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MGIS 596B Individual Studies

Effective Refuge Design in the Face of Uncertainty: A case study on the Texas Gulf Coast.

Se vogliamo che tutto rimanga com'è bisogna che tutto cambi.
If we want everything to remain as it is, everything must change.
The Leopard, di Lampedusa

Abstract

The Austin's Woods program of the US Fish and Wildlife Service, in partnership with other conservation organizations, works to conserve bottomland forest habitat in the region south of Houston, TX. The existing landscape consists of forest habitat patches interspersed with pasture, rural residences, and oilfield activities. Establishment of a system of preserves requires evaluation of desirable habitat qualities, and reserve system configuration to optimize existing habitat areas. In a fragmented landscape, land cover characteristics outside preserved areas impact habitat quality within the preserve area. Three model studies were conducted to explore the challenges of assembling a landscape-scale bio-reserve network.

Removal of forest outside of the existing refuge tracts was modeled in a Geographic Information System to measure the change in the core and edge forest. Land cover characteristics, hydrology, and proximity to protected lands were modeled in a Geographic Information System to identify the areas best qualified to be included in the conservation program. Tax parcel information from the four county region was processed to identify contiguous parcels that had common ownership. Values from the refuge suitability model resulting in a data set of land parcels evaluated as habitat for migratory birds. These tracts could be acquired or conserved as large parcels, thus minimizing the potential for future fragmentation of habitat.

As fragmentation of the bottomland forest continues with the rapid development of the Texas Gulf Coast, movement of species among the remaining patches of forest habitat will become critical to the continuation of the distinct bottomland forest ecosystem in this area. A corridor and linkage model for the Eastern Box Turtle (*Terrepene carolina triunguis)* was developed to highlight existing corridors, and to identify opportunities to improve linkages, including private land, between habitat areas on public or conserved land.

Results of the forest removal trial showed that large parcels, parcels next to other preserves, and parcels with more regular edges, lost a lower percent of their core forest in the event that forest outside the boundary were removed. Results of the comparison of the refuge suitability model and the tax parcel information showed that there are large tracts of land suitable for inclusion in a refuge with single owners, which would be the optimal people to approach. The results of the turtle corridor model highlighted the difficulty of modeling corridors in a highly fragmented landscape.

Achieving a refuge network configuration with large parcel size, minimal inholdings, and connecting corridors among the refuge units would increase the habitat value of the refuge network as a whole, by buffering large areas of the refuge network from disturbance, and by encouraging the passage of animals between refuge units. Programs to encourage conservation on private land around the refuge units are discussed.

Introduction

The Columbia Bottomlands - why they are important

Every spring migratory birds travel from Central and South America to North America to breed. For birds that use forest habitat, the first forested region they encounter, after crossing or going around the Gulf of Mexico, is an area around the Brazos, San Bernard and Colorado Rivers in Texas locally known as the Columbia Bottomlands (US Fish and Wildlife Service [USFWS], 2013). Radar data and bird count research estimate that 29 million individual birds go through this region annually (Gulf Coast Bird Observatory, 1997). Also, the area is used by many birds as a wintering habitat due to the mild climate of the Texas Gulf Coast.

The forest canopy in this region was estimated to cover 700,000 acres, interspersed with prairie and cane brakes (USFWS, 2013). Since that time oil and gas operations, cattle ranching, and residential development have significantly reduced the area of forest canopy. Expansion of the city of Houston, and recent expansion of the chemical industry are increasing exurban settlement in the area. In 1996 the Gulf Coast Bird Observatory contracted a study that was completed by Texas A&M University at Galveston, to quantify the forest change in the region (Webb, 1996). Comparison of aerial photographs from 1979 and 1995, in the four counties included in the study, reveals that forest area was reduced from 305,914 acres to 254,269 acres, a loss of 51,649 acres, or 16.9 percent.

Fragmentation as a threat to migratory birds

Neotropical migrants depend on forested areas, particularly bottomland forests, as they migrate. (Moore et al., 1995) Many Neotropical migrants are dependent on large areas of forest for breeding habitat (Petit. 1995). As a forested area is developed, land is cleared for agriculture, industry, residential and other uses. In addition to loss of habitat area, habitat quality is threatened by fragmentation, and the introduction of edge effects. Linear features like power lines, railroads and roads separate forested areas, and for some species, limit movement between divided areas. As more clearing occurs, particularly near roads, forested remnants become smaller and more isolated. The remnant patches will be too small to support some species, resulting in local extinction (Miller and Harris, 1977). Physical changes occur on the edge of the forest, including increase in solar radiation, and changes in temperature and humidity. Plant communities at the edge change; light demanding species are more common, but shade tolerant plants will be limited to the forest interior. High winds can knock over trees near the edge, and humidity and soil moisture change. The changes in microclimate change many populations of species at the edge (Saunders, et al. 1991). The intensity of the physical changes at the edge is related to the land cover outside of the forest (Harper et al., 2005). For example, bare agricultural land may introduce more extreme heat changes, while tall brush moderates the effect of sun and wind. Often, new species moving into the edge increase the total number of species in the forest remnant.

Forest fragmentation by human habitation brings with it human-subsidized predators, like cats, raccoons, dogs and skunk (Wilcove, 1985). Noise from roads, hikers and other disturbances can reach far into the forest to disturb birds (Environmental Law Institute, 2003). Increase in forest fragmentation and edge habitat has allowed brood parasites like the brown-headed cowbird (*Molothrus ater*) to expand its range into areas occupied by forest interior species (Lowther, 1993).

Austin's Woods Conservation Program

The refuges of the Texas Gulf Coast Refuge Complex were originally established in the 1970s to protect migratory waterfowl on the coastal marshes, however, due to rapid development in the region, the US Fish and Wildlife Service and other conservation organizations started a program called "Austin's Woods" to conserve habitat for Neotropical migrant birds (US FWS, 2013).

The "Austin's Woods" conservation plan was approved by the U.S. Fish and Wildlife Service in 1997 aimed to conserve 28,000 acres within the Columbia Bottomlands by acquiring, fee title or easement, properties in coordination with partner organizations, such as the Natural Resource Conservation Service, the Gulf Coast Bird Observatory, Ducks Unlimited, and Texas Parks and Wildlife. Their goal is to conserve 10 percent (70,000 acres) of the original forest area. The project was conceived as a bio-reserve network, with refuge parcels established within a larger acquisition area (Figure 1). The Texas Midcoast Refuge Complex of the US Fish and Wildlife Service was allowed to work with its partners and landowners to set up conservation easements, and to purchase land from willing sellers, or receive donations of land or easements. They have conserved 28,000 acres, as an interim goal, and the Texas Mid-coast Refuge Complex recently received permission to expand the acreage conservation goal to 70,000 acres (Cornell, 2013).

The effectiveness of the "Austin's Woods" project in conserving the Columbia Bottomlands ecosystem will be dependent on the final configuration of refuge units, including the remaining 42,000 acres that have been approved (Figure 2). Most of Texas is privately owned. The Texas Midcoast Refuge Complex cannot condemn land to create a refuge; it is required to purchase parcels from willing sellers (USFWS, 2013). This condition limits the ability of the refuge staff to design the wildlife refuge system entirely on the basis of the value of the land cover to migratory birds or other species. If a large area of good habitat is divided among a set of parcels with different owners, negotiations with all of the owners must succeed to add the whole area to the refuge complex. Failure to conserve some of the parcels may end with those parcels being converted to pasture or residential areas, compromising the habitat value of the area as a whole. If the goal is to conserve enough area to provide habitat for a species that needs large areas, remaining inholdings may decrease the habitat value of the refuge complex.

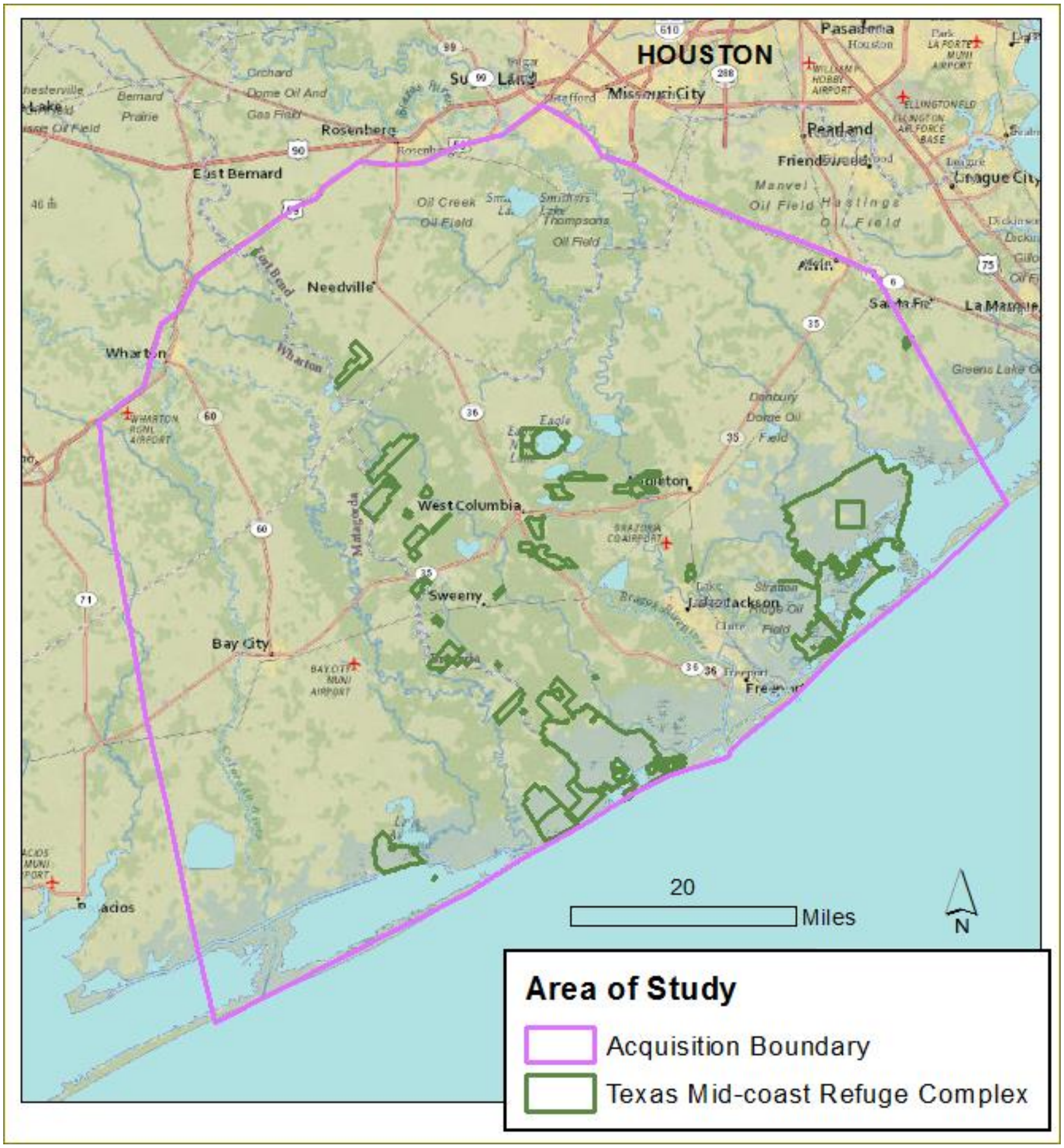


Figure 1. The study area on the Texas Gulf coast, showing the existing parcels of the Austin's Woods habitat preservation project. The Acquisition Boundary includes parts of Brazoria, Fort Bend, Matagorda and Wharton counties. Houston is the fourth largest city in the United States; the population of the metropolitan area grew 26% to 5.95 million between 2000 and 2010 (City of Houston, 2014).

Conservation Priorities

The refuge system has identified a number of factors to be considered when acquiring a parcel. These are paraphrased here from the Land Protection Plan (USFWS, 2013).

Priorities for Land Acquisitions for the "Austin's Woods" program:

Primary Priorities

1) Does the unit provide high quality old growth undisturbed habitat?
2) Does the unit include exceptional/unique plant communities (e.g., canebrakes, willow swamps, bald cypress swamps, cherry laurel stands)?
3) Is the size of tract greater than 1,200 acres, or does it have the potential to have adjacent lands conserved that would meet this criteria?
4) Does the tract complement, is adjacent to or near other protected areas, particularly where natural links exist such as the same hydrologic system or seed dispersal corridors?
5) Would acquisition maximize maintenance of natural ecological functions and processes (e.g., natural hydrological patterns)?
6) Does the unit have a high degree of structural (plant community and topographic) complexity?
7) Does the unit have great restoration potential with basic ecological processes; natural hydrological components, species presence intact and minimal invasive species?
8) Does the unit influence hydrologic or watershed patterns?

Secondary Priorities

1) No minimum size, if the majority of criteria are met.
2) Expansion capability
3) Are there other known exceptional biological elements?
4) Human-caused disturbance present but minimized?
5) The unit is in proximity to existing developments and threated with irreversible loss; is there a high potential for public use opportunities?
6) Fragmentation of surrounding habitats is minimal?
7) Does the parcel have good restoration potential?
8) Can the level and kind of current disturbance be minimized through management actions?

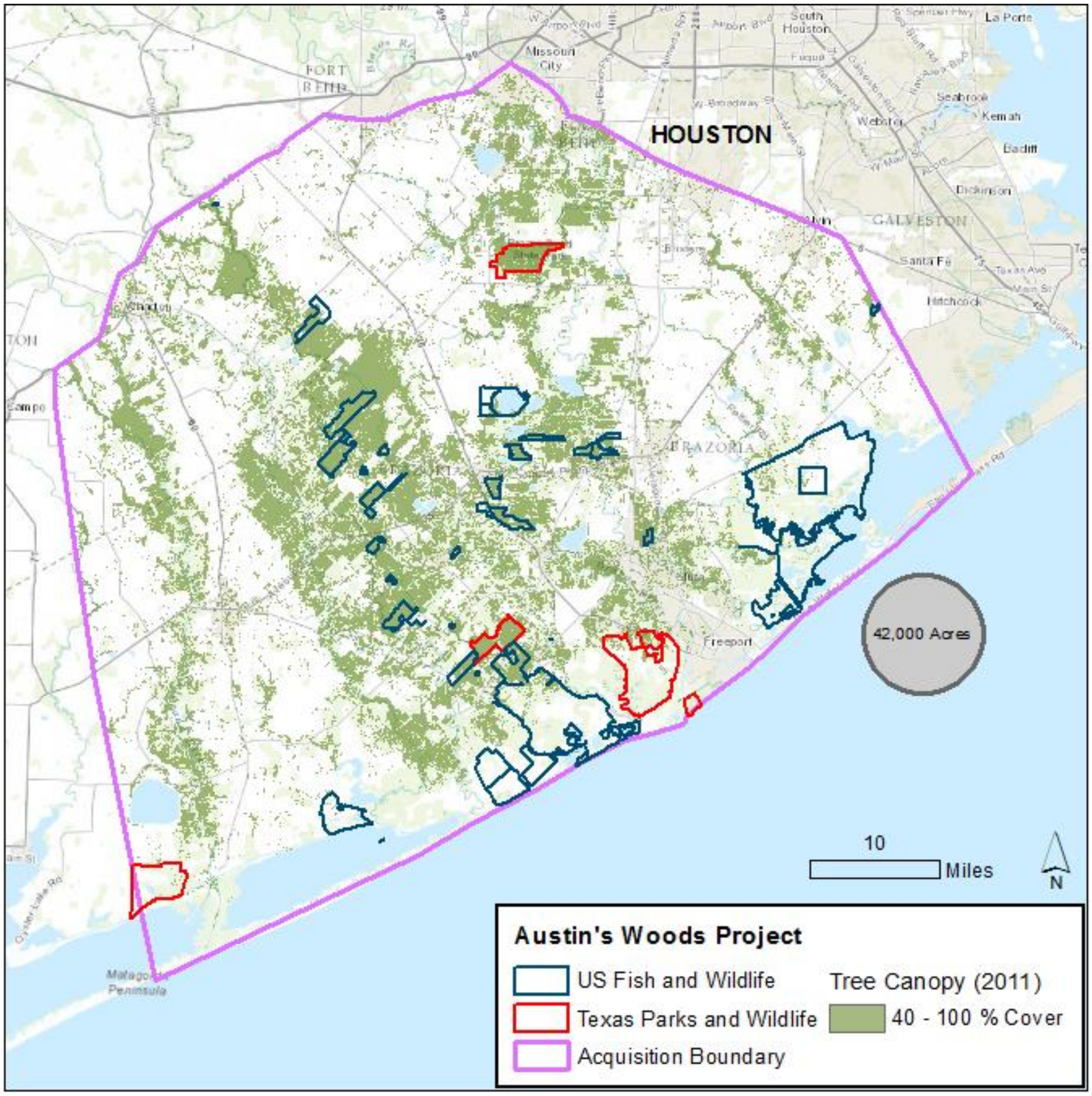


Figure 2. *Forest cover in relationship to existing USFWS Refuge units, and Texas Parks and Wildlife Preserves. The grey circle shows the relative size of an area of 42,000 acres that could be added to the refuge complex. Areas of forest canopy are shown in green. (National Land Cover Database, Tree Canopy, 2011).*

Goals and Objectives

The goal of this project is to optimize the habitat value of future additions to the Austin's Woods program, by identifying land ownership parcels that best fit the Land Preservation Plan Priorities, and by identifying parcels that facilitate the exchange of animals between refuge parcels by acting as habitat links and corridors. Given the limit on land acquisition, the habitat value of the refuge parcels is enhanced by partnering with neighboring landowners to maintain or improve the quality of forest land cover outside of the boundaries of the refuge, and enhancing corridors for wildlife travelling between parcels.

Michael Lange, the US FWS biologist who has been working on this project since its inception 18 years ago, has a thorough understanding of the natural features of the area, and has already identified many parcels and owners to approach (M. Lange, personal communication). This project will identify factors that are not obvious in aerial imagery, such as the status of managed lands, and water features. We hope that bringing this information together in a format that can be shared with conservation partners the findings will be useful when engaging stakeholder support.

Goals

Goal 1). Evaluating core and edge forest
Some of the existing Refuge units are located within larger patches of old-growth forest. These areas protect the forest in the Refuge unit from edge effects of wind, sunlight, and edge-habitat species, maintaining quality habitat composition of core forest. This section will measure how the core and edge habitat would change, if the forest cover surrounding the Refuge unit were removed.

Goal 2). Evaluating parcels for acquisition or partnership
The Land Protection Plan identifies the principal qualities that would make a parcel of land a valuable element in the system of refuge units. Many of the qualities, such as large area of forest, and proximity to streams, are obvious on an aerial photograph. Other high-priority elements, such as plant communities, wetland features, topographic complexity, and details of forest age and structure are not so obvious. This goal is to identify specific parcels that have these qualities, including proximity to existing refuge parcels and managed or "preserve" lands. The parcels will be ranked by a valuation scheme based on priorities in the Land Protection Plan.

Goal 3). A system of habitat corridors
This analysis will build a corridor model to enhance understanding of the refuge system as a network of habitat patches, and highlight parcels that would be valuable to add as corridors for wildlife passage.

Objectives

Goal 1 objectives. The GIS products for this goal:

1) A data layer of core and edge (100 m) forest on existing refuge parcels.
2) A data layer of core and edge forest if surrounding forest were to be cleared, and a table of lost core forest by parcel.
3) A table showing the change in the area of core forest habitat for each refuge parcel group, if all surrounding forest were to be removed.

Goal 2 objectives. The GIS products for this goal:

1) A collection of data layers that represent the valuation scheme factors.

2) A map visualizing the summed valuation factors as a “Refuge Suitability Index” to show the areas that best meet the criteria of the Land Protection Plan.
3) A database containing a list of large areas that have a high “Refuge Suitability Index”. Contiguous parcels with common ownership will be identified and treated as a single unit. Individual parcels or parcel groups that have large areas of high “Refuge Suitability Index” will be identified, and their relative merits evaluated.

Goal 3 objectives. The GIS product for this goal:

1) A corridor study for the Three-toed Box Turtle (*Terrapene carolina triunguis*). The model will include primary, secondary and breeding habitat, corridors and barriers to movement.

Goal 1: Evaluating Risk to Core Forest Habitat

Definition of Edge distance

The edge effect of habitat patches in a landscape depends on conditions in the matrix area immediately outside the habitat patch. For example, birds in a habitat preserve that borders a residential subdivision will be more affected by predation by cats than a habitat preserve that is bordered by a bend in a river. The distance that an edge effect penetrates the forest depends on the type of disturbance, and the nature of the area outside the forest. Harris (1986) describes a “three-tree height” rule of thumb for how far climatic effects of a surrounding clearcut will penetrate into an old-growth stand. Edge forest was defined as the area within 100 meter (328 feet) into the forest from a disturbed border. This distance is more than three times the height of the tallest tree species in the Columbia Bottomlands (Table 4).

Some of the Fish and Wildlife refuge units in the Texas Midcoast complex are deeply embedded in large areas of forest (Figure 4); the edge of the forest is outside of the edge of the parcel, and few edge effects occur in the habitat areas on the refuge. Other refuge units are bordered by open grassland or pasture matrix, and others are bordered by roads or rivers. Some of the Refuge parcels have clearings or building areas, which are either maintained or encouraged to return to forest habitat. A few of the refuge parcels have ponds – this is natural edge habitat. Many of the Refuge parcels are crossed by pipelines and utility corridors, which create a narrow disturbed break in the forest habitat.

In addition to the FWS Refuge units, there are a number of other conservation lands within the Austin’s Woods acquisition boundary (Figure 3). Some of these natural preserves are contiguous to the FWS Refuge unit, as in Figure 4. Forest that is within the Refuge unit is protected from the effects of disturbance outside the border of the unit by the natural preserve.

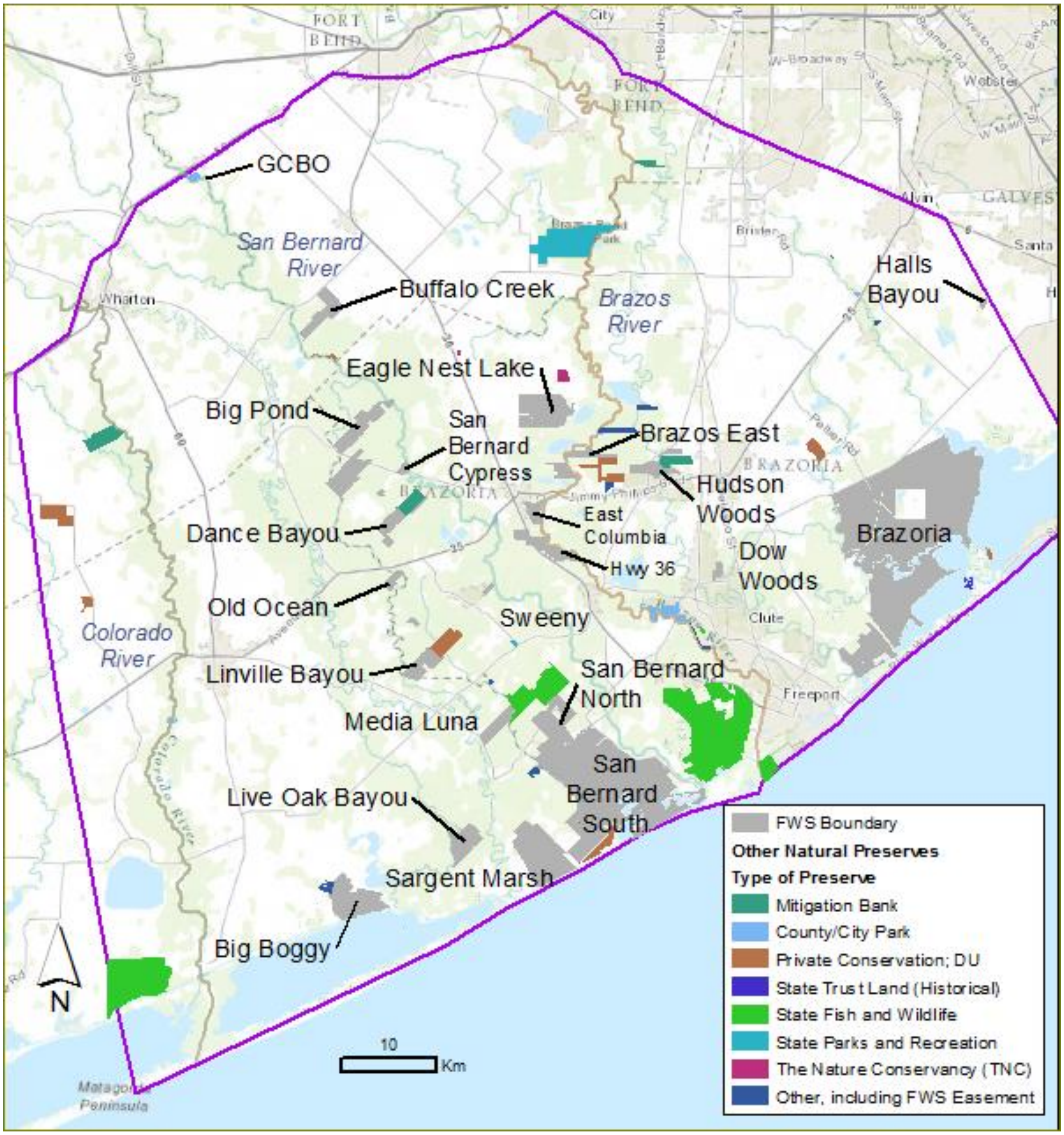


***Figure 3**. The Refuge Units of the Texas Midcoast Refuge Complex and other preserve or managed lands. Texas Parks and Wildlife has three large Wildlife Management Areas and Brazos Bend State Park. Many preserve areas are small.*

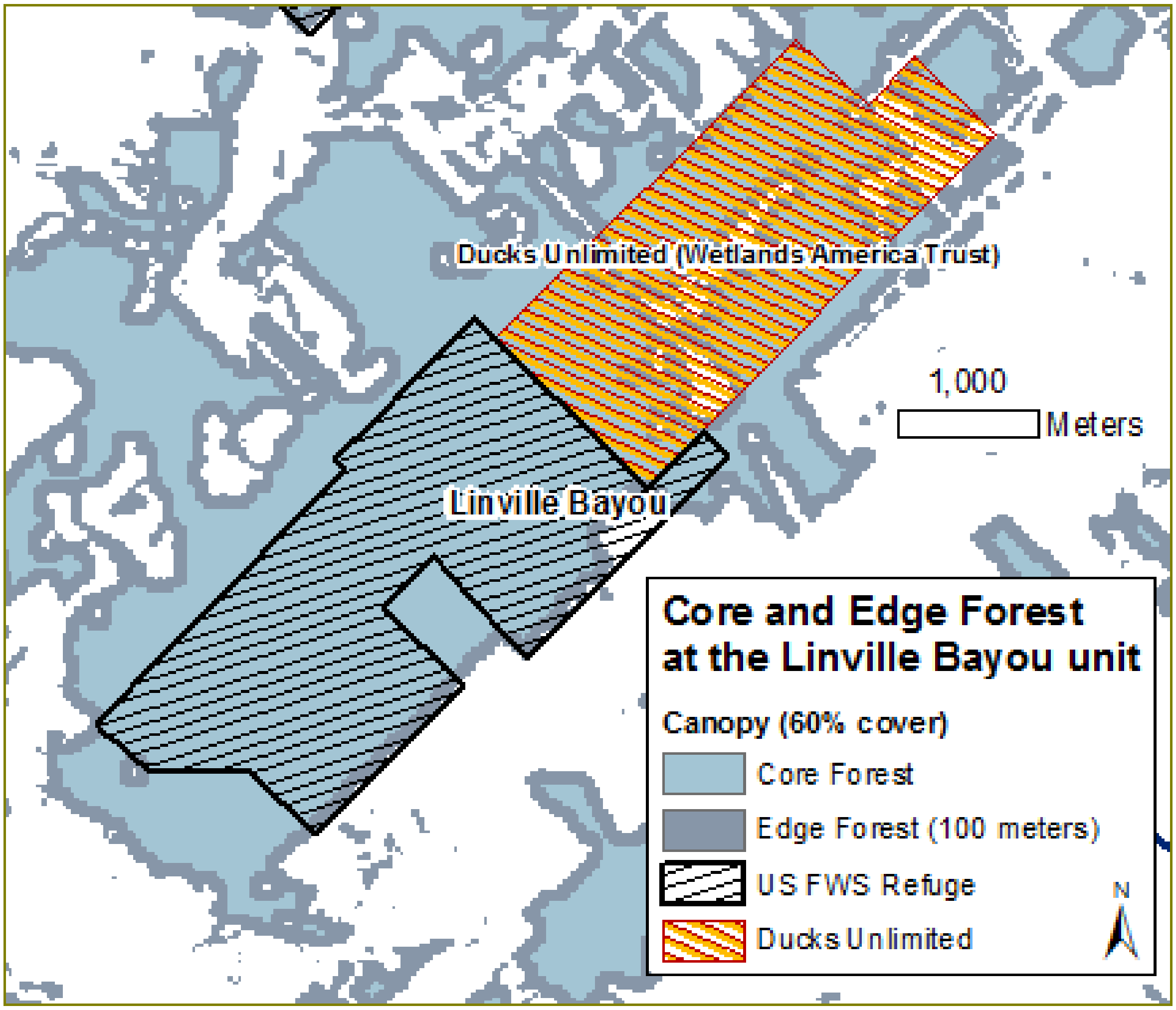


Figure 4. The Linville Bayou unit (1,593 acres) is embedded in a larger patch of forest habitat within a matrix of pasture land. It is bordered by a Ducks Unlimited preserve to the northwest.

This section will evaluate a hypothetical case, to test if all of the forest land cover surrounding a reserve were to be removed. Other natural preserves will be considered as preventing the removal of the forest habitat that is located on them. The amount of core and edge forest on the refuge units will be compared in a Before and After condition.

Goal 1 Methods

Esri ArcGIS 10.2 (2013), was used to store, manipulate and display the data. Some of the data processing used the CorridorDesigner tools for ArcGIS (Majka et al., 2007) and Patch Analyst and Patch Grid (Rempel et al., 2012).

Locations of other preserve areas were compiled from the Texas Natural Resources Information System (2014), the National Conservation Easement Database (2014), and the Protected Area Database of the United States (US Geological Survey, 2012). Mitigation Banks were located based on the “Ribbits” website of the US Army Corp of Engineers (2014), and were digitized from county parcel information. County and City parks that were of some size and located away from town centers were digitized based on county parcel information (Figure 3).

To account for forest canopy density the Tree Canopy Cover data was used from the 2011 National Land Cover Database (Benton et al., In press). Areas with 60% or greater canopy cover were used to represent forest habitat, and core forest was created from areas greater than 100 meters from the external border of the 60% canopy limit. The 60 % threshold distinguished breaks in forested areas caused by roads, ponds, open streams, major power lines and drainage-related stream clearings. However, it tended to obscure pipeline right-of-ways unless they were large. Clearings in advanced successional stages were also not easily distinguished (Figure 5).

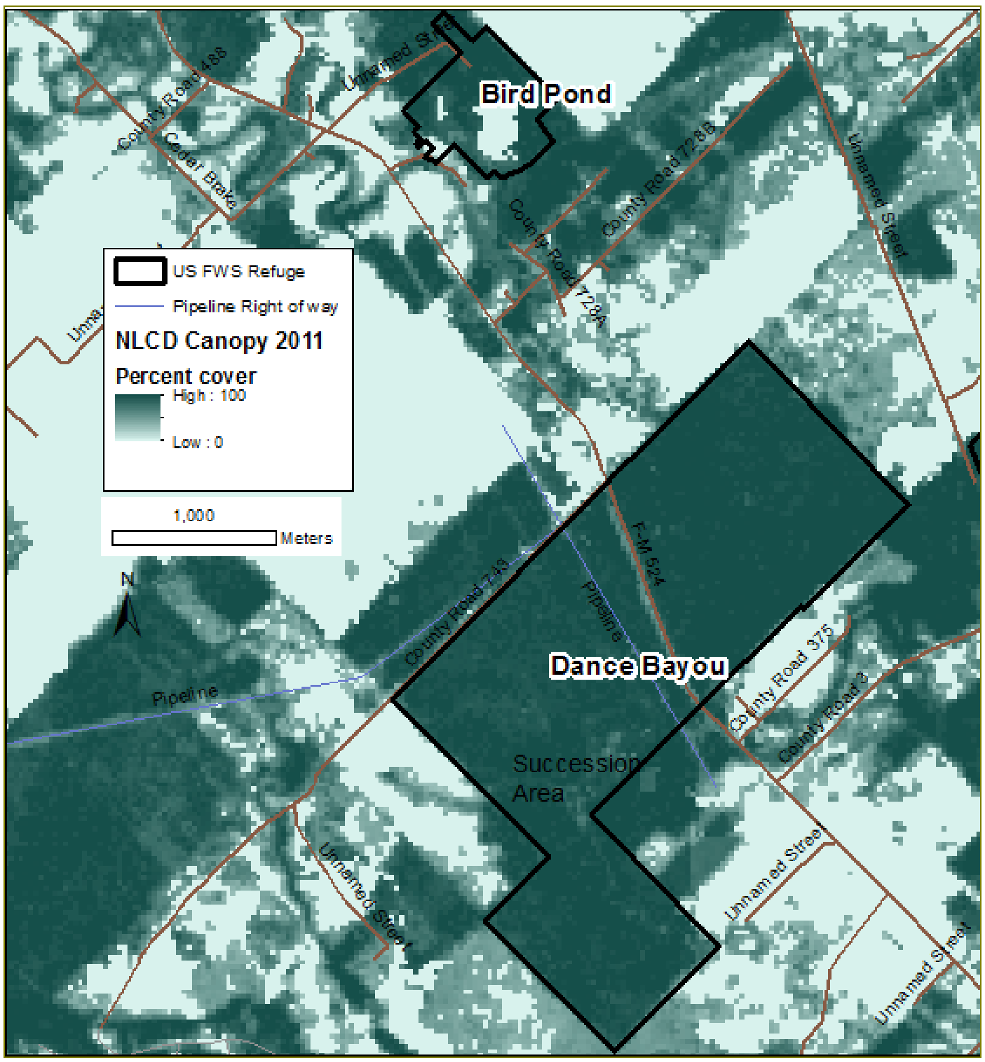


Figure 5. National Land Cover Database 2011, US Forest Service Tree Canopy Cover. Pixel values range from 0 to 100, representing the percent density of tree canopy cover. Values above 60 percent were used to represent forest cover.

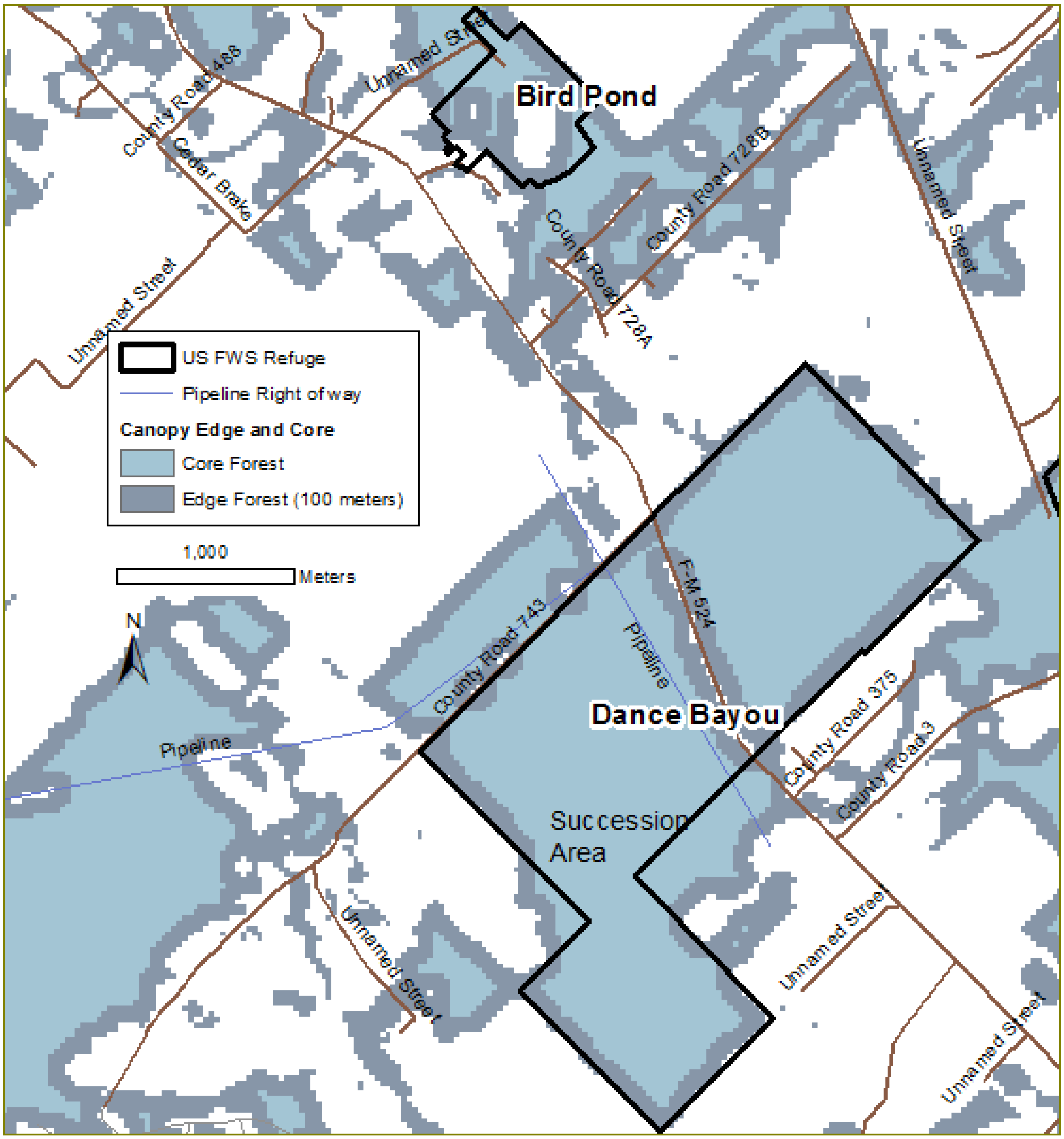


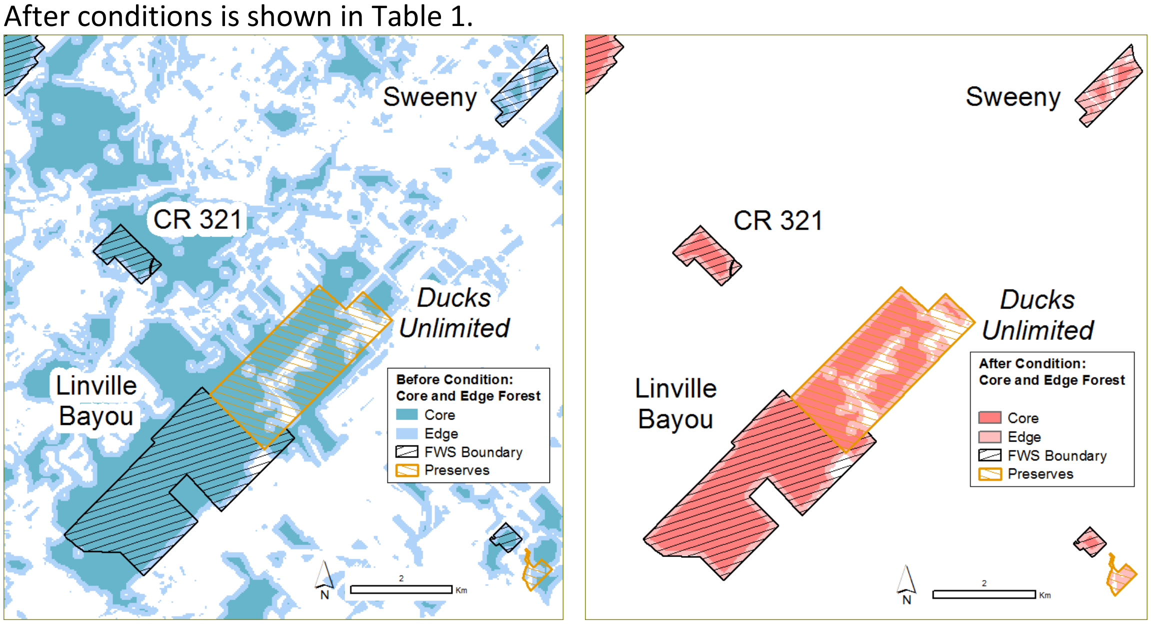
Figure 6. The Core and Edge forest layer was created from Canopy percent cover values greater than 60%. The 60 % Canopy theme showed most of the breaks in the forest, but did not show some pipeline clearings or advanced successional areas.

Canopy Cover before and after forest removal.

The Canopy Cover theme of values greater than 60 percent was grouped into regions, then converted into a polygon format to define the edges of the canopy regions. Areas within 100 meters inside the edge of these polygons were separated into Edge polygons. Areas farther inside the Canopy area were considered Core forest. These Core and Edge areas were converted back into the 30 meter pixel grid which was the data format for all of the data sets in the model (Figure 6).

For the After condition, the all of the Canopy theme outside of the refuge units and the other preserves was removed. Edge and Core forest themes were created in a procedure similar to the Before condition (Figures 7a and 7b).

Patches representing Core and Edge forest in both the Before and After conditions were tabulated by the refuge parcel groups. The area of Core and Edge forest in the Before and After conditions is shown in Table 1.



Figures 7a and 7b. Modeling remaining forest if all of the forest cover surrounding Refuge Units and other preserves were removed. The blue area represents all of the forest in the Before condition, the pink area represents the extent of the forest after all of the forest outside the Refuge units and other preserves. Core Forest on the refuge boundaries becomes edge forest in the After condition.

Goal 1 Results:

Area of Core and Edge forest in the Before and After conditions were tabulated by refuge unit and compared. The refuge units are grouped into coastal units, and small, medium and large units.

Table 1. Change in core forest by Refuge unit. Units along the coast were mostly marsh, and had very little forest. Refuge units are grouped by size.

Unit Size	Refuge Unit Group	Total Acres	Core Before	Edge Before	Core After	Edge After	Change in Core Acres	Percent Change
Small:	Betty Brown	9	0	8	0	8	0	0.0
	GCBO	22	13	8	0	21	-13	-100.0
	Cedar Creek Access	36	0	5	0	5	0	0.0
	Palm Unit	46	24	22	11	34	-13	-53.7
	Bird Pond	128	35	70	12	93	-23	-65.6
	CR 321	170	141	30	81	90	-60	-42.7
	Sweeny	195	36	119	32	123	-4	-12.3
	Halls Bayou	206	10	79	7	82	-3	-27.3
	San Bernard Cypress	288	24	108	10	123	-15	-60.6
	Dow Woods	330	203	92	146	148	-56	-27.9
Medium:	Old Ocean	529	427	93	296	223	-131	-30.6
	Brazos East	718	272	325	217	381	-55	-20.3
	Brazos West	731	374	283	354	304	-20	-5.4
	East Columbia	893	213	457	206	464	-7	-3.3
Large:	Media Luna	1,317	367	453	352	468	-15	-4.1
(>1200 ac)	Dance Bayou	1,498	1,148	320	987	482	-161	-14.1
	Hudson Woods	1,563	589	627	496	720	-93	-15.7
	Linville Bayou	1,593	1,458	97	1,234	320	-223	-15.3
	Buffalo Creek	1,809	600	264	444	421	-156	-26.0
	Hwy 36	1,940	421	552	378	594	-43	-10.2
	Live Oak Bayou	2,079	114	556	103	567	-11	-9.7
	San Bernard North	3,346	945	1,010	876	1,080	-70	-7.4
	Eagle Nest Lake	4,481	253	441	228	467	-25	-9.9
	Big Pond	4,860	3,555	1,073	3,071	1,556	-483	-13.6
Coastal	Big Boggy	4,206	0	15	0	15	0	0.0
Units	Sargent Marsh	6,260	0	0	0	0	0	0.0
	San Bernard South	25,759	24	316	21	320	-4	-14.5
	Brazoria	45,651	0	102	0	102	0	0.0
	Total	110,663	11,246	7,524	9,561	9,209	-1,684	-14.98

Units with No Core Forest

Five units have no Core forest and can be evaluated into two categories: Very small units in developed areas, like Betty Brown and the Cedar Creek Access unit, or the large units on the coast, like the Brazoria Refuge, Big Boggy Refuge, the San Bernard Refuge south of County Road 306, and the Sargent Marsh area. These parcels, in general, do not have native forest cover and are managed for migratory waterfowl, and for fresh water and salty prairie. Invasive trees like tallow and shrubs are removed by burning or other management methods.

Small and Medium Units

All of the units that started with core forest lost some core forest. Units that already had most of their surrounding forest cover removed, like the Sweeny and Media Luna units, lost relatively little core forest. Smaller units like the Palm Unit, which lost 53 percent of its core forest, and GCBO Unit, were affected because the 100 meter criterion for edge distance is larger than the size of the unit (Figure 8).

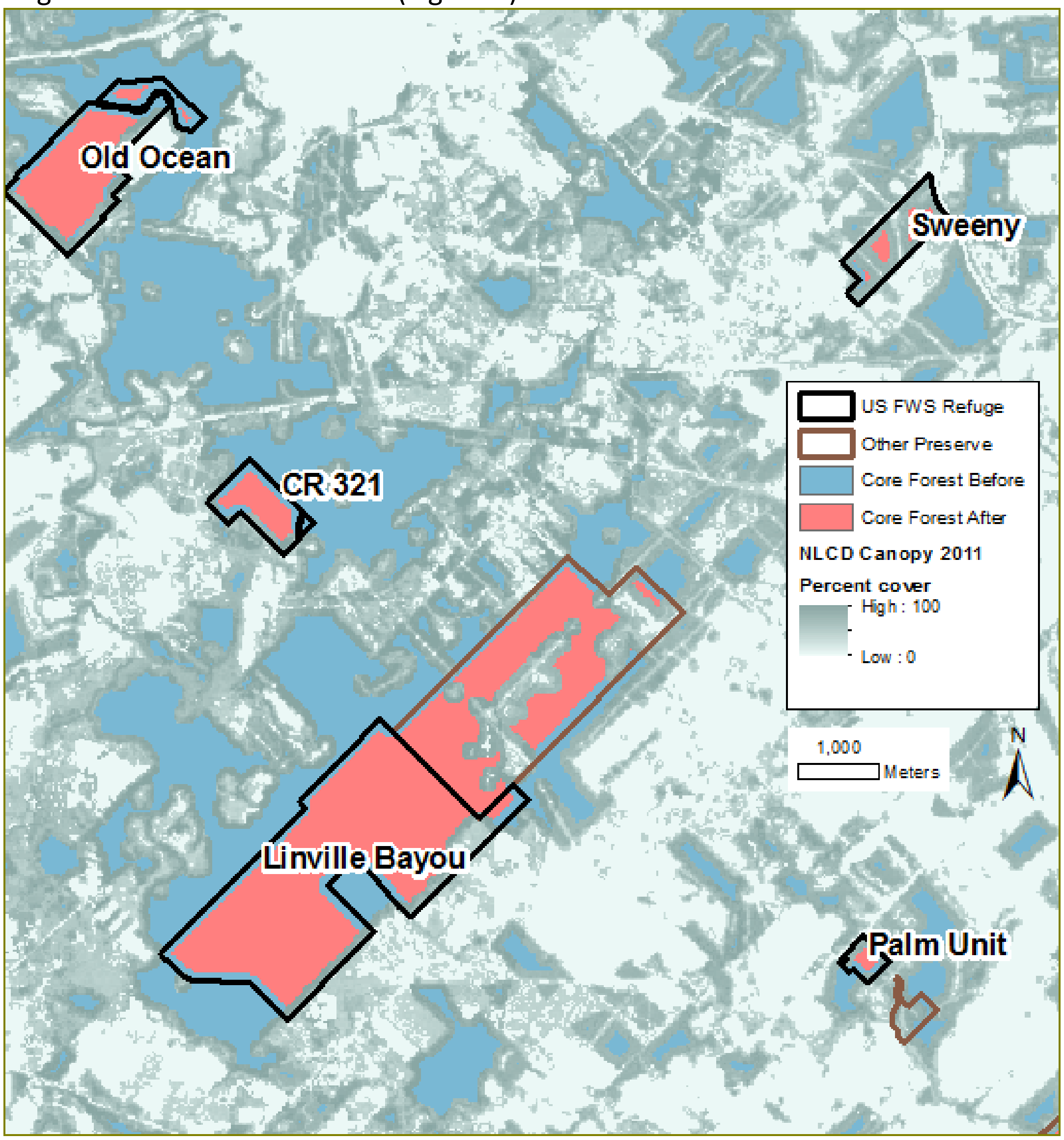


***Figure 8**. Areas where most of the surrounding forest was already removed, like the Sweeny Unit, lost minimal core forest. Units that had forest beyond their boundaries had parts of their forest converted from core forest to edge forest, except where they were bounded by another preserve; e.g., Linville Bayou.*

Medium sized units, like Old Ocean and Linville Bayou, lost less core forest due to the initial ratio between their area and their perimeter was larger. Linville Bayou is partly protected by its proximity to the Ducks Unlimited preserve, but it lost more core forest because of its irregular shape. Most of the core forest of the San Bernard Cypress unit was lost because it was located along the unit's northwestern edge, and not in the center of the unit.

Large Units.

Large units, greater than 1,200 acres (486 hectares) in size, lose less Core Forest in proportion to their size, unless their boundary is complex, as in the north end of the Big Pond Unit (13.6 percent loss), and the south end of the Dance Bayou unit (14.1 percent loss). Dance Bayou also lost core forest along the south-east side of the slender annex, though the side next to the mitigation bank preserve was not affected because it was already bare (Figure 9).

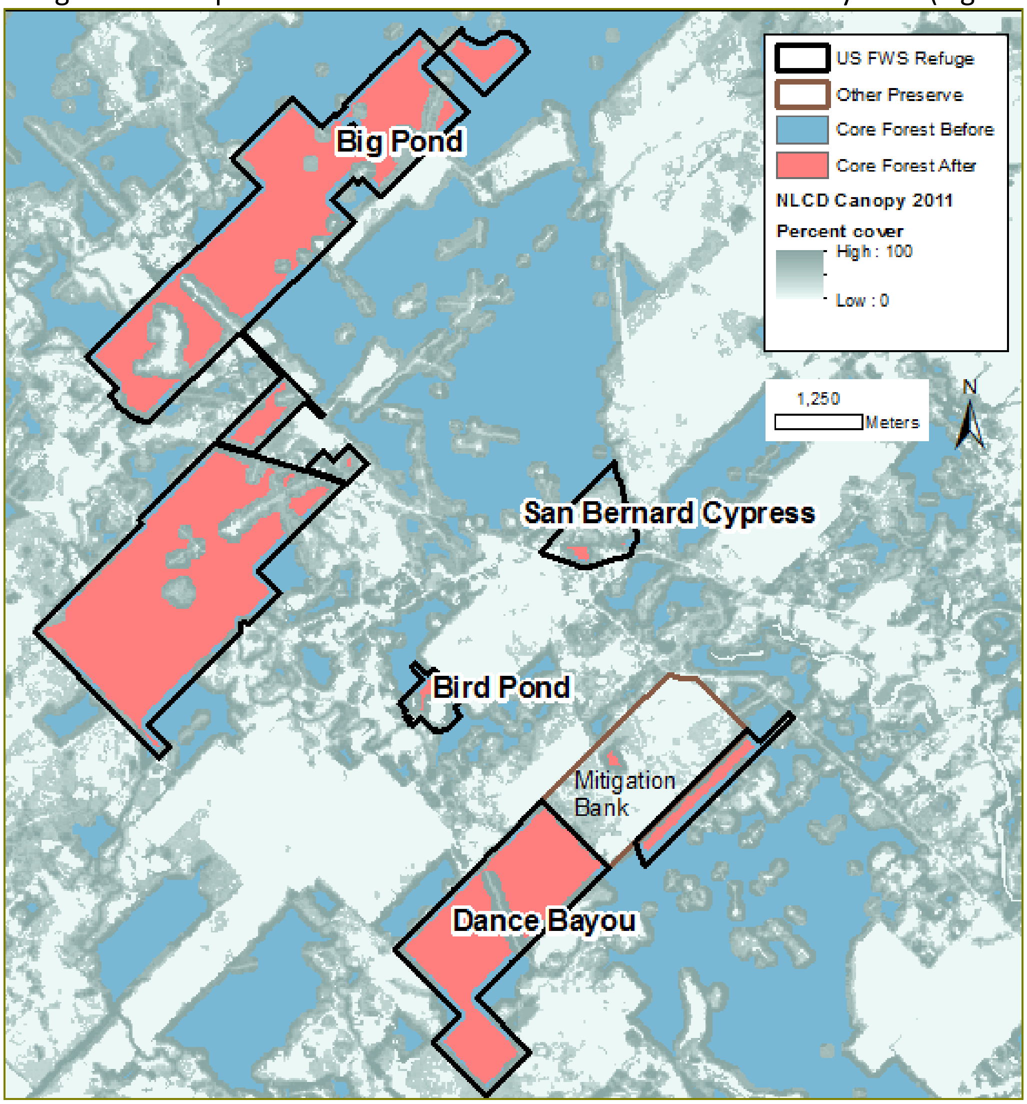


Figure 9. *Large, wide units lost less of their core forest under the hypothetical condition of removal of all of the surrounding forest. Ideally, a refuge unit would have a low perimeter-to-area ratio.*

Of the large units, Buffalo Creek lost the most, proportionally, core forest (26%), because its core forest was located around an irregular edge (Figure 10). The shape of the unit is an elongated, complex polygon.

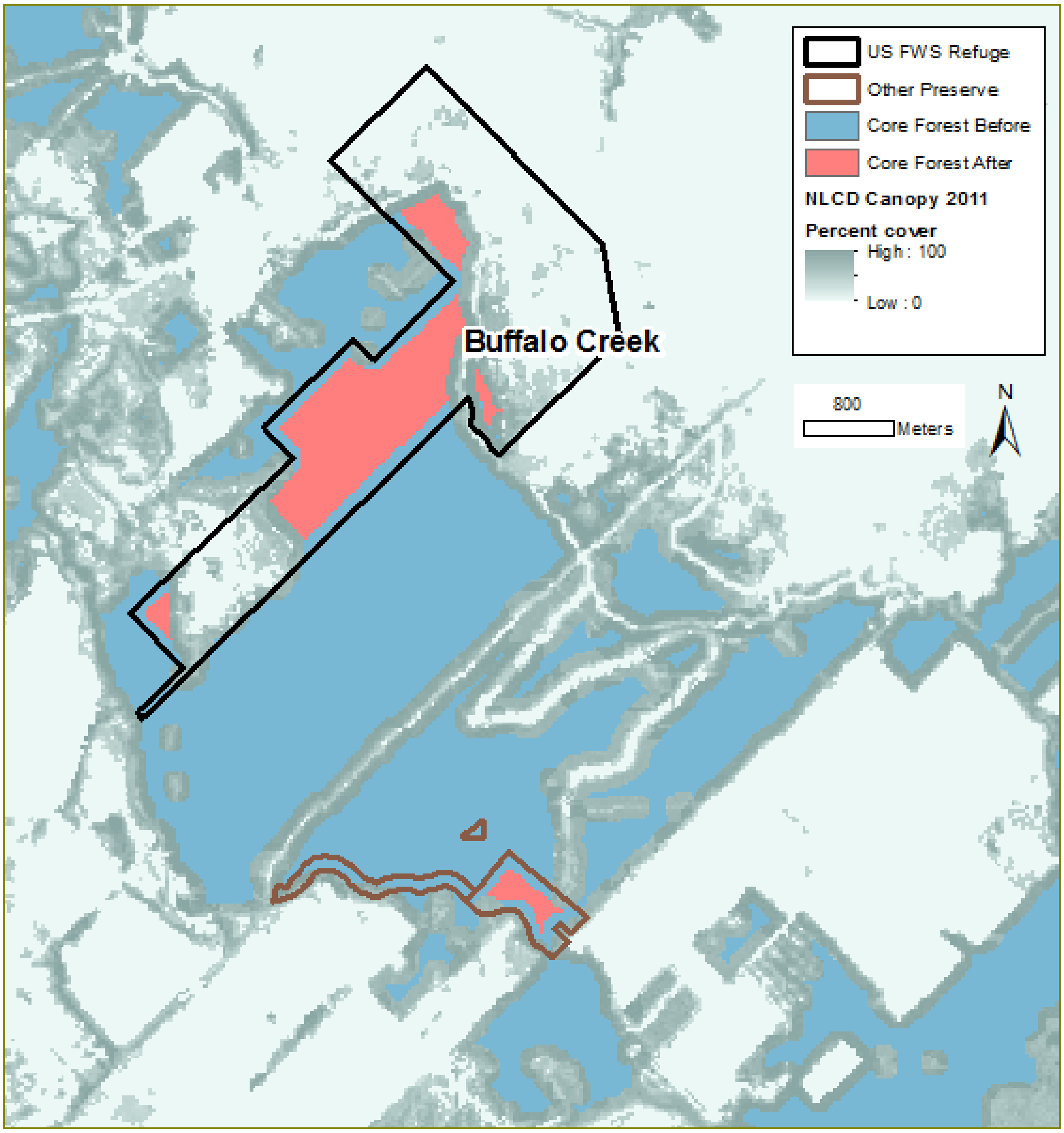


***Figure 10**. The Buffalo Creek unit. Some of its area is maintained as prairie. Proportionally more if its forest is located near an edge of the unit, because of the unit's elongated and concave shape.*

Goal 1 Discussion.

Effect of tract size

One of the priorities of the Land Protection Plan is to maintain large tract size, greater than 1,200 acres. In the forest-removal scenario there are 10 tracts larger than 1,200 that lost an average of 12.6 percent of their core forest when all of the surrounding forest was removed, while the 12 tracts smaller than 1,200 lost 37.4 percent of their core forest (Table 2). However, the loss in each tract depended on its individual surrounding landscape, and the arrangement of forest within the tract. Some tracts began with forest on the perimeter, if the surrounding forest had already been removed. Tracts with most of their forest near a perimeter, and with narrow or irregular shapes, lost proportionally more forest.

Table 2. Loss of core forest by tract size. Large tracts lost proportionally less than small tracts.

Summary Table	*Number*	Average percent Core Forest Loss
Small and Medium Tracts	*12*	37.4
Large Tracts (>1,200 acres)	*10*	12.6

Implications of tract size, and of forest patch size.
When core forest decreases in a landscape undergoing forest fragmentation, it is desirable to protect core forest by including it in the refuge system, or by encouraging conservation on parcels that are close neighbors to the existing refuges. In addition, conserving large parcels is a strategy that is more likely to lead to a more contiguous, unfragmented refuge complex than acquiring small parcels over time. The Austin's Woods program depends on willing sellers, thus, there is no guarantee that a particular parcel will be available to include in the refuge system. To maximize resources when building a refuge system, such as Austin's Woods, it is better to work on larger parcels to reduce the possibility that the final refuge configuration will be a patchwork.

Given that neighboring parcels may be acquired or conserved over time, each new refuge parcel should be located in an area that contains many parcels nearby that would be suitable to include in the refuge system. If a parcel is acquired within a large patch of forest or other natural land cover, many of the neighboring parcels will also be desirable. If the parcel is within a large area of forest, its forest cover is core forest, and it is surrounded by core forest. If the parcel is surrounded by pasture, the neighboring land is less desirable for inclusion in the refuge system, but it could be restored to forest or prairie over time. On the other hand, if a parcel is surrounded by home sites, there is little room for expansion (Figures 11a and 11b).

Figures 11a and 11b. *In Figure 11a, the Big Pond unit of 4,860 acres was acquired in three transactions. The south part of the unit is in a forested region of 3,171 acres, and the north part of the unit is in a forested region of 25,968 acres. The thin area connecting them is a large drainage ditch. In Figure 11b, the Dow Woods Unit has 330 acres within a 2,760 acre patch of forest bordered by State Hwy 288, the town of Lake Jackson, and the commercial area between Lake Jackson and Angleton. The expansion potential of the Big Pond unit is 10 times that of the Dow Woods unit.*

In summary, a strategy to reduce habitat fragmentation in the final refuge configuration of new refuge parcels is to: 1) acquire new units as large parcels, 2) focus on parcels which are located in large areas of undisturbed habitat, and 3) if possible, locate new parcels in close proximity to other refuge parcels or conserved areas.

Goal 2: Evaluating parcels for acquisition

The goal of this section is to identify county tax parcels that are suitable for inclusion in the refuge complex. The approach was to model the priorities of the Land Protection Plan using a grid representing 30 x 30 meter areas of the landscape. Data sets were collected to represent the listed priorities and converted into a grid format. Features represented by the data were rated according to their relative value in the conservation plan. Ratings were combined mathematically to make a model of valuable areas in the landscape. Grid values were tabulated to county tax parcels, grouped by common owner, within the acquisition boundary. The sum of the values is the score of that tax parcel group.

Habitat Suitability Modeling

There are two approaches for habitat suitability modelling (Beier et al, 2007). The inductive, empirical approach requires data on animal's presence or absence, as well as information about land cover and topography. Animal presence or absence is statistically associated with the land cover characteristics to create the model. The deductive approach, based on literature review and expert opinion, uses previous studies on the species life history and habits to identify land cover characteristics that have been consistently associated with animal presence. This requires good information about the animal, and again, good information on land cover and topography. For a particular animal, landscape areas are evaluated by available food, water and cover for the animal to successfully persist. Each variable is scored from 0 to 1, and then the variable values are combined, and normalized by dividing by the highest value to make a Habitat Suitability Index (HSI) (US Fish and Wildlife Service, 1981). Ideally, a habitat suitability model is critiqued by experts and validated with animal presence/absence studies. A good habitat suitability model will have a wide range of scores between 0 and 1.0, so that habitat areas are easy to distinguish (Brooks, 1997).

Application to the Austin's Woods project

In this project, the study area was modeled using the deductive approach to identify areas that are suitable for inclusion in the Austin's woods project. The study area covered the entire "Acquisition Boundary" area of 1,930,823 acres (781,377 hectares), within which parcels can be acquired (Figure 2). Habitat suitability criteria are the listed in the Land Protection Plan for the Austin's Woods project. These priorities coincide with the breeding habitat needs of select species of concern as described in the Land Protection Plan including Prothonotary Warbler, Swainson's Warbler, and Acadian Flycatcher. Priorities also coincide with the habitat needs of Neotropical migrant birds as they pass through the region, especially those favoring forested wetland habitats (Gauthreaux and Belser, 2005). The listed priorities also account for features that are important for management of wildlife refuge habitat, such as the size of the parcel, proximity of other wildland preserves, surrounding land use, the ability of managers to control access and water level, and the possibility for restoration.

Goal 2 Methods

Data sets were chosen to represent and evaluate most of the Land Protection Plan priorities: undisturbed old-growth forest, exceptional plant communities, large forest tracts, adjacency to nearby protected areas, and natural hydrological components. Seven data sets were developed to combine mathematically as factors in the model; the three forest-related data sets were combined into one Forest Patch Quality factor:

1) Forest Patch Quality
    a. Forest Patch Area
    b. Core and Edge Forest
    c. Canopy Height.
2) Proximity to existing Refuge and conservation parcels.
3) Percent "Developed" within 1 km.
4) Wetlands, ponds and natural lakes
5) Proximity to Streams (120 meters from linear or polygon feature for stream)

Each of the factors was rated on a scale of 0 to 10.

The area of forest patches was derived from the four Forest classes of the National Land Cover Dataset (NLCD) (Figure 12). Classes for Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetlands were used to define areas covered by forest (Figure 13).

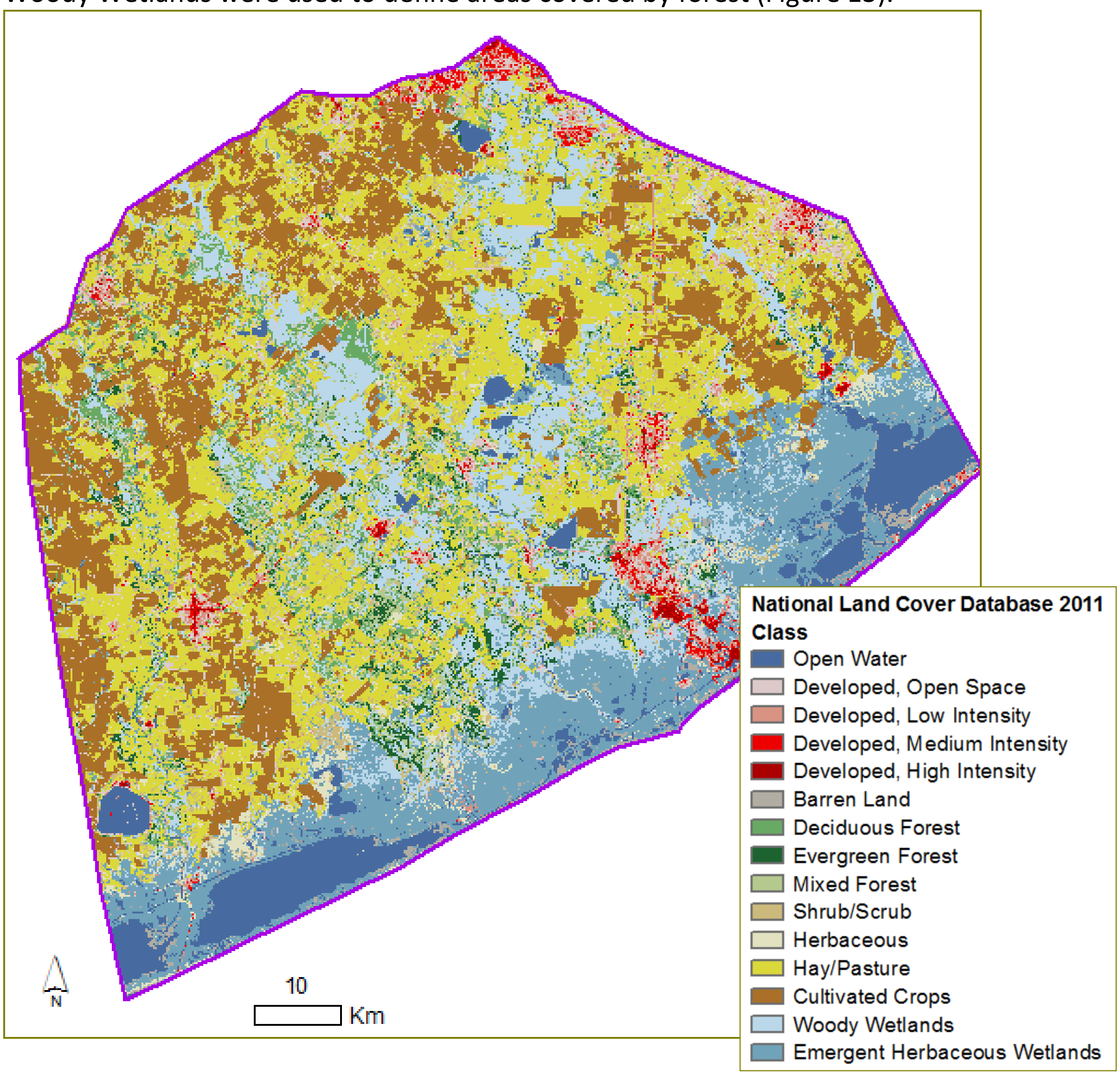


__Figure 12__. National Land Cover Database, 2011. The areas of the four forest classes, Deciduous Forest, Evergreen Forest, Mixed Forest, and Woody Wetland were combined to make the Forest Patch Area theme.

A filtering process with the GIS software was completed to remove tiny areas and reduce links between patches representing stream borders and hedgerows, and also small gaps between closely located patches. After the filtering process, the area of each forest region was calculated. Areas that were within large connected regions of forest were assigned high ratings. Forest patches that were small and isolated were assigned low ratings (Table 3).

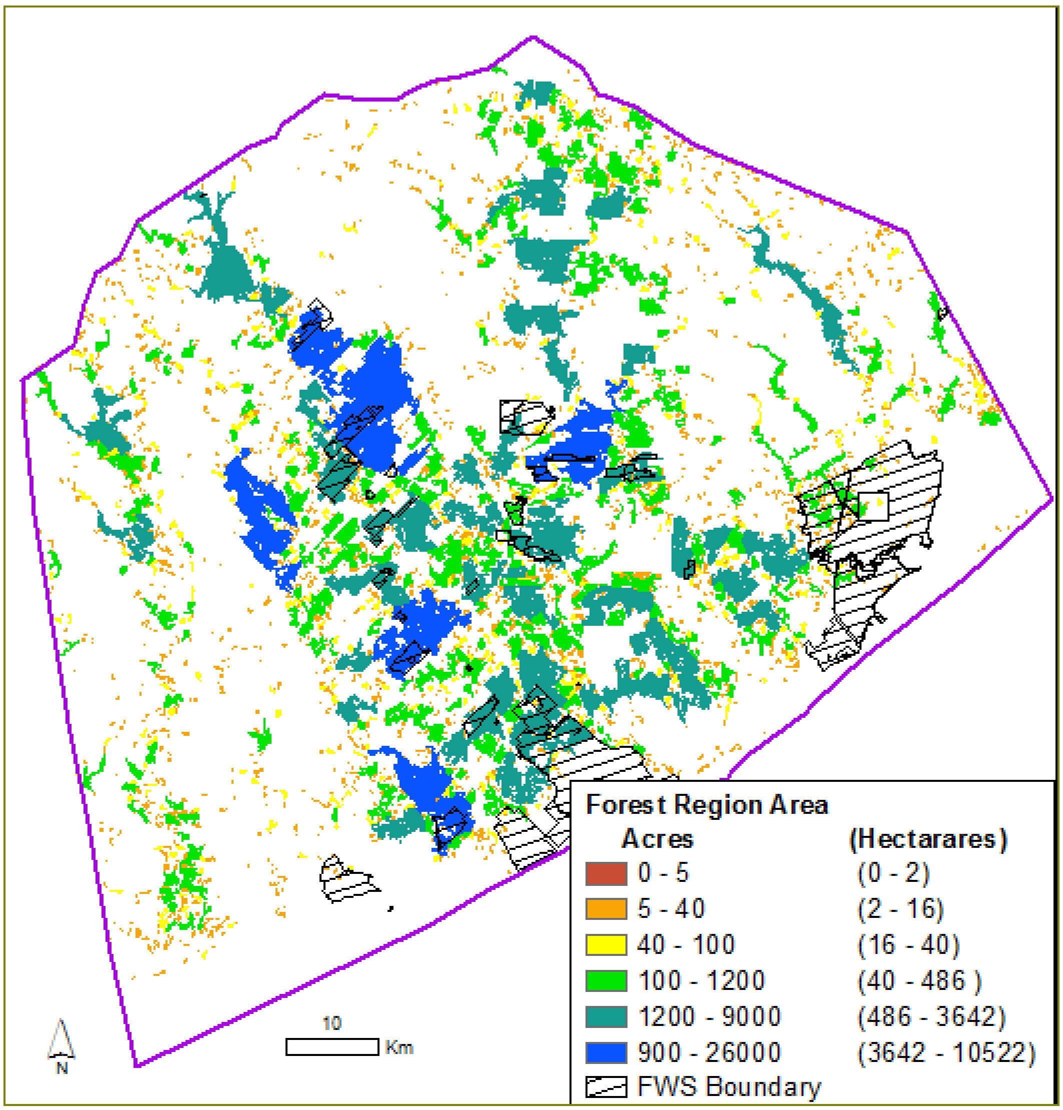


Figure 13. *Distribution of forest patches, categorized by size. Large forest patches were rated more highly than smaller patches as areas to locate new refuge units.*

Table 3. Rating for Forest Patch Area. Small patches were given low ratings. The FWS Land Protection Plan identifies 1200 acres or larger as a desirable area for a refuge tract.

Forest Region Area	
Area in Acres	**Rating**
0 - 5	0
5 - 40	2
40 - 100	6
100 - 1200	8
1200 - 9000	9
9000 - 26000	10

The Forest Region Area (Figure 13) theme was designed to connect forested areas into groups that were separated by the largest gaps of non-forest area. Forest patches were defined at a coarse scale using the forest classes of the National Land Cover Database. The NLCD Woody Wetlands accuracy in this region is 28 percent (Wickham et al., 2013), meaning that 7 out of 10 pixels in the Woody Wetlands class were incorrectly classified. The Forest Canopy represents the border of forested areas more accurately than the four forest classes of the NLCD. However, the NLCD had an advantage over the Forest Canopy dataset in that it did not connect forest patches together by hedgerows and stream borders, thus giving small forest patches the same area value as nearby larger patches.

Core and Edge Forest

The Core vs. Edge theme was derived from the NLCD Forest Canopy, which accurately represents the extent of the forest. Canopy coverage values over 60% were chosen because this cut-off point appeared to capture most breaks in the forest canopy without sacrificing the forest area. Edge forest was defined as 100 meters (328 feet) into the forest from the edge of a forest patch. Since one of the priorities in the plan is to acquire undisturbed areas, the core areas were given the highest rating.

Table 4. Rating for Core and Edge Forest. Areas with less than 60% canopy were given a 0 rating. Core forest was rated higher than edge forest.

Core and Edge Forest	
Type	**Rating**
No Canopy	0
Edge	6
Core	10
Definition of Edge = 100 meters (328 feet)	

Canopy Height

US Basal Area-Weighted Canopy Heights, 2000 (Kellndorfer et al., 2012) was used for Canopy Height data. This theme represents old-growth qualities. Michael Lange (personal communication) observed that some of the areas with low canopy height had been logged historically. Comparison of the 2000 Canopy Height data set with the 2011 NLCD Canopy Density shows where trees have been removed or thinned in recent years.

Table 5. Heights of common tree species in the Columbia Bottomlands. Old-growth, undisturbed forest is generally taller than successional forest, but trees in a forest also have a range of height by species.

Name	Species Name		Usual Height Range			
			Feet		Meters	
Chinese tallow tree	*Triadica sebifera*		25	40	7.6	12.19
Green Ash	*Fraxinus pennsylvanica*		40	60	12.2	18.29
Water oak	*Quercus nigra*		-	60	-	18.29
Southern Live Oak	*Quercus virginiana*		-	60	-	18.29
Cedar Elm	*Ulmus crassifolia*		-	60	-	18.29
Pecan	*Carya illinoinensis*		-	70	-	21.34
Hackberry	*Celtis occidentalis*		60	80	18.3	24.38
American sycamore	*Platanus occidentalis*		-	80	-	24.38
American Elm	*Ulmus americana*		-	80	-	24.38
Eastern Cottonwood	*Pupulus deltoides*		60	90	18.3	27.43
Bald Cypress	*Taxodium distichum*		80	100	24.4	30.48
Sibley, D.A., (2009) The Sibley Guide to Trees.						

Canopy Height (Figure 14) also reflects the height range of tree species: Cypress, Live Oak and Sycamore are tall trees. To avoid penalizing moderately sized tree species, most of the height values were assigned to the top two rating classes. Chinese tallow tree, an invasive species, is relatively short. The rating scheme assigns low rating values to Chinese tallow tree and early successional stages.

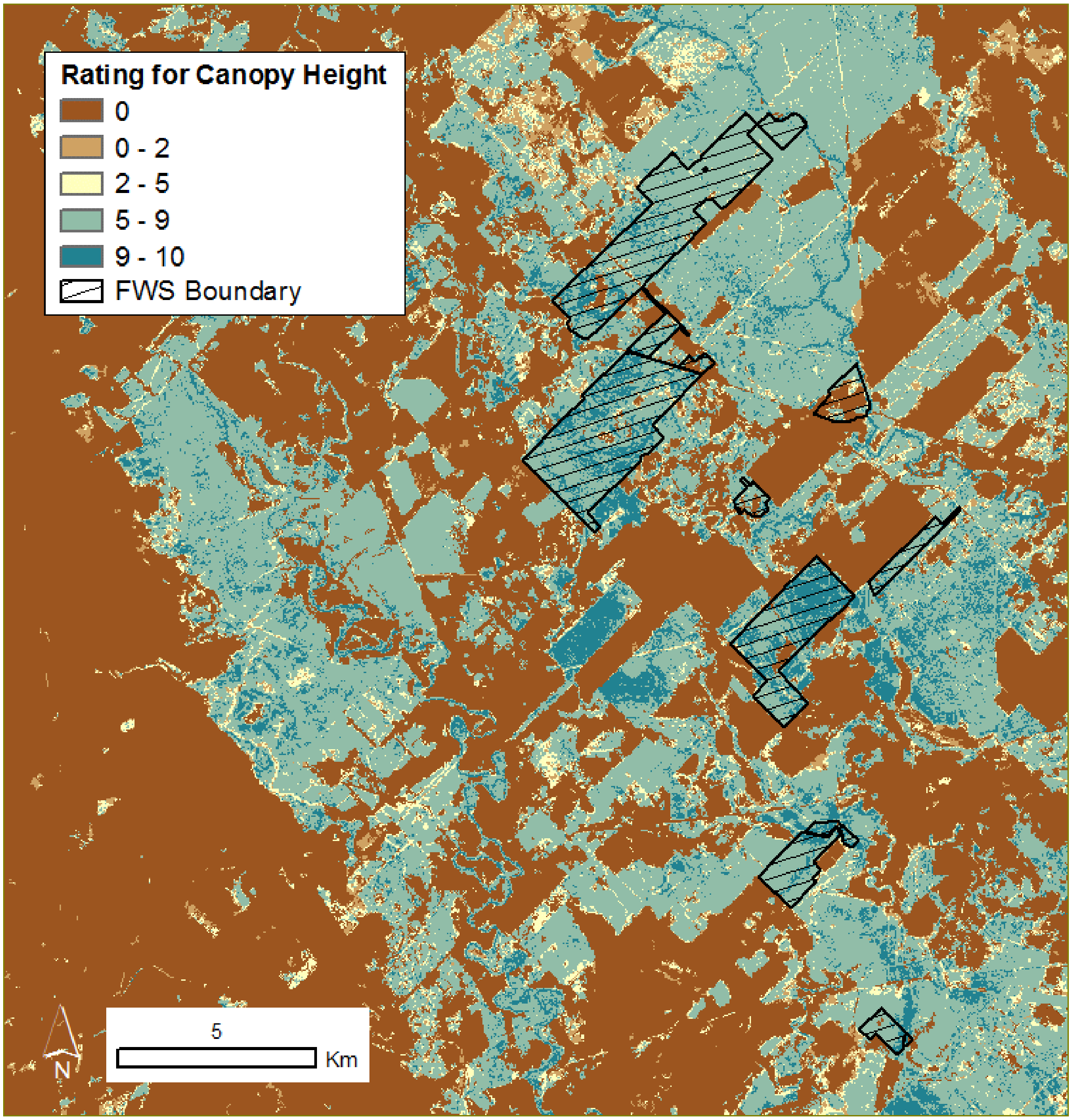

Rating for Canopy Height
0
0 - 2
2 - 5
5 - 9
9 - 10
FWS Boundary
5
Km
N

Figure 14. Canopy Height by rating class. Areas with no trees were assigned a zero value. Areas known to be successional stages are identifiable by the Canopy Height data set. This image also shows tall trees, probably cypress or cottonwood, along the banks of the San Bernard River. Live oaks in this region can also grow very tall.

Table 6. Rating table for Canopy Height. Tree heights that were likely to be early successional statges or Chinese tallow trees were given low ratings. The majority of pixels of trees were assigned a rating of 9.

Canopy Height	
(Area Weighted meters * 10)	Rating
0 - 62	2
62 - 90	5
90 - 120	9
120 - 150	10

Forest Quality Index.

The ratings for the three data sets in the Forest Quality theme were combined mathematically using the following formula:

Formula 1: Core/Edge (weight=0.20) x Forest Patch Size (weight=0.40) x Canopy Height (weight=0.40)

Because the Core and Edge theme was the most spatially accurate (on visual inspection) for depicting the actual extent of tree cover of the three themes, multiplying the values of the three data sets removed error in the NLCD-based Forest Patch Area and the 10-year old Canopy Height theme. Because areas with no forest were rated as zero in each data set, the final product had non-zero values only in areas where all three data sets confirmed there was forest (Figure 15).

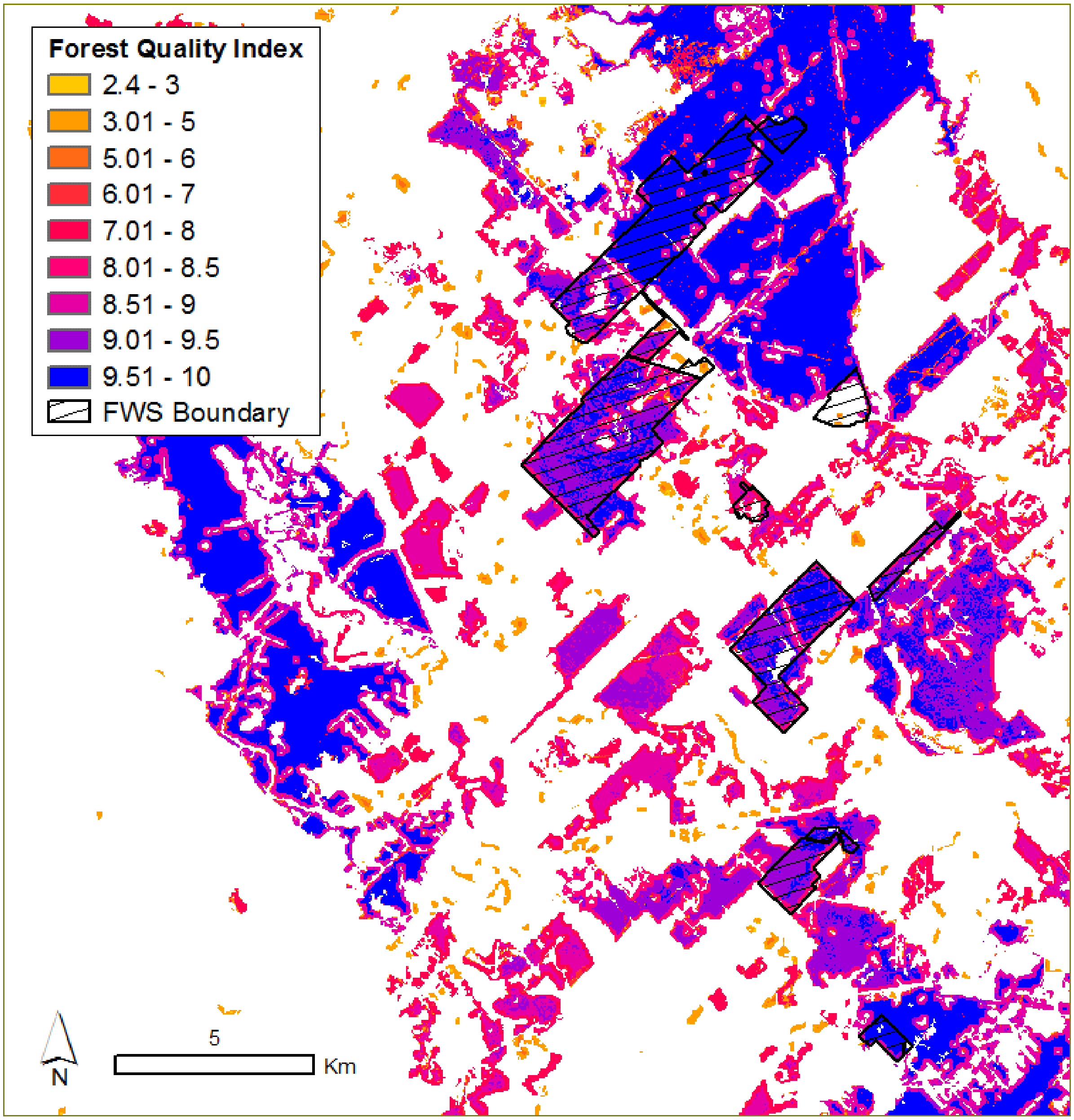


Figure 15: Forest Quality Index. Forested areas that are large and connected patches have the highest values, the edge of all those patches is valued somewhat less, and areas with shorter trees within the patches are valued less. Values range from 2.4 to 10.

Proximity to Existing Refuge Parcels or Other Preserve Areas.

The proximity to protected lands theme identifies areas which, if they were included in the refuge system, would protect larger patches of habitat. Locating a new refuge in proximity to an existing preserves effectively makes that preserve larger, reducing fragmentation and edge effects between the two preserves. Locating new refuge patches in close proximity to other refuges and preserves helps to create a linked chain of refuges that extend over a large networked area.

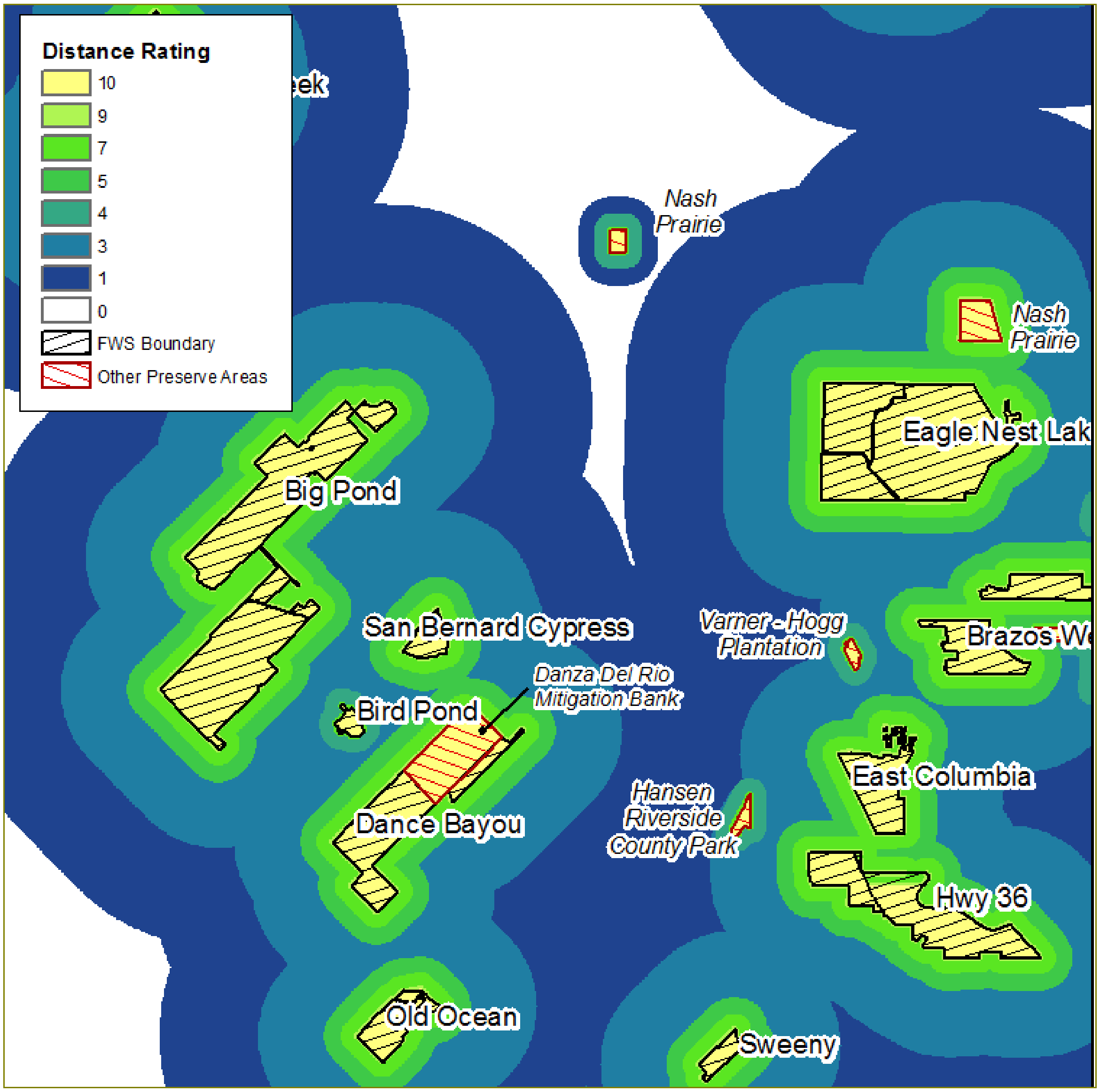


Figure 16. Areas around refuge units and preserves were rated for proximity. Large Preserve units were given a larger area of influence than smaller parcels

In MacArthur and Wilson's (1967) The Theory of Island Biogeography, most of the discussion is set in the terms of how species move from a continent or large island, which is an inexhaustible source of propagules. Harris (1984) describes how a bioreserve network is fundamentally different from the continent-island paradigm. All of the species diversity resides within the network, and there may be no "continental source". In a terrestrial network such as this, each island of patch habitat is both a source and recipient feature.

Harris (1984) points out that in an island biogeography model, if there is no continental source of organisms, the distance between the islands becomes a more important factor. This is because all of the features are recipient features in some way. The equilibrium number of species on an island is a function of the immigration rate and the extinction rate. Because of their higher extinction rate relative to large islands, as distance from the continental source increases, small islands accumulate fewer species over time than large islands. (MacArthur and Wilson, 1967)

For this reason, the rating assigned to distance from the reserve or preserve decreased more quickly for small preserves than the rating assigned to large preserves. Small stepping stone islands can disproportionally increase the transfer of species between more distant islands, however, the "archipelago" must be closely grouped together.

Table 7. Rating table for Proximity to Refuge or Preserve. High ratings were given to pixels adjacent to refuge units and preserves. The area of high ratings near large units was more extensive than the area near small units.

Rating of areas around Preserve Units			
Distance		Rating	
(meters)	(feet)	Large Units	Small Units
25	82	10	10
100	328	9	7
500	1640	7	4
1000	3280	5	1
3000	9840	3	0
6000	19680	1	0

There is no empirical evidence to support these choices of distance or rating in the Columbia Bottomlands; however, I think these choices are reasonable. The size cut-off between the two classes is 250 acres (100 hectares), however, some larger preserves are included in Class 2 because they were not as desirable due to their land cover condition. The longest distance where the parcel has any influence, 6000 meters (3.7 miles), is about the long diameter of many of the refuge units or preserves (Figure16).

One caution with regard to evaluating the distance between tracts that might be included in the refuge system is that this approach does not consider the needs of any particular species but adopts a more relative distance approach. Harris (1984) argues that distances between islands and different island sizes should be evaluated with reference to the habitat needs and probable travel distances of particular species. This project makes the assumption that larger parcels are better, especially for birds and animals that need core forest habitat, and that parcels that are close together are better.

Percent Developed Class within a 1 km radius

In a review of landscape studies, Rodewald (2003) discussed the importance of separating the effect of habitat fragmentation from the effects of the type of landscape matrix.   Because patch habitat size, perimeter and isolation in the landscape vary with the amount of matrix land cover, it is possible to confuse spatial and physical effects from fragmentation and patch distribution, with the effect of the type of land cover matrix that surrounds the forest patches.

The proximity of houses, roads and other development can affect the species richness in woodlots. Friesen et al. (1995) studied the effect of residential development within 100 meters of the forest edge on Neotropical migrant species. Regardless of the size of the forest patch, the number of houses surrounding the forest severely decreased the abundance and diversity of Neotropical migrants. The effect on Neotropical migrants increased with the level of adjacent development, but no effect was found on short-distance migrants or permanent residents.

Wilcove (1985) in a controlled experiment using artificial nests filled with quail eggs, found that suburban woodlots had higher predation rates than rural woodlot, and much higher rates than large forest tracts. Wilcove argues that the increased predation near suburban woodlots is due to the higher concentrations of small predators in suburban areas, and the low predation in large wooded tracts is due to the presence of larger predators such as bobcat and owls that regulate the population of small predators.

In the Columbia Bottomlands region, many of the edges of the forest patches are bordered by pasture, agriculture, or clearings for pipelines or utility rights of way; these land cover types and edge types may have a distinctly different effect on bird breeding success than residential or urban land cover. The impact of human activity and human-subsidized predators is better represented by Percent Developed than by the Core and Edge Forest theme. In the Columbia Bottomlands, most of the forest in the area of interest is imbedded in a matrix of pasture and agricultural lands. However, there are also areas of urbanization, and regions with rural residential development. The four “Developed” classes make up 7.38 percent of the landscape (Table 8).

Table 8. Percent of each land cover type of the NLCD (2011) within the Acquisition Boundary.

Land Cover Class	**Percent**
Open Water	6.90
Developed, Open Space	3.93
Developed, Low Intensity	1.98
Developed, Medium Intensity	1.08
Developed, High Intensity	0.38
Barren Land	1.03
Deciduous Forest	4.27
Evergreen Forest	1.83
Mixed Forest	1.84
Shrub/Scrub	4.06
Herbaceous	2.89
Hay/Pasture	26.32
Cultivated Crops	18.44
Woody Wetland	12.35
Emergent Herbaceous Wetlands	12.70
	100.00

Two studies indicate that the decrease in habitat suitability for Neotropical migrants coincides with low percentages of developed areas nearby. Lussier et al. (2006) found that individual birds that tolerate residential landscapes became more numerous than intolerant birds at a residential density of 12 percent within a 500 meter radius. The drop-off in habitat quality for forest-interior birds seems steep at low percentages of developed land cover, then it decreases more slowly until, at 60 percent residential land use, there are no intolerant birds.

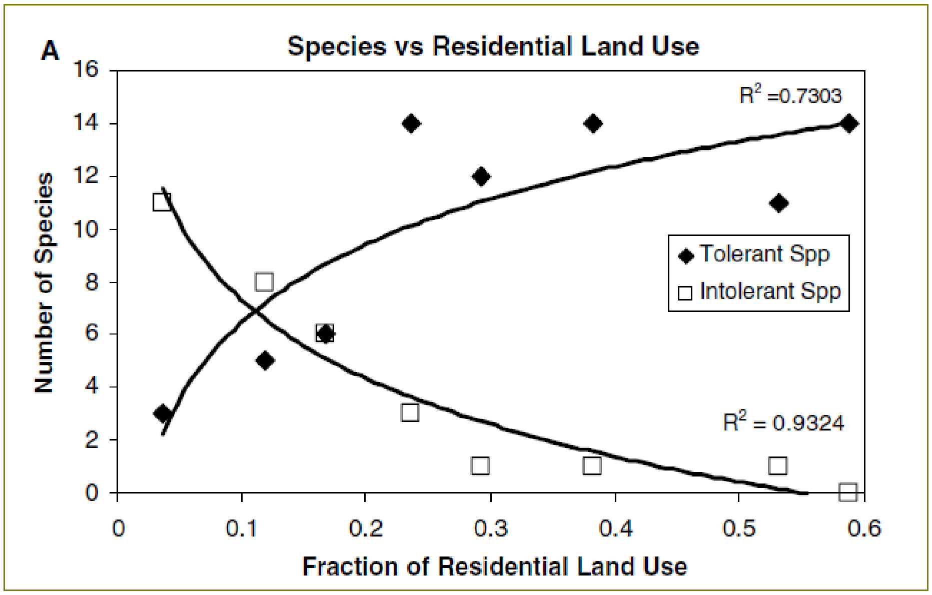


Figure 17. *From Lussier et al., 2006. Shifts from intolerant to tolerant bird species with significant R2 values (log regression) occurred with increased residential land use.*

Bakermans (2003) studied Acadian flycatchers along river bottoms in Ohio. Abundance and productivity of Acadian flycatchers were negatively associated with percent developed land cover, and numbers of predators increased with developed land cover. In riparian forests, Acadian flycatchers were more 3 times likely to be detected in areas of less than 1% urban development than in areas of greater than 10% urban development.

These two studies suggest that for disturbance-intolerant birds like Acadian Flycatchers, the desirability of an area as nesting habitat falls rapidly from 0 to 12 percent urban or residential land cover. A rating scheme for a percent Developed class theme (Table 9) was designed to reflect the rapid decrease in habitat value with increase in Developed land cover (Figure 19).

Table 9. Rating table for percent Developed class within 1 km. Rating values drop rapidly with increase in percent Developed class.

Percent Developed	
percent Developed classes of NLCD within 1 km radius	
Percent Range	**Rating**
0 - 2	10
2 - 4	9
4 - 6	8
6 - 7	7
7 - 8	6
8 - 9	5
9 - 10	4
10 - 14	3
14 - 40	2
40 - 65	1
65 - 100	0

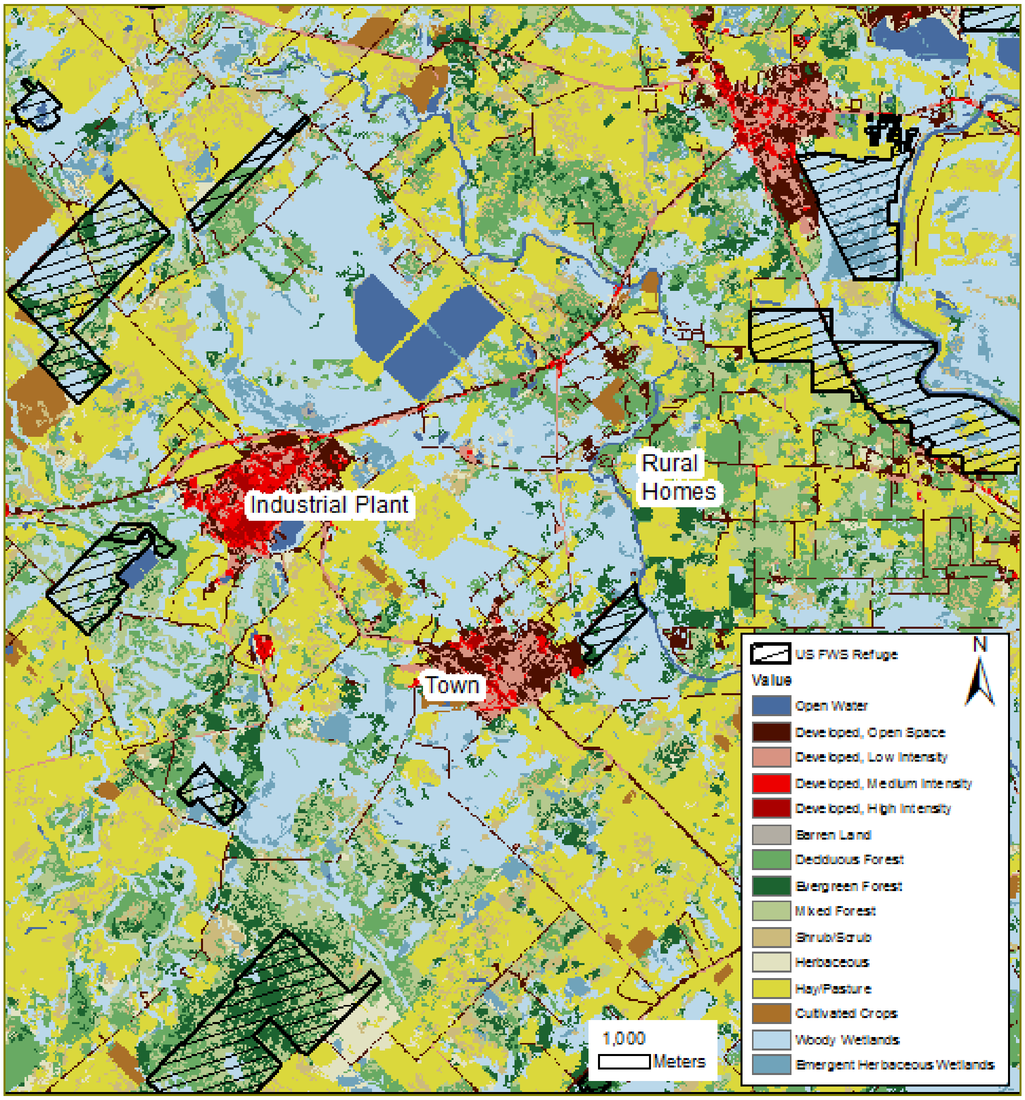


Figure 18. The Old Ocean Industrial plant, the town of Sweeny, and the forest and pastures around them, shown by the National Land Cover Database, 2011. Roads are well represented by the Developed, Open Space class.

In this flat, open landscape, few sections of roads are shaded or obscured by trees, so the NLCD represents the roads system fairly well (Figure 18). Distance to roads is often used in habitat studies as a measure of disturbance, but there are distinct advantages to using percent Developed land cover. The landscape in this area is, in general, developed by agriculture, and there are many widely distributed roads; in this case, using distance to roads does not distinguish between an area that has one road going through it versus an area that has many roads. Rodewald and Shustack (2008), using principal component analysis, found little difference in the effect of percent cover of buildings, roads, pavement and lawn as a measure of "Urban Index" and its effect on breeding Acadian flycatchers. Combining the four NLCD Developed classes into a single class allows the representation of developed areas that are not roads. Finally, the US Fish and Wildlife Service requires legal and physical access to any parcel that might be included in the refuge system (M. Lange, personal communication), so lack of road access disqualifies a parcel from being included.

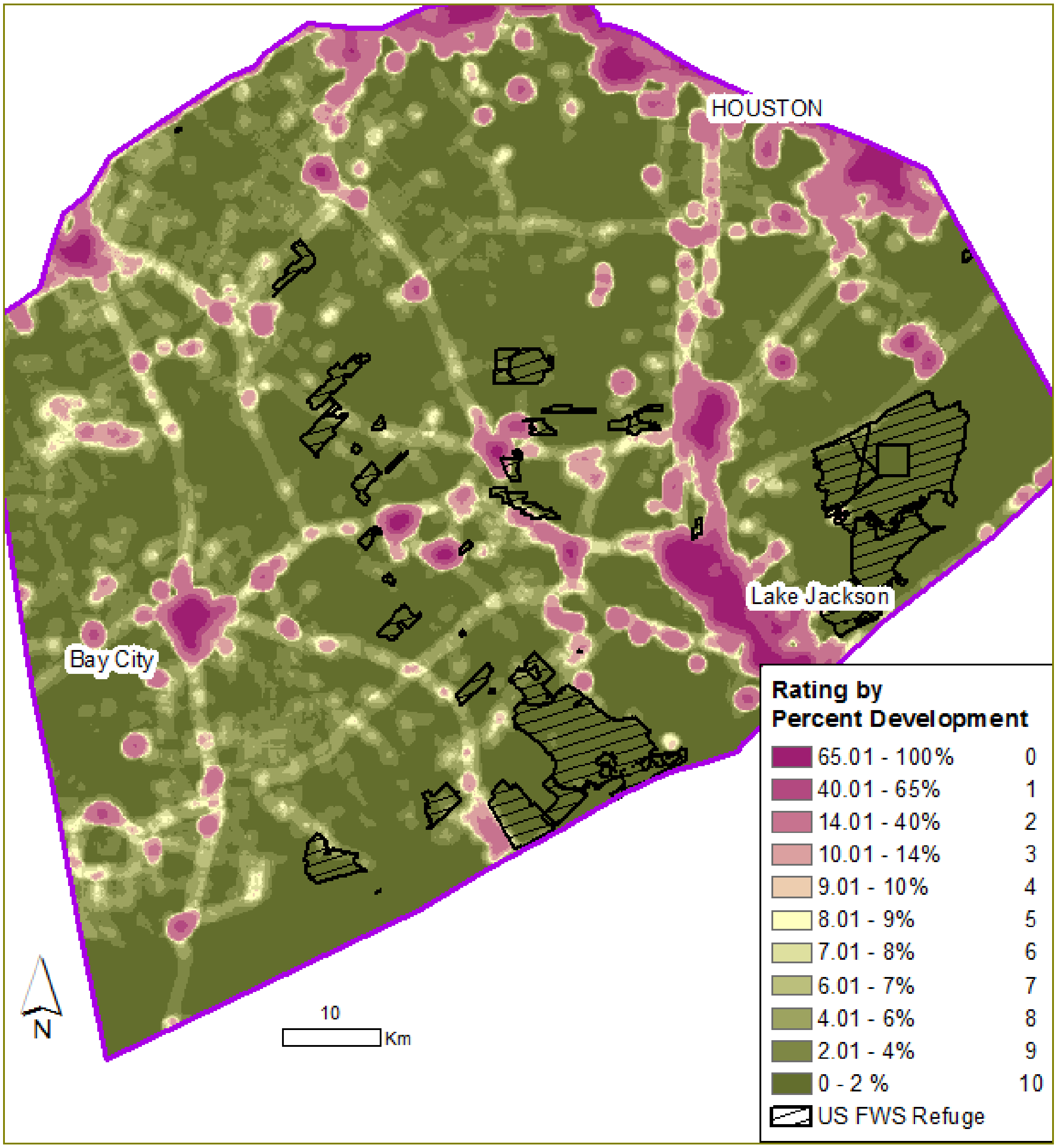


Figure 19. Rating by percent NLCD developed class. Areas with little development were highly rated. Developed areas are near cities, and follow roads between cities. Most of the landscape is pasture.

Proximity to Streams and Rivers

Proximity of streams was modeled by buffering the line and polygon features of the National Hydrology Dataset streams (US Geological Survey, 1999). Buffer width was 120 or 80 meters depending on stream importance (Figure 20). Land parcels that have more stream frontage, or that have small streams meandering through them, will accumulate more points from this theme.

Streams that have existing refuges on them should be more important in the model, because the streams can serve as corridors for seeds and animals. In this step of the model, streams that are associated with refuges have the same rating as other named streams (Table 10).

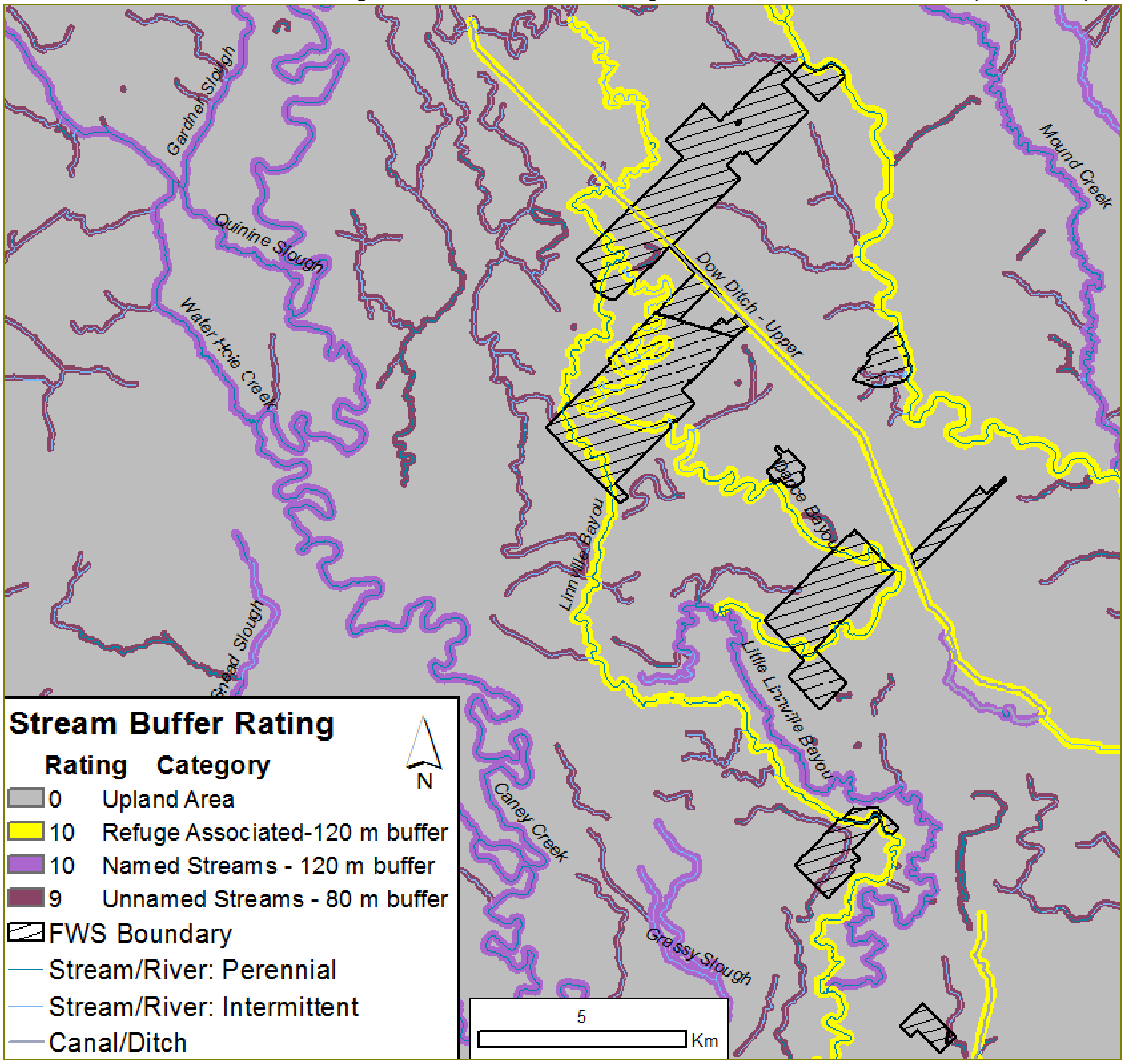


Figure 20. Stream classes within the Acquisition boundary. The width of the buffer of each stream allows grid pixels around the stream in the final model to receive a higher total score.

Table 10. Rating table for Streams and Rivers**.** Major streams were rated highly, and their buffer was wider to add their rating value to pixels on neighboring tax parcels..

Streams and Rivers			
Stream Type		**Buffer (m)**	**Rating**
FWS Refuge located on Stream		120	10
	Brazos, San Bernard, Linville Bayou, Cedar Lake Creek, Buffalo Creek, Big Boggy Creek, Bastrop Bayou, Oyster Creek,		
Other Named Stream		120	10
Unnamed Streams		80	9
No Stream			0

Wetlands, Ponds and Lakes

Wetlands are not listed as one of the Land Protection Plan Priorities, however, many of the vegetation communities associated with wetlands are described in the Land Protection Plan. These features are desirable in a bioreserve network because they are a natural variation in vegetation and topography. Because of drainage for agriculture and residential development, forested wetland areas are becoming increasingly rare. Including wetlands in the refuge system would preserve natural hydrological processes.

Another reason to include wetlands, ponds and lakes as an element in the model is to compensate for their absence in the Forest Quality theme. Ponds, lakes and rivers are counted as breaks that produce edge forest in that theme. Also, forested wetlands of the Black Willow swamp type tend to have low canopy height, as well as an open canopy (M. Lange, pers. comm.). For those reasons, they were not rated highly by that theme. Natural ponds and pond borders of herbaceous wetlands may be represented as gaps in the Forest Area, Canopy Extent, and Canopy Height themes.

The National Wetland Inventory (US FWS, 1997 to present) also gives information on whether the wetland was excavated or impounded, and some information on the substrate of the bottom of ponds and lakes. Many ponds and lakes on the Texas Gulf Coast are small excavations in pastures. While they provide water for animals and birds, man-made lakes frequently do not have natural vegetation around them. Because natural wetlands are more desirable in a new refuge, excavated ponds and lakes have been excluded from this theme (Figure 21).

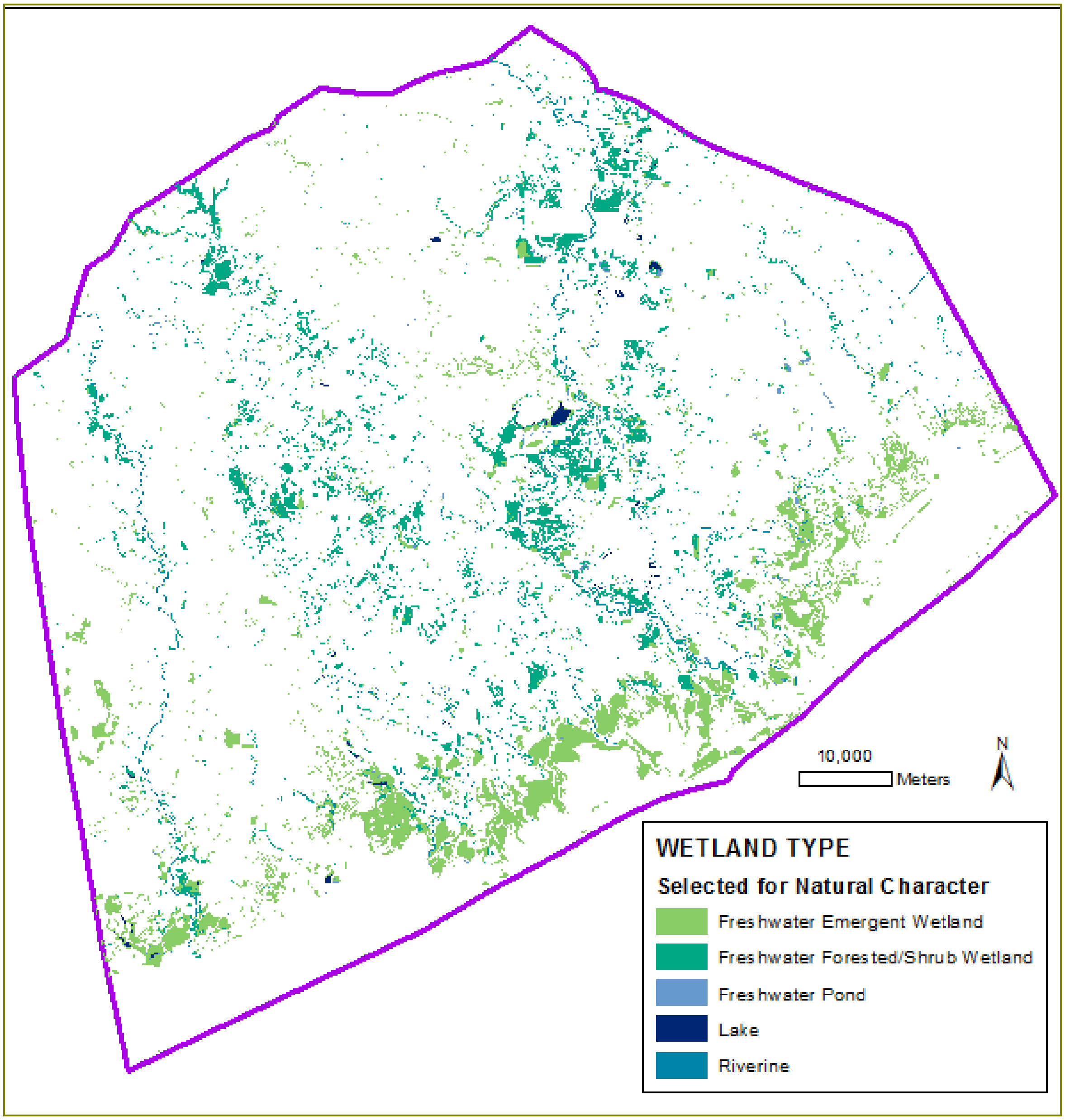

10,000
Meters
N
WETLAND TYPE
Selected for Natural Character
Freshwater Emergent Wetland
Freshwater Forested/Shrub Wetland
Freshwater Pond
Lake
Riverine

Figure 21. Distribution of wetland types from the National Wetland Inventory that were included in the model. Excavated ponds and other non-natural lakes were excluded.

Table 11. Rating table for Wetlands. All of the wetland classes added to the rating of grid pixels.

Wetlands	
Wetland Type	**Rating**
Forested/Shrub wetland	10
Fresh Emergent Wetland	10
Riverine	5
Fresh Ponds *	5
Selected Lakes *	5
** Excavated and some other non-natural features were excluded*	

Refuge Suitability Index

The five data sets were combined mathematically to produce a map of "Refuge Suitability Index" values (Figure 22). Several weighting schemes were tested, and the combination that gave distinct advantage to forested areas was chosen. Edge Forest, Forest Region Size, and Canopy Height were combined mathematically; after the weight value was applied as an exponent to the grid pixel values, they were multiplied together to create the Forest Quality theme. Any zero value grid pixel in any of the three Forest themes resulted in a zero value in the product. This reduced the extent of the Forest Quality theme to only those areas where all of the data sets confirmed there was forest. Forest Quality theme along with the other themes were combined arithmetically using the weights shown in Table 12. Results are shown as Figures 23 and 24.

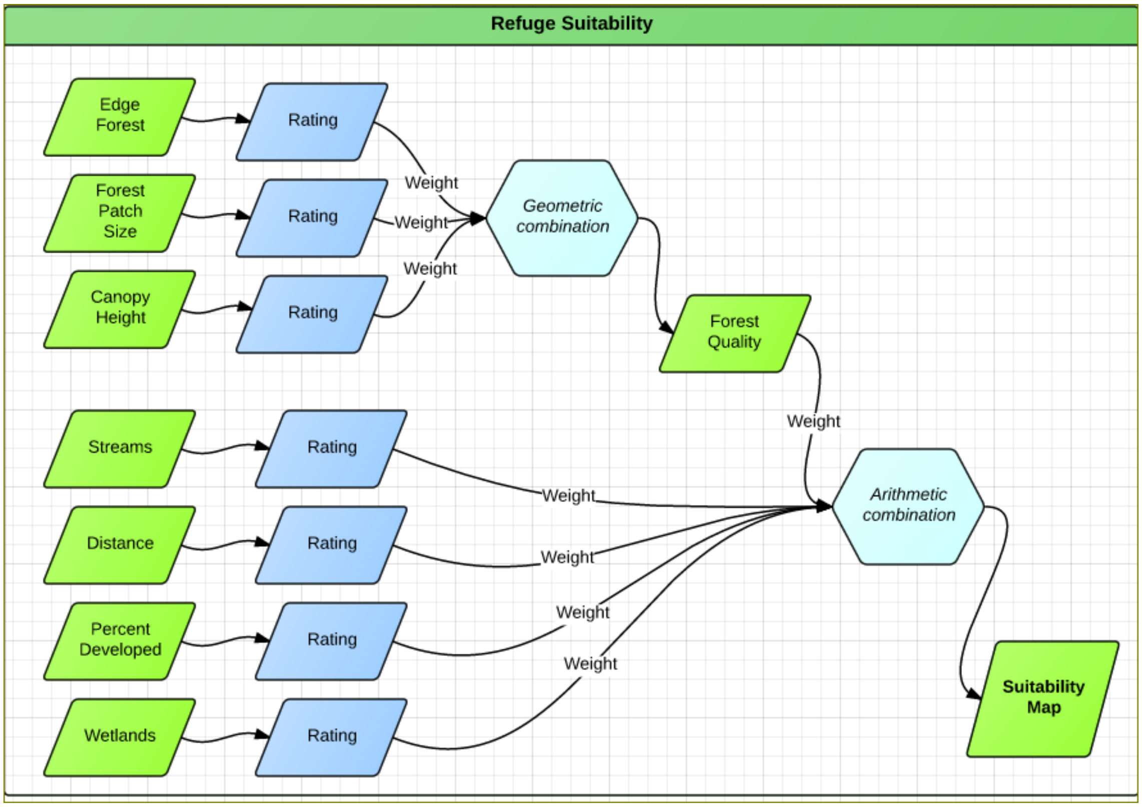


Figure 22. Data Process for combining factors to make the Refuge Suitability Model. Edge Forest, Forest Region Size, and Canopy Height were combined mathematically to produce a Forest Quality Index. The Forest Quality Index was then combined with rating data sets for Streams, Percent Developed, Wetlands and Distance from Refuge or Preserve to create a pixel grid of values representing suitability for inclusion into the Austin's Woods project.

Table 12. Weights assigned to data sets in the "Refuge Suitability" model. Forest Patch Size and Canopy Height have the most influence on the model.

Model Inputs	
Forest Quality Index: (geometric)	
Forest Patch Size - 0.40	
Core Edge - 0.20	
Canopy Height - 0.40	0.50
Distance to Preserve Areas	0.15
Percent Developed	0.10
Streams	0.15
Wetlands	0.10
	1.00

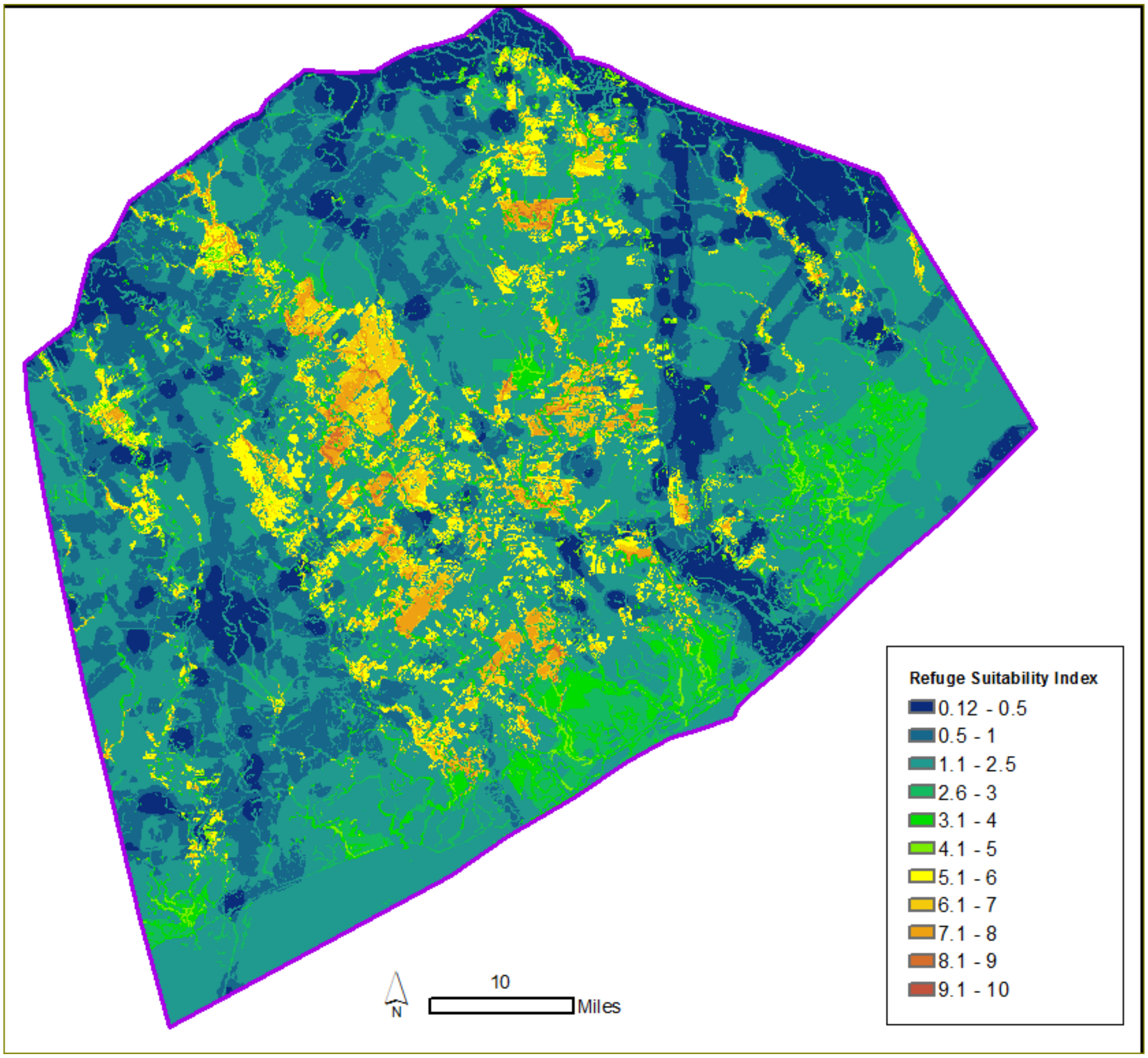

Refuge Suitability Index
0.12 - 0.5
0.5 - 1
1.1 - 2.5
2.6 - 3
3.1 - 4
4.1 - 5
5.1 - 6
6.1 - 7
7.1 - 8
8.1 - 9
9.1 - 10
N
10
Miles

Figure 23. Results of the Suitability Model. Blue areas were located in urban and industrial areas, or have a high density of roads. Green and bright green areas represent Refuge units or preserves, but have no trees. Forested areas tend to be yellow through orange. Orange areas are forested, and located closely or inside Refuge units or preserves.

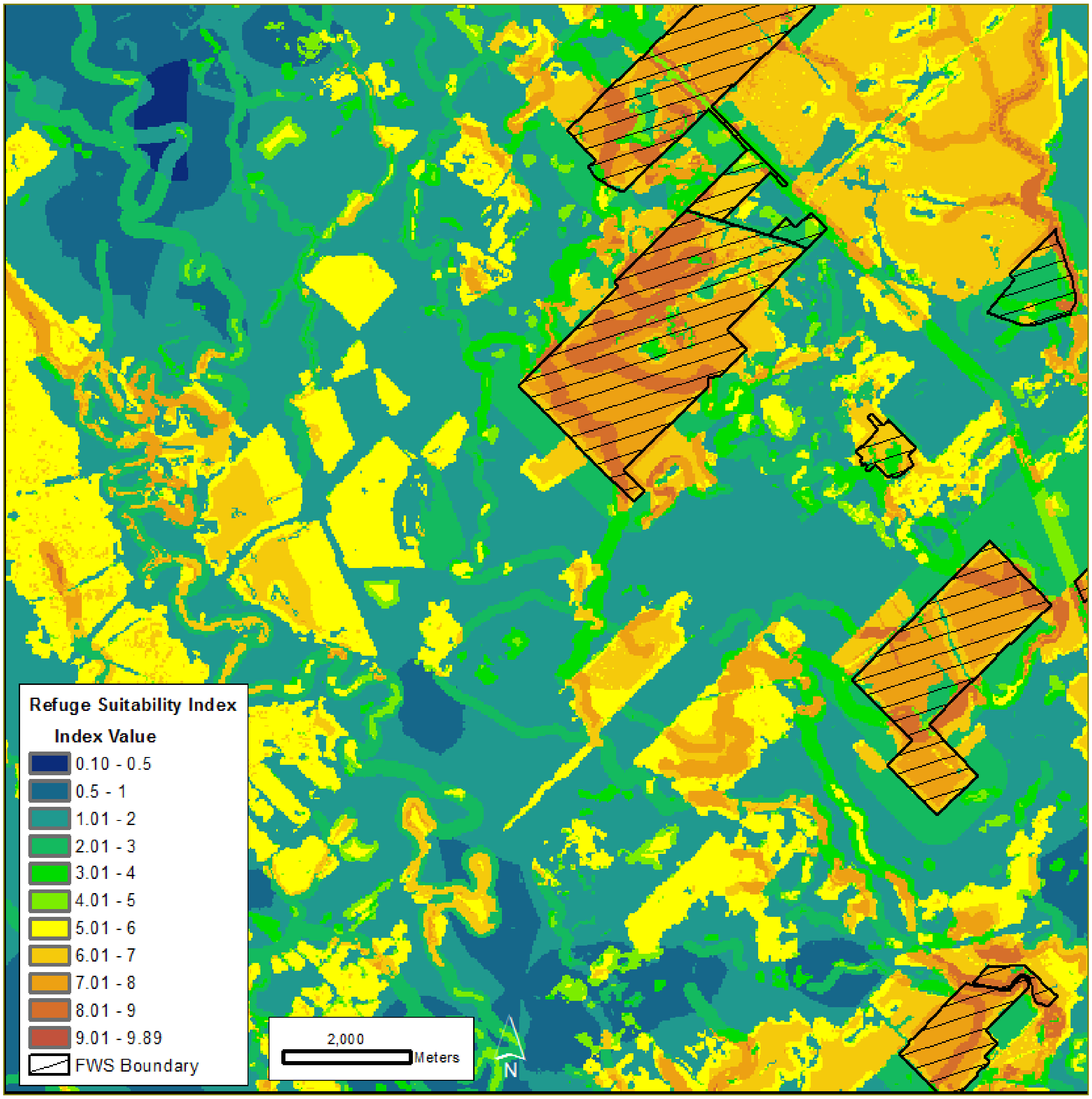


Figure 24. Detail of the "Refuge Suitability Index" map. The effects of tree height and large forest patch area can be seen in the change from orange to red areas. Developed regions show as areas of dark blue. Stream are revealed by linear features, of different colors, but raising the rating of the area around them. The "Dow Ditch," a drainage canal, is represented by the linear feature running diagonally on the right.

Removal of background values.

Areas with positive grid values below 6 were changed to zero to avoid giving large but unforested tracts an advantage in the rating scheme. Zero value was also assigned to pixels that were within established refuge units and preserves, to focus results on private lands. The result was a layer which generally resembled the distribution of the forest. There are slight variations in value dependent on canopy height, proximity to developed areas, size of forest patch area, and core versus edge status (Figures 25 and 26).

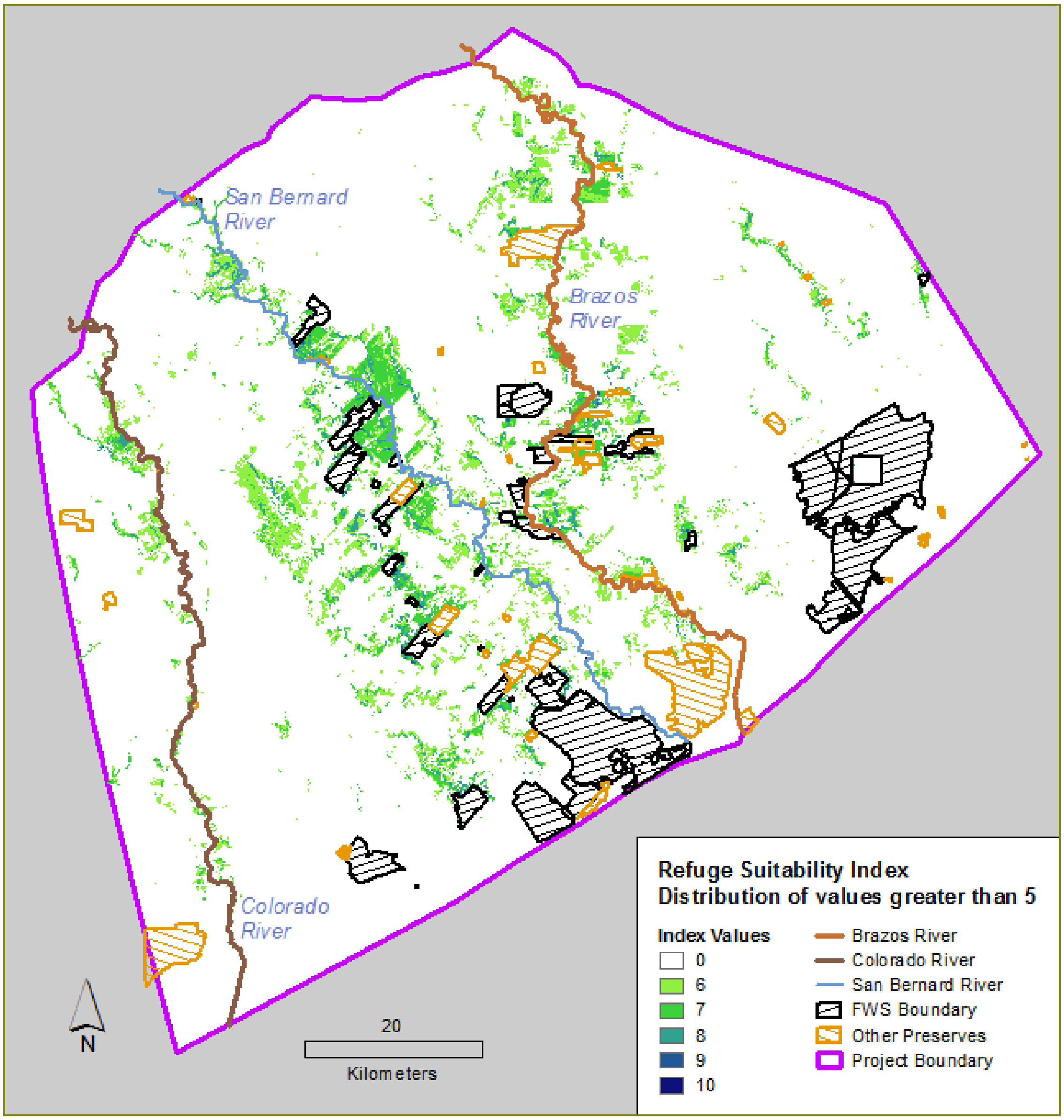


Figure 25. The distribution of "Refuge Suitability Index" values 6 and greater. Values less than 6 were set to zero to prevent giving large tax parcels groups an underserved advantage from their large area.

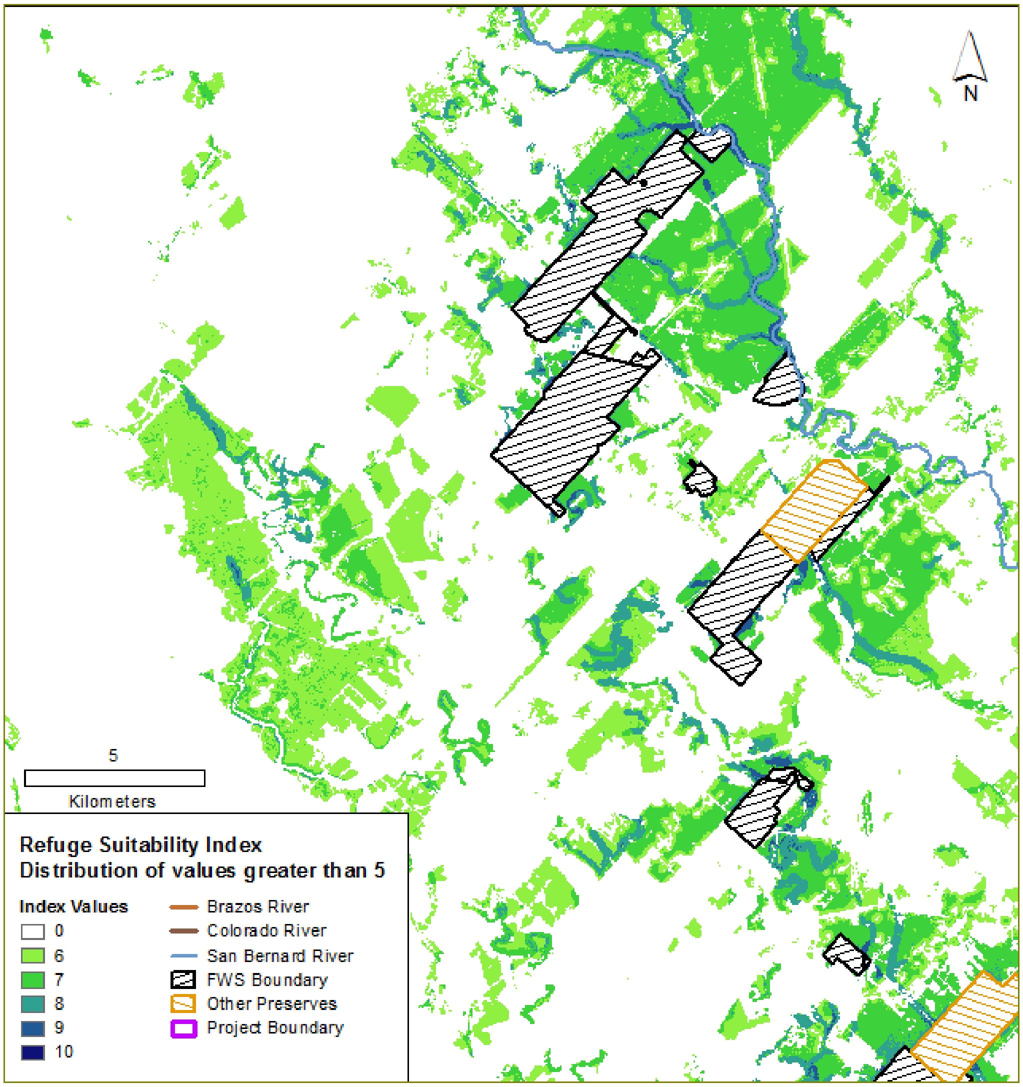


Figure 26. The pattern of the suitability index values follows the general distribution of the forest, but the values are dependent on Core vs. Edge status, distance to streams, distance to refuge units and preserves, and percent developed land cover within 1 km for each grid pixel. Forest Region Size and Canopy Height are the strongest factors, each responsible for 20 percent of the final pixel value.

County Parcels

Tax parcel ownership data were obtained from the offices of the county appraisal districts of Brazoria, Matagorda, Fort Bend and Wharton Counties (Table 13). Due to data inconsistencies these data are primarily used for making maps, rather than data analysis. Fort Bend County had very complete data, suitable for a marketing study, including a separate file for parcels where there were multiple owners.

Table 13. County parcel data formats and error sources.

Data Quality by County			
County Name	Data Format	Ownership Information Format	Common Errors or Features
Brazoria	Esri Shapefile	Text file - joined by Property ID number	Polygons without Property ID number, or no owner name in text file.
Fort Bend	Esri Shapefile	2 Comma-separated Value files, for single and multiple owners, joined by Property ID	Few errors or omissions
Matagorda	Esri Shapefile	Ownership attributes included in shapefile	A few parcels missing, some parcels missing ownership, incorrect ownership
Wharton	Bentley Microstations drawing file (.dgn)	Comma-separated value file	Tax parcels were represented by lines, not polygons; tax parcel boundaries represented by multiple layers, parcels with the same tax account number indicated by hooked line.

Boundaries of tax parcel polygons were dissolved where there was a common owner to visualize opportunities where large tracts could be conserved. The strategy to find large tracts for conservation was generally successful, despite errors in the data. Sometimes small inconsistencies in the owners' names did not allow parcels to be identified automatically by the software. Once the ownership information was used to label the polygons, some of the polygons were dissolved manually.

Parcel size and gaps in data. Because of the large number of polygons in each county, the computing effort for working with the county datasets required a considerable amount of time. To speed the work and to concentrate on larger parcels, only parcels greater than five acres were processed. Most of these parcels were in towns. Brazoria County had a number of errors and missing data in both the polygons and the data table. Wharton and Matagorda Counties also had missing polygons.

The combined parcels were given unique identity numbers. The values from the Refuge Suitability Index were tabulated to each identity number, so that every parcel received a score.

Goal 2 Results:

Tracts with scores above 9000 (n=69) were chosen for further examination (Figures 27 and 28 Of the 69 high scoring parcels, 3 were exceptionally large, ten or twenty times the size of most of the other high scoring parcels (Figure 29). The large parcels are operated as cattle ranches, and their extent includes areas of both former prairie and bottomland hardwoods. These are ranked 1, 3, and 4, and are located in the west of the region, in Wharton and Matagorda counties. Another large tract, nearly completely forested, but also used to graze cattle, is ranked 5 and 60. It is located in the north on both sides of the San Bernard River, and so is in two counties. The tract ranked 2 is on the middle section of the San Bernard, a large region of forest. This tract is large but has a very irregular border. There are several large, long tracts here that run perpendicular to the San Bernard River. Other high scoring tracts were located in close association with the San Bernard and Brazos Rivers, and existing refuge units. A few high ranking tracts were located on the Brazos nearer to Houston's suburban frontier. There were no high ranking tracts in the east of the acquisition boundary.

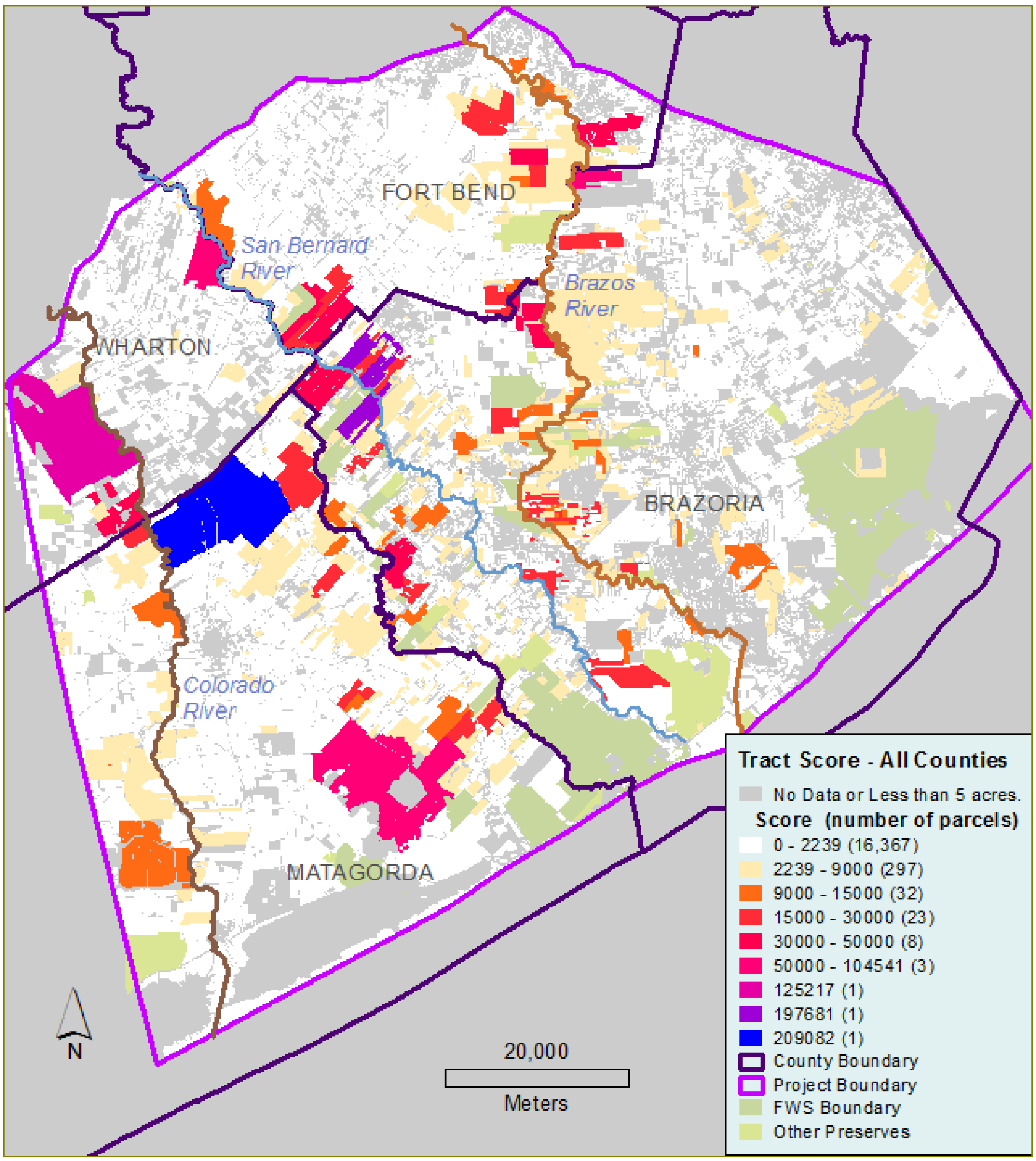


Figure 27. Distribution of high scoring parcels. Nearly all of the 16,734 parcels received very low scores. Less than 0.4 percent (69 parcels) have scores above 9000. The pattern of parcels less than 5 acres, or missing data, shows as grey areas.

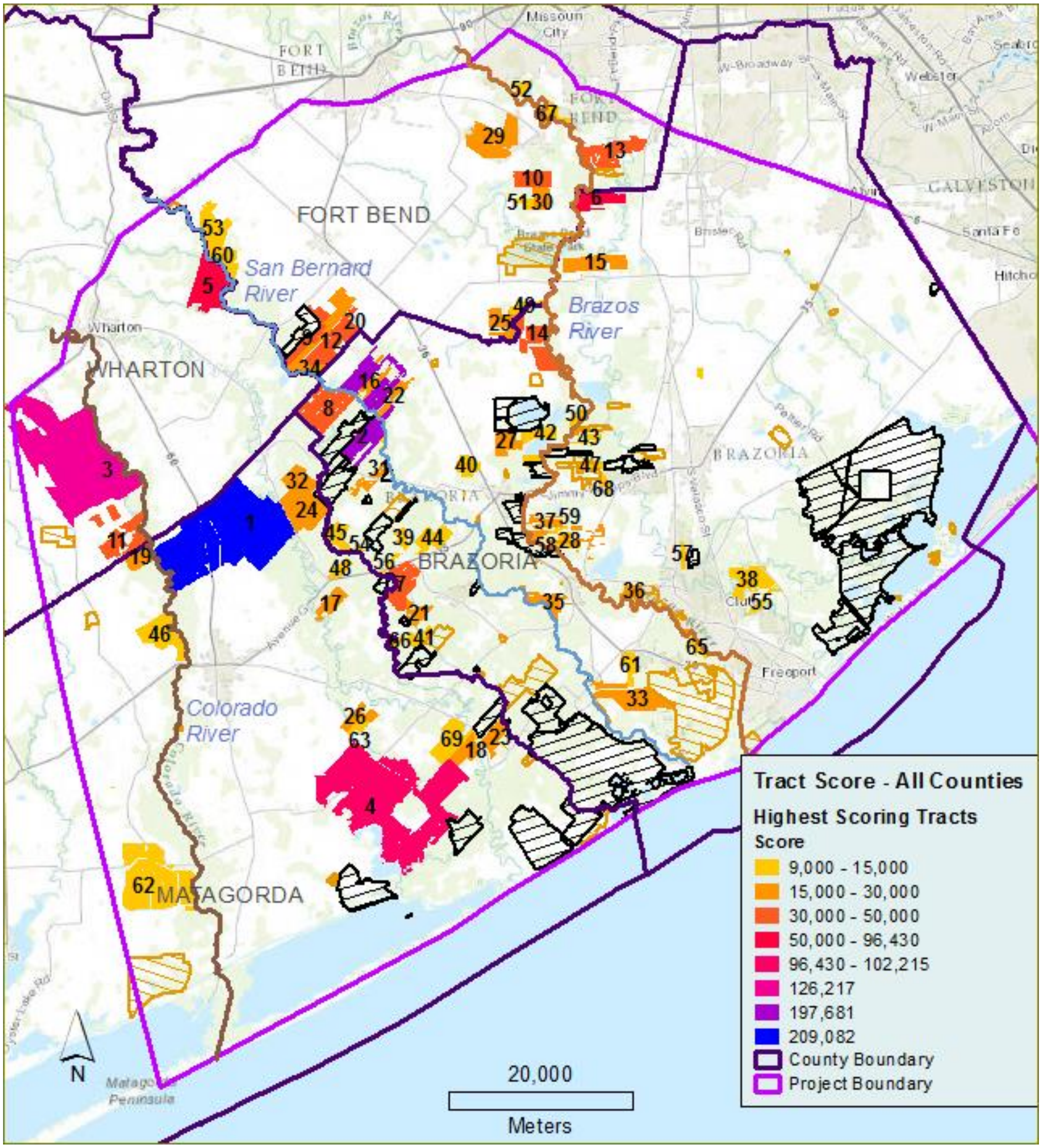


Figure 28. The 69 high scoring parcels numbered by Rank. High scoring parcels are shown in the context of towns, roads and other features.

The relationship between tract area and tract score.

Tract score, area of pixels, and mean pixel value was compared to tract size in graphs (Figures 29, 30, and 31).

The score of each tract was closely associated with the area of the tract (Figure 30), and the area of the grid pixels of Refuge Suitability Index that were within its borders (Figure 31). Only the larger tracts could have large areas of forest, and so receive a high score. The largest tracts with the exception of Tract 5 also had areas of other land cover.

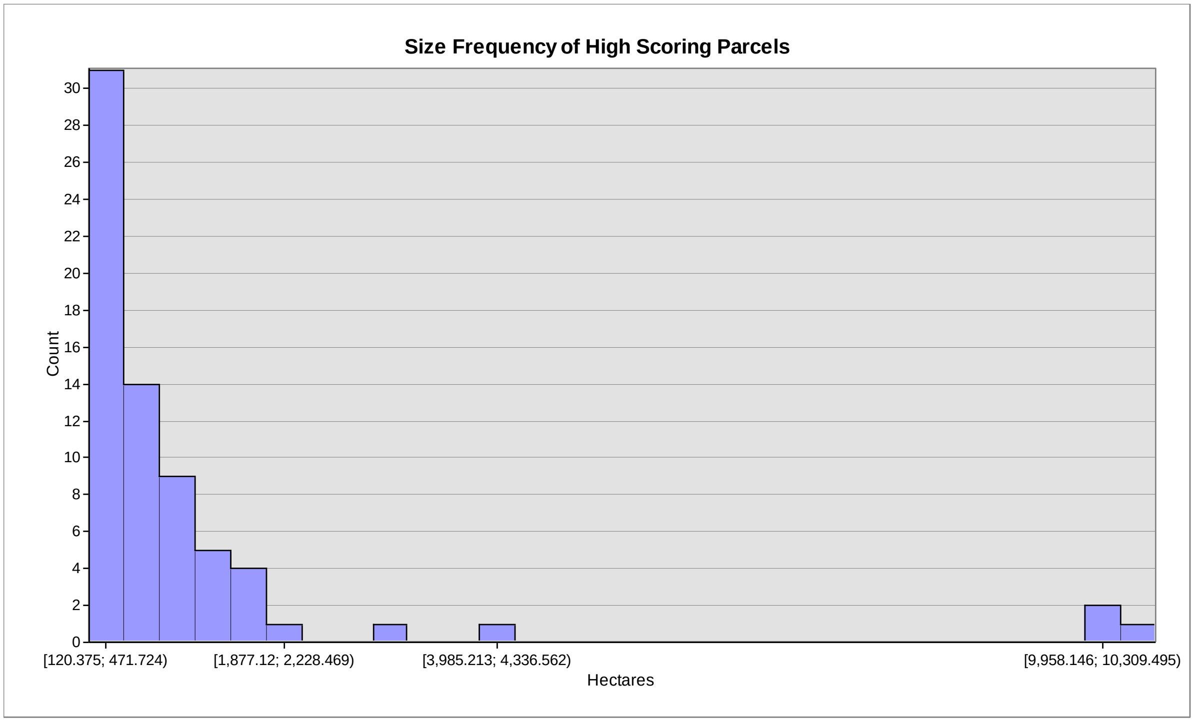


Figure 29. Three of the high scoring parcels were exceptionally large. These tracts were 10 to 20 times as large as the other high scoring tracts.

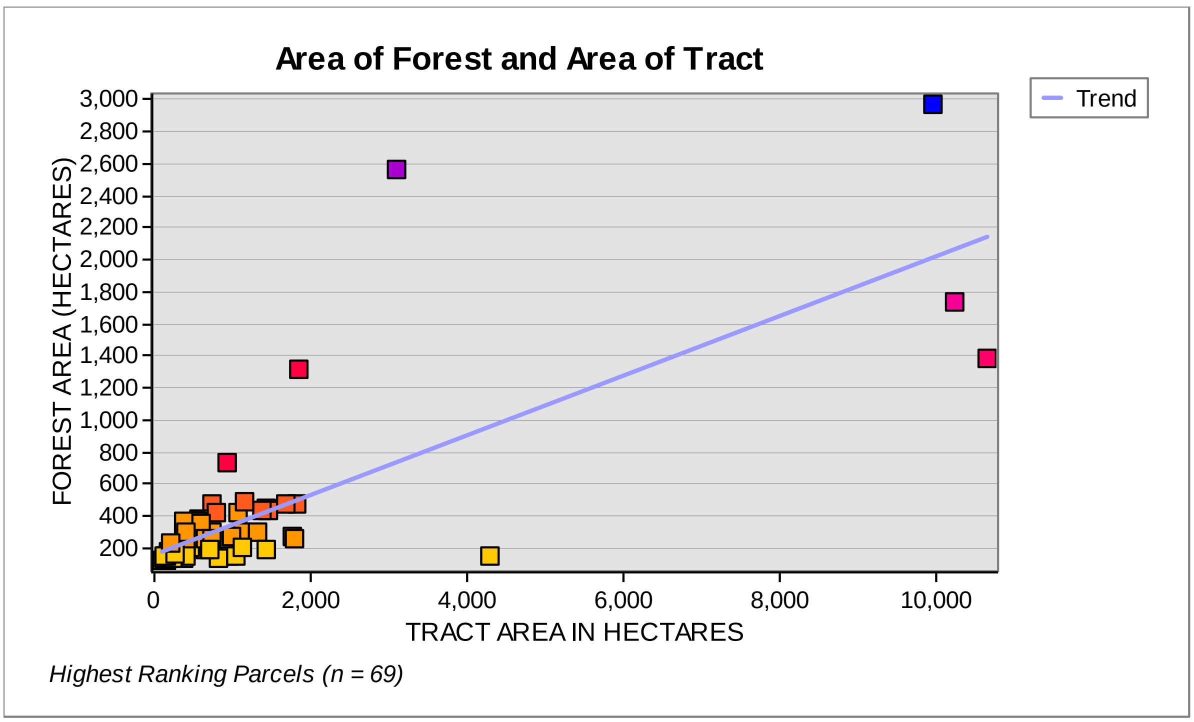


Figure 30. The trend shows the score for a tract is related to the area of the tract.

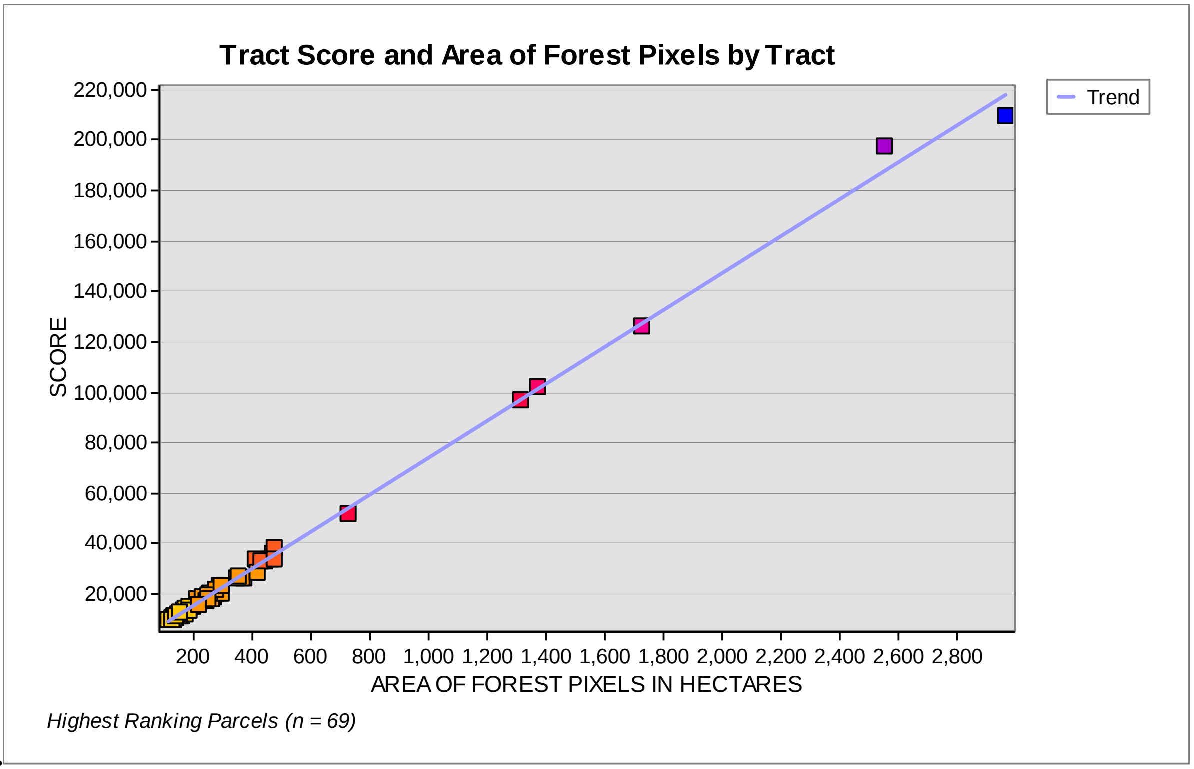


Figure 31. The score of a tract rises very closely with the number of forest pixels on the tract. Only tracts 1 (blue) and (2) purple show much variation away from the line associating score with area.

Goal 2 Discussion

Merging tax parcels by owner name worked fairly well for grouping tax parcels by common ownership. However, the many errors in the county tax parcel data may have affected the final results.

The score of a tract in relation to the Habitat Suitability Index is strongly related to the area of the tract. In particular, the tract score is strongly related to the number of pixels with values 6 and above. The Refuge Suitability Index does not affect the score of the parcel, even though the value factors making up the value of that pixel can support why a parcel has a high or low score. Removing all of the pixel values below 5 removed variability. The area of the forest on the parcel is most important for determining its score.

The value of the area of a tract is worked into the Tract score several ways. Every pixel had a value of at least 6 after the lower value pixels were removed, so that only the forested areas would add to the tract score. Other factors in the model should have increased the score for parcels that met the priorities of the land protection plan. However, to some degree they are confounded with the area of forest; Forest Patch Area, percent Developed, and the Edge vs. Core theme all have a relationship with the area of the forest that the tract contains. The area of the forest cover can be no bigger than the area of the tract, so only larger tracts have the potential to have the highest scores. The actual number of pixels, rather than their value, is the strongest influence of the resulting score of a tract.

The base score was 6 in this model, and the range of pixel grid values was 6 to 10. It may be possible to add more variation to the score by increasing the range, or removing fewer of the lower values. As a map of areas that would be good for new refuge parcels, the model produced an image that highlighted large areas of tall trees very well. As a scoring system to compare parcels, the model essentially compares the area of undisturbed forest. The main effect of the Refuge Suitability index is to filter out small patches of forest, early successional stages, and areas with high percentage of development (Figure 35a and 35b).

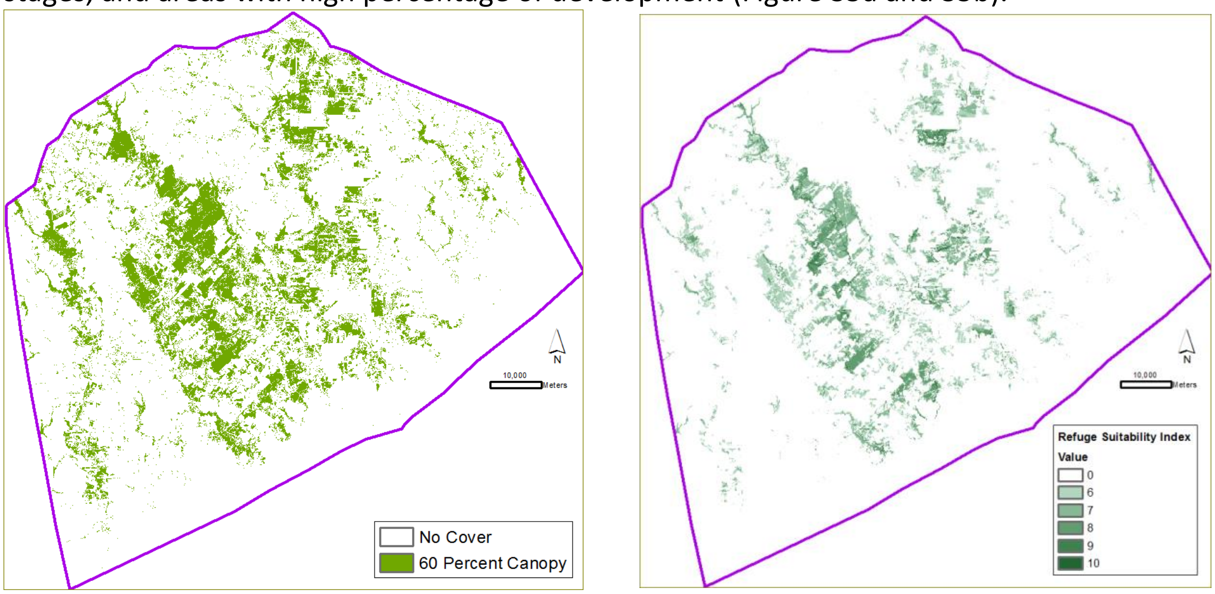


Figure 32a and 32b. Canopy cover greater than 60 percent, and the Refuge Suitability index. The index removes smaller patches of trees, and areas near developed land cover.

Goal 3: A corridor system for a model animal

The Columbia Bottomlands is isolated from other Southern bottomland forests by Galveston Bay to the east and the Houston metropolitan area to the north. Texas is characterized by a rainfall gradient from east to west; the Columbia Bottomlands area may have more plant species in common with Louisiana than in ecological regions of Texas to the west. The plant community formation in the Columbia Bottomlands is distinct (Rosen, 2008). The loss of any species within the local ecology could not easily be restored, because of the area's relative isolation from other bottomland regions.

In a bioreserve network, ideally animals and plants will move between the reserves, thereby increasing genetic variation within each reserve, and protecting each tract from extinction within its population of animals, if by chance one area were affected by a disaster, such as a hurricane or fire. Travel of individuals between reserves is especially important if the entire network is isolated from larger sources of immigrant plants and animals (Harris 1984).

While considering the optimum configuration of the eventual network system, barriers, corridors, and smaller "stepping stone" refuge units between the larger units could be valuable. Wilson and Macarthur (1967) point out that “fringing archipelagoes” of small islands increase the success of species departing from one island to colonize another. For this reason, natural corridors and stepping stone units between larger units of the Austin’s Woods project should be identified and conserved if possible. Also, barriers to animal movement between refuge units should be identified and their effect diminished.

Though the purpose of the refuge is to protect migratory songbirds, which are not affected by terrestrial barriers, the long term well-being of the Columbia Bottomlands may depend on corridors that promote the health of the entire ecosystem.

In selecting an animal to develop a corridor study, box turtles were selected because roads are a common source of their mortality (Dodd, 2003). They are dependent on brush or forest, but otherwise habitat generalists and they occupy a wide range of forest types. Box turtles are well studied and the three-toed box turtle (*Terrepene carolina triunguis*) is the subspecies found in the Columbia Bottomlands.

The goal of this section is to model corridors between habitat patches within the existing refuge units, and between some of the larger forested regions outside the refuges. Examination of the modeled corridors may lead to suggestions to facilitate movement of animals between the refuge units.

Box Turtle Life History

Box turtles, *Terrapene carolina,* are distributed widely throughout the eastern United States. The three-toed box turtle, *Terrapene c. triunguis*, is found from Missouri to Texas and Alabama (Conant, 1975). Humidity is most important factor for habitat choice, and for that reason, eastern box turtles prefer forests and brush, especially bottomland forests (Luensmann, 2006). They often are found in forest edge, presumably because of the variety of micro-habitats and forage (Dodd, 2001). Eastern Box turtles are more likely to be found in open areas in the spring and fall, when temperatures are moderate, or humidity is high. However, they are dependent on wooded areas in general, especially in months of extreme temperature (Reagan, 1974). Box turtles frequently are found in “forms”, small depressions in the ground, often under leaf litter or brush. The form provides a humid microclimate and temperature stability. Neonates and young turtles are often found under leaf litter.

Box turtles have small home ranges of less than 1 to 5 ha, averaging about 2 ha (5 acres). Sometimes turtle will use two areas separated by poorer habitat as a home range. Habitat quality and diversity account for variation in home range size. Box turtles tend to remain in their home range but, sometimes, make excursions for feeding or to locate nesting and overwintering sites, if they are not within the home range (Dodd, 2001). Eastern box turtles use open water extensively, they swim across streams and, sometimes, soak for long periods in ponds (Luensmann, 2006).

Eastern Box turtles are omnivorous, though the adults are mostly vegetarian. Younger box turtles eat more animal material, including insects, snails, slugs and worms and box turtles sometimes eat carrion (Luensmann, 2006).

Box turtles become active in the spring when the temperature is above 65 degrees. In Missouri, mating occurs May to October, and nesting occurs May to July, with hatching from August to November. A female may lay several clutches of 1-9 eggs in a year, under the leaf litter in a hole of 2 – 4 inches. Sandy, moist, well-drained soil is desirable for nesting sites and nests laid in non-flooding areas are more likely to hatch (Luensmann, 2006). Male box turtles find female box turtles by sight only and reproduction is most successful when populations are dense (Belzer, 2000). Mating occurs only between box turtles with overlapping territories (Stickel, 1989).

Adult box turtles can live many years. Threats to box turtles include domestic dogs, raccoons, skunks, coyotes, Mississippi kites and crows. Box turtles may be run over by automobiles or mowing equipment. Soft-shelled hatchling box turtles may be eaten by birds, shrews, and snakes. Eggs are eaten by snakes and ants (Luensmann, 2006). Predators are more likely to destroy box turtle nests at or near a habitat edge than in its center (Temple, 1987), though Marchand and Litvaitis (2003) using simulated nests, found that predation was more likely to happen near ponds where raccoons were likely to forage, rather than in edge habitats per se. Fire and habitat destruction also threaten box turtles.
The amount of habitat needed for a population of box turtles to survive is not well understood (Dodd, 2009). Because box turtle reproduction is slow, and eggs and young are frequently destroyed by predators, recruitment into the adult population is very low. Survival of a population depends on the survival of adult individuals. Box turtles have many characteristic that make their population sensitive to urban sprawl: they have high site fidelity, they have a slow reproductive rate, they use ground nests, and they are collected by humans (Johnson and Klemens, 2005). In Massachusetts, Erb (2003) modeled mortality rates, and found that an adult mortality rate of 1% of adults can lead to local extinction. This study also estimated that a sustainable population of 300 box turtles would require a habitat area of 612 to 3750 acres.

Eastern box turtles were assessed as “vulnerable” on the IUCN Red list of Threatened Species (van Dijk, 2013). In Texas, commercial sale of wild box turtles is prohibited, but collection of up to six specimens with a non-game permit is allowed (Texas Parks and Wildlife, unknown date).

Corridor Modeling

Corridor modeling is similar to habitat modeling where areas that are good habitat in the model are scored so that they have “low resistance” or low cost for an animal to move through as it goes through the landscape between two wildland preserves (Beier, 2007). The goal of corridor modeling is to identify corridors through the landscape that animals will use to move between two preserves. These areas are usually, but not always, good habitat for those animals.

Corridors are modeled by creating a cost surface around a point. Each pixel in a grid is assigned the cost between moving between that position and the point of interest. Cost surfaces for both the beginning and ending point are calculated separately, and then added. The resulting surface represents the cost of moving between the points (Figure 33).

Animals that can move between preserves in a day are termed passage species (Beier, 2007). Box turtles as a species are corridor dwellers; because of their fidelity to home ranges, they require multiple generations for the transmission of genetic material between habitat blocks. To accommodate corridor dwellers, Beier (2007) suggests assigning the highest suitability value to patches of potential breeding habitat. For box turtles in the Columbia Bottomlands, breeding habitat is successional forests that are not prone to flooding, and which have edge or early successional habitat. Breeding habitat for turtles is not very different from their habitat in general, except while turtles often use open areas within their territory to forage when weather conditions permit, they would be limited to the leaf litter in forest or shrubs to breed.

Goal 3 Methods

For modeling the landscape for box turtles, the following data sets were used to represent important features in the landscape for box turtles. The data sets were classified by their value to box turtle habitat, and converted into a pixel grid of rating values. The rating values were combined mathematically to create a model representing areas that are good or bad habitat for box turtles.

1. Area of Forest patch
2. Topographic Position Index
3. Core and edge forest
4. Streams and Wetlands
5. Percent Developed Land Cover
6. Roads and Railroads

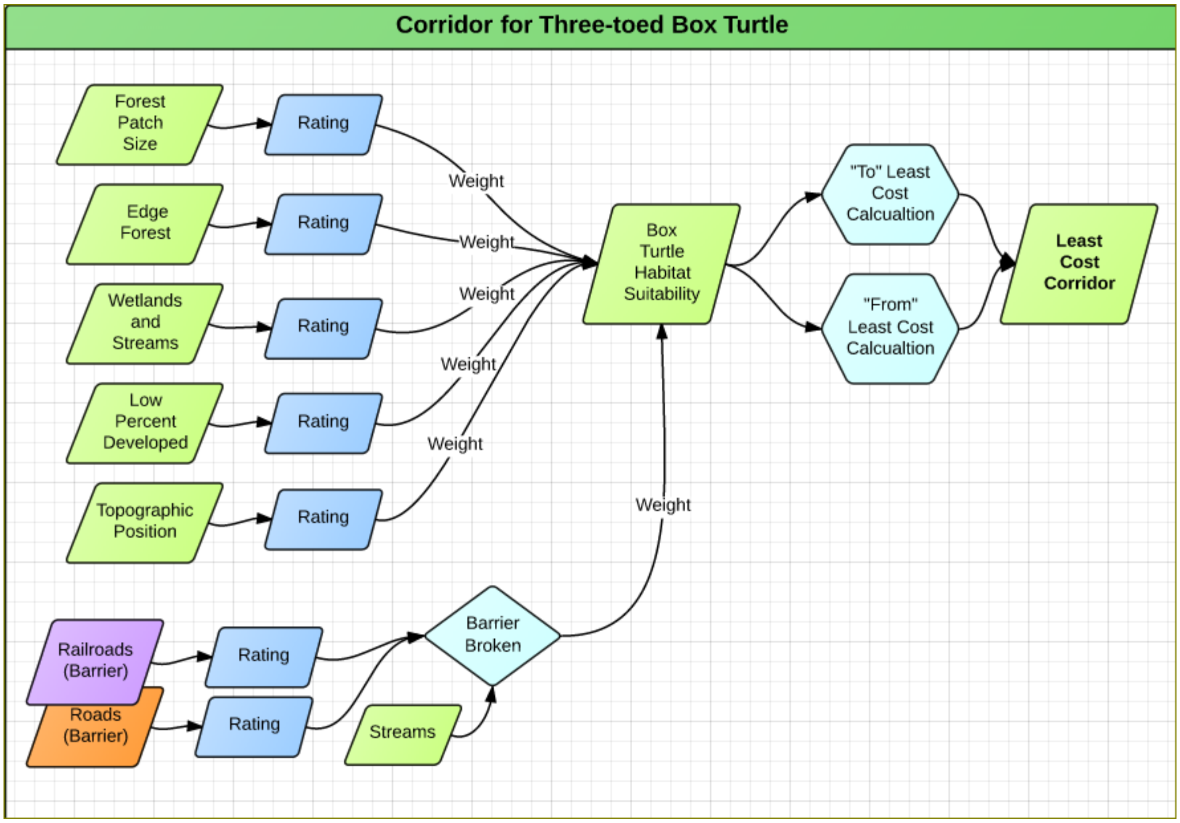


Figure 33. Data sets and Processing steps for modeling corridors for box turtles. Data sets are combined to make a habitat suitability model, representing a landscape. Travelling costs from all pixels in the model are calculated to a starting point, and then calculated to an ending point. The cost of moving between those points is the sum of the cost calculations.

Forest Patch Area

This theme was constructed to identify patches of forest or brush canopy that are large enough to be part of a good home range for a box turtle. Because box turtle prefer edge habitat and open forest, the definition of forest was canopy cover greater than 50%, not 60% as in Goal 2. Box turtles use open areas, but the humidity, leaf litter and cover associated with forests are limiting factors for them, particularly for breeding territory. The average home range is about 5 acres, a habitat patch should be large enough to support several turtles together, because turtles mate only when their ranges overlap. Forest patch size of 12 acres and above was rated at the highest value. Because the Canopy Theme is well connected, the great majority of the area of canopy was in patches larger than 12 acres (Figure 34).

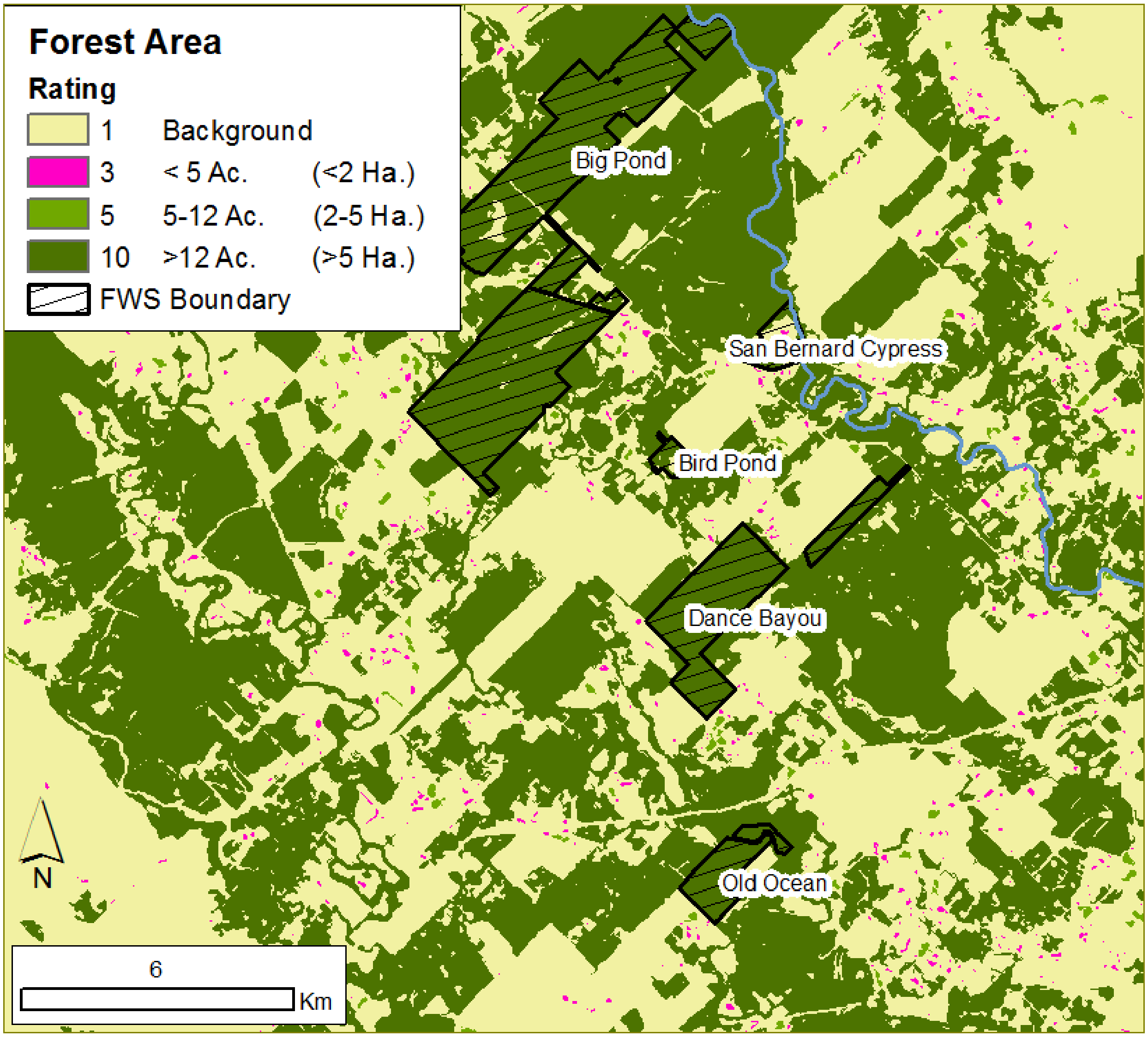


Figure 34. Patches of forest rated by area. Box turtle home ranges average 2 hectares (5 acres). Good habitat would be large enough to hold several overlapping home ranges.

Edge Forest

Box turtles prefer edge habitat, because it has high plant diversity and a choice of microclimates. Polygons of forest areas were derived from values above 50% of the Canopy Cover data set. Edge (100 meters into the forest from the forest boundary) and core habitat were given ratings of 10 and 6, respectively. Both the Forest Region Area (Figure 34) and Edge Forest (Figure 35) themes areas of no canopy were given a rating of 1.

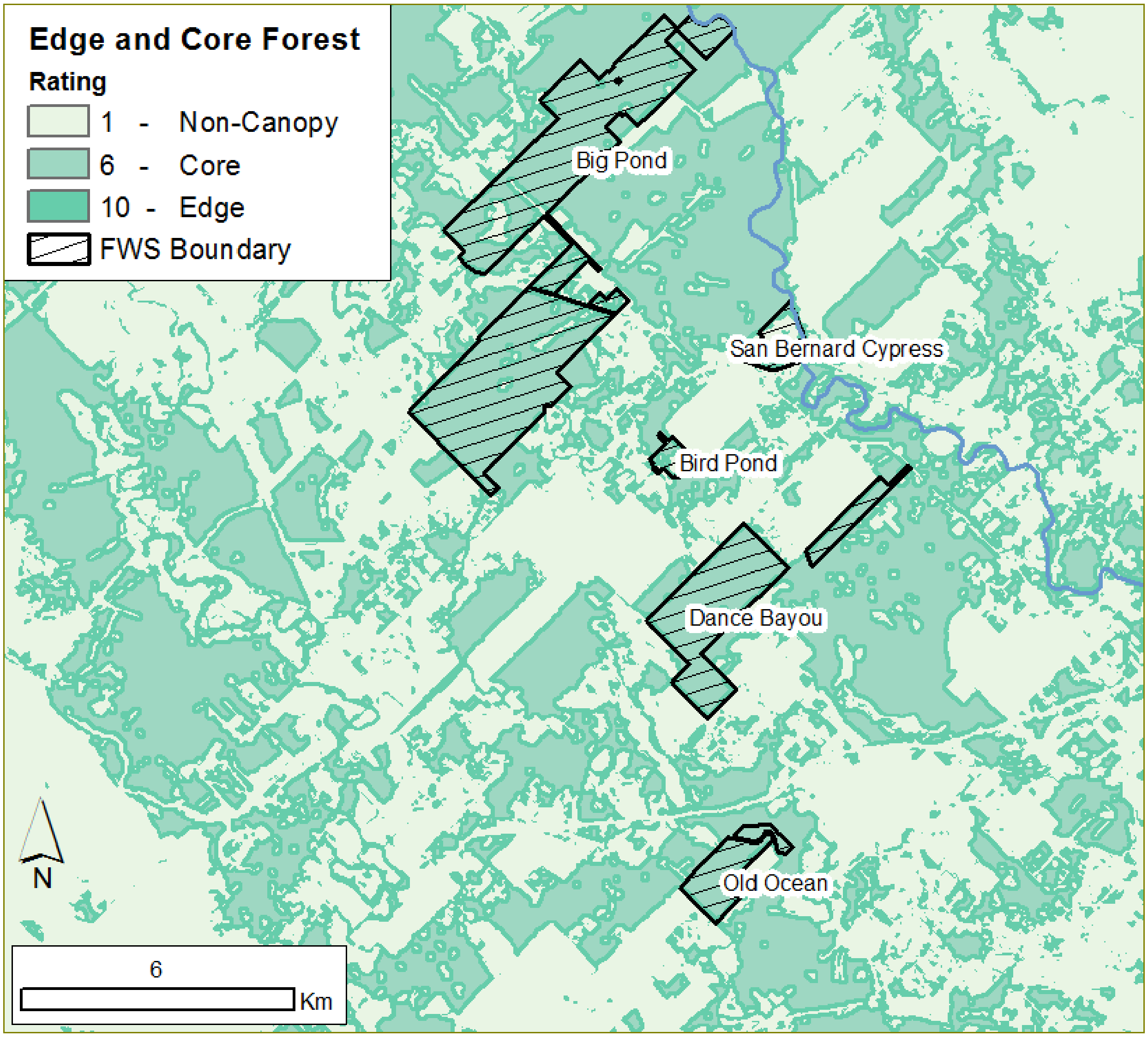


Figure 35. Edge and Core forest, derived from values above 50% in the Forest Canopy data set. Lighter green is core forest, which has the high humidity levels and leaf cover box turtles need, but they are found most often in edge forest, dark green in this image. Edge habitat along fence rows and streams connect many of the larger forest patches.

Streams

Because box turtles swim, and frequently loiter in pools on hot days, streams were included. The unbuffered streams tended to be 1 pixel (30 meters) wide. Named streams were 2 – 3 pixels (60 - 90 meters) and Major streams were 3 – 4 pixels (90-120 meters) wide. The Brazos, San Bernard and Colorado, due to their size and strength of current, were given lower ratings for habitat (Table 14). The NHD stream data set also includes drainage ditches (Figure 36). These were included as good features for box turtles.

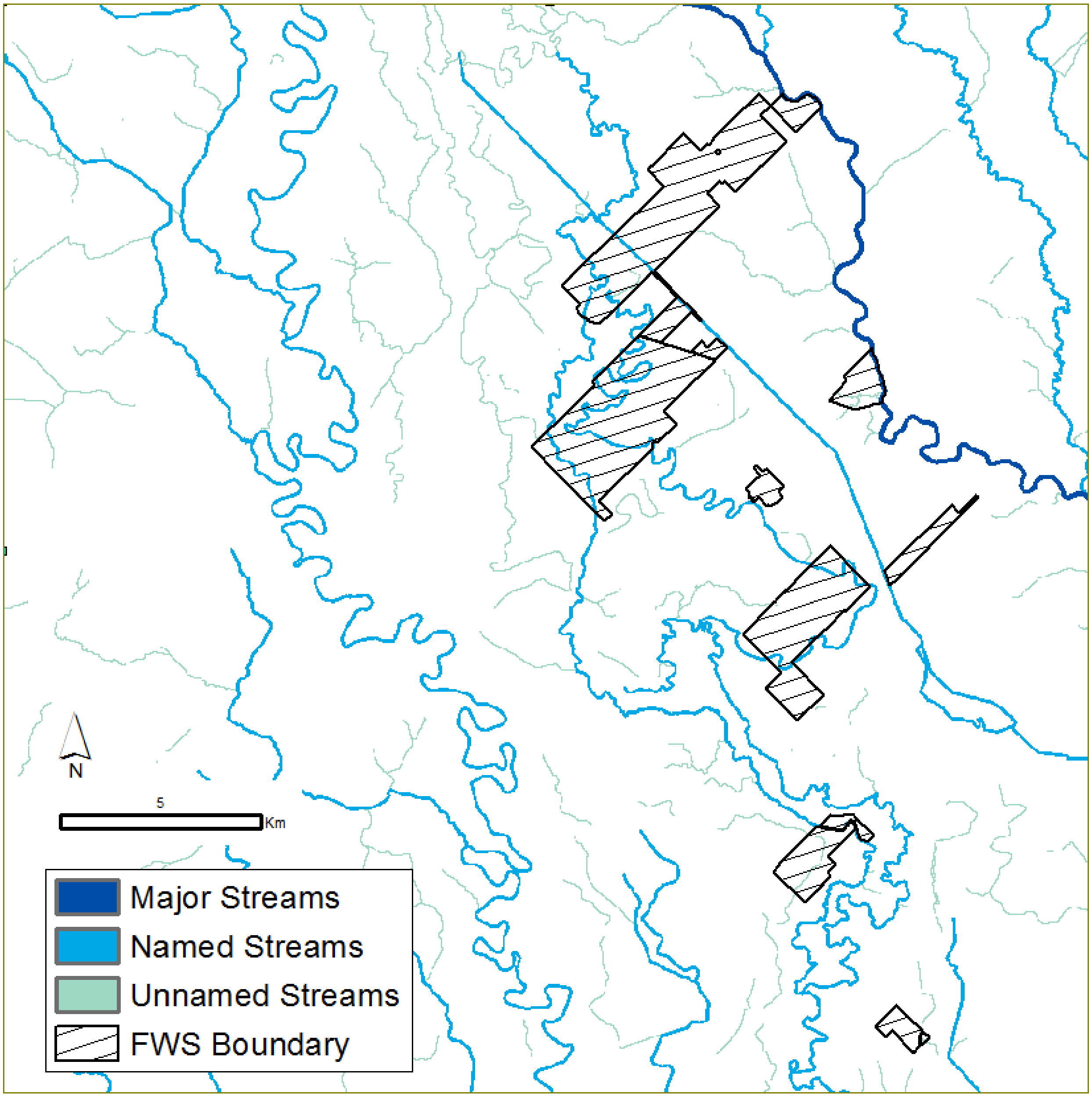


Figure 36. Stream buffers were less wide for the box turtle habitat model than for Goal 2, where the buffer was intended to increase the score of neighboring parcels.

Table 14. Rating table for Streams for box turtle habitat. Streams were rated as a positive habitat feature for box turtles, the larger, more powerful streams less so.

Streams		
Type	**Buffer**	**Rating**
Nonstream Matrix	---	1
Brazos/San Bernard/Colorado	60 m	8
Named Streams	40 m	10
Unnamed Streams	none	10

Wetlands

Fresh water Wetlands, including artificial ponds, were included, as a supplement to the box turtles preferred habitat of edge and open woodlands. Forested wetlands were not included, because of their propensity to flood. Because of Corridor modeling software was limited to 6 datasets, streams and wetlands were merged together as one theme for the model, and given a single weight (Figure 37).

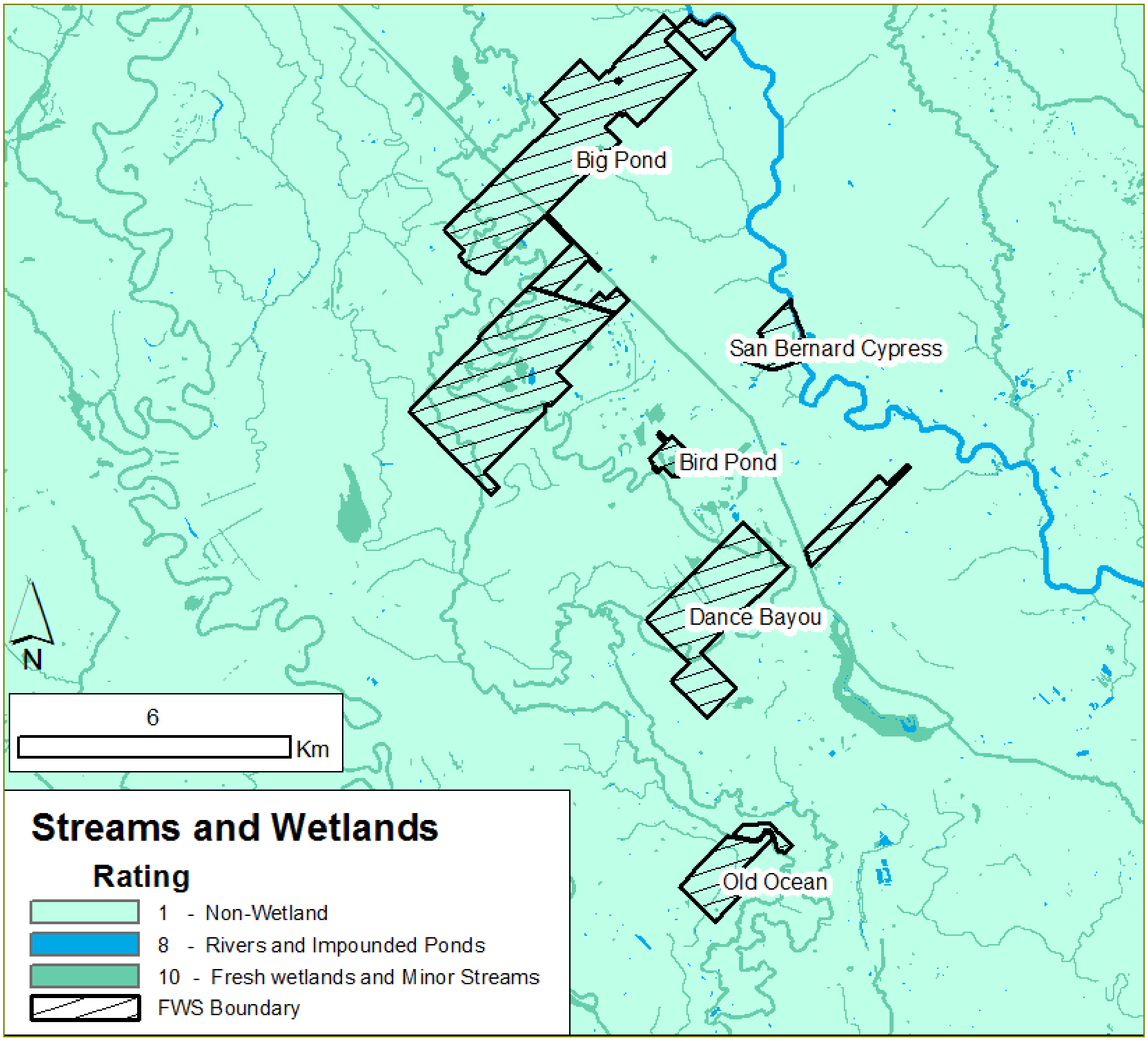


Figure 37. Ratings for streams and wetlands data sets were combined and treated with the same weight in the model. Large rivers and impounded ponds were rated not as highly as wetlands and small streams.

Percent Developed

I did not find any studies (like those for Neo-tropical birds) which indicated that turtles avoided developed areas, or that box turtles preferred areas below a certain density of development. Dodd (2001) speculates that box turtles, like sea turtles, instinctually return to the area of their birth, because of natural selection. Box turtles do not guard their nests or take care of their young. If having been hatched in a particular area, they survived to adulthood, it is likely their offspring will have a chance of reaching adulthood if the conditions in that location have not changed. This suggests that box turtles, unlike Acadian warblers (Bakermans, 2003) may persist in using a nesting area that is doomed to predation, and only the individuals that happened to have survived in areas that remain undeveloped will reproduce successfully. Because many predators of box turtles (dogs, raccoons, crows) are "human subsidized" (van Dijk, 2013), the same Percent Developed rating scheme as for the "Refuge Suitability" model was used to represent the effects of increased predation near human settlement (Figure 19).

Barriers – Roads and Railroads

Railroads can be fatal to box turtles when they are trapped between the tracks. The turtles can quickly die from dehydration. The railroad data set (Houston-Galveston Area Council, 2014) was compared with aerial photography, and edited to show where the rails were elevated by trestles, and so passable at ground level by box turtles. Pulled rails were also edited from the data set.

Road centerlines from the State of Texas (Texas Water Board, 2014) were categorized into four classes. Active railroads and roads were converted into grid format. The Streams data was then used to make breaks in the road and railroad lines, to model how a box turtle might use a bridge or a culvert to cross a road (Figure 38)

Tables 15a and 15b. Ratings for Roads and Railroads**.** Busy roads and railroads were given the lowest ratings.

Road Classification	
	Rating
Divided Highway	0
State or County Road	2
Local Road	3
Other Road	7
Non-Road	10

Railroad	
	Rating
Active	0
Trestle/Pulled	10
NonRailroad	10

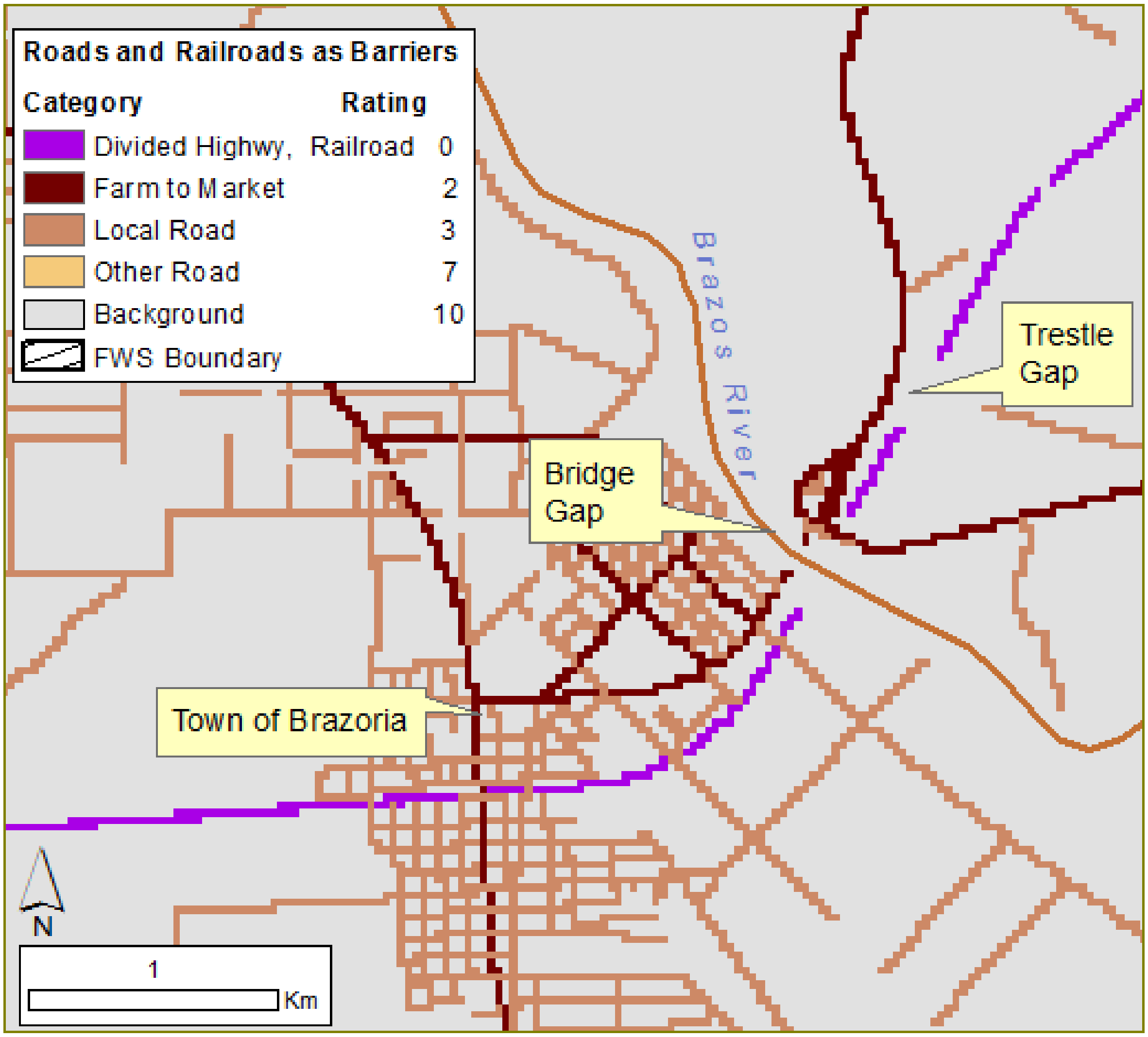


Figure 38. Roads and Railroads were coded with low ratings values. Trestles in the railroad and bridges were coded as gaps the line of pixels representing the road or railroad.

Topographic Position Index

Box turtles prefer moist, soft soils with good drainage, and avoid steep slopes and hill crests (Luensmann, 2006). A map of steep slopes, low areas, and crests was calculated using the 10 meter Digital Elevation Model (DEM) that was produced for the Gulf Coast (US Geological Survey, 2013). The Topographic Position Model was converted to the 30 meter grid format used by the other data sets. Because of the level character of most of the Gulf Coast, small processing errors were very pronounced. The edges of the Lidar data sets used to create the DEM were visible, as were a number of flaws shaped like streaks (Figure 39).

This data set was ultimately not included in the model, partly because of its visible errors, but also because the modeling software that combined the data layers could process only five data sets. It is included in the methods section for illustration.

Table 16. Rating for Topographic Position. Crests and Low areas are rated with zero values. Box turtles avoid crests, probably because of low humidity, and they cannot breed or hibernate in areas that are prone to flooding.

Topographic Position		
	Index Value	Rating
Bottoms	-16 - -6	0
Lower slopes	-6 - -0.1	4
Below Level	-0.1 - 0.01	8
Slightly Raised and Level	0.01 - 1	10
Upper slopes	1 - 6	4
Crests	6 - 12	0

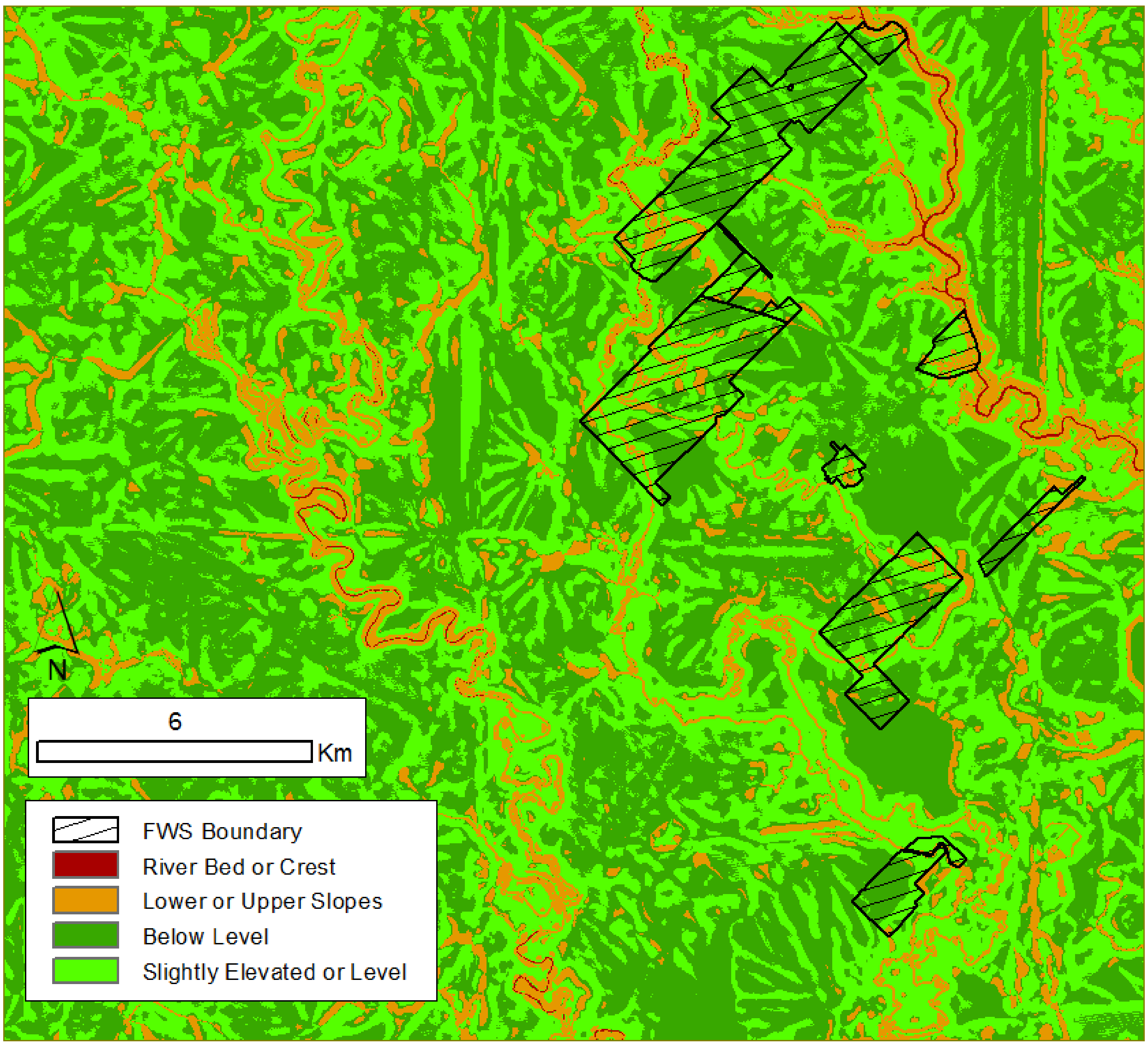


Figure 39. The Topographic Position Index rating shows with slightly elevation topography as bright green, with below level as dark green, and crests or river beds as red. Moist areas with good drainage are best for box turtles.

Data Weights and Habitat Model

The five data sets were combined arithmetically with weights as shown in Table 17, which emphasized the forest area and also the roads and railroads as barriers. The resulting habitat model is appears valid because it shows wooded areas, roads very clearly (Figure 40). Wooded areas that are near inhabited areas show decreased value as habitat. The range of values is 0.55 to 10, so good and bad habitat areas are easily distinguishable.

Table 17. Weighting values for combining the data layers for the box turtle habitat. Because box turtles are dependent on forested areas, Forest Patch area and Edge vs. Core Habitat comprised 45 percent of the ending value.

Weight	
Theme	**Percent**
Forest Patch Area	25
Edge/Core Habitat	20
Streams and Wetlands	10
Percent Developed	20
Roads/Railroads	25
	100

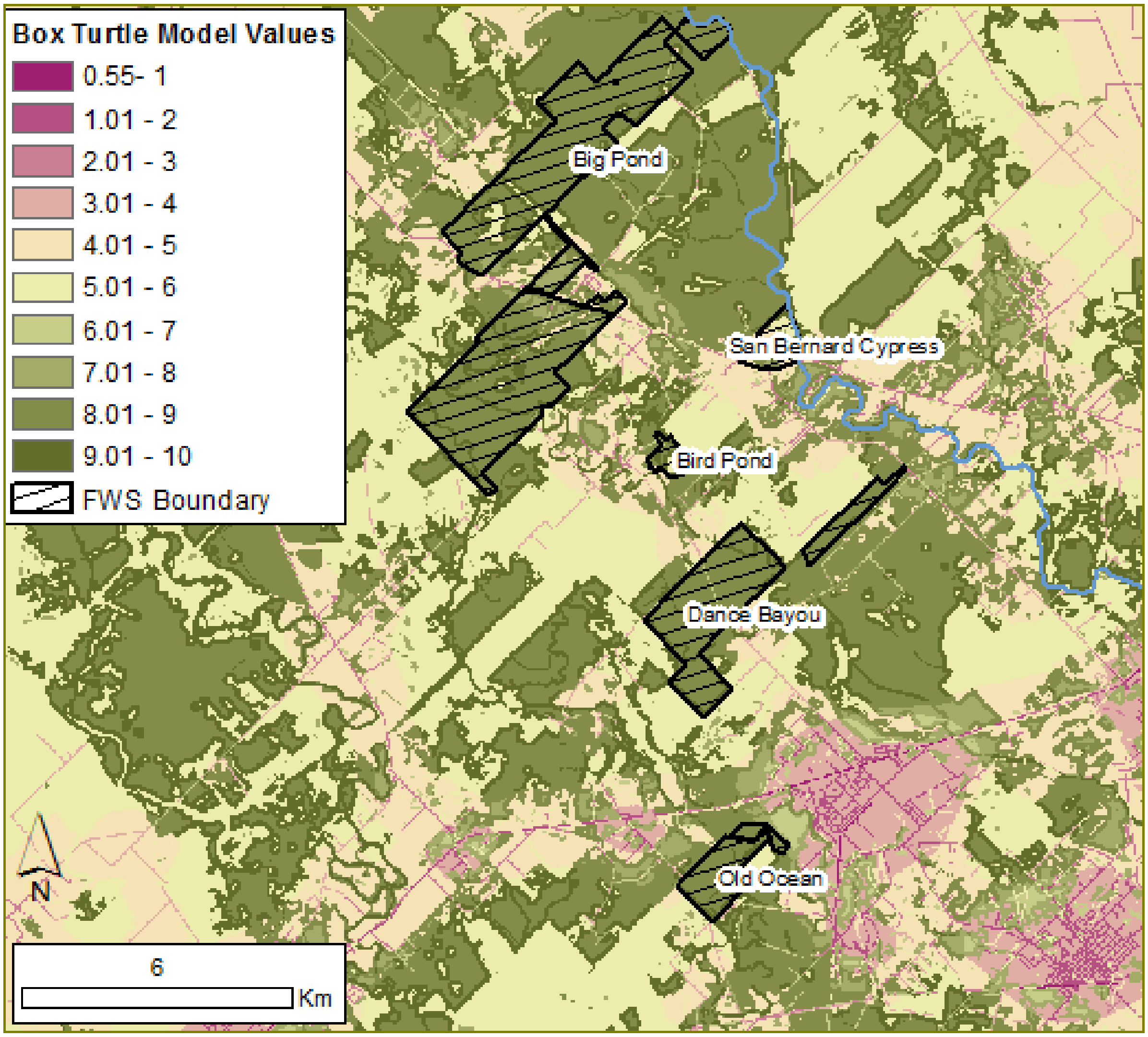


Figure 40. The Box Turtle Habitat model. Areas of poor habitat are displayed in pink, and areas of good habitat displayed as dark green. Edge habitat, roads, and developed areas are clearly visible. Areas of human habitation clearly reduce the value of neighboring woods as turtle habitat.

The Box Turtle Habitat model was converted to an integer range of 1 to 100, to fit the format of the corridor model software. A cost model was created by subtracting the habitat values from 100. Habitat patches designated as starting points for the corridors were selected from within the refuge units, at Brazos Bend, and also at the north and west extremes of the area of interest (Figure 41).

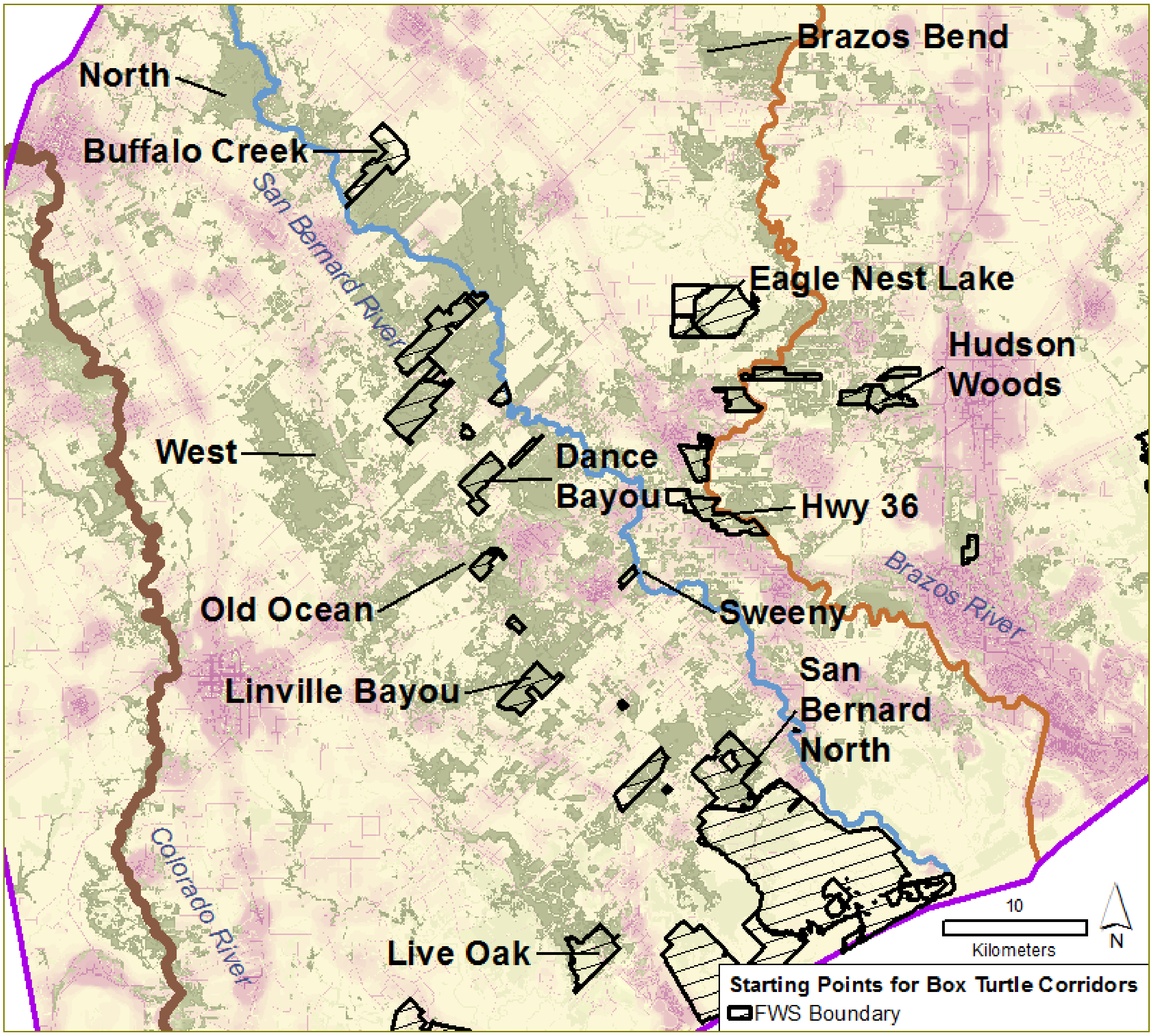


Figure 41. Thirteen starting points were selected to calculate corridors between refuge units. Small patches of turtle habitat were selected within refuge units, at the north and west extremes of the bottomland area, and also at Brazos Bend State Park.

Data Processing for Corridors

To model the cost to the box turtle of moving through the territory, the value of each pixel in the map layer was subtracted from 100, to make a cost grid. A new pixel grid was calculated for each of 15 starting habitat patches. The value of each pixel of the cost grid was the sum of the cost distance between each position and the starting point. The corridor grid between the two starting habitat patches was calculated by adding the cost models together.

Goal 3 Results

Corridor models were calculated between fourteen pairs of starting habitat patches in the area of interest. Each corridor model was visualized as a narrow corridor, and as a wider corridor by selecting the range of of the lowest cost values included within the corridor (Figure 42).

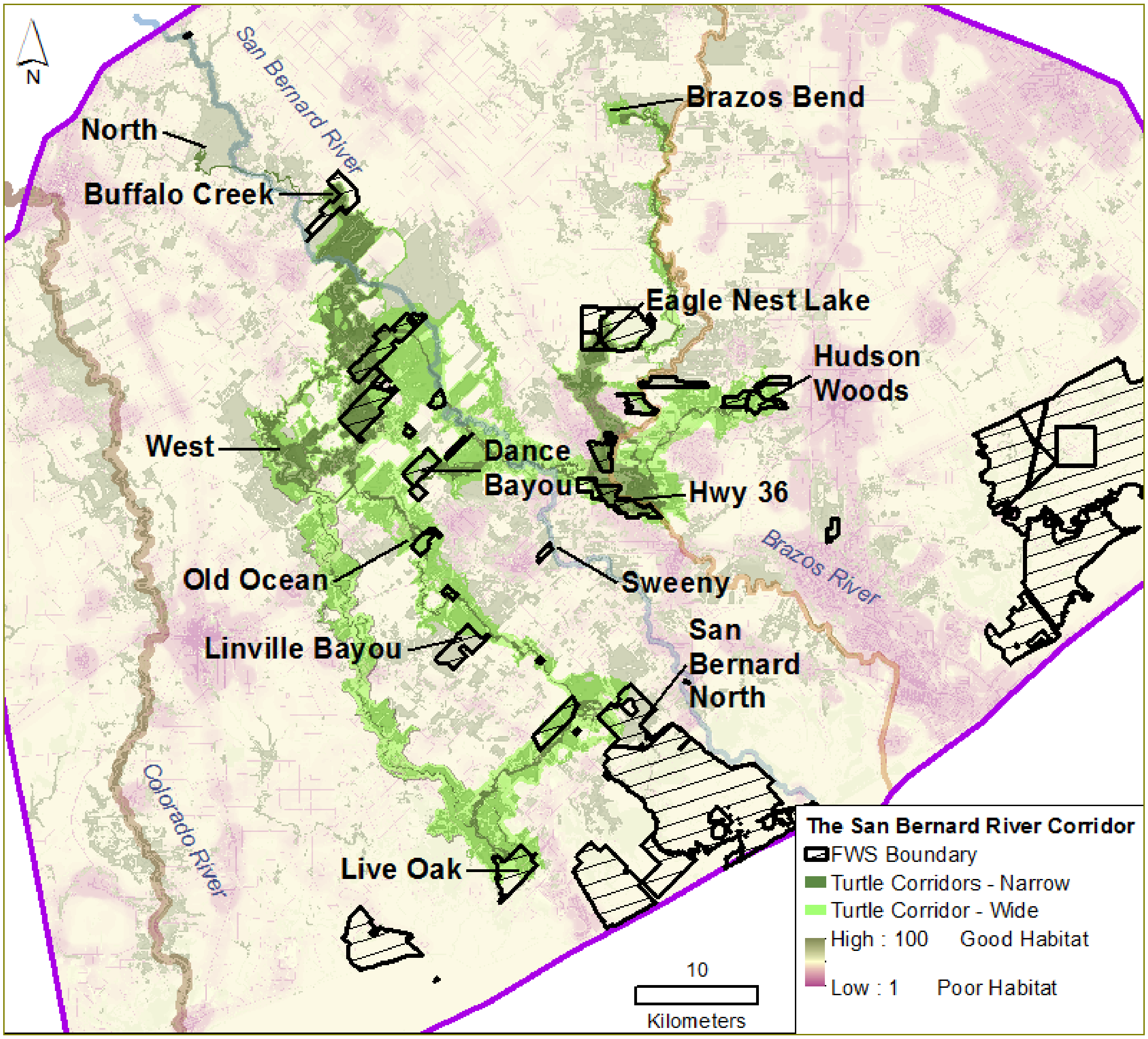


Figure 42. Narrow and wide corridor models between starting points. At a given percentage of the cost grid, corridors were narrow in regions of poor habitat, and wide in regions of good habitat.

Corridors that covered long distances, over areas of uniform habitat tended to be narrow. In regions where there were many patches of good and poor habitat, the corridor at a given percent of the cost grid would widen in regions of good habitat.

Corridor Examples

Three examples of corridors are described here to illustrate the behavior of the model, and how it could be useful for designing corridors.

Big Pond

The Big Pond units are intersected by Farm-to-Market Road 1301 and connected by the Dow Ditch, a drainage structure constructed in the early 1900s between the sulfur mine at Big Pond and the San Bernard River. Although the two parts of the unit are connected by their boundaries through the Dow Ditch, the corridor model connects the two units by the brush running along the Linville Bayou on private land (Figure 43).

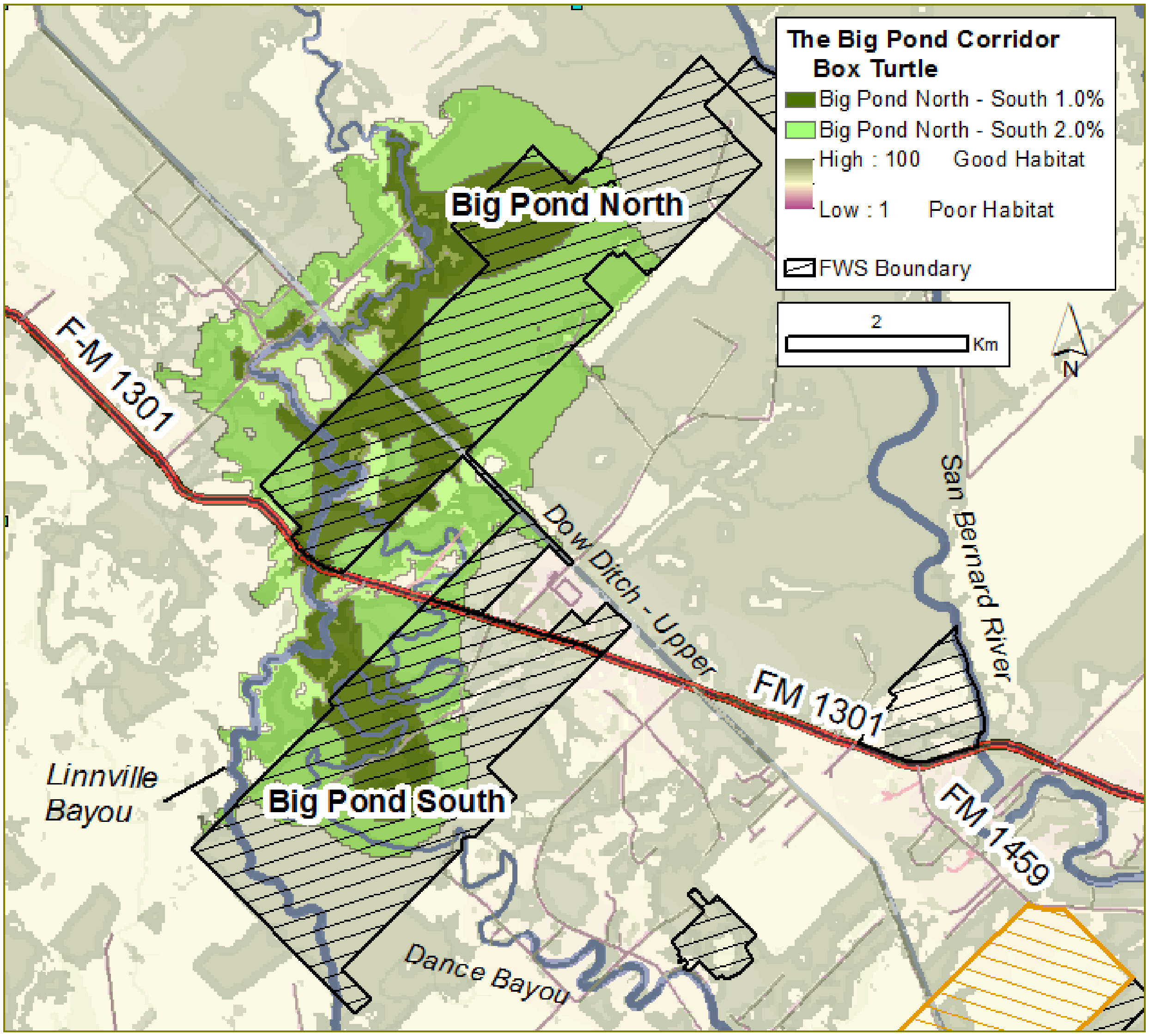


Figure 43. Though the two Big Pond refuge units are connected by the Dow Ditch, the Corridor model shows Linville Bayou as the most likely corridor between the two refuge units.

Hansen Park

Where the San Bernard River goes under the divided Highway 35, the river makes a break in the barrier. With the current model, the narrow corridor goes between the two patches of forest cover north the bridge, but not using the break in the Highway 35, which represents an elevated bridge. In the model, even though roads have the lowest values, the road does not appear to act as a barrier, here the corridor runs between the trees in Hansen County Park and the trees on the west side of the river. Increasing the model width for large highways, or increasing their weight in the habitat model, would better represent the road for box turtles. The Percent Developed theme seems to have more influence on the shape of the corridor, because its effects typically cover a wide area (Figure 44).

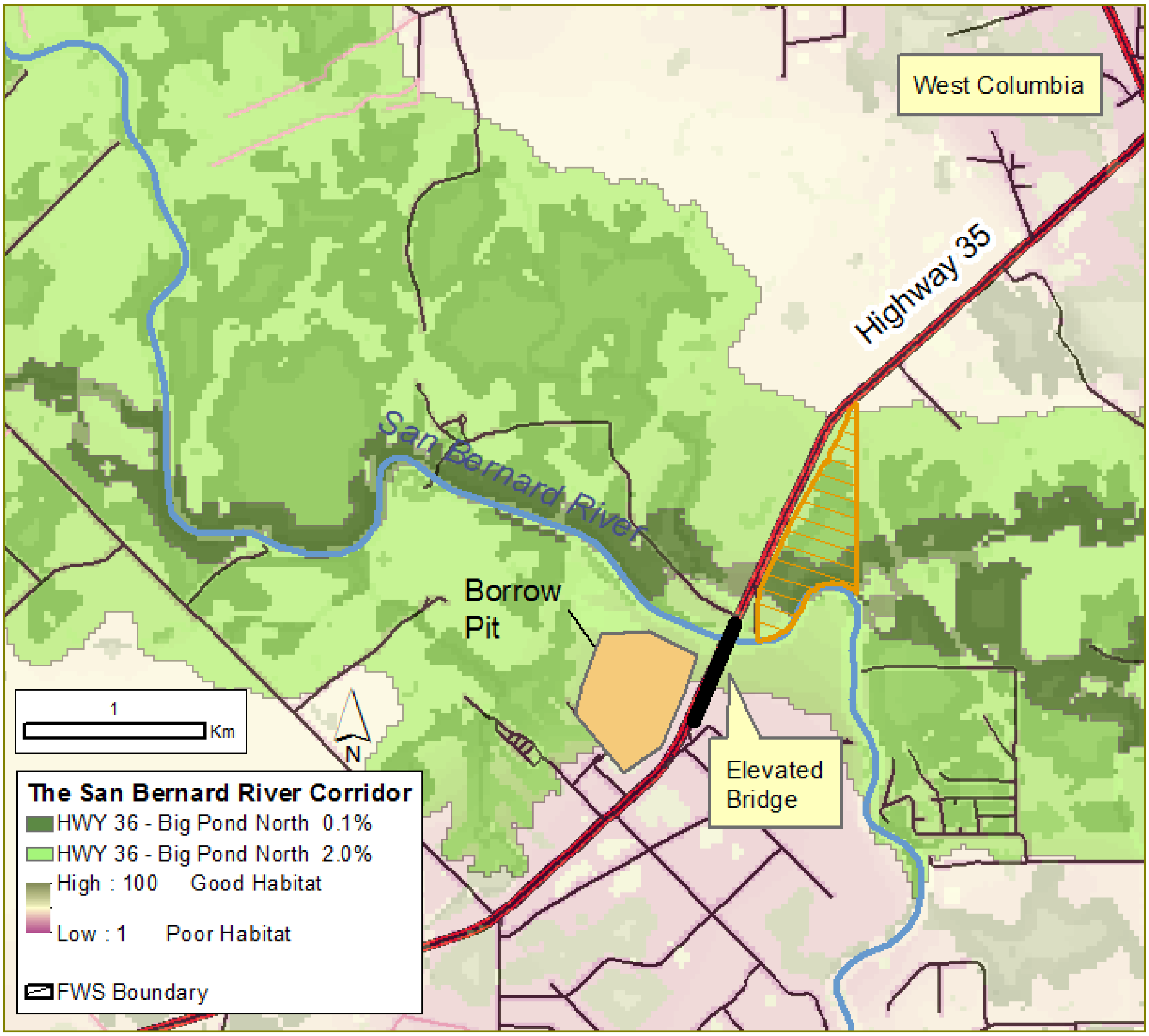


Figure 44. The corridor model shows that box turtles as more likely to move between the brush at Hansen County Park and the brush on the other side, than to go under the elevated bridge on the San Bernard River. The corridor could be enhanced for box turtles and other animals by increasing cover near and under the bridge. If cover for animals were restored on the Borrow Pit, animals would be more likely to go under the bridge.

San Bernard River

The 0.1% corridor between Big Pond and Hwy 36 units does not always follow the San Bernard River. Where the river is close to Farm – to- Market Road 1459, the least cost path for this model is on the edge habitat along the road. This implies that edge habitat is more important than river corridors in the model. It also suggests that the San Bernard could be improved as a corridor for wildlife on this section of the river (Figure 45).

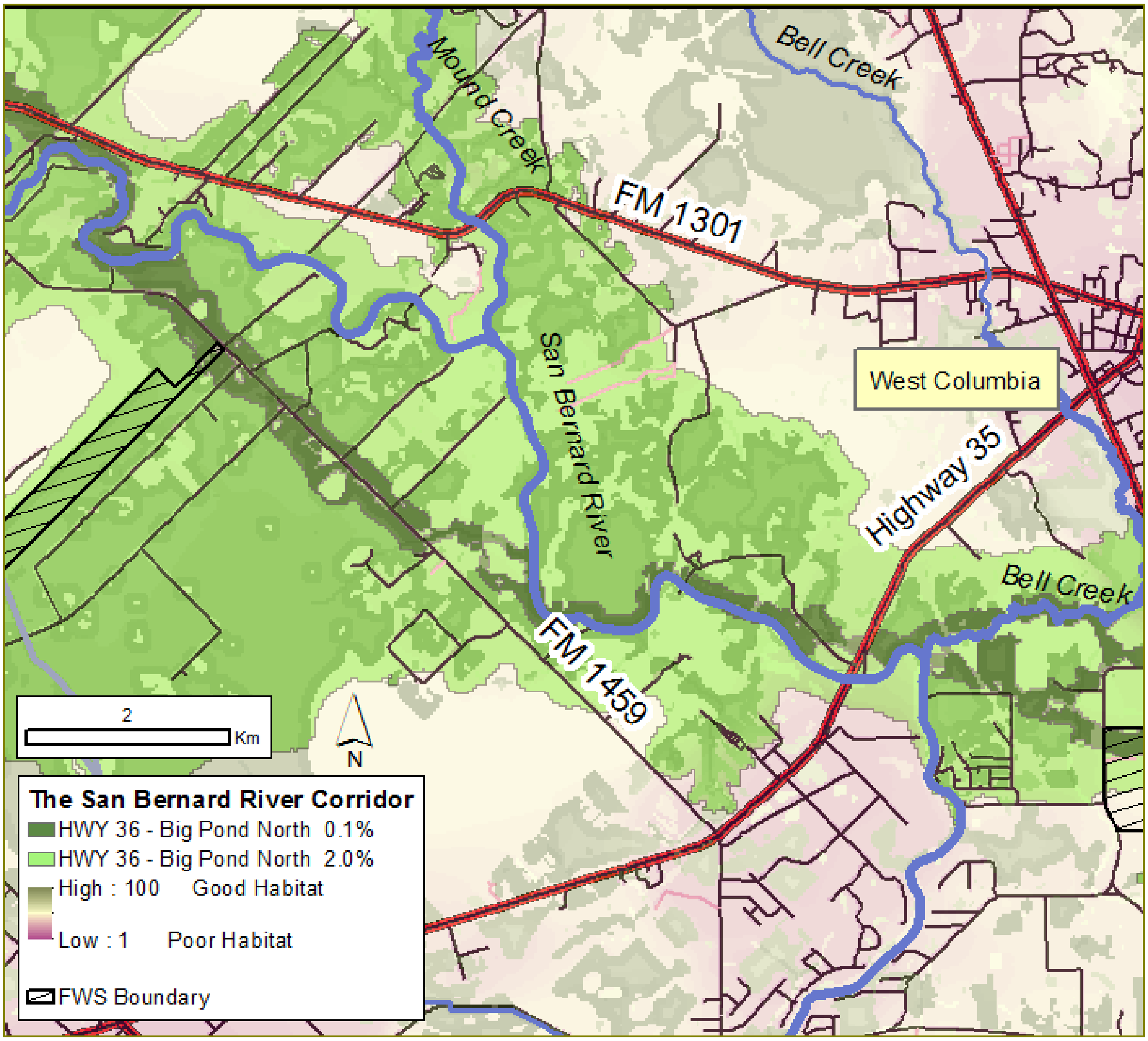


Figure 45. The model corridor follows Farm-to-Market Road 1459 instead of the San Bernard River. The line of edge habitat along the road has less cost in the habitat model. Improving tree cover along the San Bernard River would increase its value as a corridor.

Goal 3 Discussion

Roads and railroads were not complete barriers, as shown in the analysis, the proximity of two patches of good habitat have more influence on the shape of the corridor than a break in a barrier. Increasing the width for large highways, or increasing their weight in the habitat model, would increase the cost of crossing the road in the model, which may be a better representation of the landscape for box turtles. The Percent Developed theme has more influence on the shape of the corridor than roads, because its effects typically cover a wide area.

Development of the corridor models indicated two areas in which the Habitat Suitability Index for box turtles could be improved. First, corridors distinctly followed edge habitat. Only Core and Edge categories are represented in the forest. There are no variations in the habitat value of the interior forest, though variations in forest canopy density would allow more or less light to reach the forest floor, which would influence the lower-story plant communities. The model could be improved by including variations in the density of forest cover.

Secondly, the model should have included a theme that represented areas of good and poor drainage. Flooding can cause areas of otherwise good turtle habitat to be uninhabitable for months. A different Digital Elevation Model, or soil data would be an improvement in the model.

Characteristics of the corridor species

This model represents some of the characteristics of box turtles poorly. The model animal does not persist in areas of intense development, and strongly prefers edge habitat, but it does not act as though roads were a barrier. The corridors pass over roads at points between patches of good habitat, not where there are breaks in the barrier. Probably, box turtles do attempt to cross roads where there are patches of good habitat on either side.

Beier et al. (2007) caution against modeling roads as barriers, and bridges as breaks in barriers, because the corridor may not then represent where the animal actually crosses. To decide whether to model roads as an absolute barrier to box turtles, one would need to know their success rate for crossing particular roads, and whether they could be encouraged to move through the bridge area in actuality. In practice, to improve the likelihood that an animal will cross a barrier at a particular point, suitable habitat should occur on both sides of the crossing structure, and preferably, within the structure (Beier et al, 2008).

Corridor Width

Box turtles are good examples of a "corridor dweller" species, in that they typically do not move very far in their lifetimes. Corridor dwellers need to be able to breed in the corridor area for the corridor to function for that species. The corridor should be a series of habitat patches large enough for all parts of their habitat needs. Harrison (1992) suggests that for an animal that breeds in the corridor, the width should be roughly the width of a home range of that species (Beier et al., 2008). Box turtle home ranges are typically 2 hectares (5 acres) in size; a rectangle of 2 hectares would be 100 meters by 200 meters (326 by 652 feet). A corridor for box turtles should be at least 100 meters wide, preferably wider, and consist mostly of breeding habitat.

The corridor model allows visualization of "pinch points" where habitat for the passage of the animal could be improved. Visualizing the corridor at different percentage levels also reveals large areas of suitable habitat. Because the individual home ranges for box turtles are fairly small in comparison to the barriers in the landscape, the opportunites for improving corridor passage for box turtles is limited. The best strategy for conservation for box turtles is to identify the characteristics of a large preserve that could sustain a large population of box turtles, and manage the area for box turtles.

Project Discussion

For this project I explored the application of geographic information systems to several problems facing landscape conservationists. Though each project addressed methods of protecting habitat quality on the refuge units, and improving connections between refuge units, the projects worked at different scales.

The removal of surrounding forest analysis illustrated how the size of large forested tracts can protect their interior areas from conversion from core to edge forest. The importance of the neighboring tracts was highlighted by the relative protection provided by neighboring preserve areas. Units where most of the forest cover was near the border lost proportionally more core forest.

Assigning scores to parcels based on their habitat value is a coarse-scale approach. The emphasis in the study was habitat qualities of individual tracts more than their relationships with other preserve lands. Though the Refuge Suitability Index included distance from refuge units and other preserve lands, that factor did not seem to have a very large effect on the final result. The Habitat Suitability Index identified tracts that contained high quality forest habitat. However, my approach should be supplemented by an approach that considers wooded tracts in the context of other wooded tracts.

Finally, the corridor exercise highlights how management decisions on small tracts of land, in particular a string of small tracts, can make a difference in the character of the landscape. Encouraging brush to grow near or under a bridge can make it more attractive to animals moving across roads. Also small habitat islands, near bridges or other crossings, provide animals with cover while they wait for the optimum time to cross.

The Austin's Woods project to conserve bottomland forest has been successful in acquiring the fee title or a conservation easement for some large tracts, namely, the north Big Pond tract, and the Hwy 36 and East Columbia Tracts. Given the importance of large tracts to reduce fragmentation in the final configuration of the refuge complex, the emphasis on conserving large tracts should continue until the conservation of 70,000 acres is complete, and then if possible it should continue beyond that goal.

The USFWS Land Protection Plan describes the government and non-government organizations that make up the Austin's Woods project. With the exception of the Texas Parks and Wildlife Department Wildlife Management areas, however, most of the land ownership around the refuge units is private. The Refuge Suitability Index project showed that there were a few exceptionally large tracts that were privately owned, but the majority (estimated) of the neighboring landowners of the refuge complex units own smaller parcels between 5 and 400 acres.

Petit (1995) suggests that for the landscape-level management of migratory birds partnerships with private landowners be incorporated into management plans. At this time the Land Protection Plan does not discuss partnerships with private landowners, though Texas Parks and Wildlife, the Gulf Coast Bird Observatory, and other conservation organizations in the region are partners in the Austin's Woods project. As new tracts are added to the Midcoast Refuge Complex, the management challenges that apply to the new configuration of tracts will become more apparent. Refuge managers should identify neighboring tracts that are important ecologically to conserved land or to other private lands with important habitat features. Water features that pass through refuge units, like Dance Bayou, or features that connect refuge units and also connect stands of trees on private lands, like Linville Bayou, are examples.

The National Parks Conservation Association has proposed the Lone Star National Recreation Area for the Texas Gulf Coast. Public and private partners would coordinate to enhance visitor services and tourism marketing. (NPCA, 2014). It is supposed to encourage private landowners to use their land for conservation or recreation purposes (Victoria Herrin, personal communication). Though conservation of open space and natural areas is important to this project, it does not directly address conservation or habitat enhancement.

For the purpose of involving neighboring landowners in conservation within the landscape as a whole, refuge managers should assemble tool-kit of programs to encourage and recognize neighboring landowners. There could be several approaches to establishing relationships. Public recognition of private habitat restoration projects would be one way to raise awareness of the capacity of private landowners to enhance habitat. Texas Parks and Wildlife Department has a formal program to involve landowners in Wildlife Management Associations, often in association with a Wildlife Management Area (Texas Parks and Wildlife, 2004). Wildlife Management Associations often focus on improvement of habitat for game.

Due to the Texas Gulf Coast experiencing rapid development, the wildlife management exemption for county taxes (Fambrough, J. 2010) may encourage smaller landowners to manage their land for wildlife. Wildlife exemptions require a plan to be submitted to the County Appraisal District and approved by the State of Texas, and then annual reports showing the plan is being followed. There is a small industry of planners and biologists who write plans and annual reports for Wildlife Exemption projects (Landmark Wildlife Management, 2014). I had the impression that this tax exemption was difficult to get, however, research at the county appraisal districts reveals there are about 250 tax accounts with wildlife exemptions within the acquisition boundary. Refuge managers could tell neighboring landowners their list of desired outcomes if they hear that a neighbor is designing a plan or they could suggest the neighbor start an application.

Texas also allows small landowners who do not meet the acreage requirement for a Wildlife exemption to cooperate in getting one. Refuge managers must decide whether cooperating with landowners in a wildlife plan is an appropriate course of action, given the indirect effects on the county tax revenues. The benefits and hazards for a federal agency of working with private individuals to encourage conservation on private land requires careful planning.

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