ABSTRACT

Title of Thesis:	ON THE VERGE: A DESIGN FRAMEWORK USING LANDSCAPE ECOLOGY AND EDGE DESIGN PRINCIPLES TO RECONNECT HABIATAS AND DIVERSIFY VEGETATION FOR POLLINATORS IN SE TEXAS
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Pollinators are a crucial part of our ecosystem providing benefits for plant reproduction, plant diversity and agricultural crops. Pollinator habitats are constantly under threat due to human activity including pesticide use, land use change and development, pollution, and climate change. With an increase of development there is also a decrease in connectivity between natural habitats which causes habitat fragmentation and a loss of pollinators. This thesis suggests that by using landscape ecology principles and other research, a design framework that provides 1) connectivity between existing natural areas, and 2) increasing vegetation community diversity will lead to increased quantity and quality of pollinator habitat and thus more overall pollinators. This design framework is demonstrated in a case study in Hidalgo County, Texas in the Rio Grande River basin.

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by

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Dedication

To my family, this is for us.
Para mi familia, esto es para nosotros.

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Thank you all.

Table of Contents

List of Figures

List of Abbreviations

RGV- Rio Grande Valley

RGR- Rio Grande River

LRGV- Lower Rio Grande Valley

BSP- Bentsen State Park

NBC- National Butterfly Center

SANWR- Santa Ana National Wildlife Refuge

TPWD- Texas Parks and Wildlife Department

USFWS- U.S. Fish and Wildlife Service

NABA- North American Butterfly Association

TCP- Thornforest Conservation Partnership

Y2Y- Yellowstone to Yukon

Chapter 1: Introduction

Pollinators are critical to the preservation of healthy ecosystems. Biodiversity and ecosystem services are being lost because of fragmenting natural habitats (Tscharntke et al., 2016), and it is important to protect pollinator habitats because "pollinators provide an essential ecosystem service to humankind" (Fontaine et al., 2006). Pollinator habitats are constantly under threat due to human activity including pesticide use, land use change and development, pollution, and climate change. Increasing population directly impacts the need for housing as well as the need to devote more land to agriculture. Developing natural land into urban or agricultural areas results in both a loss of total pollinator habitat as well as reducing the connectivity between remaining natural landscapes. Losing these vital habitats decreases the amount of vegetation diversity, thus decreasing the overall number of pollinator populations. According to Theobald et al., (2010), we are losing a football field of natural areas every 30 seconds in the United States, which adversely impacts many species including pollinators.

This thesis suggests that by using landscape ecology principles and other research, a design framework that provides 1) connectivity between existing natural areas, and 2) increasing vegetation community diversity will lead to increased quantity and quality of pollinator habitat and thus more overall pollinators. This design framework is demonstrated in a case study in Hidalgo County, Texas in the Rio Grande River basin. Typical land uses in the case study area include residential, commercial, agriculture, transportation, recreational areas, and natural areas. Restoration plans and designs in the publicly held natural areas in the case study area provide an opportunity for connectivity.

Hidalgo County is experiencing an over 10% growth rate, over the last 10 years, and new development for suburbs is displacing natural areas or farmlands. There is a competition for space to either grow food or create housing. New urban development results as a disconnect between patches of greenspaces like state parks and wildlife management areas, a decrease of plant diversity, and a decrease of habitat for pollinators (Wenzel et al., 2020). The proposed design framework will address both connectivity and vegetation community diversity to support that pollinator habitat is conserved, restored, and connected when land around the Rio Grande River develops due to the urban and suburban expansion or other land use change.

The thesis will be organized into five chapters: introduction, literature review, site inventory and analysis, design framework, and conclusion and summary. Chapter 2: Literature Review will explore principles of landscape ecology, the relation between plant diversity and pollinator diversity, roads, stakeholder groups and applied case studies. The design framework principles will be derived from the literature, creating a framework that will increase habitat and connectivity, increasing the vegetation diversity, and therefore, enriching the overall health of pollinator habitats. Chapter 3: Site Inventory and Analysis will document the case study's land use, hydrology, vegetation, and open spaces, while noting the sites opportunities and constraints. Chapter 4: Design Framework will provide guidelines, plans and designs for promoting edge design along roads and farmlands that benefit pollinators. The design will create a connection between green spaces using landscape ecology and edge design principles, and increase vegetation structural diversity, thus increasing pollinator habitat. Chapter 5: Summary and Conclusion provides a review of the objectives of the thesis, a conclusion discussing the design framework, benefits, limitations, and an overall summary of the thesis.

Chapter 2: Literature Review

This thesis will develop a design framework after understanding design principles from landscape ecology and edge design, the relation of plant diversity and pollinator diversity, roads and their benefits or disadvantages to pollinators, stakeholder groups and applied case studies. The literature review is organized into five sections. The first section will investigate selected concepts and principles from the landscape ecology discipline, such as landscape mosaics: patches, corridors, and edges. The second section broadly reviews pollinator types and their food, habitat, nesting and water needs, and the influence of plant diversity on pollinator diversity. The third section will document benefits or detriments of roads in relation to pollinators and pollinator habitat. The fourth section will discuss groups and organizations that are stakeholders in the Rio Grande Valley. The last section will investigate precedent case studies that are successfully helping pollinator habitats at a variety of scales.

Section1: Landscape Ecology

Ecology is the study of interactions among organisms and their environment (Forman, 1995). Landscapes are “formed by two mechanisms operating together within its boundary specific geomorphological process and specific disturbances of component stands” (Forman and Gordon, 1981). Landscape ecology is the study of spatial patterns that provides scientific basis for the study and management of landscapes and their ecological systems (With, 2019). Landscapes can be studied at any scale and can occur in terrestrial systems and even aquatic and marine systems (With, 2019).

Landscape Mosaics

Landscape mosaics show an "existence of clear boundaries between neighboring patches" (Hansson and Merriam, 2012) from an aerial view. Landscape mosaics, especially ones with "barriers, conduits, and highly heterogeneous areas, determine the resistance to flow or movement of species, energy, materials, and disturbance over a landscape" (Forman, 1996). In natural areas, boundaries may be less evident than in urban areas due to being heavily altered by humans (Hansson and Merriam, 2012). The overall health of a landscape can be identified by the overall connectivity of the natural systems present (Dramstad et al., 1996).

Forman (1995) suggests that there are three mechanisms which create spatial heterogeneity within a landscape— substrate heterogeneity, natural disturbance, and human activity. Substrate heterogeneity is related to the soil types, hills and wet spots on a landscape which create vegetation patchiness. Natural disturbances are natural disasters like tornadoes, fires, and pest explosions, all of which will create heterogeneity within a landscape (Forman, 1995). Human activity is also a major cause of heterogeneity. Building roads, cutting down woodlots, and plowing fields will all cause heterogeneity within a landscape. After alterations in the landscape, whether by natural or anthropogenic events, a visual difference will be evident as landscape mosaics.

Landscape mosaics are composed of three characteristics: patches, corridors, and background matrix (Forman, 1995). Background matrixes are often developed lands like agricultural or urban areas (Bentrup, 2008). Patches are remnants that are surrounded by different plants and animal communities (Bentrup, 2008). Corridors are the link between patches and are usually valuable and suitable for biodiversity (Bentrup, 2008). The arrangement of landscape mosaics can affect the ecological systems interacting between them (Hansson and Merriam, 2012).

Patches

A patch is a wide homogeneous area that differs from its surroundings (Forman, 1995). Patches can be diverse in size and provide a variety of benefits for their inhabitants. Small patches are able to capture a range of habitats and are able to protect biodiversity in areas with limited space (Bentrup, 2008) while large patches often provide major ecological benefits (Forman, 1995).

There are ecological values of both large and small patches. Patch sizes and their benefits are often up for discussion; some believe having a single large patch is more beneficial for species, while others believe that smaller patches are more beneficial (Forman, 1995). Small patches, while valuable, cannot be the sole replacement for large patches. Due to the ever-changing landscapes, like development, large patches can quickly transform into small patches. The more land a species has to inhabit the greater number of species are able to thrive— smaller patches have less resources for species. A landscape without large patches gets eviscerated (Forman, 1995) for its limited resources, unfortunately smaller patches are the dominant form of natural habitat on Earth (Haddad et al., 2015 as cited in Tscharntke et al., 2016). A healthy landscape should have large patches with supplemental smaller patches (Forman, 1995).

While patch size is important, shape always plays a crucial factor in ecological movement and flow. Human activity plays a direct role in the formation of patch shapes. Shapes affect the ecological function of patches and there are four attributes to the patch shapes: elongated, convolution, interior, and perimeter (Forman, 1995)

Elongated patches are more efficient than round patches along areas like agriculture fields, or forest areas, but are less effective in conserving internal resources of a patch (Forman, 1995). Since these patches are long, research suggests that orientation plays a key role in the positioning and success of these patches (Forman, 1995). Patches perpendicular to an animal's route will slow down their movement because they will be more cautious when approaching the boundary (Forman, 1995). Patches placed parallel to the movement of the species may enhance their movement (Forman, 1995).

Convoluted patches have longer perimeters, and more lobes which can cause turbulence in water and wind flow (Forman, 1995). The lobes offer benefits by forming microclimates, creating shaded areas during the hot days, and blocking wind during windy times (Forman, 1995). Interior patches are often protected from solar radiation and wind and are generally a critical area for species that require remote habitats (Forman, 1995). Perimeter patches are surface boundaries with infinite vegetation varieties. They are everything surrounding the interior patch. Identifying the elongation, convolution, interior, and perimeters of patches determines the shape and ecological characteristics of a patch.

The further patches are from each other, the less abundant the pollinators are. The diversity of pollinators decreases in disconnected habitats (Rahimi et al., 2021). In ag land centric areas pollinators are dependent on nearby natural landscape patches (Olsson et al. 2015, as cited in Rahimi et al., 2021). A habitat with an abundance of natural areas compared to those of agricultural lands would result in species spillover to the surrounding fields (Kammerer et al., 2016, as cited in Rahimi et al., 2021).

Corridors

Corridors are strips of land that differ from the adjacent land on both sides (Forman, 1995). Corridors are interconnected landscape elements like wildlife habitats, riparian areas, wetlands, and prime agricultural areas (Ndubisi et al., 1995). Corridors help increase gene flow and population viability, enable recolonization of patches, and provide habitat for a variety of species by creating connectivity between patches (Bentrup, 2008).

Corridors have five functions: habitat, conduit, filter, source, and sink. Corridors are habitats to edge and generalist species; rare and endangered species are usually absent (Forman, 1995). There are two types of corridor habitats: line corridors and strip corridors. Line corridors are narrow and dominated by edge species. Strip corridors are wide enough to have interior species (Forman, 1995). The transportation or conduit through corridors are like rivers or roads moving things along them. Corridors can also function as boundaries; filtering species trying to cross between patches (Forman, 1995). Once a corridor has been established, you may find species that spread out while utilizing it to cross between patches causing a diversifying effect on the matrix (Forman, 1995). Corridors can act like a sink collecting soil, water, chemicals, and seeds from the environment (Forman, 1995).

Corridor widths can vary in size, even within the same corridor. It is useful to measure the width at different heights above the ground. Larry Harris and colleagues, as cited in Forman (1995), have recommended corridor widths for three different objectives. The first being when the movement of individual animals and their behavior is well known you can have a corridor width of tens of meters. Secondly, when you are considering an entire species and there is a lot of knowledge about them, the corridor will be hundreds of meters wide. If there is a lot known about the species, they can anticipate them using the corridors more frequently, thus justifying the wide width. Finally, when you are considering an entire assemblage of species that you know little about and expecting it to function for decades or hundreds of years, corridor widths should be measured in kilometers. Not having great knowledge of any singular species encourages a larger width to accommodate the variety of species that could potentially use the corridor.

Bentrup (2008), provides suggestions regarding the design of corridors. Managers should design corridors to perform well at several scales, and along dispersal or migratory routes of species. It is beneficial to have similar vegetation in corridors and their connecting patches and preferably have them be wide corridors of a minimum of one hundred’ for invertebrates. To avoid expanding fragmentation, Bentrup recommends using existing corridors like roads or utility corridors, and to focus on edge design. While constructing a planting plan for edge design, it's crucial that plants closest to the roads are smaller in height to reduce the potential of vehicle-wildlife collisions. It is also important to select the correct plants that can survive along busy roads and are more tolerant to pollutants.

Boundaries and Edges

"Linear habitats such as hedgerows, crop margins, and roadsides have been shown to have value to other invertebrate pollinators, primarily butterflies" (Munguira and Thomas, 1992).

Edges are described as the outer portion of a patch that differs from the interior of the patch (Dramstad et al., 1996). Often the edge and interior look different and can have different species composition and abundance. Boundaries can be political, or administrative and divided between inside and out. As human development continues, edges will be created dividing what is natural and human made (Dramstad et al., 1996). The shape of a patch can be defined by its edge and can be manipulated to accomplish ecological functions (Dramstad et al., 1996).

Forman (1995) describes three mechanisms that produce vegetation edges— a patchy physical environment, natural disturbances, and human activity. Boundaries can be differentiated by being hard or soft. Edges are generally high density and have a high diversity of plant species differing from the inner portion of species. To understand the boundaries, we recognize three important spatial scales: fine scale, intermediate scale, and broad scale. Fine scale boundaries are blown down clearings adjacent from grasslands or roads. Intermediate scale boundaries are created by landforms where a ridge meets a valley bottom. Broad scale boundaries separate climatic regions, tectonic plates, and biomes. Boundary patterns between two ecosystems are curvilinear, or straight.

Edges can influence communities by acting as a filter or barrier, which is particularly helpful to reduce invading species (Fonseca, 2008). Some species are sensitive to the conditions found in the interior and having that outer edge habitat is crucial to their survival (Clift, 2018). The population of species along the edge is normally different from those inside the patch (Clift, 2018). Edges are thought to have a higher biodiversity than the inner habitat, such as ecotones, which are soft edges with “a gentler transition between two environments” (Clift, 2018). Edge structures will diverse horizontal and vertical plantings are richer in species (Dramstad et al., 1996).

Edges are the first to receive pesticides around agriculture areas due to wind and water flow. Conservation buffers can help block the spread of pesticides onto pollinator habitats. Bentrup in (2008), recommends when designing buffers to use vegetation with a chemical tolerance, to use a mixture of plant sizes to fill in gaps, and placing buffers in areas where they would intercept prevailing winds. Plant palettes are recommended to have species that- bloom for entire growing seasons, natives, mixed plant heights, and plants that do not host pests. To decide where to place edge buffers and which plants to plant, sun studies should be taken into consideration. Plants should be selected based on their sun needs and their ability to get sun after placement

Oxbow Lakes

According to the Resource Enhancement and Protection Conservation Education Program (2019) and the Nature Conservancy, oxbows are U-shaped cut offs of rivers because of natural and human activities. Agriculture runoff, drainage improvements, and development are all causes of sediment buildup which create blockage between river bends. Restoring the riparian edge of an oxbow can improve water quality, wildlife habitat and increase flood water storage. It is best to plant native grasses, forbs, plant a quick growing nurse crop, and to utilize fallen trees as in-water structures for wildlife.

Section 2: Pollinators

There are many diverse types of pollinators, each with unique benefits to plants and vegetation communities. They are essential to the reproduction of plants and help with the production of genetically diverse vegetation. Pollinators play a necessary role in our ecosystem, providing "pollination services to over 180,000 different plant species and more than 1,200 crops" (About Pollinators, n.d.). Major pollinators groups include butterflies, bees, birds, bats, beetles, flies, and moths.

Butterflies

There are more than 700 species of native butterflies in the United States (Marks et al., 2005). During the four stages of their life cycle, egg, caterpillar, pupa, and adult, butterflies need different things for each stage. Eggs can be on leaves, branches, trees, shrubs, wildflowers, grasses, and soil (Marks et al., 2005). Caterpillars will eat host plants before they turn into pupas. While pupas don't need to eat, they do need protection and will utilize tall grasses, piles of leaves and bush (Marks et al., 2005), and butterflies will rely on nectar from flowers.

Bees

There are over 4,000 native bee species in the United States (Marks et al., 2005), and over 700 species in Texas (Warriner and Hutchins, 2016). Honeybees are essential to crop pollination and play an important role in the ecosystem. Bumblebees "live in colonies, share work, and have multiple overlapping generations throughout the spring, summer and fall" (Marks et al., 2005). Solitary bees, approximately 90% of Texas natives (Warriner and Hutchins, 2016), do not live in hives or colonies, but nest in dirt mounds, termite holes, mud, plant resins, and the ground (Marks et al., 2005).

Birds

Birds are the most helpful to plant species that are sparsely distributed (Ford 1985, as cited in Sekercioglu, 2011). Birds fertilize plants by transferring pollen from their bills from one plant to another. In North America, there are no commercial crops that rely on birds for pollination (Cirino, 2016). Birds pollinate wildflowers, but birds are suffering due to the decrease in wildflower habitats due to monoculture agriculture (Cirino, 2016). Hummingbirds are essential to pollinating many shrubs and vines and pollinate flowers as they drink nectar from them (Marks et al., 2005). Hummingbirds and other birds visit flowers that are typically tubular, have tubes, funnels, cups, supports perching, brightly colored like red, yellow, or orange, odorless, and open during the day (About Pollinators, n.d.).

Bats

Bats are essential for tropical and desert climate vegetation. Many fruits rely on bats, like "banana, mangoes, dates, figs, peaches, guava, avocado and agaves" (Marks et al., 2005). There are 45 species of bats in the United States, with the greatest concentrations living in the southwestern states (Marks et al., 2005). Two nectar feeding bats, the lesser long-nosed bat, and the Mexican long-tongued bat, which migrate north thousands of miles in the spring from Mexico to Arizona, New Mexico, and Texas, are federally endangered species (About Pollinators, n.d.) Bats are nocturnal, making them beneficial to nocturnal blossoms (Marks et al., 2005). Bats typically visit flowers that are large, pale, or white in color, and very fragrant (About Pollinators, n.d.).

Beetles and Flies

There are over 30,000 beetle species found in the United States (Ley et al., 2018). They have a bad reputation because they leave behind a mess and destroy flowers, but they still play a role in pollination (Ley et al., 2018). Beetles are important to species such as magnolias and spicebush (About Pollinators, n.d.). Beetles visit flowers that are open during the day, bowl-shaped, white, dull white, green, strongly scented, large solitary flowers, or small bunches of flowers (About Pollinators, n.d.). Flies typically visit flowers that are pale, dark brown or purple, have putrid odors like rotting meat, carrion, dung, humus, sap, and blood (About Pollinators, n.d.).

Moths

Moths, while at a glance look like butterflies, have distinct features that tell them apart (Ley et al., 2018). Moths are typically less colorful, and hairier than butterflies, and they have antennae that are featherlike (Ley et al., 2018). The majority of moths are nocturnal, which is important for night blooming flowers (Marks et al., 2005). Moths need habitats similar to butterflies. Moths typically visit flowers that are in clusters, white or dull in color, open in the late afternoon or evening, and flowers that produce ample nectar (About Pollinators, n.d.).

Plant Diversity Relation to Pollinator Diversity

In previous decades, declines of pollinator populations have been recorded worldwide. This raises concerns about the loss of the important ecological function of pollinators for wild plant communities and agricultural systems (Potts et al. 2010). One way to combat the decline of pollinator populations around agriculture areas is to "enhance plant diversity at multiple spatial scales ranging from local fields to surrounding landscapes" (Kremen & Miles, 2012; Kennedy et al., 2013 as cited in Isbell et al., 2017). The number of foraging niches positively correlates with the number of nectars, pollen profiles, and flower types available (Potts et al., 2003) eventually leading to pollinator diversity.

The relationship between plant diversity and pollinator diversity is mutualistic and will directly influence one another. Experimental evidence directly reveals that plant communities could be negatively affected by a loss of pollinator diversity (Fontaine et al., 2006). The number of pollinators in an area has a direct impact on the ability to increase plant population birth rate. Increasing plant species richness will positively affect pollinator diversity and pollination services (Orford et al., 2016 as cited in Isbell et al., 2017). The richness of a plant palette helps a variety of pollinator species because pollinators differ in floral preference and have diverse needs for their individual life cycles.

Diversity of plants is equally as important as the number of plants in one area. In a study, conducted by Ebeling et al in 2008, they comprised 82 plots with plants having six levels of species richness to determine how plant richness affects pollinator richness. They discovered that plots with one flowering plant received around 20 pollinator visits, where plots with twelve flowering plant species had over 200 pollinator visits over the same period of time. This shows that having more diverse plants provides an increase in floral resources like nectar and pollen. The study's results state that "plant species richness, blossom cover and the presence of attractive plant species enhanced the temporal stability in frequency of pollinator visits" (Ebeling et al., 2008). High diversity of plants and the frequency of pollinator visitations can be critical to the success and stability of plant communities.
The diversity of crops is also affecting the density of pollinators. A study conducted by Raderschall, and colleagues (2021), showed that an increase of crop diversity in the landscape enhanced the densities of bumble bees. This study also showed that farmland near semi natural habitats supported higher densities of managed and wild bees (Raderschall, 2021). Increasing the pollinator densities will benefit crops and incentivizes farmers to have agri-environmental schemes.

Food

Flowers are a great source of food for pollinators because it provides them, nectar, and pollination services. Native bees are only able to get food from nectar and pollen (Warriner and Hutchins, 2016). Fallen fruit is also food for pollinators like bees, beetles, and butterflies. Butterflies need host plants to be eaten by their larvae in the early stages of development. Planting diverse plants with a variety of colors, fragrance, heights, and bloom periods will attract different pollinator species (Ley et al., 2018). Most pollinator species benefit from sites with "a diverse array of native herbaceous and woody plants" (Warriner and Hutchins, 2016), so they will have food for a longer period of time.

Plants and Reproduction

Pollinators need different plants for different stages of their lives. Sites with diverse native herbaceous and woody plants are the most beneficial to pollinators (Warriner and Hutchins, 2016). Rich native plant assortments increase the availability of suitable egg-laying sites (host plants) for butterflies and moths (Warriner and Hutchins, 2016). Host plants play a key role in the ability for pollinators to continue multiplying. Some pollinators are reliant on a single species as host plants, while other pollinators are able to utilize a variety of plants. For example, Monarch butterflies (*Danaus plexippus*) are dependent on milkweed (*Asclepias*) plants during their egg laying (Warriner and Hutchins, 2016). It's important to plant vegetation in groups to increase pollination efficiency (Ley et al., 2018.)

Shelter and Nesting

To provide pollinators protection from severe weather conditions and predation, it is vital to have sites for nesting and roosting. Incorporating plants with varying heights like trees, shrubs, and perennials, provide the most opportunities for pollinators to find shelter (Ley et al., 2018). Dead trees can be a great nesting site for pollinators and should be left alone when possible (Warriner and Hutchins, 2016). Leaving soils uncovered in some areas provides nesting sites for insects that are ground nesters (Ley et al., 2018). Bees are central place foragers. Female bees collect all their food from one central point on the landscape— their nesting site (Warriner and Hutchins, 2016). The nesting site for bees can be categorized into three categories, ground nesters, tunnel nesters, and cavity nesters (Warriner and Hutchins, 2016), which is why it's important to ensure space for all their needs. Cavity nesters and generalist species usually benefit more from urbanization than ground nesters and specialists (Wenzel et al., 2020). Cavity nesters can utilize buildings, while ground nesters have less bare soil due to high intensity lawns, and sealed surfaces (Wenzel et al., 2020).

Water

Water is a necessity for pollinators, not just for drinking, but for bathing and obtaining mineral nutrients (Marks et al., 2005). It is important that fresh water is available for pollinators, free from pesticides (Marks et al., 2005), and other pollutants. Pollinators get most of their water from food, for example, caterpillars that eat plants which are mostly made of water.

Section 3: Roads

In the United States, roadsides encompass more than 10 million acres of land (Forman et al., 2003) through agricultural and urban areas. While roads are beneficial to humans, they can create a disconnect between habitats for pollinators. Roadsides offer several benefits to pollinators, including food, nesting and breeding sites, and shelter. Since roads are causing fragmentation through natural areas, roadside plantings can provide corridors between patches for pollinators. Road corridors are linear surfaces used by vehicles usually with vegetated parallel strips on either side (Forman, 1995). These roadside corridors are particularly important for pollinators in areas with highly altered landscapes, such as intensely managed agricultural lands and urban areas (Remley and Redmond, 2017). Planting for pollinators along roads also brings other benefits like "stabilizing roadsides, reducing stormwater pollution, supporting wildlife, and increasing public appreciation of the local landscape" (Remley and Redmond, 2017).

Often, a common concern in creating these diverse habitats along roads is that they increase the likelihood of pollinators getting killed by vehicles, but it actually helps reduce this issue (Remley and Redmond, 2017). When pollinators do not have the abundance, they are looking for on one side of the road they will venture off onto the other side to see if there are more resources available— causing them to be within the boundaries of fast-moving cars. If we increase the diversity and volume of plants on both sides of the road, we reduce the need for pollinators to cross to the other side to reap the benefits of flowering plants. There was a study done to evaluate this theory of pollinators crossing the road.

The study was performed, at the University of Michigan in 2021, by doctoral students Gordon Fitch and Chatura Vaidya, which evaluated to see how much of an impact road had on pollinators' ability to utilize plants along both sides of the roads. Using three plants, the students placed two on one side of the road and the third on the opposite side; all plants were placed at an equal distance from each other. The side with two plants had one of them with a luminous pigment, which was applied to the reproductive structures of the flowers. At the end of the day, the plants were brought back to a dark room to use an ultraviolet flashlight to see and record the number of flowers that had the pigment on them. The study showed that the single plant across the road had 50% less pigment than the plant on the same side of the road as the pigmented plant. The size of the road also plays a role in the reduction of pollen transfer from plant to plant. The more lanes a road had and the wider it was, the less pollinators were able to cross. Large or medium size roads obstruct the movement of bees and lowers their ability to forage and pollinate on the other side of the road. Roads pose a significant barrier for pollinators, and this study was one of the first that proved it.

Depending on the location of the road, pesticides can play a large and detrimental role with pollinators. If the roads are along farmlands, it is important to have a buffer between the diverse high-volume pollinator plantings, and crops to reduce the amount of pesticide going onto the plants. If the roads are just along urban areas, you can reduce the effects of pesticides by carefully spot spraying or completely avoiding spraying pesticides, communicating with landowners about the effects of drifting pesticides, and overall, being more conscientious about the type of pesticides used (Remley and Redmond, 2017).

In addition to pesticides and vehicular tragedies, pollinators also face other issues along roads like different forms of pollution. With plantings along roads, we expose pollinators to pollutants like “noise, light, exhaust fumes, dust and metals” (Forman et al., as cited in Philips et al., 2020). The more vehicles along roads, the more pollution, and the greater risk for pollinators to be poorly influenced. Loud noises from the speeds of vehicles and traffic can defer pollinators from foraging along roadsides (Phillips et al., 2020). A study performed by Phillips and colleagues sought the impacts of pollutants on pollinators along road verges. The results of this study note that despite originally thinking road plantings would become ecological traps for pollinators, they can have an advantageous impact. The study showed that pollinators are willing to and able to move away from pollution. The researchers still recommended having at least two meters between the high-density plantings, and road edges (Phillips et al., 2020).

Bentrup (2008), advises plants along roads be made up of a variety of colors, textures, form, and height. Areas closer to the road should have the most detail because they are what people driving by will see. Plantings for pollinators include “wildflowers, native bunch grasses, shrubs, and trees that provide pollinators with food or shelter” (Remley and Redmond, 2017). Bentrup also suggests ensuring safety, by designing and placing buffers that will allow view of oncoming traffic at intersections. To design near intersections, you need to have a view called the "site triangle," whose location is determined by the vehicular speed in that area. Setbacks are 70ft at 15 mph, 90 ft at 20 mph, 170 ft at 30 mph, 195 ft at 40 mph, 245ft at 50 mph, and 285ft at 55mph (Bentrup, 2008).

Section 4: Stakeholder Groups

Farmers

Farmlands are an essential part of our livelihoods. With the need for food to support the growing population, we often choose farmlands at the expense of biodiversity (Foley et al., 2005). Farmlands are mostly monocultures or potentially rotated with only a few other crops throughout the year. Pollinators play an essential role to the success of farmlands. Globally, $577 billion worth of annual food production relies on direct contributions by pollinators (IPBES, 2016, as cited in Betts et al., 2019). With the decline of pollinators, we can see adverse consequences on food production (Winfree et al. 2018 as cited in Betts et al., 2019) and native biodiversity (IPBES, 2016, as cited in Betts et al., 2019). While the relationship between farmlands and pollinators is a mutualistic one, pollinators respond positively to a more diverse planting palette. In an area with less natural habitats, pollinators are forced to venture out further to forage, utilizing more energy (Maurer et al., 2020, as cited in Rahimi et al., 2021). There is evidence supporting the notion that having plant diversity and natural areas around farmlands will increase pollinators and help with weed and pest suppression (Isbell et al., 2017), increasing crop yield.

While having an increase of natural habitats and pollinators around farmlands is great, it's essential to look at the issues that could arise for them. Farmers often choose to protect their crops using insecticides, herbicides, and pesticides. Common pesticide concerns are insecticides, pesticide mixtures, fungicides, synthetic-auxin herbicides, and soil fumigants (Code et al., 2016). Insecticides are acutely toxic to pollinators, specifically neonicotinoids, because of their widespread use and insect growth regulators. Pesticides move into habitats in a variety of ways, including drifting, volatilization, getting into nearby water systems, and wind erosion (Code et al., 2016). One way to have a healthy pollinator habitat near farmlands includes adding in a pesticide free buffer to block pesticides from going straight onto pollinator plants. The pollinator habitat should be a minimum of 30 feet away from farmlands using ground-based pesticide applications, 60 feet from the use of air blast sprayers, and 125 feet from crops treated with neonicotinoids (Code et al., 2016) if there is no buffer. Design and placement of buffers would be to select a site that is upwind of pesticide use, prepare the site by pulling weeds and removing weed seeds, do not include plants that are hosts for crop pests, and avoid using pesticide once the habitat is established (Code et al., 2016).

With farming being a business, we cannot expect farmers to willingly give up their land to help pollinators. Farmers rely on their land to the full extent it has to offer, and they might not be able to financially survive without the crops produced on those acres. Other issues that arise could be that the farmers need to invest in new equipment and diverse seed mixes (Isbell et al., 2017) to tend to the land they want to utilize for pollinators. While land sparing is only beneficial to biodiversity, land sharing is beneficial to both farmers and nature (Christmann et al., 2021). One of the most readily implemented strategies to increase plant diversity is planting species rich hedgerows to border crops (Isbell et al., 2017). Other ways to increase the diversity of plants include planting weedy forbs, planting forb strips, perennial hedgerow borders, intercrops, and polycultures (Garibaldi et al., 2014, as cited in Forest et al., 2017).

Pollinator Economic Benefits for Farmers

To persuade farmers to use pollinator strips along their crops, we need to only use marketable habitat enhancement plants (Christmann et al., 2021). These plants can be wildflowers that farmers could potentially sell either in bouquets or by having a community festival where people cut their own. By having pollinator strips in and around farmlands, crop yields can increase which can lead to higher profits (USDA, n.d.). Farmers could also earn biodiversity credits by dedicating any acreage of land to pollinators and selling the credit to the Biodiversity Conservation Trust (Ecosystem Services Market Consortium, 2021). Another way to persuade farmers to plant pollinator habitat is by allowing them "to gain social capital as 'pollinator stewards' and potentially charge more for their products" (Burkle et al., 2017).

Conservation Reserve Enhancement Program

CREP is the Conservation Reserves Enhancement Program that helps agriculture producers retire land to "protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water" (USDA, n.d.). The USDA's Farm Service Agency established CREP to provide farmers with financial benefits for conserving and enhancing natural resources on their farms. The commitment time for the program is 10 - 15 years for non-agriculture production on the selected land. CREP supports practices like filter strips and forested buffers to "help protect streams, lakes, and rivers from sedimentation and agricultural runoff" (USDA, n.d.). There are currently no CREP programs in Texas.

American Forests

The American Forest Organization was established in 1875 to create “healthy and resilient forests, from cities to large natural landscapes, which deliver essential benefits for climate, people, water and wildlife” (American Forest, n.d.). American Forest has projects all over the country to help plant trees, create policy, and create resilient forests. This organization is currently working on projects in the Rio Grande Valley like the Thornforest Conservation Partnership, The Reforestation Pipeline in the Rio Grande Valley, and the Climate-Smart Forest Restoration. The thornforest restoration project is complete, planting over 100,000 trees in the RGV (American Forest, n.d.).

Thornforest Conservation Partnership

In 2018, the Thornforest Conservation Partnership (TCP) was formed to help guide conservation efforts in the LRGV. Their goals are to help communicate the importance of the thornforest habitat, educate the public about conservation, and to encourage action for stronger public policies and funding. (Thornforest Conservation Plan, 2020). The TCP developed a conservation plan to protect existing thornforest habitat and potential corridors that link habitats together (Thornforest Conservation Plan, 2020). The entire thesis site is within the Thornforest Conservation Partnership conservation area.

National Butterfly Center

The National Butterfly Center (NBC) is a 100-acre plot of land located in Mission, Texas that was formed in 1998. The NBC is a project of the North American Butterfly Association (NABA), dedicated to conservation and the study of wild butterflies in their native habitat (National Butterfly Center, 2020). The NBC is a crucial part of the NABA, because it represents the whole lower Rio Grande Valley. The National Butterfly Center brings people together from all over the county to see rare butterfly's endemic to the RGV, which helps the economy via ecotourism. Without the NBC there would not be as great of a recorded history of pollinators in the RGV. They have great resources explaining the rich diversity of species that depend on their land to survive, and even as a stop along monarch butterflies' migratory routes.

Section 5: Precedent Case Studies

The following are well known precedent case studies that have utilized landscape ecology principles including a focus on hubs and corridors for conservation planning. Three projects include the Maryland GreenPrint Program, The Florida Wildlife Corridor, and The Yellowstone to Yukon (Y2Y).

The Maryland GreenPrint Program is a green infrastructure assessment which identifies almost 2 million acres of ecologically significant land (Weber, 2003). The changing landscape due to population and development changes is destroying wildlife habitat in Maryland. Hubs and corridors were identified as a proposed network for plants and animals to maintain connectivity even with the changing landscape (Weber et al., 2004). The Florida Wildlife Corridor is a statewide corridor that was created as a landscape- scale conservation approach. The corridor encompasses nearly 18 million acres of land, 9.6 million that are already protected, and 8.1 million that have no conservation status (Hoctor et al., 2015). Their goal is to advocate for the missing links within the hubs, while educating the public about the importance of land conservation. Yellowstone to Yukon (Y2Y) is a national conservation effort connecting and protecting habitats from Yellowstone to Yukon. This is a 2,000-mile corridor that "protects habitats, keeps habitats connected and inspires others to engage in similar work" (Yukon Conservation Initiative, 2022) Their goal is to bring communities together to accomplish linking these landscapes together across Northwest America and Canada.

Texas Department of Transportation (TxDOT)

The Texas Department of Transportation (TxDOT) began its wildflower program in the 1930s. This program is participating in The Texas Monarch and Native Pollinator Conservation Plan, recognizing the decline in the population of the eastern North American migrating monarchs. TxDOT owns and maintains 1.1 million acres of roadway right-of-way in Texas. Eight hundred thousand acres of these rights-of-way are vegetated and are in all ecoregions of Texas, having a wide variety of landscapes (TPWD, 2016). These landscapes help support over 900 species of wildlife and about 5,500 species of vascular plants (TPWD, 2016).

The TxDOT program is to help “reduce the cost of maintenance and labor” (TPWD, 2016) while still creating aesthetically pleasing landscapes. Using native wildflowers upwards of 2,000 species along roads, attracts tourism while helping the environment, biodiversity, pollinator health and even the economy (TPWD, 2016). Because of TxDOT’s program, communities have come together to appreciate the blooms and hold festivals, arts and crafts shows, and even sporting events.

The flowers are mowed twice a year and timed properly to ensure seed germination to ensure next year's bloom. Texas DOT does not use traditional methods of herbicide application but rather, spot spray problemed areas. TxDOT purchases approximately 30,000 pounds of seeds to be used annually, seeding over 15,000 acres of right-of-ways (TPWD, 2016). This right of ways can create vegetation corridors helping fragmented habitats in urban and agricultural areas (TPWD, 2016).

“From an ecological perspective, grasses and wildflowers planted and/or protected through the Wildflower Program have conserved water, controlled soil erosion, and provided habitats for wildlife, including pollinators, across Texas” (TPWD, 2016).

Texas Parks and Wildlife Pollinator Management Guide

The Texas Parks and Wildlife has created a guide that best helps manage Texas pollinators. Some management techniques include treating only 30% of an area at a time (Warriner and Hutchins, 2016). Prescribed burns should only be conducted from fall to early spring to avoid burning during the growing season. It is also suggested to allow dead trees, rotting logs, and dying branches to stay on site because it can be useful for tunnel-nesting bees. Lastly, avoid the use of chemical fertilizers, as they can be detrimental to wildflowers.

Missouri Biodiversity Pilot Project

Missouri developed a program that benefits pollinator habitat, and corn and soybean farmers. The program came as a result of a partnership between Ecosystem Services Market Consortium (ESMC) and the Missouri Corn Merchandising Council and the Missouri Soybean Merchandising Council. This program will allow farmers to earn biodiversity credits by participating in this project to increase conservation habitat for pollinators. Farmers can create pollinator habitats “within existing or new field borders, buffers, waterways, or on other non-productive agricultural grounds” (Ecosystem Services Market Consortium, 2021). After doing so, farmers can obtain biodiversity credits to be purchased by interested buyers or the Biodiversity Conservation Trust. Farmers can enroll in this program with any amount of acreage, and it costs nothing for farmers to participate (Ecosystem Services Market Consortium, 2021).

Ecosystem Services Market Consortium *“is a non-profit that works to compensate farmers and ranchers who improve the environment through their agricultural practices. Our market program to reduce greenhouse gases, improve water quality, and increase other ecosystem services benefits all of society. - Quote obtained through the ESMC Website*

College Park in Prince George's County, Maryland

Residents of Prince George's County in Maryland can be a part of the county wide conversation efforts for pollinators. The county distributes seed packets scientifically developed with native plantings to help butterflies, birds, bees and more. In 2020, the Prince George's Soil Conservation District distributed over 500 seed packets.

College Park, Maryland developed an initiative called "No-mow April" to encourage their residents to refrain from mowing their lawns to support local pollinators. The city worked together with the city's Bee City USA committee to motivate homeowners to help pollinators grow and thrive during this part of their lifecycle. By mowing less, we can expect to see more colors and variety in the landscapes that attract a diverse population of pollinators. After making the pledge, residents can pick up a sign to display on their lawn to help educate the local community about the benefits of 'no-mow April.' The city also has great resources and guides on how to plant in ways that best benefit native pollinators.

Literature Review Conclusions

In conclusion, the literature review provides principles and tools to 1) provide connections between existing natural areas, and 2) increase vegetation community diversity to increase quantity and quality of pollinator habitat and thus promote an overall increase in pollinators. Landscape ecology principles inform the design at a landscape scale to address the patches and their disconnect by using corridors to reconnect these natural areas. Pollinators play a crucial role in our ecosystems, including the food we eat and ecosystem services for all organisms. Increasing the amount of vegetation diversity will increase the number of pollinators in the landscape. Roads, while having detrimental qualities, can also actually provide great benefits to pollinators when used as pollinator corridor. Designing on both sides of the road can lower the fatalities with cars because they have resources keeping them on the same side of the road. Roads can function as corridors to transport pollinators from patch to patch giving them a place to rest, eat, and providing them shelter. Financial benefits and tools that have been used with farmers include programs like the Conservation Reserve Enhancement Program. Farmers may often benefit from pollinator habitats by gaining a more productive crop, and by minimizing the usage of pesticides. There are many great examples, at the regional, state, community, and habitat level that show how both large and small implementations can provide benefits for pollinators.

Chapter 3: Site Inventory and Analysis

Chapter 3 will document the inventory and analysis for the selected case study site and local area. The site inventory documents the site context, location, and history. The three main attributes documented include abiotic, biotic, and cultural which are derived from Ndubisi (1995). Abiotic attributes document the hydrology, climate, and soil around the site. Biotic attributes document the native vegetation and native pollinators. Last, cultural attributes will document and map the land use including natural areas, farmlands, and urban areas, roads, and population demographics.

Case Study Location

The Rio Grande Valley (RGV) is made up of four counties— from west to east they are Starr, Hidalgo, Willacy, and Cameron County. The southern border for three of these counties is the Rio Grande River, which divides Mexico and the United States of America. With the climate and relative location to the equator, this area has a semi tropical climate creating a hotspot for over 300 species of butterflies (Leslie, 2016) and 150 species (Wauer, 2004), which are found solely in this area.

The case study site is in a wildlife corridor proposed by the U.S. Fish and Wildlife Service, which plans to create a corridor within the four counties of the Rio Grande Valley to protect biodiversity (Texas Parks and Wildlife Department, 2020). This project site is a small section of Hidalgo, County, along the Rio Grande River which is in the proposed U.S. Fish and Wildlife Service corridor and was selected because of its familiarity with the author and the opportunity to connect major natural greenspaces in a selected section.

The green spaces along the border are crucial to the sustainability of pollinators. The western hub of the project site is Bentsen State Park. This park was selected because of its large size, popularity among the community and its monitored species diversity. The eastern hub of the project site is the Santa Ana National Wildlife Refuge. The wildlife refuge was selected because of its large size, management goals, and its accessibility. The southern boundary of the site is the Rio Grande River.

Figure 2 Site Context Maps of Texas and the Counties of the Rio Grande Valley

Figure 1 Counties of The Rio Grande Valley

History

The proposed project site is located within Hidalgo County, which is part of the four counties that make up the Rio Grande Valley. The Rio Grande Valley has a rich recorded history dating earlier than the 16th century before explorers arrived. Today, the RGV is home to over 1.4 million people and growing. Agriculture and animal husbandry are the leading industries in the Rio Grande Valley. The Rio Grande Valley is in a subtropical climate with the ability to grow crops all year round. The second and third largest industries are mining and recreation which includes national and state parks, fishing and hunting, and summer and winter resorts (Brand and Schmidt, 2020). The warm temperatures make the RGV a biodiversity hotspot for many rare species of birds and butterflies, which bring in ecotourism.

The RGV is actively growing and there has been a lot of habitat destruction due to development causing habitat fragmentation. To combat the rising issues of habitat fragmentation, the U.S. Fish and Wildlife Service plans to create a "wildlife corridor" within the four counties of the Rio Grande Valley to protect biodiversity (Texas Parks and Wildlife Department, 2020).

Abiotic Attributes

Hydrology

The Rio Grande River is the southern border of Texas and partially the northern border of Mexico. The Rio Grande River is 1,855 miles long and the fifth longest river of North America (Brand and Schmidt, 2020). The watershed of the RGR is

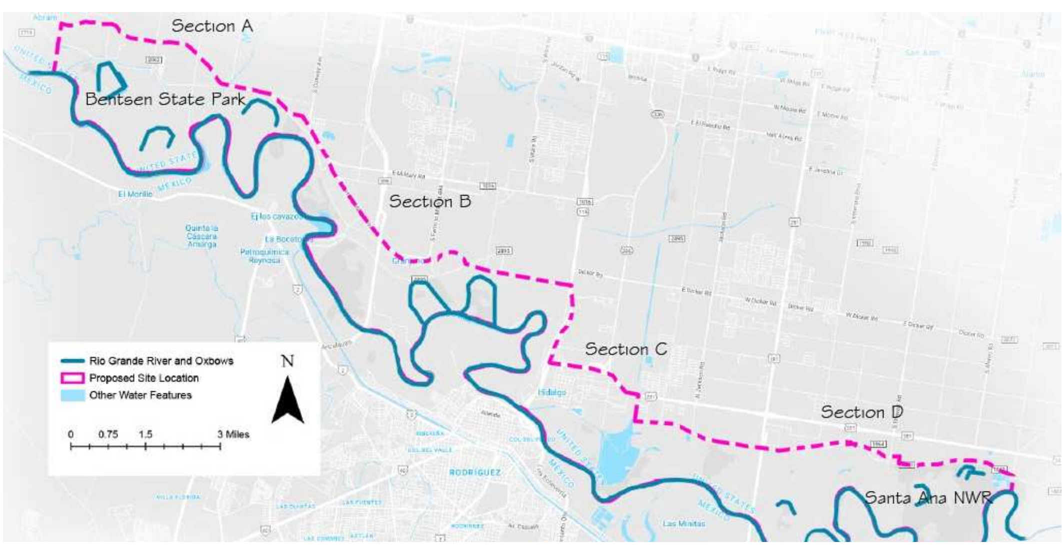


Figure 3 Hydrology Map Along Proposed Site

close to 336,000 square miles and crosses through Texas, New Mexico, and Colorado, as well as Mexican states like Chihuahua, Coahuila, Nuevo Leon, and Tamaulipas (Brand and Schmidt, 2020). The river flows into the Gulf of Mexico.

Climate

Average Monthly Temperatures

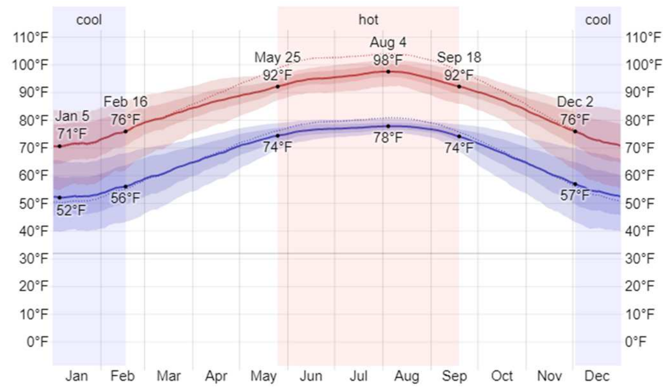


Figure 4 Average Monthly Precipitation in Hidalgo, County

The Rio Grande Valley has a subtropical climate which means it's warm to hot most of the year. Average temperatures for winter are around 52°F - 57°F, and summer temperatures are 92°F - 98°F. The coolest month is January, and the warmest month is August. Warmer temperatures make for a longer growing season benefiting many tropical plants.

Annual Average Monthly Rainfall

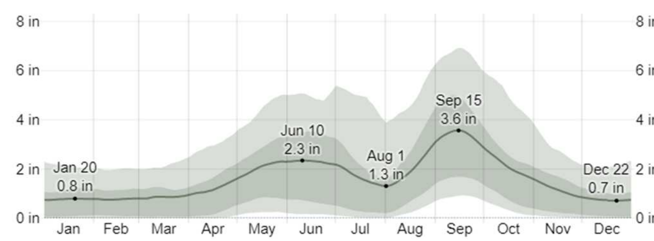


Figure 5 Average Monthly Rainfall

Hidalgo County gets an annual precipitation of 22.8 inches. The wettest month of the year is September with an average of 3.6 inches of precipitation. The driest month of the year is December with an average of 0.7 inches.

Average Wind Direction

Wind is most often blowing in from the South for 7.1 months between January and August, and two months from October to December. Wind coming from the East happens for 1.4 months between August and October. The wind only comes from the North for 1.5 months between December and January.

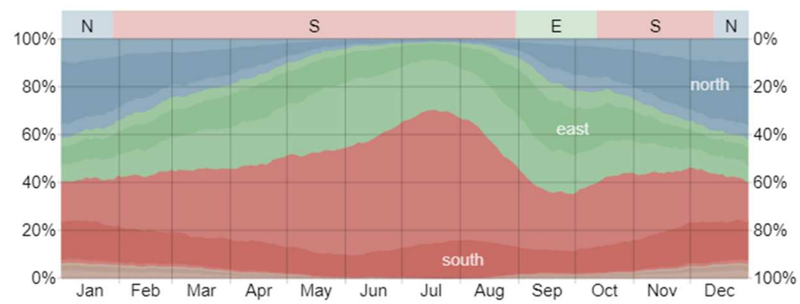


Figure 6 Average Wind Direction in Hidalgo, County

Average Annual Growing Season

The growing season is the longest continuous period of non-freezing temperatures in a calendar year. The temperatures are rarely below freezing in the area making the growing season very long. There are even comfortable temperatures in winter months like January and December.

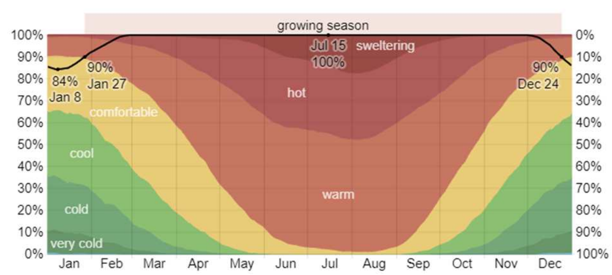


Figure 7 Annual Growing Season for Hidalgo, County

Soils

There are twenty-four identified soils within the boundaries of the proposed site. The three soils that make up most of the area are Rio Grande silt loam, Matamoros silty clay, and Reynosa silty clay loam. Rio Grande silt loam makes up 32.60% (4,103 Acres) of the site and is the predominant soil type. Rio Grande silt loam is mostly cropland soil under cotton, grain, sorghum, and a variety of cool season vegetables. Vegetation that best survives in this soil are hackberries, Rio Grande ash, cottontop and plains bristle grass (Rio Grande Soil Series, 2009).

Matamoros silty clay makes up 15.60% (2,710 Acres) of the site and is the second most predominant soil type. The Matamoros silty clay is mostly for irrigated cropland soil with a less than 1% slope and “consists of deep, moderately well drained, slowly permeable soils” (Rio Grande Soil Series, 2003). Crops using this soil are cotton, grain sorghum, sugarcane and “native vegetation consists of sacaton grass, cottontop grass, plains bristle grass, common bermudagrass, hackberry, Rio Grande ash, and mesquite trees” (Rio Grande Soil Series, 2003).

Reynosa silty clay loam makes up 10.20% (1,774 Acres) of the site and is the third most predominant soil type within the site. Reynosa silty clay loam consists of deep, well-drained soil. The slopes are usually less than 1% but can get up to 3% in some areas (Rio Grande Soil Series, 2000). This soil is primarily cropland for cotton, grain, sorghum, and also hosts native grasses such as little bluestem, Texas winter grass, and bristle grass (Rio Grande Soil Series, 2000). Woody plants that thrive in this soil include mesquite trees, sprint hackberry, lotebush, black brush, and common hackberry (Rio Grande Soil Series, 2000).

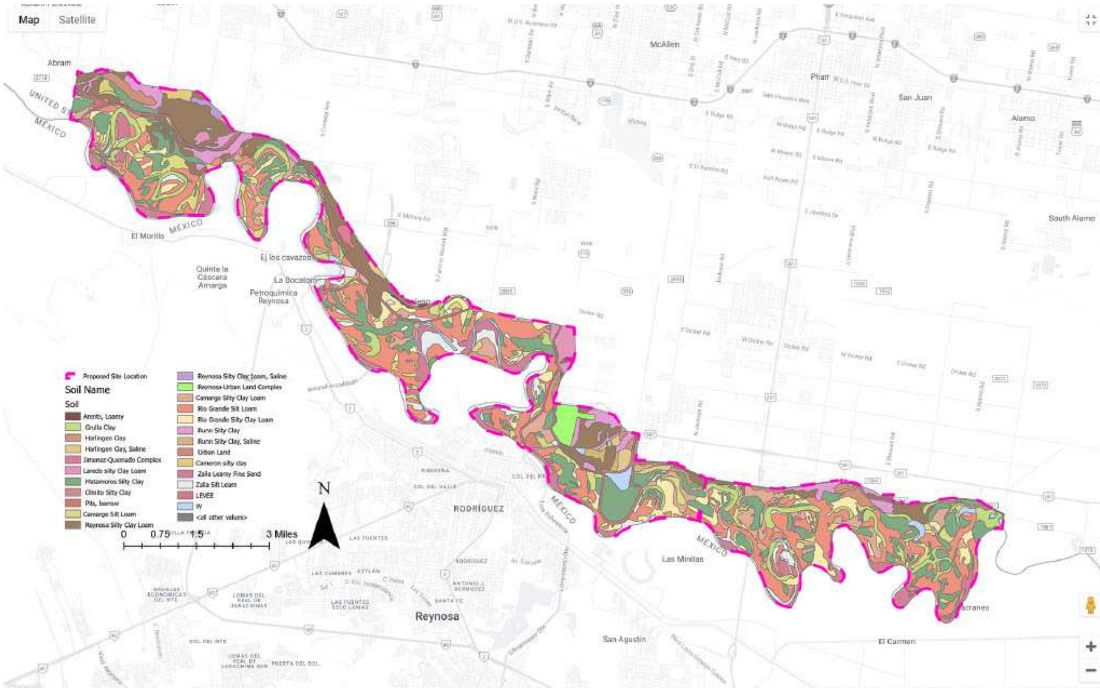


Figure 8 Soil Map in the Proposed Site

Biotic Attributes

Vegetation

The Lower RGV is in the plant hardiness zone 9b (USDA n.d.). The RGV is part of the “brush country” which encompasses the southern end of Texas. Typical plants in the brush country include mesquite, black brush, brasil, and other thorny plants (Taylor, 1998). The RGV has four counties bordering the Rio Grande River, so there are also many vegetation species around its riparian area like willows, hackberries, ashes, and mesquite.

Pollinators

There are over 325 butterfly species in the Rio Grande Valley and hundreds to thousands more pollinators like bees, moths, flies, bats, birds, and beetles. The National Butterfly Center provides a Butterfly Checklist from 2021 with over 90 species, out of the 243, that could only be found in the RGV. The RGV is along the monarch butterflies' migratory path to and from Mexico.

Cultural Attributes

Land Use

Land use has also caused declines in biodiversity through the loss, modification, and fragmentation of habitats; degradation of soil and water; and overexploitation of native species (Pimm and Raven as cited in Foley, et al, 2005). There is a total of 17,387.91 acres within the site boundaries. The three mainland uses on the site are natural areas, farmlands, and urban areas.

Figure 9 Land Use Type within the Proposed Site

Natural Areas

Natural areas are the most abundant land use on the proposed site. These natural areas consist of state, national, county, and local parks, wildlife management areas, as well as thornforest habitat. There are 10,551 acres of natural area within the four sections of the proposed site. The two end caps of the site are natural areas chosen for their similar goals of conserving pollinators and wildlife habitat. The end caps are Bentsen State Park to the west and the Santa Ana National Wildlife Refuge to the east. Two other well-known management areas are the National Butterfly Center, and Anzalduas County Park.

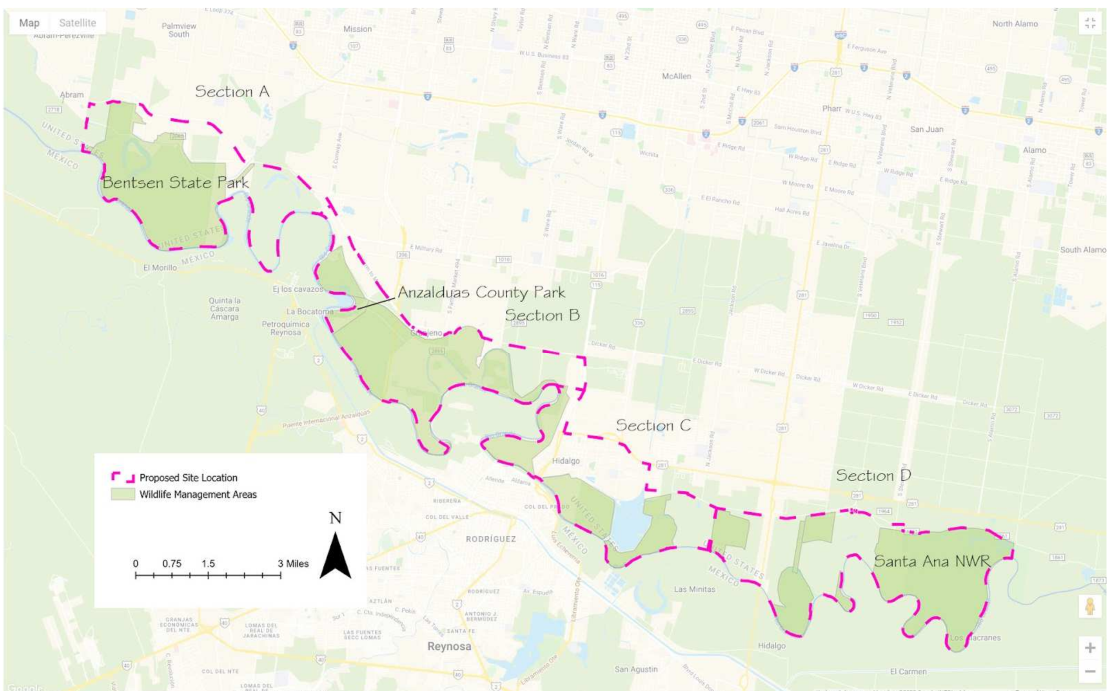


Figure 10 Natural L:and Use within the Proposed Site

Bentsen— Rio Grande Valley State Park

Bentsen State Park is a 797-acre park located in Mission, Texas established in 1962 and hosts the park headquarters for the World Birding Center. Over 360 bird species have been recorded in the park along with butterflies, javelinas, and bobcats. The park has a mix of wetland, brush, riparian, and woodland habitats (Texas Parks and Wildlife Department, 2020). The park's native plants include trees like the Montezuma bald cypress, Sabal palm and Texas wild olive which cannot be found anywhere else in North America (Texas Parks and Wildlife Department, 2020). Bentsen State Park is the western hub of my site and in section A.

National Butterfly Center

The National Butterfly Center (NBC) is a 100-acre plot of land located in Mission, Texas that was formed in 1998. The NBC is a project of the North American Butterfly Association (NABA), dedicated to conservation and the study of wild butterflies in their native habitat (National Butterfly Center, 2020). The primary focus of the butterfly center is to educate the public about the importance of biodiversity and the key role butterflies have on maintaining a healthy ecosystem. The National Butterfly Center is in section A of my proposed site.

Anzalduas County Park

Anzalduas Park is a 96- acre grassland park located in Mission, Texas established in 1951 and is best known for their birding. The area is open to the public for recreational and educational events. The site is along a bend of the Rio Grande River allowing for fishing and bird watching. The Anzalduas Park is located in section B of my site.

Santa Ana National Wildlife Refuge

Santa Ana National Wildlife Refuge (SANWR) is a 2,088-acre area located in Alamo, Texas and was established in 1943 to aid in the protection of migratory birds (U.S. Fish and Wildlife Service, 2020). The SANWR is open to the public and dedicated to conserving the area for native plants and wildlife while educating the public about the importance of conservation. The refuge also has 14-miles of walking trails to be emerged in nature and have better visibility of birds and butterflies. The wildlife refuge has approximately “400 bird species, 450 types of plants and half of all butterfly species found in North America” (U.S. Fish and Wildlife Service, 2020). The Santa Ana National Wildlife Refuge is the eastern hub of my project's scope in section D.

Farmlands

Farmlands is the second largest land use in the proposed site with an area of 4,974 acres. Crops being grown within the site are grains, citrus, cotton, corn, potatoes, sorghum, and sugarcane. Section C, which has the largest urban area, has the least amount of farmland. Farmlands are crucial to the economic wellbeing of the Rio Grande Valley.

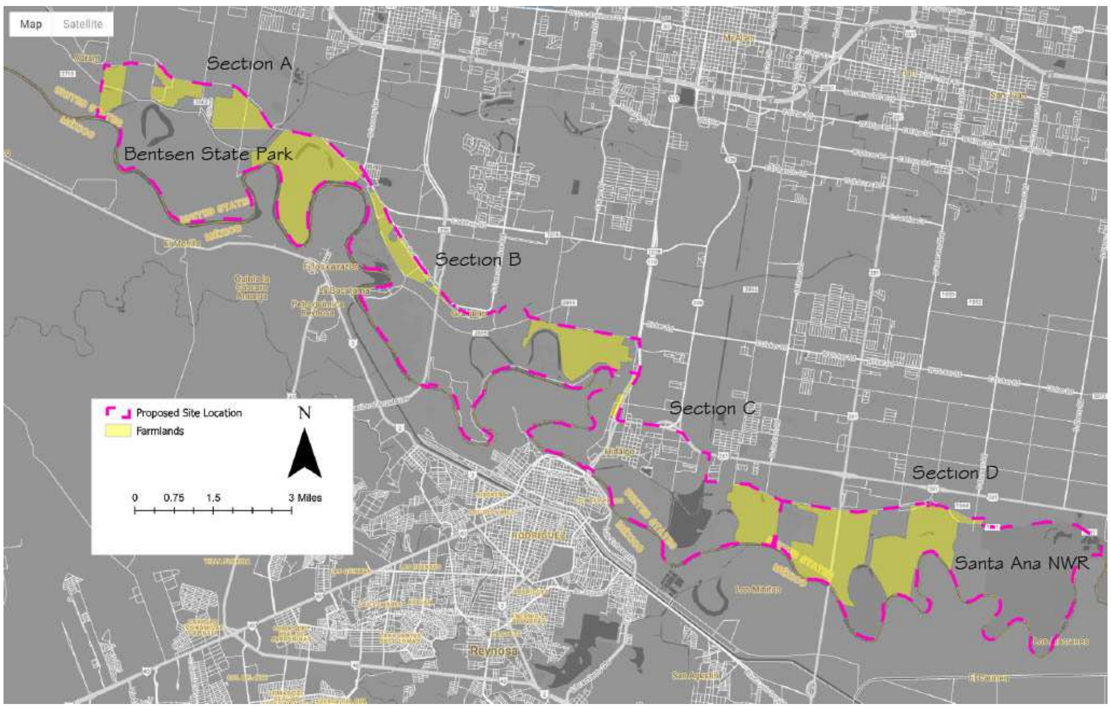


Figure 11 Farmland Land Use within the Proposed Site

Urban Areas

There are six cities with boundaries within the site from West to East: McAllen, Mission, Hidalgo, Pharr, San Juan, and Alamo. The total area of urban land use within the site is 1,479.4 acres. There are no urban areas in section D and minimal areas in sections A and B. The main city within the site is Hidalgo, Texas, located in section C. The urban area is mixed use, having commercial properties as well as residential areas. With Hidalgo having a main border crossing from Mexico, this area has a lot of imported goods. In Hidalgo County, 67% of the population live in single unit family homes.

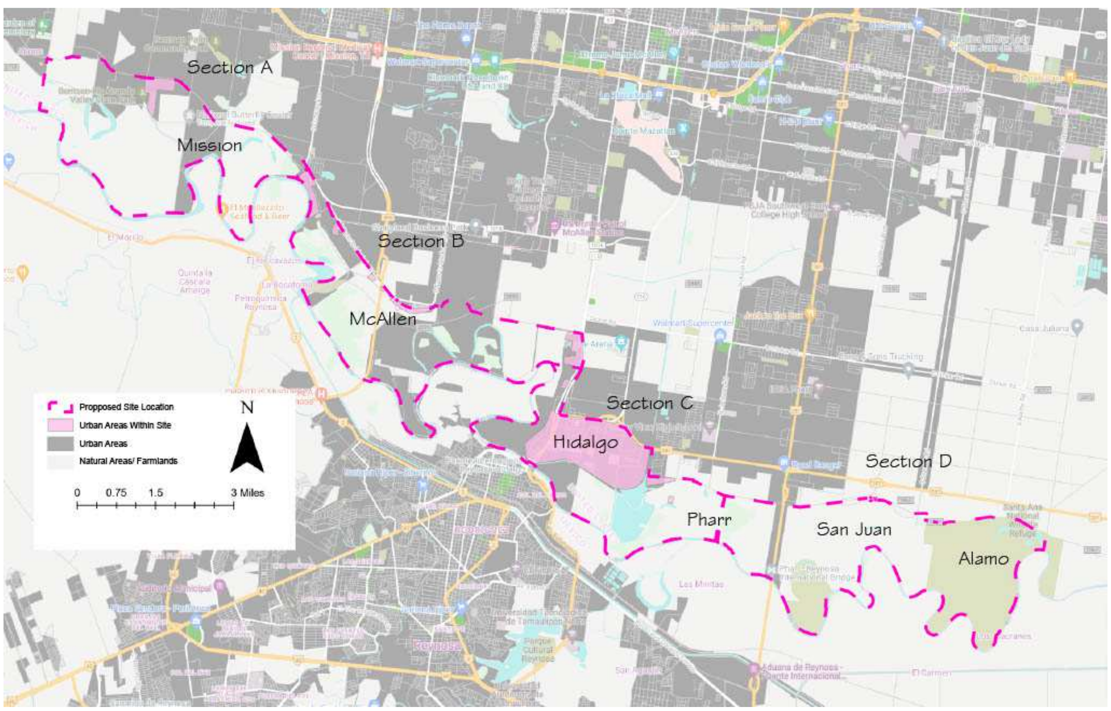


Figure 12 Urban Area Land Use within the Proposed Site

Roads

This region of Texas does not have a lot of public transportation. Cars are the main source of transportation even for everyday necessities; walking to stores, restaurants or for recreation is not common. In Hidalgo County, 70% of homes own 1-2 cars, 20% own 3-4 cars, 2% own more than 5 cars, and only 7% of homes have no cars. Within the site, there are 92 miles of road which does not include dirt roads.

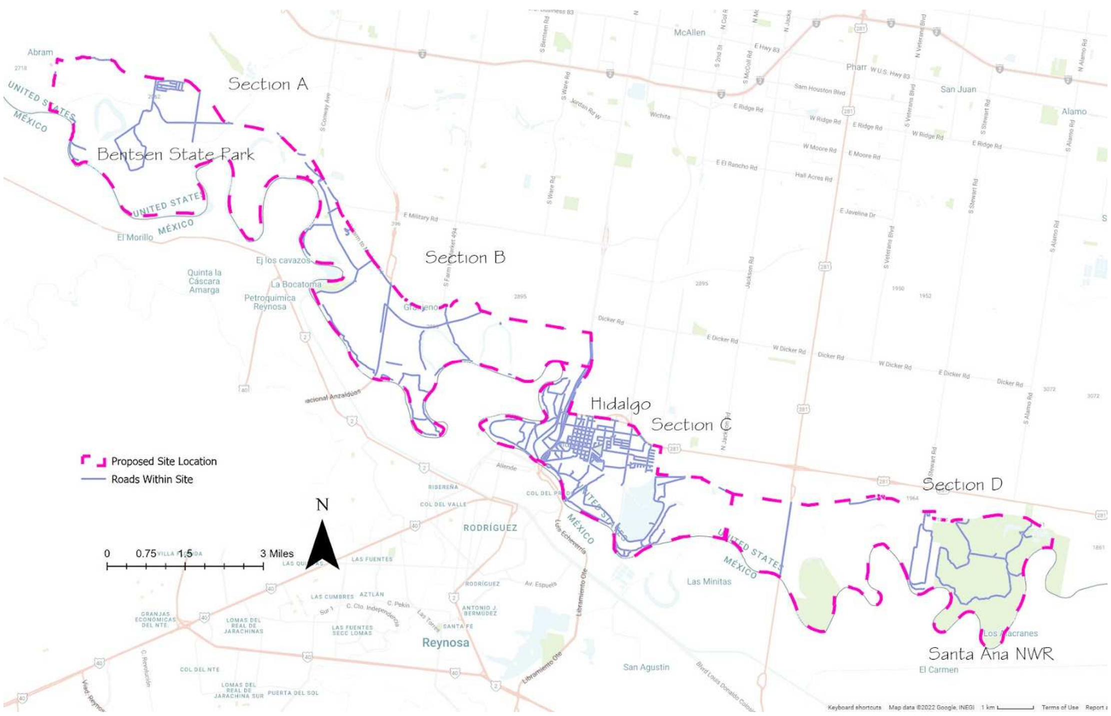


Figure 13 Main Roads within Proposed Site

Population Demographics

The population of the Rio Grande Valley is growing rapidly. In Hidalgo County, from the 2010 census to the 2020 census, we saw a population growth of 12.4%, or 95,985 people. In Cameron County, there was a 3.6% population increase of 14,797 people. In Starr County, there was an 8.1% population increase of 4,952 people. In Willacy County, population dropped by 1,970 from 2010 to 2020 with a decrease of 8.9%. Ethnicity in the RGV is 93.53% Hispanic/ Latino and 6.47% Non-Hispanic/ Latino. Race for the total RGV population of 1,402,340 is: White 87.71%, Black/African American 0.60%, American Indian/Alaskan Native 0.35%, Asian= 0.71%, Native Hawaiian/Pacific Islander 0.02%, Some Other Race 9.18% , 2+ Races 1.43%.

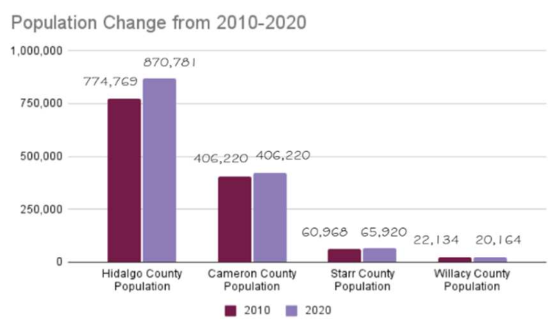


Figure 14 Population Change for Hidalgo, County

Infrastructure

Due to the location of the site being along the Rio Grande River in South Texas, the border wall runs in segments within the boundaries of the proposed site. While issues do arise due to the habitat destruction needed to build the wall it will not be taken into major consideration for this project because most pollinators are able to go through, up, and around the wall.

Site Analysis

Section A is the Eastern hub of the proposed site, selected because of the Bentsen State Park. Natural areas are enclosed by farmlands on almost every side. There are opportunities to reconnect natural areas by utilizing road verges and restoring oxbow lakes that lay within farmlands.

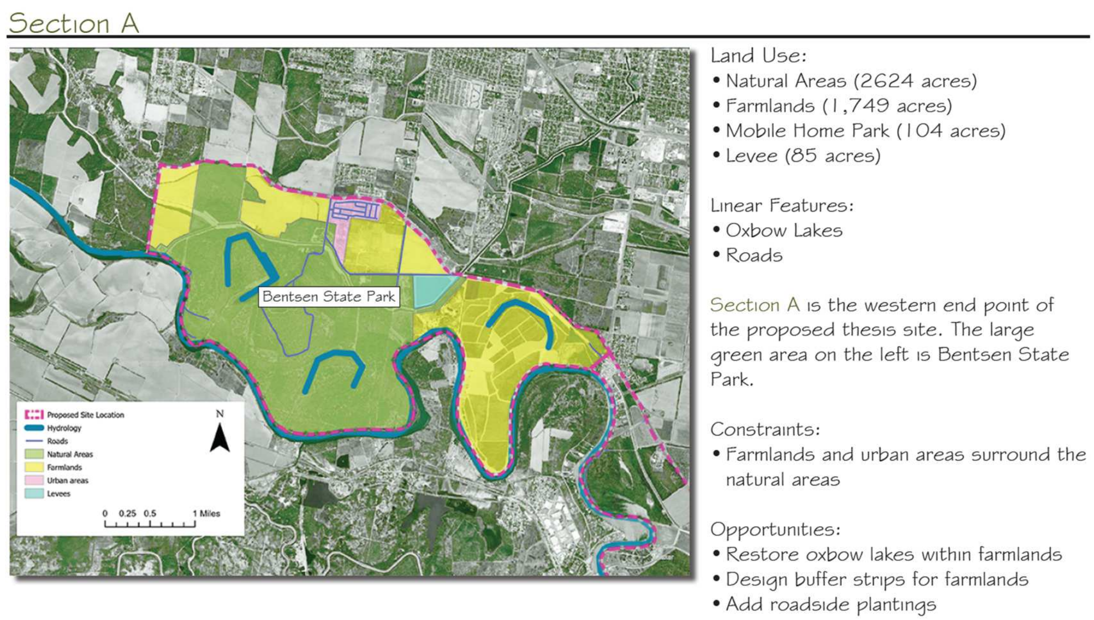


Figure 15 Section A Site Analysis

Section B has the second largest natural area of the four site sections. Section B has two functioning oxbows, which are recommended to enhance by increasing vegetation diversity. This site has the largest intact green space. This section has farmlands on either side of its large natural area patch.

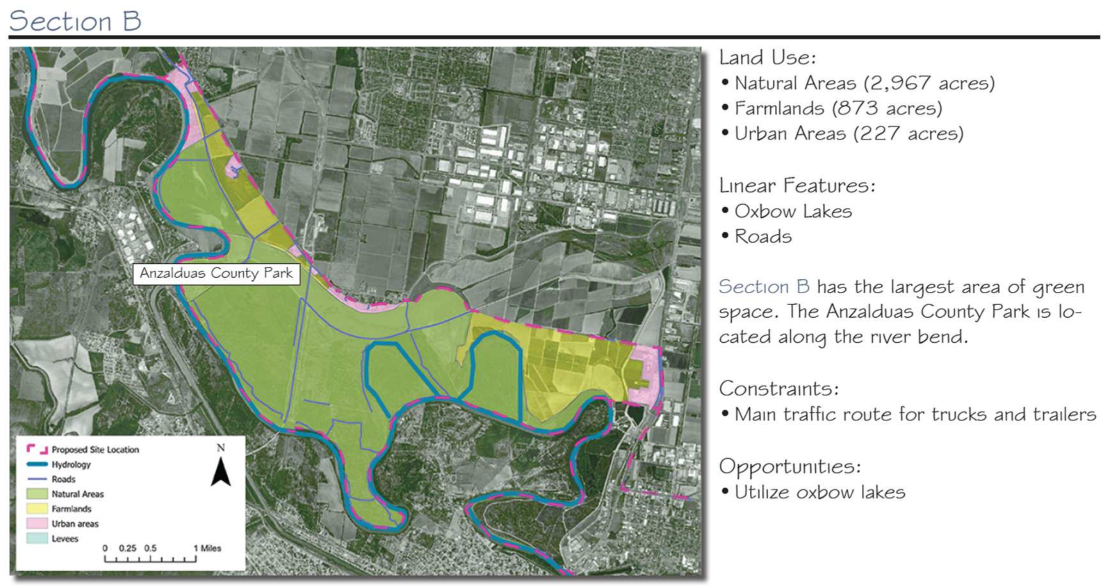
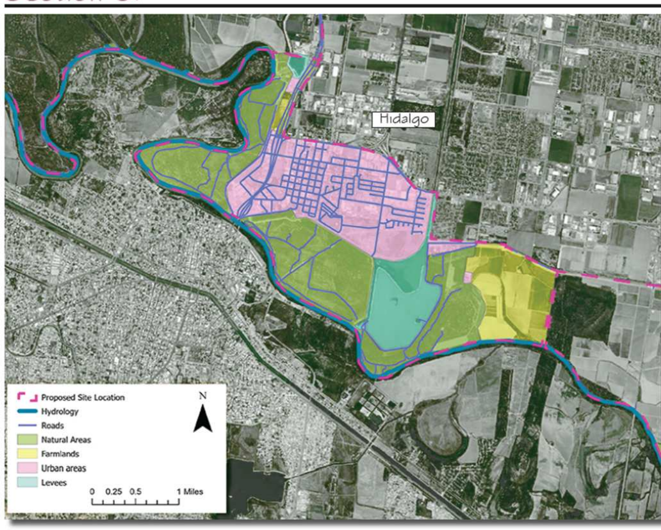


Figure 16 Section B Site Analysis

Section C has the largest urban area of all four sections with a total of 1,143 acres. This section has a portion of the city of Hidalgo, which is the main border city between Mexico and the United States within the proposed site. The city is encroaching on the natural areas to the east and west increasing the space between them causing habitat fragmentation. There are opportunities to develop a street tree program that allows refuge for pollinators.

Section C:



Land Use:
- Natural Areas (1654 acres)
- Farmlands (635 acres)
- Urban Area (1,143 acres)
- Levee (243 acres)

Linear Features:
- Roads

Section C is the section with the largest urban area. This site encases part of the city of Hidalgo which is a main border crossing between Texas and Mexico

Constraints:
- The city is high density urban on either side of the border
- Main border crossing
- Many roads

Opportunities:
- Add roadside plantings
- Suggest urban plantings

Figure 17 Section C Site Analysis

Section D has the largest acreage of natural areas along the proposed site. This section is the furthest east and has the Santa Ana National Wildlife Refuge as the hub of the proposed site. This section while having the largest amount of natural area, has the most disconnect between the patches. The most beneficial way to reconnect them is by adding corridors and obtain land through land acquisition.

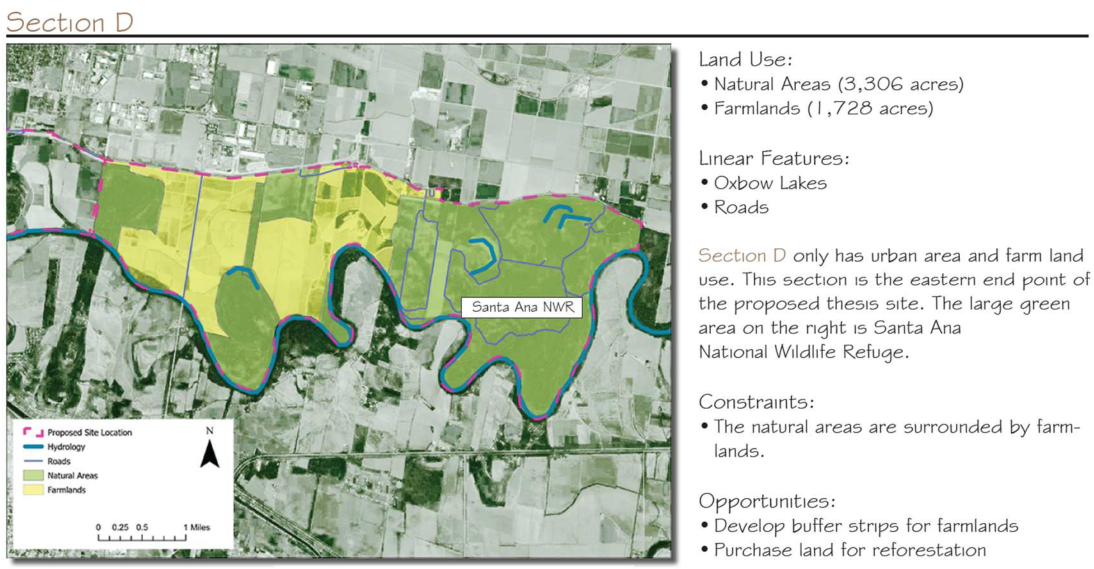


Figure 18 Section D Site Analysis

Chapter 4: Design Framework and Design

Chapter 4 discusses the design framework used to create designs that could be implemented on various parts of the proposed site.

Vision

My vision for this proposed site is to create connectivity corridors between natural landscapes that are facing detrimental effects of human activity. Within these corridors an increase of vegetation diversity is proposed to enhance the vegetation increasing pollinator diversity. This design will utilize roads and oxbow lakes to make primary corridor connections between natural hubs in each of the four sections. Farm roads will be used to make secondary connections between the existing natural hubs. Lastly, a program like CREP could be implemented and land acquisition could be proposed to increase hub size.

Design Goals

The goal of this project is to develop a design framework that will create corridor connections, increase vegetation diversity, and increase habitat for pollinators along a selected site along the Rio Grande River in Hidalgo County, Texas.

Goal 1: Increasing Connectivity

The first goal of this project is to increase the connectivity between fragmenting habitats within the site. By utilizing the roads along the site, which are abundant, corridors can be created for the transportation of pollinators between existing natural habitats and proposed reforested areas. Oxbow lakes also contribute to the connectivity between natural habitats, particularly if they are isolated around farmlands. Using farm roads along farmlands will also function as corridors allowing for pollinators to get from patch to patch.

Goal 2: Diversify Vegetation Structures

The second goal of this project is to diversify vegetation to benefit pollinators on the proposed site. Increasing the vegetation structures along road verges will increase the abundance of pollinators. Planting a variety of plant species that can be utilized throughout the stages of pollinators' lives is essential.

Goal 3: Increase Habitat

The third goal of this project is to increase pollinator habitat and natural areas on the site. This goal will be accomplished by doing the first two goals. The corridors, and vegetation diversity will increase the pollinator habitats.

Actions

The interventions are organized into primary, secondary and tertiary actions. Primary actions would be the first steps taken to create landscape scale connectivity. These steps will be done if there is a money and support for the implementations. For the next step, secondary actions would increase connections at a finer scale and seek to increase redundancy and increase connectivity density. This step will be done if there is more funding and more support from the community. Finally, provided enough resources, tertiary actions focus on policy program and acquisition as tool to strengthen corridors and increase overall habitat. This step will only be implemented if there a CREP like program where farmers can be financially compensated for their participation.

Master Plan Section A

The primary actions for this thesis are to create pollinator corridors between existing natural patches using road verges, and oxbow lakes. Starting from the furthest point West in Section A, to create a connection between Bentsen State Park and the other natural areas surrounding the proposed site, 5 roads (Old Military Highway, Levee Road, S Schuerback Road, S Greene Road and Bentsen St. Park Road) were selected to add roadside verges. A corridor created along Military Road, located above F4, creates the connection between Bentsen State Park and N2, in section B.

The second part of primary actions are to restore oxbow lakes within the proposed site. Increasing the vegetation diversity along the edge of oxbow lake #1, which is surrounded by farmland, will increase pollinator habitat, and plant diversity. The increase of vegetation diversity will attract more pollinators and provide them refuge within the farmlands. By diversifying the vegetation of Oxbow #1 (O1) and creating road verges along the selected roads, two corridor connections between Bentsen State Park in Section A and natural area 2 in Section B will be made.

The secondary actions are to create fine interstitial corridors by designing along farmland roads. The first step will be to utilize large and longer farmland roads along the perimeter of the farmlands to reduce the number of acres a farmer would have to give up. In section A, there will be two corridors along main farm roads totaling 2.25 miles. The first one will be below F3 along W. Military Highway and 1.1 miles long.

The second one will be following the road that is up against the Rio Grande River in F4 stretching 1.15 miles long. After using the large roads, smaller roads will be taken into consideration to increase the connectivity between patches. In F4, there will be nine dirt roads selected for pollinator corridors with a total of 3.66 miles.

Tertiary actions are to develop policies that allow for land acquisition to increase pollinator habitat. These steps will only be done if there is a program in place to financially incentives farmer participation. After studying maps and visiting the site, areas were selected to help increase patch size. If the given the opportunity, land acquisition should occur for F1 and F2 to increase the patch size of Bentsen State Park (N1), connecting it with the surrounding natural areas around the proposed site. Patch F1 is 190 acres, and F2 is 213 acres, reforesting these areas will increase the Bentsen State Park patch (N1) by 303 acres to a total of 2,927 acres.

Urbanization is predicted to take over farmlands. Suggesting plantings and edge designs for pollinators will help ensure benefits for them even after urban development. Farm to urban areas is predicted by studying aerial views and visiting the site. It is predicted F3 will be converted to a residential neighborhood increasing the mobile home patch (U1) by 190 acres to a total of 295 acres.

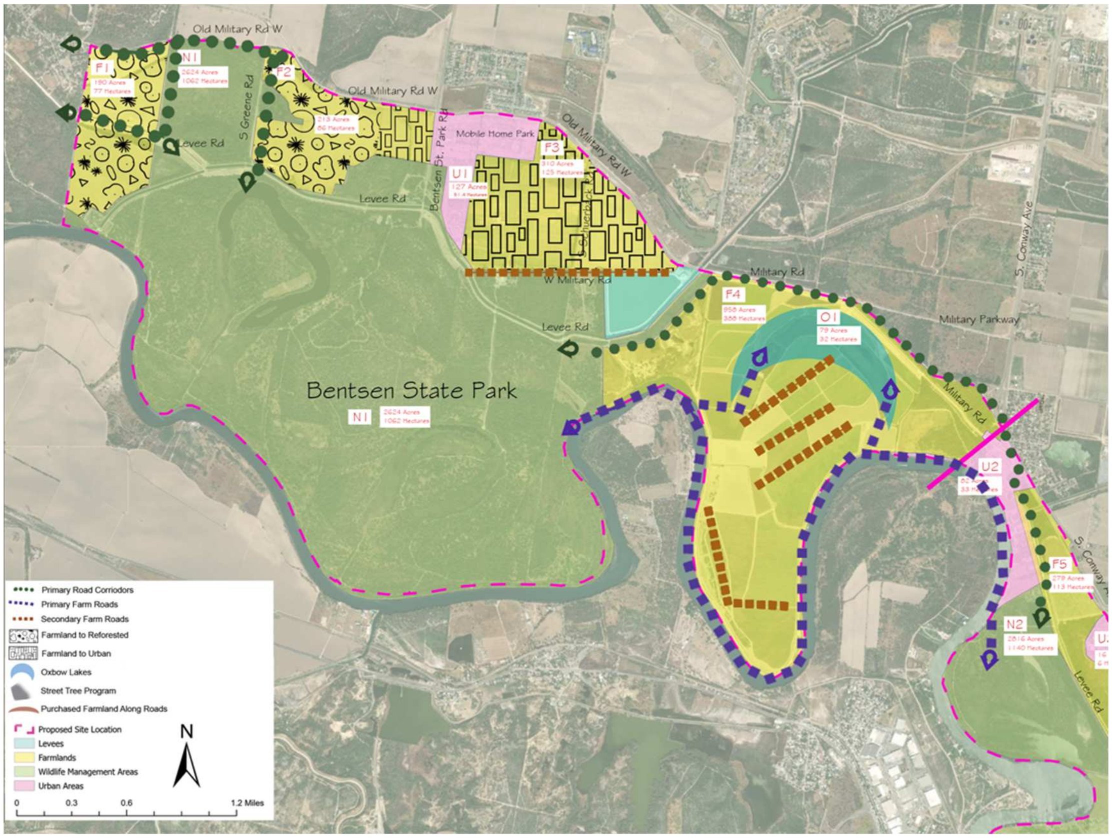


Figure 19 Master Plan Section A

Master Plan Section B

The primary actions are to create pollinator corridors between existing natural patches. In section B, by using Military Road and Levee Road as corridors, a connection between N1 and N2 can be made. On the Eastern end of Section B, to create a connection between N2 and N4, a road verge along Old Military Highway is proposed to create a corridor. The second part of the primary actions are to restore oxbow lakes and diversify the vegetation structures along them. Oxbow #2 has the southern side along N2 and its northern side along F6. Purchasing 57 acres of farmland in F6 will increase the plant diversity and strengthen the corridor along the oxbow. Oxbow #2 is functioning and connected on both ends to the Rio Grande River, increasing the vegetation diversity and adding a buffer will reduce pesticide runoff into the river. To connect N2 to N4, land acquisition should occur northeast of N3. Increasing the vegetation width north of N3 is strengthening the corridor between N2 to N4 by utilizing N3.

Secondary actions are to utilize farm roads that are along the perimeter of farmlands to increase the connectivity between patches. To create a secondary connection between N2, N3 and N4 there will be one corridor along a main farm road which is located right below F6 above N3 which is 1 mile long. In F6, there will be 6 smaller dirt roads selected for pollinator corridors with a total of 3.18 miles.

Tertiary actions are to develop policies that allow for land acquisition to increase the overall pollinator habitat. After studying aerial maps and visiting the site it is proposed that the eastern portion of F6 be reforested. Reforesting F6 will provide a buffer to minimize pesticides from the surrounding farmlands from going into the oxbow and into the Rio Grande River. Areas within the site are also predicted to be turned into urban residential. The lower portion of F5 (26.5 acres), is predicted to be converted to a residential connecting U4 (9 acres) to U5 (35 acres) and creating a larger urban area of 70.5 acres.

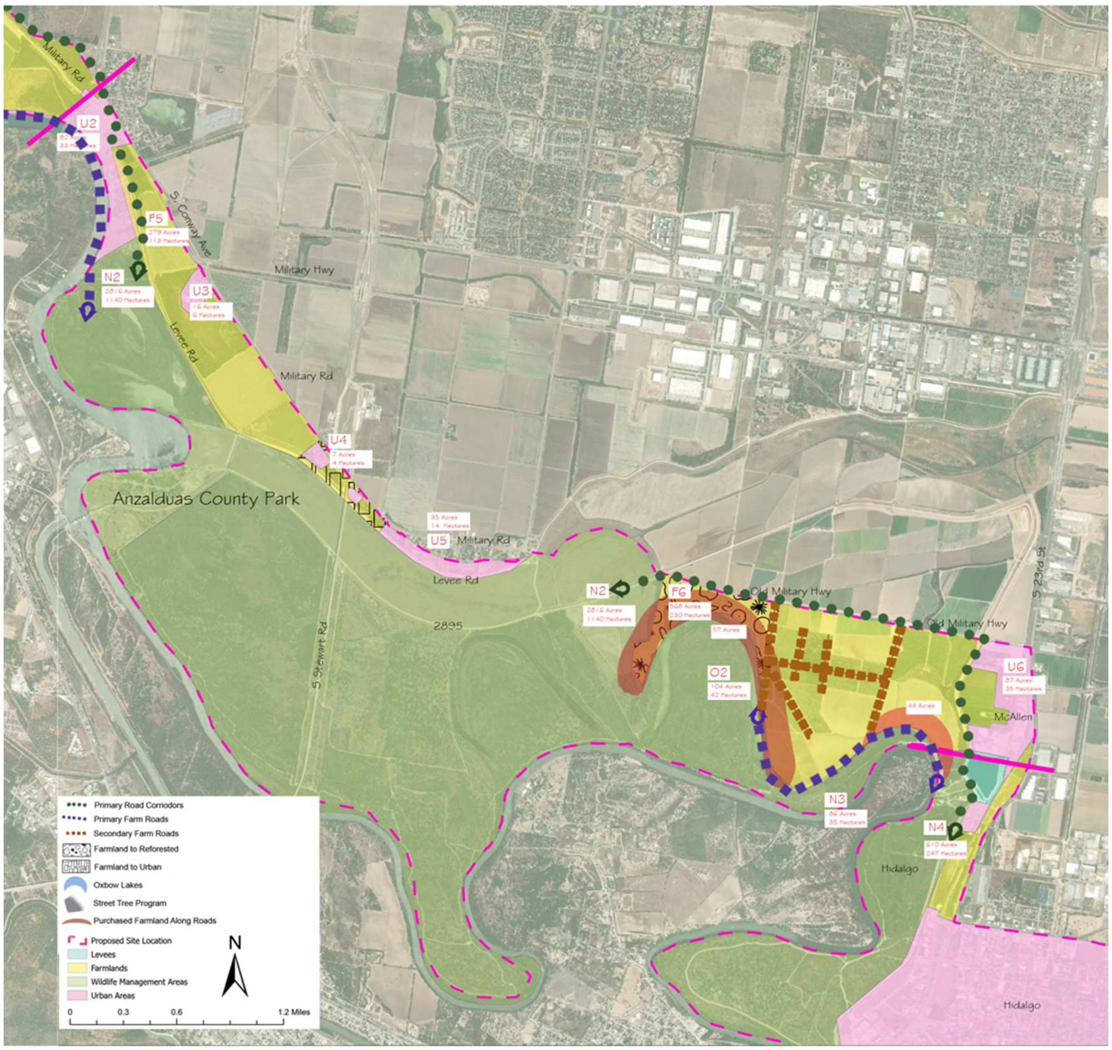


Figure 20 Master Plan Section B

Master Plan Section C

Primary actions for Section C include creating pollinator corridors along roads to connect patches. To create a primary connection with N6 and N7 a road corridor is proposed along Old Military Rd, which is the northern boundary of F8. The secondary goal of the primary action is to restore oxbow lakes by increasing the vegetation diversity. An oxbow lake between N6 and F8 should have an increase of plant diversity along its edge. To increase of vegetation diversity along the oxbow, a portion of farmland should be obtained to increase the width of the riparian area and along the lower edge of F8 along the Rio Grande River. There are no proposals for using farm roads in Section C.

The tertiary actions are to develop policies for land acquisition to increase pollinator habitat. By creating a CREP like program we can ask farmers to participate by proving those financial incentives. N7 is a 273-acre natural area with farmlands on 3 sides, F8 on the left and N9 on the right. Land acquisition is proposed on a portion of the right side of F8 to increase the patch size of N7. Secondary goals of the tertiary action are to predict where farmland will be urbanized. Its predicted F7, which is 59 acres, will be developed into an urban area connecting U6 and U7.

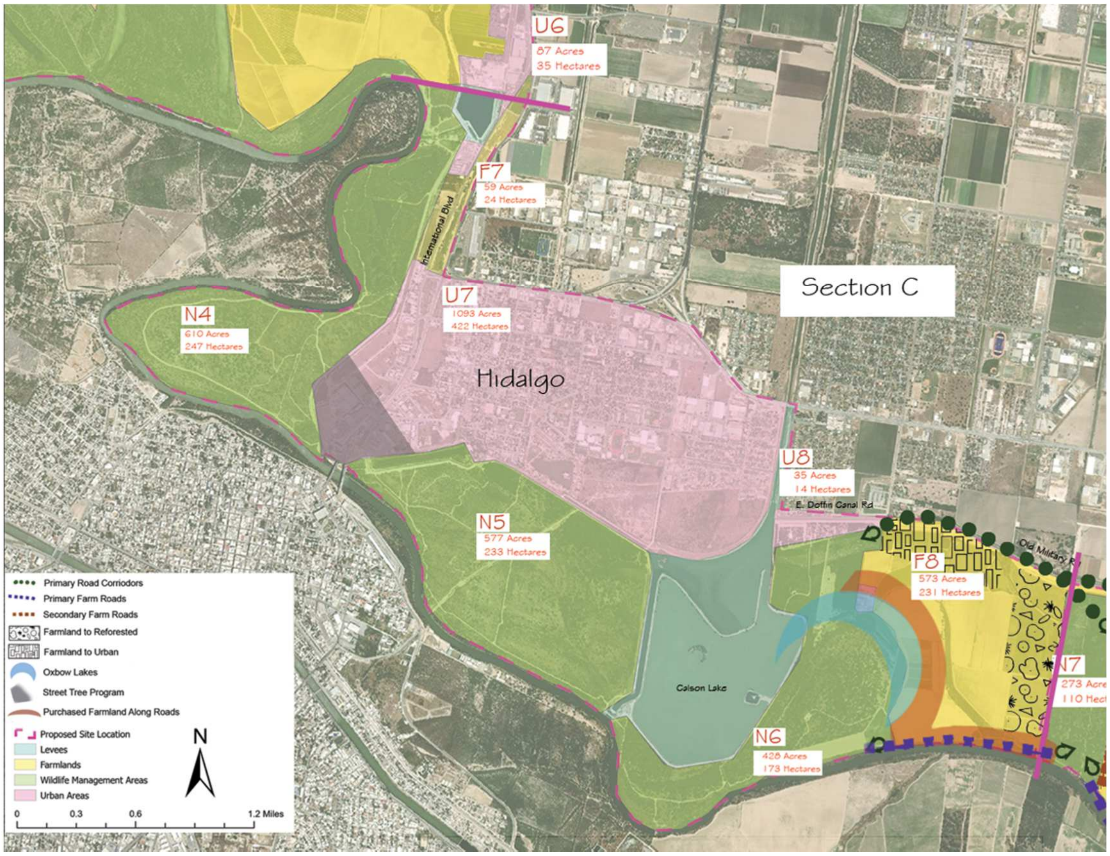


Figure 21 Master Plan for Section C

Master Plan Section D

Primary actions include creating pollinator corridors between existing natural areas. This can be done in Section D, by utilizing Military Roads' Road verges to create a connection between N7 and N9, and N9 to N10. To create a secondary connection between N7 and N8 a proposed corridor along the lower farmland edge of F9 is created along the riparian zone of the Rio Grande River. Extending the width along the riparian area of the lower edge of farmlands, which touches the Rio Grande River, is proposed in F10 to create corridors for pollinators between N8 and N10. Also, within the primary actions is to increase the vegetation diversity along the edge of oxbow lakes. Oxbow #4 is in the center of F10 and increasing the vegetation diversity will help connect N8 and N9 with N10.

Secondary actions include using farmland roads. Using farm roads along the perimeter first will reduce the number of acres a farmer would have to give up. A main corridor along S. Cage Blvd is proposed as the main North/South connection in F9. Using smaller roads can be done within F9 to increase the edge diversity and pollinator patches within farmlands. A farm road corridor in F10 is suggested to increase the north/south connection between the road corridor along Old Military Road (north) and the riparian zone along F10 (south).

Tertiary actions are to develop policies that allow for land acquisition to increase pollinator habitat if a CREP program can be implemented. Farmland restoration can be done in F9, which is between N7 and N8. F9 is the third largest farmland area within the proposed site. Two small patches are proposed to be purchased for restoration in F9 to create areas of refuge for pollinators within farmlands. F10 is the second largest farmland area within the site. Proposed land acquisition is suggested between N8 and N9 to increase the patch size and strengthen the connection between patches. There are no areas predicted to be turned into urban areas at this time.

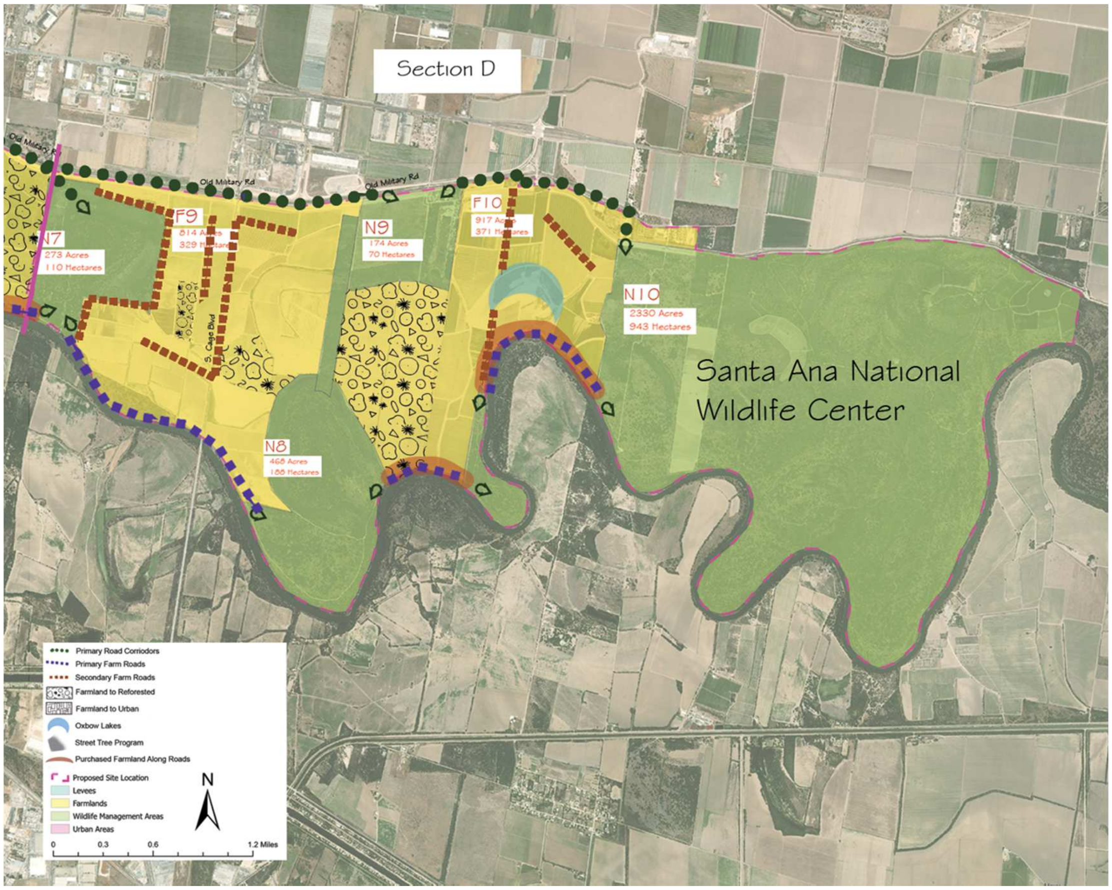


Figure 22 Master Plan for Section D

Habitat Scale Design Interventions

After the initial corridors are selected along the entire site, we look down at the habitat scale to create a design framework for the implementations. The second goal of this project is to diversify vegetation to benefit pollinators on the proposed site. The third goal of the project is to increase the pollinator habitat which can be done by implementing the first two goals. Planting a variety of plant species that can be utilized throughout the stages of pollinators' lives is essential. Design guidelines to diversify vegetation were developed by incorporating the materials obtained from the literature review. There are design guidelines for seven different landscape types that can be utilized in various areas of the site and even combined to best fit the needs of the location (Appendix 3). The guidelines were developed for a street tree program, two lane roads, farm roads, oxbow lake edge design, farmlands turned urban, and farmlands that are reforested (Appendix 3). At the habitat scale, implementations will be done alongside roads, and farmlands to create the road verge corridors, increase plant diversity and increase pollinator habitats. Plant species were investigated to decide the most beneficial species to pollinators, while considering their growing conditions regarding sunlight, water, and management needs (Appendix 1 and 2).

Design interventions will also be accomplished in primary, secondary, and tertiary actions following the master plan. Roads will be the primary action for creating the initial corridors. The habitat scale interventions will be to increase the habitat width, and vegetation structure that best fits the needs of the location, funding, and support to implement these designs. The second half of the primary action is to increase the vegetation structure diversity along oxbow lakes, particularly those in farmlands. The secondary actions are to utilize farm roads along the perimeter of farmlands to add in pollinator strips, and the secondary half of the secondary action is to utilize roads within farmlands. The tertiary actions will be to purchase land through land acquisition that can be reforested or to plan for land that will be developed for housing.

Roads

A street tree program is recommended to help pollinators in the nearby Hidalgo, County. Four lane roads are the typical road type along the natural areas within the proposed site. These implementations will allow for a more diverse vegetation and allow for pollinators to rest while going from one natural patch to another. Trees provide pollinators will pollen, nectar and shelter. Design guidelines for the street tree program can be found in Appendix 3.

Figure 23 Four Lane Roads- Street Tree Program

One of the main road types along the site are two lane roads with and without shoulders. Treatment for right of ways will be possible whether the two-lane road has shoulders or not. Right of ways along the site vary from 40ft to 100ft depending on the area. Any of the proposed treatments can be done within the right of way making them more feasible because we would not have to obtain land from farmers or developers during the primary stages of this case study.

Figure 24 Before and After Implementations of Increasing Vegetation Structure Along Two-Lane Roads with Shoulders

Roads are a main land use within the project scope distancing over 92 miles of paved roads within the proposed site. The total miles of roads increase if we consider farm roads, and country roads, which are not currently noted. There are four main road types such as two-lane roads with and without buffers, four lane roads, and farm roads within the proposed site. The main road which the implementations will be developed for are two lane roads without shoulders. All three vegetation implementations can be done along the same mile of road whether in a pattern or just altering between two.

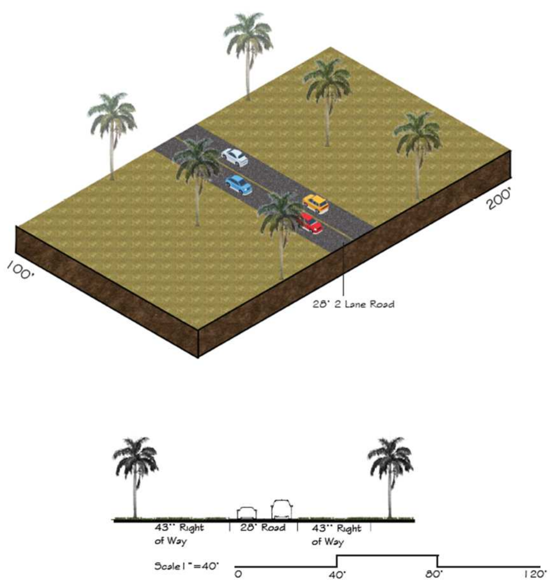


Figure 25 Two-Lane Roads as Is

By incorporated the unique designs we reduce the acres needed while still creating essential pollinator habitats. There are palm trees in the right of way along most selected roads. Design guidelines for two lane roads can be found in Appendix 3.

Two Vegetation Structure Intervention

First, if any implementations can be made given a small amount of money, road verges will be utilized for pollinator habitat Research suggests having a minimum cleared setback of 6ft to ensure driver visibility and to reduce the sounds, light, and vibrations in the pollinator habitat. Pollinator habitats should be a minimum of 20ft wide with a variety of herbaceous native plants including host plants. It is important to have bare areas within the habitat to provide nesting sites for ground nesters. In this intervention the first step will be to add herbaceous plants 6ft away from the roads and implement a 20ft wide pollinator habitat. The current vegetation structure along the road verge will now be two: herbaceous plants and the large street trees. It is important to plant the vegetation properly to ensure they meet their proper sunlight requirements. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

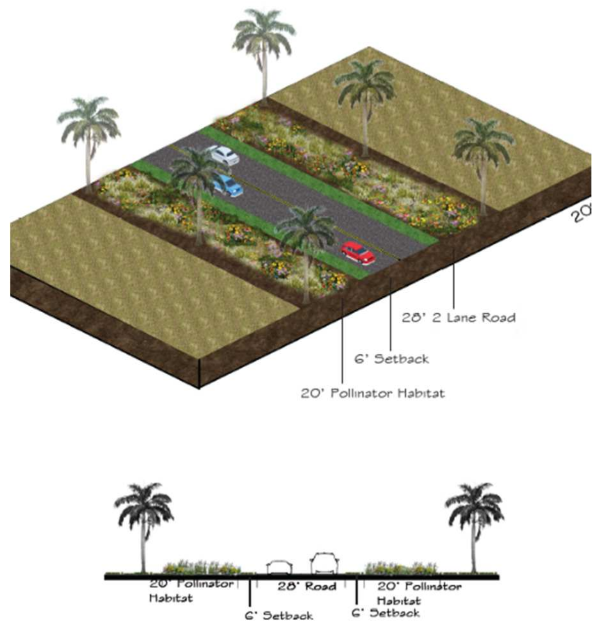


Figure 26 Two Vegetation Structure Implementations

Three Vegetation Structures Implementation

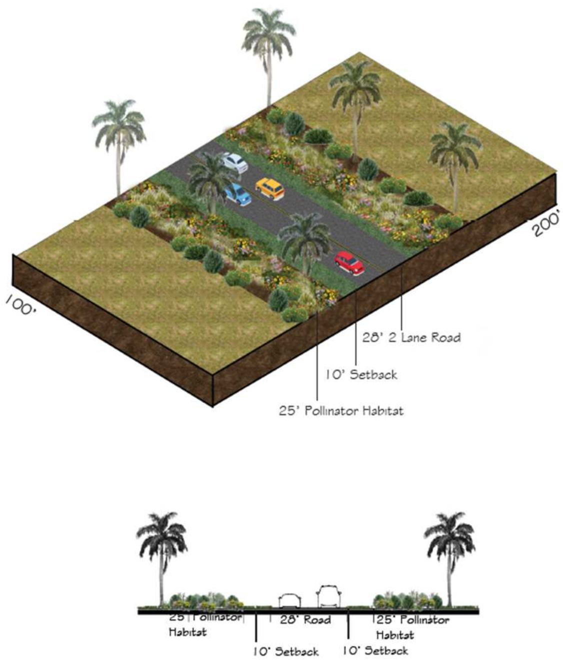


Figure 27 Three Vegetation Structures Intervention

To increase the vegetation structure within the pollinator habitat, the secondary intervention include widening both the setback and pollinator habitat. The setback was widened to 10ft to enhance the driver's visibility protecting animals from vehicular incidents, and to reduce the pollution going into the pollinator habitat. The pollinator habitat will be widened by 5ft making it 25ft and adding shrubs to the habitat, increasing the vegetation structure for pollinators. There are now three vegetation structures in the pollinator habitat including: herbaceous, large trees, and shrubs. It is important to plant the vegetation properly to ensure they meet their proper sunlight requirements. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

Four Vegetation Structures Implementation

Lastly, to increase the plant vegetation structures to four layers, small trees will be added in the pollinator habitat. This implementation will widen the setback by 5ft increase safety for drivers, and pollinators, while reducing the pollution going into the pollinator habitat. The setback will now be 15' wide. The pollinator habitat is also widened by 5ft making it 30ft to comfortably add in trees. The total vegetation structures are increased to four and will now include: herbaceous, large trees, shrubs, and small trees. It is important to plant the vegetation properly to ensure they meet their proper sunlight requirements. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

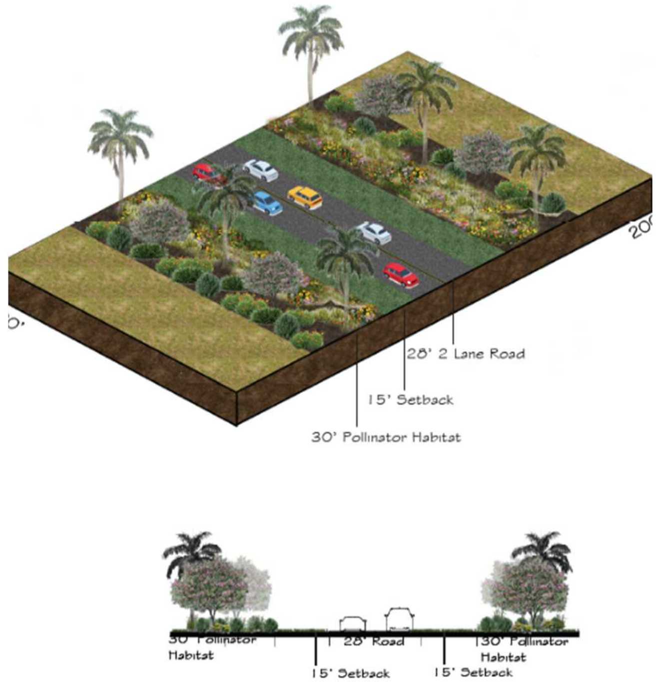


Figure 28 Four Vegetation Structures Intervention

Farmland roads

Farmlands are not hotspots for pollinators due to the considerable amounts of pesticide usage and being monocultures. While pollinators are beneficial to crops, they do not provide them with all their basic needs. Farm roads allow for tractors, and trucks to navigate through the farm fields without crushing crops.

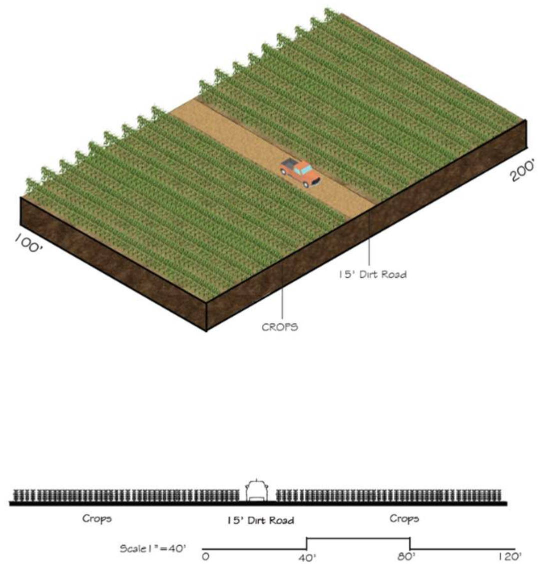


Figure 29 Farm Roads as Is

They are normally just dirt roads, and they are quite common within the proposed site. The dirt roads are typically 15ft wide and have crops on either side. While adding in pollinator habitat is beneficial to pollinators it is important to consider the pesticides being used to maintain the crops. It is helpful to add in a pollinator buffer between the crops and the proposed pollinator habitat, because it can reduce the number of pesticides going into it. It's suggested to have a minimum of 60ft away from spray pesticides if there is no buffer present, and a minimum of 30ft if there is a buffer. I am proposing adding in a buffer strip using plants that are wind pollinated to reduce the

Figure 30 Before and After Aerial and Perspective Images of Farmland Roads

need for pollinators to venture into the buffer strip. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

One Vegetation Structure Intervention

To increase habitat, and vegetation diversity for pollinators I propose adding in a pollinator corridor alongside a few selected farm roads. To ensure we are not creating pollinator death traps safety precautions must be considered. Adding buffers will minimize pesticide drift, and research suggests having a minimum width of 30 ft. To provide protection from cars, studies show a minimum of 6 ft should be cleared alongside the road creating setbacks. A minimum of 20ft is suggested for pollinator plantings so that is what will be done here. The pollinator vegetation structure will now include herbaceous planting, and the buffer will include herbaceous and shrubs. It is important to plant the vegetation properly to ensure they meet their proper sunlight requirements. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

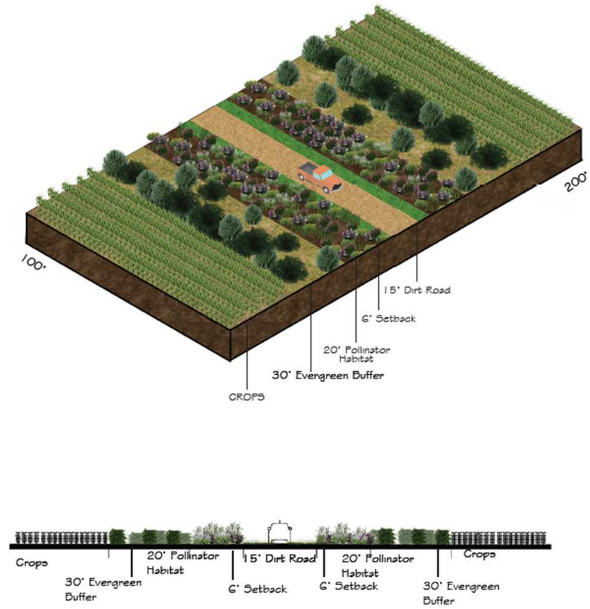


Figure 31 One Vegetation Structure Implementation

Two Vegetation Structures Intervention

The second intervention includes increasing the setback to 10ft to increase visibility and safety, increasing the pollinator habitat by 5ft to add in shrubs, and keeping the buffer width the same. The pollinator vegetation structure will now include herbaceous planting, and shrubs. The buffer will now include herbaceous, shrubs, and trees. It is important to plant the vegetation properly to ensure they meet their proper sunlight requirements. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

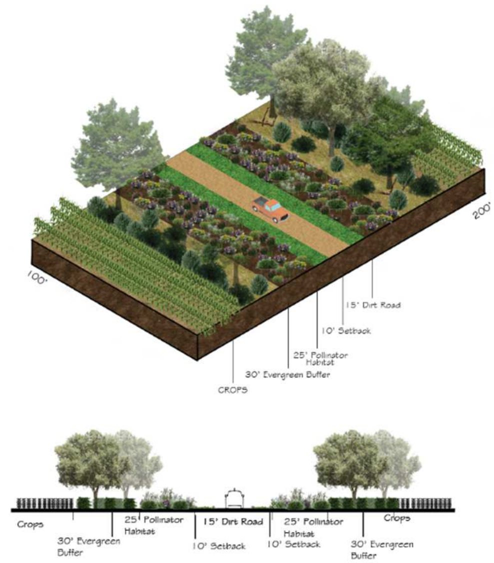


Figure 32 Two Vegetation Structures Intervention

Tree Vegetation Structures Implementations

Lastly, to increase the vegetation structure again setbacks will increase by another 5ft making it 15ft wide, which will increase the safety for small animals trying to cross the street, and for pollinators trying to use the pollinator habitats. The pollinator buffer will increase to 30ft to now add in small trees. These implementations can be done in a variety of patterns along the same road to meet the needs of the plants, pollinators, and road location and the create a more heterogenous patterns to provide for

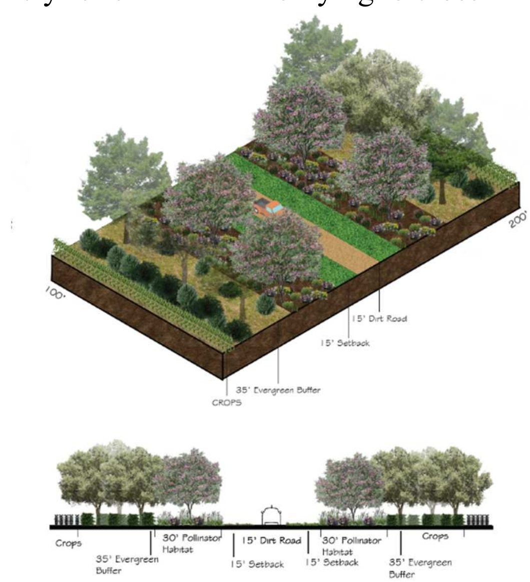


Figure 33 Three Vegetation Structures Intervention

increased vegetation structural diversity. The pollinator vegetation structure will now include herbaceous planting, shrubs, and small trees. The buffer will include herbaceous, shrubs and trees. It is important to plant the vegetation properly to ensure they meet their proper sunlight requirements. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

Land Acquisition Farmland to Reforested

Obtaining land from farmers would be the most beneficial for pollinators from a conservation perspective, but not from an economic one. While reforesting farmlands closest to natural areas will strengthen the natural patch size, it will reduce the acres a farmer can utilize. A CREP program would need to be implemented to create financial incentive for farmers. If there was enough support and money the sites selected would aid in the increase of overall pollinator habitat. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

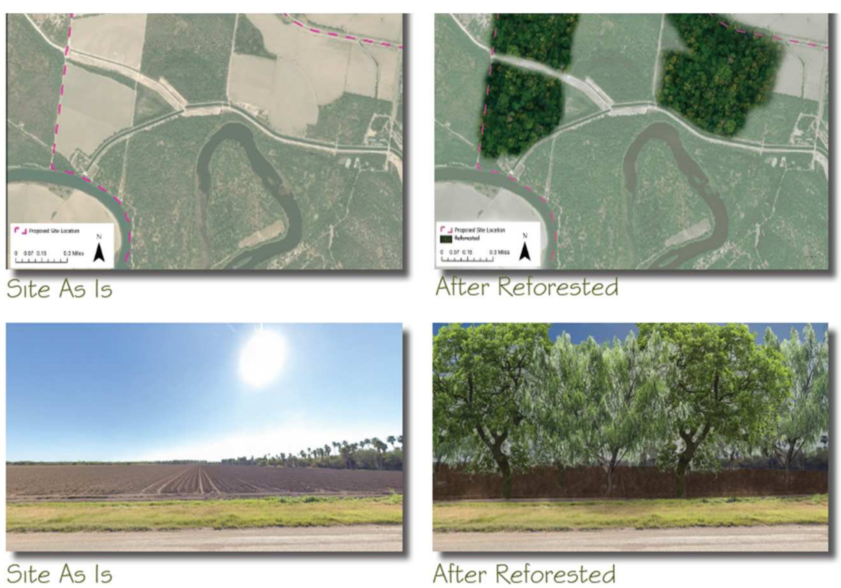


Figure 34 Before and After Aerial and Perspective Images of Reforesting Farmlands

Farmland to Urban

Due to the growing population, and the ecotourism brought in by the National Butterfly Center and Bentsen State Park housing development will more than likely be built over what once is farmed land. To best benefit pollinators, there are design goals that should be taken into consideration to ensure pollinator habitat. Urbanization will happen and its best to create design guidelines to prepare for the future with pollinators in mind. Design guidelines and suggested plantings can be found in Appendix 2 and 3.

Figure 35 Before and After Aerial and Perspective Images of Urbanizing Farmlands

Oxbow Edge Vegetation Diversity

There is a total of eight oxbow lakes withing the proposed site. By increasing the vegetation along the edges of oxbow lakes we create secondary corridors for pollinators. The increase of vegetation diversity will increase the overall number of pollinators around the site. Design guidelines can be found in Appendix 3.

Figure 36 Oxbow Lakes as Is

One Vegetation Structure Intervention

Oxbow lakes can provide a number of benefits to pollinators. Incresing the vegetation structure diversity along oxbows will help increase pollinator diversity. The first implementation should be to add in a variety of herbaceous plants along the oxbow. Since the oxbows are within farmlands, its highly reccommended to add in an buffer to decrease the amount of pesticides going into the pollinator habitat and the water supply. By doing the first impletmentation the vegetation stucutre will be herbaceous. Design guidelines can be found in Appendix 3.

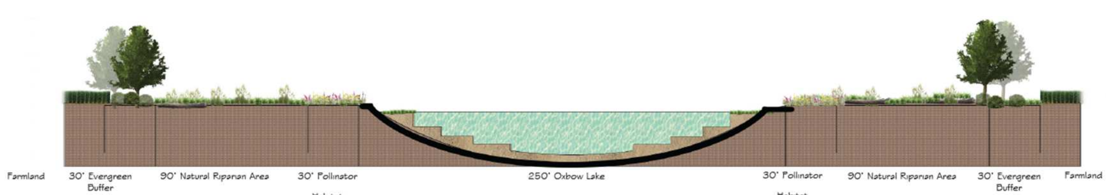


Figure 37 One Vegetation Structure Interventions

Two Vegetation Structures Intervention

The next step will be to widen the pollinator habitat to add in shrubs and widening the buffer. Widening the buffer will provide more protection for pollinators using the habitat and increase the vegetation structure to two. These implementations will increase the vegetation structure to two including: herbaceous and shrubs.

Figure 38 Two Vegetation Structures Interventions

Three Vegetation Structure Intervention

Lastly, to increase the vegetation structures further, implementations will be done to widen the pollinator habitat to add in trees. Widening the buffer will provide more protection for the pollinator habitat. The vegetation structure diversity will now increase to three and will include: herbaceous, shrubs, and small trees.

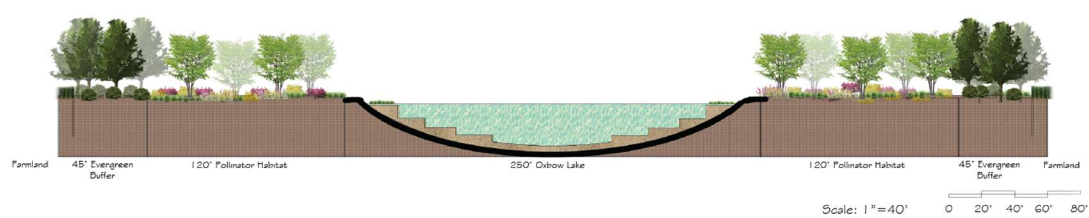


Figure 39 Three Vegetation Structures Interventions

Presentation Boards

All the preceding figures are organized on a set of presentation boards (Appendix 4) where additional information is provided. In addition to the designs, calculated metrics for the interventions are also provided. Appendix 4, Board 7 has results of the project measuring out all the miles of proposed main roads and farm roads within each section and the total throughout the site. For example, to create the first vegetation structure in the pollinator habitat along the selected two-lane roads you would need 76 acres of road verges. Board 8 also identifies all the acres needed for each implementation throughout the site, such as acres of land for proposed reforestation, proposed urban development areas, and the difference needed to increase the pollinator habitat along the entire site. For example, to reforest the selected areas along the entire site we would be increasing pollinator habitat for 1,281 acres. Further details specific to each section's implementation metrics can be found in Appendix 4.

Chapter 5: Conclusion and Summary

This thesis suggests that by using landscape ecology principles and other research, a design framework that provides 1) connectivity between existing natural areas, and 2) increasing vegetation community diversity will lead to increased quantity and quality of pollinator habitat and thus more overall pollinators. The case study provides a demonstration of the design framework that will contribute to the creation of corridor connections between natural landscapes along the Rio Grande River. The project complements and supports the corridor proposed by the U.S. Fish and Wildlife Service which plans to create the corridor within the four counties of the Rio Grande Valley. Creating these connections and restoring and creating diverse vegetation communities will help pollinators as they navigate the landscape for food, shelter, and nesting. At the landscape scale, the design framework provides a minimum of two corridors between existing natural hubs creating the redundancy needed to insure connectivity. At the habitat scale, the proposed design interventions diversify vegetation structure for a variety of locations, needs, and available resources. Using a design framework that provides the prioritization of primary, secondary, and tertiary actions, provides decision makers a prioritized road map to take steps to support a pollinator corridors and creation of pollinator habitats.

Assumptions and Limitations

Site visits were impacted by COVID-19 and the political environment surrounding the National Butterfly Center which resulted in its closure while this project was undertaken. I am a Texas native and raised 10 miles east of my site in the Rio Grande

Valley. During the COVID-19 pandemic. I moved home and decided to choose a local thesis site. I was able to drive along all ~20 miles of my site while being home. Due to the political climate surrounding the National Butterfly Center, I was unable to make connection with Center managers. This was a limitation when documenting an additional species information for my site. High border security along my site was also a limitation on how much of the site I could observe and understand. Issues related to the border wall were beyond the scope of this study. Climate change is critical, important, and a subject that would influence the case study area but is beyond the scope of this study. The design and plans proposed would still benefit pollinators even with the rising temperatures and changes in moisture regimes.

Further Research

This design thesis proposes to create initial connections between fragmenting natural habitats and diversify vegetation at a habitat scale in a selected site along the Rio Grande River. Pollinators are critical to overall sustainability of ecosystems and should be treated as such. This research is intended to support further work that needs to be undertaken to support pollinators in the Rio Grande Valley.

Appendices

Appendix 1. **From Section 7 - Selecting Wildflower by Natural Vegetation Region, in the Roadside Vegetation Management Manual from TxDOT (2018)**

Common Name	Scientific Name	Percent Per Mix	Individual Rates Per Acre	General Information
Bluebonnets	Lupinus *texensis*	42%	20lbs	State flower of Texas. Blue with white trim on spikes. Most common wildflower on roadsides and pastures. Legume family (nitrogen fitting). Needs well drained soil and prefers full sun. Blooms from March-May. 12-24 inches high. 13,500 seeds per pound.
Indian Blanket	*Gaillardia pulchella*	19%	10lbs	Hardy annual that is easily established. Red flowers with yellow trim. Needs well drained soil and full sun. Blooms from May-July. 1½-2 feet. 153,000 seeds per pound.
Annual Phlox	*Phlox drummondii*	18%	8lbs	Hardy annual. Blooms are red, pink, white and shades of rose. Likes dry soil and full sun. Blooms from February-June. 8-24 inches. 234,000 seeds per pound.
Prairie Verbena	*Verbena bipinnatifida*	6%	3 bs	Annual or short-lived perennial. Purple blooms. Prefers full sun. Popularly planted with Pink Evening Primrose. Blooms from April-November. 4-12 inches. 450,000 seeds per pound.
Clasping Coneflower	*Rudbeckia amplexicaulis*	6%	1lbs	Hardy annual. Yellow flower petals clasp around stem with black cone center. Likes dry or wet soils with full sun. Blooms from April-June. 1½-2 feet. 800,000 seeds per pound.
Plains Coreopsis	*Coreopsis tinctoria*	5%	2lbs	Hardy annual. Heavy bloomer. Prefers full sun, but will tolerate wet or dry soil. Blooms from March-July. 1-3 feet. 1,400,000 seeds per pound.
Pink Evening Primrose	*Oenothera speciosa*	3%	1-3lbs	Hardy perennial. Soft pink four petalled flowers. Popularly planted with Prairie Verbena. Blooms from March-November. 8-16 inches. 864,000 seeds per pound.
Indian Paintbrush	*Castilleja indivisa*	1%	1/4lb	Annual, perennial or biennial. Blooms red with color variations of purple, orange, pink, yellow, white, etc. throughout the state. Needs well drained soil and full sun. Blooms from March May. 6-18 inches. 5,100,000 seeds per pound.

Appendix 2. **Proposed Plant Palette:**

Herbaceous:

- Awnless Bush Sunflower (*Simsia calva*) Perennial February - December
- Indian Blanket (*Gaillardia pulchella*) Annual/Perennial February - December
- Mexican Hat (*Ratibida columnifera*) Annual/ Perennial April - September
- Milkweed (*Asclepias spp. and Cynanchum spp.)* Perennial March – December
- Scarlet Sage (*Salvia Coccinea)* Annual March - December

Shrubs:

- Rio Grande Butterflybush (*Buddleja sessiliflora*) Annual, April - July
- Spiny Hackberry *Celtis pallida* Perennial February - May
- Texas Lantana (*Lantana urticoides*) Perennial April – October
- Night Blooming Jasmine (*Cestrum diurnum*) Evergreen

Trees:

- Cedar Elm *(Ulmus crassifolia)* Perennial, July - August
- Southern Hackberry *(Celtis larvigata*) Perennial, February - April
- Anacua *(Ehretic anaua)* Perennial, April
- Honey Mesquite (*Prosopis glandulosa*) Perennial, February – September

Wind Pollinated Trees and Shrubs for Buffer:

- Live Oak (*Quercus virginiana*) Perennial, March - May
- Bur Oak (*Quercus macrocarpa*) Perennial, March - May
- Bald Cypress (*Taxodium distichum*) Perennial, April
- False Willow (*Baccharis neglecta)* Perennial, August- October
- Black Willow (*Salix nigra)* Perennial, April- May

Appendix 3. **Design Guidelines:**

- **Roadsides along Farmland**
  - Design Guidelines
    - **Vegetation buffer** to protect from pesticides
      - Use plants that do not provide pollinator resources like wind pollinated trees and shrubs
      - Pollinator Habitat at least 60ft from pesticides if there is no buffer
      - Minimum of 30ft if buffer is present
      - High-volume pollinator plantings in buffer between pollinator habitat and crop fields
      - Buffer and Pollinator Habitat should be upwind from pesticide use
    - **Pollinator Habitats** should provide pollen, nectar, and nesting habitats for a variety of bloom seasons
      - Wildflowers
      - Native plants
      - Host plants
      - Do NOT use pest host plants
      - Keep old trees (nesting)
      - Leave some open areas for ground nesters
  - Maintenance Plan
    - Mow annually
- **Roadsides along Natural Areas**
  - Design Guidelines
    - Plants to use:
      - Variety of colors, forms, textures, heights
      - Native plants
      - Meadow plants (Low Maintenance)
      - Wildflowers
      - Weedy forbes strips
      - Perennial hedgerows
    - Place smaller plants closest to the roads
    - Avoid spraying pesticides (spot spray if necessary)
    - Prep site beforehand by pulling weeds
    - Keep at least 2m (two meters) between the high-density plantings and road edges
    - Ensure plants are placed where they meet their proper sunlight needs
  - Maintenance Plan
    - Mow twice a year
- **Four Way intersections**
  - Design Guidelines

        - Plant a variety of colors, forms, textures, and heights
        - Place smaller plants closest to the roads
        - Ensure visibility with a “site triangle”
            - Setback of 90ft for 20mph
            - Setback of 170ft for 30mph
            - Setback of 195ft for 40mph
    - Maintenance Plan
        - Mow annually
- **Pollinator Patch/Strips within Farmlands**
    - Design Guidelines
        - Hedgerows for windbreaks
        - Single stem wildflowers
        - high plant species richness and complementarity of different seed mixture
        - the sowing of multiple flower strips in the landscape with a total extent of 10% in 50 ha study areas to avoid effects of fragmentation of food and nesting resources.
    - Maintenance Plan
        - Mow Annually
    - Community Involvement
        - Create cutting and harvesting events welcomed to the public to cut their own flowers/ create their own bouquets
- **Farmland turned Urban**
    - Design Guidelines
        - Use native plants
        - Use pollinator plants
        - Minimal maintenance yards
        - Diversity lawn vegetation
        - Add pocket parks/ or empty lots
        - Walking trails
        - No pesticide uses
        - Grow a garden
        - Care for current trees
        - Create a native plant pocket garden
        - Allocate land use to ensure accessibility to green spaces within walking distance
        - Promote urban agriculture
        - Preserve biodiversity
    - Maintenance Plan
        - Mow annually
- **Farmland turned Reforested**
    - Design Guidelines
        - Row, planting seedlings
            - typically, spiny native brush — ebony, Huisache, retama, catclaw acacia, anacua
            - Drought tolerant

        - Plant in 10’ intervals
        - Maintenance Plan
    - Prescribed burns
        - Mow
- **Restoring Oxbow Lakes**
    - Design Guidelines
        - high plant species richness and complementarity of different seed mixtures to provide food also for specialist pollinators (bees, butterflies, and butterfly larvae).
        - perennial species mixtures to ensure the provision of a high variation of food over the year as well as hiding and nesting sites.

Policies:

Land acquisition

CREP

- If farmers plant any acreage of pollinator habitat, they should be financially compensated.
- They can gain a label and leverage to sell their produce for more if they are labeled as “pollinator stewards”
- They should be able to gain incentives or credit
- They can sell products grown from pollinator habitat or buffers seasonally

Appendix 4: Project Boards 1-8

Introduction

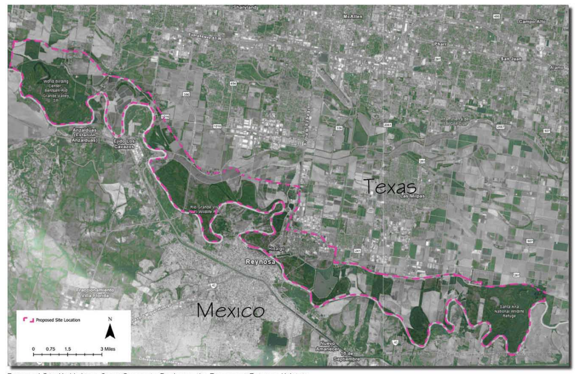
On The Verge:
A Design Framework Using Landscape Ecology and Edge Design Principles to Diversify Vegetation for pollinators in SE Texas

Problem
Pollinator habitats are under threat due to human activity like commercial and residential development, pollution, and climate change. Land uses are changing creating a disconnect between exiting natural areas

Literature Review
This thesis develops a design framework after studying select topics of landscape ecology like patches, corridors, and edges, the relation between plant diversity and pollinator diversity, roads and their benefits or detriments to pollinators, stakeholder groups, and applied case studies to sites relative in size to the proposed thesis site.

Goals
- Create corridor connections between fragmented natural areas
- Increase pollinator habitat by designing for edges along roads and farmlands which will Increase plant diversity to influence the increase of pollinator diversity

Design Proposal
This design is to develop a design framework that creates corridors for pollinators, and increases vegetation diversity along a selected site in the Rio Grande Valley.



Proposed Site Highlighting Green Spaces to Emphasize the Disconnect Between Habitats

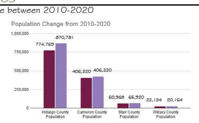
Site Rationale
This site was chosen because of its alarming and evident fragmentation along the Rio Grande River.

Proposed Site Location


State of Texas

Counties of the Rio Grande Valley

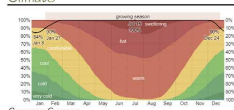
Demographics
% Population change between 2010-2020
Hidalgo: +12.4%
Cameron: +3.6%
Starr: +8.1%
Willacy: -8.9%

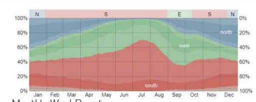


Ethnicity
Hispanic/ Latino: 93.53%
Non-Hispanic or Latino: 6.47%

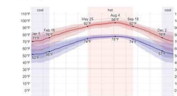
Race
Total RGV Population: 1,402,340
- White 87.71%
- Black/African American= 0.60%
- American Indian/Alaskan Native= 0.35%
- Asian= 0.71%
- Native Hawaiian/Pacific Islander = 0.02%
- Some Other Race = 9.18%
- 2+ Races= 1.43%

Climate


Growing Season


Monthly Wind Directions


Monthly Rainfall
Total Annual Rainfall: 21.5 inches


Monthly Temperatures

Site Inventory

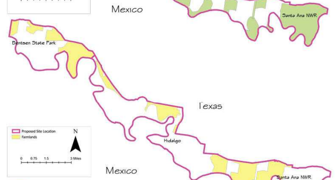
Proposed Project Site
Total Acres: 17387.91

Natural Areas
Four Main Sites:
- Bentsen State Park: 797-Acres
- National Butterfly Center: 100-Acres
- Anzalduas County Park: 96-Acres
- Santa Ana National Wildlife Refuge: 2,088- Acre

Total Acreage: 10,551.2

Farmlands
Growing:
- Grains
- Citrus
- Cotton
- Corn
- Potatoes
- Sorghum
- Sugarcane

Total Acreages: 4,973.8



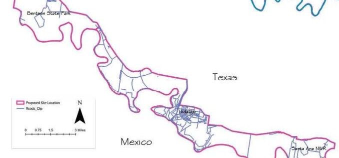
Urban Areas
Site Within City Boundaries of:
- McAllen
- Mission
- Hidalgo
- Pharr
- San Juan
- Alamo

Total Acreages: 1,479.4

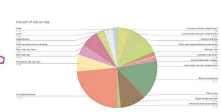
Hydrology
Oxbow Lake: 8 Total on Site
Rio Grande River: 38.2 Miles Along Site

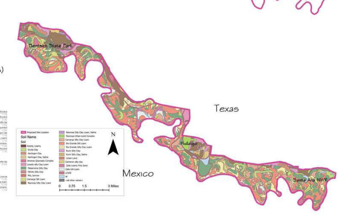
Roads
- Main Roads
- Dirt Roads

There are 92.2 miles of road mapped on the site not including dirt roads



Soil Map
Most Common Soil Type:
- Rio Grande Silt Loam: 32.60% (4,103 Acres)
- Matamoros Silty Clay: 15.60% (2,710 Acres)
- Reynosa Silty Clay Loam: 10.20% (1,774 Acres)





3 Main Soil Types

Rio Grande Silt Loam:

This soil has very deep, well drained, moderately rapidly permeable soils that formed in calcareous silty alluvium. The soil is usually on level or gently sloping terraces ranging from 0-3%.

Matamoros Silty Clay:

Reynosa silty clay loam consists of deep, well drained soil. The slopes are usually less than 1%, but can get up to 3% in some areas

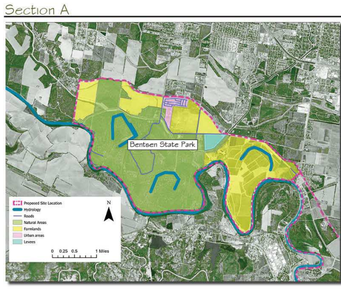
Reynosa Silty Clay Loam:

The Matamoros silty clay is mostly for irrigated cropland soil with a less than 1% slope and consists of deep, moderately well drained, slowly permeable soils.

Photographic Inventory

Site Analysis

Section A



Land Use:
- Natural Areas (2624 acres)
- Farmlands (1,749 acres)
- Mobile Home Park (104 acres)
- Levee (85 acres)

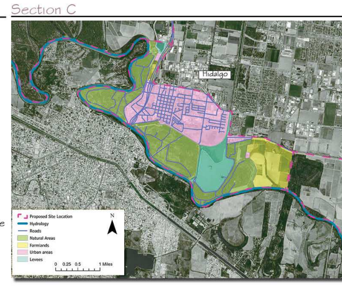
Linear Features:
- Oxbow Lakes
- Roads

Section A is the western end point of the proposed thesis site. The large green area on the left is Bentsen State Park.

Constraints:
- Farmlands and urban areas surround the natural areas

Opportunities:
- Restore oxbow lakes within farmlands
- Design buffer strips for farmlands
- Add roadside plantings

Section C



Land Use:
- Natural Areas (1654 acres)
- Farmlands (635 acres)
- Urban Area (1,143 acres)
- Levee (243 acres)

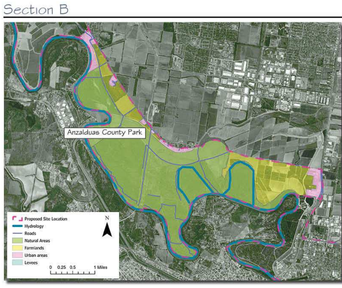
Linear Features:
- Roads

Section C is the section with the largest urban area. This site encases part of the city of Hidalgo which is a main border crossing between Texas and Mexico

Constraints:
- The city is high density urban on either side of the border
- Main border crossing
- Many roads

Opportunities:
- Add roadside plantings
- Suggest a street tree program

Section B



Land Use:
- Natural Areas (2,967 acres)
- Farmlands (873 acres)
- Urban Areas (227 acres)

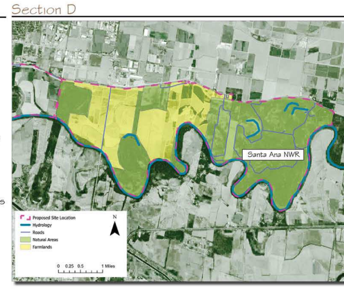
Linear Features:
- Oxbow Lakes
- Roads

Section B has the largest area of green space. The Anzalduas County Park is located along the river bend.

Constraints:
- Main traffic route for trucks and trailers

Opportunities:
- Utilize oxbow lakes

Section D



Land Use:
- Natural Areas (3,306 acres)
- Farmlands (1,728 acres)

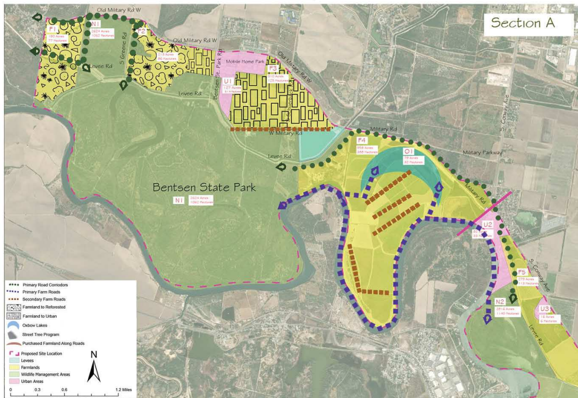
Linear Features:
- Oxbow Lakes
- Roads

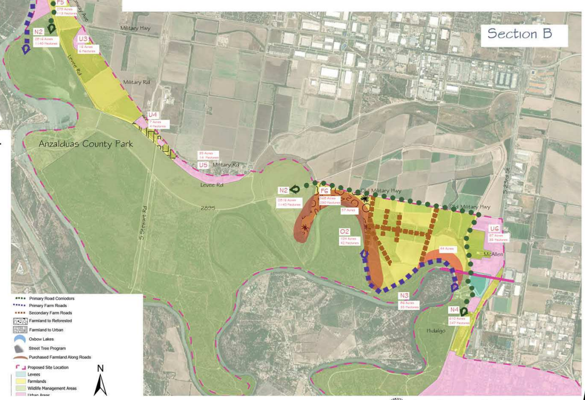
Section D only has urban area and farm land use. This section is the eastern end point of the proposed thesis site. The large green area on the right is Santa Ana National Wildlife Refuge.

Constraints:
- The natural areas are surrounded by farmlands.

Opportunities:
- Develop buffer strips for farmlands
- Purchase land for reforestation

Master Plan Sections A & B





Section A

KEY:
U# = Urban Area #
F# = Farmland Area #
N# = Natural Area #

1. Primary Actions: Create pollinator corridors between existing natural patches

1.1 Primary Road Corridors

Connection 1: Starting from the furthest point West in Section A, to create a connection between Bentsen State park and the other natural areas surrounding the proposed site 5 roads, Old Military Highway, Levee Rd, S Schuerback Rd, S Greene Rd and Bentsen St. Park Rd, were selected to add roadside verges and increase their connectivity

Connection 2: A corridor created along Military Road, located above F4, creates the connection between Bentsen State Park and N2. This corridor will be along farmlands, and go through an urban area to connect with the natural area (N2).

1.2 Oxbow Lake Restoration

Restoring oxbow lake #1, which is surrounded by farmland, will increase pollinator habitat, and plant diversity. Combining the restoration of Oxbow #1 (O1) and creating road verges a connection between Bentsen State Park in Section A and natural area 2 in Section B will be established.

2. Secondary Actions: Create secondary corridors by designing along farmland roads

2.1 Road Corridors Along Big Farm Roads

In section A there will be two corridors along main farm roads totaling 2.25 miles. The first one will be below F3 along W. Military Highway and 1.1 miles long. The second one will be following the road that is up against the Rio Grande River in F4 stretching 1.15 miles long.

2.2 Road Corridors Along Little Farm Roads

In F4, there will be 9 dirt roads selected for pollinator corridors with a total of 3.66 miles.

3. Tertiary Actions: Develop policies that allow for land acquisition to increase pollinator habitat

3.1 Farm to Restoration

If the given the opportunity, land acquisition should occur for F1 and F2 to increase the patch size of Bentsen State Park and the surrounding natural areas around the proposed site. Patch F1 is 190 acres, and F2 is 213 acres increasing the Bentsen State Park patch (N2) by 303 acres to a total of 2927 acres.

3.2 Farm to Urban

Its predicted that farmland in F3 will be converted to a residential neighborhood increasing the mobile home patch (U1) by 190 acres to a total of 295 acres.

Section B

KEY:
U# = Urban Area #
F# = Farmland Area #
N# = Natural Area #

1. Primary Actions: Create pollinator corridors between existing natural patches

1.1 Primary Road Corridors

Connection 2: To connect N1 in Section A with N2 in Section B a corridor along Military Rd and Levee Rd is proposed.

Connection 3: On the Eastern end of Section B, to create a connection between N2 and N4 a road verge along Old Military Highway is proposed to create a corridor.

1.2 Oxbow Lake Restoration

Oxbow #2 has the southern side along N2 and its northern side along F6. Purchasing 57 acres of farmland in F6 will increase the plant diversity and strengthen the corridor along the oxbow. Oxbow #2 is functioning and connected on both ends to the Rio Grande River, adding this corridor can also be used as a buffer to reduce pesticide runoff into the river. This action will be combined with connecting N2 to N3 by purchasing land located north east of N3 to strengthen the corridor of space increasing the habitat and connection between N2 to N4 utilizing N3.

2. Secondary Actions: Create secondary corridors by designing along farmland roads

2.1 Road Corridors Along Big Farm Roads

In section B there will be one corridor along a main farm road which is located right below F6 above N3 which is 1 mile long.

2.2 Road Corridors Along Little Farm Roads

In F6, there will be 6 smaller dirt roads selected for pollinator corridors with a total of 3.18 miles.

3. Tertiary Actions: Develop policies that allow for land acquisition to increase pollinator habitat

3.1 Farm to Restoration

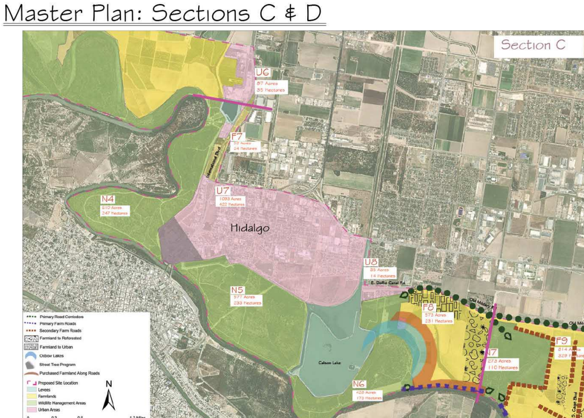
Its suggested that the eastern portion of F6 be reforested to provide a buffer to minimize pesticides from the surrounding farmlands from going into the oxbow and then into the Rio Grande River

3.2 Farm to Urban

Its predicted that farmland in the lower portion of F5 (26.5 acres) will be converted to a residential connecting U4 (9 acres) to U5 (35 acres) creating a larger urban area of 70.5 acres.

On the Verge:
A Design Framework Using Landscape Ecology and Edge Design Principles to Diversify Vegetation for pollinators in SE Texas Audrey E. Fann Spring 2022 Landscape Architecture DEPARTMENT OF PLANT SCIENCE AND LANDSCAPE ARCHITECTURE 5

Master Plan: Sections C & D



Section C

KEY:
U# = Urban Area #
F# = Farmland Area #
N# = Natural Area #

1. Primary Actions: Create pollinator corridors between existing natural patches

1.1 Primary Road Corridors

Creating a primary connection with N6 and N7 a road corridor is proposed along Old Military Rd which is the northern boundary of F8

1.2 Oxbow Lake Restoration

An oxbow lake between N6 and F8 should be restored to increase the plant diversity along the oxbow. With the restoration of the oxbow a portion of farmland should be obtained to increase the width of the riparian area along the oxbow and along the lower edge of F8 along the Rio Grande River

2. Secondary Actions: Create secondary corridors by designing along farmland roads

2.1 Road Corridors Along Big Farm Roads

A road at the bottom of F8 is suggested to be used to create a connection between N5 and N7

2.2 Road Corridors Along Little Farm Roads

There are no suggested small farm roads to be utilized in this section

3. Tertiary Actions: Develop policies that allow for land acquisition to increase pollinator habitat

3.1 Farm to Restoration

N7 is a 273 acres natural area with farmlands on 3 sides, F8 on the left and N9 on the right. Land acquisition is proposed on a portion of the right side of F8 to increase the patch size of N7.

3.2 Farm to Urban

Its predicted F7, which is 59 acres, will be developed into an urban area connecting U6 and U7.

Section D

KEY:
U# = Urban Area #
F# = Farmland Area #
N# = Natural Area #

1. Primary Actions: Create pollinator corridors between existing natural patches

1.1 Primary Road Corridors

Old Military road will also create a road corridor connection between N7 and N9, and N9 to N10.

To create a secondary connection between N7 and N8 a proposed corridor along the lower farmland edge of F9 is created along the riparian zone of the Rio Grande River. Extending the width along the riparian area of the lower edge of farmlands, which touches the Rio Grande River, is proposed in F10 to create corridors for pollinators between N8 and N10.

1.2 Oxbow Lake Restoration

Oxbow #4 is in the center of F10, restoring it will help connect N8 and N9 with N10.

2. Secondary Actions: Create secondary corridors by designing along farmland roads

2.1 Road Corridors Along Big Farm Roads

Main corridor of along S. Cage Blvd is proposed as the main North/South connection in F9.

2.2 Road Corridors Along Little Farm Roads

Smaller roads are proposed within F9 to increase the edge diversity and pollinator patches within farmlands. A farm road corridor in F10 is suggested to increase the north/south connection between the road corridor along Old Military Road (north) and the riparian zone along F10 (south).

3. Tertiary Actions: Develop policies that allow for land acquisition to increase pollinator habitat

3.1 Farm to Restoration

F9 is between N7 and N8 and the third largest farmland area within the proposed site. Two small patches are proposed to be purchased for restoration to create areas of refuge for pollinators within farmlands.

F10 is the second largest farmland area within the site. A proposed land acquisition is suggested between N8 and N9 to increase the patch size and strengthen the connection between patches.

3.2 Farm to Urban

There are no areas suggested or predicted to be urbanized in the immediate future.

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Road Interventions
4 Lane Roads- Street Tree Program
Before
After
2-Lane Road With Shoulders
Farmland Roads
2-Lane Road With or Without Shoulders
78 Acres
97.6 Acres
117Acres
23.4 Acres
39 Acres
58.5 Acres
16.6 Acres
27.6 Acres
41.5 Acres
55.3 Acres
69.1 Acres
82.9 Acres
69.1 Acres
82.9 Acres
96.7 Acres
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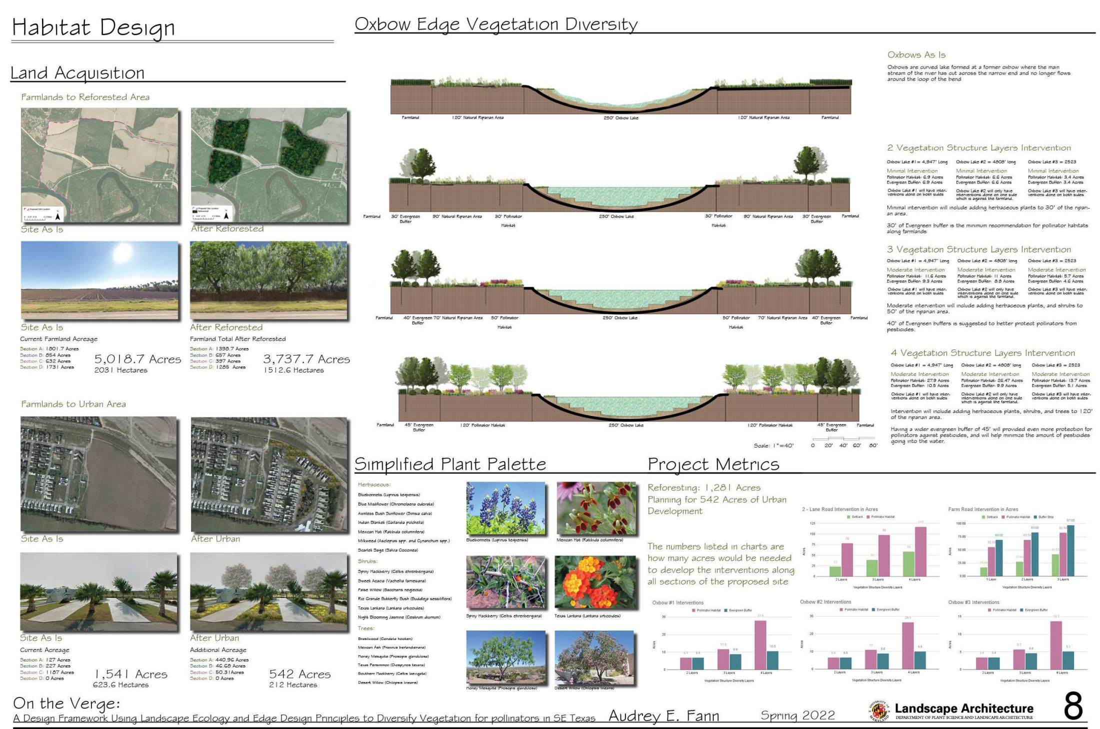
7



Habitat Design
Land Acquisition
Farmlands to Reforested Area
Site As Is
After Reforested
5,018.7 Acres
3,737.7 Acres
Farmlands to Urban Area
After Urban
1,541 Acres
542 Acres
Oxbow Edge Vegetation Diversity
Oxbows As Is
2 Vegetation Structure Layers Intervention
3 Vegetation Structure Layers Intervention
4 Vegetation Structure Layers Intervention
Simplified Plant Palette
Project Metrics
Reforesting: 1,281 Acres
Planning for 542 Acres of Urban Development
The numbers listed in charts are how many acres would be needed to develop the interventions along all sections of the proposed site
On the Verge:
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Audrey E. Fann
Spring 2022
Landscape Architecture
8

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