Thornforest Conservation Plan

A Tool to Help Guide Habitat Protection and Restoration in the Lower Rio Grande Valley of Texas

Developed by the Thornforest Conservation Partnership

February 2020

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Support for analysis provided by the Jacob and Terese Hershey Foundation, James A. "Buddy" Davidson Foundation and Meadows Foundation.

Contents

Introduction

The Lower Rio Grande Valley (LRGV) in South Texas encompasses Cameron, Hidalgo, Starr and Willacy Counties and has a combination of climate, vegetation and associated wildlife that creates an ecosystem unlike any other in the United States. The Tamaulipan thornforest ecosystem is characterized by dense and diverse vegetation (Navar et al., 2004) that provides habitat for a stunning array of wildlife, including 10 federally threatened or endangered wildlife species, 530 bird species (58% of all species in North America can be found here), 300 butterfly species (40% of all species in North America), and 1,200 plant species that live within the region (Leslie, 2016).

Yet, Tamaulipan thornforest habitats are currently represented on less than 10% of their former range in the LRGV and occur primarily in scattered fragments. The ecoregion is recognized as a "hotspot" for conservation given its high biodiversity along with high human influence (Ricketts and Imhoff, 2003).

Despite strong resource planning on local national wildlife refuges and regional recreation-based planning, no comprehensive conservation plan exists to guide restoration and protection of LRGV thornforest habitat. A properly designed conservation plan can help prioritize the allocation of scarce resources to ensure that habitat protection and restoration occur in the most ecologically important places. Using resources strategically is even more important given the challenges to habitats posed by climate change, development and invasive species.

Purpose of the Thornforest Conservation Partnership

To meet these needs, the Thornforest Conservation Partnership (TCP) was formed in 2018 to jointly develop science-based plans and goals to guide conservation efforts in the LRGV, communicate the importance of thornforest habitat and conservation progress to the public, and encourage action for stronger public policies and funding. We are a coalition of state and federal agencies, universities, non-profit and community organizations working to restore thornforest habitat in the LRGV. Our existing mission objective is to facilitate conservation of the LRGV's thornforest ecosystem for the benefit of the region's endemic biodiversity.

Partners include: American Forests, U.S. Fish and Wildlife Service, Texas Parks and Wildlife Department, The Conservation Fund, The Nature Conservancy, Rio Grande Joint Venture, USDA-Natural Resources Conservation Service, Pharr-San Juan-Alamo-School District, The University of Texas-Rio Grande Valley, Texas A&M Forest Service and others.

Purpose of this Document

We have developed this document, the Thornforest Conservation Plan (plan), as a starting point to catalyze a coordinated, regional response to thornforest conservation. The plan identifies core areas of existing thornforest habitat, potential corridors that link habitats together, and potential habitat restoration opportunities across the four-county LRGV region with a 10 km buffer that extends into neighboring Texas counties and northeastern Mexico to reference additional thornforest habitat that could enhance connectivity with areas outside the region. As end-users, we expect that TCP stakeholders will incorporate this document's approach into

their individual, organizational directives for natural resource conservation within the LRGV. We also aim to facilitate adoption of the plan's objectives for maximum benefit by recommending it as a tool to help guide habitat protection and habitat restoration among the region's general public. To this end, private landowners and other interested groups should view this document as the beginning of a more detailed and sustained effort in habitat restoration guidance for the LRGV.

Within the context of this document, we define thornforest as all areas in the LRGV where the plant communities are dominated by native woody vegetation, including but not limited to: low desert scrub and shrublands, thorn forest/woodlands, mesquite pricklypear found on saline soils, dense coastal thornscrub, riparian forests along the Rio Grande, tributaries (e.g., resacas), and ramaderos, and Sabal palm groves.

The Importance of Thornforest Habitat

The Lower Rio Grande Valley (LRGV; Figure 1) is the fertile river delta of the Rio Grande River (e.g., most of Cameron, Hidalgo and Willacy Counties) and also includes a portion of adjacent uplands father from the recent delta in Starr County. The local Tamaulipan thornforest vegetation is characterized by dense and diverse brush that provides habitat for many wildlife species. This habitat type is truly unique to southern Texas and northeastern Mexico and is required for a diverse group of wildlife and plants:

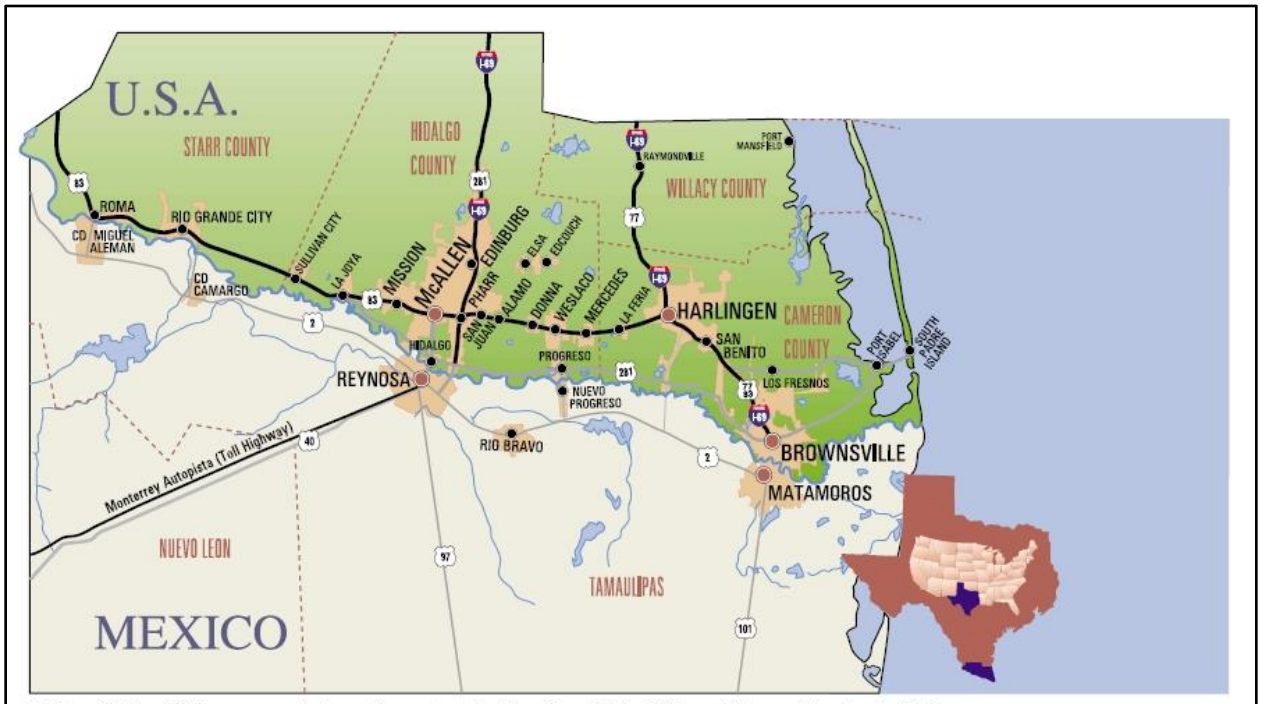
- 11 federally listed threatened or endangered wildlife species, including the ocelot, a small forest cat which has lost much of its native habitat in south Texas and surrounding states.
- 530 bird species, some reaching their northern limit in the LRGV and not found elsewhere in the U.S. The combination of both resident and neotropical migratory species make this a critical habitat for stopover and breeding ecology as well as a much-sought-after destination for visitors from around the world.
- 300 butterfly species, a number that encompasses approximately 40 percent of all butterfly species found in North America. The occurrence of many species is tied to the local presence of thornforest plant species which serve as hosts during larval development life stages. This area also includes crucial migratory habitat for dwindling numbers of monarch butterfly populations as they embark on their 2,000-mile migrations across North America.
- 1,200 plant species that live within the region, including six threatened and endangered plants. As in birds, many plants reach their northern distributional limit in south Texas, with endemism to the LRGV and neighboring regions of northeastern Mexico occurring in several species.

Thornforest was once extensive and covered most of the LRGV. Today, less than 10% of the original thornforest acreage remains, mostly on private ranches, in scattered protected areas, fence rows, highway rights-of-way, and canals. The conversion of thornforest to development and farms has had a great impact on the ecosystems of the LRGV. As wildlife habitat and migration corridors have been lost, wildlife populations have greatly diminished. For example,

there are only around 80 endangered ocelots remaining in the Valley. In Texas and northeastern Mexico, the ocelot is a Tamaulipan thornforest habitat specialist and its recovery depends on the success of habitat restoration and other conservation efforts.

The loss of intact thornforest forests has also degraded other important ecosystem functions such as the filtering of water quality pollutants, recharging of water supplies, carbon sequestration and replenishment and protection of soil.

Maintaining and restoring native thornforest is an economic development strategy as well. The remaining thornforest habitats draw in millions of birdwatchers each year to view migrations and regional specialties like the green jay (*Cyanocorax yncas*; Figure 2). In 2014, more than $340 million was generated in the LRGV from ecotourism alone (Woosnam et al., 2011).



The Lower Rio Grande Valley encompasses the four southernmost counties of Texas: Starr, Hidalgo, Willacy, and Cameron. Below them lies Mexico. (Map courtesy of Rio Grande Valley Partnership, Rio Grande Valley Chamber of Commerce.)

Figure 1. The Lower Rio Grande Valley

Figure 2. Green jay (Cyanocorax yncas) in thornforest vegetation at Laguna Atascosa NWR (photo: The Conservation Fund)

Conservation Planning in the Lower Rio Grande Valley

In the LRGV, the U.S. Fish & Wildlife Service (USFWS) manages three national wildlife refuges (Laguna Atascosa, Lower Rio Grande Valley and Santa Ana) jointly as the South Texas Refuge Complex (STRC). The complex manages over 200,000 acres of some of the most important remaining thornforest patches in the LRGV. The STRC also manages a restoration program that reforests cropland and disturbed areas with a dense and diverse mix of thornforest species. Since 1986, the refuge has planted 12,750 acres of native trees. More work remains by agencies and conservation groups to ensure these and other restoration actions result in mature, functioning habitat.

The STRC has developed six conceptual wildlife corridor areas to focus their conservation efforts: Ranchland, North, Coastal, Ranchito, Boca Chica, and River (Figure 4). These corridors were identified by the USFWS' Comprehensive Conservation Plan (CCP) for Laguna Atascosa NWR (USFWS 2010), and in general in the CCP for Santa Ana NWR and Lower Rio Grande Valley NWR (USFWS 1997).

Increasingly, the USFWS is focusing protection and restoration efforts in areas used by ocelots located in the North, Ranchland and Coastal Corridors. There are no known ocelots using the River Corridor as it is still a patchwork of intensive farming, sprawling development, border security areas, and protected lands. Restoration along the river should not be understated though, since it provides benefits to resident and migratory birds, plants, and watershed health, as well as economic and health benefits for communities.

Any conservation actions will need to be planned and implemented with care to not cause unintended consequences for species like the ocelot. For example, restoring corridors in the

coastal region of the LRGV could inadvertently cause ocelot to enter developed areas where they are at risk for car collisions and other threats.

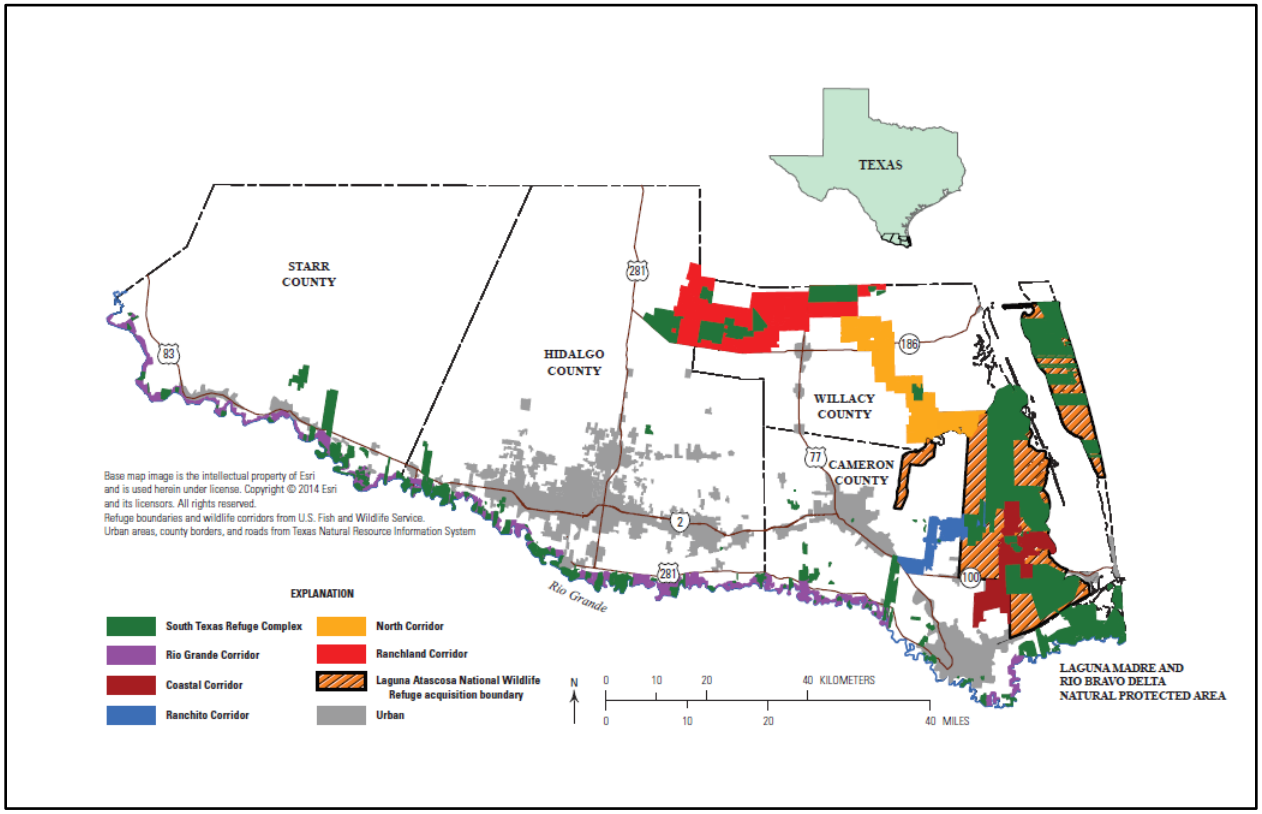


Figure 3. South Texas Refuge Complex (STRC) proposed corridors

Thornforest Conservation Plan Overview

The Thornforest Conservation Plan was developed using a green infrastructure approach. Much like how roads, utilities and other gray infrastructure provide the foundation for communities to thrive, green infrastructure like large blocks of forest, streams, and resacas are the foundation for wildlife habitat, clean water, air and other natural benefits.

At landscape scales, green infrastructure analysis and design is based on principles of conservation biology and landscape ecology. The goal is to reduce habitat fragmentation, maintain viable populations of native species, preserve interior habitat, and improve resiliency from disturbances and climate change.

The basic building blocks of the green infrastructure network include core areas and corridors.

Core Areas

Core areas contain fully-functioning natural ecosystems and provide high-quality habitat for native plants and animals. They can serve as sources for emigration into the surrounding landscape, as well as provide other ecosystem services like clean water, clean air, carbon sequestration, and recreational opportunities to nearby communities.

Corridors

Corridors are generally linear features, although still wide enough to provide adequate cover, that link core habitats together through an unsuitable matrix like row crops or development and which allow animal and plant movement between them. Retaining connectivity can help to mitigate habitat fragmentation and enhance recruitment by linking otherwise separated populations within discrete habitat patches (Bennett, 1998). The hope is that any localized extinction will be offset by recolonization and genetic exchange will maintain fitness, ensuring the long-term persistence of the species in the region. Corridors are both context and species dependent: they depend on both the composition and spatial arrangement of the landscape, and the movement abilities and landscape preferences of target plants and wildlife.

Green Infrastructure in the Lower Rio Grande Valley

The Thornforest Conservation Plan identifies existing core habitat areas for a set of focal species whose requirements are representative of the complex structural and species diversity found in mature thornforest habitats in the LRGV. The plan also identifies existing corridors that allow plant and animal movement between these core habitat areas and areas within the resulting network of "hubs and corridors" that have potential to be restored into thornforest.

Thornforest Core Area Identification

Identify Focal Species

The first step in identifying thornforest habitat was to define the range of habitats described as "thornforest." While the LRGV's Tamaulipan thornforest can be generally described as a dense, diverse mix of thorn species, the varying regional climate and underlying soils result in a mix of thornforest vegetation types ranging from desert-like stretches of short stature plants in the west, to tall and "forest-like" remnants along resacas and other riparian areas in the deltaic sections parallel to the Rio Grande and, ultimately, coastal prairies dominated by grasslands in the eastern and northern sections.

To arrive at a regional definition of thornforest, this range of vegetation types was analyzed in conjunction with the occurrence of certain wildlife species by using the focal species concept. Focal species are a conservation tool wherein a species' existing presence/non-presence data can be used as a proxy for identifying various levels of habitat quality in an area (Chase and Geupel, 2005). For example, a focal species whose habitat requirements (presence) are correlated with more developed habitat with a higher diversity of woody plant species may also serve as an indicator for the presence of greater wildlife diversity in general at that location, thereby providing value to planning exercises that seek maximum benefit to ecosystem preservation. As a critically endangered species and an iconic part of the Lower Rio Grande Valley's natural heritage, the TCP chose to use the habitat requirements of the northern ocelot (*Leopardus pardalis*) to define thornforest in our analysis. This species requires dense thornscrub, has a relatively large home range (averaging 2.5-18 km^2 for males, 2.0-11 km^2 for females), and requires adequate connectivity for interbreeding if the species is to persist in the U.S. (Navarro-Lopez, 1985; Tewes, 1986; Laack, 1991; Haines et al., 2006).

Because the ocelot is found only in Cameron and Willacy Counties, the TCP chose to use a suite of other wildlife species to identify current and potential thornforest habitat in Hidalgo and Starr Counties: Altamira oriole (*Icterus gularis*), plain chachalaca (*Ortalis vetula*), olive sparrow (*Arremonops rufivirgatus*), and Texas tortoise (*Gopherus berlandieri*). These species have much smaller home ranges than ocelot (<1 to 11.3 ha, according to NatureServe).

Identify Suitable Vegetation Types

After identifying the habitat needs of our focal species, we associated the species with existing ecological mapping systems in order to begin identification of core areas of habitat. In Texas, we identified forest and shrubland from the 2016 Texas Ecological Systems Classification (TEMS). We solicited expert feedback on which classes corresponded to thornforest, and which classes provided habitat for our five focal species.

We also compared vegetation classes to occurrence data for the focal species from the Global Biodiversity Information Facility database (GBIF). While a portion of this data was derived from research methodologies designed expressly for rigor (e.g., transects, standardized point counts, etc.) the majority can be characterized as originating from citizen science formats (e.g., e-bird) and are thus non-random and open to selection bias. Notwithstanding these limitations, we utilized this comparison to gauge a focal species' preference for individual vegetation classes by noting where their occurrence was more frequent but disproportionate to the actual percent of area covered by the class. We did not attempt to calculate statistical significance because of the source data limitations, but we only selected differences > 0 and greater than urban high intensity or open water relative occurrence.

The following breakdown lists the vegetation classes that were most likely to provide habitat for each respective focal species in the LRGV according to our analysis.

Altamira Oriole vegetation classes:

- Urban Low Intensity
- Rio Grande Delta: Evergreen Thorn Woodland and Shrubland
- South Texas: Floodplain Evergreen Forest and Woodland
- South Texas: Floodplain Mixed Deciduous - Evergreen Forest and Woodland
- South Texas: Floodplain Hardwood Forest and Woodland
- South Texas: Clayey Blackbrush Mixed Shrubland
- South Texas: Floodplain Deciduous Shrubland

Plain Chachalaca vegetation classes:

- Urban Low Intensity
- South Texas: Saline Lake Grassland
- South Texas: Floodplain Evergreen Forest and Woodland
- South Texas: Clayey Blackbrush Mixed Shrubland
- South Texas: Floodplain Mixed Deciduous - Evergreen Forest and Woodland

Olive Sparrow vegetation classes:

- Urban Low Intensity
- Rio Grande Delta: Evergreen Thorn Woodland and Shrubland
- South Texas: Clayey Blackbrush Mixed Shrubland
- South Texas: Floodplain Evergreen Forest and Woodland
- South Texas: Floodplain Mixed Deciduous - Evergreen Forest and Woodland
- South Texas: Floodplain Hardwood Forest and Woodland
- South Texas: Floodplain Deciduous Shrubland
- Coastal: Sea Ox-eye Daisy Flats

Texas tortoise vegetation classes:

- Row Crops
- Coastal: Sea Ox-eye Daisy Flats
- South Texas: Sandy Mesquite Dense Shrubland

Some of the above classes with GBIF observations (e.g., Urban Low Intensity, Saline Lake Grassland, and Row Crops), are not useful for identifying core habitat areas that can serve as source breeding areas, etc., so we used expert opinions to refine our final, comprehensive selections as listed below. Not all of the wooded areas were thornforest per se, but they do provide similar cover.

- Coastal and Sandsheet: Deep Sand Shrubland
- Coastal and Sandsheet: Deep Sand Live Oak Forest and Woodland
- Coastal and Sandsheet: Deep Sand Live Oak - Mesquite Woodland
- Coastal and Sandsheet: Deep Sand Live Oak Shrubland
- South Texas: Salty Thornscrub
- South Texas: Clayey Mesquite Mixed Shrubland
- South Texas: Clayey Blackbrush Mixed Shrubland
- South Texas: Sandy Mesquite - Evergreen Woodland
- South Texas: Sandy Mesquite Woodland and Shrubland
- South Texas: Sandy Mesquite Dense Shrubland
- South Texas: Shallow Shrubland
- South Texas: Shallow Dense Shrubland
- South Texas: Shallow Sparse Shrubland
- South Texas: Loma Evergreen Shrubland
- South Texas: Loma Deciduous Shrubland
- South Texas: Floodplain Evergreen Forest and Woodland
- South Texas: Floodplain Mixed Deciduous - Evergreen Forest and Woodland
- South Texas: Floodplain Hardwood Forest and Woodland
- South Texas: Floodplain Evergreen Shrubland
- South Texas: Floodplain Deciduous Shrubland
- South Texas: Palm Grove
- South Texas: Ramadero Evergreen Woodland
- South Texas: Ramadero Woodland
- South Texas: Ramadero Dense Shrubland
- South Texas: Ramadero Shrubland
- Rio Grande Delta: Evergreen Thorn Woodland and Shrubland

- Rio Grande Delta: Deciduous Thorn Woodland and Shrubland
- Rio Grande Delta: Dense Shrubland
- Native Invasive: Deciduous Woodland
- Native Invasive: Mesquite Shrubland
- Native Invasive: Huisache Woodland or Shrubland
- South Texas: Pond and Laguna Woodland
- South Texas: Pond and Laguna Shrubland

In Mexico, we used the 2010 Land Cover of North America (NALCMS), selecting the following classes:

- Tropical or sub-tropical broadleaf evergreen forest
- Tropical or sub-tropical broadleaf deciduous forest
- Mixed forest
- Tropical or sub-tropical shrubland
- Temperate or sub-polar shrubland

Identify Suitable Soils

To further refine thornforest core area identification, we prioritized selection of existing and potential habitat on soils that are conducive to dense thornforest development. The soils included the general associations listed below and more detailed county analyses can be found in the Appendix:

- Riparian and floodplain vegetation: soils fertile and highly suitable for thornforest.
- Ramaderos: deep-soiled drainages with higher moisture than surrounding upland areas, able to support denser and taller vegetation.
- Water or seasonal depressions.
- Permanent and seasonal wetlands or waterways.

Identify Core Areas

Thornforest core areas include existing contiguous forest or shrubland found within both suitable vegetation classes and soils, up to their edges with other land cover types, roads, or railroads. From these, we selected only those patches that contained a certain minimum amount of interior (>0.1 ha >30 m from edge, Figure 4).

Starr County had much more acreage identified as thornforest than the eastern three counties (Figure 4, Table 1), however, we recognize that the characteristics (e.g., structure) of the vegetation communities there are also quite different in stature. Further, traditional land-uses in Starr, despite some negative impacts to the function of ecological systems, allow for more vegetation to exist intact across the landscape. Keep in mind, this model and these maps intend to portray existing or potential thornforest of various types that grow throughout the LRGV.

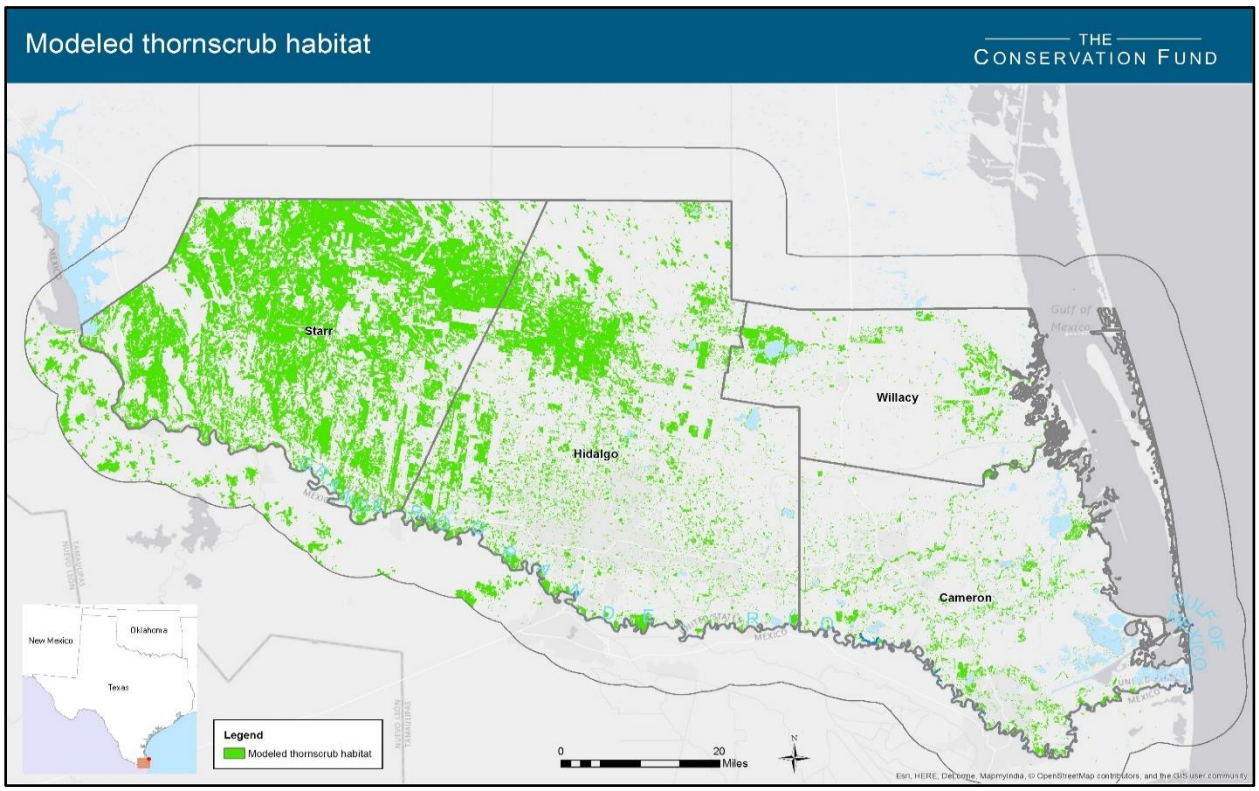


Figure 4. Potential thornforest cover in the Lower Rio Grande Valley.

Table 1. Modeled thornforest cover by county.

COUNTY	% thornforest
Cameron	5.5
Willacy	11.1
Hidalgo	17.8
Starr	66.8
TOTAL	28.0
TOTAL minus Starr	12.8

Core Area Size

After examining different patch sizes, we selected thornforest patches ≥30 ha as "core habitat" (Figure 5). The Thornforest Conservation Partnership decided that this minimum patch area was sufficient to provide breeding habitat for our focal species. Hidalgo, Willacy, and Cameron Counties were much more fragmented, with fewer and smaller patches on average, than Starr County.

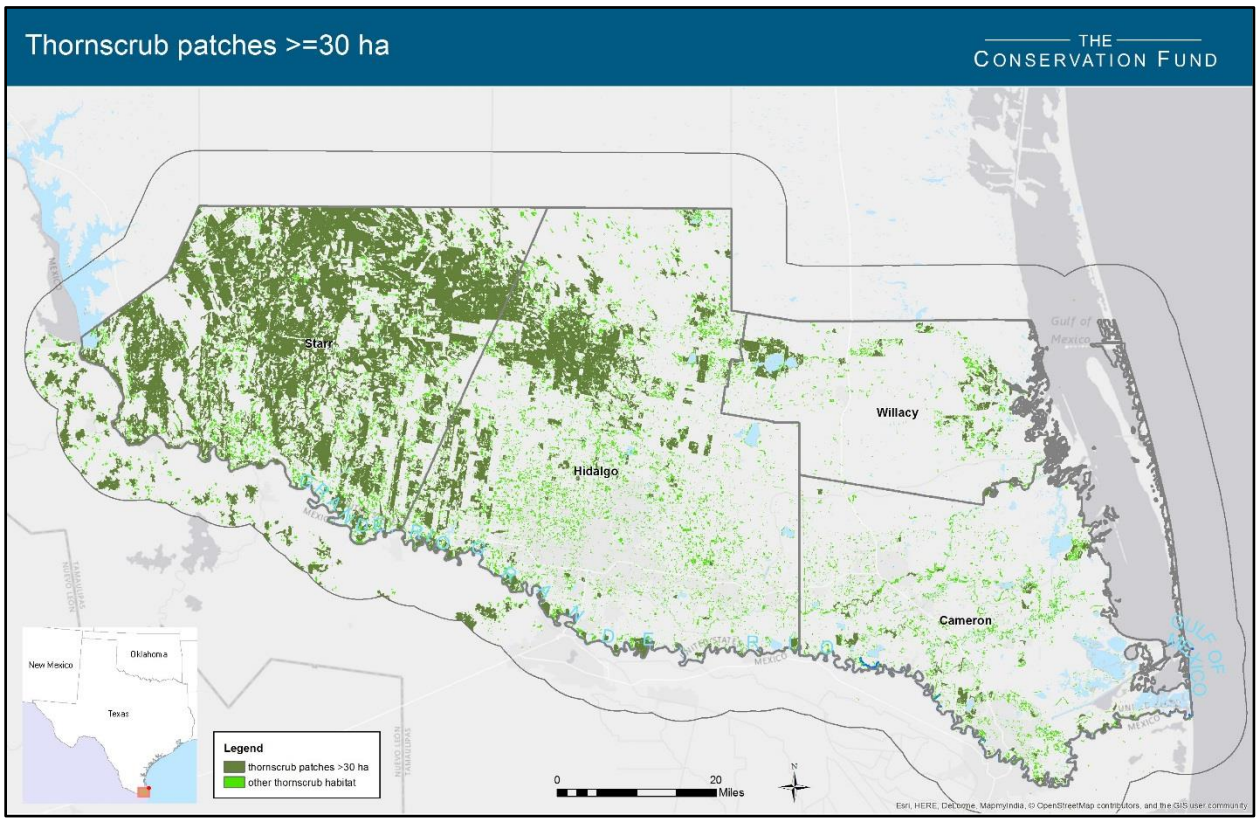


Figure 5. Thornforest patches ≥30 ha in the Lower Rio Grande Valley.

Thornforest Corridors

Identification of potential corridors that could link patches of core habitat was a key part of the project, especially for ocelots, since their remaining Texas habitat is isolated, exacerbating conditions of inbreeding and stochastic fluctuations. Collisions with motor vehicles are the leading cause of known ocelot mortality (Haines et al., 2005; USFWS, 2016). A population viability analysis predicted a 33% probability that ocelots in southern Texas would become extinct by 2050 or so, if existing conditions were not changed significantly, but improved connectivity could reduce this risk, as would translocation of ocelots from Mexico (especially females) (Haines et al., 2006; Janečka et al., 2007).

After discussion and examination of different thresholds, we modeled connectivity between thornforest patches at least 30 ha in size, and with at least a minimal amount (>0.1 ha) of interior (>30 m from edge). Based on the cover classifications found in both TEMS (2016) and NALCMS (2010), forest and shrubland were considered the most suitable cover types for inter-patch movement, especially away from edges, along waterways, or on protected land (parks, refuges, preserves, conservation easements, etc.). We considered bridges and existing or planned ocelot crossings the best places to cross roads (e.g., Figure 6). We quantified and combined these factors to derive a layer of overall suitability for focal species movement (details in Appendix A). To reflect uncertainties, we varied the suitability values randomly, while keeping them in the same order (e.g., forest and shrub cover being more suitable than cropland or developed land).

Figure 6. Wildlife crossing in Cameron County, TX (photo: The Conservation Fund).

To identify the spatial distribution of potential corridors, we used a program called the Terrestrial Movement Analysis (TMA) tool. It treats the landscape as a circulatory system, identifying those pathways most likely to be followed by wildlife. The tool generates random sets of starting locations (with each location corresponding to an individual organism) and then calculates optimal (or least cost) paths to all other habitat within the landscape. The cell values along the pathway are the summed area (the number of patch cells) that a pathway is connected to at that point. This process is executed iteratively, with each iteration having a different set of random start locations and corresponding least-cost paths. The tool identifies corridors by adding suitable land along this pathway. Finally, it calculates overall movement potential by considering both the amount of habitat connected by a linkage, and how good that linkage is (i.e., is it mostly natural land or are portions degraded or converted?). Connectivity potential exists both within and outside core areas, but we defined corridors as connectivity linkages that fell outside core areas (e.g., between patches).

Figure 7 shows modeled core habitat patches and corridors in the study area. This should be considered a first cut, to help identify potential locations to examine for restoration. We did not model connectivity in Starr County (except in a buffer along the Hidalgo County line), since core patches there were already largely connected.

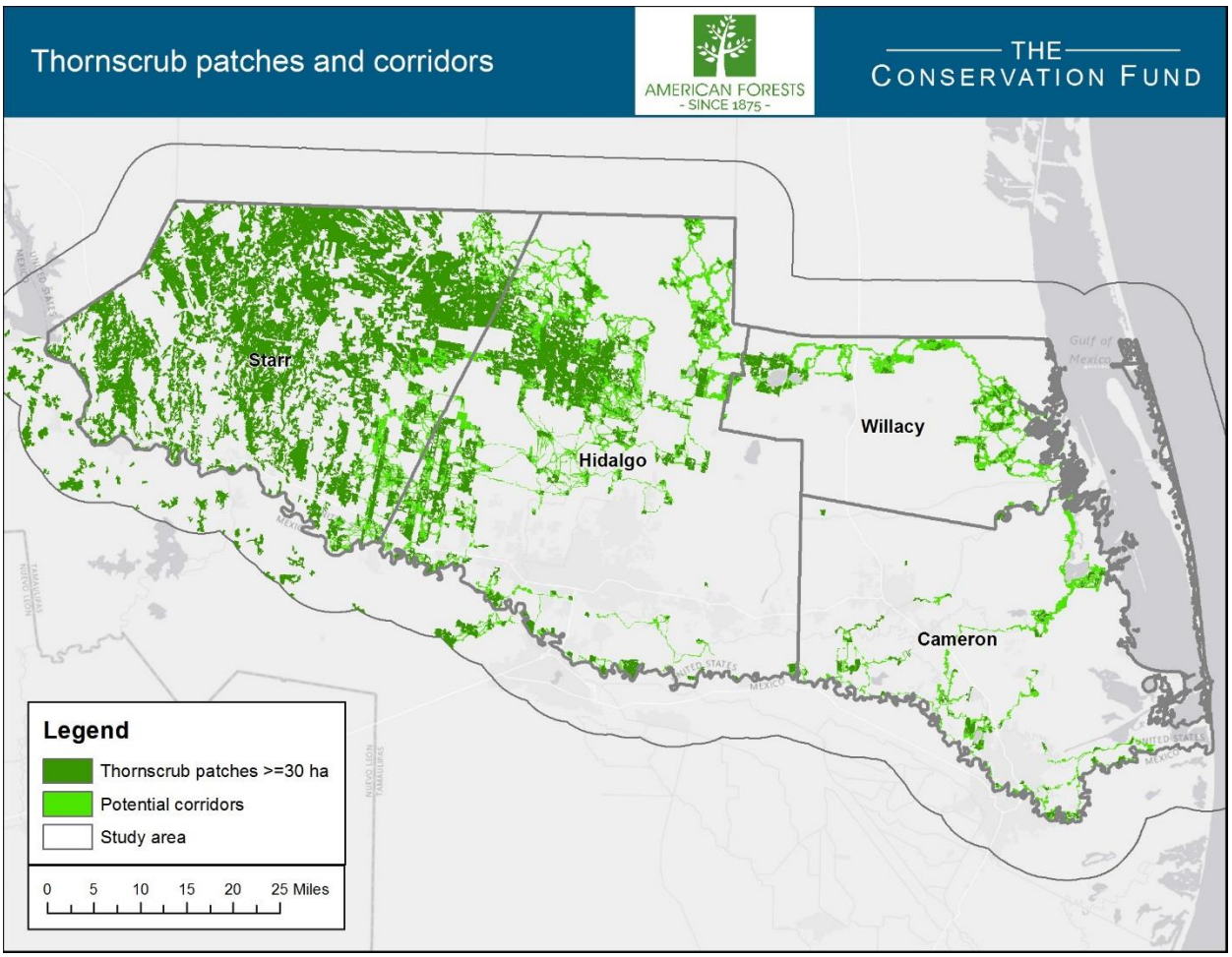


Figure 7. Modeled thornforest core areas and corridors in the Lower Rio Grande Valley.

Thornforest Habitat Restoration

After identifying core areas and potential corridors, we examined the LRGV counties for restoration potential. From the 2016 TEMS vegetation classification, we selected barren land, disturbed grassland, saltcedar shrubland, orchards, row crops, and grass farms, as areas suitable for restoration (i.e., we did not include natural or developed land). Of these, disturbed grassland and row crops were by far the most common. In partnership with the USFWS South Texas Refuge Complex, we categorized soils for thornforest restoration by identifying those most suitable for diverse thornforest development. Saline soils, deep sands, poorly drained soils, mined areas and other manmade features were considered poor candidates.

Other restoration suitability factors included proximity to open water, proximity to ocelot occurrences, proximity to existing thornforest core areas, being along a modeled corridor, being on protected land, and being in USFWS focal properties or along an identified connection. After examining the output from two different weighting schemes (see Appendix B for details), we weighted the factors as follows (Figure 8):

Factor	Weight	Value range
Land cover suitable for restoration	(required)	(required)
Suitable soils	(required)	(required)
Proximity to water	4	4-8
Proximity to ocelot occurrences	1	1-4
Proximity to existing patches	1	1-4
Along a modeled corridor	4	4-8
Protected land	4	4-8

Figure 8 displays the restoration potential from low to high in the LRGV.

The top 10% ranking of restoration opportunities that are at least five acres in size total 69,593 acres (around 2.5% of the four-county area; Figure 10). Of these, 18,157 acres (26%) were on land already owned by USFWS, Texas Parks and Wildlife Department, National Park Service, National Audubon Society, or The Nature Conservancy. These entities are expected to provide long-term ownership and consistency in management of these lands. Many private ranches are guided by similar missions and management. Private lands are highly valued for the wildlife conservation benefits they offer the LRGV.

Conclusion

We want to re-iterate that this plan is first and foremost a living document that will be subject to adaptation at subsequent intervals in time when additional research, developments and/or circumstances arise to better inform our approach to preserving and restoring thornforest habitat in the LRGV. For example, thornforest restoration potential currently exists throughout most of Cameron, Hidalgo and Willacy Counties (Figure 9). The designation of a lower restoration score is not meant to indicate that restoration efforts could not be beneficial in areas corresponding to this score. Instead, our perspective is to consider restoration in areas that would be of most benefit at the current time to producing connectivity for thornforest-dependent wildlife populations in the region as a whole (e.g., viewed from the landscape level; Figure 10). We expect to conduct refinements of this modeling in upcoming phases of the plan. These refinements will provide more detail regarding connectivity at the parcel level, which may include selection of alternative sites that are currently ranked in this low range of potential restoration. Further, we stress that landowners who are intent on utilizing restorative practices remain so inclined regardless of their location in the LRGV because these are some of the scenarios that will compel adaptation of the plan going forward.

Next Steps

This plan is intended as the first phase of a larger effort expected to include ongoing strategic design (e.g., business plans) that will eventually lead to project-based (e.g., on-the-ground restoration) activities and technical guidance services (e.g., restoration technique BMP's) sponsored by TCP membership. Components missing from this first phase plan but that will be addressed in subsequent partnership developments include but are not limited to: incorporation of other habitat types native to the LRGV (e.g., grassland, wetland-dominated,

etc.) in certain areas and designating a unified urban restoration trajectory within parts of the region. The former distinction will provide opportunities to conserve additional listed species that may benefit from less woody species cover and the latter will better reflect options that could have dual impact by offering additional value to community resilience (e.g., flood/drought mitigation, recreation, associated ecosystem services, etc.) while simultaneously providing for the basis of our mission objectives in conservation.

Building out from this document's foundation, next steps will include but are not limited to: designing a business plan to gauge regional capacity for sustained restoration, a detailed identification of targeted end-users within the LRGV and the establishment of a webpage to begin dissemination of messaging and additional resources related to TCP activities.

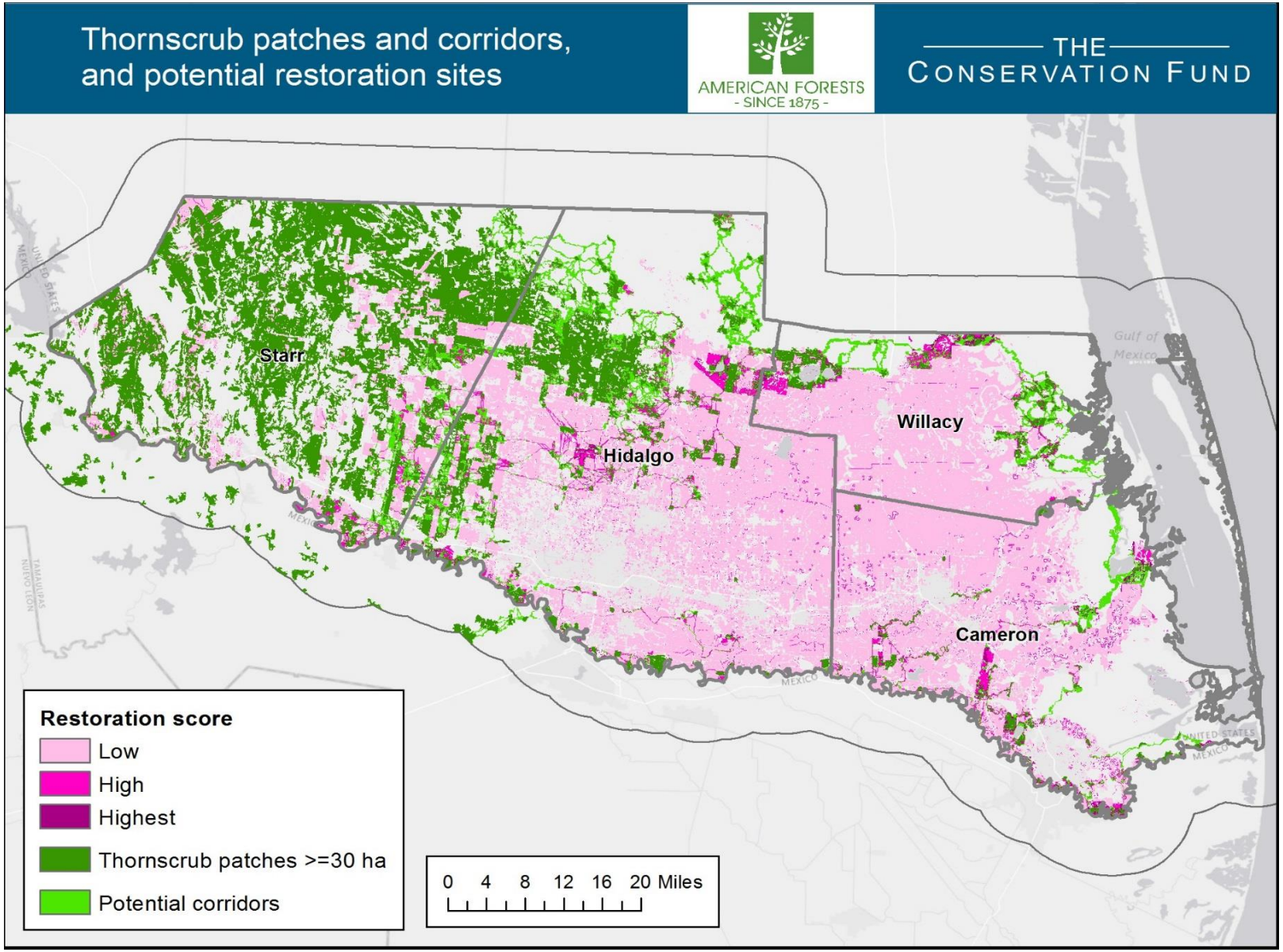


Figure 9. Thornforest core areas, corridors, and potential restoration sites

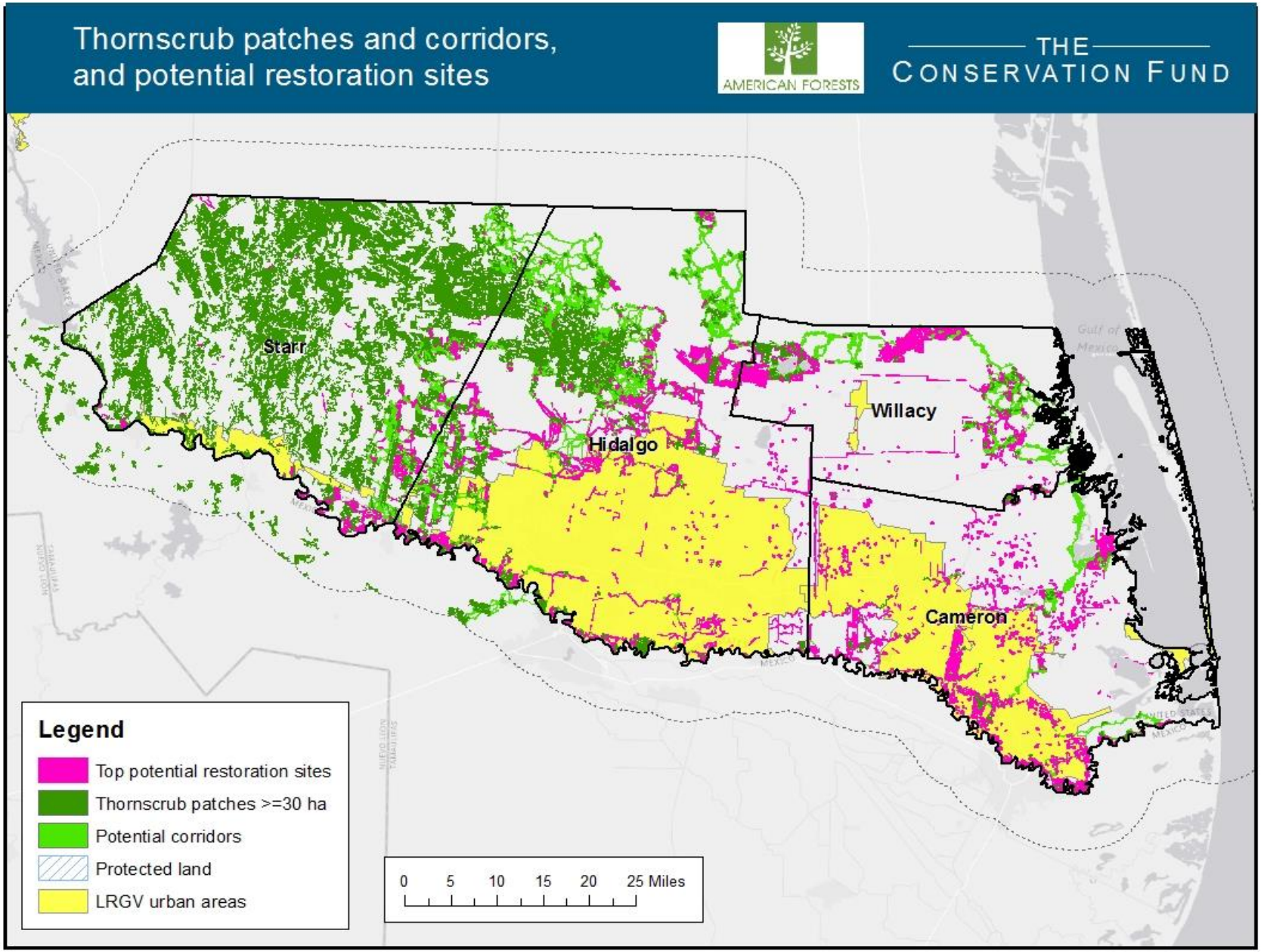


Figure 10. Thornforest core areas, corridors, and top potential restoration sites, compared to existing protected areas and urban limits.

References

Bennett, A.F. 1998. Linkages in the landscape: the role of corridors and sensitivity in wildlife conservation. IUCN, Gland, Switzerland and Cambridge, UK. 254 pp.

Chase, M.K., and G.R. Geupel. 2005. The Use of Avian Focal Species for Conservation Planning in California. In: Ralph, C.J., Rich, T.D., eds. Bird Conservation Implementation and Integration in the Americas: Proceedings of the Third International Partners in Flight Conference. 2002 March 20-24; Asilomar, California, Volume 1 Gen. Tech. Rep. PSW-GTR-191. Albany, CA: U.S. Dept. of Agriculture, Forest Service, Pacific Southwest Research Station: p. 130-142

Dramstad, W.E., J.D. Olson, and R.T.T. Forman. 1996. Landscape ecology principles in landscape architecture and land-use planning. Island Press, Washington, DC. 80 pp.

Haines, A.M., M.E. Tewes, and L.L. Laack. 2005. Survival and sources of mortality in ocelots. Journal of Wildlife Management 69:255-263.

Haines, A.M., M.E. Tewes, L.L. Laack, J.S. Horne, and J.H. Young. 2006. A habitat-based population viability analysis for ocelots (Leopardus pardalis) in the United States. Biol Conserv. doi: 10.1016/j.biocon.2006.04.035

Haines, A.M., L.I. Grassman, Jr., M.E. Tewes, and J.E. Janečka. 2006. First ocelot (*Leopardus pardalis*) monitored with GPS telemetry. European Journal of Wildlife Research 52:216–218.

Harveson, P.M., M.E. Tewes, G.l. Anderson, and L.L. Laack. 2004. Habitat use by ocelots in south Texas: implications for restoration. Wildlife Society Bulletin 32(3): 948-954.

Janečka, J.E., C.W. Walker, M.E. Tewes, A. Caso, L.L. Laack, and R.L. Honeycutt. 2007. Phylogenetic relationships of ocelot (*Leopardus pardalis albescens*) populations from the Tamaulipan biotic province and implications for recovery. Southwestern Naturalist 52:89-96.

Laack, L.L. 1991. Ecology of the ocelot (*Felis pardalis*) in south Texas. Thesis, Texas A&I University, Kingsville, Texas, USA.

Leslie, D.M. 2016. An international borderland of concern—Conservation of biodiversity in the Lower Rio Grande Valley: U.S. Geological Survey Scientific Investigations Report 2016–5078, 120 p., http://dx.doi.org/10.3133/ sir20165078.

Navar, J., E. Mendez, A. Najera, J. Graciano, V. Dale, and B. Parresol. 2004. Biomass equations for shrub species of Tamaulipan thornscrub of North-eastern Mexico. Journal of Arid Environments 59: 657–674

Navarro-Lopez, D. 1985. Status and distribution of the ocelot in south Texas. Thesis, Texas A&I University, Kingsville, Texas, USA.

Ricketts, T., and M. Imhoff. 2003. Biodiversity, urban areas, and agriculture: Locating priority ecoregions for conservation. Conservation Ecology 8(2): 1

Tewes, M.E. 1986. Ecological and behavioral correlates of ocelot spatial patterns. Dissertation, University of Idaho, Moscow, Idaho, USA.

U.S. Fish and Wildlife Service. 1997. Lower Rio Grande Valley and Santa Ana National Wildlife Refuges comprehensive conservation plan and environmental assessment. U.S. Fish and Wildlife Service, Albuquerque, New Mexico, USA.

U.S. Fish and Wildlife Service. 2010. Laguna Atascosa National Wildlife Refuge comprehensive conservation plan and environmental assessment. U.S. Fish and Wildlife Service, Albuquerque, New Mexico, USA.

U.S. Fish and Wildlife Service. 2016. Recovery Plan for the Ocelot (*Leopardus pardalis*), First Revision. U.S. Fish and Wildlife Service, Southwest Region, Albuquerque, New Mexico.

Woosnam, K.M., R.M. Dudensing, D. Hanselka, and S. An. 2011. An initial examination of the economic impact of nature tourism on the Rio Grande Valley. Texas A&M University, College Station. 18 pp.

Appendix A: Detailed Corridor Methodology

Movement impedance

1. Bridges
   a. From TX DOT bridge layer, selected ("CHNL_COND_" <> 'N') AND ("CULV_COND_" = 'N') AND ("SRVC_TYPE_" = '5'). Save as LRGV_bridges_over_water.shp.
   b. Based on examination of data, buffer 60 meters
   c. Clip hydrology (LRGV_10k_rivers_streams) within these bridge buffers
   d. Convert to grid with the same value as water in the land cover grid (NALCMS_LC; value = 18), with cell size equal to the land cover (30 m).
2. Major roads
   a. From TXDOT_roads_2015, select "RTE_CLASS" = 'On System Highways'
   b. Convert to grid with cell size equal to the land cover (30 m).
   c. Assign a unique code (99)
3. Other roads
   a. Convert all TXDOT_roads_2015 to grid with cell size equal to the land cover (30 m).
   b. Assign the same code as urban and built-up (17)
4. Railroads
   a. Convert all TXDOT_roads_2015 to grid with cell size equal to the land cover (30 m).
   b. Assign active railroads the same code as urban and built-up (17)
   c. Assign inactive railroads the same code as barren (16)
5. Overlay bridges, major roads, other roads and streets, and railroads over 2010 North American Land Cover. Save as grid lc_modified1.
6. Ocelot crossings
   a. Built
   b. Committed to be built
   c. Planned
   d. Note: At least one of the planned crossings was built in a different place.
   e. Based on examination of land cover and aerial photos (primarily land cover), buffer 90 meters.
   f. Convert buffers to grid with cell size equal to the land cover (30 m).
   g. Give developed cells (from lc_modified1, so it includes roads and railroads) within these buffers the same code as grassland (9), to reflect that this is a suitable crossing (but not as suitable as traveling through forest or shrubland).
7. Overlay ocelot crossings over lc_modified1 (bridges, major roads, other roads and streets, railroads, and 2010 North American Land Cover). Save as grid lc_modified.
8. Reclass modified land cover as follows (No Data = impassable)

Code	Description	Impedance
3	Tropical or sub-tropical broadleaf evergreen forest	10
4	Tropical or sub-tropical broadleaf deciduous forest	10
6	Mixed forest	10
7	Tropical or sub-tropical shrubland	10
8	Temperate or sub-polar shrubland	10
9	Tropical or sub-tropical grassland	20

14	Wetland	20
15	Cropland	50
16	Barren land	250
17	Urban and built-up	1250
18	Water	100
99	Major roads	10,000

a. Grid name: imp_mod_lc

9. Interior forest
   a. Reclass distance from forest edge (using grid tree_patches) as follows (1 cell diagonal = 45 m):

Distance from forest edge	Divide impedance by:
>100 m	3
45-100 m	2
<45 m, or non-forest	1

   b. Saved divisor grid as imp_intfor.

10. Proximity to water
   a. From hydrology, convert streams (both intermittent and perennial; Fcode = 46003 or 46006) and river centerlines (Fcode = 55800) to grids with value = 1.
   b. From modified land cover (imp_mod_lc), divide vegetated cells adjacent to water by 2 (i.e., not developed, barren, or open water).
   c. Save grid as imp_riparian

11. Multiply impedance of offshore water (>2 cells, or 60 m, from shore) by 10, so the program does not select forest corridors across large rivers or bays.
   a. Use water from land cover (specifically, grid lc_modified, which reclassifies bridges as water)
   b. Save grid as imp_offshore

12. Ocelot occurrences
   a. Convert ocelot occurrence polygons to grid format
   b. Divide impedance by 3
   c. Grid name: ocelot_occur

13. Soils suitable for restoration
   a. Harveson et al. (2005) identified soils associated with ocelot use
   b. The reforestation program found that Lyford and Lozano soil types are indicative of where existing remaining thornforest habitat remains, and where breeding ocelots occur. This is based upon where quality habitat was preserved (not root-plowed), rather than knowledge of how the variety of soil types do or do not support restoration efforts.
   c. Convert these to grid format
   d. Divide impedance by 2 (Grid name: imp_soil)

14. Protected lands
   a. Clipped Protected Areas (PADUS) and Conservation Easements (NCED) to the LRGV buffer.
   b. Converted to grid, grd_protected
   c. Based on results from past projects, exclude developed land and open water from receiving a discount for being within a protected area.
   Reclass protected undeveloped land = 2; elsewhere = 1. Saved as imp_protect.

15. Combine
   a. Divide land cover impedance grid by interior forest impedance (i.e., lower impedance in forest interior), ocelot occurrence (lower impedance where ocelots have been recorded), proximity to

water (lower impedance for vegetated land adjacent to water), soil impedance (lower for suitable soils), protected land (lower impedance in undeveloped protected land), and multiply by offshore water (higher impedance >60 m from shore).

b. Reclass values < 1 to 1.

c. Note that processing extent, cell size, etc. must align exactly between impedance and core area grids for the TMA tool to work.

Forest Connectivity modeling

1. Examine connections between patches at least 30 ha, with least a minimal amount (>0.1 ha) of interior (>30 m from edge)
   a. Convert to grid with 30 m cell size (name: patch30ha_30m)
2. Created uncertainty grid for impedance layer, such that each impedance value could vary but retain their rank order.

Impedance value	Min. value	Max. value	Fractional change to min.	Fractional change to max.	Smallest fractional change	Final min. value	Final max. value
4	4	4	0.000000	0.000000	0.0000	4	4
5	5	5	0.000000	0.000000	0.0000	5	5
6	6	7	0.000000	0.166667	0.0000	6	6
8	7	9	0.125000	0.125000	0.1250	7	9
10	9	11	0.100000	0.100000	0.1000	9	11
12	11	14	0.083333	0.166667	0.0833	11	13
16	14	18	0.125000	0.125000	0.1250	14	18
20	18	22	0.100000	0.100000	0.1000	18	22
25	23	29	0.080000	0.160000	0.0800	23	27
33	29	37	0.121212	0.121212	0.1212	29	37
41	37	45	0.097561	0.097561	0.0975	37	45
50	46	56	0.080000	0.120000	0.0800	46	54
62	56	72	0.096774	0.161290	0.0967	56	68
83	73	91	0.120482	0.096386	0.0963	75	91
100	92	102	0.080000	0.020000	0.0200	98	102
104	102	114	0.019231	0.096154	0.0192	102	106
125	115	166	0.080000	0.328000	0.0800	115	135
208	167	229	0.197115	0.100962	0.1009	187	229
250	229	281	0.084000	0.124000	0.0840	229	271
312	281	322	0.099359	0.032051	0.0320	302	322
333	323	374	0.030030	0.123123	0.0300	323	343
416	375	458	0.098558	0.100962	0.0985	375	457
500	458	562	0.084000	0.124000	0.0840	458	542
625	563	729	0.099200	0.166400	0.0992	563	687
833	729	916	0.124850	0.099640	0.0996	750	916
1000	917	1125	0.083000	0.125000	0.0830	917	1083
1250	1125	1458	0.100000	0.166400	0.1000	1125	1375

1666	1458	2083	0.124850	0.250300	0.1248	1458	1874
2500	2083	2916	0.166800	0.166400	0.1664	2084	2916
3333	2917	4166	0.124812	0.249925	0.1248	2917	3749
5000	4167	7500	0.166600	0.500000	0.1666	4167	5833
10000	7500	12500	0.250000	0.250000	0.2500	7500	12500

3. Run TMA, using parameters from earlier tests.
   a. maximum movement from start locations = maximum
   b. minimum pathway threshold = 10
   c. maximum movement around pathway = 1000
      i. Through ag fields, width was only 1-3 cells, so the minimum width value was not too high.
   d. analysis iterations = 100
   e. start location % = 5
   f. We had to remove Starr County to keep the program from crashing. Starr County had much more thornforest than the other counties, was therefore capturing most of the random movement starting points, and did not appear to be a connectivity priority. We buffered the other three counties by 10 km and ran TMA for this.
   g. The program took 8 hours, 49 minutes to complete 100 iterations.
   h. There were some key missing north-south connections in Cameron and Hidalgo Counties, and one needed for northern Hidalgo County linking the La Sal del Rey thornforest with the patches to the south and west.
   i. The program identified a potential corridor aligning with USFWS's proposed Rio Grande corridor, but only small subsections of the proposed PABNHS to Laguna Atascosa corridor and the Arroyo Colorado & Blue Trail.
4. Do a least cost path analysis
   a. Selected a patch in Laguna Atascosa NWR as the source. This patch was within an ocelot occupied area.
   b. Calculated cost distance from this source
   c. Selected all other 30 ha patches in Cameron or Willacy Counties, unless they were within or near an urban area, as the destinations.
   d. Computed least cost paths between the source and destination centroids, with the centroids being within the patch.
   e. Fill out corridors by calculating cost distance from least cost paths, with maximum cost distance = 1000
   f. Adding missing linkage between Sal del Ray and the patches to the south and west.
5. On the TMA output from the first run listed above (step #3; minimum pathway threshold = 10, maximum movement around pathway = 1000, start location % = 5), use the "Remove Cores from corridors" tool to remove core areas and areas that do not connect at least two core areas (they may connect different parts of the same core area, or function as buffers, or, in some cases, act as dead ends.). Save grid as patch_connect.
6. Add this to the least cost path corridors computed in step #4.
   a. Reclass to give values of 1, No Data.
   b. Merge and remove core areas and save as cwh_corridors

Appendix B: Detailed Restoration Targeting Methodology

Targeting criteria

1. Land cover
   a. From 2016 Texas Ecological Systems Classification, select the following classes:

VALUE	% of area	COMMONNAME
9000	0.40%	Barren
9187	13.91%	South Texas: Disturbance Grassland
9204	0.01%	Non-native Invasive: Saltcedar Shrubland
9304	0.23%	Orchard
9307	23.36%	Row Crops
9317	0.07%	Grass Farm

   b. Grid name: rest_landcov
2. Soil type
   a. Harveson et al. (2005) identified soils associated with ocelot use.
   b. The reforestation program found that Lyford and Lozano soil types are indicative of where existing remaining thornforest habitat remains, and where breeding ocelots occur. This is based upon where quality habitat was preserved (not root-plowed), rather than knowledge of how the variety of soil types do or do not support restoration efforts.
   c. Convert these to grid format
   d. Give a value of 2; elsewhere a value of 1 (Grid name: rest_soil)
3. Proximity to water
   a. From hydrology, convert streams (both intermittent and perennial; Fcode = 46003 or 46006) and river centerlines (Fcode = 55800) to grids with value = 1.
   b. Add waterbodies.
   c. From land cover, select all classes except water and urban.
   d. Give cells other than water or urban, and adjacent to water (<30 m), a value of 2. Give all other cells a value of 1.
   e. Save grid as rest_riparian
4. Proximity to ocelot occurrences
   a. Calculated cost distance from ocelot occurrence polygons, with the cost being land in the three counties = 1, outside (e.g. bays and Gulf) = No Data (impassable).
   b. Assign the following values:

Location	Reason	Value
Current ocelot locations	Areas of known ocelot use	4
<15 km from current locations	Dispersal distance documented in several studies (Booth-Binczik, 2007)	3
15-50 km	Longest recorded movement (Booth-Binczik, 2007)	2
>50 km from ocelot locations	Likely to take more than one generation	1

   c. Reference: Booth-Binczik, S. D. 2007. Monitoring ocelot dispersal with satellite telemetry. Endangered Species UPDATE 24(4):110-112.
   d. Grid name: prox_ocelots
5. Proximity to existing patches

a. Calculate distance to thornforest patches containing interior area (>30 m from edge) and >1 ha in size.
b. Reclassify as follows:

Distance from existing patch	Value
1 – 15 m (1 cell)	4
15 – 30 m	3
30 – 100 m	2
>100 m	1

c. Grid name: prox_patches

6. Along a modeled corridor
   a. Give corridors a value = 2, elsewhere = 1.
7. Land ownership
   a. Clipped Protected Areas (PADUS) and Conservation Easements (NCED) to the LRGV buffer.
   b. Converted to grid: protected_10m
   c. Reclass protected land = 2; elsewhere = 1. Saved as rest_protect.
8. Focal properties or along an identified connection
   a. FWS Focal Properties
   b. PABNHS to Laguna Atascosa corridor (unless already protected)
   c. Rio Grande Corridor (unless already protected)
   d. Arroyo Colorado & BlueTrail (unless already protected)
   e. Convert to grids, merge, and remove existing protected land.
   f. Reclass focal properties = 2; elsewhere = 1. Saved as rest_focal.
   g. Give this factor a lower weight than existing protection (esp. since they are only in Cameron County).
9. Combine
   a. Factor weights #1

Factor	Weight	Value range
Land cover suitable for restoration	(mask)	(mask)
Suitable soils	2	2-4
Proximity to water	2	2-4
Proximity to ocelot occurrences	1	1-4
Proximity to existing patches	1	1-4
Along a modeled corridor	2	2-4
Protected land	2	2-4
Focal properties or along an identified connection	1	1-2

      i. Use weighted sum tool.
      ii. Mask out land not suitable for restoration, and areas outside the three counties.
      iii. Convert to integer values.
      iv. The output was dominated by the proximity to ocelot occurrences.

   b. Factor weights #2

Factor	Weight	Value range
Land cover suitable for restoration	(mask)	(mask)
Suitable soils	4	4-8
Proximity to water	4	4-8
Proximity to ocelot occurrences	1	1-4
Proximity to existing patches	1	1-4

Along a modeled corridor	4	4-8
Protected land	4	4-8
Focal properties or along an identified connection	2	2-4

v. Use weighted sum tool.
vi. Mask out land not suitable for restoration, and areas outside the three counties.
vii. Convert to integer values.

c. Output grid: rest_score

10. Examine output and select threshold for top ranking areas
    a. There was a major break between values of 26 and 27.
    b. The top values (27-41) comprised 4% of all land cover suitable for restoration.
    c. Select cells/pixels with the above scores.
11. After examining size class distribution, select top ranking areas at least 5 acres in size. The 5 acre threshold only reduced top ranked potential restoration area by 19%.
    a. Grid name: pot_rest_sites
    b. These totaled 69,593 acres (around 2.5% of the three eastern counties).
    c. Of these, 18,157 acres (26% of b) were on land owned by USFWS, TPWD, NPS, and TNC.
12. These are just suggestions (as are the corridors); possible candidates to consider.

Appendix C: Soil Analysis

Starr County

Kim Wahl (USFWS South Texas Refuge Complex) divided the soils of Starr County into categories and compared them to geological features. The soils delineated floodplains from uplands well. She also categorized these soils into the potential for restoration. In Starr County, restoration was more difficult due to erosion, bedrock, and salinity issues, compounded by climate.

In Figure A, the green and blue soils had the best potential for restoration. Green, red, and blue soils were important for protection/conservation. The tans and browns had low potential.

Green - Riparian and floodplain vegetation. Soils fertile and highly suitable for restoration.

Red - "Ramaderos" - these are deep-soiled drainage ways, have a higher moisture gradient, and can support denser and taller vegetation.

Blue - These soils had potential for restoration and could support dense thornforest.

Tan - These soils were higher in salinity and natural vegetation would be more sparse. Although many of these soils are important for endangered plant conservation, they are not suitable for restoration of dense thornforest.

Yellow - These were deep, eolian sands, not suitable for restoration.

Brown - These were shallow soils, not suitable for restoration, and thornforest vegetation would not be as dense as areas highlighted in blue.

Gray - These were remnant pits from areas mined for caliche.

Black - Water or seasonal depressions - not suitable for restoration but important water sources.

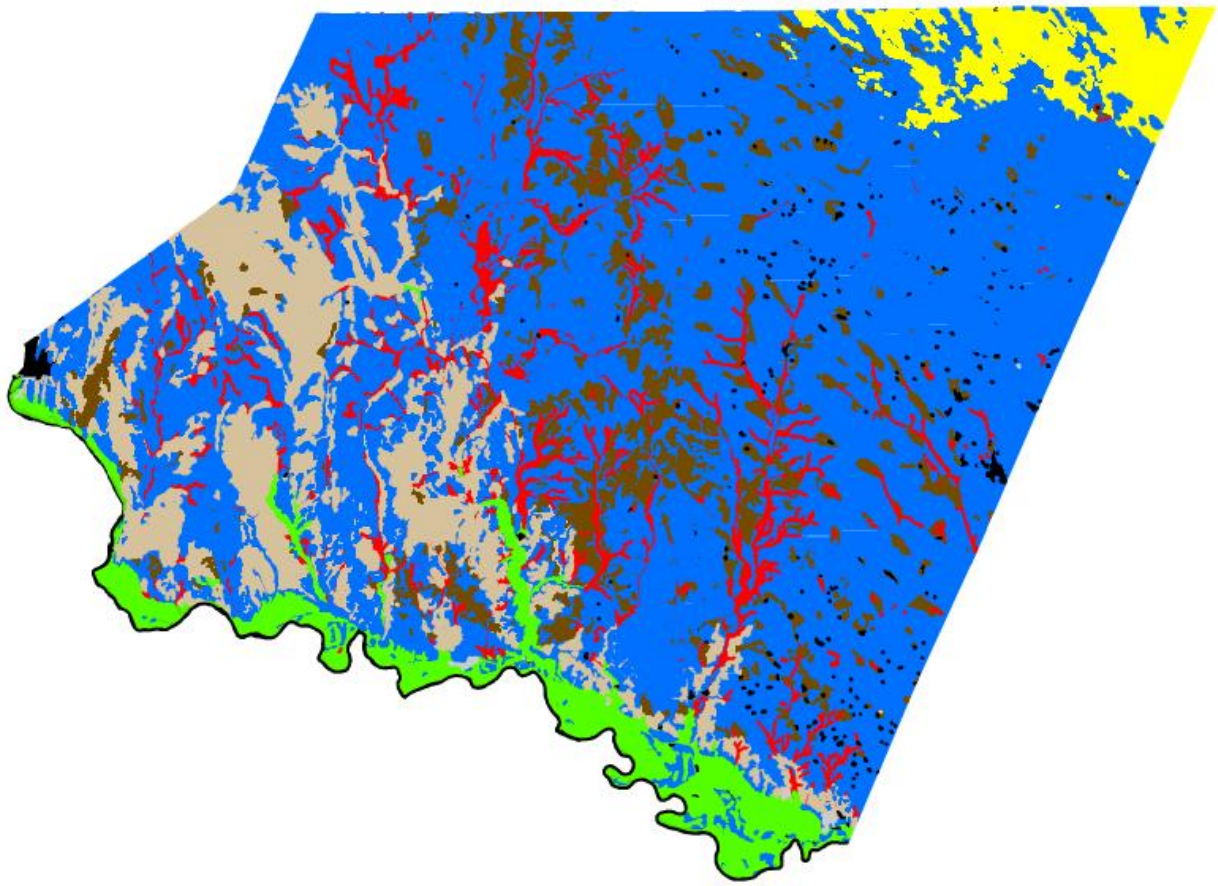


Figure A. Soil categories in Starr County. See text for explanation.

Hidalgo County

For Hidalgo County (Figure B), the green and blue soils below had the best potential for restoration. Green, red, and blue soils were important for protection/conservation.

Green - Riparian and floodplain vegetation. Soils fertile and highly suitable for restoration. Would sustain taller trees, and important for birds.

Blue - These soils had potential for restoration and can support dense thornforest. Much of these areas were suitable for crops, and many of these areas had been cleared and were still under cultivation.

Tan - These soils were higher in salinity and natural vegetation will be shorter in stature and more sparse.

Yellow - Deep eolian sands, which pose difficulties for forest restoration, or may be more suitable for grasslands with mottes.

Gray - Manmade features (levees, dams, borrow pits, landfills, etc).

Black - Prone to ponding water after heavy rainfalls. Important features on the landscape, but not good areas for investing in planting trees.

Light blue - Permanent and seasonal wetlands or waterways.

Red - "Ramaderos" - these were the deep-soiled drainage ways, have a higher moisture gradient, and can support denser and taller vegetation.

Brown - Shallow soils, not suitable for thornforest restoration due to high cost investment/low survival rates. Natural vegetation is not as dense as areas highlighted in blue due to the underlying bedrock.

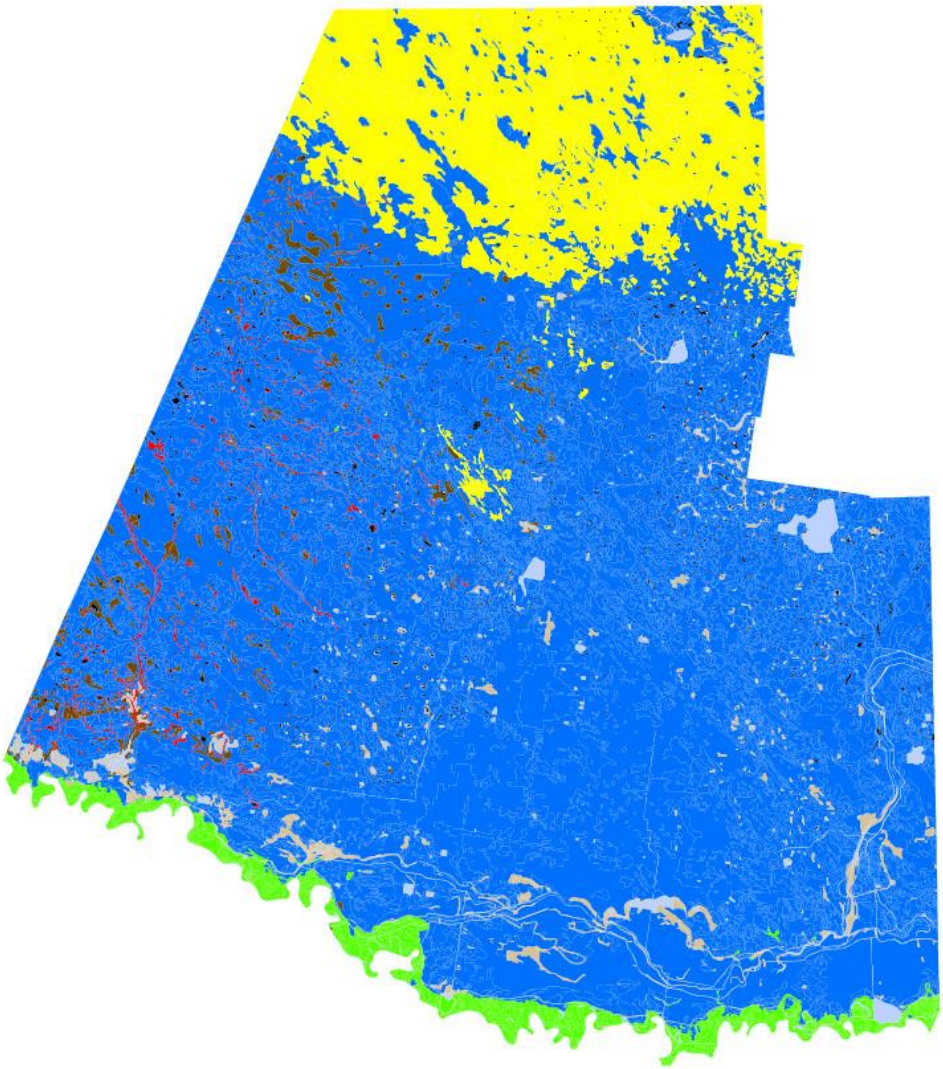


Figure B. Soil categories in Hidalgo County. See text for explanation.

Willacy County

For Willacy County, Kimberly Wahl-Villarreal (USFWS) looked primarily at restoration potential and viability. She examined three main criteria for excluding soils: deep sands (issue of restoration costs; however, suitable habitat may currently exist within those areas that would be priorities for preservation), high levels of salinity (some areas may be on a gradient from low stature/low-moderate dense thornforest to salt-tolerant grasses to open salt flats), and low permeability/prone to ponding and flooding during seasonal rainfalls (restoration investments would be lost during heavy rain events).

In Figure C, the green and blue soils had the best potential for restoration.

Green - Riparian vegetation along the Arroyo Colorado. Soils fertile and highly suitable for restoration. Would sustain taller trees, and important for birds.

Blue - These soils had potential for restoration and could support dense thornforest. Much of these areas were suitable for crops, and many of these areas are still under cultivation.

Tan - These soils were higher in salinity, and natural vegetation would be shorter in stature and more sparse, to coastal grasses, to open salt flats. However, these soils were not highly productive for crops, so much of this area has not been heavily disturbed through the cultivation of crops, but is used for grazing.

Yellow - Deep sands, which pose difficulties for forest restoration or may be more suitable for grasslands with mottes or in more coastal areas with a higher salinity, more suitable for alkali grasses.

Gray - Manmade features on the landscape.

Black - Prone to ponding water after heavy rainfalls. Important features on the landscape, but not good areas for investing in planting trees.

Light blue - Permanent and seasonal wetlands.

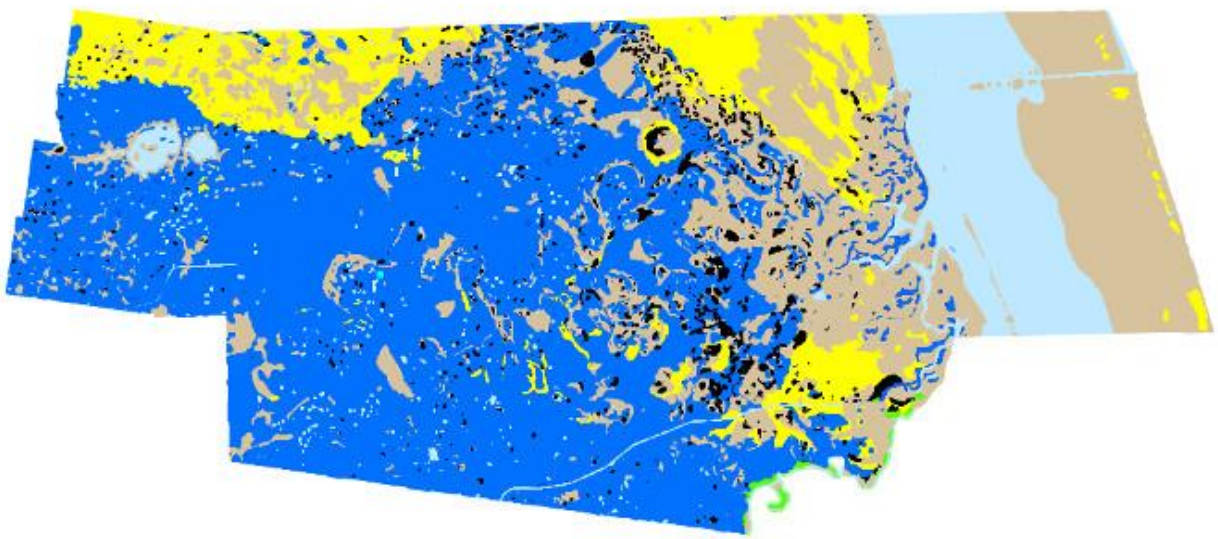


Figure C. Soil categories in Willacy County. See text for explanation.

Cameron County

For Cameron County (Figure D), the green and blue soils below had the best potential for restoration.

Green - Riparian vegetation along the Arroyo Colorado and Rio Grande, as well as some along resacas. Soils fertile and highly suitable for restoration. Would sustain taller trees, and important for birds.

Blue - These soils had potential for restoration and could support dense thornforest. Much of these areas were suitable for crops, and many of these areas are still under cultivation.

Tan - These soils were higher in salinity and natural vegetation would be shorter in stature and more sparse, to coastal prairie, to open salt flats. Some of these areas also represent beaches and sand dunes.

Gray - Manmade features on the landscape.

Black - Prone to ponding water after heavy rainfalls. Important features on the landscape, but not good areas for investing in planting trees.

Light blue - Permanent and seasonal wetlands.

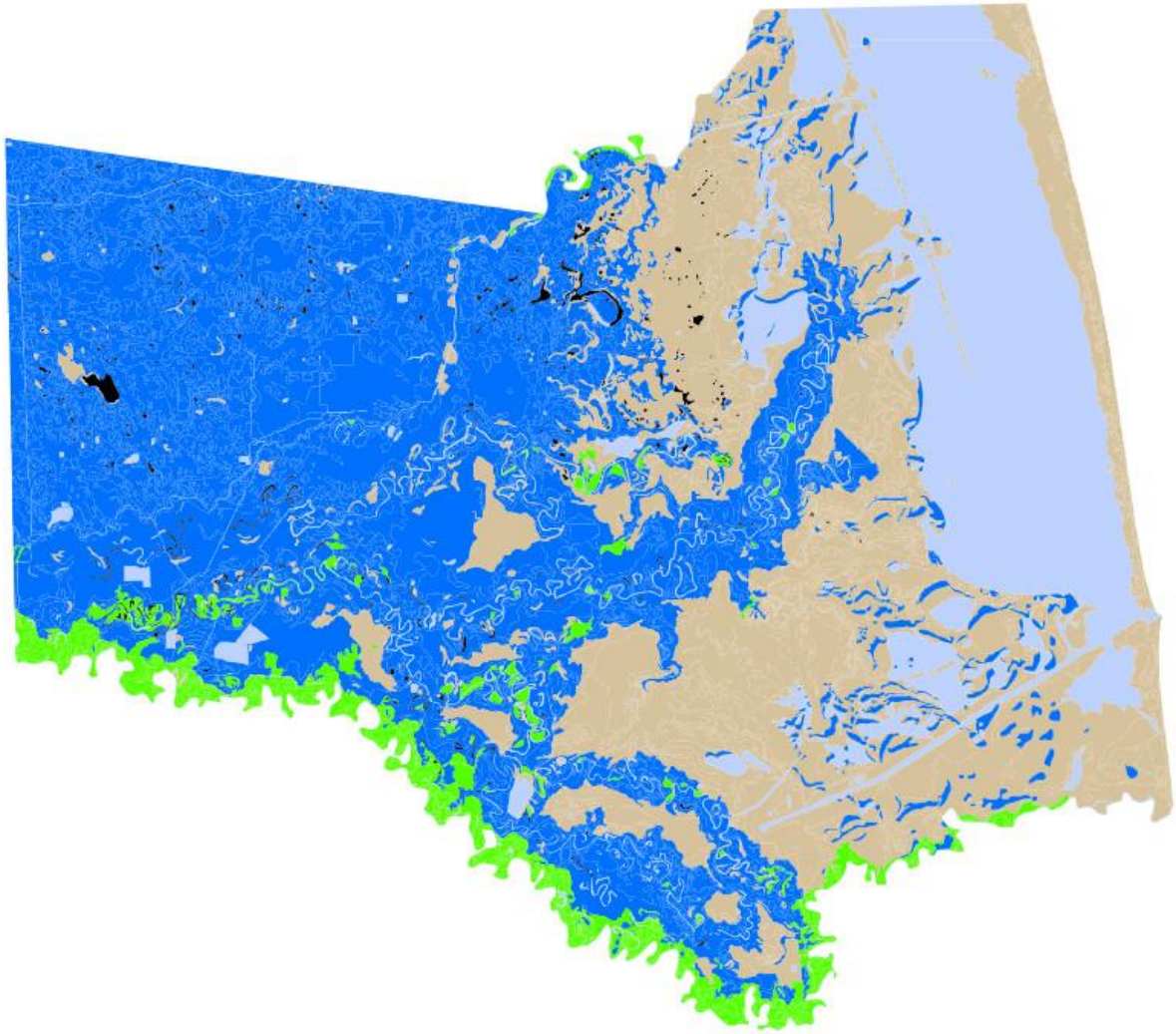


Figure D. Soil categories in Cameron County. See text for explanation.