens in good condition were pinned for curation and will be photographed using microscope photography methods to provide future resources for species identification.

Analyses

All statistical analyses including generalized linear models and linear regressions were conducted using PROC GLIMMIX and PROC REG, respectively, in SAS v 9.4 (2013, Cary, NC, USA). Post hoc tests with Tukey adjustments were applied for significant effects ($p < 0.05$). For continuous variables where Box Cox transformations did not improve model assumptions, distributions were assessed and assigned in models. For discrete data, distributions were assessed and assigned in models. For repeated measures analyses, Akaike information criterion was used to assess variance-covariance structure for longitudinal data analyses (Barnett et al. 2010).

Shannon diversity index was calculated for vegetation and invertebrate datasets to include as dependent variables for analyses. Data tables used for analyses and statistical results are reported in Supplement Table S2 – S7.

2014 Restoration Assessments and Invertebrate Utilization

Cover and richness of native and exotic annual and perennial plant growth habits and specific species or genera were assessed using longitudinal models to determine changes in vegetation detected over time among native patch plots and plots located in untreated tamarisk 10 m and 20 m from native patches. Additionally, within-visit analyses were conducted to assess community variability over time. Using publications and online materials, plants were assigned a pollination syndrome, wind-pollinated, wildlife-pollinated, or both. The total and native wind-pollinated and wildlife-pollinated species cover were calculated. Native patch plots and their respective paired 10 m and 20 m away tamarisk plot sets were grouped as fixed blocks (five blocks, Fig. 1: AB, B, D, E, and F) in statistical models. Invertebrate variables, including total count and number of taxa detected and count of specific orders or families, were analyzed using longitudinal models to determine differences in detection among the three sweep surveys within the 2014 native patches. Regression analyses were conducted to assess relationships between invertebrate variables and vegetation variables at the time of sweep netting (May 2022 and September 2022).

2021 Restoration Assessments and Invertebrate Utilization

Cover and richness of native and exotic annual and perennial plant growth habits and specific species or genera were assessed using longitudinal models to determine the effects of plot treatment type, or planting arrangement (no planting, overstory only plants, and mixed overstory and understory plants), on the vegetation community. Planted species cover, richness, and density, and non-planted species cover and richness were assessed separately and together (total cover). Invertebrate variables, including total count and number of taxa detected and count of specific orders or families, were analyzed using longitudinal models to determine differences in detection among the three sweep surveys within the 2021 restoration sites and to assess the effect of planting arrangement on detection. Regression analyses were conducted to assess relationships between invertebrate variables and vegetation variables at the time of sweep netting (May 2022 and September 2022). Soil variables with single measurements were assessed to determine if variables significantly varied among plot type and between the three sample depths. Soil moisture measurements were analyzed using longitudinal analysis to determine if soil moisture varied over time at different depths.

RESULTS

Objectives Completed

During Phase 2 of this joint project between UNLV and Clark County DCP, we successfully completed two scheduled surveys (April and September 2022) and one additional survey (late April 2023) of the 2014 restoration efforts to compare native plant patch plot vegetation to surrounding untreated tamarisk plot vegetation. Within native patches, we conducted three sweep net surveys throughout the growing season to determine utilization among native patches and assess variation of utilization by invertebrates throughout the growing season. We successfully completed two scheduled surveys (May and September 2022) of the 2021 restoration efforts to compare planting arrangement effects on vegetation communities and invertebrate utilization. We conducted three sweep surveys during the growing season to determine invertebrate utilization among experimental units. Soils were sampled from the 2021 experimental units in May 2022 to assess soil texture, particle distribution, pH, and electric conductivity. Samples were obtained from three depths to compare the uniformity of these metrics among experimental units and depths. Additionally, soils were sampled from the 2021 experimental units in May 2022, July 2022, and September 2022 from three soil depths to assess soil moisture variation. The May and September 2022 sampling correspond with vegetation surveys. Due to drought conditions and trampling and herbivory by livestock, native vegetation within both restorations was impacted. Willow species were not observed flowering until spring 2023 and the willow pollination experiment was unable to be implemented within the project period timeline, which ended April 28, 2023. However, we were able to conduct additional vegetation inventories that provided further and longer-term data on vegetation patches.

2014 Restoration

Initial analyses of the spring 2020 surveys (Phase 1) indicated successful establishment of native patches including establishment of planted species. Additionally, vegetation surveys and propagule bank assays indicated the establishment of a propagule bank within native patches, although limited to native species planted. Tamarisk plots contained few native species above- and belowground. Similar to the spring 2020 results, additional surveys conducted during spring and fall 2022 and spring 2023 indicate successful establishment and persistence of native plants within patches (Table S2). Native patch plots contained significantly higher cover of planted woody (shrub and tree) and herbaceous (forb and graminoid) species compared to tamarisk plots, resulting in significantly higher total native cover in planted patches (Fig. 2). Native perennial species that contributed most to cover in native patch plots included in order of contribution Goodding's willow (*Salix gooddingii*), yerba mansa (*Anemopsis californica*), common spikerush (*Eleocharis palustris*), sandbar willow (*Salix exigua*), Mexican rush (*Juncus mexicanus*), and broadleaf cattail (*Typha latifolia*). Cover contributed by native perennial species, such as yerba mansa, several sedge and rush species, and cattail, were significantly higher in native patch plots (Fig. 3). During the 2020 survey, we detected several native shrubs establishing in tamarisk plots 10 m from the edges of native patches, resulting in similar cover contributed by shrubs among native patch plots and plots 10 m into tamarisk stands (Table S2). Native shrub cover in tamarisk plots did not persist and declined. To more specifically evaluate pollinator resources, wind-pollinated and wildlife- or insect-pollinated species were analyzed as separate groups. Specifically for wind- and wildlife-pollinated plants, wind-pollinated plants differed significantly between native patch and tamarisk plots (Fig. 4). Native patch plots had higher cover of wind-pollinated species. For native wind- and wildlife-pollinated species, native patches contained significantly higher cover than tamarisk plots (Fig. 4). Although tamarisk, the main contributor to exotic perennial cover in native patch plots (≥ 77%), was detected in native patches throughout the monitoring period, cover remained significantly lower in native patch plots (Fig. 5). Other exotic species such as annual rabbitsfoot grass (*Polypogon monspeliensis*) and the perennial forb broadleaf pepperwort (*Lepidium latifolium*) were detected within native patch plots (< 1.0%), but contributed significantly more to cover in tamarisk plots. Marsh fleabane (*Pluchea odorata*), a main contributor to native annual species cover, had higher cover in tamarisk plots, although generally cover among plots did not significantly differ except during the initial spring 2020 survey (Fig. 6).

During the 2022 and 2023 observations, we detected a decline in native woody and herbaceous plant cover (Fig. 2 – 6) likely due to the compounding conditions of persistent severe drought and trampling and herbivory by livestock. Although drought conditions likely contributed to aboveground plant decline and a lack of flower and seed production during 2022, herbivory by livestock was a main reason for loss of aboveground biomass. Herbivory by cattle was first observed by UNLV staff during an initial site visit before April 2022 surveys, although correspondence with Clark County DCP staff suggests livestock herbivory began before this period. Much of the aboveground herbaceous layer was removed via herbivory by mid-spring 2022 (Fig. 7). Sedges and rushes appeared to begin to recover by the spring 2023 survey. Woody cover also declined, including cover contributed by willow and other naturally recruited shrubs, such as quail bush (*Atriplex lentiformis*). The lower limbs of willow appeared to be browsed, and few to no flowers were observed throughout most of the 2022 growing season. During winter and spring 2023 visits, flowers were observed on upper branches of willows, out of reach of livestock. Although declines in native patch vegetation were detected, native patch plots consistently contained planted species and had higher cover of different native growth habits, plant groups, and planted native perennial species compared to tamarisk plots.

Invertebrate sweeps conducted during 2022 significantly differed in detection (Fig. 8), with the highest number of individuals detected during spring, intermediate during summer, and lowest during fall 2022 (Table S3). A range of spiders (order Araneae, family Philodromidae), beetles (order Coleoptera), bees and wasps (order Hymenoptera), moths (order Lepidoptera), and flies (order Diptera) were detected. A dominant proportion of species detected were in the order Diptera. Few species of bees, moths, or butterflies were detected, likely because of few plants observed flowering during invertebrate sweeps.

We detected several moderate to strong positive relationships between plant and invertebrate metrics. The total number of invertebrate individuals detected was correlated with annual and perennial native forb cover ($r^2 = 0.30$, $p = 0.099$) and total native herbaceous cover ($r^2 = 0.56$, $p = 0.016$). The number of Diptera detected was correlated with the cover of common spikerush ($r^2 = 0.48$, $p = 0.027$). The total number of invertebrates and of Diptera detected were correlated with the cover of insect-pollinated plants ($r^2 = 0.36$, $p = 0.066$; $r^2 = 0.29$, $p = 0.107$; respectively) and specifically insect-pollinated native plants ($r^2 = 0.37$, $p = 0.617$; $r^2 = 0.28$, $p = 0.114$; respectively). The number of Diptera detected was also correlated with the cover of wind-pollinated ($r^2 = 0.35$, $p = 0.0914$) and specifically native wind-pollinated plant species ($r^2 = 0.32$, $p = 0.089$).

2021 Restoration

Within the 2021 restoration area, the soil was relatively uniform across the restoration sites. Sand particle size distribution, clay content, pH, and electric conductivity varied by soil depth (Table S4). Soils were siltier and sandier at the surface, containing more medium-to-coarse sand, and became more clayey in the subsurface (Fig. 9). While pH varied by soil depth, differences were small (< 0.54), or not significant enough to alter soil functions. Soil electric conductivity was significantly greater in surface soils compared to deeper soils (Fig. 10), indicating accumulation of salts on the soil surface as water transported to the upper soil layer and deposited minerals while water evaporated. The percentage of soil water content by soil mass varied by visit, although by less than 10%, and varied by depth of sample. The percentage of soil water did not vary by depth during the May and September 2022 sampling but did during the July 2022 sampling, with deeper soils having a higher percentage of water (Fig. 11).

Few vegetation metrics varied between experimental planting treatments 15 and 23 months after planting in spring and fall 2022. Among planted species, tree and woody shrub species did not perform as well as herbaceous species, and perennial plant cover, and specifically planted and naturally recruited perennial species, did not significantly differ among planting treatments (Fig. 12). However, planted species cover and richness significantly differed during the spring 2022 surveys (Table S5), with higher cover and richness in the mixed treatment compared to the other treatments (Fig. 12). Several *Salix* individuals naturally recruited into control plots, contributing to a reduction in dissimilarity among treatments of planted species cover. Cover, richness, and density contributed by perennial herbaceous graminoids and forb species were significantly greater in mixed treatment plots, suggesting planted individuals were contributing to cover and richness. However, planted herbaceous cover and richness did not contribute sufficiently to significantly increase total native perennial cover and richness in planting treatments compared to the control or the overstory-species only treatments. Planting marginally significantly increased planted species density, particularly in mixed treatment plots and among herbaceous species. Planting otherwise did not result in significantly affecting vegetation compared to the control treatment. Native annual forb cover did not significantly differ among treatments (Fig. 13), although initial observations during spring indicated higher native annual cover, mostly marsh fleabane (*Pluchea odorata*), in mixed treatment plots. Exotic plant cover did not differ among treatments (Fig. 14), although within-visit analyses revealed slight differences in tamarisk cover, likely to do resprouting during the fall 2022 surveys among planting treatments. Tamarisk, broadleaf pepperwort (*Lepidium latifolium*), and annual rabbitsfoot grass (*Polypogon monspeliensis*) contributed to exotic plant cover. Within the whole 2020 tamarisk removal area, tamarisk was observed resprouting, suggesting additional treatments are necessary to reduce reinvasion and competition with establishing native plants. Between spring and fall 2022, native cover among treatment plots became more similar to each other, as some plants senesced. During the growing season, few plants were observed flowering. Evidence of browse was observed among plots throughout the growing season. Arrow weed was one of the few perennial plants that flowered and was not observed to be browsed.

Detection of invertebrates using sweep netting did not differ among experimental planting treatment plots, and there were few relationships between plant metrics and detection of invertebrates. Similar to the 2014 restoration, most species detected were in the order Diptera, or flies. The number of flies and, generally, flying insects were correlated with total plant cover ($r^2 = 0.13$, $p = 0.045$) and richness ($r^2 = 0.16$, $p = 0.022$), planted species cover ($r^2 = 0.55$, $p < 0.001$), and exotic cover contributed by annual rabbitsfoot grass ($r^2 = 0.27$, $p = 0.002$) and tamarisk ($r^2 = 0.35$, $p < 0.001$). Total invertebrate richness was positively correlated with marsh fleabane cover ($r^2 = 0.23$, $p = 0.005$). Other groups of invertebrates, individual functional groups that crawl and jump, were not significantly correlated to plant metrics (Table S7).

TABLES AND FIGURES

List of Tables

Supplementary Tables

Supplementary tables are located within the final project data file, '2021-UNLV-2065A D05 Final Project Data' (Microsoft Excel) on tabs labeled 'Table S1' and 'Tables S2-S7.'

Statistical results from plant surveys conducted within the 2014 Restoration area between 2020 and 2023. Analyses included longitudinal analysis comparing plot type and within-visit analyses to assess statistical trends over time. Plot types included native patch plots and plots 10 m and 20 m from the edge of native patches into the remaining tamarisk stand. Letters indicate significantly different groups. For within-visit analyses, significant group assignments are listed in the following order: native patch, 10 m from native patch edge into tamarisk, and 20 m from native patch edge into tamarisk.

A list and count of invertebrate taxa collected during spring, summer, and fall of 2022 from 2014 native patches. Invertebrates were collected using sweep netting conducted for 1 minute per patch per survey. Species were identified to the best resolution possible using available resources.

Table S4. 2021 Restoration Soil Metrics Statistical Results

Statistical results from soil sampling conducted within the 2021 restoration area. Soil samples from experimental restoration planting plots were obtained in spring 2022 to assess soil texture, particle distribution, pH, and electric conductivity. Samples were obtained from three depths, 0 – 5 cm, 10 – 15 cm, and 35 – 45 cm. Soil was sampled in spring, summer, and fall 2022 from the same three depths to assess soil water content and variation among plots and depths. Samples were obtained from all experimental plots, overstory only planting, mixed overstory and understory plants, and untreated control plots. Where plot type was significant, group assignments are listed in the following order: overstory only, mixed, and control. Where soil differed significantly by depth, groups are listed by increasing depth.

Table S5. 2021 Restoration Statistical Results

Statistical results from plant surveys conducted within the 2021 Restoration area during 2022. Analyses included longitudinal analyses of plant community metrics comparing experimental planting treatment type and within-visit analyses. Treatment plots included plots nested within areas planted with only overstory plants (overstory), within areas planted with overstory and understory plants (mixed), and areas without planted individuals to act as controls. Letters indicate significantly different groups.

Table S6. 2021 Restoration Invertebrate Collection

A list and count of invertebrate taxa collected during spring, summer, and fall of 2022 from the 2021 experimental restoration planting treatments. Invertebrates were collected using timed sweep netting. Species were identified to the best resolution possible using available resources.

Table S7. 2021 Restoration Invertebrate Collection Relationships with Plant Metrics

Regression analysis results comparing invertebrate and vegetation metrics. Invertebrates were grouped into functional groups for analyses. Plants were grouped into planted and naturally recruited species cover and richness.

Appendix Tables

Appendix tables are located within the final project data file, '2021-UNLV-2065A D05 Final Project Data' (Microsoft Excel) on tabs labeled 'Table A1,' 'Table A2,' and 'Table A3.'

Table A1. 2014 Restoration. Percent cover per taxa or growth habit detected within native patch and tamarisk plots. Taxa codes area provided in Supplement Table S1. (Excel workbook)

Table A2. 2021 Restoration. Soil physical property information (Excel workbook)

Table A3. 2021 Restoration. Percent cover per taxa or growth habit detected within native patch and tamarisk plots. Taxa codes area provided in Supplement Table S1. (Excel workbook)

Table 1. 2014 Restoration Patch Locations.

Native plant patches established after clearing small patches of tamarisk in 2014 at the Mormon Mesa Subunit (Riparian Subunit 1), managed by Clark County, approximately 12 mi south of Riverside, NV, USA. Coordinates are in projection NAD 1983, Zone 11.

Native patch	Tamarisk Cleared (ft^2)	Tamarisk Cleared (m^2)	Easting	Northing
AB	886	82.3	739138	4055611
B	1506	139.9	739189	4055630
E	10921	1014.6	739249	4055590
D	2093	194.4	739224	4055571
F	3298	306.4	739284	4055538

Table 2. 2014 Restoration Patch Planting.

Species planted in tamarisk-cleared patches in 2014 at the Mormon Mesa Subunit (Riparian Subunit 1).

Native patch	Goodding's Willow (*Salix gooddingii*)		Sandbar willow (*Salix exigua*)		Cottonwood (*Populus fremontii*)	Velvet ash (*Fraxinus velutina*)	Mule-fat (*Baccharis salicifolia*)	Yerba mansa (*Anemopsis californica*)	Common spikerush (*Eleocharis palustris*)	Mexican rush (*Juncus mexicanus*)
January 2014										
Planting type	pole		pole		pole					
AB	-		60		32					
B	36		60		19					
D	80		110		48					
E	44		65		32					
F	48		65		32					
February 2014										
Planting type	1 gal	pole	1 gal	pole	1 gal	1 gal	1 gal	1 gal	1 gal	1 gal
AB	1	2	4	62	33	1	2	2	3	3
B	2	39	8	62	21	2	3	2	3	3
D	20	98	65	120	61	3	25	3	3	3
E	3	49	18	67	35	2	5	3	3	3
F	8	52	19	75	36	2	8	3	3	3

Table 3. 2014 Restoration Monitoring Plots.

Native plant patch plot locations and tamarisk plot locations 10 m and 20 m from the edge of native patches into the remaining tamarisk stand. Plot identification corresponds to native patch identification provided by Clark County. Coordinates are in projection NAD 1983, Zone 11.

Plot ID	Distance (m) from native patch	Easting	Northing
AB	0 m	739138	4055611
AB	10 m	739159	4055613
AB	10 m	739122	4055610
AB	20 m	739167	4055615
AB	20 m	739113	4055604
B	0 m	739189	4055630
B	10 m	739177	4055615
B	10 m	739171	4055619
B	20 m	739172	4055607
B	20 m	739163	4055613
D	0 m	739224	4055571
D	10 m	739249	4055557
D	10 m	739198	4055573
D	20 m	739255	4055551
D	20 m	739195	4055574
E	0 m	739249	4055590
E	10 m	739254	4055607
E	10 m	739259	4055596
E	20 m	739263	4055604
E	20 m	739265	4055603
F	0 m	739284	4055538
F	10 m	739292	4055557
F	10 m	739269	4055545
F	20 m	739300	4055561
F	20 m	739262	4055548

Table 4. 2021 Restoration Experimental Plots.

Experimental planting locations within the 2021 restoration at the Mormon Mesa Subunit (Riparian Subunit 1), managed by Clark County. Planting treatments included planting overstory plants only or a mixture of overstory and understory plants. Plots without plantings were included as a no-planting control treatment for comparison. Coordinates are in projection NAD 1983, Zone 11.

Plot ID	Type	Easting	Northing
MMO 6	Overstory	739364	4055479
MMO 5	Overstory	739408	4055498
MMO 4	Overstory	739422	4055598
MMO 3	Overstory	739473	4055634
MMO 2	Overstory	739506	4055503
MMO 1	Overstory	739609	4055602
MMM 6	Mixed	739324	4055562
MMM 5	Mixed	739407	4055409
MMM 4	Mixed	739459	4055349
MMM 3	Mixed	739484	4055535
MMM 2	Mixed	739504	4055633
MMC 6	No planting	739388	4055414
MMC 5	No planting	739395	4055611
MMC 4	No planting	739441	4055475
MMC 2	No planting	739492	4055421
MMC 1	No planting	739617	4055489

Table 5. 2021 Restoration Species Planted.

Species and planting type, either rooted individual or cutting, used for the 2021 experimental restoration treatments.

Species	Potted	Cuttings
Cottonwood (*Populus fremontii*)	600	
Goodding's Willow (*Salix gooddingii*)	487	237
Velvet ash (*Fraxinus velutina*)	26	
Sandbar willow (*Salix exigua*), syn. Coyote Willow	358	859
mule-fat (*Baccharis salicifolia*), syn. Sticky Seepwillow	517	
Yerba mansa (*Anemopsis californica*)	336	
Cooper's rush (*Juncus cooperi*)	390	
Common spikerush (*Eleocharis palustris*)	459	
Total	**3173**	**1096**

List of Figures

Figure 9. (A) Soil particle size distribution for particles less than 2 mm among soils obtained from different depths within the 2021 restoration plots. Error bars are ±1 standard error. Letters indicate significant ($p < 0.05$) differences between sampling depths.

Figure 10. Electric conductivity (1:1) measured from soils collected from three depths within the 2021 restoration plots. Error bars are ±1 standard error. Letters indicate significant ($p < 0.05$) differences between sampling depths.

Figure 11. Soil water content from soils collected from three depths within the 2021 restoration plots in May, July, and September 2022. Within the July sampling, soil-water content significantly differed with the lowest soil-water content in the upper soil layer.

Figure 12. Percent cover of (A) native perennial woody and herbaceous vegetation, (B) non-planted native perennial species, and (C) planted species, and (D) density of planted species from the 2021 restoration plots surveyed in spring and fall 2022.

Figure 13. Percent cover of native annual cover from the 2021 restoration plots surveyed in spring and fall 2022.

Figure 14. Percent cover of (A) the exotic woody perennial tamarisk, (B) the annual exotic rabbitsfoot grass, and (C) the perennial exotic broadleaf pepperwort among 2021 restoration plot surveyed in spring and fall 2022.

Figures

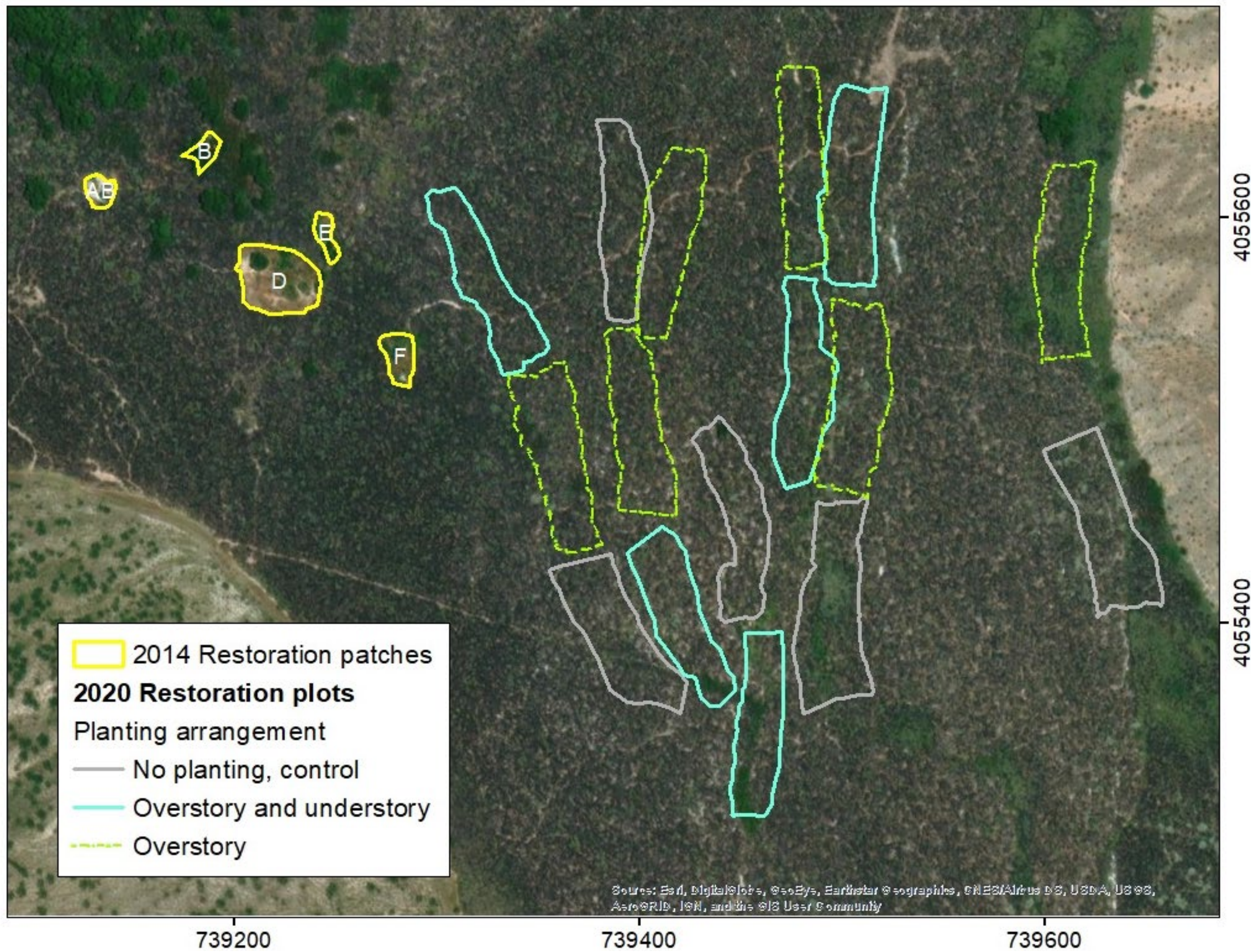

Figure 1.

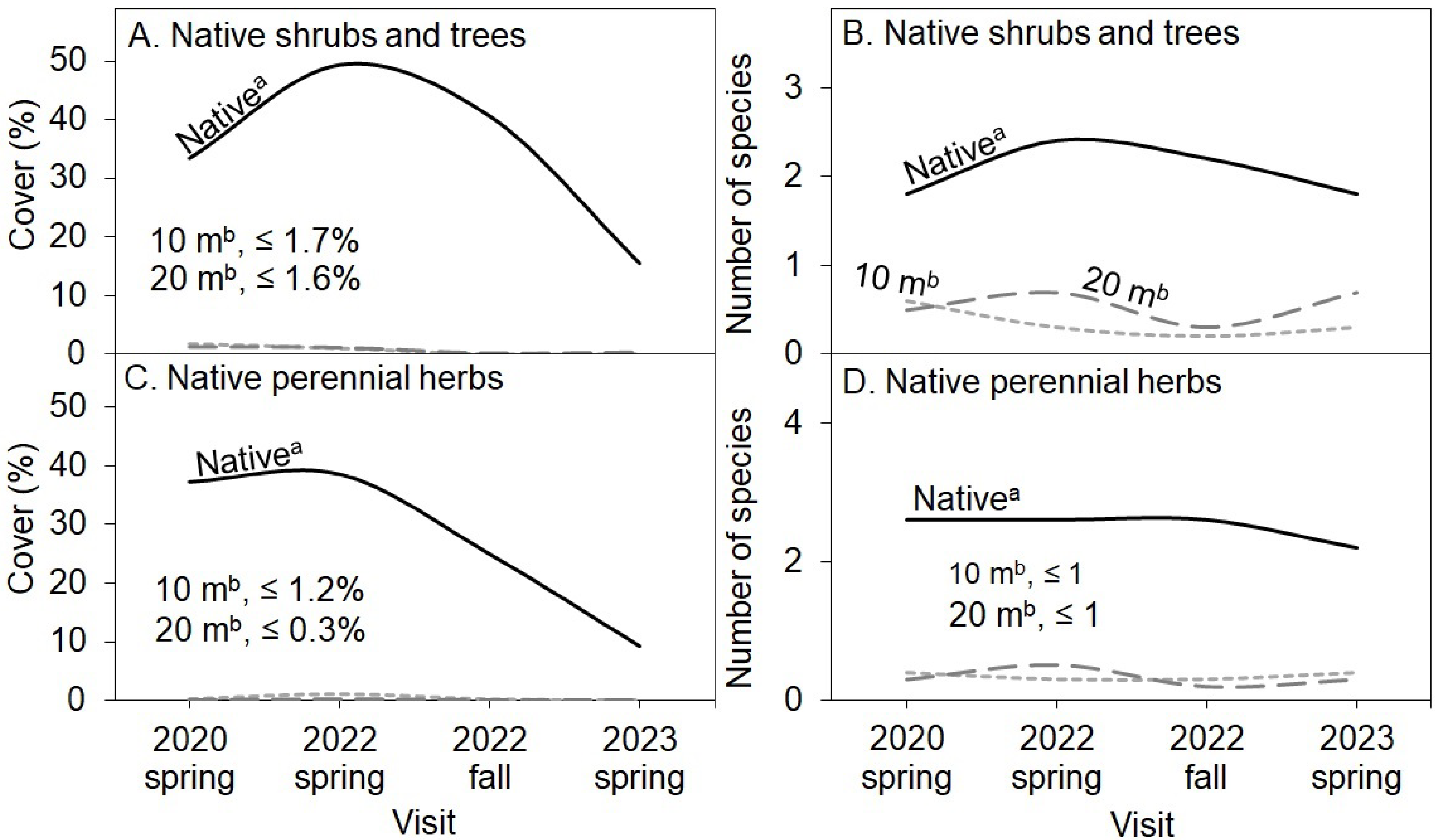
A. Native shrubs and trees
Cover (%)
50
40
30
20
10
0
Native[a]
10 m[b], ≤ 1.7%
20 m[b], ≤ 1.6%
B. Native shrubs and trees
Number of species
3
2
1
0
Native[a]
10 m[b]
20 m[b]
C. Native perennial herbs
Cover (%)
50
40
30
20
10
0
Native[a]
10 m[b], ≤ 1.2%
20 m[b], ≤ 0.3%
D. Native perennial herbs
Number of species
4
2
0
Native[a]
10 m[b], ≤ 1
20 m[b], ≤ 1
2020 spring
2022 spring
2022 fall
2023 spring
Visit
2020 spring
2022 spring
2022 fall
2023 spring
Visit

Figure 2.

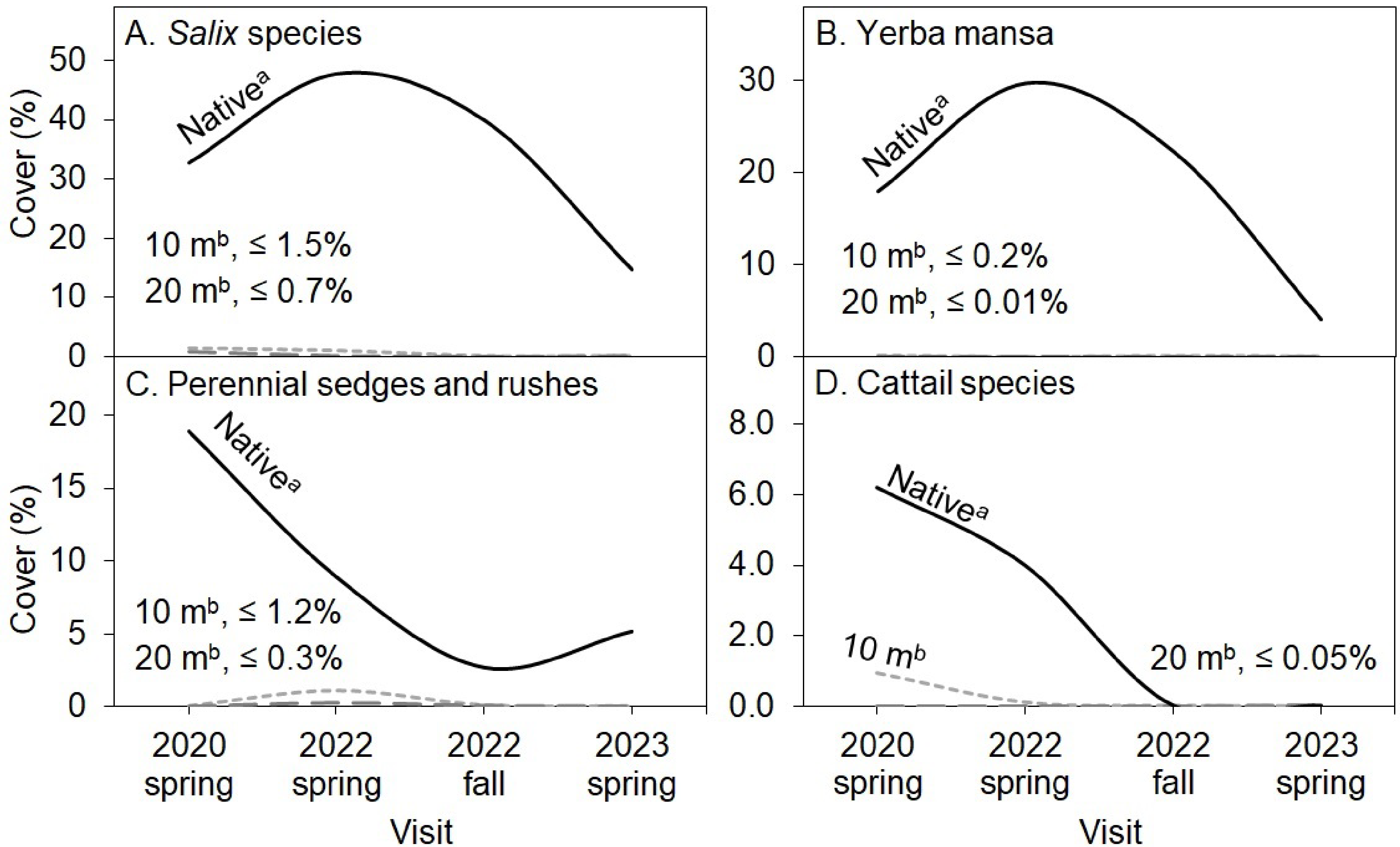
A. Salix species
Nativea
10 mb, ≤ 1.5%
20 mb, ≤ 0.7%
Cover (%)
0
10
20
30
40
50
B. Yerba mansa
Nativea
10 mb, ≤ 0.2%
20 mb, ≤ 0.01%
0
10
20
30
C. Perennial sedges and rushes
Nativea
10 mb, ≤ 1.2%
20 mb, ≤ 0.3%
Cover (%)
0
5
10
15
20
D. Cattail species
Nativea
10 mb
20 mb, ≤ 0.05%
0.0
2.0
4.0
6.0
8.0
2020 spring
2022 spring
2022 fall
2023 spring
Visit

Figure 3.

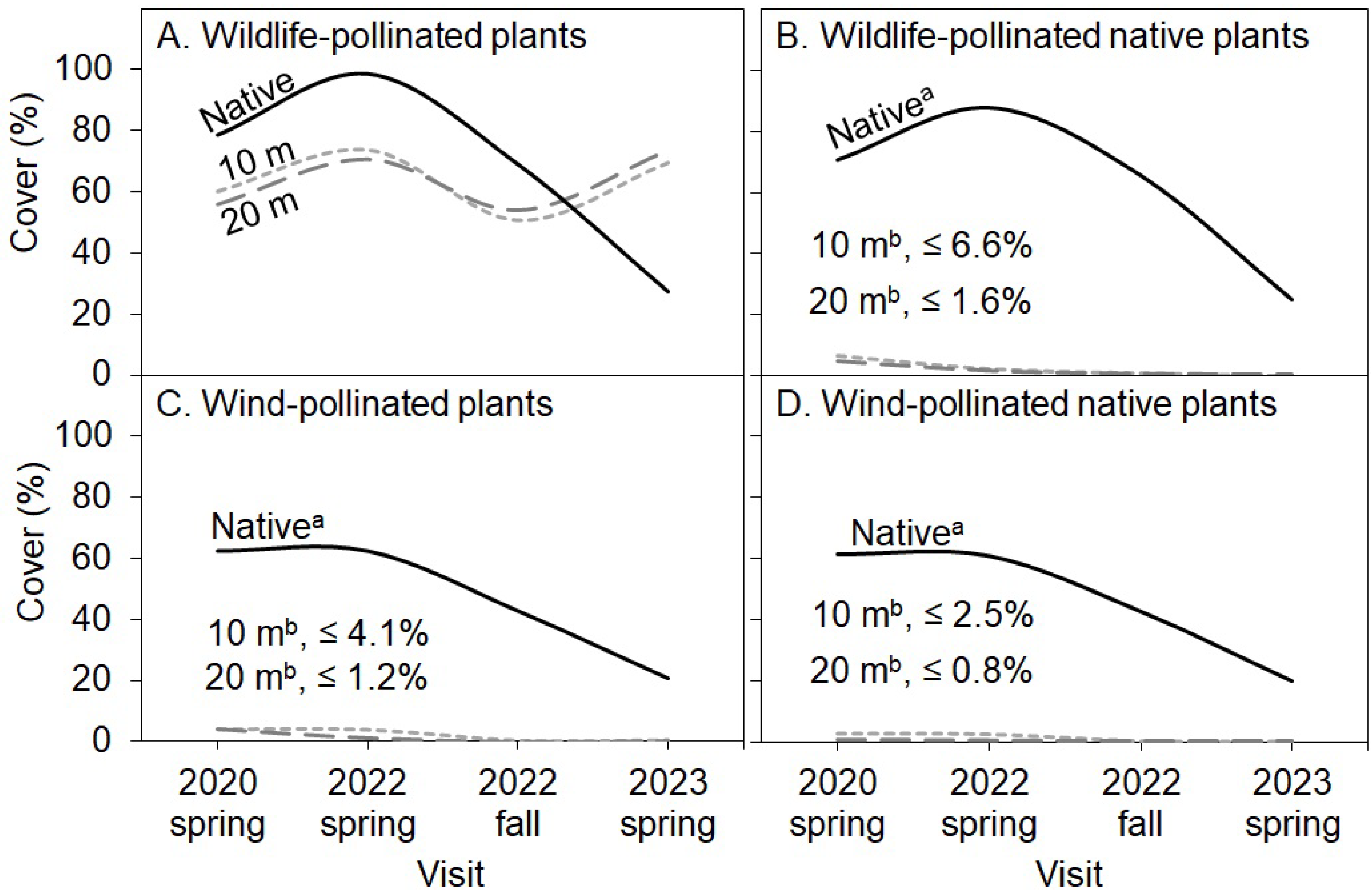
A. Wildlife-pollinated plants
B. Wildlife-pollinated native plants
C. Wind-pollinated plants
D. Wind-pollinated native plants
Cover (%)
0
20
40
60
80
100
Native
10 m
20 m
Native[a]
10 m[b], ≤ 6.6%
20 m[b], ≤ 1.6%
Native[a]
10 m[b], ≤ 4.1%
20 m[b], ≤ 1.2%
Native[a]
10 m[b], ≤ 2.5%
20 m[b], ≤ 0.8%
2020 spring
2022 spring
2022 fall
2023 spring
Visit

Figure 4.

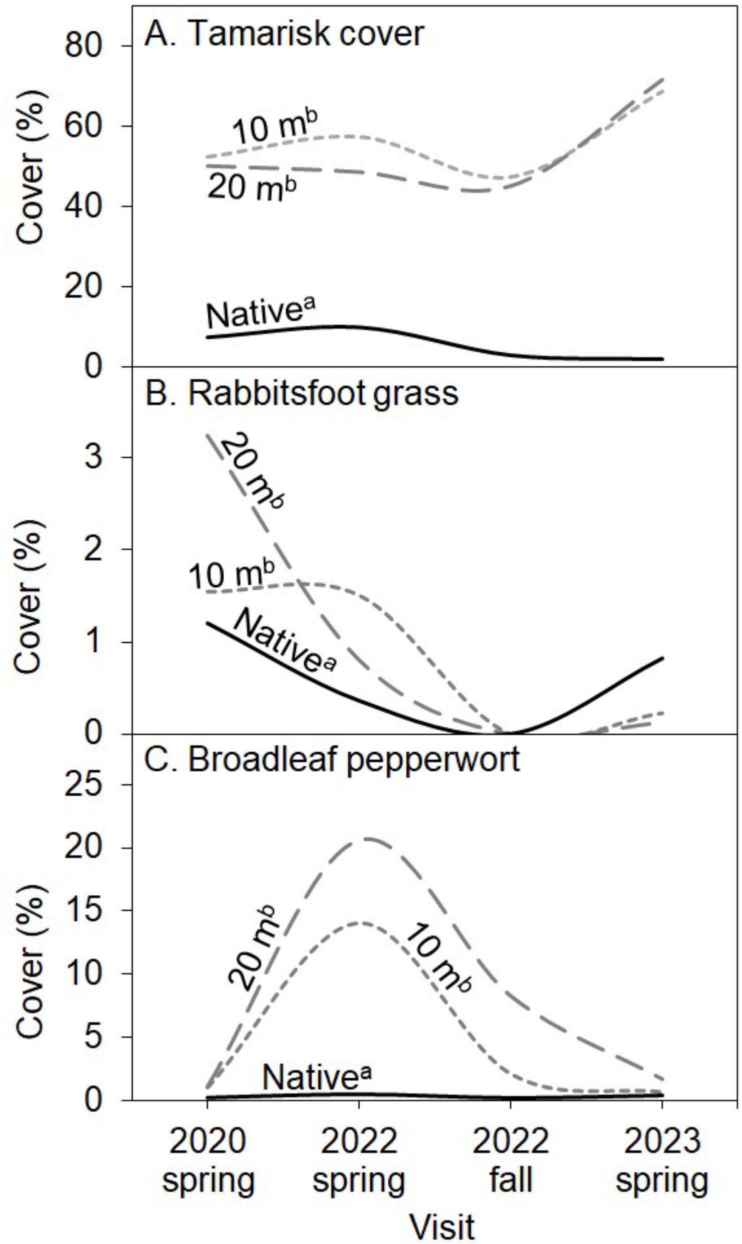
A. Tamarisk cover
Cover (%)
80
60
40
20
0
10 m^b
20 m^b
Native^a
B. Rabbitsfoot grass
Cover (%)
3
2
1
0
20 m^b
10 m^b
Native^a
C. Broadleaf pepperwort
Cover (%)
25
20
15
10
5
0
20 m^b
10 m^b
Native^a
2020 spring
2022 spring
2022 fall
2023 spring
Visit

Figure 5.

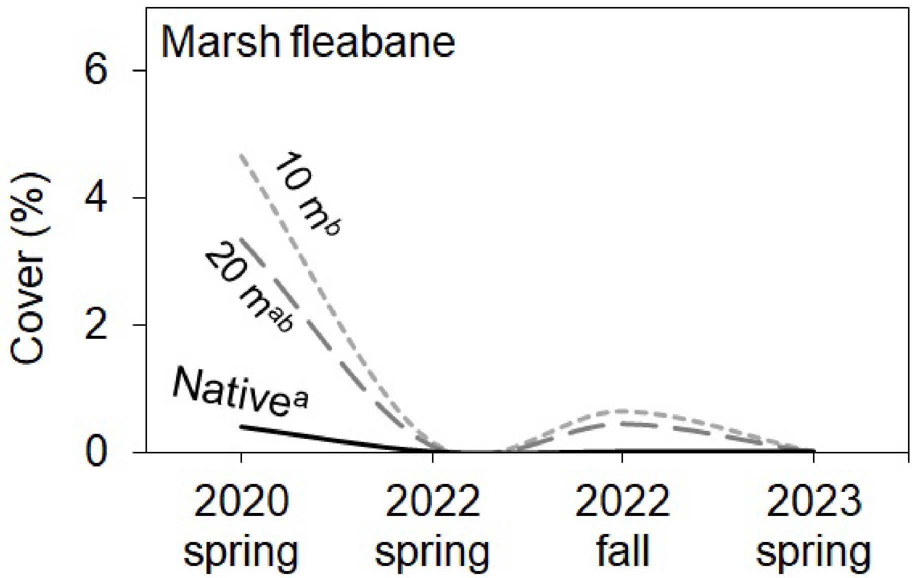
Marsh fleabane
Cover (%)
6
4
2
0
10 m^b
20 m^ab
Native^a
2020 spring
2022 spring
2022 fall
2023 spring

Figure 6.

Figure 7.

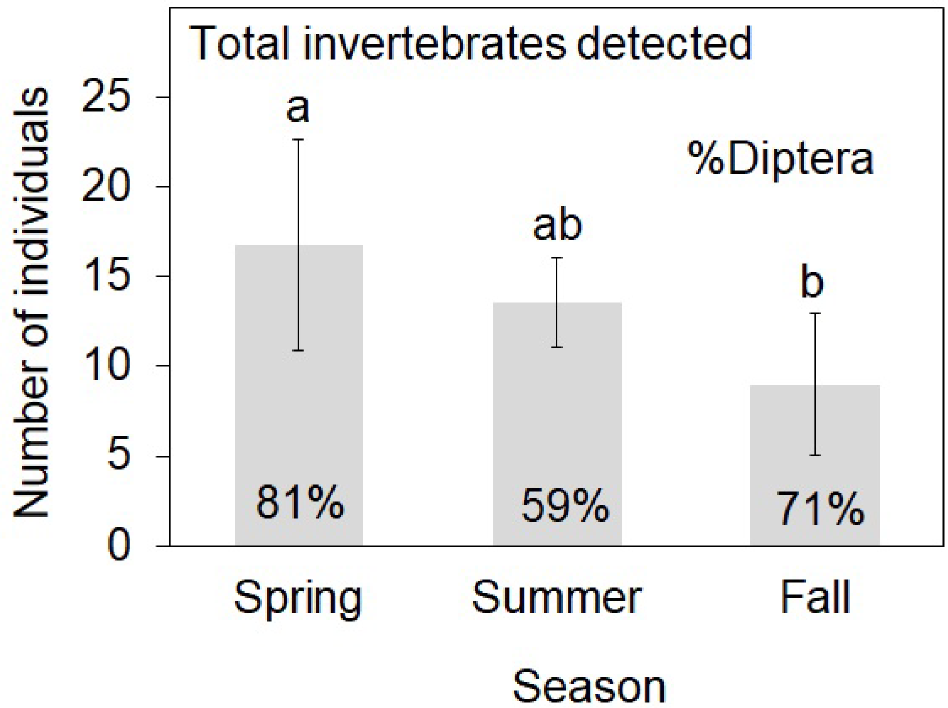
Total invertebrates detected
%Diptera
Number of individuals
25
20
15
10
5
0
a
ab
b
81%
59%
71%
Spring
Summer
Fall
Season

Figure 8.

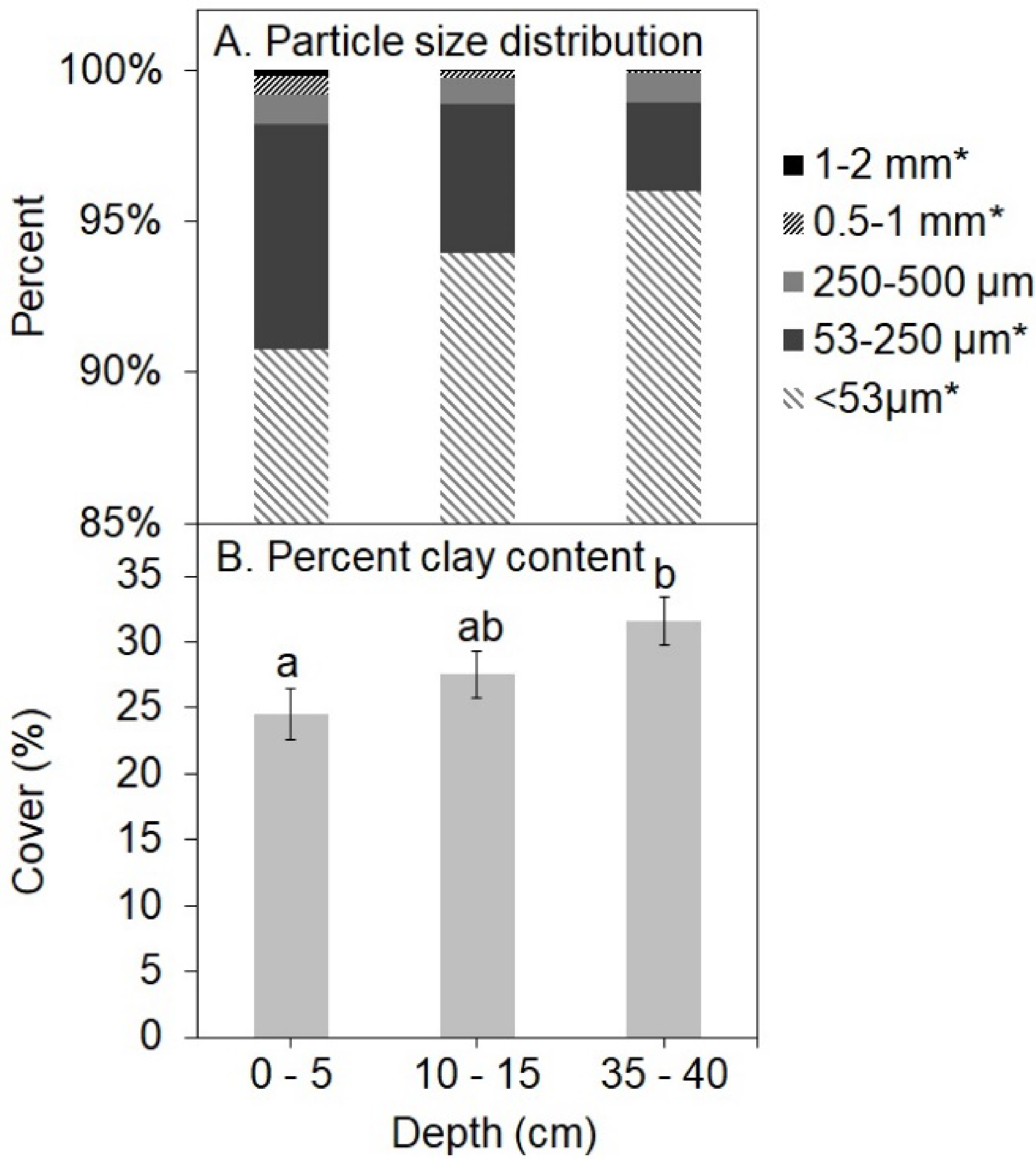
A. Particle size distribution
100%
95%
90%
85%
Percent
1-2 mm*
0.5-1 mm*
250-500 µm
53-250 µm*
<53µm*
B. Percent clay content
a
ab
b
35
30
25
20
15
10
5
0
Cover (%)
0 - 5
10 - 15
35 - 40
Depth (cm)

Figure 9.

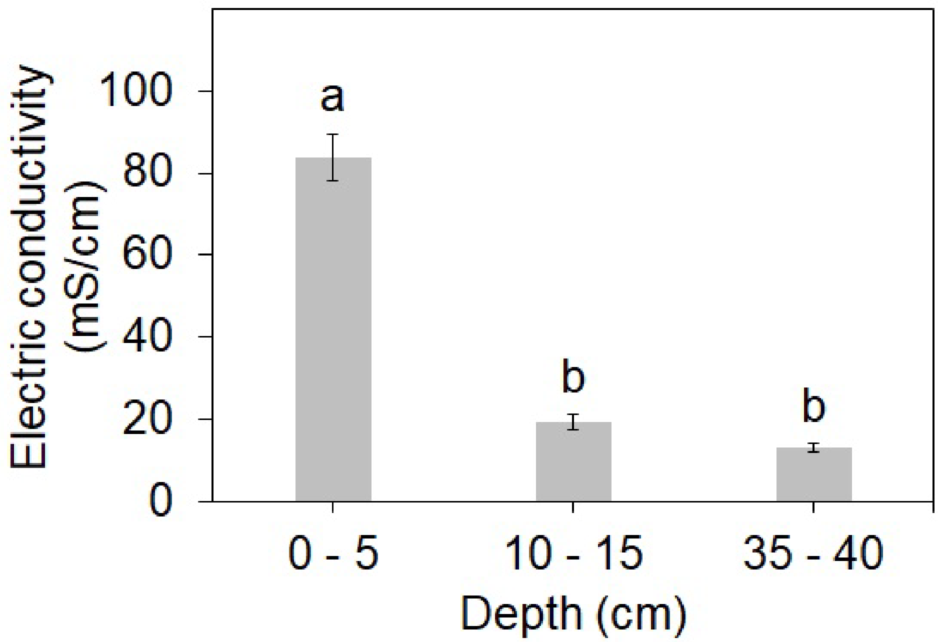
Electric conductivity (mS/cm)
100
80
60
40
20
0
a
b
b
0 - 5
10 - 15
35 - 40
Depth (cm)

Figure 10.

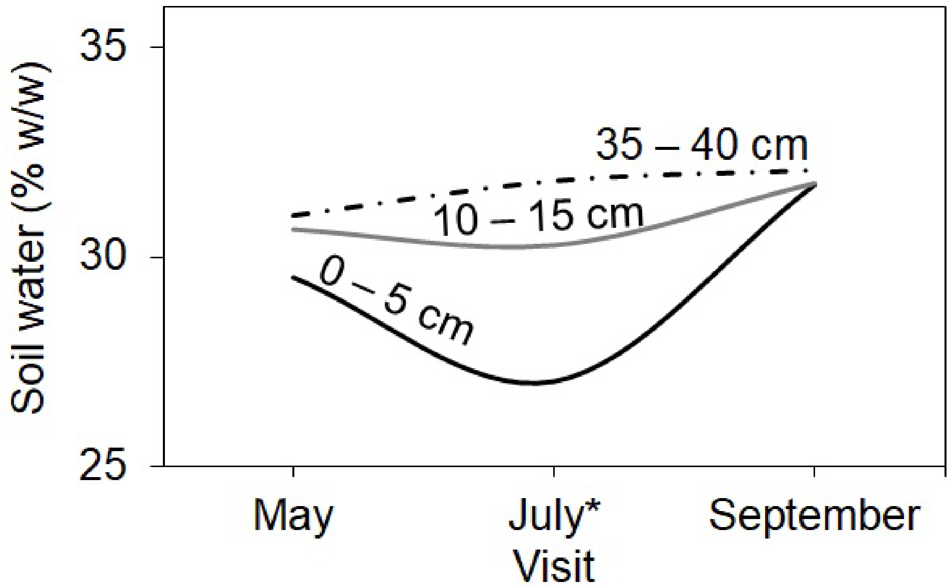
35
30
25
Soil water (% w/w)
35 – 40 cm
10 – 15 cm
0 – 5 cm
May
July*
September
Visit

Figure 11.

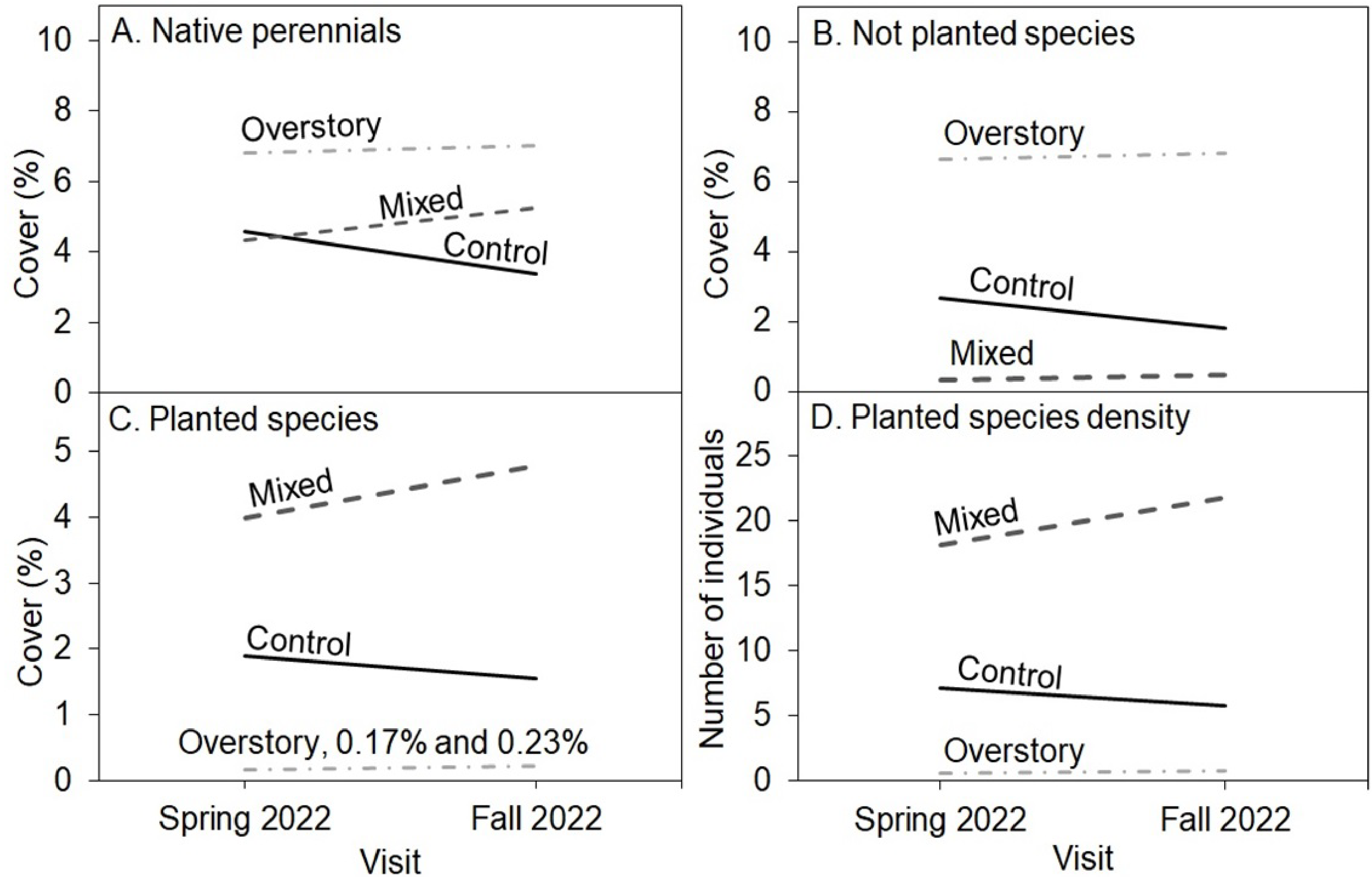
A. Native perennials
Cover (%)
10
8
6
4
2
0
Overstory
Mixed
Control
B. Not planted species
Cover (%)
10
8
6
4
2
0
Overstory
Control
Mixed
C. Planted species
Cover (%)
5
4
3
2
1
0
Mixed
Control
Overstory, 0.17% and 0.23%
Spring 2022
Fall 2022
Visit
D. Planted species density
Number of individuals
25
20
15
10
5
0
Mixed
Control
Overstory
Spring 2022
Fall 2022
Visit

Figure 12.

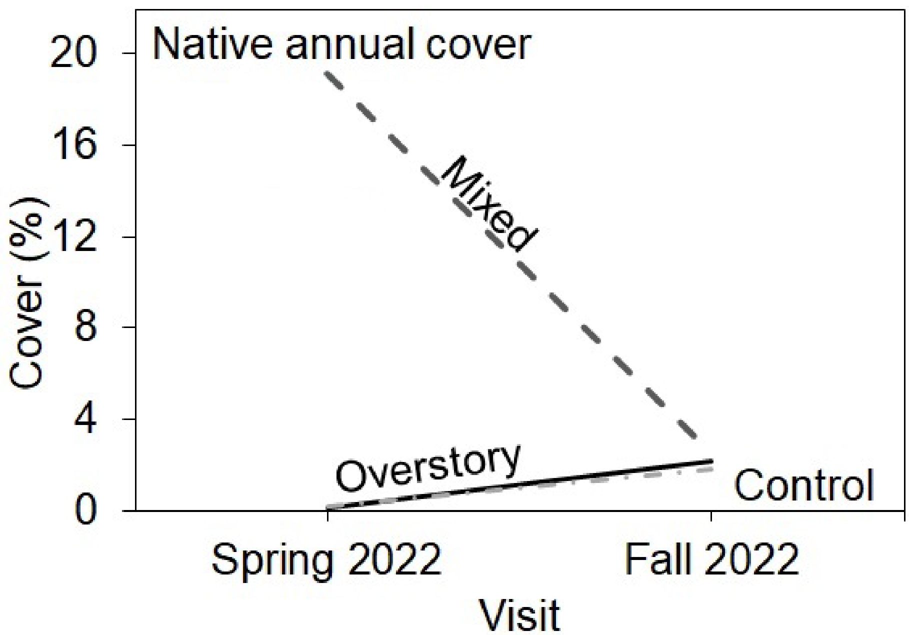
Native annual cover
Mixed
Overstory
Control
Cover (%)
20
16
12
8
4
0
Spring 2022
Fall 2022
Visit

Figure 13.

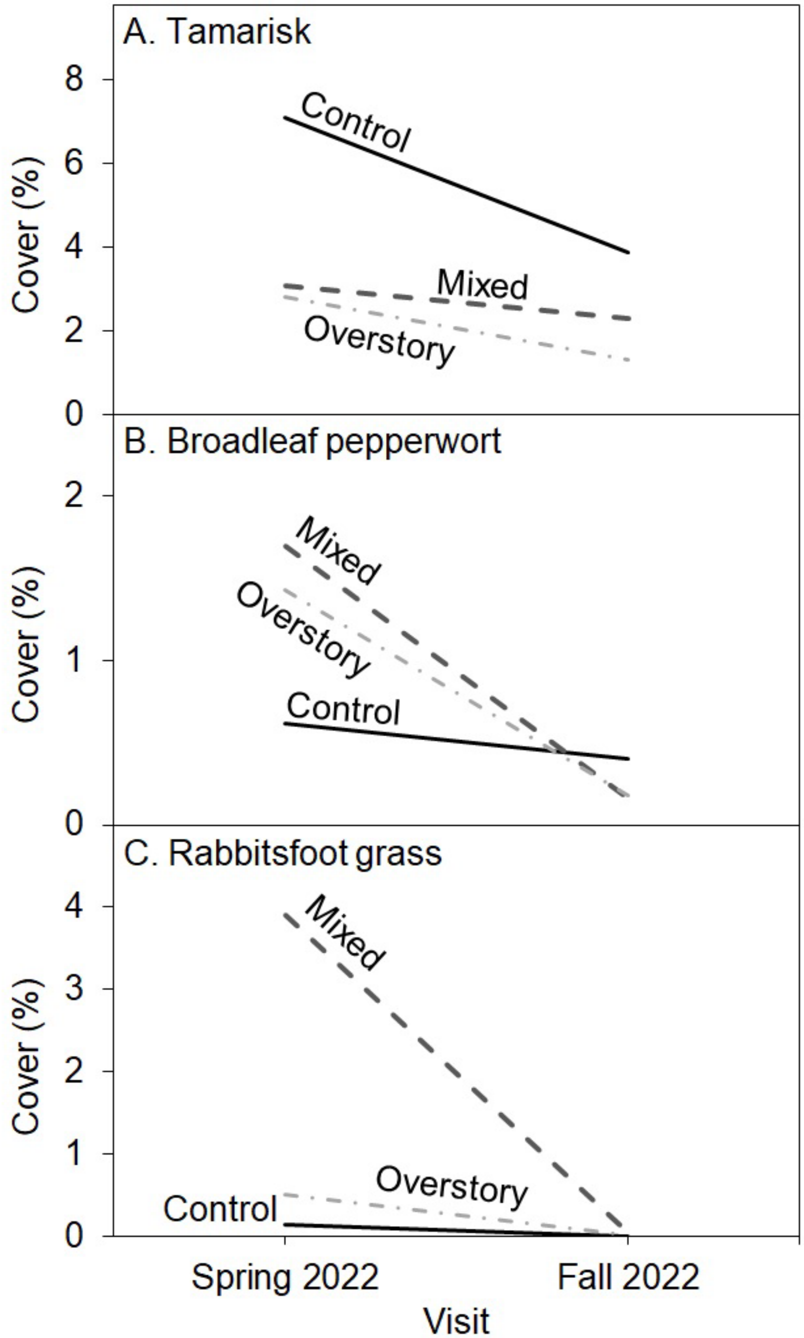
A. Tamarisk
Cover (%)
8
6
4
2
0
Control
Mixed
Overstory
B. Broadleaf pepperwort
Cover (%)
2
1
0
Mixed
Overstory
Control
C. Rabbitsfoot grass
Cover (%)
4
3
2
1
0
Mixed
Overstory
Control
Spring 2022
Fall 2022
Visit

Figure 14.

EVALULATION AND DISCUSSION OF THE RESULTS

Overall, restoration treatment results suggest planting using rooted plants or poles can result in successful plant establishment, although establishment may be mixed based on site conditions, species planted, and seasonal weather conditions. Although treated, tamarisk can persist and require additional treatments to reduce competition with native plants while plants establish. Other exotic species can invade into available habitat, suggesting additional invasive plant management is necessary. Recent severe drought conditions and herbivory by cattle impacted both restorations, resulting in decline or removal of aboveground perennial plant canopy. While drought contributed to dieback and mortality, livestock removed vegetation cover and reproductive structures, which may have implications for the long-term success of these projects. Because of these unanticipated setbacks, enrichment planting, supplemental treatments, and fencing or individual plant protection may be necessary to encourage plant patch establishment and expansion.

Results from the 2014 Restoration more specifically suggest that: (1) small-patch tamarisk removal and native planting successfully established native plants within tamarisk stands; (2) planted natives persist and support additional native recruitment via vegetative propagation or seed production; (3) removal of tamarisk can promote establishment of native species and contribute to patch expansion; (4) exotic plant management may be necessary as native plants establish; (4) drought conditions and herbivory can reduce the long-term effectiveness of native patch restoration; and (5) invertebrate utilization of native patches established within tamarisk stands can occur despite potential limitations of dispersal through the tamarisk monoculture and small size of the native patches.

Results from the 2021 restoration more specifically suggest that: (1) large-scale removal of tamarisk can successfully reduce tamarisk; (2) additional exotic plant treatments are necessary to reduce or remove resprouting tamarisk plants and prevent invasion by other exotic species; (3) planting native patches can successfully establish plants after tamarisk removal, although protection structures and supplemental treatments may be necessary to offset adverse conditions during certain seasons or years; (4) drought conditions and herbivory reduce the effectiveness of plant establishment; and (5) outplanting can increase invertebrate and pollinator habitat but limitedly during the early period of a restoration.

Small patch-size removal of tamarisk with native revegetation resulted in successfully introducing native species and structural and compositional diversity in aboveground vegetation, seed banks, and seed rain, as found by Phase 1 and 2 of this project. Native patches had greater richness and cover of species from diverse plant life history and functional groups, including trees and shrubs, herbaceous forb and graminoid species, and plants with diverse root morphologies. Recruitment through a diversity of propagules, seeds, rhizomes, stolons, or spreading roots, contributed to native patches filling in the available tamarisk-cleared area over time. Small native plant patches installed after large-scale tamarisk removal resulted in successful but limited establishment of planted species. Planted species did contribute significantly to higher cover and density of perennial plants but did establish and increase the overall site diversity. Naturally recruited plants tended to contribute just as much or more to native cover. Over time, planted perennials are anticipated to contribute to increasing cover as plants propagate and new seedlings establish, as long as conditions permit. For both restorations, the unanticipated effects of the recent severe drought conditions and herbivory resulted in restoration setbacks, including perennial dieback and the loss of planted individuals.

Although both restorations resulted in successful establishment of native plants including woody and herbaceous species, and provided invertebrate habitat, the combination of severe drought conditions and nonnative herbivore herbivory resulted in declines of vegetation cover including of flowering species that contribute to pollinator habitat. Drought conditions began at the end of spring 2020 after our initial surveys of the 2014 restoration sites. Severe conditions continued throughout 2021 and into early 2022. Within upland plant communities, severe drought conditions resulted in deciduous species not producing leaves or flowers for two growing seasons and few native annuals emerging. Similarly, we observed few species flowering at the Mormon Mesa riparian subunit throughout the Phase 2 project period. Severe conditions were alleviated with the onset of monsoon rains during the summer 2022. Precipitation events continued throughout the fall, winter, and early spring. However, similar to upland species, many plants appeared to experience the legacy of drought, including little flower production, dieback, and mortality. Additionally, we detected the presence of livestock within the subunit and browse of native patch plants. Likely due to limited upland vegetation during 2022, cattle retreated to riparian areas along the Virgin River. The reduction of native perennial plant canopy due to drought and grazing by cattle will likely result in a slower recovery. Further intervention may be necessary. Nevertheless, there was persistence of native plants in the patches.

Changing climate conditions, including the frequency and severity of drought, can have significant influences on riparian vegetation, especially in vulnerable habitats that already are under stress due to upstream water management, intense land use, and biological invasions. Many riparian ecosystems in the Southwest are impacted by a range of human activities including water management, urban development, and livestock grazing (Perry et al. 2012). Additionally, many of these ecosystems are invaded by exotic species, such as tamarisk, that benefit from land and water use changes (Cleverly et al. 1997; Stromberg & Chew 2002; Fleishman et al. 2003). Warmer growing season conditions during the spring-to-fall primary riparian vegetation growing season in the Southwest, along with drought conditions, can exacerbate already vulnerable communities. Warming can alter physiological responses by plants, including changing flowering periods and seed production, or altering photosynthesis and respiration, contributing to heat stress (Perry et al. 2012). Drought conditions can alter plant community composition and structure, hinder plant growth and propagation, flower and seed production, and seedling establishment (Touchette et al. 2007; Garssen et al. 2014), and result in plant dieback or mortality, reducing canopy and diversity, which can impact wildlife, such as birds and pollinators. Changes in plant community composition alter litter production and nutrient cycling. Where restoration activities have been conducted or are planned, increased frequency and severity of drought can result in more frequent restoration failures. Restoration techniques for southwest riparian ecosystems to offset drought and altered growing season conditions require further investigation and development.

Along with changing climate conditions, nonnative herbivores, such as cattle, horses, and sheep can have significant impacts on riparian vegetation (Brookshire et al. 2004; Kauffman et al. 2004). Livestock grazing can exacerbate climate change effects that lead to warmer and drier conditions (Kauffman et al. 2022). Free-roaming nonnative herbivores can have greater impacts on riparian vegetation than many native wildlife (Brookshire et al. 2004; Kaweck et al. 2018). As we observed within the Mormon Mesa subunit, intense herbivory by cattle can remove aboveground herbaceous cover (Kaweck et al. 2018). For newly established plants in a restoration, trampling and aggressive herbivory by these nonnative herbivores can set back restoration efforts by reducing canopy cover, removing aboveground photosynthetic biomass, and removing propagules that contribute to plant community expansion. Exclusion after previous degradation by cattle can result in recovery of riparian ecosystems when climate conditions are not adverse (Kauffman et al. 2022). Additional fencing or individual plant protection using cages or shelters may be necessary to facilitate plant establishment.

CONCLUSION

Planting patches of native riparian perennial plants that contribute to habitat structure into small or large areas recently cleared of tamarisk resulted in successful establishment of some species. However, drought and herbivory negatively impacted restoration sites, reducing vegetation cover and slowing recovery. Drought conditions are predicted to continue with increased frequency and duration, and grazing will likely continue regionally. Because of the multiple stressors on riparian ecosystems and that impact restoration efforts, additional treatments are likely necessary to consider for further restoration efforts at the Mormon Mesa subunit. Initial efforts to establish native patches within the tamarisk monoculture did result in persistent native plants and some utilization by invertebrates including pollinators, suggesting the restoration efforts implemented could be successful under certain conditions. If conditions improve, the 2014 native patches are also present to provide propagules to revegetate the area for increasing plant cover and potential floral resource availability.

To buffer against adverse site and climate conditions, additional supplemental treatments, alterative planting methods, incremental restoration installation, and greater plant or site protection may be required. Alternative planting methods that focus on deep plantings of poles or rooted plants may be more effective than planting shallow-rooted plants or short poles (Dreesen & Fenchel 2008, 2010). Although subsurface water is closer to the surface within riparian areas compared to uplands, upper surface soils may dry quickly and have lower water retention, limiting plant root growth and establishment. Although soil-water content at the Mormon Mesa subunit did not significantly vary over time at the deeper levels, the water content may not have been sufficient for plant establishing or root development due to the higher percentages of clays. Further experimentation would be necessary to determine the range of soil-water content necessary to assist plant establishment and root development of seedlings and poles. Deep-planting methods require plants that tolerate burial of the root crown, such as *Salix* species. Abiotic treatments, such as surface structural manipulations or temporary installation of protection shelters, may be necessary to create suitable protected microhabitat for plants. Surface structural manipulations may provide increased surface microhabitat diversity, while limiting movement and access by free-roaming herbivores. Using shelters that protect canopy and cover surface soils may assist with plant establishment. Plant shelters provide against herbivory protection, buffer against extreme temperature and humidity fluctuations, and increase survival among plants outplanted into adverse surface soil environments (Bainbridge & MacAller 1995; del Campo et al., 2006; Padilla et al. 2011; Chiquoine et al. 2022). Shelters range in materials, size, dimension, and coverage, and appropriate types of shelters for the preferred species and site conditions would need to be determined experimentally. Where plants are protected and developing canopies, additional species may be introduced under the canopy provided by established plants. Effective management that reduces use or access by herbivores to sensitive areas can be accomplished by controlling seasonal access to these areas (Kaweck et al. 2018). Additional protection of the restoration site through pro-active fence installation or using existing tamarisk structure to deter or limit cattle movement is likely necessary. The large-scale removal of tamarisk opened access to the subunit. The smaller 2014 restoration units had reduced access due to the existing tamarisk structure and the Clark County fence system.

RECOMMENDATIONS

- Increase site limitation by cattle through fencing; increase protection of outplants using shelters or cages. Experimentation may be necessary to identify specific shelter or cage types appropriate for particular species.

- Install biotic and abiotic surface manipulations to create greater surface topography and limit mobility and access of cattle, and to create catchments and topographical structures that increase microclimate diversity.

- Continue monitoring vegetation, phenology, and seed banks to determine the effectiveness of nucleation as a restoration technique for riparian habitats in the Southwest.

- Conduct additional experimental plantings to better elucidate plant-plant interactions between structurally significant plants (tall, woody plant) and understory canopy plants (herbaceous plants).

- Implement restoration activities incrementally and conduct enrichment planting to encourage patch biodiversity. Facilitate establishment of plants that provide the most structure and limit access or movement by nonnative herbivores.

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