1,000 Mile Living Shoreline Project

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A report by the Texas Coastal Exchange
Prepared by Sustainable Planning and Design

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EXECUTIVE SUMMARY

A 1,000-mile living shoreline project for the Texas Gulf Coast is both feasible and affordable. The basic concept is to protect a significant portion of the 500,000 acres of coastal Spartina alterniflora wetlands along the Texas Coast from the erosion that will accompany future sea level rise. This will be done with a large-scale living shoreline project potentially funded through carbon credits.

This study used a weighted suitability analysis to identify over 1,300 miles of shoreline suitable for this type of protection. By protecting these wetlands with constructed oyster reefs and similar breakwaters, these wetlands will have a chance to maintain and expand with sea level rise, saving millions of tons of carbon stored in their soils while continuing to sequester carbon dioxide for decades into the future. Additionally, the fish, shellfish, and storm abatement benefits of wetlands will continue to be realized for the next generation of coastal fishermen, along with the wonderful marshland birdlife enjoyed by birdwatchers and kayakers.

In order to pay for these living shorelines, the Texas Coastal Exchange will work with BCarbon, a non-profit carbon credit registry associated with the Baker Institute at Rice University. BCarbon is studying the appropriate methodology for awarding living shoreline carbon credits. The included case study shows two living shorelines totaling 9 miles which would cost about $4.5 million to build and would generate almost $18 million in carbon credits at $20 a ton, while providing $150,000 a year for the landowner.

The TCX 1,000-Mile Living Shoreline project is fundamentally about coastal strategic thinking and adaptive design at massive scale in the era of climate change. This 1,000-mile living shoreline is feasible both physically and financially and should provide an excellent carbon reduction project for corporations and other entities looking to reduce their carbon footprint.

INTRODUCTION

The Texas Gulf coast between Louisiana and Mexico contains almost 400 miles of ocean coastline, 7 major bay complexes and more than 3 million acres of estuary habitat (Beaver, 2006, p 3; Texas Water Development Board, n.d.). Texas estuary ecosystems, including coastal saltmarshes, are important for a myriad of reasons, with tremendous biologic and economic values. Unfortunately, around half of Texas's original coastal wetlands have been lost, primarily due to various forms of development and filling as well as land surface subsidence around Galveston Bay.

Coastal wetlands provide many essential ecological services such as carbon capture and storage in the marsh soil. Texas coastal wetlands serve as nursery grounds for over 95 percent of the recreational and commercial fish species found in the Gulf of Mexico and provide permanent and seasonal habitat for an enormous variety of wildlife, including 75 percent of North America's bird species (E.P.A., 1999; U.S.A.C.E, 2021). They provide the winter range of the endangered Whooping crane, one of the rarest birds in the world, along with the threatened Black rail.

In the modern era of global warming and sea level rise, a growing body of research is increasingly showing that coastal marshes are excellent carbon sinks. Brackish estuarine wetlands (salt marshes) actively capture, or sequester, 3-4 tons of carbon dioxide (CO_2) per acre per year in marsh soils (for sources see table 1). Long-term carbon storage in coastal wetlands has been estimated to be 300-500 tons of CO_2 equivalent per acre (for sources see table 1). In addition, oyster reefs lining Texas bay bottoms not only have substantial benefits for water quality and fishery health, but they also actively sequester around 2 tons of CO_2 per acre per year in associated sediments (for sources see table 1).

Unfortunately, these coastal wetlands are threatened by sea level rise (SLR). Coastal marshes are aquatic ecosystems, but they are highly tidally influenced, and they can drown and consequently be destroyed if they are continuously submerged. Current forecasts predict a sea level rise of over 2 feet in Galveston by 2060 (Sweet et. al., 2022). Because of future SLR, Texas's remaining coastal marshes will be more prone to marsh fragmentation, die-off, and sloughing - or marsh edge erosion. In addition to losing habitats that are critical to marine life and coastal flora and fauna, threatening the economic and ecological integrity of the Texas coast, this marsh loss would both eliminate a significant annual source of nature-based carbon sequestration and release millions of tons of previously stored carbon dioxide into the atmosphere.

In February 2022, Texas Coastal Exchange (TCX) publicly announced its program to design a 1,000-mile living shoreline for the Texas coast to combat these impacts. This project is intended to mitigate the destructive impacts of sea level rise on estuarine wetlands while creating new revenue streams for coastal landowners. The end goal is a nature-based structural support and adaptation mechanism for salt marshes along the Texas Gulf Coast.

TCX is working with BCarbon, a Houston-based non-profit that certifies measured increases in nature-based carbon stocks for carbon credit trading to create new revenue streams for coastal landowners. Landowners along the coast have never had a reason to allow salt marshes to migrate inland on their property, as these ecosystems made them no money, apart from modest hunting opportunities. TCX and BCarbon hope to change this by studying the CO_2 sequestration and storage potential of targeted wetlands and oyster reefs in order to support the issuance of carbon credits. By turning wetlands into a revenue source through the generation of carbon credits, landowners would be incentivized to actively allow wetlands to move onto their property, as opposed to combatting their inland retreat.

There are numerous other entities, including the Texas General Land Office/Texas Coastal Resiliency Master Plan(s), studying shoreline protection, wetland restoration and living shoreline feasibility along the Texas Coast. TCX's work is not intended to replace those efforts but to complement them. What is unique about the TCX project is the focus on carbon sequestration and the potential to trailblaze a new economy that leverages the power of private partners and landowners to implement coastal protection, coastwide.

PROJECT DETAILS

This is a phased project. TCX has currently completed Phase 1, which is identifying the sites most suitable for living shoreline projects which protect existing coastal marshes. The objective of this analysis is to make use of publicly available data to broadly determine the suitability of shoreline protection projects for properties on Texas bays, which can then be used to assess properties' suitability on a local scale.

In Phase 2, computer modeling will be used to inform optimal design and building techniques which prioritize erosion control, resultant marsh sedimentation, and carbon sequestration. This modeling will be used to inform both project selection, incorporating cost/benefit analysis, and to design pilot projects in which TCX designers coordinate with a few landowners to develop pilot projects to begin implementation of the 1,000-Mile Shoreline Project. These pilot projects will stand as a proof of concept and, with monitoring, inform designers of potential challenges that exist. In further phases the entire 1,000 miles of living shoreline protection will be designed and eventually constructed coast-wide, in coordination with private landowners, NGO partners, and the State of Texas.

BACKGROUND

What is a Living Shoreline?

Living shorelines incorporate substantial natural or nature-based features, potentially combined with hard structural components, to provide shoreline protection and stabilization while maintaining shoreline ecosystem functions as shown in Figure 1.

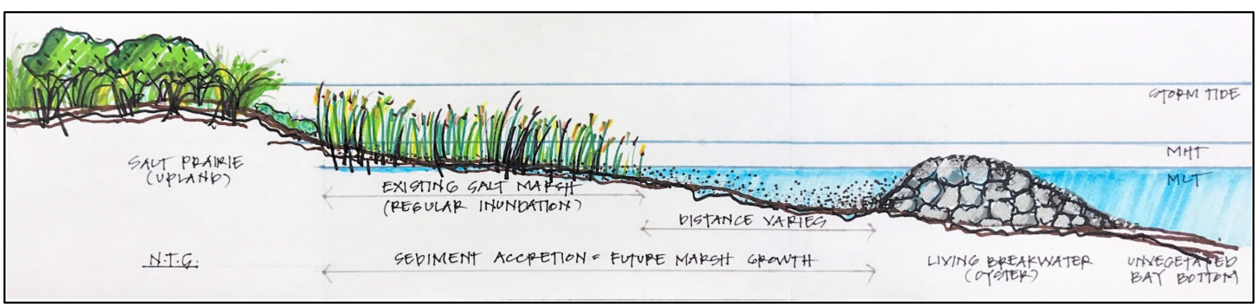


Figure 1. Diagram of the type of living shoreline envisioned for the 1,000-Mile Shoreline project. Illustration by Lalise Mason, Sustainable Planning and Design.

Living shorelines can use natural or recycled materials, along with the strategic placement of plants and/or other organic material, to reduce erosion, protect property, create habitat, and enhance resiliency. They work best in low energy environments, such as bays and estuaries or other areas protected from large waves. Living shorelines reduce shoreline erosion and deflect and absorb wave energy similar to hard structures used for shoreline protection such as breakwaters. Living shorelines also last longer than hard structures and require less long-term maintenance (GLO, 2020, p 4). The shoreline shown in Figure 1 is a so-called hybrid shoreline with submerged rock or oyster shell intended to recruit oyster spat for future oyster reef growth. Figure 2 is an example of a living shoreline project in Anahuac, Texas, East Galveston Bay.

Figure 2. Galveston Bay Foundation living shoreline project, Anahuac Texas, East Galveston Bay. Photograph by Lalise Mason, Sustainable Planning and Design.

The 1,000-Mile Shoreline focuses on building living shorelines which create viable oyster habitat. To build a living shoreline suitable for oyster growth, a hard substrate like breakwater or gabion baskets filled with rubble or shell is placed on the bay floor. Figure 1 shows a typical living shoreline utilizing nearshore breakwater. Oyster beds provide habitat for fish, crabs, and oysters in addition to improving water quality. Submerged oyster shell beds protect shorelines by reducing wave energy and trapping sediment along the shore (GLO, 2022, p 15).

According to the GLO, 114 living shoreline projects have been documented in Texas since 1987. Most of these projects are owned by NGOs, individuals, or private companies and 64 of these projects are hybrid living shorelines, with the remainder being other designs not being pursued in this project. In total this makes 37,210 acres of living shoreline projects on the Texas coast as of 2020 (GLO, 2020, p 28). In addition to these existing projects, the Army Corps of Engineers (USACE) is proposing to build approximately 130 miles of shoreline protection projects on the Texas Coast, primarily along the Gulf Intracoastal Waterway (GIWW) as part of the Coastal Texas Study. These projects include both living shorelines and hard structures. For more information on USACE projects, see Appendix A.

Carbon Credits

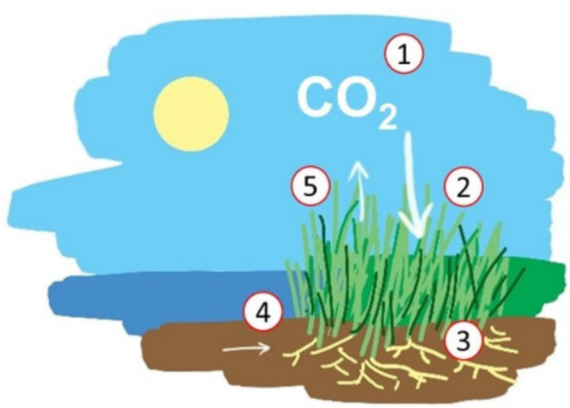
Nature can be an important ally in the fight against climate change. Plants, including those in estuarine wetlands and other coastal ecosystems, take carbon dioxide out of the atmosphere and store them in sediments as organic carbon in a process called photosynthesis, a crucial component of the global carbon cycle. To date, coastal landowners have had little incentive to leave their land in its natural state—whether as bottomland hardwood forests, coastal prairie, or emergent wetlands. Instead, economic pressures lead to the conversion of natural ecosystems to housing, commercial, or industrial uses.

One approach to incentivizing the protection and expansion of natural ecosystems is to pay landowners for the climate benefits that their land provides to the whole planet. A carbon credit represents one ton of carbon dioxide equivalent removed from the atmosphere and stored in a solid form. Emitters of carbon dioxide can purchase carbon credits to offset some of their emissions, and the money is then paid to the landowner. BCarbon soil carbon credits have been selling between $20-23 per metric ton.

In this context, two types of carbon credits are relevant – annual sequestration and avoided conversion. Annual sequestration refers to a processes like marsh grass using photosynthesis to convert carbon dioxide into plant and root structure that annually increases organic carbon in the soil. Avoided conversion refers to credits being awarded based on existing carbon stocks *not* being released in the future. For example, an agreement to not convert standing forests into croplands can generate carbon credits because the trees that would otherwise be cut down will be allowed to stand going forward in time. Avoided emission carbon credits may receive a lower price on the market or not, depending upon the circumstance of the credit and potential for loss and the additional ecological services of the project.

Historically, nature-based carbon credits have mostly been used to incentivize the protection of forest and grassland ecosystems. The voluntary market for forest carbon credits has been operational for at least 20 years, while the nascent but rapidly growing voluntary market in soil carbon credits is just now emerging. In contrast, the voluntary carbon market for credits generated by coastal ecosystems is virtually non-existent. Consequently, an important revenue source could be developed to incentivize private landowners to support coastal conservation and restoration.

The Coastal Carbon Cycle



1. Atmospheric CO_2 is at the highest level in human history.
2. CO_2 is taken from the atmosphere by plants.
3. Plants use the CO_2 to grow, producing roots, leaves, and stems through photosynthesis.
4. Dead roots remain in the soil because their decomposition is slowed due to tidal flooding by sea water, leading to high rates of carbon storage.
5. Some of the CO_2 returns to the atmosphere due to plant and bacterial respiration, but the majority of it remains stored in the soil.

Figure 3. The coastal carbon cycle showing the movement of carbon dioxide from the atmosphere to the soil in the coastal marsh. Image by Dr. Azure Bevington for Texas Coastal Exchange.

Carbon Protection: Living Shoreline Avoided Conversion

Living shorelines makes sense as both habitat creation and as protection from the erosive forces of the dominant southeast breeze that continuously works on the north shorelines of the Texas Bays. As stated earlier, the concern is that with sea level rise, our coastal marshes will become more susceptible to erosion and sloughing, which would release the carbon stored in the soil of the marsh. That is the problem facing the Texas coast in the future.

The key to the 1,000-Mile Living Shoreline project is that these constructed reefs will protect our coastal wetlands from erosion. This is extremely important. There are two major benefits to such construction: 1) it will reduce wave and wind-driven erosion, and 2) it can increase the rate of sedimentation in the wetlands themselves, hopefully allowing the marsh sediment level to keep up with the rising sea level. Figure 4 shows an example of a living shoreline project with sediment accretion inside a robust breakwater. These new sediments are now suitable for planting, or for colonization by seeds from adjacent marsh stocks.

Figure 4. Sediment accretion behind a living shoreline breakwater at Virginia Point in Galveston Bay. Photograph courtesy of Scenic Galveston.

Carbon credits can help make this vision a reality. Funders of living shoreline projects like the ones proposed in this report would be awarded a unique type of avoided conversion credit, assuming this approach was adopted and implemented by BCarbon or another carbon registry. The initial carbon credits for the creation of these barriers would help capitalize their construction, and the continued life of the marsh would provide an annual source of carbon credits from the protected wetlands. These annual credits could be sold by the private landowner on the carbon market, which is only expected to become more robust in the future. Assuming that a given project breakwater complex is successful in supporting living oysters, then the developer of the project could also be awarded carbon credits for the carbon actively sequestered by these newly-established ecosystems, which best estimates report as being at least 2 tons of carbon dioxide equivalent per acre per year (Veenstra, 2021). Further, to the extent that seagrass beds (submerged aquatic vegetation, or SAVs) might develop in protected waters adjacent to these reefs, further credits could be issued for the carbon stored by seagrass. Table 1 shows the estimated carbon storage and sequestration values of wetlands, seagrass, and oyster reefs.

Table 1. Estimated carbon storage/sequestration values based on averages of values from literature.

	Value	Source(s)
Average Carbon Storage for Coastal Wetlands	401 metric tons CO2e/acre	Uhran et al., 2021
Carbon Sequestration Rate for Salt Marsh	3.2 tons CO2e/acre/year	Engle, 2011; IPCC, 2013; McLeod, 2011; Drexler, 2019; Suir, 2019; Needelman, 2018; Ouyang, 2014
Carbon Sequestration Rate for Sea Grass	3.3 tons CO2e/acre/year	Alongi, 2018
Carbon Sequestration Rate for Oyster Reefs	1.8 tons CO2e/acre/year	Veenstra, 2021; Foedrie, 2017

BCarbon will be funding modeling that examines how the construction of the living shorelines proposed in this report would impact inland wetland migration under different climate change scenarios. There are also design implications that will be addressed in the modeling, including the appropriate width of the oyster reef to provide maximum erosion protection and sedimentation under different fetch and turbidity conditions.

1,000-MILE LIVING SHORELINE SUITABILITY ANALYSIS

In order to identify the areas most suitable for shoreline protection and carbon storage/sequestration, TCX contracted Sustainable Planning and Design to use their Geographic Information System (GIS) expertise to conduct a suitability analysis with a weighted overlay for land parcels along Texas Bay shorelines. The suitability analysis identifies candidate parcels that can then be assessed on a smaller scale.

A suitability analysis identifies the best “place” for something based on the geographical, physical, biological, and social conditions. Suitability maps result from the suitability analysis, and they can be used to visualize the spatial distribution of the analysis’ determined values. Adding weights allows metrics to be quantified by relative importance within the suitability analysis. A suitability analysis with a weighted overlay allows relevant metrics to be quantified and visualized simultaneously for a given area, in the case of this study the Texas coast. The suitability analysis is not a substitute for site specific evaluation, but it gives a good idea of which areas would be most suitable for this project.

The suitability analysis was confined to a study area which encompassed the land parcels surrounding Texas Bays. Land ownership parcels were downloaded from Texas Natural Resources Information Systems (TNRIS) and Chambers County Appraisal District (TNRIS, 2021; Chambers County Appraisal District, 2021). Areas which are primarily dominated by salt marsh and lack large algal flats and seagrass areas were of the most interest for this phase of the analysis. Therefore, the study area only included parcels within counties falling completely within the Coastal Zone Boundary’s regions 1, 2, and 3. Further, because the goal of this analysis was to identify parcels suitable for shoreline protection, inland parcels needed to be excluded. In order to do that, parcels not within 400 meters of Texas bays (TPWD, 2012) were removed from the study area. Barrier islands were also removed from the study area through scoring because they have no potential for inland wetland migration. Ocean Conservancy's barrier island shapefiles were used to identify barrier islands (Ocean Conservancy, 2013).

ELEMENTS UTILIZED IN THE SUITABILITY ANALYSIS

There were several elements that were mapped and then integrated into the suitability analysis as metrics. These were proximity to Texas Bays, land ownership, shoreline suitability as determined by the Harte Research Institute (HRI), important Whooping crane habitat, salt marsh presence, development, oyster suitability, and future sea level rise. These metrics are shown below in Figure 5. The following paragraphs discuss in detail each of these variables and how they are incorporated into the analysis.

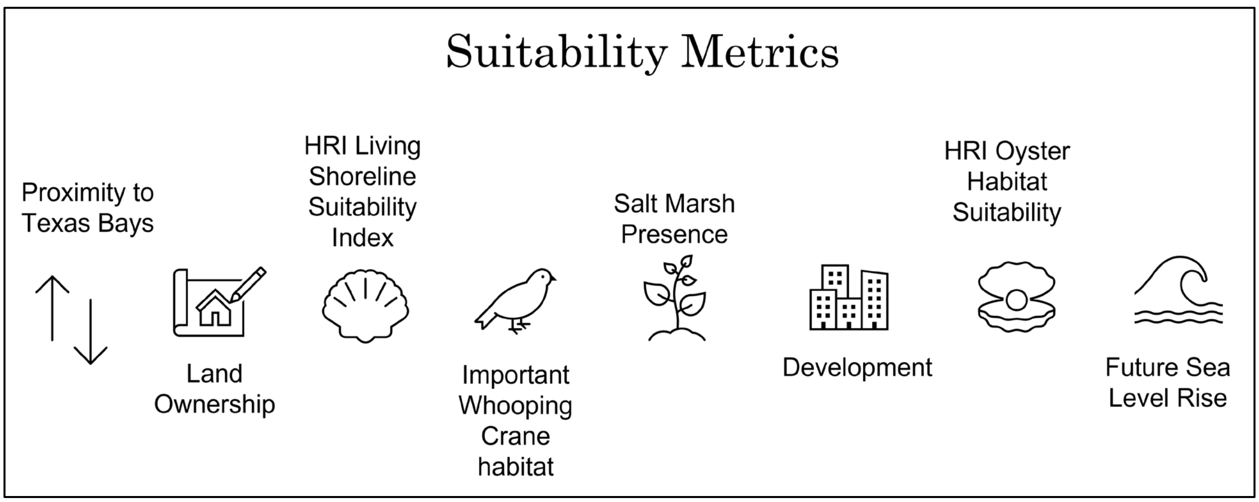


Figure 5. Metrics used in the suitability analysis for the 1,000-Mile Living Shoreline project.

Proximity to Bays

A variable of importance was proximity to Texas bays. Here, the key variable was determining which private lands to exclude based on distance from the bays. Lands more than 400 meters from the shoreline were eliminated from consideration. Texas Parks and Wildlife Department's Major Bays shapefile was used as an estimate of the edge of the shoreline (TPWD, 2012).

Land Ownership

The GIS analysis focused on privately owned, NGO and GLO owned properties in order to work in the economics of carbon sequestration as a potential financing mechanism. Federally owned wildlife refuges were omitted from this analysis because early discussions with federal authorities revealed that these lands would not be participating in carbon credit accrual and sales. If this situation were to change, significantly more land area could be added in all three regions. USGS Protected Area Database (PAD-US) was used to identify federally owned parcels in the analysis (USGS Gap Analysis Project, 2020).

Wetlands

The starting point for suitability in this project is the presence of *Spartina alterniflora* and allied saltmarsh wetlands. As discussed previously, these lands are important for their ecological services to society. The carbon sequestration value of these wetlands is particularly important because of the impact that their loss could have on our ongoing efforts to reduce CO_2 in the atmosphere and the potential for carbon emitters to pay for the construction of these living shorelines and because carbon may offer a way to finance wetland protection infrastructure.

There are approximately 500,000 acres of such wetlands adjacent to Texas bays. Sustainable Planning and Design used the USFWS National Wetland Inventory (NWI) to incorporate wetland area into the suitability analysis. The acreage of these coastal wetlands by county, excluding region 4, is shown in Table 2, and the spatial distribution of wetlands along the coast are shown in Figures 6, 7, and 8. Region 4 was excluded from the analysis because of the presence of algal flat coastal wetlands. This decision may be revisited at a later time.

Table 2. Wetland area and estimated carbon storage and sequestration resources for Texas coastal wetlands by County based on NWI data (USFWS, 2017).

Potential Carbon Storage and Sequestration Resources, Texas Coastal Wetlands by County: Excluding Region 4					
County	**Saltmarsh Wetland (Acres)**	**Total Carbon sequestration (Salt Marshes ~3.2 tons CO2e per acre per year)**	**Total Carbon Storage (Only Saltmarsh wetlands at 401 metric tons of CO2 equivalent per acre)**	**Total Storage Value ($20/ton)**	**Annual Sequestration Value ($20/ton per year)**
ARANSAS	22,041	70,531	8,838,441	$176,768,820	$1,410,624
BRAZORIA	44,831	143,459	17,977,231	$359,544,620	$2,869,184
CALHOUN	16,161	51,715	6,480,561	$129,611,220	$1,034,304
CHAMBERS	131,976	422,323	52,922,376	$1,058,447,520	$8,446,464
GALVESTON	22,195	71,024	8,900,195	$178,003,900	$1,420,480
HARRIS	1,056	3,379	423,456	$8,469,120	$67,584
JACKSON	14,270	45,664	5,722,270	$114,445,400	$913,280
JEFFERSON	46,026	147,283	18,456,426	$369,128,520	$2,945,664
KLEBERG	847	2,710	339,647	$6,792,940	$54,200
MATAGORDA	49,503	158,410	19,850,703	$397,014,060	$3,168,192
NUECES	2,130	6,816	854,130	$17,082,600	$136,320
REFUGIO	18,510	59,232	7,422,510	$148,450,200	$1,184,640
SAN PATRICIO	2,164	6,925	867,764	$17,355,280	$138,496
VICTORIA	1,401	4,483	561,801	$11,236,020	$89,664
Total	373,111	1,193,954	149,617,511	$2,992,350,220	$23,879,096

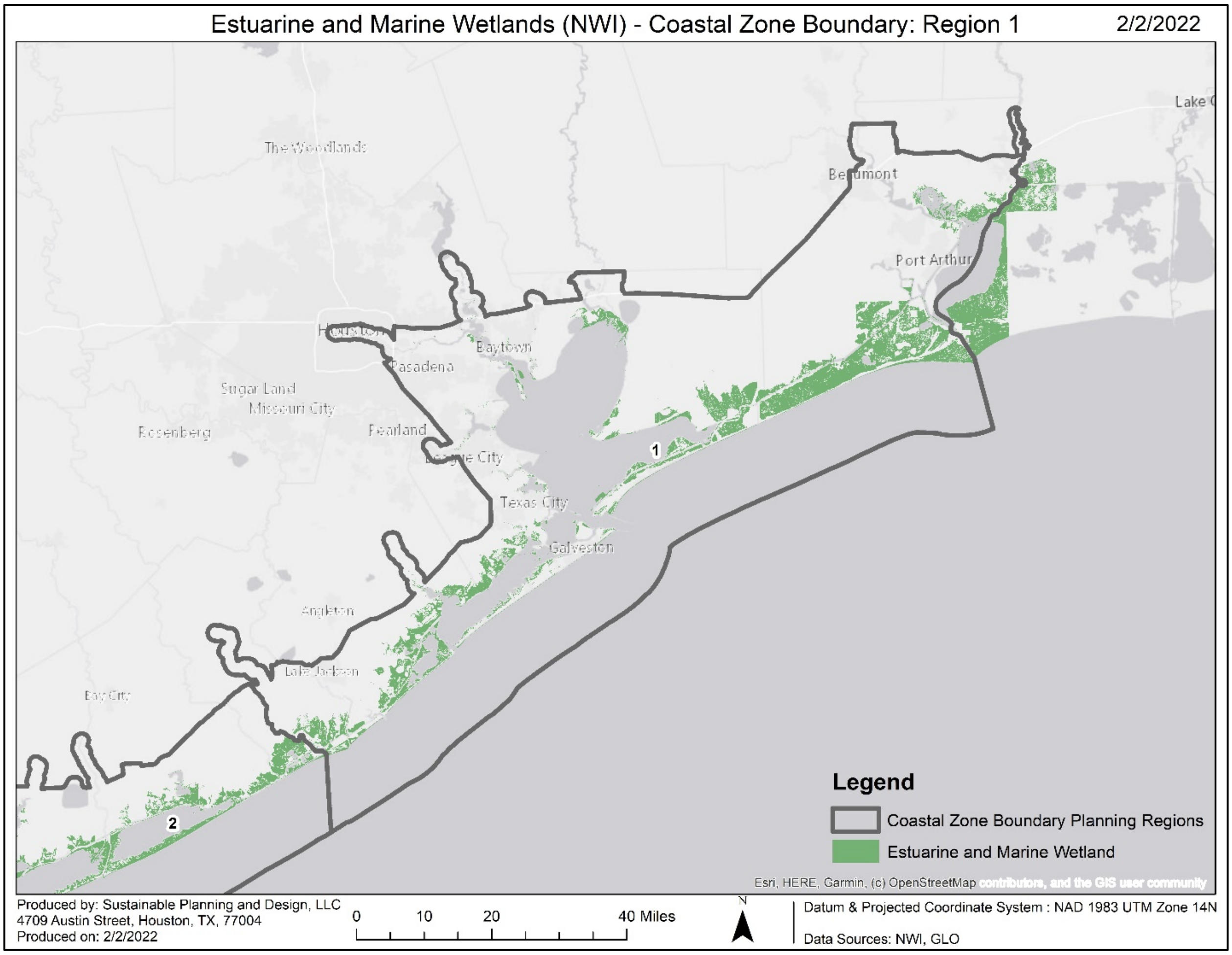


Figure 6. Estuarine and marine wetlands in Region 1 based on NWI data (USFWS, 2017).

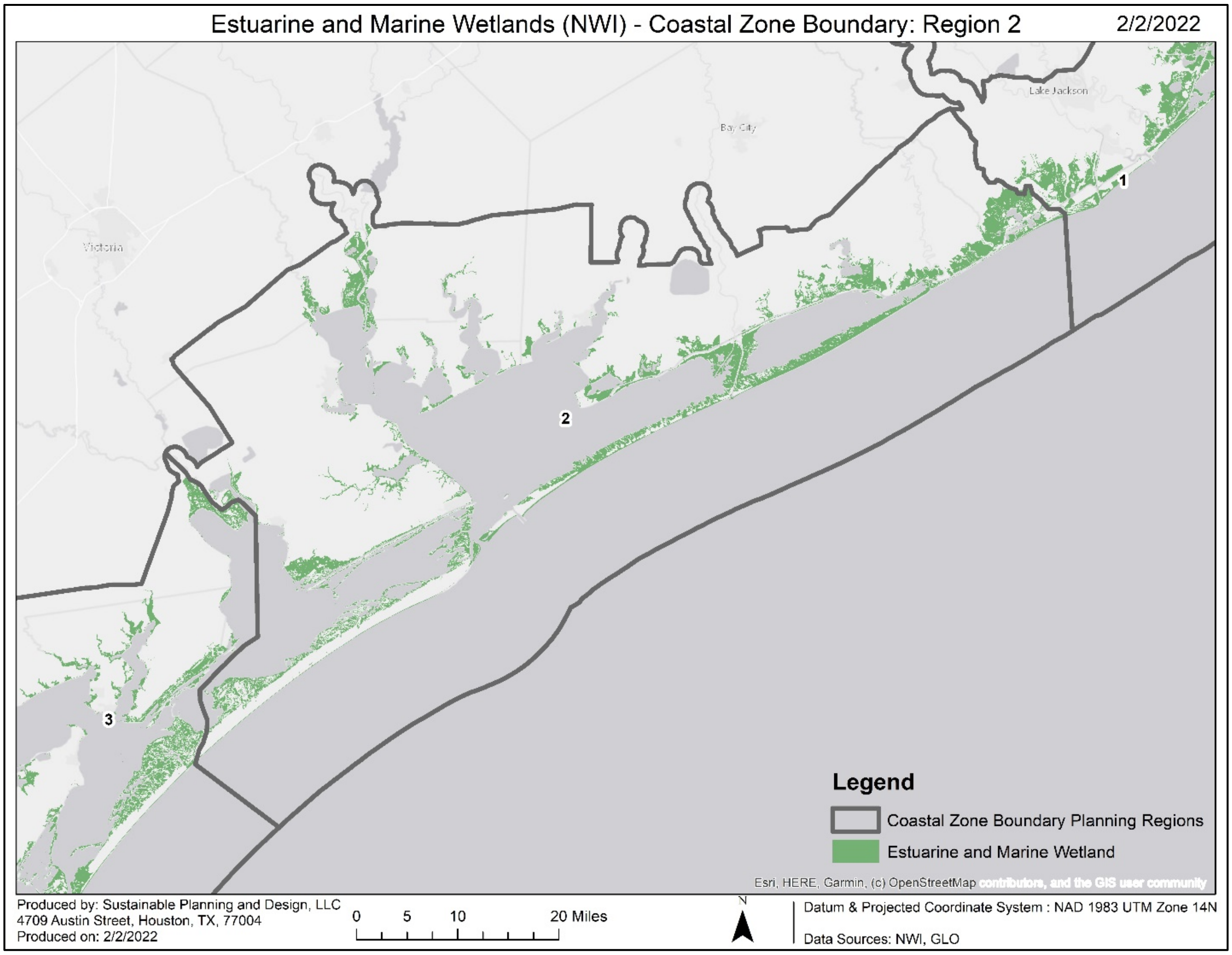


Figure 7. Estuarine and marine wetlands in Region 2 based on NWI data (USFWS, 2017).

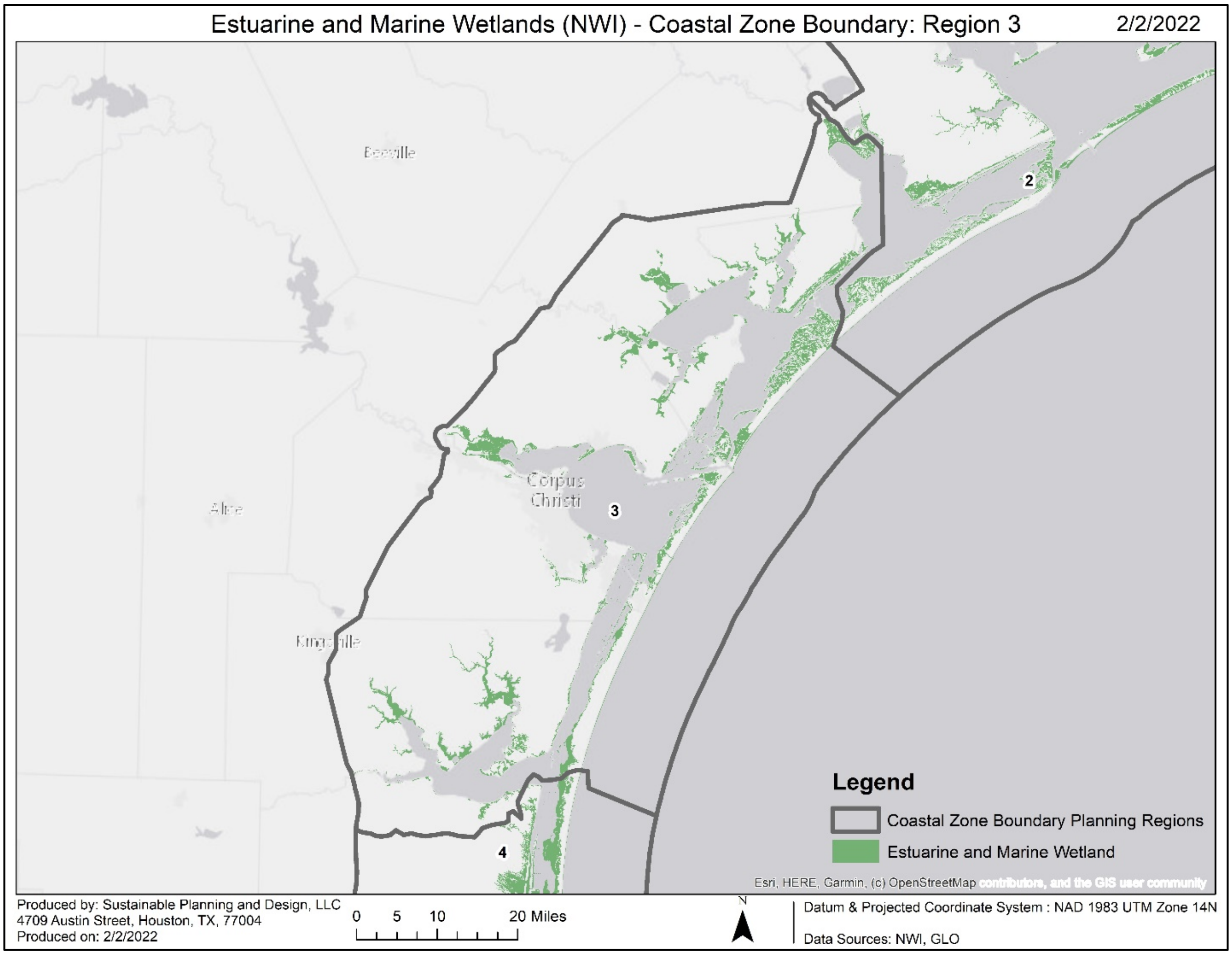


Figure 8. Estuarine and marine wetlands in Region 3 based on NWI data (USFWS, 2017).

Suitability for Oyster Propagation

Another variable of importance is the suitability of a particular area for oyster propagation. The Harte Research Institute (HRI) has undertaken a detailed evaluation of the Texas coast from an oyster suitability standpoint. This analysis used HRI's Oyster Reef Restoration Habitat Suitability Index (ORRHSI) of Texas Bays & Estuaries dataset to identify areas most suitable for oysters (Reisinger, 2020).

Oysters require a balance between freshwater inflows and salinity. Not all portions of all bays are appropriate for oyster propagation. A key aspect of the 1,000-mile Living Shoreline project is to incorporate oyster production into our breakwater to increase the habitat and ecological services value of this infrastructure that we are creating along the coast.

Oysters are well known for their filtration capabilities that remove pollutants from the bay system and their communal, or reef-building, growth habits, which can help nearshore sedimentation occur. Sea grass has been observed growing adjacent to oyster reefs, and the fishery benefit of oyster reefs is well known. Over time, carbon accumulation will occur in these oyster reefs as well (Veenstra, 2021; Foedrie, 2017). In short, the protection and other ecological services of oyster reefs are complementary to the role of coastal estuarine wetlands. The areas exhibiting oyster suitability are shown in Figures 9, 10, and 11.

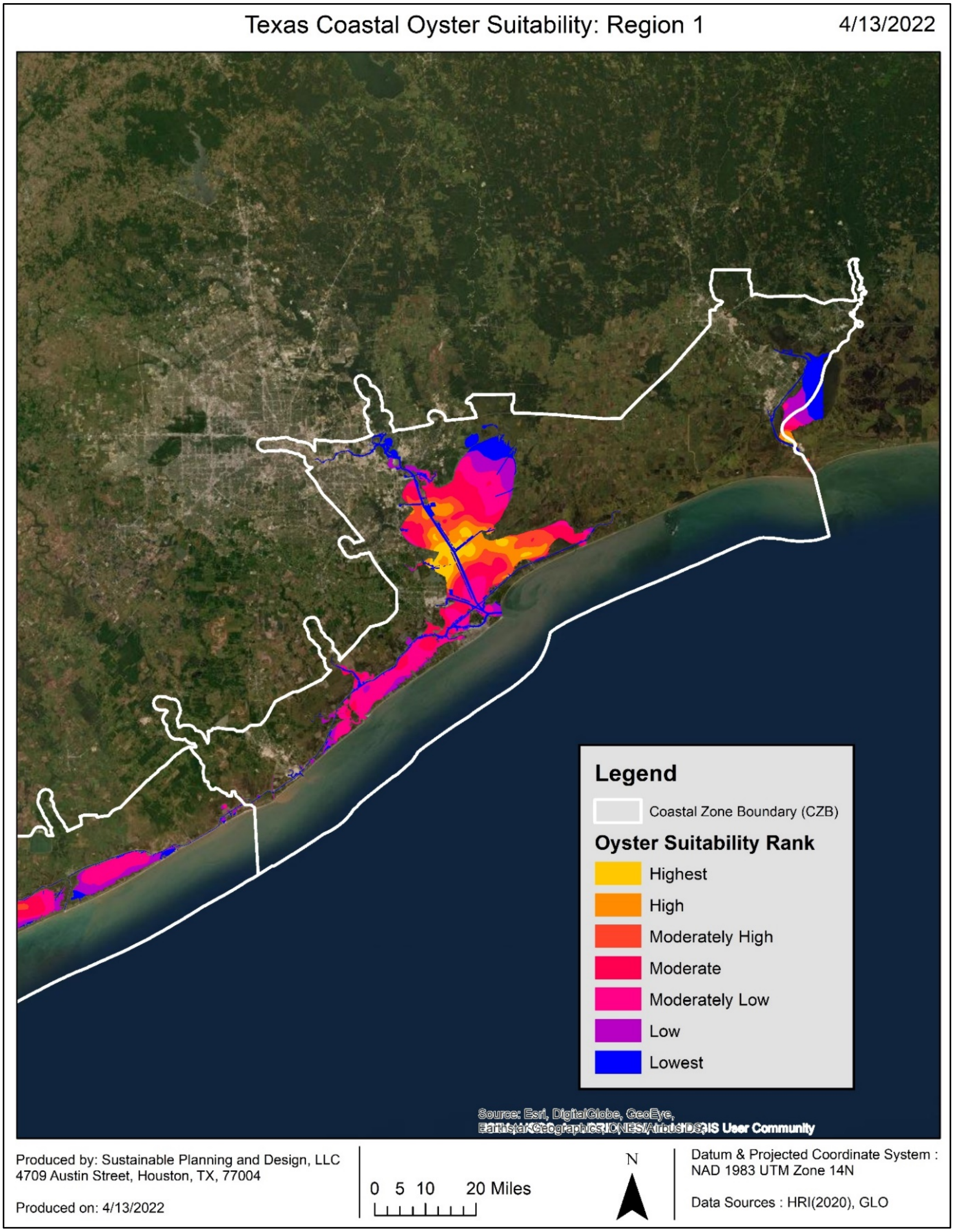


Figure 9. Oyster suitability for bays in region 1 based on HRI's ORRHSI (Reisinger, 2020).

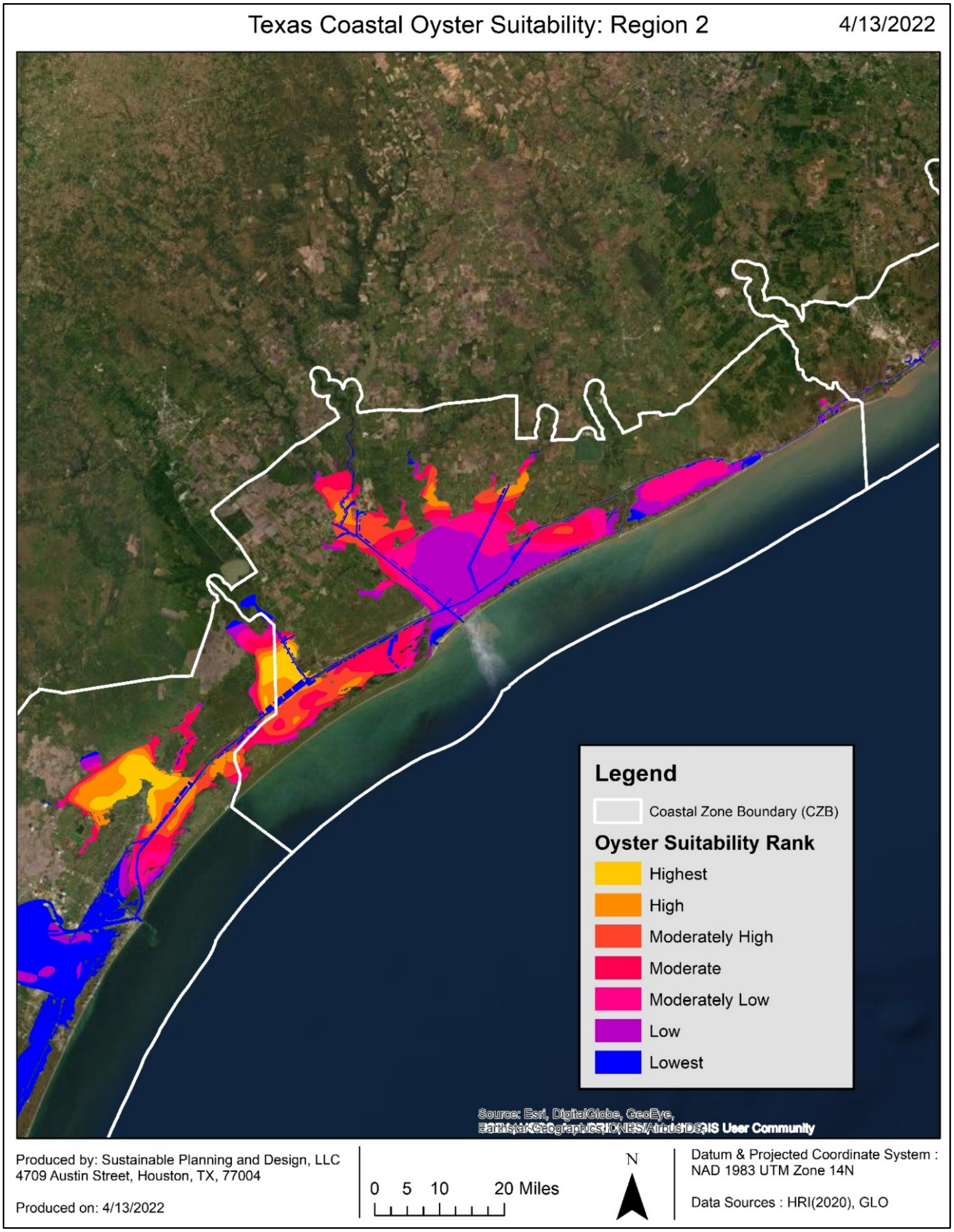


Figure 10. Oyster suitability for bays in region 2 based on HRI's ORRHSI (Reisinger, 2020).

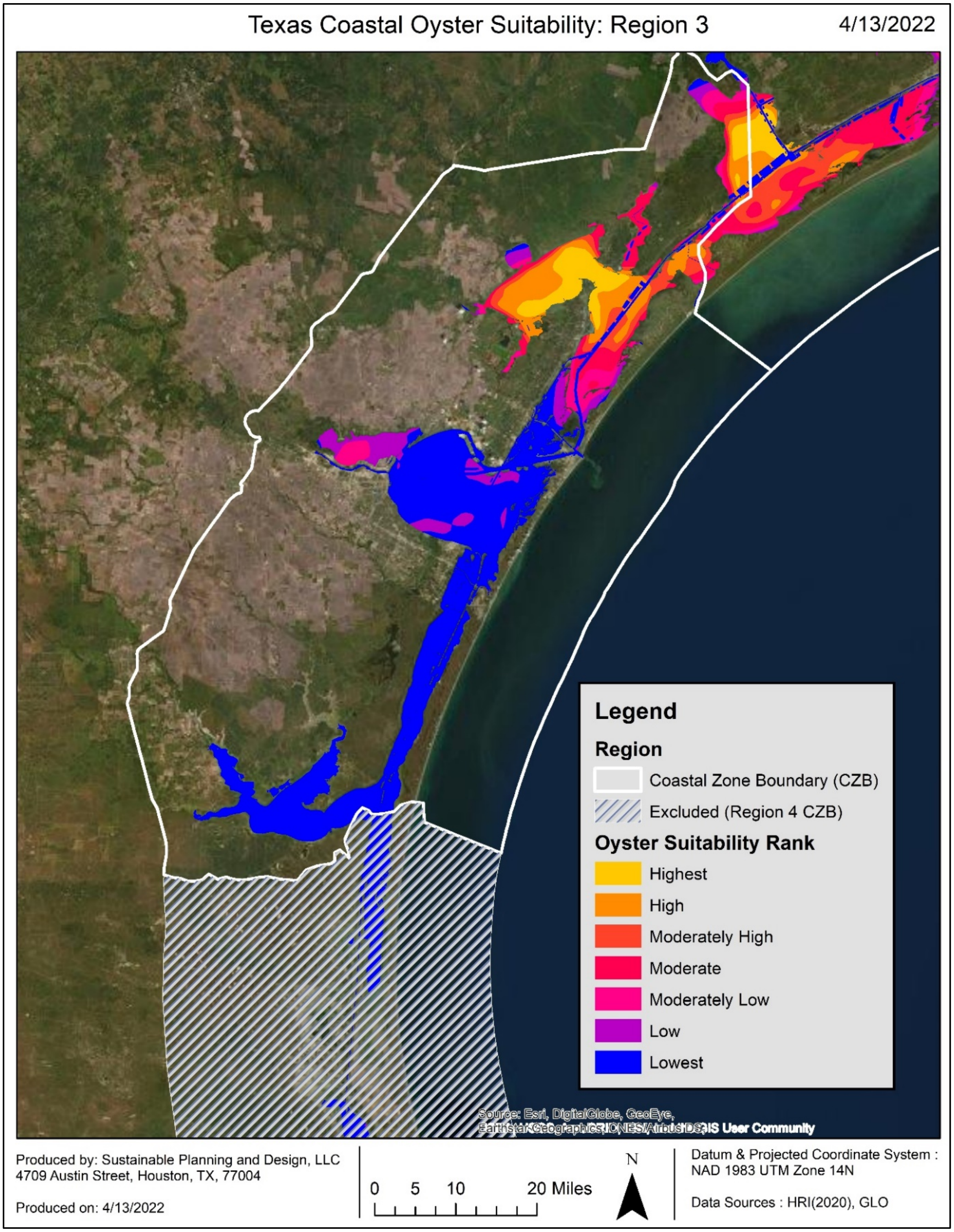


Figure 11. Oyster suitability for bays in region 3 based on HRI's ORRHSI (Reisinger, 2020).

Endangered or Threatened Species Habitat

As a general proposition, there are many endangered and threatened species inhabiting the wetlands of the Texas coast. This includes the Whooping crane (pictured below in Figure 12). The Whooping crane wintering habitat is, today, primarily in regions 2 and 3 in Copano, Aransas, Mesquite, Carlos, San Antonio, Espiritu Santo, and Matagorda Bays. With sea level rise and the increase in population of these cranes, the need for additional wintering areas will arise. This analysis used International Crane Foundation (ICF) Whooping Crane Priority Areas and observations of Whooping cranes from the Aransas Wildlife Refuge to map areas of importance to Whooping cranes (Smith & Marks, 2022; Taylor et. al., 2022). Both the existing and potential future habitat areas are shown on the map below.

Figure 12. Picture of a Whooping crane in a Texas Bay. Photograph sourced from the International Crane Foundation (Sloat, 2010).

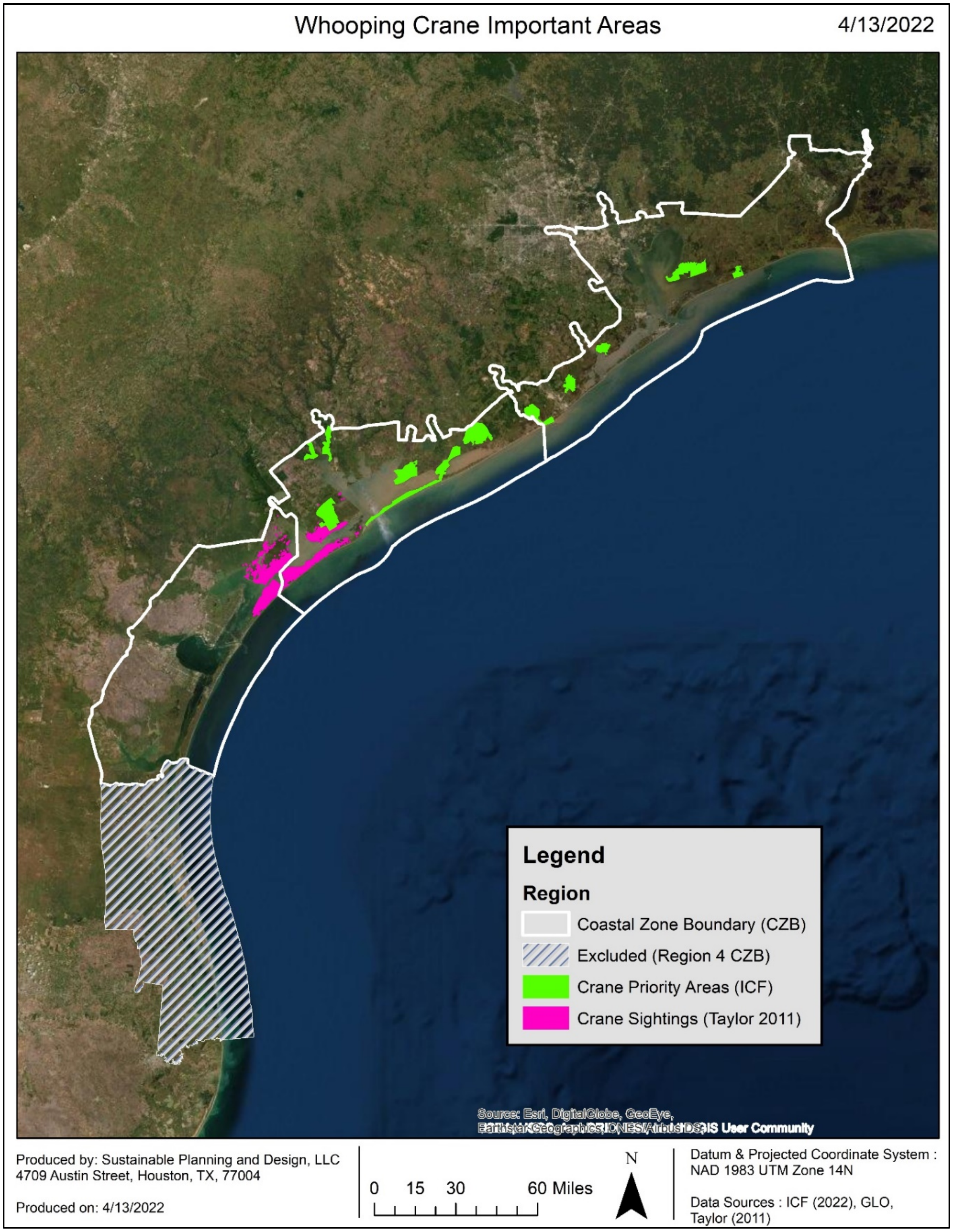


Figure 13. Important areas to Whooping cranes based on ICF Whooping Crane Priority Areas and observations from the Aransas Wildlife Refuge (Smith & Marks, 2022; Taylor et. al., 2022).

Development

Understanding where development already exists is an important aspect for this analysis. If a parcel is largely developed inland, then there is less potential for inland migration of saltmarsh with sea level rise. Minimally developed parcels were prioritized for this reason. Current development was identified using the USGS's National Land Cover Dataset (Dewitz & USGS, 2021). Categories of interest included: Developed—Open Space, Developed—Low Intensity, Developed—Medium Intensity, and Developed—High Intensity. National Land Cover Categories by coastal region can be seen in Figures 14, 15, and 16.

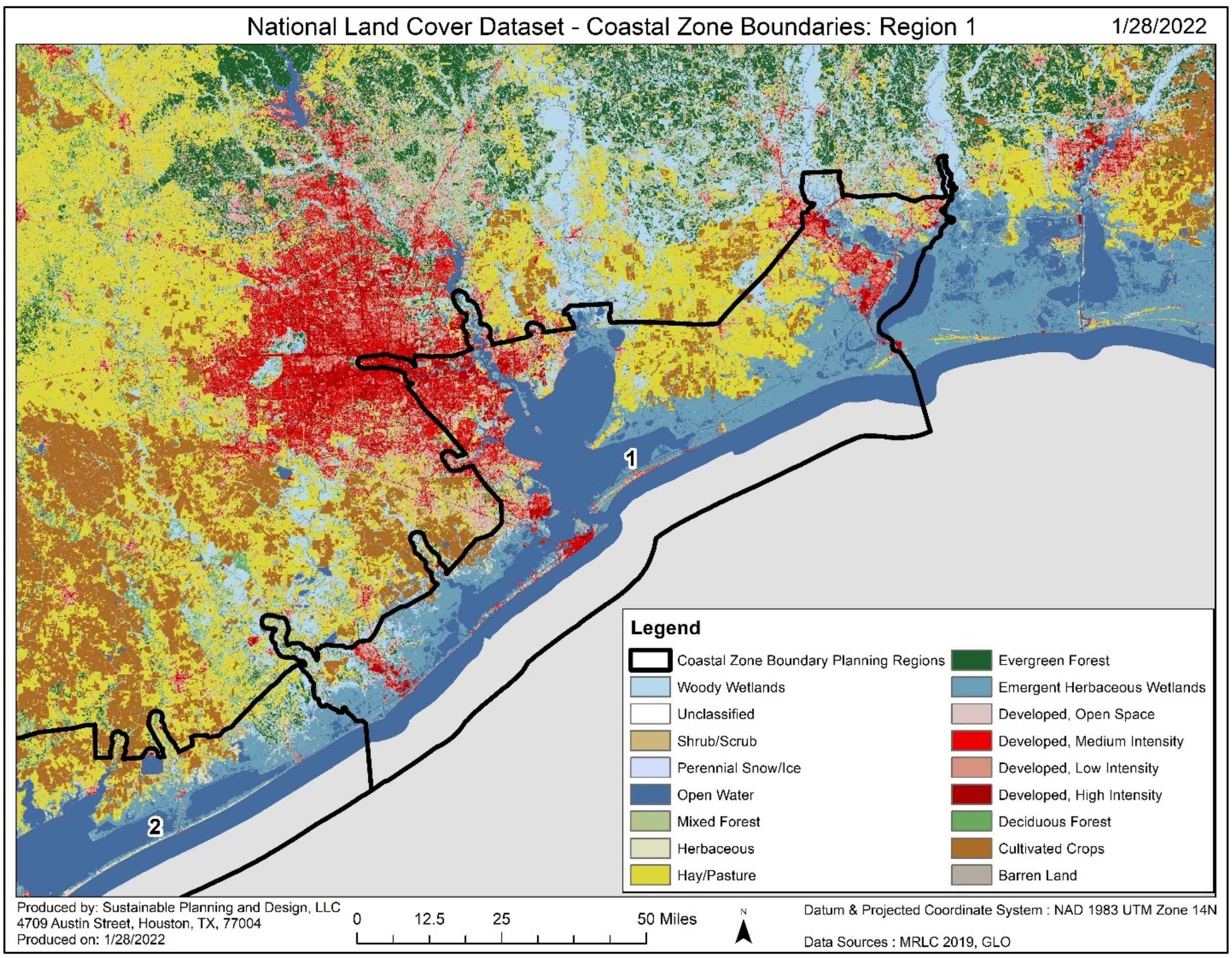


Figure 14. National Land Cover Categories for Region 1 (Dewitz & USGS, 2021).

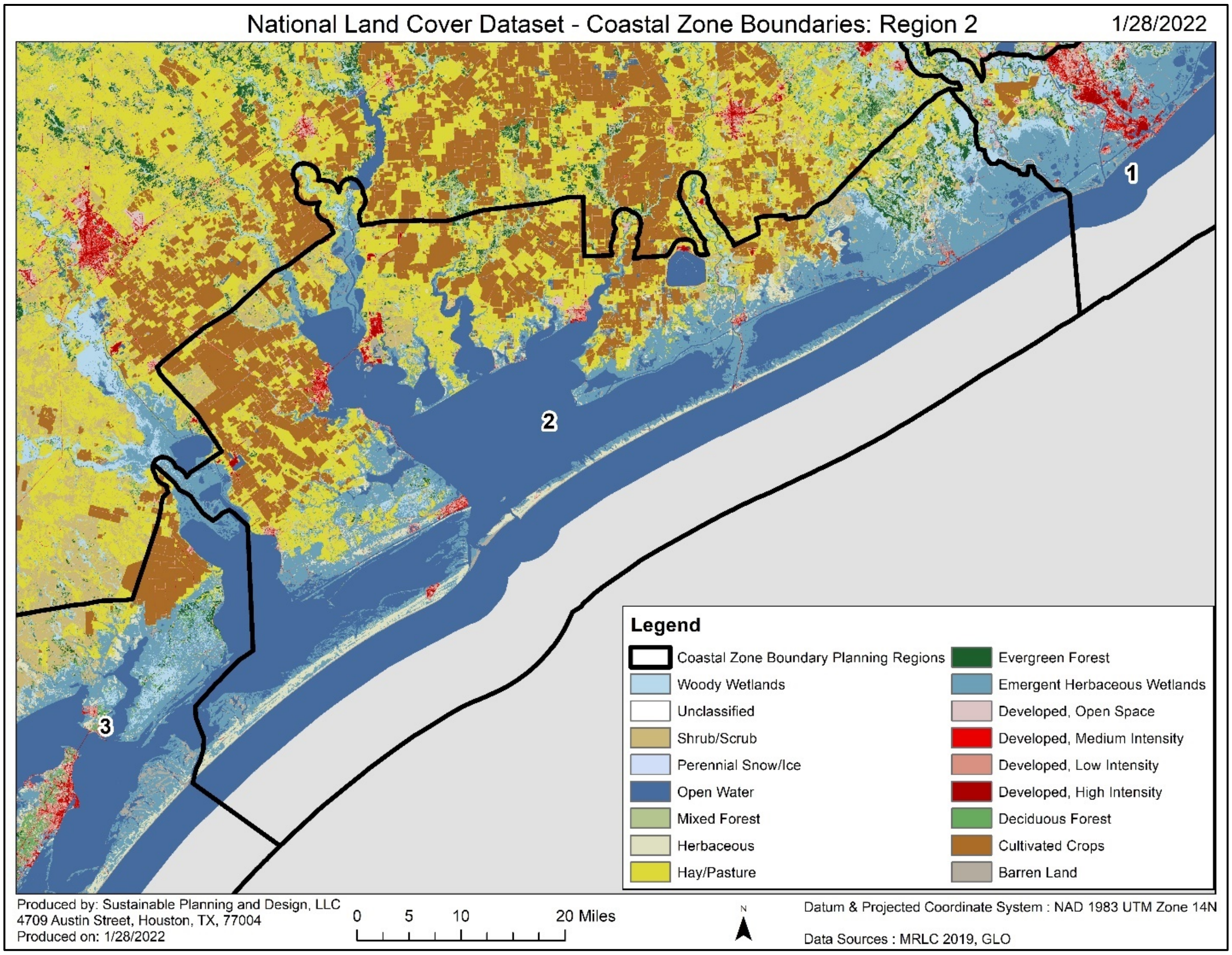


Figure 15. National Land Cover Categories for Region 2 (Dewitz & USGS, 2021).

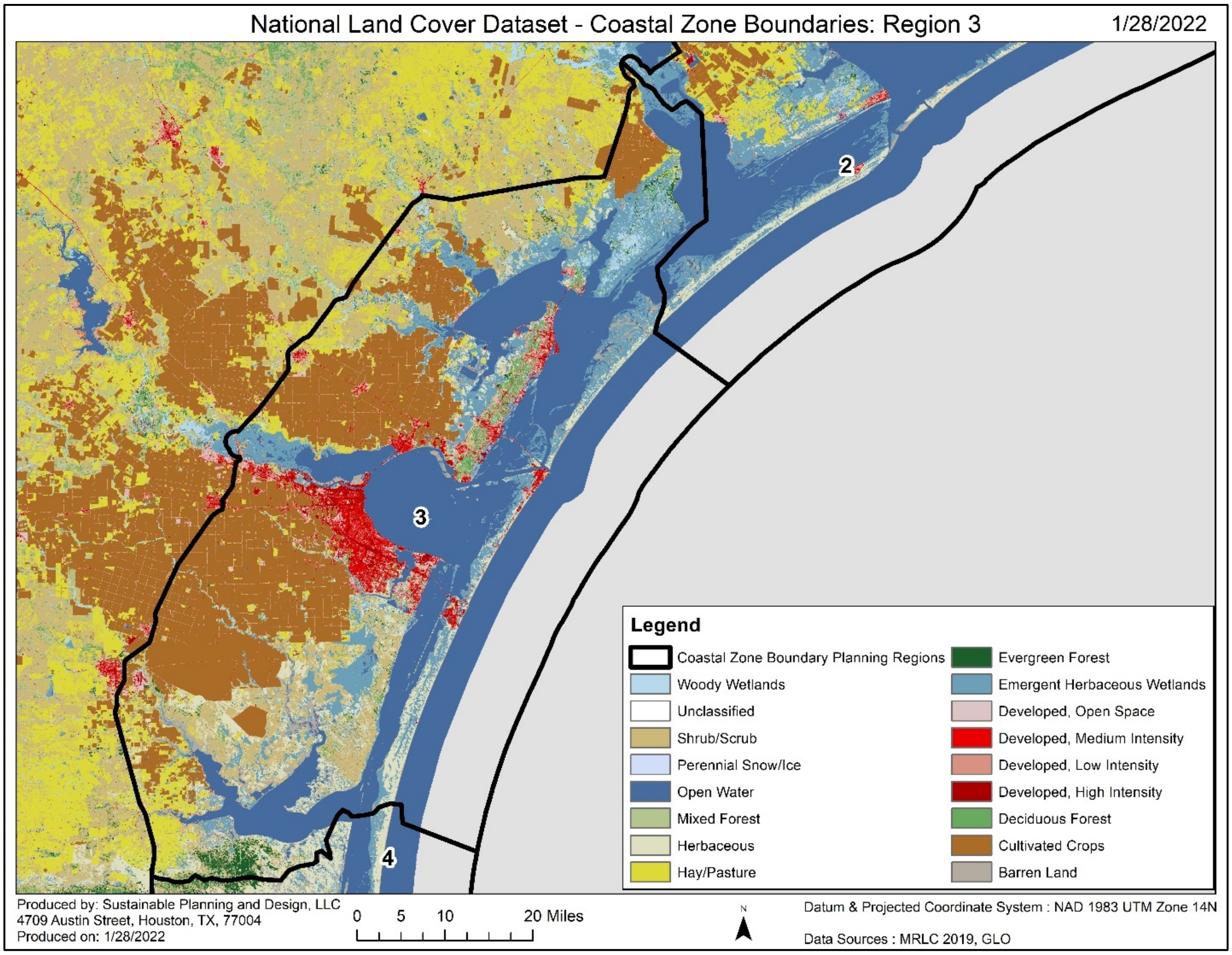


Figure 16. National Land Cover Categories for Region 3 (Dewitz & USGS, 2021).

Sea Level Rise

The inward expansion of rising water is defined by the elevation adjacent to the coastline. Where there are high bluffs, the spatial impact will be very low. Where there is a very gradual elevation change, the areal expanse could be substantial.

For purposes of this study, the areal extent of sea level rise is important as an indicator of where we can hope to see coastal wetlands expand inland. To make this assessment, the GIS team utilized the Sea Level Affecting Marshes Model (SLAMM) results that were prepared by the Harte Research Institute to be used in the 2023 Texas Master Plan to predict this variable (Dotson et. al., 2022b). The results of this SLAMM modeling are shown in Figures 17, 18, and 19.

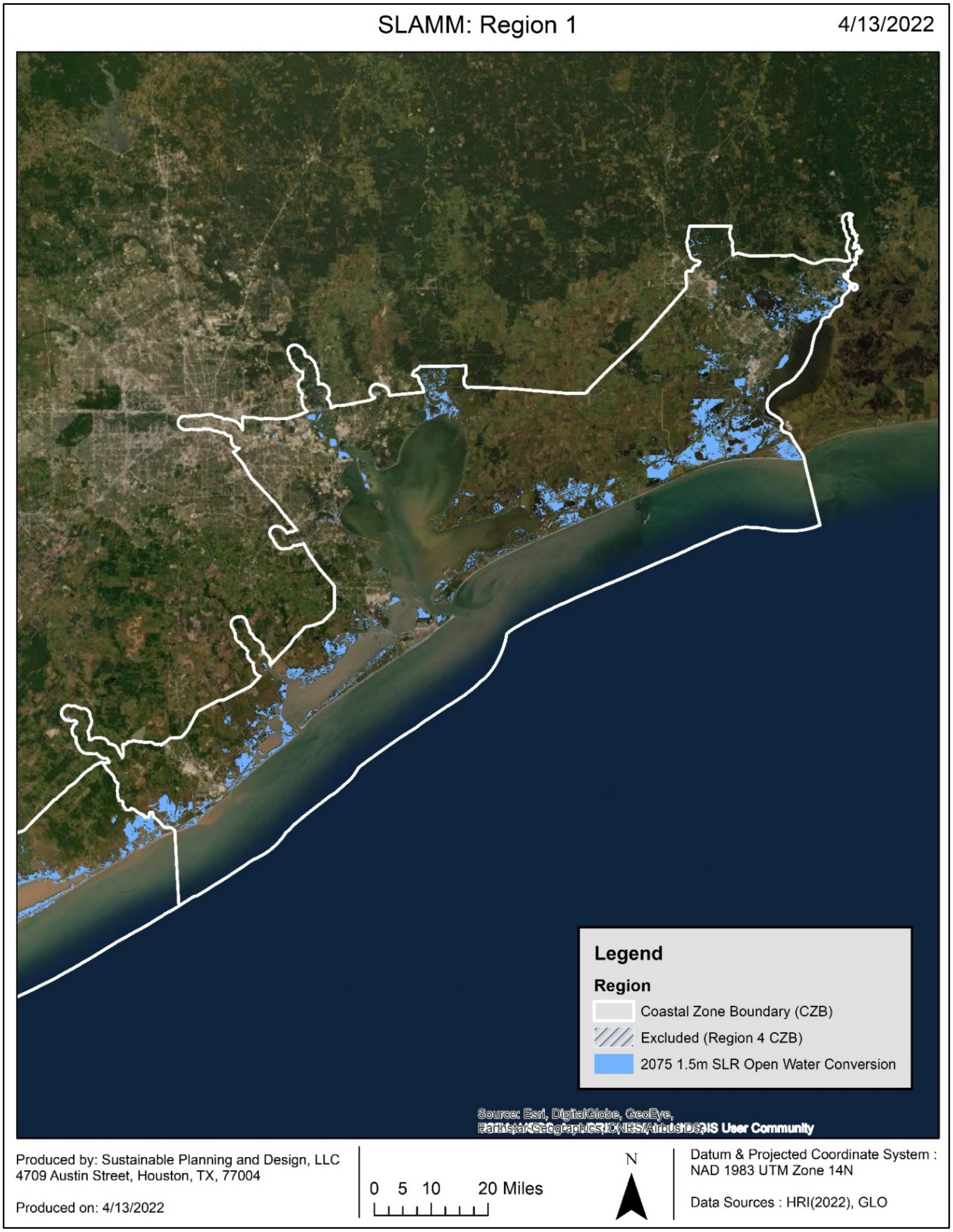


Figure 17. Predicted open water conversion resulting from sea level rise by 2075 in region 1 based on the high scenario of 1.5 m SLR using HRI SLAMM results (Dotson et. al., 2022b).

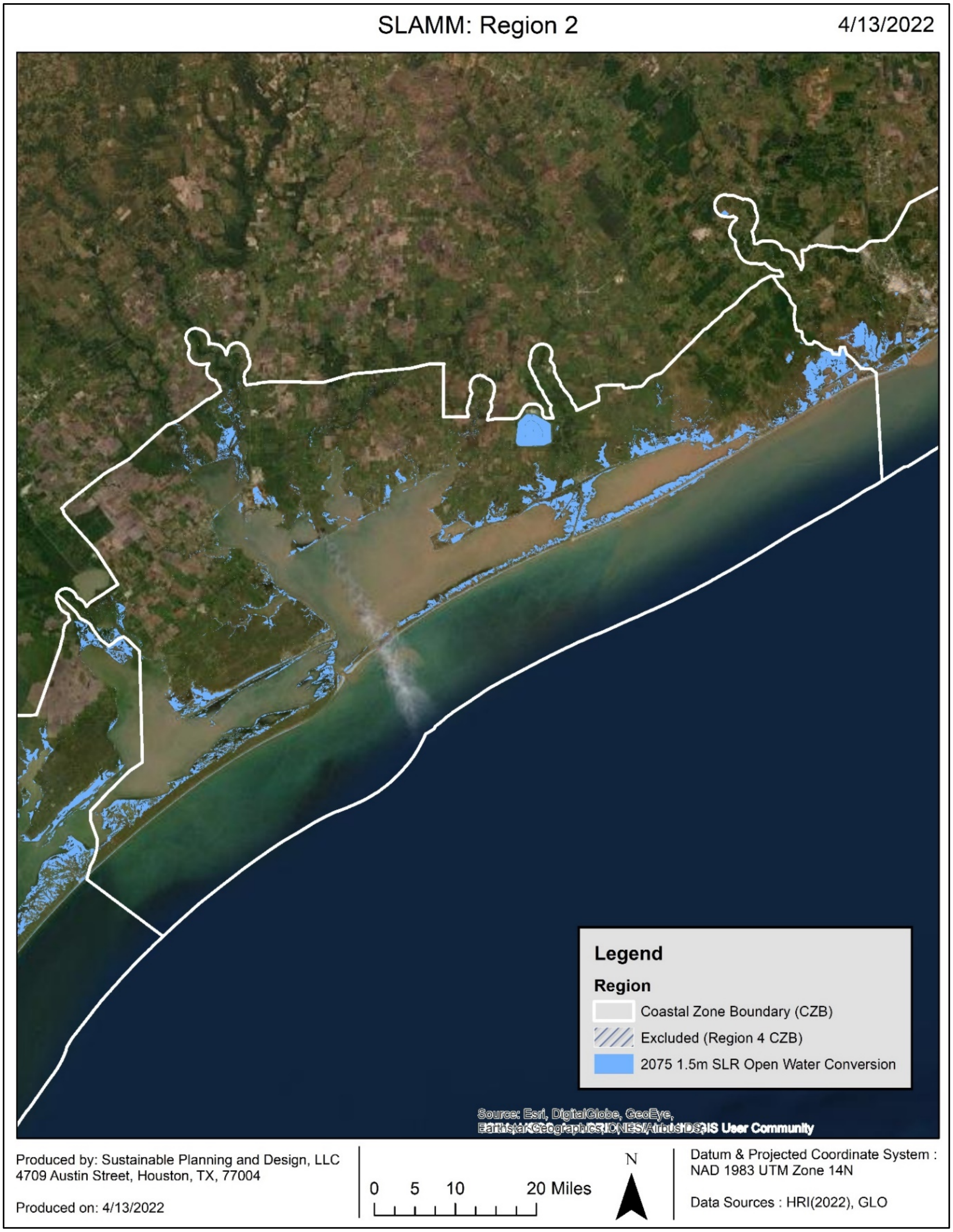


Figure 18. Predicted open water conversion resulting from sea level rise by 2075 in region 2 based on the high scenario of 1.5 m SLR using HRI SLAMM results (Dotson et. al., 2022b).

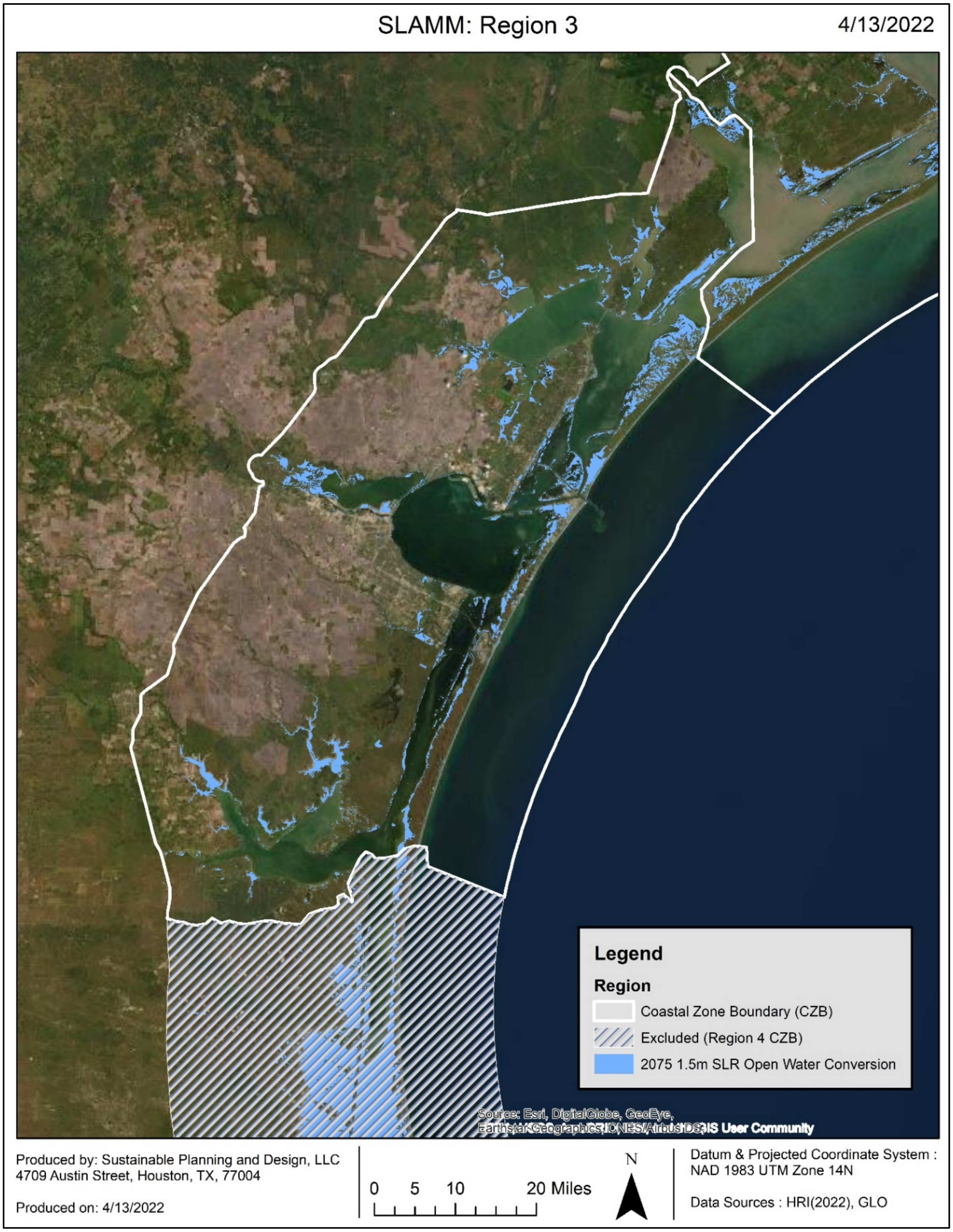


Figure 19. Predicted open water conversion resulting from sea level rise by 2075 in region 3 based on the high scenario of 1.5 m SLR using HRI SLAMM results (Dotson et. al., 2022b).

Based on this information, an important consideration is the incentive a landowner has to either allow their land to sink and erode or try to thwart these processes. For the most part, landowners do not receive income for the ecological services provided by the marsh ecosystem. With the valuation of carbon dioxide storage in the salt marsh, the economic considerations pertaining to marshland expansion inland should change. One of the goals of this project is to reward the landowners for the inward expansion of the marsh system even as existing marsh stock is protected.

HRI Living Shoreline Suitability Index

In order to better understand the erosion and site suitability of areas along the Texas coast, the project team utilized the Shoreline Suitability Index (SSI) created by the Harte Research institute (Dotson et al., 2022a). Inputs into their model included: shoreline type, water depth and nearshore slope, erosion rate, fetch, wave energy, and distance to nearest channels. The model provided six broad categories of living shorelines options: Soft Stabilization, Hybrid Stabilization, retrofit: Soft Stabilization, Retrofit: Hybrid Stabilization, Not Suitable, and Unknown (Dotson et al., 2022a).

The soft stabilization indicates a shallow, low energy environment and hybrid stabilization indicates medium energy and deeper environments. Both are satisfactory for the type of hybrid breakwater TCX is proposing to construct. The "retrofit" qualifier simply denotes that there is an existing protection structure on the shoreline, which is also acceptable for this project. The designation of "Not Suitable" mostly refers to shorelines adjacent to deep high energy environments and the "Unknown" category is where there was not enough data to make a conclusion. For the purposes of this project the category of "Not Suitable" was of the most interest because it shows shorelines that could not support a living shoreline strategy. Those areas were excluded from our analysis. Figures 20, 21, and 22 show HRI's Shoreline Suitability Index.

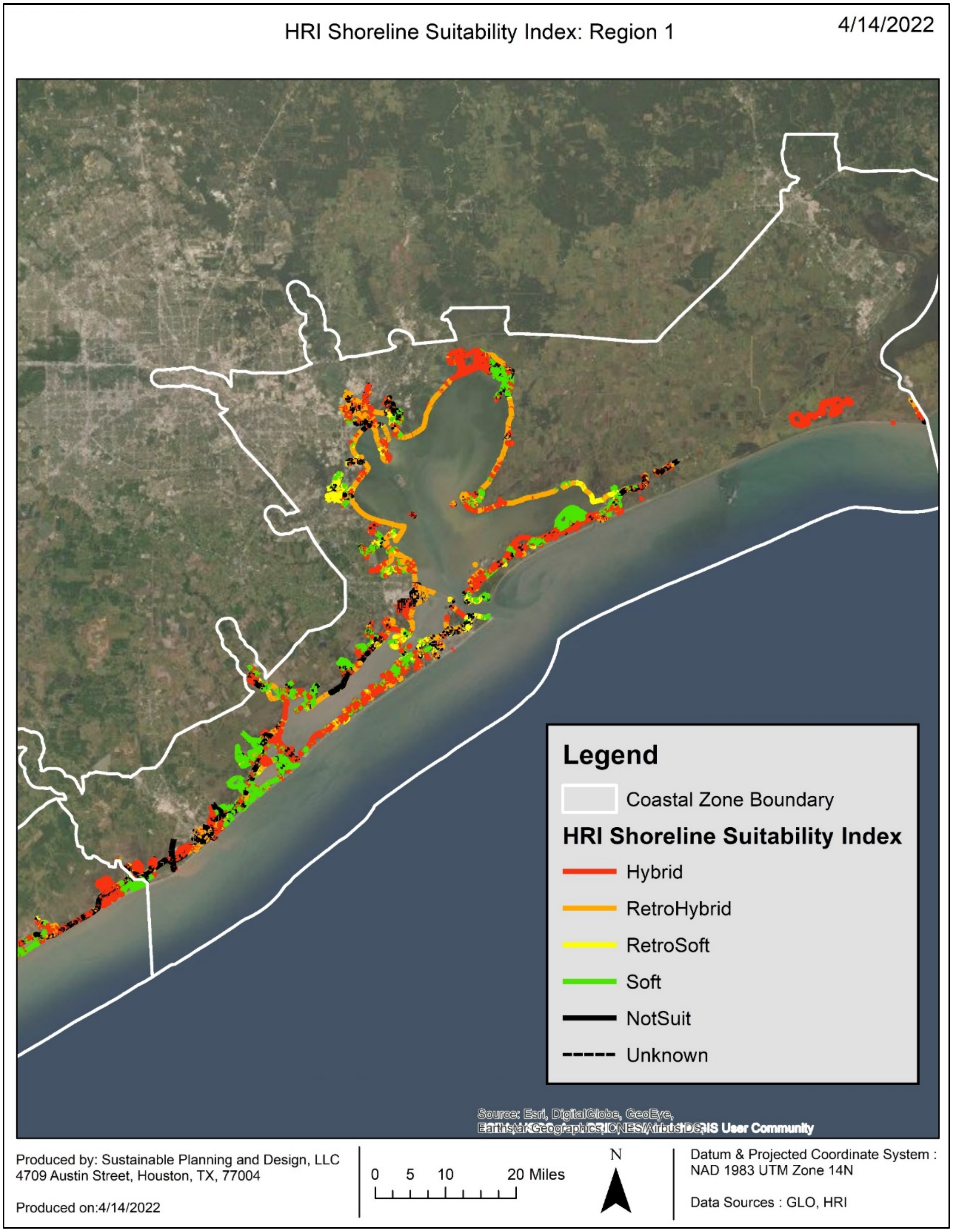


Figure 20. HRI's Shoreline Suitability Index for Region 1 (Dotson et al., 2022a).

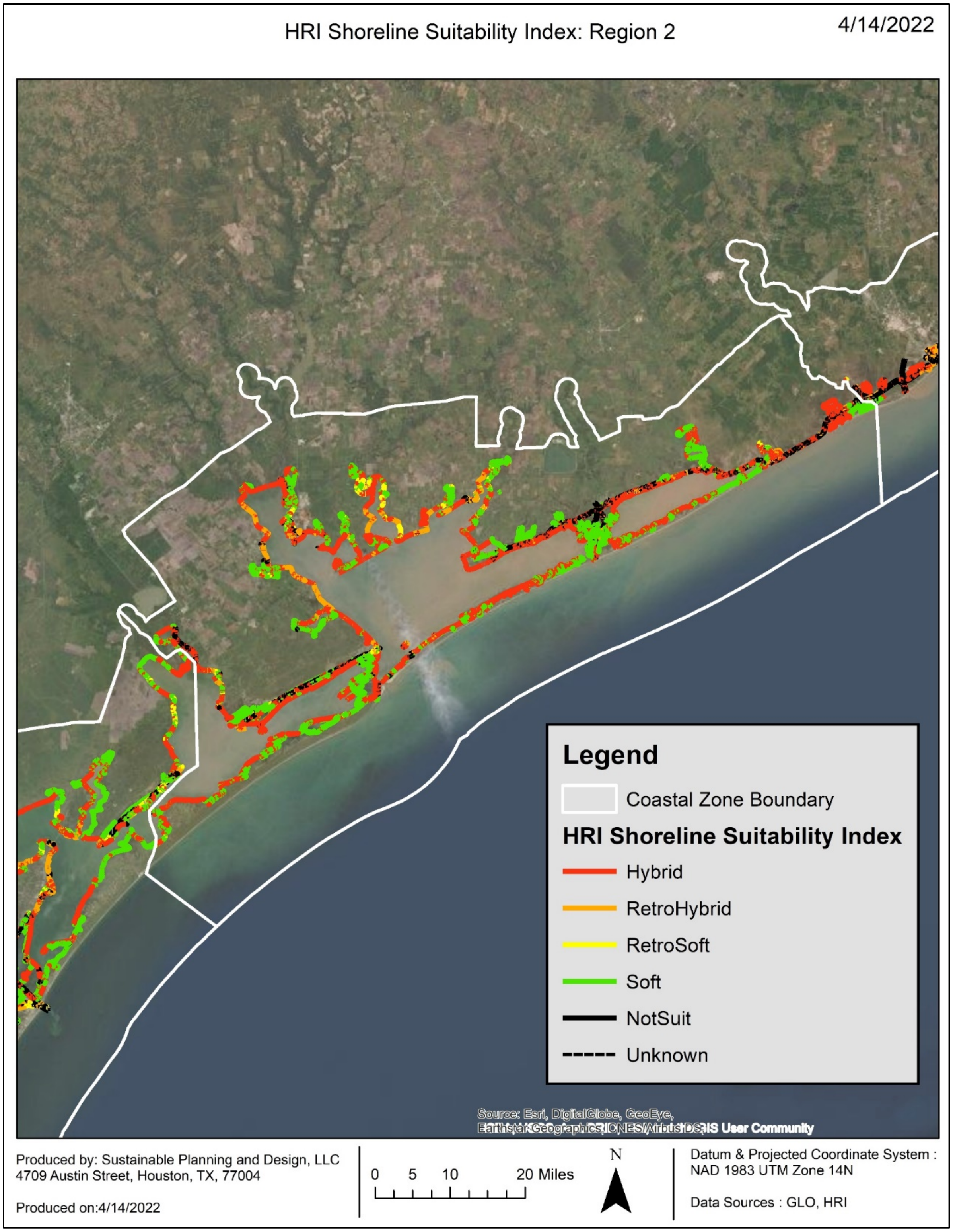


Figure 21. HRI's Shoreline Suitability Index for Region 2 (Dotson et al., 2022a).

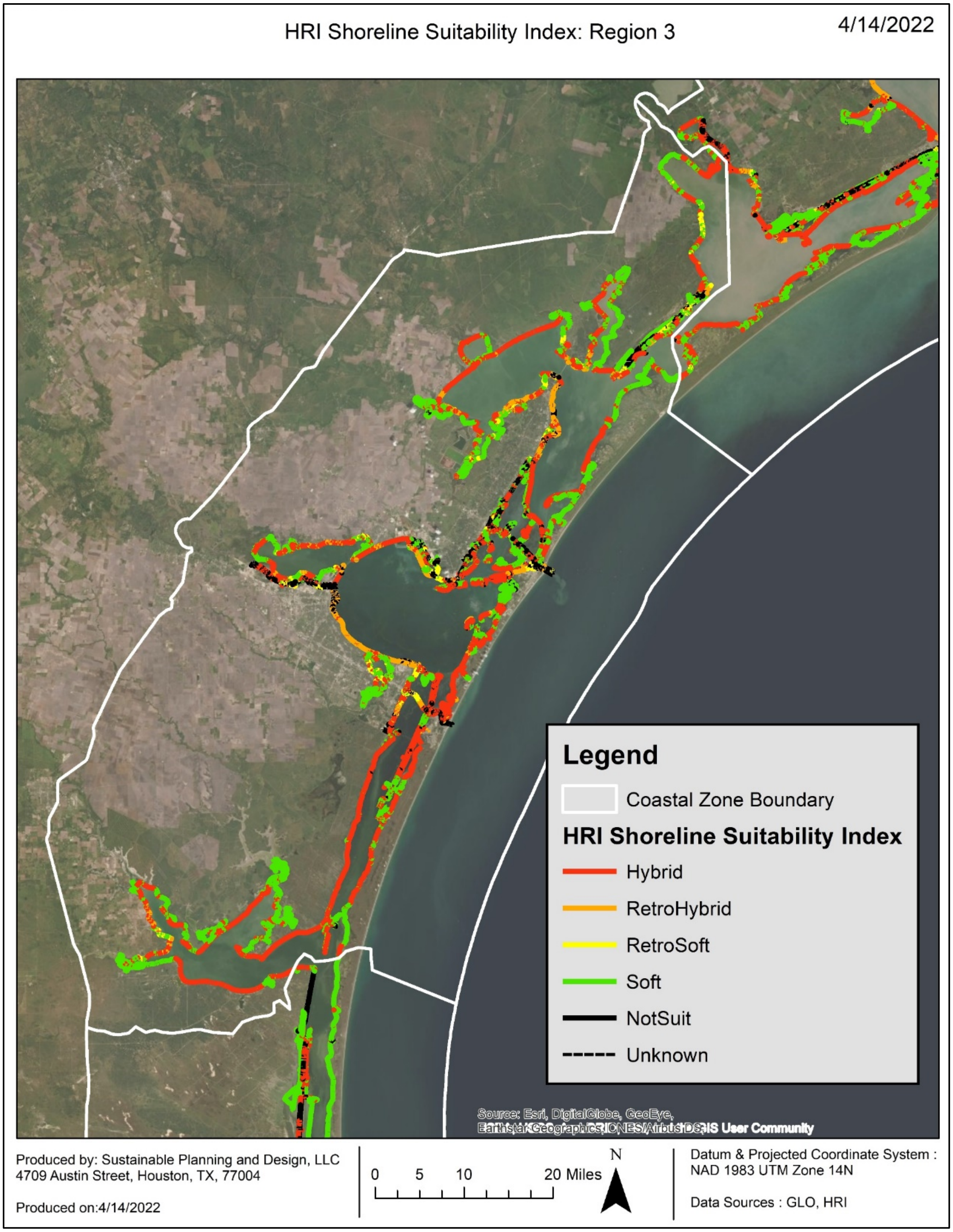


Figure 22. HRI's Shoreline Suitability Index for Region 3 (Dotson et al., 2022a).

Summary of Metrics

As explained above, these metrics were all combined in a suitability analysis which shows the priority shorelines for this project. Table 3 shows the datasets used to measure the metrics above in the suitability analysis. Each metric was weighted by its relative importance and for each metric the parcel is given a score showing how the parcel compares to others. In order to do this, metrics with non-binary scores were first broken into the "best" ranges using Natural breaks (Jenks). The Natural break optimization method minimizes the variation within each range creating "best" ranges where like areas are grouped together. Natural breaks were used instead of manually defining ranges because there is an immense number of different ways to set ranges which can be inaccurate and biased (Jenks, 1967). Ranges were used to score the parcels. Next, the scores of the metrics for each parcel were summed and broken into 7 ranges using natural breaks to be displayed on maps. These ranges (lowest, low, moderately low, moderate, moderately high, high, highest) show how suitable the parcel is to the 1,000-Mile Living Shoreline project based on this analysis. Table 4 shows the weights assigned to each metric and how each were ranked.

Table 3. Metrics used in the shoreline suitability analysis with their associated sources.

Metric	**Source(s)**
Proximity to Bays	Texas Parks and Wildlife Department's Major Bays (TPWD, 2012)
Land Ownership	U.S. Geological Survey (USGS) Protected Area Database (PAD-US) (USGS Gap Analysis Project, 2020)
Important Whooping crane areas	International Crane Foundation (ICF) Whooping Crane Priority Areas Smith & Marks, 2022); Observations of Whooping cranes collected by the Aransas Wildlife refuge and U.S. Fish

	and Wildlife Service (USFWS) (Taylor et. al., 2015)
Saltmarsh Presence	USFWS National Wetland Inventory (USFWS, 2021)
Development	U.S. Geological Survey (USGS) National Land Covert Database (Dewitz & USGS, 2021).
Oyster habitat suitability	Harte Research Institutes (HRI) Oyster Reef Restoration Habitat Suitability Index of Texas Bays & Estuaries (Reisinger et. al., 2020)
Future Sea Level Rise	HRI Sea Level Affecting Marshes Model (SLAMM) results used in the 2023 Texas Master Plan (Dotson et. al., 2022)
Living Shoreline Suitability	HRI Living Shoreline Site Suitability Model Output for the Texas Coast (Dotson et. al., 2022b)

Table 4. Metrics used in the suitability analysis with assigned weights and scores.

Non-weighted Metrics (used only for defining Areas of Interest)			
Metric	**Weighting Type**	**Weight**	**Rank**
Proximity to Texas Bays	Exclusionary	N/A	Binary: parcels greater than 400 meters from TX Bays were excluded
Land Ownership	Reclassified	N/A	All parcels were scored, but federally owned lands were reclassified as the lowest priority at the end
Living Shoreline Suitability Index	Exclusionary	N/A	All parcels were scored, but “Not Suitable” shoreline miles were excluded at the end (change not reflected in maps; most "not suitable" shoreline removed from total in table 5)
Weighted Metrics			
Metric	**Weighting Type**	**Weight**	**Scores**

Critical Habitat	Weighted	10	0—Outside of important Whooping crane areas 10—Within important Whooping crane areas
Salt marsh (Carbon Storage)	Weighted	35	Divided into 5 natural breaks (Jenks) 1 being lowest 5 being highest 0 – if no carbon storage 7- Break 1 (1-110 acres) 14- Break 2(111-410 acres) 21- Break 3(411-1,116 acres) 28- Break 4 (117-3,990 acres) 35- Break 5(>3,990 acres)
Development	Weighted	15	Divided into 3 natural breaks (Jenks) 1 being highest 3 being lowest 15– (zero acres of development) 10 – Break 1 (0-163 acres of development) 5 – Break 2 (164-762 acres of development) 0 – Break 3 (>762acres of development)
Oyster Habitat Suitability	Weighted	15	7 Jenks from HRI Used 0- Lowest 0- Low 3 - Moderately Low 6 – Moderate 9 – Moderately High 12 – High 15 – Highest
Future Sea Level Rise	Weighted	25	Divided into 6 natural breaks (Jenks) 1 being lowest 6 being highest 0 –no data 0 - Break 1 (0-152 acres open water conversion) 5- Break 2(153-696 acres open water conversion) 10- Break 3 (697-2,640 acres open water conversion) 15- Break 4 (2,641-8,404 acres open water conversion) 20- Break 5 (8,405- 17,529 acres open water conversion) 25- Break 6 (>17,529 acres open water conversion)
Total	N/A	100	Divided into 7 natural breaks (Jenks) 1 being lowest 7 being highest Lowest- Break 1 (0-11) Low – Break 2 (12-13) Moderately low – Break 3(14-18) Moderate – Break 4 (19-23) Moderately high – Break 5 (24-28) High- Break 6 (29-39) Highest – Break 7 (37-78)

1,000-MILE LIVING SHORELINE SUITABILITY ANALYSIS RESULTS

The Texas 1,000-Mile Living Shoreline Project suitability analysis shows that there are over 1,000 miles of shoreline in the Texas Bays that are highly to moderately suitable for a living shoreline project. The analysis results were checked generally for accuracy visually based on expert understanding of the coast. Results of this analysis are not a substitute for site specific evaluation. The overall suitability throughout the coast is shown in Figure 23. In subsequent figures, the regional analysis is shown in more detail.

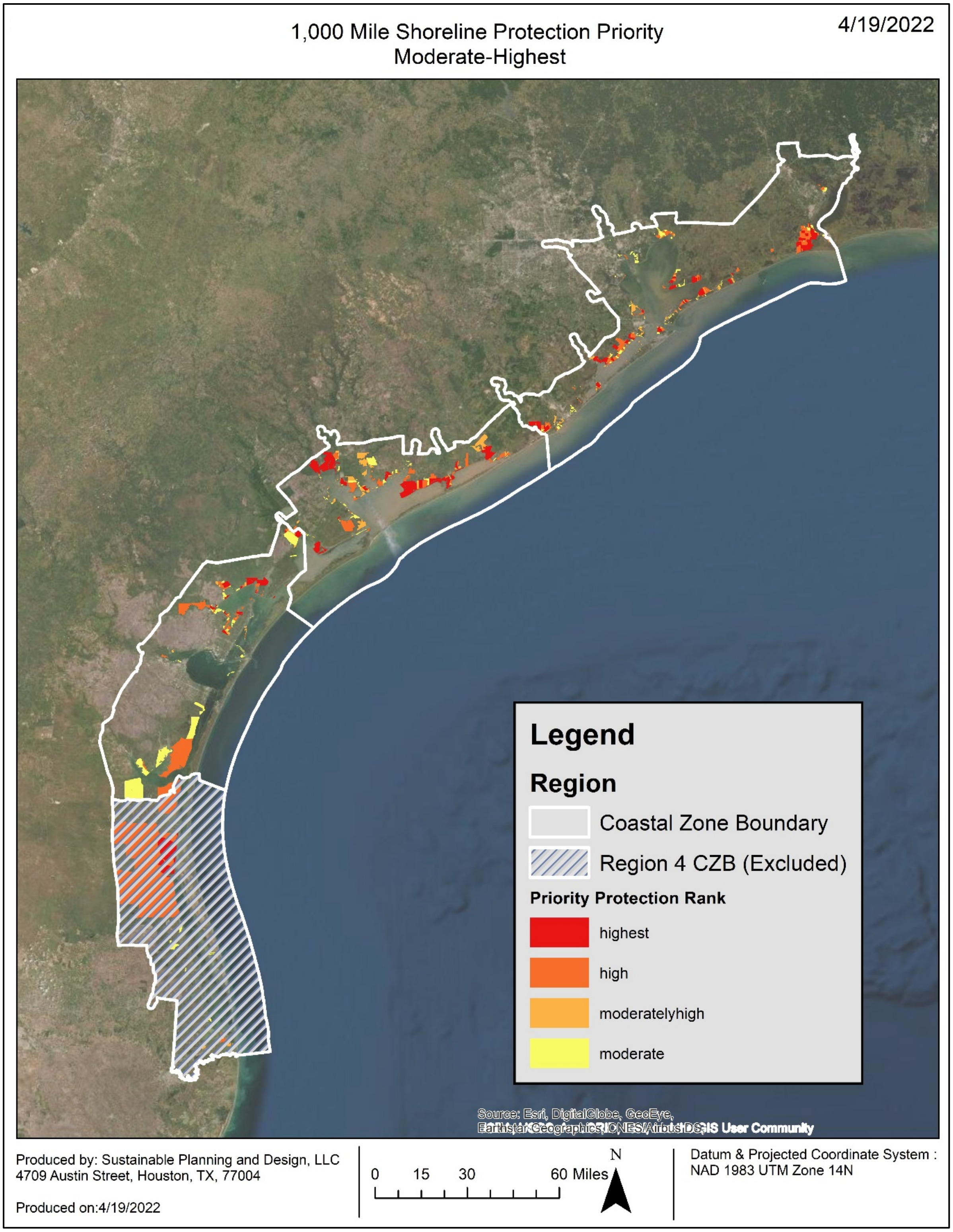


Figure 23. Priority rankings map of the Texas coast.

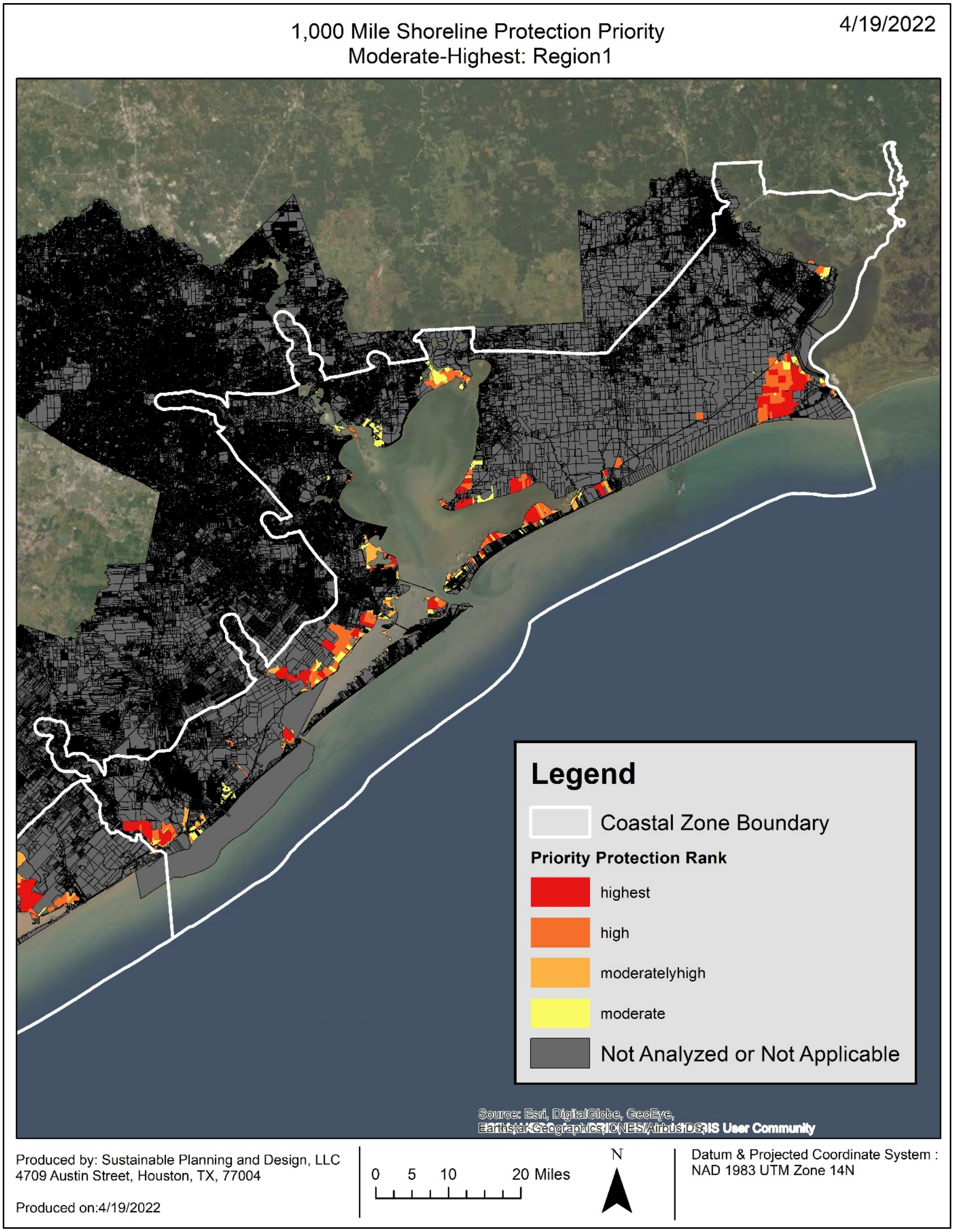


Figure 24. Priority rankings map of Region 1 based on the 1,000-Mile Living Shoreline suitability analysis.

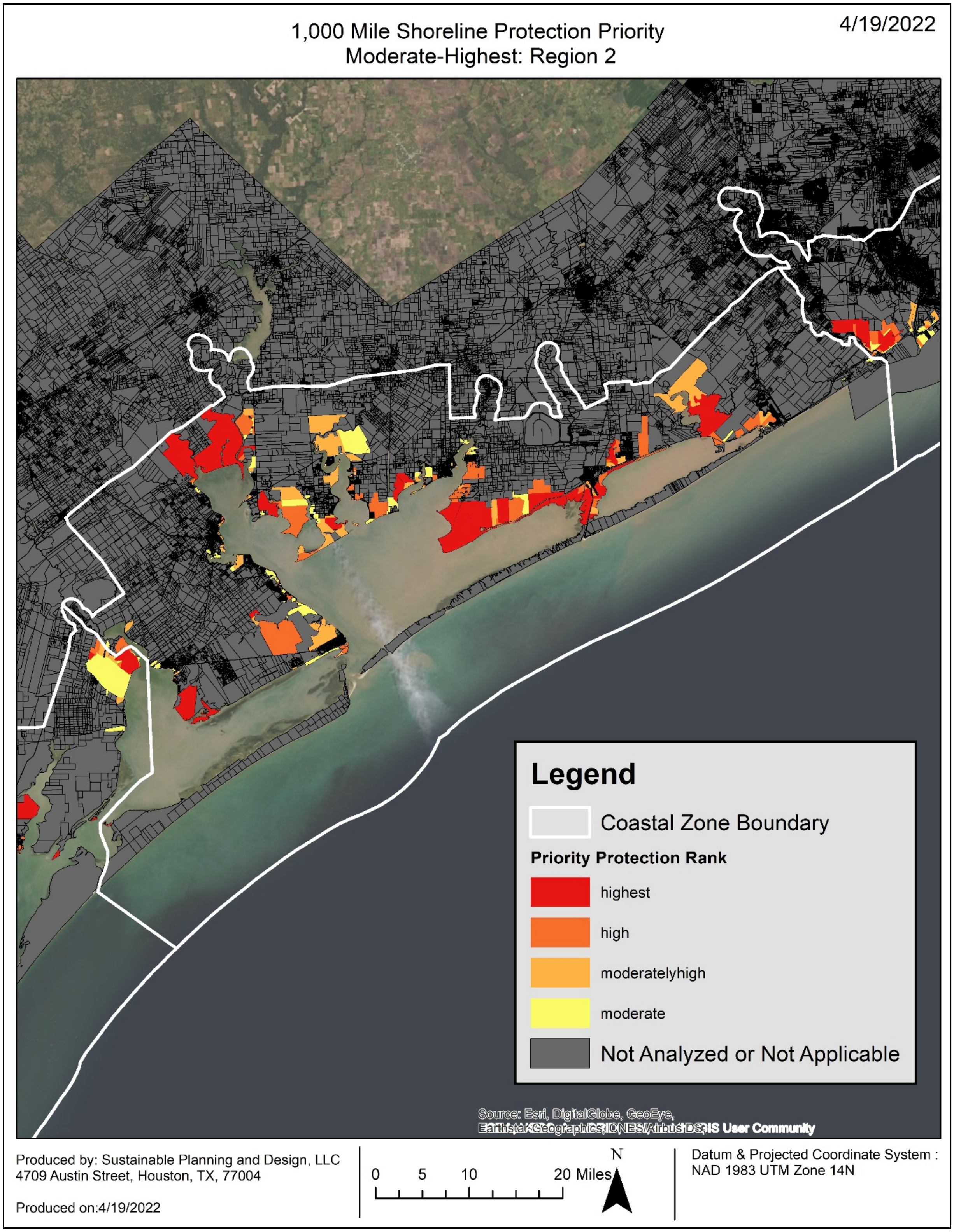


Figure 25. Priority rankings map of Region 2 based on the 1,000-Mile Living Shoreline suitability analysis.

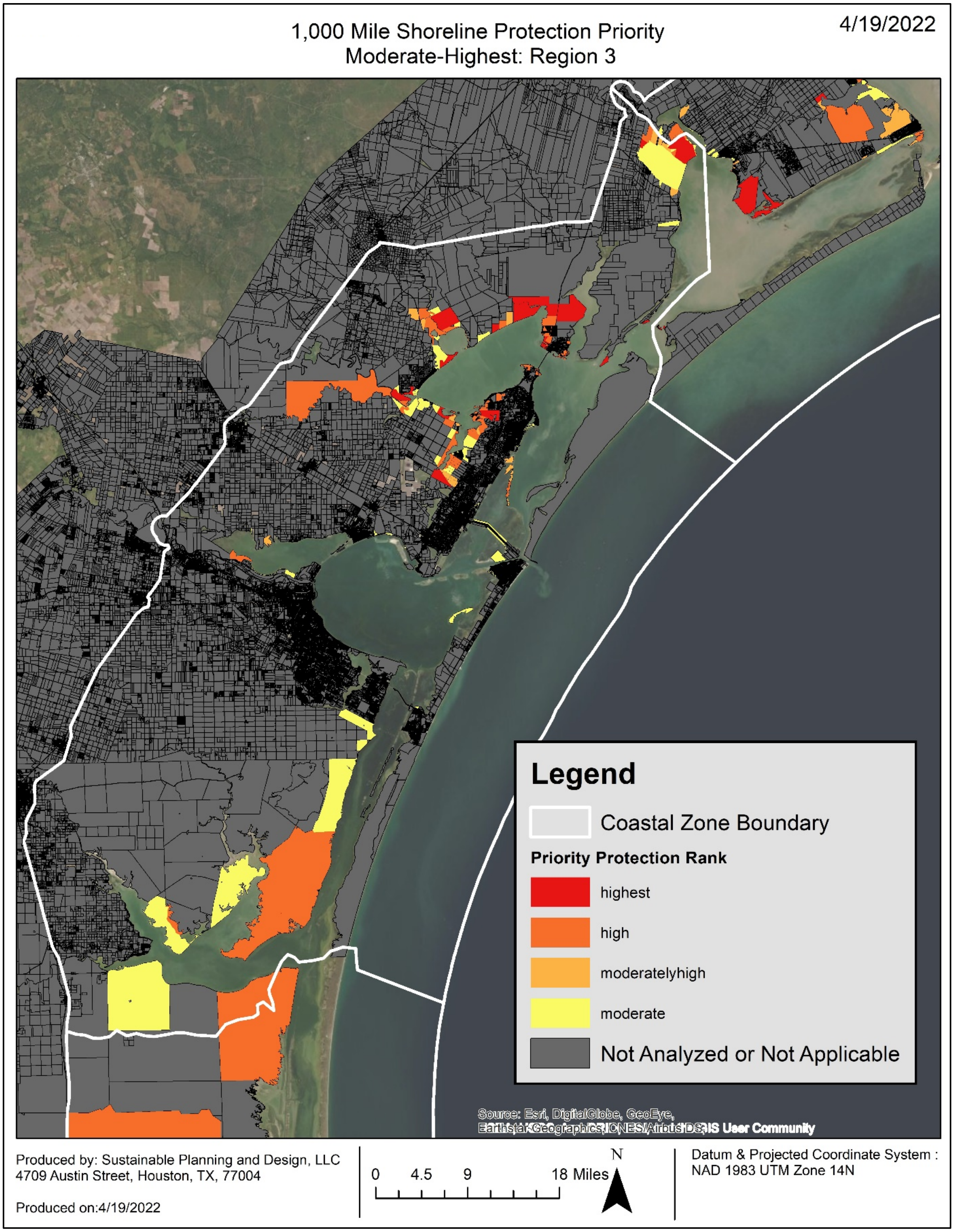


Figure 26. Priority rankings map of Region 3 based on the 1,000-Mile Living Shoreline suitability analysis.

The results of the analysis are shown in Table 5. Within the three regions there are 480 miles of highest suitability, 419 miles of high suitability, 288 miles of moderately high suitability and 339 miles of moderate suitability. Together, these four categories comprise 1,526 miles of candidate shoreline.

Table 5. Length of shoreline by priority ranking category from the 1,000-Mile Living Shoreline project suitability analysis divided into HRI Shoreline Suitability Index suggested shoreline type.

Priority Rank	Miles of Hybrid Shoreline Potential	Miles of Soft Shoreline Potential	Miles of Retrofit Hybrid Shoreline Potential	Miles of Retrofit Soft Shoreline Potential	Total Miles of Potential Suitable Shoreline
highest	207	247	21	5	480
High	199	192	23	5	419
moderately high	135	124	24	6	288
moderate	157	146	30	6	339
Total	698	709	97	22	1,526

CASE STUDY – Matagorda Bay / Oyster Lake

To demonstrate the potential applicability of this analysis, a hypothetical case study was performed on a few high-ranking parcels in Matagorda Bay to test the priority ranking system and better understand the relationship between proposed living shorelines and potential carbon sequestration and storage. The case study area chosen is in and adjacent to Oyster Lake, which is west of the town of Matagorda and south of Palacios. Figure 27 shows a map of the case study area and associated data and carbon potential for this shoreline.

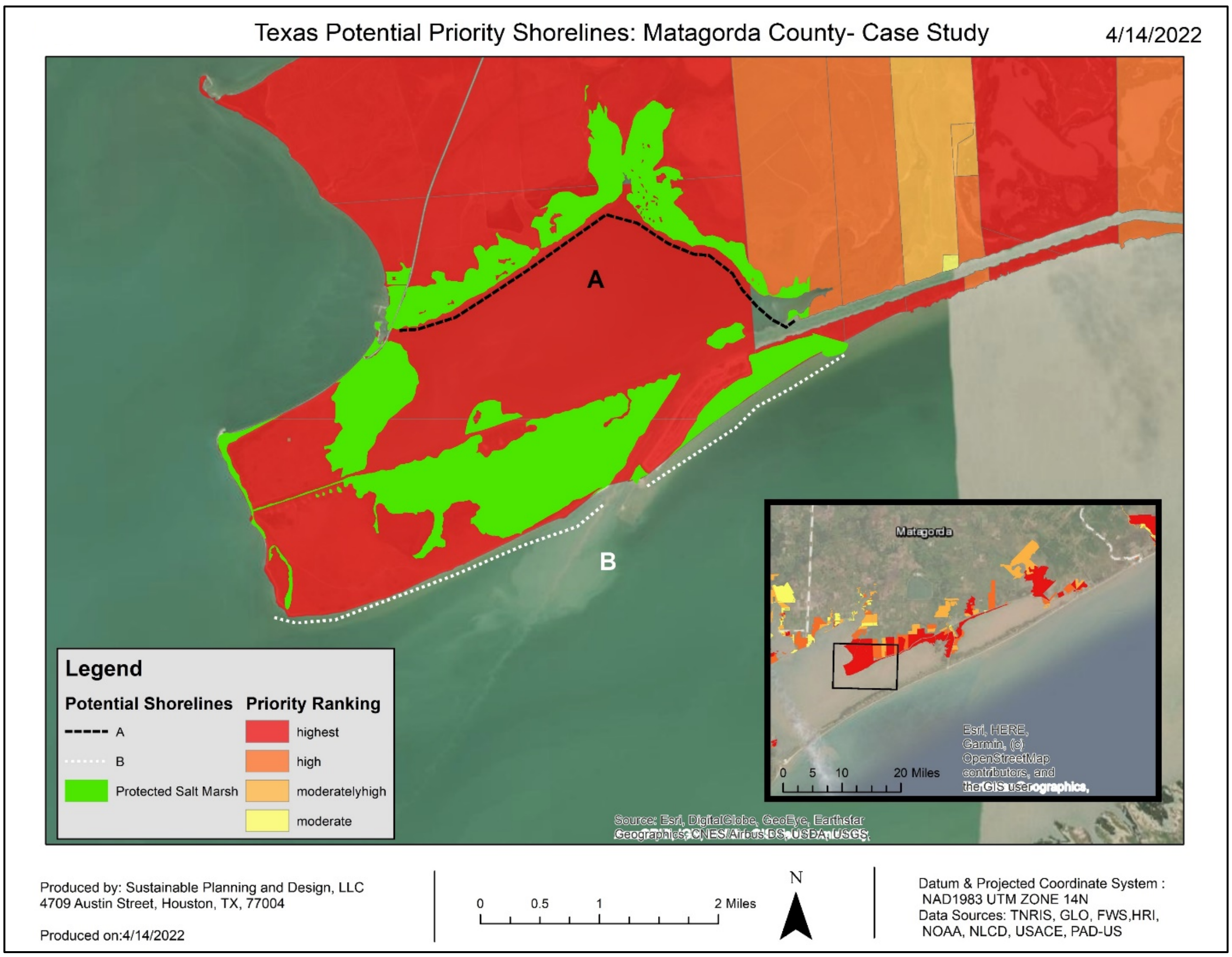


Figure 27. Case study of potential shoreline in and around Oyster Lake in Matagorda County, Matagorda Bay.

In the map above, the location of four miles of living shoreline is shown on the north shoreline of Oyster Lake (Project A) and five miles of living shoreline is shown on the north shoreline of Matagorda Bay (Project B). For purposes of this case study, several design assumptions were made. First, it was assumed that the construction cost for this living shoreline project was $500,000 per mile. Further work must be undertaken to determine if this estimated cost is reasonable or not. Second, it was assumed that the privately-owned wetlands protected by the living shoreline would be eligible for avoided conversion credits as well as annual sequestration credits.

Table 6. Financial metrics for the living shoreline project case study example.

Texas Potential Priority Shorelines: Matagorda County Case Study			
Shoreline	**A**	**B**	**Total**
Saltmarsh Wetland (~Acres)	780	1,600	2,380
Total Carbon sequestration (Salt Marshes ~3.2 tons CO_2e per acre per year)	2,496	5,120	7,616
Total Carbon Storage (Only Saltmarsh wetlands at 401 metric tons of CO_2 equivalent per acre)	312,780	641,600	954,380
Total Storage Value ($20/ton)	$6,155,600	$12,832,000	$18,987,600
Annual Sequestration Value ($20/ton per year)	$49,920	$102,400	$152,320

Given the assumptions above, Project A would cost about $2 million and could generate carbon credit revenues of about $6 million in avoided conversion of 780 acres of wetlands at a carbon cost of $20 per ton. Additionally, this project would yield about $50,000 per year in annual carbon removal and storage payments along with several tons of oyster reef payments. Similarly, Project B would cost about $2.5 million and could generate over $12 million in carbon credits at $20 per ton along with annual credits of about $100,000 per year within the marsh.

In addition to the tradeable value above, there are other quantifiable economic benefits from this case study based on environmental economic analysis. The total ecosystem goods and services value, excluding carbon value, would be about $60 million per year for the protected wetlands behind projects A and B. Additionally, the dollar value provided by the reef itself in ecological services is approximately $482,000 per year. In short, these nine miles of living shoreline make a very excellent infrastructure investment for the future of the Texas coast.

CONCLUSION AND DISCUSSION OF FUTURE PROJECT GOALS

This report is the first step to the realization of a 1,000-mile living shoreline for the Texas coast. Conceptually, this living shoreline for the Texas coast is very important as a vision for the infrastructure that we will need in the future to fight the effects of climate change such as sea level rise. If we are not proactive in addressing these issues now, we will lose a significant portion of the 500,000 acres of saltmarsh and allied wetlands along the Texas coast.

In this report, both the feasibility and potential location of these 1,000 miles of living shoreline are set out. More than 1,500 miles of suitable shoreline exist not including the Texas coastal barrier islands, which offer even further potential. **Perhaps more importantly, a partnership with a carbon registry such as BCarbon creates a pathway to funding for these 1,000 miles of living shoreline.** In the future, corporations with significant unmitigated carbon emissions can assist in funding these projects and also reduce their carbon footprint. Such funding will be very important going forward.

At this time, BCarbon has begun researching the issues and process for approving credits for living shoreline projects. BCarbon has secured funding to move forward with more detailed analysis of the carbon sequestration potential of oyster reefs and design implications of the reef/breakwater relative to long-term protection of the stored carbon in adjacent wetlands.

Concurrent with that design and evaluation work, TCX will move forward with the next phase of implementation which involves identifying and meeting with potential corporate, NGO and governmental partners to join with in implementing this 1000-mile living shoreline project.

APPENDIX A—US Army Corps of Engineers Coastal Texas Study Projects

The US Army Corps of Engineers (USACE) has identified the erosion issue occurring on the Texas Coast and developed the Coastal Texas Protection and Ecosystem Restoration Feasibility Study (Coastal Texas Study) to investigate possible solutions to these issues. This study proposes six coastal storm risk management projects, nine large-scale ecosystem restoration projects and some non-structural measures (see table A-1 for list of projects). These projects will complement Texas Coastal Exchange's Living Shoreline Project in protecting the Texas coast in the face of rising sea level and erosion. In the FEIS for the Coastal Texas Study, these projects are divided into Actionable and Tier One Measures as part of the Corps' tiered-NEPA approach. The FEIS contains a complete environmental review for Actionable Measures while future tier two NEPA documents will be needed for a complete review of Tier One Measures. The Corps chose this approach to allow Actionable Measures to move forward while further studies on the impacts for Tier One Measures continue. Actionable Measures for the most part use methods that are more routinely constructed by USACE and therefore require less study. Of these projects, seven involve some amount of shoreline protection structures similar to the ones suggested for Texas Coastal Exchange's living shoreline project. Figure A-1 shows a map of these projects. While dune restoration and beach nourishment do provide shoreline protection, this report focuses on those shoreline protection projects made from breakwater or oyster reefs. Those projects of interest are labeled as "Includes Shoreline Protection" in table A-1 below.

Table A-1. Recommended Measures from 2021 Coastal Texas Study FEIS. Table adapted from table ES-1-1 of FEIS (U.S.A.C.E., June 2021).

Recommended Plan (RP) Component	Actionable	Tier One	Includes Shoreline Protection
G-28 – Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection	X		X
B-2 – Follets Island Gulf Beach and Dune Restoration		X	

B-12 – West Bay and Brazoria GIWW Shoreline Protection	X		X
CA-5 – Keller Bay Restoration	X		X
CA-6 – Powderhorn Shoreline Protection and Wetland Restoration	X		X
M-8 – East Matagorda Bay Shoreline Protection	X		X
SP-1 – Redfish Bay Protection and Enhancement	X		X
W-3 – Port Mansfield Channel, Island Rookery, and Hydrologic Restoration		X	X
South Padre Island Beach Nourishment		X	
Bolivar Roads Gate System		X	
Bolivar and West Galveston Beach and Dune System		X	
Galveston Seawall Improvements		X	
Galveston Ring Barrier System		X	
Clear Lake Surge Gate System		X	
Dickinson Surge Gate System		X	
Non-structural Measures		X	

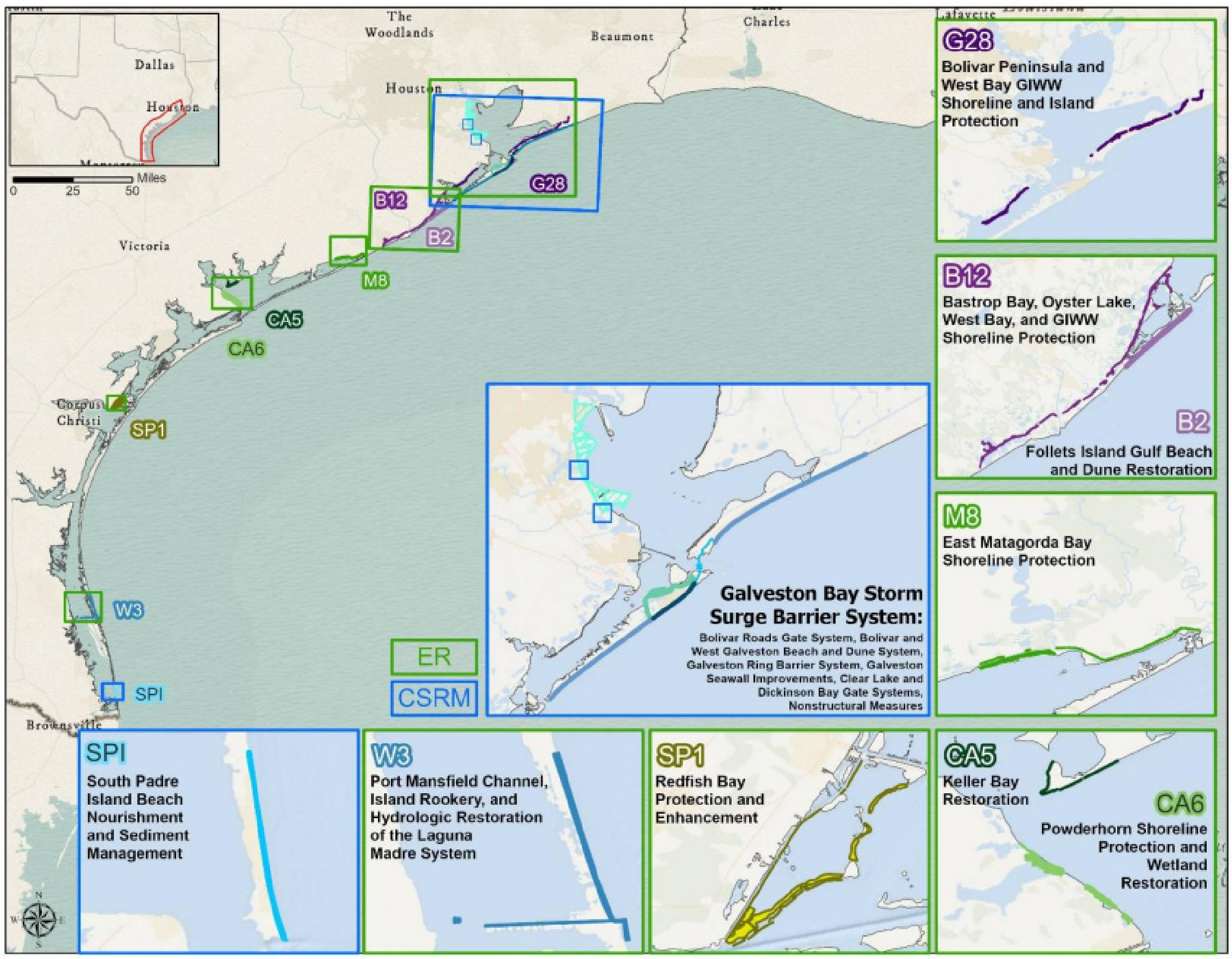


Figure ES-3: Recommended Plan

Figure A-1. Map of Recommended Plan from 2021 Coastal Texas Study FEIS.

The seven projects of interest in this report are G-28, B-12, CA-5, CA-6, M-8, SP-1, and W-3. These projects include the placement of breakwaters and sometimes living shorelines as well as ecosystem restoration. All of these projects except W-3 are Actionable. In total the recommended measures create approximately 128 miles of shoreline protection structures across the Texas coast.

The Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection project is a good example of USACE-planned projects. A summary of this project follows below.

G-28 — Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection

Figure 2-13. ER Measure G-28 with borrow sources

Figure A-2. Map showing plans for G-28 project from 2021 Coastal Texas Study FEIS (USACE, August 2021).

The Bolivar Peninsula and West Bay GIWW Shoreline and Island Protection (G-28) project includes around 40.4 miles of shoreline protection and restoration, 18 acres of oyster creation, 664 acres of marsh restoration, and 5 miles of island restoration. G-28 is located in Galveston County within Region 1 of the Texas Coast. The project protects mostly the coast of the GIWW in Bolivar Peninsula and West Bay with projects on both the north and south sides of the channel. Rock breakwater is used to create shoreline protection along the GIWW. Marsh restoration is planned for some areas behind the breakwater mostly concentrated on the Bolivar Peninsula side, but some on the West Bay side as well. Island restoration is planned in West Bay south of the GIWW in between Chocolate Bay and Carancahua Lake. The Corps proposes to construct an oyster reef south of this restoration. These plans can be seen in figure A-3 below.

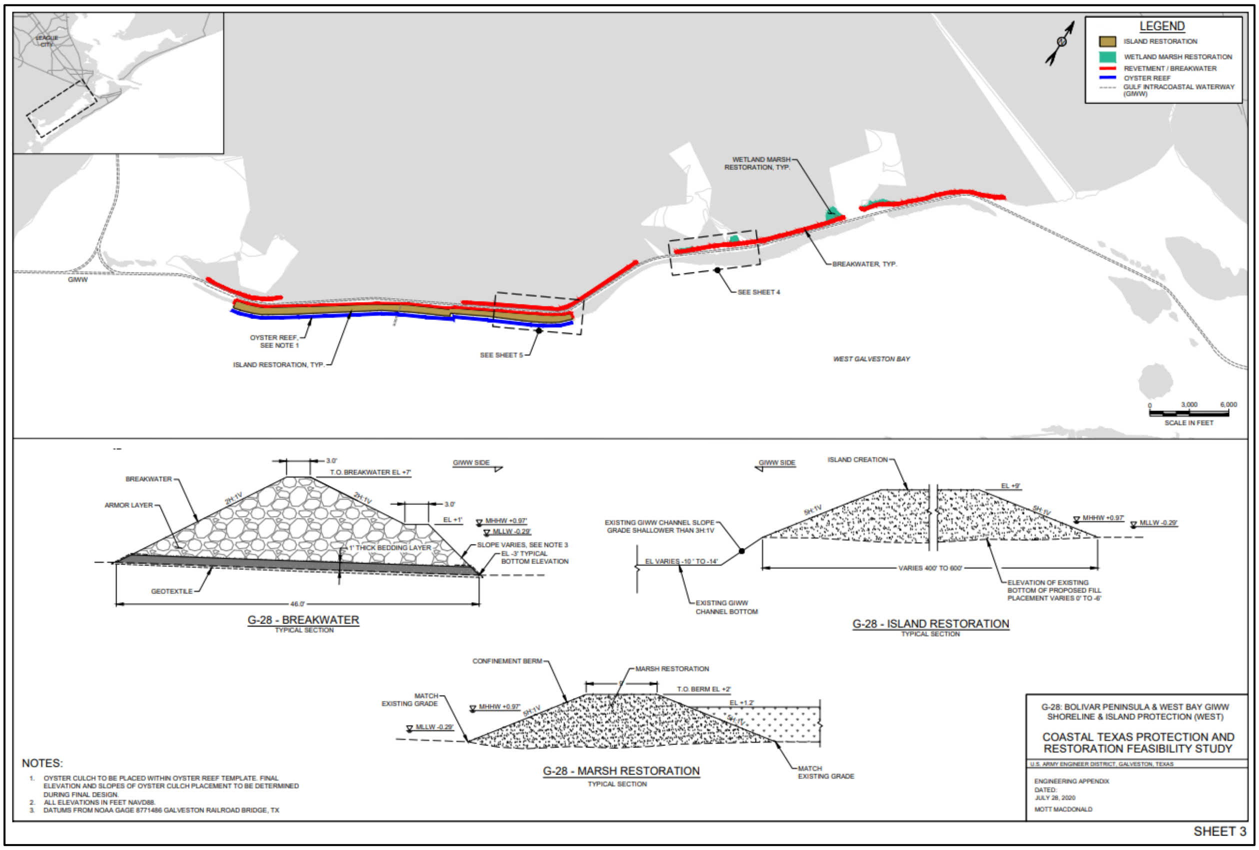


Figure A-3. Map showing plans for G-28 project from 2021 Coastal Texas Study FEIS.

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