GCPO Ecological Assessment - Gulf Coast Estuarine Tidal Marsh

Introduction to the GCPO LCC Gulf Coast subgeography

The GCPO LCC subgeographic construct for the Gulf Coast was developed by combining the western portion of the Southern Coastal Plain classification of the [Omernik Level III Ecoregions] layer (Omernik 1987) with the southern geographic extent of the Mississippi Alluvial Valley (MAV) Bird Conservation Region (BCR 26) developed by the [North American Bird Conservation Initiative (NABCI)] (**Figure TM.1**). The Omernik Level III ecoregion class Southern Coastal Plain is characterized by low-elevation flat coastal plain, coastal marsh and lowlands, and coastal barrier islands (EPA 2013). In defining the GCPO LCC Gulf Coast subgeographic construct, the Omernik Level III Southern Coastal Plain classification was bound on the eastern side by the eastern GCPO LCC boundary and on the western side by the western extent of the Southern Coastal Plain ecoregion. To facilitate operational effectiveness for GCPO partners operating along the Gulf Coast, the western extent was then merged with the southern portion of the MAV, and extends from the southern boundary of the GCPO LCC to the northern extent of the Omernik Southern Coastal Plain ecoregion, and to the western extent of the MAV BCR. The western portion of the Gulf Coast subgeography coincides with the portions of the Louisiana Deltaic plain in southeast Louisiana that are included in the GCPO LCC geography. The Gulf Coast subgeography therefore combines geographic elements of the Southern Coastal Plain, southern Mississippi Alluvial Valley, and Louisiana Deltaic Plain into a single construct.

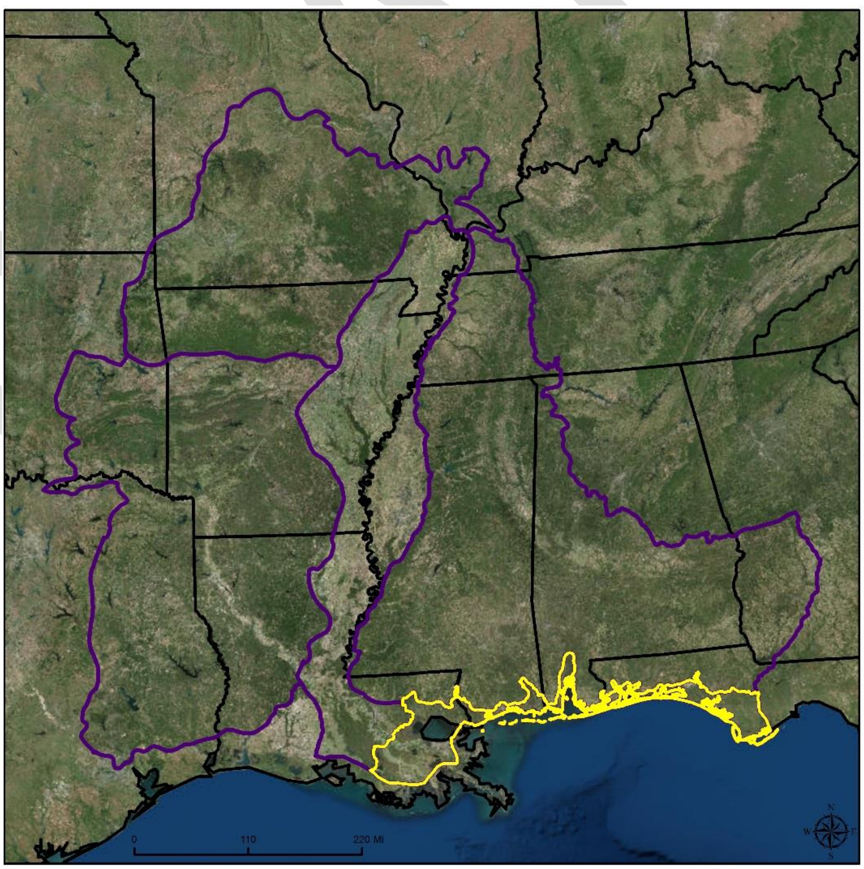

Figure TM.1. The Gulf Coast subgeographic construct (outlined in yellow) of the Gulf Coastal Plains and Ozarks LCC.

Introduction to Gulf Coast Estuarine Tidal Marsh

The Gulf of Mexico is estimated to contain nearly half of all U.S. salt marsh systems. Coastal wetlands are rapidly disappearing within some Gulf States, particularly in areas of coastal Louisiana and other states experiencing high rates of subsidence (Stedman and Dahl 2008, Couvillion et al. 2011). Coastal wetland systems provide crucial habitat for myriad wildlife species, and their filtration and natural barrier capabilities are key players in Gulf water quality and security of inland coastal areas (Handley et al. in prep). Coastal wetlands have also been proven to stabilize coastlines, counteract erosion and storm surge, and protect human life and property through attenuation (Barbier et al 2011, Engle 2011, Gedan et al. 2011). In the northern Gulf of Mexico estuarine systems are influenced by sediment and freshwater inflow from the Mississippi River and other major river systems. Estuarine systems in this region are typically dominated by herbaceous marsh species (primarily *Juncus roemerianus*, *Spartina alterniflora*, and *S. patens*) due to cumulative effects of cooler average temperatures, greater freshwater inflow, and reduced tidal range (i.e., microtidal) as compared to mangrove and salt-flat marshes in southern portions of the Gulf and other coastal system in the U.S. and beyond. These include extensive muddy bottomed and low-salinity marshes in the Louisiana Deltaic Plain near the Mississippi River delta, and less-extensive clear-bottomed, high seagrass areas east and west of the Deltaic Plain where freshwater inflow is reduced (Beck and Odaya 2001). Rates of loss in combination with impending threats to coastal marsh systems has prompted the U.S. Fish and Wildlife Service to identify restoration of wetland ecosystems and protection of estuarine island habitats as two of their eight top priority conservation strategies in their "Vision for a Healthy Gulf of Mexico" report, with focal areas for conservation within the GCPO LCC geography including the Northern Gulf Coast and Panhandle Lands (USFWS 2013). Priority conservation actions as part of this vision report include development of Strategic Habitat Units, support for long-term habitat management programs, and improvement of water quality and quantity within estuarine marsh and other systems in each focal area. The multi-institutional Gulf Coast Ecosystem Restoration Task Force also outlined a vision for Gulf Coast restoration in the 2011 report "Gulf of Mexico Regional Ecosystem Restoration Strategy", with one of the goals of the task force being to "restore and conserve coastal and near shore habitats" with a focus on marshes. Other organizations have identified tidal marsh as a priority system for conservation focus over the last several years (e.g., Beck et al. 2000). In the 2014 report "A Land Conservation Vision for the Gulf of Mexico Region" the Partnership for Gulf Coast Land Conservation, Land Trust Alliance, and other partners worked cooperatively to identify areas of high conservation value along the Gulf including locations of large contiguous wetlands (>247,000 acres) within 25 miles of the coastline. Many other planning efforts at the local, state, and regional level are also underway that highlight coastal wetlands as a priority ecological system in which to focus conservation resources.

LCC Science Agenda – Gulf Coast Tidal Marsh

The estuarine tidal marsh priority system in the GCPO Integrated Science Agenda (ISA), was derived from the Estuarine Systems class in the NatureServe/U.S. Fish and Wildlife Service series of "Broadly Defined Habitats", which includes general ecological systems of brackish and saltwater marsh and seagrass beds crosswalked to NatureServe Ecological Classifications of Mississippi Sound Salt and Brackish Tidal Marsh and Northern Gulf of Mexico Seagrass Beds. The more inclusive term "estuarine tidal marsh" was adopted as one of two initial ecological systems of focus for the Gulf Coast subgeography in the ISA, the other being beaches and dunes (see Section #). According to the Cowardin classification system, estuarine systems include "deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the open ocean, and in which ocean water is at least occasionally diluted by freshwater runoff from the land" (Cowardin et al. 1979). Emergent wetland and scrub-shrub wetland are two classes within the intertidal subsystem of the estuarine system. Emergent wetland is defined by "erect, rooted, herbaceous hydrophytes, excluding mosses and lichens" with subclasses of persistent or non-persistent vegetation (Cowardin et al. 1979). According to the recent Coastal and Marine Ecological Classification Standard, Estuarine Systems are defined by "tidally influenced waters that a) have an open-surface connection to the sea, b) are regularly diluted by freshwater runoff from land, and c) exhibit some degree of land enclosure" extending from upstream tidal limit to the seaward extent of the estuary (Federal Geographic Data Committee 2012).

The desired ecological state for Gulf Coast estuarine tidal marsh is generally described in the ISA as "stable marsh systems comprised of native vegetation and limited open water conditions occurring in large blocks with natural hydrology present". For Gulf Coast estuarine tidal marsh, desired ecological states are primarily derived from the breadth of available expertise and resources in the GCPO LCC Adaptation Science Management Team Gulf Coast multi-taxa working group. As in the other ISA priority systems, desired ecological states are defined within general categories of landscape attributes (i.e., endpoints) related to habitat amount, configuration, and condition. However, there remains limited understanding of how species using this system for all or part of their life histories respond to configuration and condition of these habitats, and how similar their needs are across taxa (Bostrom et al. 2011). We performed initial assessments of amount, condition and configuration separately, and then where possible combined condition characteristics to better summarize amount of estuarine tidal marsh both within the desired ecological state and in more general terms (i.e., total amount of tidal marsh regardless of condition) for comparison. However, limitations in endpoint definition and/or data availability (e.g., freshwater flow, salinity, native vegetation, connectivity) prevented us from assessing amount of Gulf Coast tidal marsh habitats meeting all specified criteria Included below is the relevant section from Appendix 1 of the GCPO LCC Integrated Science Agenda outlining the desired landscape endpoints for tidal marsh in the Gulf Coast within amount, configuration, and condition categories.

GULF COAST

Tidal Marsh

General description of desired ecological state: *Stable marsh systems comprised of native vegetation and limited open water conditions occurring in large blocks with natural hydrology present.*

Amount: Adequate acres to meet needs of tidal wetland wildlife at desired levels; no loss

Configuration: Large blocks of unbroken marsh (>250 ac)
Connectivity of habitat types reflective of interdigitation of marsh types
Moderate amounts of edge within large blocks of marsh
Presence of barrier islands in riverine-dominated systems

Condition: Structure

- Emergent vegetative cover: >70%
- Limited open water: <20%
- Submergent vegetative cover: 15-30%

Composition

- Dominated by native plants typical of high, mid-, intermediate, and low marsh

Water quality

- Salinity – aligned along natural gradient

Water quantity

- Adequate freshwater flows and tidal influence

Priority species for Gulf Coast estuarine tidal marsh systems identified in the GCPO ISA include river otter (*Lutra canadensis*), Gulf salt marsh mink (*Mustela vison halilimnetes*), black bear (*Ursus americanus* spp.), penaid shrimp (family Penaeidae), clapper rail (*Rallus longirostris*), king rail (*Rallus elegans*), redhead (*Aythya americana*), scaup (*Aythya marila*), West Indian manatee (*Trichechus manatus*), speckled trout (*Cynoscion nebulosus*), American oyster (*Crassostrea virginica*), and black bass (*Micropterus* spp.). In the draft ISA, each of these species is hypothesized to be limited by ecological conditions of patch size, connectivity, emergent and submergent vegetative cover, edge, salinity, and freshwater flow and other factors. Phase II of the GCPO ecological assessment will evaluate these hypothesized species-habitat relationships.

Delineating estuarine tidal marsh cover along the Gulf Coast

Successful completion of the Gulf Coast tidal marsh component of the ecological assessment requires that the most consistent, comprehensive, current, and accurate data be used in summary and analysis. Prior to assessment of individual landscape endpoints we conducted a comprehensive review and comparison of land cover data available for an assessment of estuarine tidal marsh along the northern Gulf of Mexico.

Alternative 1: Coastal Change Analysis Program

The NOAA Coastal Change Analysis Program (C-CAP) was developed as a mechanism to monitor changes to coastal upland, wetland and submersed vegetative cover along coastal areas of the conterminous U.S. (Dobson et al. 1995). The C-CAP program uses 30 m resolution Landsat TM satellite imagery and ground-validated data to classify raster format data into 25 discrete land cover classes using an adapted classification system based on Anderson et al. 1976, Cowardin et al. 1979, and U.S. Environmental Protection Agency Environmental Monitoring and Assessment Program (EMAP). Wetland classes are partitioned into palustrine (salinity due to ocean-derived salts < 0.5%) and estuarine (salinity due to ocean-derived salts >0.5%) groups, with forested, scrub/shrub, and emergent classes within each grouping. Estuarine emergent wetland (C-CAP class 18) includes "tidal wetlands dominated by erect, rooted, herbaceous hydrophytes" where salinity is >=0.5%, total cover of vegetation is >80%, and wetlands are dominated by perennial plants. Estuarine scrub/shrub wetland (C-CAP class 17) includes "tidal wetlands dominated by woody vegetation <5 m in heights" in areas with >0.5% salinity and total cover of vegetation >20% (NOAA Office for Coastal Management). These classes are distinguished from estuarine forested wetlands, which consist of saline "tidal wetlands dominated by woody vegetation >=5 m in height". Palustrine wetland classes (emergent, scrub/shrub, forested) do not distinguish between tidal and non-tidal (Dobson et al. 1995). C-CAP coverage includes all U.S. coasts to the inland extent of the estuarine drainage areas (amount of land directly impacting an estuary) and seaward to the extent of remotely sensed submersed habitat (e.g., seagrass, coral, wetlands). Comprehensive C-CAP land cover with a 2010 vintage is available for the entire Gulf Coast portion of the GCPO LCC geography (**Figure TM.2**).

Figure TM.2. NOAA Coastal Change Analysis Program (C-CAP) land cover mapping extent for the conterminous U.S. overlaid on the GCPO LCC geographic extent.

Advantages of C-CAP data for the ecological assessment project include the availability of comprehensive and standardized land cover data that has been accuracy assessed across the GCPO LCC geography. C-CAP is also updated at 1 – 5 year intervals and provides a suite of regional land cover change products (e.g., 2001-2010, 2006-2010), which are essential to assessing marsh loss over time. C-CAP classes provide a simplified breakdown of estuarine marsh systems (emergent, scrub/shrub, forested); however, if the LCC desired to include freshwater tidal marsh into the assessment, C-CAP does not differentiate palustrine tidal and non-tidal systems. This could be problematic when assessing future change from palustrine to estuarine tidal marsh with sea-level rise and other factors associated with changes in salinity levels along coastal marshes. Note also, that nearly all Florida beach land-water interfaces along the Gulf of Mexico have a misclassified fringe of emergent marsh, which may result in an overestimate of emergent marsh in Florida.

Alternative 2: National Wetlands Inventory

The National Wetlands Inventory (NWI) program was established in the mid-1970's by the U.S. Fish and Wildlife Service to standardize nomenclature for U.S. wetland systems and develop the technical capacity to map wetlands across the U.S. From these efforts the Service adopted a single uniform and hierarchical national standard of classification (Federal Geographic Data Committee 2009 and 2012, developed from Cowardin et al. 1979), from which 81% of the nation's wetlands have been digitally mapped. Salt water habitats mapped according to the Cowardin classification system included estuarine intertidal emergent, forested, and shrub. NWI wetland mapping is provided in a vector format and based on aerial image analysis, originally derived from high altitude aerial photographs and hand digitized wetland demarcation and now digitally derived from high-resolution color infrared aerial images. Advantages of NWI include capacity to map changes to small wetland areas, complex areas and long narrow shoreline features that would otherwise be overlooked or misclassified by remote sensing analyses using satellite imagery data (e.g., Landsat) (Handley et al. in prep). NWI also makes use of a standardized national classification system as opposed to the custom classification systems developed by C-CAP and the marsh type delineation project (below). The hierarchical structure of the Cowardin classification system allows for greater detail in marsh classification, including several modifiers relevant to GCPO LCC ISA landscape endpoints (e.g., salinity, water flow, submergent vegetation), as well as a distinction among tidal and non-tidal palustrine wetlands. NWI also includes mapping of rooted and floating vascular plants in the aquatic bed relevant to the GCPO LCC submergent vegetation endpoint in some areas. NWI also makes use of a rigorous ground truthing protocol to validate digitized wetlands. The primary disadvantage to use of NWI in a comprehensive GCPO LCC assessment involve the temporal discrepancies in NWI classification projects along the Northern Gulf of Mexico, ranging at times back to the 1970's (**Figure TM.3**). Although standardized in classification now, older NWI project imagery interpretation methods varied by project, resulting in minor to major inconsistencies in data interpretation across space. Temporal and project inconsistency renders assessment of marsh change over time difficult.

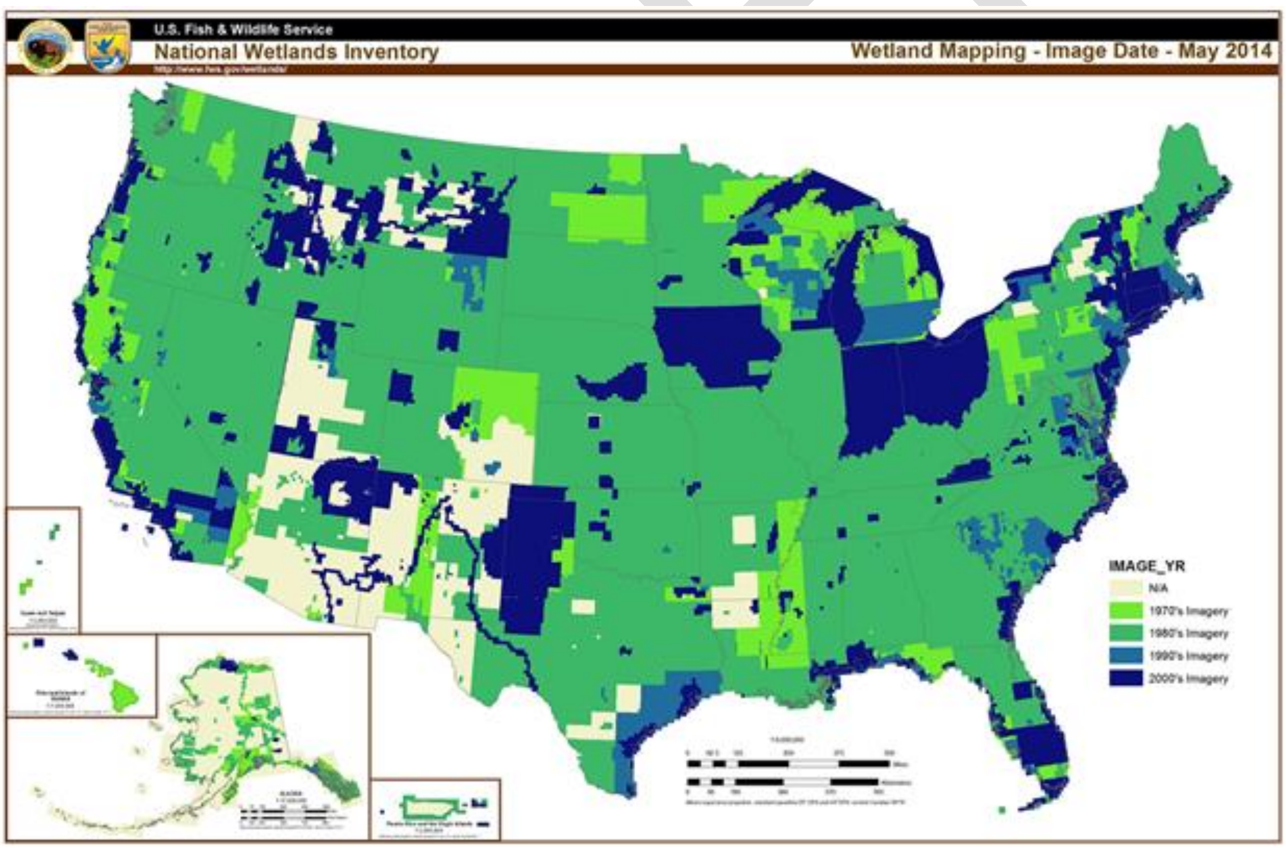

Figure TM.3. Vintage of publicly available USFWS National Wetlands Inventory (NWI) data along the Northern Gulf of Mexico. Dark blue represents data collected since 2000, light blue since 1990, dark green since 1980, light green since 1970, and tan representing missing data (image courtesy of the U.S. Fish and Wildlife Service).

Alternative 3: Marsh Type Delineation Project

The USGS marsh type delineation project was developed to address deficiencies in distinguishing between coastal marsh vegetation zones, typically described as either palustrine (<0.5 ppt salinity) or estuarine (>0.5 ppt salinity). To address these deficiencies a cooperative project was developed to provide a standardized delineation of marsh vegetation types per four salinity zones (fresh, intermediate, brackish, saline) in addition to classification of water and other non-marsh types along the northern Gulf of Mexico following the Chabreck et al. (1968) classification (**Table TM.1**). This project delineated marsh vegetation type in raster format from Corpus Christi Bay, Texas to Mobile Bay, Alabama, inland to the 10 m elevation contour line, and seaward 5-6 km from shoreline (Enwright et al. 2014). This project uses 2009-2011 Landsat TM and SPOT 4 and 5 satellite imagery and existing land cover classifications to produce a step-wise decision tree analysis in See5 and other software programs in combination with 2011-2012 ground referenced observations using helicopter surveys, site visits, and aerial photo interpretation. Urban and cropland data were excluded and resolution for delineated marsh pixels was 10 m^2.

Advantages of this dataset are that it is the most recent temporal dataset available, and is standardized and seamless using the best available classification technology throughout the LA, MS, and AL portions of the GCPO geography. The primary disadvantages are that this data is not yet publicly available throughout the FL portion of the GCPO geography and would require supplementation with other data when used in the assessment. Additionally, the temporal scale of this dataset provides no means to assess marsh change over time. The data also does not distinguish between tidal and non-tidal for freshwater marsh and could be problematic if this assessment were to include tidal freshwater marsh in the future.

Table TM.1. Salinity means and ranges for classification of fresh, intermediate, brackish, and saline marsh types and representative species as part of the USGS marsh type delineation work as defined in Enwright et al. (2014). Note representative species were listed based on the Texas portion of the marsh delineation work detailed in Enwright et al. (2014).

Marsh type	Mean salinity	Salinity range (ppt)	Representative species
Fresh	1.0	0.1 – 3.4	Maidencane (*Panicum hemitomon*), spikerushes (*Eleocharis* spp.), alligator weed (*Alternanthera philoxeroides*)
Intermediate	3.3	0.5 – 8.3	Gulf cordgrass (*Spartina spartinae*), marshhay cordgrass (*Spartina patens*), bulltongue (*Sagittaria lancifolia*), coastal waterhyssop (*Bacopa monnieri*)
Brackish	8.2	1.0 – 18.4	Marshhay cordgrass (*Spartina patens*), seashore saltgrass (*Distichlis spicata*)
Saline	18.0	8.1 – 29.4	Smooth cordgrass (*Spartina alterniflora*), seashore saltgrass (*Distichlis spicata*), needlegrass rush (*Juncus roemerianus*)

Alternative 4: Southeast GAP

The National GAP Analysis Program is designed to provide foundational data for assessments of vertebrate species by creating and combining maps of detailed land cover, species distribution, and land stewardship. Once created these data layers are analyzed to identify areas of vertebrate biodiversity, conservation gaps, and assess vertebrate species status in the U.S. Land cover products created through the GAP program are mapped to multi-season 1999-2001 Landsat ETM+ satellite imagery and include a crosswalk to NLCD land cover, and tiered land cover based on the top five National Vegetation Classification System (NVCS) levels and 538 classes provided in the NatureServe Ecological Systems Classification (NESC) (NatureServe 2007). NECS mapping units were derived as a substitute for the impractical level of floristic mapping to NVCS alliance and association levels and grouped NVCS association levels by similar ecological processes and other environmental factors, mapped to scales from tens to thousands of hectares (Comer et al. 2003). Comer et al. (2003) defines terrestrial ecological systems as a "group of plant community types (associations) that tend to co-occur within landscapes with similar ecological processes, substrates, and/or environmental gradients" and takes into account upland and wetland areas and prominent environmental features (e.g., dune, coast) into classification. Datasets used in mapping GAP land cover analysis included landscape layers derived from numerous physiographic, community, and disturbance models (e.g., elevation, slope, aspect, landform, geology, soils, hydrology, rare plant communities, fire, tree harvest, agriculture, developed) in addition to Landsat derived products such as Normalized Difference Vegetation Index. Therefore GAP land cover products incorporate both dominant vegetation and physical elements of the environment in classification. GAP land cover is provided as a national raster format data layer at 30 m resolution and combines data from four regional GAP analysis projects (California, northwest, southeast, southwest) supplemented with crosswalked LANDFIRE existing vegetation type data in other areas without GAP classification. GAP ecological classifications relevant to the assessment of GCPO Gulf Coast Tidal Marsh and Beach/Dune systems are listed in **Table TM.2** below.

Advantages of using GAP data for the tidal marsh system assessment included GAP providing a tiered and standardized set of classifications across the entire Gulf Coast portion of the GCPO LCC geography, including the capacity to assess to the level of NESC, which is not available by C-CAP, NWI, or other data layers (see comparison example in **Figure TM.4**). GAP data were trained and ground-truthed within each ecological system classification level using plot-level data. Disadvantages of GAP are related to the age of the 1999-2001 base Landsat imagery, thus relying on landscape character that is 14 years old at the time of this assessment, with land cover change metrics not readily available through GAP at this time.

Table TM.2. Table of ecological classes identified in Southeast GAP and relevant to assessment of tidal marsh and beach and dune systems within the GCPO LCC Integrated Science Agenda Gulf Coast subgeography as described by GAP and NatureServe (2007).

Relevant system, endpoint	**GAP Ecological Classification**	**Abbreviated description**
Tidal marsh, open water	Open Water (Brackish/Salt)	Open water w/<25% veg/soil cover in coastal and near-shore estuarine and/or marine waters.
Tidal marsh, open water	Open Water (Fresh)	Open water w/<25% veg/soil cover in inland waters of streams, rivers, ponds and lakes.
Tidal marsh, emergent vegetation	Mississippi Sound Salt and Brackish Tidal Marsh (CES203.303)	Salt and brackish tidal marshes of the northern Gulf of Mexico region of northwestern Florida, southern Alabama, and southeastern Mississippi. Typically associated with mud-bottom bays behind barrier islands.
Tidal marsh, emergent vegetation	Gulf and Atlantic Coastal Plain Tidal Marsh Systems (CES203.638)	Atlantic and Gulf coasts and barrier islands salt, brackish, and freshwater marshes are included and with regular tidal flooding. Salt marshes dominated by *Spartina* but *Juncus roemerianus* also common.
Tidal marsh, submergent vegetation	Northern Gulf of Mexico Seagrass Bed (CES203.263)	Seagrass bed from Florida panhandle westward to Mississippi, primarily including the true seagrass *Ruppia maritime* and the non-seagrass *Vallisneria Americana* with some representation of *Halodule, Thalassia*, and *Cymodocea* taxa.
Beach	Unconsolidated Shore	Unconsolidated material such as silt, sand, or gravel subject to inundation and redistribution due to the action of water.
Beach	Louisiana Beach (CES203.469)	Louisiana beaches are predominantly found on remnant barrier islands associated with historic delta lobes of the Mississippi River. Dominance of saltmeadow cordgrass instead of sea-oats.
Beach	Florida Panhandle Beach Vegetation (CES203.266)	The panhandle beach system ranges from northwestern Florida (Ochlockonee River) to southeastern Mississippi. It includes the outermost zone of coastal vegetation extending seaward from foredunes.
Beach/Dune	Gulf and Atlantic Coastal Plain Sparsely Vegetated Systems (CES203.646)	Includes Gulf and Atlantic coast beaches outermost zone of coastal vegetation extending seaward from foredunes on barrier islands and also limited overwash flats behind breached foredunes.

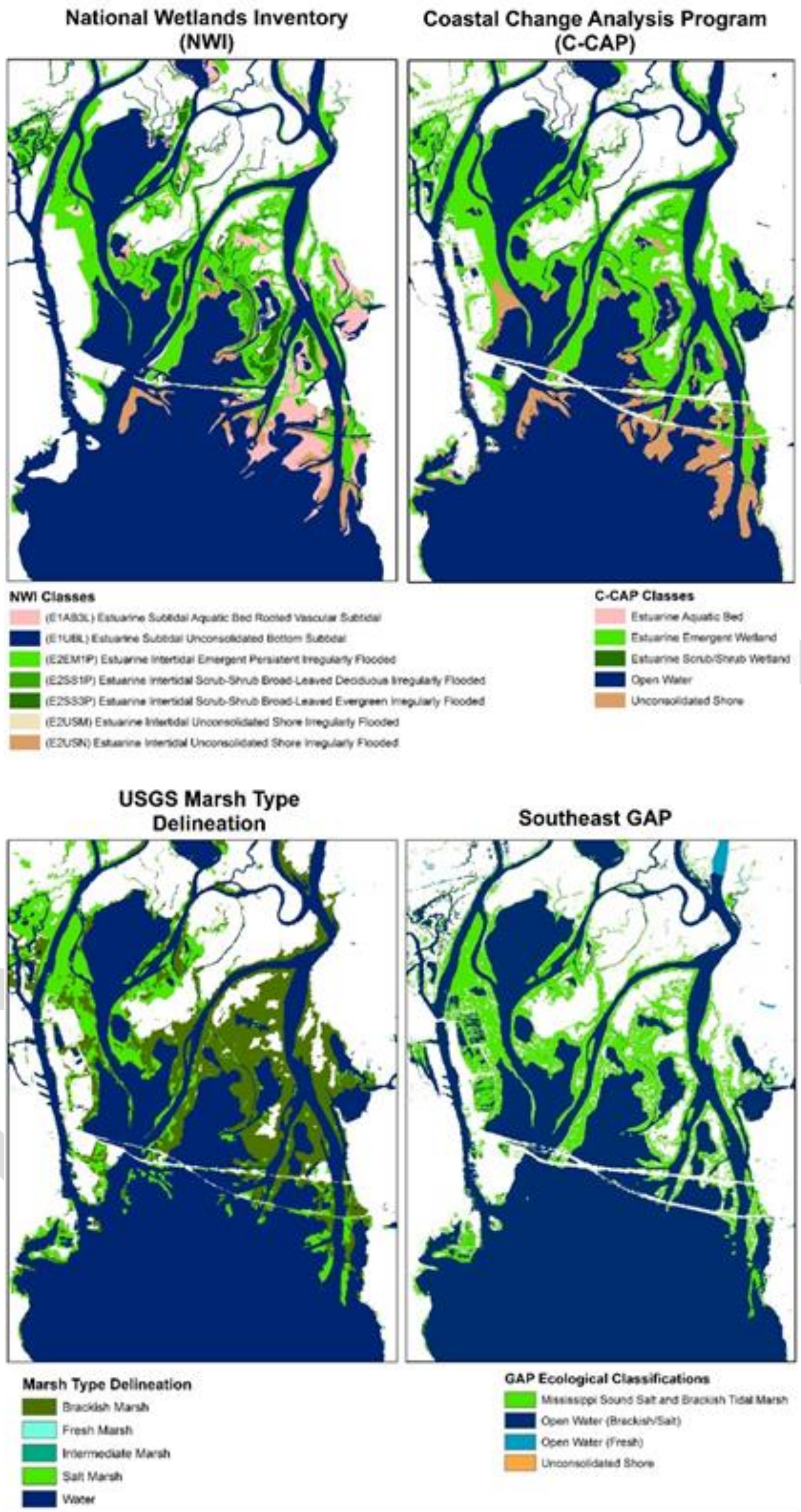

Figure TM.4. Example comparison of National Wetlands Inventory, Coastal Change Analysis Program (C-CAP), USGS marsh type delineation, and Southeast GAP data classifications in the Mobile Bay estuary system in Alabama.

Alternative 5: Florida Cooperative Land Cover

In October 2015 the cooperative Florida Fish and Wildlife Commission and Florida Natural Areas Inventory (FNAI) partnership released version 3.1 of the Florida Cooperative Land Cover Map (CLC). CLC provides a compilation of 37 land cover and vegetation data products collected into a state-wide land cover classified hierarchically to the Florida Land Cover Classification System, a unified combination of the natural community classification of FNAI and the Florida Land Use and Forms Classification System of the Florida Department of Environmental Protection (Knight et al. 2010). The Florida CLC maps land cover classification in vector and 30 m raster format at two levels of confidence, including state-level (classifications mapped with confidence at the state-level) and site-level (detailed, site-based information that may not be available at the state-level). State-level classifications of relevance to this assessment include saltwater marsh, class 5240 (**Fig. TM.5**), whereas detailed relevant site-level classifications include saltwater marsh, saltwater marsh barren, cordgrass, and needlerush are available in the framework but not yet classified widely. Advantages to use of Florida CLC in the ecological assessment reflect the variety of detailed product inputs used to produce the compiled maps, often reflecting extensive local knowledge of Florida land cover. However, CLC data is only valuable in the Florida portion of the GCPO LCC geography and therefore prohibits assessment beyond state boundaries. Variation in input data sources (in time and in mapping methodology) also adds inherent uncertainty to map products.

Figure TM.5. State-level salt marsh classification of the Florida Cooperative Land Cover Map (version 3.1, 2015) within the GCPO LCC geography of the western Florida panhandle.

Alternative 6: MTDP/CLC Composite Approach to Create Marsh Mask

We compared products of alternatives 1-5 by and found they provided varying approximations of estuarine tidal marsh location along the Gulf Coast subgeography, primarily due to temporal differences in water levels, temporal differences in wetland classification and varying degrees of classification accuracy. After extensive consideration we chose the USGS Marsh Type Delineation Project data for GCPO Gulf Coast areas in Alabama, Mississippi, and Louisiana, and Florida Cooperative Land Cover data for GCPO portions of the western Florida panhandle. The MTDP data represents the most recent temporal classification available along much of the Gulf Coast and is classified within Louisiana, Mississippi and Alabama using consistent methods. Second the MTDP project likely provides an improved measure of open water within tidal marshes in the western GCPO geography, which is particularly important in rapidly changing marshes in Louisiana. Third, the MTDP product provides a unique opportunity to examine configuration of marsh types within patches that is not available in any other marsh dataset. The Florida CLC data represents a regularly updated state-led land cover effort and though temporal classification may be inconsistent, any changes to marsh extent are reflected in these updates. CLC is also superior in classification of salt marsh compared to C-CAP and GAP layers because of the local expertise that it incorporates in marsh delineation. CLC also provides the classification framework within which more detailed site-level classification of salt marsh classes is possible (though unavailable across all salt marsh in the GCPO Florida geography at this time), and is the layer upon which many Florida conservation planning activities are based including the Florida Critical Lands and Waters Identification Project. However, in the event that the MTDP project is expanded through the western Florida panhandle, we will likely update this assessment to include that expansion to be consistent with the western LCC geography. One disadvantage of this approach, however, is that there is no measure of change with the MTDP or CLC products at this time, therefore assessment of marsh change must be based on NOAA C-CAP change only.

We reprojected the MTDP and CLC 10 m resolution data sets to an Albers Equal Area Conic projection, then clipped both to a 10 km buffer around the GCPO LCC geography, extending out to state seaward boundaries in Mississippi, Alabama, and Florida to better capture barrier island marshes. To create the estuarine tidal marsh "mask" from which subsequent patches were delineated we first reclassified the MTDP dataset to extract the saline, brackish and intermediate classes, and reclassified the state-level CLC data to extract the salt marsh class (class 5240). Both reclassified datasets represented a simplified layer of 1's (in target class) and no data (not in target class). We then mosaiced the MTDP layer with the CLC layer, taking MTDP pixels as first order preference where overlap existed. This became the estuarine tidal marsh "mask" within which most of the remaining landscape endpoints for this system were assessed. We calculated a simple measure of estuarine tidal marsh acres within GCPO portions of each coastal state and overall (by summing the count of pixels, multiplying by pixel resolution (10x10 m = 100 m^2) and converting to acres. From these datasets we estimate there are presently 202,584 acres of estuarine tidal marsh within the GCPO LCC geography (**Table TM.3, Figure TM.6**).

Table TM.3. Amount of estuarine tidal marsh habitat (in any condition and acres currently protected) calculated from a combination of USGS Marsh Type Delineation Project data (AL, LA, MS) and Florida Cooperative Land Cover v.3.1 data within the GCPO LCC.

Geographic extent	Estuarine tidal marsh acres (any condition)
Alabama	40,893
Florida (GCPO only)	37,766
Louisiana (GCPO only)	75,349
Mississippi	48,576
GCPO Total	**202,584**

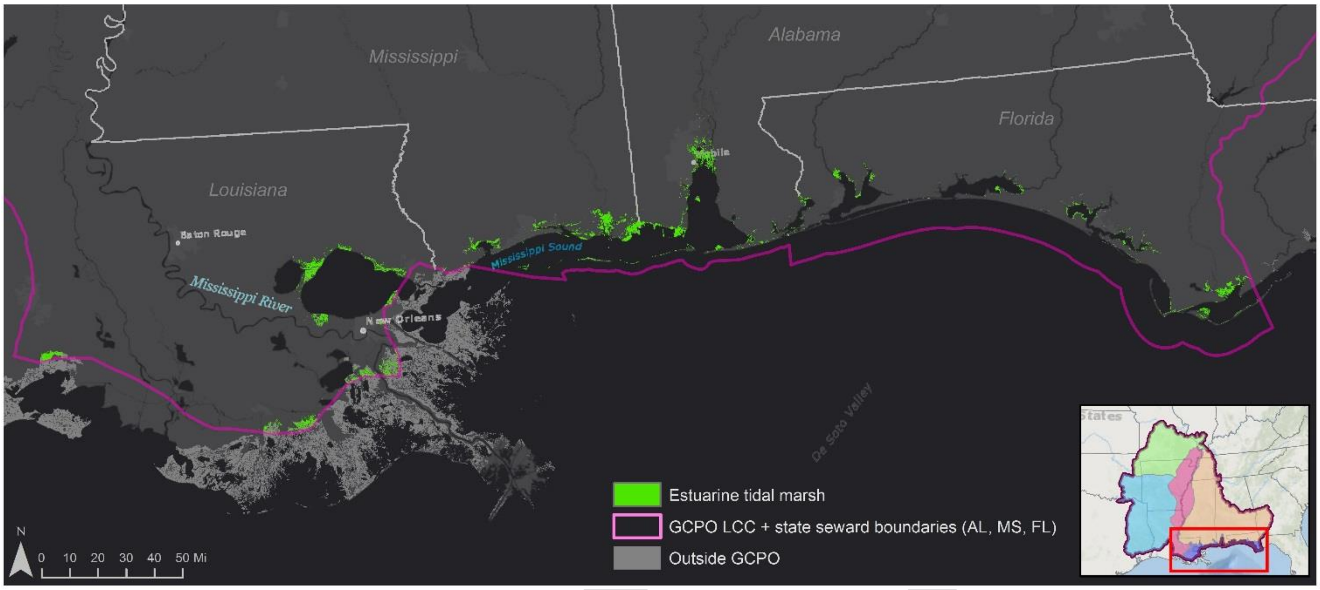

Figure TM.6. Estuarine tidal marsh pixels from the composite of USGS Marsh Type Delineation Project and Florida Cooperative Land Cover v.3.1 within data within the GCPO LCC Gulf Coast.

Conservation Planning Atlas Links to Available Geospatial Data Outputs:

- GCPO LCC Estuarine Tidal Marsh (All condition) (raster)

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Chapter 1: Amount, assessing marsh loss

Subgeography: **GULF COAST**

Ecological System: **Estuarine Tidal Marsh**

Landscape Attribute: *Amount*

Desired Landscape Endpoint: Adequate acres to meet needs of tidal wetland wildlife at desired levels; no loss

Estuarine tidal marshes are dynamic transitional systems; thus tracking change in those systems over time is challenging and dependent on temporal scale. The dynamic nature of this system renders developing target amounts for maintenance and restoration a challenging task as well. The intentionally vague endpoint component targeting adequate acreage to meet wildlife needs will vary by species and estuarine system within the GCPO LCC geography. However, regardless of the dynamic nature of the tidal marsh system, a target of no further loss is clear. Tidal marshes along the northern Gulf of Mexico have suffered tremendous losses over the past half century (Couvillion et al. 2011, Dahl and Stedman 2013, Handley et al. in prep). Coastal estuarine systems exist as a “functionally connected” mosaic of habitats, whereby loss will negatively impact nearby system components and disrupt whole-system function (Bostrom et al. 2011). Therefore an understanding of current estuarine marsh amounts and estimates of loss are important to facilitate conservation target setting and management planning.

Wetland loss along coastal portions of the U.S. is widely and frequently assessed using high-resolution aerial and satellite imagery (e.g., Handley et al. in prep, Couvillion et al. 2011, Dahl 2011, Dahl and Stedman 2013). To facilitate the rapid assessment process we used the NOAA C-CAP Regional Land Cover Change product to assess losses and gains in estuarine emergent and scrub/shrub land cover from (1996-2010). Though C-CAP change products are available back to 1975 in some regions of the U.S., the earliest change product available along the northern Gulf of Mexico is not until 1996. C-CAP change products use a combination of Landsat multi-spectral scanner (MSS), thematic mapper (TM) and enhanced thematic mapper (ETM) satellite imagery, aerial photography, and plot-level data in combination with other ancillary data (e.g., digital elevation model, normalized difference vegetation index) for historic and recent eras to produce a matrix of land cover change among C-CAP classes over time (Burkhalter et al. 2005).

To assess change amounts within the GCPO Gulf Coast subgeography portions of the C-CAP change product extent, we first evaluated estimated losses and gains by class and overall of the C-CAP estuarine emergent and estuarine scrub/shrub classes within each GCPO state. Losses to and gains from other classes included development, palustrine wetland, water, other estuarine wetland types, unconsolidated shore, non-wetland scrub/shrub, evergreen forest, and grassland/pasture or cultivation. Start and end date ranges for the land cover change assessment varied by state and ranged from 1994-1997 start dates and 2009-2011 end dates. We estimated loss independently for Louisiana, but summed loss totals across Alabama, Mississippi, and GCPO LCC portions of Florida since loss was limited in these states compared to Louisiana. We also clipped the C-CAP change product to a 10 km buffer east and west of the GCPO LCC boundary and assessed amount of total estuarine emergent and estuarine scrub/shrub wetland acreage lost, gained, and net change per HUC12 watershed from 1996 - 2010. Note we recognize the misalignment between use of C-CAP change product data for assessment of marsh loss, and use of MTDP and CLC data in creation of the marsh mask. This misalignment exists because we determined MTDP and CLC data to be more useful in compilation of the quantitative assessment of desired ecological state found at the end of this section. Estimated losses using C-CAP data were assessed and summarized but were not quantified in the empirical analysis that addressed desired ecological state.

Estimated loss

In the Gulf Coast subgeography of the GCPO LCC we estimate 19,566 acres of estuarine emergent and scrub shrub wetland were lost to other land cover classes, and 4,450 acres were gained from other land cover classes from 1996-2010, representing a net loss of 15,116 acres over a 15 year period, or roughly 1,000 acres per year though more likely punctuated rather than gradual losses. Net losses of marsh to open water dominated the C-CAP change metrics with 11,827 acres of estuarine emergent and scrub shrub marsh acres lost to water over the period (**Figure TM.7**). However, it is uncertain if net losses to the water class are a result of changes in water levels during mapping periods, or real losses, particularly in the Mississippi River delta marsh portions of the GCPO LCC geography, which are subject to a different suite of integrity stressors compared to other portions of the GCPO Gulf Coast (Couvillion et al. 2011). The GCPO LCC Gulf Coast subgeography also lost 1,326 acres of estuarine emergent and scrub/shrub wetland to low, medium, high intensity, and open space development (147 ac [LA], 378 ac [MS], 382 ac [FL], 418 ac [AL]), primarily in small pockets along fringes of existing developed lands. Also, 1,680 acres changed to other classes within estuarine systems (e.g., estuarine emergent to estuarine scrub/shrub wetland or vice versa). Other losses and gains to/from palustrine wetlands, shore or barren, grasslands or cultivated, and non-wetland forest or scrub/shrub were minimal in this geography.

The primary area of tidal marsh change (loss and gain) from 1996 – 2010 occurred in the GCPO portions of the Deltaic Plain (**Figure TM.8**). HUC 12 watersheds in this area experienced net losses of up to 1,700 ac, and net gains of up to 1,000 acres, suggesting this is a highly dynamic tidal marsh system subject to compounding effects of water levels related to Mississippi River flood events, storm event disruptions, and subsidence. Other smaller areas of net loss were found in HUCs along the western, central, and eastern Mississippi coasts, the eastern Alabama coast, and along the eastern portion of the Florida GCPO LCC geography. We observed the greatest tidal marsh gain (per HUC12) on the eastern shore of Lake Pontchartrain in Louisiana on private lands directly adjacent to Big Branch Marsh National Wildlife Refuge. However, in comparison to current aerial imagery and communications with Refuge staff, it is evident that this area is currently under development and will be a loss in the next C-CAP change product assessment.

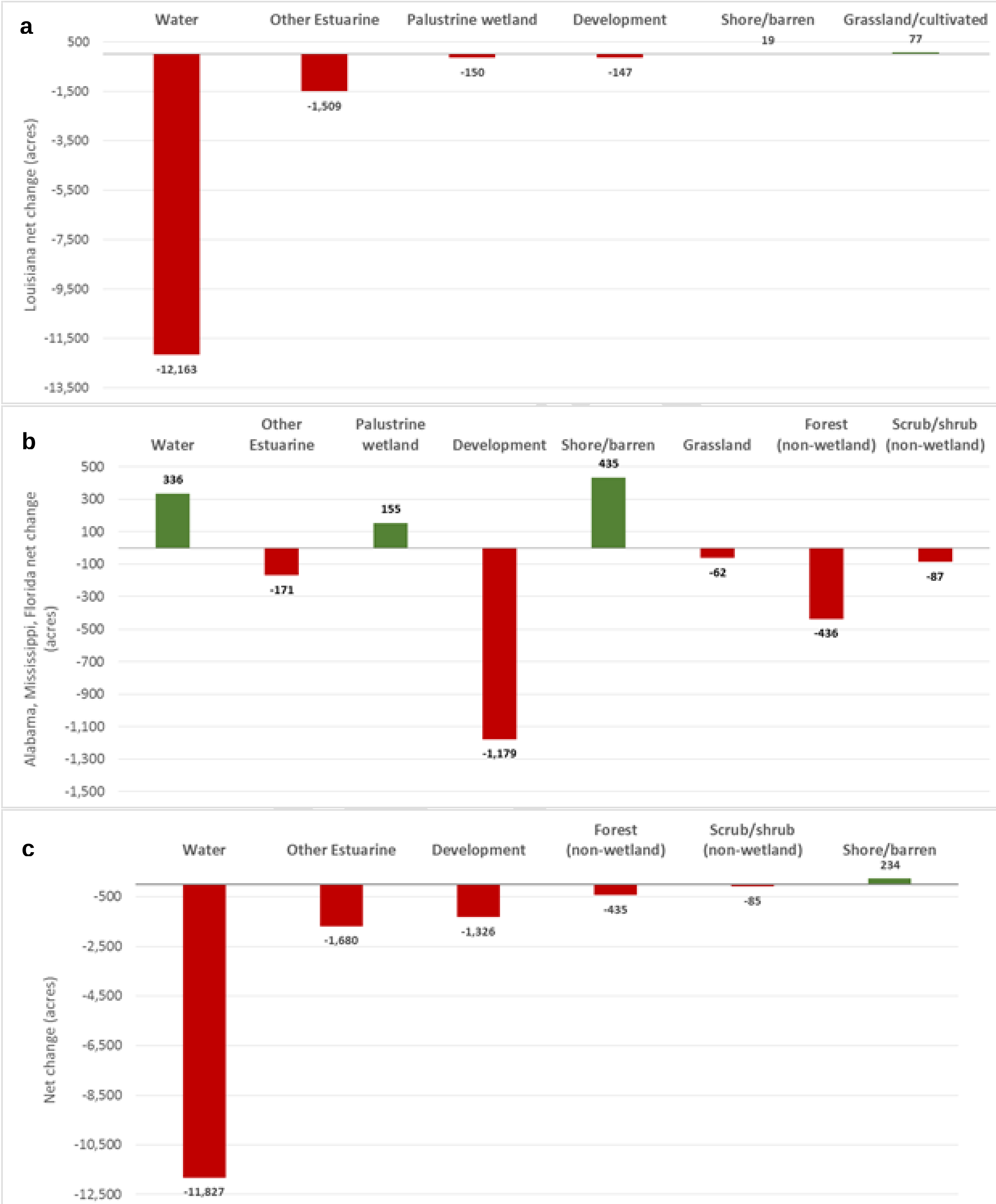

Figure TM.7. Net change in NOAA C-CAP estuarine emergent and estuarine scrub-shrub classes to other land cover categories in Louisiana (GCPO extent only) (a), Alabama, Florida (GCPO extent only), and Mississippi (b), and over the GCPO Gulf Coast subgeography (c) from 1996-2010 based on the NOAA Coastal Change Analysis Program land cover change product.

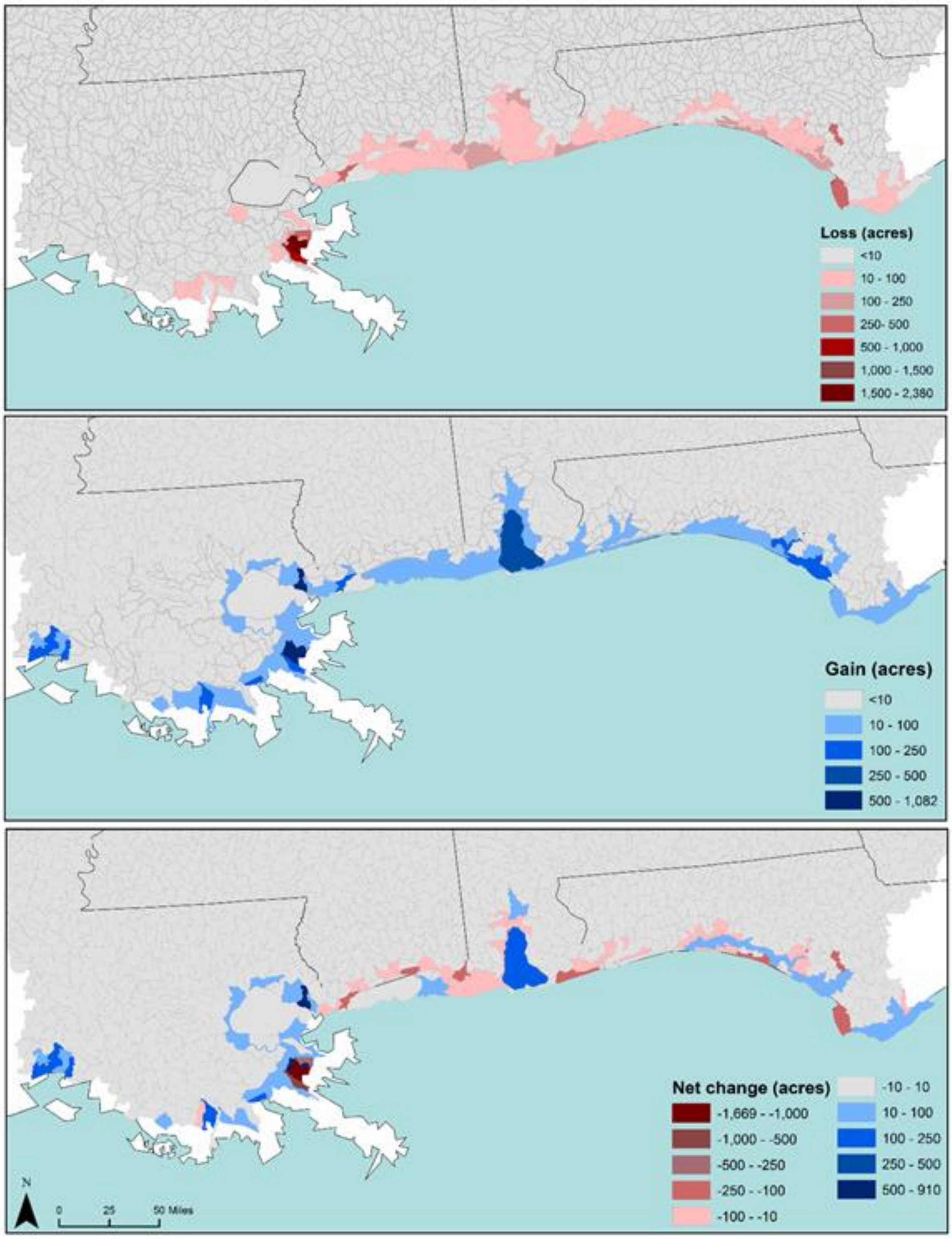

Figure TM.8. Acres of estuarine emergent and estuarine scrub-shrub per HUC 12 watershed lost (a), gained (b), and net change (c) in the GCPO LCC geography from 1996 – 2010 per the NOAA Coastal Change Analysis Program (C-CAP) land cover change product.

Future Directions and Limitations

Loss of coastal wetlands and degradation of estuarine habitat along the northern Gulf of Mexico, and particularly along coastal Louisiana have been recognized as two of the primary issues influencing the Gulf ecosystem integrity (Gulf Coast Ecosystem Restoration Task Force 2011). In a similar assessment of C-CAP land cover change from 1996-2006, Karnauskas et al. (2013) estimate a decrease in percent cover of coastal wetlands by 1.04% along the coastal portions of the Gulf of Mexico, and predicted an additional 10% loss in coastal wetlands following this trend by 2100. More dramatically, Dahl and Stedman (2013) estimated a loss of -5.2% (120,796 ac) of coastal estuarine emergent wetlands along the Gulf of Mexico from 2004-2009, with 99% of all losses to open deep-water estimated to occur in the Gulf. Handley et al. (in prep) suggest wetland loss caused by development (industrial, residential, and recreational) is the largest threat to Mississippi and Alabama coastal wetlands, with an estimated 10,000 ac loss in wetlands in Mississippi prior to passage of the 1973 Mississippi Coastal Wetlands Protection Law, and an estimated 12,820 acres estuarine emergent wetland from 1955 to 2001/2002 in Alabama. An assessment of land use/land cover change from 1974 – 2008 in Mobile Bay, Alabama using Landsat image classification suggests conversion of nearly 48,000 acres of other land cover classes to urban/developed classes and a loss of nearly 2,400 acres of non-woody wetland (766 ac attributed to development) in this area over the 30+ year time period (Ellis et al. 2011). In an assessment of land area change in coastal Louisiana (1932 – 2010) Couvillion et al. (2011) found substantial land area losses (~1.2 million acres) since 1932, with over 89,000 acres lost in the Mississippi River Delta and over 109,000 acres lost in the Pontchartrain basin alone. Most of the general land area losses occurred during major settlement/development events from 1932 to 1973. However, it appears areas of major losses of undeveloped tidal marsh areas demonstrated by the assessment of C-CAP land cover change above likely occurred following major storm events in 2004-2008.

In addition to losses from subsidence, development, and catastrophic storm events coastal marsh systems are expected to be impacted by sea level rise. Marsh systems are expected to adapt to fluctuations in sea-level through processes such as vertical accretion and horizontal migration, and in the absence of physical barriers, estuarine marshes are expected to migrate landward. Enwright et al. (2015) used five sea level rise scenarios (0.5 – 2.0 m) and predicted spread of urbanization (Terando et al. 2014) to determine the extent of estuarine marsh migration and migration barriers along the northern Gulf of Mexico out to 2100. The project found there would be sufficient unimpeded areas for marsh migration in the GCPO LCC with the exception of some areas associated with coastal bay estuaries where the urban footprint is expected to grow (**Figure TM.9**). Another modeling effort called the Sea Levels Affecting Marshes Model project along the Northern Gulf of Mexico used a decision-tree approach to predict vulnerability of marsh and other habitats to sea-level rise along the Northern Gulf of Mexico and found similar results as Enwright et al. (2015), but incorporated counter-effects of marsh accretion into models (**Figure TM.10**). Other projects such as the Ecological Effects of Seal Level Rise also address coastal changes due to SLR in National Estuarine Environmental Research Reserves. Given the plethora of loss estimates all suggesting ongoing vulnerability of the tidal marsh system in the northern Gulf of Mexico, and in particular, precipitous loss in areas of the GCPO LCC geography, it is critical that the conservation community continue efforts to better understand the ranges of tolerance that priority wildlife species have to marsh losses such that restoration and management targets can be set.

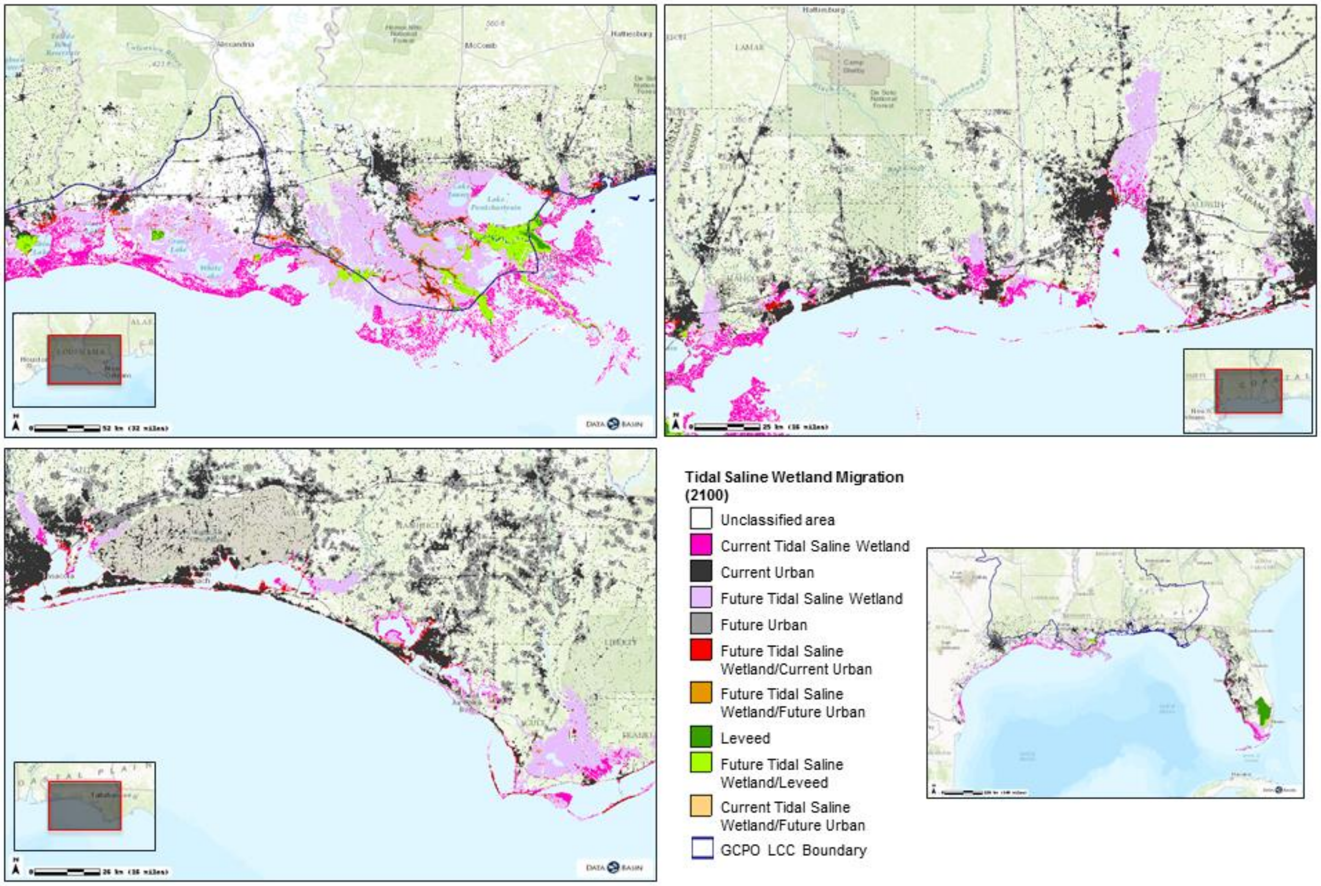

Figure TM.9. Predicted tidal saline wetland migration out to 2100 using mean 1.2 m expected sea-level rise in Louisiana (top left), Mississippi and Alabama (top right), and western Florida panhandle (bottom left) portions of the GCPO LCC Gulf Coast geography. Areas in light pink represent future marsh migration, whereas areas in red represent landscapes predicted to be urbanized and a barrier to marsh migration in 2100 (Enwright et al. 2015)

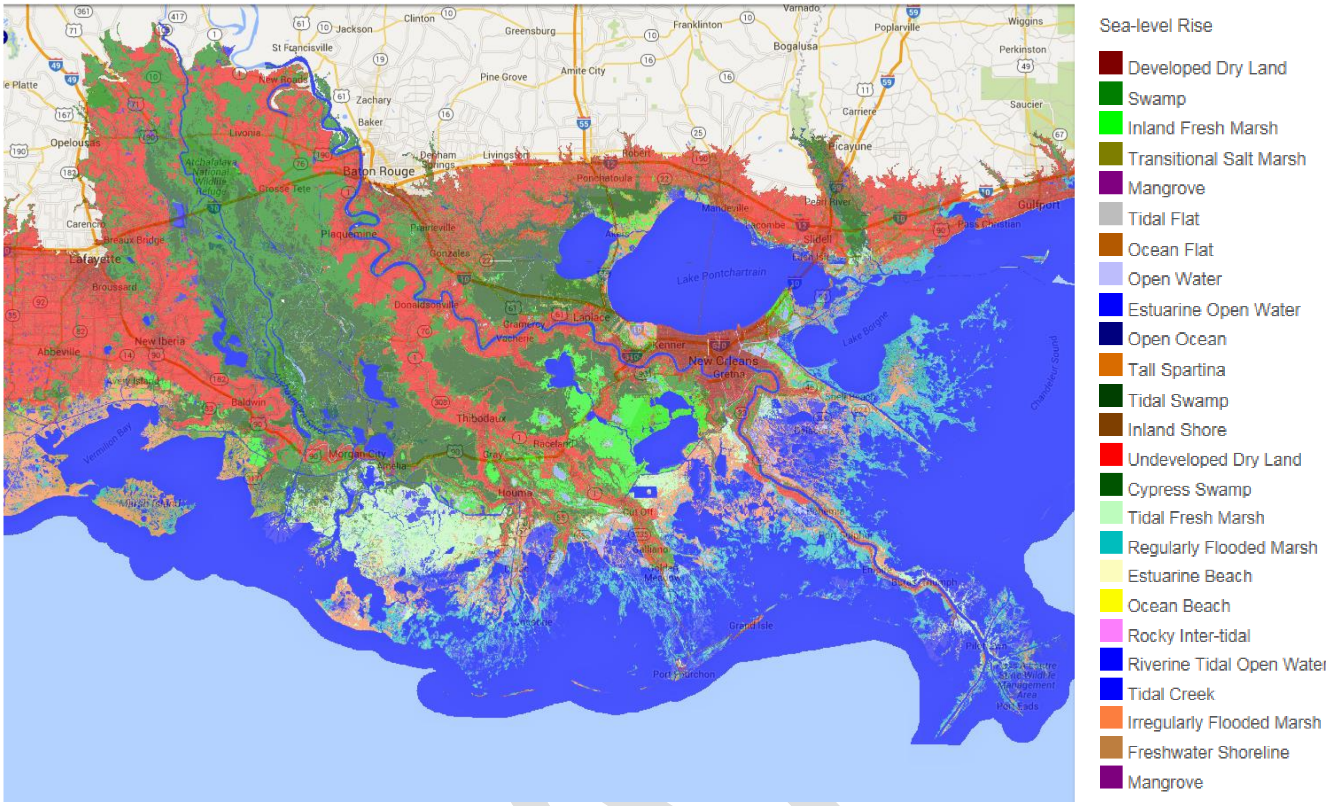

Figure TM.10. Predicted change in coastal systems in Louisiana to 2100 under a 1.2 m sea-level rise scenario using Sea Level Affecting Marshes Model data, as visualized in SLAMM View (Warren Pinnacle Consulting, Inc. 2016)

Conservation Planning Atlas Links to Available Geospatial Data Outputs:

- Net change in Estuarine Tidal Marsh (C-CAP 1996-2010) in the GCPO (vector – polygon: acres per HUC 12)
- USGS Tidal Saline Wetland Migration Along the Gulf of Mexico under alternative Sea-level Rise and Urbanization Scenarios (raster) (Enwright et al. 2015)
- SLEUTH Projected Urban Growth (raster) (Terrando et al. 2014)

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Chapter 2: Configuration, large blocks of unbroken marsh, Condition, emergent vegetative cover and limited open water

Subgeography: **GULF COAST**

Ecological System: **Estuarine Tidal Marsh**

Landscape Attributes: *Configuration*

Desired Landscape Endpoints: Large blocks of unbroken marsh (>250 ac); Emergent vegetative cover >70%; Open water <20%

Ongoing integrity of Gulf Coast tidal marsh systems may require that marshes be available in large blocks of unbroken vegetative cover to protect marshes against fragmentation and meet home range requirements for the myriad of marsh-dependent species. However, needs of species vary, depending on seasonal requirements (breeding, overwintering, resident), diurnal preferences (e.g., marshes as feeding grounds, roosting grounds, etc.), and preferences for elevation, water-depth, and proximity to open water (Shafer et al. 2002). As expected in most systems, increases in tidal marsh area (i.e., patch size) may lead to increases in species richness. However, some priority species endpoints defined in the ISA may exhibit greater sensitivity to marsh area due to large home range sizes (e.g., river otter [*Lontra canadensis*]), compared to others that may exhibit variability in home range (e.g., king rail [*Rallus elegans*], Pickens and King 2013) or be affected by limiting factors other than patch size (e.g., clapper rail [*Rallus longirostris*] and fiddler crab abundance, Rush et al. 2010). The often secretive nature of tidal marsh species and challenges associated with sampling in marshes leaves many information gaps regarding relationships between vegetative cover and patch size in this system.

Loss of tidal marsh to open water through wave effects, storm events, subsidence, sea level rise, and changes in salinity are consistently shown to be among the primary causal factors behind declines in marsh extent along the northern Gulf of Mexico. In dynamic coastal marsh systems, limited loss to open water is expected, as long as natural processes to offset these losses are maintained over time. However, all losses to open water are not equivalent in cause. Shoreline losses to open water -- typically from tidal influence, wave action, and storm surge -- are expected, but their causal mechanisms may differ from interior open water pockets (sometimes called “hotspots”) that arise within vegetated marshes and expand from within. Hotspots may stem from marsh die-back, potentially resulting from changes in water chemistry and sedimentation indicative of stress in the system (Boesch et al. 1994). Limited coverage of open water and/or open water-marsh edge may be preferable or even necessary for some of the priority species endpoints listed in the GCPO LCC ISA, including aquatic species (e.g., oysters) and marsh terrestrial species (e.g., king rail [*Rallus elegens*] [Pickens and King 2013], clapper rail [*Rallus longirostris*] [Rush et al. 2010]), and therefore is perceived as an important system component.

To effectively assess the endpoint targeting large blocks of unbroken marsh we must first incorporate the related condition endpoints of emergent vegetative cover and open water in order to delineate “unbroken” area. We therefore combined assessment of three endpoints into one section (>70% emergent vegetative cover, <20% open water, and large blocks of unbroken marsh >250 ac) due to the interdependency among the three.

Data Sources and Processing Methods

We based the assessment of estuarine tidal marsh cover and patch size on the 10 m composite estuarine marsh mask, which uses mosaiced data from the USGS Marsh Type Delineation Project (MTDP) in Alabama, Louisiana, and Mississippi and Florida Cooperative Land Cover V.3.1.

Step 1: Patch Delineation

We first buffered the GCPO eastern and western boundaries by 10 km, and extended the coastal boundary to the state seaward boundaries to allow for integrity of patches to remain intact along the GCPO boundary line. We used the Clump tool in ERDAS Imagine to group pixels in an 8-neighbor vicinity into discrete patches. We then converted the clumped patch pixels to polygons with non-simplified edges. We next ran an Eliminate Polygon Parts tool in ArcGIS to consolidate breaks within marsh interiors (followed by a Dissolve function, dissolving by original patch ID from the Clump procedure, allowing for multi-part features), to be used in subsequent analysis of percent vegetative cover, percent open water, marsh interdigitation and submergent vegetation (**Figure TM.11**). We selected marsh patches >250 ac and extracted the tidal marsh mask by the selection and reclassified to produce a binary layer of marsh pixels that fall within a large >250 acre patch (to be used in compilation assessing the desired ecological state for the system later). For summary purposes we selected only marsh patches that intersected the GCPO geography by using a select by location function.

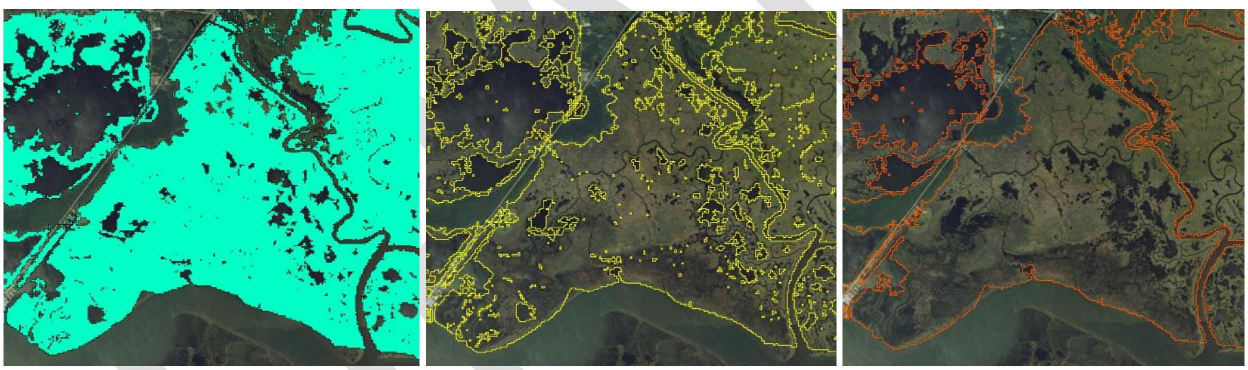

Figure TM.11. Example of a patch delineation process from conversion of 10 m marsh overlay product pixels (left) to initial marsh polygons (center), then final patch delineation (right). Delineated patches were used to quantify percent vegetative cover and open water and assess interdigitation of marsh types in the assessment.

Step 2: Emergent vegetative cover >70% and open water cover <20%

We used zonal statistics tools in ArcGIS Spatial Analyst to evaluate percent cover of emergent vegetation and open water within marsh patches delineated above. To assess percent emergent vegetative cover we ran zonal statistics on the estuarine tidal marsh mask 10 m resolution raster layer, using marsh patches as “zones” and calculating proportion of each patch comprised of emergent estuarine marsh vegetation. To assess percent cover of open water we first reclassified the MTDP data to extract out the “water” class for Louisiana, Mississippi, and Alabama, and the Florida CLC data to extract out all state-level open water classes (lacustrine [3000], natural lakes and ponds [3100], cultural lacustrine [3200], riverine [4000], natural rivers and streams [4100], cultural riverine [4200], estuarine [5000], and marine [6000]). Water classes from MTDP and CLC were mosaiced together to produce a layer of open water across the GCPO Gulf Coast. To assess percent open water cover we ran zonal statistics on the 10 m resolution open water layer, using marsh patches as "zones" and calculating proportion of each patch comprised of open water. These analyses produced two 10 m resolution raster layers with all pixels in each defined patch assigned a value of the mean percent cover of emergent vegetation and open water within the patch. We then extracted the zonal mean output layer back through the tidal marsh mask and reclassified to a binary layer of marsh pixels that meet the endpoints of mean emergent vegetative coverage in the patch >70% and mean open water coverage <20% (to be used in compilation assessing the desired ecological state for the system).

Step 4: Compilation

Using the binary outputs from steps 1-3 and map algebra in ArcGIS, we derived four sets of values representing a gradient of marsh conditions. These included: 1) marsh patches >250 acres in size with >70% emergent vegetative cover and <20% open water cover (reflecting desired endpoint of large patches of unbroken marsh); 2) marsh patches >250 acres in size with either <70% emergent vegetative cover, or >20% open water, or both, reflecting large broken patches; 3) marsh patches <250 ac in size with >70% emergent vegetative cover and <20% open water cover, reflecting small unbroken patches; and 4) marsh patches <250 acres in size with either <70% emergent vegetative cover, or >20% open water, or both, reflecting small broken patches. These classifications were later used in calculation of marsh condition index values to assess current marsh condition relative to the desired ecological state defined in the ISA, to be used in development of the GCPO LCC conservation blueprint for estuarine tidal marsh systems.

Summary of Findings

Using the methods described we estimate there are 35,097 estuarine tidal marsh patches that intersect the GCPO LCC geography. Mean estimated patch size was 7.35 acres (SD = 166 and range 0.02 – 15,057 acres), including in-patch open water breaks. Of those patches we estimate 144 patches are >250 acres in size, with mean patch size = 1,311 acres (SD = 2,235). However, large patches >250 acres comprise 73% of all patch acreage, suggesting a relatively small number of large patches hold a disproportionate amount of tidal marsh acreage.

The largest single patch (15,057 acres including open water breaks) was located north of Vermillion Bay in Iberia Parish, Louisiana surrounding Avery Island and is currently not in protected status. This patch lies along the GCPO/Gulf Coast Prairie LCC boundary, and exhibits 95% emergent vegetative and <1% open water cover. The third largest patch lies directly adjacent to the patch above and encompasses 13,521 acres. Therefore combined this area north of Vermillion Bay provides over 28,000 acres of unbroken marsh, which is currently considered unprotected. The second largest patch (13,907 acres), is found within and around the Grand Bay National Wildlife Refuge/National Estuarine Research Reserve in Mississippi and Alabama. In addition to the three above, there are three other large patches in Alabama, Louisiana, and Mississippi between 5,000 and 10,000 acres and 37 other large patches 1,000 – 5,000 acres in size spanning across the GCPO Gulf Coast geography.

Using the patches derived above as zones within which to measure mean emergent vegetation cover and open water we estimate 98% of patches exhibited >70% emergent vegetative cover and 99% of patches exhibited <20% open water cover. Two of the large patches >250 ac exhibited 31% open water cover and 68% emergent vegetative cover (one in Mobile Bay, AL, and one in Lake Pontchartrain, LA), suggesting these patches were outside the ranges of the desired endpoints. Through the compilation analysis we identified 142 large unbroken estuarine tidal marsh patches that met all three criteria of patch size >250 acres, with >70% cover of emergent vegetation and <20% cover of open water (**Figure TM.12**).

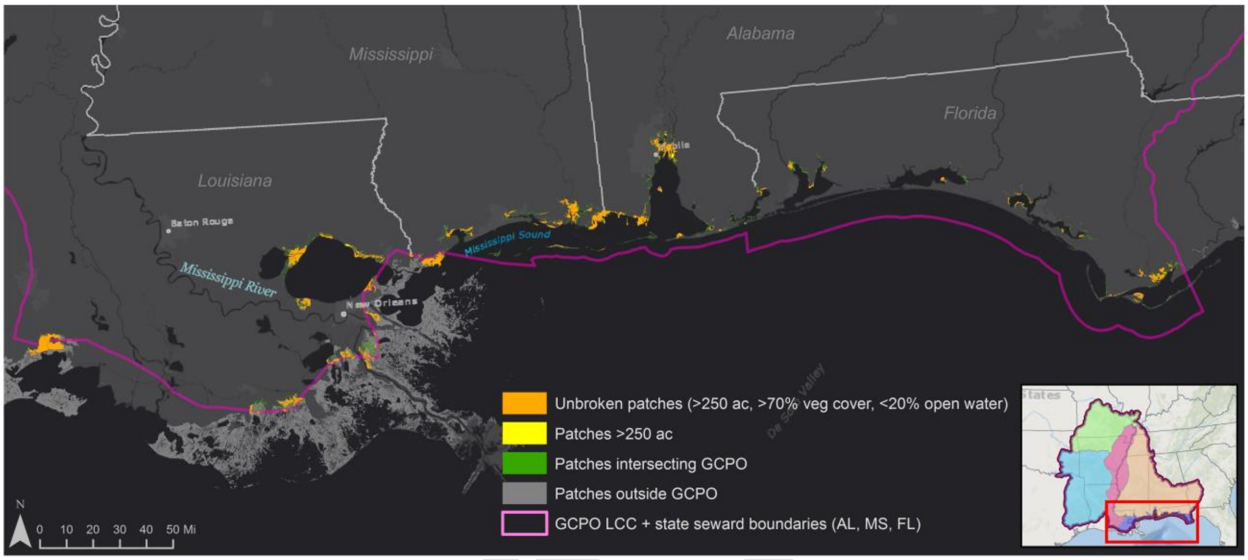

Figure TM.12. Large, unbroken patches of estuarine tidal marsh (orange) that are >250 ac in size and exhibit >70% emergent vegetative and <20% open water cover intersecting the Gulf Coast portion of the GCPO LCC geography. Note contiguous patches intersecting the GCPO-GCP LCC geography were retained for purposes of this assessment.

Future Directions and Limitations

Estuarine tidal marsh patches were delineated from raster data using current, but not comprehensive data sources, and patches were delineated through an 8-neighbor pixel adjacency approach (which includes diagonal adjacency). We assume here that breaks in adjacency determine a functional patch for the suite of species, which may be inherently problematic. The reality is that each species will perceive a patch differently, depending on its life history needs. For some species multiple large marsh patches with riverine breaks may serve as a single functional patch or as a dynamic metapopulation (e.g., Erwin et al. 1995, Woodrey et al. 2012). Since the majority of marsh breaks in the estuarine system are the result of open water, patch delineation could be liberalized beyond simple adjacency depending on what role open water breaks play in movement/dispersal of species. Unfortunately, it is unclear whether patch breaks via riverine/canal/bayou passages serve as functional barriers to priority species endpoints outlined in the ISA. We also assume that salt marsh and gradation into adjacent fresh marsh are not functioning together as a patch, which may be a false assumption for many of the terrestrial priority species. However, for simplicity in this assessment we have delineated patches solely on pixel adjacency, with the thought that this can be further developed as improved understanding of species-habitat relationships develops from the research community. An alternative argument is that it is not necessarily the patch configuration that is driving species dynamics in a systems, but instead the total amount of preferred habitat in a given landscape (Fahrig 2013). This concept can and should be evaluated using empirical data, though determination of appropriate scale will be challenging. An improved understanding of patch dynamics for priority species in estuarine tidal marsh systems is critical to understanding how best to restore and manage coastal wetland habitats.

Conservation Planning Atlas Links to Available Geospatial Data Outputs

- Large and Unbroken GCPO Estuarine Tidal Marsh Patches and Proportion Vegetative and Open Water Cover in Patches [Draft] (vector - polygon)

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Chapter 3: Configuration, connectivity of habitat types

Subgeography: **GULF COAST**

Ecological System: **Estuarine Tidal Marsh**

Landscape Attributes: *Configuration*

Desired Landscape Endpoints: Connectivity of habitat types reflective of interdigitation of marsh types

Estuarine tidal marsh systems along the northern Gulf Coast represent a diverse mix of marine-influenced, riverine-influenced, or a combined marine-freshwater influenced vegetation composition and structure (Battaglia et al. 2012). Factors related to elevation, salinity, and tidal inundation frequency, in addition to other features (e.g., sulfide, soil porosity, water transfer, and interspecific competition) play a major role in distinct interdigitation of vascular flora in estuarine tidal systems (Odum 1988, Pennings et al. 2005, Wang et al. 2007). Different plant species with different gradient tolerances results in diversity of plant species across high, intermediate, brackish and low marsh, suggesting interdigitation (i.e., interlocking) of marsh types in concert with presence of succulent-dominated salt pannes in a particular estuary will infer greater faunal diversity. This is seen in fish assemblages, whereby diversity in fish and nekton communities is greater in estuaries with increased habitat diversity, reflecting increased growth rates in areas with multiple habitat types (Jelbart et al. 2007).

Data Sources and Processing Methods

Prior to 2014, coastal estuarine marsh types had to be inferred from local marsh mapping projects, or from water chemistry modifiers included in National Wetlands Inventory when available. In many cases, determination of palustrine vs. estuarine was the only available information across a large spatial scale. The USGS marsh type delineation project (MTDP) was developed to provide a standardized delineation of marsh vegetation types per three and four salinity zones along the northern Gulf of Mexico following the Chabreck et al. (1968) classification (see **Table TM.1**) (Enwright et al. 2014). Thus far, the marsh type delineation project has delineated fresh, intermediate, brackish, and saline marsh types, in addition to water and non-marsh classes from Corpus Christi Bay, Texas to Mobile Bay, Alabama. The project uses 2009-2011 Landsat TM and SPOT 4 and 5 satellite imagery, existing land cover classifications, calculated vegetation and water indices, lidar-derived elevation data, and topographic and distance indexes to produce a step-wise decision tree analysis in See5 and other software programs in combination with 2011-2012 ground referenced observations.

We attempted to assess marsh interdigitation using NWI modifiers for water chemistry coastal halinity (hyperhaline, euhaline, mixohaline, polyhaline, mesohaline, oligohaline, fresh) for estuarine emergent (E2EM) and estuarine scrub-shrub (E2SS) classes in Florida, but these modifiers were not included in marsh classifications within the Florida portion of the GCPO LCC geography. We next evaluated estuarine classes in the Florida Cooperative Land Cover (CLC version 3.0). This classification scheme does an excellent job of providing detailed classification of freshwater wetlands, but groups most marsh vegetation into the saltwater marsh (5240 class within the estuarine intertidal group. Saltmarsh cordgrass (5242) and needle rush (5243) are broken into separate classes as part of the CLC classification but these classes are not yet differentiated from the salt marsh class within the CLC layer in version 3.0 (Knight et al. 2010). We also assessed Southeast GAP ecological classification, which groups Mississippi Sound salt and brackish tidal marsh (CES203.303), Gulf and Atlantic Coastal Plain tidal marsh systems (CES203.638), both which include brackish, salt and freshwater marshes typical of the Gulf of Mexico, but does not separate out marsh types. Given the limitations we experienced in the western Florida panhandle we concluded to later update this portion of the GCPO ecological assessment when a marsh type delineation project extension into Florida is finalized.

We used the USGS MTDP layer to assess composition of saline, brackish, and intermediate marsh as a surrogate for interdigitation in delineated marsh patches in the Louisiana, Mississippi and Alabama portions of the GCPO LCC Gulf Coast subgeography. We first ran a Tabulate Area analysis in ArcGIS to calculate the area and subsequent proportion of saline, brackish, and intermediate marsh within each patch. Then we calculated measures of interdigitation of the three marsh types, or patch richness, within each patch, with a patch richness value of three indicating presence of saline, brackish, and intermediate marsh within the patch. We used measures of composition in addition to measures of patch richness, which indicate the presence of marsh types regardless of composition, to assess interdigitation within patches. Without explicit thresholds set for interdigitation of marsh types we used a liberal range of composition in the estimate, whereby marsh patches containing >5% of each saline, brackish, and intermediate marsh types were considered interdigitated. We plan to update these measures with a specific threshold once improved information on marsh type needs are available for species.

Summary of Findings

Overall, composition of estuarine marsh was fairly well-mixed across all patches in Louisiana, Mississippi, and Alabama, with patches composed of 27% saline, 40% brackish, and 31% intermediate marsh averaged over the three states (**Table TM.4**; **Figure TM.13**). As expected, when examined independently, marsh type composition in Louisiana differed substantially from that of Alabama and Mississippi, with far greater prevalence of intermediate marsh and minimal presence of saline marsh in the estuaries influenced by the Mississippi River in GCPO (**Figure TM.14**). However, marsh systems in Alabama and Mississippi are quite similar to each other in composition of saline and brackish marsh. Note that this analysis is restricted to patches of marsh that were defined using MTDP saline, brackish, and intermediate marsh classes, and excludes salt pannes, palustrine (freshwater) marsh, and tidal freshwater forest classes.

Patch richness (i.e., the number of different marsh types in a patch) tended to be lower in the Mobile Bay estuary of Alabama than other estuaries in the study area. Of large patches >250 acres 74 out of 112 (66%) of patches contained all three saline, brackish, and intermediate marsh types (**Figure TM.15**). However, simple measures of patch richness may not accurately reflect the composition of marsh types within patches, as one marsh type may be present but only in miniscule amounts. To account for this we also measured interdigitation as patches containing at least 5% composition of each marsh type within the patch. We found 150 patches of any size contained at least 5% of each intermediate, brackish, and saline marsh types, whereas only 4 patches >250 ac in size contained 5% of each marsh type.

Table TM.4. Mean composition of saline, brackish, and intermediate marsh and mean patch richness in estuarine tidal marsh patches >250 ac (left) and of all sizes (right) in Louisiana, Mississippi, and Alabama portions of the GCPO LCC, derived from the USGS marsh type delineation project.

	Patches >250 ac					All patches				
	# Patches	% Saline	% Brackish	% Intermed.	PR	# Patches	% Saline	% Brackish	% Intermed.	PR
Louisiana	60	3%	43%	48%	2.70	20,845	10%	45%	42%	1.06
Mississippi	29	58%	38%	1%	2.72	5,135	58%	32%	9%	1.10
Alabama	23	54%	37%	4%	2.43	7,007	55%	30%	15%	1.11
Overall	112	28%	40%	27%	2.65	32,987	27%	40%	31%	1.08

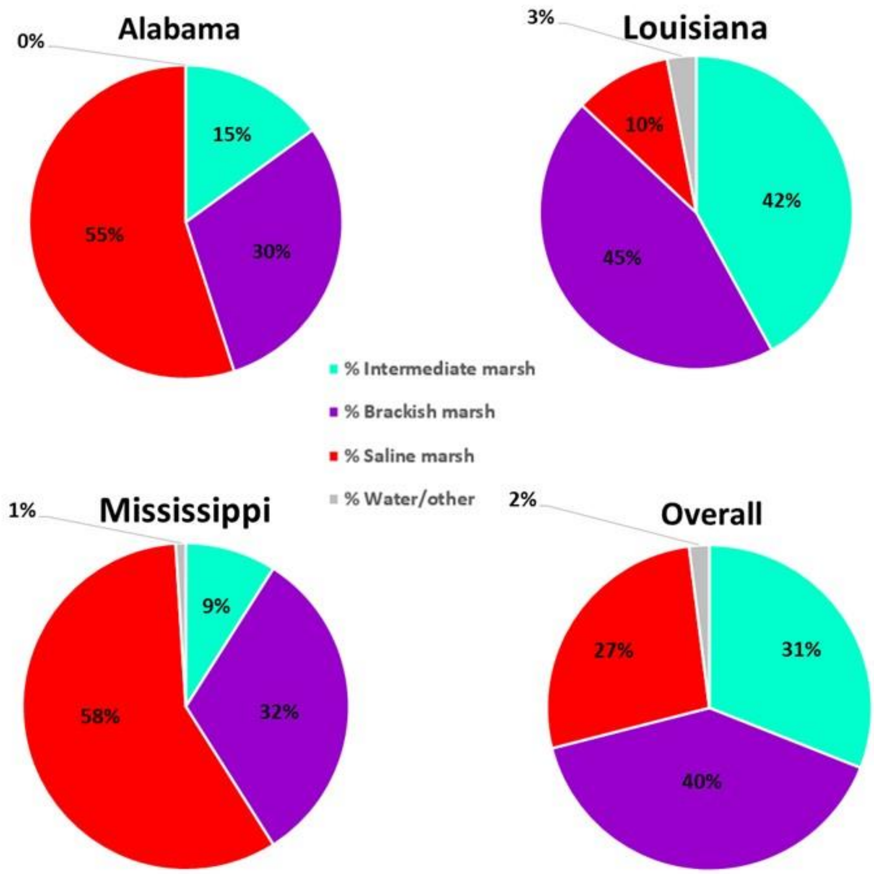

Figure TM.13. Mean composition of saline, brackish, and intermediate marsh classes in estuarine tidal marsh patches in Louisiana, Mississippi, and Alabama portions of the GCPO LCC derived from the USGS marsh type delineation project.

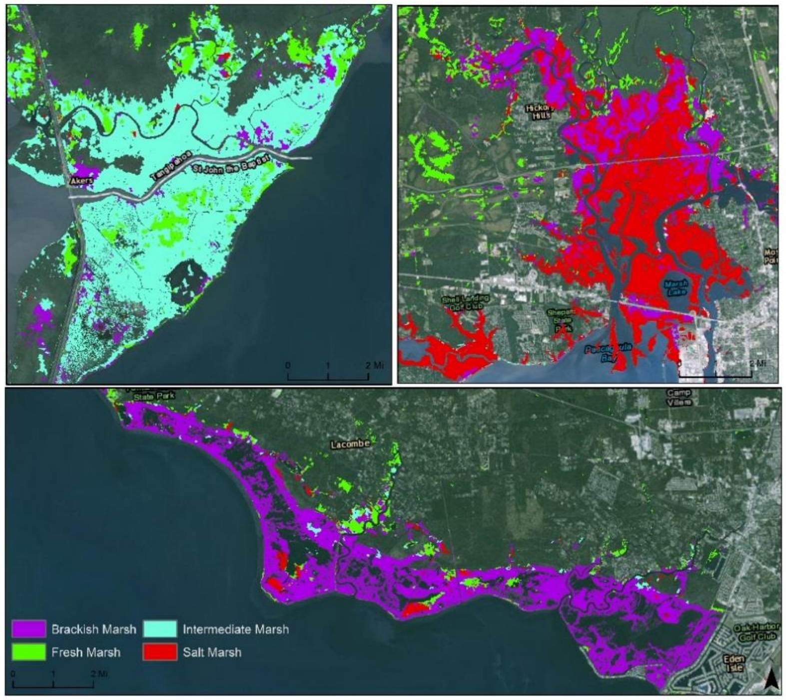

Figure TM.14. Examples of interdigitation of fresh, intermediate, brackish and saline marsh types within estuarine tidal marsh in areas surrounding Lake Pontchartrain in Louisiana (top left, bottom) and Pascagoula Bay in Mississippi (top right) derived from the USGS marsh type delineation project.

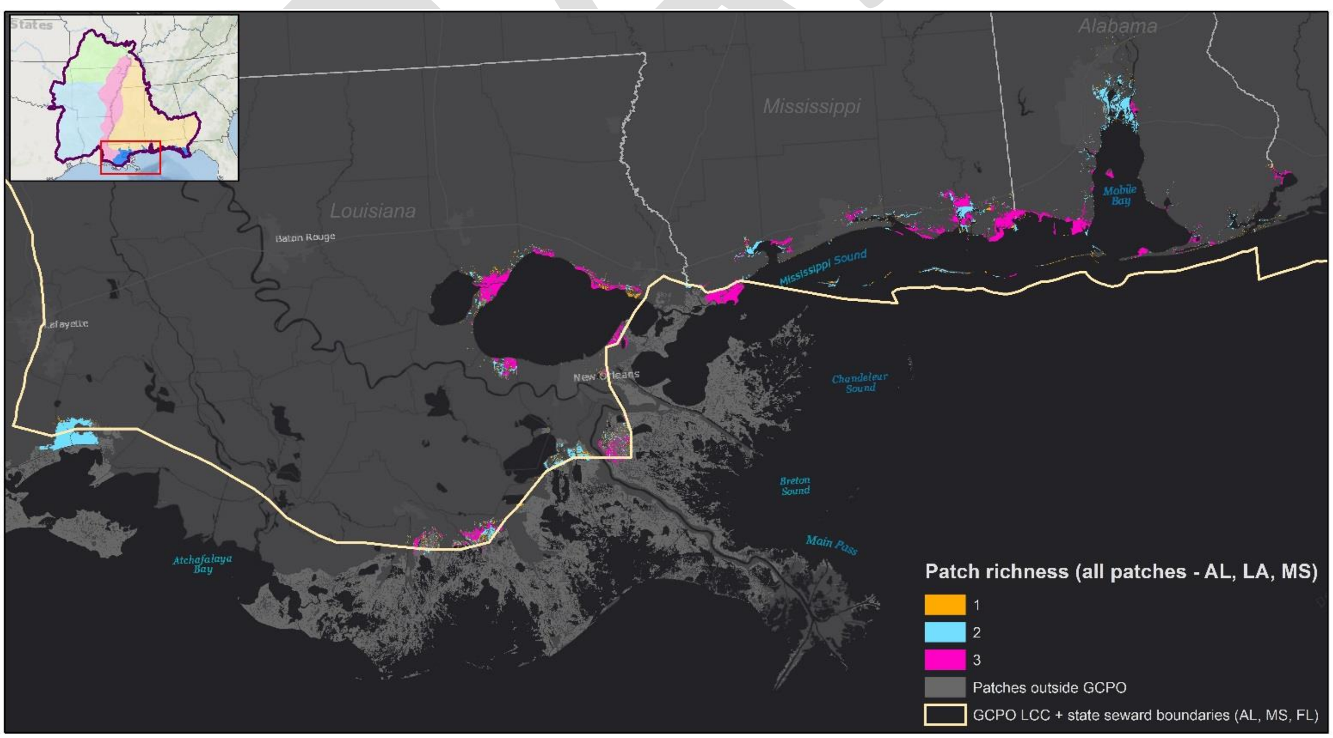

Figure TM.15. Estimates of patch richness (number of different marsh types) in estuarine tidal marsh patches in Louisiana, Mississippi, and Alabama portions of the GCPO LCC based on the USGS four-marsh type delineation project outputs.

Future Directions and Limitations

As demonstrated in the analysis, marshes that fall within the Louisiana Deltaic Plain are different in composition overall, but not necessarily within-patch richness of marsh types compared to patches in Alabama and Mississippi portions of the GCPO LCC, with the exception of the Mobile Bay estuary. Comparison of estuaries displayed in **Figure TM.14** demonstrates a striking differences between compositions of marsh types even within the same estuary system (e.g., Lake Pontchartrain) in these different patches particularly related to prevalence of saline vs. intermediate vs. brackish marsh in Mississippi/Alabama vs. Louisiana. These differences are likely already widely understood by stakeholders and conservation entities, but can now be assessed empirically and managed intentionally since the marsh type delineation work has been completed in these states. We expect to expand the analyses in this assessment if the marsh type delineation work or other efforts covering the western Florida panhandle are available.

Conservation Planning Atlas Links to Available Geospatial Data Products

- USGS four marsh type delineation for coastal TX through AL (raster)
- Patch richness (interdigitation) of estuarine tidal marsh types in GCPO LCC (LA, MS, AL) (raster)

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Chapter 4: Configuration, moderate edge

Subgeography: **GULF COAST**

Ecological System: **Estuarine Tidal Marsh**

Landscape Attribute: *Configuration*

Desired Landscape Endpoint: Moderate amounts of edge within large blocks of marsh

Presence of edge (or, areas of where land cover types change abruptly) reflects spatial patterning on the landscape, which often drives ecological phenomena related to ecosystem structure (McGarigal 2015). The magnitude and scope of edge effects varies by species, with some species responding positively to the variation in microclimate, vegetation, and faunal diversity that the presence of an edge in the landscape provides, and others actively avoiding edges and the host of potential predators that they might facilitate. In estuarine marsh systems response to edge may depend on life history needs of the taxa of interest. For example Penaid shrimp abundances have been shown to be 5-13 times greater in experimental marshes that added open-water edge through tidal-creek channelization, but crab species abundances remained unchanged (Minello et al. 1994). Zimmerman et al. (2000) demonstrated both Penaid shrimp and blue crab preferred marsh-edge habitats in Texas and Louisiana compared to non-vegetated locations. Penaid shrimp survival is also shown to be greater in marsh-edge habitats compared to open-water habitats, presumably linked to more efficient access to vegetation for foraging and cover (Haas et al. 2004), though decapod crustaceans have been shown to prefer oyster and seagrass habitats over marsh edge (Glancy et al. 2003). Evidence also suggests marsh-open water edge is an important seasonal feature for many fish species using these systems as nurseries (Baltz et al. 1993, Peterson and Turner 1994, Chesney et al. 2000, Minello et al. 2003), largely related to the increased abundance of benthic infauna, an important prey species in these habitats (Whaley and Minello 2002). Variation in response to edge is also found in terrestrial species as well. Clapper (*Rallus longirostris*) and King Rail (*Rallus elegans*) are found to associate with marsh edge during parts of their annual cycle (Rush et al. 2010, Pickens and King 2013). Though edge effects in tidal marsh systems are better understood for some of the species prioritized by the GCPO LCC than others, the Adaptation Science Management Team suggested moderate amounts of edge in large blocks of marsh would suffice to holistically meet the needs of the group of priority species.

Data Sources and Processing Methods

Rather than consider edge between estuarine marsh types (e.g., brackish vs. saline), for simplicity and spatial coverage we instead assessed only non-estuarine marsh edges, typically dominated by open-water edge, but also including a limited portion of edge with other landscape classes (developed, forested wetland, freshwater marsh, etc.). We first used the clumped marsh mask pixels converted to patches to calculate area and perimeter of marsh pixels within each patch using Zonal Geometry in ArcGIS. Given that marsh patch size varies substantially across the geography we more appropriately measured edge density per unit area (total edge (m) divided by total landscape area (m^2), multiplied by 10,000) to estimate m/ha edge and allow for comparative assessment across tidal marsh patches. There was no explicit threshold specified for marsh edge, and assigning thresholds were further complicated by the use of edge density, which skews summary data on all marsh patches due to influence of very small patches on edge density measures. We therefore calculated mean edge density based on all marsh patches 5 ac in size or greater. We assigned values to the term “moderate” for later compilation of marshes in the desired ecological state by assuming marsh patches with edge density less than one standard deviation above the mean (using patches >5 ac) were considered moderate. This will be revised at a later time when explicit thresholds of edge density are set.

Summary of Findings

Across all marsh patches, edge density measures varied widely (42-4,000 m/ha), which may be due to the preponderance of very small patches on edge measured per unit area, which inflated the mean edge density estimate in the assessment (**Table TM.5**). Also note that edge measures may be biased upward due to the geometric nature of patches that were not produced with simplified/smoothed edges. This should not be problematic in comparisons among patches in this assessment, but may impact other subsequent analyses of species-habitat relationships. Given issues related to edge density measures and without a direct threshold defining targeted levels of edge, it is not possible to define what constitutes “moderate” edge in a landscape (**Figure TM.16**).

If we remove patches <5 ac to eliminate biases in edge density measures derived from small patches, we find a mean edge density of 500 m/ha. For large patches >250 ac we estimate mean edge density of 202 m/ha. Areas of low edge density relative to other large patches were apparent in intact marshes where the Mobile Bay meets the MS Sound in Alabama, in Apalachicola Bay in Florida, as well as scattered low-edge patches throughout the remaining estuaries in the GCPO LCC (**Figure TM.17-18**). Areas of greatest edge density were found in Louisiana portions of the GCPO which may be the result of a series of recent tropical storm/hurricane events in combination with deleterious effects of subsidence, development, and sea level rise. However, this is speculative as natural variation in patch configuration and hydrologic patterns may also explain observed patterns in edge density in these areas.

Since the endpoint for edge was listed as qualitative (i.e., “moderate”) with no specified thresholds for edge density, we attempted to objectively evaluate edge in the assessment of marshes in the desired ecological state described below. For these efforts we included all marsh patches that were within one standard deviation above the mean for patch sizes >5 ac. Marsh patches exhibiting 735 m/ha or less edge density were therefore included in calculation of the marsh condition index to assess how patches reflect the desired ecological state. We estimate 2,753 marsh patches exhibit <735 m/ha edge density, including all 144 patches >250 ac in size. We expect to update this component of the ecological assessment with future versions of the ISA, where improved edge density thresholds should be provided.

Table TM.5. Number of patches, mean total length of edge (m) and edge density (m/ha), and standard deviation and range associate with edge density in estuarine tidal marsh patches >250 ac and <250 ac in size and across all patches identified in the Gulf Coast geography of the GCPO LCC.

	n	Mean total edge (m)	Mean edge density (m/ha)	SD (m/ha)	Range (m/ha)
Patches >250 ac	144	83,108	202	118	42 - 649
Patches >5 ac	2,182	9,612	500	235	42 – 1,649
All patches	35,097	784	2,708	1,224	42 – 4,000

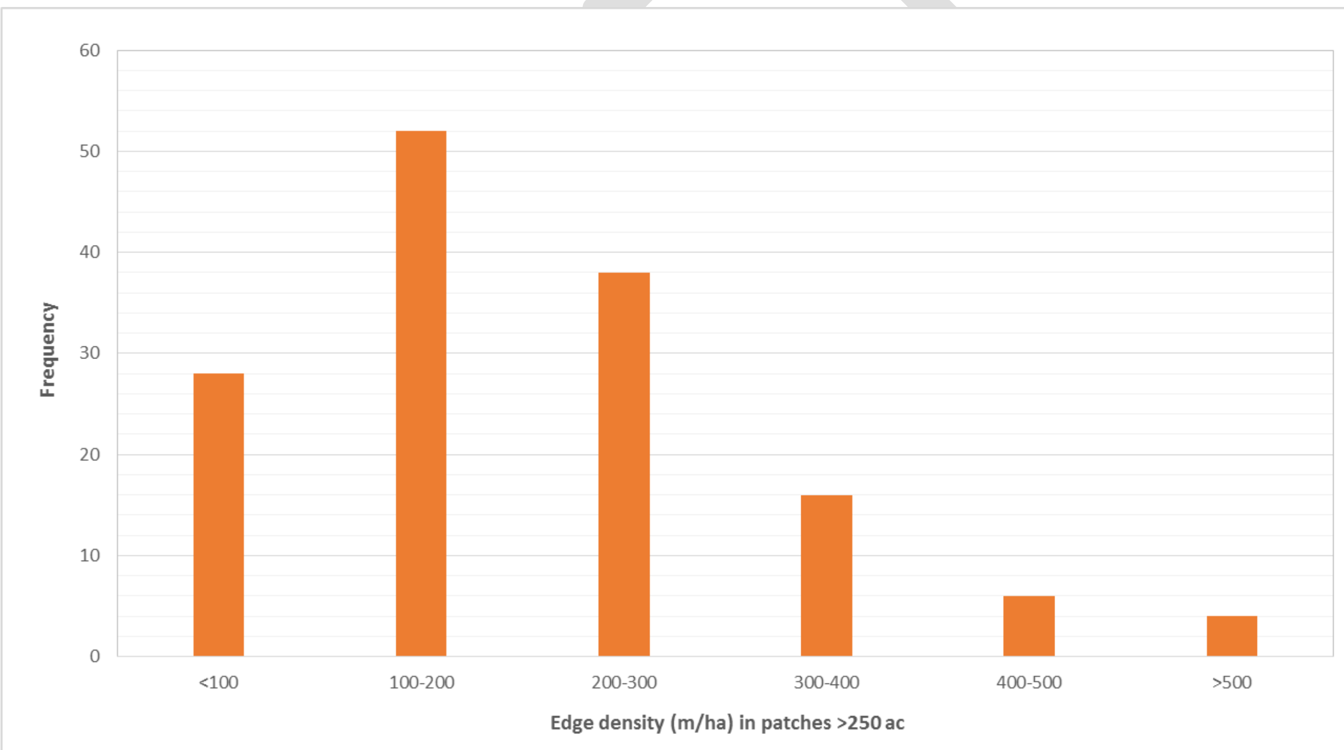

Figure TM.16. Equal-interval frequency distribution of edge density (m/ha) estimates in estuarine tidal marsh patches >250 acres (n = 144) along the GCPO LCC Gulf Coast subgeography.

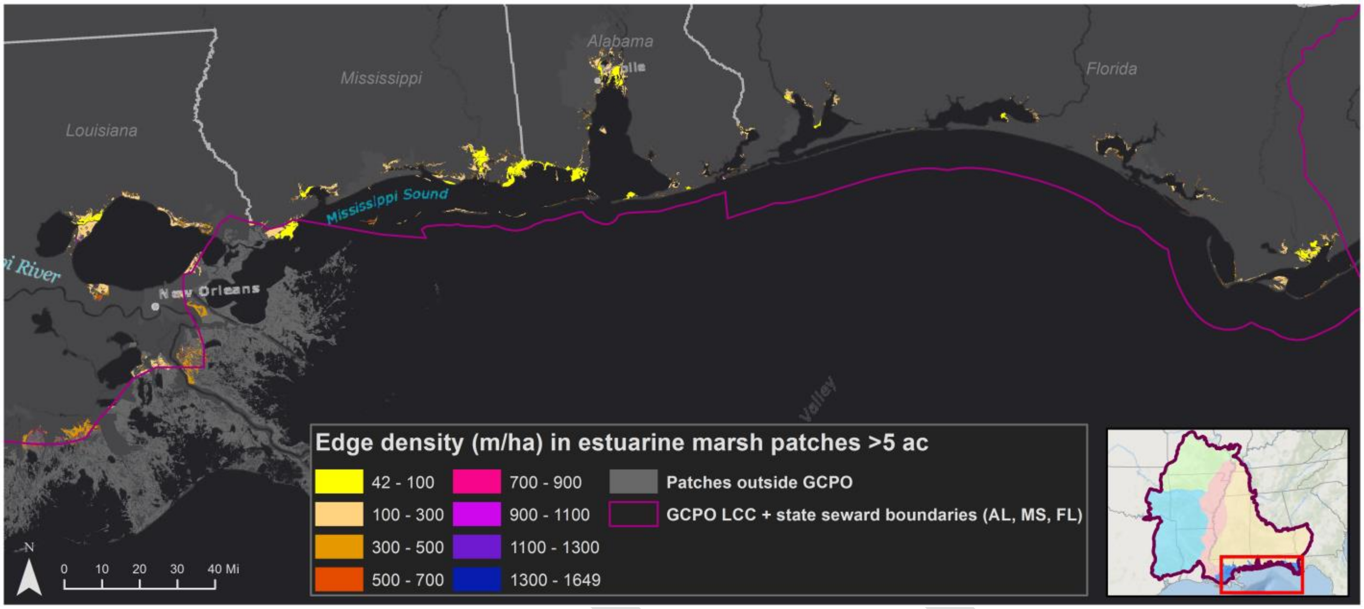

Figure TM.17. Edge density (m/ha) in estuarine tidal marsh patches >5 ac in size along the GCPO LCC Gulf Coast subgeography.

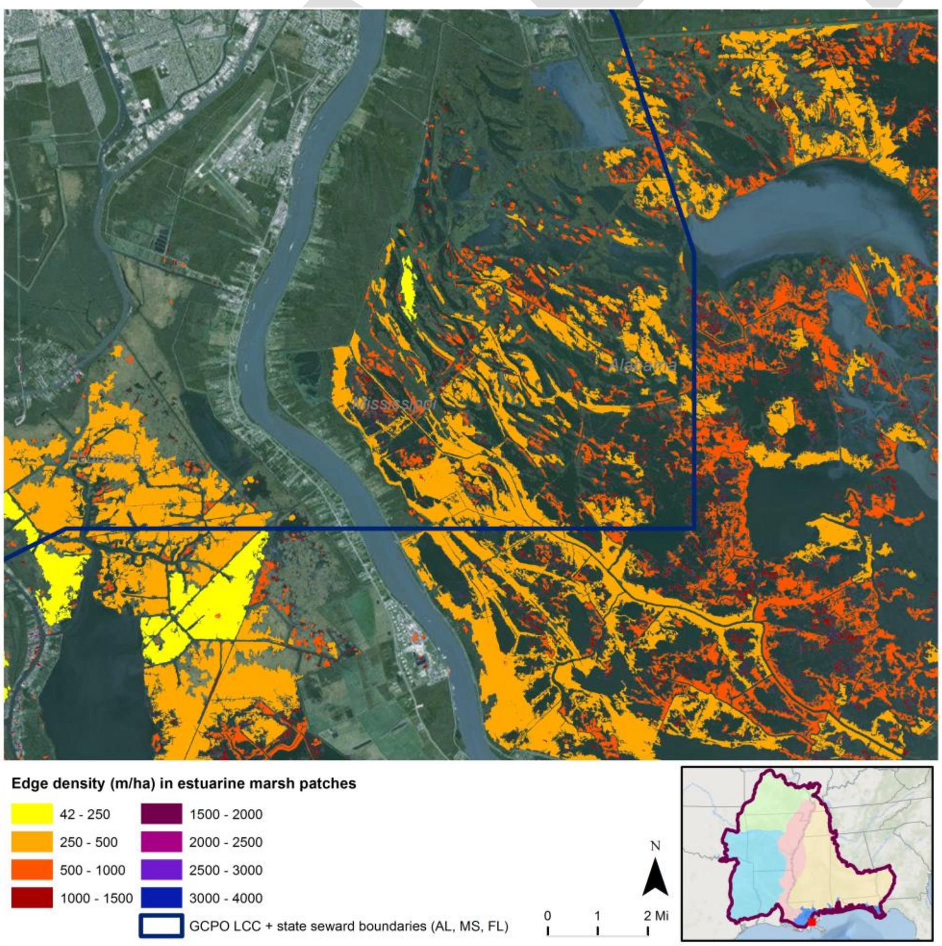

Figure TM.18. Edge density (m/ha) in estuarine tidal marsh patches in the Mississippi River delta estuaries of Louisiana within and bordering the GCPO LCC.

Future Directions and Limitations

The ISA endpoint specifies moderate amounts of edge, but operates under the assumption that different edge types (e.g., open water edge vs. freshwater marsh edge vs. developed edge) will elicit similar functional responses by the species of interest. Edge effects will undoubtedly vary with different land cover/vegetation type adjacencies. For example, a priority species will likely respond differently to a salt marsh-fresh marsh edge than marsh-open water edge. For simplicity, however, we did not assess edge within classes of estuarine tidal marsh, though some species may exhibit response to edges present among different saline, brackish, and intermediate marsh types. Assessing edge densities without a discrete range of acceptable values is also subjective and it is difficult to determine what constitutes “moderation” in large patches of estuarine habitat. This is complicated by the fact that in these systems edge density is often a function of analyses used to delineate marsh patches, which, in this case were created from contiguous marsh pixels. Delineation of the estuarine marsh patch may also fundamentally constrain an assessment of moderate edge.

From a technical perspective, pixel-based assessment of edge has inherent upward bias due to square pixel configuration (i.e., stair stepping) (McGarigal 2015), but given this is a comparison amongst marsh patches, which are all subject to this upward bias, should not have implications for this assessment. However, as the GCPO LCC science agenda is further refined with discrete species-driven thresholds of edge tolerance, this issue might be problematic and need resolution.

Conservation Planning Atlas Links to Available Geospatial Data Outputs

- Edge density (m/ha) in GCPO LCC estuarine tidal marsh patches (vector – polygon)

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Chapter 5: Configuration, presence of barrier islands

Subgeography: GULF COAST

Ecological System: Estuarine Tidal Marsh

Landscape Attribute: Configuration

Desired Landscape Endpoint: Presence of barrier islands in riverine-dominated systems

Barrier islands compose greater than two-thirds of the U.S. Gulf of Mexico coastline (Morton et al. 2004). Coastal barrier islands are formed by multiple processes, all related to ridge formation/accretion due to wind and water deposited sediments (Morton et al. 2004, Theel 2007). Barrier islands are considered dynamic “transitory geomorphic features” (Theel 2007), that serve to mitigate storm surge and flooding events (Grzegorzewski et al. 2011), but also provide critical habitat for breeding and migratory wildlife (e.g., Moore et al. 1990). Coastal barriers are also important to inland estuarine tidal marsh systems and often create island-associated marsh complexes either within island interior lagoon habitats or along their bay-side coastlines (**Figure TM.19**). However, barrier islands are dynamic systems, and typically lose area over time due to storm breaching, shoreline erosion, landward migration, deficits in sediment budget, and sea level rise (Edmiston et. al. 2008, Morton 2008, Brock et al. 2013). The morphology of each barrier island varies in the northern Gulf Coast, and will be the determining factor in barrier-integrity during storm events (Morton et al. 2004). The multitude of major storm events in the northern Gulf of Mexico over the last half century has reduced the protective features that barrier islands provide to GCPO estuarine marsh systems and coastal communities (Brock et al. 2013). Though coastal barrier islands have intrinsic value to landward riverine-dominated tidal marsh systems, it is challenging to rapidly quantify barrier effects using large-scale geospatial data. We therefore assessed presence of barrier islands in the GCPO LCC geography, length of protected coastline, and hurricane frequency and severity along GCPO barrier islands to address this endpoint.

Figure TM.19. Examples of the variability in barrier island structure and function along the GCPO LCC geography of the northern Gulf of Mexico. Horn and Petit Bois Islands in the Mississippi Sound and the associated Pascagoula Bay and Point aux Chenes estuary systems (left). St. Vincent Island in St. Vincent Sound/Apalachicola Bay in Florida and the complex of landward-side marshes and associated in-island marsh lagoons (right).

Data Sources and Processing Methods

To assess presence of barrier islands we first clipped the Ocean Conservancy's Gulf of Mexico barrier islands dataset to the GCPO LCC geography, keeping islands along the GCPO boundary intact. This dataset was delineated using 2001 – 2011 imagery and required islands be sedimentary in origin, separated from coastal mainland through natural waterway features, and possess non-marsh/mangrove Gulf frontage. We also considered an updated assessment of Gulf of Mexico barrier islands, published by the Harte Research Institute for Gulf of Mexico Studies, which excludes Deer Island in the Mississippi Sound, and includes areas separated by the Intercoastal Waterway (Gulf Highlands area near Gulf Shores; AL, Destin-Laguna Beach-Panama City, FL), and Crooked Island near Mexico Beach. After comparing the two datasets, we used the Ocean Conservancy's barrier island dataset to avoid inclusion of islands created by non-natural waterways. We then summarized barrier islands, their associated inland marshes, island area, length, and width, percent developed, and inland marshes associated with each island. We calculated island length end to end in miles and estimated mean island width by dividing island area by island length. Note that we did not include analysis of barrier islands off the Louisiana marshes as these were of greatest impact in areas of the Gulf Coast Prairie LCC that were not assessed. We estimated proportion of islands under low, medium, high, and open space development using reclassified 2010 C-CAP data and zonal statistics summing developed pixels per island and converting pixels to acreage. We also assessed the protected status of barrier islands using the Protected Areas Database ver. 1.4 (GAP status codes 1-3) and 2014 Secured Lands Database provided by The Nature Conservancy.

For a rapid assessment of protected non-island coastline we first converted the mainland coastline of the GCPO geography to a line feature, then segmented the coastline based on the perpendicular association with the eastern and western edges of each barrier island. We included the land-water interface of associated coastal bays in the segmenting procedure. We then compared total length of barrier-island protected coastline with the total length of mainland and non-barrier island coastline to estimate the proportion of coastline potentially protected by the presence of a barrier island.

We also conducted a coarse assessment of major storm activity in the GCPO geography from 1851 – 2012 using the Tropical Storm - Hurricane Tracks data layer acquired from the NOAA Gulf of Mexico Data Atlas (Fitzpatrick and Toft 2013). We assessed all Category 2 and above hurricane tracks (maximum sustained winds >95 mph [>82 knots]) that passed into the GCPO LCC geography, all tracks with a direct impact to one of the GCPO LCC specified barrier islands, and all tracks passing within 5 miles of barrier islands. However, we recognize that marshes are fragile systems and even Category 1 hurricanes and tropical storm events can pose significant threat to marsh systems.

Summary of Findings

Based on our assessment criteria we suggest there are 16 barrier islands totaling 44,860 acres within the Gulf Coast portion of the GCPO LCC geography (**Table TM.6**, **Figure TM.20**), with Cat Island in the Mississippi Sound being the westernmost, and St. George Island in the St. George Sound/Apalachicola Bay being the easternmost islands in the GCPO. Note we did not include Round Island in the assessment. Santa Rosa Island near Pensacola and St. Vincent Islands in Florida are the first and second largest barrier islands (per acres) in the GCPO LCC geography; whereas the Sand Island and East Ship Islands in the Mississippi Sound are the smallest barrier islands. Santa Rosa Island is the longest island (end to end) and Sand Island is the shortest island in the GCPO. Most estimated barrier island widths were similar (between a quarter to a half mile), with St. Vincent Island being the widest and East Ship Island being the narrowest barrier islands in the GCPO LCC. Most (69%) of islands are <2% developed, with the two most developed islands being Dauphin Island in Alabama and Perdido Key in Florida (**Table TM.6**). All but one island (Sand Island) had associated estuarine tidal marsh either within island lagoons or along the landward island edge. We estimate 35,332 acres (79%) of GCPO barrier islands are under protected public ownership, though a portion of this reflects Department of Defense lands. The National Parks Service's Gulf Islands National Seashore encompasses all of East and West Ship Islands, Sand Island, Petit Bois Island, Horn Island, and portions of Cat Island, Perdido Key, and Santa Rosa Island. Several other state parks, state, coastal and aquatic preserves, and one national wildlife refuge also contribute to island protection.

Using the coarse assessment of mainland coastline we estimate 749 miles, or 50% of the 1,500 miles of coastline/coastal bay land-water interface is protected by barrier island coverage (estimated using perpendicular coverage from island to shore). This is obviously the simplest form of assessment and relies on a breadth of assumptions. The reality is protective capacity of barrier islands will depend on many dynamic factors including storm direction, surge height, tides at surge, wind speed, precipitation and other factors that cannot be investigated as part of a rapid assessment but are good future research directions.

From the period 1851 – 2012, 16 category 2 or above tropical storms (estimated via storm track) made direct tracks over GCPO barrier islands, and 24 storms were within five miles of GCPO barrier islands (**Figure TM.21**). Blake et al. (2005) estimate that as many as 92 hurricanes have impacted the coasts of Mississippi, Alabama and the Northwest Florida panhandle from 1851 – 2004, this included all categories of hurricanes making landfall. NOAA (2006) suggests hurricane seasons in 2004 and 2005 were two of the top four activity seasons in the last half century. Ship Island and other islands in the Mississippi Sound were devastated by the >8.5 m storm surge event produced by Hurricane Katrina in 2005. Dauphin Island near Mobile Bay, AL was essentially split in half after this storm event. However storm impacts to coastal estuaries, and other coastal systems will depend on storm size and direction, wind-speeds, precipitation amounts, tide levels, and land-based features like configuration of the coastline (Edmiston et al. 2008). Inside estuary systems, major storm events can cause precipitous decreases in water temperature, depending on storm intensity, and changes in salinity, depending on storm fetch (Edmiston et al. 2008).

Table TM.6. List of the 16 barrier islands, associated states, acres, and development status within the GCPO LCC geography.

Map number	Barrier island name	State	Island area (acres)	Island length (mi)	Mn. est. island width (mi)	Percent developed	Associated inland marshes/bays
1	St. George Island	FL	4,532	19.5	0.36	33%	Apalachicola Bay, East Bay, St. George Sound
2	Little St. George Island	FL	2,100	9.5	0.35	0%	
3	St. Vincent Island	FL	8,447	8.2	1.61	1.7%	St. Vincent Sound
4	St. Joseph Peninsula	FL	3,878	15.1	0.40	23%	St. Joseph Bay
5	Shell Island	FL	2,486	14.2	0.27	0%	St. Andrews Bay, East Bay
6	Santa Rosa Island	FL	9,996	47.6	0.33	26%	Pensacola Bay, Escambia Bay,

							East Bay, Choctawhatchee Bay
7	Perdido Key	FL	3,064	14.8	0.32	35%	Perdido Bay
8	Dauphin Island East	AL	2,408	7.8	0.48	41%	Middle Bay, Bayou la Batre, W. Mobile Bay
9	Dauphin Island West	AL	736	7.1	0.16	0%	
10	Petit Bois Island East	MS	938	6.3	0.23	0%	Point aux Chenes Bay
11	Sand Island	MS	175	0.96	0.28	0%	
12	Horn Island	MS	3,213	12.0	0.42	0%	Pascagoula Bay
13	East Ship Island	MS	191	2.0	0.15	0%	
14	West Ship Island	MS	412	3.0	0.21	0%	
15	Deer Island	MS	501	4.4	0.18	0%	Biloxi Bay
16	Cat Island	MS	1,782	6.1	0.46	0%	

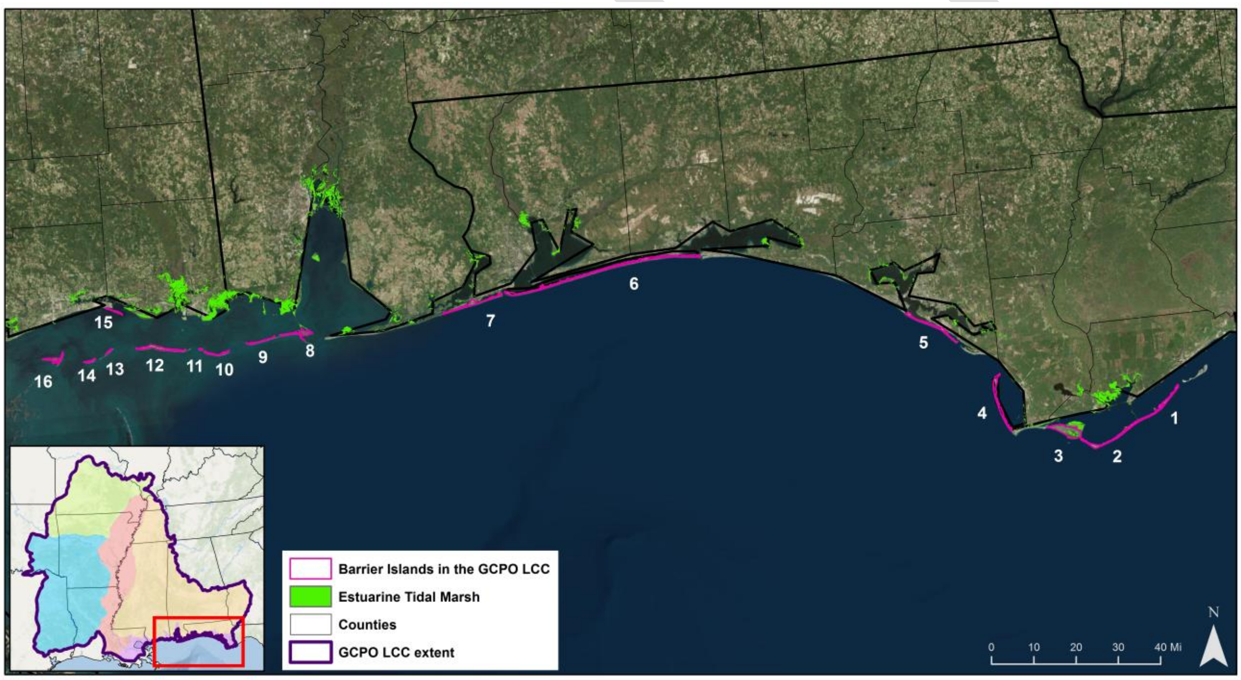

Figure TM.20. Barrier islands (pink) and estuarine tidal marsh systems (green) along the GCPO LCC geography of the northern Gulf of Mexico. Map numbers associated with island metrics listed in Table TM.8.

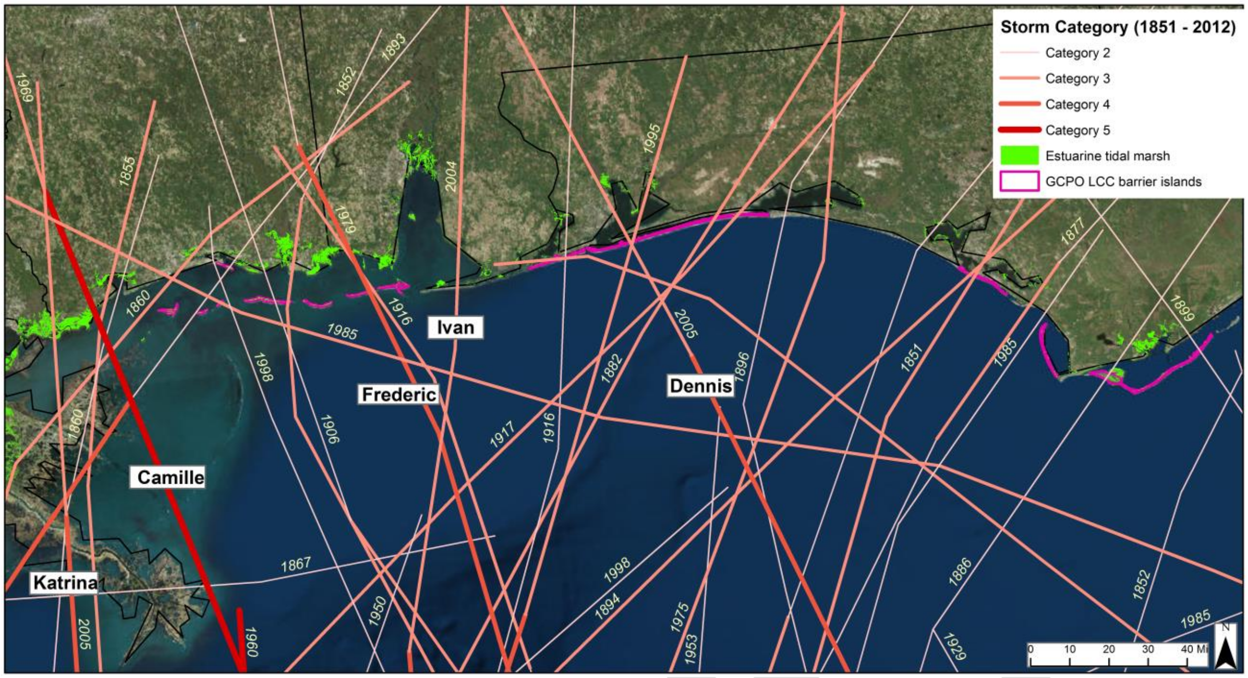

Figure TM.21. Category 2-5 tropical storm/hurricane tracks in the GCPO portion of the northern Gulf of Mexico from 1851 to 2012.

Future Directions and Limitations

Barrier islands and the weather events from which they protect inland shores are both dynamic and interdependent in nature. In the absence of major storm events barrier islands are regularly altered by shifts in sediment distribution (Davis and Fitzgerald 2004). Barrier islands are shown empirically to substantially alter surge paths and volume of flooding during major storm events (Grzegorzewski et al. 2011). However the Gulf Coast conservation community is well aware these islands are diminishing in their present state. Horn, Petit Bois, and Ship Islands suffered an estimated 23%, 52%, and 66% area loss, respectively from 1848 – 2005 as a result of wind, salt toxicity, and over wash (Otvos and Carter 2008). However in an assessment from 1990 – 2005, Theel (2007) estimated barrier islands do gain in area during hurricane-infrequent periods.

Protective effects of barrier islands on riverine and mainland estuarine tidal marsh systems is less well-understood. In a 16-year assessment of vegetation changes associated with major storm events in Mississippi and Alabama Theel (2007) used Normalized Difference Vegetation Index (NDVI) measures from Landsat satellite imagery to evaluate changes in barrier island vegetation and position pre- and post- major hurricane events. It would be appropriate to take a similar approach to assessing differences in storm impacts to estuarine marsh systems that are protected by barrier islands vs. those that are more vulnerable.

Sea level rise is another potential stressor for barrier island integrity, depending on if sedimentation and migration rates cannot outcompete rises in sea levels (**Figure TM.22**). In an assessment of 90 miles of coastal shoreline within the Gulf Islands National Seashore portions of the GCPO LCC geography, researchers found that 60% of the area under study was considered highly or moderately vulnerable to sea level rise (Pendelton et al. 2004). In this study the barrier islands of the Mississippi Sound were found to be highly vulnerable to sea-level rise, as exemplified in **Figure TM.22** below. Loss of protective Mississippi Sound barrier islands to storm events and sea level rise may have major implications to ecological integrity of coastal estuarine marshes. Therefore an improved and empirical understanding of barrier island protective capacity for marshes is highly warranted.

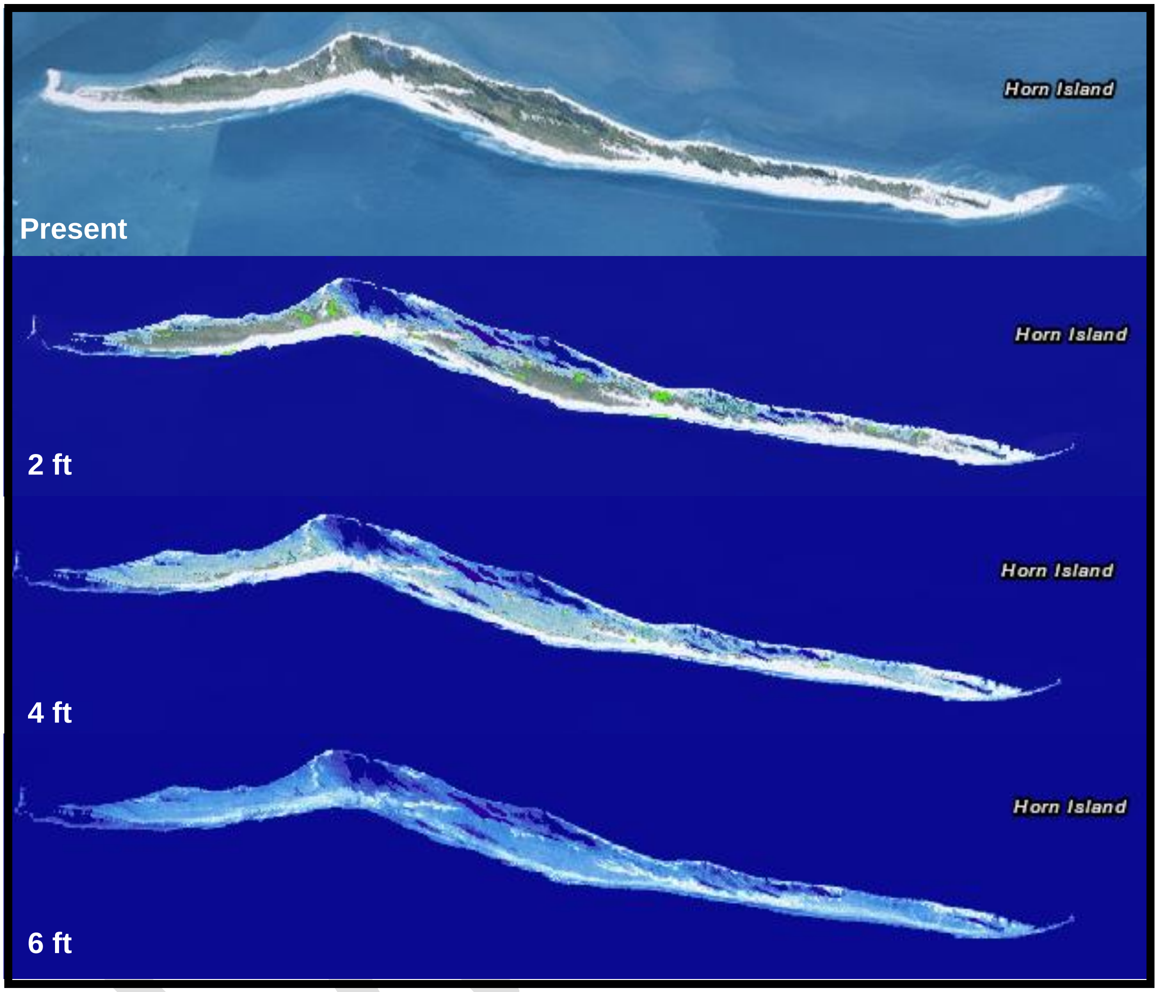

Figure TM.22. Horn Island in the Mississippi Sound as an example of potential implications of sea level rise under 2 - 6 foot SLR scenarios on Gulf Coast barrier islands (courtesy of the NOAA Sea Level Rise and Coastal Flooding Impacts Viewer.

Conservation Planning Atlas Links to Available Geospatial Data Outputs

- Gulf of Mexico Barrier Islands (vector - polygon)
- GCPO LCC Barrier Islands (vector – polygon)

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Chapter 6: Condition, submergent vegetative cover

Subgeography: GULF COAST

Ecological System: Estuarine Tidal Marsh

Landscape Attribute: Condition

Desired Landscape Endpoint: Submergent vegetative cover 15 – 30%

Submergent vegetative cover, typically deemed submergent aquatic vegetation, or SAV represents a broad community of species, including seagrasses, that consists of submerged, rooted, photosynthetic and flowering vegetation foundational in estuaries, bays and other coastal waters (Handley et al. 2007). SAV is found in a wide range of latitudes and salinity levels, but always requires non-turbid waters to maximize photosynthetic activity (USGS, undated). In the continental U.S., seagrasses, a subset of native SAV species, are primarily found in the Gulf of Mexico (Fonseca et al. 1998). Understanding distribution and dynamics of seagrasses and other SAV species is therefore a critical step in evaluating impacts of a changing environment on populations in the northern Gulf of Mexico (Merino et al. 2009).

Seagrasses and other species of SAV provide a multitude of complex ecological and economic functions including sediment stabilization, nutrient cycling, water quality improvement, wave energy mitigation and coastal protection, nekton species nursery and shelter, and commercial fishery and food and habitat for many species of concern (Fonseca et al. 1998, Handley et al. 2007). However, seagrasses in particular are threatened in the near-term by disturbance events that impact turbidity, sediment stabilization, and in the long-term by changes to water quality/clarity from land-based erosion, nutrient inputs, eutrophication and algae growth, physical removal via dredging, development and propeller scarring (**Figure TM.23**) (USGS, undated, Beck et al. 2000, Beck et al. 2007). Previous examination of seagrass status indicates that rates of seagrass loss have been substantially greater than rates of gain in the northern Gulf of Mexico, with largest impacts to continuous seagrass beds (Handley et al. 2007). However, less is known about the status of other non-seagrass SAV species. Declines and threats to seagrasses have triggered emphasis on protection and restoration in many recent Gulf of Mexico regional plans (e.g., Beck et al. 2000, USFWS 2013), and seagrass populations currently fall under the federal "no-net-loss" policy for coastal wetlands (Fonseca et al. 1998).

SAV was identified in the GCPO LCC Integrated Science Agenda (ISA) as one of the suite of desired ecological states for functioning estuarine tidal marsh systems in the northern Gulf of Mexico. The ISA indicated that cover of SAV between 15-30% is desirable in estuarine marsh systems.

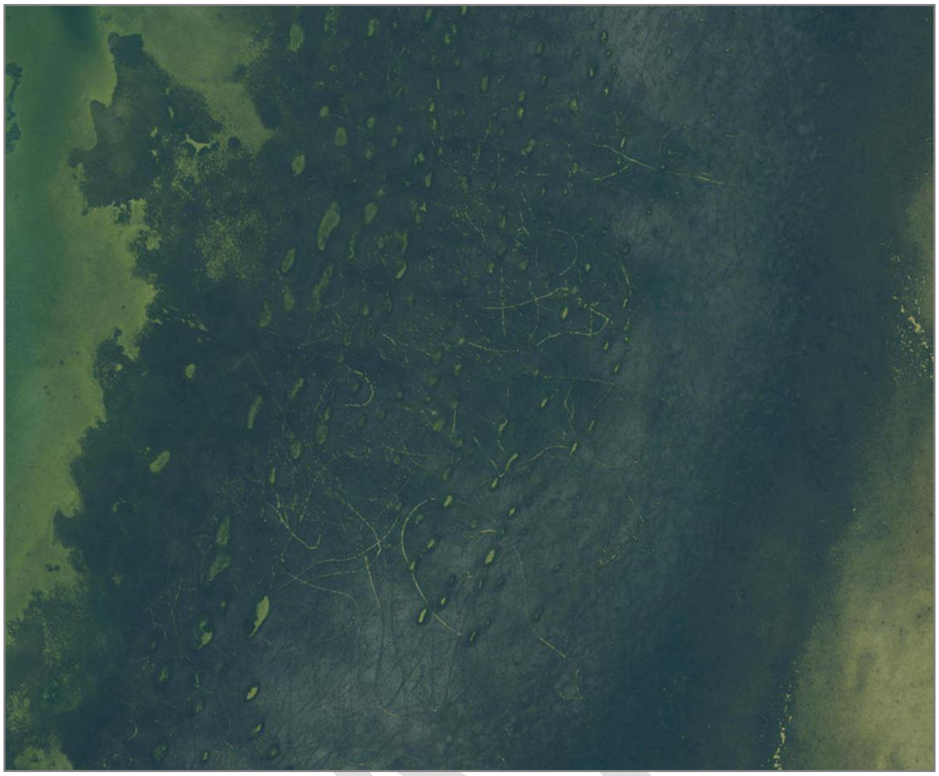

Figure TM.23. Apparent propeller scarring effects in St. Joseph Bay, Florida SAV beds (Source: ESRI World Imagery).

Data Sources and Processing Methods

SAV populations and distributions are highly dynamic over space and time, therefore it is difficult to delineate a static map of seagrass distribution that will be applicable over time and quantifiable for this assessment. In fact, episodic seagrass mapping inventories are typically not recommended when making management decisions due to these spatiotemporal dynamics (Fonseca et al. 1998). Given these caveats, we obtained multiple primary and supplemental static data sources for the assessment of SAV in GCPO Gulf Coast estuaries. Our primary data source was the Gulf-wide SAV layer produced by Handley et al. (2011) as part of the 1940-2002 Seagrass Status and Trends Report (Handley et al. 2007), which compiled multi-source photo-interpreted and field-verified seagrass data spanning up to 1999 as part of the Gulf of Mexico Ecosystem Pilot Project. This dataset contains strata of seagrass composition (<10%, 15-40%, 45-70%, 75-85% patchy seagrass cover; >90% continuous seagrass cover). We also incorporated the Seagrasses in the continental United States as of March 2015 data layer compiled and posted on MarineCadastre.gov by the NOAA Office of Coast Management in partnership with DOI Bureau of Ocean Energy Management MarineCadastre.gov. This dataset combines submerged, rooted vascular species and submerged or rooted floating freshwater tidal vascular species data in the Gulf Coast and other Eastern U.S. geographies, including the Mobile Bay National Estuary Program, Florida Fish and Wildlife Research Institute, Florida Minerals Management Service, NOAA National Centers for Coastal Ocean Science, USGS National Wetlands Research Center, University of Southern Mississippi, and NOAA Office for Coastal Management among others. We supplemented the Gulf-wide SAV and Continental Seagrass layers using 2014 National Wetland Inventory data, extracting aquatic bed rooted vascular classes (estuarine subtidal [E1AB3], estuarine intertidal [E2AB3], marine subtidal [M1AB3], marine intertidal [M2AB3]). We also incorporated seagrass (gained and unchanged categories) from local efforts in the waters adjacent to the Mississippi Sound barrier islands (Cat Island, Horn Island, Ship Island, Petit Bois Island), and SAV mapping efforts of the Grand Bay National Estuarine Research Reserve. We also explored the feasibility of using NOAA Coastal Change Assessment Program (C-CAP) land cover data estuarine aquatic bed class (class 23), though this class includes rooted and floating vascular vegetation, in addition to floating algal mats. We also examined the Florida Cooperative Land Cover (CLC) V3 submergent aquatic vegetation class (2150), but found no SAV polygons classified within the GCPO LCC portions of the western Florida panhandle. All layers were assessed within the GCPO LCC geographic extent and extending out to state seaward boundaries.

After examining all aforementioned data layers we decided to use Gulf-wide SAV, NOAA Continental Seagrass, NWI, Mississippi Sound Islands, and Grand Bay NERR data for this assessment (excluding C-CAP and Florida CLC data). We first converted each vector layer to a 10 m resolution raster layer, clipped to a 10 km buffer around the GCPO LCC. We then reclassified to a binary pixel layer (seagrass present = 1, absent = 0) and summed overlays of each data product to examine areas where datasets were in agreement, mosaicing summed products where necessary. We next reclassified to two binary data sets: 1) where all summed pixels >1 were included (i.e., all unique pixels where SAV was classified equally, regardless of presence in a single or multiple datasets); and 2) only where pixel sums ≥2 existed, such that 2 or more data layers must support evidence of SAV presence to be counted. After examining both binary pixel sum datasets, it was clear that the conservative process of eliminating all pixels with sums of <2 resulted in an underrepresentation of SAV in areas where pixels of SAV cover were non-overlapping, but that including all pixels resulted in a gross overrepresentation of SAV (see **Figure TM.24** below). Given that neither of these situations was ideal, we chose to summarize the data conservatively (requiring pixel sums ≥2, or two or more data layers must indicate a pixel is SAV to be included. Note that this does limit the application of this assessment for areas of patchy SAV distribution where non-overlapping datasets occurred (particularly in the Mississippi Sound). We assessed acreage within the GCPO LCC geography and within GCPO states by calculating acreage from sums of 10 m pixels.

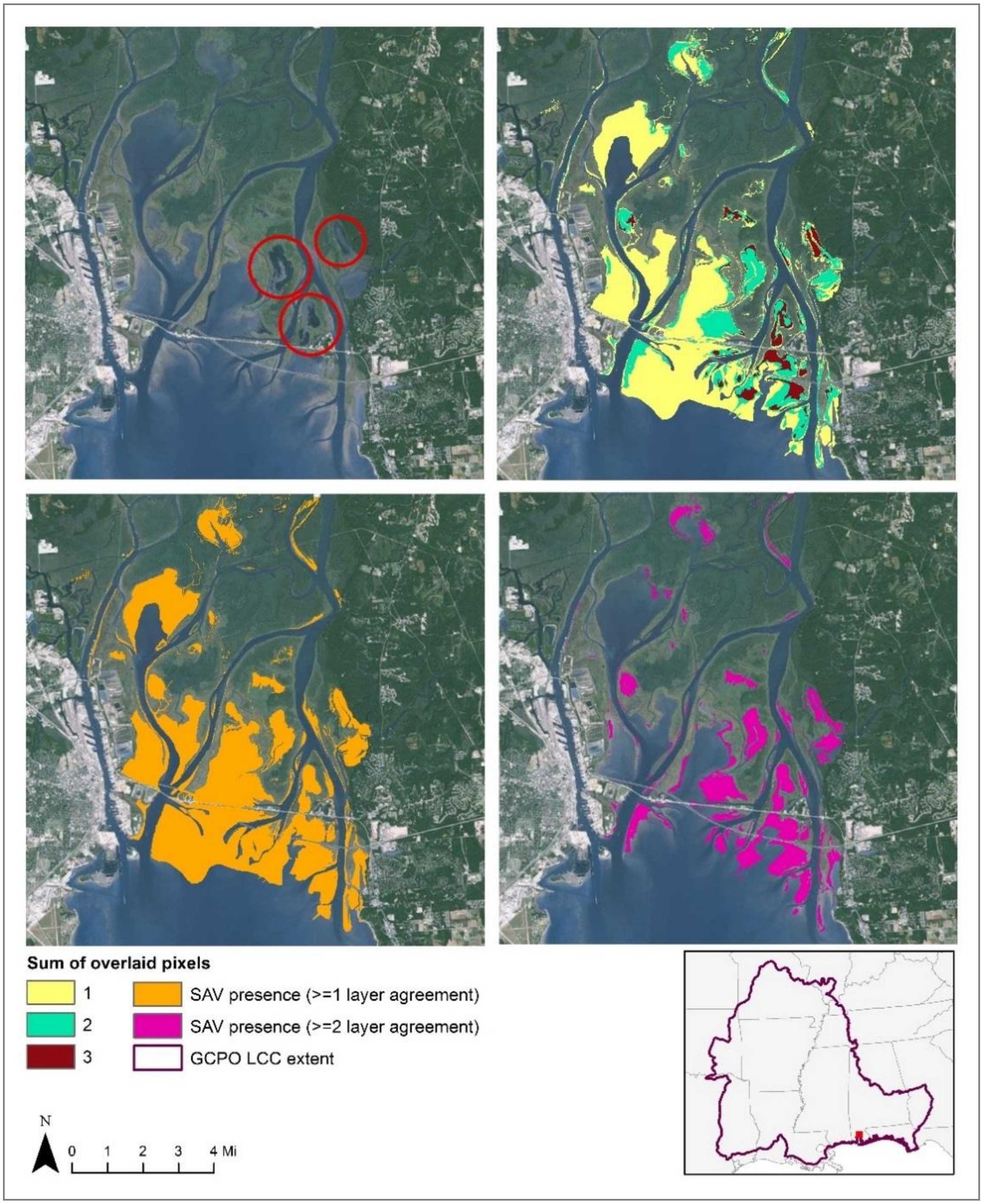

Figure TM.24. Graphical representation of pixel summing efforts to assess submergent vegetative cover in the Mobile Bay estuary in Alabama. Red circles in the top left highlight submergent vegetative cover appearing in aerial imagery. The coverage on the top right represent areas of overlaid SAV datasets where 1, 2, and 3 pixels indicated SAV presence. The coverage on the bottom left demonstrates a liberal SAV coverage layer where all pixels indicating presence were used in delineating SAV. The coverage on the bottom right demonstrates a conservative SAV coverage layer where only pixels with two or greater data layers indicating SAV presence were used in delineating SAV.

We next sought to assess SAV relationships with estuarine tidal marsh patches (all patches and large patches >250 ac) as a component of the desired ecological state for tidal marsh systems in the Gulf Coast. We first assessed proportion of SAV within large (>250 ac) estuarine tidal marsh patches, then buffered large patches by 100 and 300 m to assess the proportion of patches and adjacent areas occupied by SAV at multiple scales. We also assessed proportion of SAV coverage within all marsh patches, though we did not apply a buffer analysis due to the large number small patches in the dataset. We then used zonal statistics in ArcGIS to quantify the mean proportional coverage of SAV within each patch/patch buffer.

Summary of Findings

Using conservative ≥2 pixel overlays, we estimate 34,501 acres of SAV in the GCPO Gulf Coast, with 84% of the total found in the GCPO portions of the western Florida panhandle (**Table TM.7).** This is compared to the liberal (all pixels included) estimate of 59,126 acres of SAV in the GCPO Gulf Coast. SAV was only indicated in the GCPO portions of Louisiana via the C-CAP estuarine aquatic bed class, which may be related to inclusion of floating algal mats and was excluded from the combined assessment. SAV was most prevalent within coastal bay and near-shore sounds along the coasts of Florida and Alabama, with large populations in Mobile Bay, Alabama, and St. Andrew Bay, St. Joseph Bay, and Apalachicola Bay in Florida (**Figure TM.25**). SAV was also found along northern fringes of most barrier islands along the GCPO Gulf Coast.

Table TM.7. Acres seagrass/SAV estimated by states within the GCPO LCC geography available through the USGS Gulf-wide SAV data layer, NOAA Continental Seagrass as of March 2015 [NOAA 2015] data layer, National Wetlands Inventory [NWI] estuarine/marine aquatic bed rooted vascular classes, NOAA Coastal Change Analysis Program [C-CAP], and the final combined data overlay used for the GCPO LCC assessment.

	Acres seagrass/SAV by data source[1]					
	Gulf-wide SAV	**NOAA 2015**	**NWI**	**C-CAP[2]**	**Combined[3] (All Pixels)**	**Combined[3] (≥2 pixel overlay)**
Alabama	15,279	7,037	2,932	118	17,464	5,042
Florida (GCPO only)	21,812	42,523	27,888	1,217	39,942	29,085
Louisiana (GCPO only)	0	0	0	3,943	0	0
Mississippi	1,007	442	23	91	1,720	374
GCPO total	38,098	50,002	30,843	5,369	59,126	34,501

[1]Assessment includes continuous and patchy seagrass
[2]Note C-CAP estuarine aquatic bed class was not included in combined[3] assessment
[3]Combined assessment includes USGS gulf-wide SAV, NOAA continental seagrass, National Wetlands Inventory estuarine and marine intertidal and subtidal aquatic bed rooted vascular, in addition to local seagrass inventory data from Cat, Ship, Horn, and Petit Bois Islands in the Mississippi Sound and from the Grand Bay National Estuarine Research Reserve. The majority of other local SAV mapping efforts were captured in the gulf-wide SAV or NOAA continental seagrass data layers.

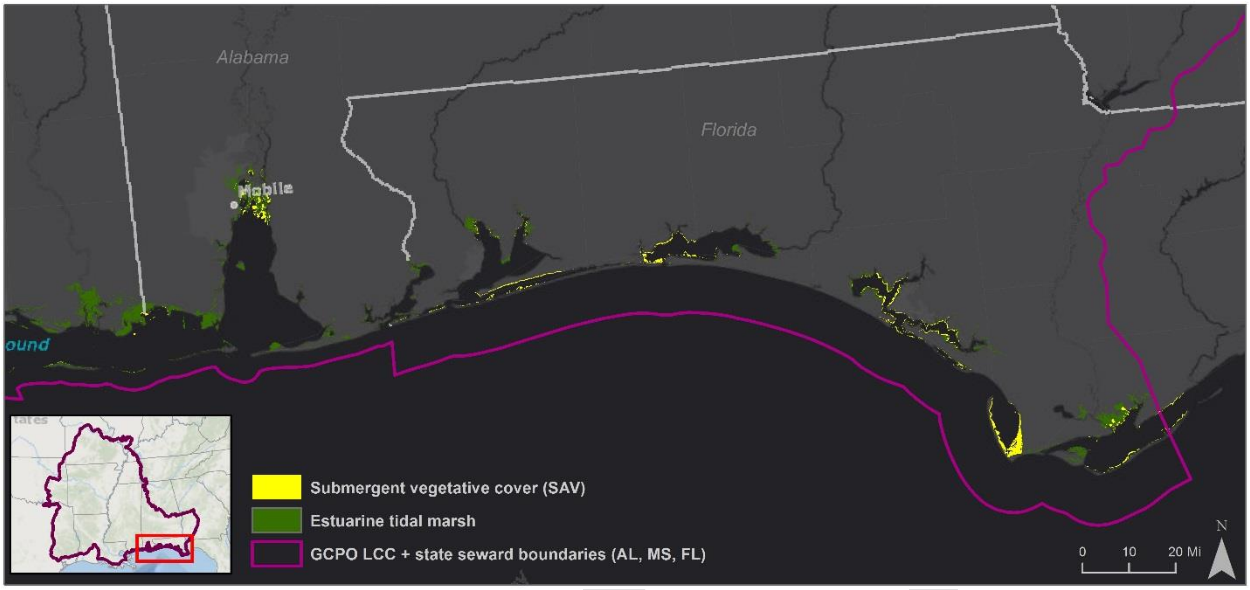

Figure TM.25. Mapped submergent vegetative cover (SAV) coverage (yellow) within the GCPO LCC Gulf Coast geography in comparison to estuarine tidal marsh patches (green). Note SAV coverage maps are not available at this time in Louisiana.

Estuarine Marsh - SAV Proximity

When assessing SAV coverage within estuarine tidal marsh patches we found only one large patches (>250 ac) along the eastern shore of Mobile Bay, AL exhibited SAV coverage within the target range (15-30%) (**Table TM.8).** This is not surprising as large unbroken marsh patches were delineated based on criteria of >70% emergent vegetative cover, therefore measures of in-patch open water in which SAV can occur will be limited. We found 3 large estuarine tidal marsh patches (>250 acres) had 15-30% SAV cover within 100 m of the patch and 6 large patches had 15-30% SAV cover within 300 m of the patch (**Table TM.8).** We found only 23 out of 35,097 marsh patches of any size exhibited 15-30% SAV cover, though we did not assess areas in proximity to all patches due to the large number of patches. Thus, the vast majority of estuarine tidal marsh patches exhibited limited co-occurrence with SAV. This is likely related to greater presence of SAV in clear water estuaries with limited marsh presence, suggesting this metric may be more validly assessed at the estuary-level rather than in association with marshes. However, the exception appears to occur within the Mobile Bay estuary and parts of St. Andrew Bay and Apalachicola Bay in Florida, where large estuarine marsh patches and SAV patches occur in proximity (**Figure TM.26**). Mobile Bay in Alabama appears to be one of the few major estuaries in the GCPO geography where SAV is occurring in tandem with estuarine tidal marsh. However, note that in 2009 the majority of SAV coverage in the Mobile Bay was dominated by Eurasian watermilfoil (*Myriophyllum spicatum*), with some presence of wild celery (*Vallisneria neotropicalis*), southern naiad (*Najas guadelupensis*), shoal grass, and widgeon grass (Vittor and Associates 2009). Large marsh patch associations with SAV coverage are also found in the East and West Bays of St. Andrew Bay in Florida, with bay fringe marsh in proximity to bay fringe SAV populations (**Figure TM.26**). However, there are also several clear water bays with abundant SAV populations like St. Joseph Bay in Florida, where estuarine marsh presence is limited, suggesting desired proximity of SAV to estuarine marsh will vary by geography.

Table TM.8. Mean proportion and range of submergent vegetative cover (SAV) inside and within 100 and 300 m of large estuarine tidal marsh patches along the GCPO Gulf Coast, as well as number of large patches that meet the target SAV endpoint of 15-30%.

Distance from patch (m)	**Mean %SAV**	**Range of SAV coverage**	**Number of patches (>250 ac) w/15-30% SAV**	**Approximate locations**
0 (within patch)	0.7%	0 - 36%	1	Mobile Bay, AL (eastern shore); East and West St. Andrew Bay, FL; East Apalachicola Bay, FL
100	1.5%	0 – 34%	3	
300	2.0%	0 – 36%	6	

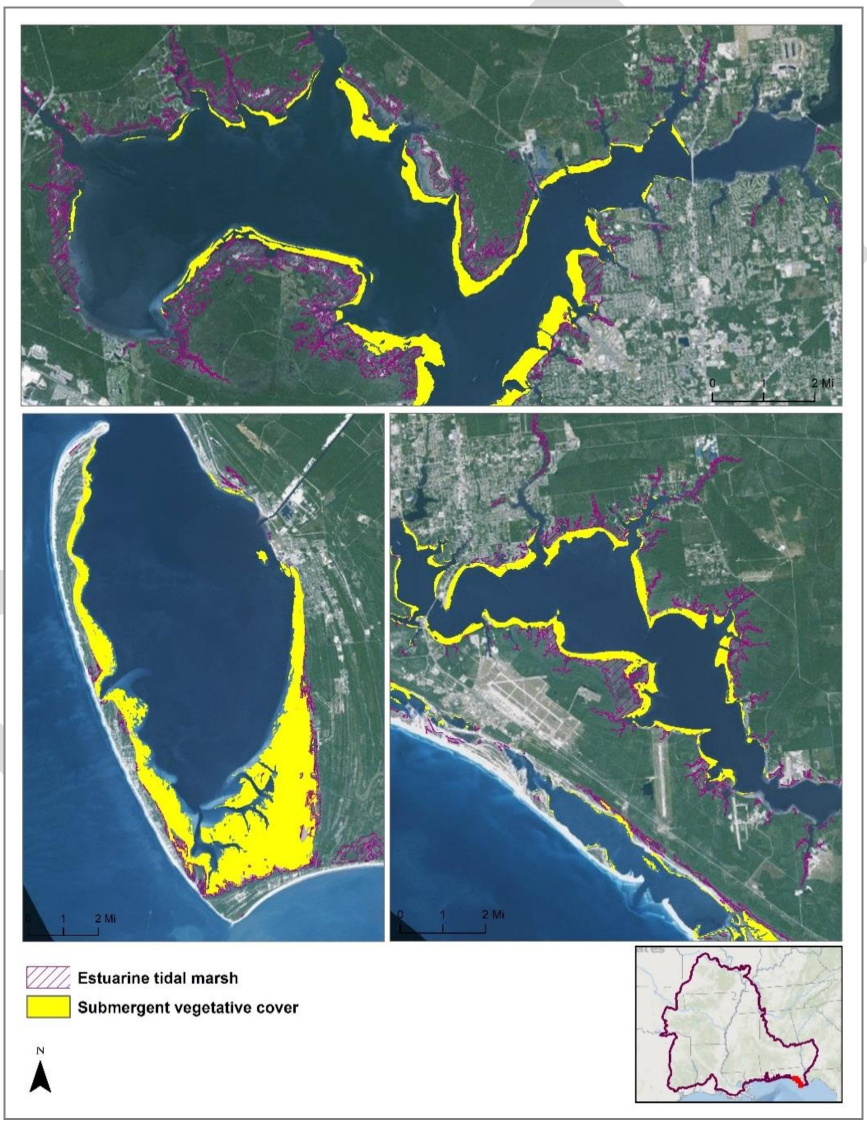

Figure TM.26. Example of proximity of estuarine tidal marsh patches (pink) to submergent vegetative cover (yellow) in the St. Andrew Bay estuary of Florida (top and bottom right) and clear waters of St. Joseph Bay, FL (bottom left) along the GCPO Gulf Coast.

Future Directions and Limitations

Assessment of SAV and seagrass distribution in the northern Gulf of Mexico is complicated by both the dynamic nature of SAV populations and the limitations presented by water clarity and albedo. Mapping of SAV in the western portions of the GCPO LCC geography is particularly challenging as water turbidity complicates delineation via remote sensing techniques. Issues of water turbidity and associated light attenuation in areas west of Alabama suggest remotely-sensed classification of SAV/seagrass populations will come with inherent limitations in accuracy (Peneva et al. 2008). Correction for factors related to water clarity, depth, and other characteristics must be applied for reliable SAV mapping from remotely-sensed application (Cho et al. 2012). The GCPO LCC has recently co-sponsored with the South-Central Climate Science Center, Gulf Coast Joint Venture to support an on-going assessment of occurrence and vulnerability of SAV in the northern Gulf of Mexico which examines SAV resources and water quality associations from the Nueces River in Texas to Mobile Bay in Alabama. This project assesses biomass and other vegetation characteristics of SAV in in salt, brackish, intermediate, and freshwater marsh systems using a stratified randomly sampled series of sampling sites over a three year period and is slated to be finalized in 2018. This includes assessment in Louisiana, which is markedly depauperate of SAV distribution data, though it is thought to occur only in the eastern Mississippi River delta area along western bays of the Chandeleur Islands and not within the GCPO geography (Poirrier 2007).

This assessment compiled data from a variety of data sources mapped at different times and using different techniques, therefore inference to present-day SAV populations must be accompanied by assumptions of limited to no shifts in SAV distribution and abundance. The multitude of local SAV/seagrass mapping and monitoring efforts point to the need for an updated comprehensive seagrass mapping and monitoring program as scales relevant to system ecological function in the Gulf of Mexico (USGS undated, Fonseca et al. 1998). Maintaining and increasing the amount of permanent monitoring transects for seagrass in concert with standardized and long-term monitoring of water quality is recommended as a priority for seagrass management (Yarbro and Carlson 2013). However, such efforts must be approached carefully as developing a universal standard for delineating seagrass beds will be difficult due to spatial and temporal variation in seagrass distribution, variation in water clarity, and variation in resources available for monitoring and mapping (Fonseca et al. 1998). An improved understanding of community and geographic variation in nursery function of northern Gulf of Mexico SAV habitats and increased partnership with recreational and commercial fishery interests is also necessary to increase the effectiveness of conservation management to strategically protect the most important SAV habitats (Beck et al. 2000).

Conservation Planning Atlas Links to Available Geospatial Data Outputs

- Submerged aquatic vegetation (SAV) (Gulf Assessment Version) (vector – polygon)

Technical References

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Chapter 7: Condition, composition

Subgeography: GULF COAST

Ecological System: Estuarine Tidal Marsh

Landscape Attribute: Condition

Desired Landscape Endpoint: Dominated by native plants typical of high, mid-, intermediate, and low marsh

In the northern Gulf of Mexico, estuarine tidal marsh systems consist of ecotonal plant species organized in pronounced zonation by capacity to tolerate salinity, inundation, elevation and other gradients (Odum 1988, Silvestri et al. 2005, Battaglia et al. 2012). The Gulf Coast subgeography of the GCPO LCC contains marshes of the Louisiana Deltaic Plain in the west and the Eastern Gulf Coastal Plain in the east, with different salinity and vegetative composition characteristics resulting from influence vs. non-influence of freshwater inflow, tidal range, and salinity levels. Estuarine marsh systems in this geography typically consist of a narrow band of low salt marsh dominated by *Juncus roemerianus* (black needle rush; needlegrass rush) and *Spartina alterniflora* (smooth cordgrass; saltmarsh cordgrass) along the seawater-marsh edge, with co-occurrences of *Distichlis spicata* (saltgrass; spikegrass), *Spartina patens* (salt meadow hay), and *Spartina cynosuroides* (big cordgrass) (Battaglia et al. 2012).

Juncus roemerianus is a native perennial graminoid that is prevalent/dominant in northern Gulf Coast marshes (Battaglia et al. 2012). This species is typically found in distinct bands within high elevation marsh ranging from saline, brackish, to intermediate salinity gradients and grows in dense deeply-rooted stands, thus providing excellent shoreline protection and filtration/sulfate reduction (Hsieh and Yang 1997, Miley and Kiene 2004, Skaradek and Henson, undated). *J. roemerianus* is widely used in marsh restoration and the seeds and some vegetative parts are consumed by a multitude of wildlife species (Skaradek and Henson, undated). *Spartina alterniflora* is a native warm season graminoid prevalent in colonies parallel to the seawater-marsh edge of the northern Gulf Coast (Battaglia et al. 2012). The species is considered a facultative halophyte, such that it tolerates intertidal brackish to saline conditions (8-33 ppt). It is sensitive to reduction in soil sulfide and high organic matter and does not establish well outside tidal zone (Materne, undated). The species shows strong evidence of filtering nitrogen and phosphorous in Louisiana coastal marshes (Buresh et al. 1980), but is considered invasive along the U.S. Pacific coast. Other native species include *Spartina patens*, which prefers saline and brackish marsh, flats and ridges, and beach and dune habitats and is a widely known wildlife food and cover source. It is also frequently used as livestock forage, and has been shown to block the spread of the invasive *Phragmites australis* (Wang et al. 2006). *Distichlis spicata* is a native drought-tolerant species that inhabits saline and brackish marsh, salt flats, and high marsh in the Gulf of Mexico (Newman and Gates 2006). The species has been historically valuable as a hay grass, and provides food and cover value for butterflies, waterfowl, and other herbivorous grazers. Other native tidal marsh grass, sedge, and rush species in the GCPO geography include *Cladium mariscus* (sawgrass; Jamaica swamp sawgrass), *Eleocharis cellulose* (Gulf Coast spikerush), *Paspalum vaginatum* (seashore paspalum), *Spartina spartinae* (Gulf cordgrass), and others. Sporadic hypersaline environments will also exhibit presence of succulent species like *Salicornia bigelovii* (glasswort).

For many thousands of years the native species *Phragmites australis* (common reed) is thought to have existed as a minor component of the Gulf Coast tidal marsh plant community and has since expanded across the North American continent (Chambers et al. 1999). Now considered a native invasive species, coverage of *P. australis* is extensive within brackish and Mississippi River delta wetlands with <18 ppt salinity in the Gulf of Mexico, but the species' distribution is not well-documented (Chambers et al. 1999). *P. australis* is even thought to respond to and sequester elevated levels of nitrogen and phosphorous in marshes and alter nutrient cycles in marsh systems (Meyerson et al. 2000). The species has limited nutritive value to herbaceous foragers (Whitman and Meredith 1987), but does provide cover and seed source for wildlife and was once and important source of medicine, material, and food for Native Americans (Tilly and St. John 2012). *Phragmites*, combined with other invasive species (e.g., *Pennisetum* spp., *Neyraudea* spp., *Triadica sebifera*) can cause a reduction in tidal marsh plant diversity and resulting changes to dependent animal communities, including decreased habitat for migratory waterfowl, exclusion of marsh specialist species and a decrease in species richness (Benoit and Askins 1999).

Data Sources and Processing Methods

Geospatial data related to native plant species distribution is limited at the scale of this assessment. However, species distributions tend to parallel other coastal gradient patterns including measures of salinity and related elevation (Battaglia et al. 2012). With many caveats, one could coarsely assess distribution of some of the dominant native plant species in GCPO Gulf Coast tidal marshes (particularly *J. roemerianus* and *S. alterniflora*) by assessing salinity patterns within tidal marsh systems (see Chapter below). However, given the potential widespread distribution of *P. australis,* it would be ill-advised to assume salinity patterns and marsh type delineation would be reflective of native vegetation without additional information.

Given the limited species-level information available at the scale of this assessment we assessed county- and parish-level distribution of a subset of four native graminoid tidal marsh species within the U.S. Department of Agriculture, Natural Resources Conservation Service PLANTS Database. This included assessment of *Juncus roemerianus*, *Spartina alterniflora*, *Spartina patens*, and *Distichlis spicata* distributions within the Gulf Coast subgeography of the GCPO LCC. We compared PLANTS database county- and parish-level occurrence summaries to USGS BISON spatial locations for specimen occurrences for each species.

We also provided a comparative assessment of the native invasive *Phragmites australis* using county- and parish-level distribution estimates via the PLANTS Database to determine broad areas of susceptible marsh. We compared county-level distributions to geospatial mapping outputs of *P. australis* as part of the USFWS National Wetlands Inventory (NWI). NWI has attempted to address the information gap on spread of invasion through demarcation of the NWI class E2EM5 (P, Pd, and Ps) = Estuarine Intertidal Emergent *Phragmites australis* (P= irregularly flooded; Pd = Irregularly flooded, partly drained; Ps = Irregularly flooded, spoil). This information was sparsely populated in the GCPO LCC geography and only mapped polygons in Alabama, Florida, and Mississippi. We also compared PLANTS database and NWI occurrences to USGS BISON inventory locations to improve assessment for this species. Finally we incorporated data on *Phragmites australis* distribution collected by the Geosystems Research Institute at Mississippi State University in the Pearl River Wildlife Management Area in St. Tammany Parish, Louisiana using unmanned aerial systems (UAS) and aerial imagery products.

Summary of Findings

Spartina alterniflora and *Distichlis spicata* are known to be distributed in 16, and *Juncus roemerianus* is known to be distributed in 18 of the 35 counties and parishes that intersect the Gulf Coast subgeography of the GCPO LCC (**Figure TM.27**). *Spartina patens* is present in all Gulf Coast subgeography counties and parishes, thus is not represented. *J. roemerianus* and *S. alterniflora* have not yet been officially documented (by NRCS and USGS) in tidal marshes along the eastern shore of Mobile Bay in Baldwin County, Alabama, though this lack of documented occurrence is not a confirmed absence of the species. *J. roemerianus* also has not been documented by NRCS and USGS as present in Lafourche and St. Charles Parishes in Louisiana or Bay County, Florida. *S. alterniflora* is also not documented as present in Escambia, Walton, and Gulf Counties in the western Florida panhandle. *D. spicata* appears to be absent from Gulf County westward to Okaloosa County in Florida.

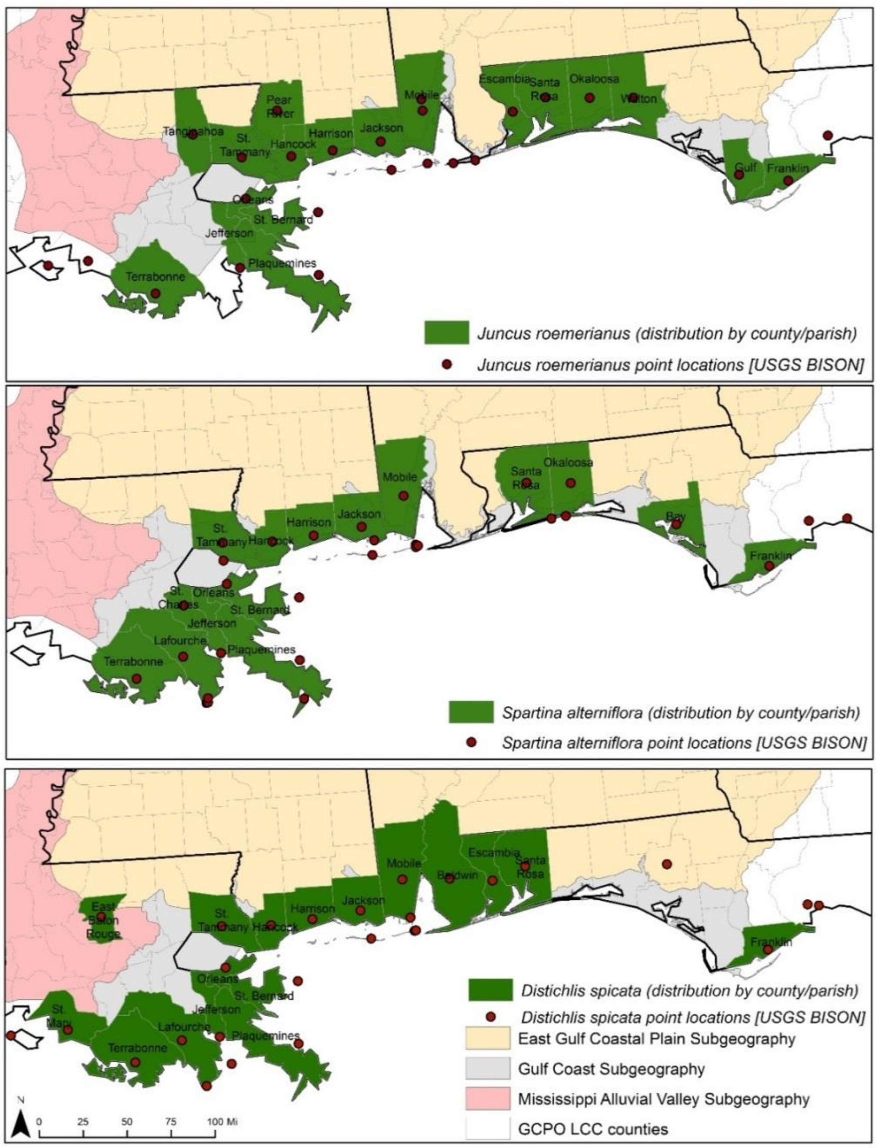

Figure TM.27. Distribution of *Juncus roemerianus*, *Spartina alterniflora*, and *Distichlis spicata* by county/parish in the Gulf Coast subgeography of the GCPO LCC.

According to the PLANTS database, *Phragmites australis* was present in 21 of the 35 counties or parishes intersecting the GCPO Gulf Coast subgeography, in addition to presence in 6 near-coast counties in the East Gulf Coastal Plain and Mississippi Alluvial Valley subgeographies of the GCPO LCC (**Figure TM.28**). The PLANTS database suggested no recorded occurrence of *P. australis* in Hancock and Harrison Counties in Mississippi and Gulf County in Florida. However, USGS BISON indicates occurrence in Harrison County Mississippi, as well as Petit Bois Island and Dauphin Islands in Mississippi and Alabama. NWI data indicate widespread coastal occurrence of *P. australis* in Escambia and Franklin Counties in Florida.

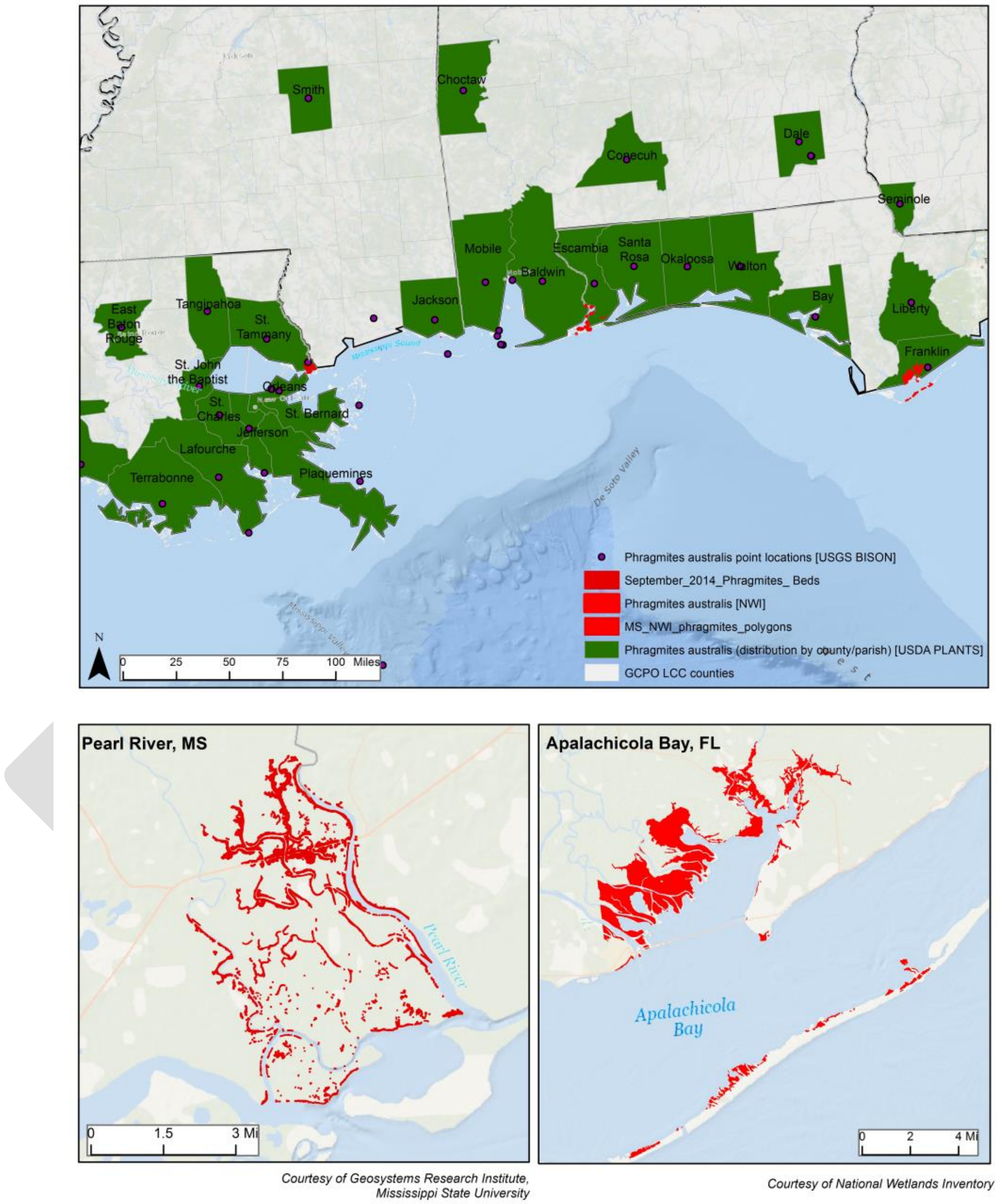

Figure TM.28. Distribution of Phragmites australis by county/parish (via USDA PLANTS database and USGS BISON species occurrence database), within National Wetlands Inventory, and west of the Pearl River in St. Tammany Parish, Louisiana (courtesy of the Geosystems Research Institute at Mississippi State University) within the GCPO LCC.

Future Directions and Limitations

Assessment of large-scale distribution of individual native plant species is difficult in any system lacking comprehensive and systematic inventory, and development of hyperspectral signatures that differentiate most native graminoid species has thus far been challenging. Potential exists to impute native plant species distributions using other gradients as surrogates (e.g., salinity, elevation). This may be effective for some dominant species existing in distinct marsh bands (e.g., *J. roemerianus*); however, these assumptions will likely be ineffective for species that regularly co-occur with dominant species. Compilation of marsh vegetation datasets collected as part of myriad data collection efforts may also produce enough data points where species distributions may be imputed or classified, but a compilation effort such as this is outside the scope of this rapid assessment.

Understanding spread and impact of native or exotic invasive species such as *P. australis* is equally as important to estuarine tidal marsh system integrity in the GCPO geography. The results demonstrated in the National Wetlands Inventory suggest this mapping technique could potentially produce a viable estimate of *P. australis* distribution if efforts to map the species could be expanded beyond the limited number of counties available in the GCPO Gulf Coast. There is also promise in using UAS systems like that demonstrated in St. Tammany Parish, LA and other remote sensing techniques to collect high resolution hyperspectral imagery that can be used to discriminate invasive species along coastal marshes. This is an active area of research that will advance coastal marsh mapping in the upcoming years.

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Chapter 8: Condition, water quality and quantity

Subgeography: GULF COAST

Ecological System: Estuarine Tidal Marsh

Landscape Attributes: Condition (water quality)

Desired Landscape Endpoints: Adequate freshwater flows and tidal influence; Salinity aligned along a natural gradient

Interactions among water quality and quantity along U.S. coastal waters are fundamental to maintaining estuarine ecological and economic function of coastal estuaries (EPA 1999, Montagna et al. 2002). Quantity and timing of freshwater inflow and effects of tidal range influence levels of salinity and other factors related to estuarine water quality. Salinity is thus among the key factors in ecological function of coastal marsh systems, serving as an indicator of hydrography and the primary determinant of vegetation character and flora and fauna composition in Southeastern estuarine tidal systems (Odum 1988, Orlando et al. 1993, Pennings et al. 2005, Howard and Rafferty 2006, Wang et al. 2007). However, salinity is variable depending on season, year, tide, freshwater pulses, wind, mixing levels and geographic location (Odum 1988) causing normal hourly, daily, monthly, and yearly fluctuations in addition to random episodic fluctuations in salinity measures (Orlando et al. 1993). However disruptions of natural freshwater flow into estuaries due to natural and anthropogenic alterations can cause long-term changes in salinity and estuarine structure and ecological function (Christensen et al. 1997, Sklar and Browder 1998). Flow disruptions caused by diversions, levees, direct consumptive withdrawals and channelization in the vast majority of streams and rivers in U.S. watersheds have impacted quantity, quality, and periodicity of freshwater flow, sediment transport, and nutrient delivery to coastal estuaries (Christensen et al. 1997, Sklar and Browder 1998, Alber 2002). Marsh salinity levels in the northern Gulf of Mexico are also influenced by freshwater inflows of the Mississippi River, particularly in the Louisiana Deltaic Plain region of the northern Gulf (Beck and Odaya 2001, EPA 2006). With changes in freshwater hydrology and climate-induced threats of saltwater intrusion into estuarine systems, there is major concern for salinity as an indicator of estuarine ecosystem function (Fuller et al. 1990, Hackney and Avery 2015). Hence acquisition of estuarine freshwater inflow and salinity data, and improved understanding of how these measures relate to ecological function, in addition to other water quality measures, have been identified as important data acquisition and research needs in the Gulf of Mexico Regional Ecosystem Restoration Strategy (Gulf Ecosystem Restoration Task Force 2011). However characterization of natural salinity gradients will vary by estuary and season, thus an assessment of natural vs. disrupted salinity gradients over time and over a large geography is challenging. Estuarine researchers have made progress in identifying the importance of and understanding the ecological and socioeconomical impacts of altered freshwater inflow in estuaries, but complexity of the system and its inputs lend difficulty to quantifying effects (Sklar and Browder 1998, Alber 2002). As Gulf of Mexico water quality is currently of great interest, building better broad-scale linkages between freshwater inflow and salinity to estuarine condition and applying gained knowledge to marsh managers is critical (Alber 2002, Montagna et al. 2014).

Data Sources and Processing Methods

Freshwater inflow

We used National Hydrography Dataset (NHDPlusV2) flow data from gauge adjustment (in ft^3/sec) (field Q0001E) from the Extended Unit Runoff Method mean annual and monthly flow estimated by NHD flowline from 1971-2000. We assessed mean non-zero annual flow at three scales by clipping NHD flow data to GCPO marsh patches, within NHD catchments intersecting marsh patches, and within HUC12 watersheds intersecting marsh patches. We first clipped mean annual flow data to each scale layer, then ran a spatial join to associate flow line segments with patch, catchment, or HUC12 identity. We then selected out only segments with non-zero measures of flow (NHD field Q0001A) due to uncertainties regarding if zero measures were empirical observations or null data at a particular segment. We then calculated minimum, maximum, sum, average, standard deviation and variance estimates of non-zero annual flow at each scale and ran a table join to associate summary statistics with marsh patch, catchment, or HUC12. Measures were calculated for associations with all estuarine tidal marsh patches and for only large patches >250 ac in size. We also assessed seasonality of flow by examining a flow seasonality layer developed for the Southern Instream Flow Network of the Southeast Aquatic Resources Partnership, which uses streamflow gages to classify rivers to high and low seasons by month and provides qualitative assessment of level of seasonal variability.

We also examined the 2012 National Anthropogenic Barrier Dataset (NABD) and dams identified as part of the 2014 Southeast Aquatic Connectivity Assessment Project (SEACAP; Martin et al. 2014) data to assess potential disruptions to freshwater flow that may impact natural salinity gradients. NABD compiles large anthropogenic barriers as a linkage between the 2009 National Inventory of Dams (NID) and Version 1 of the National Hydrography Dataset. SEACAP compiled dam data from 2009 NID, NABD, USGS Geographic Names Information Systems database, NHD dam events dataset and supplemented that information with dams identified by experts within state agencies, watershed organizations, universities, and non-governmental organizations. SEACAP further supplemented dam data using NHDPlus Version 2 waterbody and streams to identify non-natural waterbodies and subsequent impoundments. We assessed presence of dams upstream of estuaries as possible barriers to freshwater inputs during high and low salinity seasons in estuaries showing discrepancies between current empirical data and established salinity zones. However, we recognize that there are several barriers present upstream of the Gulf Coast, and outside of the GCPO geography that impact freshwater inflow to GCPO coastal estuaries, thus took a purely qualitative approach to this component.

Salinity

We examined salinity in GCPO LCC estuarine tidal marshes and adjacent water bodies by compiling existing geospatially referenced data from a multitude of coastal water quality monitoring stations and comparing to existing salinity zone models. We conducted an initial inventory of past and present salinity monitoring stations compiled primarily in the National Water Quality Monitoring Council (NWQMC) Water Quality Portal, which integrates national publicly available water quality data provided by the U.S. Geological Survey National Water Information System (NWIS) and U.S. Environmental Protection Agency STORET data warehouse, and the U.S. Department of Agriculture Agricultural Research Service STEWARDS database system. Salinity data were retrieved from stations within estuary, lake, ocean, and wetland site types in counties overlapping the GCPO LCC Gulf Coast subgeography with measures recorded from 1 Jan 2010 to 21 May 2015 to reflect recent salinity conditions in GCPO estuaries. These data were supplemented by salinity data available in the Gulf of Mexico Coastal Ocean Observing System (GCOOS), Southeast Coastal Ocean Observing Regional Association (SECOORA), Central Gulf Ocean Observing System (CenGOOS), NOAA National Data Buoy Center and National Ocean Service (NOS), National Estuarine Research Reserve System (NERRS) Centralized Data Management Office, and data utilized in the Mississippi Gulf Benthic Index analysis. Combined, these data portals/sources collectively summarize salinity data provided by the Alabama Department of Environmental Management, USGS Alabama, Florida, and Louisiana Water Science Centers, Florida Department of Environmental Protection, Louisiana Department of Environmental Quality, Louisiana Department of Health and Hospitals, Mississippi Department of Environmental Quality, National Parks Service Water Resources Division, Apalachicola, Grand Bay and Weeks Bay National Estuarine Research Reserves, Dauphin Island Sea Lab, and others. For purposes of this rapid assessment we removed duplicate station locations found within multiple data centers to avoid redundancy where appropriate and we restricted comparative data assessment to stations that provided salinity measures in the last five years (2010-2015).

We compared 2010-2015 empirical salinity monitoring data to the NOAA Gulf of Mexico 5-zone seasonal dynamic salinity zone low and high season outputs based on biological relevance and generated using principal components analysis (Bulgar et al. 1993) on depth and time-averaged salinity data from 32 Gulf of Mexico estuaries circa 1998 (Nelson 2012). NOAA dynamic salinity zones were determined based on seasonal precipitation, flow, and salinity averages and developed based on predicted response by 44 priority species to natural salinity gradients in the estuary (Orlando et al. 1993, Christensen et al. 1997) (**Table TM.9**). NOAA low and high salinity seasons for the northern Gulf Coast are dependent on periods of freshwater inflow (e.g., Louisiana Deltaic Plain) and other extrinsic factors. Transitional seasons (increasing/decreasing) were not compared in this assessment.

We also compared empirical salinity measures to the more recent Coastal and Marine Ecological Classification Standard (CMECS) 5-year (2005-2009) seasonal sea surface salinity averages (winter, spring, summer, fall) (Allee et al. 2012) derived from MODIS-Aqua color ocean imagery, which uses algorithms to establish relationships between color absorption and salinity (Ladner et al. 2008). CMECS includes six categories (zones) of salinity ranging from oligohaline to hyperhaline (**Table TM.9**). The seasonal remotely sensed salinity measures were collected by the Naval Research Laboratory at Stennis Space Center, MS during January, February, and March (winter); April, May, and June (spring); July, August, and September (summer); and October, November, and December (fall) from 2005-2009 for western, central, and eastern regions of the Gulf of Mexico.

Table TM.9. NOAA Gulf of Mexico 5-zone seasonal dynamic (left) and CMECS seasonal sea surface (right) salinity zones and salinity ranges. Note that measures of parts per thousand (ppt) are considered essentially equivalent to practical salinity units (psu) for this assessment.

NOAA Dynamic 5-Zone Salinity	Range (ppt)
I	0 – 0.5
II	0.5 - 5
III	5 - 15
IV	15 - 25
V	>25

CMECS Sea Surface Salinity	Range (psu)
Oligohaline	<5
Mesohaline	5 - 18
Lower Polyhaline	18 - 25
Upper Polyhaline	25 – 30
Euhaline	30 - 40
Hyper Haline	>40

Tidal Influence

We used the NOAA software VDatum 3.4 to assess interpolated tidal range within estuarine marshes along the GCPO LCC Gulf Coast following methods described in Osland et al. (2014). VDatum software allows for vertical transformation of geospatial data and in this case was used to calculate tidal metrics of Mean Higher High Water (MHHW), Mean High Water (MHW), Mean Lower Low Water (MLLW), and Mean Low Water (MLW) (defined in **Table TM.10**) collected from the network of NOAA tidal gauges within the geography. To calculate tidal datums we first created a systematic grid of data points within the available VDatum geography, spaced 500 m apart using the Create Fishnet tool in ArcGIS. We assigned longitude (X) and latitude (Y) and zero height values (Z) to the point grid and imported the layer as a text file into VDatum. We then specified a vertical conversion to MHHW, MLLW, MHW, and MLW from the NAVD88 digital elevation model and imported outputs as point surface with X, Y, and Z in ArcGIS. We then interpolated point Z measures for MHHW, MLLW, MHW, and MLW to a 200 m raster layer using the natural neighbor approach and calculated measures of Great Diurnal Range (GT) and Mean Range of Tide (MN) from the appropriate metrics to assess tidal range (**Table TM.10**). Raster data were interpolated to 200 m to account for approximations in VDatum transformations.

Table TM.10. Definitions of tidal datums used in the GCPO LCC assessment of estuarine tidal marsh as described verbatim by the NOAA Tides and Currents Glossary (NOAA 2000).

Tidal Datum	Abbreviation	Description
Mean Lower Low Water	MLLW	The average of the lower low water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Mean Higher High Water	MHHW	The average of the higher high water height of each tidal day observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Mean Low Water	MLW	The average of all the low water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Mean High Water	MHW	The average of all the high water heights observed over the National Tidal Datum Epoch. For stations with shorter series, comparison of simultaneous observations with a control tide station is made in order to derive the equivalent datum of the National Tidal Datum Epoch.
Great Diurnal Range	GT	The difference in height between mean higher high water and mean lower low water.
Mean Range of Tide	MN	The difference in height between mean high water and mean low water.

Summary of Findings

Freshwater inflow

Average non-zero freshwater flow in and around GCPO estuarine tidal marsh patches varied depending on scale of assessment. At the HUC12 watershed scale, non-zero flow was 4,775 ft^3/sec, and 127 ft^3/sec on average for HUC12 watersheds intersecting estuarine marsh patches of all sizes, and only large marsh patches >250 ac, respectively (**Table TM.11**). However, overall mean annual flow was largely influenced by artificial path flowline types (i.e., flow path that cuts through a waterbody) across most scales. Mean flow along streams and rivers in HUC12 watershed intersecting marsh patches was much smaller, averaging 66.1 ft^3/sec in the GCPO. As expected, maximum mean flows (>515,000 ft^3/sec) in segments within HUC12 watersheds intersecting marsh patches were found in lower portions of the Mississippi River in the GCPO geography. The lower Mobile River segments in Alabama exhibited the second greatest flow rates (71,000 - 72,000 ft^3/sec), with other larger rivers (Alabama, Apalachicola, Pascagoula, Pearl Rivers in Alabama, Florida and Mississippi also exhibiting substantial mean annual flow. Non-zero flow inside marsh patches was limited and also influenced by flowlines determined to be artificial paths, and many NHD flowlines within marsh patches contained zero values indicating either no flow or that data was not available. This is not surprising as estuarine marsh patches were delineated in this assessment based contiguous emergent vegetative cover and stream/river cuts were typically used as breaks in patch delineation. When examining mean flow within associated NHD catchments intersecting estuarine marsh patches, flow is estimated to be much greater than within a patch, with mean annual flow of 1,112 ft^3/sec over all marsh patch sizes and 584 ft^3/sec over only large patches >250 ac (**Table TM.11**).

Table TM.11. Mean non-zero measures of annual flow (ft^3/sec) across three scales (within estuarine tidal marsh patches, within NHD catchments intersecting marsh patches, and within HUC12 watersheds intersecting marsh patches) for all estuarine tidal marsh patches and large patches >250 ac in size, and summarized by overall mean, and flowlines (FTYPE) classified as stream/river, coastline, canal/ditch, or artificial path.

	Mean flow - all marsh patches (ft^3/sec)					Mean flow – marsh patches >250 ac (ft^3/sec)				
	Overall mean	**Stream or river**	**Coastline**	**Canal or ditch**	**Artificial path**	**Overall Mean**	**Stream or river**	**Coastline**	**Canal or ditch**	**Artificial path**
In marsh patch	148 Max: 72,520	14.1 Max: 1,423	3.74 Max: 22.3	18.9 Max: 76.9	671 Max: 72,520	50.8 Max: 14,925	4.26 Max: 90	0.97 Max: 18.8	27.2 Max: 76.9	168 Max: 14,925
Associated NHD catchment	1,112 Max: 517,046	22.3 Max: 2,468	1.09 Max: 22.3	17.6 Max: 108	2,688 Max: 517,046	584 Max: 72,584	4.82 Max: 132	0.79 Max: 18.8	28.4 Max: 108	1,352 Max: 72,584
Associated HUC12 watershed	4,775 Max: 517,046	66.1 Max: 10,593	1.49 Max: 22.3	15.4 Max: 108	14,352 Max: 517,046	127 Max: 12,635	43.9 Max: 1,424	1.52 Max: 13.6	1.06 Max: 108	459 Max: 12,635

When assessing flow seasonality along coastal estuaries we found most rivers in the GCPO region of the western Florida panhandle to be seasonally steady (i.e., exhibiting limited seasonal variation in flow) (**Figure TM.29**). The exception was the Choctawhatchee River in Florida, which exhibited moderate seasonal variability with a high season in March and low season from July to October. This moderate seasonal variability was also observed in Mississippi, but not areas in Alabama east of Mobile Bay, which exhibited seasonally steady flow. Areas approaching the Mississippi River in Louisiana saw a shift to high seasonal variability, with high season in February to March and low season in August to October.

According to the National Anthropogenic Barriers and Southeast Aquatic Connectivity Assessment datasets dams/impoundments were more prevalent in upper reaches of estuarine rivers and streams, with few dams within the estuaries themselves, except in Choctawhatchee and St. Andrew Bay in Florida. Choctawhatchee Bay contains several dam/impoundment structures associated with Eglin Air Force Base and other bay communities, possibly limiting freshwater flow into this estuary. Deer Point Dam in the St. Andrew North Bay in Florida creates Deer Point Lake and limits freshwater inflow from Ecotina, Bear Creeks and other drainages. This could potentially explain the limited salinity gradient observed in St. Andrew Bay, though discrepancies were observed in greater magnitude in the West Bay of St. Andrew as opposed to the North Bay. There also appears to be a series of impoundments creating Martin Lake in the St. Andrews East Bay, but bayside salinity measures do not appear to be impacted by alterations in freshwater flow in this area. Pensacola Bay in Florida, Mobile Bay in Alabama and Pascagoula Bay in Mississippi also have several dams and impoundments located nearby the estuary, but none directly impeding major bay tributary freshwater inflow.

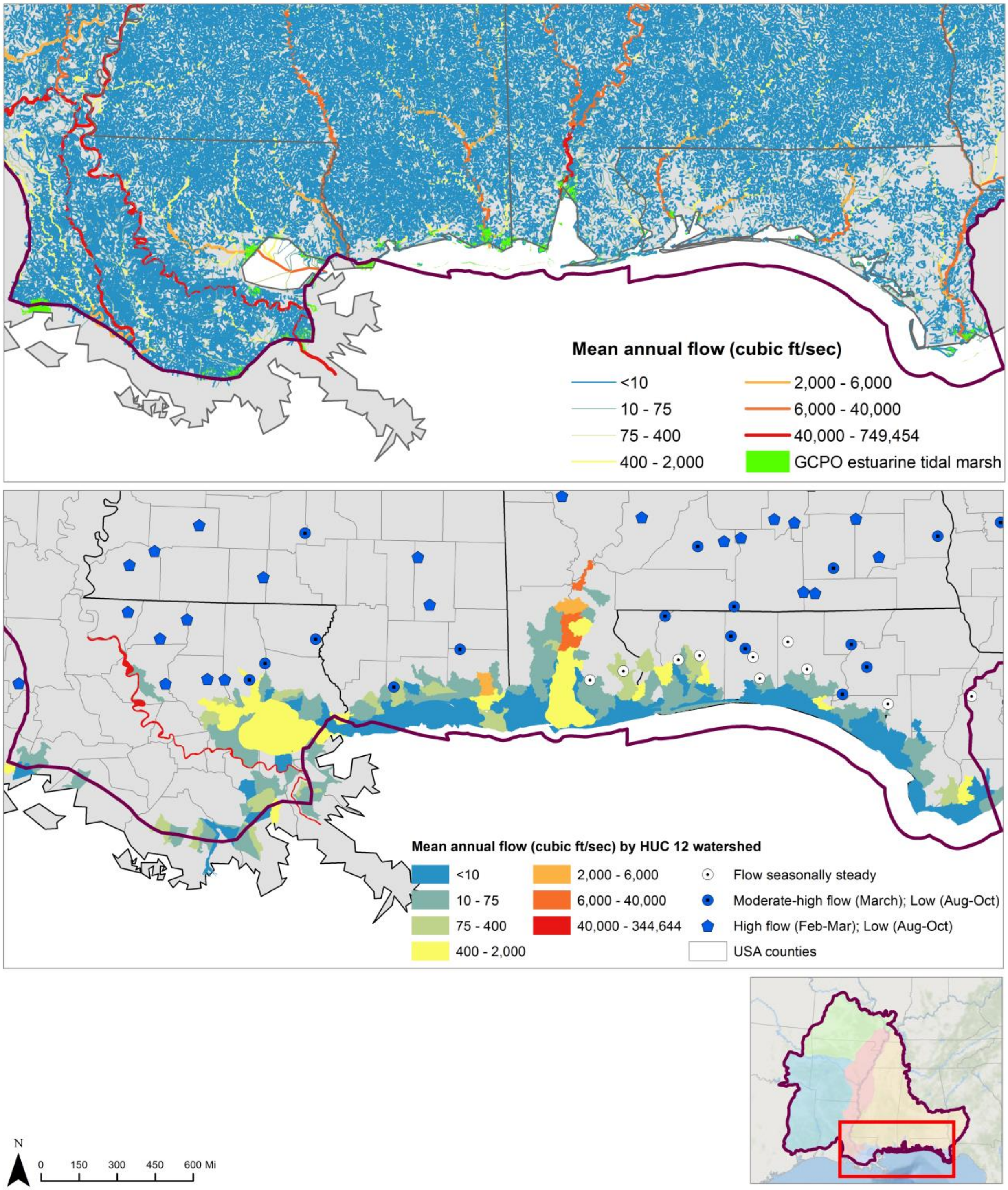

Figure TM.29. Measures of mean annual flow (ft^3/sec) for the Gulf Coast portion of the GCPO LCC geography (top), and non-zero measures summarized by HUC12 watersheds intersecting estuarine tidal marsh patches, in addition to associated qualitative measures of flow seasonality (bottom).

Salinity

We compiled 1,464 stations within the GCPO LCC geography with ongoing (hourly, daily, yearly) or point estimate salinity measures as part of this effort (**Figure TM.30).** To account for potential variation in salinity season by geography we compiled data from Feb – May as representative of the low salinity season, and from Aug – Nov as representative of the high salinity season, as determined by Christensen et al. (1997) and depicted by the NOAA dynamic 5-zone salinity data layer (**Figure TM.31**, Nelson 2012). We found 429 and 431 stations collected salinity measures during 2010-2015 in low and high salinity seasons in the GCPO LCC, respectively. Across all years of compiled data we found 451 and 849 stations in the GCPO LCC collected salinity measures during the low and high salinity season, respectively. The remaining salinity monitoring data points collected data during intermediate seasons or outside of the GCPO LCC boundaries and were excluded from this assessment.

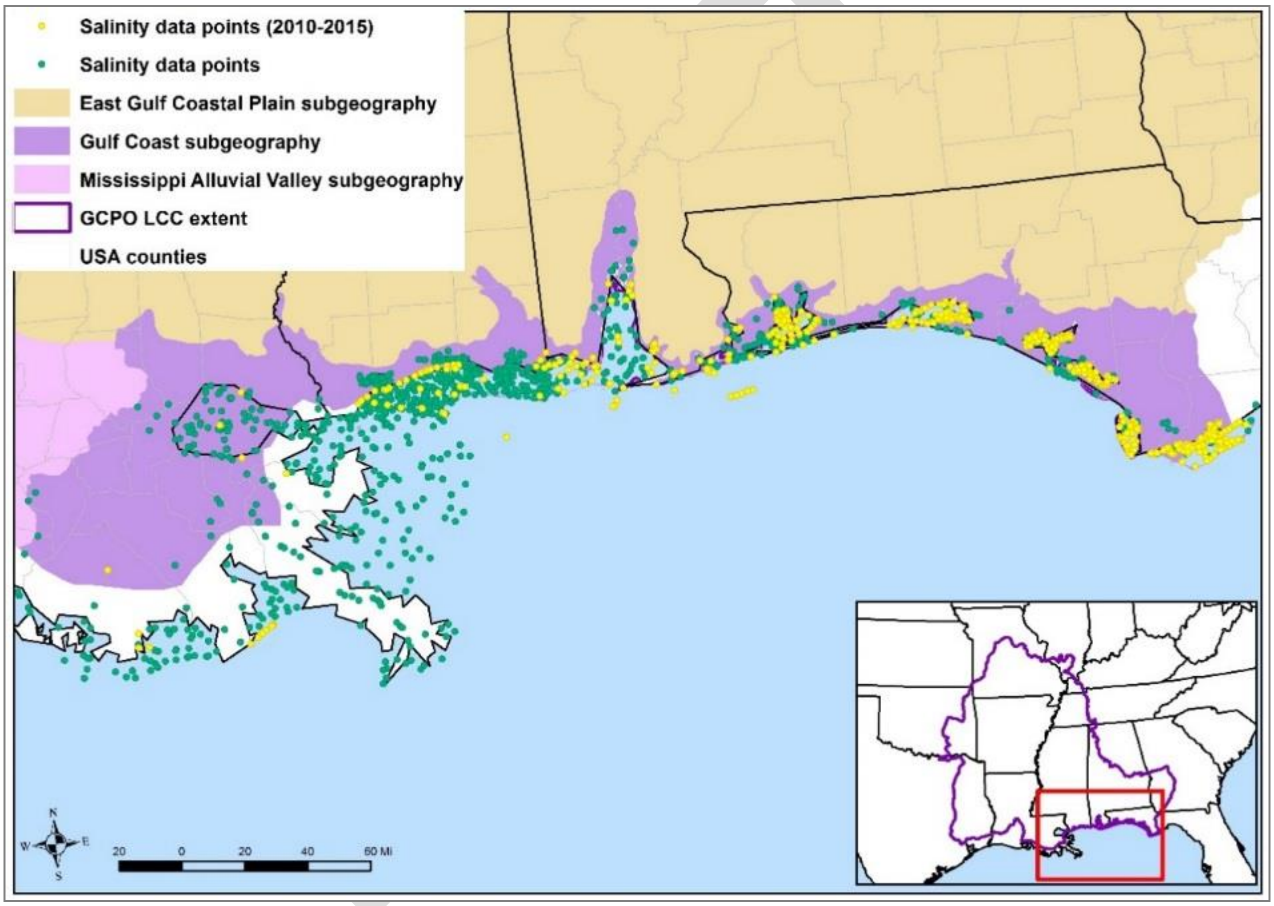

Figure TM.30. Inventory of monitoring stations with measures of salinity in the Northern Gulf of Mexico, with primary emphasis on the GCPO LCC geography.

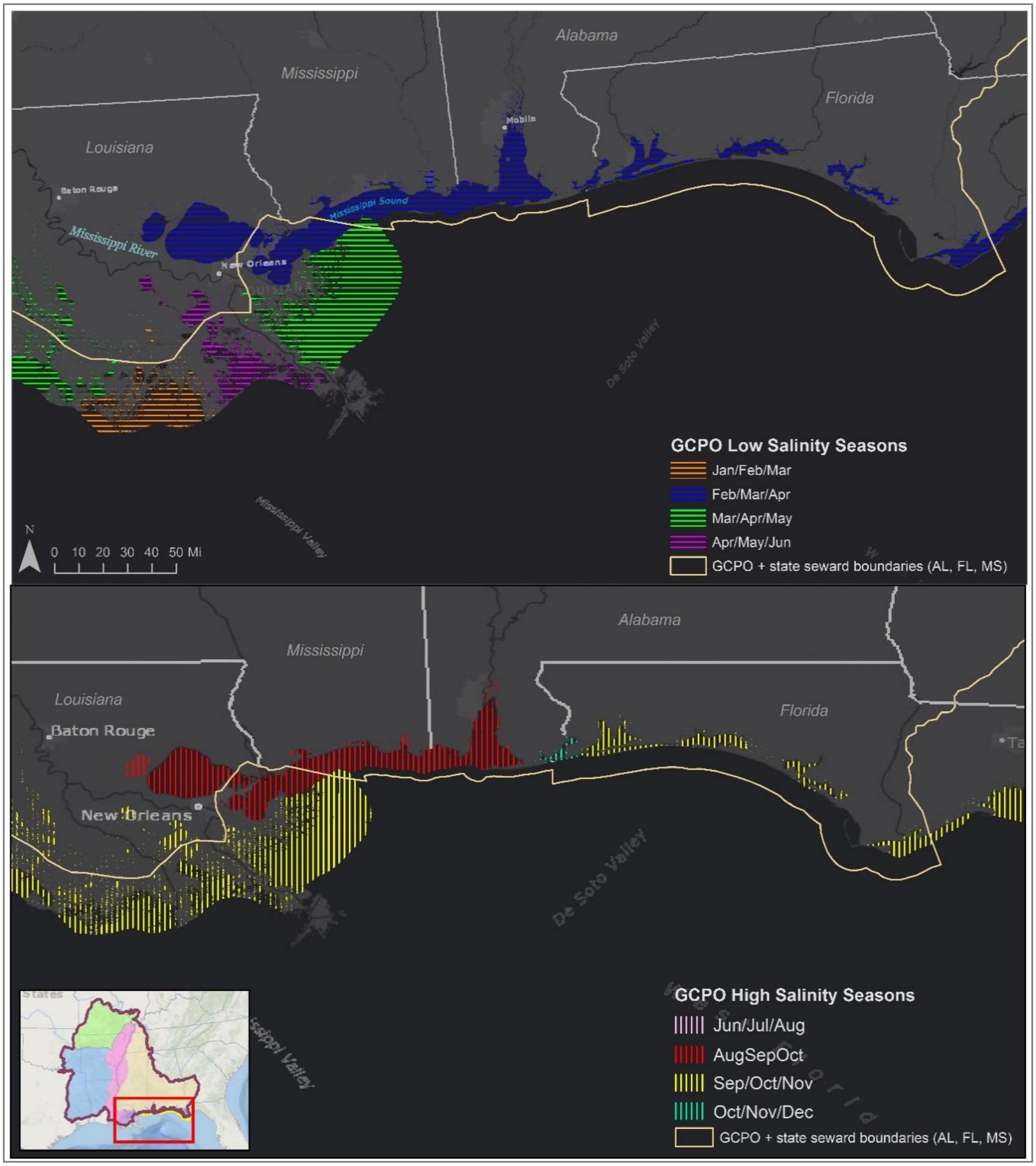

Figure TM.31. NOAA low and high salinity seasons within the GCPO LCC and bordering LCC geographies along the Northern Gulf of Mexico (Nelson 2012).

Examination of circa 1998 NOAA dynamic 5-zone salinity data zones suggest “natural” gradients were evident in most of the major riverine estuary systems at that time, though magnitude varied by geography and estuary size. The data also shows that seasonal and freshwater inflow effects are more evident in the Mississippi River delta region in Louisiana and Mobile Bay estuary in Alabama (**Figure TM.32**). Estuaries in GCPO LCC portions of the western Florida panhandle are typically subject to greater near-shore and in-bay salinity levels than their western counterparts, with the exception of freshwater inflow effects occurring in the Apalachicola, Pensacola, and Perdido Bay estuaries. Transition from the low to high salinity season renders nearly all estuaries to some period of saline inundation, with the exception of upper reaches of the Mobile Bay and areas subject to freshwater inflow in eastern Louisiana.

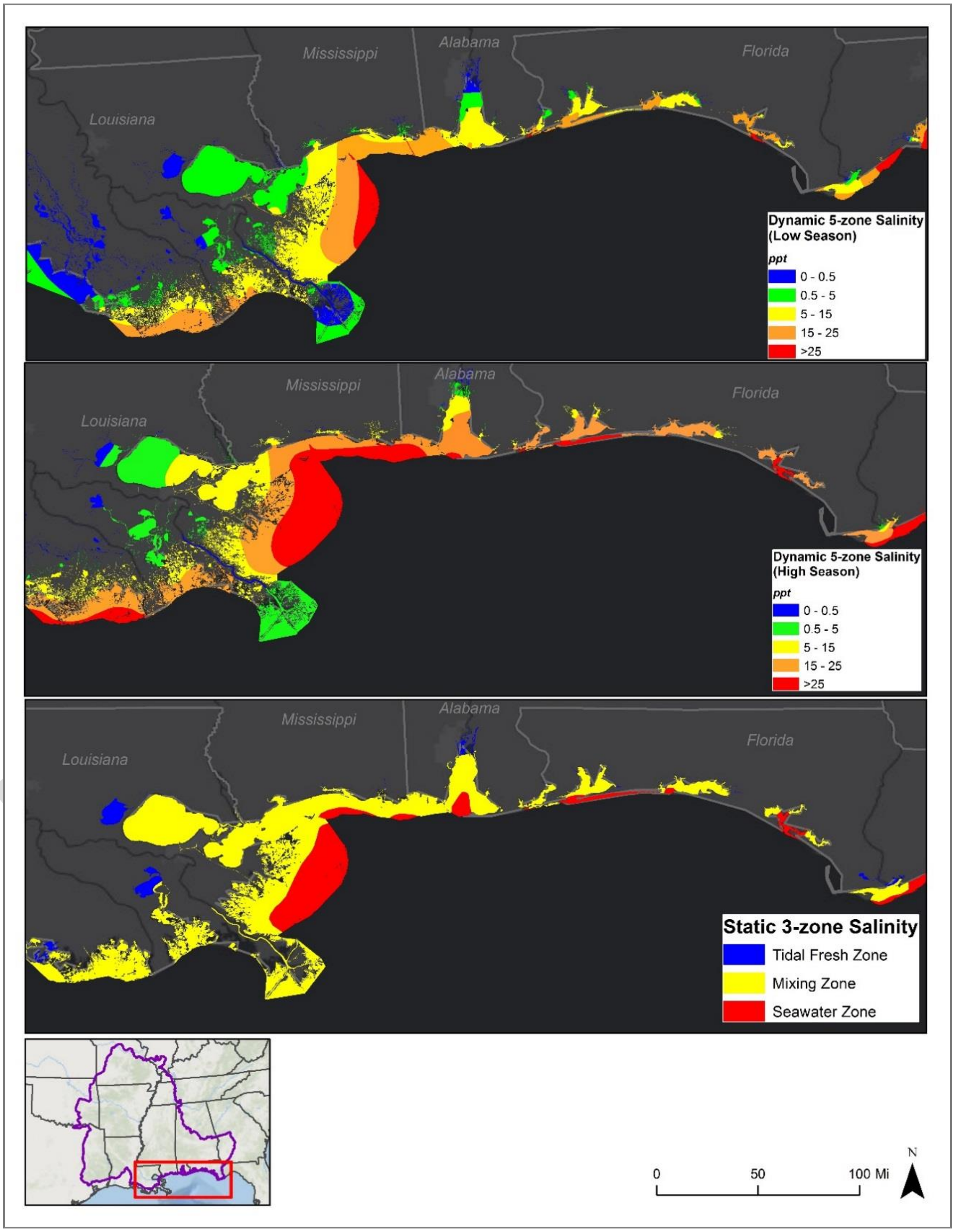

Figure TM.32. NOAA dynamic five-zone low (top) and high (middle) salinity measures in parts per thousand (ppt) and static 3-zone (bottom) salinity zones within the GCPO LCC and bordering LCC geographies along the Northern Gulf of Mexico (Nelson 2012).

Assessment of the more recent 2005-2009 remotely sensed CMECS seasonal sea surface salinity data demonstrates similar seasonal patterns in salinity, though polyhaline classes appear to push further inland during the spring and summer CMECS seasons compared to the dynamic 5-zone salinity season estimates in nearly all estuaries within the GCPO (**Figure TM.33**). In-estuary gradients are also not as evident, exemplified by the limited presence of mesohaline (5-18 psu) pixels in the northern Gulf geography. It is unclear whether these observed differences between CMECS and the dynamic 5-zone salinity data are related to temporal effects (changes in seasonal salinity patterns over the decade) or effects of sampling and analysis differences. Nevertheless, the general patterns between the two datasets are very similar.

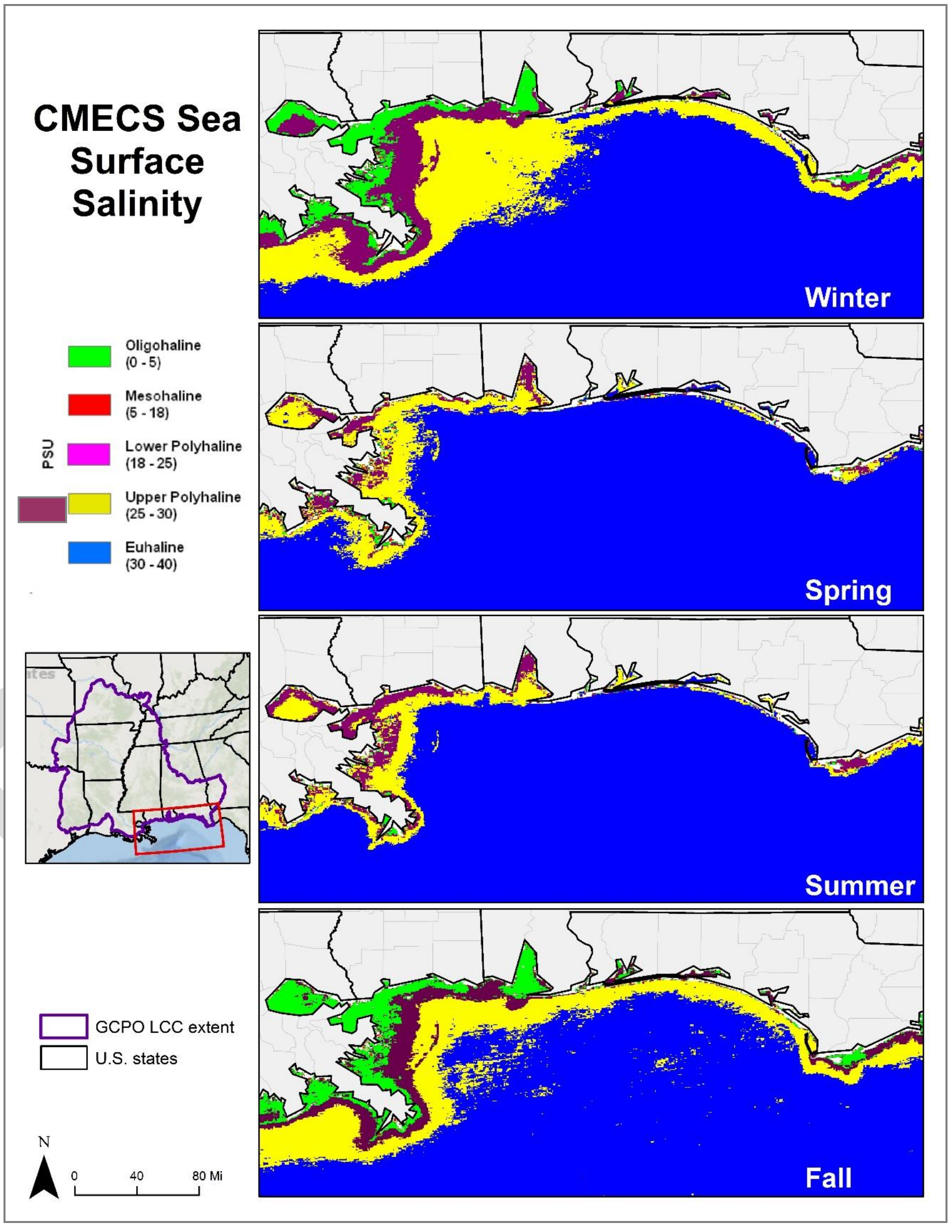

Figure TM.33. Seasonal NOAA Coastal and Marine Ecological System Classification (CMECS) application for sea surface salinity derived from remotely-sensed data in the central Gulf of Mexico mapping region (Allee et al. 2012).

Coarse assessment of average 2010-2015 empirical surface salinity data vs the circa 1998 dynamic 5-zone salinity zones suggests limited deviation from 1998 zone values in most estuaries, though data availability varied by geography. Assessment of 2010-2015 empirical surface salinity data vs the remotely-sensed 2005-2009 CMECS average sea surface salinity data also suggest adequate alignment in most classes, with the exception of the mesohaline class (5-18 psu), which was largely missing from the CMECS dataset. Though empirical data points were limited in the Louisiana Deltaic Plain region, we found general agreement with the dynamic 5-zone data in Lake Pontchartrain, Lake Borgne, and western Mississippi coast estuaries during the low and high season, and less agreement with CMECS winter and summer season data, particularly as related to empirical data exhibiting mesohaline salinity levels. This pattern continued across east Mississippi and western Alabama coasts, though empirical data aligned better with CMECS lower and upper polyhaline classes in this geography, albeit the mesohaline class was limited in the winter season. Empirical salinity measures in the Mobile Bay estuary exhibited less consistency with the dynamic 5-zone data, with a mix of measures greater, less than, or in accordance with dynamic zone (**Figure TM.34**). However differences appeared to be more prevalent in the western portions of the bay and during the low salinity season in the Mississippi Sound north of Dauphin Island than eastern portions of the bay and were minimally deviant from 1970's-era seasonal isohaline maps produced by Beault (1972). Empirical data continued to highlight the missing mesohaline class in the CMECS salinity data set when examined in Mobile Bay and surrounding areas (**Figure TM.35**).

Seasonal empirical data was in alignment with dynamic 5-zone data in Perdido Bay, Pensacola Bay, and the Santa Rosa Sound in Florida, though the southern shoreline of Pensacola Bay appears to consistently exhibit greater than expected salinity during the low salinity season (**Figure TM.34**). However, this finding was not corroborated when empirical data were compared to CMECS data, though most empirical data points exhibited mesohaline salinity measures, but were classified as oligohaline or lower polyhaline in CMECS (**Figure TM.35**). Empirical salinity measures taken during the low season in the central portions of Choctawhatchee Bay, Florida tended to be greater than expected when compared to the dynamic 5-zone data, with particularly high low season salinity measures (>25ppt) in the Sandestin Channel, and Churchill and Musset Bayou areas of the southern bay coastline. This finding was supported only at those specific locations in the CMECS data. Empirical data were better aligned in the high salinity season when compared to the dynamic 5-zone data, but measured lower than indicated during the summer season when compared to the CMECS data in the central Choctawhatchee Bay. Data exhibited alignment overall with the East and West St. Andrew Bay in Florida during the low salinity season when compared to the dynamic 5-zone and CMECS data layers, though the mesohaline class was again frequently misrepresented. Empirical data during the high season tended to be higher in East and West bays than demonstrated by the dynamic 5-zone data, but well-aligned with CMECS data during the summer season, though CMECS shows high interspersion of euhaline, upper and lower polyhaline, mesohaline, and oligohaline classes of the East, West and North portions of St. Andrew Bay. Empirical data, dynamic 5-zone data, and CMECS data for St. Andrew Bay all suggest St. Andrew Bay it is one of the only bays within the GCPO geography that demonstrates a limited gradient of salinity with even upper reaches of all 3 bays remaining above 15 ppt during the high salinity season. St. Joseph Bay is also one of the most saline bays in the GCPO geography, with limited freshwater input, and salinity levels remaining high (>25 ppt) throughout the low and high/winter and summer salinity seasons. However, because of the limited freshwater inflow influence, St. Joseph Bay is heralded as one of Florida's most important natural areas. Empirical data in the Apalachicola Bay estuary generally exhibit greater than expected salinity levels during the low season in-bay, but these shift to lower than expected salinity levels during the high salinity season when compared to seasonal dynamic 5-

zone and CMECS data (**Figures TM.34-35**). However, empirical salinity levels in the St. George and St. Vincent sound appear more aligned with dynamic 5-zone and CMECS data than in-bay measures, with the exception of prevalence of mesohaline measures in the winter season when compared to CMECS data. Empirical salinity measures in the far western portion of St. Vincent sound appear to be greater than expected during the low and high seasons when compared to dynamic 5-zone data.

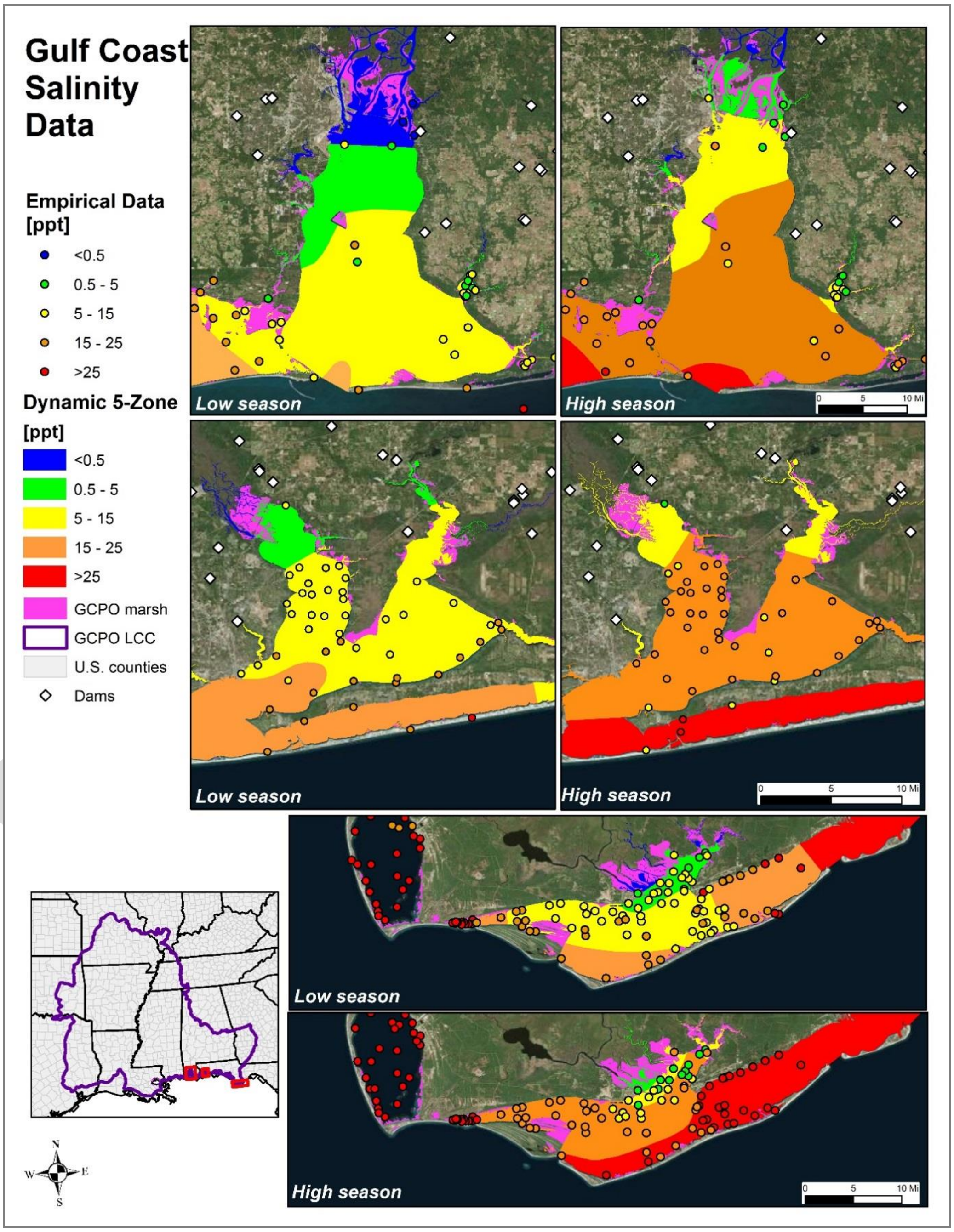

Figure TM.34. Seasonal empirical sea surface salinity measures (2010-2015) within the Mobile Bay, Alabama (upper), Pensacola Bay (middle) and St. Joseph/Apalachicola Bay (lower), Florida estuaries overlaid NOAA seasonal dynamic five-zone salinity zones for the Gulf of Mexico (Nelson 2012).

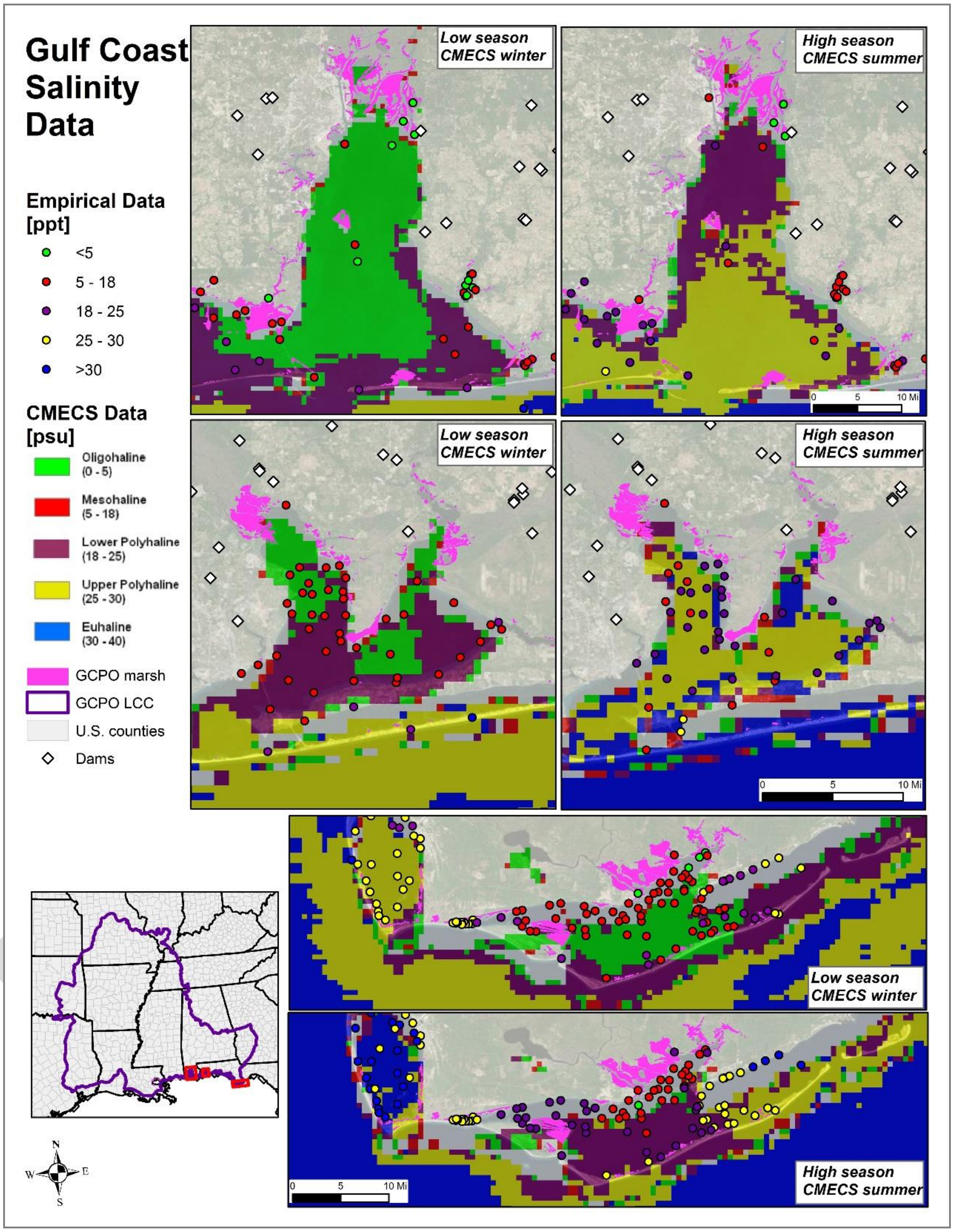

Figure TM.35. Seasonal empirical sea surface salinity measures (2010-2015) within the Mobile Bay, Alabama (upper), Pensacola Bay (middle) and St. Joseph/Apalachicola Bay (lower), Florida estuaries overlaid on winter and summer NOAA Coastal and Marine Ecological System Classification (CMECS) application for sea surface salinity derived from remotely-sensed data in the central Gulf of Mexico mapping region (Allee et al. 2012).

Tidal influence

Tidal ranges within the GCPO LCC Gulf Coast geography exhibited microtidal behavior (tidal ranges <2 m), and our analysis suggests measures of tide ranges are limited to <1 m across the GCPO with some areas approaching amphidromic point (zero tidal range). Great Diurnal Range (GT) for the GCPO LCC geography of the northern Gulf of Mexico ranged from 0.09 m (0.31 ft) to 0.82 m (2.69 ft) with greatest GT found in the eastern portions of the GCPO near Apalachicola Bay, and St. George Sounds in Florida and the second greatest GT estimates falling within the estuaries along the Mississippi Sound (**Figure TM.36**). Lowest GT estimates were found within Lake Pontchartrain in Louisiana, Perdido Bay along the Alabama-Florida line, and Choctawhatchee Bay in Florida. GT ranged from 0.10 m (0.34 ft) to 0.66 m (2.16 ft) within large estuarine tidal marsh patches greater than 250 ac, and from 0.10 m (0.34 ft) to 0.79 m (2.58 ft) in estuarine marsh patches of all sizes.

Mean Range of Tide (MN) for the GCPO LCC geography was of less magnitude than GT, and ranged from 0.10 m (0.33 ft) to 0.51 m (1.68 ft). MN range was still greatest in the Apalachicola and St. George Sound areas in Florida, but of less magnitude than GT (Fig. 44). MN ranged from 0.11 m (0.36 ft) to 0.51 m (1.68 ft) and 0.47 m (1.53 ft) in estuarine marsh patches of all sizes and patches greater than 250 ac, respectively.

Without fully understanding estuary-specific interactions between freshwater inflow and tidal influence, a coarse qualitative assessment of these two factors as presented here is applicable, and an important topic for further study. Estuaries within the GCPO LCC Gulf Coast geography exhibit a broad spectrum of perceived interactions among freshwater flow and tidal range (**Figure TM.37**). Four major estuary areas (Lake Pontchartrain and the Mississippi River Delta, Perdido Bay, and Choctawhatchee Bay) exhibit a combination of medium to high freshwater flow and low tidal range. Areas in Mississippi and the Mobile Bay experience mid-levels of tidal range and high amounts of freshwater flow. Other areas like St. Andrew Bay and St. Joseph Bay in Florida have medium tidal range and low flow conditions, whereas areas like Apalachicola Bay have both “high” tidal range (relative to the remaining GCPO LCC geography), combined with medium to high flows. Note that all estuaries exhibit microtidal conditions, therefore areas of high tidal influence must be considered relative to other estuaries in the GCPO geography.

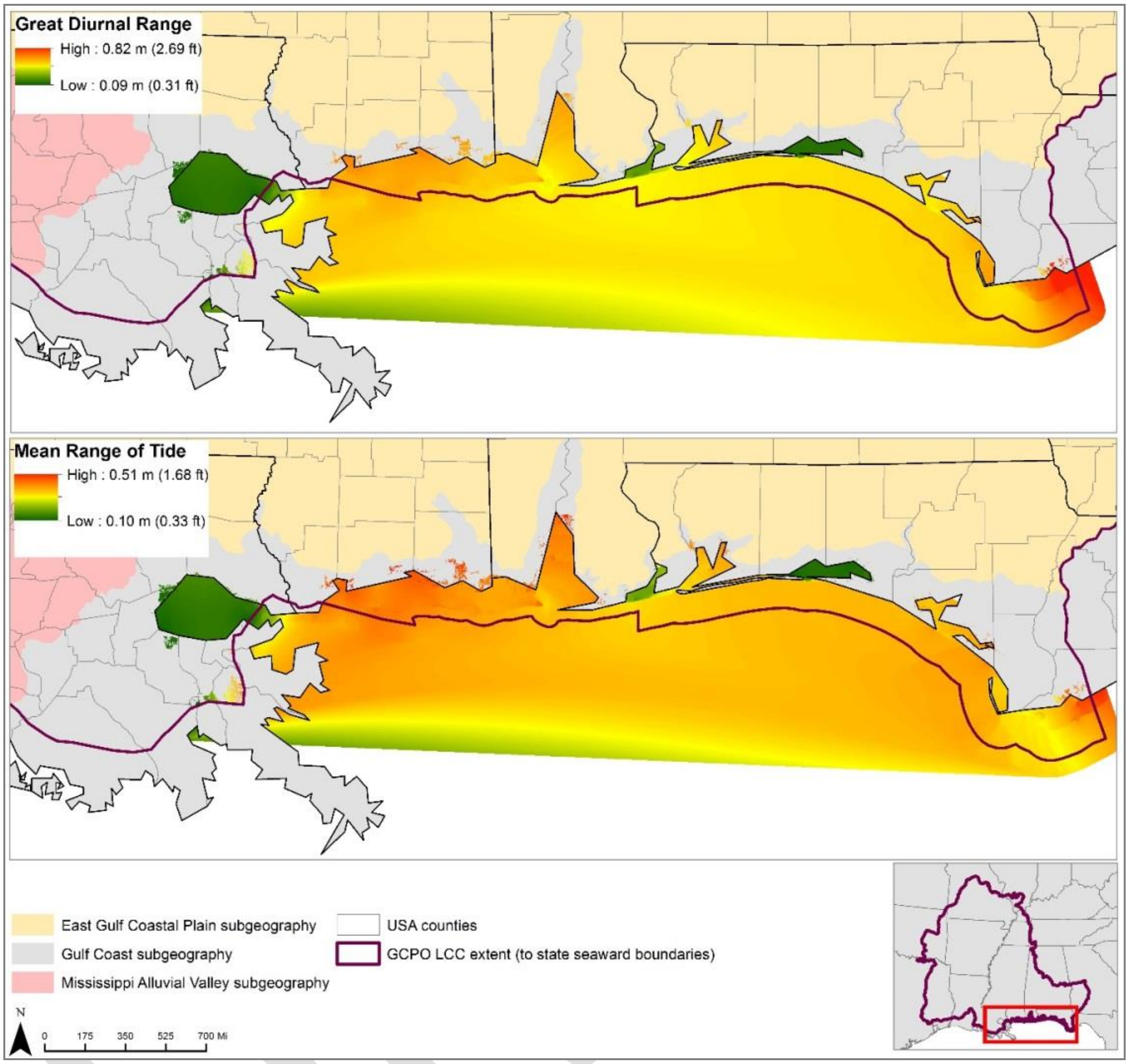

Figure TM.36. Great Diurnal Range (mean higher high water – mean lower low water) (top) and Mean Range of Tide (mean high water – mean low water) estimated from NOAA VDatum transformation in the GCPO LCC Gulf Coast geography.

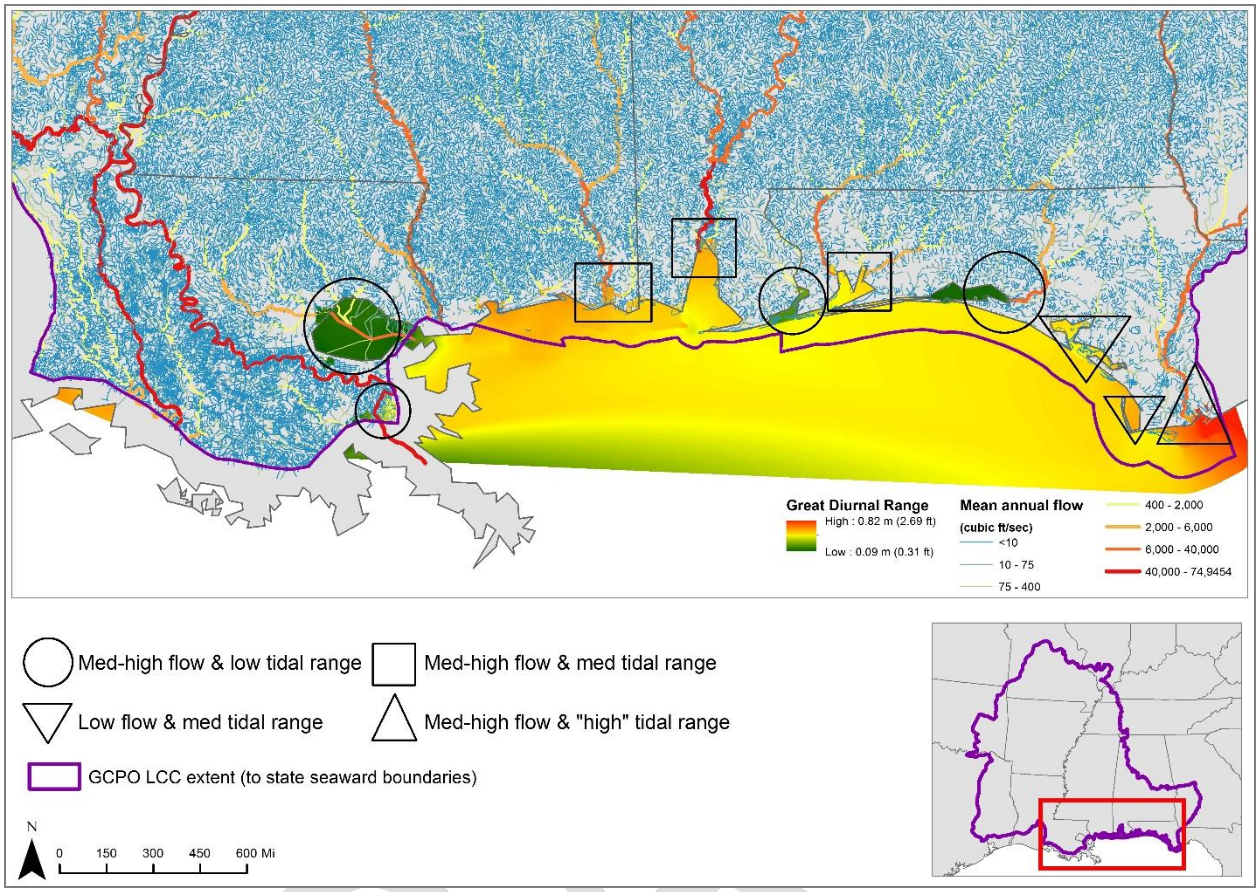

Figure TM.37. Great Diurnal Range (mean higher high water – mean lower low water) (top) and Mean Range of Tide (mean high water – mean low water) estimated from NOAA VDatum transformation in the GCPO LCC Gulf Coast geography.

Future Directions and Limitations

Though data is widely available for public consumption interrelationships of tidal range and marsh stability are not yet clearly understood (Kirwan and Guntenspergen 2010). This understanding is critical as impacts of freshwater flow on estuarine salinity levels has major coastal fishery implications, as exemplified by oyster sensitivity to changes in salinity levels (Livingston et al. 2000). Note that data used in this assessment come with inherent caveats related to quality assurance of NHD flowline data. Assessing non-zero flow may alleviate a portion of the potential issues associated with using NHD, but excluding observed zeros may artificially inflate averages relative to the real system. Fortunately, efforts to quantify and understand the impacts of freshwater flow on estuary systems are already underway. Inflow-based decision support tools like those being developed by the Harte Research Institute are currently in development to link managers to the best available geospatial information from which to make informed conservation decisions (Montagna et al. 2014).

Because of natural fluctuation in salinity measures within estuary systems it is challenging to detect long-term salinity changes to a system. Further, it is difficult to determine and subsequently quantify a natural seasonal salinity gradient for GCPO estuaries, as each estuary and source watershed will depend on varying amounts of freshwater inflow to maximize ecological function. Management to influence salinity range cannot be ubiquitously applied across all estuaries and must be tailored to specific estuary types (Orlando et al. 1993). This is exemplified by saline waters of St. Joseph Bay, Florida where a natural salinity gradient may be inhibitive to the ecological function of the system – which maintains its high biological diversity because of limited freshwater flow. Salinity gradients in estuaries, though difficult to quantify as "natural" must therefore be considered on a case by case basis. The estuaries of the Louisiana Deltaic Plain represent a reciprocal scenario, whereby ecological function depends on the fresh-saline gradient produced by the Mississippi River delta. There is also a temporal component to determining what era a "natural" gradient could be delineated in these highly dynamic systems.

In the face of climate change and subsequent displacement of freshwater marsh components by salt marsh, probabilistic, standardized and long-term monitoring of seasonal salinity levels is critical across the northern Gulf Coast. When coastal marshes are routinely flooded with saline water, a compositional shift in marsh plant communities to salt-tolerant species will result (Hackney and Avery 2015). More than twenty years ago, Orlando et al. (1993) suggested that available data is highly variable among estuaries, is often temporally and spatially sporadic, and lack comprehensive estuary-wide sampling strategies, and suggests "a greater cognizance of the need for and value of salinity data in estuary management is needed". The synthesis of data compiled for this assessment report supports Orlando et al.'s observation, though there are now several viable options for compiling data as part of the National Water Quality Council's data warehouse or the Gulf Coast Ocean Observing System portal. With a comprehensive long-term monitoring system in place, one could provide a detailed comparative assessment to Orlando et al.'s (1993) estuary-specific salinity assessment as was done at that time via the National Estuarine Inventory program. Finally, salinity is an important indicator of water quality, relative to the species that may inhabit estuarine systems along the northern Gulf Coast, but may not be the only appropriate indicator for this system.

Conservation Planning Atlas/Links to Available Geospatial Data Outputs

- USGS TNM National Hydrography Dataset
- NOAA dynamic 5-zone seasonal salinity zones
- NOAA Coastal and Marine Ecological Classification Standard Mean 5-Year Seasonal Sea Surface Salinity in the Northern Gulf of Mexico
- Great Diurnal Range and Mean Tidal Range (GCPO Gulf Coast geography)

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A Condition Index Tracking Desired Ecological States for Gulf Coast Estuarine Tidal Marsh

The goals of the ecological assessment of estuarine tidal marsh were to determine where in the GCPO Gulf Coast estuarine marsh systems exist in or nearly-in the desired ecological state outlined in the GCPO LCC Integrated Science Agenda. That is, providing a spatially-explicit determination of where on the Gulf Coast landscape all estuarine tidal marsh landscape endpoints are met. This information is critical to the coastal conservation planning community in its ongoing pursuit to strategically identify areas for marsh restoration and acquisition. This information on current status of tidal marsh can also be used to evaluate and predict change over time as a result of sea-level rise, urbanization, and other ecological stressors. This information also provides a critical input layer into GCPO LCC Landscape Conservation Blueprint process in combination with information on existing conservation investments, partner priorities, potential threats, and species-habitat associations to create a blueprint for large-scale conservation efforts into the future.

Throughout this rapid assessment we assumed the landscape endpoints are an adequate representation of the desired ecological state for estuarine tidal marsh defined by the GCPO LCC Integrated Science Agenda. We used quantifiable landscape endpoint data described in chapters above to calculate a series of condition index values as a baseline for assessing amount of marsh within or near the desired ecological state for this system. Though several endpoints were limited by availability of data or lack of measurable ISA targets, we were able to assess tidal marsh habitats that fell within desired thresholds for patch size, interdigitation of marsh types, edge, emergent vegetative cover, open water, and submergent vegetative cover. We did not include measures of salinity or freshwater flow/tidal influence, presence of barrier islands in the assessment of desired ecological state due to uncertainty in thresholds across estuaries. We also did not include the assessment of native vegetation as data is limited in availability. These excluded variables will be incorporated into subsequent assessment as quantitative targets and/or data becomes available.

Data Sources and Processing Methods

1. *Identification of potential marsh*

We used a series of raster calculations in a dichotomous decision-based framework to compile a per-pixel draft condition index value at a 10 m resolution for GCPO estuarine tidal marsh based on the number of configuration and condition endpoints met within each marsh pixel (**Table TM.12**, **Figure TM.38**). Pixels not identified as a estuarine marsh but that were identified as having the potential to be marsh were given a score of 1, provided the pixels were not classified as developed. Potential estuarine tidal marsh pixels were derived from a combination of potential estuarine tidal marsh classes in the Landfire Biophysical Settings (BPS) and future marsh in the USGS Tidal Saline Wetland Migration (TSWM) layer. Developed areas were extracted from the 2011 National Land Cover Database (NLCD) and used as a mask to indicate that areas currently under development were not expected to be converted to marsh over time. We included the BPS class “Gulf and Atlantic Coastal Plain Tidal Marsh Systems” (BPS Code

149000), as part of the Saltmeadow Cordgrass-Saltgrass-Gulf Cordgrass grouping as one of the layers of potential estuarine tidal marsh in the assessment. Note that this BPS classification does not split out estuarine vs. palustrine tidal marsh, which may or may not be relevant as marshes should be dynamic and depend on salinity and water levels over time. Further, given that tidal marshes are expected to migrate inward in many areas along the GCPO Gulf Coast we used the USGS TSWM layer to incorporate future tidal saline marsh out to a 2060 time frame, using a moderate mean sea-level rise scenario of 0.5 m. We reclassified both these layers to a binary 1, 0 and used map algebra to calculate a combined layer of potential estuarine tidal marsh. When combined, these two layers identified where estuarine tidal marsh could potentially be on the landscape based on edaphic, geographic and local site conditions in combination with where it could potentially migrate to given moderate levels of sea-level rise between now and 2060. We then used map algebra to remove developed areas using 2011 NLCD classes for developed open space (class 21), and developed low, medium, and high intensity (classes 22-24), assuming that developed, impermeable areas would not be restorable in the foreseeable future. We also removed areas of existing estuarine tidal marsh (i.e., the marsh mask) to exclude current marsh from being quantified in the potential layer. This layer of "potential" estuarine tidal marsh was calculated at 10 m resolution, then reclassified to a binary 1 or 0. The product was a layer of potential and future marsh that is not currently in estuarine marsh state, and not currently developed. Pixels of potential marsh were given a score of 1 when included in the condition index calculations below.

2. *Condition index*

In addition to pixels of potential marsh described above, pixels identified as current estuarine tidal marsh were given a score of 2, whereas pixels found in marsh patches >250 ac were given a score of 8, and pixels found in "unbroken" patches with >70% emergent vegetative cover and <20% open water cover were given a score of 4. Pixels meeting condition endpoints of edge density ≤735 m/ha, marsh type composition (≥5% each) as a surrogate for interdigitation, and submergent vegetative cover (15-30%) were given one additional point for each endpoint, totaling up to three points. This scoring system allowed for calculation of a condition index value (CIV) based on the decision tree outlined in **Figure TM.38**. Under this scoring system, existing estuarine tidal marsh pixels that were found in patches <250 ac and considered broken (<70% emergent vegetative cover and >20% open water cover) scored a CIV from 2 - 5, depending on how many condition endpoints were met. Marsh pixels found in patches <250 ac but that were considered unbroken (>70% emergent vegetative and <20% open water cover) scored a condition index value from 6 - 9, depending on the number of condition endpoints met, indicating small unbroken patches may be in better condition than small highly fragmented patches. Marsh pixels that were found in large (>250 ac) patches but considered broken or fragmented scored a CIV from 10-13. This scoring system assumes a large broken patch may be in better overall condition than a small unbroken patch, but this assumption needs to be validated with empirical research. Marsh pixels that were found in large (>250 ac) patches and considered unbroken scored a CIV from 14-17. An index value of 17 represents marsh pixels that are estimated to be in the desired ecological state, as determined by the suite of measurable condition endpoints. CIVs were developed in a series of ArcGIS raster calculator computations to classify each pixel in the GCPO landscape to a value from 0 to 17, with 0 representing pixels that were not nor had the potential to be estuarine tidal marsh, 1 representing pixels that were not presently estuarine tidal marsh but had the potential to be, and values from 2 to 17 representing the gradient of index values associated with pixels that were classified as estuarine tidal marsh.

Table TM.12. Landscape endpoints defining desired ecological state (DES) for estuarine tidal marsh in the GCPO LCC Gulf Coast subgeography, including the value specified by the GCPO Integrated Science Agenda (ISA), and metric and value used in the rapid ecological statement. *Note values for interdigitation and edge were not identified as thresholds in the ISA.

Endpoint	Value specified	Metric assessed	Value used
Large blocks of unbroken marsh	>250 ac	Patch size	≥250 ac
Interdigitation of marsh types*	Connectivity	Composition of saline, brackish, and intermediate marsh w/in patch	≥5% each
Edge within large blocks of marsh*	Moderate	Edge density	≤735 m/ha
Barrier island in riverine-dominated systems	Presence	Not included in DES assessment	
Emergent vegetative cover	>70%	Percent cover	>70%
Open water	<20%	Percent cover	<20%
Submergent vegetative cover	15-30%	Percent cover w/in patch	15-30%
Native plants typical of high, mid-, intermediate, and low marsh	Dominance	Not included in DES assessment	
Salinity	Natural gradient	Not included in DES assessment	
Freshwater flow/tidal influence	Adequate	Not included in DES assessment	

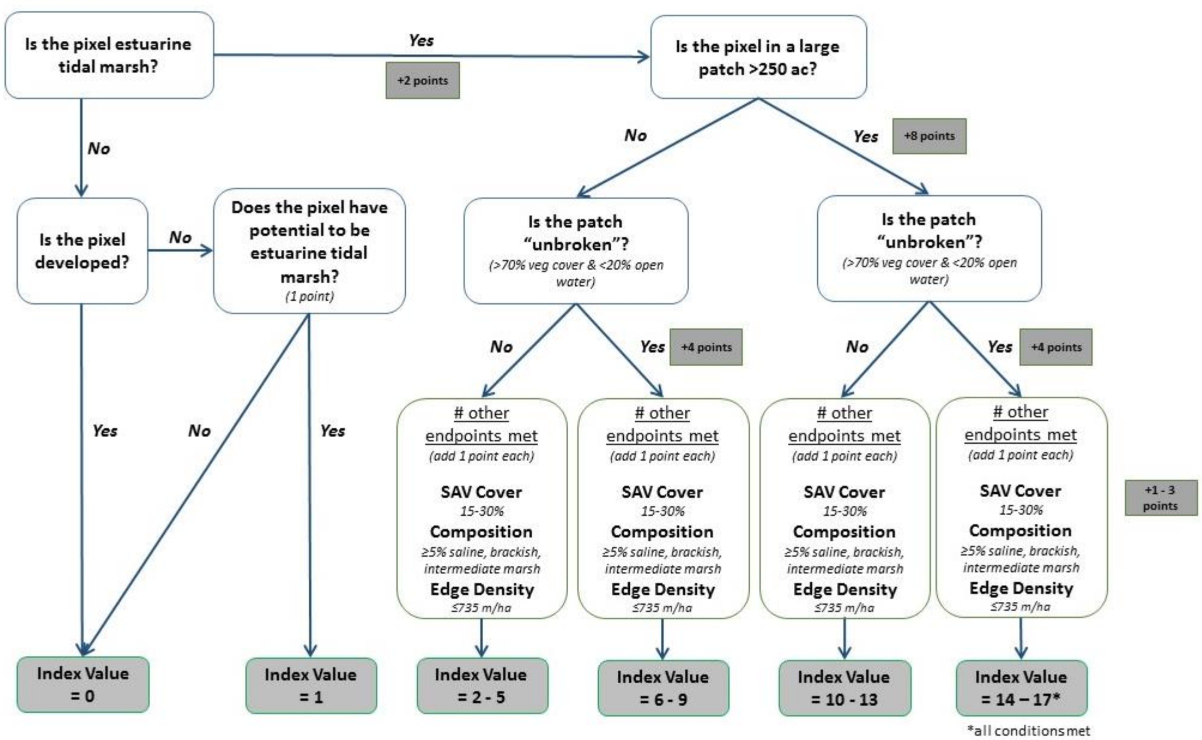

Figure TM.38. Draft decision tree for assigning condition index values (CIV) based on meeting estuarine tidal marsh landscape endpoints for incorporation into the GCPO LCC conservation blueprint for estuarine tidal marsh systems. An index value of 17 suggests a particular marsh pixel is found in a large unbroken patch >250 ac, and within targets of edge density, marsh type composition (as a surrogate for interdigitation), and submergent vegetative cover (SAV).

1. *Determining Relative Contribution of Landscape Endpoints using a Barcode Approach*

Up to this point information contributing to the calculation of the marsh condition index score using a point scoring system has been additive. That is, we could determine a condition index score value, but not what individual landscape endpoints contributed to the value. Therefore, we may know a particular patch is in high quality, but not describe what marsh conditions were met to create that score. Recently the LCC has shifted its approach to calculation of condition index values whereby contributing elements are identified in addition to the additive condition index value calculated when summing individual scores for landscape endpoints. This “bar code” approach provides a unique identifier for each combination of endpoint scores for marsh pixels within the landscape as exemplified in **Figure TM.39** below. To create the barcodes we simply used raster calculations in ArcGIS to concatenate landscape endpoint scores into a single field. This, however, required careful tracking of the order of condition endpoints going into the concatenation. This approach provides a much greater amount of information to conservation planners regarding the relative contribution of endpoint data to the summed condition index value in a transparent framework.

Potential estuarine tidal marsh? *(1 point)*	Current estuarine tidal marsh? *(2 points)*	Pixel in a large patch >250 ac? *(8 points)*	Patch “unbroken”? (>70% veg cover & <20% open water) *(4 points)*	Submergent vegetative cover 15-30%? *(1 point)*	Composition of marsh types ≥25% each ? *(1 point)*	Edge density ≤735 m/ha? *(1 point)*	Condition Index Score	Barcode Value
1	0	0	0	0	0	0	1	1000000
0	2	0	0	0	0	0	2	0200000
0	2	0	0	0	0	1	3	0200001
0	2	0	4	0	0	0	6	0204000
0	2	0	4	0	0	1	7	0204001
0	2	0	4	0	1	0	7	0204010
0	2	0	4	1	0	0	7	0204100
0	2	0	4	0	1	1	8	0204011
0	2	0	4	1	0	1	8	0204101
0	2	8	0	0	0	1	11	0280001
0	2	8	0	0	1	1	12	0280011
0	2	8	4	0	0	1	15	0284001
0	2	8	4	0	1	1	16	0284011
0	2	8	4	1	0	1	16	0284101

Figure TM.39. Matrix of possible barcode value scores produced via condition index value (CIV) calculations to determine individual endpoint contribution to condition index scores.

Summary of Findings

Estimates addressed at the beginning of this assessment suggested a cumulative 202,584 acres of estuarine tidal marsh in any condition along the Gulf Coast portions of the GCPO LCC geography. We found no areas on the landscape that met all measurable landscape endpoints (CIV = 17), and only a small portion of marsh acreage (8%) reflecting a CIV of 16, which indicated pixels were found in large (>250 ac) unbroken patches and met two of three desired ecological state, as determined by measurable landscape endpoints (**Table TM.13**). This includes nearly 16,000 acres of large unbroken patches that contained >5% each of saline, brackish, and intermediate marsh and exhibited moderate amounts of edge density (Barcode = 0284011). Much of this acreage occurred in the Grand Bay marshes in Mississippi and Alabama, the eastern portion of Mobile Bay, the northern portion of Perdido Bay in Florida, and within the Bayou Labranche area along the southern edge of Lake Pontchartrain in Louisiana (**Figure TM.40-41**). However, several other areas with a CIV=16 were located within 10 km of the GCPO LCC boundary in Louisiana, along the north shore of Lake Borgne, and in marshes along and west of the Mississippi River (**Figure TM.41**). Note that limitations in westward extent of SAV data and eastern extent of marsh type data used in composition metrics result in portions of Florida east of Perdido Bay and portions of Louisiana being susceptible to downward bias due to lack of data availability. However, these issues will be resolved when an extent map of SAV cover in Louisiana and expansion of the marsh type delineation project along the Florida panhandle are available.

We found 60% of tidal marsh acres exhibited a CIV=15, suggesting the majority of marsh in the GCPO geography was found in large (>250 ac) unbroken patches, within the desired range of edge density (Barcode = 0284001; **Table TM.13**). Over 51,000 acres of marshes exhibiting a CIV of 15 were found throughout GCPO portions of coastal Louisiana, though substantial additional acreage (20,000 – 25,000 acres each) was found along coastal Mississippi, Alabama, and Florida (**Table TM.13**). In Louisiana, large intact patches were found along fringes of Lake Pontchartrain, throughout the GCPO portion of Mississippi River delta marshes, and along Vermillion Bay (**Figure TM.41**). There were also large intact patches just outside the GCPO geography along the far western Mississippi Sound portions of Mississippi and Alabama, and in St. Louis Bay in Mississippi. Large intact patches were also very prevalent in the Pascagoula, Grand Bay, and Mobile Bay areas of Mississippi and Alabama, in addition to several large patches along barrier islands and peninsulas (**Figure TM.40**). Three large, intact patches were found within the Pensacola Bay area, one in the Choctawhatchee Bay, six in east and west St. Andrew Bay, and several in the Apalachicola Bay vicinity (**Figure TM.42**).

There were very few marshes considered in either a large or small "broken" patch (i.e., a >250 ac or <250 ac patch, exhibiting >20% open water and <70% emergent vegetative cover) (**Table TM.13**). This is likely an artifact of delineation of patches based from an 8-neighbor adjacency of marsh pixels, which would result in patches determined by contiguity of emergent cover, and may change if an alternative patch delineation technique were used (e.g., on-screen digitizing of patch extent). We estimate 32% of marsh acreage to be found in unbroken patches that are <250 ac in size (CIV=6-9), with over a third of that acreage located in GCPO portions of Louisiana (**Table TM.13**). Marshes along St. Joseph Bay and Perdido Bay in Florida and in parts of Mobile Bay in Alabama, as well as other small scattered patches throughout Mississippi and Louisiana exhibited a CIV=8, suggesting small unbroken patches also met two of three other landscape endpoints, predominately configuration endpoints of interdigitation of marsh types, as measured by marsh type composition, and edge density (**Figures TM.40** and **TM.42**). We found much more acreage scoring a CIV=7, with the majority of acreage found in small unbroken patches distributed evenly across the states and that met the target landscape endpoint for edge density (**Table TM.13**). There were also nearly 13,000 acres of tidal marsh, primarily in Louisiana, that were considered small and unbroken but did not meet any additional landscape endpoint criteria (**Table.TM.13**). These results suggest significant potential to target marsh conservation and restoration efforts to strategically connect small unbroken patches together or to existing large patches to strengthen connectivity of marsh systems along the coast. Examples of these opportunities to expand connectivity of marsh networks can be found along the entirety of the GCPO Gulf Coast (**Figures TM.40-42**). However, there still exists a critical research need to determine effective patch size and ecological barriers across marsh patches for estuarine tidal marsh systems to help target conservation and restoration strategies. Finally, we estimate over 1.2 million acres of potential estuarine tidal marsh along the GCPO Gulf Coast landscape, using composite data from Landfire Biophysical Settings in combination with USGS data on predicted future migration of tidal saline wetlands (**Table TM.13**, Barcode = 10000000). Potential marsh is prevalent along most major bay systems in the GCPO but most prevalent along Apalachicola Bay in Florida, Mobile Bay in Alabama, and throughout much of coastal Louisiana (**Figures TM.40-42**).

Table TM.13. Total acres estuarine tidal marsh reflected in each Condition Index Value (CIV) category (1-16) and Barcode category by state representing relative contribution of each landscape endpoint to the Condition Index Value score within the GCPO Gulf Coast geography. Marsh acreage is described by general condition category, or bin, reflective of the decision tree and barcode descriptor demonstrated in Figures TM.38-39.

General condition category	Condition Index Value	Acres Condition Index Value	Barcode Value	Acres Barcode Value			
				Alabama	Mississippi	Louisiana	Florida
Potential	1	1,226,977	1000000	80,928	17,760	1,065,265	63,024
Small (<250 ac) broken patches	2	60	0200000	34	0	1	26
	3	293	0200001	223	0	0	70
Small (<250 ac) unbroken patches	6	12,786	0204000	2,535	1,616	6,906	1,729
	7	49,316	0204001	9,470	10,854	14,632	14,096
			0204010	67	23	152	8
			0204100	6	0	0	8
	8	3,050	0204011	737	744	1,074	63
			0204101	41	0	0	391
Large (>250 ac) broken patches	11	947	0280001	560	0	387	0
	12	1	0280011	0	0	1	0
Large (>250 ac) unbroken patches	15	119,393	0284001	21,783	25,371	51,815	20,424
	16	16,708	0284011	4,712	9,961	354	953
			0284101	728	0	0	0

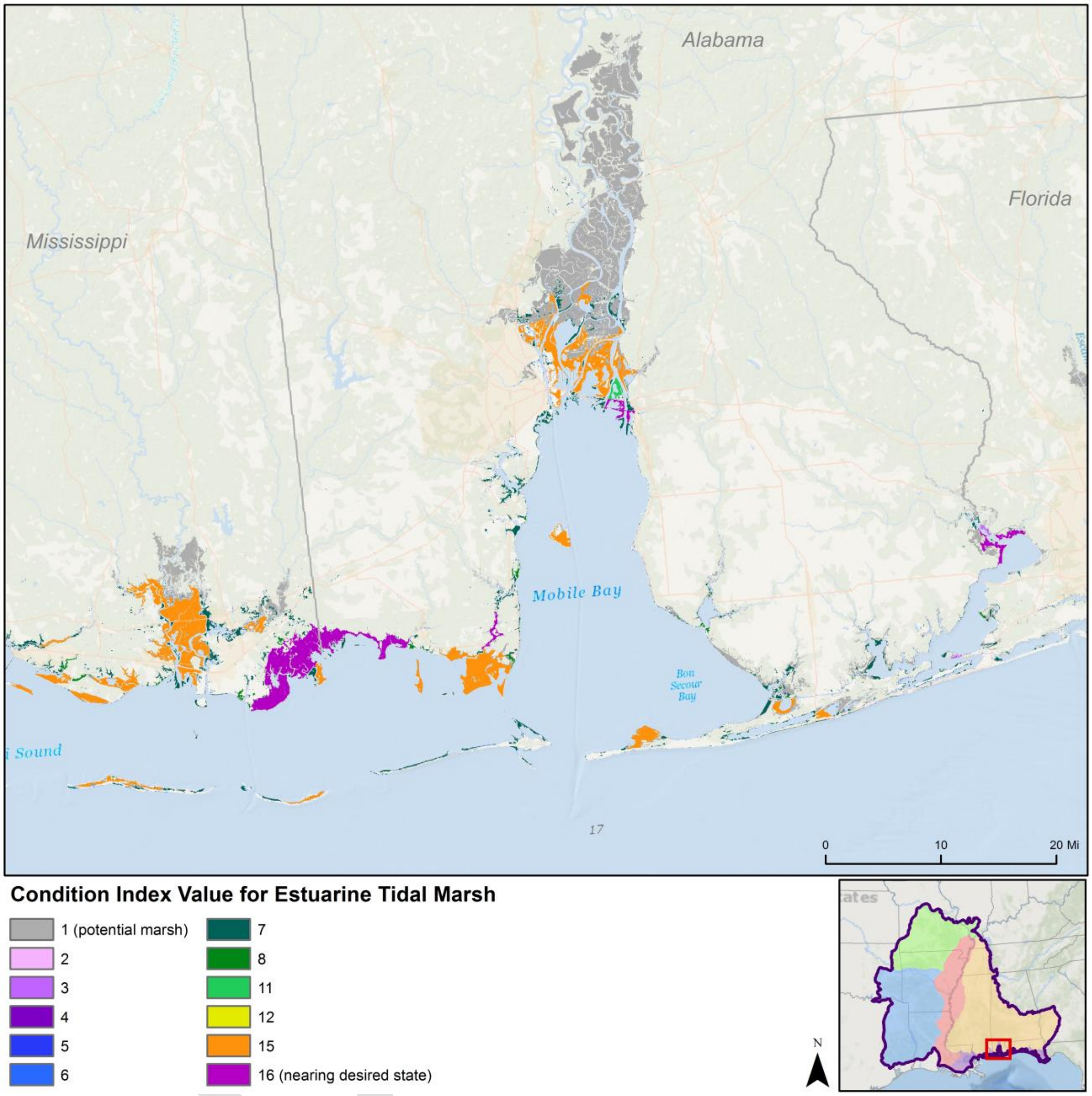

Figure TM.40. Draft condition index value scores (1 - 16) for marshes from Pascagoula Bay, Mississippi to Perdido Bay, Florida, based on the decision tree outlined in Figure TM.38 for use in the GCPO LCC conservation blueprint for estuarine tidal marsh systems.

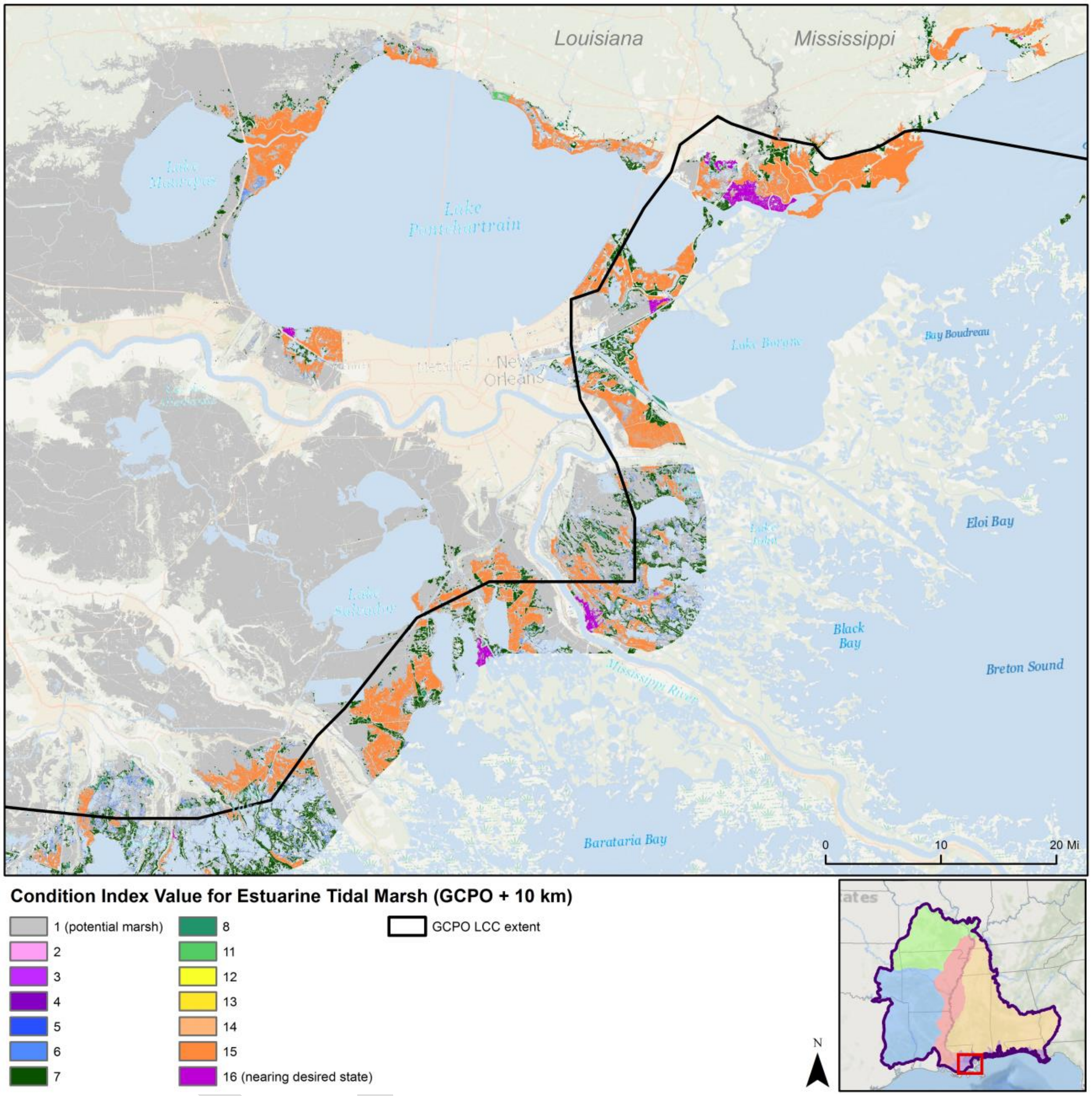

Figure TM.41. Draft condition index value scores (1 - 16) for marshes within and along the GCPO Gulf Coast in east Louisiana and west Mississippi, based on the decision tree outlined in Figure TM.38 for use in the GCPO LCC conservation blueprint for estuarine tidal marsh systems.

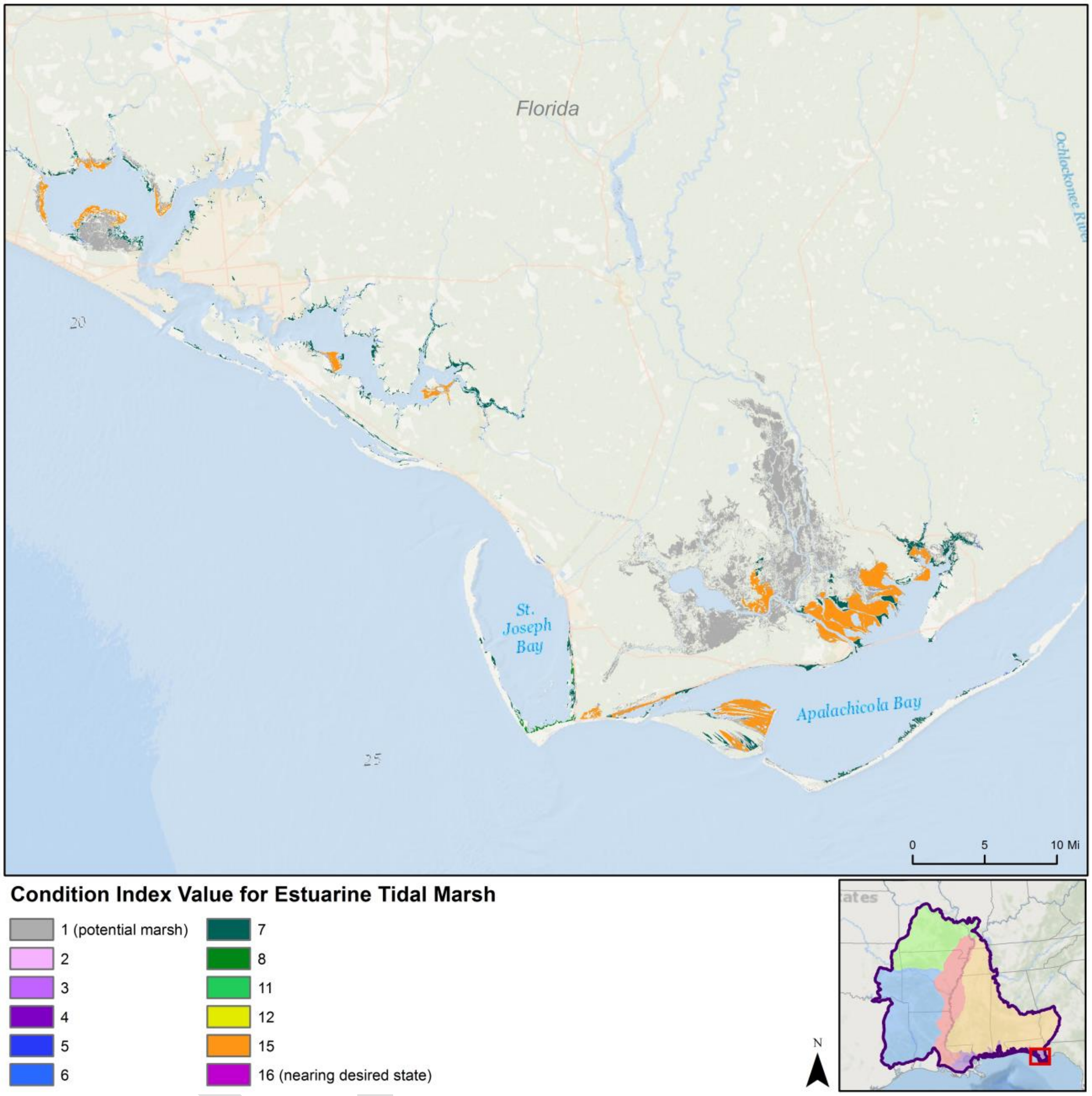

Figure TM.42. Draft condition index value scores (1 - 16) for marshes from St. Andrew Bay to Apalachicola Bay in Florida, based on the decision tree outlined in Figure TM.38 for use in the GCPO LCC conservation blueprint for estuarine tidal marsh systems.

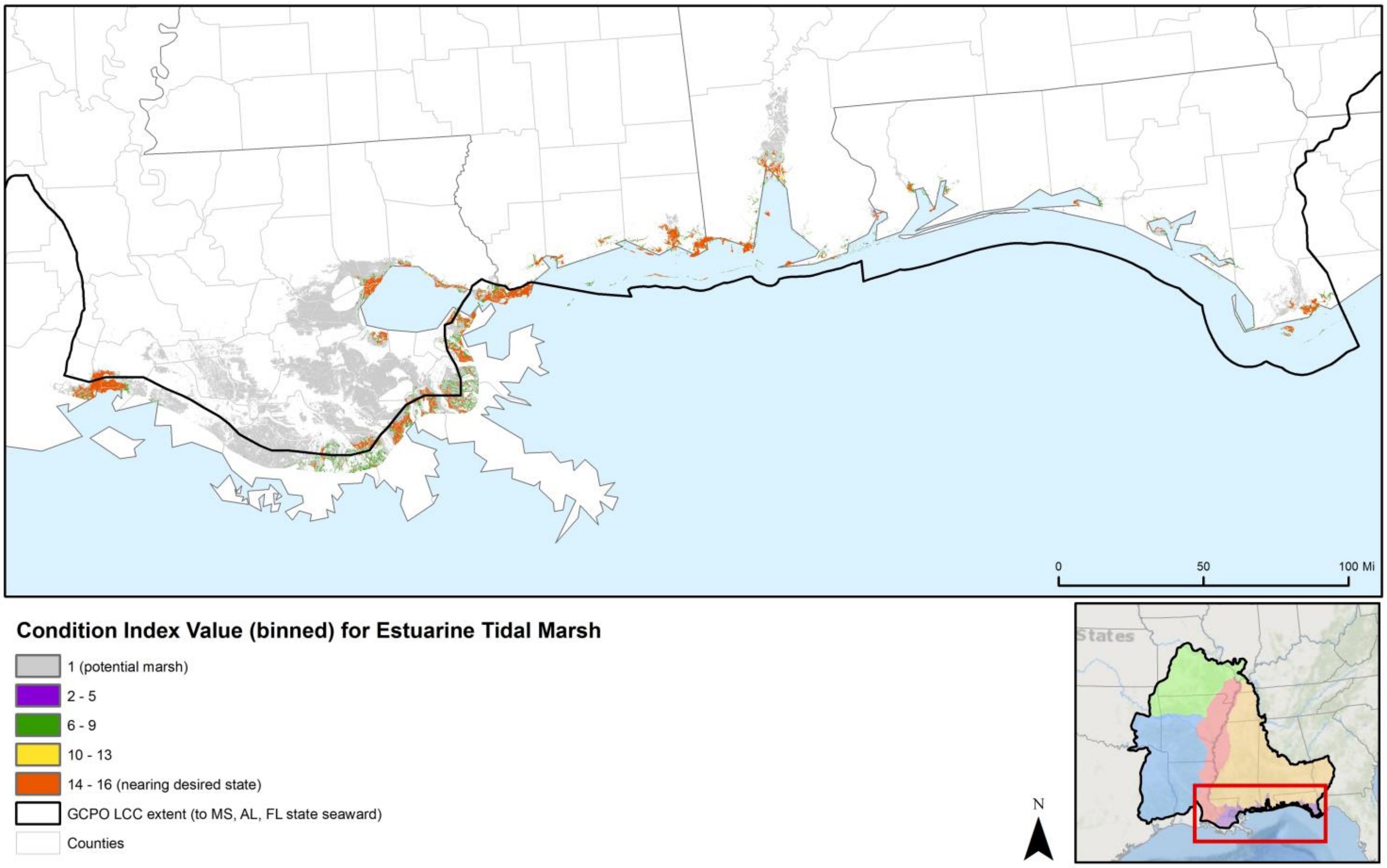

Figure TM.43. Draft condition index value scores in categories (1, 2-5, 6-9, 10-13, 14-17) based on the decision tree outlined in Figure TM.38 for use in the GCPO LCC conservation blueprint for estuarine tidal marsh systems. Marshes in orange reflect existing large (>250 ac) patches of unbroken marsh within and adjacent to the GCPO LCC. Analysis was completed to within 10 km of the GCPO boundary.

We estimate 51% of estuarine tidal marsh acres along the GCPO Gulf Coast are currently considered protected under GAP Status Code 1, 2, or 3 according to the U.S. Protected Areas Database version 1.4 (PAD-US 1.4; USGS 2016) (**Table TM.14**). Though Louisiana portions of the GCPO contain the greatest marsh acreage, Mississippi contains the greatest amount of protected estuarine tidal marsh, with 87% of existing marsh currently under protected status, and 97% of marsh demonstrating a CIV between 14 and 16 protected. Louisiana contains nearly double the marsh acreage compared to every other state, but also contains the least proportion of protected marsh acreage. We estimate over half (59%) of large, unbroken patches of estuarine tidal marsh demonstrating a CIV between 14 and 16 are currently in protected status, whereas only 35% of small, unbroken patches are currently protected. Given these results, efforts toward connecting and protecting smaller unbroken patches either to existing large patches or to each other to form larger continuous patches may be warranted, in addition to working with private landowners to manage unprotected marshes for improved resilience.

Table TM.14. Acres estuarine tidal marsh currently protected in GAP Status 1 – 3 found to be in any condition, in small unbroken patches (CIV = 6-9), and in large unbroken patches (CIV = 14-16) compared to total acres in each category by state within the GCPO LCC geography.

	Any condition			CIV = 6 - 9 (Small unbroken patches)			CIV = 14 - 16 (Large unbroken patches)		
Geographic extent	**Total acres**	**Acres protected**	**% protected**	**Total acres**	**Acres protected**	**% protected**	**Total acres**	**Acres protected**	**% protected**
Alabama	40,893	16,415	40%	12,856	2,780	22%	27,224	13,063	48%
Florida (GCPO only)	37,766	22,329	59%	16,295	6,721	41%	21,377	15,608	73%
Louisiana (GCPO only)	75,349	22,408	30%	22,765	5,155	23%	52,169	16,862	32%
Mississippi	48,576	42,386	87%	13,237	8,088	61%	35,333	34,298	97%
GCPO Gulf Coast	**202,584**	**103,538**	**51%**	**65,153**	**22,744**	**35%**	**136,103**	**79,831**	**59%**

Conclusion: Final Insights, Opportunities and Future Directions for GCPO Gulf Coast Estuarine Tidal Marsh

In order to sustainably manage any ecological system it is critical to first understand the current state of that system. We used the most current and comprehensive data available in this rapid ecological assessment of estuarine tidal marsh systems along the GCPO LCC Gulf Coast to understand how much estuarine tidal marsh habitat is available in any condition and meeting GCPO LCC desired ecological states. The results of this assessment support the premise that the GCPO geography remains rich in estuarine tidal marsh habitat. Marsh systems are frequently found in large-intact patches, the majority of which is currently under protected status. However, estuarine marsh systems are also in decline and of varying ecological integrity. There appears to be ample opportunity to manage large intact marsh patches to improve in-marsh conditions in addition to improving the connectivity of smaller marsh patches through marsh restoration and management efforts.

This assessment also provides an understanding of where estuarine tidal marsh habitat exists in certain conditions across the GCPO geography, and can begin to help managers and conservation planners apply a regional context into understanding where and how to manage to bring estuarine marsh into desired ecological state. However, data are provided with varying levels of uncertainty and must be approached with acknowledgement of the possible limitations associated with its use. Most of the input land cover datasets have corresponding measures of users and producers accuracy for cover classes, but pixel-based measures of uncertainty are unavailable. Other data inputs either did not provide uncertainty measures or they could not be incorporated into this assessment. In other cases, landscape endpoints were vaguely defined such that available data could not be adequately quantified. These caveats are described in greater detail below. Final condition index value scores assessing the state of the estuarine tidal marsh system are therefore limited by the measurability and quality of data inputs, in addition to the analysis methodology used to quantify the data.

Landscape endpoint opportunities

The ecological assessment of estuarine tidal marsh systems was an effort to quantify, in a spatial context the features in a landscape that would reflect a sustainable marsh system with ecological integrity. Estuarine marsh systems are particularly challenging in this respect as each is inextricably linked to the character of the coastal estuary with which they are associated. These differences are largely associated with freshwater inputs from major river systems, but also affected by other edaphic and physiographic features on the landscape. Landscape endpoints also represent hypothesized target thresholds, or the range of conditions for a particular landscape or habitat feature that we would expect particular priority species to occur in. However, in many cases relationships among species and habitat are only generally understood, such that knowledge of a preferred range of habitat conditions in estuarine tidal marsh is primarily speculative.

Several of the landscape endpoints for the estuarine tidal marsh system were developed to be intentionally vague to allow for plasticity in estuarine systems. The target for adequate acres to meet needs of tidal wetland wildlife is the first of these vague targets, which renders quantifying progress toward meeting this objective challenging. Even quantifying a discrete endpoint for marsh block size (> 250 ac) was challenging due to the uncertainty associated with species response to marsh channel breaks as possible barriers or non-barriers to dispersal. An improved understanding of patch dynamics (e.g., relationships with patch size and configuration) for priority species in estuarine tidal marsh systems is critical to understanding how best to restore and manage these habitats to maximize ecological function. Other measures of water quantity and quality were conveyed in more of a qualitative manner suggesting adequate natural gradients of freshwater and salinity would reflect a healthy marsh system. However, though entirely appropriate and likely estuary-specific, these qualitative endpoints were difficult to measure in a quantitative framework such as this assessment and the result was that critical elements of the tidal marsh system were excluded from calculation of the condition index value.

We recommend that future versions of the ISA attempt to define quantitative targets for landscape endpoints to the extent possible, even if they are estuary-specific. This is particularly important for critical drivers of system function like freshwater inflow and salinity, which could not be adequately quantified in the assessment, though data were available. We recognize that the ISA was intentionally built for continued refinement and revision and provides a "strawman" from which improved data and understanding of estuary-specific system thresholds can be facilitated. We encourage the LCC ASMT to take on this challenge to define desired conditions for the system within either specific estuary systems or estuarine drainages.

Finally the estuarine tidal marsh system is a case where the ASMT should be encouraged to re-evaluate the priority species endpoints to determine if those species are appropriate indicators of a healthy marsh system. The LCC is actively engaged with the Adaptation Science Management Team to refine ISA targets based on improved understanding of priority species and species-habitat relationships over time such that future ISA endpoint targets more accurately reflect the habitat needs over the range of priority species within a system.

Data limitations

In addition to limitations regarding definition of ISA landscape endpoints, there are also situations where the geospatial data available to address an endpoint are limited in scope, resolution, or temporal scale. However, many areas of the coast are data-rich, therefore decisions on use of available data were made acknowledging tradeoffs associated with each. We decided to focus on a compilation of USGS marsh type delineation project (MTDP) data and Florida Cooperative Land Cover (CLC) data from which the remainder of the assessment was based for a number of reasons. First, after examination of marsh overlays we determined the MTDP data to be the most detailed dataset available for assessment of marsh in the GCPO area. This was due to the spatial resolution, imagery vintage, and detailed classification of marsh types. In the absence of MTDP data in the western Florida panhandle we decided to use CLC data as it is the accepted standard used by state cooperators over other land cover products. Of course the compilation across two data resource types created a suite of caveats, but the advantages of these two data sources for our purposes outweighed the benefits of using a comprehensive dataset such as GAP or C-CAP.

In some cases comprehensive datasets available for use were outdated, and had to be supplemented with more current local data and used in tandem. This occurred in the assessment of submergent vegetative cover, for which several estuary-specific datasets were overlaid on a previous compilation of Gulf-wide submergent cover. The result was use of a temporally, and likely spatially inconsistent dataset to analyze a dynamic feature of the estuarine system. In other cases, like the assessment of native marsh vegetation composition, data was so limited in scope it simply could not be incorporated in any reasonable manner into the assessment even though it is an extremely important endpoint to target. In these cases the assessment has been valuable in identifying tangible information gaps which have the capacity to be addressed through funding of future mapping endeavors.

Figure TM.44 below represents a qualitative assessment of each landscape endpoint and the regional data available to evaluate that endpoint. For each landscape endpoint identified in the ISA for estuarine tidal marsh systems we present a sliding scale from red (low quality) to green (high quality) based on our experiences in compilation of the ecological assessment. Each endpoint was assessed based on its measurability, or utility in developing a spatially-explicit assessment of that metric, and not on its relevance to the integrity of the system. Thus, we recognize that salinity and freshwater flow are critical elements to the integrity of the estuarine marsh system, but the endpoints were not defined in a manner that could be adequately quantified in this assessment. We also assessed the availability of data that could be used to assess each endpoint and have assigned a place on the sliding scale based on data inputs that could be used. In taking this purely qualitative approach there are some clear issues that arose. In some cases we have adequate data available with which to assess the endpoint, but the endpoint is vaguely defined such that it is difficult to quantify. In other cases we have adequately defined endpoints, but comprehensive data was not available to assess it. Finally, in the best case scenario we were provided with a measurable endpoint and comprehensive data is available from which to assess that endpoint. Ideally, this provides a baseline from which we can strive to work with the ASMT to improve either the description of the landscape endpoint, or seek to improve the data used to assess the endpoint.

Category	Landscape Endpoint	Endpoint Assessment	Regional Data Assessment
Amount	Adequate acress to meet needs of tidal wetland wildlife at desired levels, no loss		
Configuration	Large blocks of unbroken marsh (>250 ac)		
	Connectivity of habitat types reflective of interdigitation of marsh types		
	Moderate amounts of edge within large blocks of marsh		
	Presence of barrier islands in riverine-dominated systems		
Condition: Structure	Emergent vegetative cover >70%		
	Limited open water <20%		
	Submergent vegetative cover 15-30%		
Condition: Composition	Dominated by native plants typical of high, mid, intermediate, and low marsh		
Condition: Water quality	Salinity – aligned along natural gradient		
Condition: Water quantity	Adequate freshwater flows and tidal influence		

Figure TM.44. Qualitative assessment of measurability and data availability/utility for each landscape endpoint identified in the GCPO LCC Integrated Science Agenda for estuarine tidal marsh systems. Each endpoint was evaluated based on its measurability (i.e., utility in developing a spatially-explicit assessment of that metric) and availability of data for assessment, and not on its relevance to the integrity of the system.

Future directions

The assessment has highlighted ample future opportunity to refine GCPO ISA-defined landscape endpoints to reflect estuary-specific gradients of desired marsh condition and improve understanding of empirical relationships between priority species and estuarine habitat endpoints. As the body of scientific literature related to estuarine system dynamics grows we anticipate revisions to both the Integrated Science Agenda and this rapid ecological assessment. Fortunately the Northern Gulf of Mexico is rich with ongoing data collection and mapping efforts and an existing cooperative platform through the Gulf of Mexico Alliance and other entities. Existing systems like the Gulf of Mexico Coastal Ocean Observing System (GCOOS), network of National Estuarine Research Reserves, NOAA Northern Gulf of Mexico Sentinel Site Cooperative and many others are actively collecting and synthesizing monitoring and mapping data on wetlands and other coastal and marine systems along the Northern Gulf of Mexico.

The state of Louisiana has implemented a standardized and coordinated field-based monitoring system of 390 wetland sites as part of their Coastwide Reference Monitoring System (CRMS) to enhance long-term understanding of coastal wetland restoration and management across a range of wetland conditions. CRMS provides site-level information on salinity, water level, water temperature, dominant vegetation, floristic quality, marsh classification, edaphic features, surface elevation and accretion, land-water analysis, as well as site-level report cards and customizable land cover change analysis tools as part of their CRMS mapper. There are currently 85 CRMS sites intersecting the GCPO LCC geography, with several of these sites located in areas identified as nearing the GCPO desired ecological state for estuarine tidal marsh systems. CRMS has been discussed as an effective model from which to expand into a standardized monitoring system Gulf-wide to track change in floristic, hydrologic, and physiographic features in Gulf of Mexico marsh systems. In the context of a regional assessment such as presented here CRMS is a valuable source of field-level information upon which marsh condition index value scores can be validated and tracked over time.

Figure TM.45 below is an example from Bayou Labranche in the Pontchartrain Basin, where the GCPO ecological assessment indicated this particular marsh area met nearly all measurable landscape endpoints and is nearing the desired ecological state for the estuarine tidal marsh system. Investigation through the CRMS system indicates an active CRMS monitoring site in addition to Coastal Protection and Restoration Authority (CPRA) monitoring throughout the marsh patch, which was an active Coastal Wetlands Planning, Protection and Restoration Act marsh creation project site (PO-17), completed in 2000 and resulting in the conversion of 300 acres of open water to shallow water marsh habitat. Report card analysis through the CRMS tool indicates this mash has maintained a high degree of floristic and hydrologic quality over time.

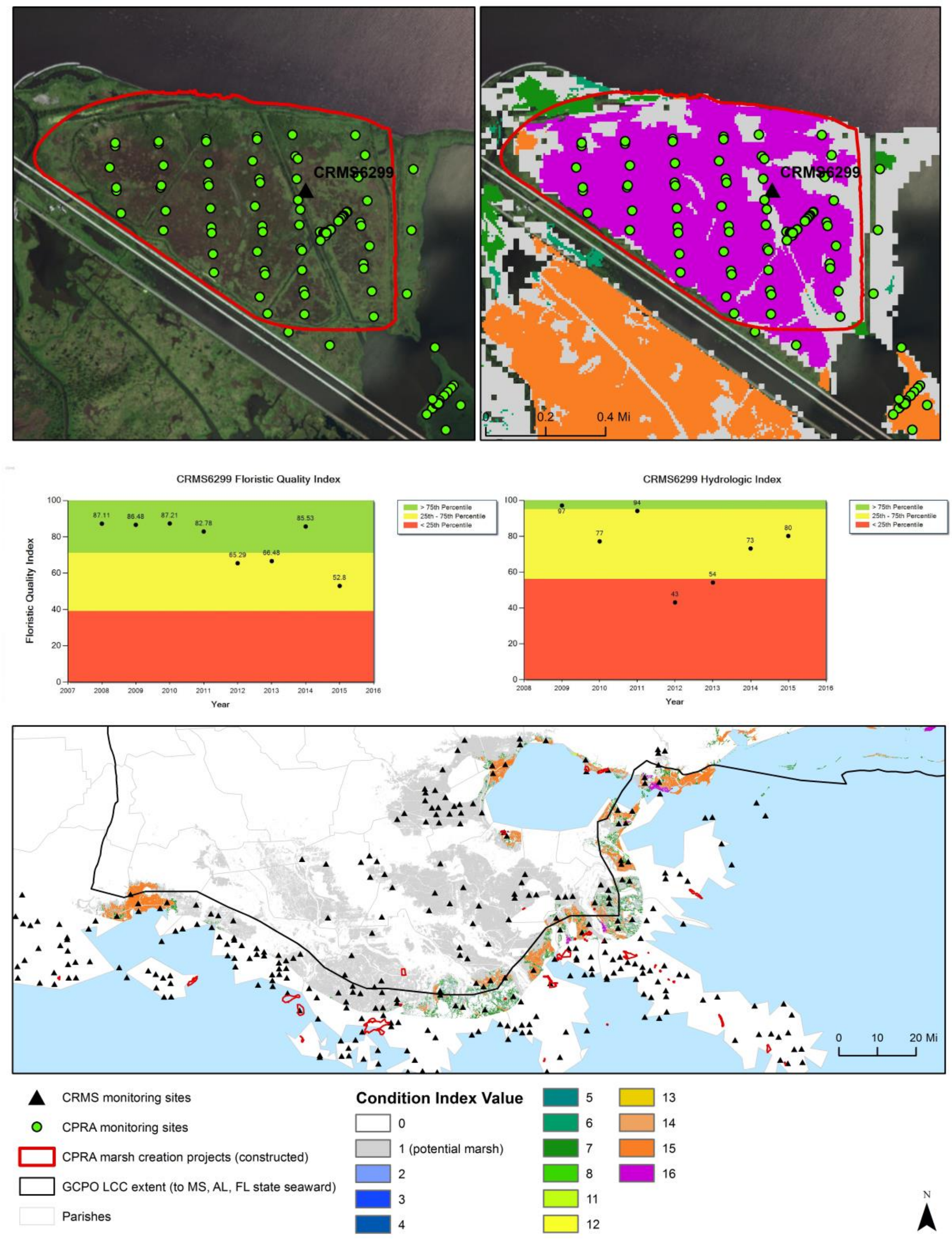

Figure TM.45. Example overlay of Louisiana Coastwide Reference Monitoring System (CRMS) and Coastal Protection and Restoration Authority (CPRA) monitoring sites on the Bayou Labranche marsh creation project PO-17 and across the state of Louisiana, in comparison with the GCPO LCC Condition Index Value assessing desired ecological states for estuarine tidal marsh in the northern Gulf of Mexico.

The outcomes of this ecological assessment effort are currently being incorporated into early versions of the GCPO LCC conservation blueprint. The intent of the blueprint is to map out a connected network of lands and waters that is deliberately designed to sustain natural and cultural landscapes in the GCPO geography now and into the future. Outcomes of the ecological assessment reflect the current state of each of the nine priority ecological systems identified by the ASMT. However, the blueprint also reflects shared partner conservation priorities, stressors and threats like sea-level rise and urbanization, as well as species distribution models. These four elements combined (current system state, stressors, species, and partner priorities) represent the initial set of elements the GCPO LCC is using to develop a conservation blueprint for the future.

Conservation Planning Atlas Links to Available Geospatial Data Outputs

- Condition Index Value and Barcode Value scores for GCPO estuarine tidal marsh (raster)
- Barcode Value scores for GCPO estuarine tidal marsh (raster)

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