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Aquatic Ecosystem Restoration in the Texas Western Gulf Coast Plain / Lower Rio Grande Alluvial Floodplain Ecoregion

Resaca Boulevard Resaca Section 206—Vegetation Community Adaptive Management

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Abstract

As part of the US Army Corps of Engineers (USACE) Continuing Authorities Program (CAP), Section 206 projects focus on restoring aquatic habitats for the benefit of fish and other wildlife. From 2017–2021, USACE Engineer Research and Development Center–Environmental Laboratory researchers in the Aquatic Ecology and Invasive Species Branch (ERDC-EL EEA) at the Lewisville Aquatic Ecosystem Research Facility (LAERF) collaborated with USACE Galveston District, The Nature Conservancy, US Fish and Wildlife Service, National Park Service, and local nonfederal sponsors—Brownsville (Texas) Public Utility Board and the City of Brownsville—to study restoration methods on former, naturally cut-off, channels of the Lower Rio Grande River. These aquatic ecosystems, locally termed "resacas," are home to endemic plants and animals and are thus an important natural resource of national interest. This technical report documents the planning, design, construction, monitoring, and adaptive management activities throughout the Resaca Boulevard Resaca Section 206 Aquatic Ecosystem Restoration project. Methods and results for invasive species management—primarily Brazilian peppertree (*Schinus terebinthfolia*)—and aquatic and riparian vegetation establishment in endemic Texas ebony resaca forest, subtropical Texas palmetto woodland, and Texas ebony/snake-eyes shrubland habitats are discussed.

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Preface

This report was written presenting results of a reimbursable project between the US Army Corps of Engineers (USACE) Galveston District (SWG) and the US Army Engineer Research and Development Center (ERDC) Aquatic Ecology and Invasive Species Branch. The ERDC technical POC was Mr. Aaron Schad and SWG project manager was Mr. Shakhar Misir. Funding for this reimbursable project was provided by the SWG under ERDC PSWA "Schad-20-14" and MIPR W45VAK90711523.

This report was prepared under the general supervision of Mr. Alan Katzenmeyer, chief, Aquatic Ecology and Invasive Species Branch; Mr. Mark D. Farr, chief, Ecosystem Evaluation and Engineering Division; and Dr. Edmund Russo, director, Environmental Laboratory (EL).

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At the time of the publication, COL Christian Patterson was commander of ERDC, and Dr. David W. Pittman was the director.

1 Introduction

1.1 Background

Resacas are unique aquatic ecosystems characterized as paleochannels and distributaries of the Lower Rio Grande River in southern Texas (Perez et al. 2017). Located within the Texas Western Gulf Coast Plain / Lower Rio Grande Alluvial Floodplain Ecoregion, these aquatic resources and diverse vegetation communities support a variety of subtropical fish, migratory birds, and other wildlife species. For example, Montezuma cypress (*Taxodium mucronatum*), a scarce conifer, and Texas sabal palm (*Sabal mexicana*) only natively occur within the US in the Rio Grande Valley. The endangered (International Union for Conservation of Nature) red-crowned parrot (*Amazona viridigenalis*) also utilizes the associated habitat—one of only a few locations within the US.

Resacas also provide various drainage points away from the river and adjacent terrestrial areas during flooding events. Historically, with water capture from surrounding aquatic and terrestrial systems, resacas and adjacent lowlands filled in with sediment from the Rio Grande River during high water periods and supported bottomland ecosystems.* In the riparian areas, Texas ebony resaca forest or subtropical Texas palmetto woodlands vegetation communities dominated lower areas around the resaca perimeter and transition to Texas ebony/snake-eyes shrubland communities as elevations increase, followed by an upland Texas ebony-anacua/brasil forest community at higher elevations. Beginning in the 1950s, urbanization and water management, including levees and dams caused many resacas to become disconnected and degraded, which significantly lowered the quality of habitat for various fish and other wildlife (Castillo 1997). Changes in elevation and hydrology and vegetative communities associated with these areas have also transitioned. The resulting lack of adequate riparian buffers and degradation of habitat placed additional pressure on native aquatic biota, particularly those sensitive to poor water quality (Jahrsdoerfer and Leslie 1988).

* https://tshaonline.org/handbook/online/articles/rbrnp

Non-native plant species have invaded and further impacted resacas. These include Brazilian peppertree (*Schinus terebinthifolia*), Chinaberry tree (*Melia azedarach*), salt cedar (*Tamarisk* spp.), Chinese tallow (*Triadica sebifera*), Australian pine (*Casuarina equisetifolia*), white leadtree or river tamarind (*Leucaena leucocephala*), and giant cane (*Arundo donax*). Brazilian peppertree—the dominant invader—is an aggressive woody weed with a high growth rate and wide environmental tolerance. In addition, it is a prolific seed producer, has a high germination rate, produces shade-tolerant seedlings, and can form dense thickets (NPS 2019). Currently, it is the most prominent invasive species in resacas as it displaces native vegetation and rapidly invades disturbed sites, particularly shorelines (UF 2021). Due to the negative impacts caused by Brazilian peppertree and other non-natives, it is important natural resource managers implement effective invasive species control, among other restoration measures, to allow native vegetation communities to properly establish and expand for the benefit of resaca habitat and its fish and other wildlife. US Federal, state, and local agencies have realized this value and the necessity to restore resaca ecosystems, which contain specific habitat supporting equally unique and threatened components.

1.2 Objective

In one such project—The Resaca Boulevard Resaca (RBR) Section 206 Aquatic Ecosystem Restoration Project, City of Brownsville, TX—the US Army Corps of Engineer Research and Development Center Environmental Lab (ERDC-EL) Lewisville Aquatic Ecosystem Restoration Facility (LAERF) provided support to the US Army Corps of Engineers (USACE) Galveston (SWG) in invasive species management, and the establishment and adaptive management of native vegetation (Figure 1). The project was designed to reduce invasive species impacts and restore native species plant communities as a means for improving resaca habitat within the Western Gulf Coastal Plain / Lower Rio Grande Alluvial Floodplain ecoregion. The authority for construction was contained in Section 206 of the Water Resources Development Act (WRDA).

Figure 1. Location of Resaca Boulevard Resaca (shaded green); *blue* areas represent the remainder of the Town Resaca system, Brownsville, Texas.

The project location was in the City of Brownsville in Cameron County, Texas (SWG 2016). The study area included the RBR and surrounding lands between Belthair Street and a downstream weir located at the southern end of the resaca. The total project area encompassed approximately 2.16 ha (5.35 acres), which was composed of 0.75 acres of aquatic and emergent wetland habitat and 4.6 acres of riparian habitat (Figure 2). The RBR was part of the Town Resaca system that flows west to east across the southern section of Brownsville. The area had subtropical climate with warm maritime influence from the Gulf of Mexico. The RBR study area had a relatively flat topography associated with a large river delta at elevations of 25 ft above mean sea level.

Figure 2. Resaca Boulevard Resaca study area includes the resaca and adjacent lands.

ERDC-EL-LAERF participated in the development of restoration features with SWG, City of Brownsville, Texas (COB), Brownsville (TX) Public Utility Board (BPUB), US Fish and Wildlife (USFW), The Nature Conservancy (TNC), US National Parks Service (NPS), and Texas Parks and Wildlife (TPWD) with (1) the provision of native vegetation for plantings, installation of plants, and assistance/oversight during construction phase of restoration efforts and (2) monitoring and adaptive management of plant communities and an operations and maintenance manual for long-term, post-construction management. Goals were achieved by introducing native plants to suitable areas following removal of targeted invasive plant species. Due to unpredictable future conditions, an adaptive management approach was applied. Vegetation management and establishment efforts, and lessons-learned at RBR (2018–2020) throughout the project's phased timeline—planning, design, construction, monitoring and adaptive management, and operations and maintenance—are described herein.

1.3 Approach

Overrun by invasive vegetation—primarily, Brazilian peppertree and a lack of native vegetation for the benefit of fish and other wildlife, collaborators developed strategies to ecologically restore the RBR during the project planning and design phases. The RBR restorative measures or alternatives called for (1) aquatic and emergent plantings, (2) riparian plantings, (3) invasive plant species management, (4) creation of red-crowned parrot nesting structures, and (5) bank-slope restoration. The project goal was to create habitat consistent with reference resaca vegetation to support a diverse community of local, indigenous wildlife (SWG 2016). The restoration plan at RBR was designed to ensure successful establishment of aquatic, wetland, and riparian plant communities sustainable and well-suited to withstand periodic flooding coupled with persistent drought events. Establishing native vegetation along the restored bank-slope also functioned to improve water quality by filtering stormwater runoff and reduce sediment deposition at the RBR.

Management of Brazilian peppertree and other nuisance tree species was a substantial component of the overall project and was conducted via mechanical removal and herbicide treatment by an external contractor. ERDC-EL-LAERF followed these efforts by establishing native species to restore plant communities. Additionally, work was conducted in bank slope restoration, followed by native wetland vegetation planting and establishment. Five specific objectives for native vegetation restoration by ERDC-EL-LAERF included

1. developing techniques for establishing vegetation in project restoration features;
2. propagating and providing suitable riparian, aquatic, and wetland plants for project use;
3. aiding and oversight during construction (related to vegetation) and implement planting;
4. monitoring vegetation community development and employing adaptive management strategies to achieve project goals; and

5. developing an Operation, Maintenance, Repair, Rehabilitation, and Replacement (OMRR&R) manual for long-term management of the site.

Construction of the project (contractor invasive species removal) began in September 2018 and was substantially complete in December 2020. Vegetation planting, monitoring, and adaptive management began in 2018 and continued through December 2020 by USACE SWG and ERDC-EL-LAERF (Table 1). Years 1–2 focused on site habitat evaluation, preparation, plant propagule acquisition, plant culture, and plant restoration design. Years 2–3 included plant establishment, monitoring, adaptive management, and production of an OMRR&R manual.

Table 1. RBR Section 206 native vegetation establishment schedule.

Item	Year 1	Year 2	Year 3
Objective 1: (Planning; site evaluations; prep)	√	√	
Objective 2: (Propagule & materials acquisition; plant production	√	√	√
Objective 3: (Invasive removal oversight; planting)		√	√
Objective 4: (Monitoring; adaptive management)		√	√
Objective 5: (Reports and OMRR&R)		√	√

These objectives were complete at time of this report, including planning and design, provision of propagules, planting, nuisance plant management oversight, and monitoring. A draft OMRR&R manual was produced and submitted to SWG, COB (non-Federal sponsor responsible for long-term maintenance), and BPUB in December 2020. An on-site training to the non-Federal sponsor was given by ERDC on 08 December 2020.

2 Materials and Methods

An integrated management approach utilizing physical/mechanical and chemical control techniques followed by native vegetation establishment was implemented for the management of invasive plant species such as Brazilian peppertree at RBR. First, ERDC-EL-LAERF participated in collaborative meetings with USACE SWG and SWF, NPS, TNC, FWS, TPWD, and contractors to determine specific goals of the restoration in terms of vegetation community components (woody, herbaceous, and all aquatic growth-forms) and timing of revegetation efforts. Restoration species to be used were identified coupled with recommendations for nuisance species removal in a manner compatible with native vegetation protection and establishment. Transplant lists were developed for plant propagation (Appendix A) during the design phase and seeding species list and rates were developed for contractor use during the construction phase. Specifications for invasive species management, the post-treatment monitoring, soil replacement, seeding timing, transplant installations, mowing height and timing, and adaptive management were also all developed as part of the design phase.

2.1 Invasive species removal

2.1.1 Design

Before construction, the invasive Brazilian peppertree was the dominate plant species at the project site and occurred in approximately 50% of the area at 100% densities primarily along the water's edge. Other non-native woody vegetation occurred sporadically throughout the site and accounted for <10% of vegetation coverage. Similarly, native vegetation occurred sporadically throughout the site, and where applicable, was marked to preserve (see Native Plant Establishment and Monitoring and Adaptive Management sections). Specifications developed for the invasive species removal process included felling and cutting of all non-native trees and removal of other debris within the clearing limits. This was conducted when no/minimal seeds were present on the trees or shrubs, typically between May 15 and August 1. Trees, stumps, roots, brush, and other vegetation were cut off flush with or slightly above the original ground surface. All non-native woody vegetation, including Australian Pine, Chinese Tallow, Chinaberry, river tamarind, and Brazilian Peppertrees were then treated with triclopyr herbicide (triclopyr amine formulation containing three pounds acid equivalent per gallon according to the manufacturer's label) within 5 min of cut completely covering the cut-stump, especially the vascular cambium area. Prior to herbicide application, the cut-stump was cleared of all sawdust and/or debris before applying herbicide (Appendix B).

Following a two-month post-herbicide treatment period, removal and disposal of stumps and roots larger than 3 in. in diameter to a minimum depth of 12 in. below the finished or existing grade and matted roots from areas where excavation was required. Depressions excavated below the original ground surface for or by the removal of stumps and roots, except in areas of excavation, were filled with satisfactory material and compacted so the surface conformed to the surrounding ground surface. Follow-up herbicide treatments were made as necessary (see Results - Monitoring and Adaptive Management Section) to eliminate regrowth of the invasive trees and shrubs. All above-ground biomass of invasive woody vegetation was chipped to prevent resprout and moved to a higher onsite location and dispersed to dry. Excess materials obtained from clearing, grubbing, and removal of debris operations were removed from the project site.

Several non-native palms (Mexican fan palm or *Washingtonia robusta*) were also designed to be treated with herbicide to create nesting habitat, primarily for the red-crowned parrot and golden-fronted woodpeckers (*Melanerpes aurifrons*). One third of non-native palms were snagged in construction, 1/3 scheduled to-be snagged in 5yr, and the remainder in 10 yr. A snag here refers to a standing dead tree rooted into ground. Palms were converted to snags by treatment with glyphosate herbicide using the following procedure: drill three 5/16 to ½ in. diameter holes in the palm tree spaced evenly around the trunk at chest height ensuring each hole reaches the center of the tree; fill with a 41 % solution of glyphosate herbicide; let herbicide soak into the tree and repeat; after a few days, fill with herbicide one more time, and leave in place.

2.1.2 Construction

A chief initial construction component of the RBR restoration project was removal of Brazilian peppertree and other invasive plant species. BPUB and SWG coordinated with SAMES, a private contractor located in McAllen, Texas, to provide services and vegetation maintenance in RBR. The design and specifications for removal of Brazilian peppertree within the fruiting season was specified for completion in October 2018, prior to maturation of seeds. In addition to Brazilian peppertrees, several other tree species were treated or removed where necessary and possible (Figure 3). Scattered Chinaberry and Chinese tallow trees were cut and stump-treated in the same manner as Brazilian peppertree. Additionally, a large stand of Australian pines was removed from near the center of the site.

Figure 3. Brazilian peppertree removal process at RBR project site.

The initial deadline was established to avoid the spread of seeds across the study area and elsewhere, and thereby minimizing the need to treat additional areas where the seeds may sprout. However, due to significant delays, the implementation of Brazilian peppertree treatment was not initiated until late-summer 2018. With treatment being conducted after fruiting was completed, USACE SWG and ERDC identified mitigation measures that would minimize the spread of seeds outside the existing distribution of Brazilian peppertree. Initial mitigation measures involved placing tarps abutting the existing edges of the Brazilian peppertree footprint. Vehicles and trailers used to haul off debris were positioned adjacent to these tarps ensuring any fallen seed material during such transfer would not fall on bare ground. Seeds situated on the tarp or those that may have inadvertently fallen off were collected and properly disposed of. Following invasive species treatment, the entire site was continually monitored for Brazilian peppertree and other nuisance tree species seedlings and treated as needed.

By incorporating these measures into the construction plan, the risk associated with the removal and treatment of Brazilian peppertree during the fruiting season was minimized to an acceptable risk level. The SAMES construction crew, herbicide treatment crew, and USACE Biologists (RPEC and ERDC) then conducted several site visits to remove the peppertrees and followed the mitigation measures to reduce the spread of fruits and seeds. Non-fruiting branches were dragged to the disposal piles. On-site district biologists, often with ERDC assistance, continually monitored progress of Brazilian peppertree and other nuisance tree removal at the onset of the project. Documentation and recommendations were made as removal progressed, including estimates of efficacy of treatments, occurrences of missed trees, provision of protecting desirable tree species (e.g., flagging), and identification and locations (by flagging) of seedlings and saplings that occurred postremoval.

Working maps were continuously created to show the next treatment dates for each area and document the fate of invasive trees in the project area. This identified the six-week windows (to confirm invasive plant mortality from herbicide before grubbing) for the separate segments of Brazilian peppertree and other nuisance tree treatment areas. The last treatment and the earliest grubbing dates were marked for each segment. They also identified the fate of targeted trees and the species of trees that remain, non-native palms that were treated and killed, those that will be treated in 5 yr, and those that will be treated in 10 yr. Non-native palm trees were thinned, and a subset of the palms were treated with glyphosate to create standing snags to serve as nesting habitat for golden-fronted woodpeckers and red-crowned parrots (Figure 4).

After invasive management actions were complete, areas at the site where bank sloping construction was slated to occur were identified and marked. Most marked locations were along the sections of the resaca bank where nuisance trees had not occurred. However, several locations that required slope modifications required removal of Brazilian peppertree stumps remaining after cutting and treatment. Following re-sloping, vegetation monitoring was initiated to ascertain which species would establish naturally, with plans to supplement those plant communities with additional beneficial riparian and aquatic plant species. Shoreline areas were monitored annually for significant erosion. Although, minimal was expected due to the lack of major hydrological shifts in the system. Appendix B provides detailed photographs of the invasive species removal operations during the construction phase; Appendix C provides photographs for native and non-native plant identification.

Figure 4. Nonnative palm snags at RBR for the purposes of red-crowned parrot and woodpecker habitat.

2.2 Native plant establishment

ERDC-EL-LAERF provided all equipment, materials, facilities, and labor necessary to collect local seed, grow plants, and deliver appropriate containerized native plants for project use. Plant propagules (seeds, cuttings, etc.) used for restoration efforts were collected locally within the Texas Western Gulf Coastal Plains and the Southern Texas Plains ecoregions (Griffith et al. 2004).* To increase genetic diversity amongst specimens of the same species, propagules were collected across a large spatial area, where possible. Collected propagules were processed, stored, sown, and cultivated in containers following standard methods (Nokes 2001; Dick et al. 2013).† Containerized plant species used in the project are given in Table 2. Following invasive species removal, areas were also seeded by contractor.

Table 2. Aquatic, emergent, and riparian transplants used at RBR.

Common Name	Scientific Name
Aquatic/Emergent	
Herb of grace	*Bacopa monnieri*
Fragrant flatsedge	*Cyperus odoratus*
Creeping burhead	*Echinodorus cordifolius*
Squarestem spikerush	*Eleocharis quadrangulata*
Water mudplantain	*Heteranthera dubia*
American water-willow	*Justicia americana*
Bigfoot waterclover	*Marsilea macropoda*
Yellow waterlily	*Nymphaea mexicana*
American white waterlily	*Nymphaea odorata*
Longleaf pondweed	*Potamogeton nodosus*
Delta arrowhead	*Sagittaria platyphylla*
California bulrush	*Schoenoplectus californicus*
Common threesquare	*Schoenoplectus pungens*
Softstem bulrush	*Schoenoplectus tabernaemontani*
Riparian - trees, shrubs, vines	
Twisted acacia	*Acacia schaffneri*
Whitebrush	*Aloysia gratissima*
Sugarberry	*Celtis laevigata*
Spiny hackberry	*Celtis pallida*
Hog plum	*Colubrina texensis*

* http://plants.usda.gov

† nativeplantnetwork.org

Common Name	Scientific Name
Brazilian bluewood	*Condalia hookeri*
Anacahuita	*Cordia boissieri*
Texas persimmon	*Diospyros texana*
Knockaway	*Ehretia anacua*
Mexican holdback	*Erythrostemon mexicana*
Texas Lignum-vitae	*Guaiacum angustifolium*
Tenaza	*Havardia pallens*
Tepeguaje (great leadtree)	*Leucaena pulverulenta*
Mexican ash	*Fraxinus berlandieriana*
Jerusalem thorn	*Parkinsonia aculeata*
Texas paloverde	*Parkinsonia texana var. texana*
Texas ebony	*Pithocellobium ebano*
Crucillo	*Randia rhagocarpa*
Black willow	*Salix nigra*
Texas sabal palm	*Sabal mexicana*
Guajillo	*Senegalia berlandieri*
Catclaw acacia	*Senegalia greggii*
Montezuma bald cypress	*Taxodium mucronatum*
Sweet acacia	*Vachellia farnesiana*
Blackbrush acacia	*Vachellia rigidula*
Lotebush	*Ziziphus obtusifolia*
Riparian herbaceous	
Slender grama	*Bouteloua repens*
Green sprangletop	*Leptochloa dubia*
Vine mesquite	*Panicum obtusum*
Turkey tangle fogfruit	*Phyla nodiflora*
Southwestern bristlegrass	*Setaria scheelei*
White tridens	*Tridens albescens*

According to species' needs and final size requirements, propagules were sown, cultured, and transferred as necessary to appropriately sized containers prior to being delivered to the project site for transplanting.

Beginning in FY2018, ERDC-EL-LAERF initiated cultivation of each species in various manners dependent on growth form for multiple installations of several container sizes for each. Using vegetation of multiple age and size classes during initial plantings was important for establishing woody species and enabled the demonstration of the most successful methods across all habitat types of this project, thereby maximizing project resources through application of adaptive management.

Aquatic (submerged aquatic vegetation or SAV, emergent, and floating-leaved) plants were mature transplants (Figure 5) with well-developed root balls, grown in appropriately sized 4 in. (quart) to 6 in. (gallon) plastic containers to facilitate recovery and growth after planting. Propagules (seeds, apical tips, and/or bareroot plants) were collected from appropriate ecoregions. Herbaceous plant species (grasses and forbs) were mature transplants with well-developed root balls with most species grown in 2 in. diameter x 6 in. deep plastic containers. In some cases, variations in container size were needed to facilitate growth. Propagules (seeds or bareroot plants) from appropriate ecoregions were collected and grown to specifications at LAERF. Deep root producing woody plant species were grown in appropriately sized containers designed to direct roots downward and self-prune at bottom air holes to induce branching and reduced root curling. Most seedlings and cuttings were grown in 2 in. x 6 in. deep "cone-tainers" and 4 in. x 8 in. to 12 in. tall (1/4+ gal) ridged, deep plastic containers. Variations in container size were dependent upon species and modified as needed; Appendix A provides detailed photographs of the production of containerized herbaceous and woody plants.

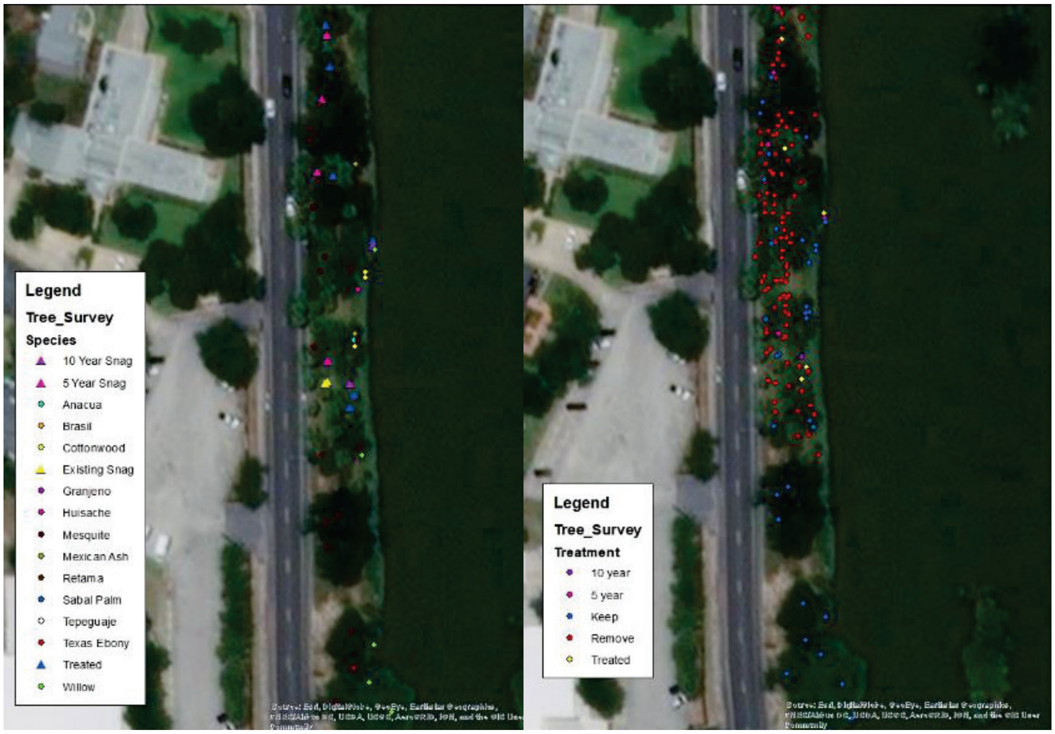
Figure 5. Field-ready containerized longleaf pondweed (*Potamogeton nodosus*) and other species were used to establish aquatic and emergent species at RBR.

To commence the onsite ecosystem restoration efforts, SWG, USACE Regional Planning and Environmental Center or RPEC, COB, BPUB, and ERDC-EL-LAERF biologists cohosted a groundbreaking event for the RBR Project in August 2018. Brownsville Mayor Tony Martinez, Galveston District Commander Lars N. Zetterstrom, Texas State Representative Eddie Lucio III, US Congressmen Filemon Vela Jr., and a representative from the office of Senator John Cornyn were in attendance. During the groundbreaking event, south Texas native plants such as Montezuma cypress (Figure 6) and sabal palms were planted.

Figure 6. Groundbreaking ceremony held for the RBR; *left* – attendants digging and *right* – planted Montezuma cypress.

ERDC-EL-LAERF assisted with onsite biological monitoring of invasive species removal, native plant avoidance, improvements in installations, and other contractor activities throughout construction to ensure project success. Figure 7 illustrates an example of native plants to stay during invasive species removal phase (USACE RPEC).

Figure 7. Paired maps that identify fate of trees to keep, remove, and treat (*left*) and the species of trees that remain (*right*).

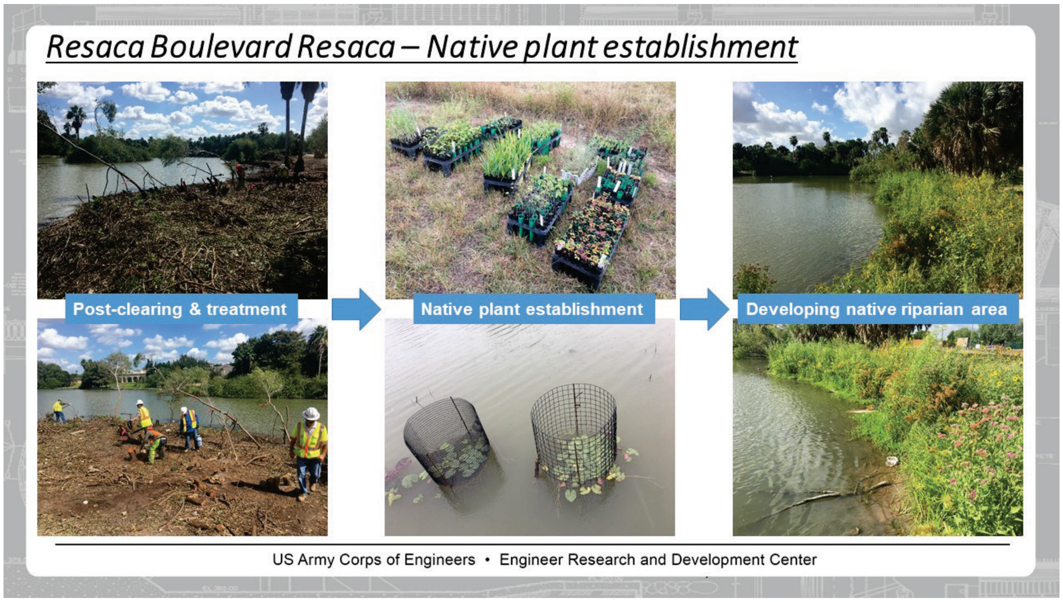


Native plant establishment efforts began in January 2019 with a seeding effort by the contractor. A list of grasses and forbs approved by SWG, ERDC, and project partners was compiled to serve as cover crop immediately following removal of invasive species. These plants served to minimize erosion, provide immediate ecological benefits, and aid in the natural spread of containerized plants installed later in the growing season. Seeds were purchased from an approved vendor in which 20 lb of live seeds per acre were broadcast seeded. Percentages by weight of the 18 selected species are provided in Table 3. The contractor also irrigated the seeded site as needed and created an irrigation path on the site to be seeded closer to the conclusion of the project. The site was first ready for native transplants when invasive species were clear and post-removal seeding was complete by the contractor by April 2019. Figure 8 shows the general vegetation community trajectory post-invasive species removal realized throughout the project.

Table 3. Seed mix used at RBR; 20 lb per acre.

Common Name	Scientific Name	Percent (%)
Hairy grama	*Bouteloua hirsuta*	5
Slender grama	*Bouteloua repens*	5
Hooded windmillgrass	*Chloris cucullata*	5
Shortspike windmillgrass	*Chloris subdolistachya*	5
Wand-like bundleflower	*Desmanthus virgatus*	2
Canada wildrye	*Elymus canadensis*	15
Green sprangetop	*Leptochloa dubia*	5
Hall's panicgrass	*Panicum hallii*	5
Switchgrass	*Panicum virgatum*	5
Whiplash pappusgrass	*Pappophorum bicolor*	5
Rio Grande clammyweed	*Polanisia dodecandra spp. Riograndensis*	1
Plains bristlegrass	*Setaria leucopila*	15
Little bluestem	*Shizacyrium scoparium*	5
Awnless bush sunflower	*Simsia calva*	1
False rhodesgrass	*Trichloris crinita*	5
Multiflower false rhodesgrass	*Trichloris pluriflora*	15
Orange zexmania	*Wedelia hispida*	1
Total		100

Figure 8. Native plant establishment process at RBR; *top left* – clearing project section and treatment of Brazilian peppertree and other invasive species; *bottom left* –contractors clearing project area; *middle top*–terrestrial native plants are planted following clearing and seeding; *middle bottom*–aquatic plants caged for herbivore protection during early establishment; and *top and bottom right*–developing native riparian area after resloping and planting.



The first planting effort consisted of woody and herbaceous containerized plants (riparian or shoreline and upland) to promote the RBR ecosystem restoration goals of native plant establishment. Plantings occurred in two general areas, south and north sites from a species selected list (Table 4). Plants were placed in clusters leaving 7–10 ft between to enable mowing over herbaceous cover when necessary. Holes were dug using small gas-powered augers and plantings were backfilled with on-site sediment. Most of the plants were planted on the landside of the existing silt fence, while 26 Montezuma cypress and 9 ash trees were planted 4 ft away from the silt fence towards the water (lower elevation, saturated soils). On the south site, a total of 330 plants were planted including five Rio Grande palmettos and ten Montezuma cypress. On the north site, 231 plants were transplanted, including three clusters of sabal palms (approximately 25 each) along with 16 Montezuma cypress plants. The north end also included a one 10 ft x 30 ft flag marked woody seeding location containing native plants (Rio Grande palmetto, sweet acacia, ebony, blackbrush acacia, cedar elm, crucillo, tenaza, hog plum, and anacua). Starting monthly on 15 April 2019, ERDC-EL-LAERF assessed plant and vegetation site conditions (see Results). Figure 9 illustrates planting method results of first plantings efforts, April 2019.

Table 4. Woody and herbaceous plant species selected for transplant, April 2019.

Common Name	Scientific Name
Guajillo	*Acacia berlandieri*
Twisted acacia	*Acacia schaffneri*
Whitebrush	*Aloysia gratissima*
Slender grama	*Bouteloua repens*
Mexicana poinciana	*Caesalpinia mexicana*
Sugarberry	*Celtis laevigata*
Spiny hackberry	*Celtis pallida*
Hog plum	*Colubrina texensis*
Brasil	*Condalia hookeri*
Mexican olive	*Cordia boissieri*
Texas ebony	*Ebenopsis ebano*
Anacua	*Ehretia anacua*
Mexican ash	*Fraxinus berlandieriana*
Texas lignum-vitae	*Guaiacum angustifolium*
Tenaza	*Havardia pallens*
Green sprangletop	*Leptochloa dubia*
Sabal palm	*Sabal mexicana*
Montezuma cypress	*Taxodium mucronatum*
Sweet acacia	*Vachellia farnesiana*
Blackbrush acacia	*Vachellia rigidula*
Lotebush	*Ziziphus obtusifolia*

Figure 9. Woody and herbaceous vegetation planting in riparian areas at RBR in April 2019.

Wetland fringe vegetation naturally develop following invasive species removals (Figure 10); dominated by native emergent volunteer species. To increase diversity of the wetland fringe and ensure establishment of floating-leaved and SAV, a planting was undertaken by ERDC-EL-LAERF the week of 9 September 2019 from an approved species list decided by the team (Table 5).

Figure 10. Wetland fringe developing with native plants: *left*–within silt fence in no-mow designated area; *right*–waterhyssop and spikerushes.

Table 5. Species list for emergent and aquatic planting on 10 September 2019.

Common Name	Scientific Name
Creeping burhead	*Acacia berlandieri*
Squarestem spikerush	*Acacia schaffneri*
Water mudplantain	*Aloysia gratissima*
American water-willow	*Bouteloua repens*
Floating primrose	*Caesalpinia mexicana*
Bigfoot waterclover	*Celtis laevigata*
Yellow waterlily	*Celtis pallida*
American white waterlily	*Colubrina texensis*
Longleaf pondweed	*Condalia hookeri*
Delta arrowhead	*Cordia boissieri*
California bulrush	*Ebenopsis ebano*
Common threesquare	*Ehretia anacua*
Softstem bulrush	*Fraxinus berlandieriana*

Emergent species were planted along the length of the shoreline at the water's edge at 5 ft centers. Submerged and floating-leaved plants were planted in herbivore exclosures or PVC welded-wire ring-cages at three different "founder-colony" locations. These sites would serve as a propagule source to spread aquatic vegetation throughout the resaca wetland. The caged protection was also constructed to determine whether herbivore protection would be needed to prevent plant disturbance of native submerged and floating-leaved aquatic plants throughout the project. At each SAV site, four species were planted (American pondweed, water stargrass, Mexican waterlily, and American white waterlily). Each species was planted in each of the three levels of protection: unprotected, protected by 1 in. ×1 in. mesh, and protected by 2 in. × 2 in. mesh. All SAV was planted at 1.5 ft depths (Figure 11). One transplant of each species at each site was also planted at 0.5 ft depth unprotected within the wetland vegetated fringe to determine if the natural-vegetation protection served as adequate herbivore masking/protection. After woody and aquatic first-year plantings, monitoring and adaptive management began, which included supplemental plantings as needed (see Results, Monitoring and Adaptive Management).

Figure 11. Planting 10 September 2019: *top left* – highlighted areas show planting locations; *top right* – containerized aquatic plants; *bottom left* – planted, flagged emergent vegetation; *bottom right* – submerged and floating leaf plants were caged for herbivore protection.

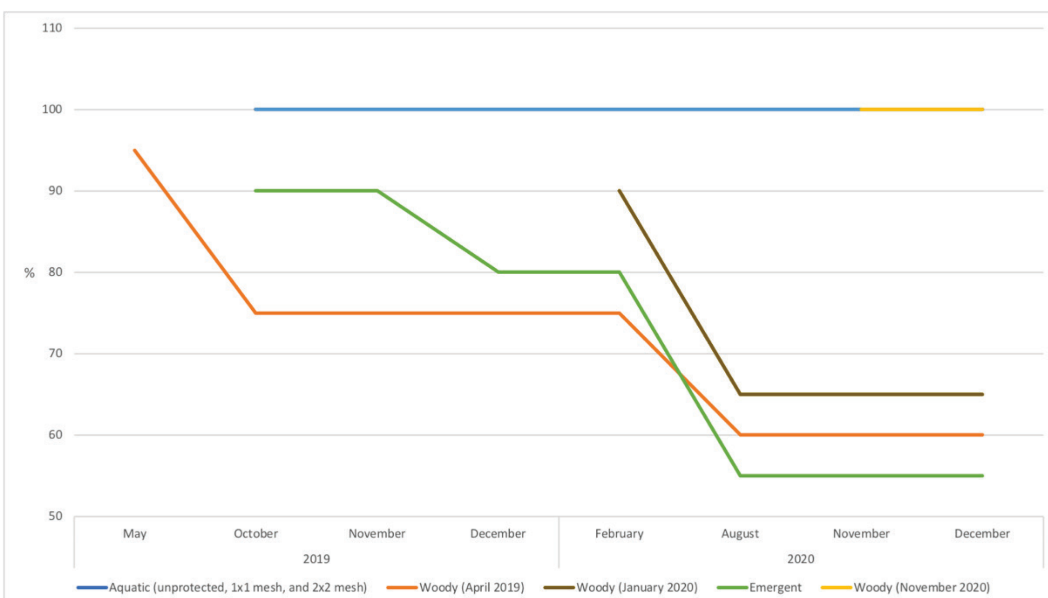
3 Results

3.1 Vegetation community

To assess the restoration efforts and direct management decisions, vegetation community development, invasive species treatments, seeding and transplant survival, growth, and spread, were monitored periodically following treatments and plant installations. Surveys in the final year were used to gauge long-term success of the project. Overall, invasive species treatments were highly successful, reducing plant coverages to an initial near 0% two-months post-treatment. However, minor foliar herbicide retreatments of saplings and seedlings were required throughout monitoring (these are documented in the following section).

Native plant percent survival by growth form and planting date is represented in Figure 12. Aquatic vegetation was reported to have an overall 100% survival rate throughout the project. Woody plants slightly declined throughout the project and averaged 60–65% survival by December 2020. As woody vegetation herbivory was not a substantial factor, mortality was likely due to warmer temperatures in the summer leading to desiccation.

Figure 12. Percent survival by growth form and planting date; note y-axis range 50%–100%.



Individual aquatic and riparian vegetation mean percent survival, max spread, and fitness rating are listed in Table 7, with fitness ratings defined in Table 6. Although aquatic plant communities were 100% established overall, bigfoot waterclover and common threesquare were the poorest individually developed with 45% or less survival rate. Longleaf pondweed was the most highly spread species encompassing 125 linear feet along the shoreline. Woody species were generally in the higher range of fitness (rating of 2–3). Texas sabal palm and Montezuma bald cypress were both at the highest range of fitness (rating of 3) with 80% or more survival rate. Some species such as southwestern bristlegrass and white tridens may have experienced severe disturbance, with 25% or less survival rate. No species was completely unestablished warranting a fitness rating of zero.

Table 6. A plant fitness ranking scale was used to assess species establishment at RBR.

Rating	Description
0	Aquatic: No establishment Riparian: Dead
1	Aquatic: Minimal establishment (<5 individuals) with minimal spread, growth (0-2 linear ft per plant), and general lack of phenological variation. Riparian: Lack of growth, severe disturbance. Generally, <40% mean survival. Requires additional establishment efforts.
2	Aquatic: Moderate establishment (>5 individuals), moderate spread (2-5 linear ft per plant), exhibiting phenological variations and propagule production. Riparian: Establishment and minimal or <1 ft growth, minimal disturbances. Generally, >40% mean survival. May require additional establishment efforts.
3	Aquatic: Fully established, spreading (>5 linear ft per plant), reproducing and a permanent member of ecosystem function. Riparian: Establishment, significant or >1 ft growth, no disturbances. Generally, >70% mean survival. Requires no additional establishment efforts.

Table 7. Aquatic and riparian vegetation mean percent survival, max spread, and fitness rating.

Common Name	Scientific Name	% Survival Mean	Max Spread (linear ft along shoreline)	Fitness
Aquatic/Emergent				
Herb of grace	*Bacopa monnieri*	100	5	3
Creeping burhead	*Echinodorus cordifolius*	30	3	2
Squarestem spikerush	*Eleocharis quadrangulata*	60	2	2
Water mudplantain	*Heteranthera dubia*	100	15	3
American water-willow	*Justicia americana*	45	3	2
Bigfoot waterclover	*Marsilea macropoda*	30	2	1
Yellow waterlily	*Nymphaea mexicana*	100	20	3
American white waterlily	*Nymphaea odorata*	100	30	3
Longleaf pondweed	*Potamogeton nodosus*	100	125	3
Delta arrowhead	*Sagittaria platyphylla*	50	4	2
California bulrush	*Schoenoplectus californicus*	90	3	2
Common threesquare	*Schoenoplectus pungens*	45	3	1
Softstem bulrush	*Schoenoplectus tabernaemontani*	90	5	2
Riparian- trees, shrubs, vines				
Twisted acacia	*Acacia schaffneri*	70		3
Whitebrush	*Aloysia gratissima*	70		3
Sugarberry	*Celtis laevigata*	85		3
Spiny hackberry	*Celtis pallida*	90		3
Hog plum	*Colubrina texensis*	30		1
Brazilian bluewood	*Condalia hookeri*	35		1
Anacahuita	*Cordia boissieri*	80		2

Common Name	Scientific Name	% Survival Mean	Max Spread (linear ft along shoreline)	Fitness
Texas persimmon	*Diospyros texana*	80		2
Knockaway	*Ehretia anacua*	65		2
Mexican holdback	*Erythrostemon mexicana*	95		3
Texas Lignum-vitae	*Guaiacum angustifolium*	75		2
Tenaza	*Havardia pallens*	50		2
Mexican ash	*Fraxinus berlandieriana*	85		3
Jerusalem thorn	*Parkinsonia aculeata*	80		2
Texas ebony	*Pithocellobium ebano*	85		3
Texas sabal palm	*Sabal mexicana*	95		3
Guajillo	*Senegalia berlandieri*	60		2
Catclaw acacia	*Senegalia greggii*	75		2
Montezuma bald cypress	*Taxodium mucronatum*	80		3
Sweet acacia	*Vachellia farnesiana*	95		3
Blackbrush acacia	*Vachellia rigidula*	40		1
Lotebush	*Ziziphus obtusifolia*	45		2
Riparian herbaceous				
Slender grama	*Bouteloua repens*	60		2
Green sprangletop	*Leptochloa dubia*	60		2
Vine mesquite	*Panicum obtusum*	50		1
Turkey tangle fogfruit	*Phyla nodiflora*	60		3
Southwestern bristlegrass	*Setaria scheelei*	25		1
White tridens	*Tridens albescens*	20		1

3.2 Monitoring and adaptive management

The first site assessment occurred 01 May 2019, following the January 2019 seeding and April 2019 woody planting. Six of the seeded native species were observed along with some desirable volunteer vegetation (e.g., cowpen daisy) (Figure 13) and some less than desirable vegetation (goosefoots and annual sunflowers). Minimal herbivory (estimated at 1% or less) was observed on woody transplants throughout the site (Figure 13). Appendix E provides detailed photograph examples of woody plantings. Due to this and the short duration since planting, survival was near 100%. Mowing was prohibited in several areas at that time because some native vegetation was flowering and needed to go to seed before mowing. Annual sunflowers were also culled by hand to allow for better establishment of desirable species. In addition to grasses and forbs, Chinese tallow seedlings were observed and designated for treatment during this assessment.

Figure 13. First site assessment (1 May 2019); *top left* – successful seeding; *top-right* – cowpen daisy; *bottom left*–woody species planted, Mexican Ash; *bottom right* –Texas lignum-vitae.

A second site assessment occurred 28 May 2019. Transplant survival was estimated at approximately 95% with minimal herbivory observed.

Smaller transplants appeared more successful than larger transplants. Most previously seeded native herbaceous vegetation had gone to seed (Figure 14), whereas remaining aggressive annual sunflowers had just begun flowering. Therefore, the project-site first mow was scheduled for late June at an appropriate height to minimize damage to shorter, desirable species, reduce annual sunflower seed production, and promote native grass spread in the following growing season. Other native volunteer wildflowers were observed in the seeded area, including Mexican hat and plains coreopsis. A volunteer wetland vegetation fringe dominated by native volunteers was observed to be developing between the silt fence and shoreline (Figure 15) and was designated as a no-mow area.

Figure 14. *Left* – showing growth of seeding, and *right* – planted Montezuma cypress, 28 May 2019.

Figure 15. Wetland fringe developing within silt fence in no-mow designated area.

Additional nuisance species management during construction included development of a schedule and prescribed areas for mowing seeded areas. Mowing such areas contributed to reducing the establishment of undesirable forbs and grasses, thereby promoting the establishment of seeded and volunteer desirable species. By targeting growth of tall, aggressive annual species (annual sunflowers, for example), unfavorable populations can be reduced, freeing niche space for more diverse, native species. Once established, the native community demonstrated a higher resistance to reinvasion by unwanted forbs. Some areas were designated as no-mow zones to prevent damage to areas in which plantings had been conducted following removal of invasive trees, while areas that would be mowed were determined on an “as-needed” basis (Figure 16). For the first mow, newly (May 2019) seeded areas in the truck irrigation pathway were avoided to permit establishment. Other locations were designated as no-mow to permit native vegetation still in flowering stages to go to seed. Invasive guineagrass (*Urochloa maximus*) was observed in some areas at that time.

The next assessment occurred on 17 July 2019, in which woody vegetation transplant survival remained around 90% with minimal herbivory observed (Figure 17). As in the earlier assessment, smaller transplants continued to be more successful than larger transplants (lowest mortality observed in smaller, younger, and 1-year-old transplants). Other observations included measurable above-ground growth in certain species, such as Montezuma cypress, acacias, ebony, hackberries, and Mexican Poinciana. The post-seeded truck irrigation path exhibited poor establishment from seed in a few areas. Guineagrass had moderately expanded in no-mow areas to an estimated 15% coverage and occasional Brazilian peppertree and Chinese tallow seedlings occurred in small numbers and were scheduled for later treatment (Figure 17).

Figure 16. Map showing area with no-mow locations and the invasive guineagrass.

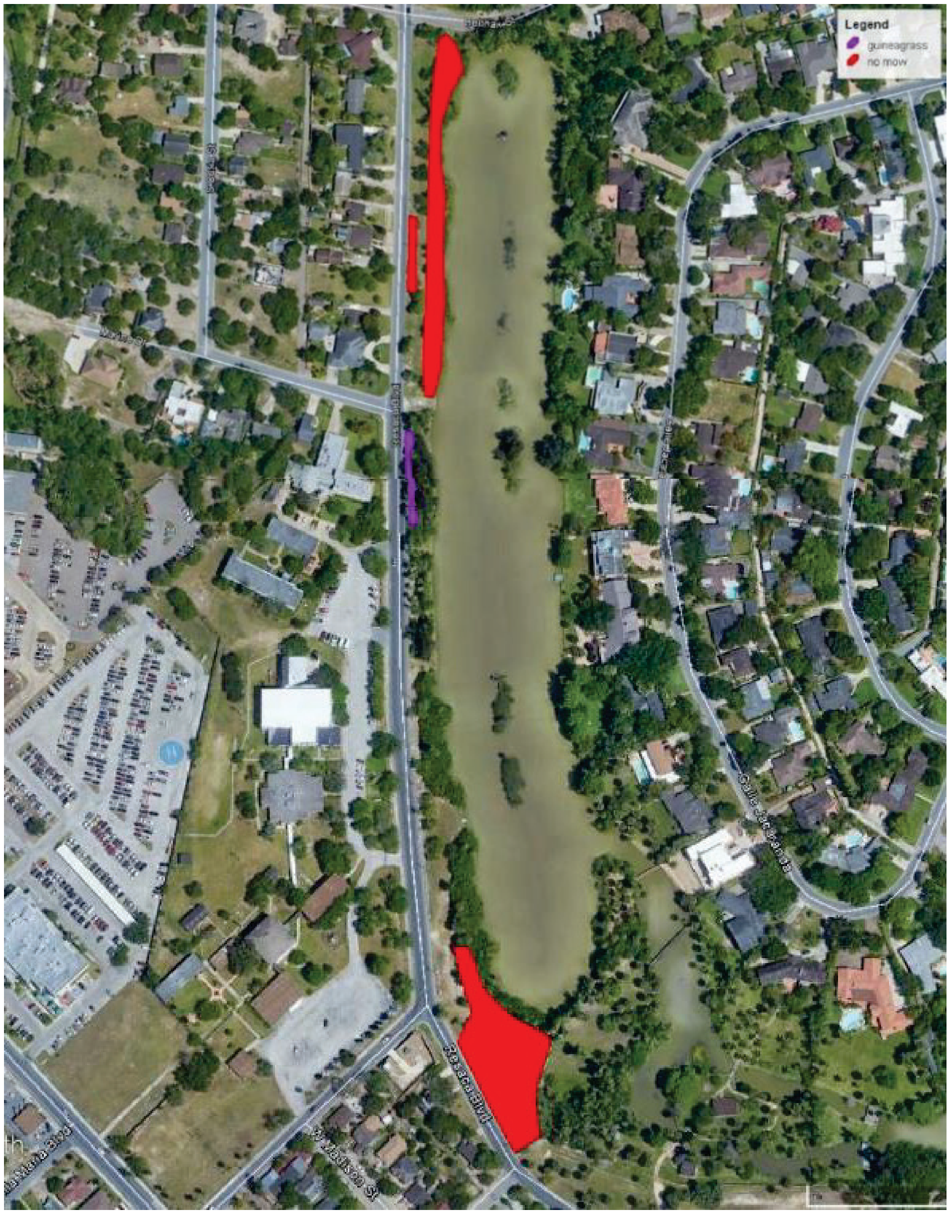


Figure 17. July 2019: *top left* – acacia transplant; *top right* – Mexican holdback transplant; *bottom left* – invasive guineagrass; and *bottom right* – invasive Brazilian peppertree regrowth.

The first mow versus non-mow areas was assessed and appeared to be successful by the contractor (Figure 18). Thirteen species from the seeding efforts were observed (Table 8) and ground coverage was >80%. Some remaining annual sunflowers had gone to seed and occurred at their highest density in the north planting area. Annual plant senescence was expected to reduce the "eye-sore" issue raised by some residents. After going to seed, any contractor efforts to remove standing vegetation would be for general aesthetics and would not contribute to control in subsequent growing seasons. Targeted mowing prior to seeding to continue management that promotes other native perennial species was a better use of resources to meet project goals, and to reduce sunflower populations over time.

Figure 18. *Left* – mow, and *right* – no-mow zones, 17 July 2019.

Table 8. Site visit on 17 July 2019 observed 13 species (bolded) from the previous year's seeding mix planting conducted from May 2018.

Common Name	Scientific Name	Percent (%) of 20 lb Total Per Acre Mix
Hairy grama	***Bouteloua hirsuta***	5
Slender grama	***Bouteloua repens***	5
Hooded windmillgrass	***Chloris cucullata***	5
Shortspike windmillgrass	***Chloris subdolistachya***	5
Wand-like bundleflower	***Desmanthus virgatus***	2
Canada wildrye	*Elymus canadensis*	15
Green sprangletop	***Leptochloa dubia***	5
Hall's panicgrass	*Panicum hallii*	5
Switchgrass	*Panicum virgatum*	5
Whiplash pappusgrass	***Pappophorum bicolor***	5
Rio Grande clammyweed	***Polanisia dodecandra spp. Riograndensis***	1
Plains bristlegrass	***Setaria leucopila***	15
Little bluestem	*Shizacyrium scoparium*	5
Awnless bush sunflower	***Simsia calva***	1
False rhodesgrass	***Trichloris crinita***	5
Multiflower false rhodesgrass	***Trichloris pluriflora***	15
Orange zexmania	***Wedelia hispida***	1
Total		100

Aquatic plantings, in addition to general site conditions and other vegetation community developments, were assessed monthly from October 2019–February 2020. Throughout, minimal, if any, herbivory was observed on SAV founder colony sites. This was surprising due to the potential existing herbivores, including nutria, backing turtles, and armored catfish, but fortunate as sites would successfully serve as propagule sources for wetland-wide spread. This was first observed as early as 29 October 2019 (Figure 19). Emergent vegetation was also observed to be successfully established; bulrushes, spikerushes, delta arrowhead, and water hyssop being the most successful species. Appendix D provides aquatic vegetation photographs throughout the project.

Figure 19. Emergent and aquatic vegetation condition–October 2019, *left* - delta arrowhead; *right* – American white waterlily.

In October 2019, seeded areas were again thriving (Figure 20), but scattered woody invasives remained an issue. Thus, a priority on subsequent site visits was the coordination of retreatments of invasive species seedlings with the contractor. Continued removal of invasive species provides space for establishing native plant communities, which in turn reduces the ability of invasive species to recover. Another assessment occurred on the 13 November 2019 with onsite observations of various invasive species (Brazilian peppertree, Chinese tallow, Chinaberry tree, and river tamarind). They were identified and flagged for contractor removal/retreatment (Figure 21). Approximately 50 invasive Chinese tallow seedlings marked for removal were sparsely located throughout site, but denser in the north section. Other observations during this time included occurrences of native woody plant recruitment in no-mow areas, including willows and retama. Aquatic plant establishment was successfully progressing with minimal herbivory observed. Unauthorized public disposal of excess brush was found onsite, in which the contractor was informed to facilitate its removal.

Figure 20. Native seeding condition as of 1 October 2019.

Figure 21. Invasive species respouting; marked for removal.

The next assessment was completed on 04 December 2019. It was determined the central area needed to be reseeded by a contractor and planted with additional containerized plants by ERDC-EL-LAERF team by January 2020 due to the previous irrigation path, which had resulted in a few bare areas. The north no-mow seeded area supported wildflowers and the south no-mow area exhibited native grass seed cover (Figure 22).

Previously planted containerized plants were highly productive and required no further management actions at that time. Other observations indicated successful establishment of native aquatic plants, as evidenced by spread of American pondweed and American whitewater lily planted on 10 September 2019. In the aquatic no-mow riparian zone, a volunteer sedge community was developing and planted softstem bulrush was seeding (Figure 22). It appeared that herbivores were inhibiting potential nuisance cattails but were not yet causing substantial damage to desirable plant species.

Figure 22. Plant observations during 4 December 2019 site visit: *left* – seeding development and *right* – softstem bulrush showing seeding.

A follow-up woody planting occurred on 10 January 2020 and involved a site-wide planting that included installation of 12 plant species totaling 800 plants (Table 9). Containerized plantings were flagged (Figure 23), while bare areas in the north site that had been reseeded by the contractor were included in the planting area. The contractor completed spot-treatment of Brazilian peppertree and Chinese tallow and removed treated biomass by this time. ERDC-EL-LAERF requested mowing cease following this effort to avoid damage to planted trees and shrubs. In coordination with COB and BPUB, ERDC-EL-LAERF continued monitoring vegetation community development and provided recommendations for any management needs through 2020.

Table 9. Species planted 10 January 2020.

Common Name	Scientific Name
Whitebrush	*Aloysia gratissima*
Sugarberry	*Celtis laevigata*
Spiny hackberry	*Celtis pallida*
Hog plum	*Colubrina texensis*
Mexican olive	*Cordia boissieri*
Texas persimmon	*Diospyros texana*
Texas ebony	*Ebenopsis ebano*
Anacua	*Ehretia anacua*
Tenaza	*Havardia pallens*
Rio Grande palmetto	*Sabal mexicana*
Montezuma cypress	*Taxodium mucronatum*
Cedar elm	*Ulmus crassifolia*

Figure 23. Plantings, 10 January 2020: *left* – transplants and *right* – flagged area.

The next assessment occurred in February 2020. Submersed and floating-leaved species protected by exclosures exhibited high survival and showed signs of spread outside of protected areas. Colonies of planted emergent and desirable volunteer species had expanded, dominated by bulrushes and sedges. Containerized plantings (2019) in other areas were also exhibiting good survival and growth, including Texas ebony, Mexican poinciana, and Mexican olive plants. Due to travel restrictions by the 2020 pandemic, the site was not assessed again until August 2020. As illustrated in Figure 24 and Appendix D, most of the planted vegetation, especially aquatics, were spreading and thriving. However, additional nuisance woody plants were observed to be recruiting at that time, including a few Brazilian peppertree, Chinese tallow, and Chinaberry trees. Woody vegetation survival of the previous two plantings was approximately 65%. Being that the project would be turned over from the Federal to the non-Federal sponsor at the end of the 2020 and the contractor was off-site already, ERDC-EL-LAERF made arrangements to accomplish to adaptive management activities prior to project handoff: (1) treatment of all existing woody vegetation saplings observed and (2) supplemental woody vegetation planting throughout the project site.

Figure 24. August 2020: aquatic and emergent vegetation spread.

The final ERDC-EL-LAERF planting occurred in November 2020 and involved a site-wide supplemental / adaptive management planting that included installation of 17 plant species totaling 700 plants. Species planted included anacua, Texas lignum-vitae, catclaw acacia, sabal palm, Mexican holdback, milkweeds, whitebrush, lotebush, Mexican olive, blackbrush acacia, spiny hackberry, Texas ebony, Brazilian bluewood, Texas persimmon, Montezuma cypress, and guajillo (Figure 25). During this time, site conditions were also assessed. SAV founder colony sites were functioning as planned and the most successful woody vegetation remained was anacua, Mexican holdback, Montezuma cypress, Mexican olive, Mexican ash, acacias, sabal palms, hackberries, cedar elms, Texas persimmons, and whitebrush (Appendices D and E).

Figure 25. Transplant examples from November 2020 adaptive management supplemental planting: *left* – Montezuma cypress and *right* – anacua.

In December 2020, two primary activities occurred. First, an on-site training by ERDC-EL-LAERF biologists to COB and BPUB for perpetual operations and maintenance purposes. Second, remaining flagged invasive vegetation, including Brazilian peppertree, Chinese tallow, and Chinaberry, was herbicide treated for successful project turnover.

4 Discussion

4.1 Adaptive management

Adaptive management is a strategy commonly applied to ecosystem restoration practices where environmental conditions are uncertain and there is a need for innovative approaches to meet project goals (Stankey et al. 2005). Information acquired during monitoring throughout the project was used to direct subsequent nuisance plant management and planting efforts. This determined any need to alter management strategies, with primary focus on native plant community development. The plan involved active manipulation (as needed) to sustain project goals and objectives, primarily by applying an iterative process of assessing and learning from the results of management actions. The application of adaptive management principals in this project provided decision support tools to address site changes that occurred as the project progressed, as well as integrated additional project resources or technologies as needed.

Mowing activities were directed by vegetation community status; where undesirable species were managed with minimum damage to native vegetation, mowing was prescribed within a narrow timeframe and area to improve performance of both objectives. Another prominent example is seen in determination of the need to protect aquatic plantings from herbivores. Evidence from initial plantings suggested that most of these species do not require protection in this system, enabling reallocating of resources from exclosure construction and installation to producing and installing more plants to hasten the process of site-wide establishment. Likewise, initial planting survival data directed reallocation of resources such as modifying species selection for plantings based upon successes and failure of earlier plantings. This approach was used to meet project goals as defined by tree, shrub, vine, and herbaceous plant establishment combined with nuisance plant control. As part of adaptive management, replacement plantings were made in 2020 following first year plantings (2019) to ensure project goals were met. Those final plantings followed guidelines informed by earlier plantings.

All initial nuisance vegetation control—herbicide and removal—was accomplished by the contractor SAMES in 2018 and early 2019. This included a follow-up treatment of saplings in late 2019. However, after the contractor was off the site, and during the adaptive management phase beginning in 2020, there were still nuisance vegetation germination observed at the site. ERDC-EL-LAERF reallocated resources and selectively controlled these small, new infestations of Chinese tallow, Chinaberry, Brazilian peppertree, and river tamarind according to O&M specifications before project turnover to the non-Federal sponsor. Although treatments like this are expected throughout the O&M phase, accomplishing the task before project turnover and annually throughout O&M supports project goal trajectories.

4.2 Operations and maintenance

The successful functioning of an ecosystem restoration project is not assured by mere construction of engineered riparian and wetland features. If the system is to function properly over a period of years, it must be carefully maintained to ensure the desirable vegetation succeeds, invasive species are controlled or excluded, and recreation features are functional for the long term. Proper maintenance and operation require responsible ownership personnel—here, COB—have a thorough understanding of the functions of the various units of the system and the knowledge of best methods of maintaining and operating the system. With this purpose in mind, ERDC-EL-LAERF assisted in the production of an OMRR&R Manual at the conclusion of this project to describe techniques used to establish and manage native vegetation, techniques used to control nuisance vegetation, and other techniques applied to the project pertinent for long-term integrity of the vegetation community. Methods recommended for monitoring and evaluations were included in the manual, as were predictable management responses to unfavorable changes in the vegetation communities.

Weed management within the restoration planting area is the primary O&M activity. Weeds in the restoration plantings are defined as any plant species identified as non-native to the project area. Additionally, some aggressive native species will potentially require management to meet the goals of the restoration plantings. These plants are problematic for the site because they can spread rapidly in the site, creating a monotypic plant community, outcompeting and reducing native species diversity and coverage. Because woody vegetation is the primary invasive species target, cut-stump treatments and/or foliar application herbicides is the preferred method of weed control at RBR. During O&M, all non-native volunteer woody plants will be targeted for removal by the non-Federal sponsor.

COB will always use the most appropriate chemical herbicide and equipment for the task and follow directions on the product label.

A team comprised of a COB staff POC and USACE ecologist and engineer will survey the RBR project annually to assess the encroachment of invasive species and native species diversity/evenness of the vegetation within the project area. The team will ensure the vegetation community is meeting project ecological goals. Management measures will be determined to address any issues using the following guidance.

Mowing or mechanical plant removal is not expected necessary on a regular basis as the entire project area is considered a “grow-zone” (Figure 26). However, targeting growth of tall, aggressive annual species and other unfavorable populations, such as guineagrass can free niche space for native species. This can be coordinated and approved by USACE biologists. Additionally, it is appropriate for the non-Federal sponsor to maintain mowed buffer areas (5 ft) from the road/curb and maintenance path. Herbaceous invasives, such as guineagrass, buffelgrass, KR bluestem, etc. must be culled when coverage is >25% for a 0.25-acre area. An integrated pest management methodology consisting of chemical, mechanical, or hand treatments may be appropriate.

Figure 26. Grow zone signage at RBR.

Wetlands should be monitored for sediment accumulation every five years; nuisance species presence and extent, implement control as needed; native plant community status annually, conduct replantings or other management strategy as needed; founder colony / herbivore protective exclosures annually for functionality, removal, and/or theft. All areas at RBR have been planted with woody, emergent wetland, and aquatic native vegetation. However, areas of the project may require remedial planting to achieve the project goals. Areas will be prioritized on an annual basis during monitoring and replanting will be completed as possible based on resource availability, timing, expected climate conditions and other factors. Specific annual monitoring tasks include the monitoring of planting survival and overall vegetation community; installation of native vegetation in target areas using previously scoped specifications when mortality in restoration plots is >50%, bare area in wetlands is >75% within proximity of founder colonies, or coverage of other locations in the project footprint experience bare areas devoid of beneficial vegetation >50%.

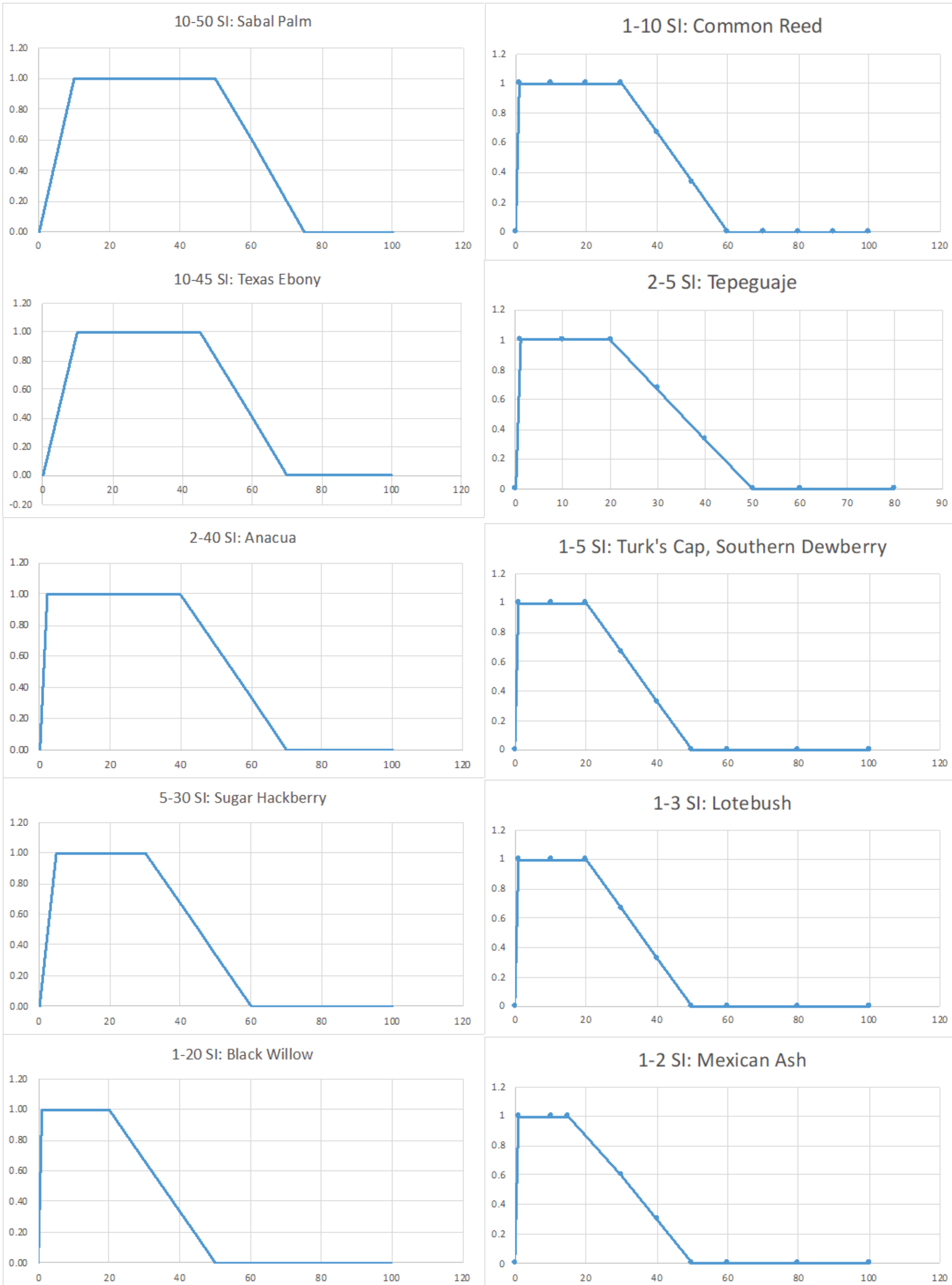
The adaptive management techniques and ERDC-EL-LAERF annual vegetation establishment status reports should be used as guides to replace lost plants with species proving suitable and successful at particular locations based upon physical/environmental factors such as open canopy and elevation. Establish woody and herbaceous non-aquatic vegetation during dormant season (December-February); aquatic vegetation can be installed throughout the calendar year. Overall community structure (coverage and diversity) of the native plant community should adhere to the goals listed in Table 10, and Figure 27.

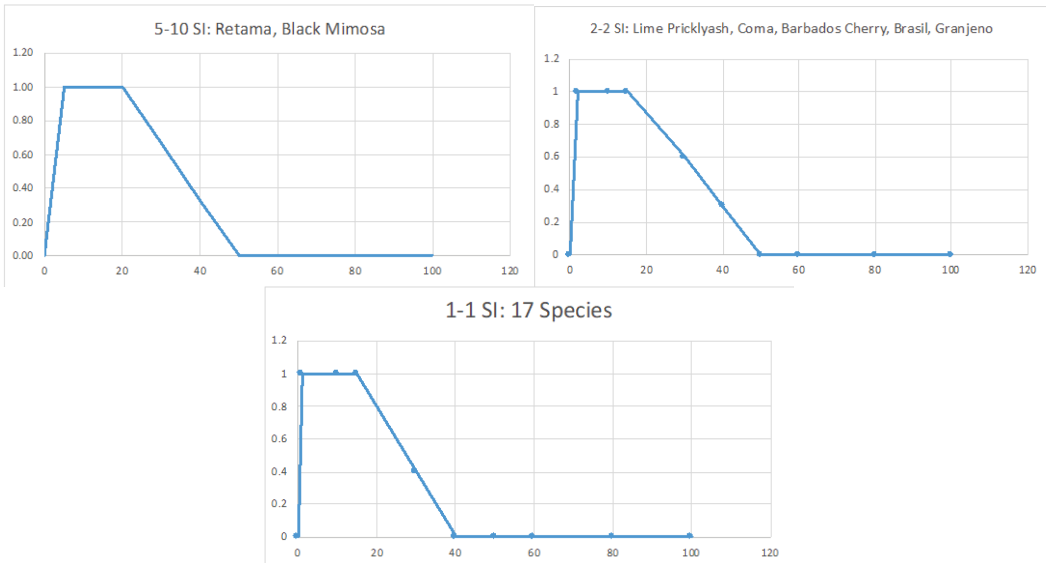
Table 10. Target native community.

Species	Minimum Ideal Coverage (% per area)	Maximum Ideal Coverage (% per area)
Abutilon trisculatum	1	1
Acacia smallii (minuata)	1	1
Cardiospermum halicacabum	1	1
Celtis laevigata	5	30
Celtis pallida	2	2
Chiococca alba	1	5
Cissus trifoliata	1	1
Cocculus diversifolius	1	1

Species	Minimum Ideal Coverage (% per area)	Maximum Ideal Coverage (% per area)
Condalia hookeri	2	2
Cyperus odoratus	1	1
Ehretia anacua	2	40
Eupatorium odoratum	1	1
Fraxinus berlandieriana	1	2
Havardia pallens	1	1
Leucaena pulverulenta	2	5
Ludwigia octovalvis	1	1
Malpighia glabra	2	2
Malvaviscus arboreus	1	5
Mimosa pigra (asperata)	5	10
Nekemias arborea	1	1
Parkinsonia aculeata	5	10
Phaulothamnus spinescens	1	1
Phragmites australis	1	10
Pithocellobium ebano	10	45
Polygonum hydropiperoides	1	1
Prosopis glandulosa	1	1
Rivina humilis	1	1
Rubus trivialis	1	5
Sabal mexicana	10	50
Salix nigra	1	20
Sideroxylon celastrinum	2	2
Solanum triquetrum	1	1
Tillandsia usenoides	1	1
Ulmus crassifolia	1	1
Zanthoxylum fagara	2	2
Ziziphus obtusifolia	1	3

Figure 27. Individual coverage goals at RBR for dominant species; *x*-axis = percent coverage, *y*-axis = habitat suitability index or HSI.





4.3 Future outlooks

In 2019, the US Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) approved the use of the Brazilian peppertree thrips (*Pseudophilothrips ichini*) as a biocontrol agent for Brazilian peppertree in the contiguous US (Meszaros 2019).* Biological control is the application of host-specific predators/herbivores or pathogens that suppress the target species with no direct impacts on non-target species. Biological controls are sustainable and often require less follow-up management than other nuisance plant management technologies. Although establishment of biological control agent populations may benefit from follow-up releases and maintenance, once established, many agents are able to build their populations and integrate into the ecosystem, providing long-term, cost-effective benefits. In many cases, biological control can be incorporated into integrated pest management (IPM) strategies, such as those that apply herbicides for initial control followed by native vegetation restoration plantings. Biological control may provide an added benefit due to agent dispersal outside of release areas, potentially reducing existing or recruiting populations of targeted species. The thrips naturally occur throughout the native range of Brazilian peppertree and has undergone extensive dietary host range studies in quarantine to ensure safety to beneficial native plant species. Studies have shown that Brazilian peppertree thrips selectively

* https://www.aphis.usda.gov/aphis/ourfocus/planthealth/import-information/permits/regulated-organism-and-soil-permits

choose the Brazilian peppertree as their primary host and are effective at reducing growth rates, height, and number of green stems (Prade et al. 2019). ERDC, BPUB, and other collaborators are evaluating the use of these thrips in the RBR restoration project as an adaptive management O&M strategy as well as analogous future projects in similarly infested resaca systems. The USACE ERDC Aquatic Plant Control and Ecosystem Management and Restoration Research Programs (APCRP and EMRRP) are funding these efforts (2020–2025) through a work unit entitled "Applying biological control for invasive weed management in USACE Environmental Business Line/Program projects: A Best Practices Framework and Case Study."

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Appendix A: Transplant Examples

Figure A-1. Propagation of Montezuma cypress (*Taxodium mucronatum*) at the Lewisville Aquatic Ecosystem Research Facility (LAERF) for resaca restoration plantings.

Figure A-2. Other woody native plant propagation efforts at LAERF for resaca restoration

Figure A-3. Larger transplant example, sugarberry, grown at LAERF for resaca restoration.

Appendix B: Invasive Species Removal

Figure B-1. Manual cutting of Brazilian peppertree (BPT) stumps before herbicide (triclopyr) application.

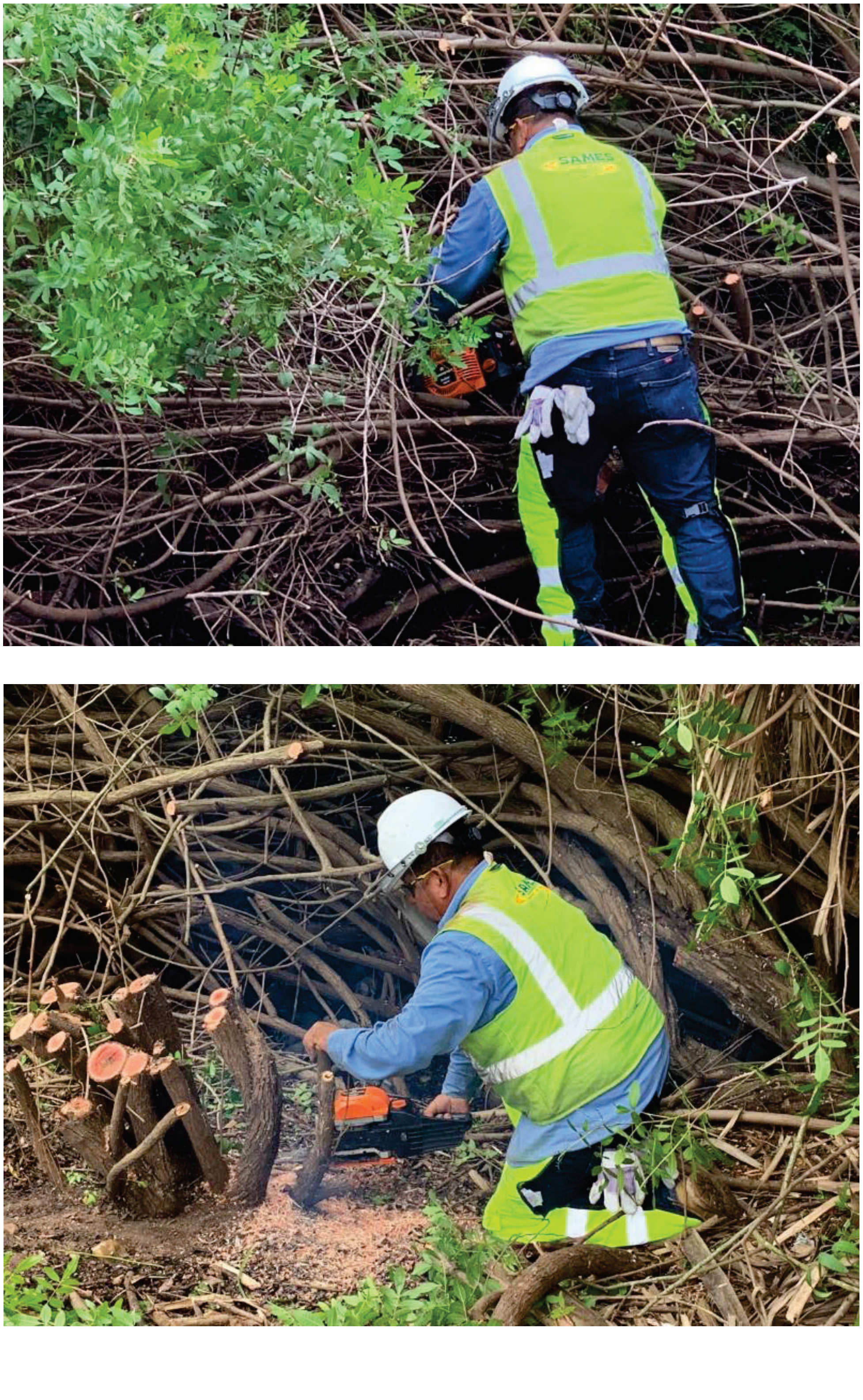

Figure B-2. Brazilian peppertree (BPT) stump-cut herbicide (triclopyr) application.

Figure B-3. Creating snag habitat from nonnative palms by herbicide injection

Figure B-4. Physical biomass removal of cut invasive species.

Figure B-5. Example of removing BPT around native vegetation (willows).

Figure B-6. Project site post-invasive species management and preplanting; looking north from the south end of the project area.

Appendix C: On-Site Native and Non-Native Plant Identification

C.1 Non-natives

Figure C-1. Brazilian peppertree (*Schinus terebinthifolia*).

Figure C-2. Buffelgrass (*Pennisetum ciliare*).

Figure C-3. Chinaberry (*Melia azedarach*).

Figure C-4. Chinese Tallow (*Triadica sebifera*).

Figure C-5. Guineagrass (*Urochloa maximus*).

Figure C-6. River tamarind or white leadtree (*Leucaena leucocephala*).

Figure C-7. Australian pine (*Pinus nigra*).

C.2 Natives

Figure C-8. American Pondweed (*Potamogeton nodosus*).

Figure C-9. Marsh fleabane (*Pluchea odorata*).

Figure C-10. Anacua (*Ehretia anacua*).

Figure C-11. Black Willow (*Salix nigra*).

Figure C-12. Brasil (*Condalia hookeri*).

Figure C-13. Hooded windmill grass (*Chloris cucullate*).

Figure C-14. Mesquite (*Panicum obtusum*).

Figure C-15. Tropical milkweed (*Asclepias curassavica*).

Figure C-16. Mexican ash (*Fraxinus berlandieriana*).

Figure C-17. Mexican hat (*Kalanchoe daigremontiana*).

Figure C-18. Mexican olive (*Cordia boissieri*).

Figure C-19. Mexican poinciana (*Caesalpinia pulcherrima*).

Figure C-20. Mexican waterlily (*Nymphaea mexicana*).

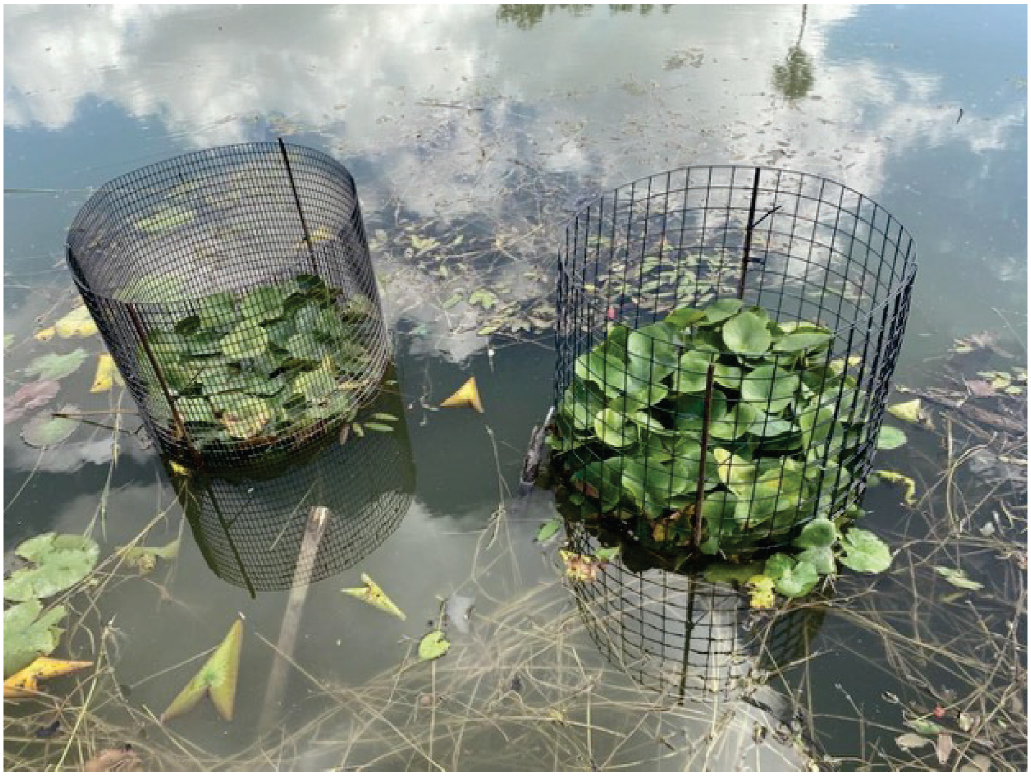

Figure C-21. Cattails (*Typha latifolia*).

Figure C-22. Montezuma cypress (*Taxodium mucronatum*).

Figure C-23. Palo verde (*Parkinsonia aculeata*).

Figure C-24. Common reed (*Phragmites australis*).

Figure C-25. Sabal palm (*Sabal mexicana*).

Figure C-26. Softstem bulrush (*Schoenoplectus tabernaemontani*).

Figure C-27. Spiny hackberry (*Celtis pallida*).

Figure C-28. Sugarberry (*Celtis laevigata*).

Figure C-29. Cowpen daisy (*Verbesina encelioides*).

Figure C-30. Sweet acacia (*Vachellia farnesiana*).

Figure C-31. Tenaza (*Havardia pallens*).

Figure C-32. American white waterlily (*Nymphaea odorata*).

Figure C-33. Texas ebony (*Pithocellobium ebano*).

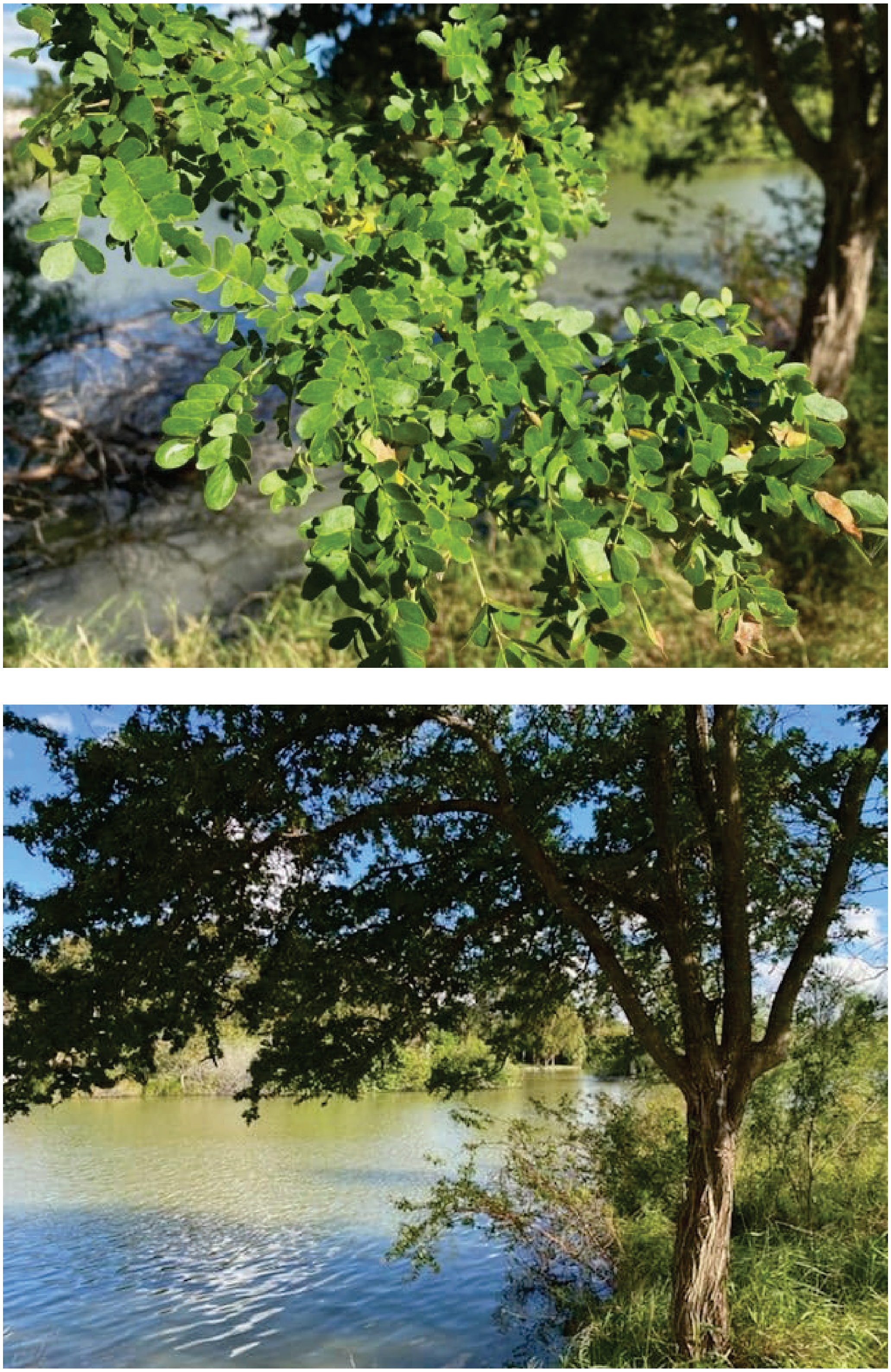

Figure C-34. Texas persimmon (*Diospyros texana*).

Figure C-35. Seeded Rio Grande clammyweed (*Polanisia dodecandra spp. Riograndensis*).

Figure C-36. Seeded green sprangletop (*Leptochloa dubia*).

Figure C-37. Texas palafox (*Palafoxia texana*).

Figure C-38. Seeded Shortspike windmill grass (*Chloris subdolistachya*).

Figure C-39. Seeded hooded windmill grass (*Chloris cucullate*).

Figure C-40. Seeded (*Tricholris sp.*).

Figure C-41. Annual sunflower (*Helianthus annuus*).

Figure C-42. American Water-willow (*Justicia Americana*).

Figure C-43. Creeping burhead (*Echinodorus cordifolius*).

Figure C-44. Squarestem spikerush (*Eleocharis quadrangulata*).

Figure C-45. Delta arrowhead (*Sagittaria platyphylla*).

Appendix D: SAV Establishment

Figure D-1. Native submerged aquatic vegetation established at project site.

Figure D-2. Native submerged aquatic vegetation established at project site.

Figure D-3. Native submerged aquatic vegetation established at project site, showing extensive spread from herbivore cages.

Appendix E: Woody Planting Examples

Figure E-1. Planted twisted acacia (*Acacia schaffneri*).

Figure E-2. Mexican ash (*Fraxinus berlandieriana*).

Figure E-3. Spiny hackberry (*Celtis pallida*).

Figure E-4. Planted sugarberry (*Celtis laevigata*).

Figure E-5. Planted Montezuma cypress (*Taxodium mucronatum*).

Figure E-6. Sabal palm (*Sabal mexicana*).

Figure E-7. Anacua (*Ehretia anacua*).

Figure E-8. Mexican olive (*Cordia boissieri*).

Figure E-9. Planted whitebrush (*Aloysia gratissima*).

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14. ABSTRACT
As part of the US Army Corps of Engineers (USACE) Continuing Authorities Program (CAP), Section 206 projects focus on restoring aquatic habitats for the benefit of fish and other wildlife. From 2017–2021, USACE Engineer Research and Development Center–Environmental Laboratory researchers in the Aquatic Ecology and Invasive Species Branch (ERDC-EL EEA) at the Lewisville Aquatic Ecosystem Research Facility (LAERF) collaborated with USACE Galveston District, The Nature Conservancy, US Fish and Wildlife Service, National Park Service, and local nonfederal sponsors—Brownsville (Texas) Public Utility Board and the City of Brownsville—to study restoration methods on former, naturally cut-off, channels of the Lower Rio Grande River. These aquatic ecosystems, locally termed "resacas," are home to endemic plants and animals and are thus an important natural resource of national interest. This technical report documents the planning, design, construction, monitoring, and adaptive management activities throughout the Resaca Boulevard Resaca Section 206 Aquatic Ecosystem Restoration project. Methods and results for invasive species management—primarily Brazilian peppertree (*Schinus terebinthfolia*)—and aquatic and riparian vegetation establishment in endemic Texas ebony resaca forest, subtropical Texas palmetto woodland, and Texas ebony/snake-eyes shrubland habitats are discussed.

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