IDENTIFYING HABITAT CONSERVATION NEEDS FOR THE ENDANGERED WHOOPING CRANE ALONG THE CENTRAL TEXAS COAST

By

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Abstract

The Aransas-Wood Buffalo whooping cranes (Grus americana) make up the only natural self-sustaining population of these endangered migratory wading birds in the world. Human and natural pressures threaten habitat quantity, quality, and integrity on their wintering grounds along the central Texas coast. This project developed tools for habitat conservation planning to support the endangered species downlisting goal of 1,000 cranes in the Aransas-Wood Buffalo population. First, a Comprehensive Habitat Type Database (CHTD) of benthic, wetland, and upland environments was developed from best available land cover information and bathymetric data. Then, habitat preference was determined using the CHTD and a spatially explicit dataset of whooping crane sightings from 2004 to 2010. About 1,000 km^2 of preferred habitat were mapped across the 7,000 km^2 study area. Projected losses and gains of preferred habitat as a result of sea level rise were then identified using results from the Sea Level Affecting Marshes Model (SLAMM) for various sea level rise scenarios up to the year 2100. Under 1 m of sea level rise, about 33% of preferred habitat is expected to be lost by 2100. Results showed that to reach the International Recovery Plan downlisting goal of 1,000 cranes, habitat conservation efforts must extend beyond the central Texas coast.

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Chapter 1: Introduction

The central Texas coast, and specifically the Aransas National Wildlife Refuge, is the winter home to the last remaining wild, migratory population of the endangered whooping crane (*Grus americana*). Currently consisting of a population of about 300 individuals, the International Recovery Plan for the Whooping Crane sets a population goal of 1,000 individuals, or 250 reproductive pairs in this population to down-list the whooping crane from endangered to threatened status. To reach this population goal, whooping cranes will have to occupy previously unused habitat beyond the protected lands of the Aransas National Wildlife Refuge. Additionally, the extent and configuration of estuarine marsh and related intertidal wetlands—primary habitat for whooping cranes—is threatened by sea level rise impacts such as erosion and inundation by open water. To reach the conservation goal for the whooping cranes, conservation planners should prioritize conservation of currently unprotected lands, taking into account potential sea level rise impacts on whooping crane habitat. This project seeks to develop conservation planning tools, such as conservation priority maps, using available data to aid in the maximization of conservation effort in locations where it would be most effective.

Introduction

The goal of this study is to develop decision support tools for the conservation of wintering habitat to support 1,000 whooping cranes along the central Texas coast. The habitat conservation planning (HCP) framework developed by the U.S. Fish and Wildlife Service (U.S. Fish and Wildlife Service 2006) provides an approach for the development of a spatially explicit, assumption-driven analysis of land cover information and biological data to answer the following questions for this study area: (1) what constitutes good wintering habitat for whooping cranes along the central Texas coast: (2) where is that habitat located, (3) is there enough habitat to support a conservation goal of 1,000 whooping cranes along the central Texas coast, and (4) In what ways might the spatial configuration of that habitat change as a result of sea level rise?

To answer these questions, the following objectives were set:

1.) Develop a continuous land cover dataset using best available information that describes the study area at the highest spatial and thematic resolution possible and in terms that are ecologically meaningful and commonly understood.

2.) Using this dataset and a long-term record of whooping crane aerial surveys, identify potential whooping crane habitat beyond their current range.

3.) Explore future impacts on potential whooping crane habitat under various sea level rise scenarios.

The Aransas-Wood Buffalo whooping cranes

The whooping crane (*Grus americana*), is the tallest bird in North America and one of only two crane species found on the continent. Though whooping cranes were most likely never observed in large numbers, their historic range was wide, once extending throughout the North American Great Plains, from the central latitudes of Canada to the high grasslands of central Mexico, with observations made as far east as New Jersey and as far west as Utah (Allen 1952). It has been estimated that, prior to European settlement of North America, whooping cranes numbered in the thousands, dwindling to around 1,300 birds by 1870 and reaching an all-time low of about 15 birds around 1940 (Allen 1952). The last naturally occurring population of whooping cranes- known as the Aransas-Wood Buffalo Population (AWBP) or the Western Migratory Flock- was estimated to consist of 304 birds in the wintering season of 2013-14 (Harrell 2014). The AWBP spends almost 6 months out of the year in and around the marshes and tidal flats of Aransas National Wildlife Refuge between late October and the first of May. The 4,000 km spring migration to their breeding grounds at Wood-Buffalo National Park in Alberta, Canada begins in late March, during which the cranes travel through critical habitat in Oklahoma, Nebraska, Kansas, South Dakota, and North Dakota. It has been well documented that the whooping crane is strongly tied to wetland environments on its breeding grounds in Canada (e.g. Allen 1952, Timoney 1999), throughout its migration (e.g. Armbruster 1990, Austin and Richert 2005), and on its wintering grounds on the central Texas Gulf coast (e.g. Labuda and Butts 1979, Stehn and Johnson 1987).

The International Recovery Plan for the Whooping crane, initiated in 1980 and most recently revised in 2005 (Canadian Wildlife Service and U.S. Fish and Wildlife Service 2005),outlines several population goals for the down-listing of the whooping crane from Endangered to Threatened status. The primary objective for down-listing is to establish multiple self-sustaining, geographically distinct, wild whooping crane populations.

Since 1975, four attempts at whooping crane reintroduction have been made with varying levels of success. A cross-fostering experiment in Gray’s Lake, Idaho was initiated in 1975 and discontinued in 1989 when it was determined that though many of the whooping cranes successfully reached maturity and learned the migration route, the flock had a low probability of ever becoming self-sustaining because they failed to form successful breeding pairs (Travsky and Beauvais 2004). In 1993, a non-migratory population was established on the Kissimmee Prairie in Florida. Over an 11 year period, 289 captive-reared juvenile whooping cranes were released; in 2008, 31 birds remained (Folk et al 2008). Disease transmission, a series of extreme drought years, and habitat loss to development were identified as factors contributing to the low survival and productivity of this flock (Harrell and Bidwell 2013). Currently, two experimental populations of whooping cranes exist- one non-migratory flock of about 25 adult and 10 juvenile birds near White Lake, Louisiana (where a small natural, non-migratory population was once located), and the Eastern Migratory Population of about 100 birds that migrate between breeding grounds in Wisconsin and summer grounds on the northern Florida Gulf coast (Harrell and Bidwell 2013). Both populations are still very young, and it is too early to determine whether these reintroduction efforts will be successful.

If these or additional whooping crane reintroduction efforts are not successful and the AWBP remains the only self-sustaining population, it would need to grow to 1,000 individuals, including 250 productive pairs, to attain down-listing from endangered to threatened status (Canadian Wildlife Service and U.S. Fish and Wildlife Service 2005).

It is thought that primary limiting factors as the Aransas-Wood Buffalo population grows will be available wintering habitat along the central Texas Gulf coast. Major direct and immediate anthropogenic pressures include reduced freshwater inflow into the bay systems that impact the health and productivity of estuary-dependent food sources such as blue crabs and Carolina wolfberry, pollution and disturbance from increasing residential coastal development, potential pollution impacts and disturbance caused by commercial ship traffic along the Gulf Intracoastal Waterway shipping channel, nearby oil drilling, and transition of natural ecosystems to cultivated agricultural land (Meine and Archibald 1996). Potential whooping crane habitat is also threatened by longer-term process such as sea level rise, which will most likely lead to loss of whooping crane habitat to open water inundation of salt marsh, and transition of salt marsh habitat to mangrove forest as a result of increased mean annual winter temperatures (Osland et al 2013). Stehn and Prieto (2009) estimate that under current conditions, suitable whooping crane habitat contiguous to their current range can support between 329 and 576 whooping cranes, or 33%-58% of the population size needed to reach the down-listing goal of 250 productive whooping crane pairs.

To ensure the future viability of the whooping crane population, and to reach the down-listing goal of 1,000 whooping cranes in the Aransas-Wood Buffalo Population, conservation efforts should focus on identifying and protecting lands outside the current range of whooping cranes on the central Texas coast, taking into consideration potential impacts sea level rise on important potential whooping crane habitat.

Strategic Habitat Conservation

Over the last decade, theoretical and technological advancements in the science and practice of conservation have widened the scope of conservation planning from a site-specific, opportunity- or activity-based approach to a landscape-level discipline. In response to these changes, and recognizing increased demand for cost efficiency in habitat management, The U.S. Fish and Wildlife Service (USFWS) in partnership with the U.S. Geologic Survey (USGS) established a framework for conservation planning that can be applied by any agency or organization whose mandate is the conservation of wildlife populations. Termed strategic habitat conservation (SHC), the focus of this process is to achieve measureable biological conservation outcomes through the incorporation of adaptive management principles and assumption-driven research (U.S. Fish and Wildlife Service 2006). The ultimate goal of SHC is to conserve biological populations and the ecological functions that sustain them; conservation of habitat is identified as a means to reach that goal.

Within the strategic habitat conservation framework, conservation goals are developed to emphasize biological outcomes such as *conserve enough habitat to sustain 1,000 whooping cranes on their wintering grounds*, as opposed to an activity- based objective such as *protect and improve more habitat for whooping cranes*. Though protecting *more* habitat for whooping cranes may be a worthwhile goal, the questions "What habitat?", "Where?" and "How much?" are left unanswered. Setting conservation goals in terms of specific biological objectives necessitates a clear understanding of how exactly these objectives may be met, facilitates the identification of knowledge gaps, helps to highlight potential factors that could limit success, and provides the starting point for a scientific approach to determining whether the objective had been (or can be) met.

SCH also emphasizes the use of spatial variables such as land cover and elevation in conjunction with biological data to create models that tie biological populations to the landscape. Such models provide a basis for setting justifiable population objectives. Because models include identifiable uncertainties and explicit assumptions, the development of conservation actions using models creates an opportunity to employ the strategy of adaptive management. Results from conservation actions based on biological models can be used to refine future models, which can then be used to develop future conservation actions (Fig. 1).

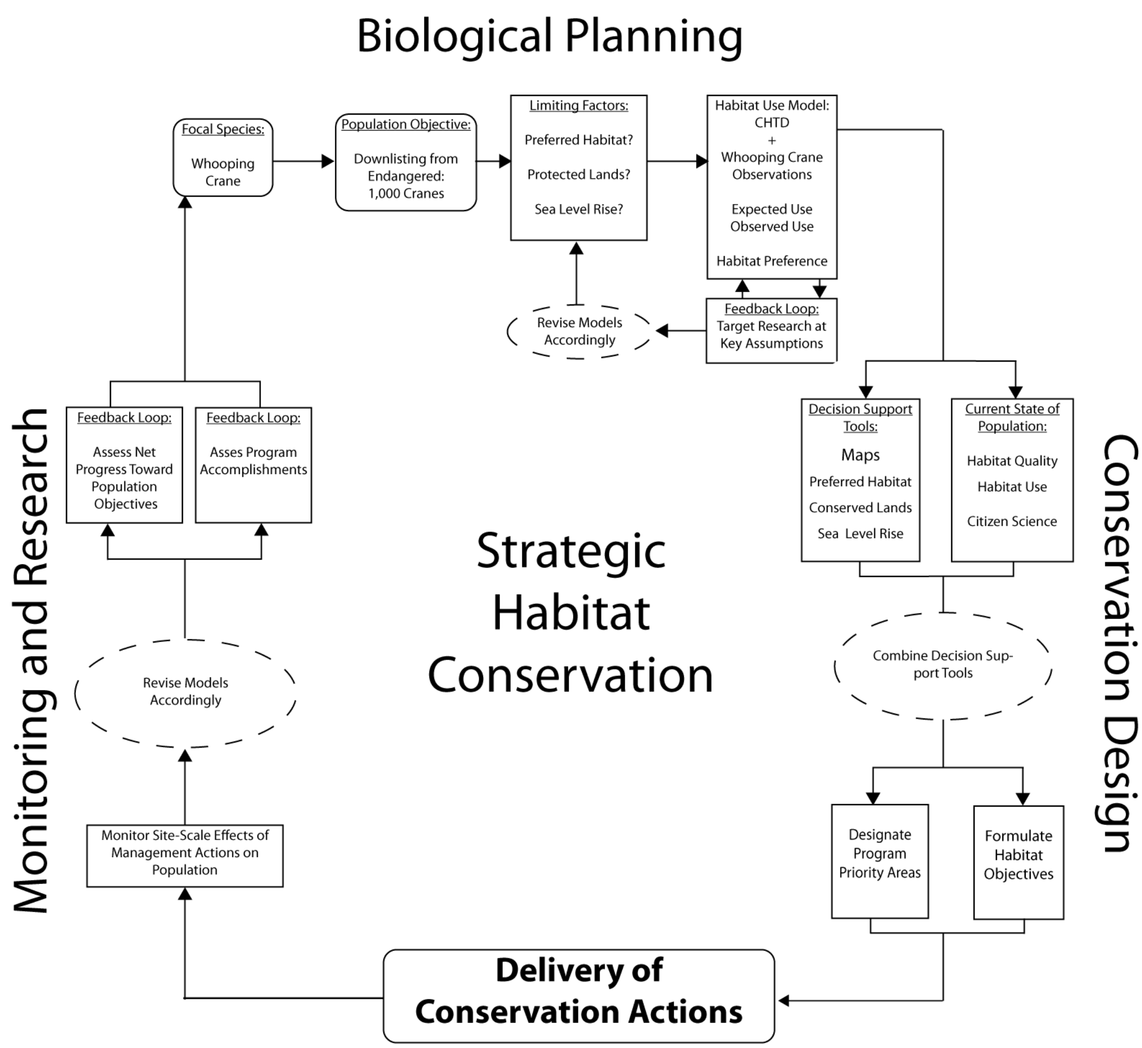

Fig. 1 The Strategic Habitat Conservation framework is an iterative process that applies the concept of adaptive management to the field of conservation science (adapted from U.S. Fish and Wildlife Service 2006)

This project uses the SHC framework within the Biological Planning and Conservation Design phases to develop tools to support the delivery of on-the-ground conservation actions for the whooping cranes along the central Texas coast.

Study area

The general geographic area for this project was chosen to encompass the central Texas coast between the Colorado River to the north and Corpus Christi Bay to the south, including the current extend of the whooping crane winter range in and around the Aransas National Wildlife Refuge (Fig. 2).

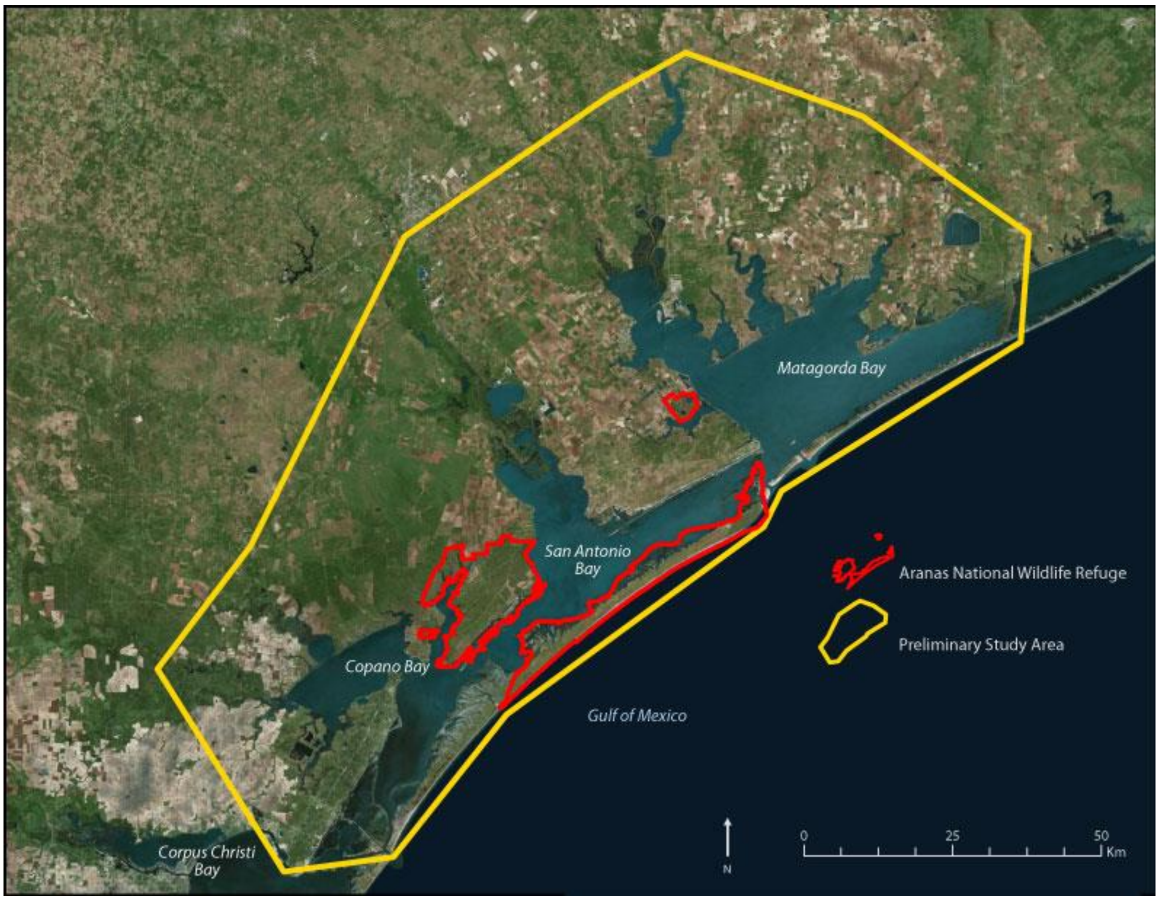

Fig. 2 Preliminary study area surrounding the Aransas National Wildlife Refuge

The Colorado River and its related delta and Corpus Christi bay is not included in the study area. Mainland landforms on this low, flat coastal plain include the Pleistocene Ingleside barrier strandplain peninsulas known as the Seadrift-Port O'Connor Ridge, Blackjack Peninsula, and Lamar Peninsulas. From north to south, the study area includes three major estuarine systems—the Lacava-Colorado estuary to the north including Matagorda and Lavaca Bays, the Guadalupe-San Antonio estuary including Espiritu Santo, San Antonio, and Mesquite Bays, and the Mission-Aransas estuary to the south, including St. Charles, Aransas, Redfish, and Copano Bays. Barrier islands and peninsulas included in the study area are Matagorda Peninsula, Matagorda Island, San Jose Island, and the northernmost tip of Mustang Island.

The inland boundary was developed using outputs from the SLOSH (Seas, Lakes, and Overland Surges from Hurricanes) model developed by the National Weather Service (Jelesnianski et al 1992). The SLOSH model predicts inundation by storm surge under thousands of hypothetical hurricanes with varying wind speeds and directions, angles of landfall approach, and initial tide levels. A variety of products are produced from results of these model runs for the purpose of storm preparedness and emergency management decision making. The MOM product, or Maximum of the Maximum Envelope of High Water, is recommended for Tier 3 hurricane response planning and mitigation activities. This product combines the highest storm surge values for all hypothetical hurricanes of a given storm category within the SLOSH model basin at mean and high tide. For this project, the MOM for a category 5 hurricane striking Matagorda Bay, Texas, at high tide was used. This approach represented a "worst case scenario" for storm surge inundation that would affect vegetation assemblages or other factors related to whooping crane habitat, and was determined to be a good proxy for hydrologic impacts related to future sea level rise scenarios.

MOM data from a SLOSH model run in 2008 for the Matagorda Bay SLOSH basin were downloaded from the National Weather Service Meteorological Development

Laboratory (http://slosh.nws.noaa.gov/sloshPriv/meow.php?L=6, registration required). Following a methodology developed by the NOAA Coastal Services center (NOAA CSC 2012), the MOM vector grid was imported into ArcMap and a "surge zone" polygon was developed to identify the spatial extent of dry land projected to be inundated to any extent by the storm surge resulting from a category 5 hurricane striking Matagorda Bay at high tide. All spatial data used in further analysis were clipped to this Study Area polygon (Fig. 3).

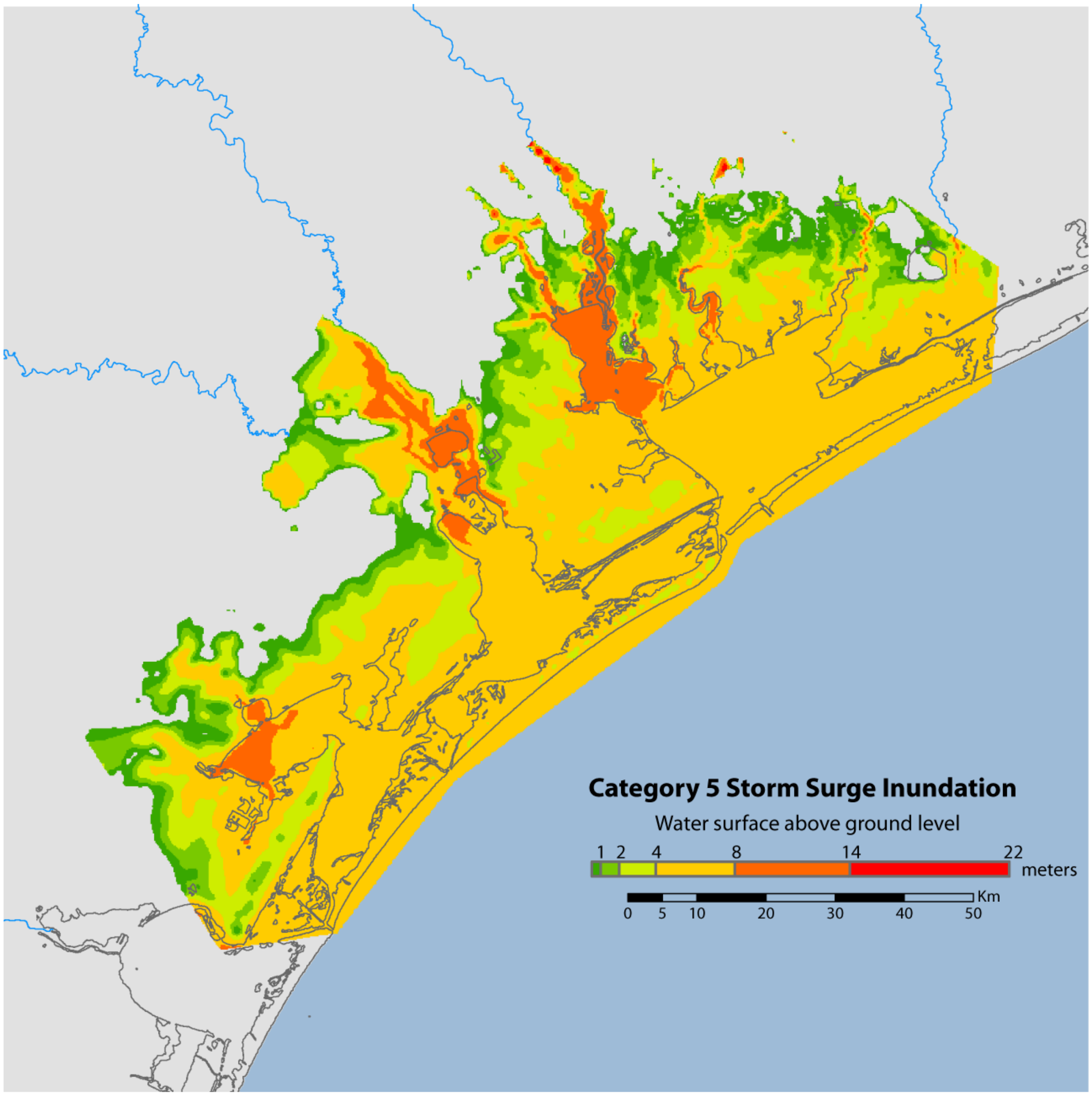

Fig. 3 The final study area boundary was determined by projected storm surge inundation from a category 5 hurricane striking Matagorda Bay

Chapter 2: Development of land cover database

Introduction

The first objective of this project was to develop a continuous land cover data set using best available information that describes the study area at the highest spatial and thematic resolution possible and in terms that are ecologically meaningful and commonly understood. Upon examination of the available land cover datasets, it was determined that no single dataset included thematically detailed information for subtidal, intertidal wetland, fresh marsh, and upland environments. Because all these environments are important to the whooping crane for some aspect of its life cycle, and because sea level rise can potentially affect environments from deep water to upland in coastal regions, the development of a land cover dataset combining the best available information for benthic/subtidal, wetland/intertidal, and upland environments was undertaken.

Data and methods

A matrix was developed to assess potentially useful spatial data for this project (Appendix A). Datasets were grouped into broad types: (1) elevation; (2) vegetation/land cover; (3) land use; (4) species ranges; and (5) models. Attributes examined for each dataset included originator, map projection, horizontal and spatial reference, mapping theme, classification system and method, data type (raster, vector), data format, age of the dataset, spatial resolution, minimum mapping unit, mapping scale, data source, spatial coverage, and intended application. Datasets were evaluated for issues such as poor resolution, inadequate spatial coverage, or outdated data, and other notes were made including possible future changes or improvements to the dataset or recent application of the dataset in other projects. Datasets deemed suitable for this project included those most recently developed, displaying a high degree of spatial and thematic resolution, using classifications based on a commonly used or well-documented standard, and having spatial coverage across the entire study area.

The NOAA Benthic Habitat Atlas (BHA), the USFWS National Wetlands Inventory (NWI), and the Texas Parks and Wildlife Department (TPWD) Ecological

Mapping System of Texas (EMST) were clipped to the general study area and further evaluated for their appropriateness for inclusion into a combined land cover dataset. It was determined that information from these three land cover datasets should be merged to create a single continuous land cover layer across the study area.

Each land cover dataset uses different classification schemes with varying levels of descriptive detail. A framework was developed by Smith et al. (2014) to allow for the grouping of land cover types from different datasets at three nested spatial and thematic scales while retaining a high level of descriptive detail for each land cover type. This framework was adapted from Block and Brennan’s (1993) nested classification approach for avian habitat selection (Fig. 1). Following this framework, land cover types from all data sets were grouped hierarchically at the micro, meso-, and macro- scales.

In this study, Macrohabitat referred to landscape-scale features such as stages of vegetation succession or broad geoenvironmental zones that are correlated with the distribution and abundance of an avian population within the larger landscape (Block and Brennan 1993). Broad ecological system categories such as upland or estuarine were classified at the Macrohabitat level. Microhabitats as described by Block and Brennan (1993) are fine-scaled units or patches within a macrohabitat, differentiated by specific vegetation species or explicit environmental attributes that contribute to selection and use of individual land cover units by an individual bird. An example of an attribute within this study area that differentiated Microhabitats is water regime (e.g. irregularly exposed or regularly flooded tidal marsh within the estuarine macrohabitat). The term Mesohabitat was introduced by Smith et al. (2014) as a level of scale between Macrohabitat and Microhabitat to describe mid-scale landscape features to which Microhabitats can be generalized such as vegetated marsh within the estuarine Macrohabitat, which would include Microhabitat types such as Intertidal Emergent Regularly Flooded Marsh and Salt and Brackish High Tidal Marsh.

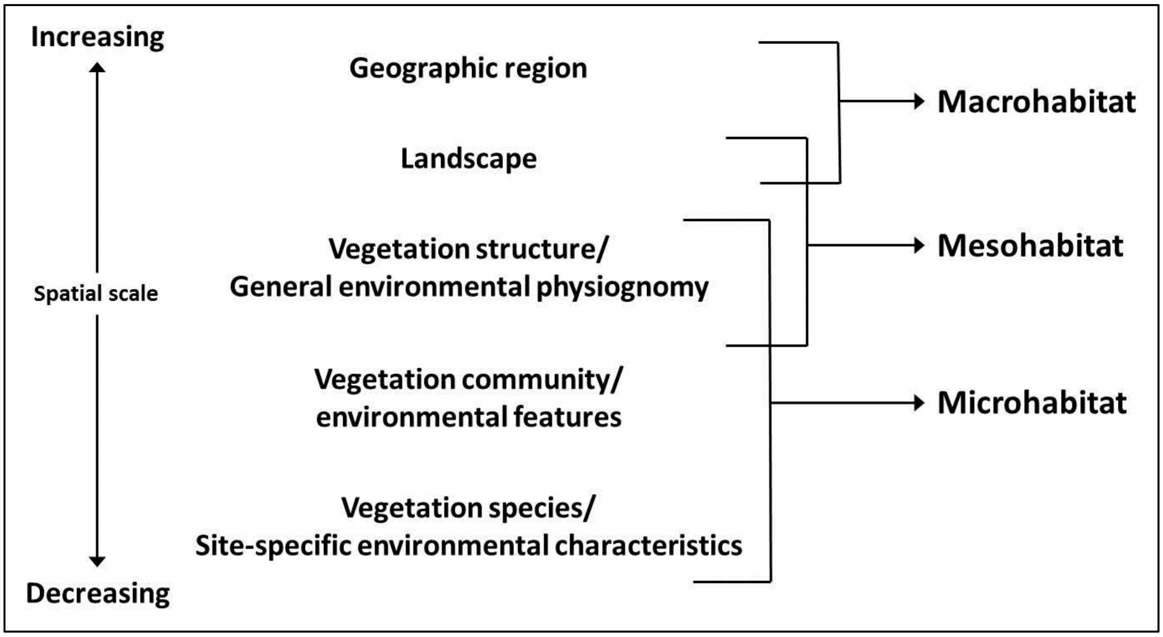

Fig. 4 Continuum of spatial scales for habitat classification. Modified from Block and Brennan (1993)

The land cover classification scheme for each source land cover data set was examined in detail to identify attributes within the classification scheme that could be used to identify Meso-, Macro-, and Micro- habitat types. A crosswalk was created to relate each land cover type in the EMST, NWI, and BHA to Macro-, Meso-, and Microhabitat types (Appendix B). New fields “Macrohabitat”, “Mesohabitat”, and “Microhabitat” were added to each dataset (feature class within an ArcGIS file geodatabase), and a look-up table was generated to classify each land cover feature (polygon) in all feature classes according to the Block and Brennan (1993) hierarchy. A fourth new field “Source” was also added to identify the data source of each polygon in the final merged product (EMST, NWI, or BHA). The EMST, NWI, and BHA feature classes were then projected to a common spatial reference (NAD 1983, UTM Zone 14N) and clipped to the general study area. The data sets were clipped to the study area.

Portions of each source dataset were combined according to the following rules (Fig. 5):

- Across entire project area:

  EMST *except* where more appropriate wetland/intertidal (NWI) data exists

  - In intertidal estuarine and upland freshwater wetland areas:

    NWI *except* where more appropriate benthic/subtidal data exists (BHA)

    - In mangrove, oyster reef, and seagrass areas

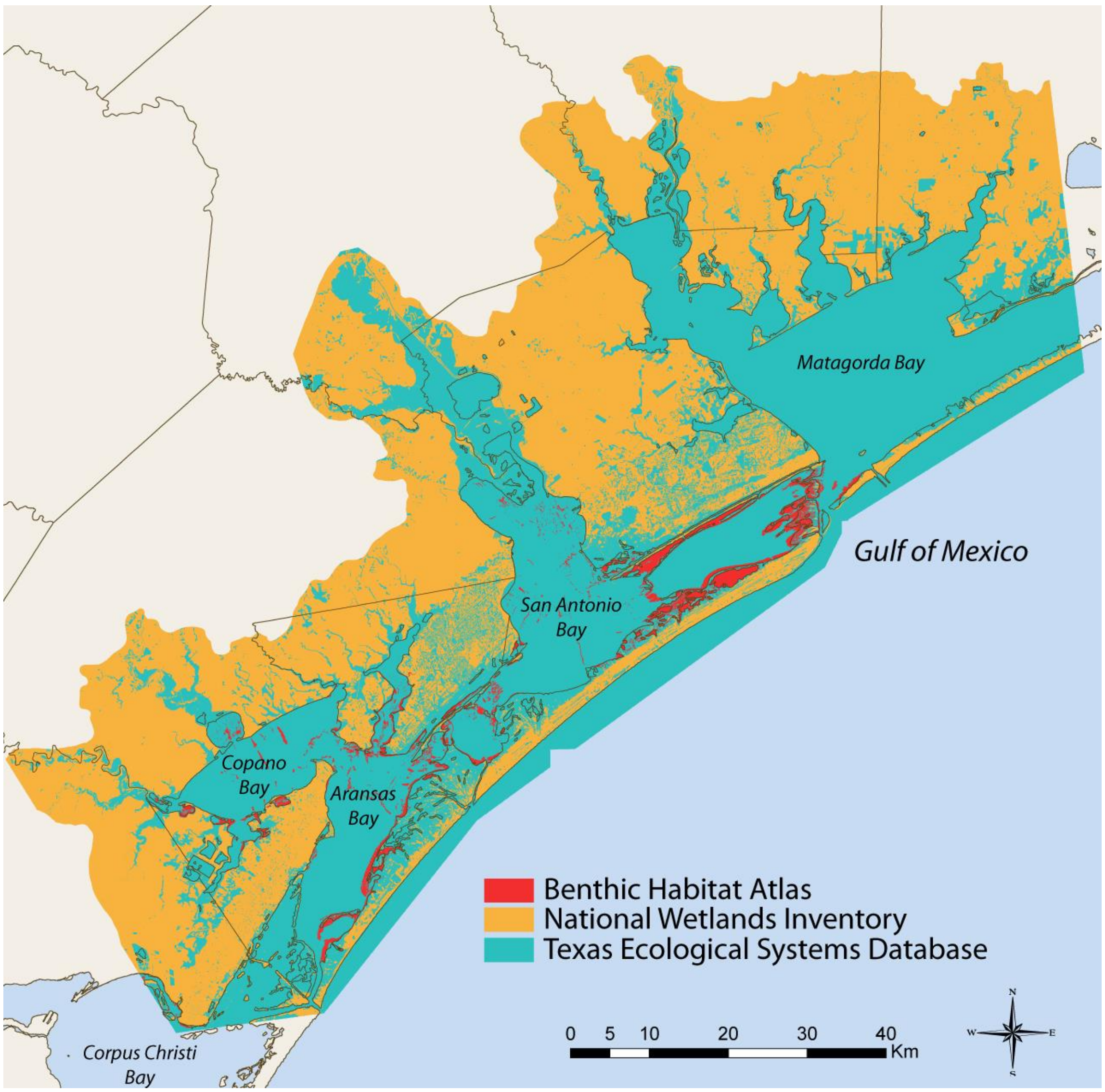

Fig. 5 Extent of each land cover dataset used to develop the Comprehensive Habitat Type Database

Because of the extensive size of the study area (more than 7,000 km^2 or about 1.8 million acres), performing geoprocessing tasks across the entire study area at once was computationally expensive. To reduce the amount of processing time, manageable subsets of the data were processed in succession, as opposed to processing a single “Godzilla” dataset at once. A rectangle enclosing the entire study area was drawn and converted to a georeferenced polygon feature, then divided into sixteen polygons of equal area, creating a 4x4 grid, or sixteen “data zones” (Fig. 2). The Split Polygon editing tool was used to accomplish this task, as well as to divide the source datasets (EMST, NWI, BHA) into “zones” coinciding with each grid cell (**Fig. 6**).

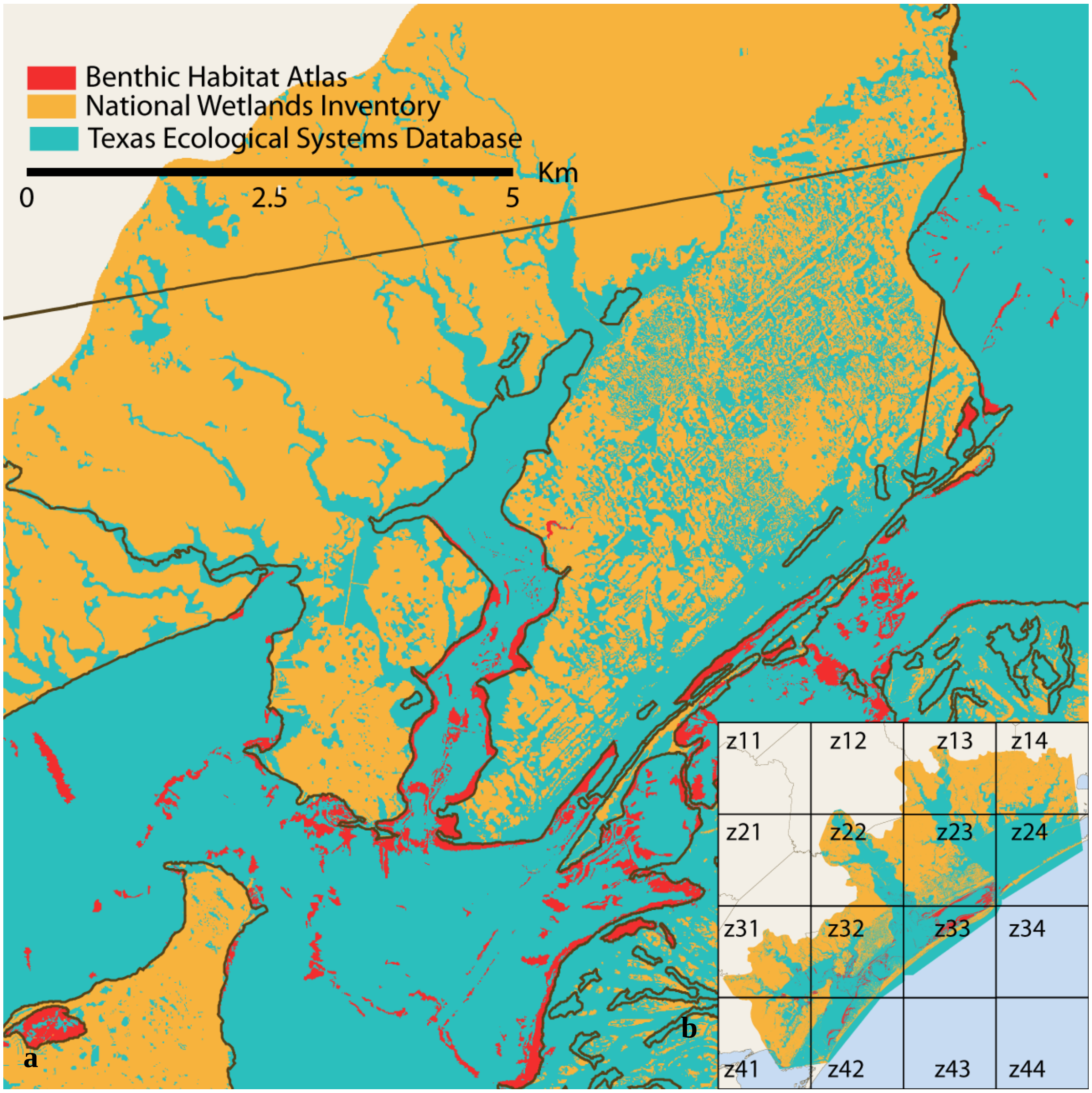

Fig. 6 a. Subset of polygon land cover data, zone 32. **b.** The study area was divided into sixteen tiles for more efficient processing

The ArcGIS Analysis tool "Update" was used to combine EMST, NWI, and BHA data in each zone. A Python script automated the process for all zones. "Update" created a new feature class with all the polygons of the "Update" feature class and all polygons, or parts of polygons, in the "Base" feature class that were not covered by Update polygons. Thus, all polygons in the Update feature class were preserved. Base polygons, or parts of polygons, were carried over into the output feature class where Update polygons did not exists. This tool was run once for all zones using EMST as the Base layer and NWI as the Update layer and again for the zones where BHA data existed, using the result from the first Update as the Base layer and BHA as the Update layer.

The following seven step correction methodology was applied to the feature classes for all updated zones.

1. Fix Geometry (ET Geowizards)- removes null/empty shapes; snaps vertices of neighboring polygons together.

2. Clean Polygons (ET Geowizards)- deletes overlaps within default x/y tolerance, identifies and makes new polygons from overlaps greater than default x/y tolerance.

3. Clean Gaps (ET Geowizards)- creates polygons where holes or slivers exist between polygons, such as areas deleted in Clean Polygons step.

4. Eliminate gaps (ET Geowizards)- joins Gap polygons created in previous step to neighboring polygons with the longest shared boundary.

5. Add Geometry Attributes (arcpy) "POLY_AREA" and calculate area of each polygon.

6. Eliminate by area (ET Geowizards)- - joins polygons with area $<100m^2$ to neighboring polygons with longest shared boundary. This size was chosen because it represents the minimum mapping unit for the EMST.

7. Dissolve (arcpy)- Joins adjacent polygons with same CHTD code.

The fields "Macrohabitat," "Mesohabitat," "Microhabitat," "CHTD Code," and "Source" were retained in the combined data set.

Each polygon dataset was then converted to raster format with a cell size of 10 m x 10 m—the minimum mapping unit of the EMST dataset. A “snap raster” was created with a cell size of 10 m that coincided with the grid created to divide the source datasets in the previous step. The “Polygon to Raster” tool was used to convert the 4x4 polygon grid (Fig. 6b) created previously to a raster. This spatial extent of the raster was set to “round number” locations in the UTM projection to ensure that each zone consisted of exactly the same number of cells of exactly 10 m on each side, and that cells within each zone matched up with no gaps or spaces between. Because numerical values are easier to work with than text in rasters, an integer field was added to the look-up table containing CHTD code, Microhabitat, Mesohabitat, Macrohabitat, and original data source. Each entry within the look-up table (essentially each alphanumeric CHTD code) was given a unique integer value. The attribute tables of the polygon dataset for each zone were updated with this numeric value before conversion to raster. When converted to raster, the text fields would be lost, but this numeric value would remain. The combined land cover datasets for each grid were then converted to rasters using the Polygon to Raster tool. Cells were given the value of the polygon with the greatest area within that cell.

A mosaic dataset was then created to contain the rasters for all 11 zones. Advantages of using a raster mosaic dataset include faster symbolization because overviews and polygons are stored within the mosaic dataset and used to represent the raster at various extents. Additionally, a single attribute table and colormap can be attached to the mosaic dataset and applied to all rasters within the dataset. Geoprocessing toolboxes such as Map Algebra, Spatial Analysis, and Spatial Statistics can be applied to the entire mosaic instead of each constituent raster, and perform faster than they would on a single large raster dataset.

One final level of refinement for the land cover classification was necessary to address an important aspect of habitat use by whooping cranes not included in any of the source land cover data sets. Whooping cranes spend a large portion of their time foraging in shallow estuarine open water and submerged aquatic beds, but do not venture into water greater than about .66 m (2 ft) in depth (Chavez-Ramirez 1996). The source land cover datasets made no distinction between shallow or deep open water, so a bathymetric DEM (Fig. 7) from NOAA Coastal Services Center (National Oceanic and Atmospheric Administration 1997) was used to identify land cover classes that could potentially occur in deep or shallow open water (such as Estuarine Subtidal, Estuarine Open Water, Marine Subtidal, and Submerged Vegetation) that occurred in depths greater than .66 m. Pixels identified as existing in "deep" water were appended with a "D" at the end of their CHTD code and "Deep" at the end of their mesohabitat identifier (Fig. 4).

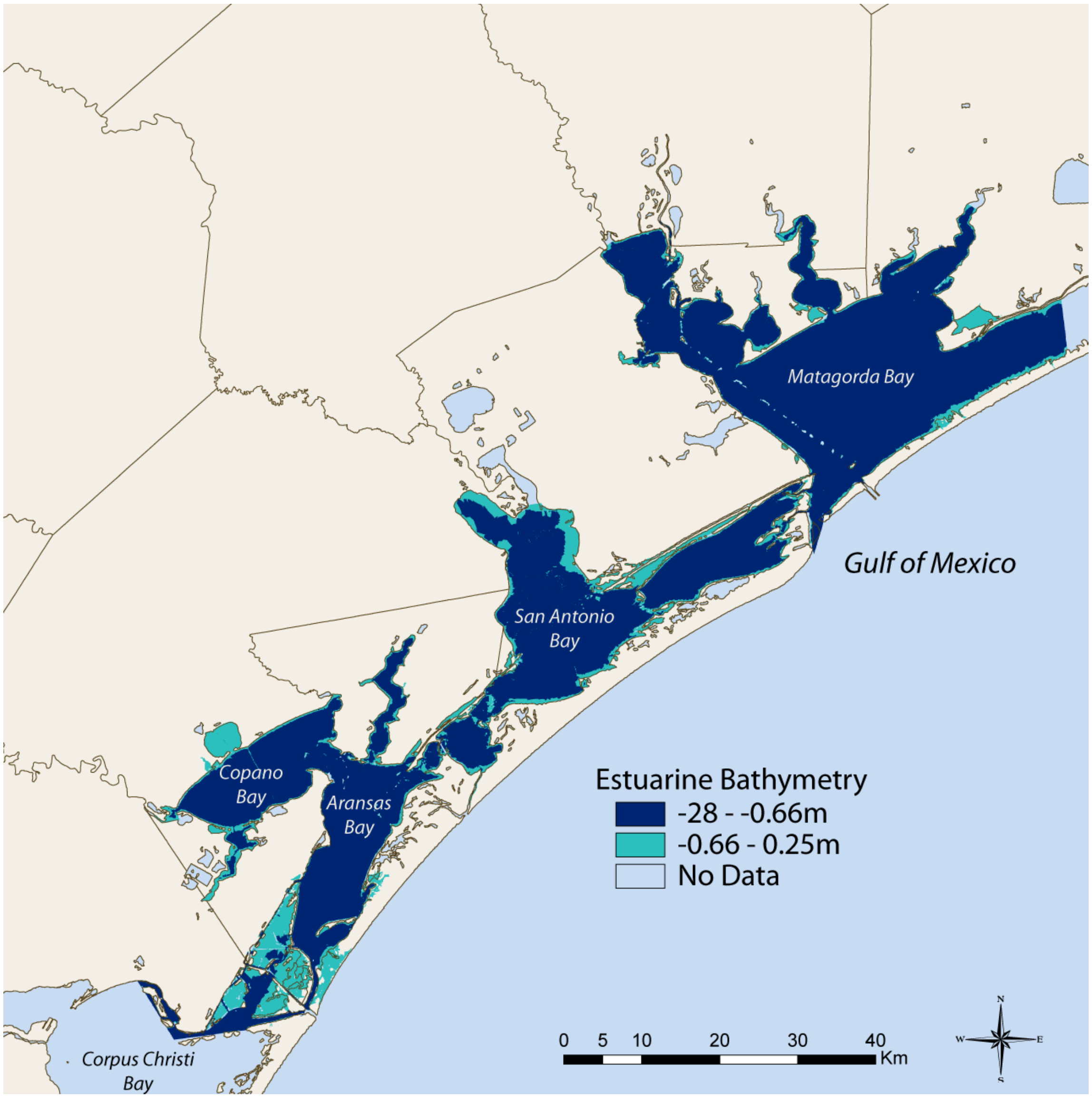

Fig. 7 A NOAA estuarine bathymetric DEM was reclassified to represent potential whooping crane foraging grounds in terms of water depth

Ecological Mapping System of Texas

The EMST was developed by the TPWD beginning in 2008 for the purpose of providing a land cover classification of high spatial and thematic resolution to accomplish planning and management at a sub-county or large land ownership scale (Diamond and Elliott 2008). Classification of land cover was accomplished through a semi-automated process starting with decision-tree imagery analysis of Landsat Thematic Mapper satellite data acquired in 2005-2007 combined with ancillary data to achieve an initial 30 m resolution land cover geodatabase that delineated discrete vegetation types across Texas. The geodatabase was then gridded to a spatial resolution of 10 m and overlain by EPA ecoregion boundaries, county soils maps, stream centerlines from the USGS National Hydrologic Dataset, a 10 m digital elevation model (DEM), and road and railway data.

The EMST land cover classification scheme was based on NatureServe's International Terrestrial Ecological Systems Classification (Comer et al. 2003).The classification structure was hierarchical, and was based on the identification of repeating patterns of physiognomic (structure, growth form, and leaf characters) and floristic (species composition) characteristics of the dominant vegetation (Grossman et al 1998). Land cover types were grouped by physiognomic type, then into systems according to the NatureServe classification, and each land cover type within the system was assigned a "Vegetation Type" and a "Common Name" descriptor which incorporates a discrete subset of the ecological system and vegetation type (Elliott 2010).

This classification resulted in over 150 mapped Vegetation Types describing unique vegetation communities within the context of their underlying soil type, landform, hydrology, and ecoregion (Comer et al 2003). In terms of the Block and Brennan (1993) continuum, Macro- and Mesohabitat types were defined by the broad physiognomic descriptions and the NatureServe ecological systems which each Vegetation Type was grouped into as described in the Texas Ecological Systems Interpretive Guide (Elliott 2010). Microhabitats were defined by either Vegetation Type or Common Name depending on which descriptor included the most detail (Smith et al 2014).

Table 1 EMST Vegetation Types organized by microhabitat into 3 upland mesohabitats

Macrihabitat: Upland		EMST Physiognomic Type: Herbaceous Vegetation			
Mesohabitat	Microhabitat	EMST code	NatureServ Ecological System	EMST Vegetation Type	EMST Common Name
Upland Grassland	Blackland Tallgrass Disturbance or Tame Grassland	207	Texas Blackland Tallgrass Prairie	Blackland Prairie: Disturbance or Tame Grassland	Blackland Tallgrass Disturbance or Tame Grassland
	Gulf coast: Coastal Prairie	5207	Texas-Louisiana Coastal Prairie	Gulf coast: Coastal Prairie	Texas-Louisiana Coastal Prairie
	Gulf Coast: Salty Prairie	2206	Texas Saline Coastal Prairie	Gulf Coast: Salty Prairie	Gulf Coast: Salty Prairie
	Coastal Plain: Terrace Sandyland Grassland	7907	Central Texas Coast River Terrace Sandyland Grassland	Coastal Plain: Terrace Sandyland Grassland	Central Texas Coast River Terrace Sandyland Grassland
	Texas Coast Dune and Coastal Grassland Active Dune	6200	Texas Coast Dune and Coastal Grassland	Active Sand Dune	Texas Coast Dune and Coastal Grassland Active Dune
	Texas Coast Dune and Coastal Deep Sand Grassland	6307		Coastal and Sandsheet: Dune and Coastal Grassland	Texas Coast Dune and Coastal Deep Sand Grassland
Upland Shrub	South Texas: Caliche Grassland	6707	Tamaulipan Caliche Grassland	South Texas: Caliche Grassland	Tamaulipan Caliche Grassland
	Gulf Coast: Salty Shrubland	2207	Texas Saline Coastal Prairie	Gulf Coast: Salty Shrubland	Texas Saline Shrub Coastal Prairie
	Coastal and Sandsheet: Deep Sand Shrubland	6306	Texas Coast Dune and Coastal Grassland	Coastal and Sandsheet: Deep Sand Shrubland	Texas Coast Dune and Coastal Deep Sand Shrubland
Upland Woodland/ Shrub	East-central Texas Plains Xeric Sandyland Woodland and Shrubland	707	East-Central Texas Plain Xeric Sandyland	Post Oak Savanna: Sandyland Grassland	East-central Texas Plains Xeric Sandyland Woodland and Shrubland

National Wetlands Inventory

The National Wetlands Inventory (NWI) was initiated in 1974 by USFWS in cooperation with USGS for the purpose of providing the most current information on the status and extent of wetlands and deep water habitats across the United States and to support research, education, policymaking, and resource management. All NWI data follows the Cowardin wetland classification scheme (Cowardin et al 1979), a hierarchical system that describes wetland types according to general System (e.g. marine, estuarine); Subsystem (e.g. subtidal, intertidal); Class based on substrate, flooding regime, or vegetation; and Dominance Type describing the characteristic vegetation or animal forms present. Additional Modifiers related to water regime, water chemistry, soil type, and human influence may be added at the finest level.

Most of the study area was covered by NWI data from two major mapping efforts. The southernmost extent of the study area including Live Oak Peninsula and the southern part of San Jose Island and the Nueces and Mission-Aransas estuary system were mapped in 2008 (National Wetlands Inventory Program Region 2 2009). This effort used sub-meter true color imagery from 2006 (USGS) and color infrared imagery from 2004 (NAIP) as the primary sources for heads-up digitizing of wetlands environments at a scale of 1:10,000. 1990's- era NWI digital data, National Hydrologic Database data (USGS), digital topography (USGS Digital Raster Graphics), and submerged lands data (Texas General Land Office) were used as ancillary data to meet or exceed the Wetlands Mapping Standard accuracy requirements.

The central portion of the study area was mapped in 2008 as part of an application of the Sea Level Affecting Marshes Model (SLAMM) in and around the Aransas National Wildlife Refuge. The geographic area included Lamar and Blackjack

Peninsulas, the Seadrift-Port O'Connor Ridge, the northern portion of San Jose Island, Matagorda Island, and the bay-estuary-lagoon system of Aransas, St. Charles, San Antonio, Espiritu Santo, and Matagorda Bays which are fed by the Guadalupe-San Antonio and Lavaca-Navidad river systems (National Wetlands Inventory Program Region 2 2010). Wetlands were delineated using four-band imagery containing color infrared and near-infrared information from 2008 (NAIP) and the same ancillary data noted above to achieve or exceed NWI Wetlands Mapping Standard accuracy requirements.

A third dataset covering wetlands associated with Matagorda peninsula was completed in 2002 using color infrared imagery from 2001 for the purpose of characterizing the status and trends of wetlands along Texas barrier islands from Matagorda to San Antonio Bay (White et al 2002). Wetlands were delineated at a scale of 1:8,000 in a heads-up environment. On-the-ground topographical surveys and in-situ characterization of wetland vegetation communities at field locations were used as ancillary data to improve mapping accuracy.

Wetlands data for the remainder of the study area was developed using color infrared imagery from 1992 (National Standards and Support Team 2012). Further details regarding the specific methods of wetlands delineation were not available, but the data was determined to meet the NWI Wetlands Mapping Standard accuracy requirements.

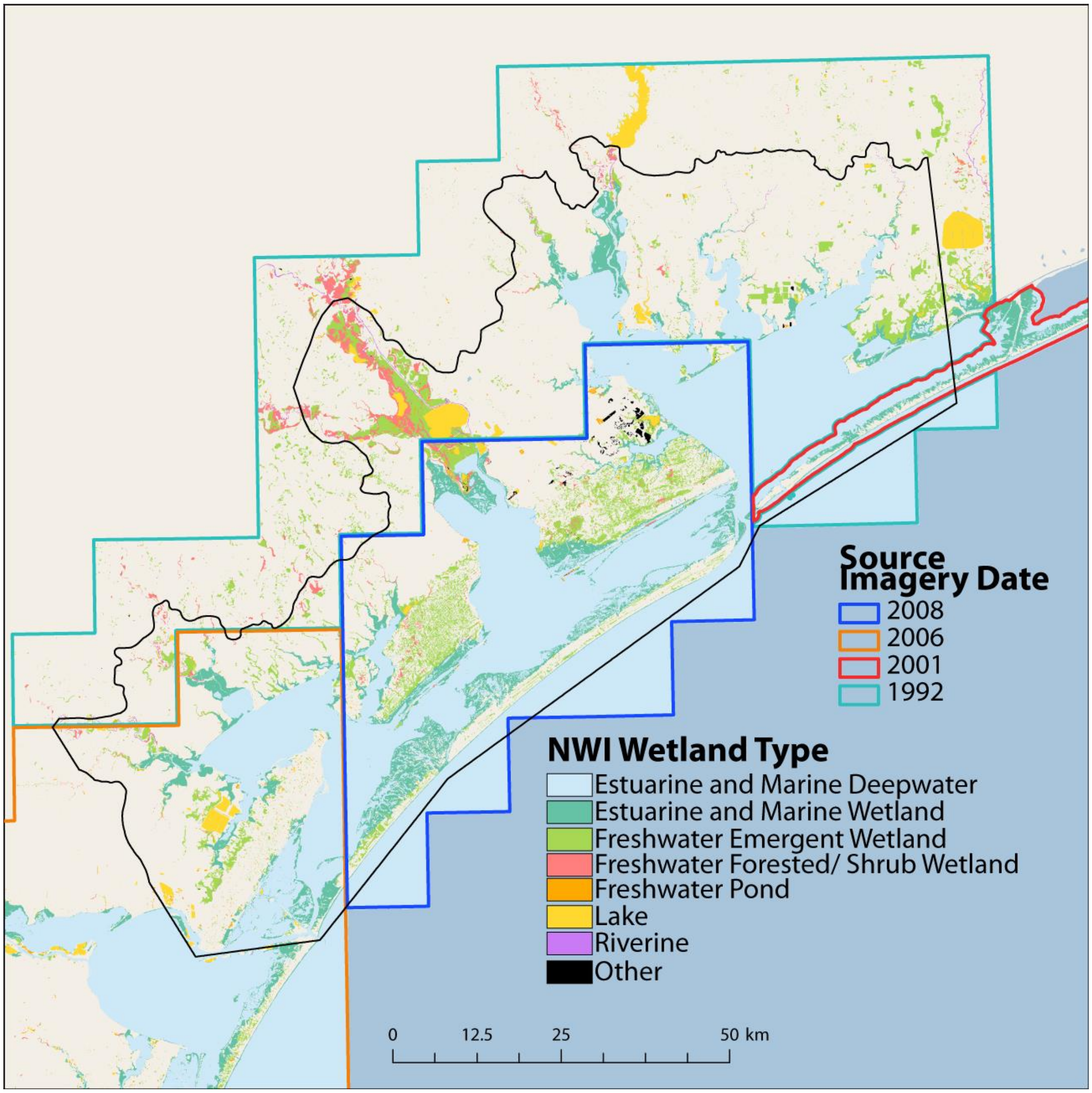

Fig. 8 National Wetlands Inventory data was derived from source imagery from 1992, 2001, 2006, and 2008

Interpreting the Cowardin (Cowardin et al 1979) classification scheme in terms of the Block and Brennan (1993) continuum of spatial scales for habitat classification was fairly straightforward. System level classifications translated to macrohabitat type, mesohabitat was indicated by Subsystem and Class classification, and information related to microhabitat type was found in the land cover type's Subclass and Modifiers (Table 2).

Table 2. NWI classes organized by microhabitat into 3 palustrine mesohabitats.

Macrohabitat: Palustrine			NWI System: Palustrine	
Mesohabitat	Microhabitat	NWI code	NWI Class	NWI Subclass/Modifiers
Palustrine Veg Shrub/Veg Marsh	Palustrine Scrub-Shrub/Emerg Marsh Mix Temp/Seas/Semiperm Fl	PSS1/EM1A	Scrub-Shrub/Emergent Marsh	Broad-Leaved Deciduous/ Temporarily Flooded
		PSS1/EM1C		Broad-Leaved Deciduous/ Seasonally Flooded
		PSS3/EM1A		Broad-Leaved Evergreen/ Temporarily Flooded
		PSS3/EM1C		Broad-Leaved Evergreen/ Seasonally Flooded
		PSS3/EM1F		Broad-Leaved Evergreen/ Temporarily Flooded
		PSS3/EM1J		Broad-Leaved Evergreen/ Intermittently Flooded
		PSS4/EM1A		Needle-Leaved Evergreen/ Temporarily Flooded
		PSS4/EM1J		Needle-Leaved Evergreen/ Intermittently Flooded
Palustrine Veg Woodland/Veg Shrub	Palustrine Forested/Scrub-Shrub Mix Temp Fl	PFO1/SS1A	Forested/ Scrub-Shrub	Broad-Leaved Deciduous Temporarily Flooded
		PFO4/SS4A		Needle-Leaved Evergreen Temporarily Flooded
Palustrine Veg Woodland -	Palustrine Forested Temp Fl	PFO1A*	Forested	Broad-Leaved Deciduous Temporarily Flooded
		PFO1S		Broad-Leaved Deciduous Temporarily Flooded- Tidal
		PFO4A		Needle-Leaved Evergreen Temporarily Flooded
	Palustrine Forested Seas Fl -	PFO1C*	Forested	Braod-Leaved Deciduous Seasonally Flooded
		PFO1F*		Broad-Leaved Deciduous Seasonally Flooded
		PFO3C		Broad-Leaved Evergreen Seasonally Flooded

NOAA Benthic Habitat Atlas

Commonly referred to as the Benthic Habitat Atlas (BHA), The Atlas of Shallow-Water Benthic Habitats of Coastal Texas was developed in 2009 for the primary purpose of providing baseline or change detection data for monitoring seagrass resources in the state of Texas (Finkbeiner et al 2009). Seagrass meadows, oyster reefs, intertidal marshes, and black mangrove (*Avicennia germinans*) were the focus of this mapping effort. Benthic habitat type units were mapped using automated, object-oriented processing using 4-band multispectral NAIP imagery from 2004 and 2007 resampled to 2-m resolution, followed by manual interpretation (Finkbeiner et al. 2009). Benthic habitat data was available as individual shapefiles for all bay systems within the study area except Matagorda Bay.

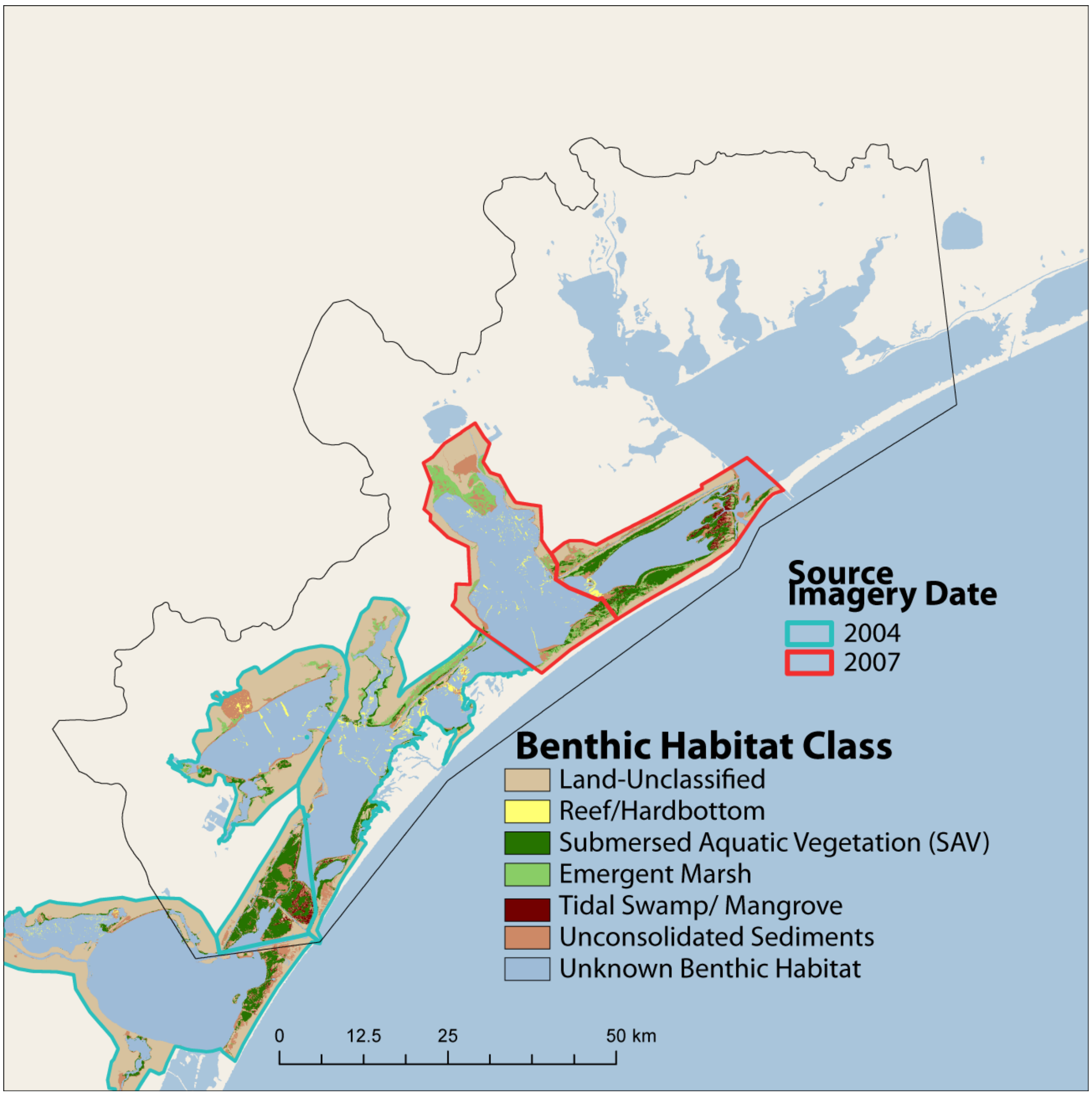

Fig. 9 Benthic Habitat data was derived from source imagery from 2004 and 2007, and covered all bay systems within the study area except Matagorda Bay

Habitat type classification followed the Florida System for Classification of Habitats in Estuarine and Marine Environments (SCHEME), which is hierarchical in structure and similar to the Cowardin classification (1979) at the Class level (Madley et al 2002). Class is the broadest level of classification within the SCHEME hierarchy, and four levels of Subclasses allow for the inclusion of incrementally more specific information related to the taxonomic assemblage or spatial character of the habitat type. Modifiers can be used to indicate more specific information such as taxonomy of individuals species or members of a species assemblage, natural or anthropogenic structural attributes, or tidal regime (Madley et al 2002).

All habitat types mapped in the BHA fell within the Block and Brennan (1993) macrohabitat type Estuarine. Level of detail varied among mapped benthic habitat type and between bays, so benthic habitat types were grouped to a common subclass level. Microhabitat information came directly from the common subclass, while mesohabitat was inferred from general knowledge of the benthic habitat type. For example, oyster reefs were assigned the “Subclass 2” attribute “Bivalve Reef,” but in various cases modifiers or secondary characteristics describing the specific location were included such as “Shells and Shell Hash,” “Mat Algae,” and “Drift Mat Algae”. For simplification, all polygons classified as “Bivalve Reef” were assigned the microhabitat “Bivalve Reef,” regardless of subsequent subclass or accompanying modifiers, and the mesohabitat “Estuarine Reef”. Table 3 gives an example of how the nested hierarchical classifications within the SCHEME system fit into the habitat hierarchy.

Table 3. BHA classes organized by microhabitat into a single estuarine microhabitat.

Macrohabitat: Estuarine				
Mesohabitat	Microhabitat	SCHEME Code	SCHEME Class	SCHEME Subclass I-IV
Estuarine Vegetated Seagrass	Submerged Rooted Vegetation	2	Submerged Aquatic Vegetation	
		211		Continuous Sumberged Rooted Vascular Plants
		212		Discontinuous Submerged Rooted Vascular Plants

Results

Following the crosswalk levels defined for each dataset used to construct the CHTD, the hierarchical organization included six macrohabitats: Upland, Estuarine, Marine, Palustrine, Lacustrine and Riverine; with 33 mesohabitats and 122 microhabitat types. EMST data were used in three macrohabitats: Upland, Estuarine, and Palustrine, 16 mesohabitat types and 68 microhabitat types. EMST microhabitat types provided a comprehensive description of vegetation types within the upland areas and provided complete coverage of the project area.

Information from the NWI was used to define habitat types within five of the seven macrohabitats: Riverine, Palustrine, Lacustrine, Estuarine, and Marine; 25 mesohabitats and 47 microhabitat types (generalized from 240 unique wetland types). The Benthic Habitat Atlas contributed information for the Estuarine microhabitat, providing 8 microhabitat type descriptions for more detailed information for four key mesohabitat types: mangrove, seagrass, and bivalve reefs (oysters).

The total area encompassed 725,301 hectares (Appendix C). The most abundant macrohabitat type was Upland, comprising about 46% of the total area. The largest mesohabitat within the Upland category was Upland Grassland (47% of Upland), and within Upland Grassland, Gulf Coast Coastal Prairie was the most abundant microhabitat types (about 13% of the total area). Within the Estuarine macrohabitat, the most extensive mesohabitat was Estuarine Open Water Deep, covering about 22% of the total area and about 59% of all Estuarine area. The microhabitat type Estuarine Subtidal Unconsolidated Bottom Deep comprised over 99% of Estuarine Open Water Deep habitat types.

Palustrine was the third most extensive macrohabitat (9.8% of total area). The mesohabitat Palustrine Vegetated Marsh made up 6.6% of the total area and 68% of Palustrine habitat types. The most common microhabitat type within Palustrine Vegetated Marsh was Palustrine Emergent Marsh Temporarily Flooded (48% of Wetland Vegetated Marsh).

Marine, Lacustrine, and Riverine microhabitat types comprised the remainder of habitat types within the study area covering 5%, 1%, and 0.2% of the study area, respectively . Within Marine, Marine Open Water was by far the most prevalent mesohabitat (97% of the aerial extent of all Marine habitat types), including just a single microhabitat type- Marine Unconsolidated Bottom. Marine Unconsolidated Bottom comprised the nearshore region of the Gulf of Mexico at the seaward extent of the study area. The Lacustrine mesohabitat Lake Open Water (1% of study area) was comprised mostly of the microhabitat Lacustrine Unconsolidated Bottom Permanently and Semipermanently Flooded (85% of all Lacustrine extent). The vast majority of the Riverine macrohabitat (.2% of total area) was classified as belonging to the Riverine Open Water mesohabitat (98% of Riverine habitat types), and specifically the microhabitat Riverine Unconsolidated Bottom Permanently Flooded, Tidal (79% of Riverine Open Water).

Conclusions

A strong emphasis for this project is placed on using the best available data and developing quantifiable, science-based methods and results. To this end, some attention should be paid to the difference between data and information. Data can be defined as "the result of measurement of some agreed phenomenon," while information is "the result of interpretation, categorization, classification, or some other form of processing" (Comber et al 2005b). This is an important difference in the case of land cover classification. The term land cover is generally used to describe the dominant physiographic attributes of a parcel of land (Franklin and Wulder 2002). While commonly referred to as data, it should be kept in mind that the application of any type of land cover classification system to a specific landscape (e.g., land cover map, habitat map) represents the interpretation and transformation of data to information. The development of each set of land cover information included in this work was a result of an agency acting to fulfill a specific policy goal by employing the technological and scientific resources available to that agency. Data such as multi-spectral satellite imagery, digitized aerial imagery, Lidar-derived elevations, vegetation characteristics, soil types, and environmental conditions are processed, transformed, combined, interpolated, and interpreted to create a land cover map that is meaningful in a specific way to a specific set of users (Comber et al 2005b). Additionally, thematic and spatial accuracy of land cover maps can vary depending on scale, complexity of the particular classification scheme, and accuracy, resolution, and temporality of underlying data used in the classification process (Yu et al 2014). Finally, users' biases and preconceptions as to what a particular classification actually represents may affect how the land cover information is ultimately used (e.g., "wetland" may have a substantially different meaning to a duck hunter compared to an industrial developer compared to a conservation biologist) (Comber et al 2005a). It should be kept in mind that what is referred to as a combined land cover dataset presented here actually represents a combined set of information- not data- and any biases or inconsistencies within each source data set are concomitant with the final combined land cover data.

Combining the best information from each available land cover data set is the only way to include the best information for all environments within the study area. Additionally, because the land cover type descriptions were generalized to Macro-, Meso-, and Microhabitat type, interpretation and analysis of use by whooping cranes or other species can be made using this dataset in an accessible and ecologically meaningful way.

Perhaps the best way to minimize potential thematic or spatial inaccuracies within the combined land cover database would have been to create a land cover map using a single classification scheme. The National Estuarine Research Reserve System Classification Scheme (Kutcher et al 2008), is based on a modified Cowardin (1979) classification system, expanded to upland, ice/snow, and "cultural" or developed land cover types using elements of the Anderson (1976) classification scheme and others in a hierarchical structure. A crosswalk exists for the conversion of NWI information to NERSSCS (Kutcher et al 2008), as well as implementation protocols for developing a classification database using existing map resources such as existing land cover information, satellite and aerial imagery, or hard copy maps (Walker and Garfield 2005). For the purposes of creating a continuous land cover data set for the analysis of whooping crane or other avian habitat use from benthic to upland environments along the central Texas coast, future work may benefit from developing a classification database following a protocol such as the one defined by the NERRSCS using currently available data instead of attempting to modify multiple land cover databases to new purposes. This would remove at least one level of interpretation between the underlying data used to characterize land cover classes or habitat types and the resulting land cover or habitat type maps.

Chapter 3: Identifying potential whooping crane habitat

Introduction

The ultimate goal of this project was to provide decision support tools for conservation planning toward the goal of preserving enough wintering habitat to support 1,000 whooping cranes in the Aransas-Wood Buffalo population. The first tool developed was a Comprehensive Habitat Type Database (CHTD) which interpreted land cover types across the study area in terms of micro-, meso-, and macro- scale avian habitat selection.

The second objective of this project was to identify the extent and location of potential whooping crane habitat along the central Texas coast. Within the Strategic Habitat Conservation framework, this objective is part of the biological planning process, wherein spatial variables such as land cover are used in conjunction with biological data such as population surveys to tie biological populations to the landscape and develop models to describe how the landscape is used by the population of interest (U.S. Fish and Wildlife Service 2006).

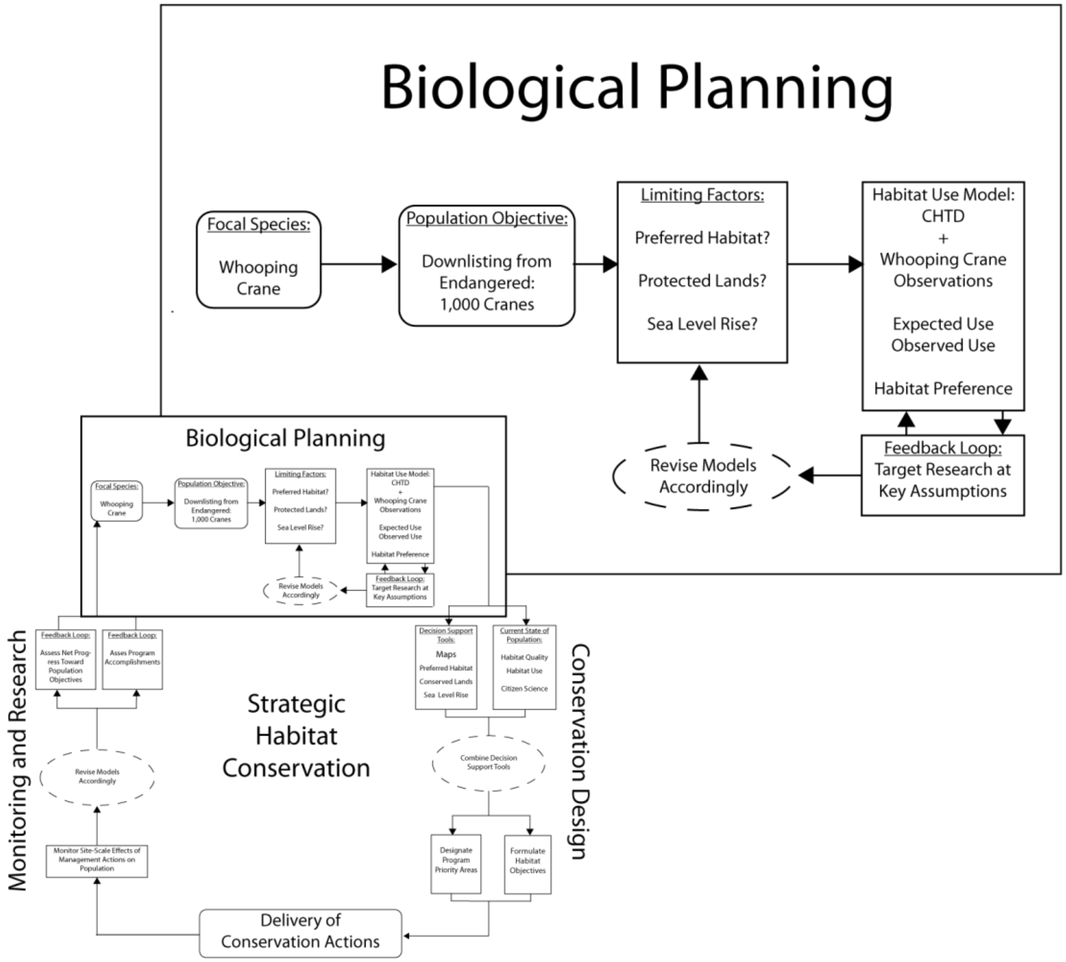

Fig. 10 The Biological Planning phase of Strategic Habitat Conservation uses models to tie biological populations to the landscape. Adapted from U.S. Fish and Wildlife Service (2006)

A habitat use model was developed for the whooping crane using the CHTD and six seasons of whooping crane aerial surveys following procedures for habitat use analysis outlined by Neu et. al. (1974), Byers and Steinhorst (1984), and Alldredge and Griswold (2006). The observed frequency of use of each habitat type was compared to the expected use frequency as defined by that habitat type's areal extent within the whooping cranes' winter distribution. A chi-square goodness of fit test was performed to answer the question "Do whooping cranes use habitat types preferentially, or do they just use what is available?" Then, the proportional use of each habitat type was compared to expected use to answer the question "Which habitat types are preferred or avoided?"

Once habitat preference was determined, a Potential Whooping Crane Habitat map was developed for use as a conservation planning tool for identifying habitat that would have the most value for whooping cranes.

Data and methods

Whooping crane surveys

For the purposes of this project, a dataset containing spatially explicit whooping crane survey data collected from 1950-2011 was made available by the USFWS. This data was collected in weekly or biweekly aerial surveys throughout the wintering season from November through April following a standard methodology. Transects were flown across the whooping crane winter range covering Aransas National Wildlife Refuge, Lamar Peninsula, Matagorda Island National Wildlife Refuge and State Natural Area, San Jose Island, and Welder Flats (Stehn and Taylor 2006). As the cranes' range expanded, so did the survey area.

Stehn and Taylor (2006) determined that over the wintering seasons 1988-89 through 2004-05, the percentage of cranes located by aerial surveys averaged 95.3%. During drought years such as 1993-94 when typical food resources such as blue crabs and Carolina wolfberry were scare, cranes spent more time in unusual locations such as uplands (Stehn 1992), bringing the location accuracy to a minimum of 89.4% (Stehn and Taylor 2006). In years when food resources were considered good such as 1996-97, location accuracy was closer to 98% (Stehn and Taylor 2006).

Prior to 1997, locations of observed cranes were plotted on hand drawn maps. Subsequent surveys plotted crane locations on color infrared imagery from Texas Digital

Ortho Quarter Quads. Starting in 2001, transects were tracked on a GPS unit to ensure complete coverage of the census area.

A review of the survey techniques of Stehn and Taylor was undertaken by Stroebel et al (2012). Major concerns with the survey methods included a lack of formal survey protocol for the aerial surveys; post-hoc definition of survey objectives; inconsistencies in altitude, flight speed, transect location, and search effort; unrecorded and inconsistent search effort; inconsistent incorporation of ancillary data; the assumption that individual cranes do not leave their territories, no defensible estimates of survey precision or bias; and imperfect detection of individuals (Strobel et al 2012). Stehn and Taylor point out some of these concerns themselves, but propose no changes to the method (Stehn and Taylor 2006). Even so, the whooping cranes survey data is one of the most complete and longest-term datasets for the growth of a small population of endangered birds in the study of wildlife (Stehn and Taylor 2006), and no comparable location data for the whooping cranes on their winter range exists. Stehn and Taylor (2006) also point out that the annual winter population census is the only time when accurate monitoring of the AWB whooping crane population can be undertaken—they are much more disperse on their summer grounds in an area with less visibility from the air—and monitoring the population size is the most important management action that can be undertaken as long as the species is classified as endangered.

USFWS Region 6 Inventory and Monitoring Program digitized the hard copy maps in 2012 and provided it for limited use in this project. Date and time of day for each survey and associated information including weather conditions, general habitat type (e.g. marsh, upland, burned area), and other observations such as descriptions of leg bands or expert biologists' identification of individual cranes were noted where possible and included as attributes in the digital data. Point data for each survey season from 1950-2010 was provided as an individual feature class within a Microsoft Access database. Each point in the feature class represented a single crane or group of cranes in close proximity to each other.

For this study, point data from the six wintering seasons from 2004-2005 through 2010-2011 were used. This range of years was chosen because it corresponds chronologically with the most recent land cover data used in this study. As the whooping crane population has steadily increased over the years, the largest crane populations and the greatest spatial extent of habitat use also occur in most recent years (Didrickson 2011).

Habitat information from the CHTD (Micro-, Meso-, and Macrohabitat types) was spatially joined to a feature class containing six winters of whooping crane observations to obtain a dataset showing the location and habitat type utilized by every whooping crane observed over wintering seasons 2004-05 to 2010-11.

Winter distribution

Because the study area was much larger than the area actually utilized by the whooping cranes, it was necessary to constrain the spatial extent of habitat considered "available."

A variety of techniques exist for the determination of home ranges for species or populations. Common techniques include developing minimum convex polygons (MCP) or other geometric shapes from known locations of individuals (Schoener 1981, Southwood and Henderson 2009), delineating utilization distributions (UD) encompassing 50% or 95% of the space used by an animal or group of animals (Calhoun and Casby 1958, Jenrich and Turner 1969, Ford and Krumme 1979), and creating weighted distribution and density rasters for individuals or groups using bivariate kernel density estimators (KDE) (Anderson 1982, Worton 1987). The use of UD or KDE was rejected because both of these techniques require the ability to differentiate individuals' movements across the landscape and over time either through remote sensing technologies such as radio telemetry or highly detailed sets of in-situ observations. In most cases, the whooping crane dataset did not distinguish between observed individuals over time.

By far the simplest technique for delineating home range, a minimum convex polygon is a polygon of the smallest possible area that contains all observations of the species of interest. Many software packages including ArcGIS have tools for determining MCP from a set of observation points. This approach works well in areas of fairly uniform land cover, but the MCP does not consider boundaries that would exclude animal movement within the home range such as open water or steep topography.

In the case of the whooping crane data set, cranes were located on both the barrier island and mainland edges of the bay systems. A minimum convex polygon would include a vast amount of open bay unusable by whooping cranes, so this technique was also rejected.

Instead, a simple distribution polygon was constructed by buffering each whooping crane observation by 2 km, then merging all overlapping buffers to obtain a single polygon feature class that encompassed all whooping crane observations from season 2004-2005 to 2010-2011. This was considered to be the extent of whooping cranes' winter distribution.

The CHTD was clipped by this polygon to obtain the area of available habitat. CHTD Mesohabitat values were also extracted to the whooping crane observation points to obtain the proportionate use of each mesohabitat (**Fig. 11**).

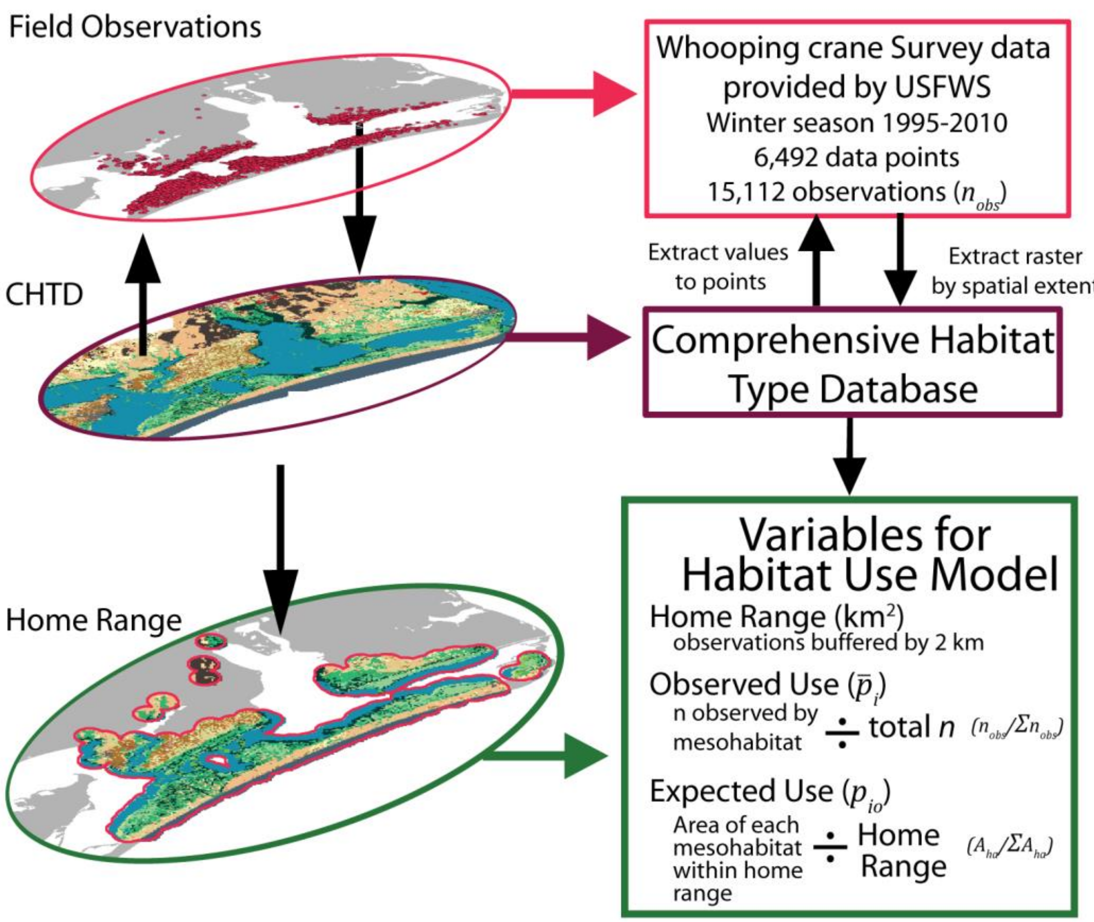

Fig. 11 Geospatial information was extracted from whooping crane field observations and the CHTD to derive variables for a habitat use model

Once the winter distribution for the AWB whooping cranes within the study area was determined, The fraction of each Mesohabitat type as a proportion of the total area

(p_{i_o}), the number and proportion of whooping cranes observed in each Mesohabitat type (n_{obs}, $\bar{p}_i$), and the number of whooping cranes expected in each Mesohabitat type (n_{exp})was determined.

Habitat use model

The first step in understanding wintering habitat preference for the AWB whooping cranes was to determine whether cranes exhibited habitat preference, or alternatively, if their habitat use corresponded to the availability of each habitat type within the cranes' winter distribution. The Pearson's chi-squared test (X^2) was used to determine whether there was a significant difference in the frequency of use of habitat types by the whooping cranes than would be expected if whooping cranes used each habitat type in exact proportion to its availability (Neu et al 1974).

The null hypothesis for this test is that there is no difference between expected and observed frequency of use of habitat types by whooping cranes. In other words; the distribution of whooping cranes among each Mesohabitat type is the same as the distribution of each Mesohabitat type across the landscape.

Once it was determined that whooping cranes use available habitat in a different proportion than would be expected through random use of available habitat, the use of each habitat type was compared to its expected use to understand which habitat types contributed to the overall significant difference in habitat use. To achieve this, the expected frequency of use for each habitat was compared with 95% confidence intervals constructed for the observed frequency of use for each habitat type.

Use intervals were constructed using the Wilson score confidence interval method. The Wilson method was selected over the more commonly used Wald large sample normal test (i.e. asymptotic normal intervals) because it performs better when the proportions are much less than .5, as in this case (Agresti and Coull 1998, Wallis 2013). Additionally, the P-value (α) for each interval was adjusted using the Bonferroni correction for simultaneous comparisons as recommended by Neu et al (1974). This correction adjusts the required confidence level for each of a family of simultaneous statistical tests to reduce the chances of obtaining a type I error (false positive) over multiple comparisons (Gotelli and Ellison 2004). For a desired overall confidence level (1-α) with k number of individual confidence intervals, each individual interval is calculated to the (1-α/k) confidence level. For example, for 5 habitat types and an overall 95% confidence level (α=.05) for the family of comparisons being made, the confidence interval for observed proportion of use of each habitat is calculated at the 99% confidence level (1-.05/5=.01).

The observed use ratio for each mesohabitat was subtracted from the expected use ratio and the upper and lower bounds of the confidence interval for each Mesohabitat, resulting in values normalized by the observed use ratio for each Mesohabitat. This enabled the expected values and observed use intervals for all Mesohabitats to be plotted on the same axes for comparison.

If the interval for observed use in a particular habitat type was greater than expected value, the habitat type was used preferentially (Fig. 12). Additionally, since the values were all relative to observed use, expected use for preferred habitat was always negative. If the observed use interval was less than the expected value, the habitat type was avoided, and the expected value was always positive. Habitat types where expected use was within the observed use interval were considered neutral habitat. These expected values could be negative or positive. Habitat types were then ranked according to preference and assigned a numerical index according to whether the habitat was shown to be Preferred, used as expected (Neutral), or Avoided.

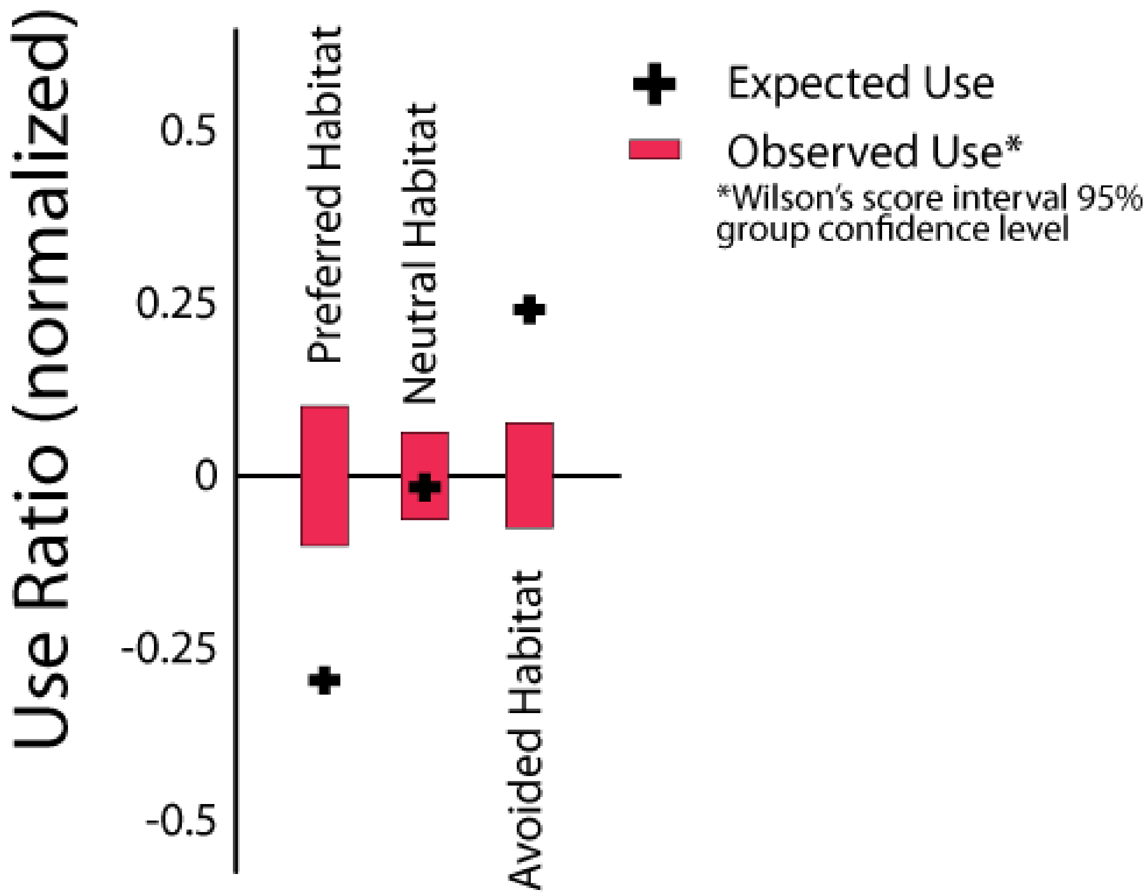

Fig. 12 The habitat use model compared expected and observed use for each Mesohabitat type. Habitat types whose use was greater than expected were considered Preferred habitat. Habitat types used less than expected were considered Avoided habitat.

Potential whooping crane habitat map

The CHTD was then re-symbolized according to habitat preference and a Potential Whooping Crane Habitat map was produced showing Preferred and Neutral whooping crane habitat across the study area. The purpose of this map and associated habitat type information is to guide conservation planners to areas that may become important whooping crane habitat as the population continues to grow beyond the protected borders of the Aransas National Wildlife Refuge.

Results

Whooping crane surveys

15,112 observations of whooping cranes were made in and around the Aransas National Wildlife Refuge during the 2004-05 to 1020-11 wintering seasons. Location data were not available for 118 of these observations, so 14,994 whooping cranes were included in this analysis (Fig. 13). This included 2,061 juveniles and 12,933 white-plumaged adult and sub-adult cranes. 51.72% of birds were observed in Estuarine Vegetated Marsh, the habitat type most commonly considered whooping crane winter habitat (Table 4).

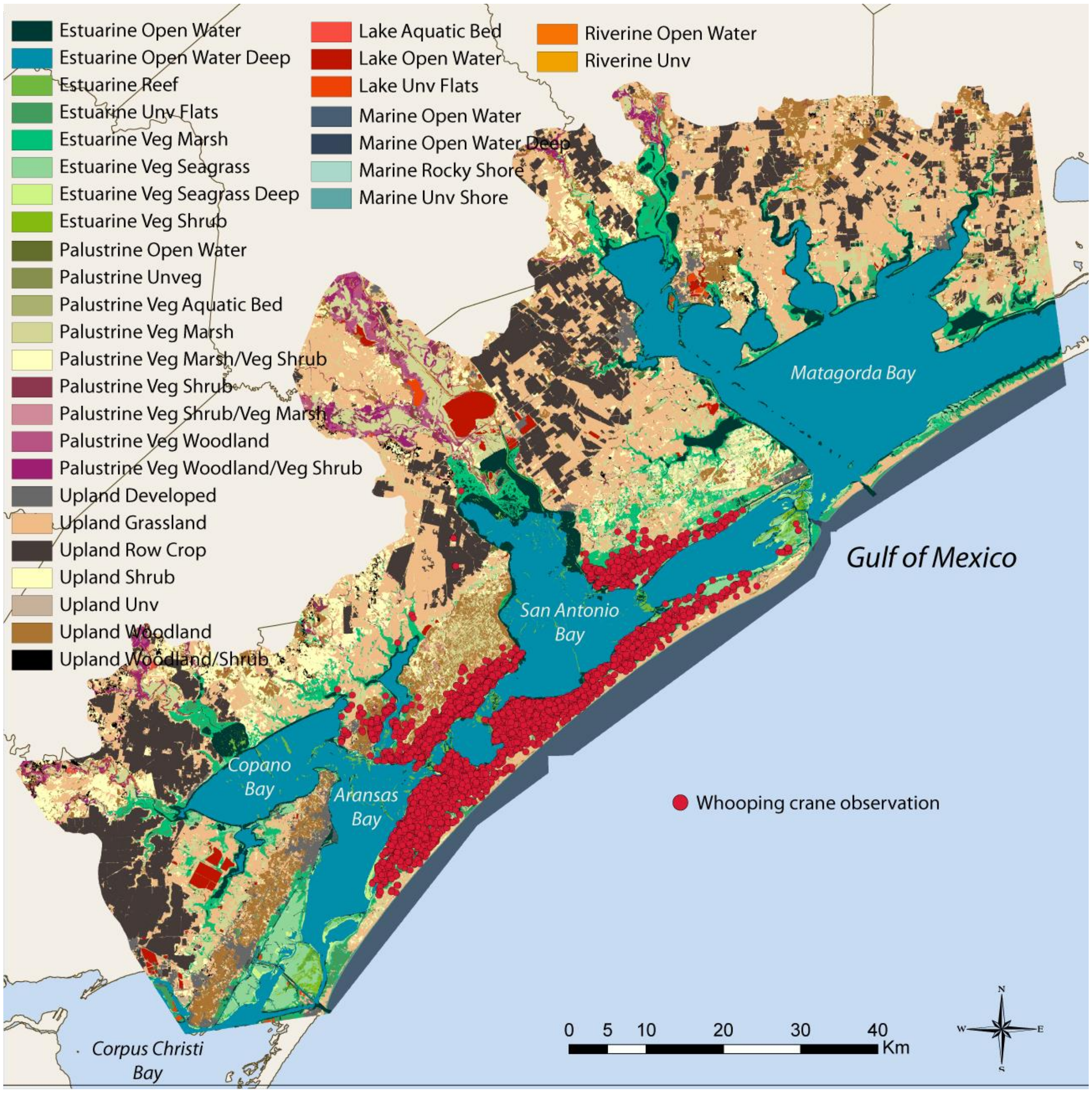

Fig. 13 All 14,994 whooping crane sightings during wintering seasons 2004-05 to 2010-11 overlain on the Comprehensive Habitat Type Database.

Winter distribution

The AWB whooping crane winter distribution from 2004-05 to 2010-11 encompassed 105,813 ha and 27 Mesohabitat types (Fig. 14). The most common mesohabitat types were Estuarine Open Water Deep (22 % of winter distribution), Estuarine Vegetated Marsh (14.5%), and Upland grassland (13.5%). Least common were Upland Unvegetated and Upland Vegetated Woodland/Scrub (both <0.01 %, Table 4).

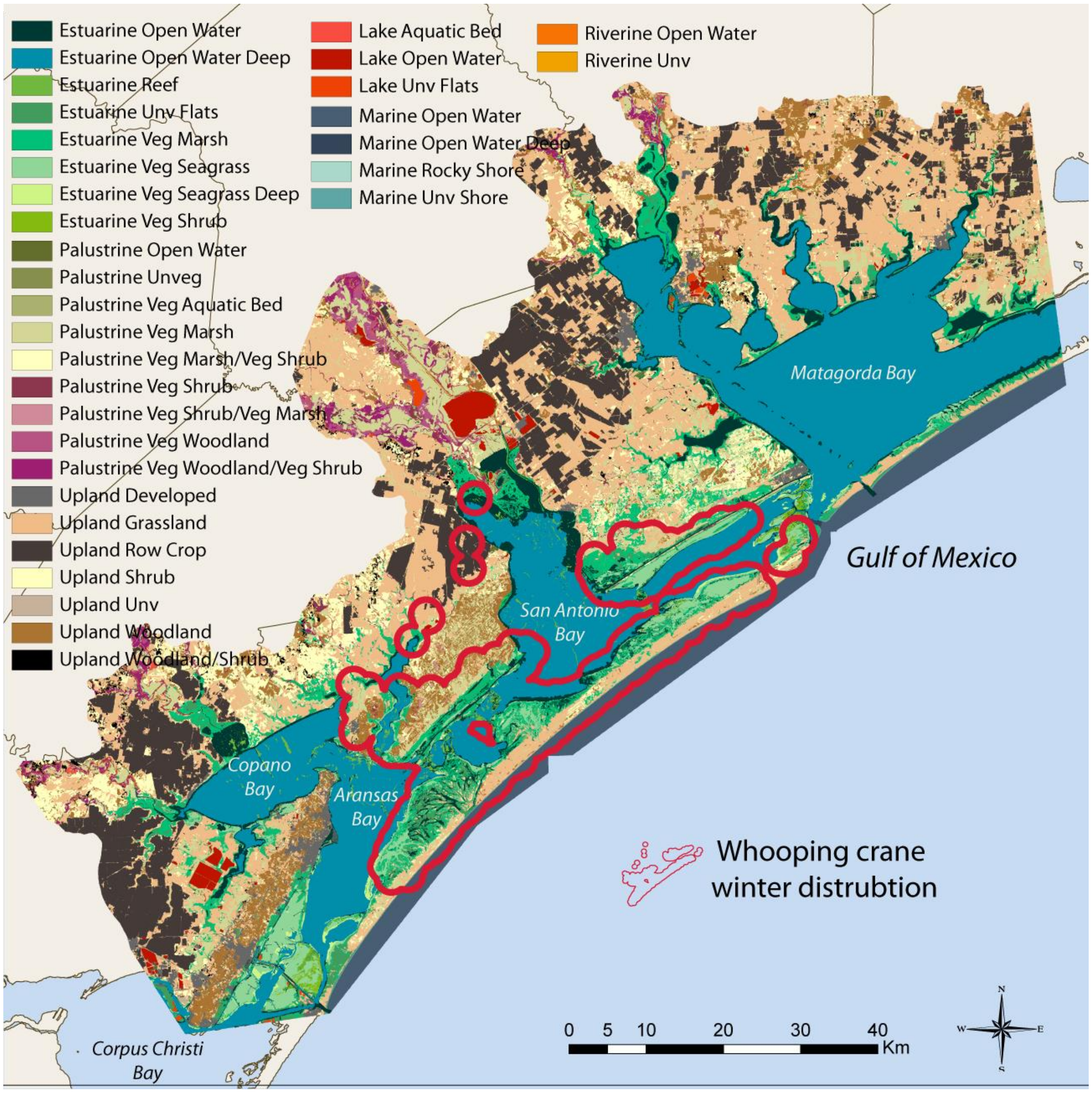

Fig. 14 The Aransas-Wood Buffalo whooping crane population's winter distribution was determined by creating a 2 km buffer around all whooping crane sightings from wintering seasons 2004-05 to 1010-11.

Table 4 Variables for use in the Habitat Use Model. Observed use variables were obtained by extracting CHTD values to whooping cranes points and expected use variables were obtained by clipping the CHTD by the whooping cranes' winter distribution polygon.

Mesohabitat	Area (ha) by Mesohabitat A_{ha}	Proportion of total area (Proportion of whooping cranes expected) $p_{i_o} = \frac{A_{ha}}{\sum A_{ha}}$	Number of whooping cranes observed n_{obs}	Proportion of all whooping cranes observed $\bar{p}_i = n_{obs}/\sum n_{obs}$	Number of whooping cranes expected $n_{exp} = p_{i_o} \times \sum n_{obs}$
Estuarine Veg Marsh	15,339.82	0.1450	7,755	0.5172	2,174
Estuarine Open Water	8,777.06	0.0829	2,499	0.1667	1,244
Estuarine Veg Seagrass	9,550.79	0.0903	1,953	0.1303	1,353
Estuarine Unveg Flats	4795.15	0.0453	1,150	0.0767	679
Upland Grassland	14,306.68	0.1352	860	0.0574	2,027
Palustrine Veg Marsh	7,316.98	0.0692	420	0.0280	1,037
Upland Shrub	1,829.70	0.0173	155	0.0103	259
Upland Woodland	4,947.52	0.0468	108	0.0072	701
Estuarine Open Water Deep	23,232.43	0.2196	23	0.0015	3,292
Estuarine Veg Seagrass Deep	766.63	0.0072	21	0.0014	109
Estuarine Veg Shrub	616.05	0.0058	13	0.0009	87
Estuarine Reef	1,319.15	0.0125	12	0.0008	187
Palustrine Open Water	136.77	0.0013	10	0.0007	19
Palustrine Veg Shrub	296.11	0.0028	4	0.0003	42
Palustrine Unveg	19.45	0.0002	3	0.0002	3
Palustrine Veg Aquatic Bed	14.99	0.0001	3	0.0002	2
Palustrine Veg Marsh/Veg Shrub	400.09	0.0038	3	0.0002	57
Upland Developed	349.04	0.0033	2	0.0001	49
Lake Open Water	46.72	0.0004	0	0	7
Marine Open Water	8,874.37	0.0839	0	0	1,258
Marine Open Water Deep	26.98	0.0003	0	0	4
Marine Unveg Shore	451.98	0.0043	0	0	64
Palustrine Veg Shrub/Veg Marsh	144.04	0.0014	0	0	20
Palustrine Veg Woodland/Veg Shrub	6.00	0.0001	0	0	1
Upland Row Crop	2,218.65	0.0210	0	0	314
Upland Unveg	0.43	0.0000	0	0	0
Upland Woodland/Shrub	29.53	0.0003	0	0	4
Total	**105,813.11**	**1**	**14994**	**1**	**14,994**

Habitat use model

The Pearson’s chi-squared test (X^2) rejected the null hypothesis that there was no difference between expected and observed frequency of use of Mesohabitat types by whooping cranes. In other words, the distribution of whooping cranes among each Mesohabitat type differed significantly from what would be expected if whooping cranes used Mesohabitat type randomly across the landscape (X^2=23,123.47, df=26, p <..001). Whooping cranes exhibit habitat preference within their winter distribution. Expected use was compared to confidence intervals constructed for the observed proportion of use for each Mesohabitat within the winter distribution.

To determine which Mesohabitat types contributed to the significance in the X^2 test, a 95% confidence level family of intervals was constructed for the observed use of the 26 Mesohabitat types within the whooping crane winter distribution with observed or expected use >0. If the observed use confidence interval was greater than the expected use of a Mesohabitat type, then that habitat type was Preferred. If the calculated expected use was within the confidence interval for observed use, then the Mesohabitat type was used as expected, or considered Neutral habitat. If the observed use confidence interval was less than the expected use, the Mesohabitat type was Avoided. All values were normalized to zero and plotted for ease of comparison (**Fig. 15**). Normalized values were calculated by subtracting the proportion of observed use from the proportion of expected use and the confidence intervals for each Mesohabitat, bringing the center of each observed use confidence interval to zero.

At the Mesohabitat level, Estuarine Open Water (depth < .33m), Estuarine Vegetated Marsh, Estuarine Vegetated Seagrass (depth < .33m), and Estuarine

Unvegetated Flats were determined to be Preferred habitat. 7 Mesohabitats were used as expected (Neutral habitat types) including Palsutrine, Upland, Marine, and Lacustrine aquatic bed, barren, woodland/shrub, and open water habitat types. The remaining 15 Mesohabitat types within the whooping cranes' winter distribution were determined to be Avoided habitat types including Estuarine Reef, Palustrine Vegetated Shrub, and Upland Developed (**Fig. 15**).

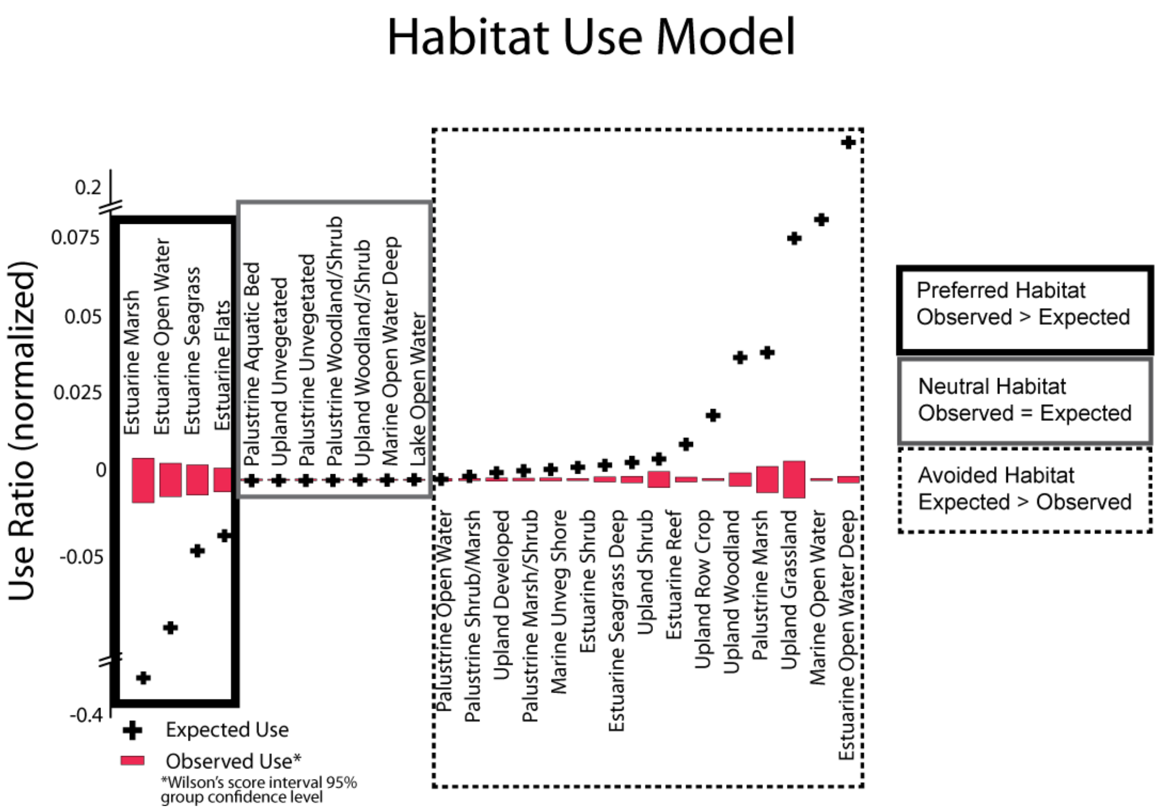

Fig. 15 Habitat Use Model for the use of Mesohabitats by whooping cranes during wintering seasons 2004-05 to 2010-11.Though 27 habitat types existed within the study area, only 26 were included in the habitat use model. The habitat use model was only applied to habitat types with observed or expected use >0.

Potential whooping crane habitat map

The CHTD was reclassified to reflect the habitat preferences determined by the habitat use model. A new attribute "Preference" was added to the CHTD raster attribute table and a value of "Preferred," Neutral," or "Avoided" was given to corresponding

Mesohabitat types. The CHTD was then symbolized and summarized according to preference (Fig. 16). Across the entire study area (725,301 ha), 108,034 ha of potential preferred habitat was identified (15% of total area). 20,374 ha of neutral habitat (3% of total area) was also identified (Table 5). Preferred habitat followed a general pattern of fringing bay margins along barrier islands and the mainland and river deltas.

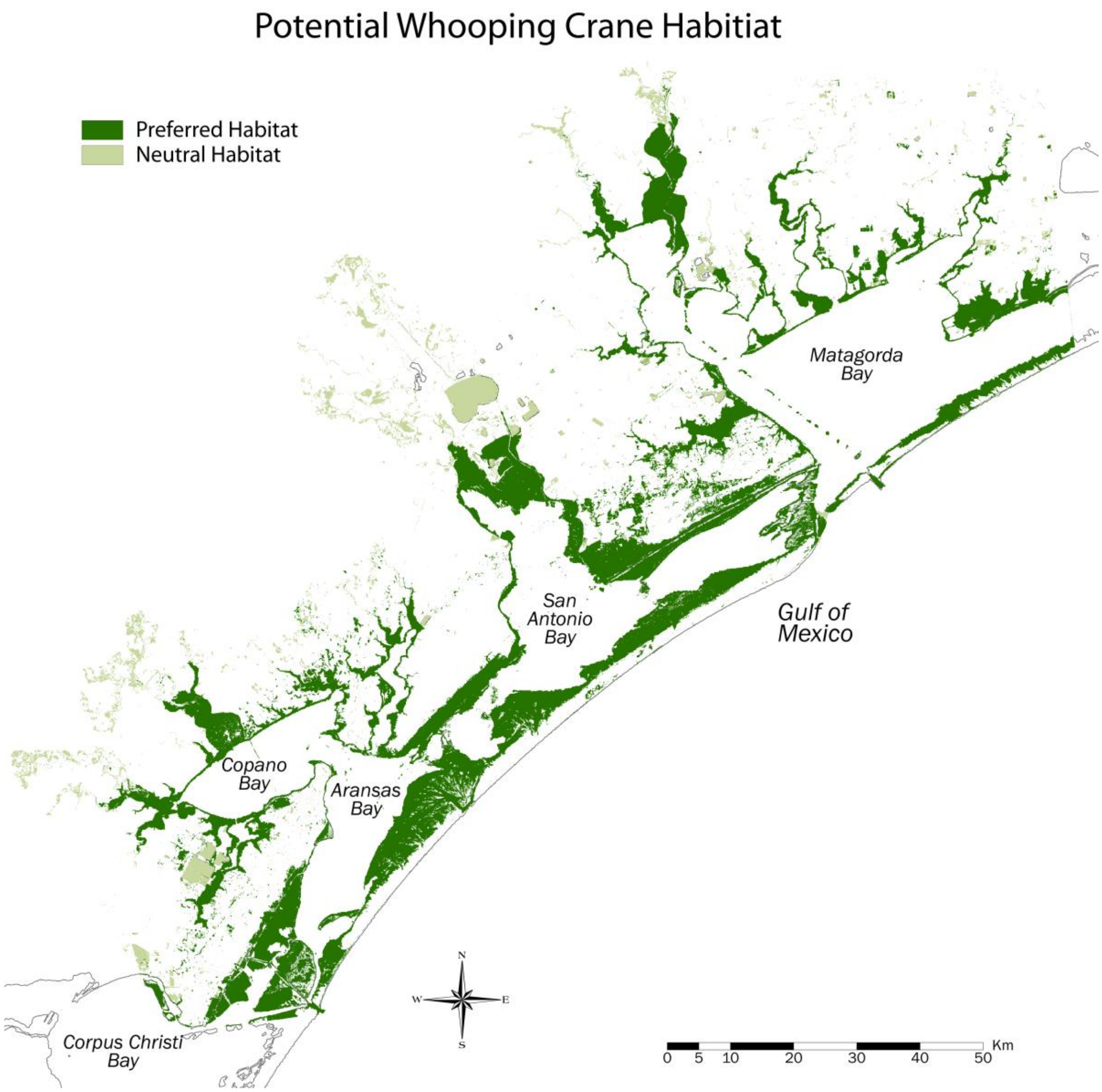

Fig. 16 Potential Preferred and Neutral whooping crane habitat across the central Texas coast.

Table 5 Area (ha) of Mesohabitat types by preference across the entire study area.

Habitat Preference	Area (ha) by Preference	Proportion of total area	Mesohabitat Type	Area (ha) by Mesohabitat
Preferred	**108,034.35**	**0.15**	Estuarine Open Water	34,863.60
			Estuarine Unveg Flats	12,324.26
			Estuarine Veg Marsh	42,453.98
			Estuarine Veg Seagrass	1,8392.51
Neutral	**20,373.96**	**0.03**	Lake Open Water	6,351.71
			Marine Open Water Deep	95.08
			Palustrine Open Water	1,457.25
			Palustrine Unveg	1,869.63
			Palustrine Veg Aquatic Bed	280.12
			Palustrine Veg Woodland/Veg Shrub	6,610.93
			Upland Unveg	470.25
			Upland Woodland/Shrub	3,238.99
Avoided	**589,826.80**	**0.81**	Estuarine Open Water Deep	163,149.05
			Estuarine Reef	2,692.63
			Estuarine Veg Seagrass Deep	2,183.88
			Estuarine Veg Shrub	2,465.05
			Marine Open Water	34,606.68
			Marine Unveg Shore	954.38
			Palustrine Veg Marsh	47,994.37
			Palustrine Veg Marsh/Veg Shrub	2,623.85
			Palustrine Veg Shrub	4,794.34
			Palustrine Veg Shrub/Veg Marsh	527.18
			Upland Developed	11,256.52
			Upland Grassland	156,802.15
			Upland Row Crop	83,088.11
			Upland Shrub	40,501.98
			Upland Woodland	36,186.63
Not Ranked	**7,066.00**	**0.01**	Lake Aquatic Bed	180.40
			Lake Unveg Flats	905.70
			Marine Rocky Shore	1.86
			Palustrine Veg Woodland	4,832.47
			Riverine Open Water	1,124.09
			Riverine Unveg	21.48
Total	**725,301.11**	**1**		**725,301.11**

Conclusions

The Potential Whooping Crane Habitat map and associated habitat type information can be a valuable tool in the strategic habitat conservation toolkit. Conservation planners could combine this information with information related to land ownership status, parcel size, proximity to currently conserved areas, and habitat use preferences for other species to prioritize the use of conservation resources in areas that will have the most impact to the functioning of an entire ecosystem.

Unlike some previous attempts to quantify habitat use and preference for the whooping crane, this analysis takes into account the relative abundance of habitat types in assessing the cranes' preference for them. The habitat use model revealed at least one Preferred Mesohabitat type that could otherwise be overlooked because its relative abundance is low. Estuarine Unvegetated Flats was used by about 7.7% of all whooping cranes observed (**Table 4**). This may seem insignificant, but this proportion is almost twice as high as would be expected by chance alone (4.5%). This observation is important because in parts of the coast where Estuarine Unvegetated Flats are relatively more abundant, overlooking these habitat types in conservation planning could result in a lost conservation opportunity for the whooping crane.

This analysis represents a "first-cut" in determining preferred habitat for the whooping crane across the central Texas coast. In subsequent versions, it may be useful to add additional maps describing more sophisticated habitat variables beyond whooping crane presence/absence data and habitat type. Examples of other potentially useful variables include distance to various water features (manmade ponds, estuarine, marine, or freshwater features that may provide valuable food resources), distance to transportation or human activity corridors (highways, the Gulf Intracoastal Waterway, popular outdoor recreation locations that may deter cranes from using otherwise ideal habitat), proximity to residential or industrial development , or barriers to sight such as steep terrain, dense woodland/shrub, or man-made features like high fences or billboards.

Additionally, the territoriality of whooping cranes on their winter grounds is well described (Allen 1952; Stehn and Johnson 1987; Meine and Archibald 1996; Stehn and Prieto 2009) but not included in this analysis. Habitat use is likely strongly influenced by some combination of an individual's territory status (part of a pair or family group with an established territory, versus part of a pair trying to establish a new territory, versus a group of unpaired young adults with no territory), Meso- and Microscale habitat type, and available resources. This use may be highly variable among individuals.

As mentioned previously, determining boundaries for the Aransas- Wood Buffalo whooping cranes' winter distribution presented a challenge. Several different techniques for determining the home range of individuals or populations may be appropriate according to the type of location information available and characteristics of the population in question. The whooping crane is a highly mobile avian species whose available winter habitat could theoretically cover the entire Texas Gulf coast or beyond. The choice to define winter distribution as within 2 km of any whooping crane sighting in the study was somewhat arbitrary, as the reported distance whooping cranes may travel to find resources varied from 200 m (Timoney 1999) to 40 km (Stehn 1992).

It was decided to use the 2 km buffer because the process was simple to implement and communicate, required no complicated statistical justification, and could be easily repeated in subsequent analyses. The 2 km buffer distance assumed that the dataset represented all whooping cranes in the Aransas-Wood Buffalo population on their winter range and captured any “unusual” habitat use such as use of upland areas or man-made ponds in times of drought or habitat used while fleeing a threat or traveling between preferred habitat.

A standardized delineation of winter home range for the Aransas-Wood Buffalo whooping cranes would be useful to allow for comparisons between studies, but may not be possible due to a growing population, changes in land use and cover type under various climatological conditions, or destruction or enhancement of preferred habitat that may alter use. One solution could be an update to the extent of the federally designated critical habitat along the central Texas coast (US Fish and Wildlife Service 1978), which currently does not encompass all areas used by whooping cranes in this analysis.

Finally, it should be acknowledged that the coastal environment is highly dynamic and will likely become even more so as the effects of climate change and sea level rise become more apparent. To get some idea of the effect sea level rise may have on preferred whooping crane habitat along the central Texas coast, the habitat use model analysis applied in this work was repeated using initial conditions and results of the Sea Level Affecting Marshes Model (SLAMM) applied to the Aransas National Wildlife Refuge and surrounding areas in 2010.

This work represents a substantial advance in the quantification of potential whooping crane habitat along the central Texas coast using best available information and data-driven, repeatable GIS methodologies. Future work includes a more sophisticated habitat use analysis taking into consideration other geoenvironmental variables, the territorial behavior of the whooping crane, a standardized delineation of the Aransas- Wood Buffalo winter home range, and potential impacts of sea level rise and climate change.

Chapter 4: Effects of sea level rise on potential whooping crane habitat

Introduction

No assessment of coastal habitat preference or availability would be complete without some consideration paid to the potential impacts of sea level rise. This consideration is especially vital in the field of conservation planning. Limited resources for conservation actions require an understanding of potential changes to the landscape that may cause significant changes to the spatial configuration or quality of preferred habitat types.

The ultimate goal of this project was to provide decision support tools for conservation planning toward the goal of preserving enough wintering habitat to support 1,000 whooping cranes in the Aransas-Wood Buffalo (AWB) population. The first tool developed was a Comprehensive Habitat Type Database (CHTD) which interpreted land cover types across the study area in terms of micro-, meso-, and macro- scale avian habitat selection.

The second conservation planning tool developed was a Potential Whooping Crane Habitat map to guide conservation planning towards locations likely to be preferred habitat as the AWB whooping cranes expand beyond their current winter distribution.

The objective of this chapter is to develop a third conservation planning tool that takes into account potential impacts to preferred whooping crane habitat under various sea level rise scenarios. The methodology for this analysis follows the methodology for the previous chapter, Identifying Potential Whooping Crane Habitat except that results from a 2010 application of the Sea Level Affecting Marshes Model (SLAMM, Clough et al 2010) were used as the source of habitat-type information instead of the Comprehensive Habitat Type Database.

A habitat use model was developed for the whooping crane using the SLAMM initial condition raster and six seasons of whooping crane aerial surveys following the procedure described previously. Once habitat preference was determined, Potential Whooping Crane Habitat maps were developed for five different sea level rise scenarios to explore possible impacts of sea level rise on potential whooping crane habitat. Preferred Whooping Crane Habitat maps were produced for all scenarios under current and future conditions projected for the years 2025, 2050, and 2100.

Data and methods

All methods and data were exactly the same as the previous analysis with two exceptions:

1.) The SLAMM initial condition raster was used instead of the CHTD to provide habitat use information for the Habitat Use Model.

2.) In the development of the CHTD, deep and shallow water habitat types were identified using a bathymetric DEM. This allowed for a separation of open water habitats that were likely to be used by whooping cranes (depth <0.33 m) from open water habitats unlikely to be used (depth >0.33 m).

To achieve a differentiation between deep and shallow estuarine water habitats similar to the one made in the CHTD, all SLAMM rasters were clipped to 500 m of the current shoreline prior to any further analysis. This resulted in the removal of potential deep water marine and estuarine habitat types unusable by whooping cranes. Constraining the data in this manner most likely resulted in a more realistic analysis of habitat preference.

SLAMM

The Sea Level Affecting Marshes Model (SLAMM 6) was applied to the Aransas National Wildlife Refuge and surrounding areas in 2010 by Warren Pinnacle Consulting, Inc. (Clough and Larson 2010).

The SLAMM is a dynamic model that projects changes in wetland habitat type and distribution in response to sea level rise as a function of five primary geoenvironmental processes- water inundation, soil erosion, barrier island overwash, ground saturation as a result of a rising fresh water table, and sediment accretion (Clough et al 2010).

Table 6 Input parameters to the SLAMM 6 model run for Aransas National Wildlife Refuge and surrounding areas. Adapted from Clough and Larson (2010)

Parameter	Value	Source	Date
Wetland Type	-	NWI	2008
Lidar DEM	- m	NOAA	2006
Historic SLR trend	5.16 mm/yr	NOAA tide gauges	long term
Mean Tide Level MTL above NAVD88	0.107-0.339 m	NOAA tide gauges	long term
Great Diurnal Tide Range	0.111-0.499 m	NOAA tide gauges	long term
Saline Inundation Above MTL	0.36-0.48 m	TCOON tide stations	long term
Marsh Erosion	0 horiz mm/yr	-	-
Swamp Erosion	0 horiz mm/yr	-	-
	0 horiz mm/yr		
Tidal Flat Erosion	0 horiz mm/yr	-	-
Reg. Flooded Marsh Accretion	4.4 mm/yr	Callaway et. al.	1997
Irreg. Flooded Marsh Accretion	4.4 mm/yr	Callaway et. al.	1997
Tidal Fresh Marsh Accretion	5.9 mm/yr	Callaway et. al.	1997
Beach Sed. Rate	0.5 mm/yr	Callaway et. al.	1997
Overwash Frequency	20 mm/yr	-	-

All input parameters were rasterized to a 30 m grid. The model output produced a grid of cell values (1-23) representing projected land cover types following the same classification scheme as National Wetlands Inventory (Clough and Larson 2010). The SLAMM model was run using a suite of sea level rise scenarios to predict the future distribution of wetlands as a result of sea level rise including two based on climate change projections from the Intergovernmental Panel on Climate Change Working Group 1 Fourth Assessment Report and three based on eustatic sea level rise projections up to the year 2100.

The IPCC climate change A1B family of sea level rise projections was based on a future greenhouse gas emissions scenario including very rapid economic growth, a global population that peaks in mid-century and rapid introduction of new and more efficient technologies incorporating both fossil-based and alternative energy sources (IPCC 2007).

The A1B Mean scenario was the most conservative sea level rise scenario used in the SLAMM. It predicted sea level rising 0.39 m by 2100, the IPCC A1B Maximum scenario predicted 0.69 m of sea level rise by 2100 (IPCC 2007). Sea level rise of 1 m, 1.5 m, and 2 m by 2100 were also modeled. SLAMM raster outputs also included a wetland type raster representing the initial condition or starting point for all model runs. The initial wetland type raster was used for the habitat use analysis in this work.

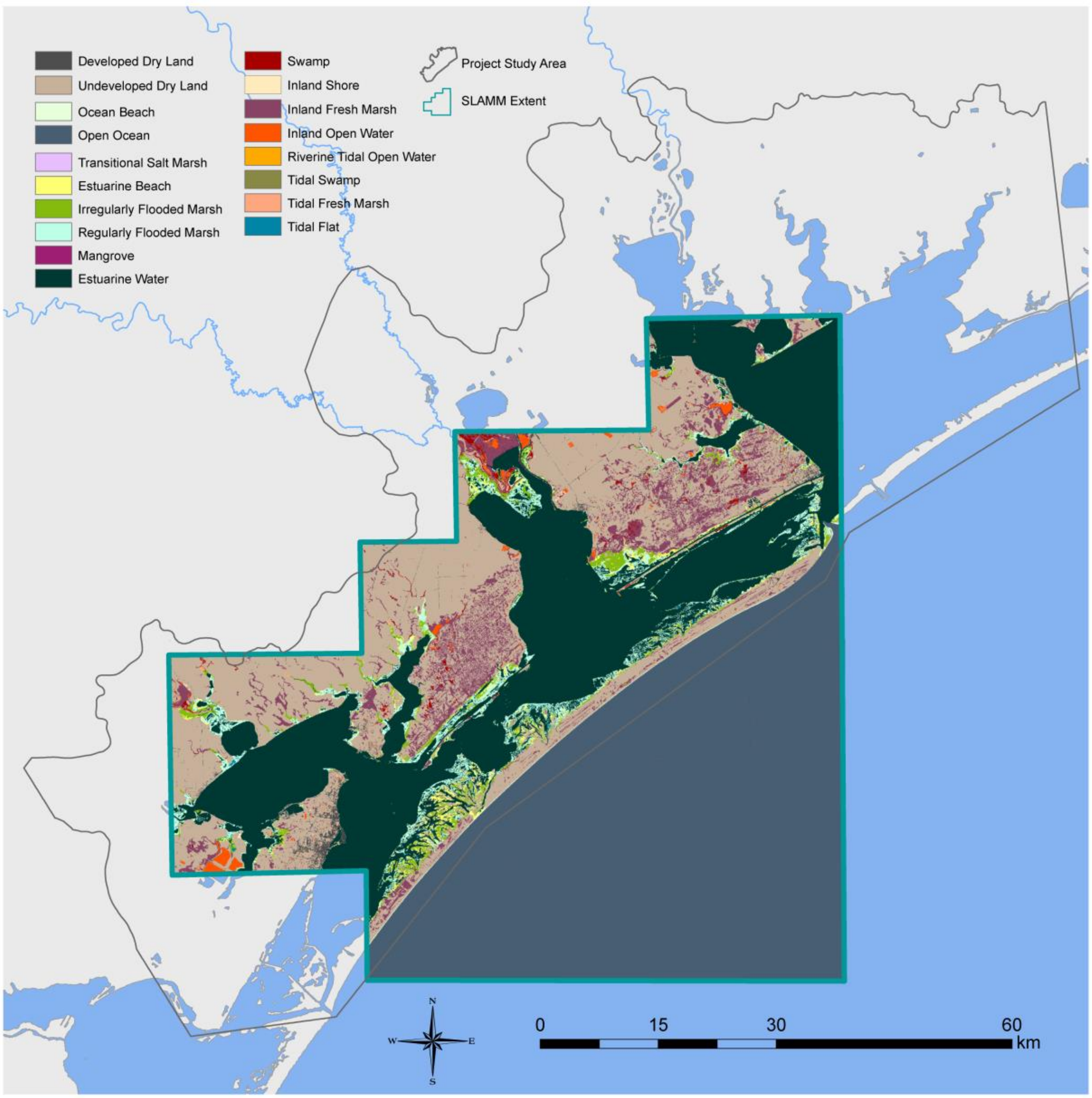

Fig. 17 SLAMM initial wetland type raster. The spatial extent of the SLAMM project did not cover the entire study area but did cover the extent of the whooping crane winter distribution

Whooping crane surveys

As in the previous analysis of Potential Whooping Crane Habitat, point data from the 2004-2005 through 2010-2011 wintering seasons were used.

Land cover information from the SLAMM initial condition raster was extracted to the whooping crane observation points to obtain a dataset showing the location of every whooping crane and each habitat type utilized over wintering seasons 2004-05 to 2010-11.

Winter distribution

The same winter distribution polygon was used as in the previous analysis. The SLAMM initial condition raster was clipped by the winter distribution polygon to obtain the area of available habitat. SLAMM land cover values were extracted to the whooping crane observation points to obtain the proportionate use of each mesohabitat (Fig. 18).

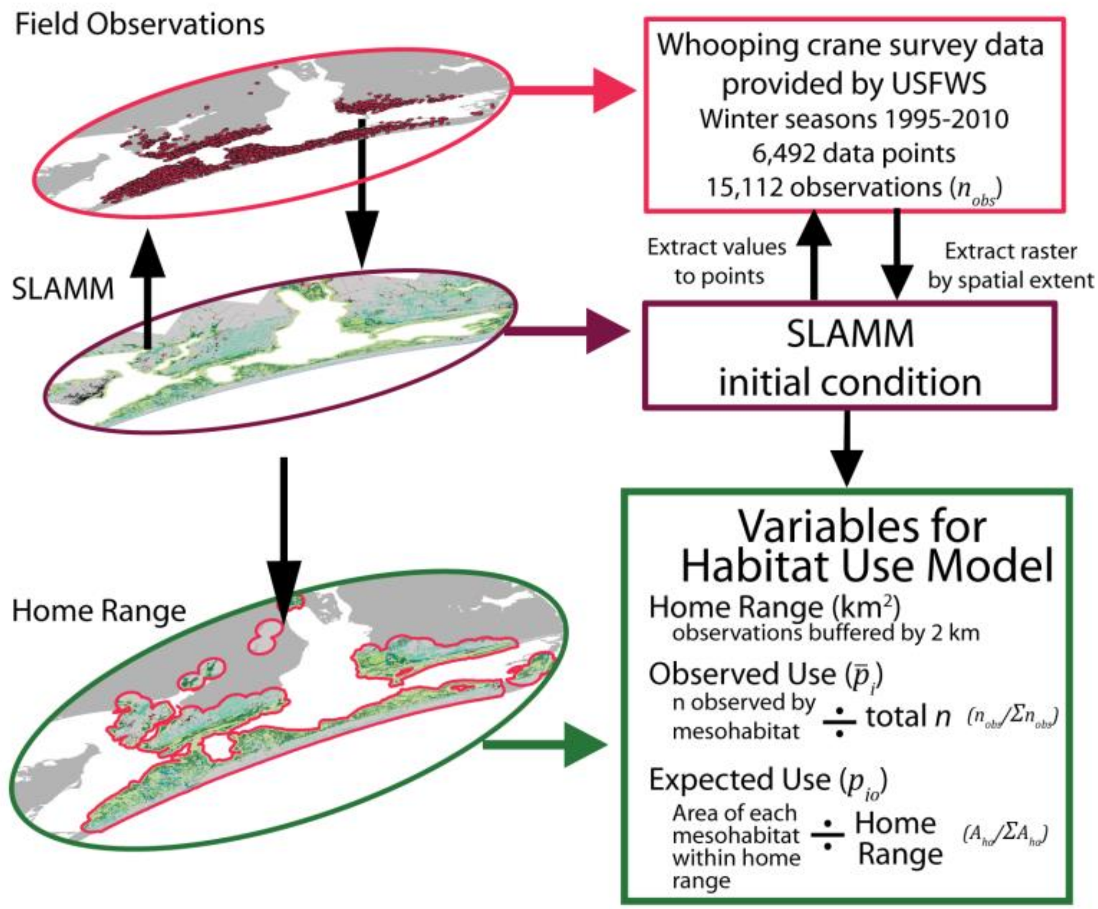

Fig. 18 Geospatial information was extracted from whooping crane field observations and the SLAMM initial condition raster to derive variables for a habitat use model

Habitat use model

The Pearson's chi-squared test (X^2) was used to determine whether there was a significant difference in the frequency of use of land cover types by the whooping cranes than would be expected if whooping cranes used each land cover type in exact proportion to its availability (Neu et al 1974).

The null hypothesis for this test was that there was no difference between expected and observed frequency of use of land cover types by whooping cranes. In other words; the distribution of whooping cranes among each land cover type was the same as the distribution of each land cover type across the landscape.

To identify land cover types that were Preferred, Avoided, or Neutral, the use of each land cover type was compared to its expected use for that land cover type. As with the habitat use model using the CHTD, the expected frequency of use for each land cover type was compared with 95% confidence intervals constructed for the observed frequency of use for each land cover type.

Use intervals were constructed using the Wilson score confidence interval method. The P-value (α) for each interval was adjusted using the Bonferroni correction for simultaneous comparisons as recommended by Neu et al (1974).

All values were normalized by the observed use ratio for each mesohabitat. If the interval for observed use in a particular land cover type was greater than expected value, the land cover type was used preferentially. If the observed use interval was less than the expected value, the land cover type was avoided. Land cover types with expected use ratios that fell within the observed use ratios confidence interval were considered Neutral land cover (Fig. 12).

Potential whooping crane habitat maps

The SLAMM initial raster and all sea level rise projection rasters were re-symbolized according to preference determined by the habitat use model. A series of Potential Whooping Crane Habitat maps were produced showing Preferred and Neutral whooping crane habitat within the SLAMM study area under initial conditions and all five sea level rise scenarios for the time steps 2025, 2050, 2075, and 2100. The purpose of these maps and associated information is to guide conservation planners to areas that may become important whooping crane habitat under potential sea level rise scenarios and as the population continues to grow beyond the protected borders of the Aransas National Wildlife Refuge.

A spatially explicit time series describing the effects of various sea level rise scenarios is useful to identify where preferred habitat is likely to persist, where preferred habitat may currently exist but may not in the future, and to gain some understanding of the likelihood that there will be enough preferred habitat along central Texas coast to support the endangered species downlisting goal of 1,000 cranes in the Aransas-Wood Buffalo population.

Results

Winter distribution

When the winter distribution polygon developed in the previous section was combined with the SLAMM initial raster with portions of the raster >500 m from shoreline removed, the resulting winter distribution encompassed 80,883 ha and16 land cover types.

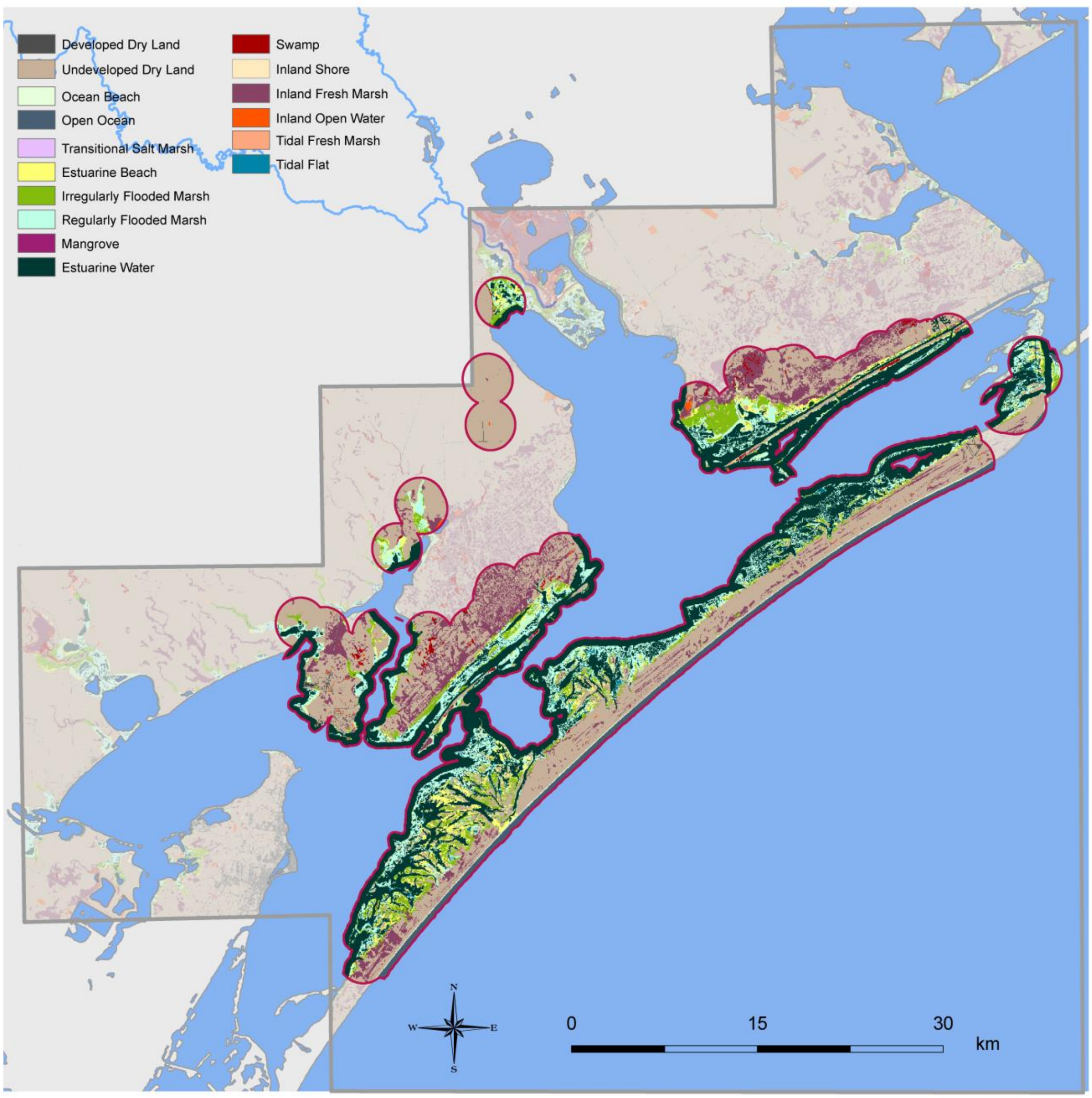

Fig. 19 The Aransas-Wood Buffalo whooping crane population's winter distribution was determined by creating a 2 km buffer around all whooping crane sightings from wintering seasons 2004-05 to 1010-11

The most common land cover types within the winter distribution were Undeveloped Dry Land (33% of winter distribution), Estuarine Water (31%), and Regularly Flooded Marsh (10.1%). Least common were Tidal Fresh Marsh and Transitional Salt Marsh (both <0.01 %). Highest use land cover types were Regularly Flooded Marsh (43.3% of all cranes observed) and Estuarine Water (30.5%).

Table 7 Variables for use in the SLAMM Habitat Use Model. Observed use variables were obtained by extracting SLAMM initial condition values to whooping crane occurrence points and expected use variables were obtained by clipping the SLAMM initial raster by the whooping crane winter distribution polygon

SLAMM land cover categories	**Area (ha) by Mesohabitat** A_{ha}	**Proportion of total area (Proportion of whooping cranes expected)** $p_{i_o} = \frac{A_{ha}}{\sum A_{ha}}$	**Number of whooping cranes observed** n_{obs}	**Proportion of all whooping cranes observed** $\bar{p}_i = n_{obs} / \sum n_{obs}$	**Number of whooping cranes expected** $n_{exp} = p_{i_o} \times \sum n_{obs}$
Regularly Flooded Marsh	8,141.94	0.1007	6,491	0.4329	1,509
Estuarine Water	25,338.78	0.3133	4,571	0.3049	4,697
Undeveloped Dry Land	26,941.41	0.3331	1,586	0.1058	4,994
Irregularly Flooded Marsh	4,381.38	0.0542	863	0.0576	812
Estuarine Beach	3,513.78	0.0434	737	0.0492	651
Inland Fresh Marsh	7,762.23	0.0960	392	0.0261	1,439
Tidal Flat	471.78	0.0058	323	0.0215	87
Inland Open Water	194.94	0.0024	17	0.0011	36
Developed Dry Land	257.67	0.0032	4	0.0003	48
Swamp	429.48	0.0053	4	0.0003	80
Tidal Fresh Marsh	7.92	0.0001	3	0.0002	1
Mangrove	19.53	0.0002	3	0.0002	4
Inland Shore	18.99	0.0002	0	0	4
Transitional Salt Marsh	0.18	0.0000	0	0	0
Ocean Beach	441.72	0.0055	0	0	82
Open Ocean	2,961.36	0.0366	0	0	549
Total	**80,883.09**	**1**	**14,994**	**1**	**14,994**

Habitat use model

The Pearson's chi-squared test (X^2) rejected the null hypothesis that there was no difference between expected and observed frequency of use of land cover types by whooping cranes. The distribution of whooping cranes among each land cover type differed significantly from what would be expected if whooping cranes used land cover randomly across the landscape (X^2=19,419.9, df=11, p <..001). Whooping cranes exhibit habitat preference within their winter distribution. Expected use was compared to confidence intervals constructed for the observed proportion of use for each Mesohabitat within the winter distribution.

To determine which Mesohabitat types contributed to the significance in the X^2 test, a 95% confidence level family of intervals was constructed for the observed use of the 16 land cover types within the whooping crane winter distribution. All values were normalized to zero and plotted for ease of comparison (Fig. 15).

Estuarine Beach, Tidal Flat, and Regularly Flooded Marsh were determined to be Preferred habitat. Six land cover types were used as expected (Neutral habitat types) including Estuarine Water, Irregularly Flooded Marsh, Inland Shore, Tidal Fresh Marsh, Transitional Salt Marsh, and Mangrove. The remaining 7 land cover types within the whooping cranes' winter distribution were determined to be Avoided habitat types including Developed Dry Land, Open Beach, Inland Open Water, and others (Fig. 15).

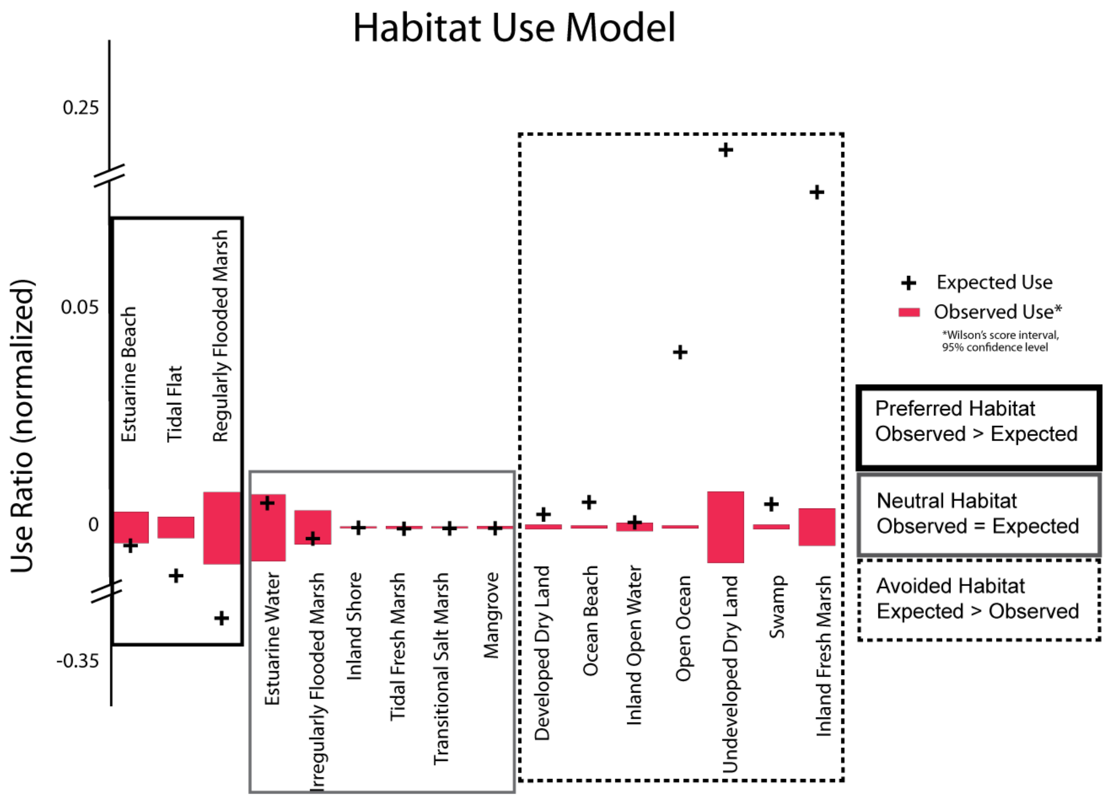

Fig. 20 Habitat Use Model for SLAMM land cover types used by whooping cranes during wintering seasons 2004-05 to 2010-11

Potential whooping crane habitat map

The SLAMM initial condition raster was reclassified to reflect the habitat preferences determined by the habitat use model. A new attribute "Preference" was added to the raster attribute table and a value of "Preferred," Neutral," or "Avoided" was given to corresponding land cover types. A value of "Not Ranked" was applied to the 3 land cover types with no expected or observed use in the habitat use model.

"Not Ranked" habitat types are not necessarily avoided by whooping cranes; they merely did not fall within the whooping cranes' winter distribution. It could be inferred that because these habitat types are outside the whooping cranes' winter distribution they are not preferred (or "Avoided"), but caution should be taken when making such assumptions. Factors such as the cranes' tendency to use habitat and establish territories adjacent to those already in use could prevent cranes for using otherwise potential Preferred habitat (Allen 1952; Stehn and Johnson 1987; Stehn and Prieto 2009). There is not enough information about these habitat types to determine preference

The raster was then symbolized and summarized according to preference. Across the entire study area (222,539 ha), 18,419 ha of potential preferred habitat was identified (8% of total area). 53,918 ha of neutral habitat (25% of total area) was also identified. Preferred habitat followed a pattern of fringing bay margins along the mainland and back sides of barrier islands and low lying river deltas similar to the Potential Whooping Crane Habitat map developed from the CHTD (Fig. 21). Though Estuarine Water was determined to be Neutral habitat in the habitat use model, it was depicted in blue for all habitat maps to better visualize sea level rise inundation. Estuarine Water is included with Neutral Habitat for all area calculations.

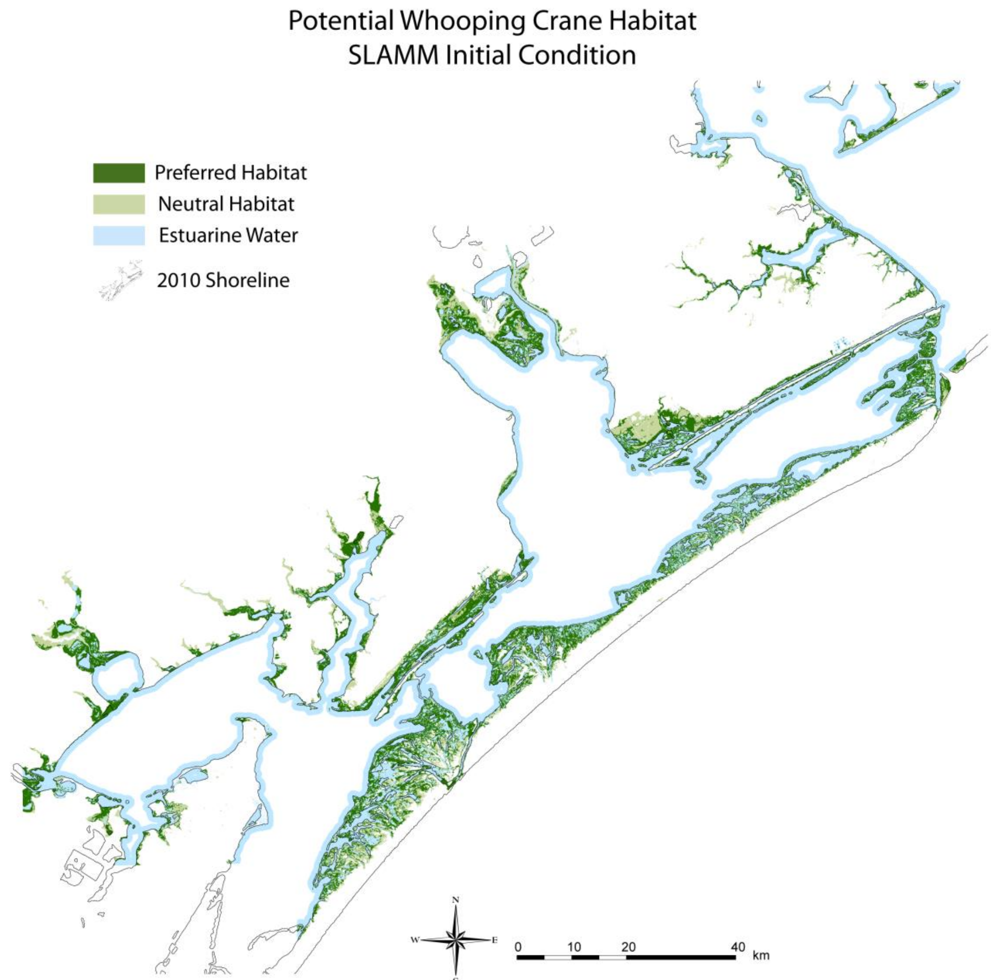

Fig. 21 Potential Preferred and Neutral whooping crane habitat within the extent of the SLAMM model run.

Table 8 Area (ha) of land cover types by preference across the entire study area

Habitat Preference	Area (ha) by Preference	Proportion of total area	SLAMM land cover type	Area (ha) by land cover type
Preferred	**18,419.22**	**0.0828**	Estuarine Beach	4,711.23
			Regularly Flooded Marsh	13,035.15
			Tidal Flat	672.84
Neutral	**53,917.56**	**0.2423**	Estuarine Water	46,160.01
			Inland Shore	209.61
			Irregularly Flooded Marsh	7,299.09
			Mangrove	169.65
			Tidal Fresh Marsh	79.02
			Transitional Salt Marsh	0.18
Avoided	**150,175.53**	**0.6748**	Developed Dry Land	2,494.89
			Inland Fresh Marsh	24,043.14
			Inland Open Water	2,585.25
			Ocean Beach	544.32
			Open Ocean	3,867.12
			Swamp	2,039.58
			Undeveloped Dry Land	114,601.23
Not Ranked	**27.18**	**0.0001**	Cypress Swamp	0.54
			Riverine Tidal Open Water	23.13
			Tidal Swamp	3.51
Total	**222,539.49**	**1**		**222,539.49**

Sea level rise scenarios

Sea level rise scenarios for Preferred and Neutral whooping crane habitat were generated from SLAMM for the A1B Mean, A1B Max, 1 m, 1.5m, and 2 m of sea level rise by 2100. Time steps 2025, 2050, 2075, and 2100 were all mapped.

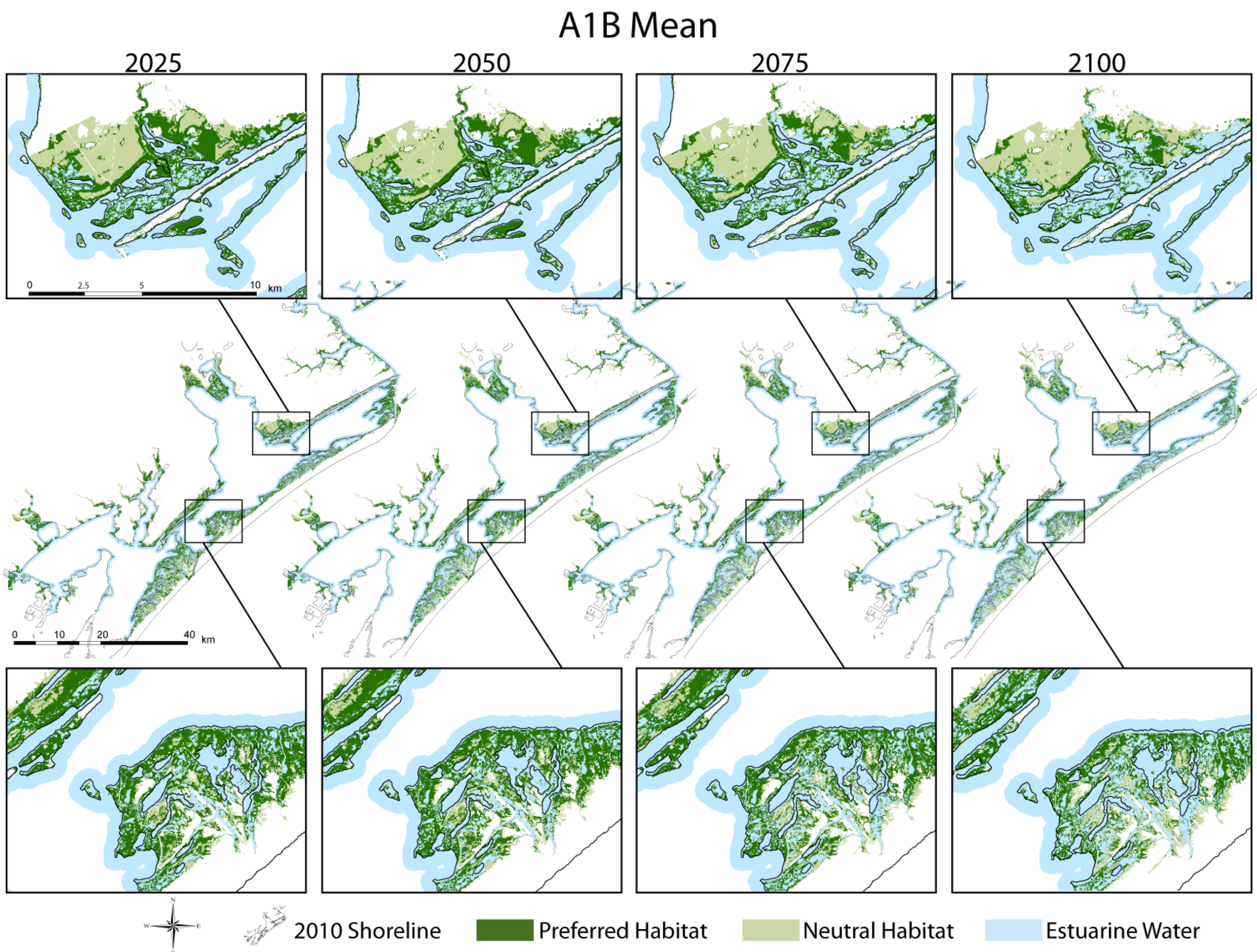

Fig. 22 Projected distribution of Preferred and Neutral potential whooping crane habitat under the A1B Mean sea level rise scenario (.39 m by 2100)

A1B Mean

The A1B Mean sea level rise scenario (Fig 22**Error! Reference source not found.**) was the most conservative sea level rise scenario used in the SLAMM. It predicted .39 m of sea level rise by 2100, increasing at a steady rate through all time steps.

Under this scenario, potential Preferred habitat for whooping cranes decreased by 31.7% to 12,590 ha by 2100 (Table 9**Error! Reference source not found.**) as almost 6,000 ha of Preferred habitat consisting of low lying marsh and flats were converted to Estuarine Water (Table 10) Neutral habitat (including Estuarine Water) increased by 18.2 % or slightly less than 10,000 ha by 2100. In addition to the conversion of Preferred habitat to Estuarine Water, about 3,000 ha of Undeveloped Dry Land (Avoided habitat) was converted to Transitional Salt Marsh.

Table 9 Change in quantity of Preferred and Neutral potential whooping crane habitat under sea level rise scenario A1B mean (.39 m by 2100)

		Initial	2025	2050	2075	2100
Preferred	Area (ha)	18,419	17,565	16,458	14,670	12,590
	% change from initial	--	-4.64	-10.65	-20.36	-31.65
Neutral	Area (ha)	53,918	55,326	57,130	59,981	63,745
	% change from initial	--	+2.61	+5.96	+11.25	+18.23
Total	Area (ha)	72,337	72,891	73,588	74,651	76,335
	% change from initial	--	+0.77	+1.73	+3.20	+5.53

Table 10 The quantity of all land cover types by preference under the A1B mean scenario (.39 cm SLR by 2100). Much of the transition from Preferred to Neutral habitat was due to inundation by Estuarine Water and conversion of upland to Transitional Salt Marsh

		Area (ha) by land cover type				
	land cover type	**Initial**	**2025**	**2050**	**2075**	**2100**
Preferred	Regularly Flooded Marsh	13,035	12,422	11,869	10,864	9,064
	Estuarine Beach	4,711	4,416	3,690	2,506	1,399
	Tidal Flat	672	728	899	1,301	2,127
Neutral	Estuarine Water	46,160	47,163	48,365	50,501	53,125
	Irregularly Flooded Marsh	7,299	7,218	7,168	6,984	6,681
	Inland Shore	209	203	197	184	174
	Mangrove	169	168	168	168	167
	Tidal Fresh Marsh	79	77	77	76	74
	Transitional Salt Marsh	--	496	1,155	2,068	3,523
Avoided	Undeveloped Dry Land	114,601	114,090	113,551	112,692	111,326
	Inland Fresh Marsh	24,043	23,992	23,976	23,951	23,896
	Open Ocean	3,867	3,933	3,946	3,971	4,003
	Inland Open Water	2,585	2,582	2,574	2,552	2,526
	Developed Dry Land	2,494	2,476	2,434	2,366	2,258
	Swamp	2,039	2,016	1,921	1,820	1,678
	Ocean Beach	544	538	531	519	504
Not Ranked	Riverine Tidal Open Water	23	18	16	14	9
	Tidal Swamp	3	3	3	3	2
	Cypress Swamp	--	1	1	1	0

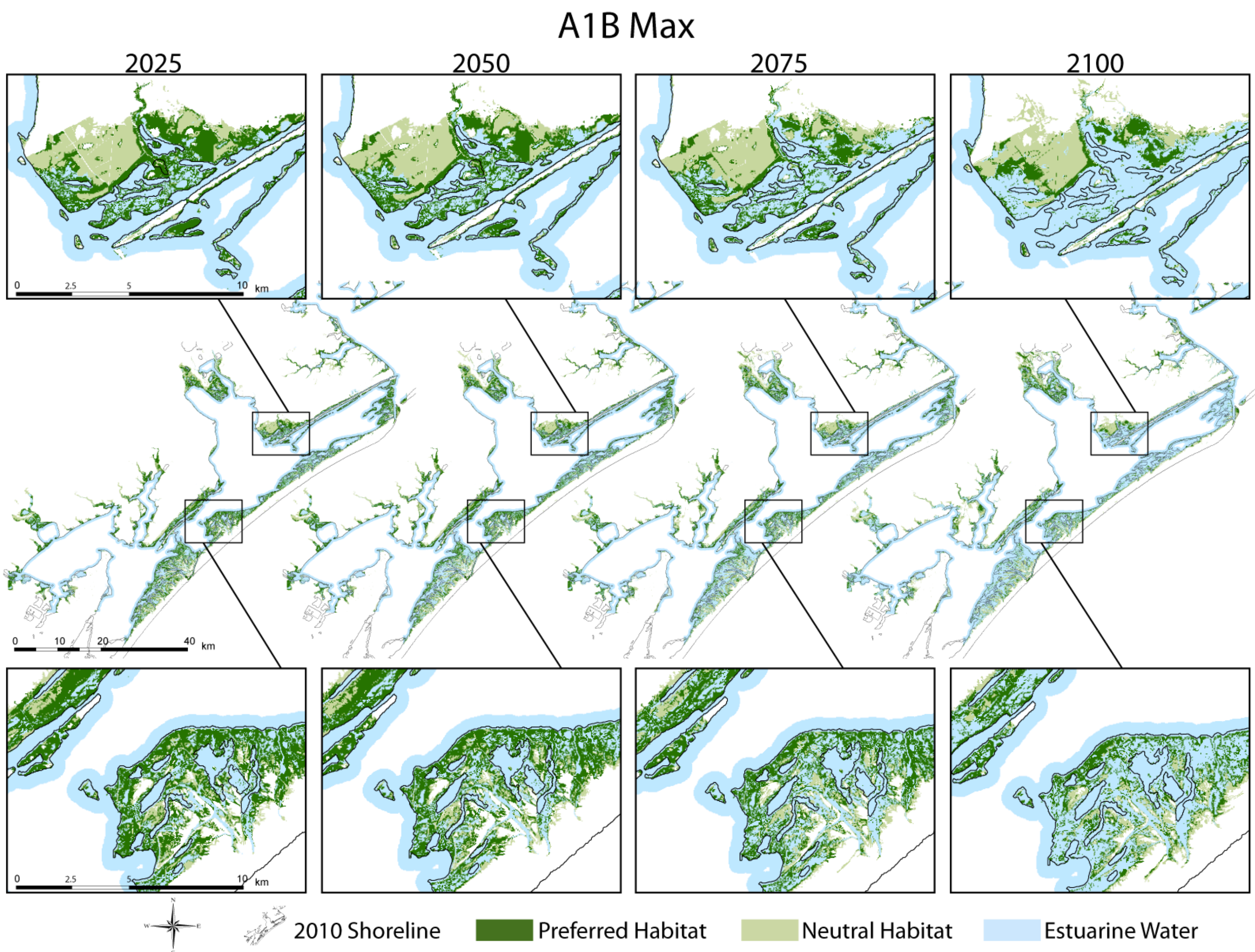

Fig. 23 Projected distribution of Preferred and Neutral potential whooping crane habitat under the A1B Max sea level rise scenario (.69 m by 2100)

A1B Max

The A1B Max sea level rise scenario (Fig 23**Error! Reference source not found.**) predicted .69 m of sea level rise by 2100, increasing at a steady rate through all time steps.

Under this scenario, potential Preferred habitat for whooping cranes decreased by 41.7% to 10,730 ha by 2100 (Table 11). As in the A1B Mean scenario, a large portion of Preferred habitat was converted to Estuarine Water (about 8,000 ha, Table 12). In this scenario, about 2,000 ha was also converted to Estuarine Water. The area of Neutral habitat increased by about 25%, with an addition of about 6,000 ha of Estuarine water and 4,500 ha of Inland Shore.

Table 11 Change in quantity of Preferred and Neutral potential whooping crane habitat under sea level rise scenario A1B Max (.69 m SLR by 2100).

		Initial	**2025**	**2050**	**2075**	**2100**
Preferred	Area (ha)	18,419	17,490	15,887	13,742	10,743
	% change from initial	--	-5.04	-13.75	-25.39	-41.68
Neutral	Area (ha)	53,918	55,488	58,179	62,654	69,525
	% change from initial	--	2.91	7.90	16.20	28.95
Total	Area (ha)	72,337	72,978	74,066	76,397	80,267
	% change from initial	--	0.89	2.39	5.61	10.96

Table 12 The quantity of all land cover types by preference under the A1B Max scenario (.60 m SLR by 2100).

		Area (ha) by land cover type				
	land cover type	**Initial**	**2025**	**2050**	**2075**	**2100**
Preferred	Regularly Flooded Marsh	13,035	12,292	10,843	7,175	5,307
	Estuarine Beach	4,711	4,347	3,146	5,153	4,913
	Tidal Flat	673	851	1,898	1,414	523
Neutral	Estuarine Water	46,160	47,271	49,236	53,023	59,380
	Irregularly Flooded Marsh	7,299	7,205	6,971	6,098	5,124
	Inland Shore	210	564	1,540	3,137	4,659
	Mangrove	170	203	192	175	156
	Tidal Fresh Marsh	79	168	165	154	147
	Transitional Salt Marsh	--	77	75	68	58
Avoided	Undeveloped Dry Land	114,601	114,016	113,193	111,412	108,510
	Inland Fresh Marsh	24,043	23,988	23,935	23,743	23,188
	Open Ocean	3,867	3,934	3,958	4,003	4,072
	Inland Open Water	2,585	2,580	2,565	2,530	2,438
	Developed Dry Land	2,495	2,473	2,404	2,270	2,138
	Swamp	2,040	2,012	1,880	1,678	1,484
	Ocean Beach	544	537	519	493	437
Not Ranked	Riverine Tidal Open Water	23	18	15	11	4
	Tidal Swamp	4	3	3	2	1
	Cypress Swamp	1	1	1	--	--

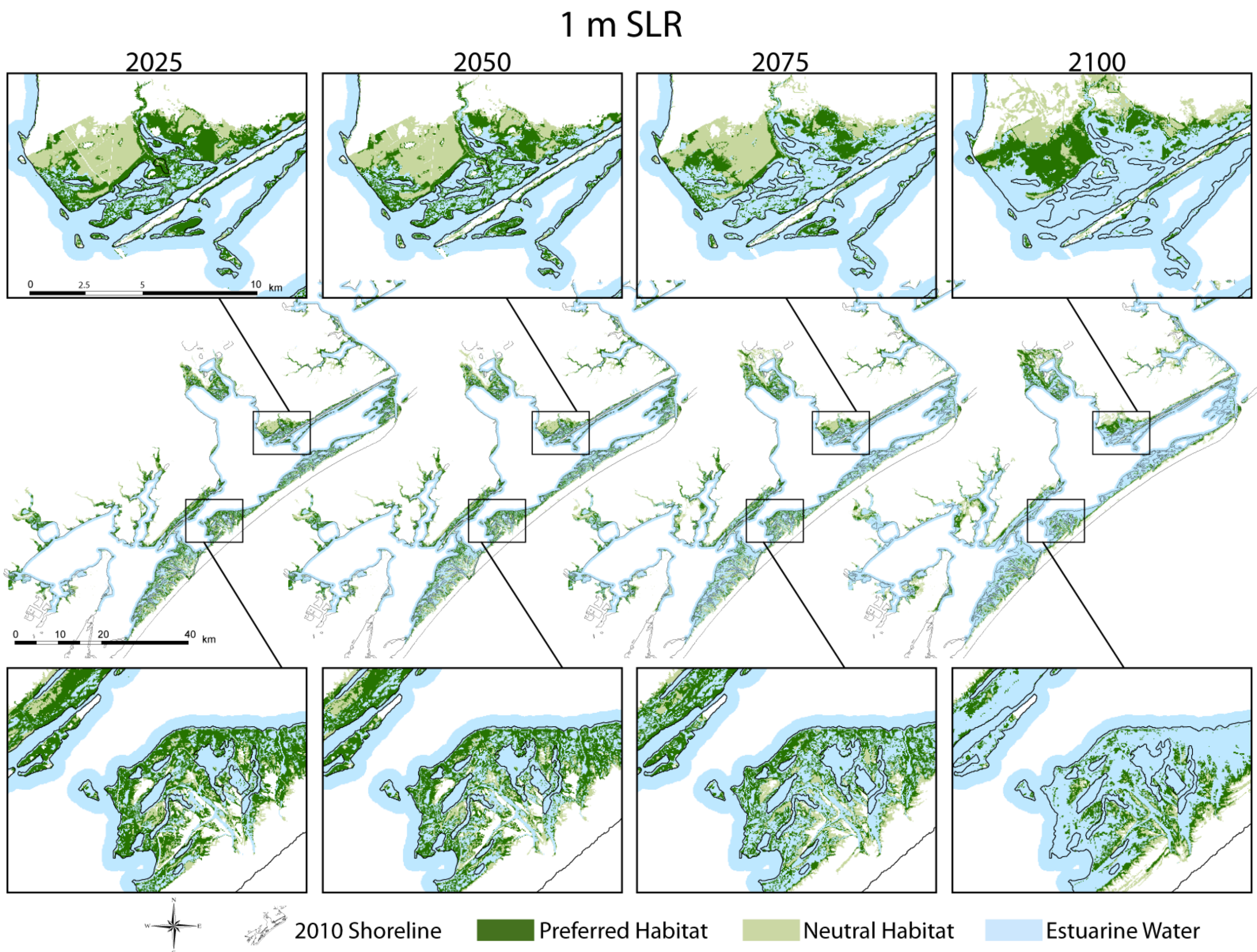

Fig. 24 Projected distribution of Preferred and Neutral potential whooping crane habitat under 1 m sea level rise

1 m Sea Level Rise

Under the 1 m sea level rise scenario (Fig 24), potential Preferred habitat for whooping cranes decreased by 33.4% to 12,253 ha by 2100 (Table 13). As expected, a large portion of Preferred habitat was converted to Estuarine Water (almost 8,000 ha, Table 14). In this scenario, about 10,000 ha of Undeveloped Dry Land was also converted to Estuarine Water. The area of Neutral habitat increased by about 32%, with an increase of about 18,000 ha of Estuarine water and 7,500 ha of Transitional Salt Marsh.

Table 13 Change in quantity of Preferred and Neutral potential whooping crane habitat under 1 m sea level rise by 2100.

		Initial	**2025**	**2050**	**2075**	**2100**
Preferred	Area (ha)	18,419	17,411	15,512	13,236	12,253
	% change from initial	--	-5.47	-15.78	-28.14	-33.48
Neutral	Area (ha)	53,918	58,828	60,824	66,563	71,135
	% change from initial	--	+9.11	+12.81	+23.45	+31.93
Total	Area (ha)	72,337	76,239	76,336	79,799	83,388
	% change from initial	--	+5.40	+5.53	+10.32	+15.28

Table 14 The quantity of all land cover types by preference under 1 m sea level rise by 2100.

		Area (ha) by land cover type				
	land cover type	**Initial**	**2025**	**2050**	**2075**	**2100**
Preferred	Regularly Flooded Marsh	13,035	12,107	9,012	6,826	7,106
	Estuarine Beach	4,711	1,053	2,499	726	258
	Tidal Flat	672	4,251	4,001	5,684	4,889
Neutral	Estuarine Water	46,160	47,394	50,232	56,212	63,827
	Irregularly Flooded Marsh	7,299	7,183	6,592	4,667	2,418
	Inland Shore	209	202	185	163	130
	Mangrove	169	166	156	142	123
	Tidal Fresh Marsh	79	76	71	54	31
	Transitional Salt Marsh	--	635	1,967	4,497	7,555
Avoided	Undeveloped Dry Land	114,601	113,941	112,729	109,761	104,356
	Inland Fresh Marsh	24,043	23,981	23,853	23,045	21,579
	Open Ocean	3,867	3,934	3,974	4,060	4,529
	Inland Open Water	2,585	2,580	2,557	2,507	2,345
	Developed Dry Land	2,494	2,470	2,370	2,186	2,024
	Swamp	2,039	2,006	1,817	1,557	1,327
	Ocean Beach	544	537	507	440	39
Not Ranked	Riverine Tidal Open Water	23	18	15	9	3
	Tidal Swamp	4	3	3	2	--
	Cypress Swamp	--	1	1	0	--

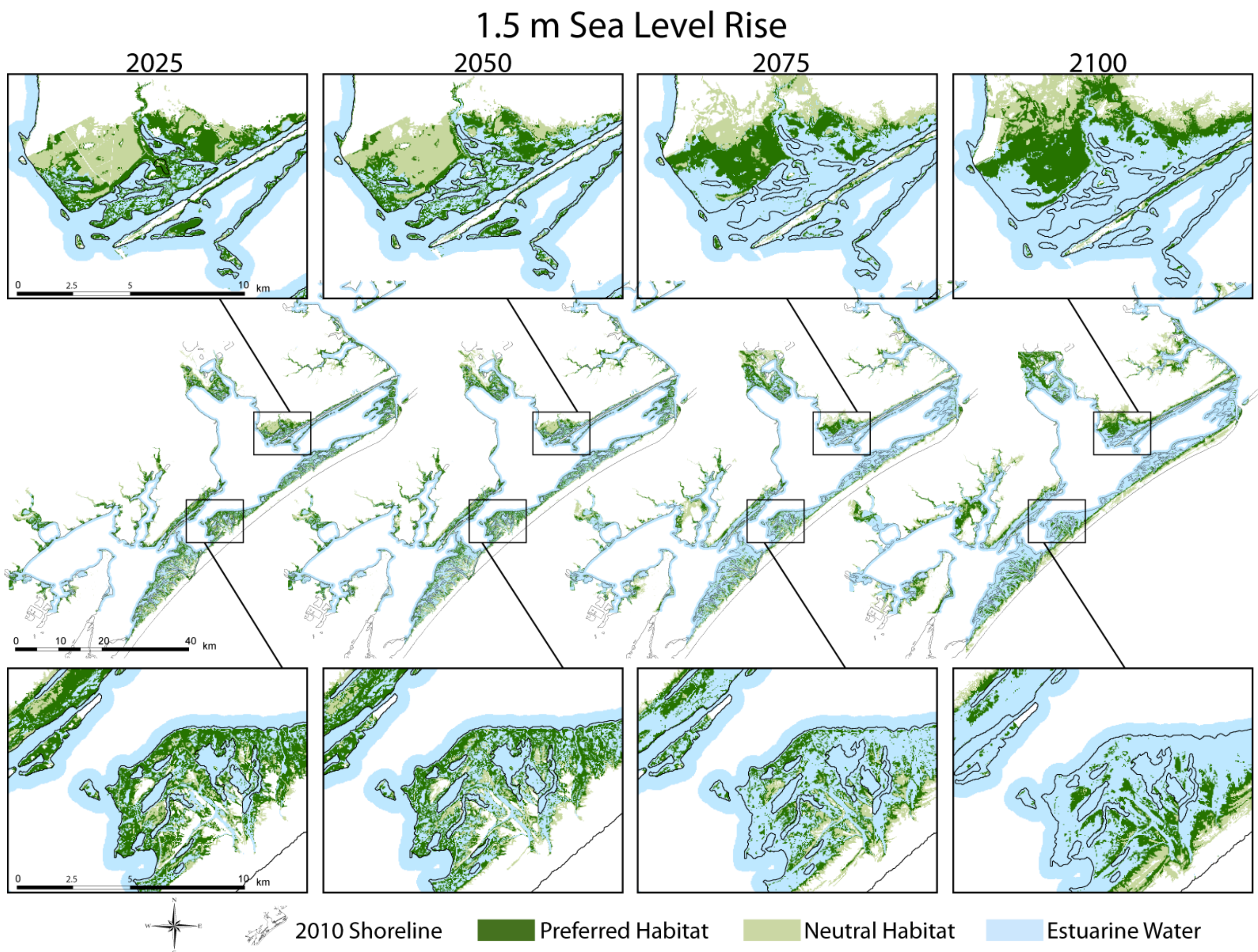

Fig. 25 Projected distribution of Preferred and Neutral potential whooping crane habitat under 1.5 m sea level rise

1.5 m Sea Level Rise

Under the 1.5 m sea level rise scenario (Fig 25), potential Preferred habitat for whooping cranes decreased by only about 4.6% by 2100 (Table 15). Neutral habitat increased by more than half, with an addition of about 21,000 ha of Estuarine Water, coming primarily from the conversion of Inland Fresh Marsh and Undeveloped Dry Land (Avoided habitat), as well as about 2,000 ha of Regularly Flooded Marsh (Preferred, Table 16). Though there was a relatively small net loss of Preferred habitat by 2100, 6,000 ha of Regularly Flooded Marsh was lost by 2075. Almost 4,000 ha were regained in the next time step, as well as over 6,000 ha of Tidal Flat.

Table 15 Change in quantity of Preferred and Neutral potential whooping crane habitat under 1.5 m sea level rise by 2100.

		Initial	2025	2050	2075	2100
Preferred	Area (ha)	18,419	17,266	15,583	12,590	17,631
	% change from initial	--	-6.68	-16.42	-33.76	-4.56
Neutral	Area (ha)	53,918	56,012	60,737	72,712	82,075
	% change from initial	--	+3.74	+12.18	+33.55	+50.27
Total	Area (ha)	72,337	73,278	76,321	85,302	99,707
	% change from initial	--	+1.29	+5.44	+17.69	+37.35

Table 16 The quantity of all land cover types by preference under 1.5 m sea level rise by 2100.

		Area (ha) by land cover type				
	land cover type	**Initial**	**2025**	**2050**	**2075**	**2100**
Preferred	Regularly Flooded Marsh	13,035	11,713	6,039	7,011	10,884
	Estuarine Beach	4,711	4,053	1,521	5,278	158
	Tidal Flat	673	1,500	8,024	301	6,590
Neutral	Estuarine Water	46,160	47,646	51,827	61,368	67,119
	Irregularly Flooded Marsh	7,299	7,120	5,507	2,252	580
	Inland Shore	210	201	177	138	81
	Mangrove	170	164	145	115	88
	Tidal Fresh Marsh	79	75	61	26	12
	Transitional Salt Marsh	--	807	3,020	8,814	14,196
Avoided	Undeveloped Dry Land	114,601	113,812	111,682	105,665	94,087
	Inland Fresh Marsh	24,043	23,964	23,497	21,195	18,223
	Open Ocean	3,867	3,937	4,010	4,511	4,729
	Inland Open Water	2,585	2,579	2,543	2,416	2,259
	Developed Dry Land	2,495	2,462	2,298	2,060	1,768
	Swamp	2,040	1,951	1,695	1,372	1,158
	Ocean Beach	544	534	478	15	607
Not Ranked	Riverine Tidal Open Water	23	18	13	4	1
	Tidal Swamp	4	3	2	0	--
	Cypress Swamp	1	1	0	--	--

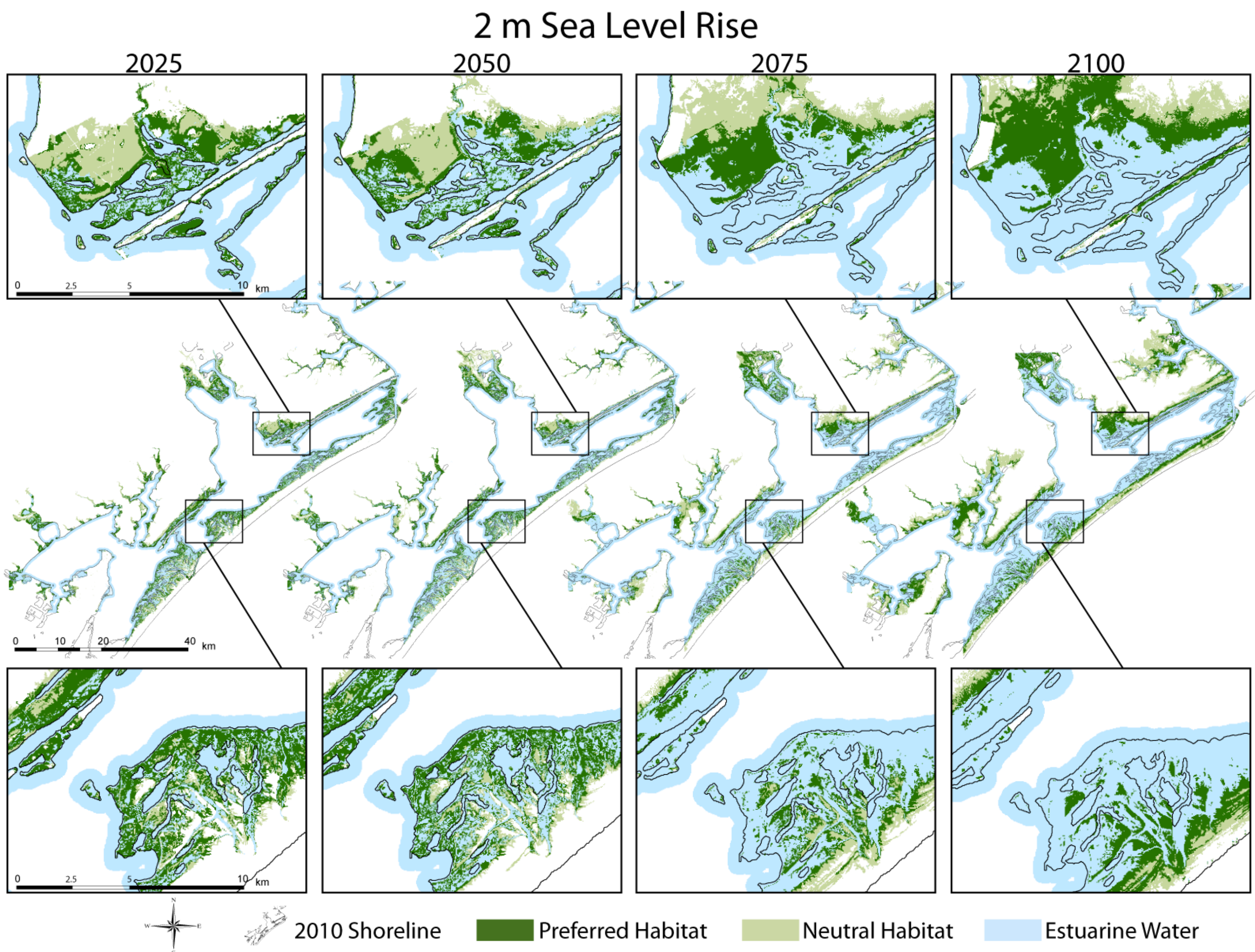

Fig. 26 Projected distribution of Preferred and Neutral potential whooping crane habitat under 2 m sea level rise

2 m Sea Level Rise

Under the 2 m sea level rise scenario (Fig 26), potential Preferred habitat actually increased by about 31.5% by 2100 (Table 17). This occurred in the last time step, as Inland Fresh Marsh and Undeveloped Dry Land (Avoided) were converted to Regularly Flooded Marsh and Tidal Flat (Table 18). Following a similar patterns as the 1.5 m sea level rise scenario, this increase in Preferred habitat followed loss of more than 4,000 ha Preferred habitat by 2075. Other notable changes include an increase of over 20,000 ha of Inland Shore (Neutral).

Table 17 Change in quantity of Preferred and Neutral potential whooping crane habitat under 2 m sea level rise by 2100.

		Initial	**2025**	**2050**	**2075**	**2100**
Preferred	Area (ha)	18,419	17,129	15,747	14,167	24,205
	% change from initial	--	-7.00	-14.51	-23.09	+31.46
Neutral	Area (ha)	53,918	56,354	62,932	79,293	90,284
	% change from initial	--	+4.52	+16.72	+47.06	+64.75
Total	Area (ha)	72,337	73,483	78,679	93,460	114,489
	% change from initial	--	+1.59	+8.77	+29.20	58.27

Table 18 The quantity of all land cover types by preference under 2 m sea level rise by 2100.

		Area (ha) by land cover type				
	land cover type	**Initial**	**2025**	**2050**	**2075**	**2100**
Preferred	Regularly Flooded Marsh	13,035	11,203	9,420	8,983	15,444
	Estuarine Beach	4,711	3,820	5,456	186	133
	Tidal Flat	673	2,106	871	4,998	8,628
Neutral	Estuarine Water	46,160	47,941	53,209	63,676	69,067
	Irregularly Flooded Marsh	7,299	7,015	4,275	861	274
	Inland Shore	210	965	5,104	14,549	20,797
	Mangrove	170	199	167	101	70
	Tidal Fresh Marsh	79	160	132	92	68
	Transitional Salt Marsh	--	74	45	13	7
Avoided	Undeveloped Dry Land	114,601	113,670	110,313	99,858	82,257
	Inland Fresh Marsh	24,043	23,937	22,730	18,934	14,936
	Open Ocean	3,867	3,943	4,481	4,580	5,268
	Inland Open Water	2,585	2,579	2,525	2,339	2,188
	Developed Dry Land	2,495	2,444	2,208	1,913	1,495
	Swamp	2,040	1,934	1,581	1,214	1,015
	Ocean Beach	544	528	9	240	891
Not Ranked	Riverine Tidal Open Water	23	17	12	2	0
	Tidal Swamp	4	3	2	--	--
	Cypress Swamp	1	1	0	--	--

Conclusions

All sea level rise scenarios show a net loss of potential Preferred whooping crane habitat by 2100 except the 2 m scenario. The increase in Preferred habitat in the 2 m sea level rise scenario may be partially attributed to an overtopping of the topographic ridge that exists along the eastern edges of the major peninsulas within the study area. This ridge, known as the Ingleside Barrier Strandplain, may prevent marsh migration inland across the coastal plain. As this ridge is overtopped, marsh migration is unimpeded across upland environments at higher elevations.

This is only one reason why conservation of habitat should extend beyond habitat identified as potential Preferred habitat under current conditions. Marsh migration can also be impeded by built structures such as roads, culverts, and buildings. If development can be concentrated on upland areas least likely to be impacted by sea level rise, potential whooping crane habitat and human economic investment can be protected.

In terms of Strategic Habitat Conservation, it may be beneficial to focus conservation efforts in two places: Preferred habitat that is likely to remain Preferred habitat and adjacent habitat that is not currently considered Preferred but may become so in the future. Identifying these areas is simply done by comparing the initial and final habitat rasters for any scenario.

One of the goals of this project was to determine whether enough habitat existed along the central Texas coast to support 1,000 whooping cranes in the Aransas-Wood Buffalo population, or at least 250 breeding pairs. A commonly used estimate for the amount of habitat needed by whooping cranes is about 200 ha per pair (Smith et al 2014).

Even under the 2 m sea level rise scenario where Preferred habitat increases by more than 31%, less than half the area needed to support the down-listing goal population size exists within the study area of the SLAMM on and around the Aransas National Wildlife Refuge.

Sea level rise should be modeled along the entire Texas coast. This would improve our ability to more completely understand potential effects of sea level rise on whooping crane recovery and many other issues related to coastal conservation and management.

Another useful addition to this analysis would be to examine the current and future state of freshwater inflows to the estuarine system. Whooping cranes rely on the contribution of freshwater to sustain much of their food and drinking water needs. Municipal, agricultural, and industrial retention of upstream freshwater supplies as well as decreased precipitation could impact the salinity of coastal wetlands that may alter habitat preference independent of sea level rise.

As in the previous section, this analysis represents a “first-cut” in understanding changes to preferred habitat for the whooping crane across the central Texas coast. In keeping with the Strategic Habitat Conservation goal of revising models b y targeting research at key model assumptions, some future recommendations are offered.

In subsequent versions, it may be useful to add additional rasters to the GIS analysis describing more sophisticated habitat variables beyond whooping crane presence/absence data and habitat type. Examples of other potentially useful variables include distance to various water features, distance to transportation or development, or barriers to sight. Habitat quality variables such as estuarine salinity, abundance of food items, or potential climate related changes to vegetation type and structure could also be incorporated. Ecological variables such as patch size and corridors, as well as territory size, location, and establishment patterns may also be helpful.

This work represents a substantial advance in understanding potential changes to the quantity and distribution of potential whooping crane habitat along the central Texas coast due to sea level rise. Future work includes a more sophisticated habitat use analysis taking into consideration other geoenvironmental variables, the territorial behavior of the whooping crane, and potential impacts of climate change.

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Elevation Data

	TNRIS DEM	Matagorda Island Lidar	NOAA Estuarine Bathymetry
Projection:	UTM Zone 14N	....	NAD_1927_UTM (zone varies by location)
Horizontal Spatial Reference:	NAD 1983	....	NAD 1927
Vertical Spatial Reference:	NAD 1983	....	local tidal datum, MLLW
Mapping theme:	elevation	elevation	bathymetry
Classification system:	....	....	....
Classification method:	....	....	....
Data type:	point cloud, raster	point cloud, raster	raster, from point soundings
Data format:	LAS, ascii XYZ, .dem	LAS, ascii XYZ, DEM	LAS, ascii XYZ, DEM
Date of source data:	2006	2002	1839-1989
Spatial resolution:	0.1-8 points/m2, 1.4 m and 5 m DEM	1 m, finer point data	30 m
Mimimum mapping unit:	....	....	....
Mapping scale:	....	....	....
Data source:	Lidar	Lidar	soundings
Coverage:	all counties	Matagorda Island only	all estuaries within study area (exluding tertiary bays in some locations)
Attributes/ application:	high resolution elevation data	very high accuracy, resolution elevation data	medium/high resolution bathymetric data- estuarine mapping, modeling, research
Possibe issues:	problems with bias and accuracy in some counties	....	data does not extend into some teritary bays (e.g. Powderhorn Lake)
Other notes:	point cloud may be useful for determination of vegetation type/density	may be useful for focusing in on "pilot project"- example of what could be done with high accuracy, high resolution Lidar data over entire Tx coast	may be useful for determining exclusionary depth for wading birds
Planned changes/updates:	intensity returns also available	....	none planned

Land Cover Data

	C-CAP regional land cover	EMST	Wetland and Aquatic Habitat	NWI	NOAA Benthic Habitat Atlas	USGS National Land Cover Dataset (NLCD)
Projection:	Albers Conical Equal Area	Albers Conical Equal Area	UTM Zone 14N	Albers Conical Equal Area	UTM Zone 14N	Albers Conical Equal Area
Horizontal Spatial Reference:	NAD 1983	NAD 1983	NAD 1983	NAD 1983	NAD 1983	NAD 1983
Vertical Spatial Reference:	NAD 1983	NAD 1983	NAD 1983	NAD 1983	NAD 1983	NAD 1983
Mapping theme:	land cover classification; 16 classes	defines ecological systems with respect to major vegetation types, >100 classes	wetland and riparian polygon data	wetland and riparian polygon data	shallow water benthic habitat classification	land surface thematic class, percent impervious surface, percent tree canopy, 16 classes
Classification system:	modified from Anderson, Cowardin, others	NatureServ Ecological System Classification System (Comer 2003)	Cowardin (1979)	Cowardin (1979)	SCHEME (2002)	Anderson (1976)
Classification method:	semi-automated	semi-automated, Ecognition	manual	manual or semi-automated	semi-automated	semi-automated decision tree
Data type:	raster	vector and raster	vector	vector	vector	raster
Data format:	.img	.img	.shp	ArcSDE geodatabase	.shp	.tif
Date of source data:	2006	2005-2007	2002-2008	1992, 2001, 2004, 2006, 2008	2009	2011
Spatial resolution:	30 m	10 m	varies	varies, sub-meter to meters	10 m	30m
Mimimum mapping unit:	30 m	100m	1:5,000	1:5,000	10 m	1 ac (~60m)
Mapping scale:	1:100,000	……………	……………	1:24,000, 1:25,000, 1:144,448	……………	……………
Data source:	Landsat ETM+, Landsat TM	Landsat TM 30 m- 3 date, soils, 10 m DEM, ecoregions, stream centerlines	2002 and 2008 NAIP 0.5 m color infrared imagery	hard copy wetland maps, NAIP imagery, DEM, GLO sumberged lands data	1 m multi spectral imagery	Landsat TM
Coverage:	entire U.S.	entire study area	entire study area	entire study area	excludes Matagorda Bay	national
Attributes/ application:	coastal intertidal areas, wetlands, adjacent uplands	designed for sub-county level land analysis	designed for TPWD seagrass monitoring program	common classification and mapping standard	……………	lu/lc classification- veg. type secondary to use classification
Possibe issues:	may need higher resolution for wetland areas; doesn't provide impervious surface data (refers to USGS impervious surface data based on 2001 Landsat)	very broad estuarine/marine classifications	some discrepancies in metadata re: dates of imagery shapefiles are based on	……………	……………	very broad estuarine/marine classifications
Other notes:	good dataset for upland areas; other products downloadable from NOAA CSC (e.g. developed area gains/losses, forest fragmentation)	provides increased thematic/spatial reolution of landcover mapping for Texas	in-house created "NWI-like data", relies heavily on vegetation for delineation of geoenvironments/wetland types	……………	……………	……………
Planned changes/updates:	……………	TPWD project 2013-2015: mapping "Conservation Opportunity Areas"	new Lidar device in the works: mapping bay shoreline change; would like to add hyperspectral to observe habitats (e.g. mangrove mapping)	……………	……………	……………

Species Data

	USFWS Critical Habitat for Threatened and Endangered Species	GLO rookeries	Coastal animal and plant species
Projection:	....	....	....
Horizontal Spatial Reference:	WGS 1984	NAD 1927	NAD 1927
Vertical Spatial Reference:	WGS 1984	NAD 1927	NAD 1927
Mapping theme:	polygons delineating critical habitat for wintering Piping Plover and Whoopiong Crane	polygons representing colonial waterbird rookeries (gulls, terns, wading birds)	points representing occurrence/distribution of animals, plants, and/or plant communities
Classification system:	critical habitat polygons as described in the Federal Register	....	....
Classification method:	....	manual	manual
Data type:	vector	vector	vector
Data format:	shapefiles	shapefiles	shapefiles
Date of source data:	....	1982-1996	1998
Spatial resolution:	....	....	....
Mimimum mapping unit:	1:5,000	....	....
Mapping scale:	....	1:24000	1:24000
Data source:	2005 NAIP imagery (Gulf coast), 1992 and 2001 NWI vector data (bay coasts)	GLO, along with TPWD, USFWS, Tx Colonial Waterbird Society	GLO based on consultation with TPWD, USFWS, many public agencies, institutions, and private groups
Coverage:	entire study area	Tx coastal counties and bays	areas adjacent to coastal bays and GOM
Attributes/ application:	intended for planning and land mamagement, not for legal survey use	....	....
Possibe issues:	bias/accuracy not quantified	data may be somewhat outdated?	per metadata: needs revision. Also, info may be obsolete, no stated accuracy assessment, no stated sampling methods, etc.
Other notes:	....	....	may be useful to map possible food sources (e.g. blue crab for whooping cranes)
Planned changes/updates:	....	....	....

Models

	NOAA Impervious Surface	**SLAMM**	**EDYS: Ecological Dynamics Simulation Model**	**SLOSH**
Projection:	User defined	State Plane Texas South Central 4204	....	....
Horizontal Spatial Reference:	User defined	NAD 83	....	NAD 1927
Vertical Spatial Reference:	User defined	NAD 83	....	NAVD 88
Mapping theme:	water quality and land cover change	Sea Level Affecting Marshes Model	....	Sea, Lake, and Overland Surges from Hurricanes
Classification system:	ISAT	Cowardin (NWI)	....	....
Classification method:	model	model	model- mechanistic, DELPHI Pascal language	model
Data type:	raster	raster	cells with variable length/width	polygon
Data format:		ESRI GRID	....	shapefiles
Date of source data:	User defined	2008	....	2008
Spatial resolution:	depends on input data	30 m	modeling abilities based on quality/resolution of input data	~1m
Mimimum mapping unit:	depends on input data	....	....	....
Mapping scale:	User defined	....	depends on resolution of input data	....
Data source:	user defined: raster based land cover/land use, impervious surface coefficients, population density	NWI, DEM, erosion and accretion rates	user-determined: temperature, soils, wind, soils, plants, stressors, climate, elevation, bathymetry etc.	NOAA
Coverage:	depends on input data	Mission-Aransas NERR	SA Bay	entire study area
Attributes/ application:	Categorizes polygons to represent water quality based on calculated imperviousness. Incorporates land cover change scenarios to examine how changes influence impervious surface coefficients.	maps distribution of wetlands under conditions of sea level rise	primary terrestrial model in USACE SWWRP	storm response and preparedness planning
Possibe issues:	....	....	code not currently publicly available, output not GIS-based	....
Other notes:	....	....	useful to evaluate potential effects of climate change, sea level rise, salinity changes, habitat use change, etc.	....
Planned changes/updates:	....	....		....

CHTD Land Cover Crosswalk

Source Datset	Macrohabitat	Mesohabitat	Microhabitat	Original ID	CHTD alpha-numeric ID	CHTD numeric ID
BHA	Estuarine	Estuarine Reef	Bivalve Reef	321	B321	197
		Estuarine Veg Seagrass	Continuous Submerged Rooted Vegetation	211	B211	195
			Patchy Submerged Rooted Vegetation	212	B212	196
			Submerged Rooted Vegetation	2	B2	194
		Estuarine Veg Shrub	Mangroves	5	B5	198
EMST	Estuarine	Estuarine Open Water	Open Water	9600	9600	193
		Estuarine Unv Flats	Coastal: Beach	6100	6100	148
			Coastal: Tidal Flat	5600	5600	173
			South Texas: Algal Flats	6610	6610	150
			South Texas: Wind Tidal Flats	6600	6600	149
		Estuarine Veg Marsh	Coastal: Borrichia Flats	5605	5605	174
			Coastal: Salt and Brackish High Tidal Marsh	5617	5617	178
			Coastal: Salt and Brackish Low Tidal Marsh	5607	5607	176
		Estuarine Veg Shrub	Coastal: Mangrove Shrubland	5606	5606	175
			Coastal: Salt and Brackish High Tidal Shrub Wetland	5616	5616	177
	Palustrine	Palustrine Unveg	Gulf Coast: Coastal Prairie Pondshore	5307	5307	179
		Palustrine Veg Marsh	Coastal and Sandsheet: Deep Sand Live Oak Swale Marsh	6407	6407	139
		Palustrine Veg Marsh	Coastal Bend: Floodplain Grassland	4507	4507	163
			Coastal Bend: Floodplain Herbaceous Wetland	4517	4517	164
			Coastal Bend: Riparian Grassland	4607	4607	170
			Coastal Bend: Riparian Herbaceous Wetland	4617	4617	171
			Marsh	9007	9007	185
		Palustrine Veg Shrub	Coastal Bend: Floodplain Deciduous Shrubland	4506	4506	162
			Coastal Bend: Floodplain Evergreen Shrubland	4505	4505	161
			Coastal Bend: Riparian Deciduous Shrubland	4606	4606	169
			Coastal Bend: Riparian Evergreen Shrubland	4605	4605	168
		Palustrine Veg Woodland/Veg Shrub	Coastal Bend: Floodplain Hardwood Forest	4504	4504	160
			Coastal Bend: Floodplain Live Oak / Hardwood Forest	4503	4503	159
			Coastal Bend: Floodplain Live Oak Forest	4502	4502	158
			Coastal Bend: Riparian Hardwood Forest	4604	4604	167
			Coastal Bend: Riparian Live Oak / Hardwood Forest	4603	4603	166
			Coastal Bend: Riparian Live Oak Forest	4602	4602	165
	Upland	Upland Developed	Urban High Intensity	9410	9410	181
			Urban Low Intensity	9411	9411	182
		Upland Grassland	Coastal and Sandsheet: Deep Sand Grasslands	6307	6307	156
			Coastal and Sandsheet: Deep Sand Grasslands Swale Marsh	6507	6507	172
			Coastal Plain: Terrace Sandyland Grassland	7907	7907	154
			Gulf Coast: Coastal Prairie	5207	5207	151
			Gulf Coast: Salty Prairie	2207	2207	152
			Post Oak Savanna: Savanna Grassland	607	607	133
			South Texas: Sandy Mesquite Savanna Grassland	7107	7107	147
			Texas Coast Dune and Coastal Grassland Active Dune	6200	6200	155
		Upland Row Crop	Row Crops	9307	9307	180
		Upland Shrub	Coastal and Sandsheet: Deep Sand Shrubland	6306	6306	157
			Gulf Coast: Salty Shrubland	2206	2206	153
			Invasive: Evergreen Shrubland	9505	9505	184
			Native Invasive: Baccharis Shrubland	9116	9116	186
			Native Invasive: Common Reed	9107	9107	187
			Native Invasive: Huisache Woodland or Shrubland	9124	9124	189
			Native Invasive: Mesquite Shrubland	9106	9106	190
			Non-native Invasive: Saltcedar Shrubland	9204	9204	191
			South Texas: Clayey Blackbrush Mixed Shrubland	7005	7005	142
			South Texas: Clayey Mesquite Mixed Shrubland	7004	7004	141
			South Texas: Sandy Mesquite Dense Shrubland	7105	7105	146
		Upland Unv	Barren	9000	9000	183
		Upland Woodland	Coastal and Sandsheet: Deep Sand Live Oak / Mesquite Woodland	6403	6403	137
			Coastal and Sandsheet: Deep Sand Live Oak Forest and Woodland	6402	6402	136
			Coastal and Sandsheet: Deep Sand Live Oak Shrubland	6405	6405	138
			Native Invasive: Deciduous Woodland	9104	9104	188
			Post Oak Savanna: Live Oak Motte and Woodland	633	633	128
			Post Oak Savanna: Live Oak Shrubland	605	605	131
			Post Oak Savanna: Live Oak Slope Forest	622	622	134
			Post Oak Savanna: Oak / Hardwood Slope Forest	624	624	135
			Post Oak Savanna: Post Oak / Live Oak Motte and Woodland	602	602	127
			Post Oak Savanna: Post Oak / Live Oak Slope Forest	643	643	129
			Post Oak Savanna: Post Oak / Yaupon Motte and Woodland	613	613	132
			Post Oak Savanna: Post Oak Motte and Woodland	604	604	130
			South Texas: Clayey Live Oak Motte and Woodland	7002	7002	140
			South Texas: Sandy Live Oak Motte and Woodland	7102	7102	143
			South Texas: Sandy Mesquite / Evergreen Woodland	7103	7103	144
		Upland Woodland/Shrub	Non-Native Invasive: Chinese Tallow Forest, Woodland, or Shrubland	9214	9214	192
			South Texas: Sandy Mesquite Woodland and Shrubland	7104	7104	145
NWI	Estuarine	Estuarine Open Water	Estuarine Subtidal Unconsolidated Bottom	E1UBL	E1UBL	23
				E1UBLh		
				E1UBLx		
		Estuarine Reef	Bivalve Reef	E2RF2M	E2RF2M	1
				E2RFN	E2RFN	2
		Estuarine Unv Flats	Estuarine Intertidal Uncons Shore Irreg Exp	E2USM	E2USM	19
				E2USMs		
				E2USMx		
			Estuarine Intertidal Uncons Shore Irreg Fl	E2USP	E2USP	20
				E2USPr		
				E2USPs		
				E2USPx		
			Estuarine Intertidal Unconsolildated Shore Reg Fl	E2USN	E2USN	21
				E2USNs		

			E2USNx		
	Estuarine Veg Marsh	Estuarine Intertidal Aquatic Bed Regularly Flooded	E2ABN	E2ABN	4
			E2ABNh		
			E2ABNs		
		Estuarine Intertidal Emerg marsh Irreg Exp	E2EM1M	E2EM1M	5
			E2EM1Ms		
		Estuarine Intertidal Emergent Marsh Irreg Fl	E2EM1/USP	E2EM1/USP	6
			E2EM1P	E2EM1P	7
			E2EM1Ph		
			E2EM1Ps		
			E2EM1Px		
			E2EM5P	E2EM5P	8
			E2US/EM1P	E2US/EM1P	9
		Estuarine Intertidal Emergent Marsh Reg Fl	E2EM1/USN	E2EM1/USN	10
			E2EM1N	E2EM1N	11
			E2EM1Nh		
			E2EM1Ns		
			E2EM1Nx		
			E2US/EM1N	E2US/EM1N	12
	Estuarine Veg Seagrass	Estuarine Intertidal Aquatic Bed Irreg Exp	E2AB3M	E2AB3M	3
			E2AB3Ms		
			E2ABM		
			E2ABMs		
		Estuarine Subtidal Aquatic Bed	E1AB3L	E1AB3L	22
			E1AB3Lx		
	Estuarine Veg Shrub	Estuarine Intertidal Scrub-Shrub Irreg Fl	E2EM1/SS3P	E2EM1/SS3P	13
			E2SS1P	E2SS1P	14
			E2SS3/EM1P	E2SS3/EM1P	15
			E2SS3P	E2SS3P	16
			E2SS3Ps		
			E2SS5P		
		Estuarine Intertidal Scrub-Shrub Reg Fl	E2EM1/SS3N	E2EM1/SS3N	17
			E2SS3N	E2SS3N	18
			E2SS3Ns		
Lacustrine	Lake Aquatic Bed	Lacustrine Aquatic Bed Perm Fl	L1ABH	L1ABH	24
			L1ABHh		
			L1ABKh	L1ABK	25
			L2AB3F	L2AB3F	26
			L2AB3H	L2AB3H	27
			L2AB3Hh		
			L2AB3V	L2AB3V	28
			L2AB4Fh	L2AB4F	29
			L2AB4Hh	L2AB4H	30
	Lake Open Water	Lacustrine Uncons Bottom Perm, Semiperm Fl	L1UBH	LUBH	31
			L1UBHh		
			L1UBHx		
			L2UBHh		
			L1UBKh	LUBK	32
			L1UBKhs		
			L1UBKx		
			L2UBKx		
			L2UBF	LUBF	33
			L2UBFh		
	Lake Unv Flats	Lacustrine Uncons Shore Mixed Fl	L2USA	L2USA	34
			L2USAx		
			L2USC	L2USC	35
			L2USCh		
			L2USCx		
			L2USJs	L2USJ	36
			L2USKh	L2USK	37
			L2USKhs		
			L2USKs		
Marine	Marine Open Water	Marine Uncons Bottom	M1UBL	M1UBL	41
	Marine Rocky Shore	Marine Intertidal Rocky Shore	M2RS2P	M2RS2P	38
	Marine Unv Shore	Marine Intertidal Uncons Shore Irreg Fl	M2USP	M2USP	39
		Marine Intertidal Uncons Shore Reg Fl	M2USN	M2USN	40
Palustrine	Palustrine Open Water	Palustrine Uncons Bottom Artif/Sermiperm/Perm Mix Fl	PUBF	PUBF	113
			PUBFh		
			PUBFs		
			PUBFx		
			PUBH	PUBH	114
			PUBHh		
			PUBHx		
			PUBKh	PUBK	115
			PUBKhs		
			PUBKx		
			PUBV	PUBV	116
			PUBVx		
	Palustrine Unveg	Palustrine Uncons Shore Artif/Seas/Temp Fl	PUS/EM1C	PUS/EM1C	117
			PUS/EM1Ch		
			PUSA	PUSA	118
			PUSAd		
			PUSAh		
			PUSAx		
			PUSC	PUSC	119
			PUSCh		
			PUSCx		
			PUSKh	PUSK	120
			PUSKhs		
			PUSKx		
			PUSR	PUSR	121

Palustrine Veg Aquatic Bed	Palustrine Aquatic Bed Float/Rooted SemiPerm/Perm Fl	PAB3F	PAB3F	42
		PAB3Fh		
		PAB3Fx		
		PAB3H	PAB3H	43
		PAB3Hh		
		PAB3Hx		
		PAB3V	PAB3V	44
		PAB4F	PAB4F	45
		PAB4Fh		
		PAB4Fx		
		PAB4H	PAB4H	46
		PAB4Hh		
		PABF	PABF	47
		PABFh		
		PABFx		
		PABH	PABH	48
		PABHh		
		PABHx		
		PABKh	PABK	49
Palustrine Veg Marsh	Palustrine Artificially Flooded	PEM1Kh	PEM1K	50
		PEM1Khs		
		PEM1Kx		
	Palustrine Emerg Marsh Intermit Fl	PEM1J	PEM1J	62
		PEM1Jh		
		PEM1Jx		
	Palustrine Emerg Marsh Mix Fl Tidal	PEM1R	PEM1R	63
		PEM1S	PEM1S	64
		PEM1T	PEM1T	65
	Palustrine Emerg Marsh Seas Fl	PEM1C	PEM1C	66
		PEM1Cd		
		PEM1Ch		
		PEM1Cs		
		PEM1Cx		
	Palustrine Emerg Marsh Semiperm Fl	PEM1F	PEM1F	67
		PEM1Fd		
		PEM1Fh		
		PEM1Fx		
	Palustrine Emerg Marsh Temp Fl	PEM1A	PEM1A	68
		PEM1Ad		
		PEM1Ah		
		PEM1As		
		PEM1Ax		
	Palustrine Farmed	PEMf	PEMf	92
		Pf	Pf	93
Palustrine Veg Marsh/Veg Shrub	Palustrine Emerg Marsh/Scrub-Shrub (mix) Interm/Tem/Seas Fl	PEM1/SS1A	PEM1/SS1A	69
		PEM1/SS1Ah		
		PEM1/SS1C	PEM1/SS1C	70
		PEM1/SS1Ch		
		PEM1/SS1Cx		
		PEM1/SS1F	PEM1/SS1F	71
		PEM1/SS1Fx		
		PEM1/SS1J	PEM1/SS1J	72
		PEM1/SS1Jd		
		PEM1/SS1Kx	PEM1/SS1K	73
		PEM1/SS3A	PEM1/SS3A	74
		PEM1/SS3Ad		
		PEM1/SS3Ah		
		PEM1/SS3C	PEM1/SS3C	75
		PEM1/SS3Ch		
		PEM1/SS3F	PEM1/SS3F	76
		PEM1/SS3J	PEM1/SS3J	77
		PEM1/SS4A	PEM1/SS4A	78
		PEM1/SS4C	PEM1/SS4C	79
		PEM1/SS4S	PEM1/SS4S	80
Palustrine Veg Shrub	Palustrine Deciduous Scrub-Shrub Semiperm/ Seas Fl	PSS1C	PSS1C	51
		PSS1Ch		
		PSS1Cx		
		PSS1F	PSS1F	52
		PSS1Fd		
		PSS1Fh		
		PSS1Fx		
		PSS1R	PSS1R	53
		PSS2C	PSS2C	54
		PSS3F	PSS3F	55
		PSS3Fh	PSS3Fh	56
		PSS3R	PSS3R	57
	Palustrine Deciduous Scrub-Shrub Temp/ Interm Fl	PSS1A	PSS1A	58
		PSS1Ad		
		PSS1Ah		
		PSS1As		
		PSS1Ax		
		PSS1J	PSS1J	59
		PSS1S	PSS1S	60
		PSS2A	PSS2A	61
	Palustrine Evergreen Scrub-Shrub Semiperm/ Seas F	PSS3C	PSS3C	81
		PSS3Ch		
		PSS3Cx		
		PSS4C	PSS4C	82
	Palustrine Evergreen Scrub-Shrub Temp/ Interm Fl	PSS3A	PSS3A	83
		PSS3Ah		
		PSS3Ax		
		PSS3J	PSS3J	84

				PSS3S	PSS3S	85
				PSS4A	PSS4A	86
			Palustrine Evergreen/ Deciduous Mix Scrub-Shrub Seas Fl	PSS1/3C	PSS1/3C	87
				PSS3/1C	PSS3/1C	88
			Palustrine Evergreen/ Deciduous Mix Scrub-Shrub Temp/Interm Fl	PSS1/3A	PSS1/3A	89
				PSS1/3J	PSS1/3J	90
				PSS3/1A	PSS3/1A	91
			Palustrine Scrub- Shrub Artificially Flooded/Farmed	PSS1Kh	PSS1K	102
				PSS1Khs		
				PSS1Kx		
				PSS3Kh	PSS3K	103
				PSSf	PSSf	104
		Palustrine Veg Shrub/Veg Marsh	Palustrine Scrub-Shrub/Emerg Marsh Mix Temp/Seas/Semiperm Fl	PSS1/EM1A	PSS1/EM1A	105
				PSS1/EM1C	PSS1/EM1C	106
				PSS3/EM1A	PSS3/EM1A	107
				PSS3/EM1C	PSS3/EM1C	108
				PSS3/EM1F	PSS3/EM1F	109
				PSS3/EM1J	PSS3/EM1J	110
				PSS4/EM1A	PSS4/EM1A	111
				PSS4/EM1J	PSS4/EM1J	112
		Palustrine Veg Woodland	Palustrine Forested Seas Fl	PFO1C	PFO1C	94
				PFO1Cd		
				PFO1Ch		
				PFO1Cx		
				PFO1F	PFO1F	95
				PFO1Fx		
				PFO3C	PFO3C	96
			Palustrine Forested Temp Fl	PFO1A	PFO1A	97
				PFO1Ad		
				PFO1Ah		
				PFO1Ax		
				PFO1S	PFO1S	98
				PFO4A	PFO4A	99
		Palustrine Veg Woodland/Veg Shrub	Palustrine Forested/Scrub-Shrub Mix Temp Fl	PFO1/SS1A	PFO1/SS1A	100
				PFO4/SS4A	PFO4/SS4A	101
	Riverine	Riverine Open Water	Riverine Uncons Bottom Perm Fl	R1UBV	R1UBV	125
			Riverine Uncons Bottom Perm Fl Tidal	R2UBH	R2UBH	126
				R2UBHx		
		Riverine Unv	Riverine Streambed Seas Fl	R2USA	R2USA	122
				R2USC	R2USC	123
				R4SBC	R4SBC	124
				R4SBCx		
				R4USCx		

Total Area by Mesohabitat

Macrohabitat	Mesohabitat	Total Area (Ha)	% of Total Area
Upland		**331544.63**	**45.71**
	Upland Grassland	156802.15	21.62
	Upland Row Crop	83088.11	11.46
	Upland Shrub	40501.98	5.58
	Upland Woodland	36186.63	4.99
	Upland Developed	11256.52	1.55
	Upland Woodland/Shrub	3238.99	0.45
	Upland Unv	470.25	0.06
Estuarine		**278524.96**	**38.40**
	Estuarine Open Water Deep	163149.05	22.49
	Estuarine Veg Marsh	42453.98	5.85
	Estuarine Open Water	34863.60	4.81
	Estuarine Veg Seagrass	18392.51	2.54
	Estuarine Unv Flats	12324.26	1.70
	Estuarine Reef	2692.63	0.37
	Estuarine Veg Shrub	2465.05	0.34
	Estuarine Veg Seagrass Deep	2183.88	0.30
Palustrine		**70990.14**	**9.79**
	Palustrine Veg Marsh	47994.37	6.62
	Palustrine Veg Woodland/Veg Shrub	6610.93	0.91
	Palustrine Veg Woodland	4832.47	0.67
	Palustrine Veg Shrub	4794.34	0.66
	Palustrine Veg Marsh/Veg Shrub	2623.85	0.36
	Palustrine Unveg	1869.63	0.26
	Palustrine Open Water	1457.25	0.20
	Palustrine Veg Shrub/Veg Marsh	527.18	0.07
	Palustrine Veg Aquatic Bed	280.12	0.04
Marine		**35658.00**	**4.92**
	Marine Open Water	34606.68	4.77
	Marine Unv Shore	954.38	0.13
	Marine Open Water Deep	95.08	0.01
	Marine Rocky Shore	1.86	0.00
Lacustrine		**7437.81**	**1.03**
	Lake Open Water	6351.71	0.88
	Lake Unv Flats	905.70	0.12
	Lake Aquatic Bed	180.40	0.02
Riverine		**1145.57**	**0.16**
	Riverine Open Water	1124.09	0.15
	Riverine Unv	21.48	0.00
Grand Total		**725301.11**	**100.00**

Total Upland Area

Mesohabitat	Microhabitat	Total Area (Ha)	% of Mesohabitat
Upland Grassland		**156802.15**	**47.29**
	Gulf Coast: Coastal Prairie	96760.41	29.18
	Gulf Coast: Salty Prairie	42773.12	12.90
	Coastal and Sandsheet: Deep Sand Grasslands	16125.95	4.86
	Coastal and Sandsheet: Deep Sand Grasslands Swale Marsh	753.61	0.23
	Coastal Plain: Terrace Sandyland Grassland	326.49	0.10
	Texas Coast Dune and Coastal Grassland Active Dune	33.56	0.01
	South Texas: Sandy Mesquite Savanna Grassland	15.7	0.00
	Post Oak Savanna: Savanna Grassland	13.31	0.00
Upland Row Crop		**83088.11**	**25.06**
	Row Crops	83088.11	25.06
Upland Shrub		**40501.98**	**12.22**
	Native Invasive: Mesquite Shrubland	8648.79	2.61
	South Texas: Clayey Mesquite Mixed Shrubland	7868.03	2.37
	Invasive: Evergreen Shrubland	6612.14	1.99
	Native Invasive: Common Reed	5212.08	1.57
	Gulf Coast: Salty Shrubland	3961.9	1.19
	Native Invasive: Huisache Woodland or Shrubland	3081.51	0.93
	Native Invasive: Baccharis Shrubland	2151.52	0.65
	Coastal and Sandsheet: Deep Sand Shrubland	1916.54	0.58
	South Texas: Clayey Blackbrush Mixed Shrubland	785.72	0.24
	Non-native Invasive: Saltcedar Shrubland	182.13	0.05
	South Texas: Sandy Mesquite Dense Shrubland	81.62	0.02
Upland Woodland		**36186.63**	**10.91**
	Coastal and Sandsheet: Deep Sand Live Oak Shrubland	8358.13	2.52
	Coastal and Sandsheet: Deep Sand Live Oak Forest and Woodland	8144.3	2.46
	Native Invasive: Deciduous Woodland	7957.86	2.40
	Post Oak Savanna: Post Oak / Live Oak Motte and Woodland	7268.17	2.19
	Post Oak Savanna: Live Oak Shrubland	1647.89	0.50
	South Texas: Clayey Live Oak Motte and Woodland	1475.84	0.45
	South Texas: Sandy Live Oak Motte and Woodland	640.22	0.19

	Post Oak Savanna: Post Oak Motte and Woodland	456.73	0.14
	Coastal and Sandsheet: Deep Sand Live Oak / Mesquite Woodland	121.3	0.04
	Post Oak Savanna: Live Oak Motte and Woodland	63.35	0.02
	South Texas: Sandy Mesquite / Evergreen Woodland	36.29	0.01
	Post Oak Savanna: Post Oak / Yaupon Motte and Woodland	14.46	0.00
	Post Oak Savanna: Live Oak Slope Forest	1.08	0.00
	Post Oak Savanna: Oak / Hardwood Slope Forest	0.92	0.00
	Post Oak Savanna: Post Oak / Live Oak Slope Forest	0.09	0.00
Upland Developed		**11256.52**	**3.40**
	Urban Low Intensity	8933.87	2.69
	Urban High Intensity	2322.65	0.70
Upland Woodland/Shrub		**3238.99**	**0.98**
	South Texas: Sandy Mesquite Woodland and Shrubland	2451.11	0.74
	Non-Native Invasive: Chinese Tallow Forest, Woodland, or Shrubland	787.88	0.24
Upland Unv		**470.25**	**0.14**
	Barren	470.25	0.14
Total		**331544.63**	**100.00**

Total Estuarine Area

Mesohabitat	Microhabitat	Total Area (Ha)	% of Total Estuarine
Estuarine Open Water Deep		**163149.05**	**58.58**
	Estuarine Subtidal Unconsolidated Bottom Deep	163136.74	58.57
	Open Water Deep	12.31	0.00
Estuarine Veg Marsh		**42453.98**	**15.24**
	Estuarine Intertidal Emergent Marsh Reg Fl	17381.69	6.24
	Estuarine Intertidal Emergent Marsh Irreg Fl	12681.66	4.55
	Coastal: Salt and Brackish High Tidal Marsh	7997.04	2.87
	Coastal: Borrichia Flats	2455.15	0.88
	Coastal: Salt and Brackish Low Tidal Marsh	1140.74	0.41
	Estuarine Intertidal Emerg marsh Irreg Exp	697.91	0.25
	Estuarine Intertidal Aquatic Bed Regularly Flooded	99.79	0.04
Estuarine Open Water		**34863.6**	**12.52**
	Estuarine Subtidal Unconsolidated Bottom	33720.68	12.11
	Open Water	1142.92	0.41
Estuarine Veg Seagrass		**18392.51**	**6.60**
	Estuarine Subtidal Aquatic Bed	8454.98	3.04
	Continuous Submerged Rooted Vegetation	7858.99	2.82
	Patchy Submerged Rooted Vegetation	1518.69	0.55
	Estuarine Intertidal Aquatic Bed Irreg Exp	559.51	0.20
	Submerged Rooted Vegetation	0.34	0.00
Estuarine Unv Flats		**12324.26**	**4.42**
	Estuarine Intertidal Unconsolildated Shore Reg Fl	5062.63	1.82
	Estuarine Intertidal Uncons Shore Irreg Fl	3115.22	1.12
	Estuarine Intertidal Uncons Shore Irreg Exp	2237.41	0.80
	Coastal: Tidal Flat	1241.51	0.45
	Coastal: Beach	396.79	0.14
	South Texas: Wind Tidal Flats	169.53	0.06
	South Texas: Algal Flats	101.17	0.04
Estuarine Reef		**2692.63**	**0.97**
	Bivalve Reef	2692.63	0.97
Estuarine Veg Shrub		**2465.05**	**0.89**
	Mangroves	970.23	0.35
	Estuarine Intertidal Scrub-Shrub Reg Fl	708.14	0.25
	Coastal: Salt and Brackish High Tidal Shrub Wetland	550.78	0.20
	Estuarine Intertidal Scrub-Shrub Irreg Fl	195.48	0.07
	Coastal: Mangrove Shrubland	40.42	0.01
Estuarine Veg Seagrass Deep		**2183.88**	**0.78**
	Continuous Submerged Rooted Vegetation Deep	913.83	0.33

	Estuarine Subtidal Aquatic Bed Deep	795.62	0.29
	Patchy Submerged Rooted Vegetation Deep	474.43	0.17
Total		**278524.96**	**100.00**

Total Palustrine Area

Mesohabitat	Microhabitat	Total Area (Ha)	% of Total Palustrine
Palustrine Veg Marsh		**47994.37**	**67.61**
	Palustrine Emerg Marsh Temp Fl	19866.81	27.99
	Palustrine Emerg Marsh Seas Fl	10544.72	14.85
	Palustrine Farmed	5643.24	7.95
	Coastal Bend: Floodplain Grassland	3400.55	4.79
	Palustrine Emerg Marsh Semiperm Fl	2443.29	3.44
	Palustrine Emerg Marsh Intermit Fl	2403.35	3.39
	Coastal Bend: Riparian Grassland	1816.87	2.56
	Coastal Bend: Floodplain Herbaceous Wetlar	777.16	1.09
	Coastal and Sandsheet: Deep Sand Live Oak !	464.38	0.65
	Palustrine Emerg Marsh Mix Fl Tidal	431.87	0.61
	Palustrine Artificially Flooded	171.32	0.24
	Coastal Bend: Riparian Herbaceous Wetland	28.14	0.04
	Marsh	2.67	0.00
Palustrine Veg Woodland/Veg Shrub		**6610.93**	**9.31**
	Coastal Bend: Floodplain Hardwood Forest	4184.83	5.89
	Coastal Bend: Floodplain Live Oak / Hardwoc	1043.29	1.47
	Coastal Bend: Floodplain Live Oak Forest	776.81	1.09
	Coastal Bend: Riparian Hardwood Forest	366.18	0.52
	Coastal Bend: Riparian Live Oak Forest	137.29	0.19
	Palustrine Forested/Scrub-Shrub Mix Temp F	53.08	0.07
	Coastal Bend: Riparian Live Oak / Hardwood	49.45	0.07
Palustrine Veg Woodland		**4832.47**	**6.81**
	Palustrine Forested Temp Fl	4027.37	5.67
	Palustrine Forested Seas Fl	805.1	1.13
Palustrine Veg Shrub		**4794.34**	**6.75**
	Palustrine Deciduous Scrub-Shrub Temp/ Int	1432.56	2.02
	Coastal Bend: Floodplain Deciduous Shrublar	1200.17	1.69
	Palustrine Evergreen Scrub-Shrub Temp/ Int	571.02	0.80
	Palustrine Deciduous Scrub-Shrub Semiperm	563.78	0.79
	Coastal Bend: Floodplain Evergreen Shrublar	419.27	0.59
	Coastal Bend: Riparian Deciduous Shrubland	242.27	0.34
	Palustrine Evergreen Scrub-Shrub Semiperm	122.94	0.17
	Coastal Bend: Riparian Evergreen Shrubland	99.34	0.14
	Palustrine Scrub- Shrub Artificially Flooded/F	76.91	0.11
	Palustrine Evergreen/ Deciduous Mix Scrub-!	64.05	0.09
	Palustrine Evergreen/ Deciduous Mix Scrub-!	2.03	0.00
Palustrine Veg Marsh/Veg Shrub		**2623.85**	**3.70**
	Palustrine Emerg Marsh/Scrub-Shrub (mix) Interm/Tem/Seas Fl	2623.85	3.70
Palustrine Unveg		**1869.63**	**2.63**
	Gulf Coast: Coastal Prairie Pondshore	1518.60	2.14

Palustrine Uncons Shore Artif/Seas/Temp Fl	351.03	0.49
Palustrine Open Water	**1457.25**	**2.05**
Palustrine Uncons Bottom Artif/Sermiperm/Perm Mix Fl	1457.25	2.05
Palustrine Veg Shrub/Veg Marsh	**527.18**	**0.74**
Palustrine Scrub-Shrub/Emerg Marsh Mix Temp/Seas/Semiperm Fl	527.18	0.74
Palustrine Veg Aquatic Bed	**280.12**	**0.39**
Palustrine Aquatic Bed Float/Rooted SemiPerm/Perm Fl	280.12	0.39
Total	**70990.14**	**100.00**

Total Lacustrine Area

Mesohabitat	Microhabitat	Total Area (Ha)	% of Total Lacustrine
Lake Open Water		**6351.71**	**85.40**
	Lacustrine Uncons Bottom Perm, Semiperm Fl	6351.71	85.40
Lake Unv Flats		**905.70**	**12.18**
	Lacustrine Uncons Shore Mixed Fl	905.70	12.18
Lake Aquatic Bed		**180.40**	**2.43**
	Lacustrine Aquatic Bed Perm Fl	180.40	2.43
Total		**7437.81**	**100.00**

Total Marine Area

Mesohabitat	Microhabitat	Total Area (Ha)	% of Total Marine
Marine Open Water		**34606.68**	**97.05**
	Marine Uncons Bottom	34606.68	97.05
Marine Unv Shore		**954.38**	**2.68**
	Marine Intertidal Uncons Shore Irreg Fl	766.82	2.15
	Marine Intertidal Uncons Shore Reg Fl	187.56	0.53
Marine Open Water Deep		**95.08**	**0.27**
	Marine Uncons Bottom Deep	95.08	0.27
Marine Rocky Shore		**1.86**	**0.01**
	Marine Intertidal Rocky Shore	1.86	0.01
Total		**35658.00**	**100.00**

Total Riverine Area

Mesohabitat	Microhabitat	Total Area (Ha)	% of Total Riverine
Riverine Open Water		**1124.09**	**98.12**
	Riverine Uncons Bottom Perm Fl Tidal	890.14	77.70
	Riverine Uncons Bottom Perm Fl	233.95	20.42
Riverine Unv		**21.48**	**1.88**
	Riverine Streambed Seas Fl	21.48	1.88
Total		**1145.57**	**100.00**