Final Report:

Recent Bayhead Delta Shoreline and Wetland Loss: Potential Factors and Future Projections

Contract: 19-047-000-B081

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CRediT (Contributor Roles Taxonomy)

The following is a CRediT (Contributor Roles Taxonomy) authorship contribution report on the roles play by all contributors (M.R. Besonen = MB, M. Dotson = MD. J. Gibeaut = JG, B. Lupher = BL, J. Magolan = JM, A. Reisinger = AR, and L. Su = LS).

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    - Methods: MB, MD, JM, LS
    - Results: MB
    - Discussion: MB
    - Conclusions: MB
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Abbreviations and Acronyms

CMVA	Coastal Modeling and Vulnerability Assessment
DEM	Digital Elevation Model
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GLO	General Land Office
GMSLR	Global Mean Sea Level Rise
HRI	Harte Research for Gulf of Mexico Studies at Texas A&M University-Corpus Christi
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection and Ranging
NOAA	National Oceanic and Atmospheric Administration
NWI	National Wetland Inventory
RSLR	Relative Sea Level Rise
SLAMM	Sea Level Affecting Marshes Model
SLR	Sea Level Rise
TCRMP	Texas Coastal Resiliency Master Plan
TNRIS	Texas Natural Resources Information System
TWDB	Texas Water Development Board
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey,
UTM	Universal Transverse Mercator

Executive Summary

Bayhead deltas host large expanses of coastal wetlands, which provide myriad ecosystem services including serving as critical and protective buffers against storms and floodwaters, providing a variety of hydrological benefits like filtering and infiltration of water into the groundwater system, and importantly, providing critical nursery and habitat for many aquatic and terrestrial organisms. Most bayhead deltas along the Texas coast have experienced significant degradation and erosional loss over the last few decades, which marks a change in trend as many were growing and expanding during historic times.

Sea level rise (SLR) is one of the primary controlling factors that moderates bayhead delta health and that of other coastal ecosystems, too. During the early Holocene about 10,000 years ago, melting of continental ice masses led to high rates of SLR along the Texas coast. These elevated rates of SLR prevented the majority of coastal ecosystems and environments that we know today from becoming established and growing. Only over the last few thousand years as rates of SLR slowed, and the relative roles of sediment supply and other factors increased accordingly, were these coastal ecosystems and environments able to stabilize and slowly develop into the systems we know today. Given current and future projected trends for SLR, which are approaching and will eventually exceed rates seen during the early Holocene, there is concern that our bayhead delta systems are at the tipping point of catastrophic retreat.

To understand likely changes in these systems over the next sixty years, we used the Sea Level Affecting Marshes Model (SLAMM) to model potential wetland and landcover changes for the Trinity, Lavaca-Navidad, Guadalupe, and Nueces bayhead delta systems at three different time steps in the future (2040, 2060, and 2080), and under three different projected SLR scenarios including 1.0, 1.5, and 2.0 m of global mean SLR by 2100. The four systems show different potential responses and landcover changes ranging from gradual, to accelerating, to threshold-like under different SLR scenarios. Model results for the Lavaca-Navidad system show the greatest susceptibility to change among all the systems. For example, open water composes about 29% of the total areal extent of the Lavaca-Navidad system at present day. Under the 1.0, 1.5, and 2.0 m of global mean SLR by 2100 scenarios mentioned above, SLAMM projects that by 2080, open water in the system will increase to 44%, 57%, and 65%, respectively. Another observation is that under higher SLR scenarios, several of the bayhead delta systems show a potential convergence in the areal percentages of landcover classes, suggesting that higher SLR rates might drive the systems towards a common evolutionary model.

Overall, these model results help provide coastal resource planners and managers, decision makers, and the general public with up-to-date information about the status of our bayhead delta systems and their potential outlook for the near future. In general, model usage can better inform decision-making processes to make the most of finite and limited resources.

A. Introduction and Background

Bayhead deltas are low-lying tracts of land that form where river systems reach the coast at the head of a bay or estuary. These features represent a critical component of our coastal resource base because they host large expanses of coastal wetlands. Such coastal wetlands are recognized as "Critical Areas" under the Texas Coastal Coordination Act (Natural Resources Code, Chapter 33, Subchapter F) for the myriad ecosystem services they provide. For example, they serve as critical and protective buffers against storms and floodwaters, they provide a variety of hydrological benefits like filtering and infiltration of water into the groundwater system, and importantly, they provide critical nursery and habitat for many aquatic and terrestrial organisms. In fact, the Galveston Bay Plan recognizes that 90% "of commercially and recreationally important fish and shellfish species in the Gulf of Mexico use coastal wetlands for one or more stages in their life cycle," which clarifies their critical economic importance (GBNEP 1995).

The health of our bayhead deltas—and, indeed, all of our coastal landforms—depends on a complex balance of factors with the primary ones including:

1. sediment supply (overall quantity, type, and rates of sediment delivery/removal),

2. basin/delta characteristics (geometry and size of a delta relative to drainage basin area, antecedent topography, and other basin characteristics), and

3. relative sea level changes (global/eustatic ocean volume changes related to thermal expansion of water plus water mass additions from continental ice sheets +/- local to regional scale vertical land movement caused by subsidence, isostatic adjustment, and other factors)

In general, if there is a net neutral balance between factors, a bayhead delta will be stable and maintain its position and extent. If there is a net positive balance, a bayhead delta will prograde and grow out into its basin increasing its extent, and in the case of a negative net balance, retreat landward and loss of extent will occur. Intuitively, these factors are influenced by both natural and anthropogenic forcings. For example, sediment supply to the coast is closely linked to natural variations in precipitation, but it can also be drastically moderated by human activity such as dam building, agricultural practices, and other land use changes that alter sediment yield. Subsidence is similar, and partly driven by the natural compaction of sediments, but potentially accelerated by the removal of subsurface liquids like oil, gas, and water.

Most bayhead deltas along the Texas coast have experienced significant degradation and erosional loss over the last few decades. For example, the Galveston Bay system has lost almost 20% of its wetland habitat, much of which was lost from the Trinity Delta, since the 1950's (GBNEP 1995). This is a pronounced change from the long-term historical trend, which saw these bayhead deltas either growing or stable. For example, shorelines extracted from historical maps and imagery show that the Nueces Delta was continuously prograding into its basin from

1882 through at least 1949 (Figure 1). But following that period, the trend reversed, and by 1975, the delta front had receded some 20-30 m landward of the 1949 position, and the recession has continued progressively through the present day. In light of current and future projected sea level rise (SLR) trends, the change is so worrying that Anderson *et al.* (2014) warned that our "bayhead deltas are at the tipping point of catastrophic retreat."

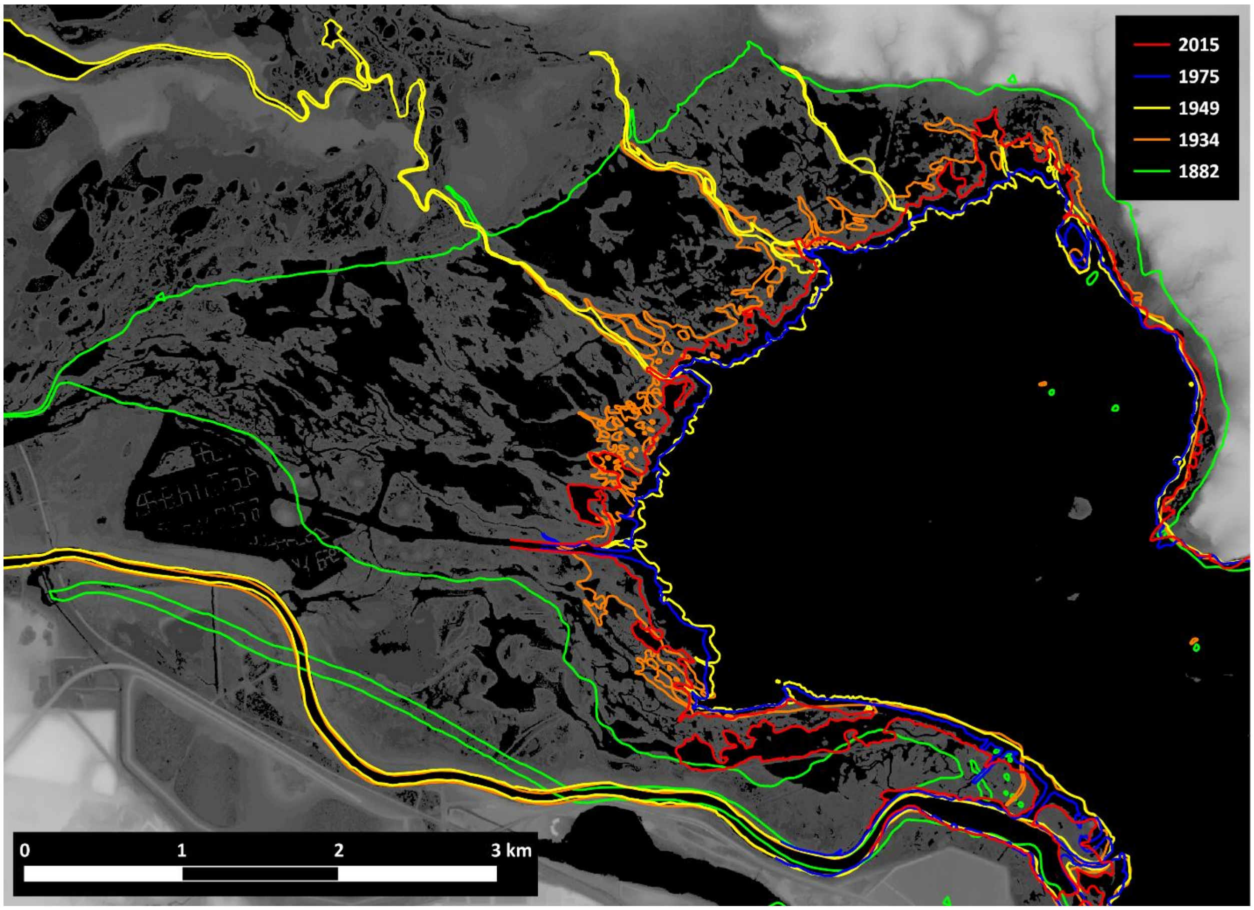

Figure 1—Nueces Delta shoreline positions from 1882 to 2015
The 1882, 1934, and 1949 shorelines were obtained from the NOAA Historical Surveys (T-Sheets) archive (https://shoreline.noaa.gov/data/datasheets/t-sheets.html). The 1975 and 2015 shorelines were digitized from the USGS and Texas Orthoimagery Program archives, respectively.

The Bureau of Economic Geology (BEG) at the University of Texas at Austin undertook a major initiative in the 1980's and 1990's to examine historical changes along the entire Texas coast, and bayhead deltas were included in that effort. This project builds on that work, but focuses on four bayhead delta systems, in particular—the Trinity River bayhead delta in Galveston/Trinity Bay, the Lavaca-Navidad River bayhead delta in Matagorda/Lavaca Bay, the Guadalupe River bayhead delta in San Antonio Bay, and the Nueces River bayhead delta in Corpus Christi/Nueces Bay (Figure 2). These four estuaries were chosen because they span a strong climatic gradient (annual precipitation is approximately halved from north to south) and include drainage basins and bay systems with significantly different characteristics.

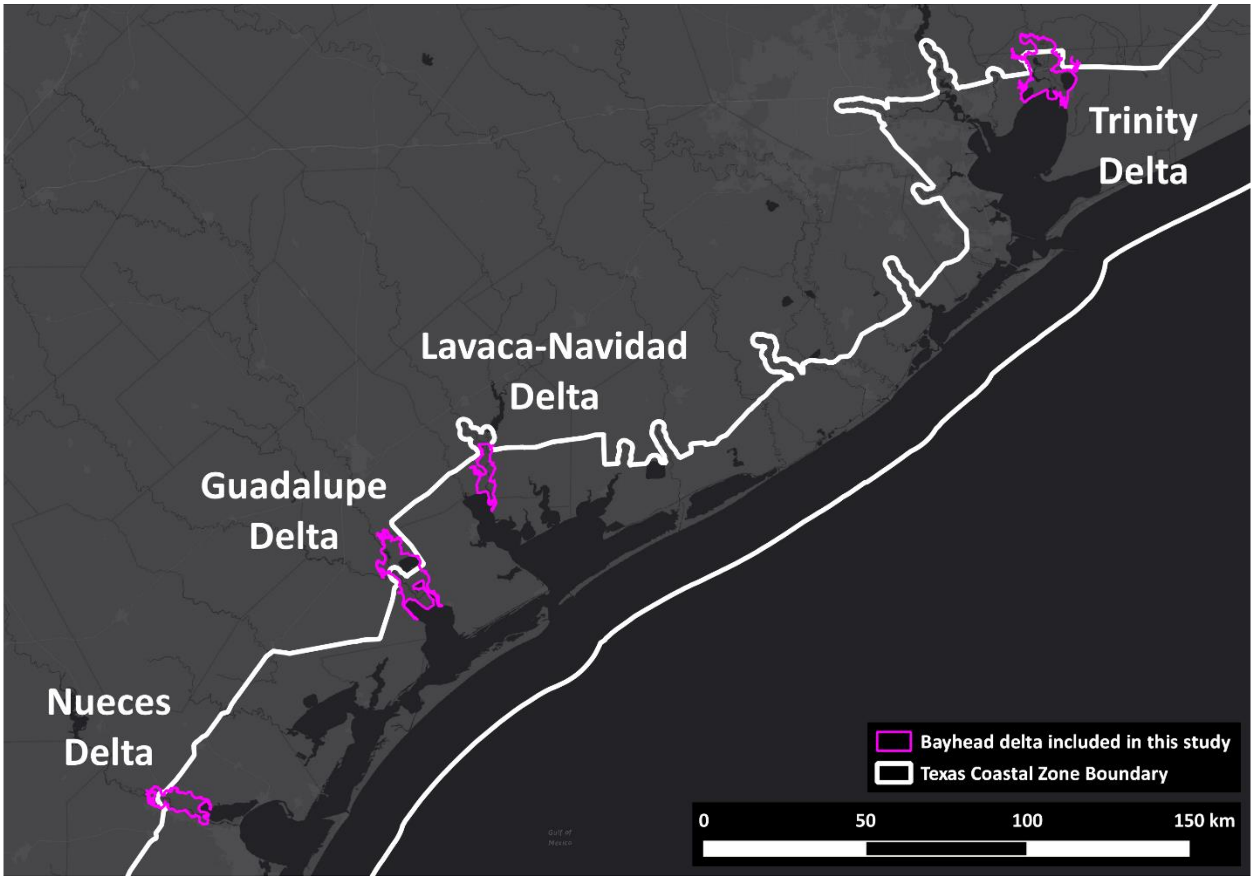

Figure 2—Bayhead delta systems included in this study
Source for dark gray basemap: ESRI ArcGIS Online.

Beyond documenting changes since the BEG initiative, this project takes an important "next step", and models how these systems will continue to change over the next 60 years related to SLR, a primary control on these systems. The results from this work include mostly geographic information systems data files and other visualization products that provide coastal resource planners and managers, decision makers, and the general public with up-to-date information about the status of our bayhead delta systems, the major stresses they are experiencing, and their outlook for the near future.

A.1 Rates of SLR and the Stability of Texas Coastal Environments

Anderson *et al.* (2014) provides a long-term perspective about the development of our Texas coastal environments that is insightful for this study. Changes in sediment supply, and to a lesser extent antecedent topography, are recognized as important controls on the development and stability of coastal landforms on geologic time scales. However, changing global sea levels due to the waxing and waning of continental ice masses are recognized as the primary control. Based on geologic evidence from around the northwestern Gulf of Mexico, Anderson *et al.* (2014) shows how the rate of global SLR progressively slowed through the Holocene as large scale, continental ice sheets decayed due to a warming climate, and the resulting melt waters returned to the ocean basins (Figure 3). Early in the Holocene about 10,000 years before present, global mean sea level was rising along the Texas coast at a rate of about 9 mm/year. By 8,000 years ago, it had slowed to about 5 mm/year, and then to about 2 mm/year around 5,000 years ago before finally slowing down to just 0.6 mm/year or less over the last 2,000 years.

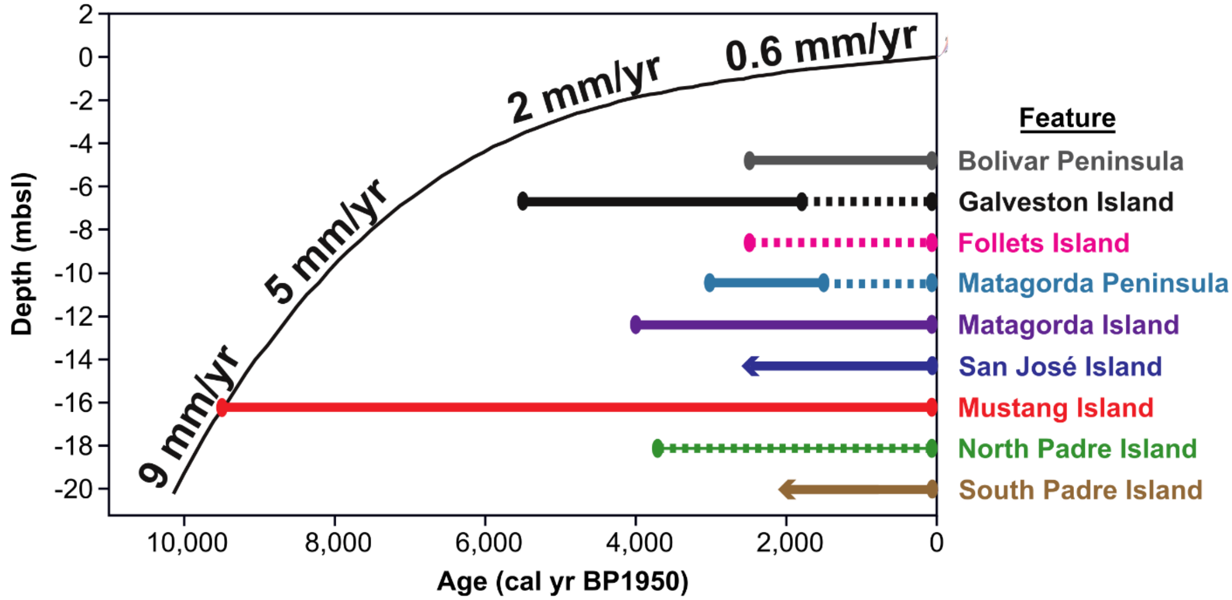

Figure 3—Rates of SLR in the northwestern Gulf of Mexico over the last 10,000 years
Horizontal colored bars show when barrier islands along the Texas coast were stable, prograding/growing seaward, or aggrading in place. Figure modified from Anderson *et al.* (2014).

The most important observation from Anderson *et al.* (2014) for the purpose of the present study, however, is the recognition of when the various barrier islands along the Texas coast were stable, prograding/growing seaward, or aggrading in place (see horizontal colored bars next to each barrier island name in Figure 3). The vast majority of the barrier islands only reached this state in approximately the last 4,000 years. The main implication is that during the first half of the Holocene, these barrier island systems were simply not able to reach stability and grow because of the higher rates of SLR. By extension, bayhead deltas and other coastal environments must share a similar history as they are also products of the same complex balance of factors. Importantly, Anderson *et al.* (2014) note that the very modest rates of global sea level rise seen over the last few thousand years are no longer the case. Due to rising global temperatures, global mean SLR (GMSLR) rates are accelerating and approaching values seen during the early Holocene, when barrier islands and other coastal landforms were not able to reach stability. And the issue has been exacerbated over historical times due to anthropogenic factors such as changes in river systems that reduce sediment delivery to the coast, and the extraction of subsurface fluids that has greatly increased subsidence in some areas leading to relative SLR (RSLR) rates that even exceed early Holocene GMSLR rates in some cases. *Anderson et al.* (2014) concludes with the sobering statement that the acceleration of GMSLR that we are seeing "will continue to severely impact low gradient coasts at rates that, thus far, exceed the reaction time of policy makers to respond."

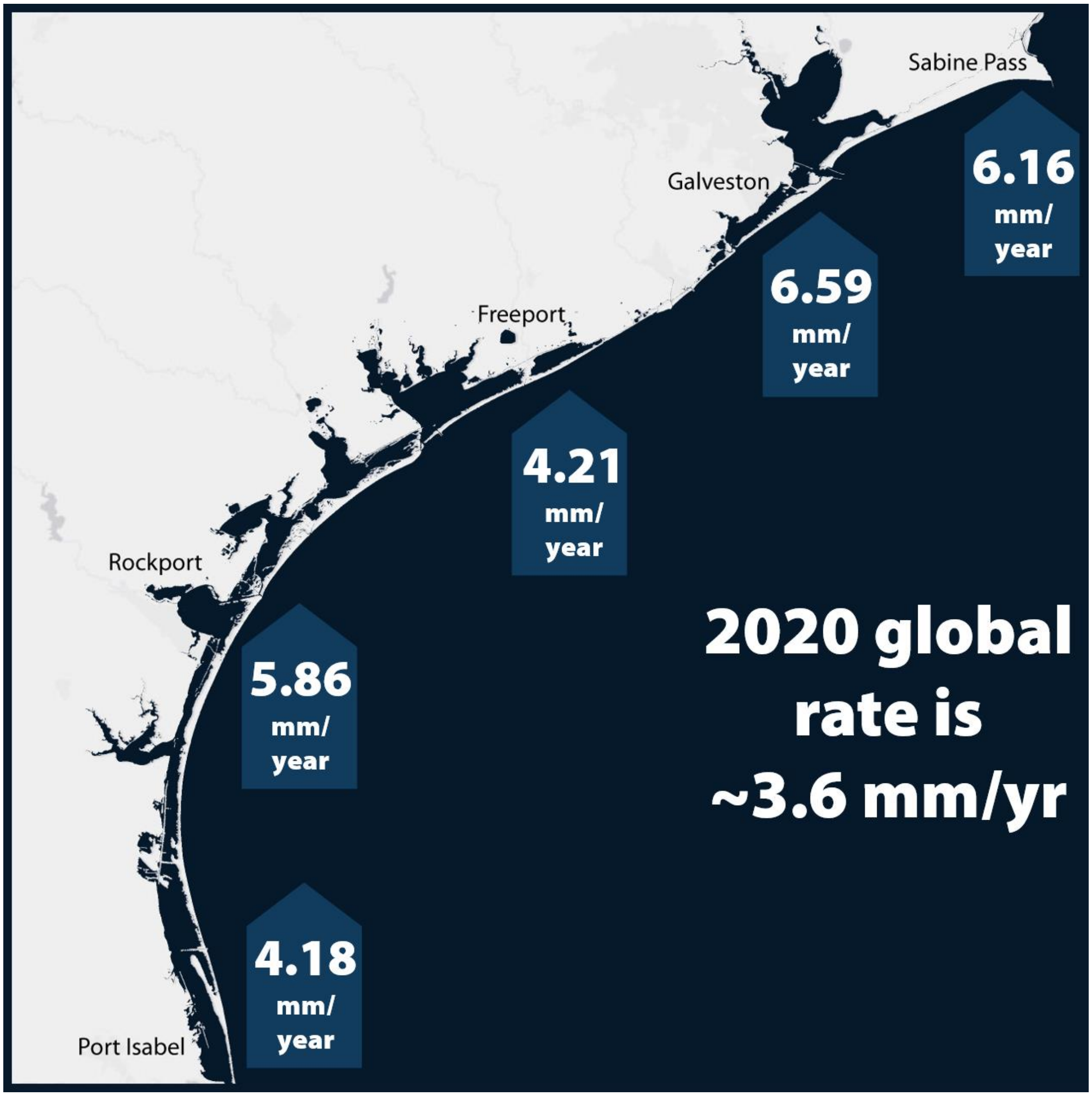

Figure 4—Current rates of RSLR along the Texas coast
All local rates of RSLR along the Texas coast exceed that of the current GMSLR rate of ~3.6 mm/year given additive local effects, in particular, subsidence.

A.2 Current and Expected Future Rates of RSLR Along the Texas Coast

While GMSLR during much of the 20th century averaged about 1.7 mm/year, it has continued to accelerate over the last few decades reaching about 3.2 mm/year by 1993 and 3.6 mm/year for the period from 2006-2015 (https://www.climate.gov/). However, this rate is exceeded at all tide gauge stations along the Texas coast (Figure 4), which have calculated RSLR rates for the present day ranging from about 4.18 to 6.59 mm/year (NOAA Tides & Currents website, https://tidesandcurrents.noaa.gov/sltrends/). These higher rates are due to local effects, in particular, land surface subsidence due to subsurface fluid extraction and natural compaction of sediments, that are additive to the GMSLR rate. Nonetheless, whether global or Texas-specific, the reality is unsettling as this range of rates occurred along the Texas coast during the early

Holocene from about 9000 to 6500 years before present, when barrier island systems and other coastal features were not able to develop and stabilize given the rapid rates of SLR (Figure 3).

Figure 5 shows historical sea levels back to 1700 and up to the present day combined with future projected sea levels out to 2100. This figure is sourced from Church *et al.* (2013), which is part of the Working Group 1 contribution to the IPCC Fifth Assessment Report. The projected sea levels out to 2100 are based on two hypothetical greenhouse gas concentration scenarios, or representative concentration profiles (RCP). The blue curve and envelope represent projected sea levels under the RCP2.6 low concentration scenario, which is based on the notion of a strong mitigation response and net-negative greenhouse gas emissions in the last decades of the 21st century. The red curve and envelope represent projected sea levels under the RCP8.5 high concentration scenario, which would reflect a fossil-fuel-intensive, ‘business-as-usual’ emission scenario with essentially no efforts at mitigation. Under the RCP2.6 low concentration scenario, global mean sea level is projected to accelerate to about 4.5 mm/year at 2100. Under the RCP8.5 high concentration scenario, SLR continues to accelerate up to 2100 reaching rates as high as 11.0 mm/year. This rate is even faster than the very fastest rates that Anderson *et al.* (2014) documented for the Texas coast during the earliest Holocene. Both scenarios are just best guesses about plausible climate futures based on what does and does not happen with respect to greenhouse gas emissions and mitigation efforts. This said, Schwalm *et al.* (2020) note that as of now, atmospheric concentrations are actually closely tracking the RCP8.5 high emissions scenario, and suggest that "RCP8.5, the most aggressive scenario…for global climate models, will continue to serve as a useful tool for quantifying physical climate risk, especially over near- to midterm policy-relevant time horizons. Not only are the emissions consistent with RCP8.5 in close agreement with historical total cumulative CO_2 emissions (within 1%), but RCP8.5 is also the best match out to midcentury under current and stated policies with still highly plausible levels of CO_2 emissions in 2100." Given this reality, it is understandable that Anderson *et al.* (2014) felt it appropriate to warn that our "bayhead deltas are at the tipping point of catastrophic retreat," and that the effects of accelerating SLR "will continue to severely impact low gradient coasts at rates that, thus far, exceed the reaction time of policy makers to respond."

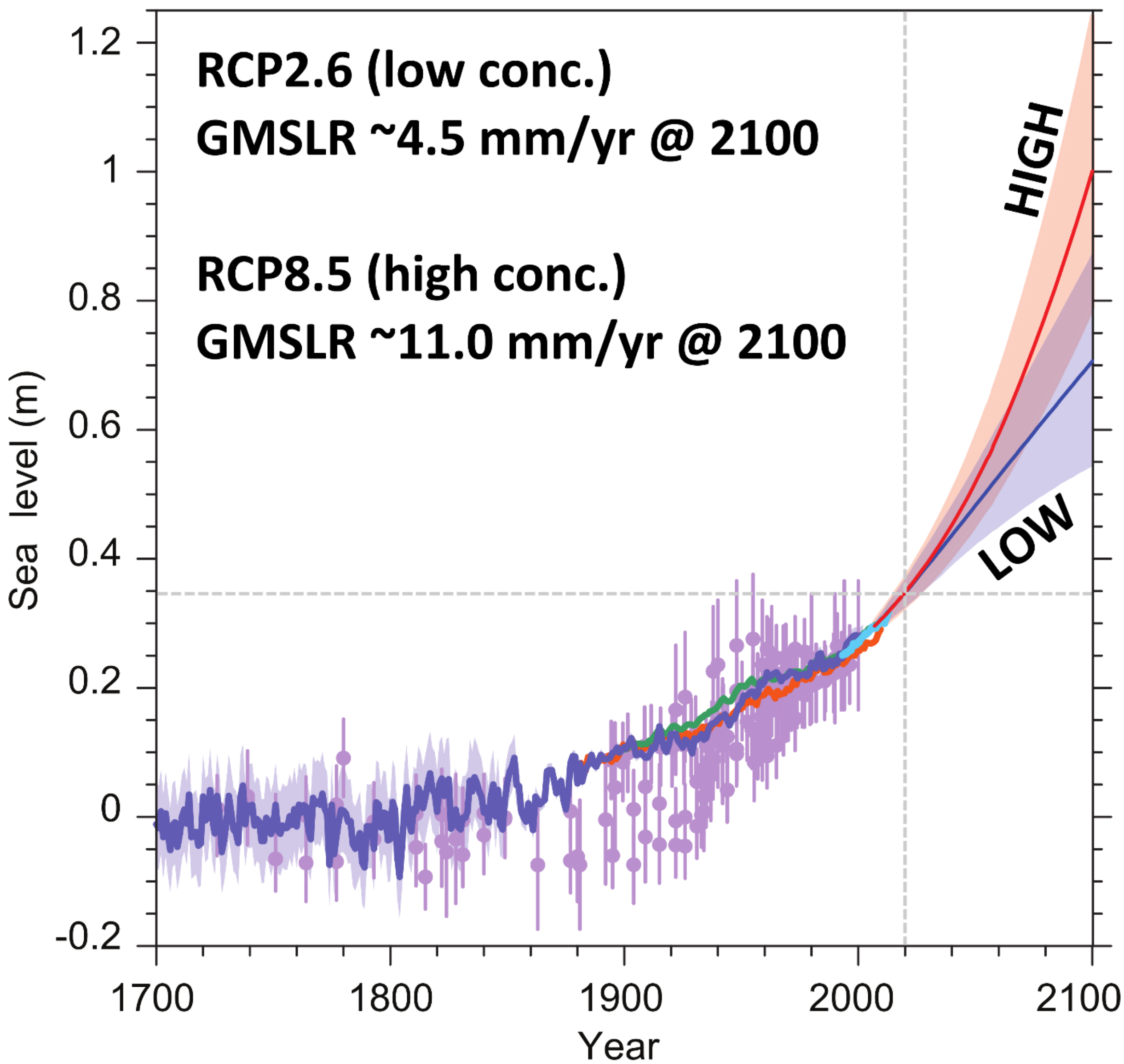

Figure 5—Historical and future projected global mean sea levels
Paleo and historical sea level data from salt marshes, tide gauges, and altimeter data compose the left part of this GMSLR curve. Projections for future global mean sea levels under low concentration (RCP2.6, blue) and high concentration (RCP8.5, red) scenarios compose the right side of this curve. The high concentration scenario curve accelerates through time reaching a maximum GMSLR rate of about 11 mm/year around 2100. The curve representing the low concentration scenario reaches only about 4.5 mm/year at the same time. Figure slightly modified from Church *et al.* (2013) [IPCC WG1 AR5].

B. Methods

B.1 General Overview

This study modeled potential wetland and landcover changes for the Trinity, Lavaca-Navidad, Guadalupe, and Nueces bayhead delta systems at three different time steps in the future (2040, 2060, and 2080), and under three different projected SLR scenarios including 1.0, 1.5, and 2.0 m of GMSLR by 2100. This was accomplished using the Sea Level Affecting Marshes Model (SLAMM). This study closely followed the strategy and methodology that was used for the Coastal Modeling and Vulnerability Assessment (CMVA) portion of the Texas Coastal Resiliency Master Plan (TCRMP), and details for that effort are extensively documented there (Texas GLO 2019). The main difference is that the CMVA effort included additional storm surge, wave, and hazards modeling steps, but these additional steps were not necessary for this study. Two other differences resulted from the fact that the geographic scope of the CMVA work focused on the whole Texas coast whereas this study focused on just four bayhead delta systems with limited footprints. Given this distinction, this study was able to run SLAMM at an increased resolution (2-m versus 3-m resolution), and it was able to provide model runs for three different SLR scenarios versus one.

SLAMM (http://warrenpinnacle.com/prof/SLAMM/) is a mathematical spatial model that uses digital elevation data, wetlands classifications, and other information to simulate the potential evolution of wetlands and shorelines driven by long-term SLR. SLAMM models the landscape as a raster of discrete cells (cell size is user definable) with specific landcover classes linked to specific elevational ranges, and simulates dynamic processes such as inundation, edge erosion, subsidence, overwash, saturation, accretion, and salinity. Via a complex but flexible decision tree, it tracks transfers between cells, and updates landcover classes based on changes in elevations with respect to the changing relative sea level (Clough *et al.* 2016). Results are provided in both tabular/numeric and graphical form and can be used to visualize the impacts from various SLR amount scenarios, compare impacts from multiple scenarios over multiple timeframes, identify vulnerable wetlands and affected uplands, and similar.

SLAMM, like all models and simulation tools, has a range of strengths and weaknesses that the CMVA study (Texas GLO 2019) examined with a robust discussion, and that discussion is summarized here. First, while SLAMM is not the most complex wetlands and landscape transition modeling tool available, given that it simulates a range of dynamic processes as mentioned above, it is a substantial improvement over simple "bathtub" models that merely raise relative sea level and project new landcover classes from there. Importantly, the input datasets required for SLAMM (discussed in the sections that follow below) are generally available for most locations. In turn, a more complex model for wetlands transitions might incorporate additional input parameters such as temperature, precipitation, sediment load, plant growth/mortality rates, and other ecological considerations and feedbacks. But these additional factors impose a much higher computational load for model runs, and increased complexity for people running such models. Importantly, such additional primary input datasets are often not available in many areas. Thus, SLAMM provides an excellent, mid-level compromise by incorporating a range of fundamental dynamic processes, requiring realistically achievable input datasets, and requiring computational loads that are appropriate for mainstream desktop workstations. Beyond these factors, SLAMM is free, well-documented, and open source, all of which have encouraged the development of a strong user community that provides excellent support.

The sections that follow below provide information about the methodology and overall workflow employed for this project. Many of the steps provide details about dataset preparation for the SLAMM model, and though the sections appear sequentially, many occurred in parallel.

B.2 Data Sources Compilation

Multiple input datasets are needed to run the SWIMM model, and for subsequent steps such as producing the final projected wetland and landcover change maps from SWIMM output. The main data sources that were compiled for this study are recorded in Table 1 below.

Table 1—Data sources compiled for this study

Data type	Specifications and Source
Aerial photography	1996 1-m resolution TOP (Texas Orthoimagery Program) imagery and 2018 60-cm USDA NAIP (National Agriculture Imagery Program) imagery available from TNRIS (https://data.tnris.org/)
Elevation/ Topography	2-m resolution topographic digital elevation model produced from ten lidar datasets; see Table 2 for dataset names and sources
Wetland classification	2017 USFWS National Wetlands Inventory (NWI) available from https://www.fws.gov/GIS/data/national/index.html
SLR/ Subsidence	Future SLR and RSLR models and projections from NOAA Technical Report NOS CO-OPS 083 (i.e. Sweet *et al.* 2017) https://tidesandcurrents.noaa.gov/pub.html GPS monitoring data from Harris-Galveston Subsidence District https://hgsubsidence.org/science-research/measuring-subsidence/ Releveling data from National Geodetic Survey https://geodesy.noaa.gov/NGSDataExplorer/

B.3 Details About Lidar DEM for Elevational/Topographical Control and Slope Input

Precise elevational data is one of the fundamental input datasets for SLAMM, and the individual topographic models used for each bayhead delta system in this study were extracted from a seamless, statewide, lidar-based, high resolution DEM that was developed via in-house processing at HRI. An extensive discussion about the technical processing steps used to produce the DEM for the CMVA study is found in the TCRMP Technical Report (Texas GLO 2019), and is not repeated here. The same steps were used to produce the seamless DEM that was subsampled for this study, but the main difference is that the original lidar data sources were completely reprocessed to a higher, 2-m pixel resolution versus the 3-m pixel resolution DEM used for the CMVA effort.

The original lidar datasets that provide coverage for the areas of the bayhead deltas in the 2-m resolution DEM are recorded in Table 2 below.

Table 2—Original lidar datasets used to produce DEMs for this study

Lidar Dataset Name and Source	UTM Zone
Trinity system	
2006 FEMA/TWDB Lidar: Chambers County https://coast.noaa.gov/dataviewer/#/lidar/search/where:id=90	15
2011 FEMA Lidar: Liberty County https://data.tnris.org/collection/2407d7a6-c33a-4095-915d-ac464293ef50	15
Lavaca-Navidad system	
2006 FEMA/TWDB Lidar: Jackson County https://coast.noaa.gov/dataviewer/#/lidar/search/where:ID=92	14
2015 BEG Lidar: Matagorda Bay Bureau of Economic Geology, University of Texas at Austin	14
Guadalupe system	
2006 FEMA/TWDB Lidar: Aransas and Refugio Counties https://coast.noaa.gov/dataviewer/#/lidar/search/where:ID=96	14
2006 FEMA/TWDB Lidar: Calhoun County https://coast.noaa.gov/dataviewer/#/lidar/search/where:ID=97	14
2006 FEMA/TWDB Lidar: Victoria County https://coast.noaa.gov/dataviewer/#/lidar/search/where:ID=88	14
2013 BEG Lidar: Guadalupe Delta Bureau of Economic Geology, University of Texas at Austin	14
Nueces system	
2006 FEMA/TWDB Lidar: San Patricio County https://coast.noaa.gov/dataviewer/#/lidar/search/where:ID=87	14
2011 USGS ARRA Lidar: Calhoun, Nueces, Willacy, and Hidalgo Counties https://data.tnris.org/collection/6a825941-a80b-4a61-a2b2-1da205f2f28b	14

SLAMM also requires a slope raster for input that provides the rate of maximum change in the z-value for each cell, and this was calculated from the DEM and expressed in degrees.

B.4 Development of Wetlands Environments Landcover Raster

SLAMM requires an input raster of wetland and landcover types/classes to relate current habitats to specific elevational ranges in conjunction with the DEM. These rasters were generated for each of the bayhead delta systems by clipping the USFWS National Wetlands Inventory (NWI) shapefile data layer to the SLR modeling area around each system. Beside an NWI-vector/SLAMM-raster distinction, the NWI follows the Cowardin classification system (Cowardin *et al.* 1979), which allows for potentially generic classification of environments using non-specific term such as "Lacustrine" or "Riverine", though more specific descriptions are possible. These do not exactly correspond with SLAMM's 24 wetland and landcover classification codes (Table 3) so directly ingesting NWI data into SLAMM is not possible. To address this issue, NWI landcover attributes were mapped to the appropriate SLAMM landcover classification codes ("SLAMMCODE"). This mapping was done using a well-documented, crosswalk technique using an NWI→SLAMM code lookup table that is provided as part of the SLAMM package. After the mapping crosswalk, the polygon shapefile was converted to a raster at 2-m resolution to match the DEM, and the "SLAMMCODE" attribute was used to assign pixel values in the output raster. Areas without NWI data coverage were assigned a default pixel value of "2" (the "Undeveloped Dry Land" class in SLAMM) and estuarine open water was filled with the appropriate SLAMM code of "17".

Table 3—SLAMM landcover class codes and class descriptions
Landcover classes "21" and "24" are currently unused, and thus, excluded from the table below.

SLAMM Class	Class Description
1	Developed Dry Land
2	Undeveloped Dry Land
3	Swamp
4	Cypress Swamp
5	Inland-Fresh Marsh
6	Tidal-Fresh Marsh
7	Transitional Salt Marsh
8	Regularly-Flooded Marsh
9	Mangrove
10	Estuarine Beach
11	Tidal Flat
12	Ocean Beach
13	Ocean Flat
14	Rocky Intertidal
15	Inland Open Water
16	Riverine Tidal
17	Estuarine Open Water
18	Tidal Creek
19	Open Ocean
20	Irregularly Flooded Marsh

22	Inland Shore
23	Tidal Swamp
25	Flooded Developed Dry Land
26	Flooded Forest

B.5 Determination of Vertical Sediment Accretion Rates

Vertical sediment accretion rates are needed as a SLAMM input, and they are based on habitat type. Separate inputs exist for low marsh, high marsh, tidal-fresh marsh, inland-fresh marsh, and mangrove environments, and a single beach sedimentation rate is applied to marine and estuarine beaches as well as tidal flats environments.

The CMVA study reviewed published, peer-reviewed literature to determine average accretion rates for wetland habitat types on a subregional basis along the Texas coast (Texas GLO 2019). This study used those same resources (Table 4) and calculated average accretion rates (Table 5), which are reproduced below in slightly modified format. The CMVA study notes that a special adjustment was needed for low and high marsh accretion rates given that their elevations overlap, and further details can be found in the TCRMP Technical Report (Texas GLO 2019).

Table 4—Studies used to determine average vertical sediment accretion rates
Source: slightly modified from CMVA Study in TCRMP Technical Report (Texas GLO 2019)

Delta system	Habitat Type	Source
Trinity	Low Marsh	White and Calnan (1990)
		Callaway *et al.* (1997)
		Feagin and Yeager (2007)
		Ravens *et al.* (2009)
		Williams (2003)
	High Marsh	White and Calnan (1990)
		Callaway *et al.* (1997)
		Williams (1995)
	Tidal Fresh Marsh	Williams (2003)
		White *et al.* (2002)
Lavaca-Navidad	Low Marsh	White and Calnan (1990)
		Callaway *et al.* (1997)
		Feagin and Yeager (2007)
	High Marsh	White and Calnan (1990)
		Callaway *et al.* (1997)
		Williams (1995)
	Tidal Fresh Marsh	White *et al.* (2002)
Guadalupe and Nueces	Low Marsh	White *et al.* (2002)
		Callaway *et al.* (1997)
		Radosavljević (2011)

	High Marsh	White *et al.* (2002)
		Callaway *et al.* (1997)
		Radosavljević (2011)
	Tidal Fresh Marsh	White *et al.* (2002)

Table 5—Average vertical sediment accretion rates by habitat type
Source: slightly modified from CMVA Study in TCRMP Technical Report (Texas GLO, 2019)

Habitat Type	Delta system	Average Accretion Rate (mm/yr)	Source
High Marsh	Trinity	3.57	See Table 4
	Lavaca-Navidad	3.03	
	Guadalupe and Nueces	1.72	
Low Marsh	Trinity	6.55	
	Lavaca-Navidad	7.82	
	Guadalupe and Nueces	4.35	
Tidal Fresh Marsh	Trinity	4.04	
	Lavaca-Navidad		
	Guadalupe and Nueces		
Inland Fresh Marsh	Trinity	1.6	Yeager *et al.* (2007)
	Lavaca-Navidad		
	Guadalupe and Nueces		
Mangrove	Trinity	6.55	Same as low marsh average for Trinity system
	Lavaca-Navidad		
	Guadalupe and Nueces		
Tidal Swamp	Trinity	1.1	Clough *et al.* (2016)
	Lavaca-Navidad		
	Guadalupe and Nueces		
Swamp	Trinity	0.3	
	Lavaca-Navidad		
	Guadalupe and Nueces		

B.6 RSLR Projections and Subsidence Data

Relative sea level change—the effective sea level variation perceived at any particular location—is the combination of global mean sea level change together with any local to regional vertical land movement effects such as subsidence. Understandably, this is one of the primary drivers needed as a SLAMM input. But it is also one of the input datasets that is potentially hard to obtain at the local scale as long-term tide gauge stations that are needed for good control are limited in number and, thus, location. Also, there can be high degrees of variability in local vertical land movement contributions like subsidence over very short distances.

Regarding the global mean sea level component, as discussed in the "A.2 Current and Expected Future Rates of RSLR Along the Texas Coast" section above, it is currently around 3.6 mm/year. But this rate it is also expected to increase and accelerate in the future due to climate change. How much it will increase/accelerate, however, is not known because the reality depends on a complex mix of potential changes to greenhouse emissions and other climate change mitigation efforts that are linked to hard-to-predict social, economic, demographic, political, and natural factors, too.

Local to regional vertical land movement effects such as subsidence are also hard to project into the future because again, there may be a high degree of variability over short distances, and long-term tide gauge stations that are needed for good control are limited. Another important factor is that past variations are not necessarily good predictors of future variations. This is because much of the variability—in particular, related to subsidence—is tied to anthropogenic activity that may change through time. For example, subsidence issues due to subsurface fluid extraction are well-known in the Houston-Galveston area, but a regulatory plan focused on groundwater extraction that was implemented in 1999 has made a large difference. Thus, even with good records of past variation in local subsidence at a certain location, the older rates are not necessarily valid for future projection if anthropogenic drivers are involved.

These combined issues are the direct focus of NOAA Technical Report NOS CO-OPS 083 (Sweet *et al.* 2017), which provides updated scenarios of projected GMSLR that are expected to range from 0.3 to 2.5 m by 2100. Furthermore, the publication provides similar, regionalized RSLR projections that incorporate vertical land movement like subsidence on top of the GMSLR component. The projected scenarios are provided for the regular NOAA CO-OPS tide gauge network, but also on a 1-degree grid along the whole coastal zone of the U.S. to provide coverage for areas where tide gauge coverage is sparse or non-existent. The NOAA report splits up its GMSLR scenario projections into six intervals with up to 0.3 m rise by 2100 classified as the Low scenario (RCP2.6 equivalent), 0.5 m as Intermediate-Low (RCP4.5 equivalent), 1.0 m as Intermediate (RCP8.5 equivalent), 1.5 m as Intermediate-High (no RCP equivalent), 2.0 m as High (no RCP equivalent), and 2.5 m as Extreme (no RCP equivalent).

The CMVA study in the TCRMP Technical Report (Texas GLO 2019) includes a detailed consideration of the Sweet *et al.* (2017) scenarios for the Texas coast together with local insight that was not possible to include in the nationwide study. Given the CMVA's focus on the entire Texas coastal zone, it took a compromise approach for providing SLR input data for SLAMM on a zone-by-zone basis. The study settled on the Sweet *et al.* (2017) Intermediate scenario of 1.0 m of GMSLR by 2100 (RCP8.5 equivalent), but used the high scenario for RSLR based on upper estimates of land subsidence. Some local adjustments were made for subsidence where either no tide gauges are present or the Sweet *et al.* (2017) gridded results seemed potentially incorrect. A primary exception was also made for the Houston-Galveston area because of the existence of abundant and well-controlled subsidence data, as discussed further below.

Regarding SLR input for SLAMM for this study (Figure 6), it builds on the CMVA analysis, but as it has a more limited geographic focus on just four bayhead delta systems, two additional SLR scenario model runs were undertaken beyond the 1.0 m of GMSLR by 2100 scenario. In particular, this study also ran SLAMM using the Sweet *et al.* (2017) Intermediate-High and High scenarios, i.e. 1.5 m and 2.0 m of GMSLR by 2100, respectively. As with the CMVA analysis, the high RSLR scenarios based on upper estimates of land subsidence were also used.

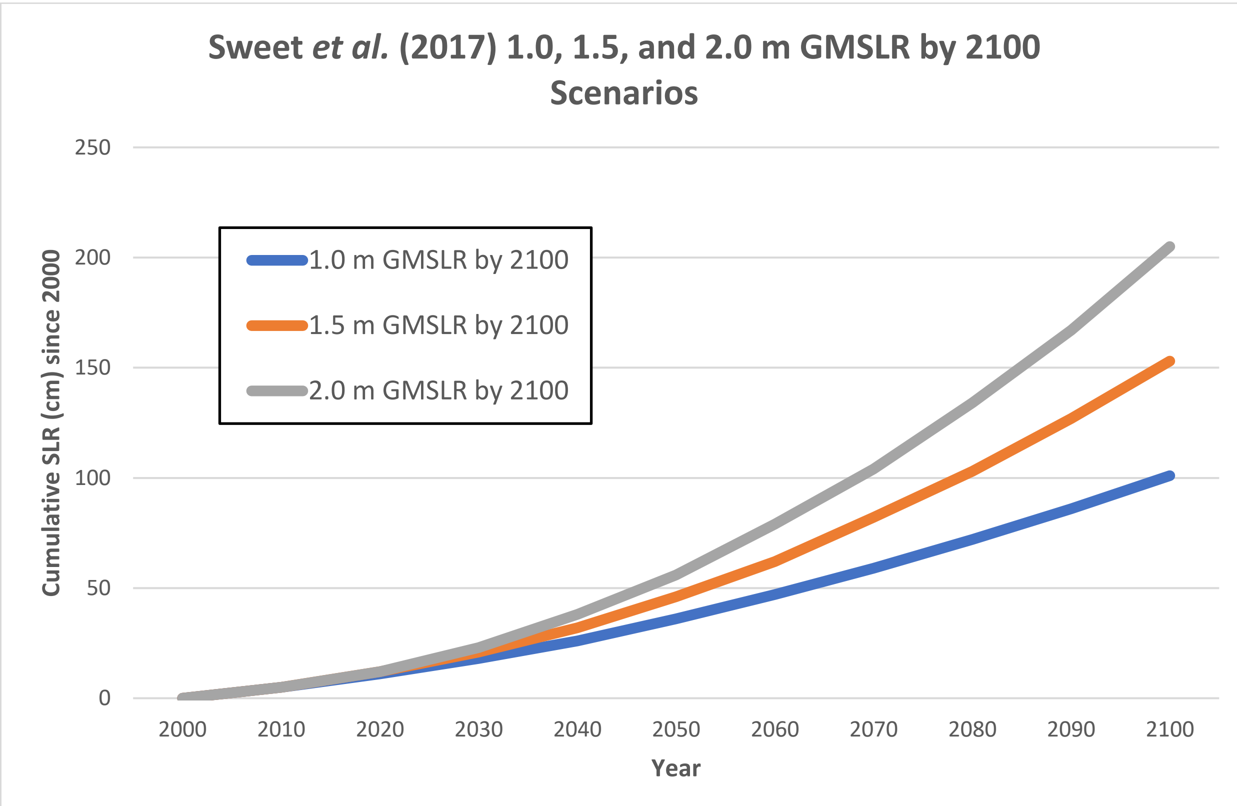

Figure 6—GMSLR by 2100 scenarios used in this study
This study used the Intermediate, Intermediate-High, and High scenarios (1.0, 1.5, and 2.0 m of GMSLR by 2100, respectively) from Sweet *et al.* (2017) to drive SLAMM.

Subsidence rates along the Texas coast are variable and can also change substantially over short distances primarily due to major differences in historical rates of subsurface fluid extraction and to a lesser part, the natural compaction of sediments. In fact, in some areas, subsidence meets or even potentially exceeds the rate of GMSLR. For example, the Galveston Pier 21 record shows a long-term RSLR trend of about 6.59 mm/year based on the period from 1904 to 2020 (see https://tidesandcurrents.noaa.gov/sltrends/). As GMSLR averaged about 1.7 mm/year over the 20th century (https://www.climate.gov/), this means about 4.9 mm/year of SLR at Galveston Pier 21 can be attributed to local factors, in particular, subsidence due to subsurface fluid extraction.

Good control of land surface subsidence on a spatially-varying basis is possible for the Trinity system and the Galveston Bay area, in general, because of ongoing data collection efforts by the Harris-Galveston Subsidence District (HGSD) and National Geodetic Survey (NGS). The HGSD and NGS have been using the Global Positioning System (GPS) to measure and document land-surface elevation changes in the region based on elevation data measured by borehole-extensometer, Continuously Operating Reference Stations (CORS), and a GPS Port-A-Measure (PAM) (Zilkoski *et al.* 2003). Subedee *et al.* (2016) developed a subsidence rate grid for the region using the HGSD and NGS data, and the CMVA study in the TCRMP Technical Report (Texas GLO 2019) provides an extensive discussion regarding the steps and processing techniques that were used. This study follows that guidance and uses the Subedee *et al.* (2016) subsidence rate grid as the subsidence input for the Trinity bayhead delta system SLAMM modeling.

Similar detailed subsidence data is not yet available for the Lavaca-Navidad, Guadalupe, and Nueces bayhead delta systems; thus, it was not possible to develop subsidence rate grids with spatial variability for these systems. In this case, a constant rate of subsidence was applied to all of the SLAMM grid cells on a delta-by-delta basis. For the Nueces and Guadalupe bayhead delta systems, this was based on the Sweet *et al.* (2017) RSLR projections for the Corpus Christi and Rockport tide gauges respectively. In the case of the Lavaca-Navidad system, there is no tide gauge in the immediate vicinity, but there is a close grid point (28.5°N, 96.5°W) from the Sweet *et al.* (2017) report. Unfortunately, this grid point seems to be heavily influenced by the Freeport tide gauge record leading to a RSLR projection that is potentially too high. Following guidance by the CMVA study (Texas GLO 2019), this project averaged the long-term Corpus Christi and Rockport tide gauge trends as a substitute to provide a historical RSLR rate for the Lavaca-Navidad system. Using this approach, SLAMM calculates subsidence by subtracting the long-term, 20th century GMSLR average of 1.7 mm/year from the historical trend.

B.7 Erosional Rates Input

Erosional rates are another data input used to run SLAMM though the CMVA study (Texas GLO 2019) recognized the model's erosional component as one of its limitations. The model incorporates only horizontal erosion rates at the land-water boundaries of marshes, swamps, tidal flats, and ocean beaches. With respect to ocean beaches, it is possible to apply the Bruun rule for coastal recession versus a simple, horizontal erosion rate (Clough *et al.* 2016). The Bruun rule provides a simplified, 100:1 relationship between SLR and coastal recession, i.e. 1 cm of SLR would produce 100 cm of coastal erosion, but that option was not used for this study. Instead, erosion of ocean beaches was modeled with the same horizontal erosion rates, which do not take into consideration the myriad complex feedbacks between storms, currents, waves and sediment supply that shape beach and dune systems (Texas GLO 2019). Despite these limitations, the CMVA study—and this study, too, as it follows suit—used horizontal erosion rates for modeling work based on the BEG's shoreline change rates from 1931-2000 for the Galveston and Corpus Christi systems (Paine *et al.* 2014) and from a more recent dataset from the BEG for the Matagorda and San Antonio Bay systems (Paine *et al.* 2016). The horizontal erosion rates determined from the BEG resources are provided in Table 6 below, and additional details about the actual processing steps that were needed to generate this dataset can be found in the CMVA discussion section of the TCRMP Technical Document (Texas GLO, 2019).

Table 6—Horizontal erosion rates used in this study

Delta system	Horizontal erosion rate (m/year)
Trinity	1.550769
Lavaca-Navidad	0.859024
Guadalupe	1.140609
Nueces	0.703

Overall, SLAMM appears to underestimate erosion, and thus, for the present study, an extra step was taken to project future shorelines that were then used to clip SLAMM output. Details about this extra step are found in the "B.11 Construction of Bayhead Delta Change Maps" section below.

B.8 Other Ancillary SLAMM Input Datasets and Parameters

SLAMM also uses several other ancillary datasets and parameters as input including geospatial raster layers that provide footprints for 1.) development and 2.) dikes/shoreline armoring features. The development footprints were generated based on the 2011 National Land Cover Database, and the dikes/shoreline armoring footprints were developed from the NWI database as well as the Environmental Sensitivity Index produced by HRI (Gibeaut *et al.* 2013). The tide range was also needed as a site-specific parameter for each bayhead delta system, and this was computed for each site by using NOAA's VDATUM tool (https://vdatum.noaa.gov/) and subtracting Mean Lower Low Water values from Mean Higher High Water values to derive the great diurnal tide range. Finally, a correction factor was needed to match the input DEM's orthometric NAVD88 datum with the vertical tidal datum used by SLAMM, which is Mean Tide Level (MTL). Tide range values and the MTL-NAVD88 correction factor can be found in Table 7 below. Further details about how the geospatial footprint layers and other parameters were developed and/or calculated can be found by consulting the CMVA study in the TCRMP Technical Document (Texas GLO 2019).

Table 7—Other input parameters used for SLAMM

Delta system	Great diurnal tide range (m)	MTL-NAVD88 correction (m)
Trinity	0.390691	0.200572
Lavaca-Navidad	0.29667	0.097978
Guadalupe	0.117848	0.161313
Nueces	0.196141	0.040519

B.9 SLAMM Runs and 3x3 Matrix of Time Step Versus SLR Scenarios

Following the collection and preparation of the various input datasets and parameters discussed above, a 3x3 matrix of different scenarios was run for each bayhead delta system using SLAMM 6.7 beta (Build Number 6.7.0242). The 3x3 matrix of scenarios includes three different time steps (i.e. 2040, 2060, and 2080) and three different SLR scenario (i.e. 1.0, 1.5, and 2.0 m of GMSLR by 2100). Thus, nine distinct scenarios were produced for each bayhead delta system. The SLAMM output was then reviewed, used to construct bayhead delta projected change maps, and analyzed to draw up conclusions about each system in particular, and the systems with respect to one another.

B.10 Recent Shoreline Digitization and Future Projected Shorelines via DSAS

Recent historic shorelines for each bayhead delta system were digitized by tracing the delta front water/vegetation boundary on 1996 1-m resolution TOP (Texas Orthoimagery Program) and 2018 60-cm USDA NAIP (National Agriculture Imagery Program) imagery. The goal behind this task was to provide an update to BEG shorelines, but to also use the Digital Shoreline Analysis System (DSAS) as a cross-check on SLAMM output results given the simple, horizontal erosion rate model that SLAMM uses. DSAS is a freely available software package used to compute rate of change statistics for a time series of vector shorelines (Himmelstoss *et al.* 2018; https://www.usgs.gov/centers/whcmsc/science/digital-shoreline-analysis-system-dsas). The software works as an add-in within the Esri Geographic Information System (ArcGIS) software.

DSAS was used to project future shoreline positions in 2040, 2060, and 2080, i.e. coincident with the SLAMM time step scenarios that were modeled. A baseline was generated parallel to the 1996 and 2018 shorelines and transects were generated every 5 m perpendicular to the shorelines to give a high level of detail. While running DSAS, the smoothing distance, baseline orientation, baseline placement, and intersection parameters varied due to differences in shoreline orientation, and therefore, various baselines were generated for each delta. DSAS calculates various statistics, but with only two shorelines, the End Point Rate (EPR) method was used to determine the amount of change that occurred between 1996 and 2018. The EPR was then used to determine the amount of change that occurred on an annual basis (i.e. EPR / 22 years). After running DSAS, a formula that incorporated the X and Y coordinates in 1996 and 2018 and the EPR was used to determine the 2040, 2060, and 2080 shoreline position along each transect. After generating the 2040, 2060, and 2080 shoreline positions, the shorelines were manually edited to 1.) remove abnormally large erosion or accretion rates, 2.) modify or remove unnatural rates because of inland water bodies, 3.) modify shorelines where overlapping future projections occurred due to curves in baselines, and 4.) modify shorelines where accretions rates closed a river channel. Lastly, future shorelines were converted to polygons and smoothed with the PAEK (Polynomial Approximation with Exponential Kernel) algorithm with a Smoothing Tolerance of 100.

B.11 Construction of Bayhead Delta Change Maps

SLAMM's erosion model is simplistic and incorporates only horizontal edge erosion as discussed in the "B.7 Erosional Rates Input" section above. This appears to cause it to substantially underestimate erosion when compared with future shorelines projected by DSAS. This can be seen in the left panel of Figure 7 below, which features the original SLAMM output for the Nueces bayhead delta front at 2040 under the 1.0 m of GMSLR by 2100 scenario. The magenta line that is superimposed on top is the DSAS-projected shoreline for the same 2040 time step. It is clear that the DSAS shoreline falls considerably landward of the SLAMM-modeled delta front.

To address this issue, this study chose to use the DSAS-projected shorelines to clip the SLAMM output. For each time step, any SLAMM land classes seaward of the DSAS-projected shorelines for the same time step were manually adjusted to SLAMM landcover class "17", which represents Estuarine Open Water. This is illustrated in right panel of Figure 7 below, which shows the updated SLAMM raster clipped to the DSAS shoreline. This solution is a compromise and not necessarily ideal because it is not iterative. For example, the next SLAMM time step modeling run does not use this clipped version of the raster as the starting point. Final bayhead delta change maps are provided in Appendix A.

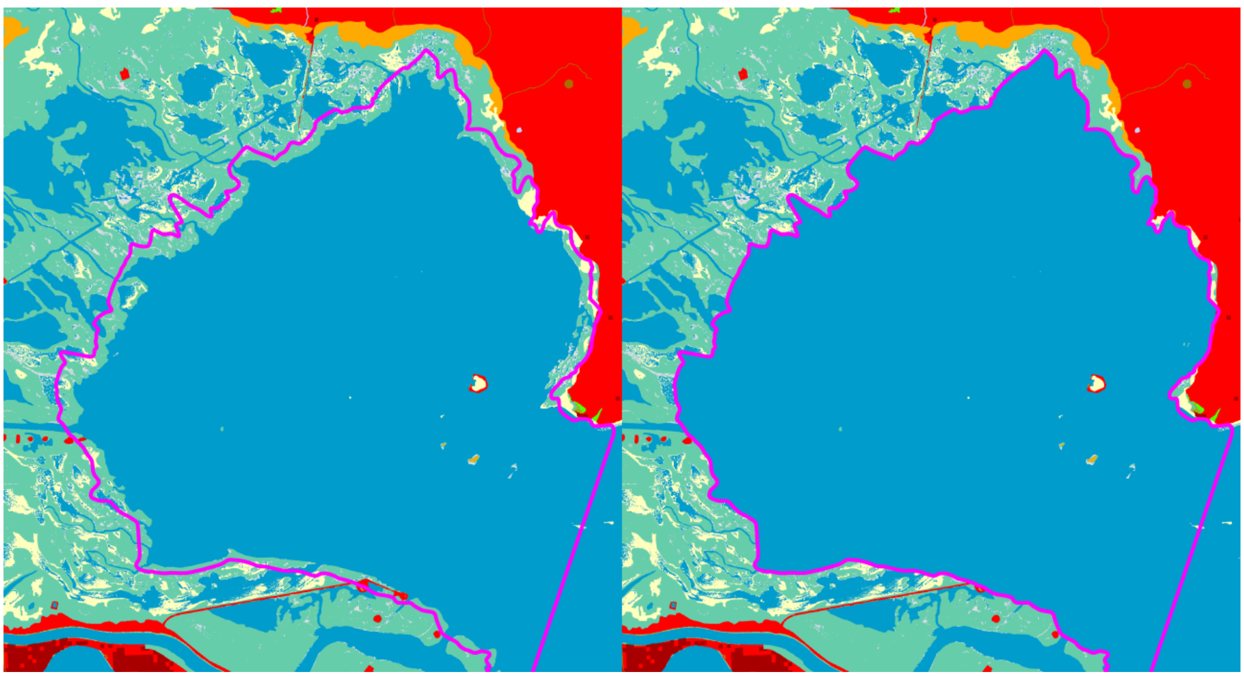

Figure 7—SLAMM output versus DSAS-projected shoreline and clipping solution
The left panel of this figure shows SLAMM output for the Nueces bayhead delta front at 2040 under the 1.0 m of GMSLR by 2100 scenario. The magenta line, which is noticeably landward of the SLAMM delta front position, is the DSAS-projected shoreline for the same time step, i.e. 2040. The right panel shows the solution this study employed. The DSAS-projected shoreline was used to crop the SLAMM output, and any pixels seaward of the DSAS shoreline were manually assigned to the SLAMM Estuarine Open Water class.

B.15 Bayhead Delta Map Analysis

Landcover statistics were calculated for all nine scenarios for each bayhead delta system to provide quantitative statistics for analysis. However, some adjustments were needed before the statistics were run. In particular, to avoid edge effects with the SLAMM modeling, which might have occurred if the delta regions of interest were too tightly cropped, large rectangular regions containing considerable amounts of upland landcover class environments were used. For example, the rectangular region used for SLAMM modeling of the Nueces bayhead delta system is generously buffered with almost 80% of the pixels representing SLAMM upland classes "1" and "2" (i.e. the Developed Dry Land and Undeveloped Dry Land classes). Thus, if landcover class statistics were performed over these large rectangular domains, statistics for the important delta wetland classes of most interest would be less obvious and more muted.

To address this issue, the landcover class statistics were run only on the SLAMM output that corresponded to the deltas themselves (without the adjacent uplands). This required a boundary polygon to delineate each delta. Based on a survey of the systems, it was decided that the most straightforward and objective way to define each delta was based on elevation. SLAMM landcover class "20", i.e. Irregularly Flooded Marsh, has a maximum vertical elevation of around 1 m in these bayhead delta systems, and given that model scenarios included up to a 2.0 m of GMSLR, it was decided to use three meters above sea level as a common limit for defining the deltas. Thus, all pixels in the DEMs under that elevation were extracted. The largest feature in each extraction (i.e. the delta) was kept and then underwent manual cleaning to fill gaps and remove other non-delta elements. The rasters were then converted to polygons, which were smoothed by a 50-m filter to remove jagged edges. For the delta front boundaries, a 150-m buffer from the shoreline position was chosen to represent the seaward side of the delta. Finally, the land and sea polygons were merged to create a final delta boundary polygon for each system. Landcover statistics were then run on the SLAMM raster outputs, but limited to the area within the delta boundary polygons. Statistics were aggregated into tabular format in a Microsoft Excel spreadsheet, and are provided here in Appendix B.

B. 16 Web-based Visualization Tool

To facilitate access to the modeling results from this project, but in an accessible manner that is easy to understand for potential stakeholders like coastal resource planners and managers, decision makers, and the general public, a web-based visualization tool was developed using Esri's ArcGIS Online Experience Builder platform. This webapp can be found at:

https://experience.arcgis.com/experience/71b75b5065ab4c28becff9f8762c9639

The webapp includes a landing page with a brief discussion and background information about the project, and then links that lead to a visual 3x3 matrix scenario page for each delta system. When a particular time step versus SLR scenario is chosen, the user is brought to a map viewer tool page that displays the SLAMM modeling results for the scenario of interest with a swiper tool that allows the user to view the results against the current (2019) distribution of wetlands environments. The interface has basic functionality like zoom in/out with the mouse wheel, pan by dragging, change basemap, etc., that should be very familiar to most people who have used any type of web-based geospatial application. Widgets to perform searches, measure linear distances, plot elevational profiles, print the current map canvas, capture screen shots, and share the view are also provided.

The webapp also provides downloadable SLAMM modeling results in the basic PNG image format, links to YouTube videos that provide animations of the scenario results through time, and links to actual GIS data layers for those who desire results in that format.

C. Results

Bayhead delta change maps are provided in Appendix A, but to provide a quantitative review of SLAMM modeling results, the tabulated landcover statistics in Appendix B will be used. To keep this review comprehensible, SLAMM's 24 landcover classes will be condensed into five, larger thematic environmental classes (TEC) following the general strategy employed by the CMVA study (Texas GLO 2019). Table 8 shows the mapping of the 24 classes to their TEC counterparts. The tabulated landcover statistics in Appendix B were recalculated into the condensed TEC equivalents, and are provided for each bayhead delta system and the nine associated modeling scenarios in Appendix C.

Table 8—Mapping of SLAMM landcover classes to thematic environmental classes (TEC)

SLAMM Class	Class Description	New thematic class description
1	Developed Dry Land	Upland
2	Undeveloped Dry Land	
25	Flooded Developed Dry Land	
26	Flooded Forest	
3	Swamp	Freshwater, non-tidal
4	Cypress Swamp	
5	Inland-Fresh Marsh	
6	Tidal-Fresh Marsh	Saltwater and brackish tidal marshes
7	Transitional Salt Marsh	
8	Regularly-Flooded Marsh	
9	Mangrove	
20	Irregularly Flooded Marsh	
23	Tidal Swamp	
10	Estuarine Beach	Beaches and flats
11	Tidal Flat	
12	Ocean Beach	
13	Ocean Flat	
14	Rocky Intertidal	
22	Inland Shore	
15	Inland Open Water	Open water
16	Riverine Tidal	
17	Estuarine Open Water	
18	Tidal Creek	
19	Open Ocean	

C.1 Trinity River Bayhead Delta

Condensed TEC results (Appendix C) for the Trinity bayhead delta showing area percent change through time for the 1.0, 1.5, and 2.0 m of GMSLR by 2100 scenarios are presented as plots in

Figure 8, Figure 9, and Figure 10 below. In general, at the present day (2019) and for the nine future time step versus SLR scenarios that were modeled, the *Upland* and *Beaches and flats* TECs represent the smallest classes by percent area coverage (expected as delta polygon was defined by < 3 m elevation), the *Freshwater, non-tidal* TEC occupies an intermediate amount of percentage area coverage, and the *Saltwater and brackish tidal environments* and *Open water* TECs compose the majority of the bayhead delta system. There is one small exception to this observation for the 2080 time step under the high end SLR scenario model results. But overall, this observation about a consistent relationship between percent area coverage of TECs for the various future scenarios only holds true for the Trinity system, and not for the other three bayhead delta systems that were modeled.

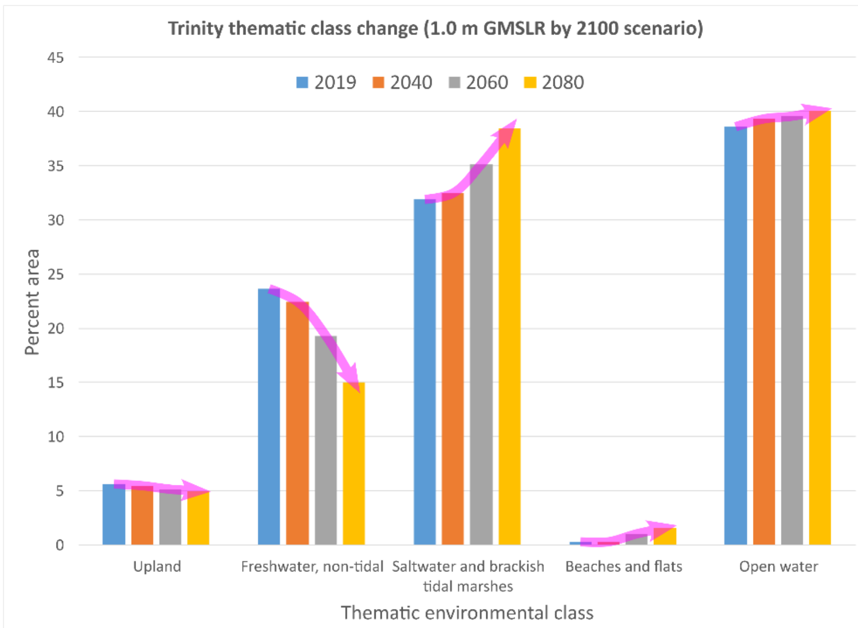

Figure 8—Trinity TEC area percent change plot (1.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

In the Trinity system, the modeled *Upland* TEC gradually decreases in areal extent through time under all of the three SLR scenarios. This reflects the gradual transition and replacement of < 3 m elevation upland habitats by wetland habitats due to SLR.

The *Beaches and flats* TEC accounts for a negligible amount of area (< 0.5%) at present and through 2040 in all of the modeled SLR scenarios. Under the 1 m of GMSLR by 2100 scenario (Figure 8), SLAMM results suggest this TEC will continuously expand slowly reaching about 1.5% by 2080. But under the 1.5 and 2.0 m of GMSLR by 2100 scenarios (Figure 9 and Figure 10), model results suggest that this TEC will accelerate and expand rapidly between 2060 and 2080 reaching > 7% and > 11% areal extent, respectively. This rapid increase comes at the expense of the *Saltwater and brackish tidal marshes* TEC, as discussed further below, and represents the drowning of marsh environments and their conversion to tidal flats.

The *Freshwater, non-tidal* TEC generally decreases from almost 24% area in 2019 down to about 15%, 11%, and 8% in 2080 under the 1.0, 1.5, and 2.0 m GMSLR rise by 2100 scenarios, respectively. The rate of decrease slightly accelerates through time as can be noted based on the shapes of the magenta guidelines in Figure 8 through Figure 10.

Modeled evolution of the *Saltwater and brackish tidal marshes* TEC is slightly more complex. With a starting point of almost 32% areal coverage at present, under the 1.0 m of GMSLR by 2100 scenario (Figure 8), this TEC increases areal extent slightly (< 1%) by 2040 and then accelerates and reaches about 38% areal coverage by 2080. But under the 1.5 and 2.0 m of GMSLR by 2100 scenarios (Figure 9 and Figure 10), 2060 represents the maximum extent of this TEC. Model results show this TEC contracting in areal extent by 2080 as the marshes cannot keep up with the pace of sea level rise, and are converted to mostly tidal flats with a smaller portion transitioning to open water.

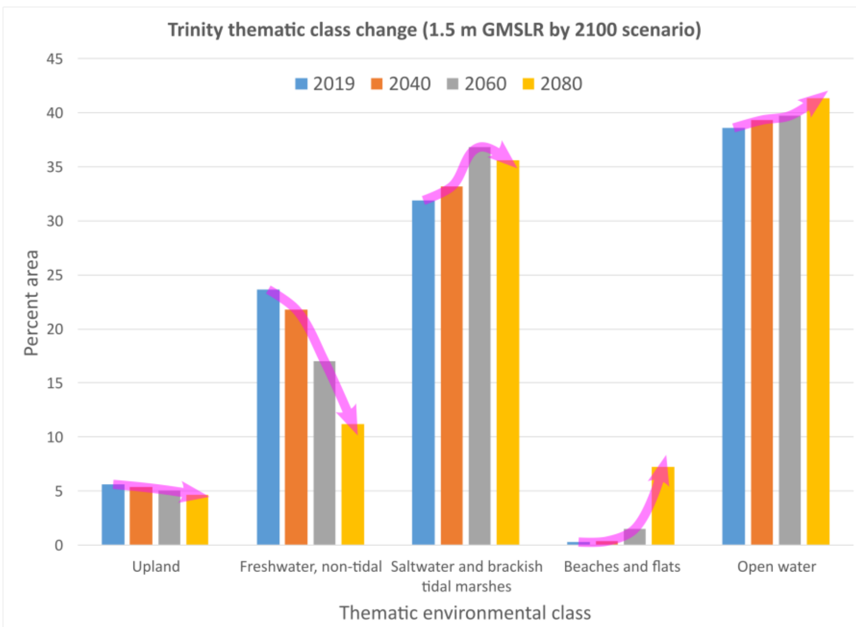

Figure 9—Trinity TEC area percent change plot (1.5 m GMSLR by 2100 scenario)

The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

Areal extent of the *Open water* TEC starts off at almost 39% at present for the Trinity system, which is much higher than the same TEC for the other bayhead deltas. This is related to the large lakes like Lake Anahuac, Dutton Lake, Lost Lake, Round Lake, Old River Lake, Lake Miller, Lake Charlotte, and myriad other smaller lakes that are located within the footprint of the delta, and are aggregated into this *Open water* TEC. Overall, this TEC shows a slow, gradual expansion over time for the three different GMSLR scenarios with about a 0.5% increase for each time step. The exception is a 2080 jump under the high-end GMSLR scenario (Figure 10), which is more abrupt at about 3.5% and is almost threshold-like. The noted increases for all scenarios are related directly to changes in the SLAMM "17" class for Open Estuarine Water as the other elements in this TEC like the large lakes mentioned above do not change in size, and thus, this change can be attributed to shoreline retreat. This can be confirmed by examining the complete SLAMM results with 24 individual classes in Table 11 (Appendix B) instead of this TEC, which consolidates multiples classes.

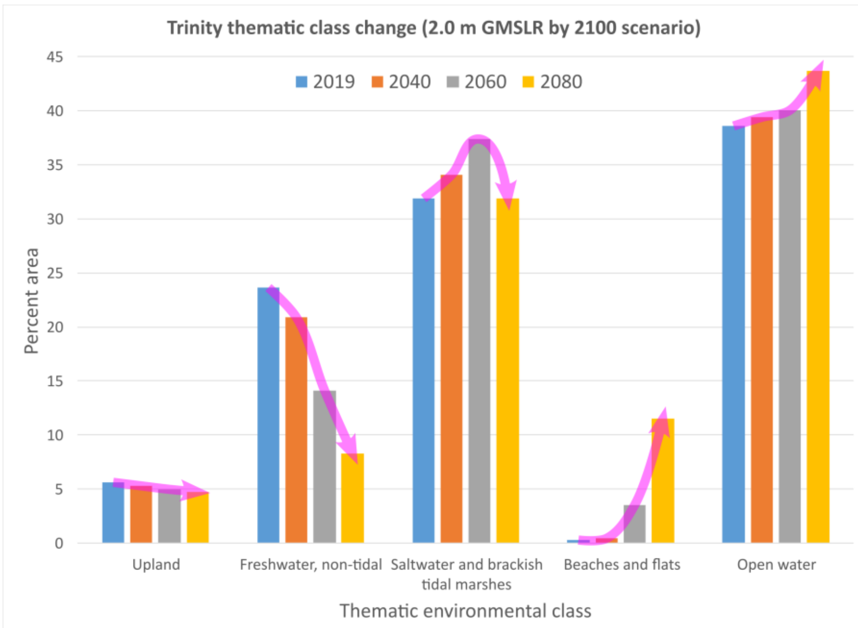

Figure 10—Trinity TEC area percent change plot (2.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

C.2 Lavaca-Navidad River Bayhead Delta

Condensed TEC results (Appendix C) for the Lavaca-Navidad bayhead delta showing area percent change through time for the 1.0, 1.5, and 2.0 m of GMSLR by 2100 scenarios are presented as plots in Figure 11, Figure 12, and Figure 13 below. In general, the *Upland*, *Freshwater, non-tidal*, and *Beaches and flats* TECs account for smaller areal percentages, and the *Saltwater and brackish tidal marshes* and *Open water* TECs account for larger areal percentages of this system for most of the time step versus SLR scenarios. But several of the TECs show threshold-like responses starting with the 2060 time step as discussed below, and the relative balance between TECs as described above no longer holds true.

The modeled *Upland* TEC gradually decreases in areal extent through time under all of the three SLR scenarios, but at progressively faster rates that correspond to the progressively higher GMSLR amounts by 2100. The decreases are very modest (~0.5-2.0% range) for all GMSLR scenarios at the 2040 and 2060 time steps, but then accelerate to 3-6% for the 2080 modeled time step. The same explanation as for the Trinity system serves here as well—this change reflects the gradual transition and replacement of < 3 m elevation upland habitats by wetland habitats due to SLR. The 3-6% jumps potentially represent terraces or antecedent topography from other features and landforms that allow for more rapid loss of this TEC with a progressively rising sea level.

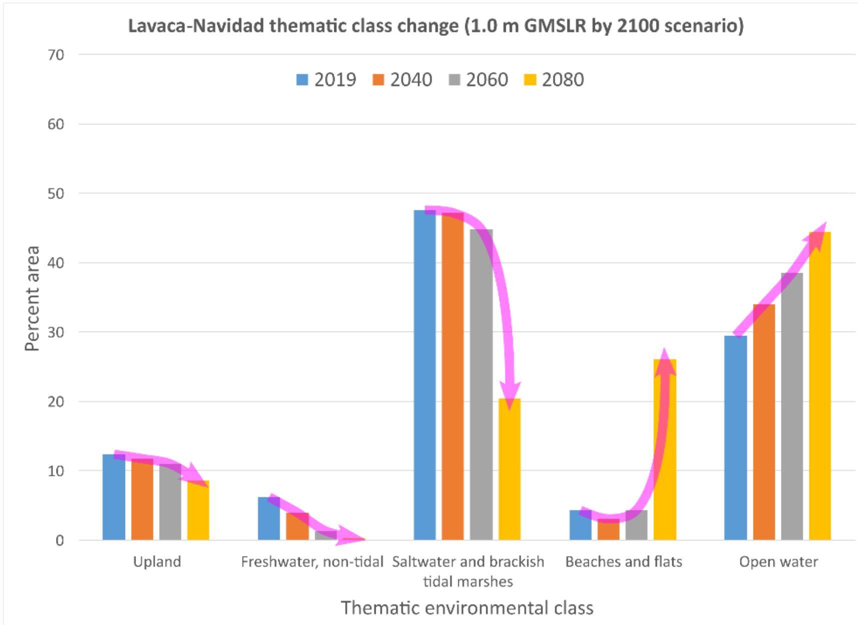

Figure 11—Lavaca-Navidad TEC area percent change plot (1.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

Model results for the *Freshwater, non-tidal* TEC are similar between the three GMSLR scenarios with the 2019 value of areal extent at about 6%, but decreasing a few percent by the 2040 time step, and virtually disappearing for the 2060 and 2080 time steps. The *Beaches and flats* and *Open water* TECs are rapidly expanding during these time steps so the reduction in the *Freshwater, non-tidal* TEC may simply indicate that change is occurring so quickly this TEC is not able to shift and migrate up valley as needed. One other consideration is that when the DEM for this area was originally extracted, the criteria used for defining the bayhead delta polygons (see "B.15 Bayhead Delta Map Analysis" section) had not yet been established. Thus, the DEM does not extend far enough up valley to cover all of the < 3 m elevations, which potentially limits the extent of this TEC.

The modeled *Beaches and flats* TEC results show clear, threshold-like responses under all three of the different GMSLR scenarios. Under the 1.0 m GMSLR by 2100 scenario (Figure 11), this TEC comprises a 3-4% area of the delta in 2019, 2040, and 2060, and then it jumps to 26% coverage (a 22% increase) for the 2080 time step. This correlates with a simultaneous 24% drop in the *Saltwater and brackish tidal marshes* TEC, as discussed further below. In the results from the 1.5 m GMSLR scenario (Figure 12), this TEC composes 3-4% of the delta landcover classes in 2019 and 2040, but then it jumps to about 16% and 20%, respectively, for the 2060 and 2080 time steps. And finally, in the 2.0 m of GMSLR by 2100 scenario (Figure 13), model results are further complicated—after the 3-4% cover in 2019 and 2040, the areal coverage rapidly jumps to about 24% in 2060, and then drops down to about 19% in 2080. These rapid jumps in areal extent with approximately simultaneous and equivalent drops in the *Saltwater and brackish tidal marshes* TEC are threshold-like, and indicate that the saltwater and brackish marshes are not able to keep up with SLR, and are being drowned and converted to tidal flats environments.

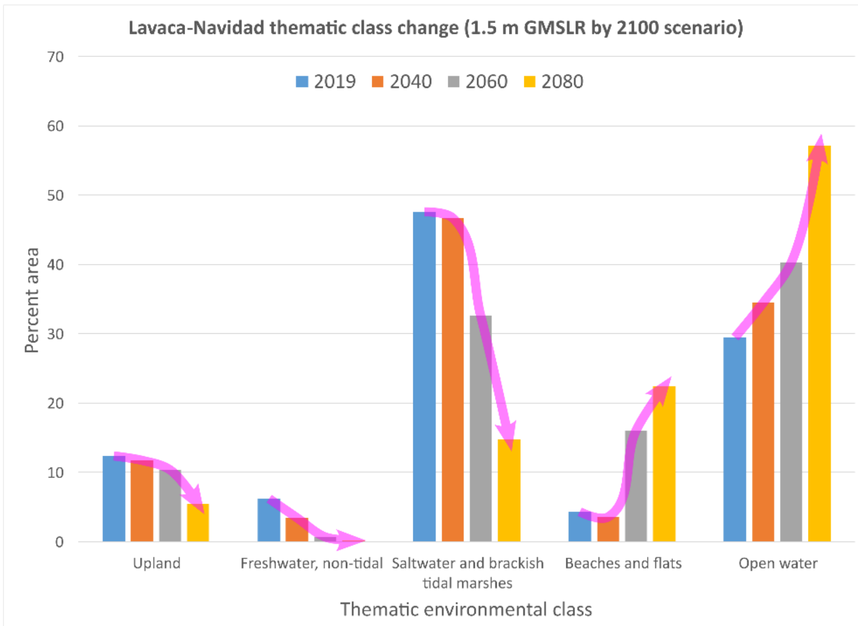

Figure 12—Lavaca-Navidad TEC area percent change plot (1.5 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

Model results for the *Saltwater and brackish tidal marshes* TEC also show clear, threshold-like responses. Under the 1.0 m of GMSLR by 2100 scenario (Figure 11), this TEC hovers in the range of 45-50% areal coverage of the delta through 2060, but it drops about 20% coverage (a 25% drop) for the 2080 time step. Under the 1.5 m of GMSLR by 2100 scenario (Figure 12), the 2019 and 2040 time step remain the same, but there is a drop in areal extent of about 14% down to about 33% in the 2060 modeled time step, and another 18% drop down to about just 15% coverage for the 2080 time step. Results for this TEC for the 2.0 m of GMSLR by 2100 scenario are similar (Figure 13). After hovering in the range of 45-50%, the 2060 time step reflects about 26% areal coverage (a 21% drop from the 2040 time step value), and then there is another 13% drop down to about 13% total areal coverage in the 2080 model result. These rapid and threshold-like responses are coincident with rapid growth in the *Beaches and flats* TEC environments, and also in the *Open water* TEC for the 2080 time step. These model results indicate that Lavaca-Navidad bayhead delta's lush, nearly 50% coverage by saltwater and brackish marshes may survive up to about 2040, but after that, it is projected to be rapidly lost as the marshes drown and transition to tidal flats and open estuarine water environments.

Finally, model results for the *Open water* TEC also show strong, threshold-like changes. For all three SLR scenarios, there is a gradual and nearly constant increase of about 5% areal coverage for each time step from 2019 to 2060, and this continues for the 2080 time step under the 1.0 m of GMSLR by 2100 scenario (Figure 11). But under the 1.5 m of GMSLR by 2100 scenario (Figure 12), the coverages increases by about 17% to 57% total areal coverage, and for the 2.0 m of GMSLR by 2100 (Figure 13), the final modeled 2080 time step jumps by 25% to 65% total areal coverage. Thus, the present footprint of the delta is projected to be composed of from about 45-65% open water by 2080. As mentioned above, the clear implication is that saltwater and brackish marshes simply cannot keep up with the accelerate rates of SLR, and are replaced by tidal flats and open estuarine water environments.

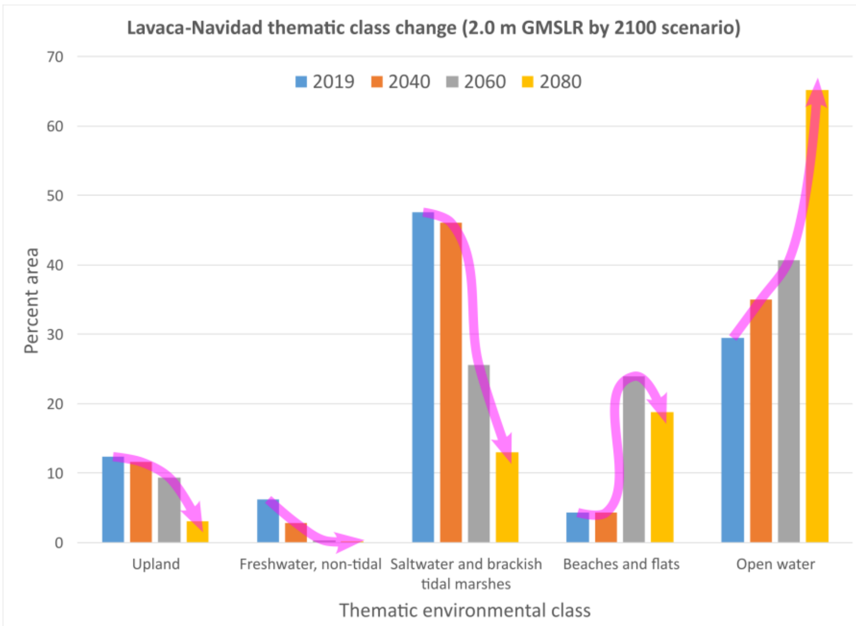

Figure 13—Lavaca-Navidad TEC area percent change plot (2.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

C.3 Guadalupe River Bayhead Delta

Condensed TEC results (Appendix C) for the Guadalupe bayhead delta showing area percent change through time for the 1.0, 1.5, and 2.0 m of GMSLR by 2100 scenarios are presented as plots in Figure 14, Figure 15, and Figure 16 below. In general, at the present day and for the nine future time step versus SLR scenarios that were modeled, the *Upland* and *Beaches and flats* TECs represent the smallest classes by percent area coverage, which is similar to the Lavaca-Navidad system. In the early time steps, the *Freshwater, non-tidal* and *Open water* TECs generally dominate areal coverage percentages with the *Saltwater and brackish tidal environments* TEC holding middle ground, but by the later time steps and the two higher SLR scenarios, the *Freshwater, non-tidal* and *Open water* and *Saltwater and brackish tidal environments* TECs swap positions as discussed below.

Model results for the Guadalupe system suggest that the *Upland* TEC areal extent gradually decreases through time under all of the three SLR scenarios, but at progressively faster rates that correspond to the progressively higher GMSLR amounts by 2100. The decreases are very modest (~0.2-1.0% range) for all GMSLR scenarios at the 2040 and 2060 time steps, but the decreases accelerate to 1-3% for the 2080 modeled time step. As with the results from the previous two bayhead delta system, this change reflects the gradual transition and replacement of < 3 m elevation upland habitats by wetland habitats due to SLR. The 1-3% jumps may potentially reflect a response to a simple acceleration in SLR, but may also represent terraces or antecedent topography that allow for more rapid loss of this TEC with a progressively rising sea level.

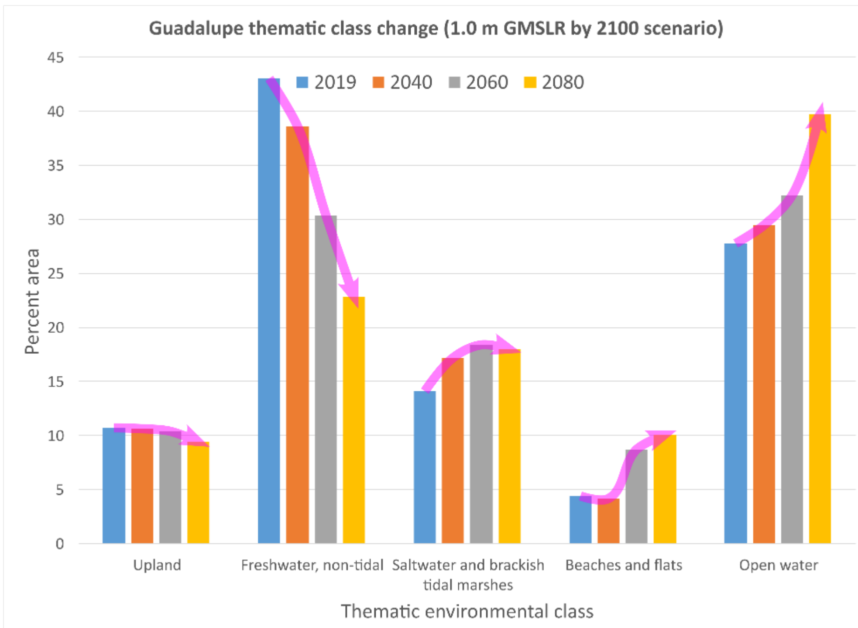

Figure 14—Guadalupe TEC area percent change plot (1.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

Modeled evolution of the *Beaches and flats* TEC under the 1.0 and 1.5 m of GMSLR by 2100 scenarios (Figure 14 and Figure 15) is very similar. Areal coverage under these scenarios is about 4-5% for the 2019 and 2040 time step, but jumps to about 8-10% of the delta areal extent for the 2060 and 2080 time steps. For model results from the 2.0 m of GMSLR by 2100 scenario (Figure 16), however, the progression is different and approximately linear. From the current state in 2019 with about 4% areal coverage, it jumps 2-3% for each subsequent time step until it reaches about 11% for the final 2080 time step. In general, these jumps in the areal extent of beaches and flats correspond with drops noted in the *Freshwater, non-tidal* TEC results.

The pattern of change in the *Saltwater and brackish tidal marshes* TEC is generally consistent between the 1.5 and 2.0 m of GMSLR by 2100 scenarios (Figure 15 and Figure 16), albeit at different rates of change, but the pattern of changes modeled for the 1.0 m of GMSLR by 2100 scenario (Figure 14) is different. In the 1.0 m of GMSLR by 2100 scenario (Figure 14), areal extent of this TEC is around 14% in 2019, but then it jumps up to 17-18% for the 2040, 2060, and 2080 time steps. The shape of the magenta guideline suggests this is a decelerating trend.

In turn, with the 1.5 and 2.0 m of GMSLR by 2100 scenarios (Figure 15 and Figure 16), areal extent appears to rise at an approximately constant rate from the 14% starting point in 2019. It increases by about 3% for each time step in the 1.5 m of GMSLR by 2100 scenario to end at about 24% total. The rate increase for the 2.0 m of GMSLR by 2100 scenario is also approximately constant and linear, but increases at a rate of about 5% per time step ending up at 29% total with the 2080 time step. Increases in this TEC appear to be coincident with decreases in the *Freshwater, non-tidal* TEC.

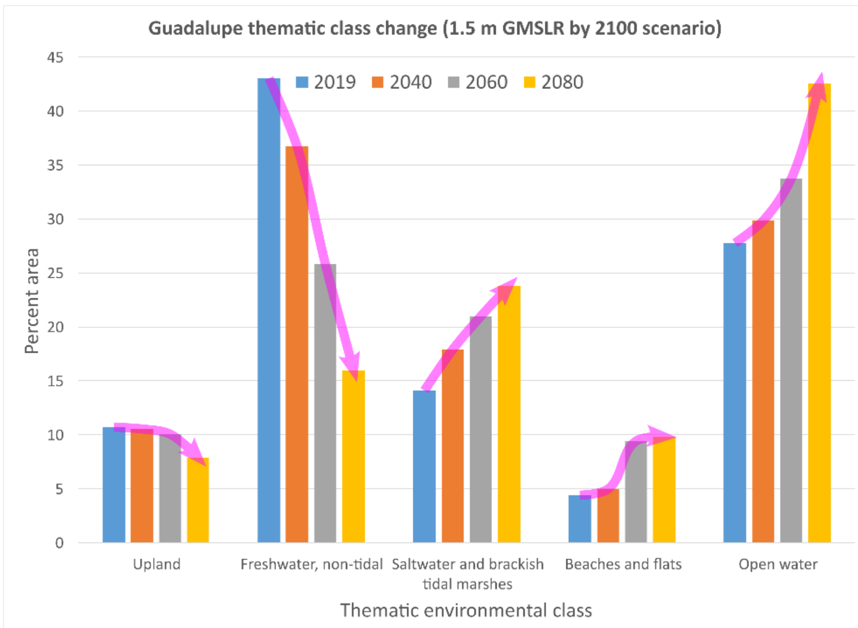

Figure 15—Guadalupe TEC area percent change plot (1.5 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

Modeled results for the *Freshwater, non-tidal* TEC show straightforward progressions under each of the three SLR scenarios. In all cases, the areal extent of this TEC is projected to gradually decrease through time at constant to slightly accelerating rates, but rates are progressively faster for each progressively higher SLR scenario. Under the 1 m of GMSLR by 2100 scenario (Figure 14), the areal extent at 2019 is about 43%, but drops to about 23% by 2080 so about 7% per 20-year time step. For the 1.5 m of GMSLR by 2100 scenario (Figure 15), areal coverage drops from about 43% in 2019 down to about 16% for the 2080 so about 9% per time step. And finally, under the 2.0 m of GMSLR by 2100 scenario (Figure 16), the 2019 start point is identical, but the end point in 2080 is around 9% areal coverage, which reflects about an 11% loss in areal extent for each time step under this SLR scenario. This 7% to 9% to 11% progression reflects the progressively faster rates at progressively higher SLR scenarios relationship mentioned above.

The *Open water* TEC in the Guadalupe system also shows straightforward, progressive increases in areal extent through time for all SLR scenarios, but the rate of change is not constant and accelerates. For example, starting with the 1.0 m GMSLR by 2100 scenario (Figure 14), areal extent is calculated as about 28% in 2019, and it increases by about 1.5%, 3%, and 7.5% over the three modeled time steps to end up at around 40% total by 2080. Under the 1.5 m of GMSLR by 2100 scenario (Figure 15), the modeled increases progress from about 2% to about 4% to about 9% to end around 43% total areal coverage. And the acceleration increases yet again for the 2.0 m of GMSLR by 2100 scenario (Figure 16). The increases in the areal extent over time start at 2.5% by 2040 then jump by 5.5% by 2060 and then jump by 8.5% to finish at about 43% total areal coverage by 2080.

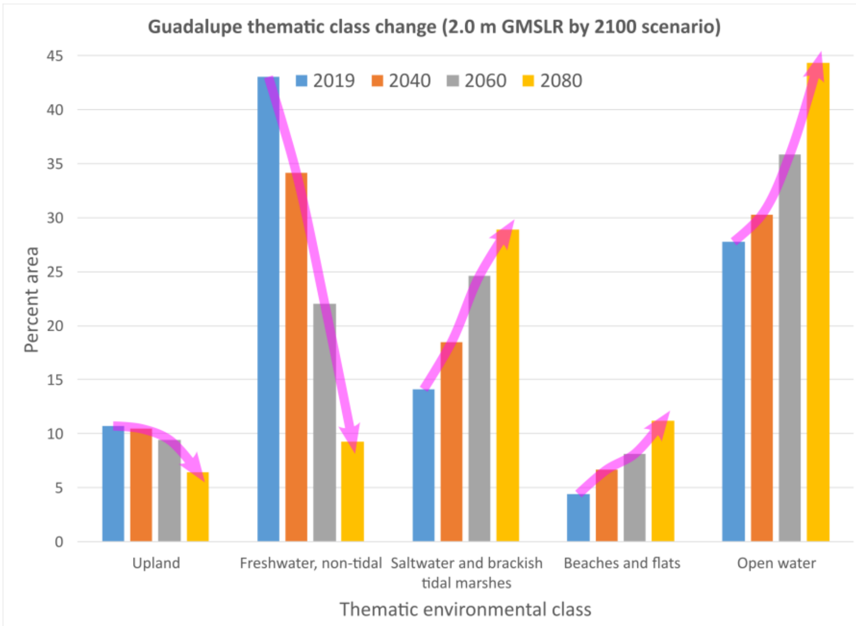

Figure 16—Guadalupe TEC area percent change plot (2.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

C.4 Nueces River Bayhead Delta

Condensed TEC results (Appendix C) for the Nueces bayhead delta showing area percent change through time for the 1.0, 1.5, and 2.0 m of GMSLR by 2100 scenarios are presented as plots in Figure 17, Figure 18, and Figure 19 below. In general, the first impression received when viewing any one of the Nueces system plots is that there is a more equitable distribution in areal extent between the five TECs than for the other three delta systems. For example, with the 1.0 m of GMSLR by 2100 plot (Figure 17), all TECs over all time steps generally range between 10-35%. A further review of each TEC follows below.

Model results for the *Upland* TEC in the Nueces system show the same overall pattern as recognized for the *Upland* TEC in the Lavaca-Navidad and Guadalupe systems, but the overall values are different. In particular, the areal extent of the *Upland* TEC gradually decreases through time under all of the three SLR scenarios, but at progressively faster rates that correspond to the progressively higher GMSLR amounts by 2100. For the 1.0 m of GMSLR by 2100 scenario (Figure 17), there is a continuous but very modest decrease (only 0.7%) in areal extent of this TEC from 2019 to the 2080 time step. For the 1.5 m of GMSLR by 2100 scenario

(Figure 18), there is a very modest decrease in total areal extent of only ~0.5% through 2080, but a slightly increased drop by 1.5% for the 2080 time stamp to end up at about 16% overall areal coverage. The result for the 2.0 m of GMSLR by 2100 scenario (Figure 19) is almost identical, but the final decrease for the 2080 time step is about 5% leaving this TEC at about 12% area coverage for the delta. As with the results from the other bayhead delta systems, this change reflects the gradual transition and replacement of < 3 m elevation upland habitats by wetland habitats due to SLR. The 5% jump is larger than seen in the other systems, and it may potentially reflect just a response to a simple acceleration in SLR, but may also represent terraces or antecedent topography that allow for more rapid loss of this TEC with a progressively rising sea level.

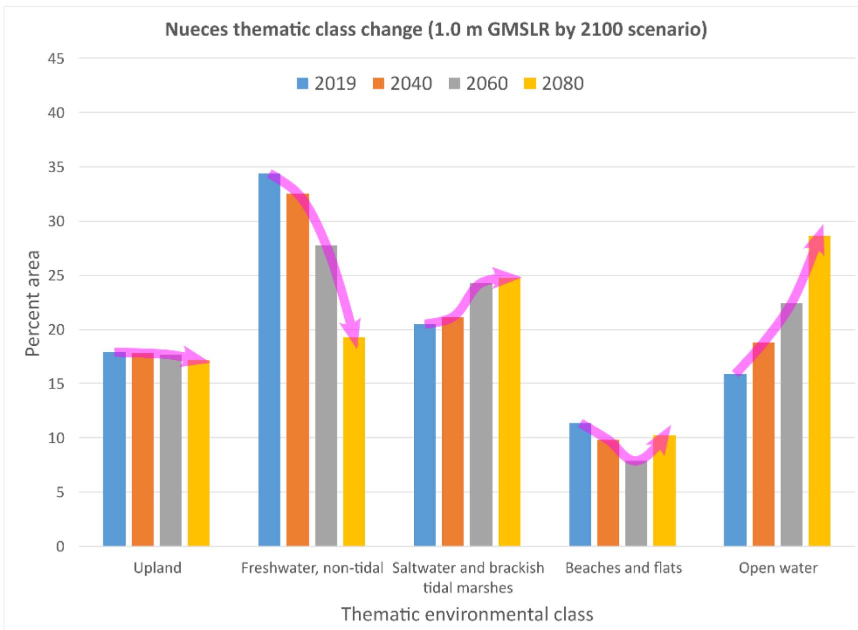

Figure 17—Nueces TEC area percent change plot (1.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

Results for the *Beaches and flats* TEC do not show a show a high range of variability for any of the SLR scenarios in the Nueces system, but the small amount of variation is not consistent from scenario to scenario. For example, under the 1.0 m of GMSLR by 2100 scenario (Figure 17), starting at about 11% areal coverage in 2019, it progressively decreases to about 8% by 2060, but then rises to about 10% areal coverage by 2080. Under the 1.5 m of GMSLR by 2100 scenario (Figure 18), there is drop from about 11% areal coverage in 2019 to about 9.5% areal coverage in 2040, but then a gradual increase to about 10.5% total areal coverage by 2080. The model results for the 2.0 m of GMSLR by 2100 scenario (Figure 19) are even more variable starting at 11%, dropping to 9.5%, rising to 13%, and then dropping again to about 8%.

With respect to the *Saltwater and brackish tidal marshes* TEC in the Nueces system, model results from the 1.0 and 1.5 m of GMSLR by 2100 scenarios (Figure 17 and Figure 18) are very similar. Areal extents for 2019 and the 2040 time step hover around 20-21%, and then increase to about 24-25% for the 2060 and 2080 time steps. The 2.0 m of GMSLR by 2100 scenario (Figure 19), however, shows a threshold-like change. After modest variation in the 20-22% range for 2019 and the 2040 and 2060 time steps, there is an abrupt increase to 31% in the modeled total areal extent for the 2080 time step.

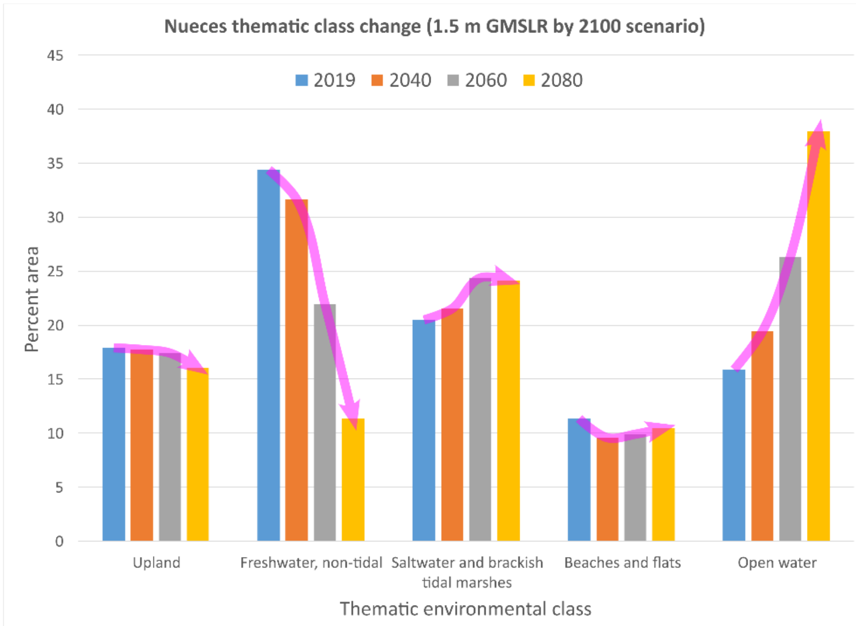

Figure 18—Nueces TEC area percent change plot (1.5 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

The modeled *Freshwater, non-tidal* TEC results for the Nueces system show a consistent decrease in areal extent at accelerating rates for the three SLR rise scenarios. With the 1.0 m of GMSLR by 2100 scenario (Figure 17), areal extent in 2019 was calculated as about 34.5%, but over the three modeled time steps, it decreased by about 2% then 4.5% then 8.5% to end up at about 19% total areal coverage projected for 2080. Under the 1.5 m of GMSLR by 2100 scenario (Figure 18), the 2040 step shows a 3% drop from the 2019 starting value, then a 9.5% and 10.5% drop over the 2060 and 2080 time steps to reach a final areal extent value of about 11.5%. And under the 2.0 m of GMSLR by 2100 scenario (Figure 19), there are drops of 4% then 12.5% then 12% for a final total areal extent of just 6% of the delta surface.

Finally, the Nueces *Open water* TEC also shows a consistent response through time and under the various SLR scenarios, but the trend increases and accelerates through time. Under the 1.0 m of GMSLR by 2100 scenario (Figure 17), the *Open water* TEC starts off at about 16% areal extent in 2019, but it increases by about 3% then 3.5% then 6% in the 2040, 2060, and 2080 scenarios to end up at about 28.5%. Under the 1.5 m of GMSLR by 2100 (Figure 18), the numbers increase to about 3.5%, 7%, and 11.5% for the 2040, 2060, and 2080 time steps ending up at about 38% total areal coverage. And the 2.0 m of GMSLR by 2100 scenario (Figure 19) shows the greatest acceleration starting off at about 16%, and then increasing by about 4% then 9.5% then 14% to end up at about 43% total areal coverage by 2080.

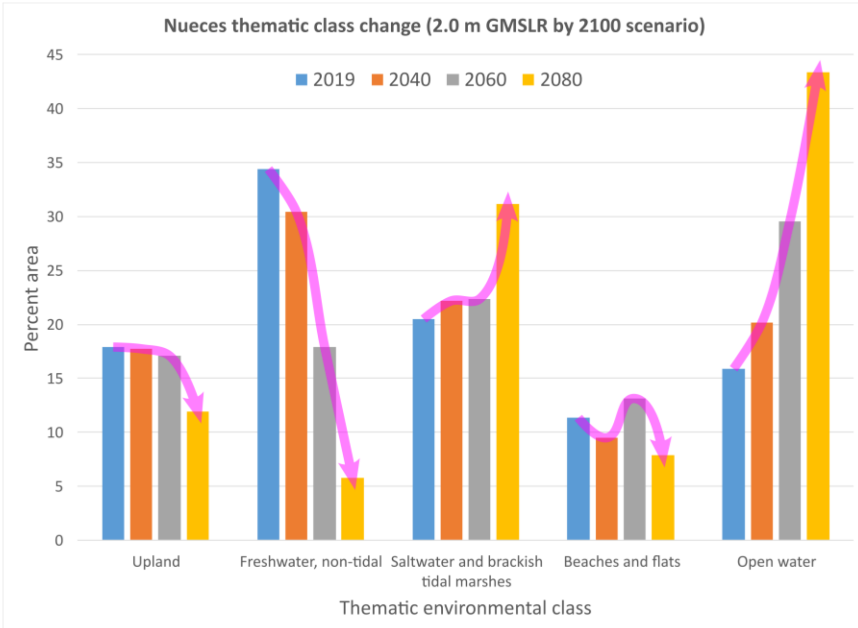

Figure 19—Nueces TEC area percent change plot (2.0 m GMSLR by 2100 scenario)
The semi-transparent magenta curve overlay shows the temporal trend from present to 2080 for each TEC.

C.5 Comparison of Trends Between Bayhead Delta Systems

TEC trends in percent areal coverage between the bayhead delta systems in order of increasing GMSLR amount by 2100 are plotted in Figure 20, Figure 21, and Figure 22. These plots permit quick comparisons to understand the differences and similarities between systems, and importantly, how they are projected to evolve through time. The plots are provided at the same scale/range/physical size between SLR scenarios so the changes noted between scenarios are real and proportional, and not just apparent changes due to changes in the Y-axis scale or range.

Figure 20 shows summarized modeling results for the 1.0 m of GMSLR by 2100 scenario. When considering the *Upland* TEC plot, all systems show relative stability with a general slow decrease in percent area of this TEC through time. The Lavaca-Navidad system does show a greater decrease than the other systems. Another obvious difference is that the Nueces bayhead delta system has about three times more areal coverage with this *Upland* TEC than the Trinity system whereas the Guadalupe and Lavaca-Navidad systems hold middle ground positions. Inspection of the *Freshwater, not tidal* TEC plot shows that the Lavaca-Navidad system has markedly less of this environmental class than the other three delta systems. All delta systems show a reduction in the areal extent of this TEC through time with the Trinity, Guadalupe, and Nueces systems coalescing into a range of about 15-24% coverage by 2080. In turn, this TEC essentially disappears from the Lavaca-Navidad system at that point. The *Saltwater and brackish tidal marshes* TEC plot shows an interesting trend, too. The Nueces, Guadalupe, and Trinity systems start off with from 14-32% coverage by this environmental class whereas it composes almost 50% of the areal coverage in the Lavaca-Navidad system in 2019.

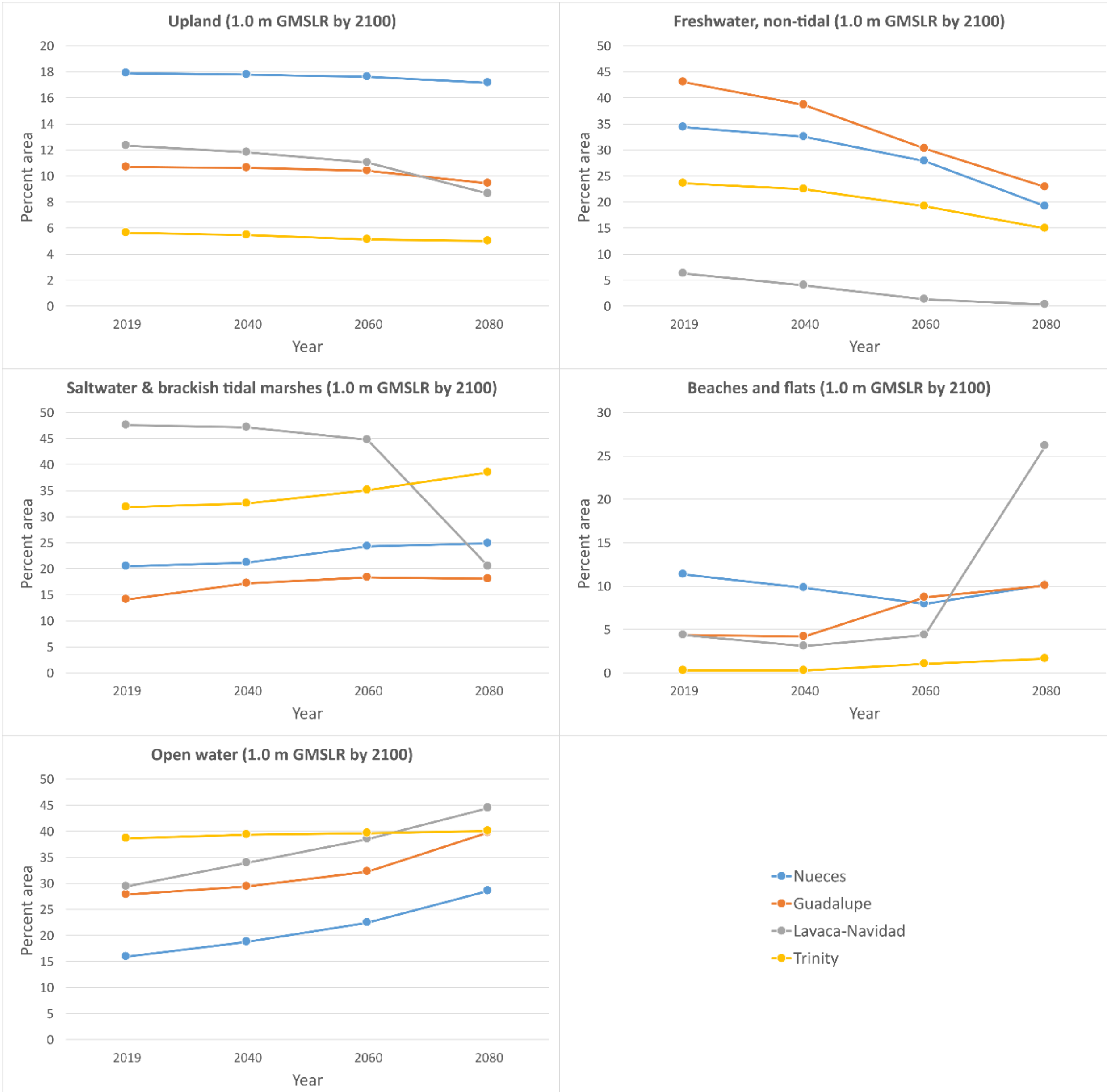

Figure 20—Comparison of TEC trends between deltas (1.0 m GMSLR by 2100)

While this TEC generally increases in areal extent through time for the first three deltas, the Lavaca-Navidad system shows a downward trend instead, and from 2060 to 2080, a solid 25% of the total delta area that is covered by this TEC is lost. The *Beaches and flats* TEC shows a mixture of trends, but the system that stands out again is Lavaca-Navidad as it shows an abrupt, 22% increase in this TEC between the 2060 and 2080 time steps. Finally, with respect to the *Open water* TEC, the Lavaca-Navidad, Guadalupe, and Nueces system all show visibly upward and accelerating trends for this TEC on the order of 12-15% total between 2019 and 2080. In turn, the trend for the Trinity delta is upward, too, but the trend is very subtle and on the order of just a 1% difference overall.

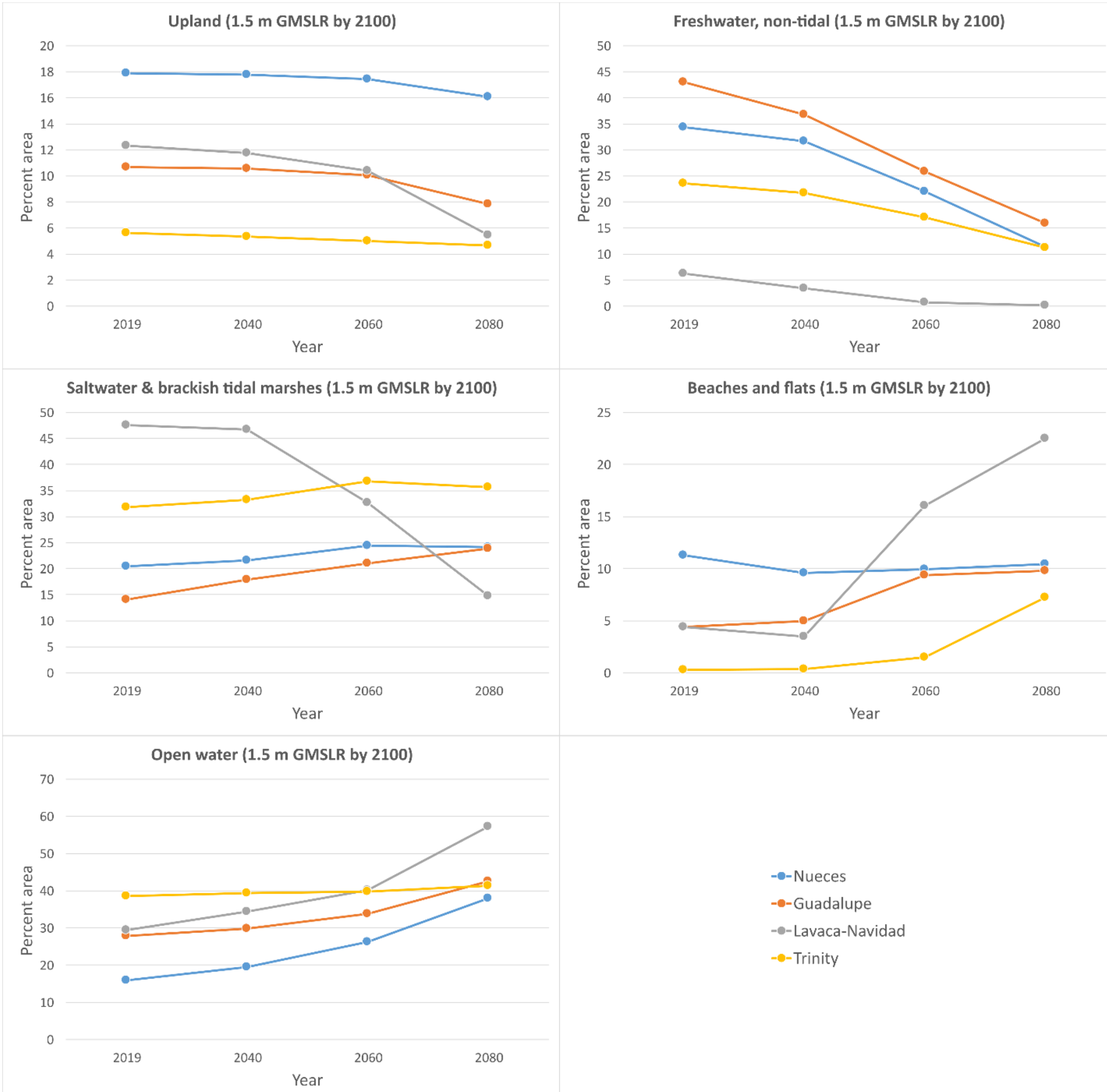

Figure 21—Comparison of TEC trends between deltas (1.5 m GMSLR by 2100)

Figure 21 shows summarized modeling results for the 1.5 m of GMSLR by 2100 scenario, and as might be expected, more variability is obvious in TEC trends due to the increased amount of SLR incorporated into the scenario. From the *Upland* TEC plot, the Trinity, Guadalupe, and Nueces delta curves show decreases that are approximately similar to the 1.0 m of GMSLR by 2100 scenario, but the Lavaca-Navidad trend shows a substantial decrease from the 2060 to 2080 time steps of about 5%. The *Freshwater, non-tidal* TEC also shows more marked decreases than the previous scenario with the Trinity, Guadalupe, and Nueces systems coalescing into a tighter 5% spread by 2080. As little *Freshwater, non-tidal* TEC was present in the Lavaca-Navidad system to begin with, it is negligible in extent by 2060 and essentially non-existent by the 2080 time stop. For the *Saltwater and brackish tidal* TEC, the Lavaca-Navidad system shows a very substantial and marked decrease (~32% of total delta area) starting with the 2060 time step whereas under the previous SLR scenario, the marked decrease did not occur until the 2080 model time step. Similarly, as this co-varies with the *Beaches and flats* TEC, the latter sees a marked rise starting with the 2060 time step. Finally, for the *Open water* TEC, the Trinity trend is still rather muted compared to the other three deltas, which show increases in the areal extent of this TEC through time, but at accelerating rates given the concave upwards shape of the curves.

Figure 22 show summarized modeling results for 2.0 m of GMSLR by 2100 scenario, and again, a visible increase in delta trendlines is noticeable as might be expected due to the increased amount of SLR incorporated into the scenario. In general, the slopes of all the curves are steepened whether they are increasing or decreasing. The *Upland* TEC plot shows that marked change is no longer only projected for the Lavaca-Navidad system and the Nueces system shows a substantial decrease in areal extent of the TEC start at the 2080 time step. Another observation can be made—for several of the TECs, results for several of the delta systems seem coalesce around a relatively tight range by the 2080 time step. The is obvious from the *Freshwater, non-tidal* TEC plot in which the Trinity, Guadalupe, and Nueces system coalesce into the 5-10% range by 2080. The same three deltas coalesce around the 30% areal extent range for the *Saltwater and brackish tidal marshes* TEC by 2080, and similarly, the same three deltas have the *Beaches and flats* TEC within a 4% range by 2080. Finally, the same thing is noted for the *Open water* TEC with these three deltas maintaining a small, 5% spread, centered around 40% total area, by the 2080 time step. In sum, under this scenario with the highest rate of GMSLR, the Trinity, Guadalupe, and Nueces systems show an apparent convergence in evolution based simply on the areal percent of the five TECs. The Lavaca-Navidad system is projected to follow its own unique evolution with a greater variability that becomes noticeable in earlier modeling time steps.

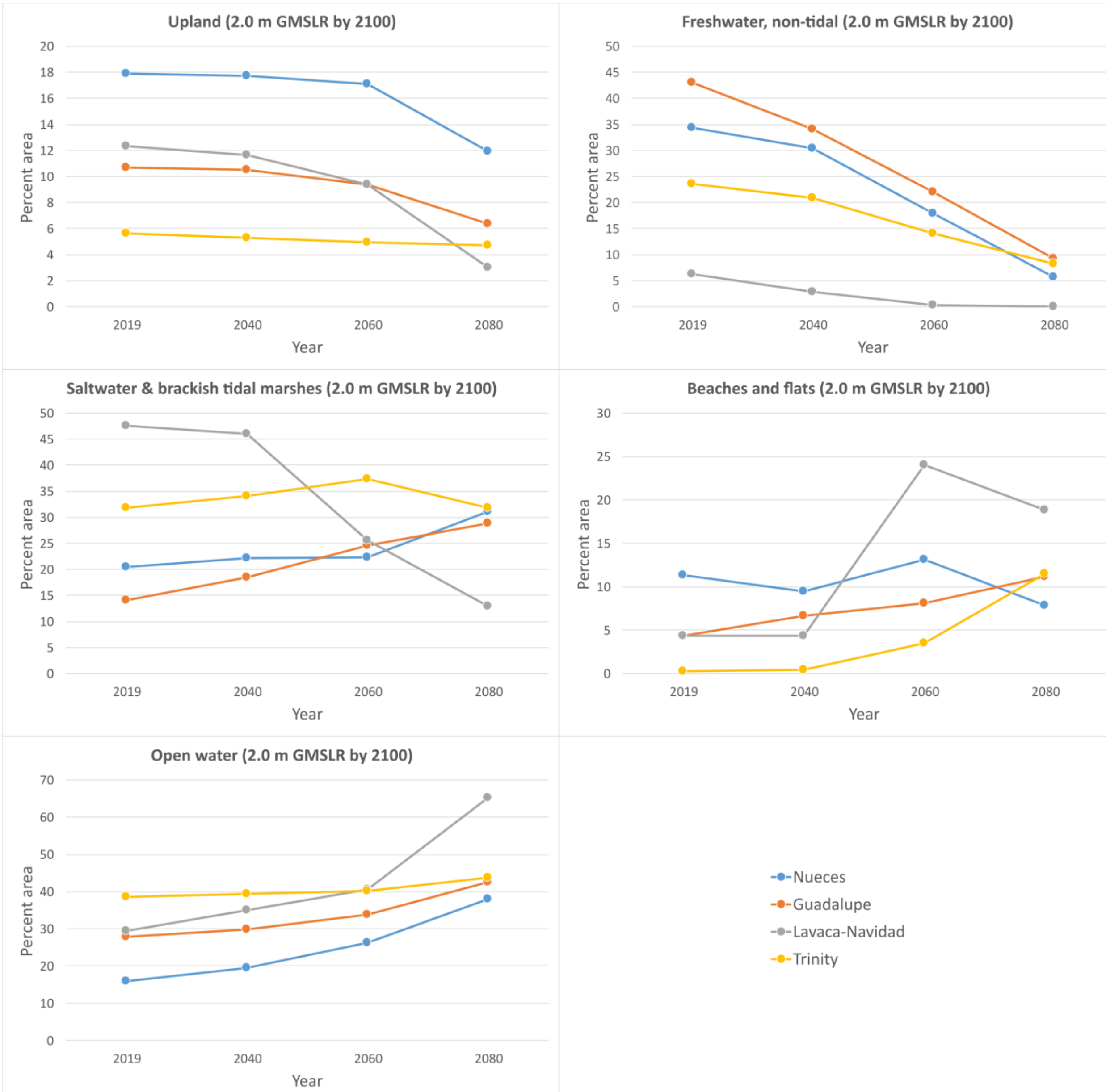

Figure 22—Comparison of TEC trends between deltas (2.0 m GMSLR by 2100)

D. Discussion

This study used SLAMM to investigate how the Trinity, Lavaca-Navidad, Guadalupe, and Nueces bayhead deltas might change over the next 60 years related to three plausible SLR scenarios. We make several observations here based on the results of this work.

D.1 Delta Systems Respond Differently to Similar SLR Forcings

Though perhaps obvious, one broad conclusion to draw from the results of this project is that our bayhead delta systems, though exposed to the same GMSLR scenarios, may respond in very different manners. This becomes exceptionally clear when considering the comparison of TEC trends between bayhead delta systems (see "C.5 Comparison of Trends Between Bayhead Delta Systems" section and Figure 20 through Figure 22). The Lavaca-Navidad system, for example, follows the trends of the other three deltas in some cases, but in many other cases, it forges a completely unique trajectory from the other deltas even though it is experiencing the same amount of GMSLR and same time steps. There are myriad reasons why this is the case—each delta starts off with its own unique set of characteristics beyond just GMSLR. These factors include local vertical land movement effects like subsidence or uplift, different sediment supplies, different impacts from human activity, different wetland species and habitats and different relative proportions of areal coverage by these systems, among many other differences.

On a related front, though SLR, climate change, and other natural processes happen on a slow, gradual basis, environmental responses to these changes do not necessarily happen on the same slow, gradual basis in parallel. For example, the semi-transparent magenta curves used in Figure 8 through Figure 19 help show the overall trend of changes in the areal extent of the TECs through time. If changes were happening at constant, linear rates, for example, a 5% increase per 20-year time step, the magenta curves would form straight lines tracking the changes. However, very few examples like this exist, and it seems to be more the exception than the norm. Instead, many curves indicate the rates of change themselves are changing, for example, accelerating. In a few cases, trends reverse even as forcing factors remain constant, but in other cases, threshold-like responses occur. For example, the *Saltwater and brackish tidal marshes* TEC in the Lavaca-Navidad system under the 1.0 m of GMSLR by 2100 scenario (Figure 11) shows a classic, threshold response. The TEC accounts for 47%, 47%, and 45% of the delta areal extent under the 2019, 2040, and 2060 time steps, respectively. Then, for the final 2080 time step, there is an abrupt 25% drop down to just 20% coverage.

These observations are not necessarily novel, but they very much help reinforce the potential benefits of modeling work for coastal management and planning. Historical observations and investigating past systems are critical for establishing rates of change and understanding potential environmental responses to forcing events. But especially with decision making, planning, and preparation for the future, models such as SLAMM can provide a potential glimpse about how certain coastal systems might be expected to change in the future under given scenarios. Importantly, they may provide guidance about potential threshold-like events that have simple not yet been considered or imagined, but that would be critically important for the long-term viability and effectiveness of management and planning decisions.

One particularly interesting aspect of model usage is that with the requisite skill, input data, and computing power, one can run a wide range of scenarios and gather an equally wide range of future outcomes that can inform decision-making and management possibilities. For example, the primary forcing used in this project was three different rates of SLR. But equally well, an ensemble of scenarios with changing subsidence rates or vertical sediment accretion rates or simulated mitigation/restoration efforts could have also been run. For example, the CMVA study (Texas GLO 2019) modeled mitigation/resiliency scenarios via hypothetical, Beneficial Use of Dredge Material (BUDM) restoration projects. They did this by stopping model runs, and artificially raising the input DEM elevations over specific project areas to simulate sediment additions by BUDM restoration efforts. This type of analysis could be very useful for evaluating the long-term viability and effectiveness of proposed mitigation and restoration efforts before any action is actually taken. In sum, model usage can better inform decision-making processes to make the most of finite and limited resources.

D.2 Susceptibility of Lavaca-Navidad Bayhead System

The potential model results for the Lavaca-Navidad bayhead delta are thought-provoking and somewhat alarming, in particular, the very pronounced loss of *Saltwater and brackish tidal marsh* TEC environments and their replacement by *Beaches and flats* TEC environments (mostly tidal flats). The Lavaca-Navidad delta has the highest percentage of salt and brackish marshes at present (about 47.5% total areal coverage of the delta surface) out of the four deltas that were the focus of this study. But all three modeled SLR scenarios suggest this may change very significantly in the future. Under the 1.0 m of GMSLR by 2100 scenario, the *Saltwater and brackish tidal marsh* TEC precipitously drops by 25% between 2060 and 2080 to reach about 20% coverage. But under the 1.5 m and 2.0 m of GMSLR by 2100 scenarios, it drops into the 13-15% range whereas it is increasing for all the other deltas through time as new land is flooded and converted into saltwater and brackish marsh. It is not clear why the Lavaca-Navidad system is projected/modeled to vary so distinctly from the other three bayhead delta systems. The very low, up-valley gradient is one potential factor, but other local factors such as the vertical sediment accretion rate and the rate of subsidence may play a role, too, and this difference would seem to warrant further investigation.

D.3 Potential Future Convergence of Delta Evolution Under High SLR Scenarios

A very interesting observation was made from Figure 22 and Table 15—that the Trinity, Guadalupe, and Nueces bayhead deltas at present are composed of very different proportions of TEC environments, but that under the 2.0 m of GMSLR by 2100 scenario (and also the 1.5 m scenario, too, but to a lesser extent), the TECs in these three systems seem to converge around common, percent area values that differ by just a few points. For example, there is a ~20% range in *Freshwater, non-tidal* TEC environments between these systems in 2019, but this is reduced to just a ~4% range by 2080. Similarly, *Saltwater and brackish tidal marsh* TEC environments have a range of about 18% in 2019 that shrinks to just ~3% difference in 2080, *Beaches and flats* TEC environments start with an ~11% range difference in 2019, which shrinks to just ~4% difference in 2080, and *Open water* TEC environments shrink from a ~21% range in 2019 to a < 1% range in 2080. This observation suggests that under higher rates of GMSLR, evolution of our coastal wetlands may converge to a common evolutionary model. Thus, it might also be expected that other wetlands along the Texas coast that were not specifically studied by this project might follow this same model. Alternatively, it could also indicate that SLAMM may not be able to accurately model these environments under high rates of SLR, and that its algorithm will eventually cause convergence irrespective of starting compositions. Whatever the case, this observation is intriguing, and potentially merits further investigation.

D.4 Limitations of Models and Potential Areas for Improvement

Models can provide important insights about potential future changes, but like any tool, they have limitations that must be recognized. As discussed in the "B.1 General Overview" section, SLAMM is not the most complex model, but it presents a nice compromise and is far superior to simple, bathtub models. Still, models can only provide generalizations of complex, real world processes at finite resolutions. Therefore, model results should be recognized as generalizations of potential future changes, and they should not be treated as perfect, grid cell level forecasts at specific future points in time.

SLAMM is a relatively mature model, but possibilities for improvement in the model itself or how it is used are myriad. For example, during stakeholder outreach sessions, several comments were fielded about how SLAMM might address future increases in hurricane and storm frequency that are expected to occur under globally warmer climates in the future. The direct incorporation of hurricane and storm frequency into SLAMM will probably not happen given that the model simulates dynamic processes such as inundation, edge erosion, subsidence, overwash, saturation, accretion, and salinity as discussed above. But erosion and overwash are common physical, dynamic processes associated with such storm events; thus, one could simulate an increase in storm impacts by feeding SLAMM a timeseries showing variations in these parameters.

Another limitation of SLAMM is its simple erosion model, which appears to substantially underestimate erosion based on comparison with DSAS-projected results of future shoreline positions. In this study, we opted for the solution of clipping SLAMM outputs with DSAS-projected shorelines as discussed in the "B.11 Construction of Bayhead Delta Change Maps" section above. But the ideal solution would be to improve the erosion model itself, or, for example, to use DSAS-determined erosion rates as the erosion rate inputs versus the Paine *et al.* (2014 and 2016) references that were consulted. But this would require adjustments to SLAMM itself to account for spatially-variable erosion rates.

Finally, while this brief discussion focuses on the SLAMM model itself, one area of potential improvement in all cases is that of input datasets. For example, there is a general lack of detailed spatial data with respect to subsidence with the exception being the in the Houston-Galveston Bay area due to the Harris-Galveston Subsidence District monitoring efforts. Similarly, better control of vertical accretion rates for specific systems and field/observational data on other processes could potentially improve input datasets that lead to more accurate modeling results. Finally, constraints on potential rates of future SLR are continuously improving, and this will allow for continuously improving model results as well.

D.5 Stakeholder Outreach Efforts

Several outreach efforts were undertaken during the course of this project to not only make its existence known to stakeholders, but also to facilitate their access to the results in an appropriate and easy-to-use manner.

The first effort consists of a web-based visualization tool that allows stakeholders to view the current (2019) distribution of wetlands environments in the four bayhead delta systems together with the nine modeled results for each system (i.e., the 3x3 matrix of time step versus SLR scenarios). Details about this tool were briefly discussed in the "B. 16 Web-based Visualization Tool" section above and are not repeated here. This tool will be available into perpetuity while maintenance efforts remain reasonable.

The other efforts consisted of two rounds of stakeholder outreach meetings—the first round in July 2021 and the second round in September 2021. These outreach meetings were held virtually using the Zoom videoconferencing platform due to public health considerations related to the COVID-19 situation. Each round consisted of four, one hour-long meetings dedicated to the individual bayhead delta systems examined in this study with the first and second rounds reaching 81 and 26 total stakeholder participants, respectively.

The meetings began with presentations by HRI staff about the origin and goals of the project, sea level as a primary control on bayhead delta systems, the methods and tools used to conduct the study, preliminary results for the bayhead delta system of interest, and then a brief demonstration of the web-based map viewer tool. Towards the end of each meeting, ample time was provided with a session for questions, comments, and discussion, and importantly, for soliciting suggestions about other data products that might be of interest to the stakeholders.

As a direct result of stakeholder feedback and requests, additional data products were generated and a "Downloads & Other Materials" webpage was added to the web-based visualization tool website. These additional data products include easy-to-access project modeling results in PNG image format versus specialized GIS image formats (Table 9). A second additional data product was a series of YouTube videos to animate the changing landcover types through time for each of the bayhead delta systems for the three SLR scenarios (Table 10).

Table 9—Project modeling results in PNG image format

Delta system	URL for PNG image package
Trinity	https://drive.google.com/file/d/1hFUl2y5ItPGi5Xknkbu_pL4Dmfe4WfcE
Lavaca-Navidad	https://drive.google.com/file/d/13hEEtYL--YZvfcjbTLYXy97j1kd5u9RE
Guadalupe	https://drive.google.com/file/d/1BN1nPcz91zn-Xky8hblFMBwwfLgku0aU
Nueces	https://drive.google.com/file/d/10OA7SxiX1SjZwD6xOaR6Ia1WTYFqilNG

Table 10—Project modeling results as YouTube videos

Delta system	URL for video
Trinity	https://youtu.be/etZbTse76rE
Lavaca-Navidad	https://youtu.be/2w_QlLLAfqo
Guadalupe	https://youtu.be/EJo79CtenKY
Nueces	https://youtu.be/8YrOXFuSI7w

Given that the stakeholder outreach meetings were held as virtual Zoom videoconferences, actual event photos are not available, but several screenshots of the meetings are provided by Figure 23 through Figure 31 below.

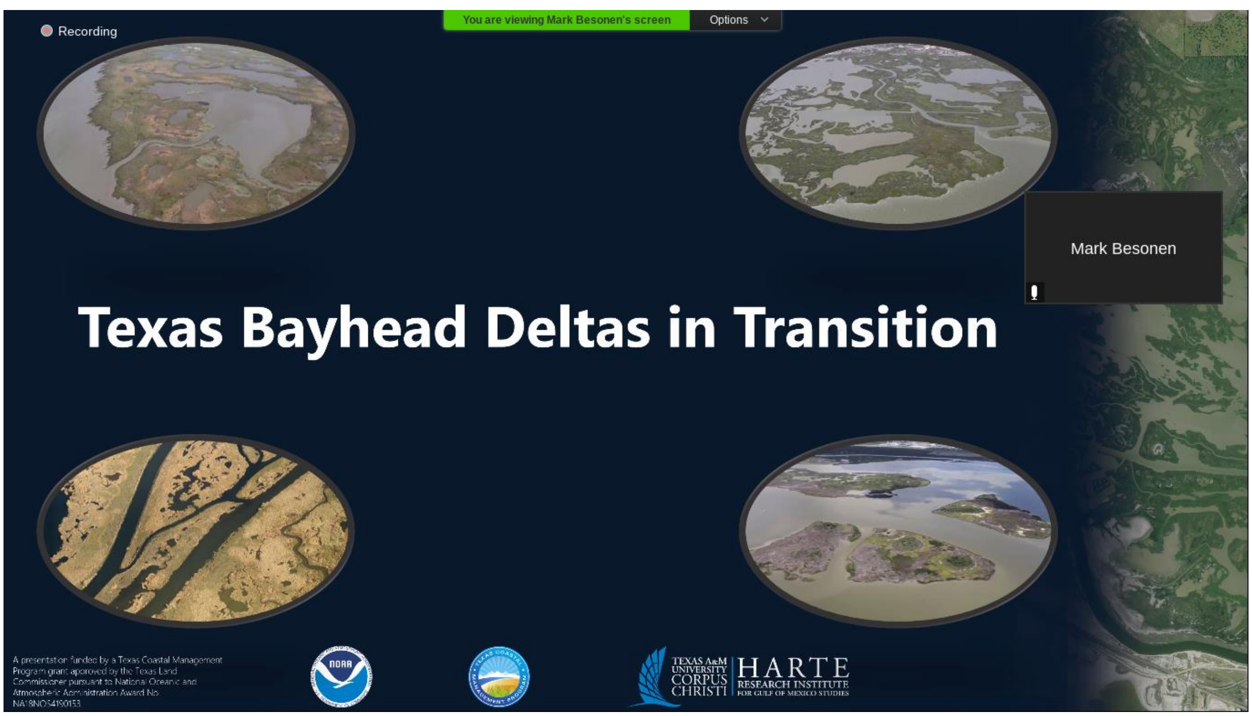

Figure 23—Opening slide from stakeholder outreach meetings

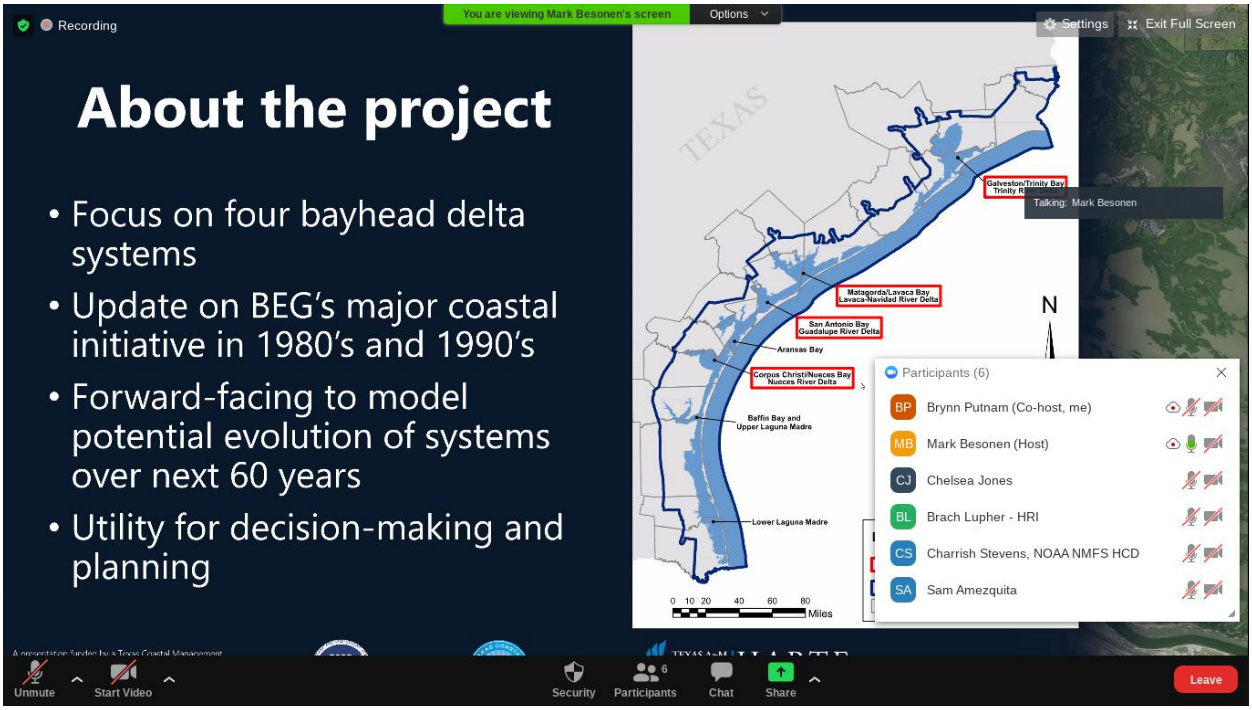

Figure 24—Project background slide from stakeholder outreach meetings

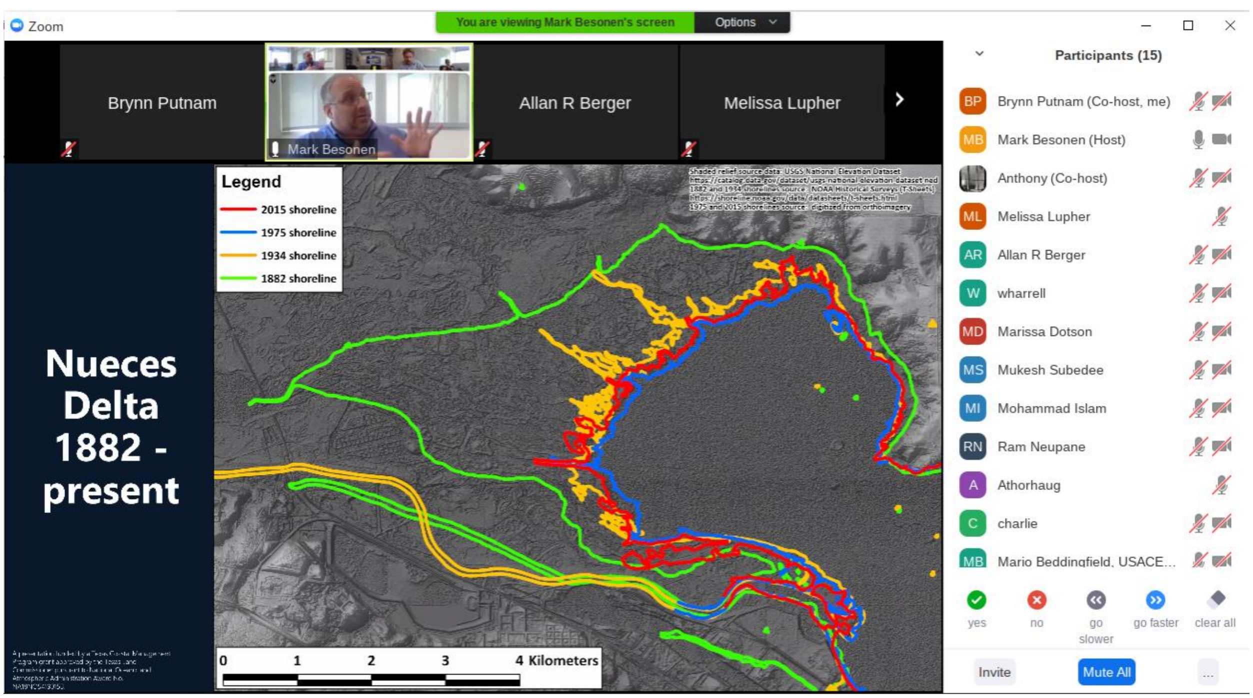

Figure 25—Nueces Delta recent mode shift slide from stakeholder outreach meetings

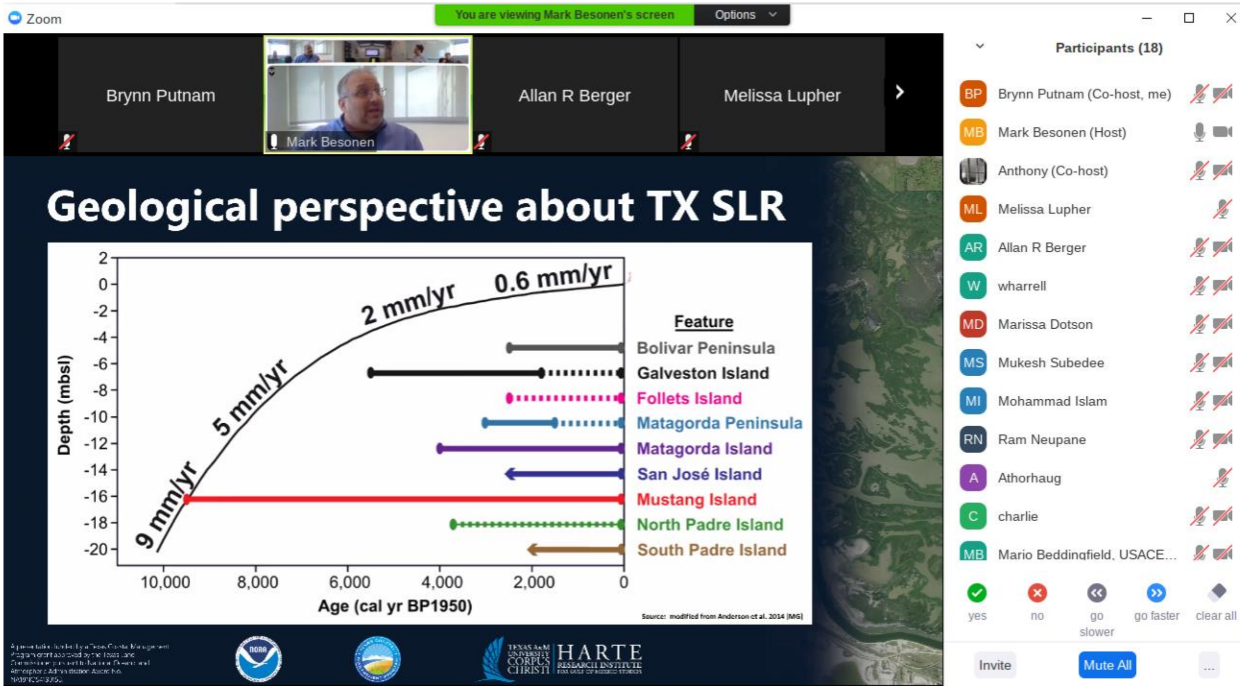

Figure 26—Texas sea level over last 10,000 years slide from stakeholder outreach meetings

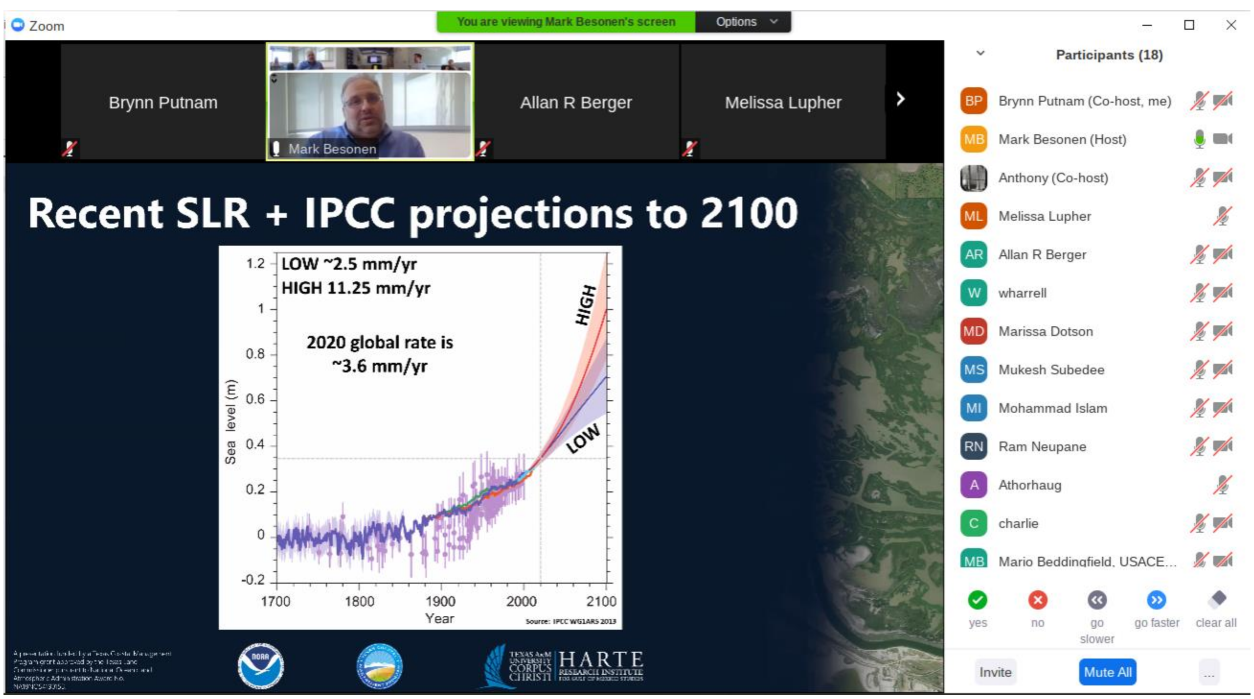

Figure 27—Projected sea level to 2100 slide from stakeholder outreach meetings

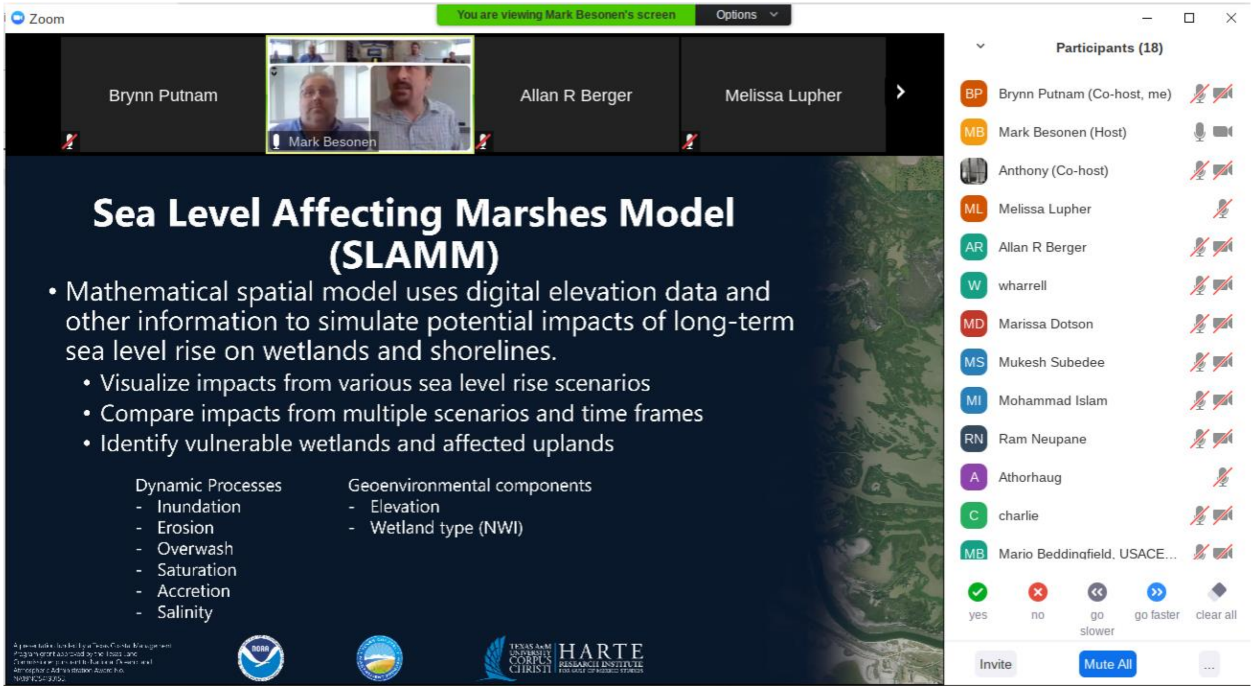

Figure 28—SLAMM introduction slide from stakeholder outreach meetings

Figure 29—DSAS and shoreline retreat slide from stakeholder outreach meetings

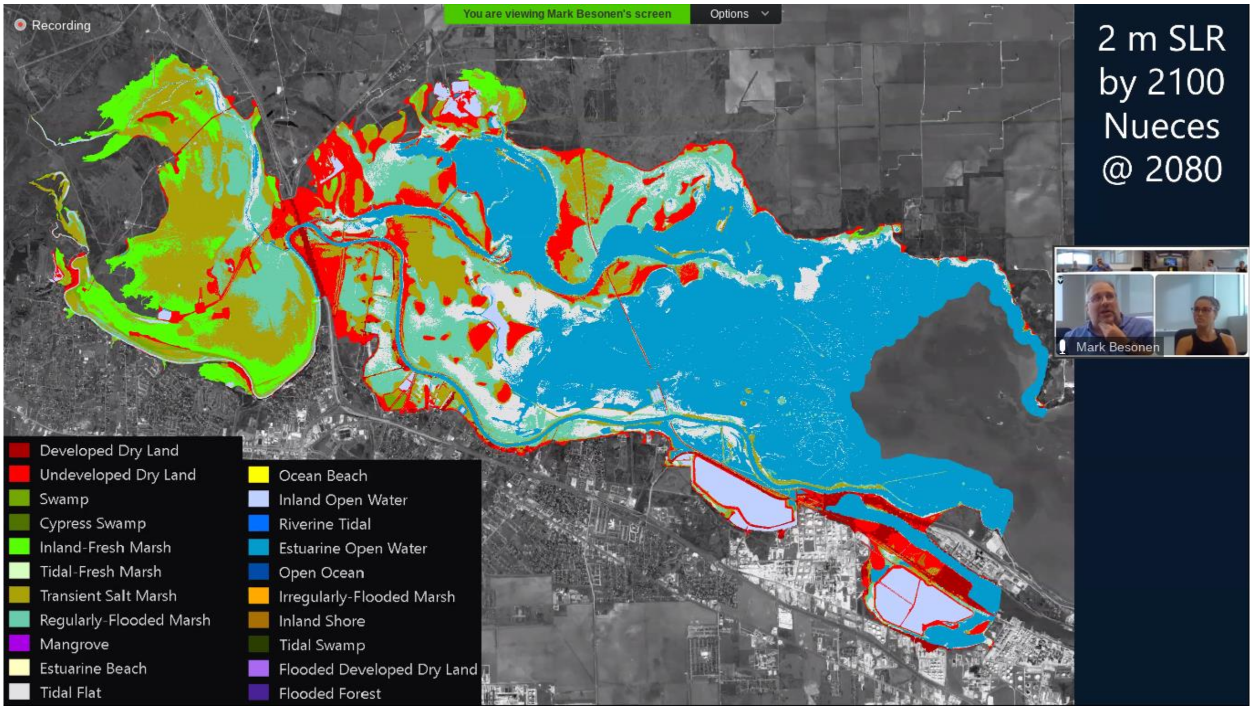

Figure 30—Nueces bayhead delta example results from stakeholder outreach meetings

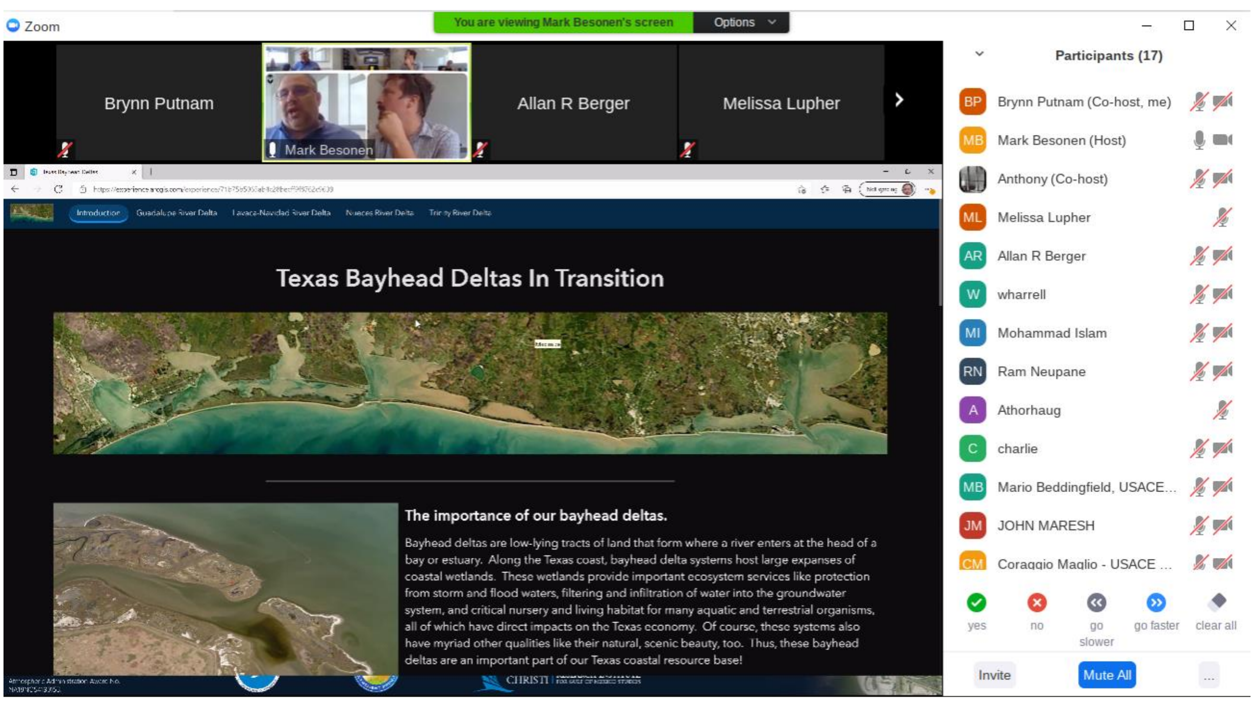

Figure 31—Web-based map viewer tool introduction from stakeholder outreach meetings

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Appendix A: SLAMM-modeled Bayhead Delta Change Maps

This appendix contains the SLAMM-modeled bayhead delta change maps for the Trinity, Lavaca-Navidad, Guadalupe, and Nueces bayhead delta systems. There are ten maps for each system—a 2019 map to show the present day distribution of wetlands environments, and then an additional nine maps that show the three time step versus three SLR scenarios.

Side-by-side comparisons of maps in this report may be difficult given formatting, but the reader is encouraged to visit this project's online webapp at:

https://experience.arcgis.com/experience/71b75b5065ab4c28becff9f8762c9639

Beyond the online map viewer tool available there, electronic versions of these same maps are also archived there, and they may allow for an enhanced viewing experience.

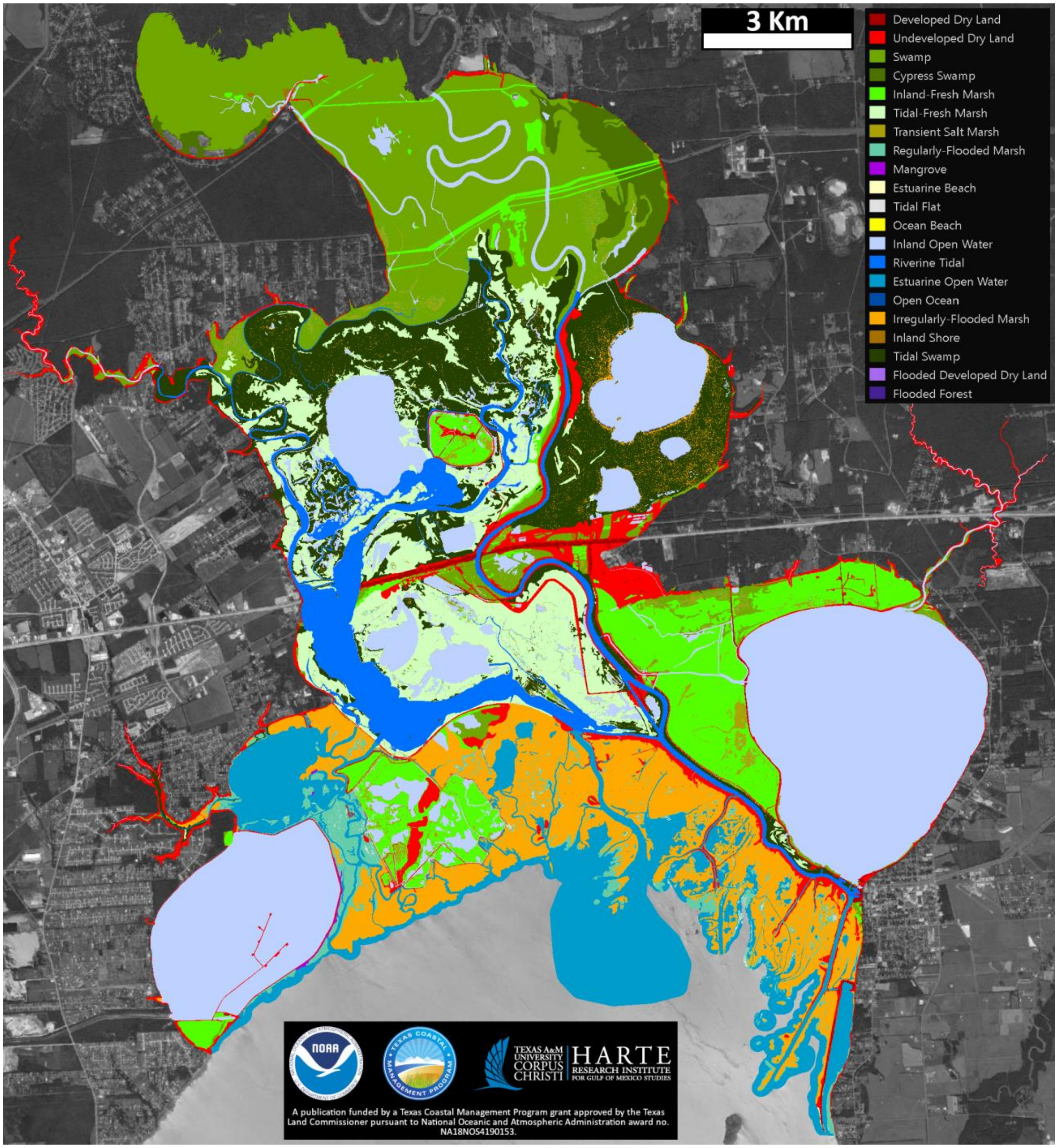


Figure 32—Trinity River bayhead delta @ 2019

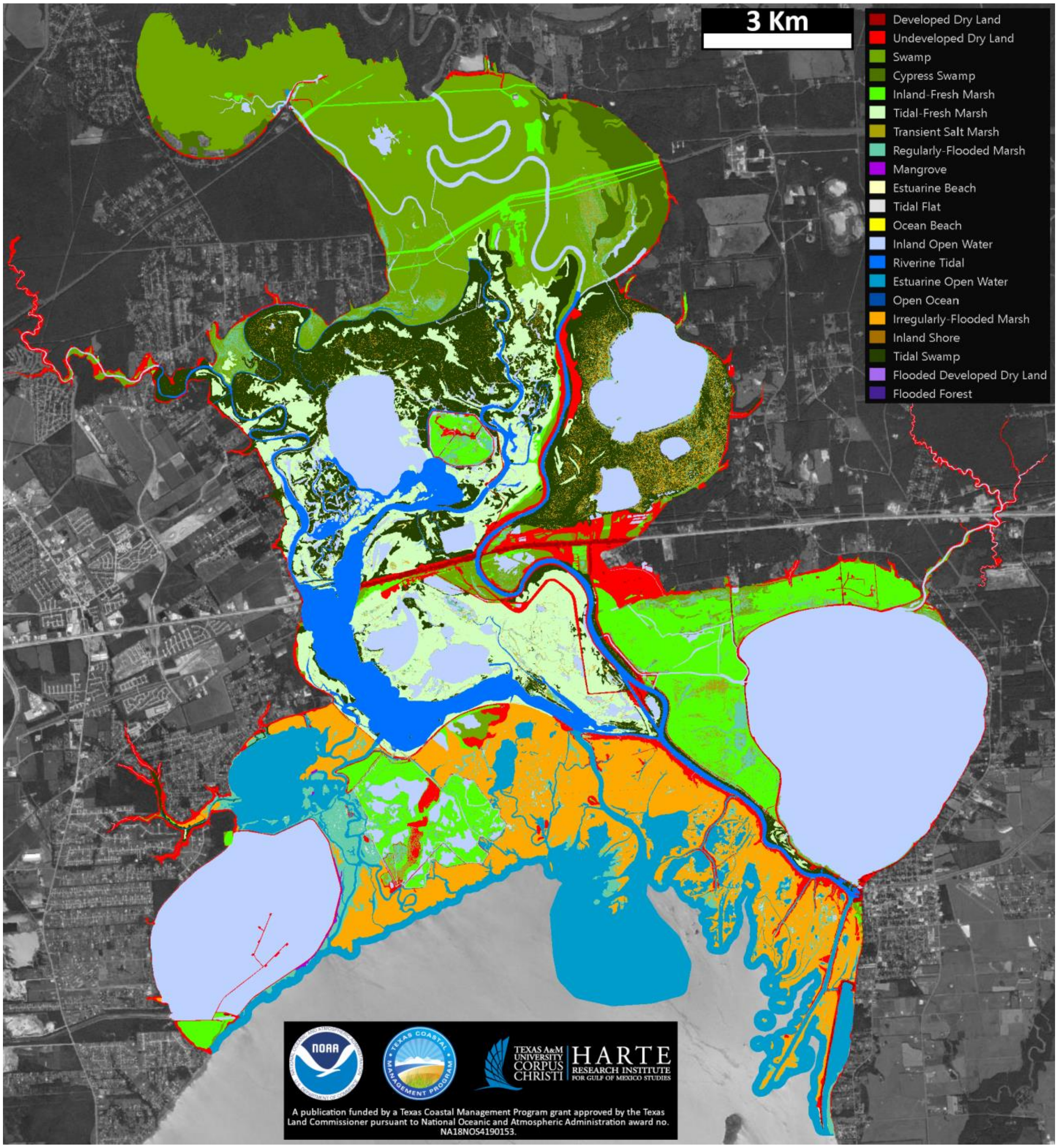


Figure 33—Trinity River bayhead delta @ 2040, 1.0 m GMSLR by 2100

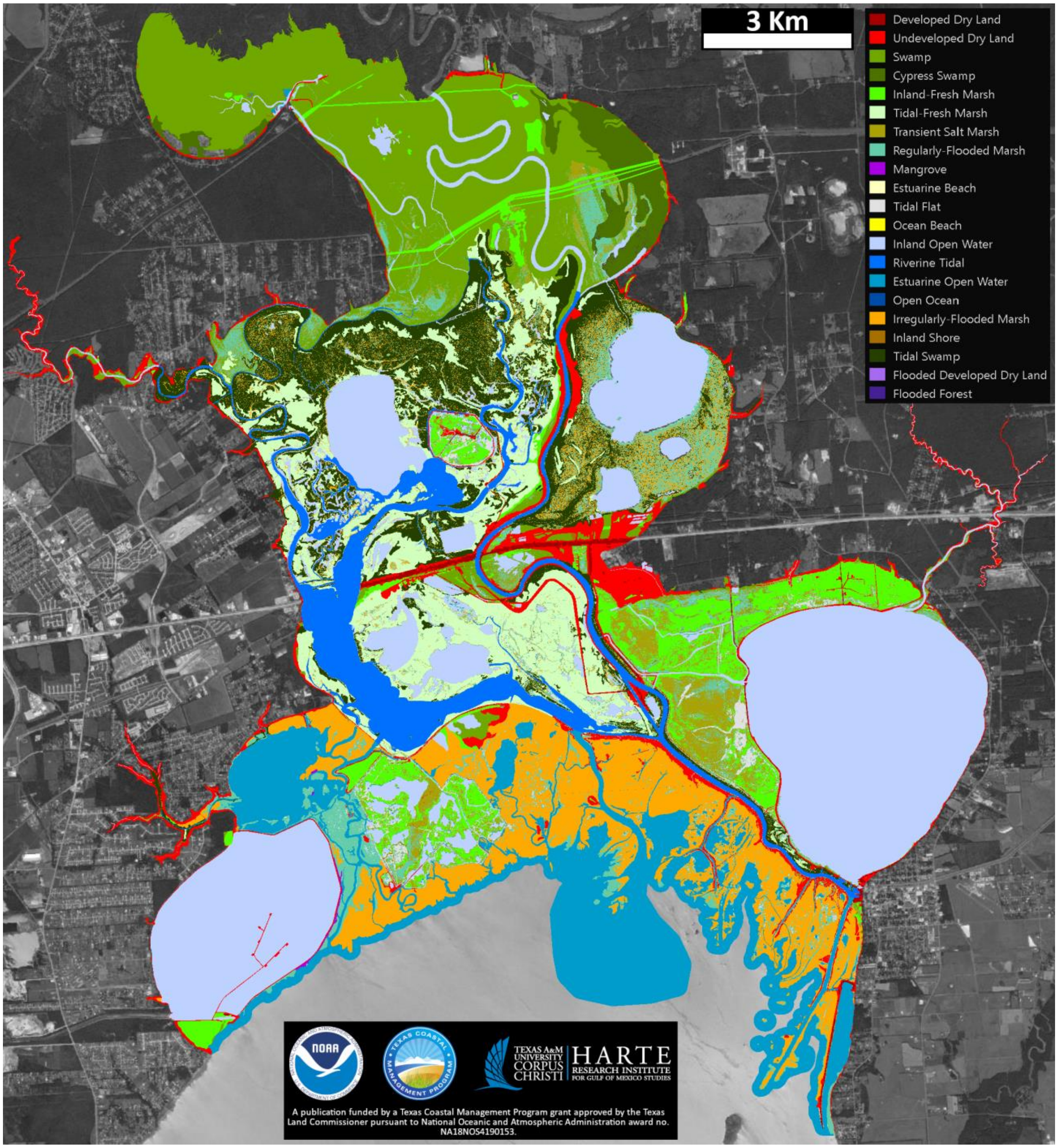


Figure 34—Trinity River bayhead delta @ 2060, 1.0 m GMSLR by 2100

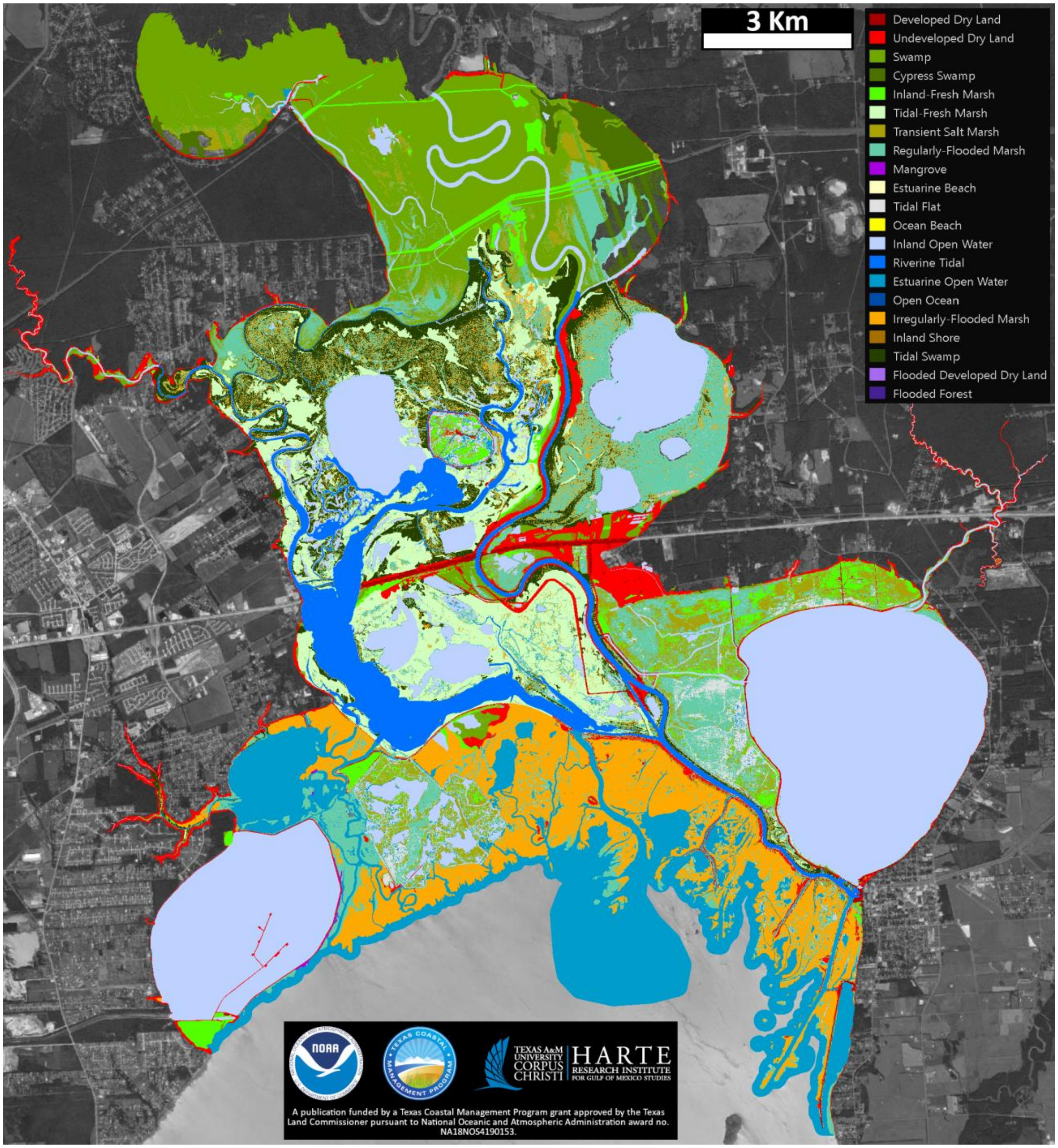


Figure 35—Trinity River bayhead delta @ 2080, 1.0 m GMSLR by 2100

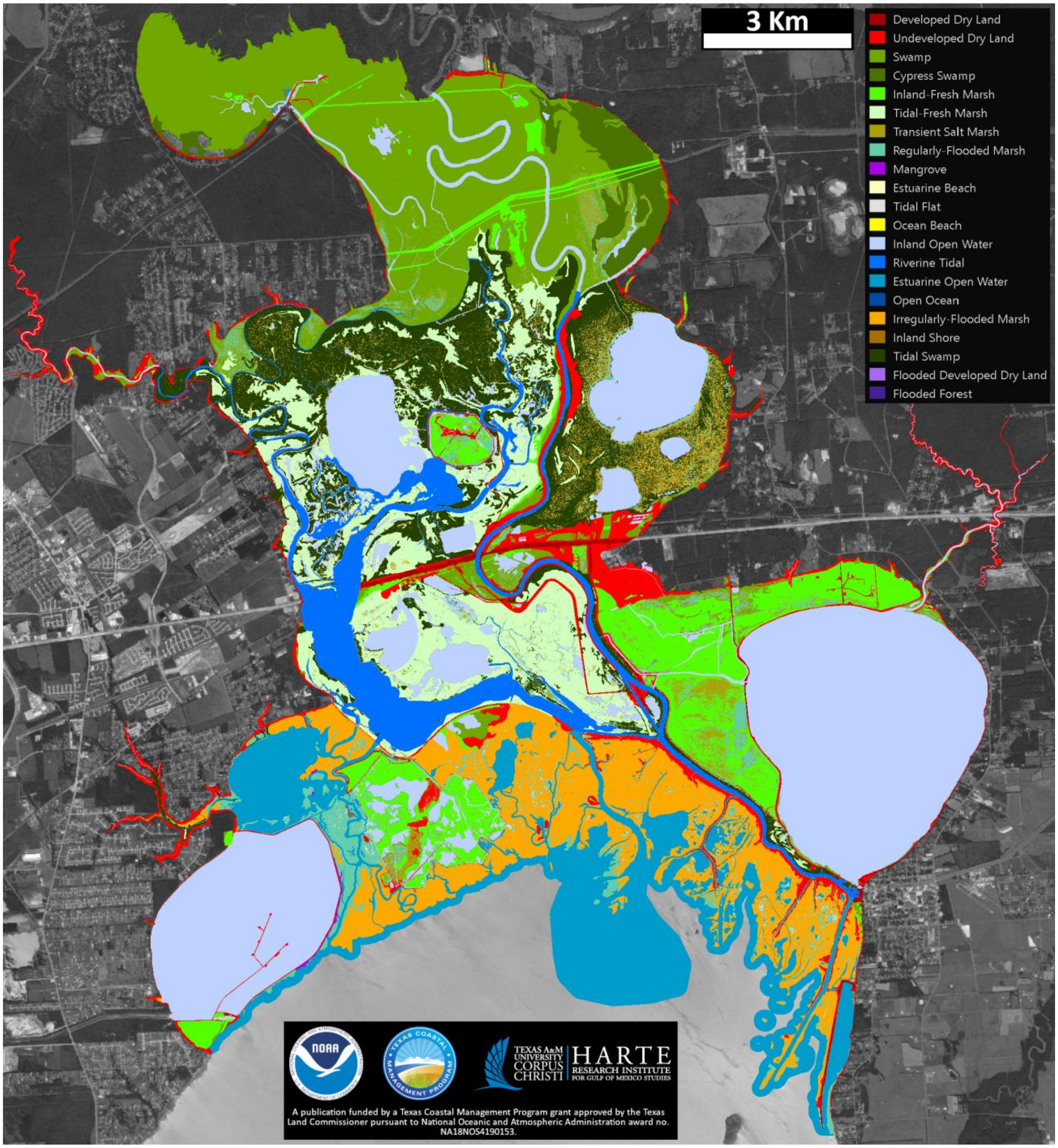


Figure 36—Trinity River bayhead delta @ 2040, 1.5 m GMSLR by 2100

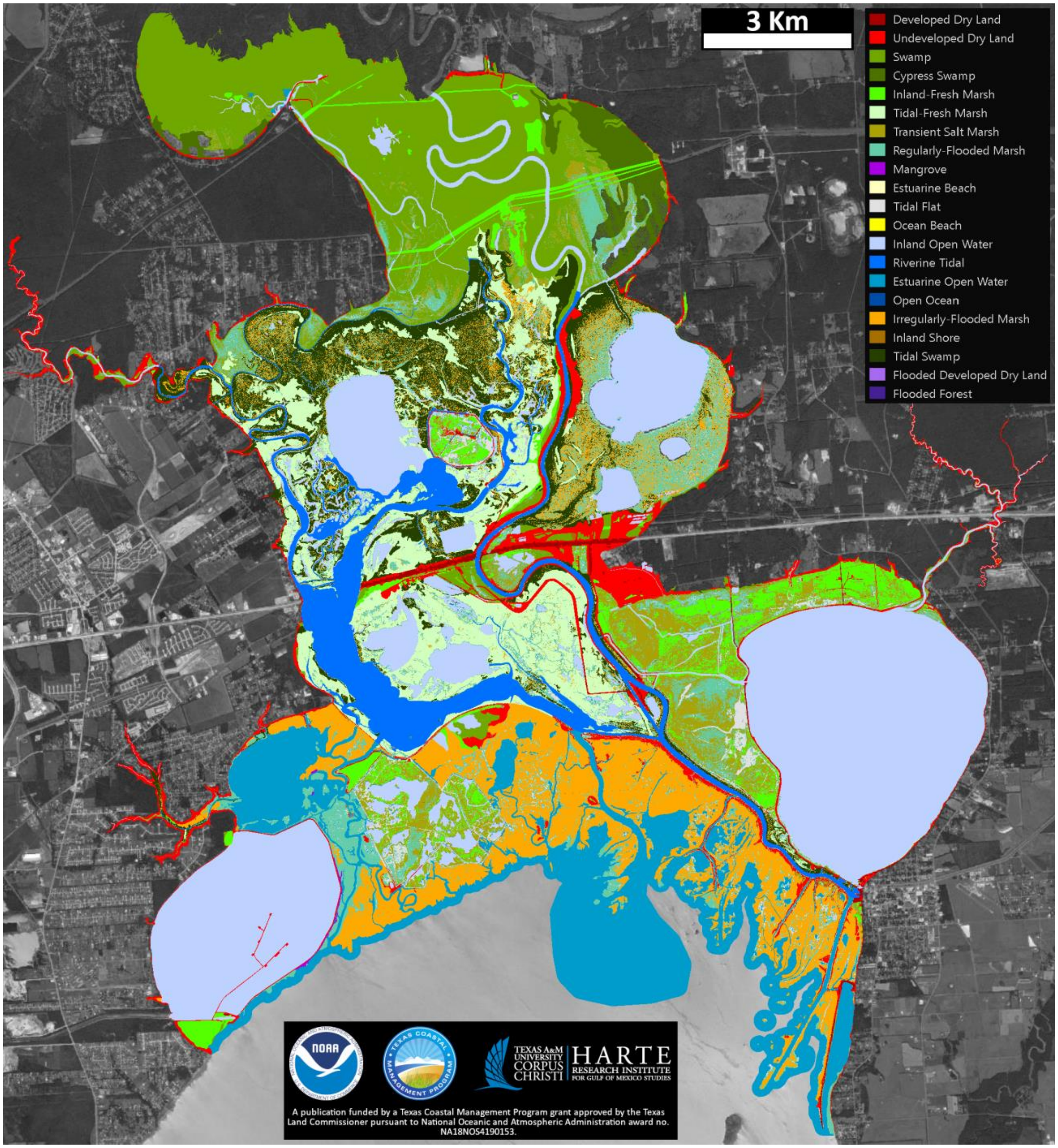


Figure 37—Trinity River bayhead delta @ 2060, 1.5 m GMSLR by 2100

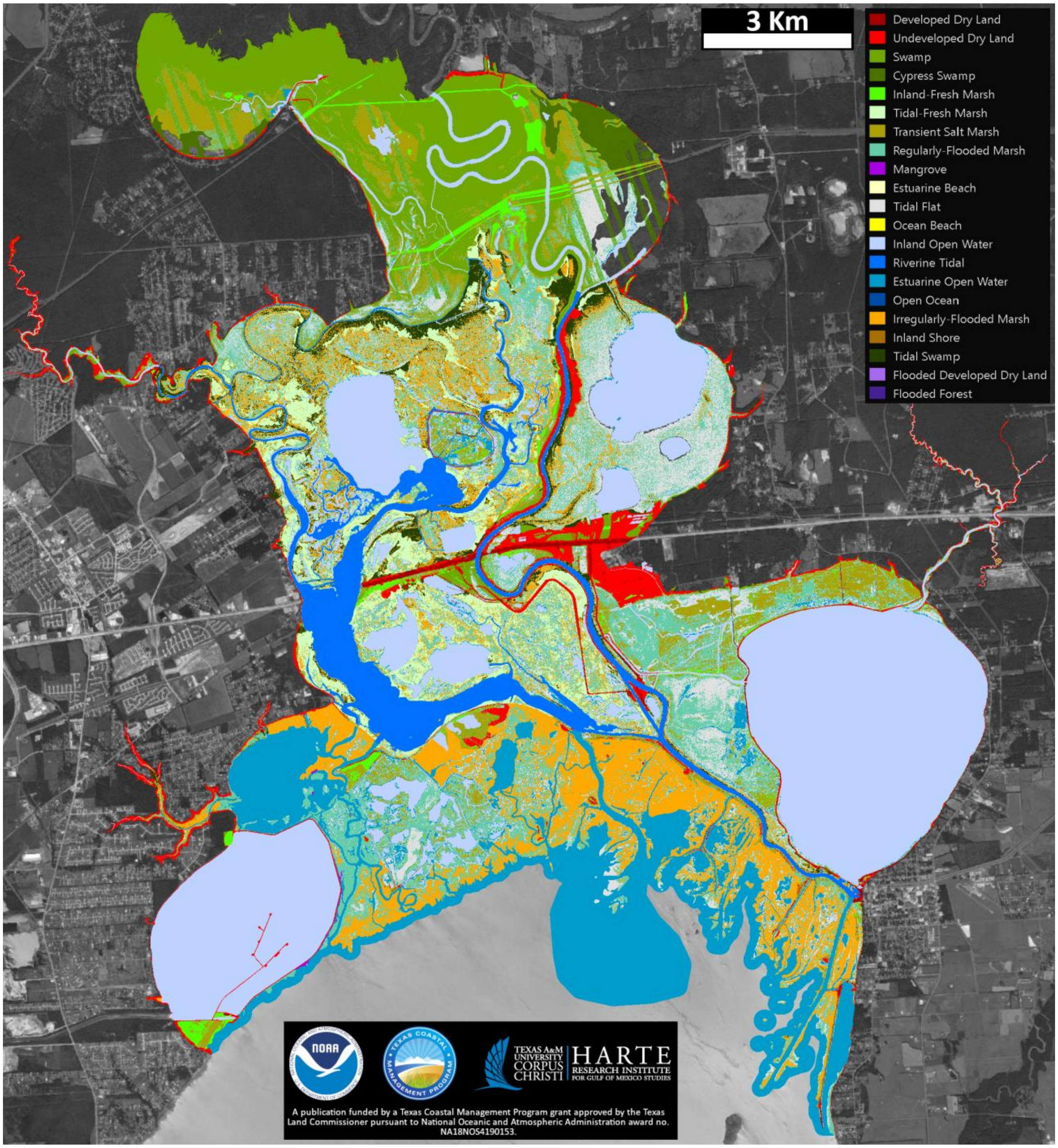


Figure 38—Trinity River bayhead delta @ 2080, 1.5 m GMSLR by 2100

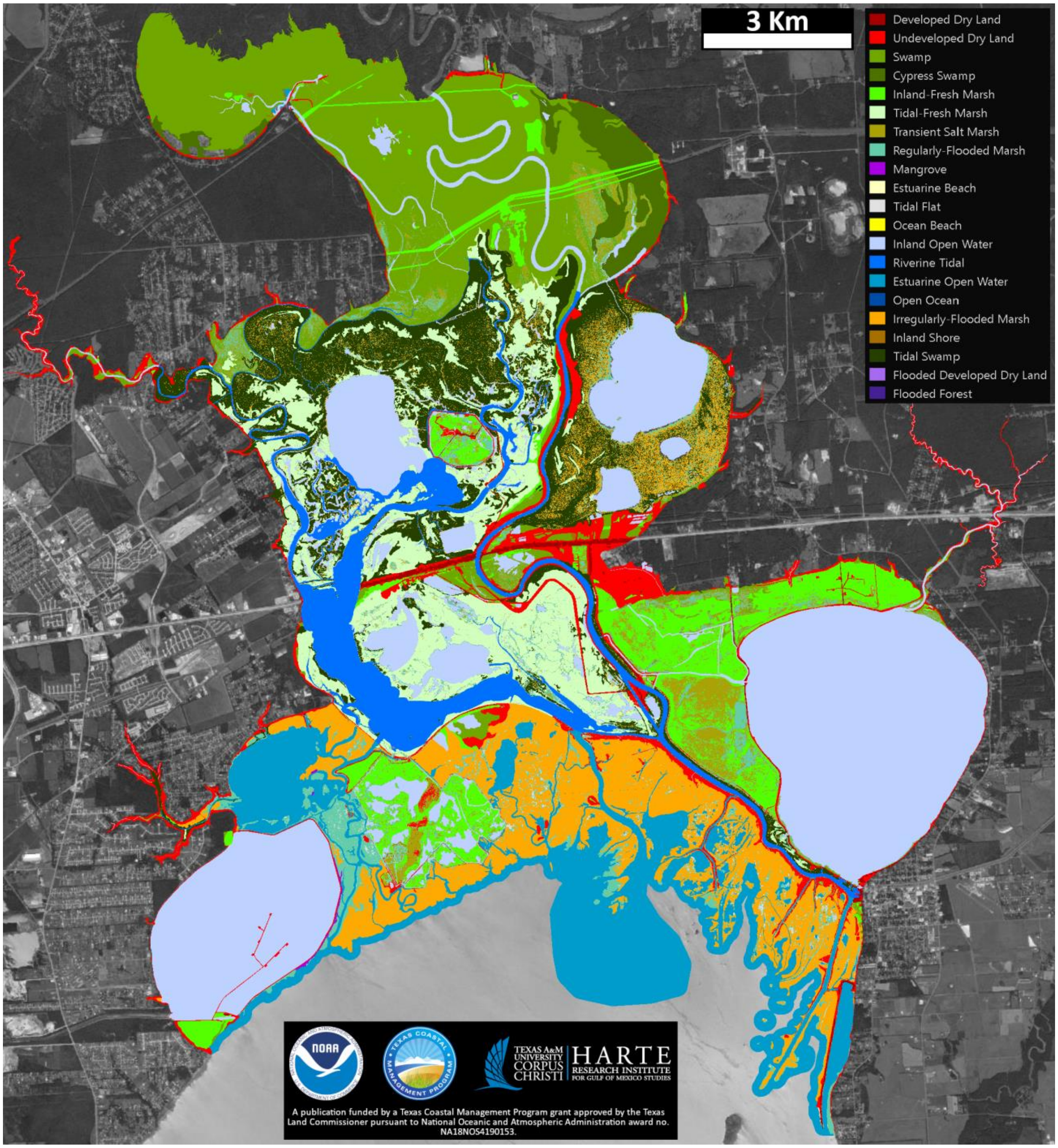


Figure 39—Trinity River bayhead delta @ 2040, 2.0 m GMSLR by 2100

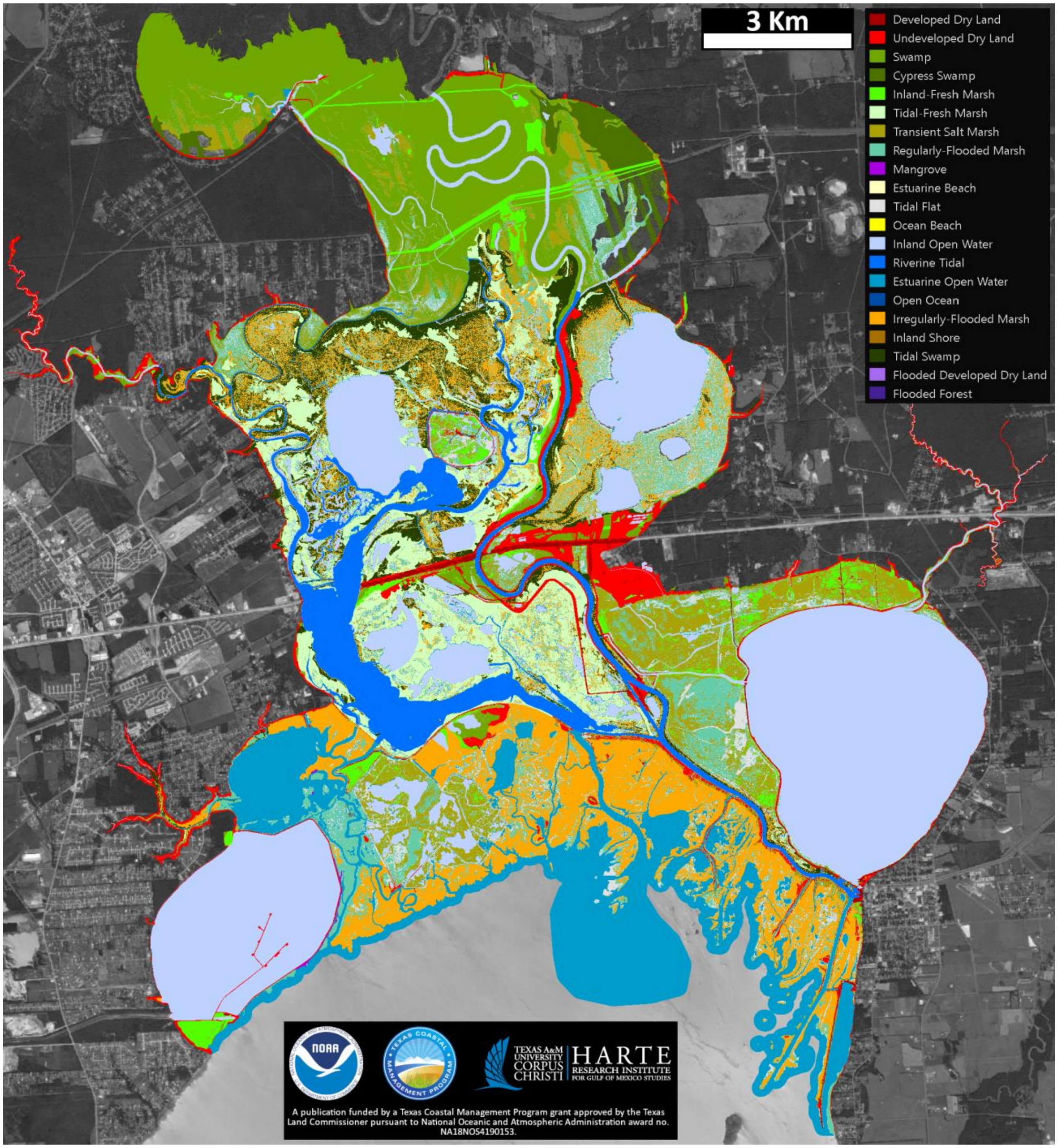


Figure 40—Trinity River bayhead delta @ 2060, 2.0 m GMSLR by 2100

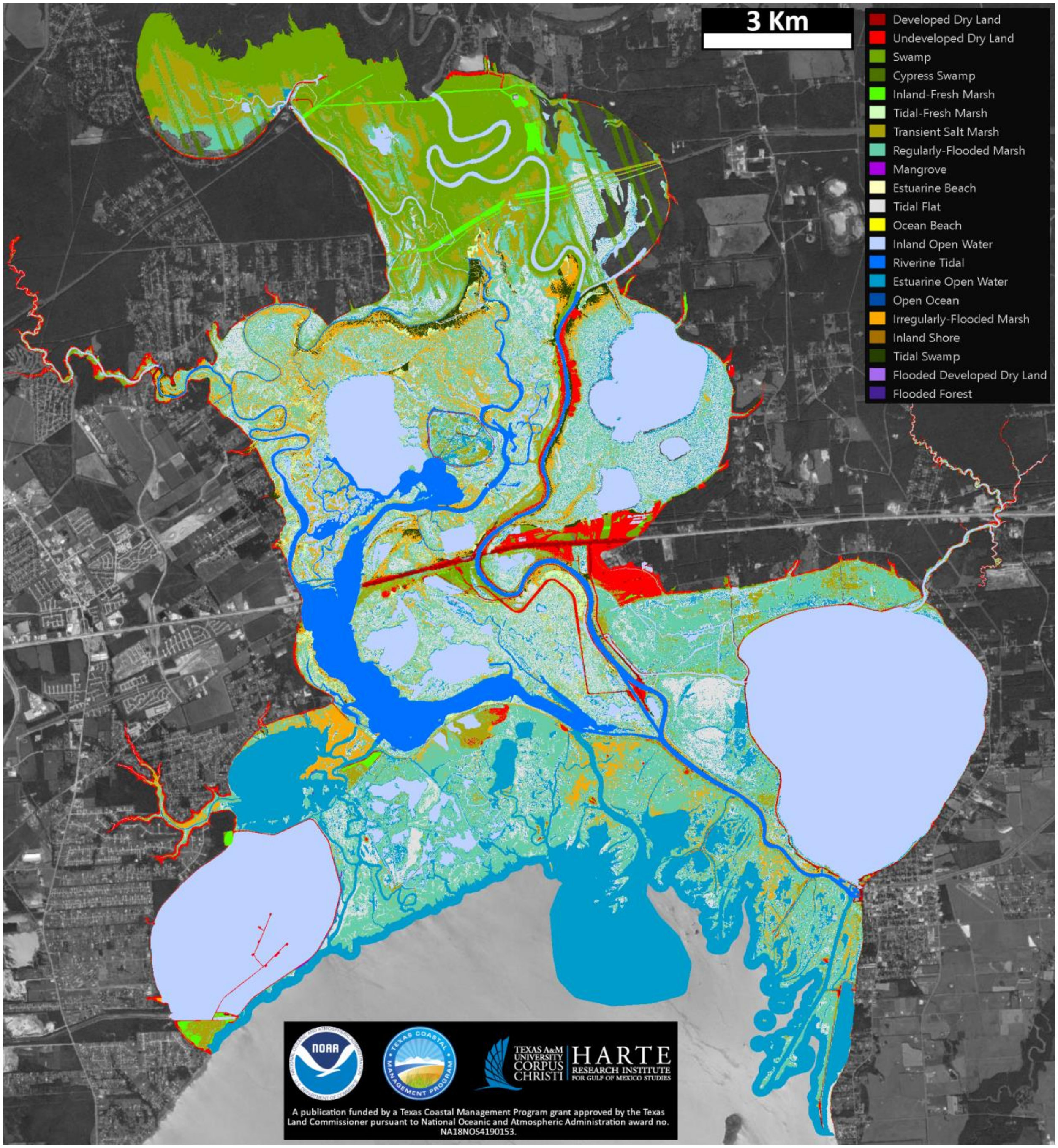


Figure 41—Trinity River bayhead delta @ 2080, 2.0 m GMSLR by 2100

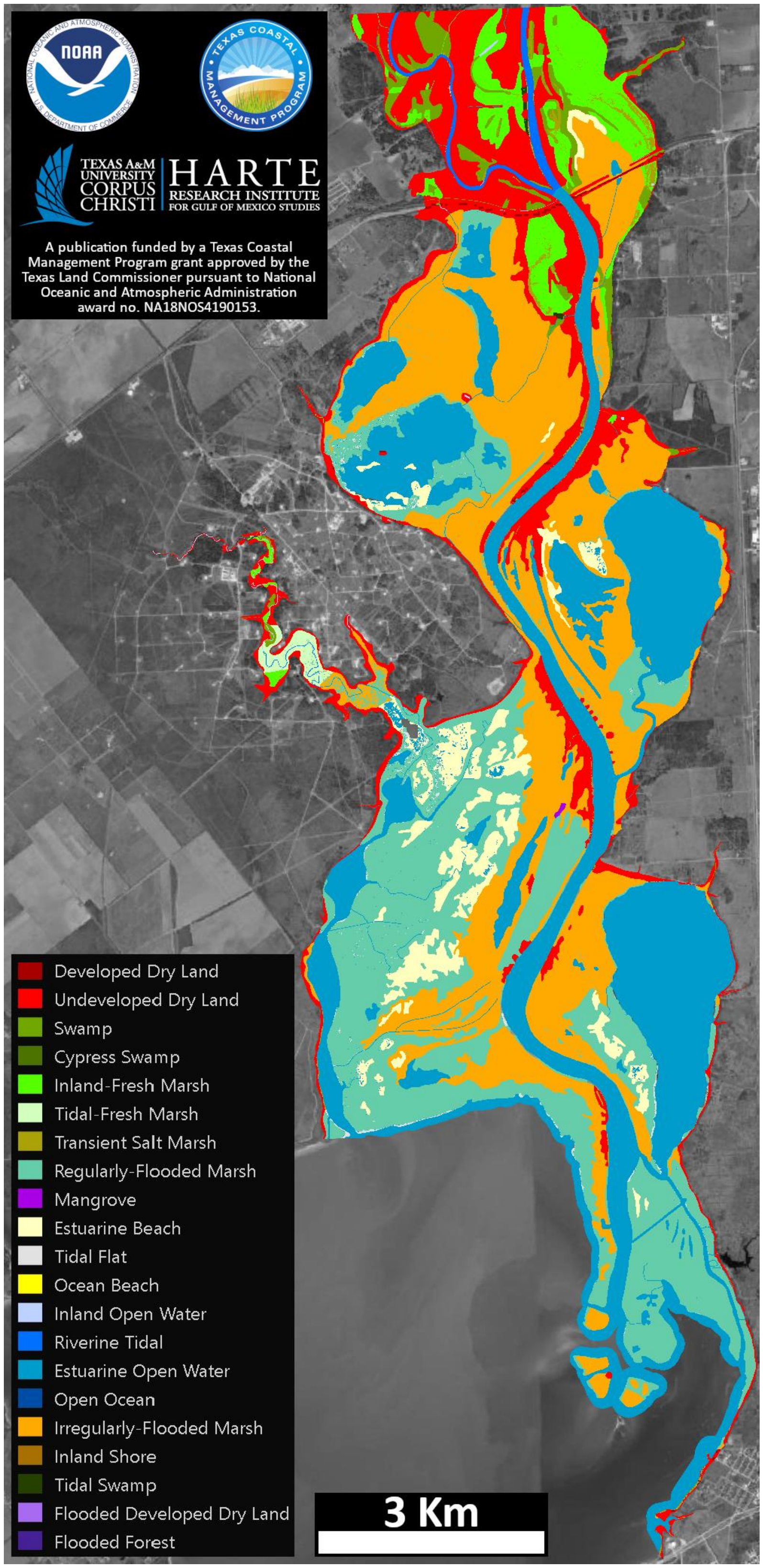


Figure 42—Lavaca-Navidad River bayhead delta @ 2019

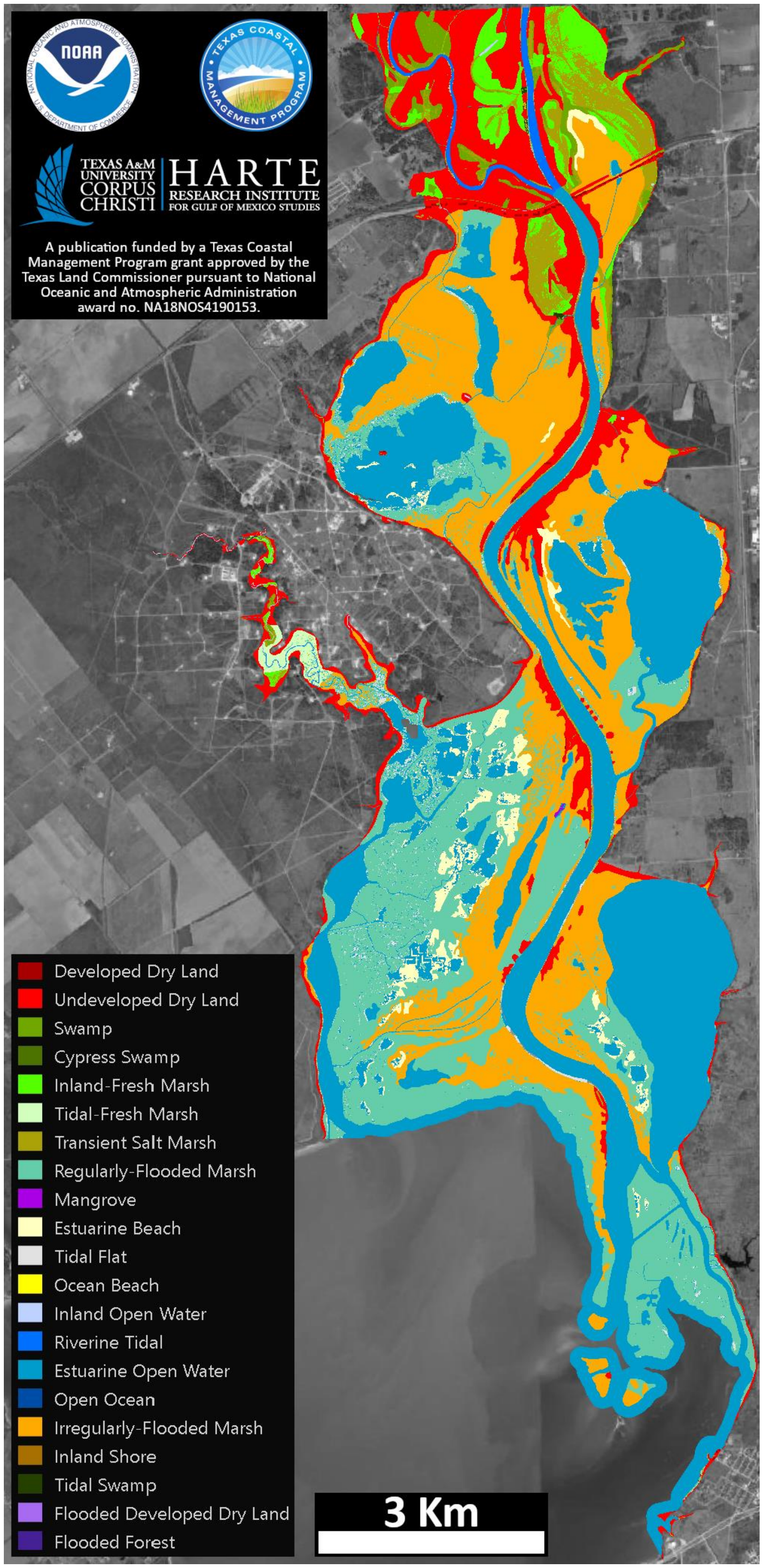


Figure 43—Lavaca-Navidad River bayhead delta @ 2040, 1.0 m GMSLR by 2100

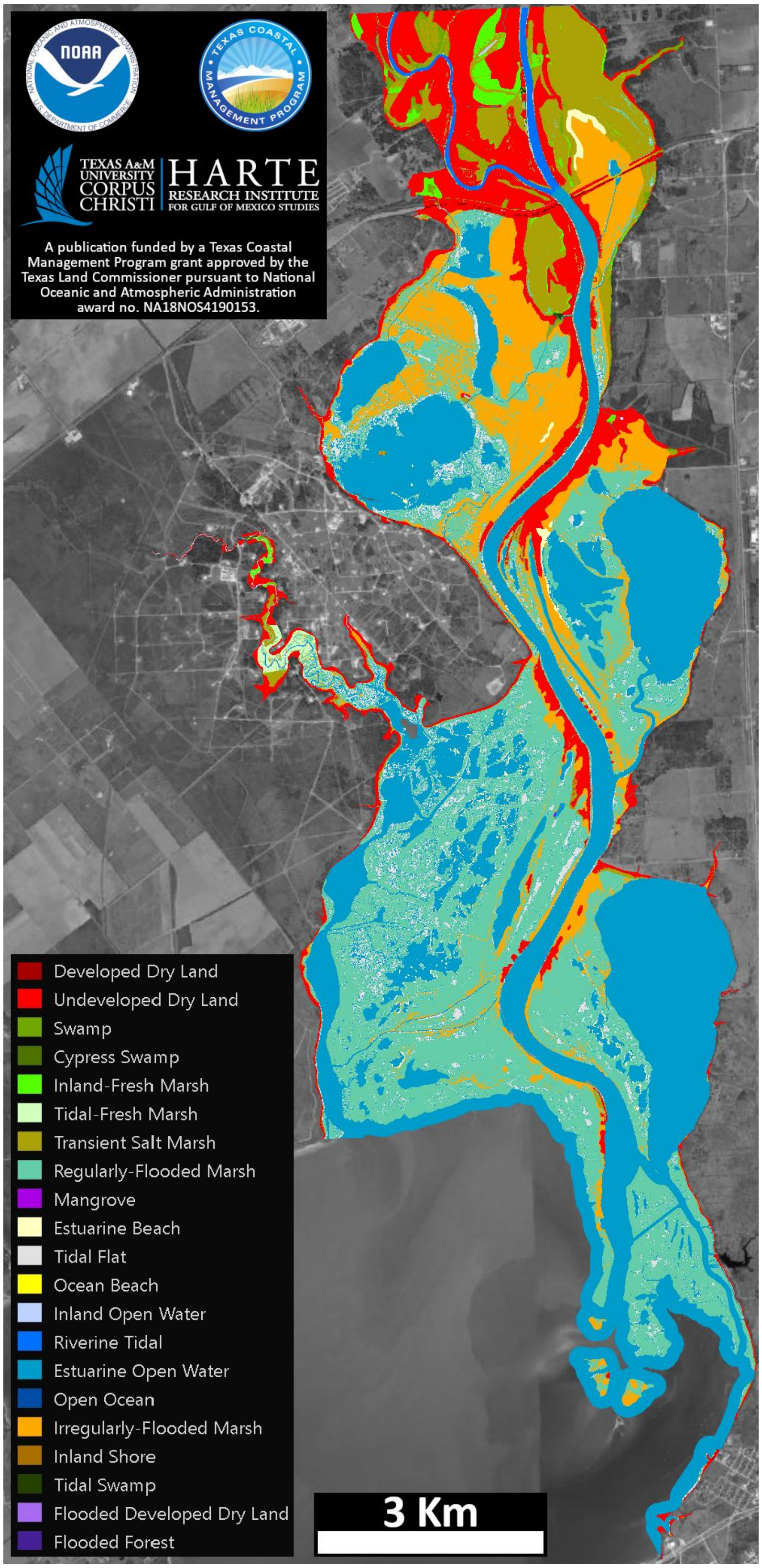


Figure 44—Lavaca-Navidad River bayhead delta @ 2060, 1.0 m GMSLR by 2100

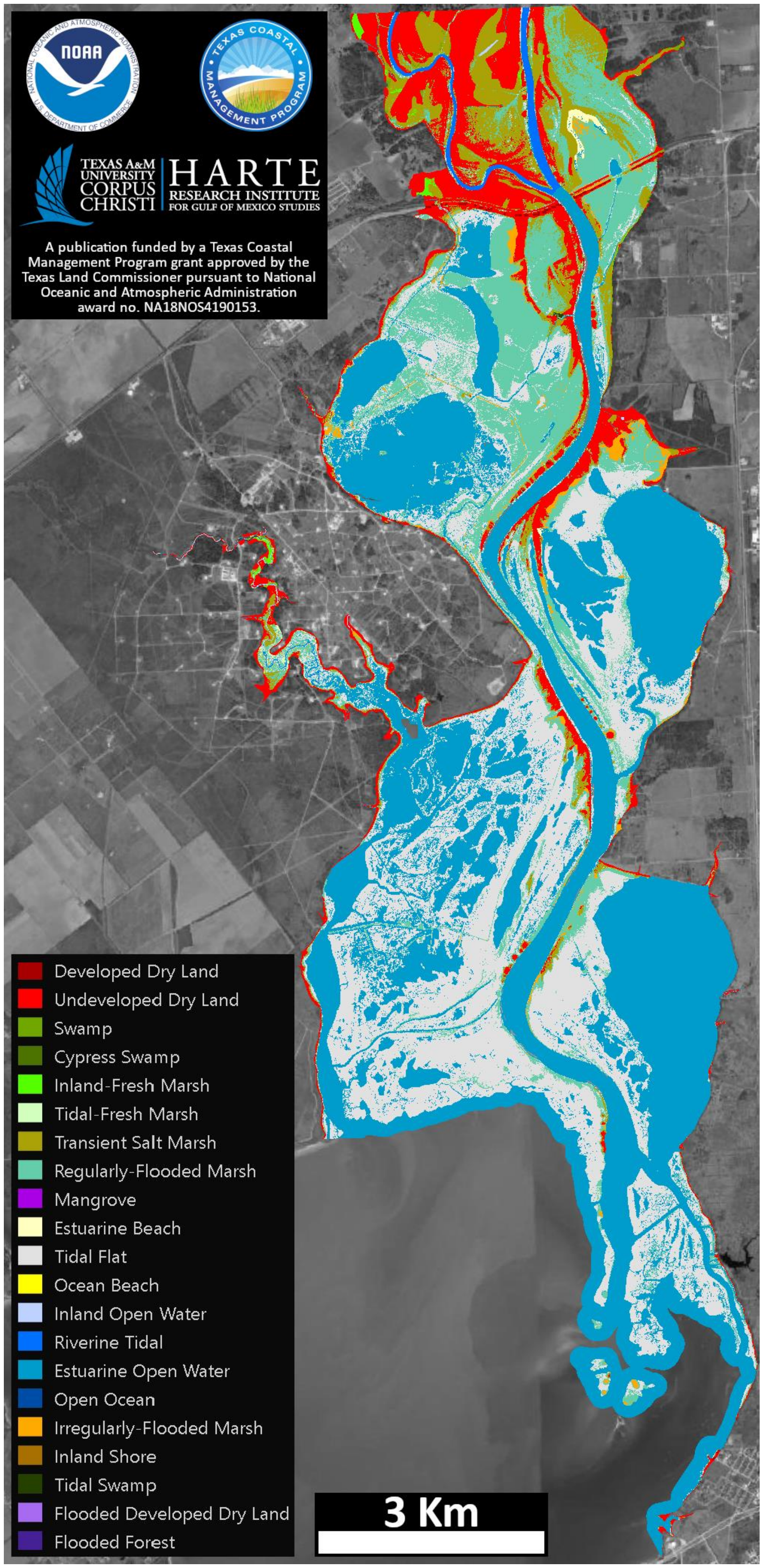
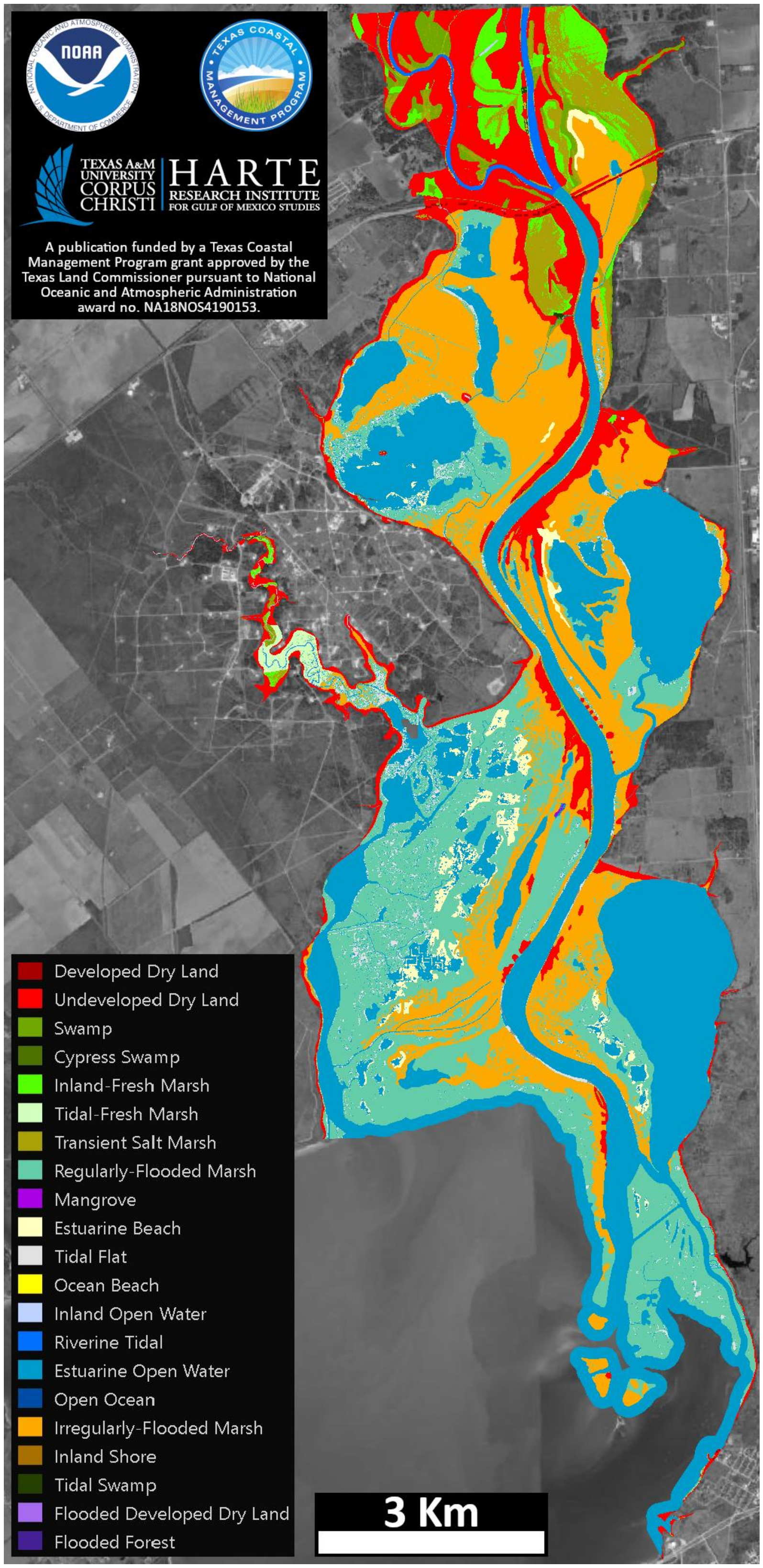


Figure 45—Lavaca-Navidad River bayhead delta @ 2080, 1.0 m GMSLR by 2100



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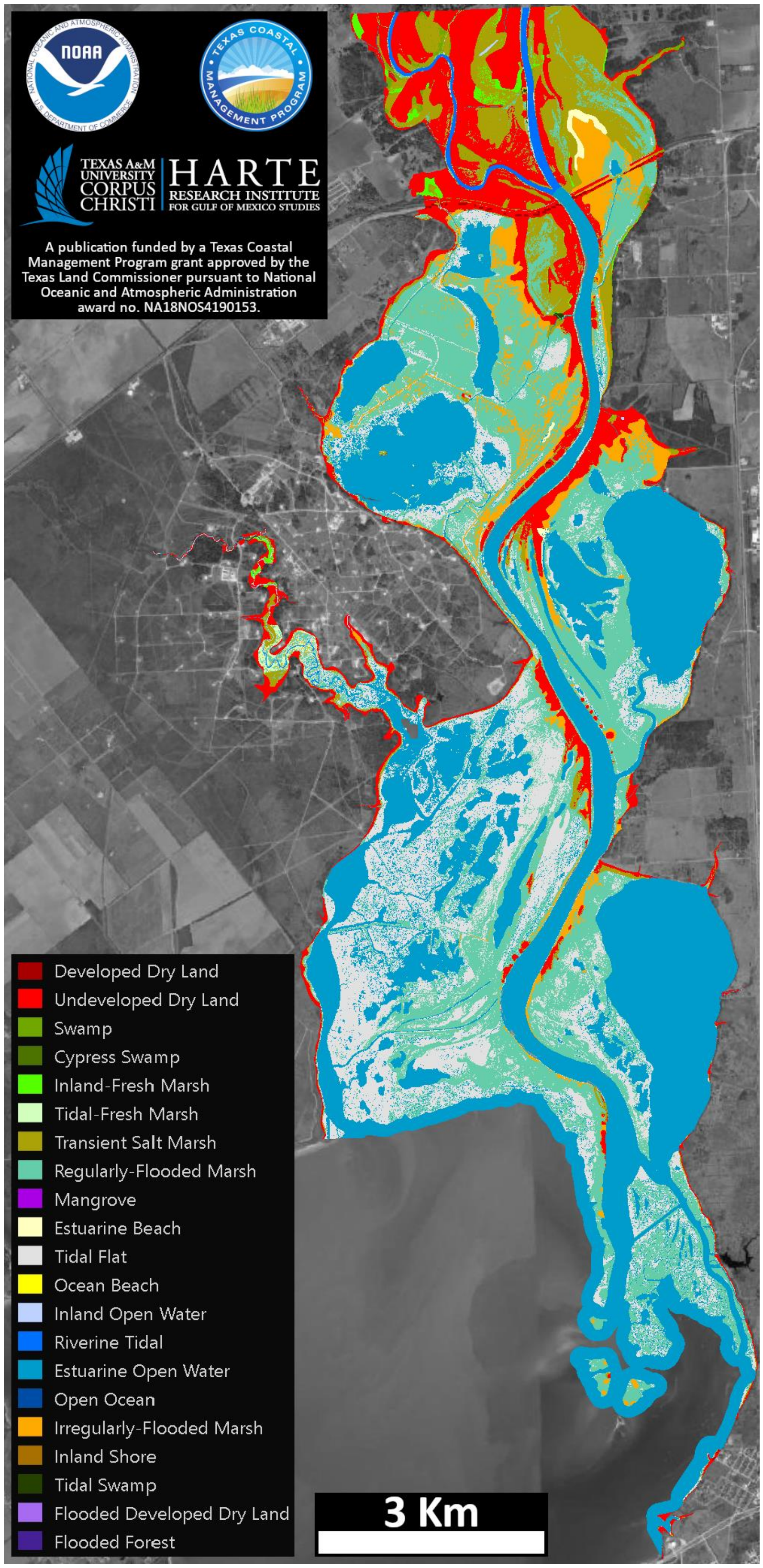

Figure 47—Lavaca-Navidad River bayhead delta @ 2060, 1.5 m GMSLR by 2100

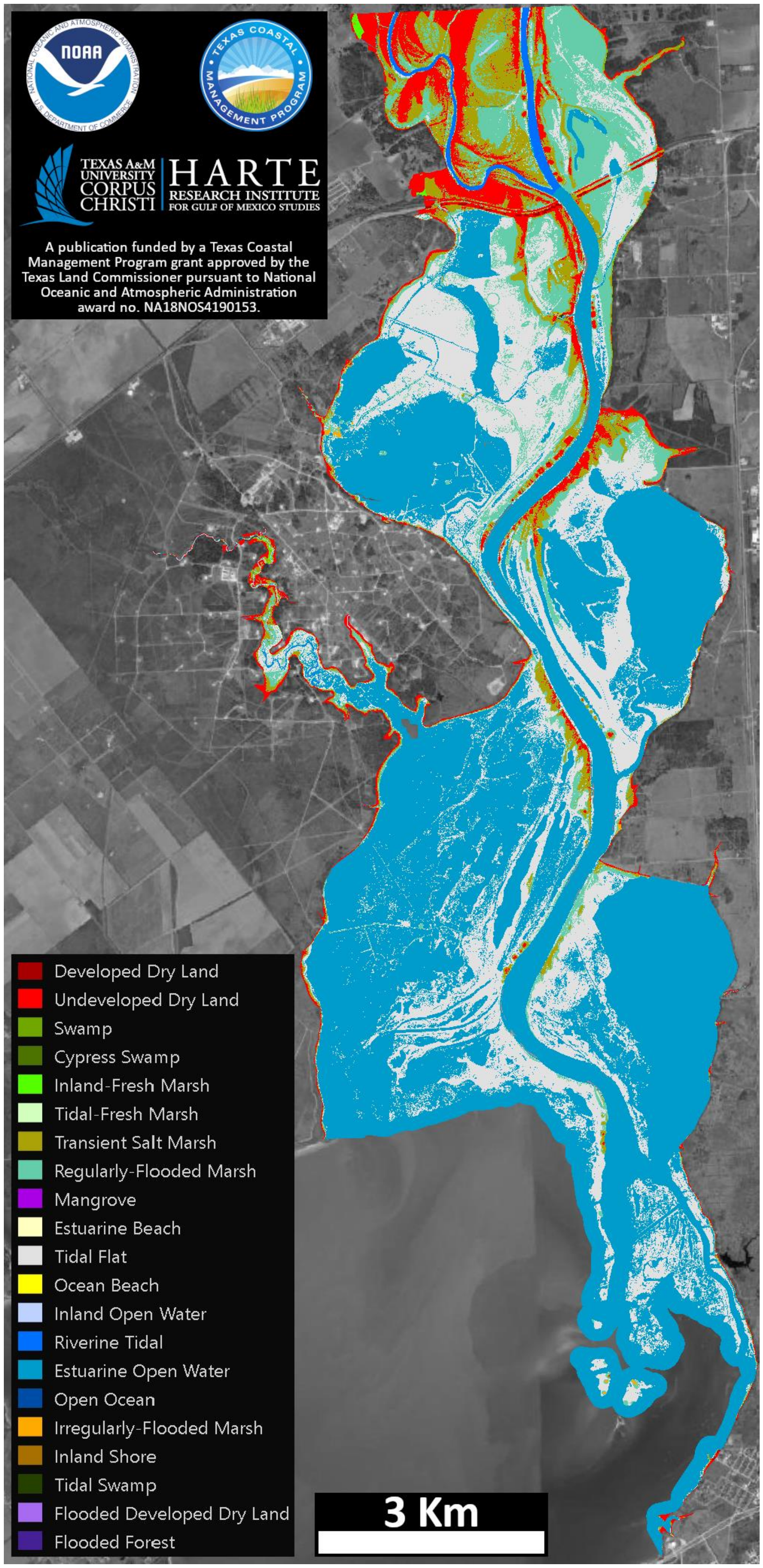

Figure 48—Lavaca-Navidad River bayhead delta @ 2080, 1.5 m GMSLR by 2100

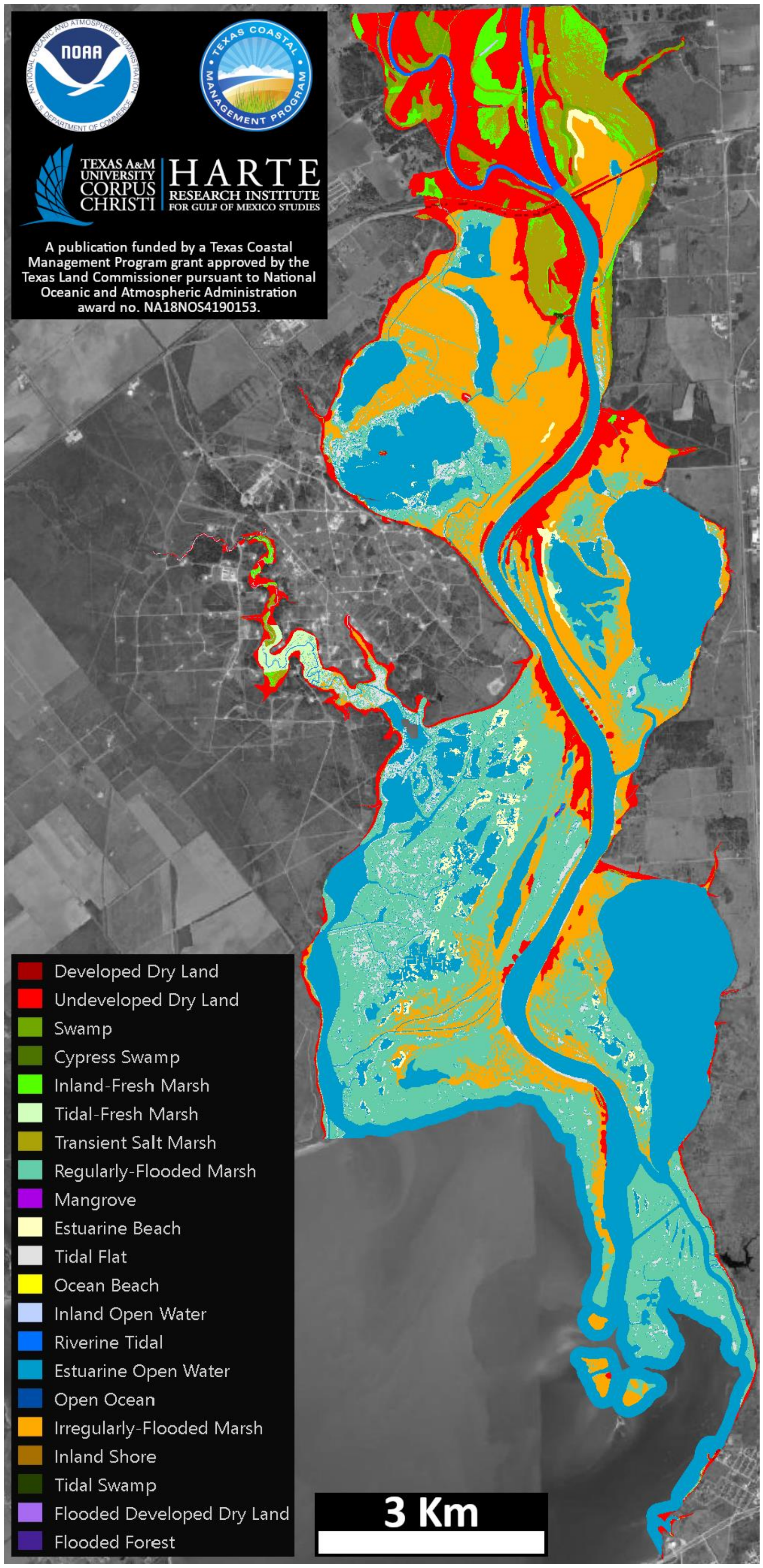

Figure 49—Lavaca-Navidad River bayhead delta @ 2040, 2.0 m GMSLR by 2100

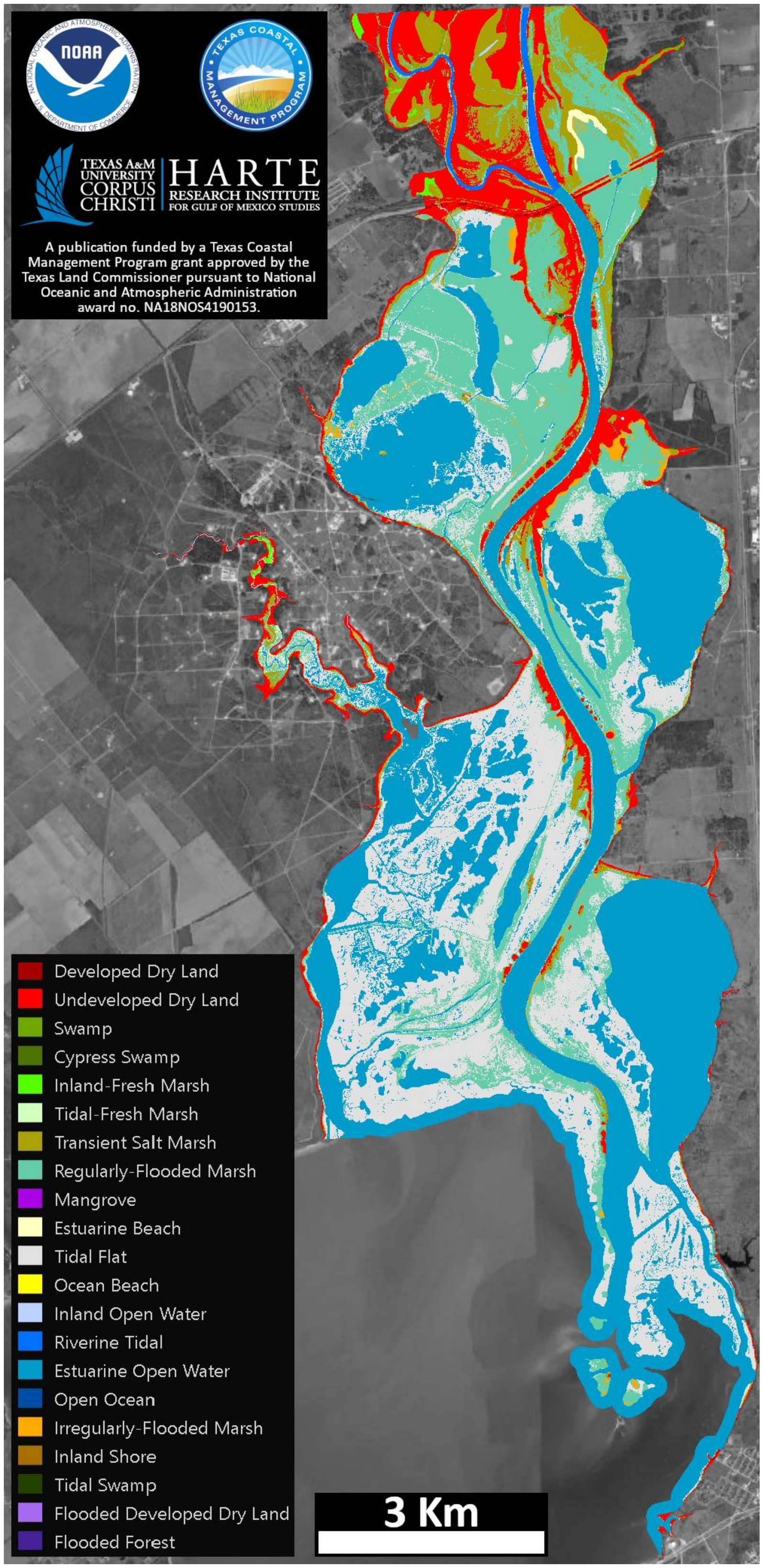

Figure 50—Lavaca-Navidad River bayhead delta @ 2060, 2.0 m GMSLR by 2100

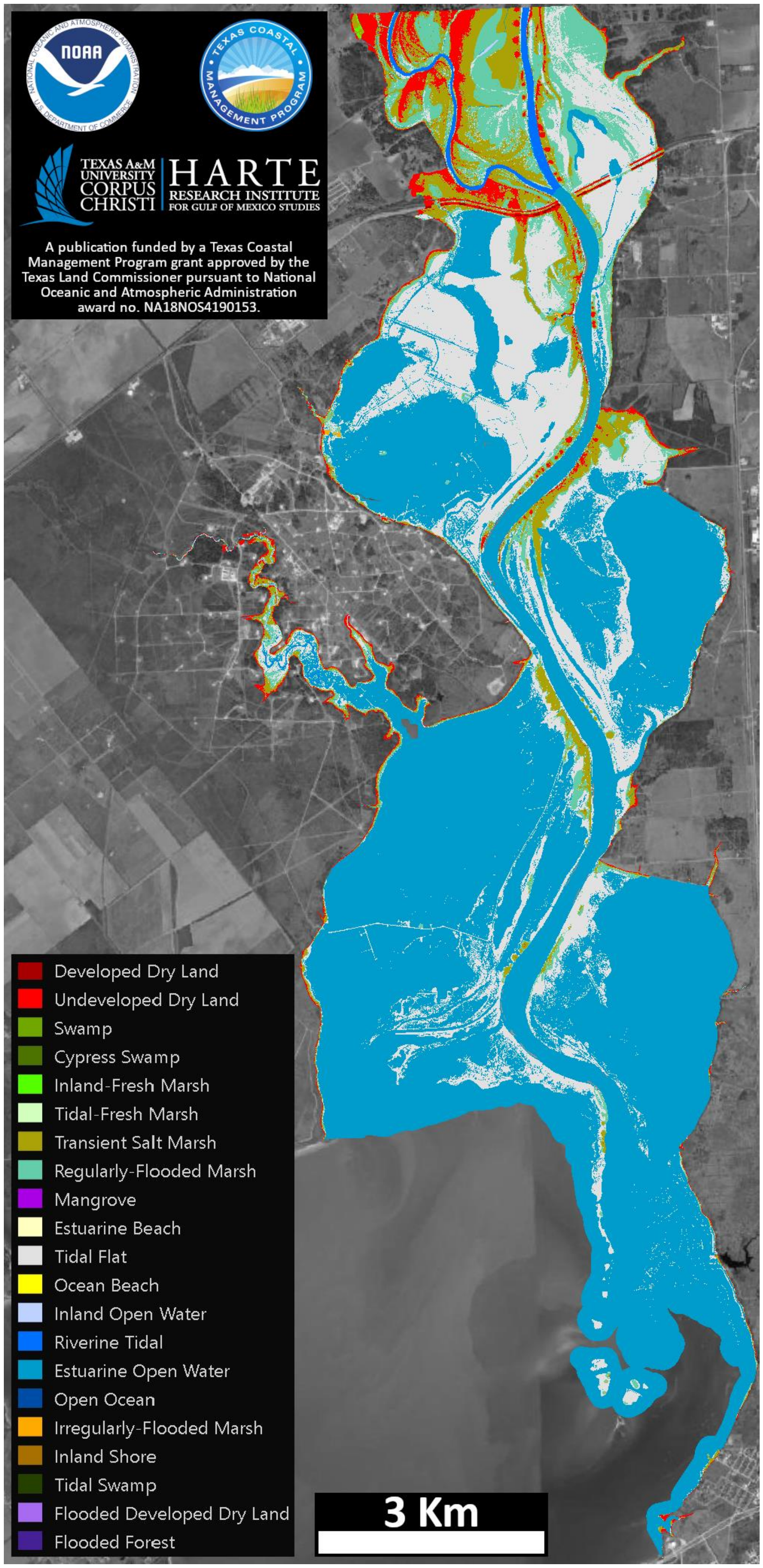

Figure 51—Lavaca-Navidad River bayhead delta @ 2080, 2.0 m GMSLR by 2100

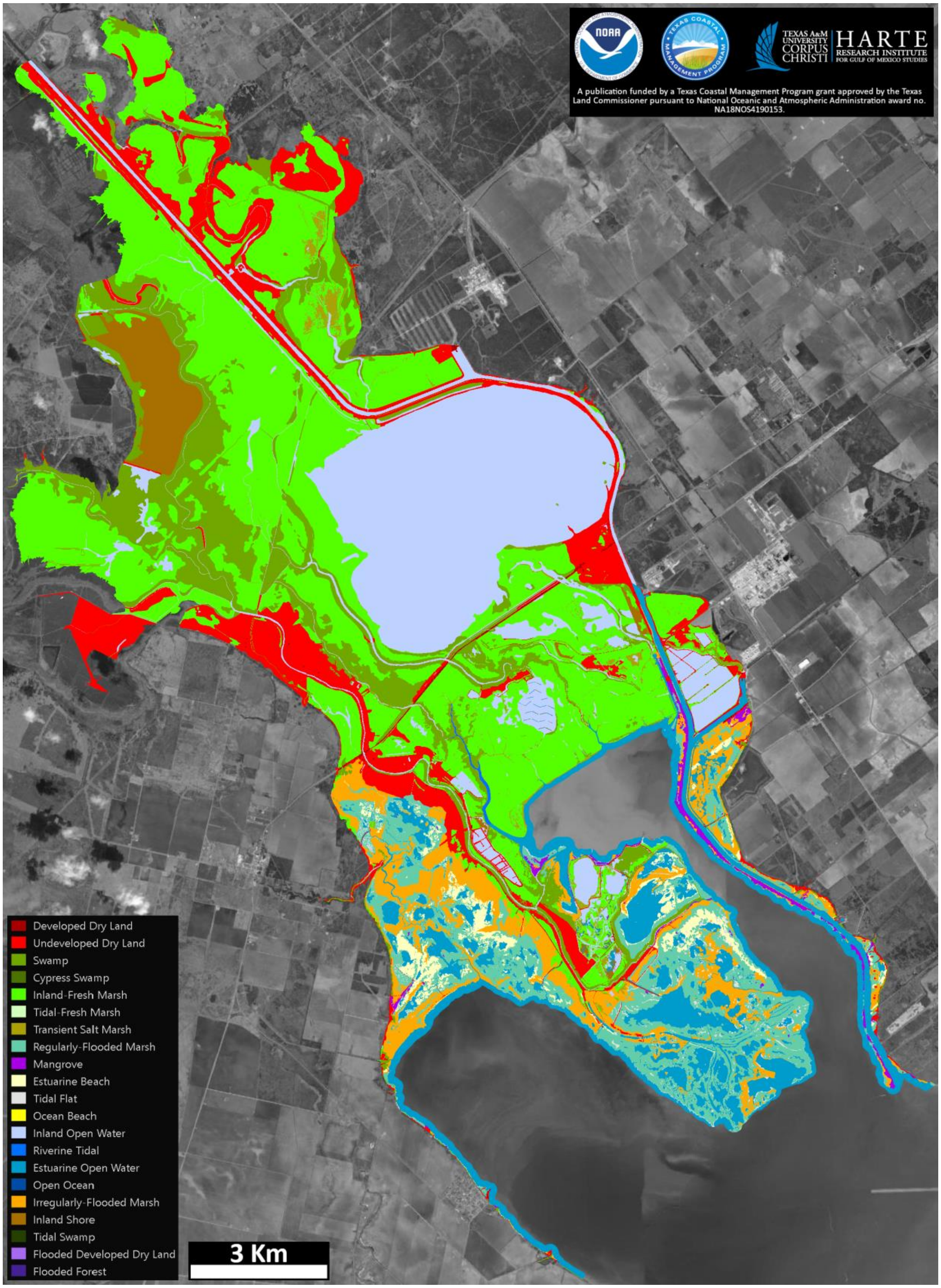

Figure 52—Guadalupe River bayhead delta @ 2019

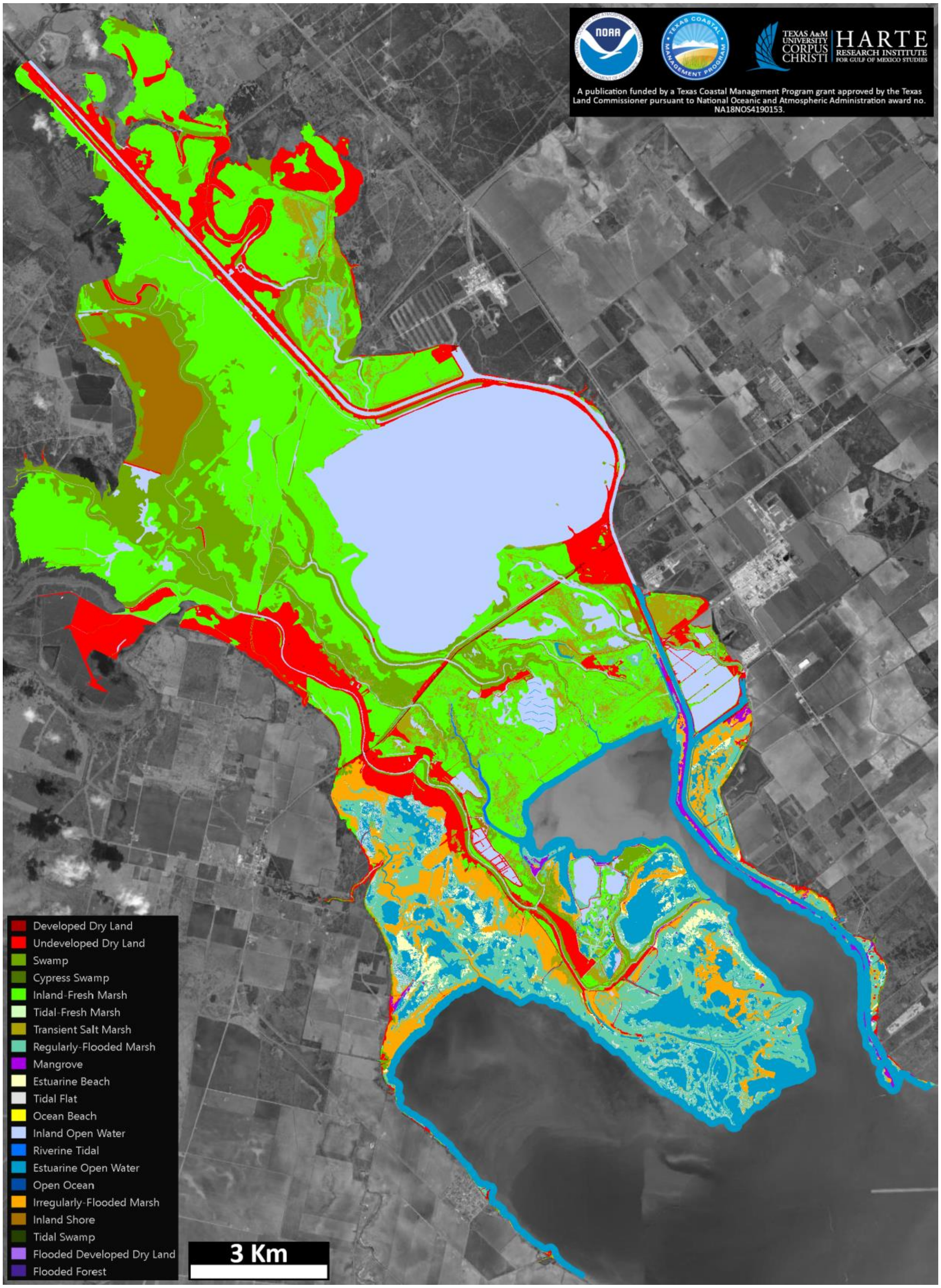

Figure 53—Guadalupe River bayhead delta @ 2040, 1.0 m GMSLR by 2100

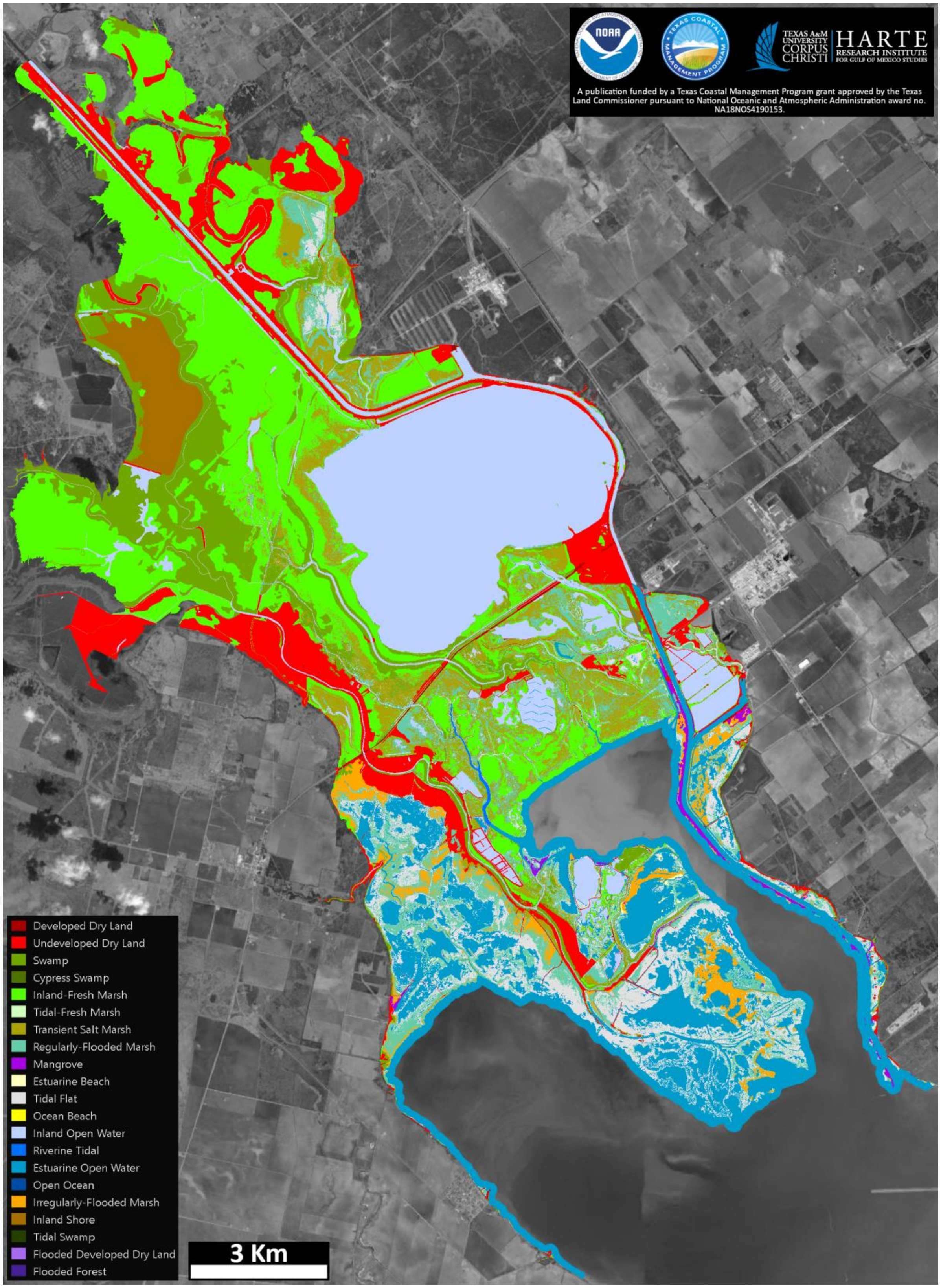

Figure 54—Guadalupe River bayhead delta @ 2060, 1.0 m GMSLR by 2100

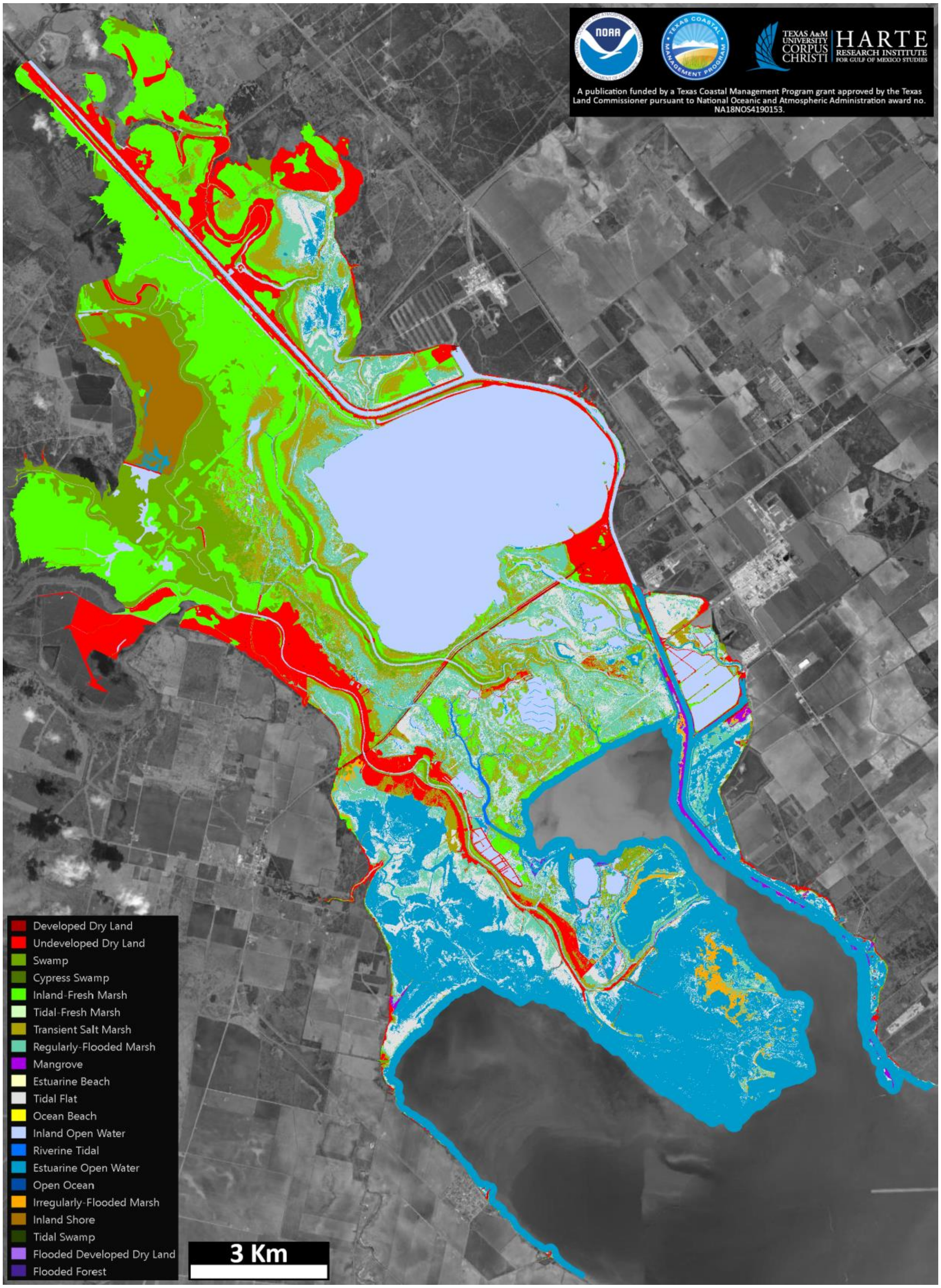

Figure 55—Guadalupe River bayhead delta @ 2080, 1.0 m GMSLR by 2100

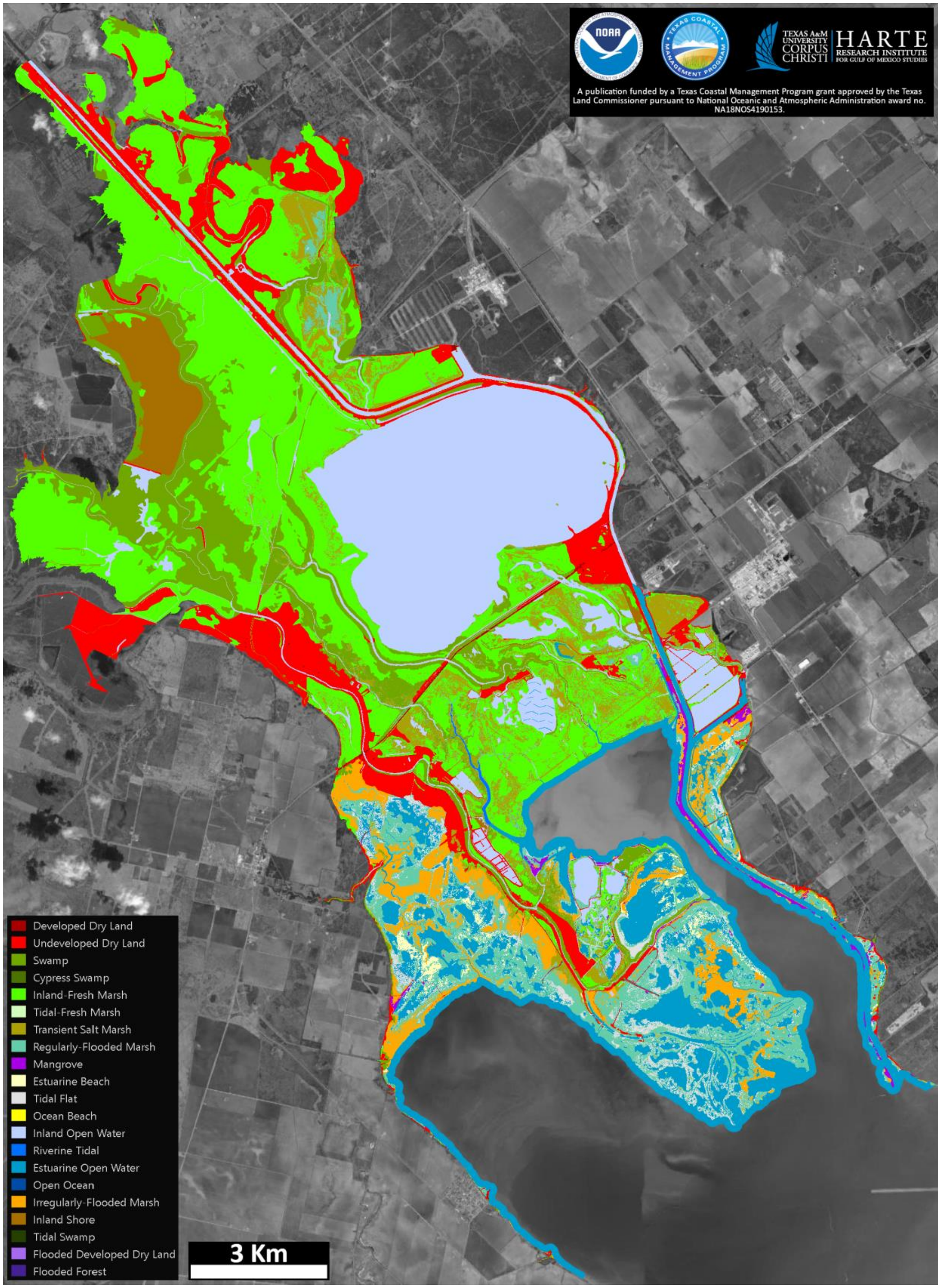

Figure 56—Guadalupe River bayhead delta @ 2040, 1.5 m GMSLR by 2100

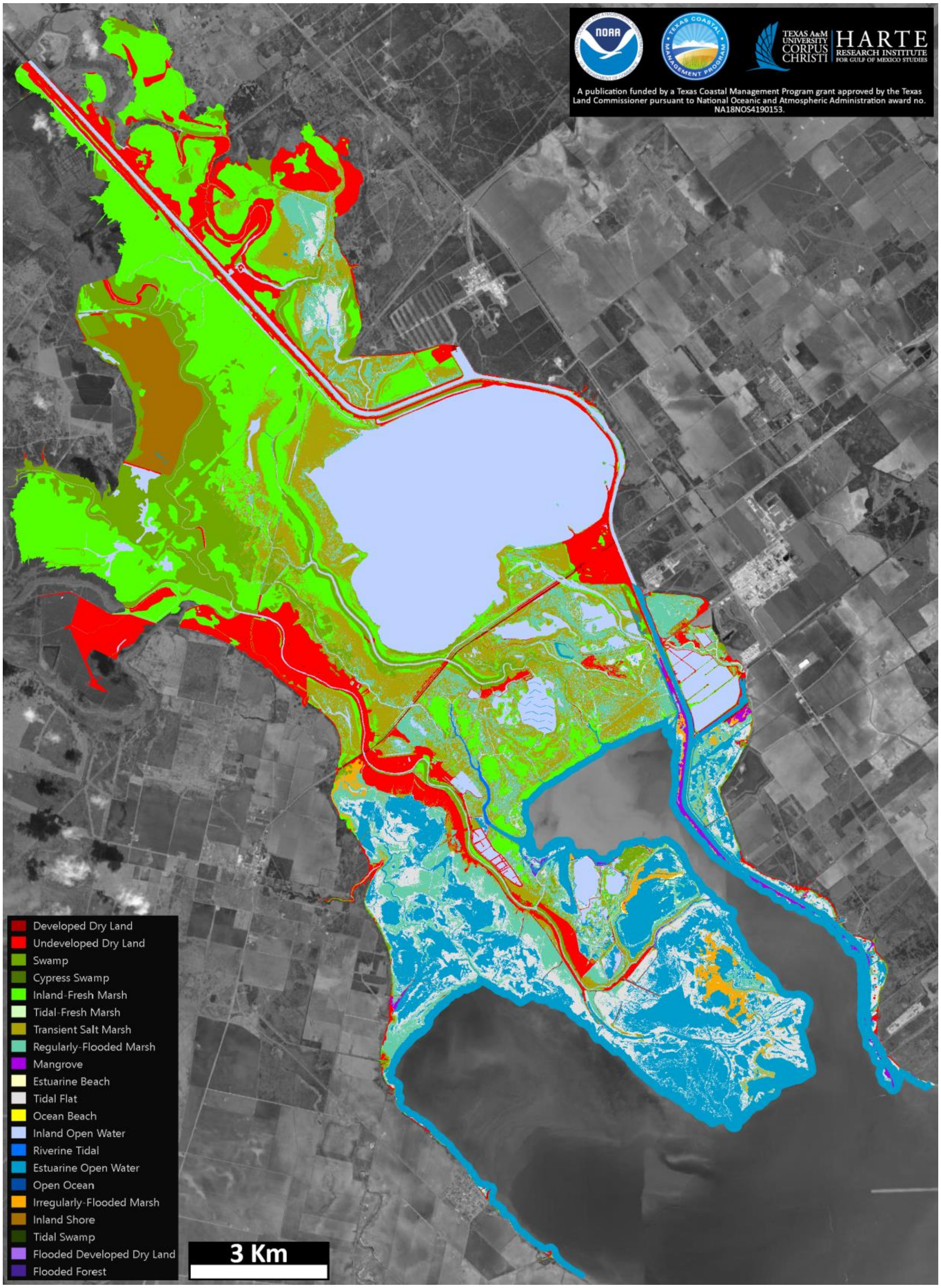

Figure 57—Guadalupe River bayhead delta @ 2060, 1.5 m GMSLR by 2100

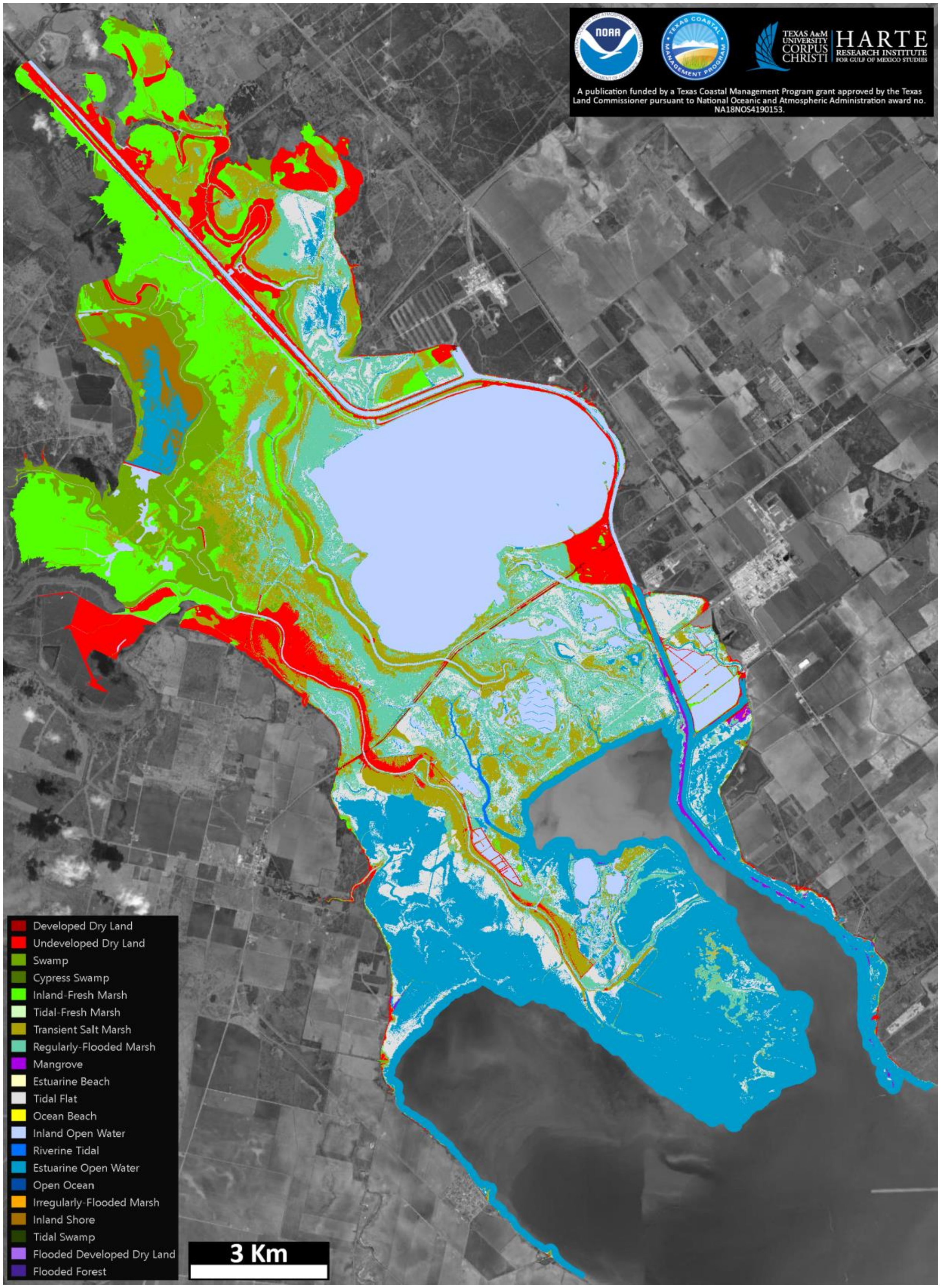

Figure 58—Guadalupe River bayhead delta @ 2080, 1.5 m GMSLR by 2100

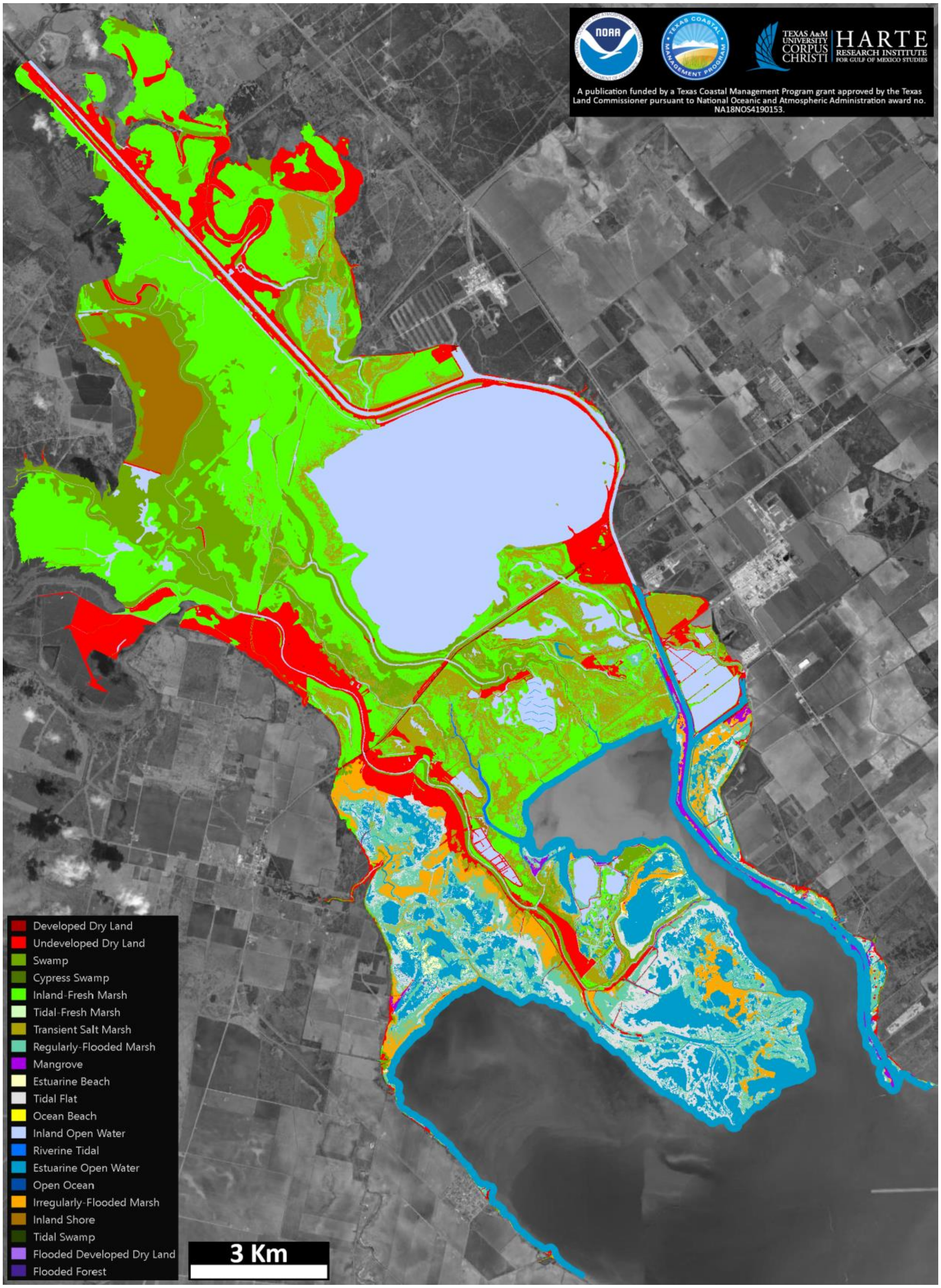

Figure 59—Guadalupe River bayhead delta @ 2040, 2.0 m GMSLR by 2100

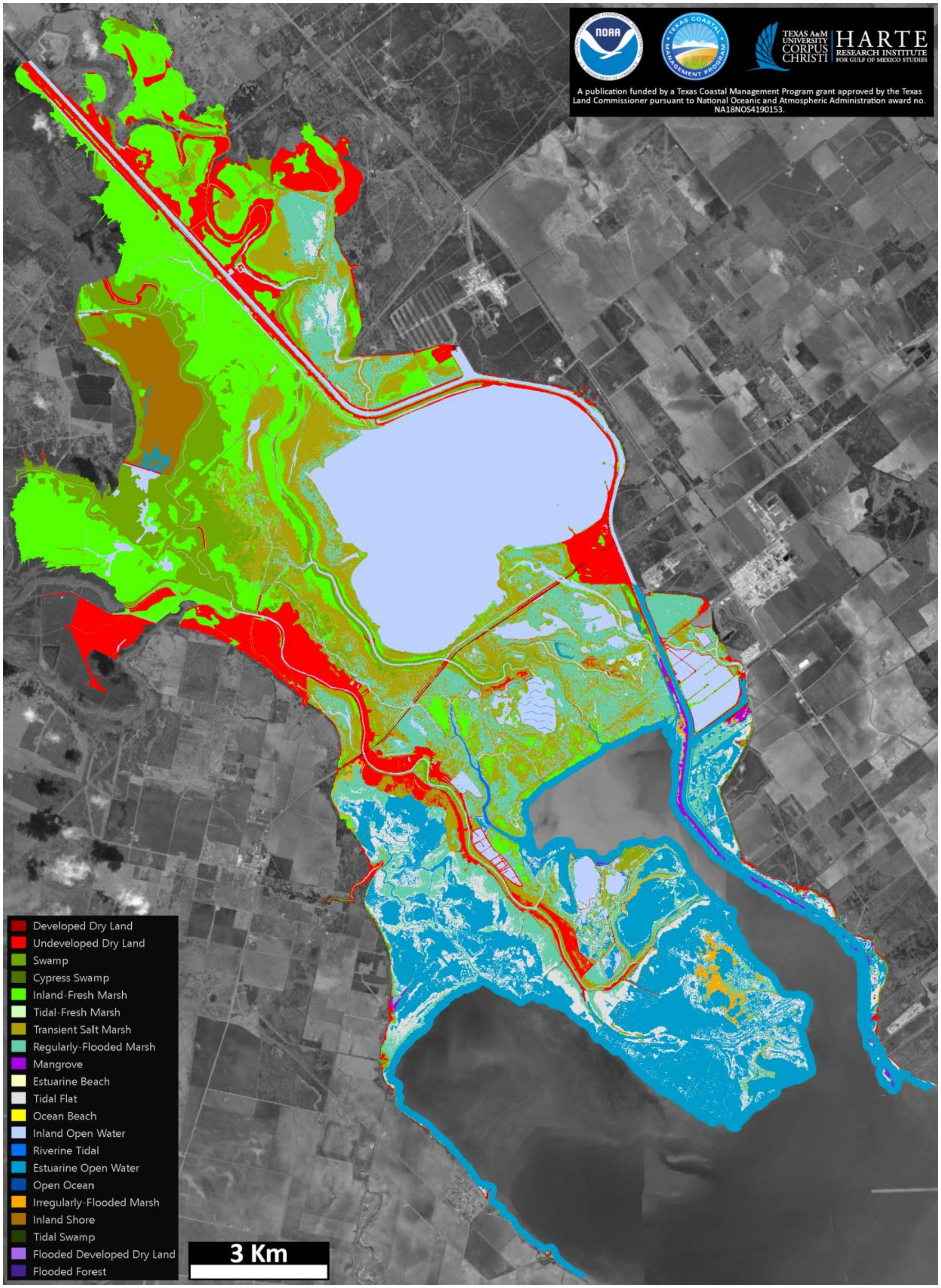

Figure 60—Guadalupe River bayhead delta @ 2060, 2.0 m GMSLR by 2100

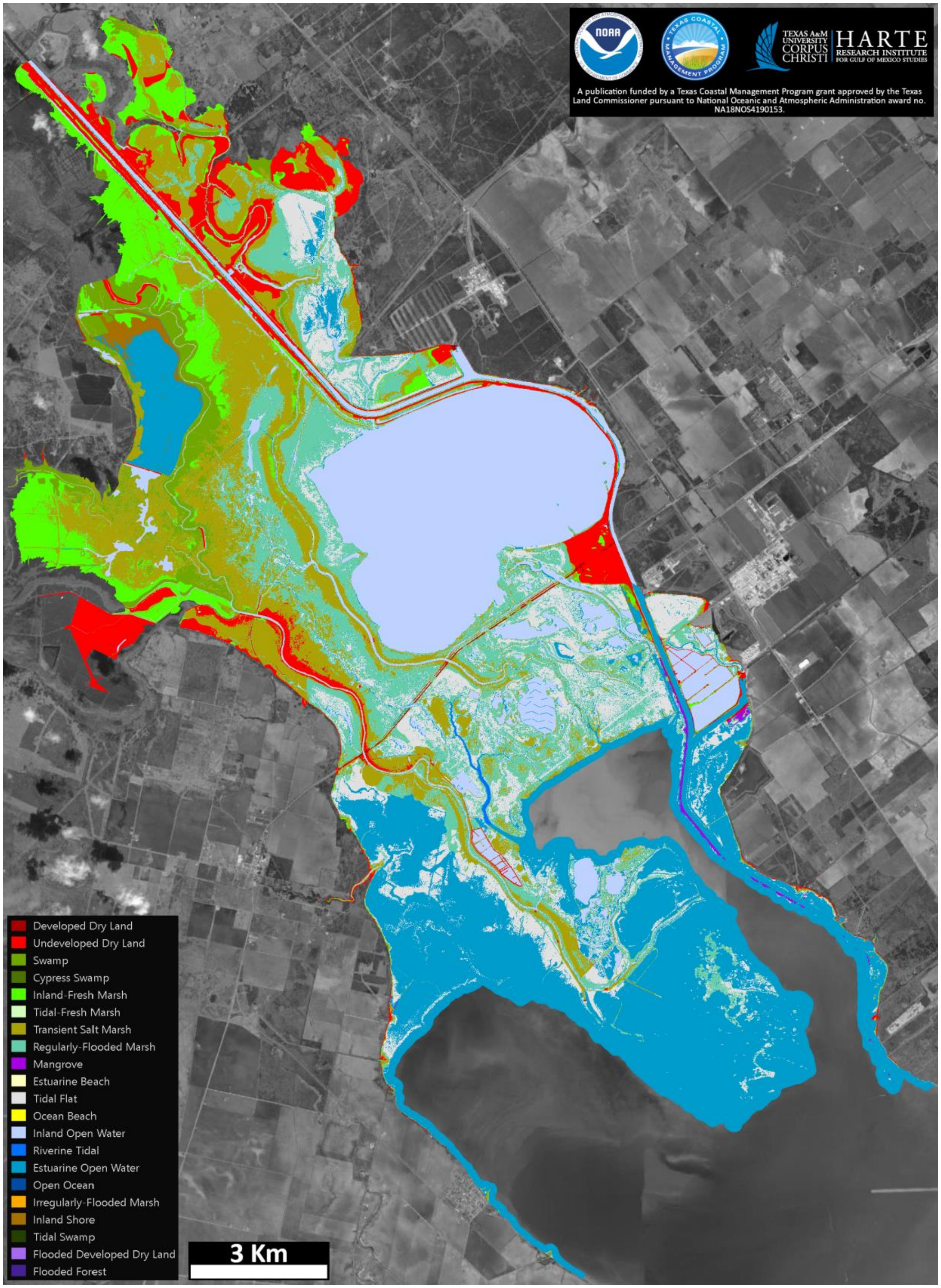

Figure 61—Guadalupe River bayhead delta @ 2080, 2.0 m GMSLR by 2100

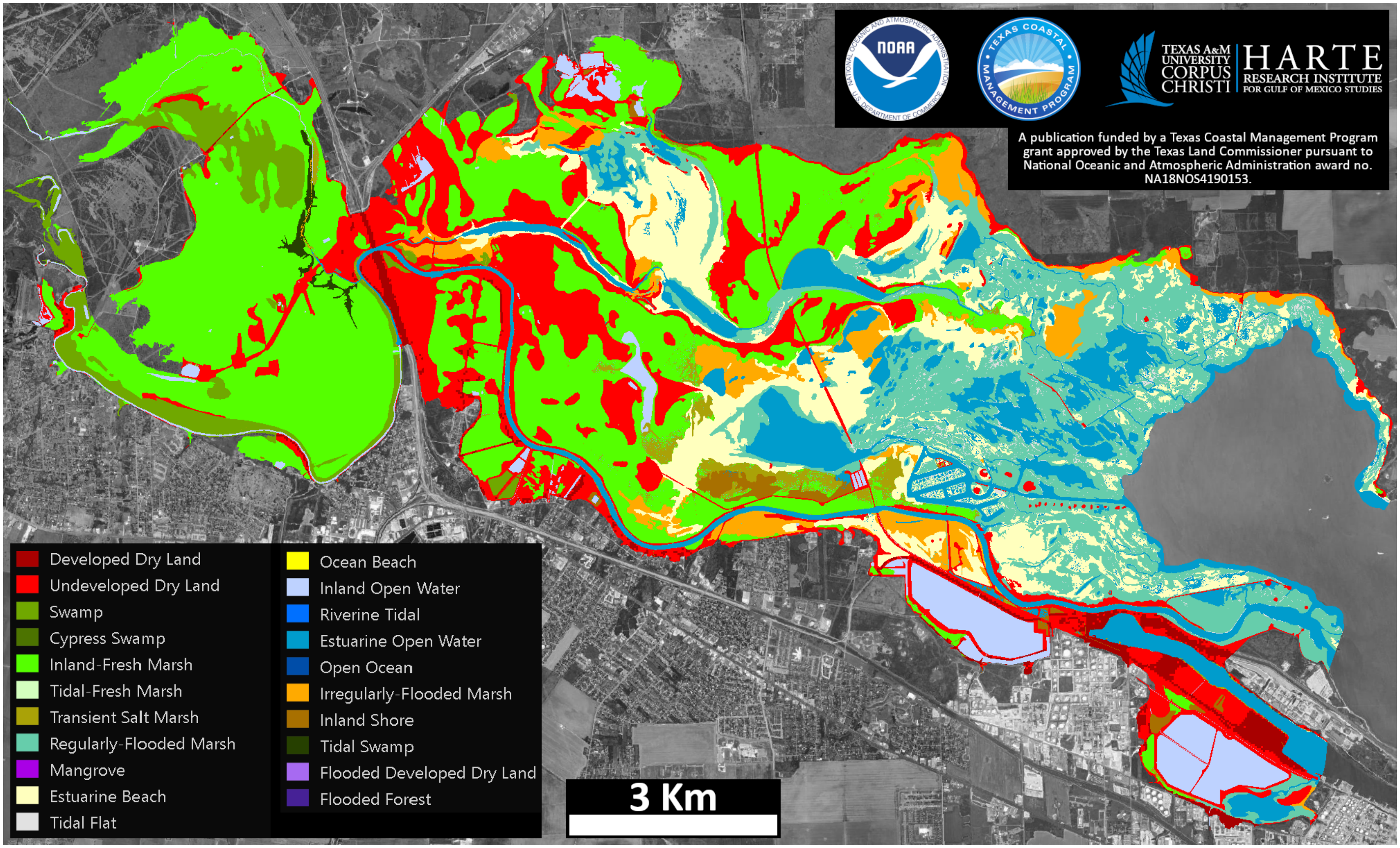

Figure 62—Nueces River bayhead delta @ 2019

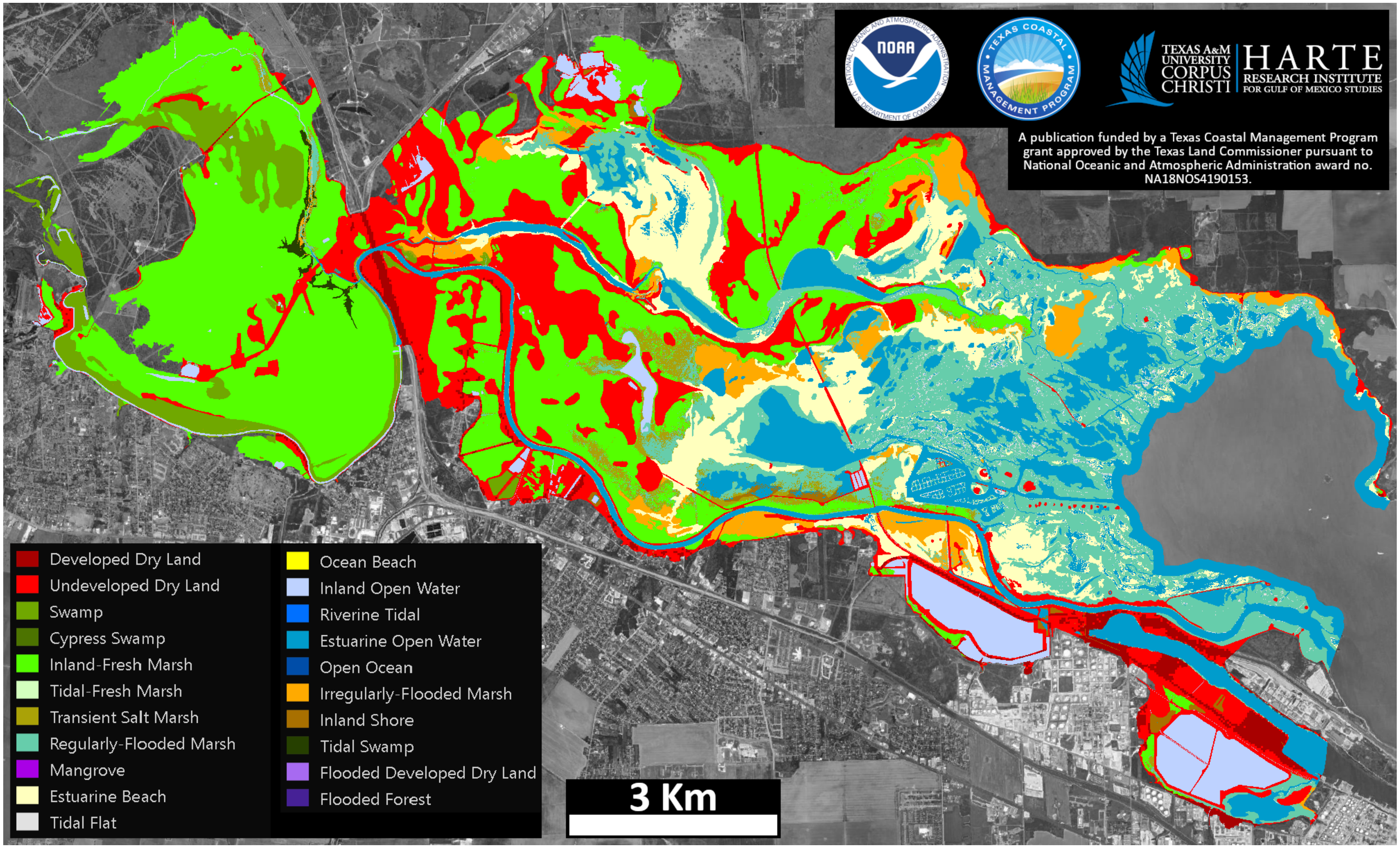

Figure 63—Nueces River bayhead delta @ 2040, 1.0 m GMSLR by 2100

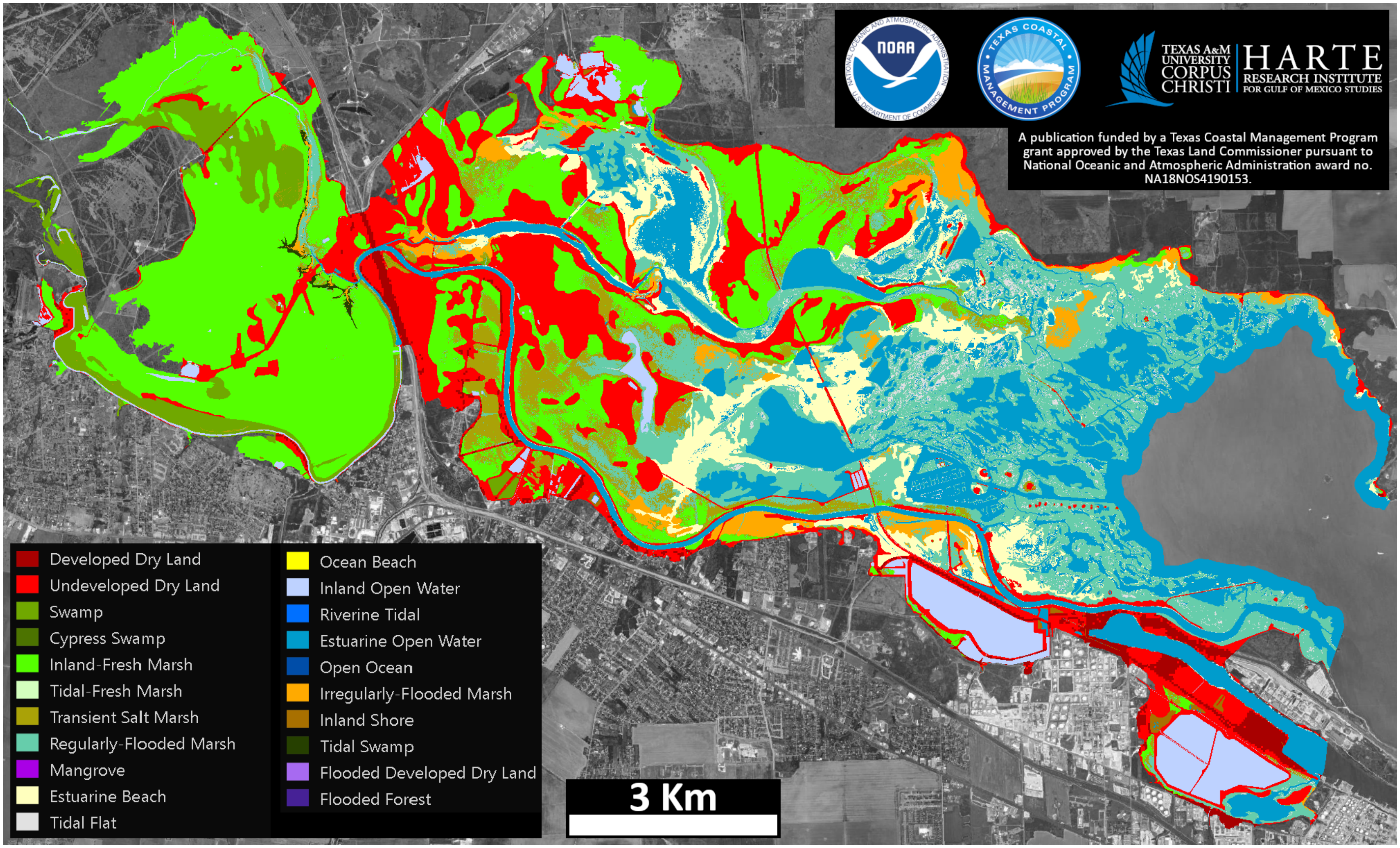

Figure 64—Nueces River bayhead delta @ 2060, 1.0 m GMSLR by 2100

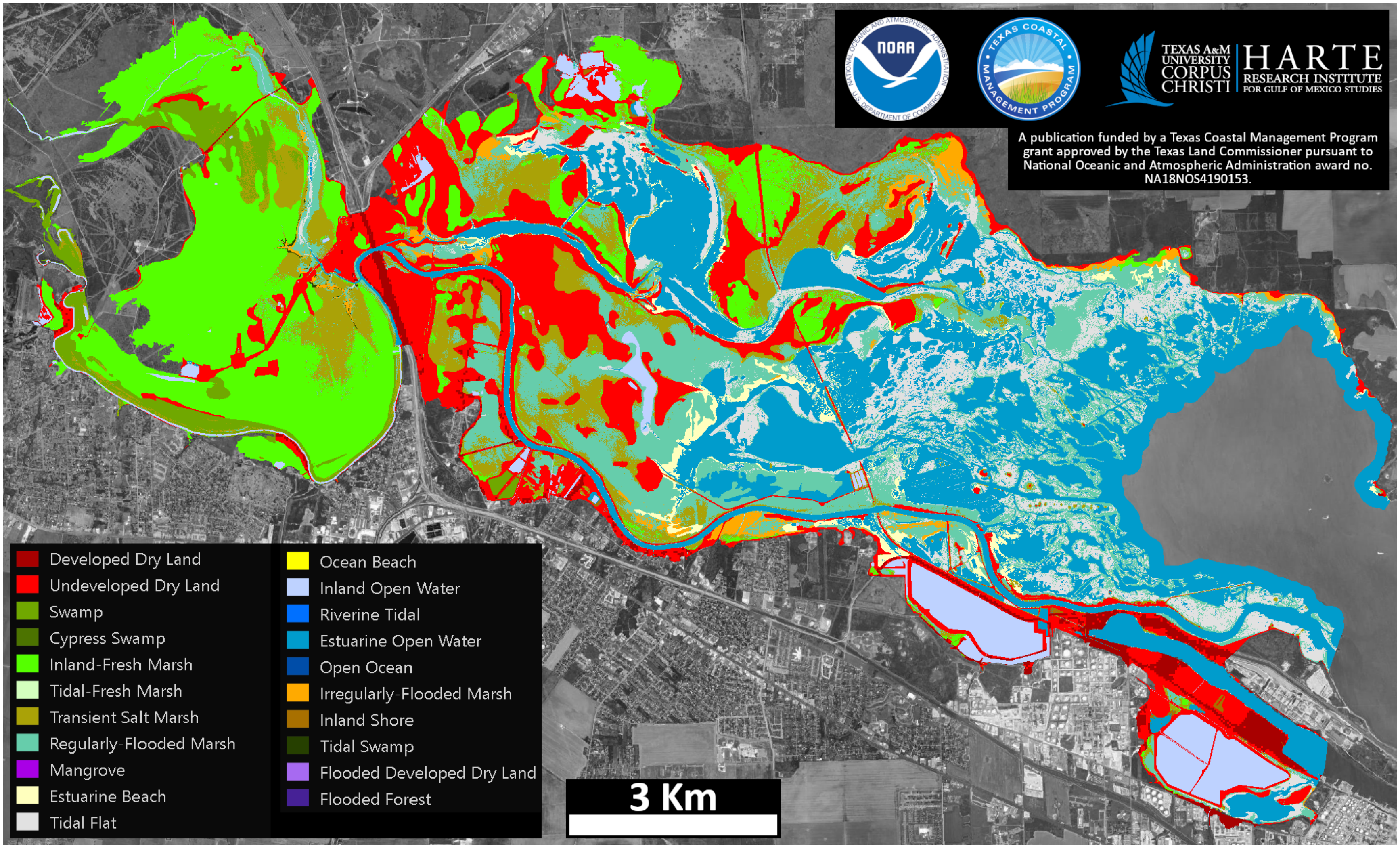

Figure 65—Nueces River bayhead delta @ 2080, 1.0 m GMSLR by 2100

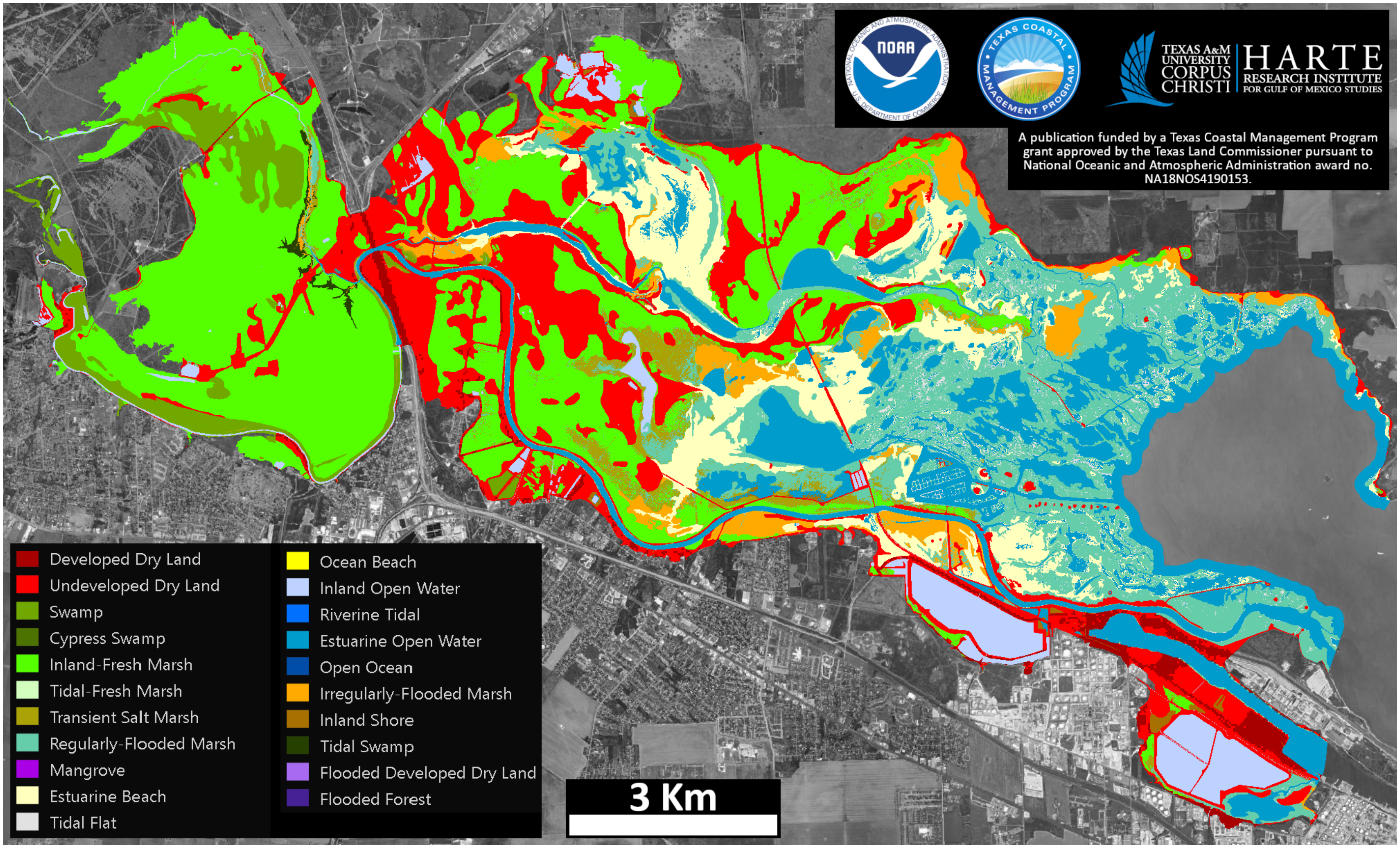

Figure 66—Nueces River bayhead delta @ 2040, 1.5 m GMSLR by 2100

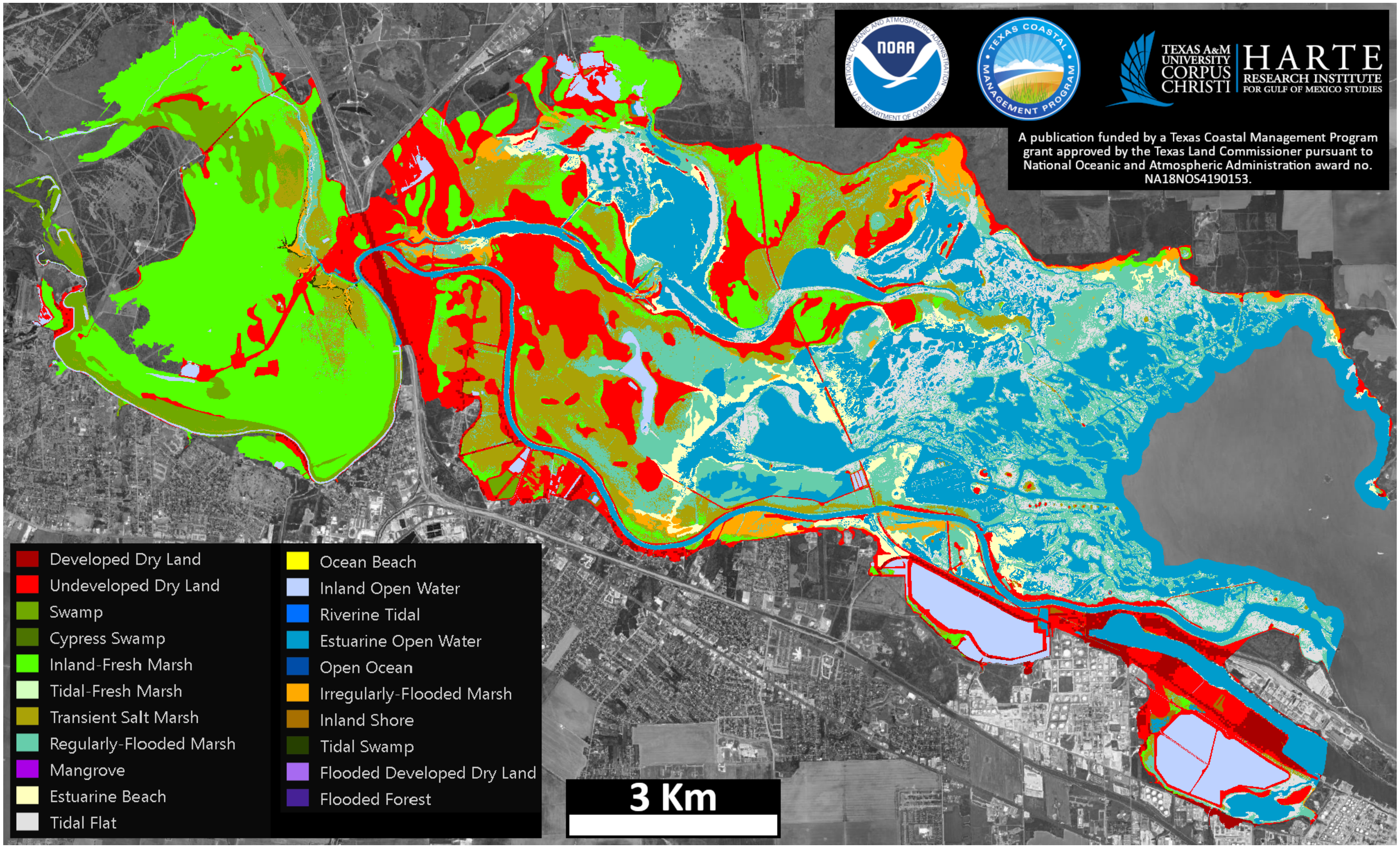

Figure 67—Nueces River bayhead delta @ 2060, 1.5 m GMSLR by 2100

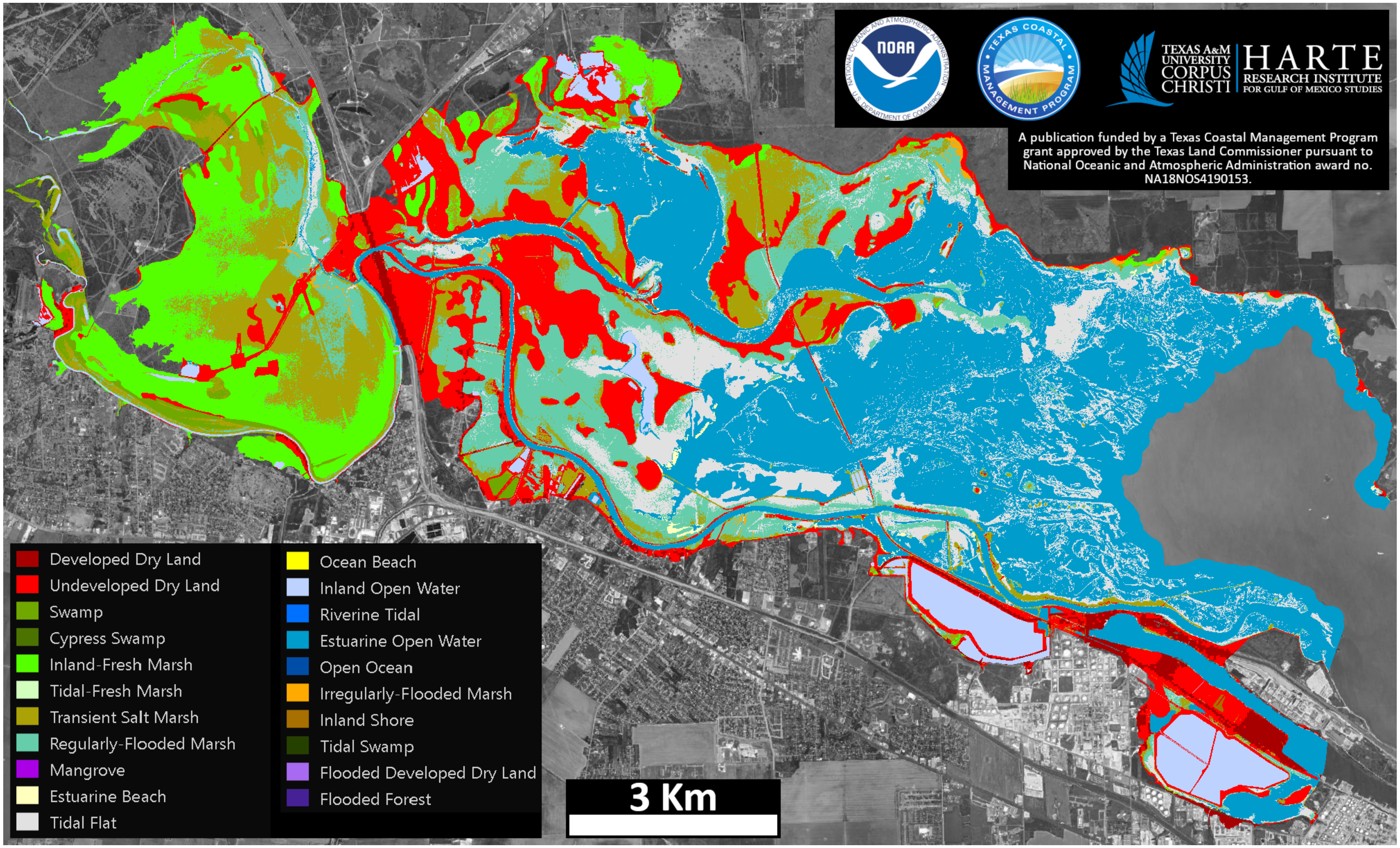

Figure 68—Nueces River bayhead delta @ 2080, 1.5 m GMSLR by 2100

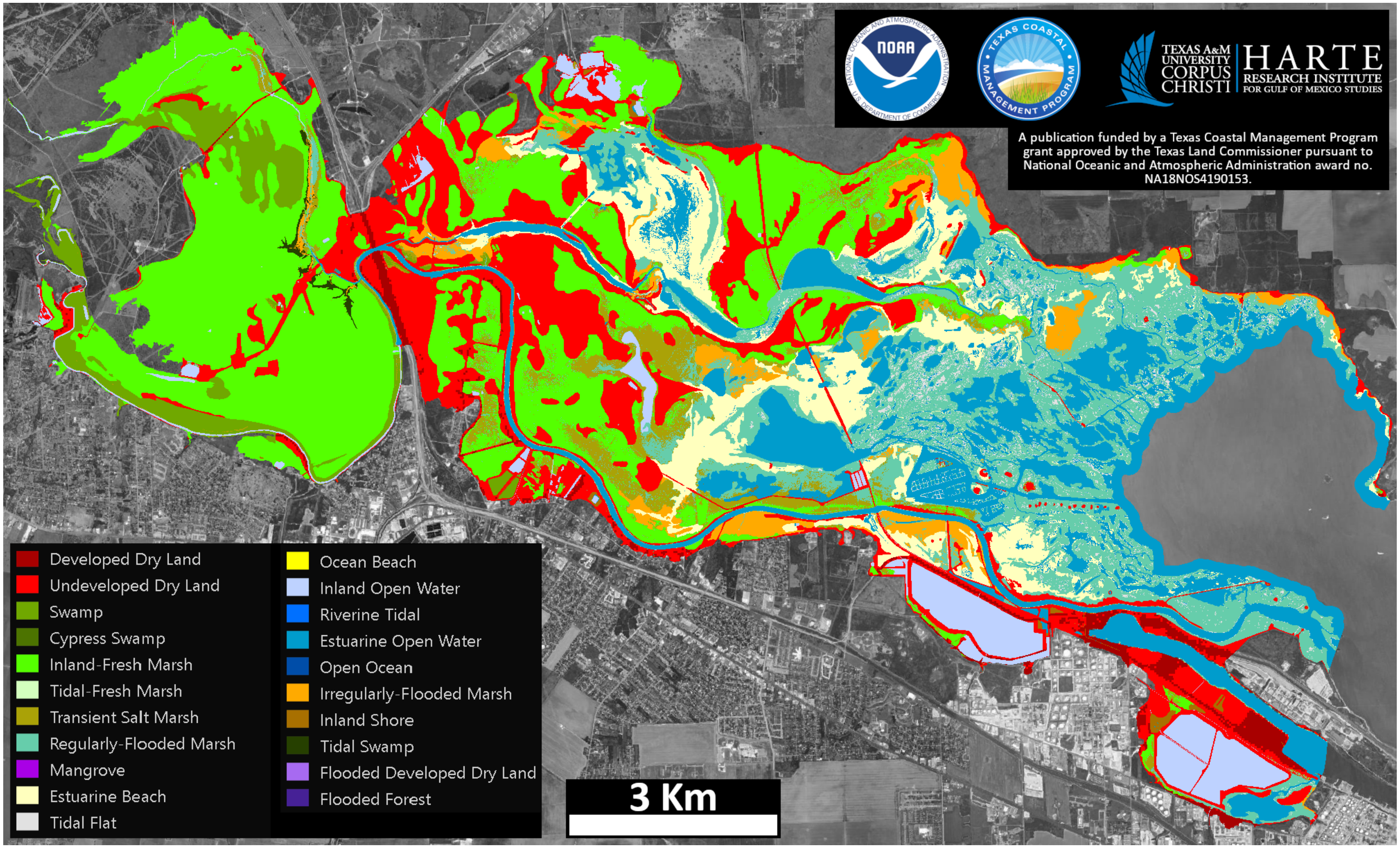

Figure 69—Nueces River bayhead delta @ 2040, 2.0 m GMSLR by 2100

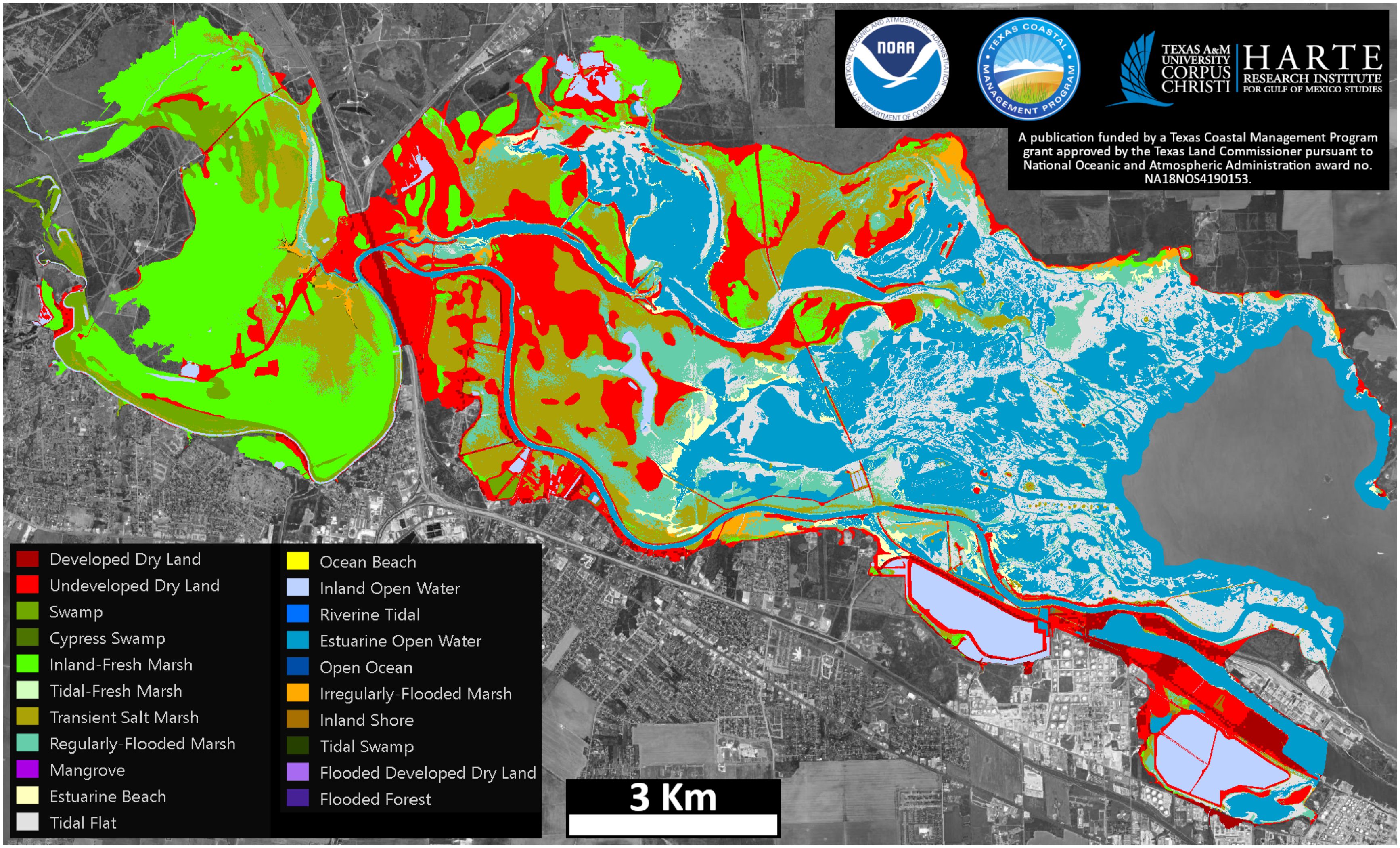

Figure 70—Nueces River bayhead delta @ 2060, 2.0 m GMSLR by 2100

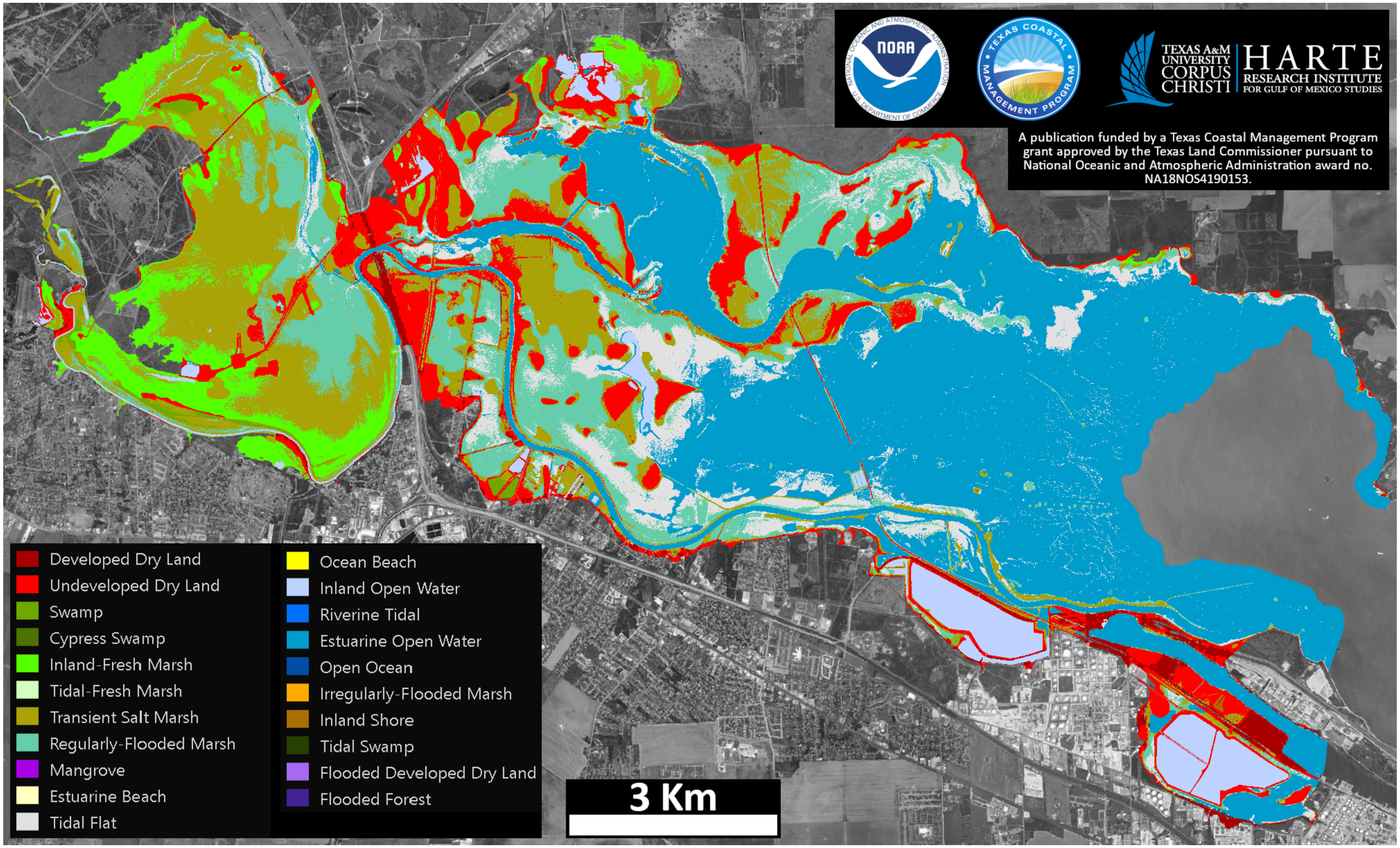

Figure 71—Nueces River bayhead delta @ 2080, 2.0 m GMSLR by 2100

Appendix B: SLAMM Landover Class Statistics

This appendix contains the complete, SLAMM landcover class statistics for the four bayhead delta systems in tabular format.

Table 11—Trinity bayhead delta SLAMM landcover class statistics

Upper panel is area in m^2 and lower panel is percentage area

SLAMM Class	Class Description		1.0 m GMSLR by 2100			1.5 m GMSLR by 2100			2.0 m GMSLR by 2100		
		2019	2040	2060	2080	2040	2060	2080	2040	2060	2080
1	Developed Dry Land	918,976	904,400	870,176	806,732	899,500	841,928	731,400	892,084	801,740	658,136
2	Undeveloped Dry Land	10,432,790	10,068,900	9,301,152	8,275,716	9,905,668	8,853,852	7,059,892	9,700,384	8,135,868	5,892,124
3	Swamp	28,916,610	27,567,990	25,554,250	22,658,390	27,099,920	24,290,740	18,181,480	26,526,890	21,778,900	14,438,590
4	Cypress Swamp	3,563,936	3,559,948	3,489,344	2,690,912	3,555,984	3,196,224	2,170,068	3,547,440	2,591,472	898,676
5	Inland-Fresh Marsh	15,235,250	14,189,980	9,814,180	4,865,548	13,333,510	6,872,132	2,298,740	12,059,000	4,133,380	1,329,060
6	Tidal-Fresh Marsh	16,207,670	15,951,850	15,349,270	14,078,280	15,755,850	14,457,920	8,019,940	15,473,500	12,140,720	1,402,468
7	Transitional Salt Marsh	2,076,064	1,910,736	5,992,588	7,586,456	3,245,388	9,037,268	11,290,040	5,161,568	12,966,450	11,145,580
8	Regularly-Flooded Marsh	5,001,716	8,159,848	12,963,750	25,039,700	9,057,844	16,736,400	27,036,890	9,846,980	18,244,320	40,374,610
9	Mangrove	73,764	71,960	67,404	61,588	70,776	61,932	45,820	68,692	54,116	21,608
10	Estuarine Beach	7,636	5,156	3,284	1,936	5,124	3,120	1,816	5,204	3,264	1,760
11	Tidal Flat	442,080	501,984	1,977,728	3,157,640	602,432	2,916,988	14,564,000	804,972	6,964,920	23,193,630
12	Ocean Beach	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
13	Ocean Flat	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
14	Rocky Intertidal	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
15	Inland Open Water	48,257,840	48,257,840	48,257,840	48,257,840	48,257,840	48,257,840	48,257,840	48,257,840	48,257,840	48,257,840
16	Riverine Tidal	10,491,260	10,491,260	10,491,260	10,491,260	10,491,260	10,491,260	10,491,260	10,491,260	10,491,260	10,491,260
17	Estuarine Open Water	19,192,190	20,654,940	21,108,670	22,091,220	20,673,890	21,372,880	24,643,840	20,714,470	22,157,450	29,438,460
18	Tidal Creek	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
19	Open Ocean	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
20	Irregularly Flooded Marsh	18,741,800	19,277,560	20,537,280	20,320,960	19,560,830	21,274,050	21,151,460	20,227,940	23,314,680	9,846,068
22	Inland Shore	103,784	80,916	63,980	49,656	77,356	54,020	40,548	72,760	48,136	30,336
23	Tidal Swamp	22,211,180	20,207,430	15,916,550	10,464,070	19,260,650	12,718,790	4,316,700	17,986,880	8,707,892	1,536,872
25	Flooded Developed Dry Land	10,732	20,792	54,172	116,544	25,692	82,420	191,876	33,108	122,608	265,140
26	Flooded Forest	188	4,176	74,780	873,212	8,140	367,900	1,394,056	16,684	972,652	2,665,448
	Total (m^2)	201,885,466	201,887,666	201,887,658	201,887,660	201,887,654	201,887,664	201,887,666	201,887,656	201,887,668	201,887,666

SLAMM Class	Class Description		1.0 m GMSLR by 2100			1.5 m GMSLR by 2100			2.0 m GMSLR by 2100		
		2019	2040	2060	2080	2040	2060	2080	2040	2060	2080
1	Developed Dry Land	0.46	0.45	0.43	0.40	0.45	0.42	0.36	0.44	0.40	0.33
2	Undeveloped Dry Land	5.17	4.99	4.61	4.10	4.91	4.39	3.50	4.80	4.03	2.92
3	Swamp	14.32	13.66	12.66	11.22	13.42	12.03	9.01	13.14	10.79	7.15
4	Cypress Swamp	1.77	1.76	1.73	1.33	1.76	1.58	1.07	1.76	1.28	0.45
5	Inland-Fresh Marsh	7.55	7.03	4.86	2.41	6.60	3.40	1.14	5.97	2.05	0.66
6	Tidal-Fresh Marsh	8.03	7.90	7.60	6.97	7.80	7.16	3.97	7.66	6.01	0.69
7	Transitional Salt Marsh	1.03	0.95	2.97	3.76	1.61	4.48	5.59	2.56	6.42	5.52
8	Regularly-Flooded Marsh	2.48	4.04	6.42	12.40	4.49	8.29	13.39	4.88	9.04	20.00
9	Mangrove	0.04	0.04	0.03	0.03	0.04	0.03	0.02	0.03	0.03	0.01
10	Estuarine Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	Tidal Flat	0.22	0.25	0.98	1.56	0.30	1.44	7.21	0.40	3.45	11.49
12	Ocean Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Ocean Flat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Inland Open Water	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90	23.90
16	Riverine Tidal	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20	5.20
17	Estuarine Open Water	9.51	10.23	10.46	10.94	10.24	10.59	12.21	10.26	10.98	14.58
18	Tidal Creek	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Open Ocean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Irregularly Flooded Marsh	9.28	9.55	10.17	10.07	9.69	10.54	10.48	10.02	11.55	4.88
22	Inland Shore	0.05	0.04	0.03	0.02	0.04	0.03	0.02	0.04	0.02	0.02
23	Tidal Swamp	11.00	10.01	7.88	5.18	9.54	6.30	2.14	8.91	4.31	0.76
25	Flooded Developed Dry Land	0.01	0.01	0.03	0.06	0.01	0.04	0.10	0.02	0.06	0.13
26	Flooded Forest	0.00	0.00	0.04	0.43	0.00	0.18	0.69	0.01	0.48	1.32
	Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 12—Lavaca-Navidad bayhead delta SLAMM landcover class statistics

Upper panel is area in m^2 and lower panel is percentage area

SLAMM Class	Class Description	2019	1.0 m GMSLR by 2100 2040	1.0 m GMSLR by 2100 2060	1.0 m GMSLR by 2100 2080	1.5 m GMSLR by 2100 2040	1.5 m GMSLR by 2100 2060	1.5 m GMSLR by 2100 2080	2.0 m GMSLR by 2100 2040	2.0 m GMSLR by 2100 2060	2.0 m GMSLR by 2100 2080
1	Developed Dry Land	88,200	83,560	75,976	64,596	83,132	71,684	56,820	82,316	67,044	48,692
2	Undeveloped Dry Land	7,765,884	7,449,076	6,948,552	5,455,192	7,416,152	6,546,840	3,432,168	7,350,288	5,921,816	1,884,384
3	Swamp	1,176,412	811,296	296,712	65,716	734,604	163,608	17,356	628,996	91,536	2,508
4	Cypress Swamp	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
5	Inland-Fresh Marsh	2,788,560	1,718,016	571,488	114,360	1,493,652	273,968	53,352	1,179,860	140,304	17,236
6	Tidal-Fresh Marsh	308,660	279,828	188,032	33,356	271,428	100,168	6,400	257,204	39,556	1,752
7	Transitional Salt Marsh	381,356	1,922,964	3,711,644	3,686,536	2,248,424	3,868,112	3,681,952	2,714,164	3,761,756	4,063,628
8	Regularly-Flooded Marsh	13,705,570	13,202,400	17,445,270	8,716,672	13,698,490	14,315,140	5,657,620	15,446,970	12,011,740	4,152,684
9	Mangrove	12,648	7,488	948	<Null>	5,956	20	<Null>	3,912	<Null>	<Null>
10	Estuarine Beach	2,594,752	1,403,712	401,840	95,356	1,200,576	171,384	5,008	931,992	120,092	<Null>
11	Tidal Flat	183,480	567,004	2,369,180	16,560,500	1,036,752	10,050,100	14,326,320	1,860,280	15,178,440	11,995,350
12	Ocean Beach	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
13	Ocean Flat	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
14	Rocky Intertidal	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
15	Inland Open Water	55,856	55,856	55,856	55,856	55,856	55,856	55,856	55,856	55,856	55,856
16	Riverine Tidal	469,724	469,724	469,724	469,724	469,724	469,724	469,724	469,724	469,724	469,724
17	Estuarine Open Water	18,257,050	21,121,080	24,018,330	27,847,190	21,457,040	25,130,020	35,928,420	21,839,060	25,379,280	41,041,180
18	Tidal Creek	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
19	Open Ocean	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
20	Irregularly Flooded Marsh	15,920,540	14,648,330	7,199,024	597,704	13,571,110	2,540,584	76,560	10,924,900	524,016	36,656
22	Inland Shore	16,196	8,476	4,252	796	7,664	2,496	324	6,772	1,216	156
23	Tidal Swamp	29,364	22,252	14,228	7,512	20,508	11,360	3,176	18,772	8,696	1,252
25	Flooded Developed Dry Land	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
26	Flooded Forest	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	Total (m^2)	63,754,252	63,771,062	63,771,056	63,771,066	63,771,068	63,771,064	63,771,056	63,771,066	63,771,072	63,771,058

SLAMM Class	Class Description	2019	1.0 m GMSLR by 2100 2040	1.0 m GMSLR by 2100 2060	1.0 m GMSLR by 2100 2080	1.5 m GMSLR by 2100 2040	1.5 m GMSLR by 2100 2060	1.5 m GMSLR by 2100 2080	2.0 m GMSLR by 2100 2040	2.0 m GMSLR by 2100 2060	2.0 m GMSLR by 2100 2080
1	Developed Dry Land	0.14	0.13	0.12	0.10	0.13	0.11	0.09	0.13	0.11	0.08
2	Undeveloped Dry Land	12.18	11.68	10.90	8.55	11.63	10.27	5.38	11.53	9.29	2.95
3	Swamp	1.85	1.27	0.47	0.10	1.15	0.26	0.03	0.99	0.14	0.00
4	Cypress Swamp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Inland-Fresh Marsh	4.37	2.69	0.90	0.18	2.34	0.43	0.08	1.85	0.22	0.03
6	Tidal-Fresh Marsh	0.48	0.44	0.29	0.05	0.43	0.16	0.01	0.40	0.06	0.00
7	Transitional Salt Marsh	0.60	3.02	5.82	5.78	3.53	6.07	5.77	4.26	5.90	6.37
8	Regularly-Flooded Marsh	21.50	20.70	27.36	13.67	21.48	22.45	8.87	24.22	18.84	6.51
9	Mangrove	0.02	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00
10	Estuarine Beach	4.07	2.20	0.63	0.15	1.88	0.27	0.01	1.46	0.19	0.00
11	Tidal Flat	0.29	0.89	3.72	25.97	1.63	15.76	22.47	2.92	23.80	18.81
12	Ocean Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Ocean Flat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Inland Open Water	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
16	Riverine Tidal	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74	0.74
17	Estuarine Open Water	28.64	33.12	37.66	43.67	33.65	39.41	56.34	34.25	39.80	64.36
18	Tidal Creek	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Open Ocean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Irregularly Flooded Marsh	24.97	22.97	11.29	0.94	21.28	3.98	0.12	17.13	0.82	0.06
22	Inland Shore	0.03	0.01	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00
23	Tidal Swamp	0.05	0.03	0.02	0.01	0.03	0.02	0.00	0.03	0.01	0.00
25	Flooded Developed Dry Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Flooded Forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 13—Guadalupe bayhead delta SLAMM landcover class statistics

Upper panel is area in m^2 and lower panel is percentage area

			1.0 m GMSLR by 2100			1.5 m GMSLR by 2100			2.0 m GMSLR by 2100		
SLAMM Class	Class Description	2019	2040	2060	2080	2040	2060	2080	2040	2060	2080
1	Developed Dry Land	305,128	297,088	276,864	244,804	291,256	265,176	191,932	284,528	242,548	160,664
2	Undeveloped Dry Land	19,386,430	19,192,440	18,811,920	17,098,330	19,097,730	18,226,910	14,263,230	19,008,480	17,003,460	11,596,520
3	Swamp	20,501,820	19,308,450	16,617,130	13,614,040	18,815,860	15,036,300	10,360,340	18,089,940	13,447,860	6,301,068
4	Cypress Swamp	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
5	Inland-Fresh Marsh	58,635,620	51,649,390	39,137,250	28,335,430	48,753,480	32,399,270	18,986,700	44,707,940	27,070,860	10,740,320
6	Tidal-Fresh Marsh	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
7	Transitional Salt Marsh	1,805,224	7,202,904	14,250,100	14,321,860	10,508,590	19,726,270	21,041,180	15,259,830	23,044,660	27,946,070
8	Regularly-Flooded Marsh	13,241,240	15,839,570	15,276,740	17,093,590	14,943,860	16,616,280	22,129,140	12,618,030	20,752,680	24,801,680
9	Mangrove	1,059,264	883,208	765,216	619,228	870,088	683,804	480,172	847,180	606,432	331,376
10	Estuarine Beach	2,606,364	1,715,344	220,996	61,436	1,225,004	97,508	4,040	722,492	62,704	492
11	Tidal Flat	1,029,336	1,747,932	11,625,440	14,452,070	3,720,896	13,079,370	15,697,450	7,294,144	10,964,210	19,690,210
12	Ocean Beach	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
13	Ocean Flat	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
14	Rocky Intertidal	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
15	Inland Open Water	34,625,990	34,625,580	34,623,860	34,620,610	34,625,580	34,623,860	34,620,610	34,625,580	34,623,860	34,620,610
16	Riverine Tidal	139,592	139,592	139,592	139,592	139,592	139,592	139,592	139,592	139,592	139,592
17	Estuarine Open Water	16,337,800	19,365,220	24,482,280	38,325,330	20,082,240	27,277,680	43,478,530	20,860,000	31,141,280	46,731,160
18	Tidal Creek	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
19	Open Ocean	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
20	Irregularly Flooded Marsh	9,809,224	7,687,868	3,506,292	1,066,900	6,590,468	1,608,936	135,028	5,219,592	917,052	14,728
22	Inland Shore	4,428,044	4,256,492	4,177,380	3,917,848	4,246,436	4,130,112	2,383,128	4,233,740	3,893,872	836,588
23	Tidal Swamp	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
25	Flooded Developed Dry Land	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
26	Flooded Forest	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	Total (m^2)	183,911,076	183,911,078	183,911,060	183,911,068	183,911,080	183,911,068	183,911,072	183,911,068	183,911,070	183,911,078

			1.0 m GMSLR by 2100			1.5 m GMSLR by 2100			2.0 m GMSLR by 2100		
SLAMM Class	Class Description	2019	2040	2060	2080	2040	2060	2080	2040	2060	2080
1	Developed Dry Land	0.17	0.16	0.15	0.13	0.16	0.14	0.10	0.15	0.13	0.09
2	Undeveloped Dry Land	10.54	10.44	10.23	9.30	10.38	9.91	7.76	10.34	9.25	6.31
3	Swamp	11.15	10.50	9.04	7.40	10.23	8.18	5.63	9.84	7.31	3.43
4	Cypress Swamp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Inland-Fresh Marsh	31.88	28.08	21.28	15.41	26.51	17.62	10.32	24.31	14.72	5.84
6	Tidal-Fresh Marsh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Transitional Salt Marsh	0.98	3.92	7.75	7.79	5.71	10.73	11.44	8.30	12.53	15.20
8	Regularly-Flooded Marsh	7.20	8.61	8.31	9.29	8.13	9.03	12.03	6.86	11.28	13.49
9	Mangrove	0.58	0.48	0.42	0.34	0.47	0.37	0.26	0.46	0.33	0.18
10	Estuarine Beach	1.42	0.93	0.12	0.03	0.67	0.05	0.00	0.39	0.03	0.00
11	Tidal Flat	0.56	0.95	6.32	7.86	2.02	7.11	8.54	3.97	5.96	10.71
12	Ocean Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Ocean Flat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Inland Open Water	18.83	18.83	18.83	18.82	18.83	18.83	18.82	18.83	18.83	18.82
16	Riverine Tidal	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
17	Estuarine Open Water	8.88	10.53	13.31	20.84	10.92	14.83	23.64	11.34	16.93	25.41
18	Tidal Creek	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Open Ocean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Irregularly Flooded Marsh	5.33	4.18	1.91	0.58	3.58	0.87	0.07	2.84	0.50	0.01
22	Inland Shore	2.41	2.31	2.27	2.13	2.31	2.25	1.30	2.30	2.12	0.45
23	Tidal Swamp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Flooded Developed Dry Land	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Flooded Forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 14—Nueces bayhead delta SLAMM landcover class statistics

Upper panel is area in m^2 and lower panel is percentage area

SLAMM Class	Class Description	2019	1.0 m GMSLR by 2100			1.5 m GMSLR by 2100			2.0 m GMSLR by 2100		
			2040	2060	2080	2040	2060	2080	2040	2060	2080
1	Developed Dry Land	1,697,724	1,688,234	1,681,248	1,662,969	1,686,609	1,672,797	1,608,787	1,684,779	1,660,205	1,423,636
2	Undeveloped Dry Land	15,341,920	15,233,820	15,078,970	14,644,710	15,207,340	14,872,240	13,588,970	15,173,550	14,594,480	9,671,492
3	Swamp	3,325,980	3,258,499	3,084,993	2,374,836	3,226,556	2,749,460	1,126,254	3,187,764	2,243,019	404,890
4	Cypress Swamp	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
5	Inland-Fresh Marsh	29,396,790	27,703,250	23,373,980	15,953,290	26,918,440	18,171,030	9,697,365	25,794,950	14,788,480	5,061,840
6	Tidal-Fresh Marsh	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
7	Transitional Salt Marsh	1,304,508	1,641,336	4,251,316	8,230,128	2,428,978	9,094,631	10,870,300	3,548,498	12,087,560	15,844,920
8	Regularly-Flooded Marsh	13,853,870	14,397,210	15,984,000	14,044,120	14,285,390	12,320,130	11,843,030	14,166,540	8,145,880	13,778,090
9	Mangrove	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
10	Estuarine Beach	9,483,496	8,237,502	5,909,035	1,707,850	7,802,865	3,013,472	253,260	7,320,884	1,362,043	31,966
11	Tidal Flat	643,124	757,984	1,448,031	7,891,753	1,054,762	6,313,925	9,667,546	1,500,849	11,040,760	7,404,383
12	Ocean Beach	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
13	Ocean Flat	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
14	Rocky Intertidal	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
15	Inland Open Water	3,990,472	3,990,473	3,990,473	3,990,473	3,990,473	3,990,473	3,990,473	3,990,473	3,990,473	3,990,473
16	Riverine Tidal	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
17	Estuarine Open Water	11,154,770	13,927,140	17,369,350	23,264,220	14,549,760	21,074,020	32,185,340	15,215,550	24,150,270	37,276,050
18	Tidal Creek	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
19	Open Ocean	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
20	Irregularly Flooded Marsh	4,112,592	3,848,183	2,732,696	1,305,916	3,631,755	1,747,263	262,265	3,259,599	1,021,411	37,194
22	Inland Shore	658,652	321,248	185,475	102,554	243,883	134,167	55,125	207,304	96,770	41,299
23	Tidal Swamp	275,728	225,665	134,105	32,750	202,112	61,613	2,670	176,356	21,278	<Null>
25	Flooded Developed Dry Land	18,700	27,924	34,801	52,903	29,550	43,252	107,085	31,380	55,844	292,236
26	Flooded Forest	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>	<Null>
	Total (m^2)	95,258,326	95,258,469	95,258,473	95,258,472	95,258,473	95,258,472	95,258,470	95,258,476	95,258,472	95,258,469

SLAMM Class	Class Description	2019	1.0 m GMSLR by 2100			1.5 m GMSLR by 2100			2.0 m GMSLR by 2100		
			2040	2060	2080	2040	2060	2080	2040	2060	2080
1	Developed Dry Land	1.78	1.77	1.76	1.75	1.77	1.76	1.69	1.77	1.74	1.49
2	Undeveloped Dry Land	16.11	15.99	15.83	15.37	15.96	15.61	14.27	15.93	15.32	10.15
3	Swamp	3.49	3.42	3.24	2.49	3.39	2.89	1.18	3.35	2.35	0.43
4	Cypress Swamp	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	Inland-Fresh Marsh	30.86	29.08	24.54	16.75	28.26	19.08	10.18	27.08	15.52	5.31
6	Tidal-Fresh Marsh	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	Transitional Salt Marsh	1.37	1.72	4.46	8.64	2.55	9.55	11.41	3.73	12.69	16.63
8	Regularly-Flooded Marsh	14.54	15.11	16.78	14.74	15.00	12.93	12.43	14.87	8.55	14.46
9	Mangrove	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	Estuarine Beach	9.96	8.65	6.20	1.79	8.19	3.16	0.27	7.69	1.43	0.03
11	Tidal Flat	0.68	0.80	1.52	8.28	1.11	6.63	10.15	1.58	11.59	7.77
12	Ocean Beach	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Ocean Flat	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	Inland Open Water	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19	4.19
16	Riverine Tidal	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
17	Estuarine Open Water	11.71	14.62	18.23	24.42	15.27	22.12	33.79	15.97	25.35	39.13
18	Tidal Creek	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
19	Open Ocean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Irregularly Flooded Marsh	4.32	4.04	2.87	1.37	3.81	1.83	0.28	3.42	1.07	0.04
22	Inland Shore	0.69	0.34	0.19	0.11	0.26	0.14	0.06	0.22	0.10	0.04
23	Tidal Swamp	0.29	0.24	0.14	0.03	0.21	0.06	0.00	0.19	0.02	0.00
25	Flooded Developed Dry Land	0.02	0.03	0.04	0.06	0.03	0.05	0.11	0.03	0.06	0.31
26	Flooded Forest	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Appendix C: Summarized Landcover Class Statistics by Thematic Environmental Class (TEC)

This appendix contains the SLAMM landcover class statistics for the four bayhead delta systems, but summarized into thematic environmental classes (TEC) in tabular format as defined in Table 8.

Table 15—Summarized area percentage values for thematic environmental classes (TEC)

			1.0 m GMSLR by 2100 scenario			1.5 m GMSLR by 2100 scenario			2.0 m GMSLR by 2100 scenario		
	Thematic environmental class	**2019**	**2040**	**2060**	**2080**	**2040**	**2060**	**2080**	**2040**	**2060**	**2080**
Trinity	Upland	5.63	5.45	5.10	4.99	5.37	5.03	4.64	5.27	4.97	4.70
	Freshwater, non-tidal	23.64	22.45	19.25	14.97	21.79	17.02	11.22	20.87	14.12	8.26
	Saltwater and brackish tidal marshes	31.86	32.48	35.08	38.41	33.16	36.80	35.59	34.06	37.36	31.86
	Beaches and flats	0.27	0.29	1.01	1.59	0.34	1.47	7.23	0.44	3.48	11.50
	Open water	38.61	39.33	39.56	40.04	39.34	39.69	41.31	39.36	40.08	43.68
Lavaca-Navidad	Upland	12.32	11.81	11.02	8.66	11.76	10.38	5.47	11.66	9.39	3.03
	Freshwater, non-tidal	6.22	3.97	1.36	0.28	3.49	0.69	0.11	2.84	0.36	0.03
	Saltwater and brackish tidal marshes	47.62	47.17	44.78	20.45	46.75	32.67	14.78	46.05	25.63	12.95
	Beaches and flats	4.38	3.10	4.35	26.12	3.52	16.03	22.47	4.39	23.99	18.81
	Open water	29.46	33.94	38.49	44.49	34.47	40.23	57.16	35.07	40.62	65.18
Guadalupe	Upland	10.71	10.60	10.38	9.43	10.54	10.05	7.86	10.49	9.38	6.39
	Freshwater, non-tidal	43.03	38.58	30.32	22.81	36.74	25.79	15.96	34.15	22.03	9.27
	Saltwater and brackish tidal marshes	14.09	17.19	18.38	18.00	17.90	21.01	23.81	18.46	24.64	28.87
	Beaches and flats	4.38	4.20	8.71	10.02	5.00	9.41	9.83	6.66	8.11	11.16
	Open water	27.79	29.43	32.21	39.74	29.82	33.73	42.54	30.25	35.84	44.31
Nueces	Upland	17.91	17.79	17.63	17.17	17.77	17.41	16.07	17.73	17.12	11.95
	Freshwater, non-tidal	34.35	32.50	27.78	19.24	31.65	21.96	11.36	30.43	17.88	5.74
	Saltwater and brackish tidal marshes	20.52	21.11	24.25	24.79	21.57	24.38	24.12	22.20	22.34	31.14
	Beaches and flats	11.32	9.78	7.92	10.19	9.55	9.93	10.47	9.48	13.12	7.85
	Open water	15.90	18.81	22.42	28.61	19.46	26.31	37.98	20.16	29.54	43.32