DECISION SUPPORT TOOL FOR SHORELINE PROTECTION ALONG THE TEXAS GULF INTRACOASTAL WATERWAY

Ducks Unlimited
June 2013

Executive Summary

The Gulf Intracoastal Waterway (GIWW) is economically important to the nation and to the State of Texas as it provides an effective and safe transportation system for goods. However, balancing economic values with environmental concerns borne from effects on adjacent coastal marsh systems along the Texas coast is challenging. Upon its construction in the mid-20th century, the GIWW caused initial negative impacts to the coastal marshes of the Gulf Coast. Over time, impacts have continued to occur through shoreline erosion and saltwater intrusion. Coastal marshes provide both ecological and economic benefits, so concerns over decades of degradation from these factors caused via construction and presence of the GIWW are of interest. Texas has over 144,000 acres of fresh and intermediate marsh and nearly 430,000 acres of brackish-saline marsh that are tidally influenced. While overall coastal marsh loss rates have declined over recent years, threats such as conversion of marsh from lower to higher salinity marsh types is of concern. Sections of coastal marsh along the GIWW continue to be threatened as shoreline erosion rates along the GIWW average up to 4 feet annually.

Continued shoreline erosion and alteration or loss of marsh will impact the ability of these wetland systems to support wintering waterfowl populations and other coastal fish and wildlife. North American Waterfowl Management Plan population objectives suggest that coastal marshes provide 33-50% of waterfowl energy demands in the Texas mid-coast and Chenier Plain regions. However, current habitat estimates (energy supply) suggests significant deficits in coastal marsh as well as other important waterfowl foraging habitats such as rice and moist soil in the coastal prairies. Any additional loss of coastal marsh due to shoreline erosion and habitat conversion will be detrimental to wintering waterfowl populations as well as other commercially important fisheries including brown shrimp, blue crabs, American oysters and red drum.

Rock breakwaters can mitigate some effects of erosion along the GIWW. These structures dissipate wave energy, stabilize shorelines and support reestablishment of emergent marsh along the GIWW shoreline through retention of sediments. These structures also protect against degradation of interior marshes located adjacent to the GIWW. Currently, along the GIWW in Texas there are approximately 57 miles of breakwater and revetments protecting critical marsh resources and maintenance dredge disposal areas. However, funding for additional shoreline protection remains limited. Thus the ability to evaluate, prioritize, and strategically deliver breakwater protection where it is most urgently needed is a necessity.

Herein, we address the development of Ducks Unlimited's decision support tool (model) to inform site selection for breakwater construction. While the current modeling scenarios primarily addresses protection of coastal marshes (General Marsh Model) and those that would have a large impact on waterfowl foraging resources (Marsh Specific

Model), we believe this can serve as a foundation for future modification to include other datasets or parameters that may be important to other agencies or organizations concerned with impacts from the GIWW.

Model output for the decision support tool indicates that approximately 32.5 miles of the 475 mile GIWW shoreline within our focus area are classified by the General Marsh Model as being high priority. Further classification by the Marsh Specific Model, which assigns more weight to those marsh types more beneficial to waterfowl (e.g., fresh and intermediate) indicates that approximately 45.2 miles are considered high priority for shoreline protection.

Current costs to deliver rock breakwaters range from $800,000 - $1,000,000 per mile. Using these estimates, funding of nearly $46 million would be needed to deliver approximately 45 miles of rock breakwater to protect prioritized marsh habitats from immediate or further degradation so that they can remain beneficial to waterfowl and other wetland dependent species. An additional $108 million would be needed to fully support delivery of the second tier (medium) priority areas.

Construction of breakwaters will have additional benefits beyond coastal marsh protection. Implementation of breakwaters will resolve land loss issues of concern to private landowners along the GIWW, will improve water quality with reduced turbidity, and may decrease Operation and Maintenance costs of the GIWW by reducing the amount of dredging. Constructing breakwaters at a large scale may be supported by a number of public/private interests. Our model should have applicability to federal and state agencies responsible for GIWW maintenance and operation.

Constructed Breakwater in Jefferson County, Texas

Introduction

Marshes are dynamic systems with the capacity to produce extraordinary ecological and economic benefits, and the coastal marshes along the Gulf of Mexico are no exception. Adapted to constant, but usually gradual, physical and chemical changes, these ecosystems are extremely productive and invaluable for wildlife functions. Additionally, coastal marshes provide benefits to the human population by improving water quality, recharging aquifers, and damping storm surges. These systems have naturally occurring variations in numerous ecological variables, but human development has altered natural patterns of variation and created significant negative and potentially irreversible changes. Effects such as rapid salinity flux, erosion, and subsidence cause marsh degradation at alarming rates, and also negatively affect most aquatic and terrestrial wildlife populations that depend on healthy marshes.

The coastal marshes and wetlands on the Texas Coast adjacent to the Gulf Intracoastal Waterway (GIWW) provide significant ecological and economic benefits, but are being lost or degraded due to several factors including shoreline erosion and rapid increases in salinity. Waves generated from vessel traffic (i.e. recreational boats and commercial barges) and winds have caused erosion of GIWW shoreline in many areas to as much as four times the designed 221-foot width (125-foot wide bottom channel plus side slopes) maintained by the U.S. Army Corps of Engineers. Eroded shorelines and widened tidal channels allow saline water to enter marshes that were historically freshwater/intermediate wetland systems prior to the construction of the GIWW. This hydrological alteration and resulting increased salinity typically kills or stresses vegetation not adapted to such conditions, thereby decreasing marsh diversity and productivity. As fresh and intermediate emergent marsh communities decrease, marsh typically converts to open-water subject to increased wave energy that further accelerates shoreline erosion and emergent marsh loss.

Rock breakwaters are a successful and widely supported technique for eliminating or reducing shoreline erosion. Construction of breakwaters was a recommended practice determined by a multi-agency planning team led by the U.S. Army Corps of Engineers addressing similar shoreline erosion and marsh loss along the GIWW in Matagorda County. Constructed within the GIWW parallel to the shoreline, breakwaters dissipate wave energy away from the shoreline. Breakwaters allow for the stabilization and protection of the existing shoreline, and also support the reestablishment of intertidal emergent vegetation along the shoreline through retention of sediments.

Hundreds of miles of GIWW shoreline and thousands of acres of coastal marsh adjacent to the GIWW would benefit from breakwater protection. However, funding is typically not available to meet these needs simultaneously. Therefore, we developed an assessment and prioritization tool for implementation of breakwaters along the Texas Coast to enable strategic allocation of limited funding for breakwater construction. Our prioritization tool uses GIS technologies coupled with marsh attributes to assess the greatest threats to Texas Gulf Coast wetlands along the GIWW, with a particular focus towards those coastal marsh systems important to waterfowl conservation. This tool should help guide financial resource allocations, policy, regulatory, and implementation decisions at local, state and federal levels.

Objective

Our objective was to develop a decision support tool to assist policy makers, administrators, regulatory agents, landowners, and conservation planners with an evaluative and cost effective means of implementing shoreline protection along the GIWW.

GIWW History

The motivation for inland waterways to provide military, political, and commercial benefits to our nation can be traced back as early as Thomas Jefferson and other founding fathers. Waterway canals along the eastern US shoreline began in the early 1800s. In 1826 upon assignment of the President John Quincy Adams, the Army Corps of Engineers began to examine the difficulties and expense of creating a protected passage to permit inland navigation along the Gulf Coast, which became the groundwork for the GIWW.

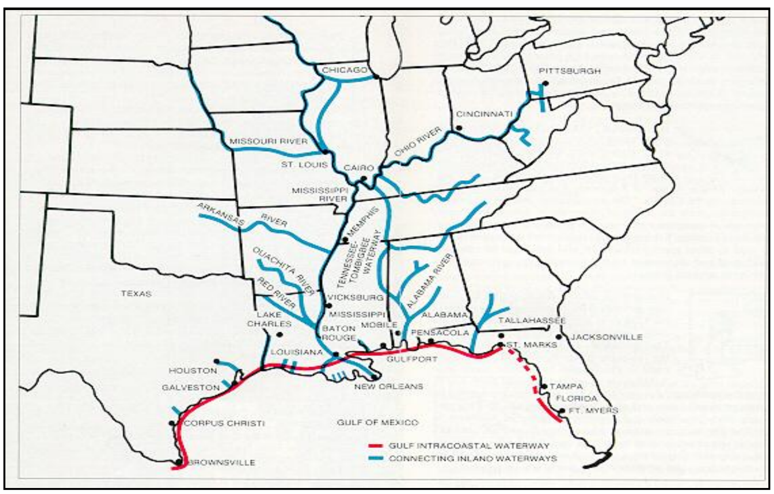

Figure 1. Gulf Intracoastal Waterway and Connecting waterways

Though the route for the eastern portion of the GIWW was described by 1829, significant construction would not begin for almost one hundred years due to more urgent domestic and military issues of the 19th century. In the early 1900s President Theodore Roosevelt, as a champion for national transportation, leveraged Congress to approve surveys for inland waterway projects from Boston to Brownsville. Another notable contributor to the creation of the GIWW was a group of businessmen from Victoria, Texas named the Interstate Inland Waterway League. With a goal to create a continuous system connecting the Great Lakes, through the Mississippi River, to the coastlines of Louisiana and Texas, the League played an integral role with the establishment of the GIWW. The Gulf Intracoastal Canal Association, as the League is known today, serves as a prominent private industry leader in the use and management of the GIWW.

Though smaller, privately-funded man-made alterations for inland waterways had been created in Texas prior to 1875 (West Galveston Bay to Brazos River Canal, and the Caney Creek re-channel to Matagorda Bay), construction of the first segment of the main canal route for the GIWW by the federal government began January 19, 1893 in West Galveston Bay. Over the course of the next 50 years, there were several events and efforts that contributed to the completion of the GIWW. The Rivers and Harbors Act of 1925 authorized the first continuous Louisiana-Texas waterway from New Orleans to Galveston, with an extension to Corpus Christi following two years later.

The Second Supplemental National Defense Appropriation Act of October 26, 1942 funded the construction of a continuous waterway with the minimum dimensions of 12-foot depth and 125-foot bottom width (current maintenance dimensions performed by US Army Corps of Engineers) extended from Carrabelle, Florida to Corpus Christi, Texas. Construction for the final segment of the main channel, Corpus Christi to Brazos Santiago Pass near Brownsville, began December 12, 1945, and was completed on June 18, 1949, which completed the GIWW's main channel construction.

Since its creation, technological breakthroughs in vessels, barges, and navigation have required periodic updates and modifications to the GIWW. Modifications such as alteration of bridges, pipelines and roads along with land acquisition and condemnation are typically assumed by a local sponsor. Prior to1975, Texas had no single sponsor, but rather an assemblage of navigation districts, port and river authorities. The Texas Coastal Waterway Act of 1975 authorized the state to become the GIWW's local sponsor and designated the State Highway and Public Transportation Commission to act on behalf for the state. The act further mandated the Commission to carry out the state's coastal policy, emphasizing the importance of protecting the environment in conjunction with supporting shallow-draft navigation improvements.

Coastal Marsh: Importance, Types, Loss and Threats

Coastal marsh habitats have significant biological and economic value. They provide vital nursery grounds for recreational and commercial fish species, support threatened and endangered species of plants and animals and provide permanent and seasonal habitat for many species of wildlife including migratory birds. In addition, these systems perform chemical and physical functions such as nutrient and pollutant filtration, and coastal storm protection and flood abatement. Thus the ability to maintain a functioning and healthy coastal marsh component within the estuarine ecosystem is essential to the biological and economic sustainability of coastal regions.

Coastal marshes are complex systems that inhabit the transitional zone between intertidal marine and terrestrial uplands. Both biotic and abiotic factors in these systems influence the structure and function of wetland communities by influencing wetland plant community composition. However, general characteristics of coastal marshes primarily include: tidal inundation, gradual variation in salinity, and vegetation adapted to inundation and saturated soil. The salinity gradient within coastal marsh is predominantly a result of changes in elevation away from the shore and tidal creek systems, and therefore marsh vegetation tends to align itself in zonal bands. The four common types of marsh (from higher to lower elevation gradient) found in these parallel bands are fresh, intermediate, brackish and saline. Within Texas, it is estimated that around 834,000 acres of the previously described coastal marsh types exist. Of that total acreage, those acres of tidally influenced coastal marsh consists of approximately 144,000 acres of fresh and intermediate marsh and around 430,000 acres brackish and saline wetlands as derived from TPWD Ecological System Classification Data (tidally influenced marsh; Phase 2 and 3). The remaining 260,000 acres are comprised of non-tidally influenced coastal marsh.

Figure 2. Shoreline erosion along GIWW

It is estimated that Texas had a net loss of approximately 210,590 acres of coastal wetlands from the mid-1950's to early 1990's. This is an average annual loss of nearly 5,700 acres of wetlands. While loss rates have declined over recent years, coastal wetlands still remain under threat primarily due to conversion. Threats include development, land fragmentation, pollution, channelization, invasive exotic species, sea level rise and subsidence, reduced freshwater inflows, alterations of hydrology, and erosion. Threats to coastal marsh habitats adjacent to the GIWW are primarily those derived from loss of freshwater inflows, erosion, and changes in hydrology which include changes in marsh composition or conversion to open water due to increased salinity.

The route of the GIWW is located near the coastline of the Gulf of Mexico, and connects many coastal towns and communities to each other. Unfortunately, the route was made primarily through bays, coastal prairie, coastal marshes and wetlands. This route had significant impacts to the hydrology of the coastal marsh watershed by dividing drainage areas and preventing salinity gradients and inflows, and by creating a large artificial channel that allows higher salinity water from the Gulf of Mexico to enter into marshes that were historically fresh or intermediate. Much of the wetlands and coastal habitats located on the south and east side of the GIWW (between GIWW and Gulf of Mexico) are thought to have higher salinities than prior to the construction of the GIWW. Consequently, subsidence and marsh conversion to open water can be observed in these areas. In Jefferson County, rainwater drainage from the North has been altered and in several places there is too much standing freshwater. This situation affects habitats north of the GIWW by drowning them.

The GIWW is authorized with a bottom channel maintenance width of 125 feet, an over-depth of 16 feet, and side slopes with a 1:3 (Vertical / Horizontal) ratio from the channel toe to the top of slope. Therefore, the designed width of the operated and maintained GIWW is ~221 feet wide. Unfortunately due to vessel and wind generated waves, the waterway has eroded to a width several times wider than originally constructed. In some places, estimated erosion rates along the shoreline of the GIWW are as much as 10 feet in some years, with an average annual loss of up to 4 feet in most years (Figure 2).

The concern with erosion is not only the direct loss of land and resulting loss of emergent shoreline habitats to open water, but also the increased introduction of higher salinity water and tidal energy into fresh and intermediate salinity, low tidal energy wetlands. A natural or artificial channel will introduce higher salinity water into marsh interiors that do not typically receive regular inundation of saltwater, and may not be adaptable for these influences of inflows. Additionally, boat and wind-driven waves spill over marshplain elevations forcing higher salinity water into these wetlands. The introduction of higher salinity water results in a degradation and loss of ecologically important wetland plants, and typically results in conversion of marsh to open water. Rapid increases in salinity kill marsh vegetation not adapted to such conditions. As the plants die or decompose soil composition changes causes organic soils typically found in coastal marshes to breakdown. Subsequently, pond bottom elevation becomes too low to support intertidal plant species and an open water condition results. Shoreline erosion and wetland loss rates are further exacerbated by wave energies and erosive forces related to increased wave fetch and tidal energy in the open water areas.

Waterfowl Habitat Deficits

The Gulf Coast Joint Venture has derived migrating and wintering waterfowl population objectives for habitats within the TX Mid-Coast and TX Chenier Plain Initiative Areas (Figure 3) to support nearly 4.2 million ducks and geese. These Initiative Areas also correspond to the area of interest in development of the shoreline protection decision support tool. The coastal marsh habitats of the TX Mid-Coast and TX Chenier Plain comprise 32 and 46%, respectively, of all the waterfowl energy demand in these two regions during the wintering period. Additionally, estimates also show that based on current waterfowl population objectives, significant energy deficits exist across all habitat types within these regions with coastal marsh incurring 39% of the energetic deficit and rice/ moist soil habitats in the coastal prairies accounting for the remaining 61%.

Figure 3. Gulf Coast Joint Venture Initiative Areas

Given that palustrine (coastal prairie) wetlands are the fastest disappearing wetland type in Texas, and the additional uncertainty introduced by declines in rice production along the coast, the need to maintain functional coastal marsh systems become more important than ever for the Texas coastal landscape and the waterfowl that use them. Any decrease in coastal marsh habitats will further reduce the ability of these coastal systems to support waterfowl populations. Therefore the ability to evaluate and prioritize areas for marsh protection and at minimum maintains current capabilities of habitat are vital toward supporting waterfowl populations migrating through and wintering along the Texas Coast.

Reduced Fisheries Habitat Concerns

Tidal marsh habitats are not only beneficial to waterbirds, but also serve important functions for aquatic organisms by providing food and shelter. Approximately 95 percent of marine organisms found in the Gulf of Mexico depend on estuarine habitats during their life cycle. The production of phytoplankton in marshes and estuaries create the basis of the food chain for many species. Emergent vegetation, such as *Spartina alterniflora*, provides shelter and nursery areas for many marine species. Recreationally and commercially important species such as brown shrimp, American oyster, blue crab, red drum, spotted sea trout, and flounder depend upon emergent marsh habitats at some stage in their life cycles. The loss or reduction of emergent marsh habitats along the Texas Coast can have significant impacts to these ecologically and economically important species. For instance, brown shrimp, considered to be most valuable fishery in the United States, enter bays and estuarine marshes during their post larval stage, in spring months to feed on organic matter until they reach an adequate size to move into bays or the Gulf. Decreased area of coastal marsh habitat, and increased open water areas yield less organic matter, and thus reduced foraging opportunities and shrimp carrying capacity. Furthermore, spotted sea trout (also known as speckled trout) and red drum will migrate into bays, bayous, and tidal openings to feed on invertebrates such as shrimp, crab, and smaller fish that are produced from emergent marshes.

Breakwater Design and Implementation

The primary function of the breakwater structure is to stop or greatly reduce the energy of waves before reaching the shoreline. The reduction in wave energy allows for shoreline stability and the re-establishment of emergent vegetation in the protected area between the breakwater and the shoreline. Sediment trapped behind the breakwater will result in soil accretion on the protected side of the breakwater structure, thus providing for the re-establishment of wetland vegetation. The decrease in erosion rate also prevents damage to sensitive marsh habitats from rapid salinity variation. In addition, the construction of low-water crossings or crested weirs in conjunction with breakwater development can

Figure 4. Typical Breakwater structure along GIWW

limit saltwater intrusion while still providing adequate hydrologic exchange and fishery movements.

Various breakwater structures have been constructed within the GIWW in Louisiana and Texas (Figure 4). These efforts have been rather "piece-mealed" by public agencies and NGOs to address specific concerns. In Texas, McFaddin National Wildlife Refuge (NWR) in Jefferson County has installed dozens of miles of breakwater along the GIWW. They have served as the model example for several other projects at J.D. Murphree WMA, Anahuac NWR, and San Bernard NWR. Ducks Unlimited has assisted in several of these efforts by securing funds, developing engineering drawings and specifications, obtaining regulatory permits, and contracting construction. In the past 5 years, DU has constructed more than 3 miles of breakwaters along the GIWW with several more miles in the planning and regulatory review stages.

Figure 5. Typical Plan View of Breakwater Placement outside of GIWW ROW and Maintained Channel

Breakwater structures are built in shallow water (<3 feet deep) along the edge of the GIWW, at varying distances from the shoreline and were soils are conducive to supporting without subsidence. In some places the breakwater is constructed on the edge of the shoreline and in some places it may be up to 60 feet out into the shallow water of the GIWW, yet not within the Right Of Way. Typical design is a trapezoidal structure built of rock (400 lb, C stone) up to a height of 3.0 – 3.5 NAVD 88, which yields approximately 1- 1.5 feet of rock exposed above the mean high tide level. Other approximate features of the design include a 3-4 foot wide crown, a 1-1.5:1 slope, and a base no more than 25 feet wide (Figure 5 and 6).

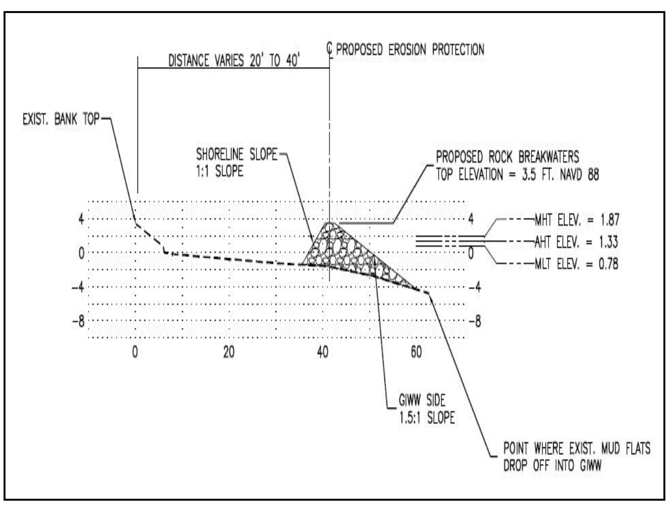

Figure 6. Typical Cross Section of Breakwater

Shoreline protection projects using breakwater structures have been successful in reducing the rate of shoreline erosion along the GIWW. In several areas, the shoreline has accreted and marsh vegetation has re-established behind the breakwater. Many conservation agencies and organizations recognize breakwater structures as being an important strategy for protecting and preserving marsh habitat along the GIWW. The U.S. Fish and Wildlife Service, with assistance from Texas Coastal Erosion, Protection, and Restoration Act (CEPRA) funding, has constructed several breakwater projects along the GIWW at McFaddin and Anahuac National Wildlife Refuges. Additionally, funding from federal sources such as Coastal Impact Assistance Program (CIAP) and the North American Wetlands Conservation Act (NAWCA), along with private funding, has supported breakwater construction to protect ecologically valuable shorelines in Jefferson and Brazoria counties.

Methodology and Development of Breakwater Decision Support Tool

We chose marsh, inflow (tidal channels), and distance to open water habitat as the three parameters to construct the breakwater decision support tool. We believe these are the primary drivers for identifying and prioritizing lands in need of protection from internal erosion and marsh degradation through saltwater intrusion. Loss of the land barrier between the shoreline and the open water also leaves an area more vulnerable to emergent marsh loss and increased erosion rates. Likewise natural and artificial tidal channels can contribute to increased saltwater inflow and intrusion and overall higher salinities and more rapid and frequent changes in salinity.

Marsh areas were defined using the TPWD Ecological Systems Classification Project (Phases 2 and 3). From this dataset, we extracted only tidally influenced fresh / intermediate and brackish / saline marsh types. Marsh that fell within a 500 m buffer of the GIWW centerline was included as the marsh parameter in the model run. Inflow was defined by the presence of tidal channels which were identified using Tiger 2012 hydrographic line data in combination with manual editing based on ESRI world imagery. Any tidal channels intersecting the GIWW were determined to influence inflow into adjacent marsh and were included in the analysis. These tidal channels were buffered by 100m and any transects, calculated with the Digital Shoreline Analysis System (DSAS) ArcGIS extension, that crossed the buffers were selected and converted to a 100 m raster dataset. We derived open water distance by delineating features within 2000m of the GIWW center using digital topographic maps, and we calculated distance to these features with DSAS (Figure 7).

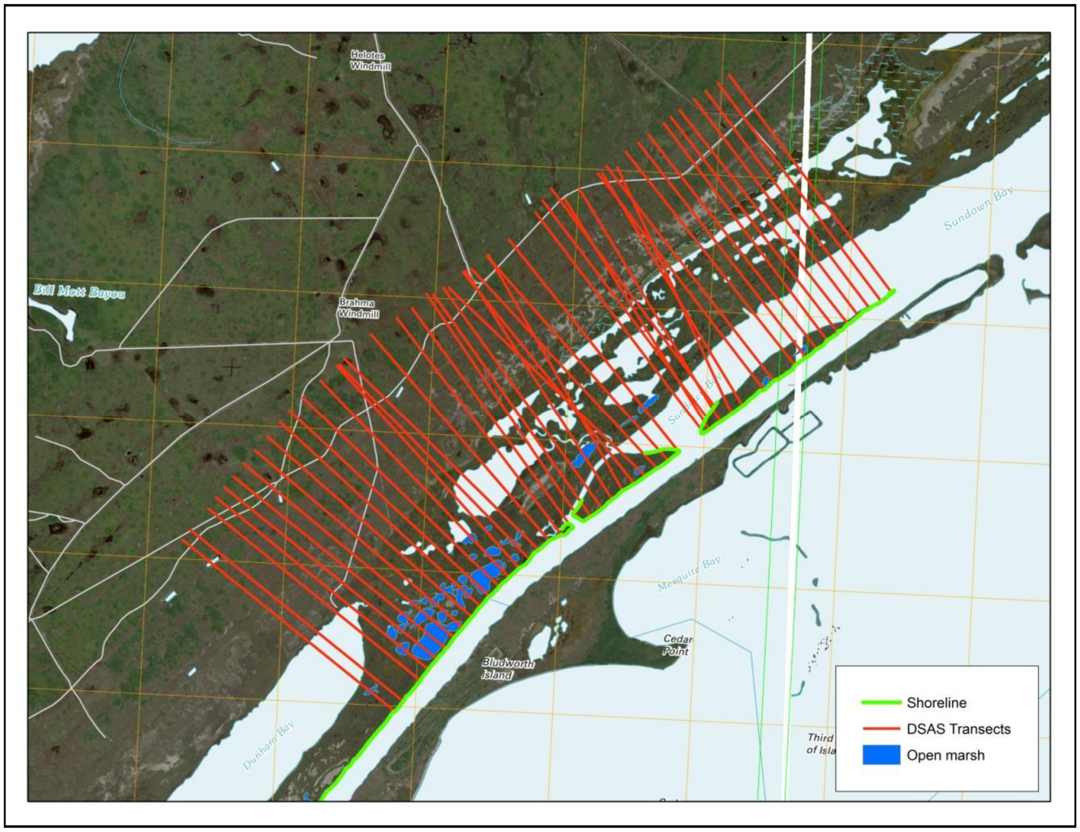

Figure 7. DSAS output transects used to calculate distance to marsh features

We computed output for the breakwater decision tool using various model equations to prioritize shoreline protection. The General Marsh Model,

Equation 1: marsh presence * (marsh presence + inflow + distance to open water),

was used to derive priorities based on the presence or absence of marsh within 2000 meters, the existence of inflow channels and distance to open water.

As previously stated, coastal marsh types provide varying foraging carrying capacity for waterfowl with freshwater marsh generally providing the greatest available energy and salt marsh the lowest. Considering this variation, a Marsh Specific Model was constructed for prioritization. Like the General Marsh Model, the Marsh Specific Model also incorporates inflow and distance to open water as parameters. However, additional weight is given to marsh type and the following equation was used:

Equation 2: marsh presence * (marsh type + inflow + distance to open water).

We converted all parameters to 100 m pixel resolution raster datasets for input into the model. Values within each raster dataset were given appropriate values based on the weights provided in Table 1 and run through the model, on a pixel by pixel basis, using the aforementioned equations.

The GIWW currently has some shoreline protection in the form of rock breakwaters and shoreline revetments. These areas were digitally delineated using high resolution imagery (Google earth imagery, ESRI Image services, and Bing maps) and removed from the dataset prior to estimating final prioritization output.

Table 1. General Marsh and Marsh Specific Model Parameter Weights to derive

Parameter	Weight
Marsh Presence (General)	
Present	1
Absent	0
Marsh Type (**Specific**)	
Fresh / Intermediate	6
Brackish / Saline	3
Inflow	3
Distance to open water (model parameter)	
< 100 m (dist5)	5
100 – 500 m (dist4)	4
500 – 1000 m (dist3)	3
1000 – 2000 m (dist2)	2

In order to establish priorities, the values were categorized. The General Marsh Model produced values ranging from 0 to 9, and is delineated into priorities based on the following scores: low priority score of 1-3; medium priority scores of 4-5; and high priority for scores 6-9. The rational for establishing how the scores fall within these priority classifications is that low value or priority would be given to an area that is marsh with an open water area more than 1000 meters (dist 2) from the GIWW shoreline. Medium priority would be given to transects including presence of marsh and open water at least 500 meters (dist 3) from GIWW shoreline or any area that has a tidal inflow. Higher priority is given to any marsh with open water within close proximity to the GIWW shoreline (less than 500 meters; dist 4 and 5) or any marshes with open water within 1000 meters that has a tidal inflow. The conditions for establishing high priority categorization were those that have the most immediate threat for direct shoreline erosion affecting open water marshes within a relatively short period of time, or marshes that could be degraded internally through tidal inflows (Table 2).

The Marsh Specific Model considers value for marsh type, instead of just marsh presence, producing values ranging from 0 to 14. Priority classifications for the corresponding scores were as follows: low priority for scores 1-3; medium priority for scores 4-7; and high priority for scores 8-14. The rational for priority classification under the Marsh Specific Model was similar to the General Marsh Model, with additional consideration for marsh type. Low priority areas were considered those with marshes with no open water within 2000 meters of the GIWW shoreline. Medium priority areas are those where any brackish/saline marsh (sal), with open water exists between 100 to 2000 meters of the GIWW shoreline or any situation where brackish /saline marsh with open water within 2000 meters and a tidal inflow exists. High priority was given to any area with fresh/intermediate marsh (fresh) and open water, any marsh type with open water within 500 meters of the GIWW shoreline, or any marsh type with open water within 2000 meters and tidal inflow (Table 3).

Table 2. General Marsh Model scoring scenarios and prioritization

Model input	Model value	Priority level
no marsh at the location	0	no
marsh and nothing else	1	low
marsh + dist2	3	low
marsh + inflow	4	med
marsh + dist3	4	med
marsh + dist4	5	med
marsh + inflow + dist2	6	high
marsh + dist5	6	high
marsh + inflow + dist3	7	high
marsh + inflow + dist4	8	high
marsh + inflow + dist5	9	high

Table 3. Marsh Specific Model scoring scenarios and prioritization

Model input	Model value	Priority level
no marsh at the location	0	no
sal + nothing	3	low
sal + dist2	5	med
sal + dist3	6	med
sal + inflow	6	med
fresh + nothing	6	med
sal + dist4	7	med
sal + dist5	8	high
sal + inflow + dist2	8	high
fresh + dist2	8	high
sal + inflow + dist3	9	high
fresh + dist3	9	high
fresh + inflow	9	high
sal + inflow + dist4	10	high
fresh + dist4	10	high
sal + inflow + dist5	11	high
fresh + dist5	11	high
fresh + inflow + dist2	11	high
fresh + inflow + dist3	12	high
fresh + inflow + dist4	13	high
fresh + inflow + dist5	14	high

Figure 8 is a representation of how the general marsh model output is calculated. Assuming the entire area is marsh and given a value of 1, the distance to open water weights the pixels in the model area based on how close the open water resources are to the shoreline. As seen in the figure the closer body of water (blue polygon) is given a weight of 5 and is <100 m from the shoreline. The other open water resource in the image is < 500 m from the shoreline and given a weight of 4. Tidal channels are buffered by 100 m and given a weight of 3. The middle image shows the section of the model that will be influenced by the tidal channel input. The model ouput is summarized and computed based on these parameters and is illustrated in the bottom portion of Figure 8. Thus the yellow pixels (medium priority) in this figure are computed as follows:

Marsh presence (1) * marsh presence (1) + inflow(0) + distance to open water (4) = 5 and high priorty areas (red) are calculated as :

Marsh presence (1) * marsh presence (1) + inflow(3) + distance to open water (4 or 5) = 8 or 9

When substituting in marsh type, the variable for marsh presence within the parenthesis changes based on the marsh type weight. Marsh presense outside of the parenthesis would remain the same (0 or 1).

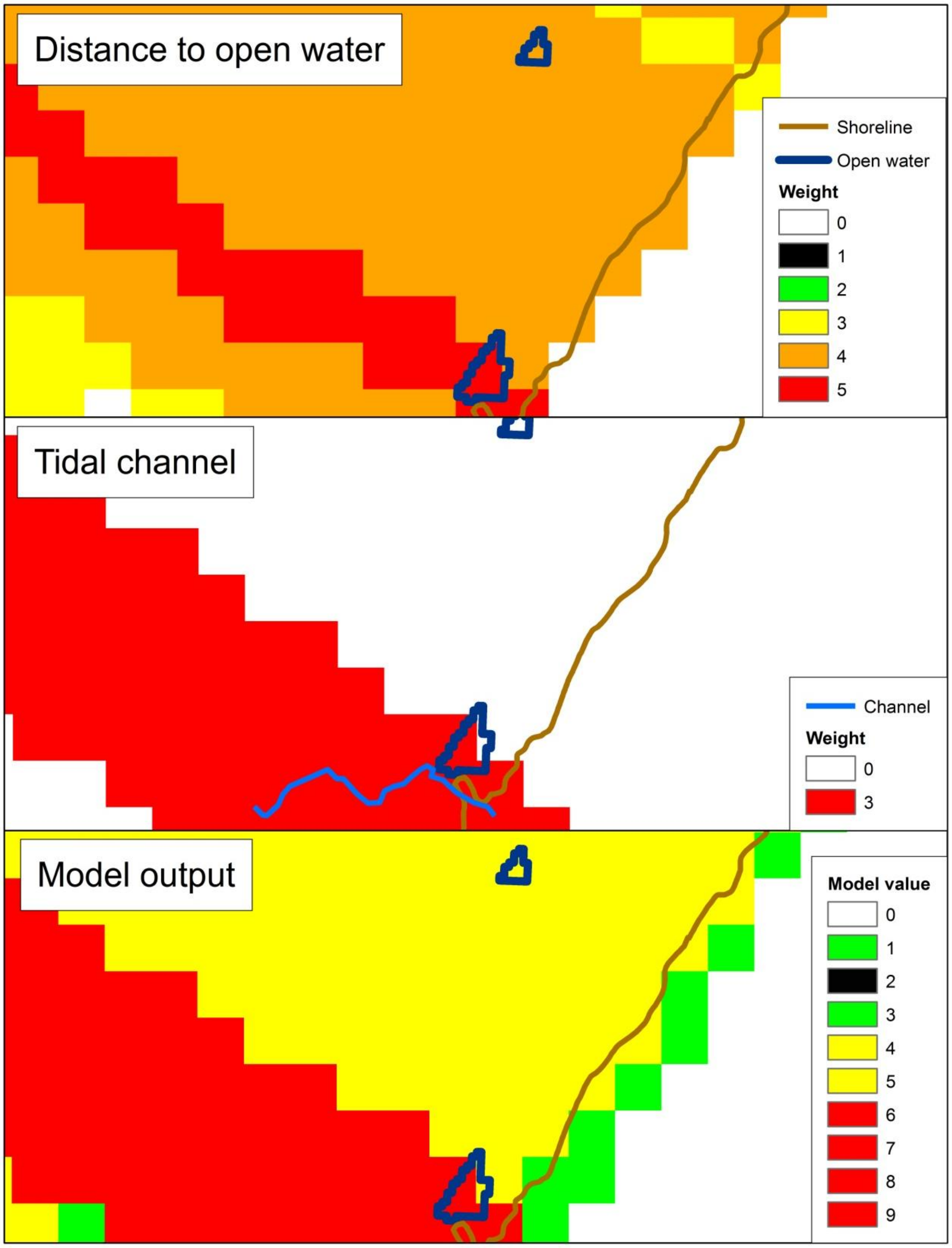

Figure 8. Example of general marsh model calculation and prioritization

Results

The linear extent of marsh adjacent to both sides of the GIWW from the Corpus Christi Bay to the Sabine River totals 336.5 miles. Eighty-six percent of this marsh is brackish or saline and the remainder (14%) is classified as fresh or intermediate. By separating the land into left (landward) and right (gulfward) portions, based on the location from the GIWW, 93.7% of fresh/intermediate marsh is landward. Proportions of brackish/saline marsh are equally split between the landward and gulfward sides of the GIWW.

Fifty miles of the Texas GIWW are currently protected by breakwater or revetment structures, leaving 294.3 miles of unprotected marsh shoreline on the landward and gulfward sides of the GIWW. Table 4 illustrates the priority classification of the remaining unprotected shoreline for both the General Marsh Model and the further defined Marsh Specific Model.

Table 4. Decision Support Tool Output Classification

ALL LANDS	Model	
Classification	**General**	**Specific**
	Distance (miles)	
Left side		
High	21.6	37.3
Medium	45.5	60.9
Low	85.3	54.1
Right side		
High	7.0	7.9
Medium	34.5	46.9
Low	100.4	87.0
TOTAL		
High	28.6	45.2
Medium	80.0	107.8
Low	185.7	141.1

Incorporating marsh type into the model increased both high and medium priority areas on the left side of the GIWW (where the greatest availability of fresh/intermediate marsh exists) by 16 and 15 miles, respectively. Overall, using the General Marsh Model as the prioritization tool identified approximately 28.6 miles of shoreline to be deemed high priority for protection. The Marsh Specific Model prioritizes nearly 45.2 miles of shoreline in need of protection to maintain significant coastal marsh habitats for waterfowl.

Output from the General Marsh and Marsh Specific Models indicates that approximately 30% (8.7 miles) and 27% (12.3 miles), respectively, of the high priority for shoreline identified in each model are adjacent to public owned lands (Table 5). See Appendix I for detailed public land shoreline protection model output.

Table 5. Decision Support Tool Output Classification For Shoreline Protection adjacent to Public Owned Lands

Public Ownership	Model	
Classification	General	Specific
	Distance (miles)	
Left side		
High	8.0	11.1
Medium	12.8	16.6
Low	12.7	5.9
Right side		
High	0.7	1.2
Medium	6.0	10.1
Low	14.8	10.1
TOTAL		
High	8.7	12.3
Medium	18.8	26.7
Low	27.5	16.0

Summary and Recommendations

Protecting coastal marshes is a necessary and heavily supported conservation action on the Gulf Coast. The ecosystem functions and values provided by these habitats are too important to lose or allow to continually degrade; such loss or degradation would have nearly immeasurable ecological and economic impacts. It is vital that the federal, state and private sectors recognize the importance of coastal marsh protection and restoration and make every effort to reduce, mitigate or eliminate negative impacts to these wetland systems. As funding or conservation collaboratives begin to address erosion and marsh degradation along the GIWW, we believe this support tool will aid resource allocation decisions. The models clearly identify areas that may be in immediate danger and require breakwater protection. Costs associated with breakwater projects that Ducks Unlimited has coordinated and implemented within the past 3 years range $800,000 - $1,000,000 per linear mile. With approximately 45 miles of high priority areas delineated, roughly $46 million is required in today’s dollars to protect these marsh habitats from immediate or further degradation

The current decision support tool assists in prioritizing coastal marsh habitats that are of importance to foraging habitat for wintering waterfowl and does not address all parameters that may be of interest to all partners. However, it is envisioned that this effort would serve as a foundation for development of further prioritization efforts. This model can be modified to include additional parameters that may be of importance to other agencies or conservation organizations. Some additional model parameters that could be further expanded include other habitat types, infrastructure, and/or physical features.

Several parameters that we have identified but are not incorporated into the current model include:

a. Marshplain Elevation – Some of the marsh in jeopardy is just above high tide while others have some elevation gradient or barrier such as a levee or spoil from the original construction of the GIWW. Low marsh areas are more susceptible to interior degradation since higher tides and waves can discharge saline water into the marsh. Correlating marsh elevation data with tide levels and wave amplitudes would allow for further analysis of salt water intrusion across the marshplain. Elevations of man-made and natural levees that separate the GIWW from marsh habitat could also be evaluated. Elevation data could be acquired through ground surveying or by using datasets such as LiDAR or DEMs.

b. Sea Level Rise Scenarios- The potential exists to incorporate sea level rise projection results into this decision support tool to identify those coastal marsh areas that have the greatest potential of exhibiting increased rates of erosion and loss.

c. Net shoreline erosion – We delineated GIWW shoreline at two time periods using digital raster graphics (DRG) from the 1950s and 2010. We used a USGS ArcGIS add on (Digital shoreline analysis system; DSAS) to calculate the net shoreline change between the two time periods. This may be a useful parameter to discover what areas have eroded the most and why, and to also project future erosion rates and threats.

d. Soil type – Incorporating SSURGO data into our model may give a better idea of the erosion capability of the GIWW shoreline or the vulnerability of organic soils within interior marshes. Soil types with these indicators could be given more weight. There may be a correlation between the net shoreline erosion dataset and soil type.

e. Distance to Infrastructure – Protecting infrastructure directly adjacent to the GIWW is extremely important. Incorporating distance to roads, bridges, and pipelines, and large water control structures, and weighting based on the distance may be a valuable parameter.

f. Marsh Values for Other Species – Consideration to other species such as incorporating Essential Fish Habitat (EFH), T&E Critical Habitats, State Scientific Areas, or public ownership / conservation properties could also be evaluated.

g. Reduction in Maintenance Dredging – As breakwaters decrease shoreline erosion rates, it is reasonable to assume some reduction of the amount of material deposited on the bottom of the GIWW. A reduction in the amount of material to be removed may also lengthen the time interval between maintenance dredge cycles and placement of material into Dredge Material Placement areas (DMPs).

Areas between breakwaters and the shoreline may also serve as a potential "beneficial placement location" for dredge. Consideration of these Operation & Maintenance factors may delineate areas of the GIWW where it is most cost effective to construct breakwaters.

Ducks Unlimited will continue to work with public and private property owners along the GIWW to protect their conservation interests. Implementation of projects based on the results of this decision support tool will require the support of the landowners, as well as the regulatory community. The amount of breakwaters to be constructed to address high and medium priority marshes is a significant endeavor. Regulatory review and authorization will be mandatory. This model may assist with streamlining that effort by offering support toward consideration of the creation of a Regional General Permit for Breakwater Construction. A Nationwide Permit (NWP13) already exists for shoreline protection efforts, but it has a linear limitation of projects less than or equal to 500 feet.

Previously noted was the implementation cost of the structures. In order to deliver these projects to achieve protection of high and moderate priority areas, substantial funding will be required. Garnering agency support towards delivery is paramount. Ducks Unlimited is capable and highly motivated to coordinate and deliver breakwaters at any scale. The Texas Gulf Coast is one of the highest continental priority areas for DU's conservation mission. The application of breakwaters to protect and sustain wetland functions and values for waterfowl, wildlife and people is an activity that DU fully supports. We are currently coordinating breakwater projects at small scales (less than 5 miles), and interested in working with agencies for delivering this conservation practice at larger scales.

As application of the model results progress into project planning and implementation phases, DU and its partners will perform on-the-ground visits to the areas of interest to ground truth the models and further refine considerations for project design. This decision support tool serves as one element to a larger process of scaling and implementing breakwaters along the GIWW. Landowner perspectives, agency coordination, and other logistics will also be factors for coordinating large scale delivery. This report provides a foundation, scale, and funding amount for delivering breakwaters to help sustain ecological and economic values of our coastal marsh resources.

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APPENDIX I
Detailed Public Lands Intersecting Breakwater Priority Model

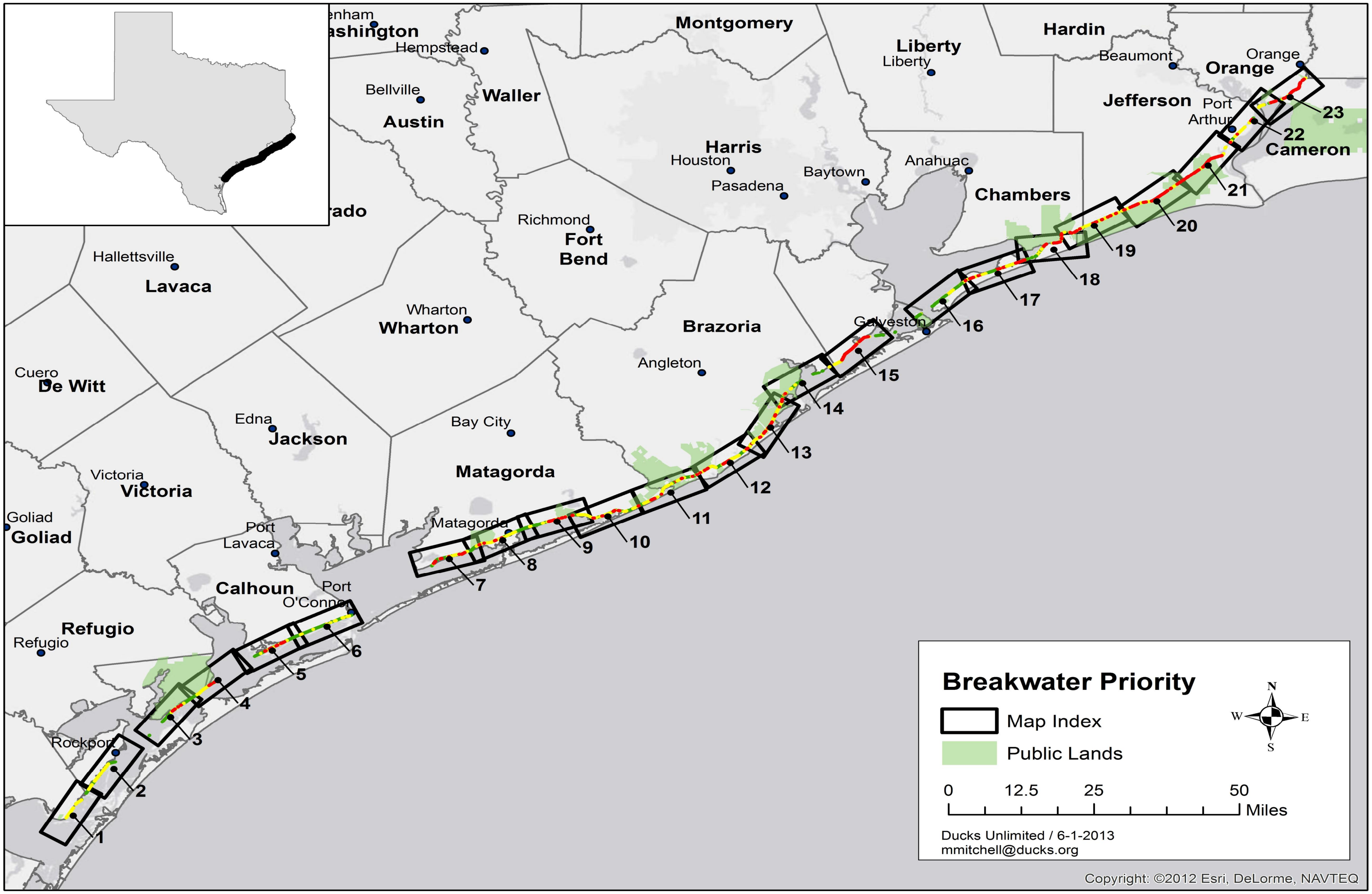
GENERAL MODEL				
Left Side of GIWW				
		Miles By Class		
Public Land		High	Medium	Low
Anahuac National Wildlife Refuge	Federal	0.5	0.7	0.8
Aransas National Wildlife Refuge	Federal	1.2	2.3	2
Big Boggy National Wildlife Refuge	Federal	0.8	0.7	0.1
Brazoria National Wildlife Refuge	Federal	1.7	4.6	2.8
McFaddin National Wildlife Refuge	Federal	0.5	0.9	0.8
San Bernard National Wildlife Refuge	Federal	0.4	1.5	2.9
J. D. Murphree-13 Acre Pond	State	2.6	0.7	0.1
Justin Hurst Wildlife Management Area	State	0.2	0.1	1.1
Lower Neches Wildlife Management Area	State	0	0	0.6
Mad Island Wildlife Management Area	State	0.1	1	1.4
Welder Flats Wildlife Management Area	State	0	0.3	0.1
		8	12.8	12.7
Right side of GIWW				
		Miles By Class		
		High	Medium	Low
Brazoria National Wildlife Refuge	Federal	0.4	2.9	7
McFaddin National Wildlife Refuge	Federal	0	0.6	0.5
Pelican Spit Military Reservation	Federal	0		0.1
San Bernard National Wildlife Refuge	Federal	0.1	0.2	5.8
J. D. Murphree-13 Acre Pond	State	0.2	2.2	0.8
Justin Hurst Wildlife Management Area	State	0	0.1	0.6
		0.7	6	14.8
TOTAL		8.7	18.8	27.5

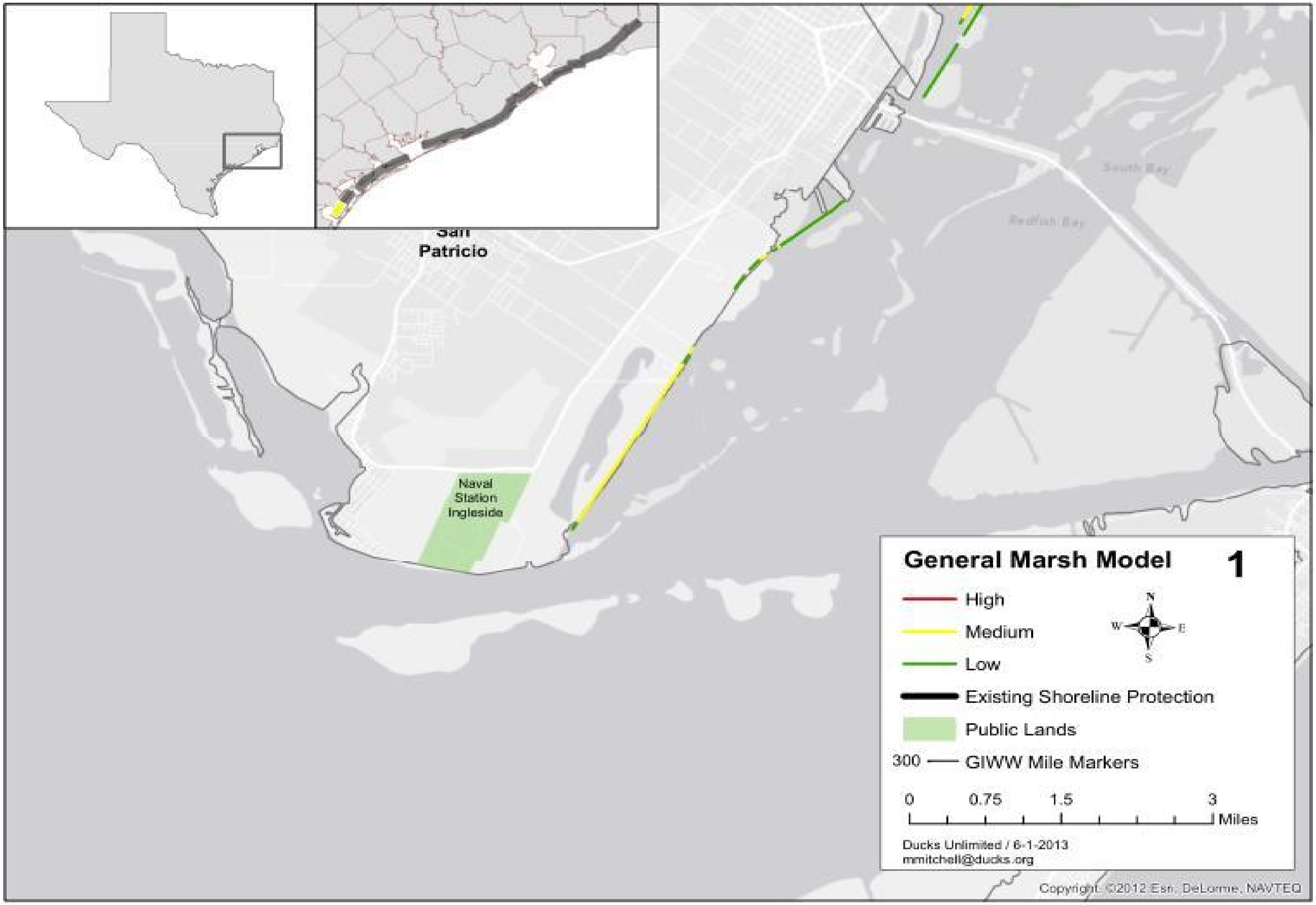
MARSH SPECIFIC MODEL				
Left Side of GIWW				
		Miles By Class		
Public Land		High	Medium	Low
Anahuac National Wildlife Refuge	Federal	1.6	0.4	0.1
Aransas National Wildlife Refuge	Federal	1.2	3	1.3
Big Boggy National Wildlife Refuge	Federal	0.8	0.7	0.1
Brazoria National Wildlife Refuge	Federal	1.7	5.9	1.5
McFaddin National Wildlife Refuge	Federal	1.7	0.5	0
San Bernard National Wildlife Refuge	Federal	0.4	3	1.4
J. D. Murphree-13 Acre Pond	State	3.4	0	0
Justin Hurst Wildlife Management Area	State	0.2	1	0.2
Lower Neches Wildlife Management Area	State	0	0.6	0
Mad Island Wildlife Management Area	State	0.1	1.2	1.2
Welder Flats Wildlife Management Area	State	0	0.3	0.1
		11.1	16.6	5.9
Right Side of GIWW				
		Miles By Class		
		High	Medium	Low
Brazoria National Wildlife Refuge	Federal	0.4	3.8	6.1
San Bernard National Wildlife Refuge	Federal	0.1	2.4	3.6
McFaddin National Wildlife Refuge	Federal	0	1	0.1
Pelican Spit Military Reservation	Federal	0	0.1	0
J. D. Murphree-13 Acre Pond	State	0.7	2.2	0.2
Justin Hurst Wildlife Management Area	State	0	0.6	0.1
		1.2	10.1	10.1
TOTAL		12.3	26.7	16

APPENDIX II

Breakwater Prioritization Maps

MODEL OUTPUT REFERENCE MAP




San
Patricio
Naval
Station
Ingleside
South Bay
Redfish Bay
General Marsh Model
1
High
Medium
Low
Existing Shoreline Protection
Public Lands
300
GIWW Mile Markers
0
0.75
1.5
3
Miles
N
W
E
S
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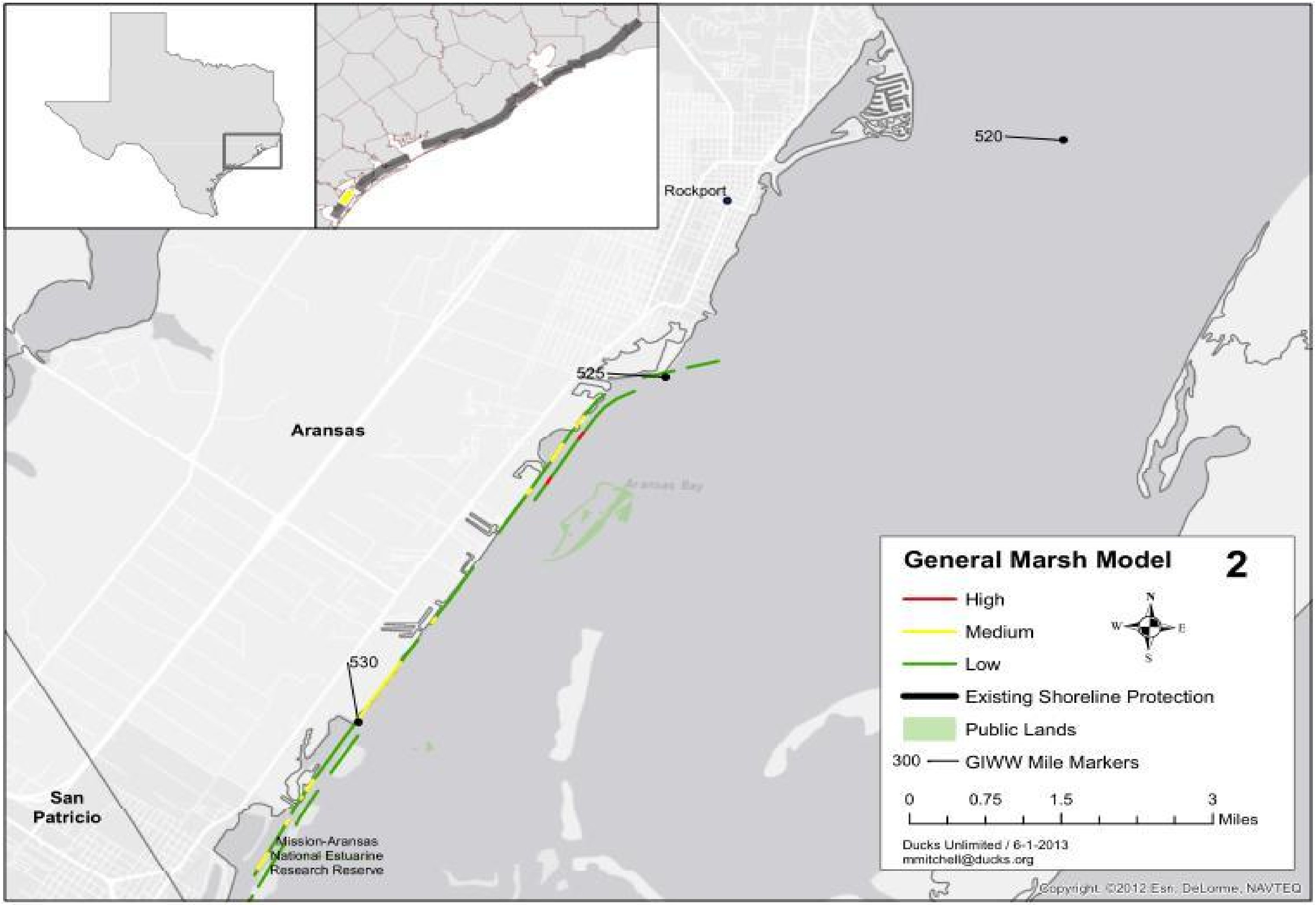

520
Rockport
525
Aransas
Aransas Bay
530
San Patricio
Mission-Aransas National Estuarine Research Reserve
General Marsh Model
2
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
N W E S
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mmitchell@ducks.org
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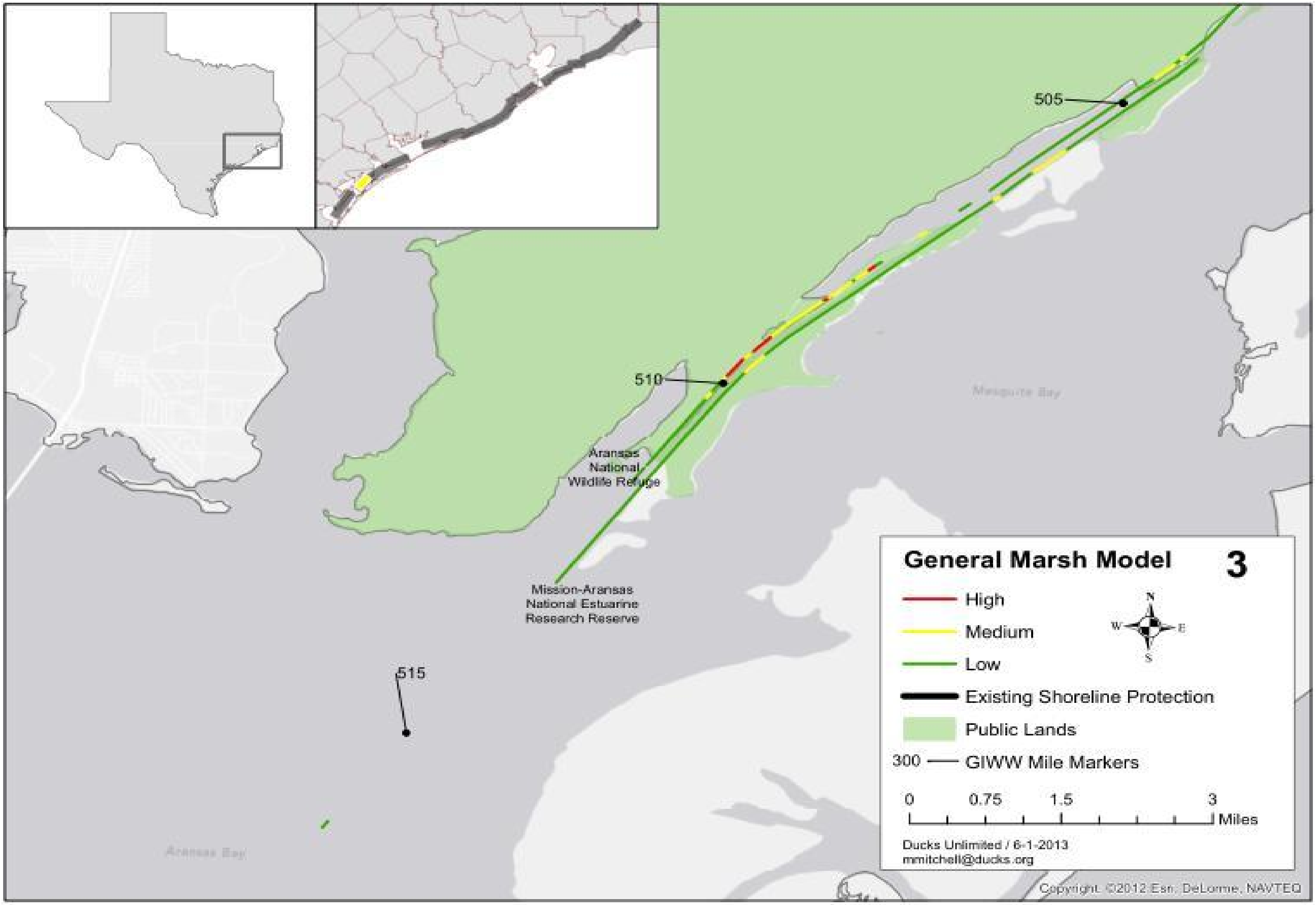
505
510
515
Aransas National Wildlife Refuge
Mission-Aransas National Estuarine Research Reserve
General Marsh Model
3
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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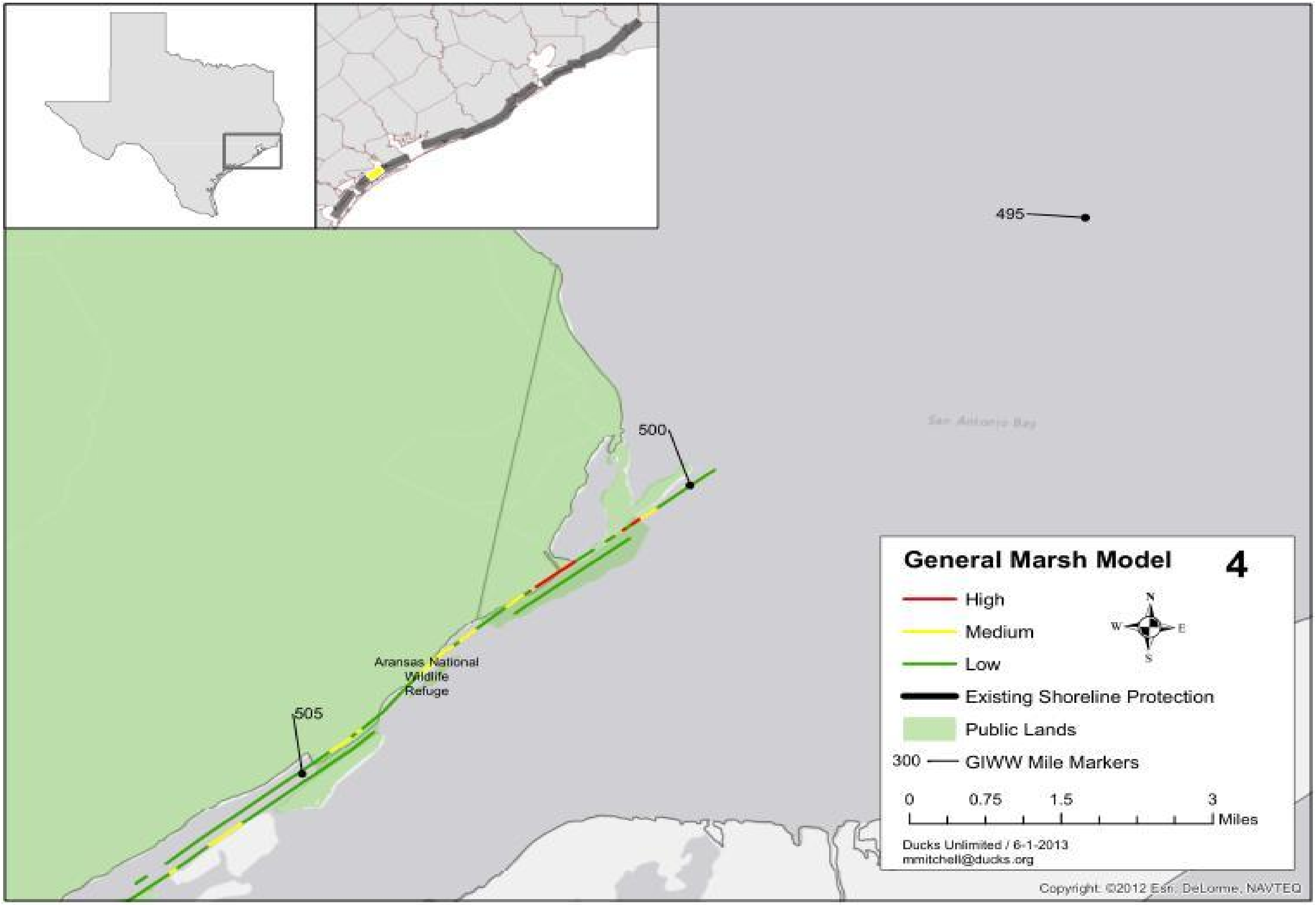
495
500
505
Aransas National Wildlife Refuge
General Marsh Model
4
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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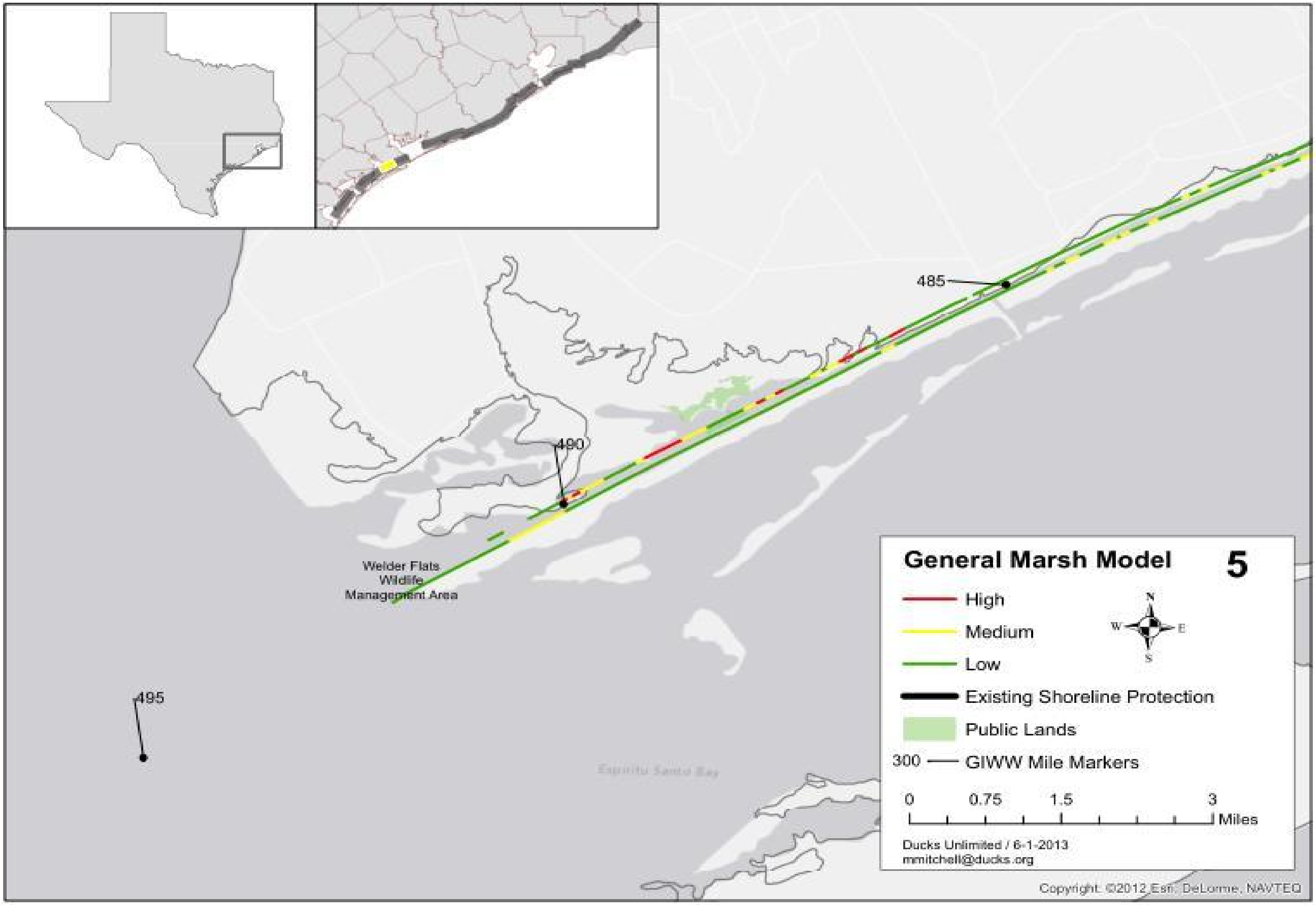
485
490
495
Welder Flats
Wildlife
Management Area
General Marsh Model
5
High
Medium
Low
Existing Shoreline Protection
Public Lands
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0 0.75 1.5 3 Miles
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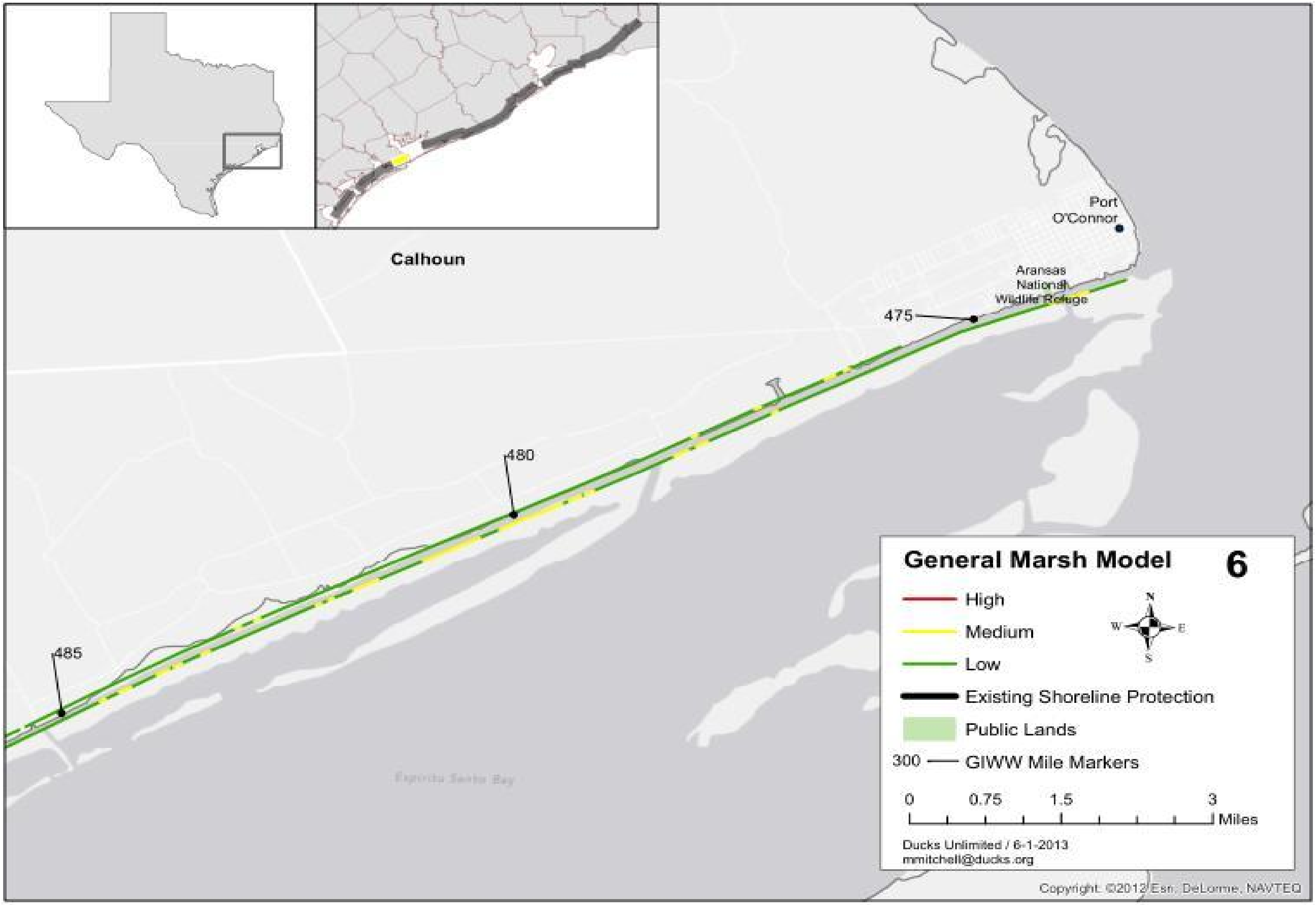
Calhoun
Port O'Connor
Aransas National Wildlife Refuge
475
480
485
General Marsh Model
6
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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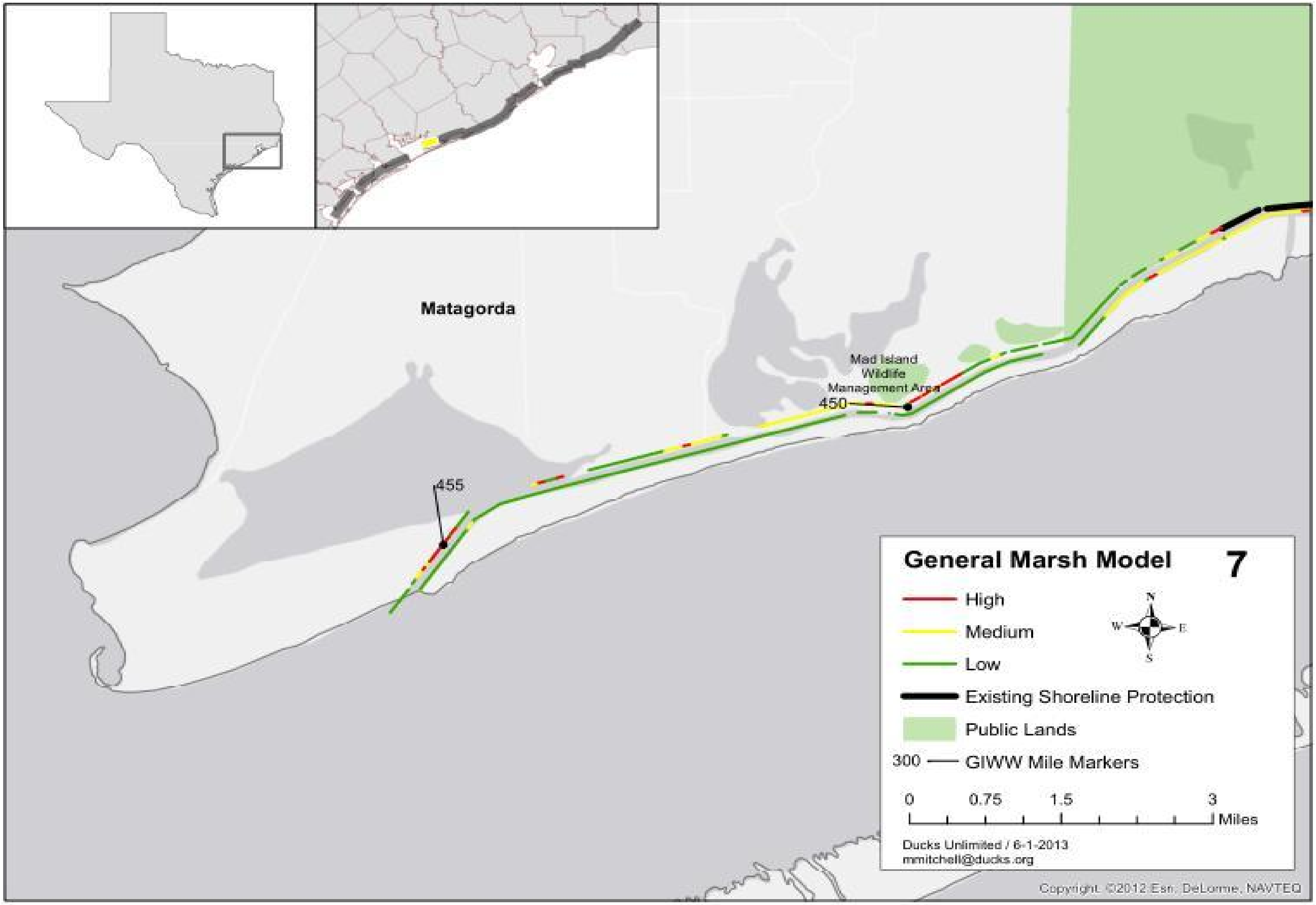
Matagorda
Mad Island Wildlife Management Area
450
455
General Marsh Model
7
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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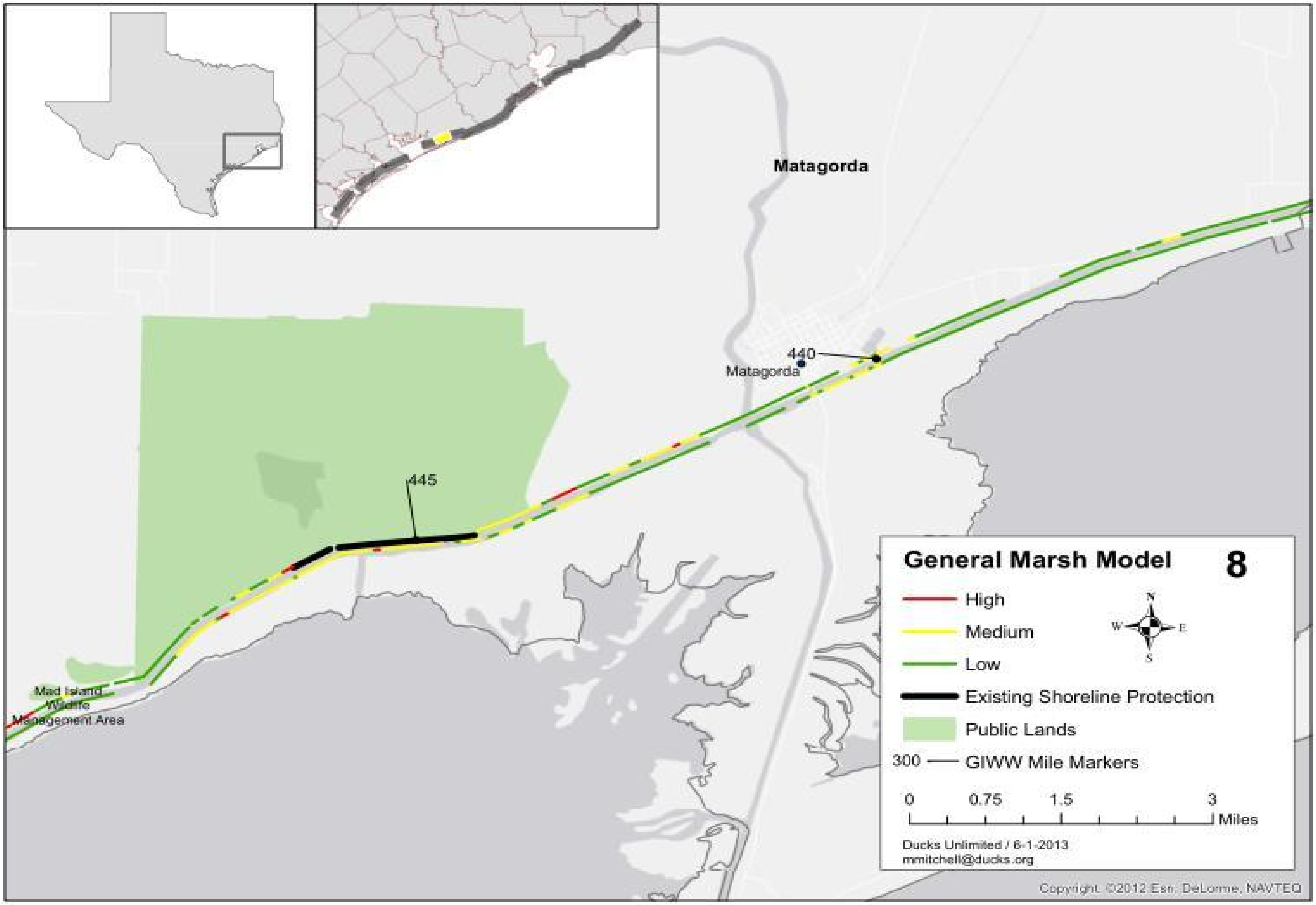

Matagorda
440
Matagorda
445
Mad Island
Wildlife
Management Area
General Marsh Model
8
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
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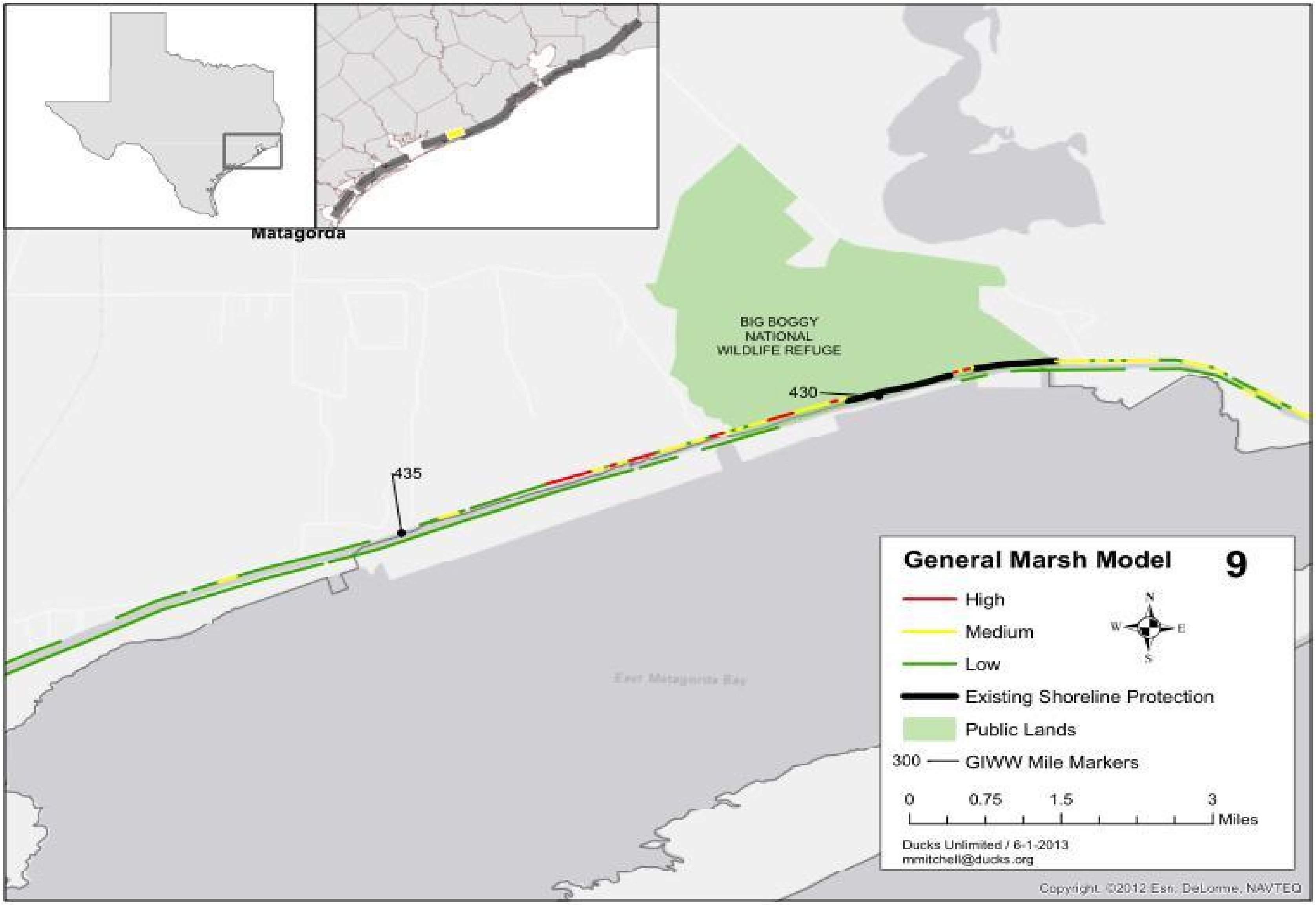
Matagorda
BIG BOGGY
NATIONAL
WILDLIFE REFUGE
430
435
East Matagorda Bay
General Marsh Model
9
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
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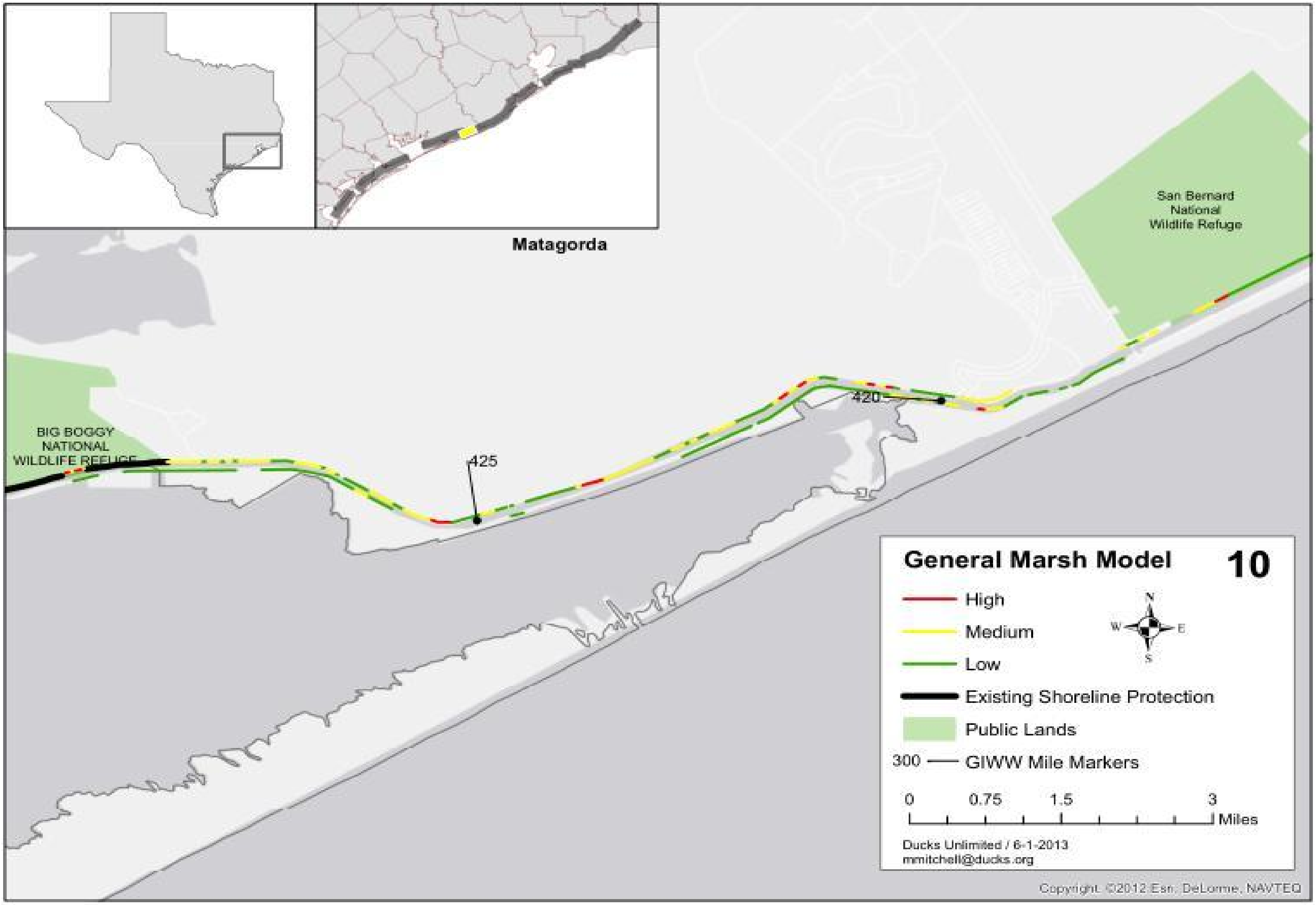
Matagorda
San Bernard
National
Wildlife Refuge
BIG BOGGY
NATIONAL
WILDLIFE REFUGE
425
420
General Marsh Model
10
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3
Miles
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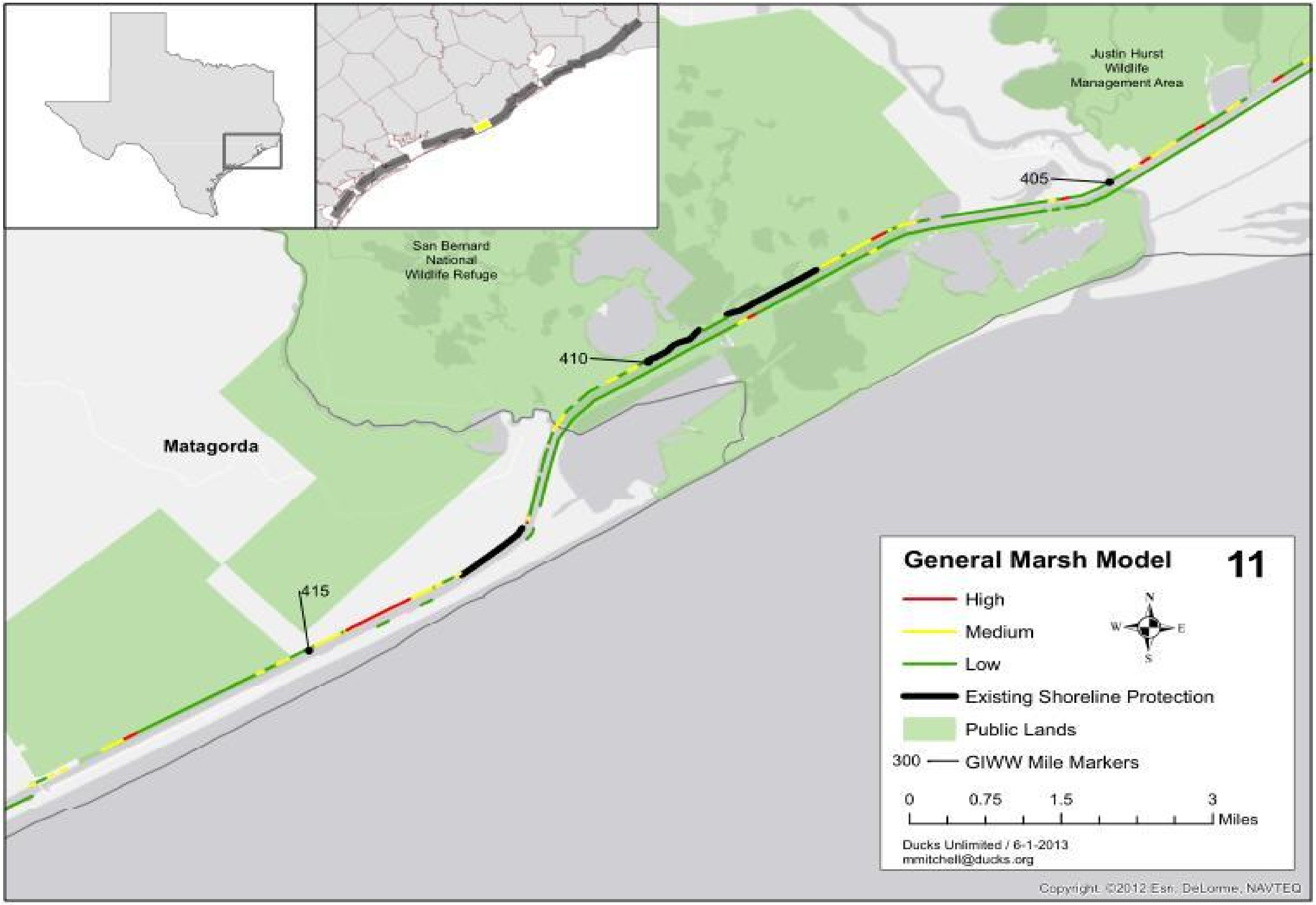
Justin Hurst
Wildlife
Management Area
405
San Bernard
National
Wildlife Refuge
410
Matagorda
415
General Marsh Model
11
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
N
S
E
W
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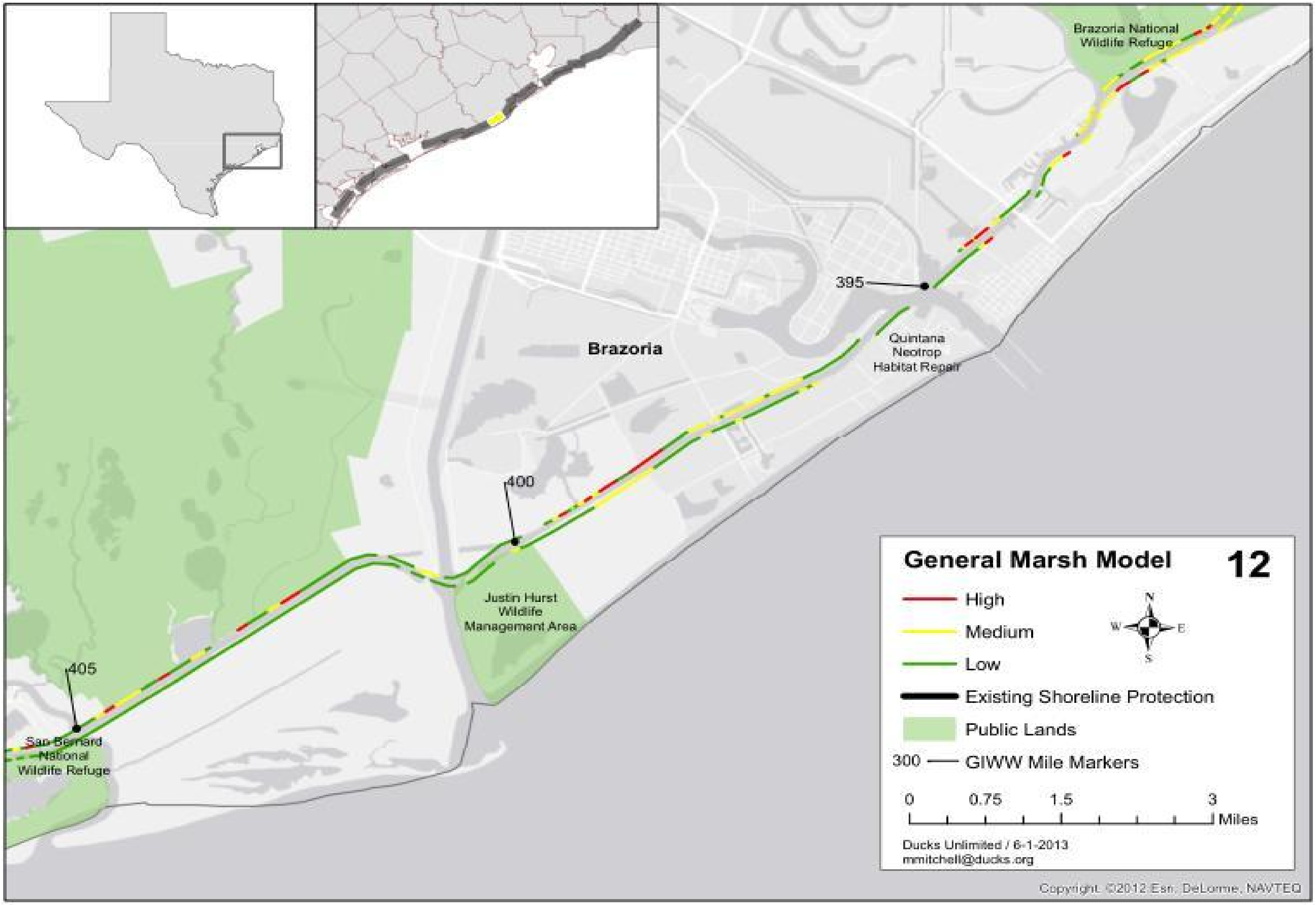

Brazoria National Wildlife Refuge
395
Brazoria
Quintana Neotrop Habitat Repair
400
Justin Hurst Wildlife Management Area
405
San Bernard National Wildlife Refuge
General Marsh Model
12
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
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0.75
1.5
3
Miles
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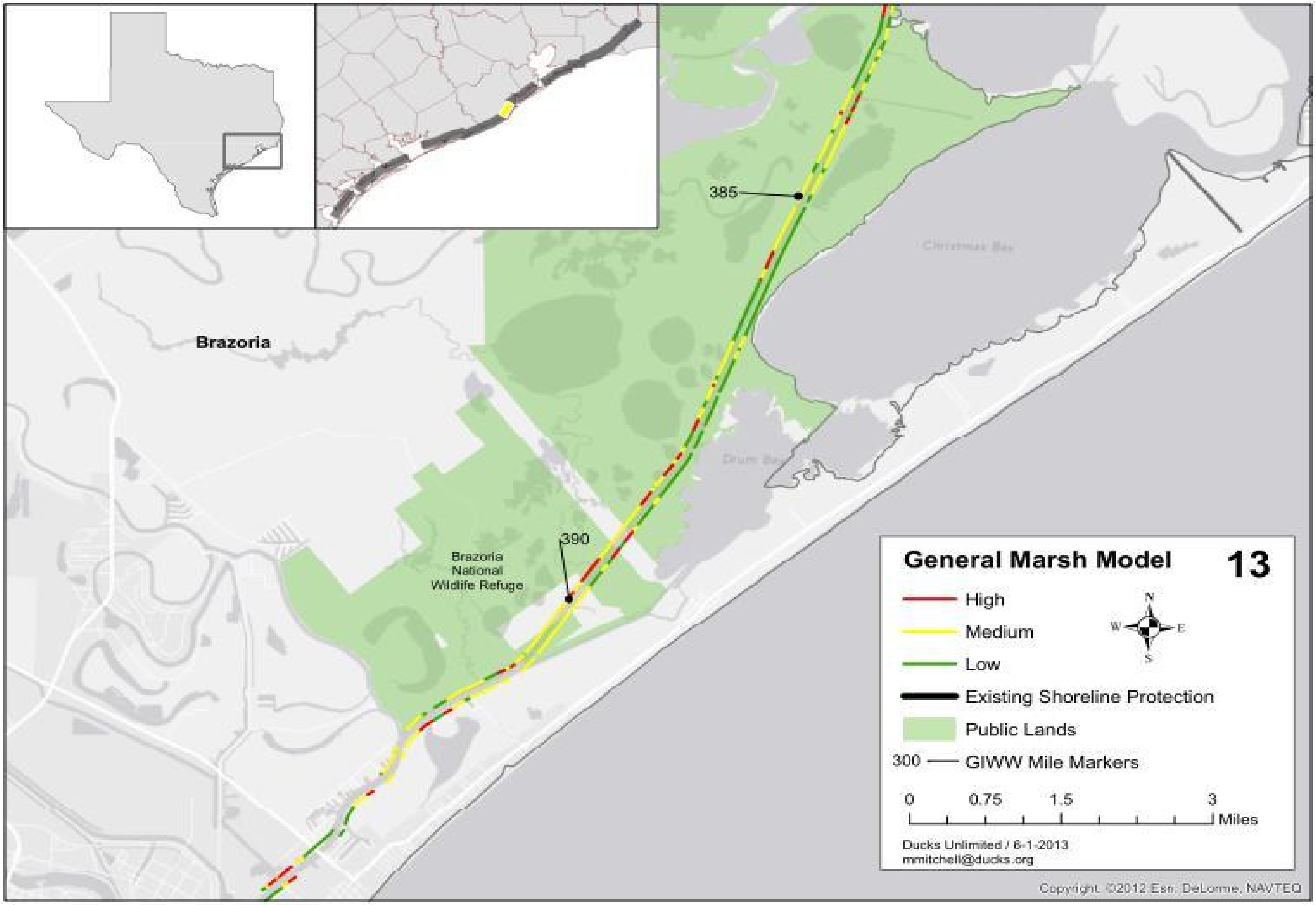
385
390
Brazoria
Brazoria National Wildlife Refuge
General Marsh Model
13
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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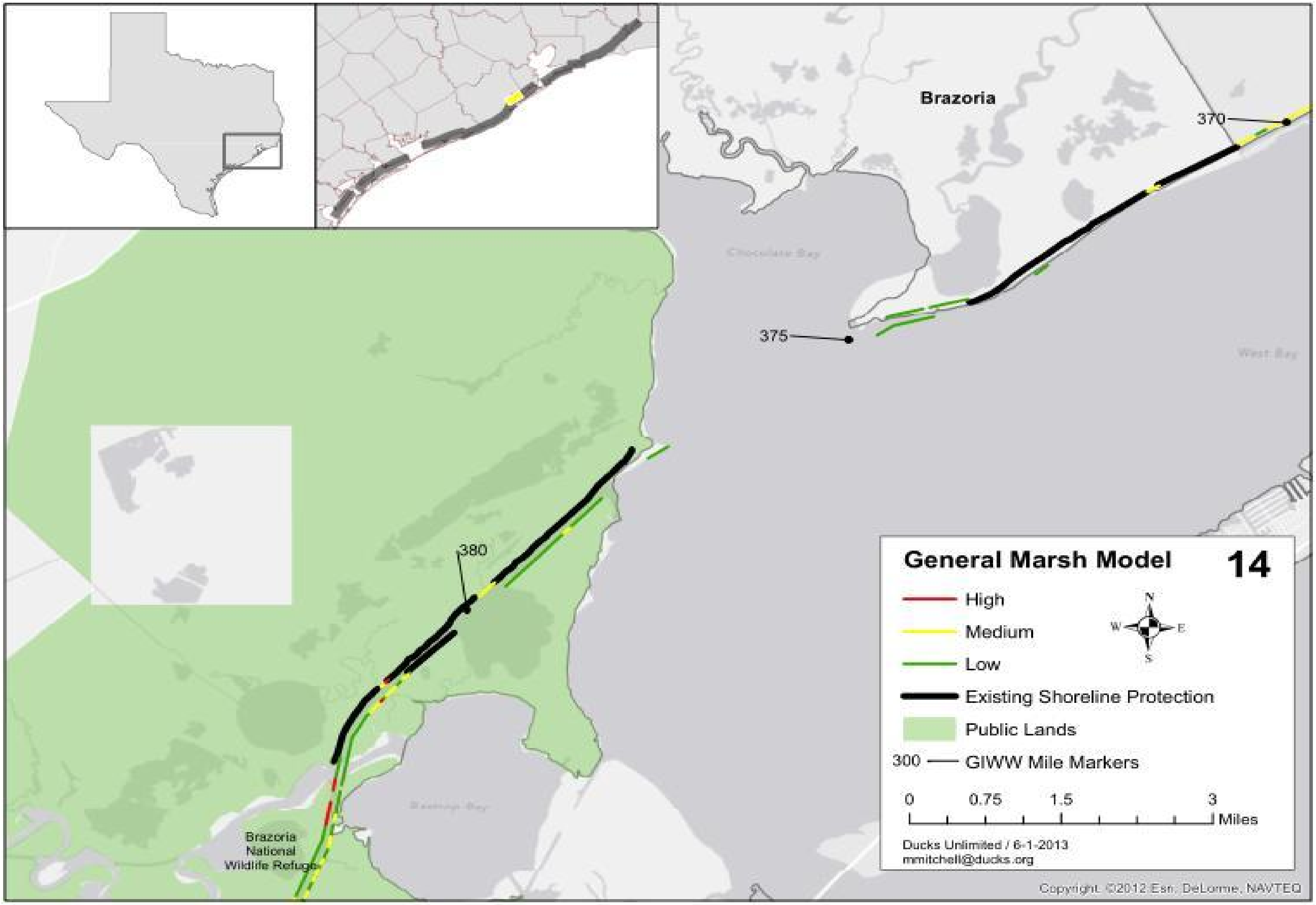
Brazoria
370
375
380
Brazoria National Wildlife Refuge
General Marsh Model
14
High
Medium
Low
Existing Shoreline Protection
Public Lands
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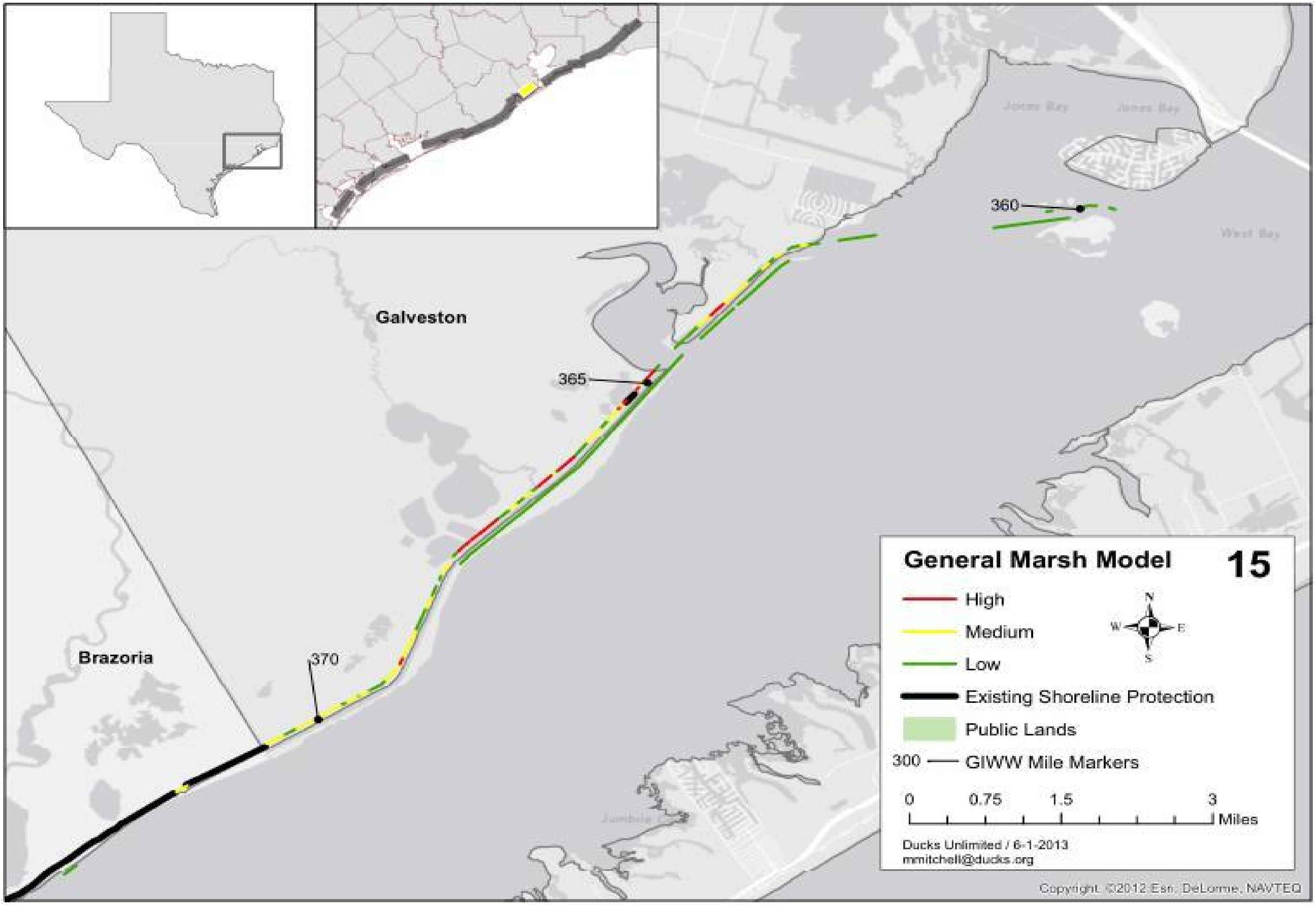
Galveston
Brazoria
365
370
360
General Marsh Model
15
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
N
S
E
W
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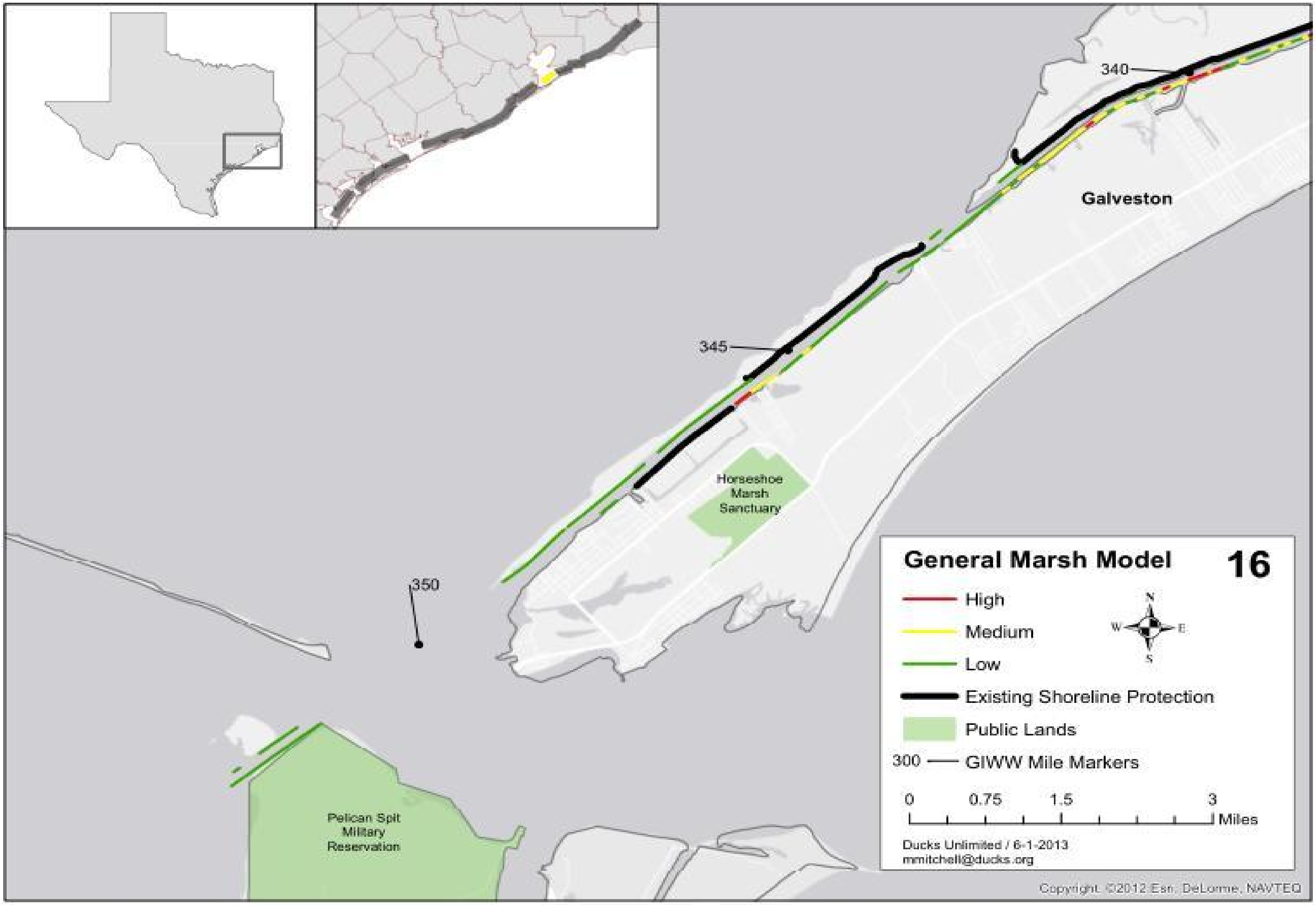
340
345
350
Galveston
Horseshoe Marsh Sanctuary
Pelican Spit Military Reservation
General Marsh Model
16
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
N
S
E
W
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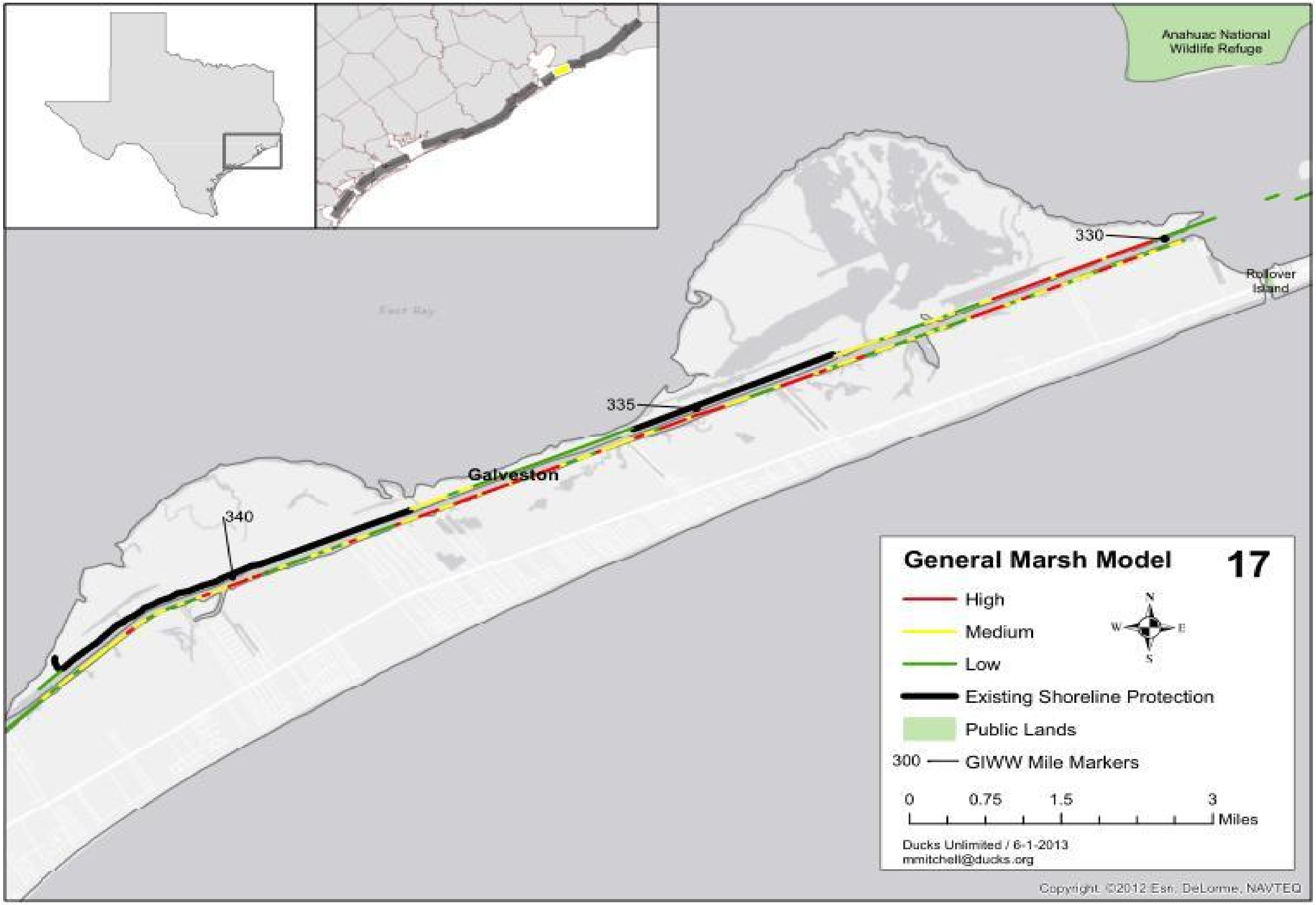
Anahuac National Wildlife Refuge
330
Rollover Island
335
Galveston
340
General Marsh Model
17
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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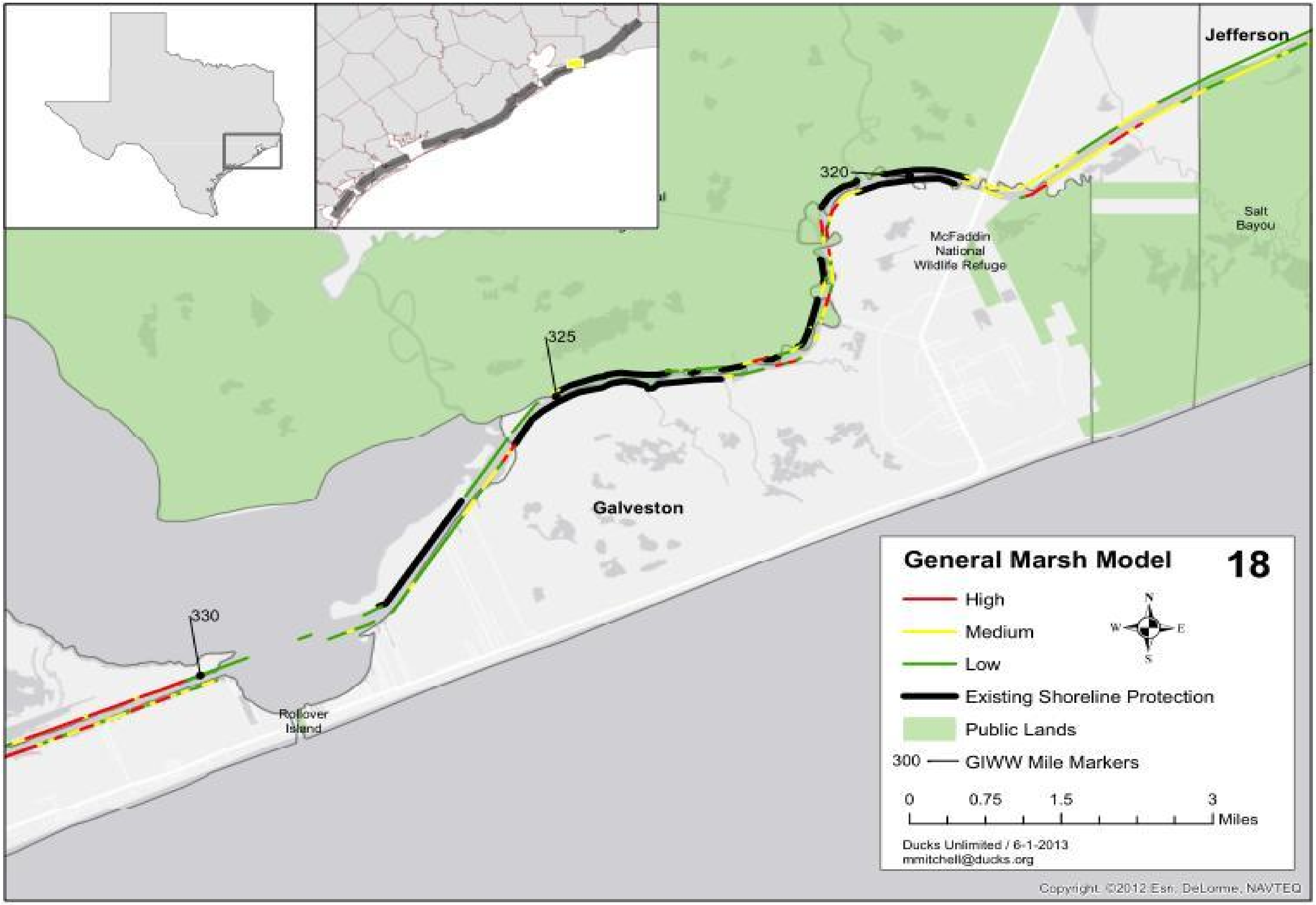
Jefferson
320
325
330
McFaddin
National
Wildlife Refuge
Salt
Bayou
Galveston
Rollover
Island
General Marsh Model
18
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
N
S
E
W
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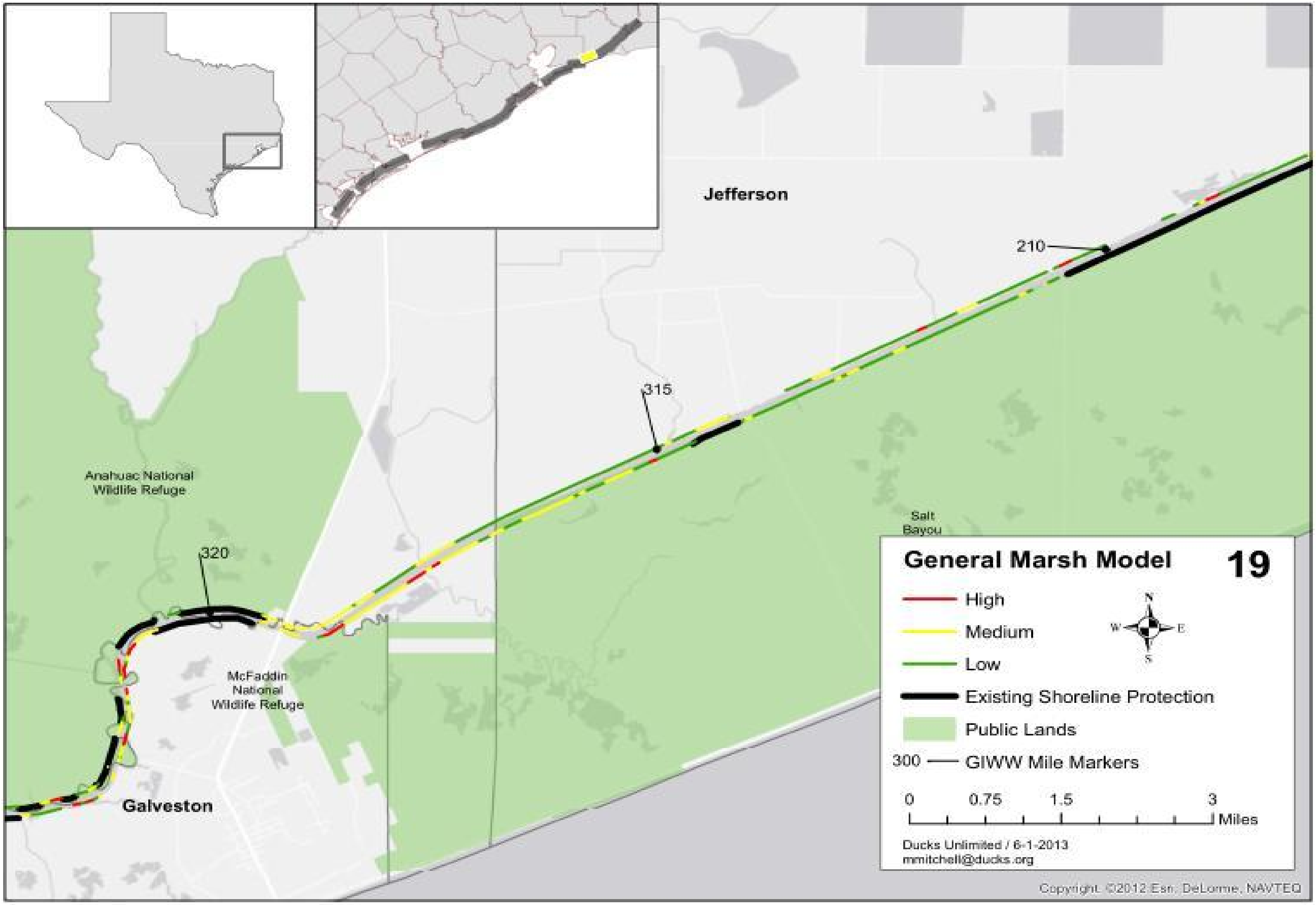
Jefferson
210
315
320
Anahuac National Wildlife Refuge
McFaddin National Wildlife Refuge
Galveston
Salt Bayou
General Marsh Model
19
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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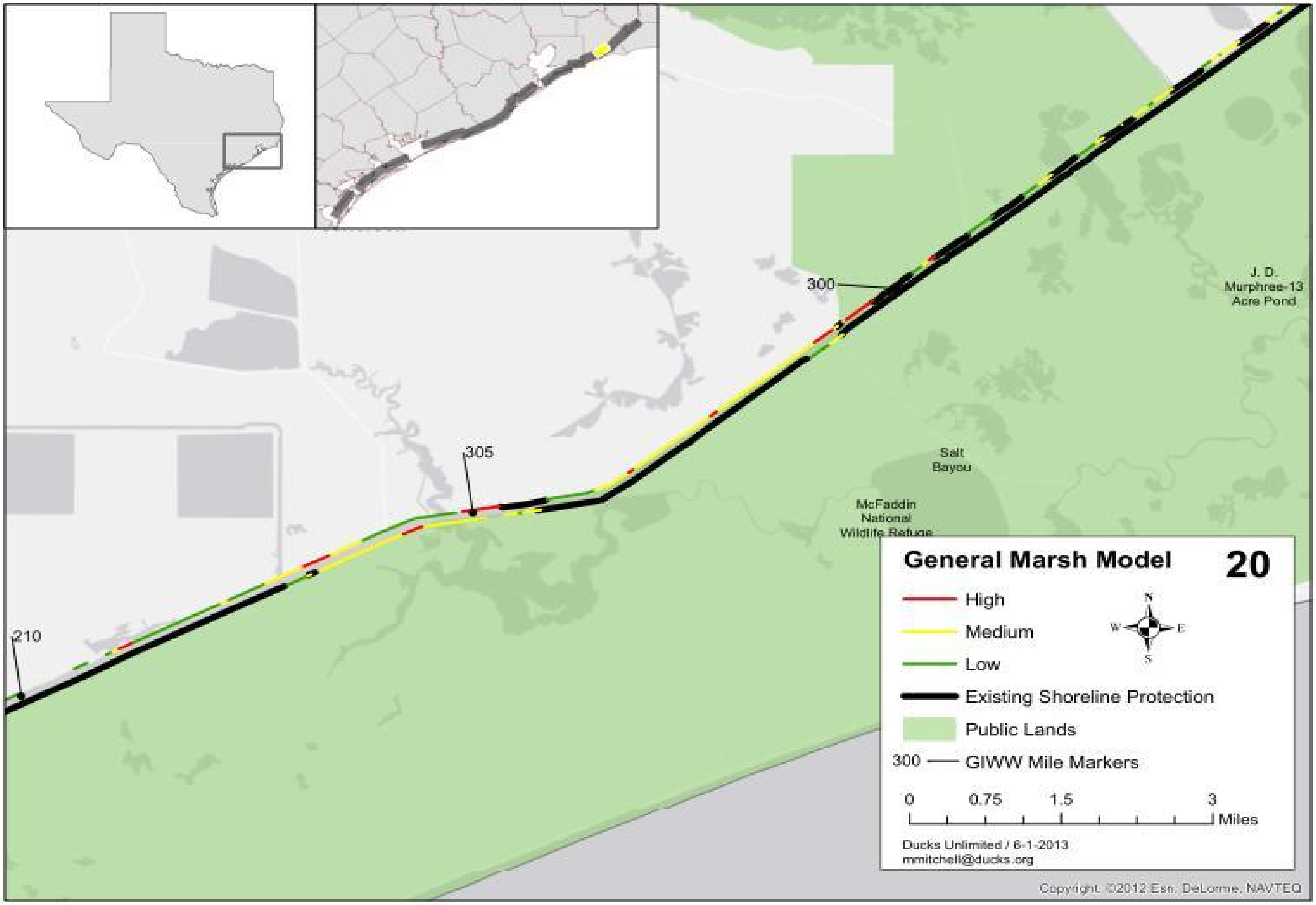
300
305
210
J. D.
Murphree-13
Acre Pond
Salt
Bayou
McFaddin
National
Wildlife Refuge
General Marsh Model
20
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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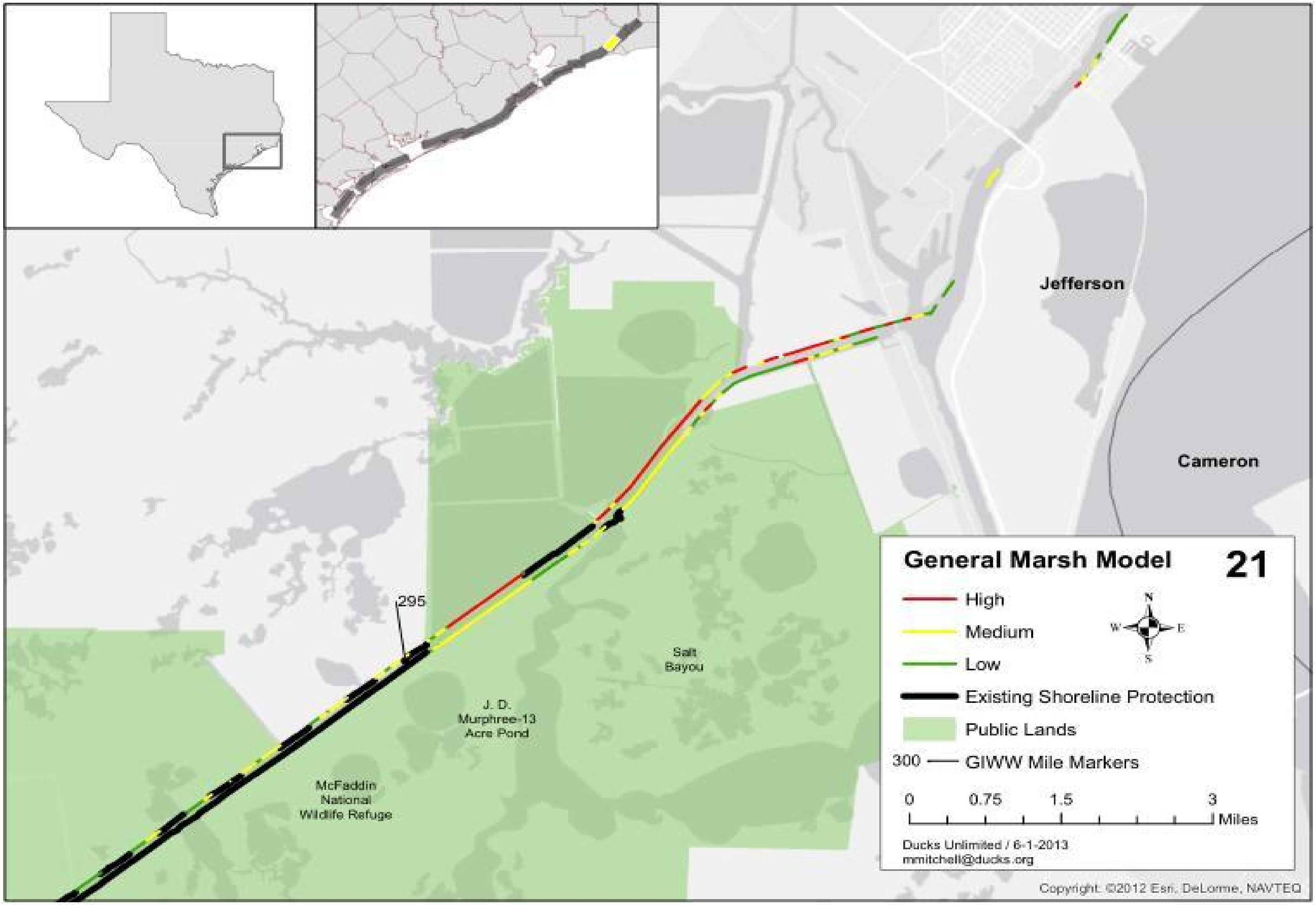
Jefferson
Cameron
295
Salt Bayou
J. D. Murphree-13 Acre Pond
McFaddin National Wildlife Refuge
General Marsh Model
21
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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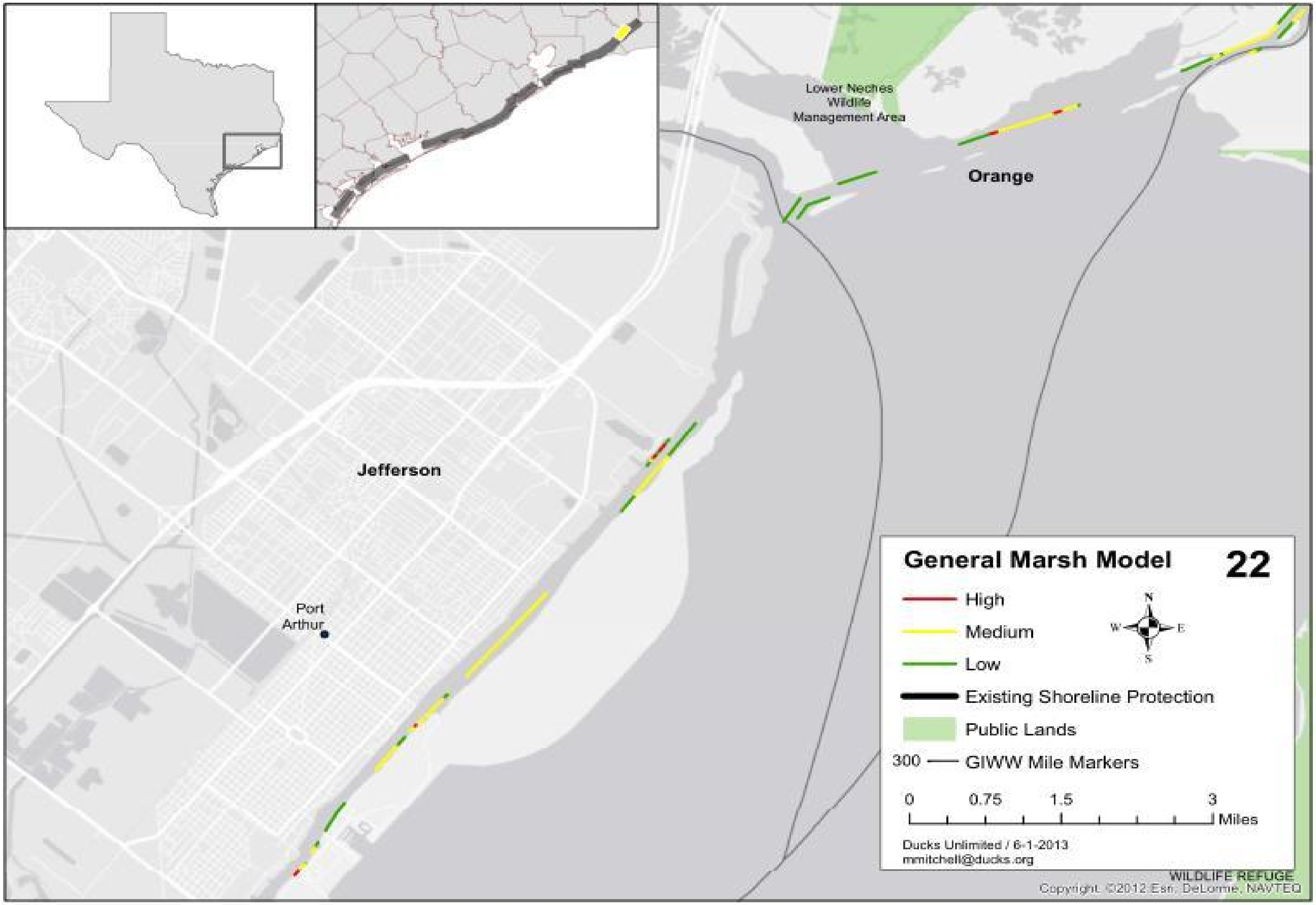
Lower Neches
Wildlife
Management Area
Orange
Jefferson
Port
Arthur
General Marsh Model
22
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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WILDLIFE REFUGE
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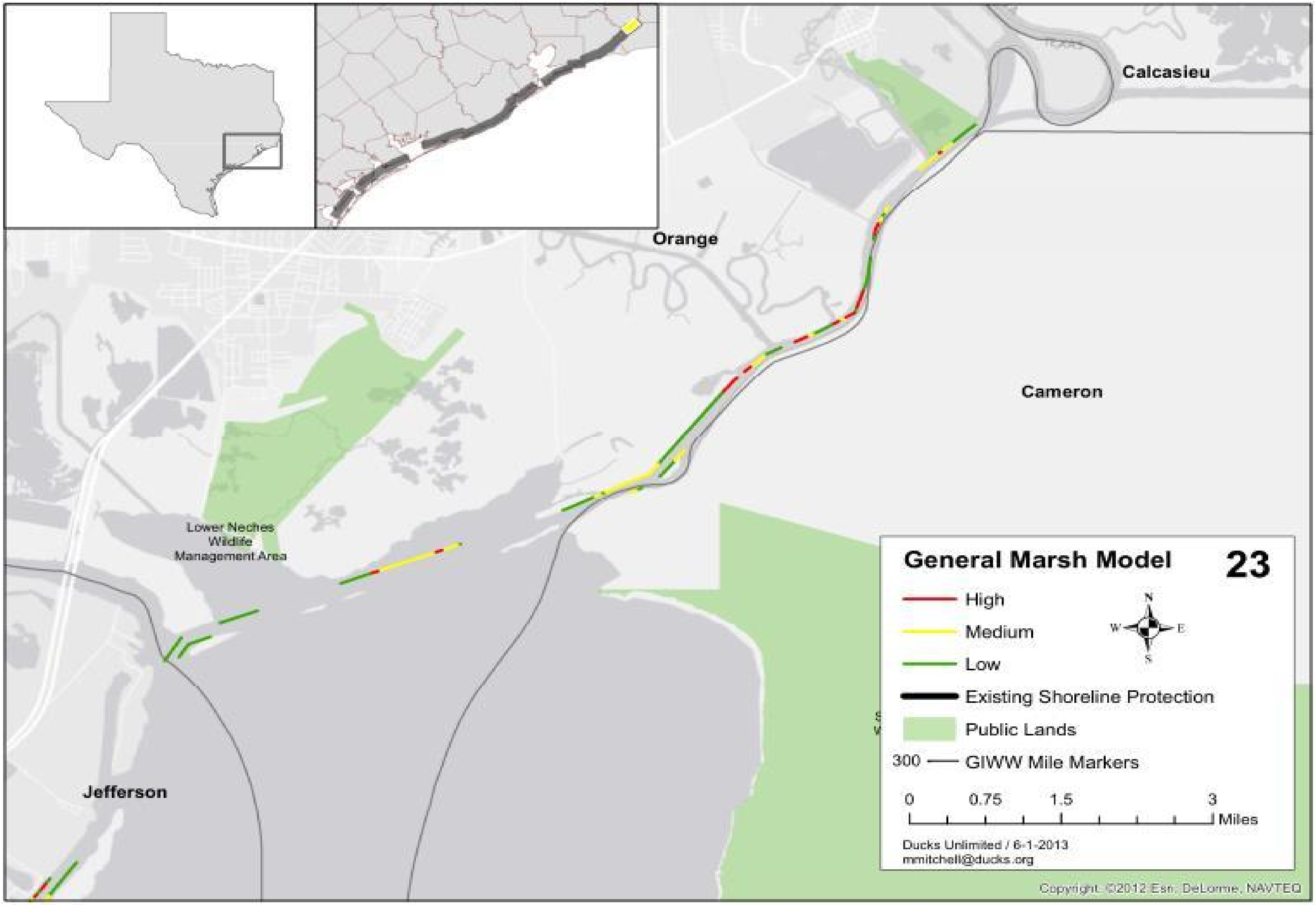
Calcasieu
Orange
Cameron
Lower Neches
Wildlife
Management Area
Jefferson
General Marsh Model
23
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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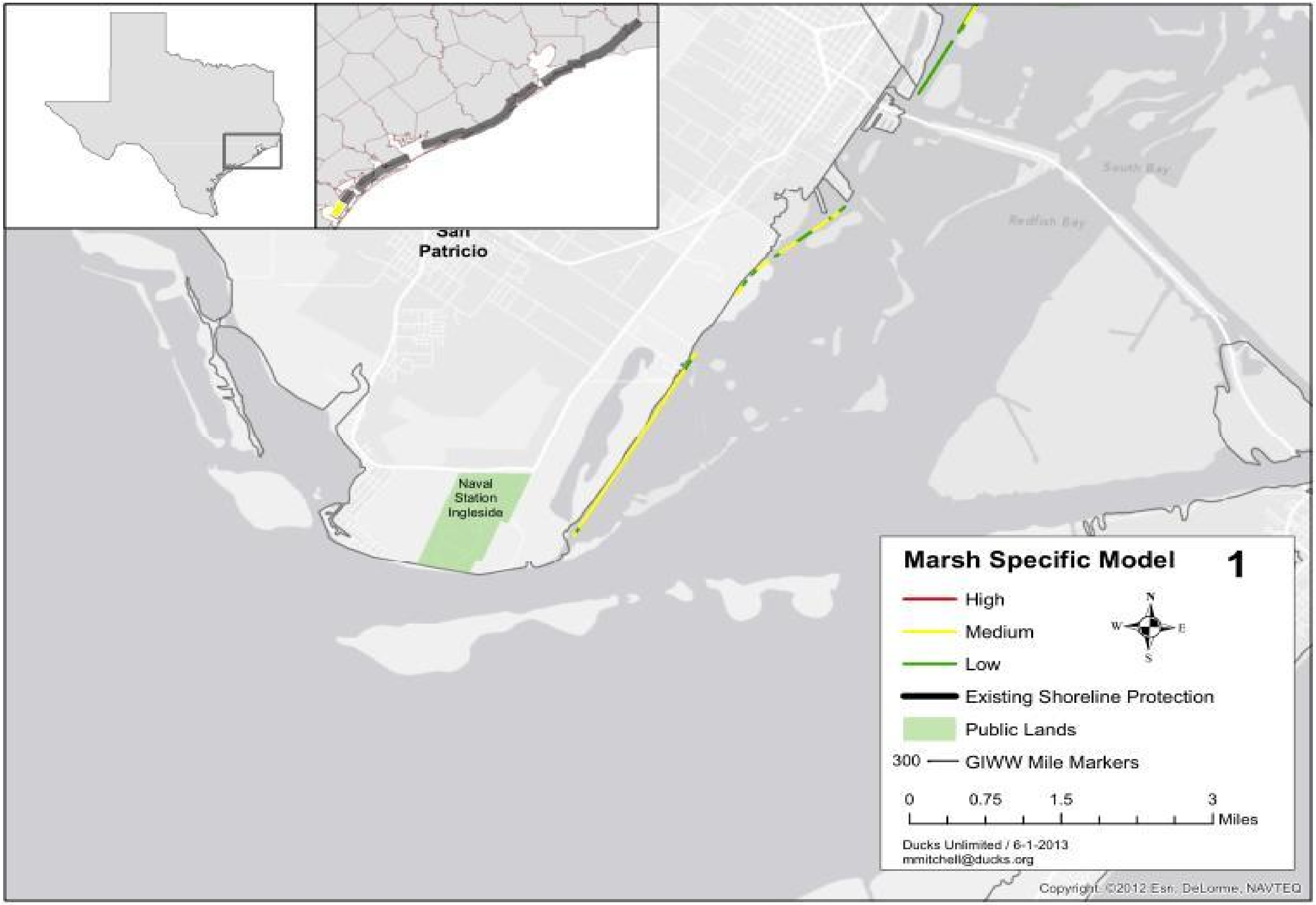
San
Patricio
Naval
Station
Ingleside
South Bay
Redfish Bay
Marsh Specific Model
1
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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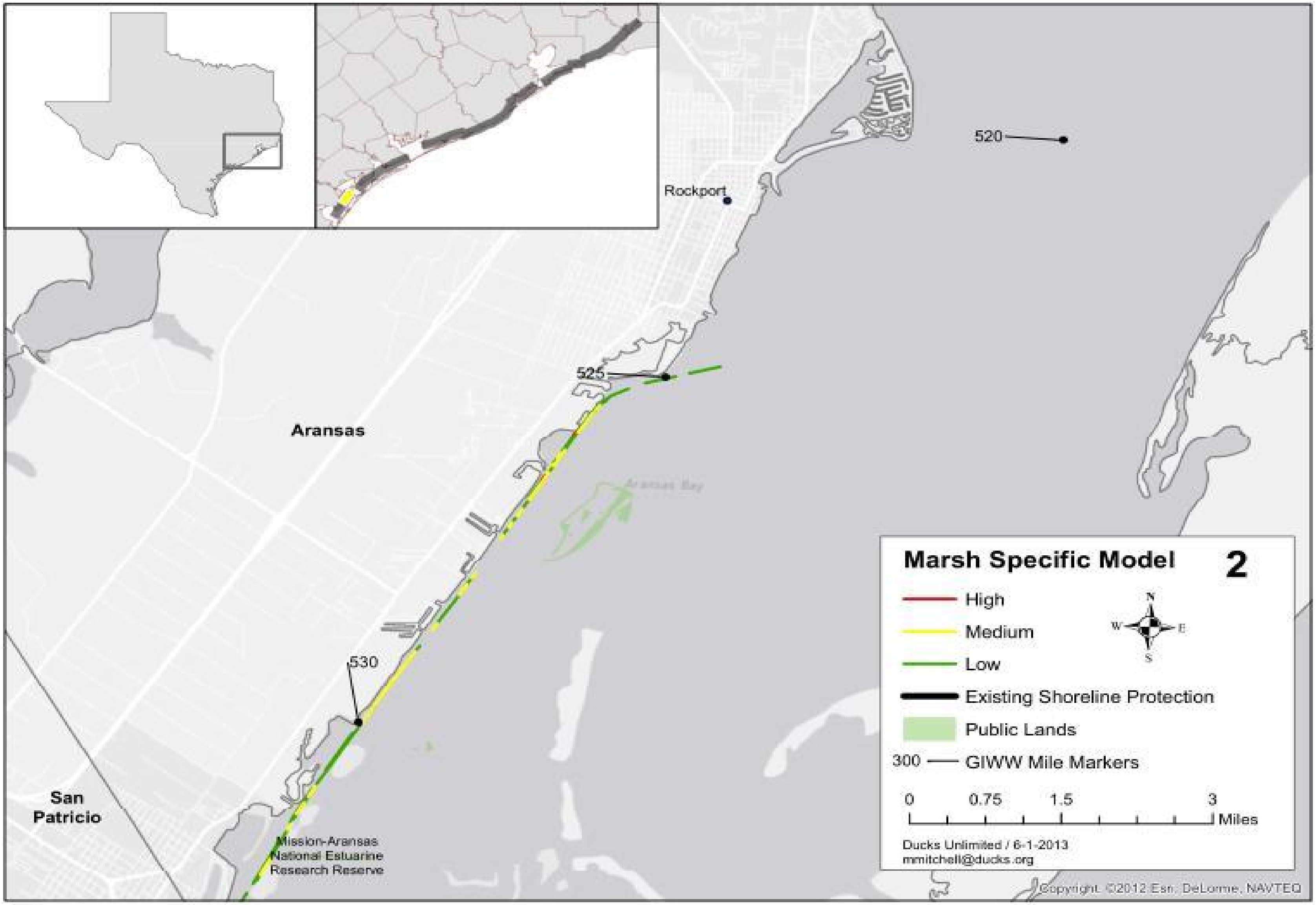
Rockport
520
525
530
Aransas
San Patricio
Mission-Aransas National Estuarine Research Reserve
Marsh Specific Model
2
High
Medium
Low
Existing Shoreline Protection
Public Lands
300
GIWW Mile Markers
0
0.75
1.5
3
Miles
N
W
E
S
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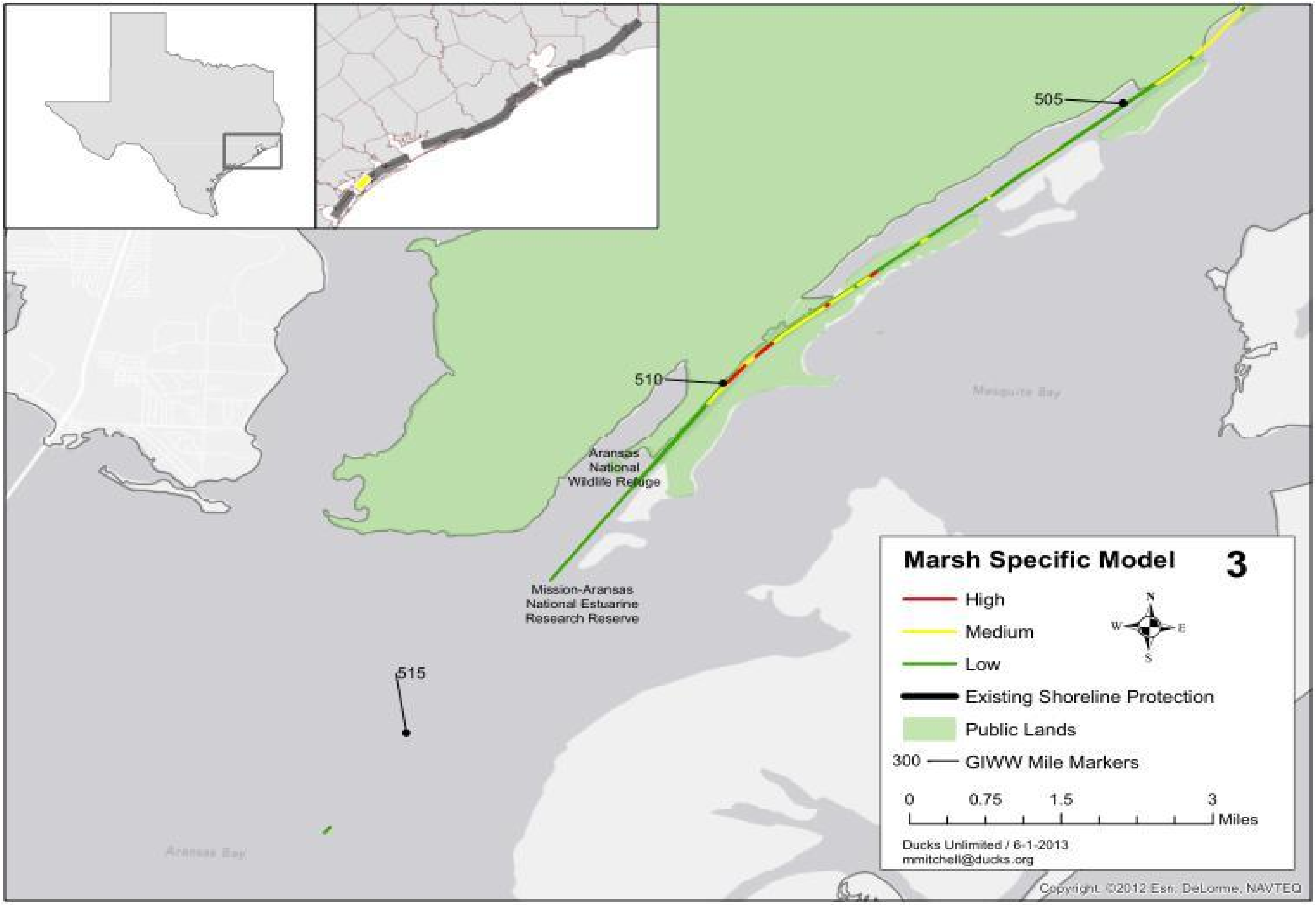
Marsh Specific Model
3
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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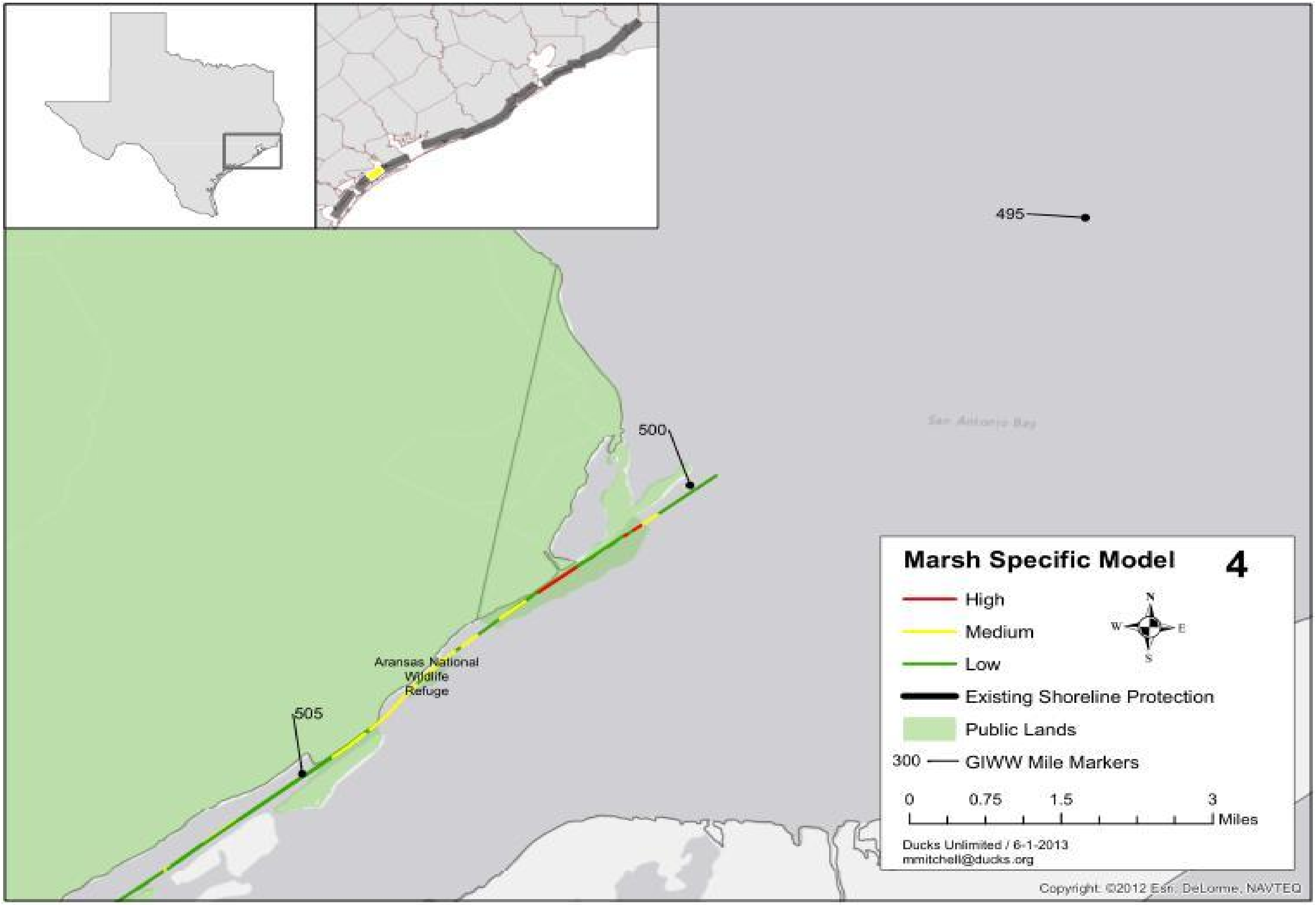
505
510
515
Aransas National Wildlife Refuge
Mission-Aransas National Estuarine Research Reserve


495
500
505
Aransas National Wildlife Refuge
Marsh Specific Model
4
High
Medium
Low
Existing Shoreline Protection
Public Lands
300
GIWW Mile Markers
N
S
E
W
0
0.75
1.5
3
Miles
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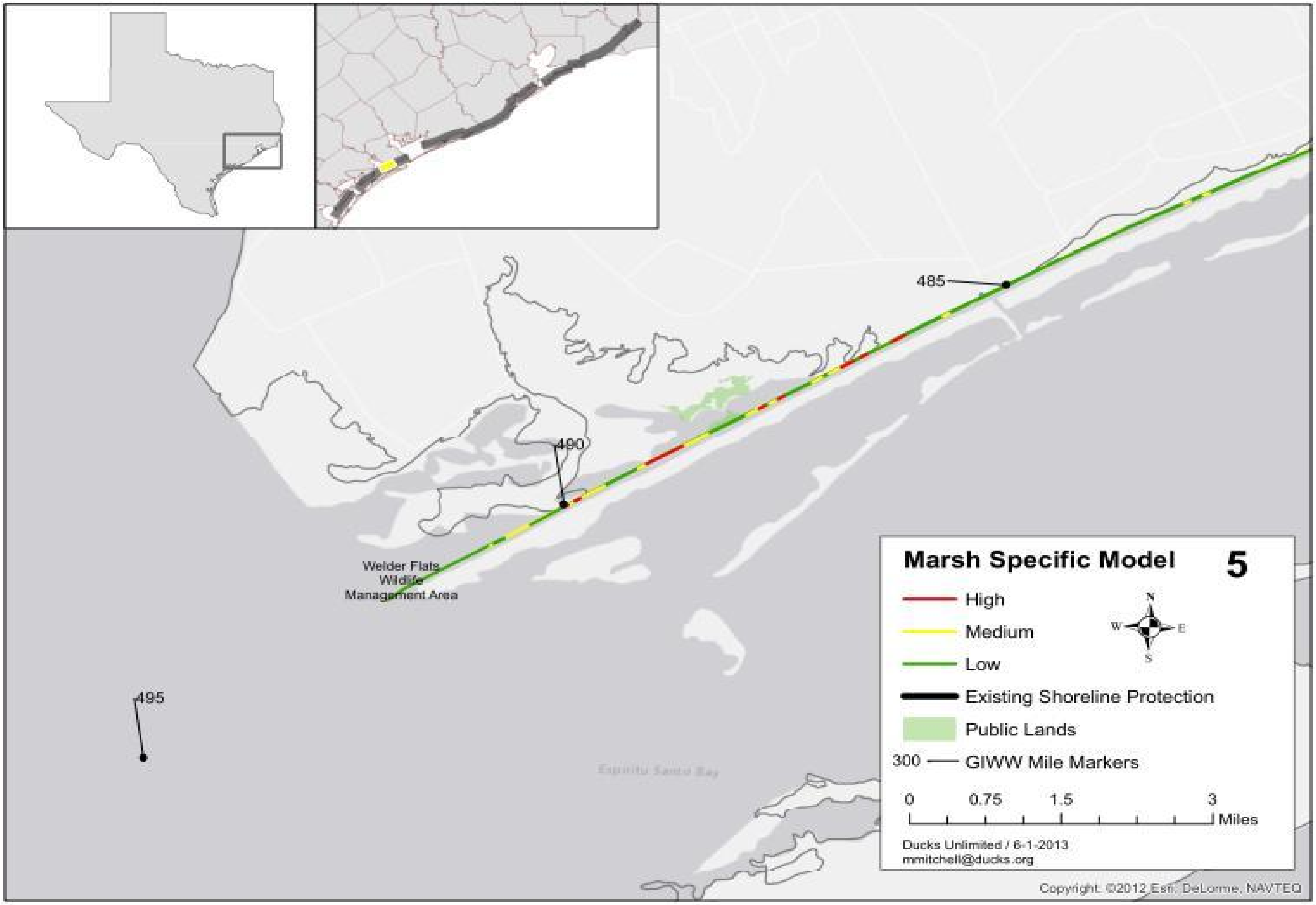
485
490
495
Welder Flats Wildlife Management Area
Marsh Specific Model
5
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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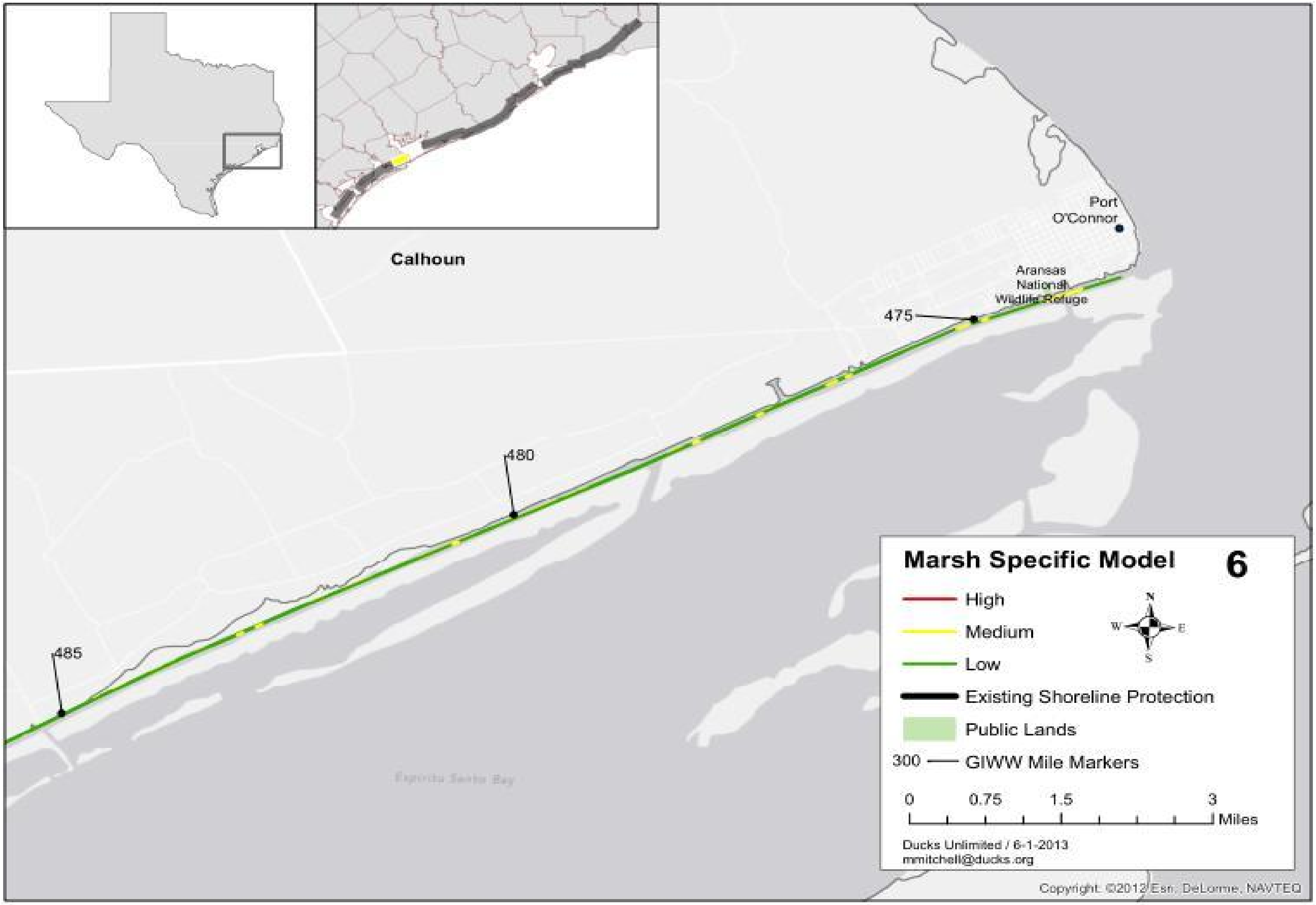
Calhoun
Port
O'Connor
Aransas
National
Wildlife Refuge
475
480
485
Marsh Specific Model
6
High
Medium
Low
Existing Shoreline Protection
Public Lands
300
GIWW Mile Markers
0
0.75
1.5
3
Miles
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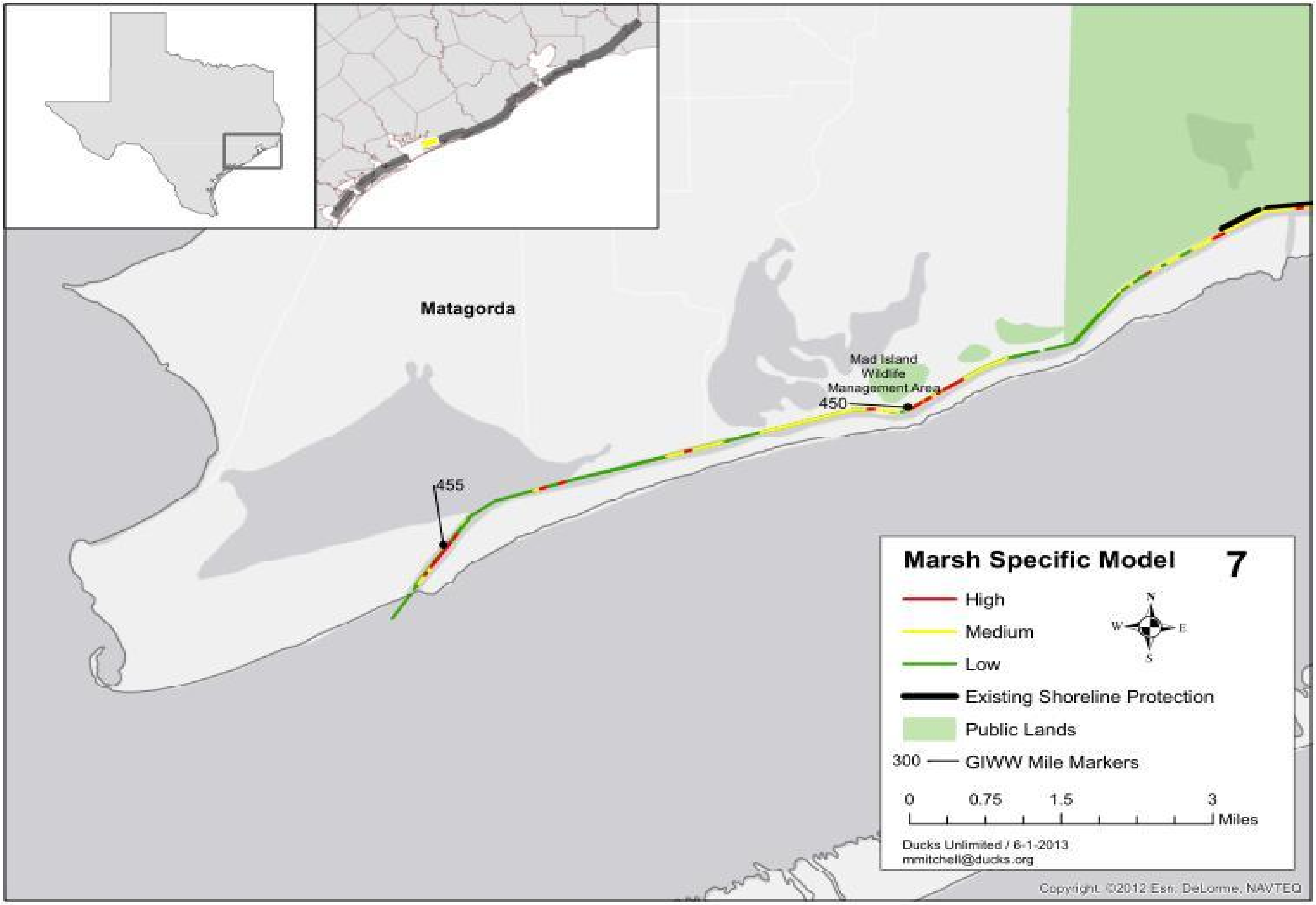
Matagorda
Mad Island Wildlife Management Area
450
455
Marsh Specific Model
7
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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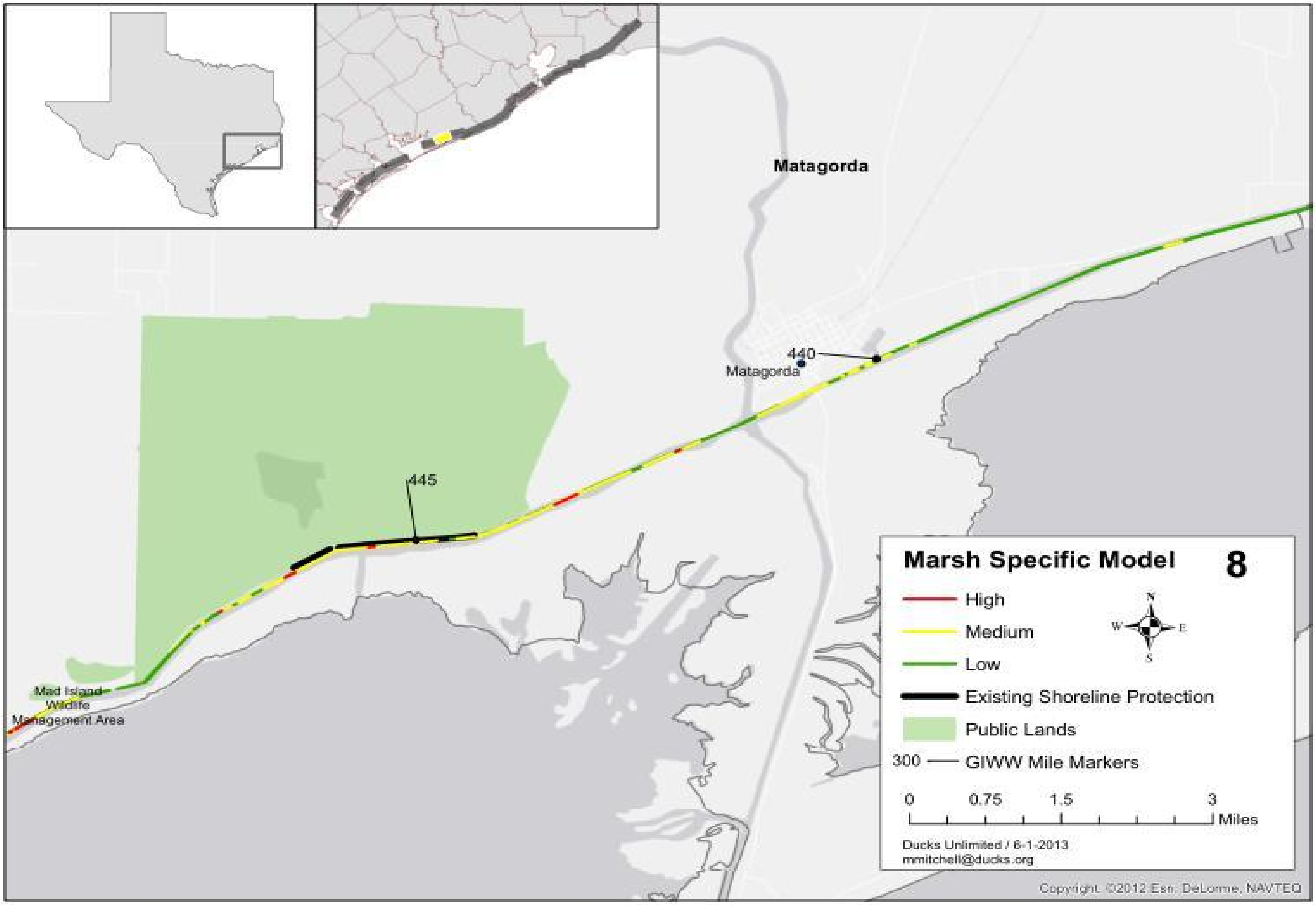
Matagorda
440
Matagorda
445
Mad Island
Wildlife
Management Area
Marsh Specific Model
8
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3
Miles
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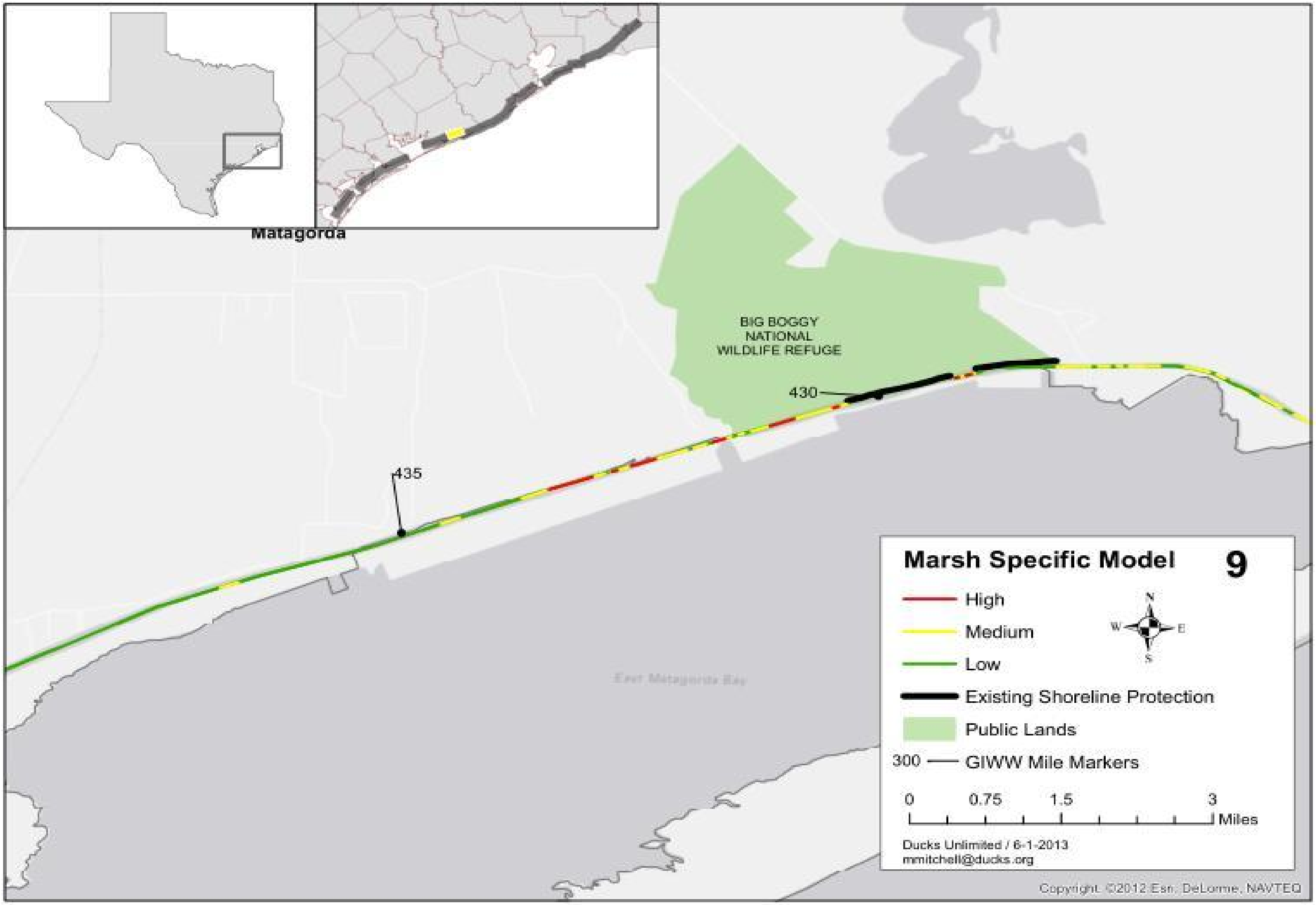
Matagorda
BIG BOGGY
NATIONAL
WILDLIFE REFUGE
430
435
East Matagorda Bay
Marsh Specific Model
9
High
Medium
Low
Existing Shoreline Protection
Public Lands
300
GIWW Mile Markers
0
0.75
1.5
3
Miles
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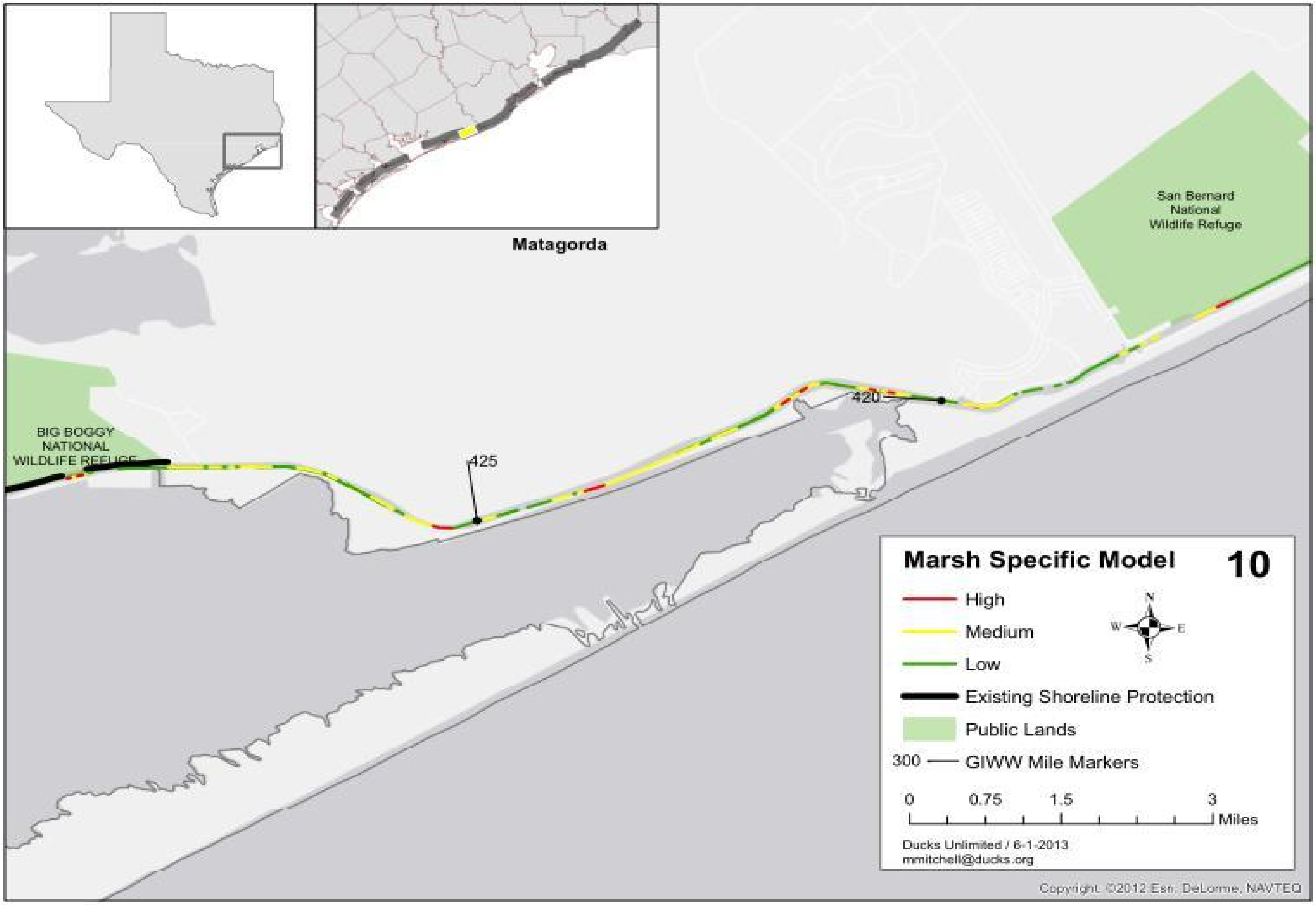
Matagorda
San Bernard
National
Wildlife Refuge
BIG BOGGY
NATIONAL
WILDLIFE REFUGE
425
420
Marsh Specific Model
10
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
N
S
E
W
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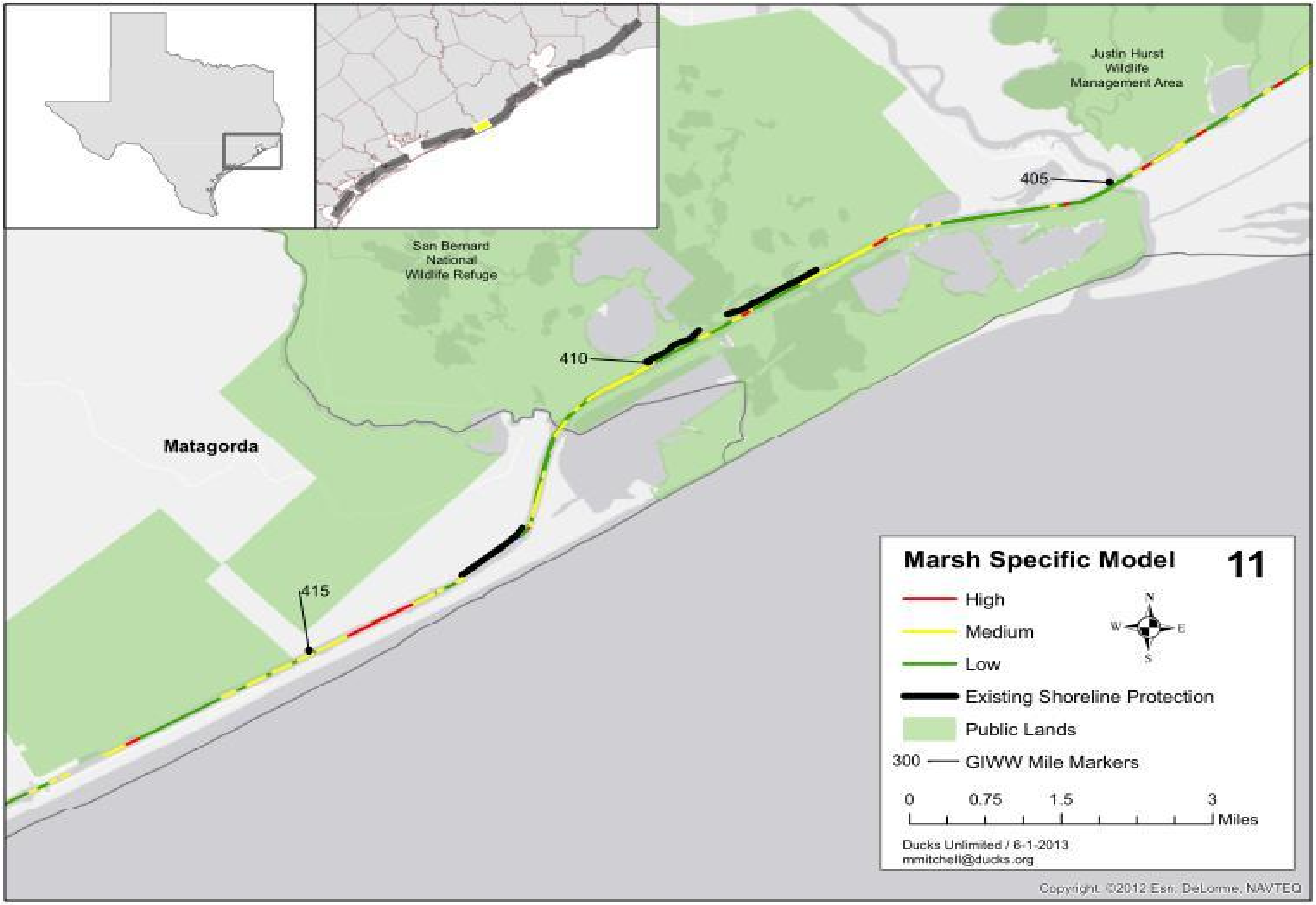
Justin Hurst
Wildlife
Management Area
405
San Bernard
National
Wildlife Refuge
410
Matagorda
415
Marsh Specific Model
11
High
Medium
Low
N
W
E
S
Existing Shoreline Protection
Public Lands
300
GIWW Mile Markers
0
0.75
1.5
3
Miles
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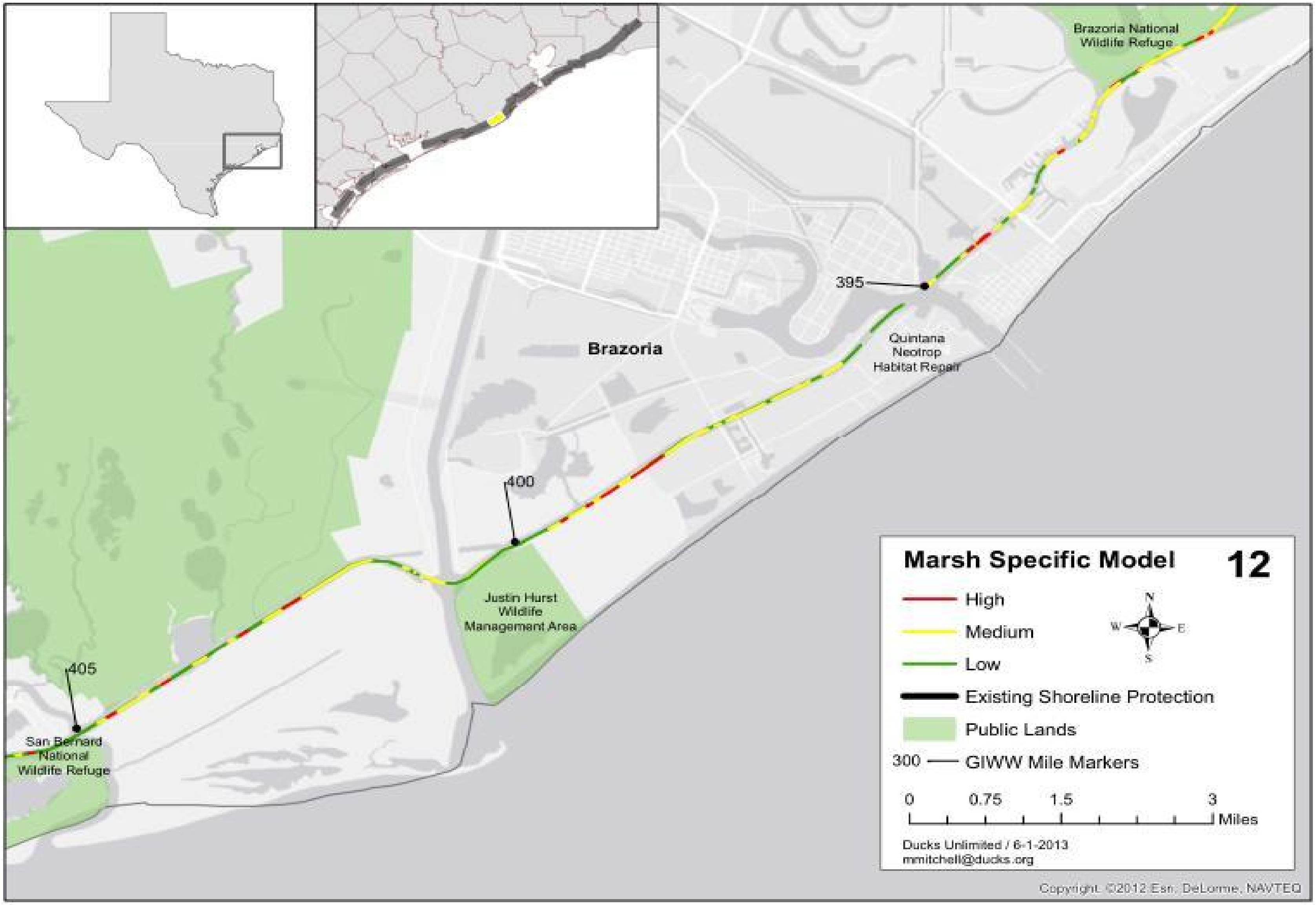
Marsh Specific Model
12
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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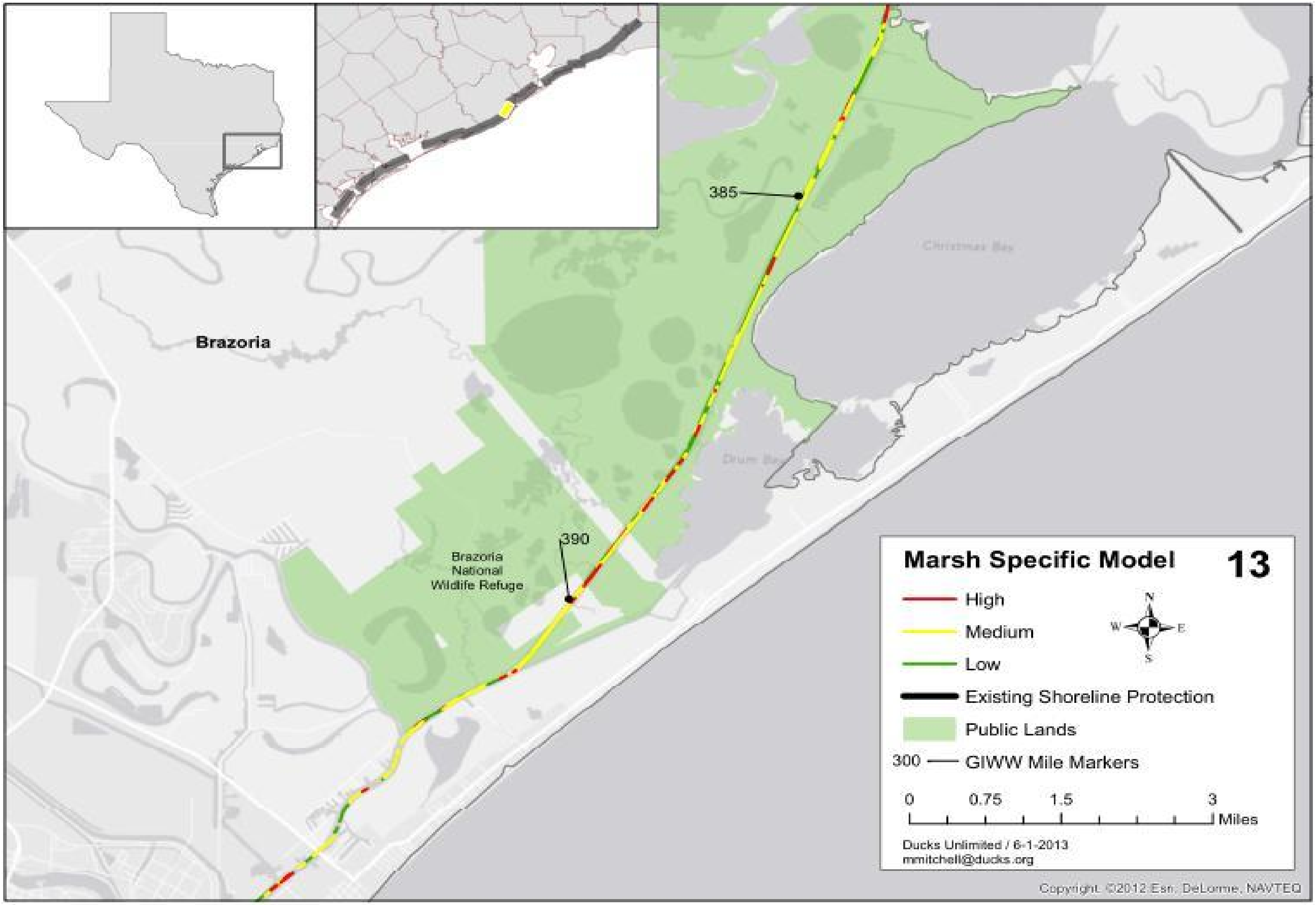
Brazoria National Wildlife Refuge
Brazoria
395
400
405
Quintana Neotrop Habitat Repair
Justin Hurst Wildlife Management Area
San Bernard National Wildlife Refuge


Brazoria
Brazoria National Wildlife Refuge
385
390
Marsh Specific Model
13
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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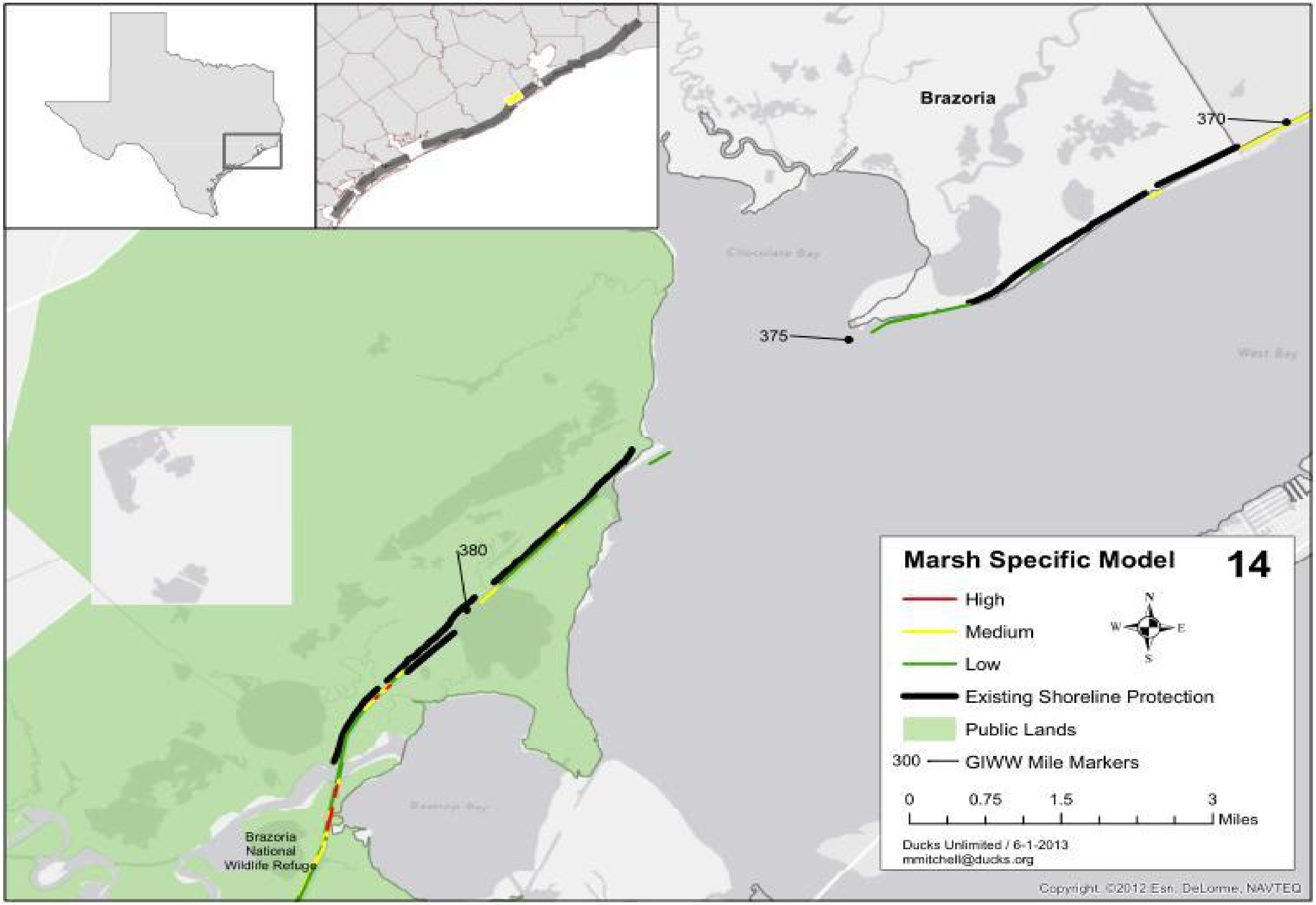
Brazoria
370
375
380
Brazoria National Wildlife Refuge
Marsh Specific Model
14
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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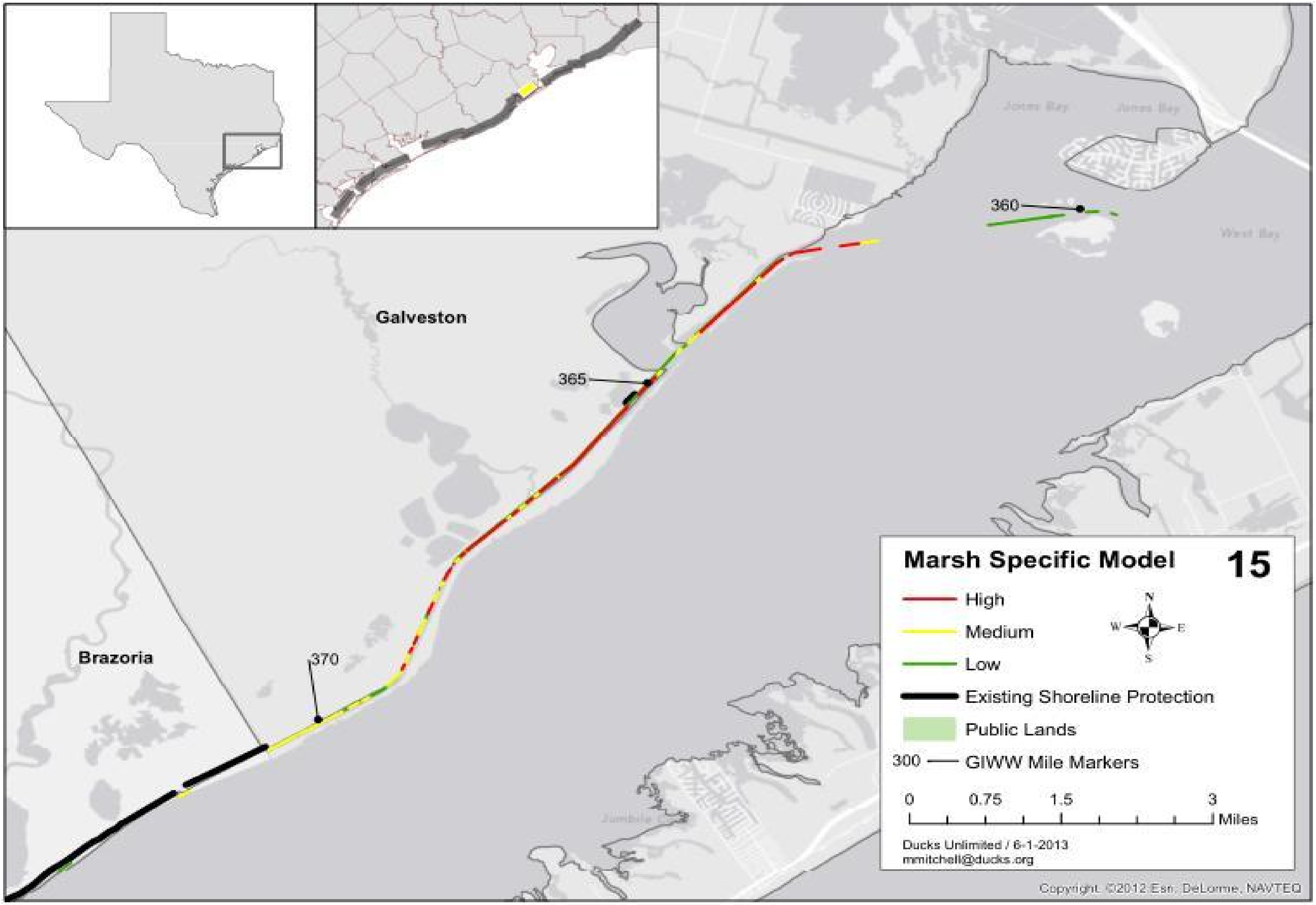
Galveston
Brazoria
360
365
370
Marsh Specific Model
15
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
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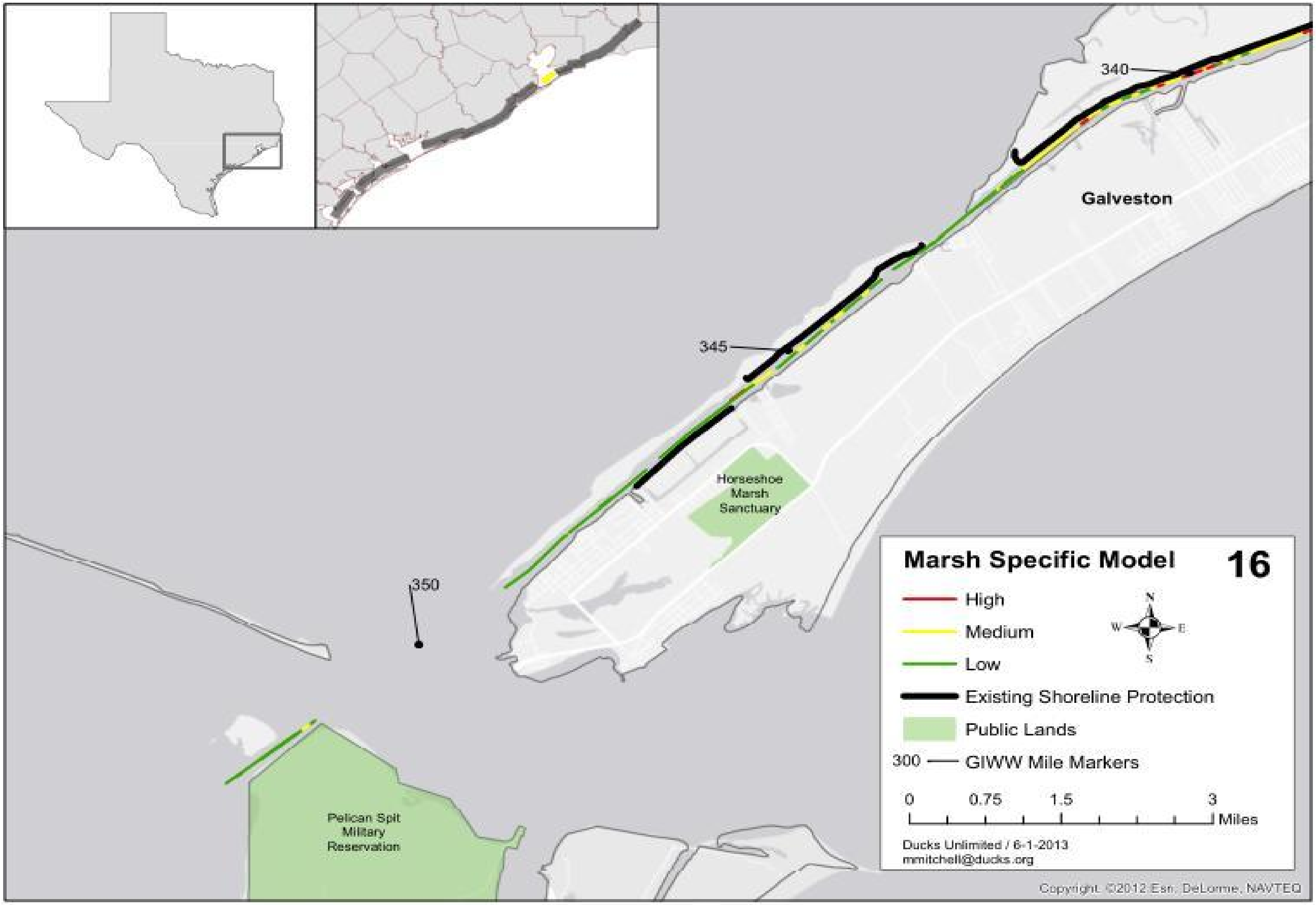

340
345
350
Galveston
Horseshoe Marsh Sanctuary
Pelican Spit Military Reservation
Marsh Specific Model
16
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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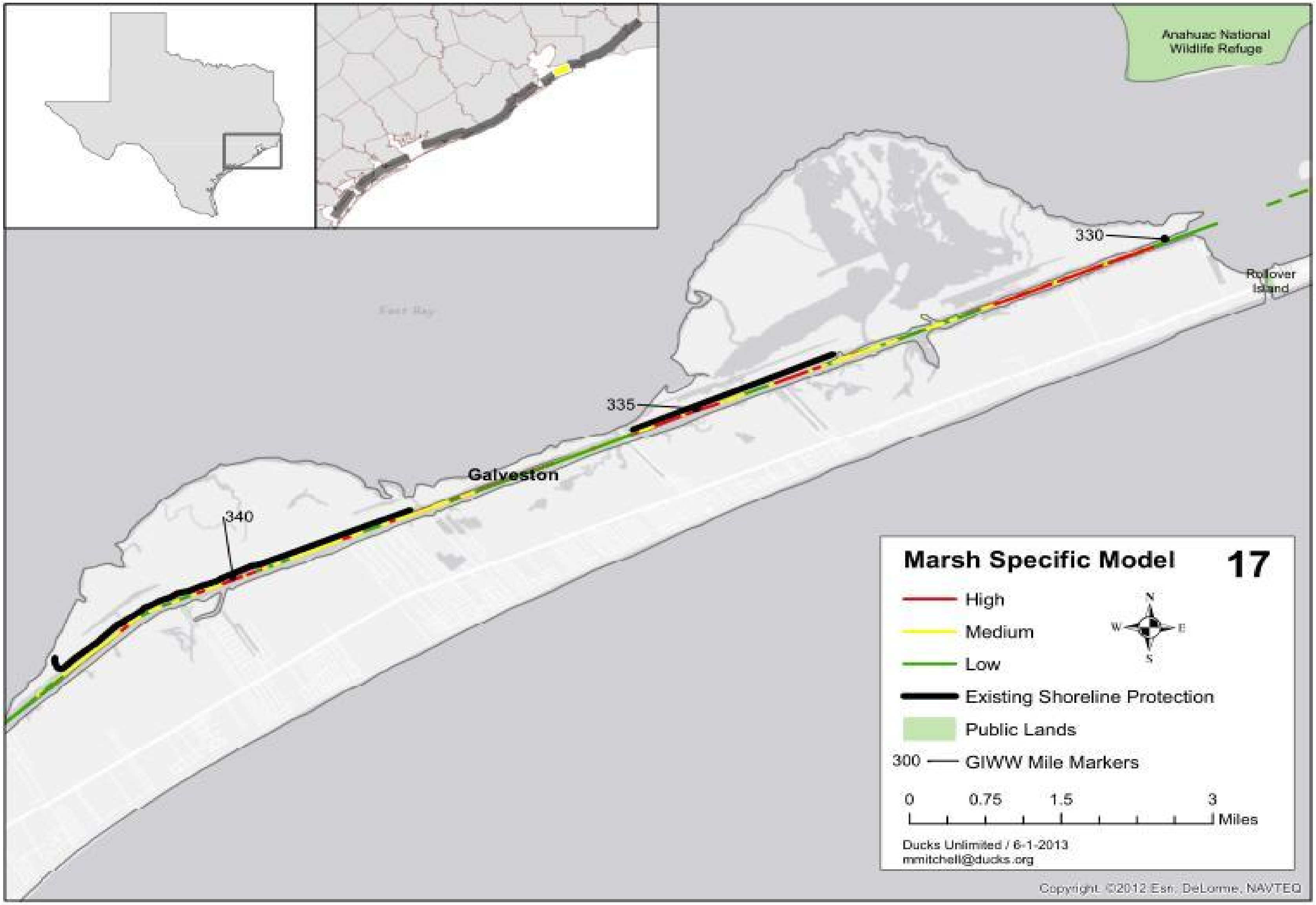
Anahuac National Wildlife Refuge
330
Rollover Island
335
Galveston
340
Marsh Specific Model
17
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0
0.75
1.5
3
Miles
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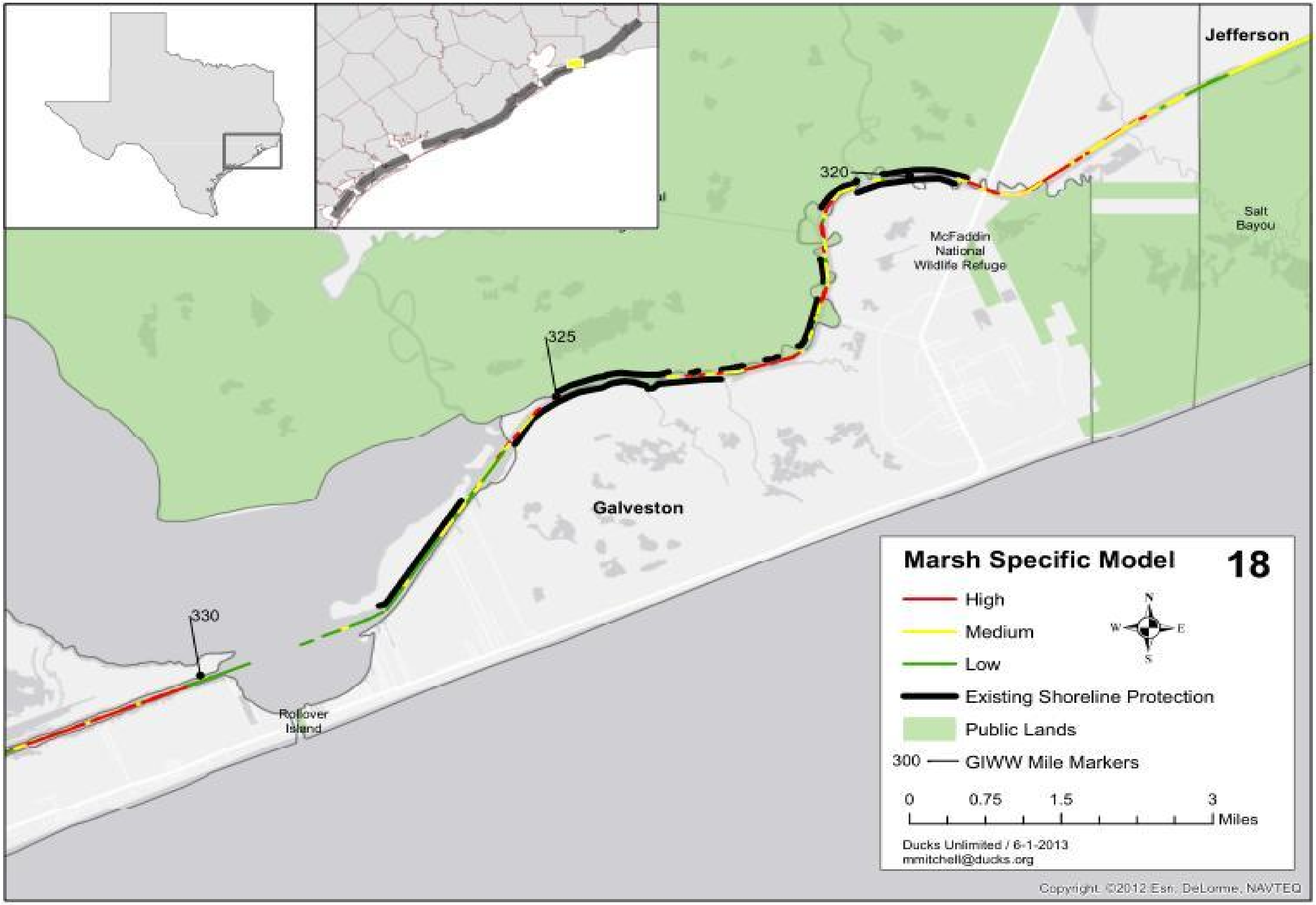
Jefferson
320
Salt Bayou
McFaddin National Wildlife Refuge
325
Galveston
330
Rollover Island
Marsh Specific Model
18
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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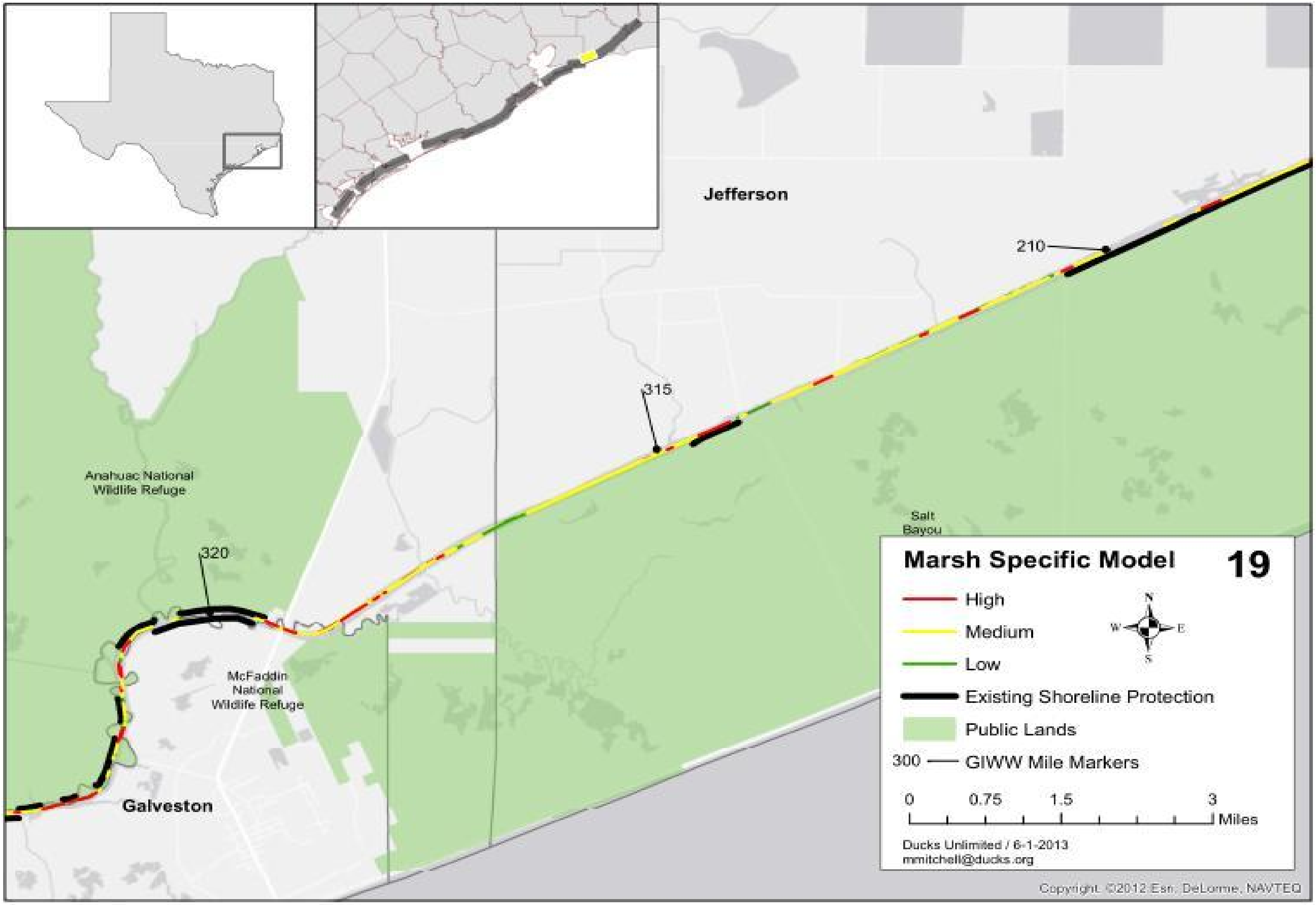
Jefferson
210
315
320
Anahuac National
Wildlife Refuge
McFaddin
National
Wildlife Refuge
Galveston
Salt
Bayou
Marsh Specific Model
19
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
N
S
E
W
0
0.75
1.5
3
Miles
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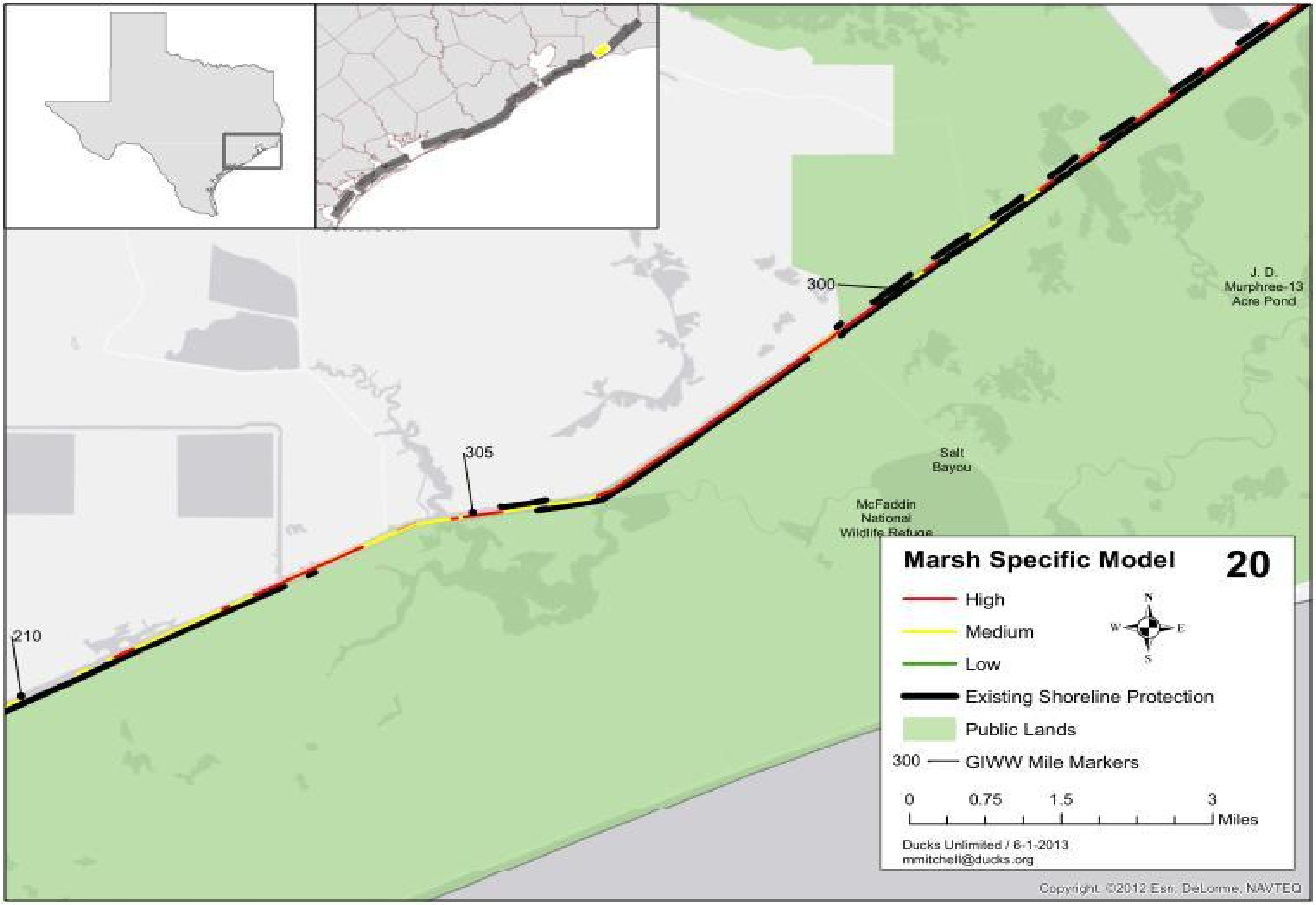
300
305
210
J. D.
Murphree-13
Acre Pond
Salt
Bayou
McFaddin
National
Wildlife Refuge
Marsh Specific Model
20
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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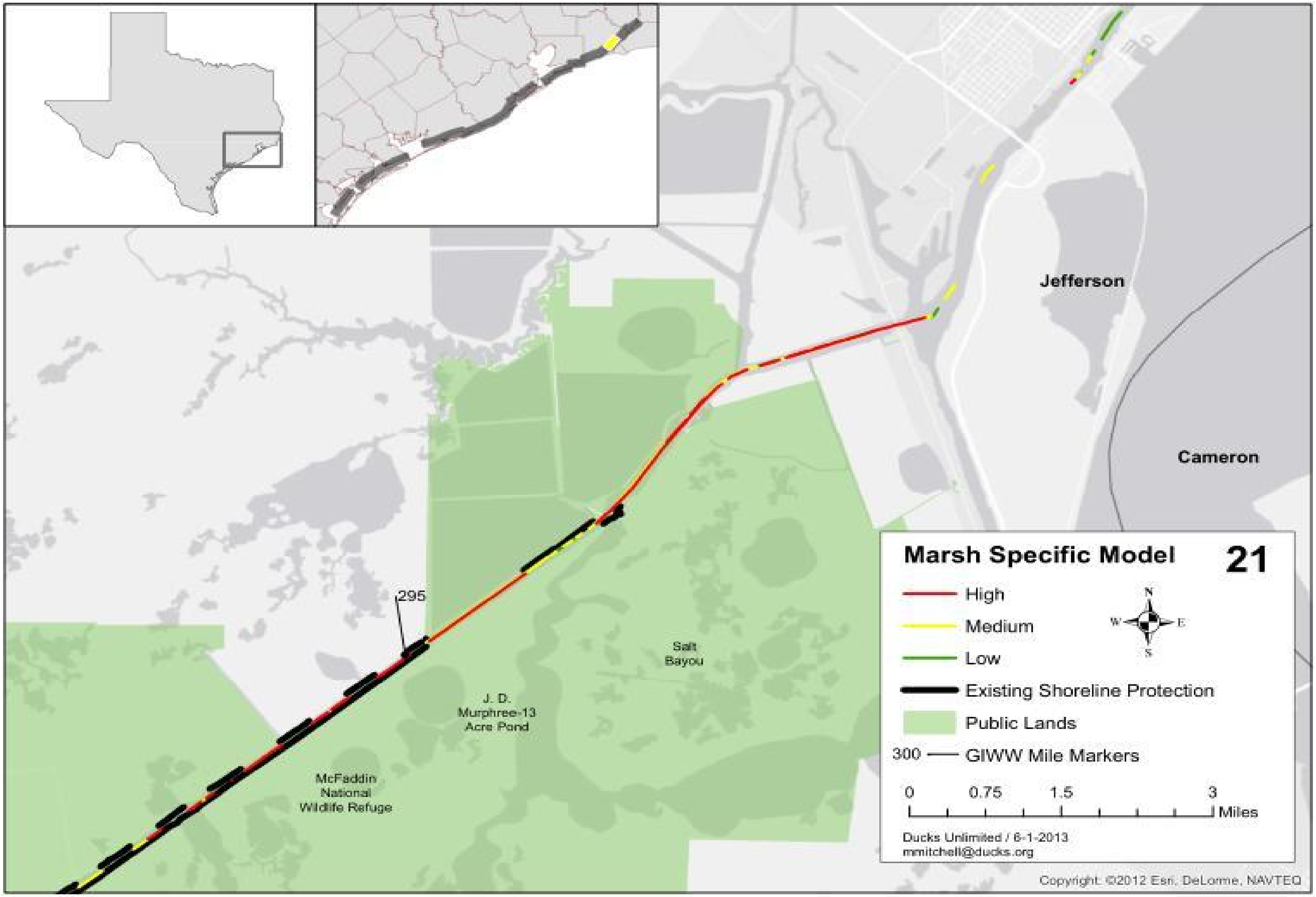
Jefferson
Cameron
295
Salt Bayou
J. D. Murphree-13 Acre Pond
McFaddin National Wildlife Refuge
Marsh Specific Model
21
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
N S E W
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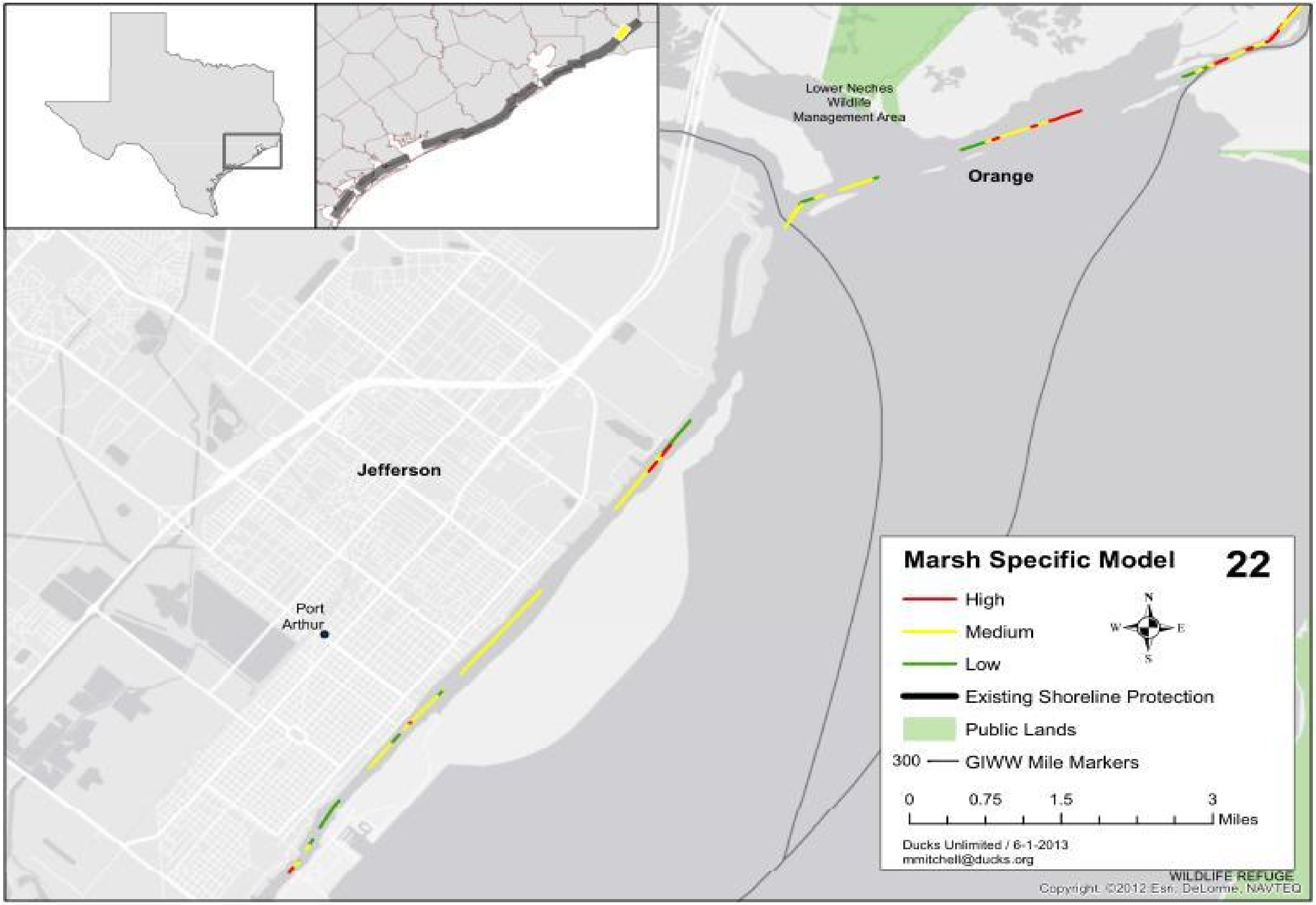
Lower Neches
Wildlife
Management Area
Orange
Jefferson
Port
Arthur
Marsh Specific Model
22
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
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WILDLIFE REFUGE
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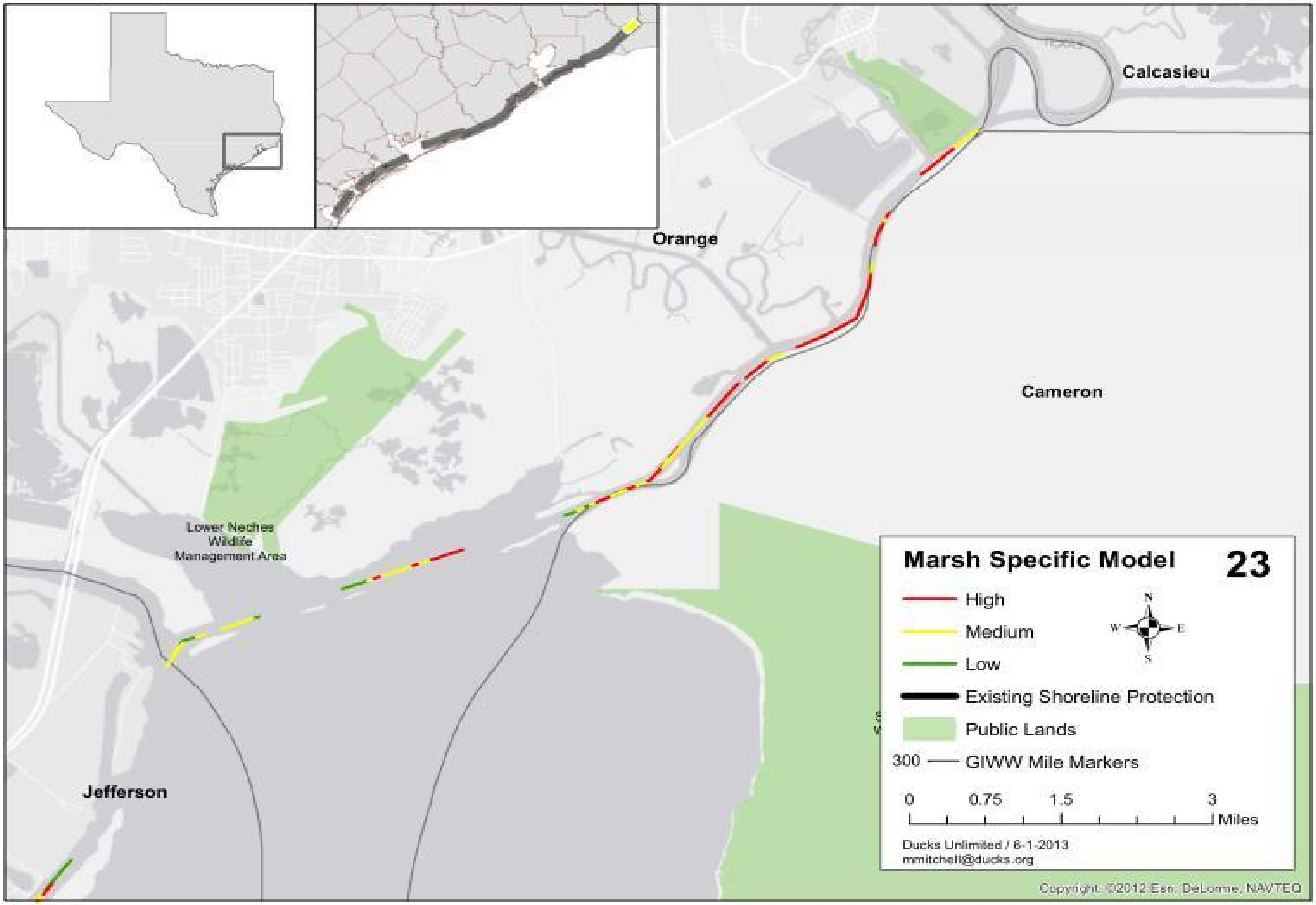
Calcasieu
Orange
Cameron
Lower Neches Wildlife Management Area
Jefferson
Marsh Specific Model
23
High
Medium
Low
Existing Shoreline Protection
Public Lands
300 GIWW Mile Markers
0 0.75 1.5 3 Miles
N
W
E
S
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