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FISHERY HABITAT IN ESTUARIES OF THE U.S. GULF OF MEXICO: A COMPARATIVE ASSESSMENT OF GULF ESTUARINE SYSTEMS (CAGES)

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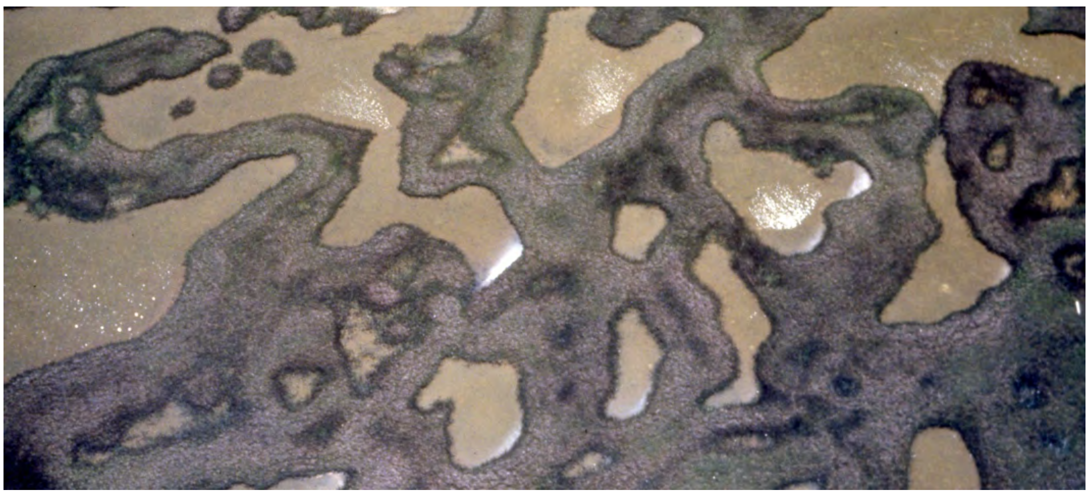

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NOTICE

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Executive Summary

The productivity of many fishery species in the northern Gulf of Mexico (GoM) depends upon habitats and environmental conditions present in coastal estuaries used as nursery grounds. But all estuaries are not equal in this regard, and there is evidence that the abundance of juvenile fishery species varies substantially among estuarine systems. This report is the second in a series designed to provide a Comparative Assessment of Gulf Estuarine Systems (CAGES). In an earlier project, Brown et al. (2013) described abundance and biomass patterns of nekton commonly collected in trawls from 24 estuaries in the northern GoM. Our objective in that report was to begin describing data that reflect the relative fishery productivity of these estuaries. In this project, we report on habitats present in these same estuaries based mainly on analyses using remotely sensed data. Our main objective was to assess variability in overall estuarine area within watersheds, the amount of different fishery habitats in each estuary, and some habitat characteristics that may be important in supporting fishery species.

We used the USGS Estuarine and Coastal Drainage Areas to identify estuarine boundaries for analysis. Habitats within estuarine systems were identified using data from NOAA's Coastal Change Analysis Program (C-CAP) and the USFWS National Wetland Inventory (NWI). Our analysis centered on estuarine emergent marsh, and in addition to the amount of marsh in each system, we identified the amount of marsh edge. Analyses were conducted using ESRI ArcView 10.2 Software with the Spatial Analysis Extension and the Polygon Neighbors tool. We also estimated the amount of time that the marsh edge was flooded in 2013 for 13 of the estuaries.

The total estuarine area potentially available for exploitation by fishery species was highly variable among the 24 estuaries ranging from around 15,000 ha in Perdido Bay to over 600,000 ha in Breton-Chandeleur Sounds, with this area generally largest in systems from northern Texas through Louisiana. The most abundant estuarine habitat was generally Estuarine Emergent Marsh, following a spatial pattern similar to the total estuarine area with the highest values in Louisiana estuaries. Although areas of Estuarine Aquatic Beds were identified, confidence in these results were relatively low, due to limitations of the remotely sensed data. Marsh edge was measured in a variety of ways using both C-CAP and NWI data, and edge was greatest in Louisiana estuaries. Flooding of the marsh edge also was high in most of the 13 estuaries examined; lowest values were from Louisiana marshes just east of the Mississippi River.

The estuaries we examined appear to vary greatly in their capability to support coastal fishery populations based on their nursery habitat. Estuaries near the Mississippi River Delta have the greatest potential for providing essential nursery support for fishery species, and these estuaries do support high abundances of the young of fishery species based on survey data from long-term monitoring programs of Gulf coast states (Brown et al. 2013). The characteristics that these estuaries have in common include large areas of emergent marsh and marsh edge habitat, high rates of flooding at the marsh edge, and elevated nutrient inputs from the Mississippi and Atchafalaya Rivers. Seagrass and SAV are also important for fishery species, but our ability to quantify the area of this habitat in GoM estuaries is limited by available remote-sensing technology.

Introduction

Estuaries in the northern Gulf of Mexico (GoM) support economically important fisheries including penaeid shrimp (*Farfantepenaeus aztecus, Farfantepenaeus duorarum,* and *Litopenaeus setiferus*), Gulf menhaden *Brevoortia patronus*, spotted seatrout *Cynoscion nebulosus*, red drum *Sciaenops ocellatus*, and blue crab *Callinectes sapidus*. The productivity of these species depends upon habitats and environmental conditions present in estuaries (Boesch and Turner 1984, Minello 1999, Zimmerman et al. 2000). Spawning generally occurs in coastal waters, and larvae recruit into estuaries and settle in nursery habitats such as salt marshes, seagrass beds, tidal flats, and mangroves (Beck et al. 2001) where they obtain protection from predators and an abundance of food for rapid growth. After three to six months of growth in these estuarine habitats, sub-adults generally migrate back to the GoM to mature.

While estuaries appear important in supporting fishery production in the GoM, there is evidence that this support varies widely among different estuarine systems. Deegan et al. (1986), Turner (2001), and Greene et al. (2015) discussed this variability and the potential causes. Correlative studies have identified vegetative cover (Turner 1977, 1982) and nutrient inflow (Day et al. 1982, Deegan et al. 1986) as two estuarine characteristics related to fishery production. However, the availability of data on both fishery production and associated estuarine characteristics limit the value of such comparisons, and the functional mechanisms behind these correlations have not been fully elucidated. This report is the second in a series designed to provide a Comparative Assessment of Gulf Estuarine Systems (CAGES). In an earlier project, Brown et al. (2013) described abundance and biomass patterns of nekton commonly collected in trawls from 24 estuaries in the northern GoM. Our objective in that report was to begin describing data that reflect the relative fishery productivity of these estuaries. In this project, we report on habitats present in these same estuaries based mainly on analyses using remotely sensed data.

Pritchard (1967) defined an estuary as "a semi-enclosed coastal body of water which has a free connection with the open sea and within which seawater is measurably diluted by fresh water derived from land drainage." Such a restrictive definition has generally not been recognized in the Gulf of Mexico, however, where some systems considered estuaries such as the Laguna Madre in Texas have limited freshwater input, and areas with a great deal of fresh water such as Mississippi Sound are only marginally enclosed. NOAA's Coastal Assessment Framework has identified 88 Coastal and Estuarine drainage and subdrainage areas in the GoM, and we used this framework to identify estuarine systems. Information on nekton from 24 of these systems was reported by Brown et al. (2013), and we are reporting habitat information on these same systems in this report (Figure 1). The main objective of this project was to assess variability in overall estuarine area within watersheds, the amount of different fishery habitats in each estuary, and some habitat characteristics that may be important in supporting fishery species.

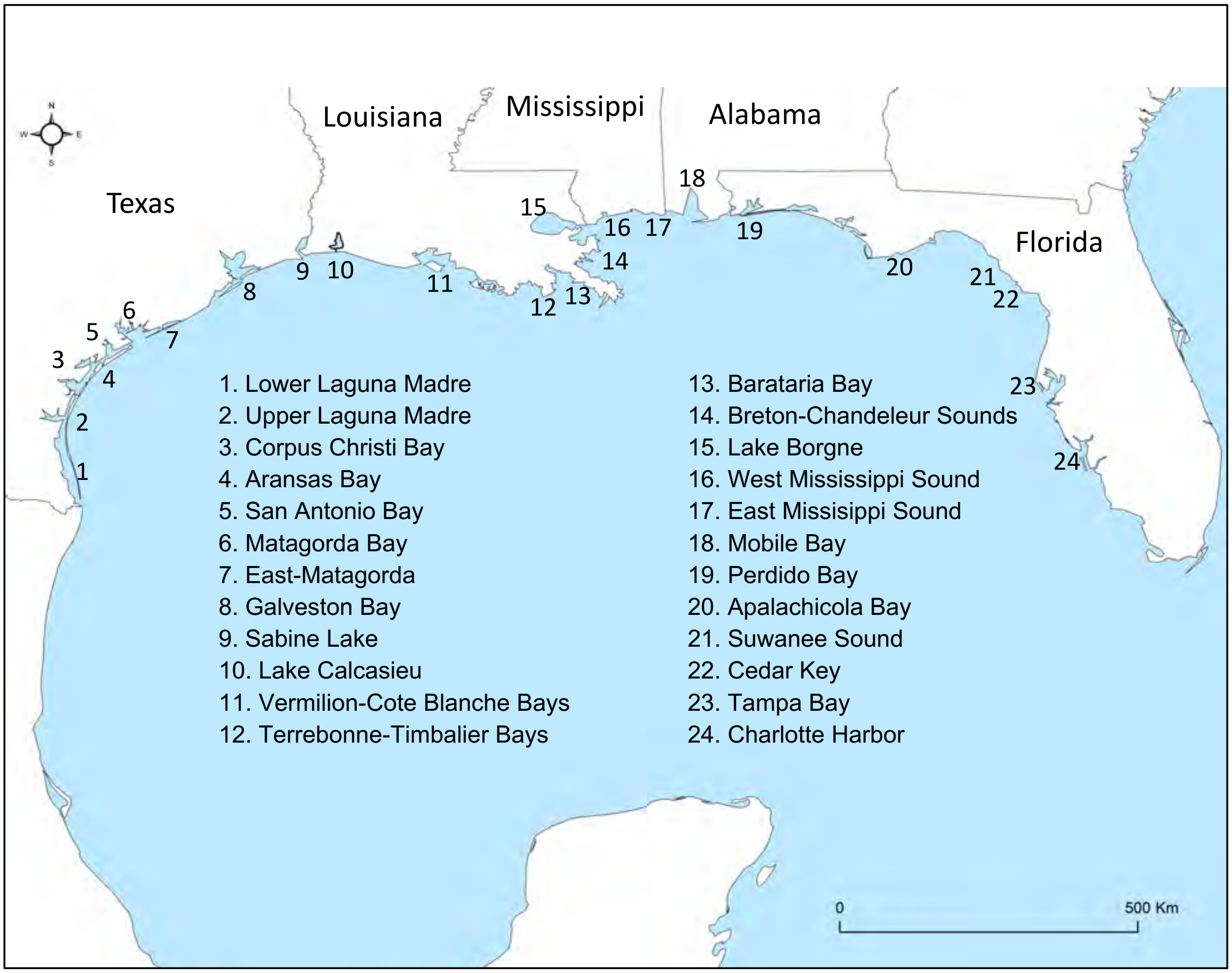


Figure 1. Estuaries examined in the northern Gulf of Mexico.

Methods

We used the Estuarine and Coastal Drainage Areas identified by the U. S. Geological Survey, listed in NOAA's Coastal Assessment Framework (CAF), and described by Burgess et al. (2004) to identify the estuaries examined (Figures 2 and 3). We compared habitats present in the estuaries using Geographical Information System (GIS) analyses with ArcView software. We defined estuarine areas and used a variety of other data sets to characterize fish habitat. In addition to the 1999 CAF and the CAF averaged salinity zones, we used data from NOAA's Coastal Change Analysis Program (C-CAP) landuse and landcover analyses for 1996, 2001, 2006 and 2010 (http://csc.noaa.gov/CCAPftp) and the U.S. Fish and Wildlife Service's (USFW) National Wetland Inventory (NWI) (http://www.fws.gov/wetlands/Data/State-Downloads.html). Marsh flooding data from 13 of the estuaries were collected in 2013.

Fishery habitats in the 24 estuaries examined were defined within CAF Estuarine Drainage Areas (EDAs). The C-CAP landuse and landcover data used to delineate habitats within these EDAs have the advantage of being consistent spatially and temporally, cover the

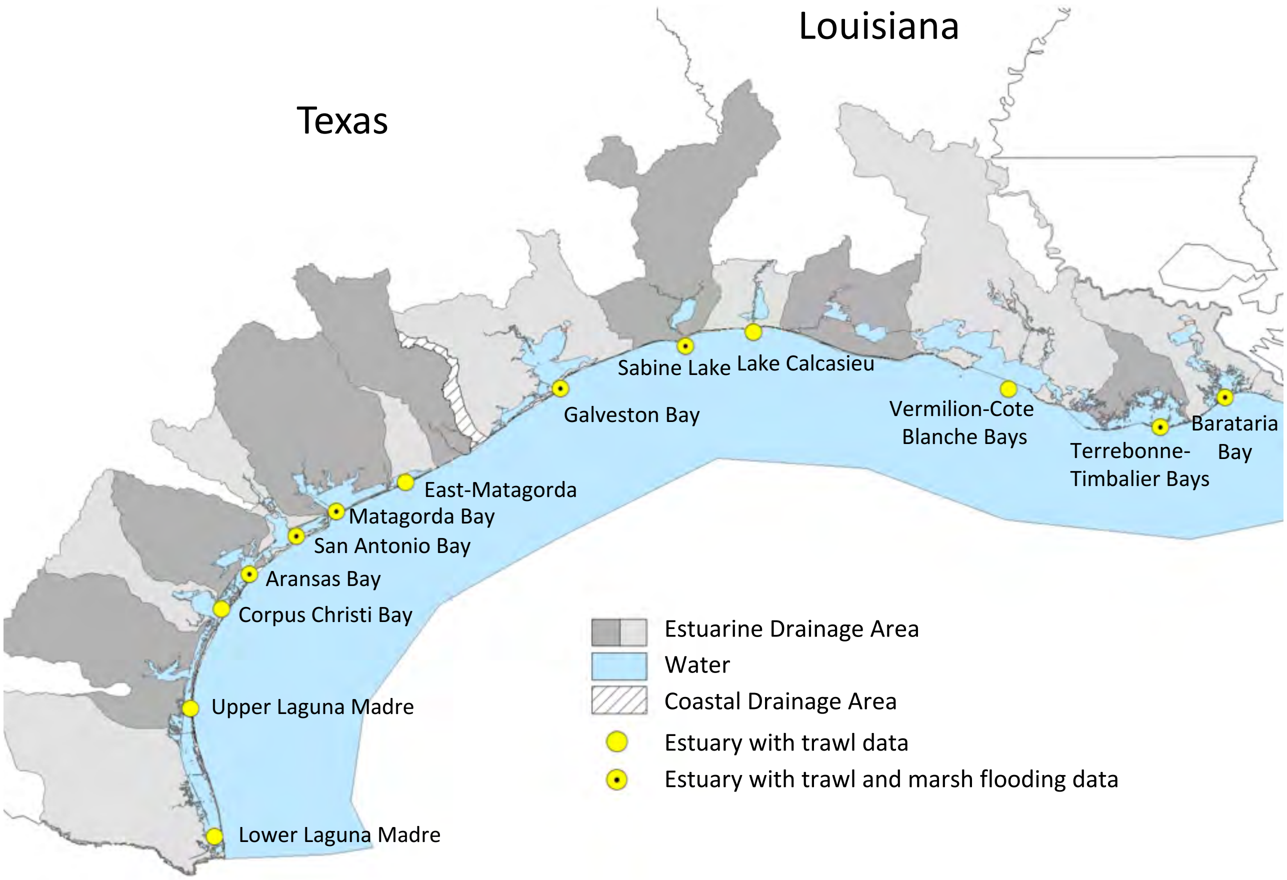


Figure 2. Estuarine Drainage Areas in northwestern GoM used to identify estuaries.

entire EDA, and are produced every 5 years. The utility of C-CAP data for our analyses was limited, however, because the data are derived from satellites with a 30-m pixel resolution and are distilled into 22 land-cover classes in the GoM. The C-CAP marsh habitat classification also does not distinguish between regularly flooded (low) and irregularly flooded (high) marsh areas, potentially important for fishery species that use the marsh surface. NWI vector files were used for a more detailed classification of certain wetlands used as fishery habitat, because these files were created from aerial photographic images with a 1-m pixel resolution. NWI files also have limitations, however, because they do not cover the entire EDA, and the available files were not temporally consistent. The image dates for the NWI files we used ranged in Texas from 1981 to 2010, in Louisiana from 1973 to 2010 with the majority in 1988-1989, in Mississippi from 1980 to 2010 with the majority in 2002-2010, in Alabama from 1979 to 2010, and in Florida from 1972 to 2010. Neither NWI nor C-CAP provide adequate coverage of subtidal habitat such as aquatic beds, seagrasses, oyster reefs, or coral reefs.

Estuarine Drainage Areas were used to extract data from C-CAP and NWI for each estuary. All of the GIS analyses were performed using Environmental Systems Research Institute INC. Software: ArcView 10.2 with Spatial Analysis Extension. One of our objectives was to define and quantify the entire area of the estuary within the EDAs including both estuarine habitats and water. C-CAP defines the area of water in the EDA but does not distinguish between

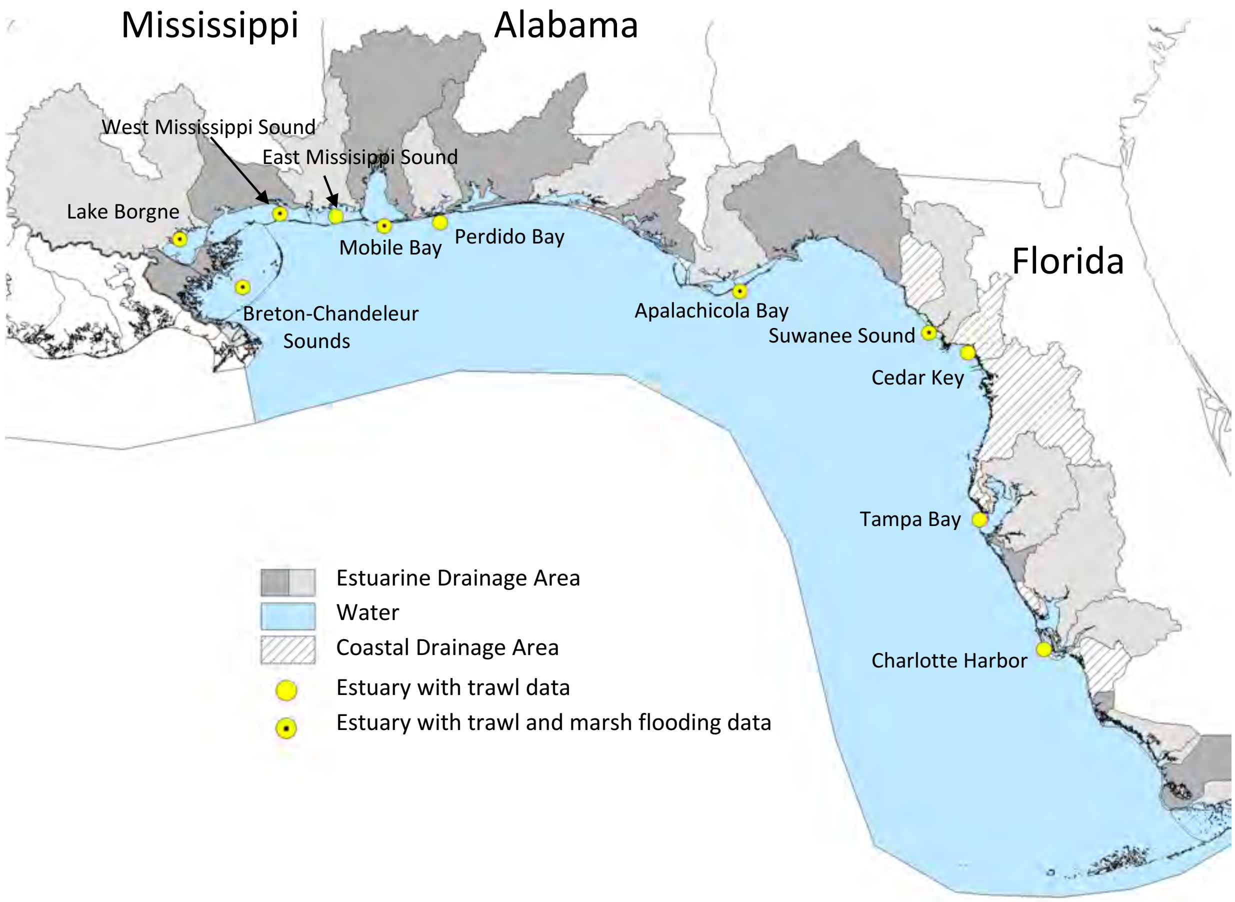


Figure 3. Estuarine Drainage Areas in northeastern GoM used to identify estuaries.

fresh and estuarine water; CAF identifies water areas with different average salinities, but does not include all of the water identified by C-CAP in the EDA. In the habitat analysis with C-CAP data, we identified estuarine water in the EDAs using a GIS technique that combined C-CAP and CAF covers. From the 2006 C-CAP data, a 150-m buffer of water was calculated around all estuarine classes combined, and this buffer area was then added to the CAF averaged water salinity file to delineate all water areas not designated as fresh. The results were then used to extract data from the C-CAP Water cover, resulting in a separation of this area into Estuarine Water and Fresh Water. This ratio of Estuarine Water to Fresh Water that was established for each estuary in 2006 was applied to the other years analyzed as well.

In each of the 24 EDAs, we calculated the area (ha) of the following C-CAP classes as potential fishery habitat: Estuarine Aquatic Bed, Estuarine Emergent Wetland, Estuarine Scrub-Shrub, and Estuarine Forested Wetland. The C-CAP Water cover was divided into Fresh Water and Estuarine Water, as indicated above. In our habitat maps, we also show C-CAP areas of Unconsolidated Shore and Palustrine wetlands (a combination of four habitat classes including Palustrine Aquatic Bed, Palustrine Emergent Wetland, Palustrine Scrub-Shrub, and Palustrine Forested Wetland).

The habitat data available from NWI are more detailed. We combined these data at the subclass level creating the following groups (NWI codes are in parentheses):

- Estuarine Aquatic Bed
  - Estuarine Intertidal Aquatic Bed (E2AB)
  - Estuarine Subtidal Aquatic Bed (E1AB)
- Estuarine Reef
  - Estuarine Intertidal Reef (E1RF)
  - Estuarine Subtidal Reef (E2RF)
- Estuarine Forested Wetland (E2FO)
- Estuarine Emergent Irregularly Flooded Wetland
  - Estuarine Intertidal Emergent Persistent Irregularly Flooded (E2EM1P)
  - Estuarine Intertidal Emergent Irregularly Flooded (E2EMP)
- Estuarine Emergent Regularly Flooded Wetland
  - Estuarine Intertidal Emergent Persistent Regularly Flooded (E2EM1N)
  - Estuarine Intertidal Emergent Regularly Flooded (E2EMN)
- Estuarine Scrub-Shrub (E2SS)
- Estuarine Unconsolidated Shore (E2US)
- Estuarine Water
  - Estuarine Subtidal Unconsolidated Bottom (E1UB)
  - Estuarine Subtidal Rock Bottom (E1RB)
  - Estuarine Subtidal Open Water (E1OW)
- Fresh Water
  - Riverine (R)
  - Palustrine Unconsolidated Bottom (PUB)
  - Palustrine Open Water (POW)
  - Lacustrine Unconsolidated Bottom (LUB)
- Palustrine Wetlands
  - Palustrine Aquatic Bed (PAB)
  - Palustrine Moss-Lichen (PML)
  - Palustrine Emergent (PEM)
  - Palustrine Scrub-Shrub (PSS)
  - Palustrine Forested (PFO)
  - Palustrine Unconsolidated Shore (PUS)

Note that estuarine water is identified in NWI, but we also included tidal areas in the Fresh Water Riverine Class as Estuarine Water. The total estuarine area includes all of the estuarine habitat classes including estuarine water.

Marsh edge was calculated for the C-CAP and NWI data using the ArcView 10.2 Polygon Neighbors tool that calculates the distance of edge between two habitat classes. For C-CAP data, the distance of edge was calculated between the 30-m pixels identified as Estuarine Emergent Wetland and a water class consisting of Estuarine Water and Estuarine Aquatic Beds, under the assumption that these aquatic beds were in water. For the 2006 C-CAP data, we also examined the effect of this decision on defining the water class in the analysis by calculating marsh edge using only Estuarine Water as water and by including Estuarine Water, Estuarine Aquatic Beds, and Unconsolidated Shore as water. Unconsolidated Shore might be considered water in such a comparison under the assumption that this habitat adjacent to marsh might be water at high tide. For the NWI vector data, Estuarine Water and Estuarine Aquatic Beds were considered water, and two approaches were used to calculate marsh edge. In the first approach, edge was determined between water and Estuarine Emergent Regularly Flooded Wetlands. In the second calculation from NWI data, edge was calculated between water and a combination of Estuarine Emergent Regularly Flooded Wetlands and Estuarine Emergent Irregularly Flooded Wetlands. This second calculation should be more comparable to the edge measurement made with C-CAP data, as the C-CAP classification does not separate the Estuarine Emergent Wetlands into regularly and irregularly flooded classes.

Marsh flooding data were estimated for the year 2013 following the approach of Minello et al. (2012) at 57 marsh sites in 13 estuaries. During the summer of 2013, we measured the elevation of the marsh edge at ten random locations along approximately 1 km of marsh shoreline within each of these sites. Marshes were all vegetated with *Spartina alterniflora* and located near active tide gauges, and marsh locations are shown in the Appendix figures. Hourly tide measurements from the gauges were then used to estimate the percentage of time during 2013 that the marsh edge was flooded.

Results

We have presented C-CAP habitat data for four time periods (1996-2010) in Appendix Tables 1-4, but our focus is not on temporal trends but rather on spatial differences among estuarine systems. Spatial habitat trends from the 2006 C-CAP data are presented in maps (Appendix Figures 1-24) and reported in more detail in this report, and most of the spatial trends are consistent over the other time periods examined. The areal coverage of the EDAs was variable among the 24 estuaries examined, ranging from 183,839 ha in East Matagorda Bay to 2,024,217 ha in Lake Borgne (Appendix Tables 1-4). While the seaward boundaries of the EDAs generally coincided with obvious geographical boundaries of estuaries such as barrier islands, this boundary for Breton-Chandeleur Sounds, Suwanee Sound, Cedar Key and to a lesser extent East and West Mississippi Sound is necessarily more arbitrary, and these EDAs include open water of the Gulf of Mexico. Because this boundary location affects the area calculation of the EDA and the total estuarine area, estimates for these systems should be considered with some caution. Based on the 2006 C-CAP analysis of estuarine versus fresh water, the percentage of estuarine water of the total water identified by C-CAP in the EDAs ranged from a low of 69.1% in Charlotte Harbor to a high of 100% (all estuarine water) in Breton-Chandeleur Sounds (Appendix Table 2). The total estuarine area potentially available for exploitation by fishery species was highly variable among the 24 estuaries ranging from around 15,000 ha in Perdido Bay to over 600,000 ha in Breton-Chandeleur Sounds, with this area generally largest in systems from northern Texas through Louisiana (Figure 4). The most abundant estuarine habitat was generally Estuarine Emergent Marsh, following a spatial pattern similar to the total estuarine area with the highest values in Louisiana estuaries (Figure 5). The percentage of the total estuarine area that was Estuarine Emergent Marsh also was highly variable ranging from < 7% in Tampa Bay, Charlotte Harbor, and the Laguna Madre at the ends of the geographic range to 56-61% in Sabine Lake and Lake Calcasieu.

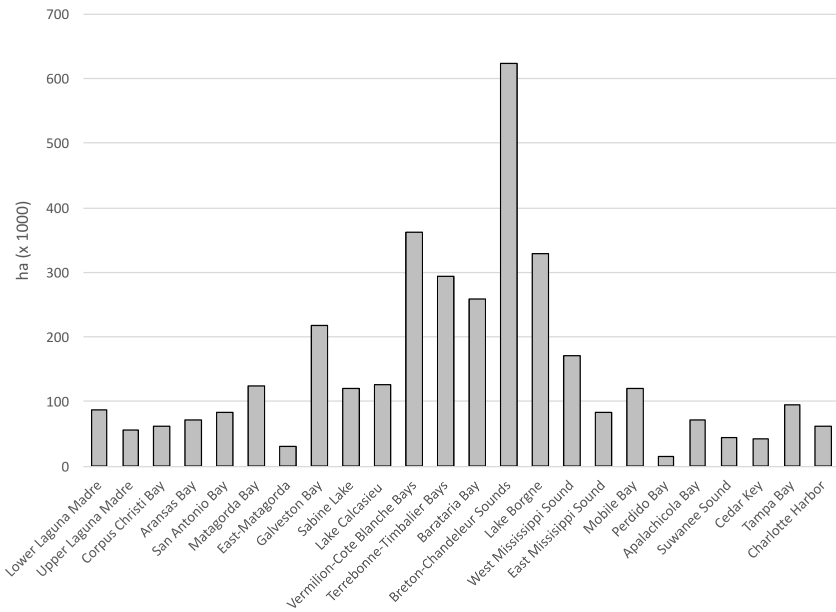


Figure 4. The total estuarine area based on the 2006 C-CAP data within the Estuarine Drainage Areas in the 24 estuaries examined from the northern GoM.

Extensive loss of wetlands has occurred in GoM estuaries due to a variety of causes and is a major concern in the region. While wetland loss is apparent in C-CAP data shown in our tables from 1996 to 2010, wetland loss here is not directly comparable to other estimates of land loss, for example those reported by Couvillion et al. (2011) in Louisiana. Habitat change analyses are complex, because changes can occur in both directions and between many land cover classifications (Klemas et al. 1993, Ramsey et al. 2001). In addition, the spatial resolution of Thematic Mapper and C-CAP data apparently results in an overestimation of wetland loss (Ramsey and Laine 1997). Details on temporal habitat changes, including wetland loss, in the northern GoM are reported at https://coast.noaa.gov/digitalcoast.

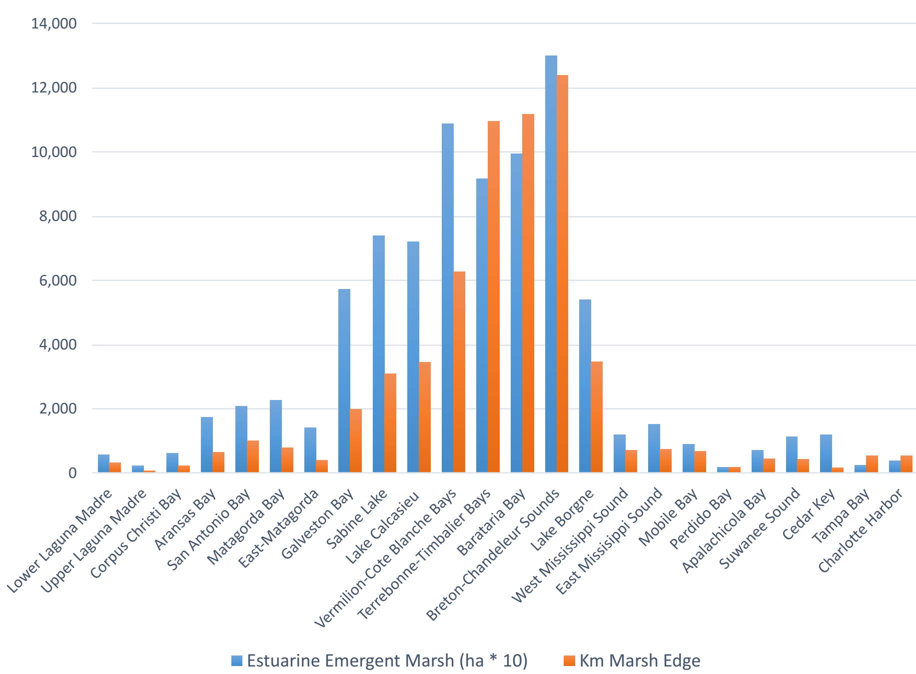
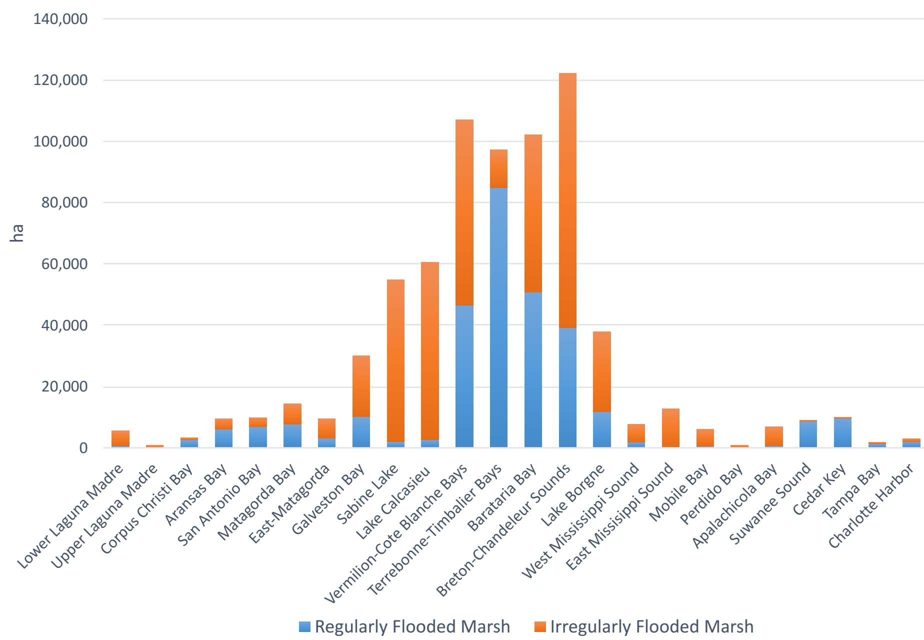


Figure 5. The area of Estuarine Emergent Marsh from 2006 C-CAP data (ha * 10) and the distance of marsh edge (km) in the 24 estuaries examined from the northern GoM.

Confidence in the areal estimates of Estuarine Aquatic Beds in the C-CAP data is relatively low because of the large pixels analyzed, the potential inability of the satellite sensors to identify submerged aquatic signatures, the problem of water depth and turbidity, and the ephemeral nature of some plant species (McKensie et al. 2001). The areas identified as this habitat type were generally most extensive in the estuaries farthest away from the Mississippi River (Charlotte Harbor and Laguna Madre), and these areas were likely dominated by seagrass (Appendix Tables 1-4). In the Laguna Madre, Estuarine Aquatic Beds that also were likely seagrass made up between 7-10% of the estuarine area. While Estuarine Aquatic Beds never comprised more than 2.7% of the estuarine area in other systems, this habitat was identified as abundant in Terrebonne-Timbalier Bays, Barataria Bay, and Breton-Chandeleur Sounds; in these systems the habitat was most likely present in low salinity water as other species of submerged aquatic vegetation (SAV) rather than seagrass. Within the Breton-Chandeleur Sounds, however, SAV near the Chandeleur Islands has been identified as seagrass (Handley et al. 2007).

Habitat areas identified from NWI data are shown in Appendix Table 5, and additional information on compatibility and cross-walking between NWI and C-CAP classifications can be found in Klemas et al. (1993) and Ramsey et al. (2001). The total estuarine area from the NWI data consisted of areas identified as estuarine wetlands plus estuarine water, and generally these areas were similar to those identified in the C-CAP data, except for the Laguna Madre where the NWI estuarine area was substantially larger than the C-CAP estimates. This difference was due to the large amount of estuarine unconsolidated shore identified as wetlands by NWI in these systems and not included as wetlands in the C-CAP analysis. The distribution pattern of estuarine marsh among the estuaries was similar to that in the C-CAP data, with the largest areas in Louisiana and northern Texas (Figure 6), and regularly flooded marsh was most abundant in Terrebonne-Timbalier Bays. The overall mean percentage of estuarine marsh that was identified as regularly flooded was 41% (SE=6.3%), but these estimates were highly variable among

Figure 6. The area (ha) of Regularly Flooded and Irregularly Flooded Estuarine Emergent Marsh based on NWI data from the 24 estuaries in the northern GoM.



estuaries, with values as high as 98-100% in Suwanee Sound and Cedar Key and as low as 2-4% in East Mississippi Sound, Sabine Lake, and Lake Calcasieu. As in the C-CAP data, the area of aquatic beds in the NWI data was greatest at the ends of our range of estuaries, with 40-42% of the estuarine area in the Laguna Madre identified as aquatic beds and 10.5% and 12.6% in Tampa Bay and Charlotte Harbor, respectively. This general trend also was apparent in seagrass coverage from data sets collected by different state and federal agencies and reported by NOAA's National Coastal Data Development Center (now the National Centers for Environmental Information; http://www.ncddc.noaa.gov/).

The marsh edge has been identified as an important habitat for many juvenile fishery species. When we estimated the distance of this edge using the C-CAP data, we assumed that marsh edge was between pixels of Estuarine Emergent Marsh and water; water in this analysis was a combination of estuarine water and estuarine aquatic beds. This marsh edge habitat was greatest in Louisiana estuaries (Figure 5, Appendix Table 6). We also examined the 2006 C-CAP data in more detail to see whether our selection of water in the analysis affected the results. If only water (excluding aquatic beds) was used in the analysis, the amount of marsh edge was underestimated in Terrebonne-Timbalier Bays, Barataria Bay, and Breton-Chandeleur Sounds, likely due to the large amount of aquatic beds in these systems and the large amount of estuarine emergent marsh (Figure 7). If we included unconsolidated shore as water, there was a substantial increase in marsh edge in Texas estuaries, although the overall amount of marsh edge in these systems was still relatively low compared to Louisiana systems.

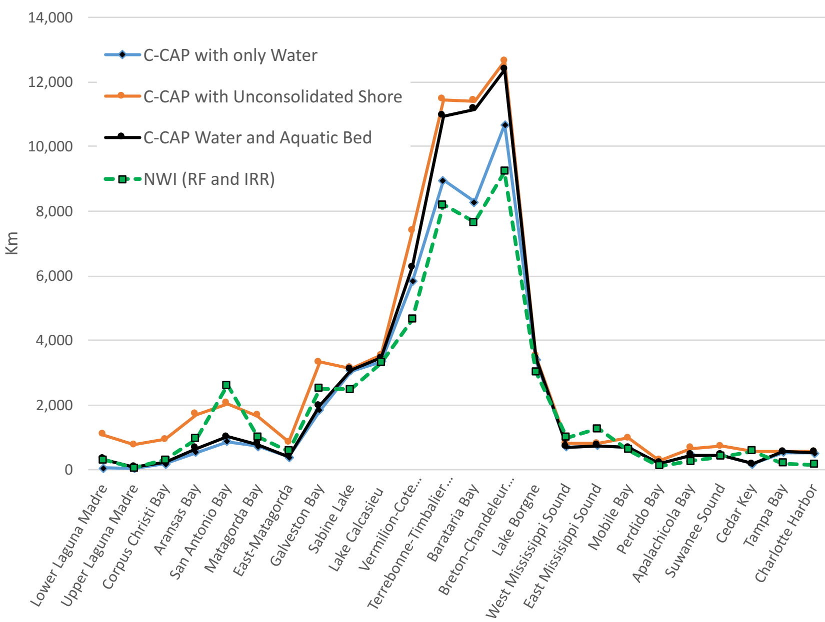


Figure 7. Various estimates of Estuarine Emergent Marsh edge (km) in different estuaries of the northern GoM. Edge is shown from 2006 C-CAP data in relation to only estuarine water; a habitat class including water, aquatic beds, and unconsolidated shore; and water and aquatic beds. Edge from combined regularly flooded (RF) and irregularly flooded (IRR) marsh also is shown from NWI data.

The amount of marsh edge also was calculated from the NWI data between marsh and water; water in this analysis was a combination of estuarine water and estuarine aquatic beds. We calculated the distance of marsh edge in both regularly flooded and irregularly flooded marsh from the NWI data (Figure 8), and the largest amount of marsh edge in regularly flooded estuarine marsh was present in Terrebonne-Timbalier Bays and Barataria Bay. While the spatial pattern of marsh edge among estuaries was similar to the pattern in the C-CAP data, with the highest amount of edge in central Louisiana estuaries, the extent of marsh edge in the NWI analyses was generally lower than in the C-CAP analyses. For example, when the NWI comparison included both regularly flooded and irregularly flooded estuarine emergent marsh, the estimated distance of marsh edge was 31.5% lower in Barataria Bay compared with the C-CAP analysis (Figure 7). In contrast, the estimated distance of marsh edge in San Antonio Bay was higher in the NWI analysis, although the overall amount of edge from both analyses was relatively low in this system (Appendix Table 6).

We also estimated the amount of marsh edge in relation to the total estuarine area and the amount of estuarine emergent marsh (Figure 9, Appendix Tables 7 and 8). The amount of marsh edge in relation to the total estuarine area was highest in Louisiana and northern Texas estuaries. Within these systems that also had a large amount of estuarine marsh, the distance of edge in relation to the area of marsh also was relatively high. This metric may be an indicator of marsh degradation, because the amount of marsh edge generally increases as marshes disintegrate and degrade (Browder et al. 1985). The general marsh configuration also should affect this ratio of edge to marsh area, with narrow shoreline marshes having high values. The amount of marsh edge in relation to marsh area was highest in Tampa Bay and Charlotte Harbor, systems with little marsh present (see Appendix Figures 23 and 24).

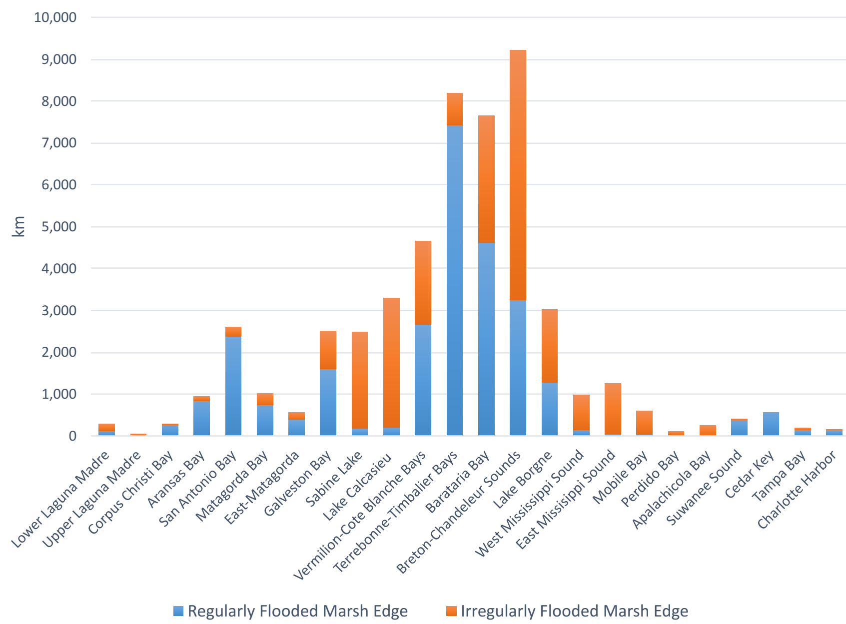


Figure 8. Regularly flooded and irregularly flooded estuarine marsh edge (km) from NWI data in different estuaries of the northern GoM.

The value of marsh edge habitat to fishery species is likely controlled by its elevation and tidal flooding duration (Minello et al. 2012, Baker et al. 2013). We measured the elevation of the marsh edge in 2013 at 57 marshes dominated by *Spartina alterniflora* (Appendix Table 9). The marshes were located in 13 different estuaries, but most were in Galveston Bay (42%) and Barataria Bay (14%) where active tide gauges were available to measure flooding (Table 1). The annual mean flooding percentage of the marsh edge in 2013 was lowest in Lake Borgne and Breton-Chandeleur Sounds and highest in South Texas estuaries. Mean marsh flooding was over 80% of the year in 9 of the 13 estuaries where data were available. Our 13 independent estimates in Terrebonne-Timbalier

Table 1. Flooding of the *Spartina alterniflora* marsh edge during 2013 in different estuaries of the northern GoM. Marsh locations are shown in the Appendix figures and individual marsh values in Appendix Table 9.

Bay System	N	Mean	SE
Suwanee Sound	1	70.5%	
Apalachicola Bay	3	89.8%	5.1%
Mobile Bay	2	85.3%	0.0%
West Mississippi Sound	1	89.4%	
Lake Borgne	1	59.5%	
Breton-Chandeleur Sounds	2	63.0%	7.9%
Barataria Bay	8	83.8%	1.9%
Terrebonne-Timbalier Bays	5	80.2%	4.1%
Sabine Lake	1	74.7%	
Galveston Bay	24	80.3%	2.5%
Matagorda Bay	1	85.0%	
San Antonio Bay	5	94.7%	2.0%
Aransas Bay	3	93.2%	2.6%

Bays and Barataria Bay had a mean marsh edge flooding of 82.4% (SE =1.8%). Previous estimates in these systems were limited by the availability of active tide gauge data and likely underestimated marsh edge flooding (Minello et al. 2012).

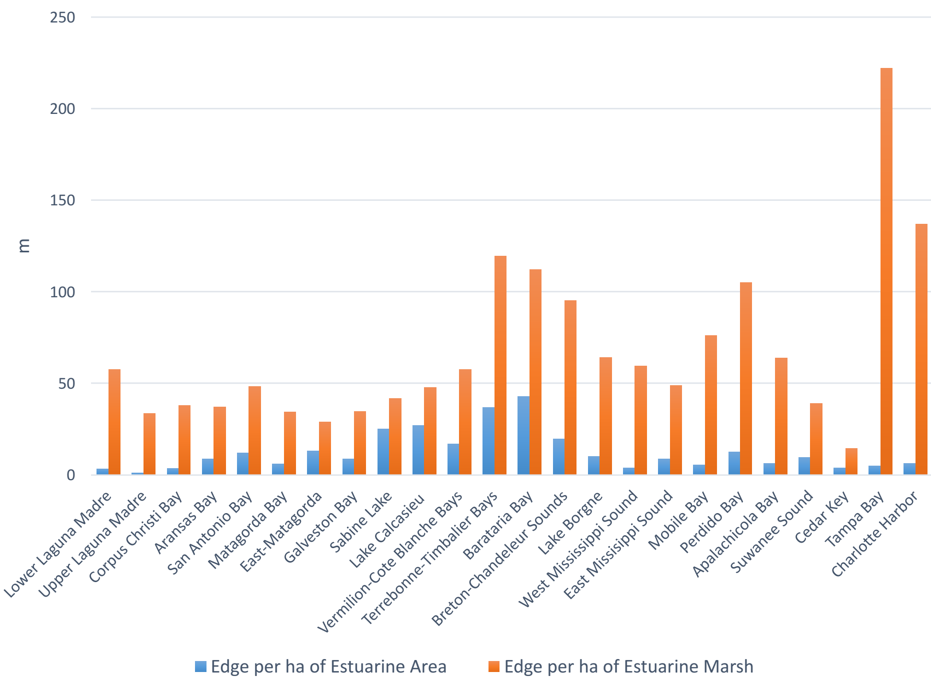


Figure 9. The amount of marsh edge in relation to the total estuarine area and the area of estuarine marsh based on 2006 C-CAP data for the 24 estuaries examined from the northern GoM.

Discussion

The 24 estuaries examined in this study range across approximately 2500 km of coastline in the northern GoM and over 4 degrees of latitude. One of the most striking conclusions apparent from our analysis of estuarine fishery habitats is that the total estuarine area available for exploitation by juvenile fishery species varies dramatically among the 24 estuaries examined. This estuarine area was highest in Louisiana estuaries near the Mississippi River and undoubtedly reflects the current and historical influence of the river and its deltaic processes.

It was not our intent to provide a detailed analysis of all potential stressors or factors that could affect the use of GoM estuaries by nekton. Such a modeling analysis has been developed by Miller et al. (in review) and focuses on nutrient loading, pollution, eutrophication, and salinity as important factors in determining the presence or absence of nekton species. Such analyses (e.g., Greene et al. 2015) generally consider high nutrient loading and eutrophication as stressors with negative impacts on fishery species (at least their presence or absence), but these conditions also can benefit fishery production (Nixon and Buckley 2002). Our analysis was intended to look broadly at GoM estuaries in relation to the spatial distribution of nursery habitats that are known to support fishery species. While long-term habitat change in the region, such as salt marsh and seagrass loss, are areas of concern, we have not attempted to address this issue. In addition, we acknowledge that shorter-term changes in estuarine habitat value also occur in these systems. Such important temporal changes include varying freshwater inflow and salinity caused by droughts and floods, hurricane and storm impacts, cold fronts, and changes in coastal current patterns affecting larval recruitment. We have focused our analyses on the presence and condition of salt marshes that have been identified as important nursery habitats for many fishery species (Boesch and Turner 1984, Zimmerman et al. 2000, Minello et al. 2003). In addition to large estuarine areas, the amount of estuarine emergent marsh was generally highest in Louisiana systems, although the percentage of the estuarine area that was marsh varied from as low as 16.3% in Lake Borgne to a high of 56.9% and 60.9% in Lake Calcasieu and Sabine Lake, respectively (2006 C-CAP data).

The estuaries examined were selected for analysis because they appear to support a wide range of fishery productivity, and there are sampling programs in each of them attempting to assess abundance of fishery resources. Despite the universal use of trawls in these sampling programs, results from attempts to standardize the catch data and make detailed comparisons among the estuaries with regard to fishery production remain questionable (Brown et al. 2013). The general catch data from these resource trawl surveys, however, and the commercial and recreational fishery catch data available (https://www.st.nmfs.noaa.gov/commercial-fisheries/index) indicate that Louisiana estuaries and coastal waters are the most productive for many fishery species such as brown shrimp *Farfantepenaeus aztecus,* white shrimp *Litopenaeus setiferus*, blue crab, Gulf menhaden, spotted seatrout, red drum, and southern flounder *Paralichths lethostigma*. The extensive estuarine area in these Louisiana systems may at least partially explain the disparity in fishery landings among Gulf states. The value of an estuarine system for a fishery species, however, should be reflected in both the overall estuarine area and the quality of the habitats within that area, as discussed by Beck et al. (2001) and Dahlgren et al. (2006) with regard to nursery habitats. The resource survey data indicate that Louisiana estuaries also support high abundances of many fishery species per area of estuary sampled (Brown et al. 2013). The large amount of marsh per ha of estuarine area, the amount of edge in these marshes, and the nutrient inputs into these systems likely contribute to this high fishery productivity per estuarine area.

Deegan et al. (1986) examined many physical and biological characteristics from 64 estuaries located throughout the GoM and identified correlations among estuarine area, the slope of the coast, the amount of intertidal area, the amount of emergent vegetation (marsh and mangroves), and rainfall. Using total fishery catch from estuaries in the southern GoM, they reported a strong correlation between river discharge and catch per area of open estuarine water. Turner (2001) also discussed the variability of many estuarine characteristics in the GoM and identified the importance of morphology and size, water depth and flushing times, nutrient loading, and wetland:water ratios; he identified a positive relationship between shrimp yield and the amount of intertidal estuarine vegetation (Turner 1977, 1992). Green et al. (2015) examined habitat stressors for estuaries throughout the contiguous U.S. with a focus on land cover, river flow, pollution, and eutrophication; most of these indicators were correlated. In the GoM their composite stressor index was highest for estuaries in the Northwest GoM and Texas, intermediate for the central GoM, and lowest for the estuaries in Northwest Florida. The data reported in our analyses focus on the area of emergent wetlands, wetland edge, and wetland flooding duration. The ratio of wetland area to estuarine water in these systems is of interest but is affected by the seaward boundaries identified for the estuaries. This ratio is potentially misleading for estuarine systems such as Breton-Chandeleur Sounds, West Mississippi Sound, East Mississippi Sound, Suwanee Sound, and Cedar Key where estuarine boundaries include much of the open GoM.

Seagrass beds have been identified as important nurseries for many species such as pink shrimp *Farfantepenaeus duorarum*, brown shrimp, blue crab, red drum, and spotted seatrout (Minello 1999, Heck et al. 2003). The loss of seagrass habitats that support fisheries and functional estuaries is an important area of concern both worldwide and in the GoM (Chesney et al. 2000, Orth et al. 2006, Heck et al. 2008, Waycott et al. 2009). The remote sensing data we analyzed may not accurately reflect the distribution and abundance of seagrass and SAV, but the largest areas of estuarine aquatic beds generally occur in the southern-most systems at the ends of our geographical range (also see Handley et al. 2007). Large areas of submerged aquatics in relatively low salinity areas of Louisiana estuaries also occur (Merino et al. 2009), but water clarity and other issues make remotely-sensed surveys undependable for assessing the amount of this habitat (McKensie et al. 2001). This SAV in lower salinity waters, therefore, was likely underrepresented in our analyses, although this habitat also appears to function as a nursery for many fishery species (Castellanos and Rozas 2001, Rozas and Minello 2006). The nursery function of salt marshes, seagrass beds, and SAV may be similar in these estuaries of the northern GoM (Rozas and Minello 1998, Minello et al. 2003), especially considering the high flooding rates for marsh edge that make salt marshes highly accessible in the region.

The southern-most estuarine systems in Florida (Tampa Bay and Charlotte Harbor) had relatively large areas of Estuarine Forested Wetlands or mangroves. The relative value of this habitat as a nursery in support of fishery production is still under debate (Sheridan and Hays 2003, Faunce et al. 2004, Manson et al. 2005, Koenig et al. 2007, Igulu et al. 2014). The lack of Estuarine Forested Wetlands in the databases for southern Texas estuaries perhaps reflects the presence of smaller black mangroves in these systems, that were not identified as forest. The invasion of black mangroves into all Texas and Louisiana estuaries is more recent and apparently driven by climate change (Pickens and Hester 2011, Comeaux et al. 2012, Osland et al. 2013).

The data analyzed in our study are consistent with the conclusion that salt marshes are an important habitat supporting fishery production in the northern Gulf of Mexico. The extensive areas of emergent marsh, the amount of edge, and the high flooding durations of the marsh edge in estuaries near the Mississippi River generally coincide with high fishery production in the region. These characteristics, however, are correlated with total estuarine area, high freshwater input, and elevated nutrient inputs. Salinity patterns in these estuarine systems are important, because abundance for many juvenile fishery species in salt marsh habitats is reduced in low salinity areas (Minello 1999). Density, growth and production of penaeid shrimps is negatively related to salinity (Rozas and Minello 2010, 2011, Adamack et al. 2012, Leo et al. 2016, Mace and Rozas 2017). In addition to salinity, the value of estuarine salt marshes can be negatively affected by impoundments that are common in Louisiana systems or by other structures that affect accessibility for transient nekton (Rogers et al. 1994, Rozas and Minello 1999, Secor and Rooker 2005, Rozas et al. 2013).

The estuaries included in our study appear to vary greatly in their capability to support coastal fishery populations based on the quantity and quality of their nursery habitat. Estuaries of the Mississippi River Delta have the greatest potential for providing essential nursery habitat for these species, and these estuaries do support high abundances of the young of fishery species based on survey data from long-term monitoring programs of Gulf coast states (Brown et al. 2013). The characteristics that these estuaries have in common include large areas of emergent marsh and marsh edge habitat, high rates of flooding at the marsh edge, and elevated nutrient inputs from the Mississippi and Atchafalaya Rivers. Seagrass and SAV are also important for fishery species, but our ability to quantify the area of this habitat in GoM estuaries is limited by available remote-sensing technology.

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Appendix Tables

Appendix Table 1. 2010 C-CAP data showing the area (ha) of estuarine habitats in 24 estuaries from the Gulf of Mexico.

2010	Estuarine Forested	Estuarine Scrub/Shrub	Estuarine Emergent Marsh	Estuarine Aquatic Bed	Estuarine Water	Fresh Water	Total Estuarine Area	Total EDA Area
Lower Laguna Madre	0	57	5,331	8,549	73,678	6,246	87,615	1,447,379
Upper Laguna Madre	1	65	2,481	4,075	49,541	1,035	56,162	1,141,146
Corpus Christi Bay	1	7	5,979	450	54,040	7,439	60,478	506,253
Aransas Bay	1	5	17,024	466	53,074	623	70,570	694,463
San Antonio Bay	1	104	20,714	490	61,214	3,128	82,522	401,332
Matagorda Bay	5	37	21,656	328	101,253	9,686	123,279	1,332,243
East-Matagorda	0	0	13,387	51	16,811	871	30,249	183,839
Galveston Bay	15	89	56,517	297	160,276	9,135	217,194	1,150,509
Sabine Lake	0	289	71,418	108	48,552	15,585	120,367	1,244,463
Lake Calcasieu	0	422	63,436	296	61,031	1,003	125,186	267,532
Vermilion-Cote Blanche Bays	0	446	108,669	1,540	245,709	46,084	356,364	1,889,235
Terrebonne-Timbalier Bays	0	623	83,739	4,889	205,692	3,301	294,944	389,541
Barataria Bay	0	173	95,926	5,576	156,986	10,193	258,661	563,568
Breton-Chandeleur Sounds	0	280	119,765	5,874	498,067	0	623,987	645,170
Lake Borgne	8	433	50,968	141	279,522	18,964	331,071	2,024,217
West Mississippi Sound	14	253	11,524	29	160,198	3,271	172,018	563,092
East Missisippi Sound	1	145	15,115	16	67,938	7,175	83,215	528,669
Mobile Bay	1	199	8,798	37	109,457	15,313	118,492	1,258,620
Perdido Bay	2	100	1,765	14	13,118	1,083	14,999	305,674
Apalachicola Bay	186	22	7,125	6	58,094	4,955	70,388	491,907
Suwanee Sound	110	4	11,301	0	32,781	1,535	44,196	491,502
Cedar Key	283	62	12,033	0	29,489	269	41,867	244,443
Tampa Bay	7,377	1,081	2,478	1,591	90,774	15,394	103,302	660,508
Charlotte Harbor	16,096	2,276	3,851	2,122	56,959	25,471	81,304	1,226,155

Appendix Table 2. 2006 C-CAP data showing the area (ha) of estuarine habitats in 24 estuaries from the Gulf of Mexico.

2006	Estuarine Forested	Estuarine Scrub/Shrub	Estuarine Emergent Marsh	Estuarine Aquatic Bed	Estuarine Water	Fresh Water	Total Estuarine Area	Total EDA Area
Lower Laguna Madre	0	83	5,699	8,646	73,541	6,221	87,968	1,447,379
Upper Laguna Madre	1	73	2,314	4,142	49,215	1,004	55,745	1,141,146
Corpus Christi Bay	1	6	6,261	483	54,890	7,556	61,642	506,253
Aransas Bay	1	6	17,434	473	52,948	643	70,861	694,463
San Antonio Bay	1	104	20,877	491	60,907	3,138	82,380	401,332
Matagorda Bay	6	37	22,750	329	100,615	9,625	123,738	1,332,243
East-Matagorda	0	0	14,153	51	16,736	867	30,941	183,839
Galveston Bay	21	93	57,103	300	159,561	9,108	217,077	1,150,509
Sabine Lake	0	240	73,804	121	47,007	15,089	121,171	1,244,463
Lake Calcasieu	0	426	71,965	312	53,812	875	126,514	267,532
Vermilion-Cote Blanche Bays	0	420	108,726	1,421	252,153	47,316	362,720	1,889,235
Terrebonne-Timbalier Bays	0	690	91,553	4,950	198,062	3,221	295,256	389,541
Barataria Bay	0	182	99,404	5,711	154,202	10,017	259,498	563,568
Breton-Chandeleur Sounds	0	295	129,957	3,718	490,270	0	624,240	645,170
Lake Borgne	0	470	53,853	117	275,825	18,714	330,265	2,024,217
West Mississippi Sound	0	305	11,930	31	159,801	3,263	172,067	563,092
East Missisippi Sound	0	164	15,191	16	67,880	7,209	83,251	528,669
Mobile Bay	0	226	9,052	39	110,585	14,088	119,901	1,258,620
Perdido Bay	0	111	1,839	14	13,066	1,075	15,030	305,674
Apalachicola Bay	188	15	7,165	6	58,117	4,989	70,480	491,907
Suwanee Sound	106	3	11,298	0	32,808	1,546	44,216	491,502
Cedar Key	285	60	12,045	0	29,422	269	41,812	244,443
Tampa Bay	7,846	1,093	2,473	1,591	89,922	15,250	102,926	660,508
Charlotte Harbor	16,304	2,438	3,929	2,124	56,516	25,273	81,311	1,226,155

Appendix Table 3. 2001 C-CAP data showing the area (ha) of estuarine habitats in 24 estuaries from the Gulf of Mexico.

2001	Estuarine Forested	Estuarine Scrub/Shrub	Estuarine Emergent Marsh	Estuarine Aquatic Bed	Estuarine Water	Fresh Water	Total Estuarine Area	Total EDA Area
Lower Laguna Madre	0	55	5,546	9,101	71,140	6,031	85,842	1,447,379
Upper Laguna Madre	0	70	2,284	4,285	48,787	1,019	55,425	1,141,146
Corpus Christi Bay	0	6	6,040	510	52,829	7,272	59,385	506,253
Aransas Bay	0	5	16,877	516	53,077	623	70,476	694,463
San Antonio Bay	0	106	20,725	506	61,151	3,125	82,487	401,332
Matagorda Bay	0	22	21,608	323	101,276	9,688	123,229	1,332,243
East-Matagorda	0	0	13,380	57	16,739	867	30,176	183,839
Galveston Bay	0	96	56,229	404	161,745	9,219	218,475	1,150,509
Sabine Lake	0	264	73,259	122	47,081	15,113	120,726	1,244,463
Lake Calcasieu	0	532	70,189	310	54,254	892	125,284	267,532
Vermilion-Cote Blanche Bays	0	449	108,509	1,328	247,646	46,448	357,932	1,889,235
Terrebonne-Timbalier Bays	0	648	91,291	4,951	197,625	3,213	294,515	389,541
Barataria Bay	0	187	100,033	5,719	152,530	9,904	258,469	563,568
Breton-Chandeleur Sounds	0	315	132,017	3,732	497,310	0	633,374	654,170
Lake Borgne	0	463	54,249	117	275,373	18,683	330,202	2,024,217
West Mississippi Sound	0	276	11,823	32	159,827	3,263	171,958	563,092
East Missisippi Sound	0	104	15,211	16	67,908	7,211	83,240	528,669
Mobile Bay	0	227	8,896	39	109,272	15,325	118,433	1,258,620
Perdido Bay	0	120	1,786	14	13,064	1,079	14,985	305,674
Apalachicola Bay	188	15	7,162	6	58,132	4,957	70,461	491,907
Suwanee Sound	110	3	11,310	0	32,714	1,532	44,137	491,502
Cedar Key	285	60	12,044	0	29,422	269	41,811	244,443
Tampa Bay	7,850	1,082	2,470	1,592	86,190	14,581	99,183	660,508
Charlotte Harbor	16,357	2,413	3,841	2,127	53,637	23,985	78,375	1,226,155

Appendix Table 4. 1996 C-CAP data showing the area (ha) of estuarine habitats in 24 estuaries from the Gulf of Mexico.

1996	Estuarine Forested	Estuarine Scrub/Shrub	Estuarine Emergent Marsh	Estuarine Aquatic Bed	Estuarine Water	Fresh Water	Total Estuarine Area	Total EDA Area
Lower Laguna Madre	0	55	5,546	9,136	71,090	6,027	85,827	1,447,379
Upper Laguna Madre	0	70	2,282	4,285	48,764	1,019	55,400	1,141,146
Corpus Christi Bay	0	6	6,036	510	52,819	7,271	59,372	506,253
Aransas Bay	0	5	16,844	516	53,061	623	70,426	694,463
San Antonio Bay	0	106	20,692	506	61,131	3,124	82,434	401,332
Matagorda Bay	0	22	21,597	323	101,189	9,680	123,131	1,332,243
East-Matagorda	0	0	13,393	57	16,737	867	30,187	183,839
Galveston Bay	0	96	56,227	394	161,681	9,215	218,398	1,150,509
Sabine Lake	0	265	73,315	129	46,976	15,080	120,685	1,244,463
Lake Calcasieu	0	532	70,049	347	54,165	890	125,093	267,532
Vermilion-Cote Blanche Bays	0	453	109,319	1,286	255,492	47,919	366,550	1,889,235
Terrebonne-Timbalier Bays	0	650	91,892	4,933	197,119	3,205	294,594	389,541
Barataria Bay	0	187	100,568	5,716	151,917	9,864	258,388	563,568
Breton-Chandeleur Sounds	0	318	133,070	3,696	487,153	0	624,238	645,170
Lake Borgne	0	462	54,215	142	274,959	18,655	329,778	2,024,217
West Mississippi Sound	0	277	11,821	43	159,368	3,254	171,508	563,092
East Missisippi Sound	0	104	15,225	20	67,718	7,191	83,067	528,669
Mobile Bay	0	222	8,792	48	108,736	15,212	117,798	1,258,620
Perdido Bay	0	120	1,783	18	12,993	1,069	14,914	305,674
Apalachicola Bay	188	28	7,073	6	58,125	4,957	70,376	491,907
Suwanee Sound	106	3	11,298	0	32,817	1,536	44,225	491,502
Cedar Key	280	60	12,034	0	29,500	269	41,873	244,443
Tampa Bay	7,807	1,146	2,492	1,591	86,504	14,634	99,540	660,508
Charlotte Harbor	16,408	2,427	3,921	2,101	53,989	24,143	78,847	1,226,155

Appendix Table 5. National Wetland Inventory estimates of estuarine habitat areas (ha) for 24 estuaries in the northern Gulf of Mexico. The Total Estuarine Area is the sum of wetland habitats, Reef, Estuarine Unconsolidated Shore (Est Uncons Shore), and Estuarine Water.

	NWI Estuarine Wetland Classification										
Estuary	Forested	Scrub /Shrub	Regularly Flooded	Irregularly Flooded	Aquatic Bed	Reef	Est Uncon Shore	Estuarine Water	Fresh Water	Total Estuarine Area	Total EDA Area
Lower Laguna Madre	0	340	692	4,997	57,912	0	51,201	29,417	12,440	144,559	1,447,378
Upper Laguna Madre	0	0	63	906	39,470	0	27,270	26,707	2,798	94,416	1,141,146
Corpus Christi Bay	0	51	2,615	872	6,761	0	5,238	49,547	11,291	65,084	506,253
Aransas Bay	0	626	6,121	3,452	6,118	0	5,909	48,479	3,114	70,704	694,466
San Antonio Bay	0	135	6,853	3,106	4,322	0	3,333	58,354	7,798	76,104	401,334
Matagorda Bay	0	50	7,629	6,876	896	8	3,945	100,685	17,482	120,089	1,332,241
East-Matagorda	0	4	3,093	6,579	812	9	1,038	17,053	1,263	28,589	183,838
Galveston Bay	0	40	10,120	19,982	143	25	6,205	160,749	19,706	197,263	1,150,508
Sabine Lake	2	214	1,964	52,837	334	0	2,113	46,220	21,862	103,683	1,244,467
Lake Calcasieu	2	244	2,690	57,876	641	0	1,238	52,815	7,124	115,505	267,530
Vermilion-Cote Blanche Bays	2	781	46,585	60,446	0	0	3,285	236,812	56,597	347,911	1,889,268
Terrebonne-Timbalier Bays	214	1,881	84,802	12,593	684	0	1,864	189,572	5,011	291,610	389,538
Barataria Bay	0	655	50,729	51,486	1,604	0	483	141,685	18,500	246,642	563,571
Breton-Chandeleur Sounds	0	283	39,117	83,046	2,306	0	3,851	483,546	402	612,149	645,149
Lake Borgne	0	145	11,713	26,237	650	0	3,939	261,709	48,696	304,393	2,024,218
West Mississippi Sound	0	257	1,791	6,111	12	0	948	162,909	3,593	172,029	563,103
East Missisippi Sound	0	159	233	12,601	116	0	531	70,360	6,635	84,001	528,670
Mobile Bay	4	669	482	5,711	1,061	0	1,678	111,288	13,294	120,893	1,258,617
Perdido Bay	70	151	201	750	233	0	383	13,448	2,669	15,236	305,743
Apalachicola Bay	298	93	625	6,353	763	19	2,674	56,281	5,756	67,105	491,908
Suwanee Sound	276	236	8,737	193	127	0	2,735	34,188	4,386	46,492	491,499
Cedar Key	800	187	9,653	17	38	0	948	32,706	1,468	44,350	244,442
Tampa Bay	185	5,591	1,329	575	10,758	0	6,112	78,250	21,374	102,799	660,510
Charlotte Harbor	4,444	13,168	1,921	1,206	10,799	3	2,848	51,215	31,453	85,605	1,226,154

Appendix Table 6. The amount of marsh edge (km) in different estuaries of the northern Gulf of Mexico. In the C-CAP series of analyses, this is a measure of the edge between 30-m pixels of water (including aquatic beds) and Estuarine Emergent Marsh. The NWI data are from a variety of years, and we measured edge between water (including aquatic beds) and a combination of Regularly Flooded (RF) and Irregularly Flooded (IRR) wetlands and between water and only Regularly Flooded wetlands.

	C-CAP				NWI	
Estuary	**1996**	**2001**	**2006**	**2010**	**RF and IRR**	**only RF**
Lower Laguna Madre	340	340	328	343	299	122
Upper Laguna Madre	66	66	78	94	57	14
Corpus Christi Bay	220	220	238	240	299	268
Aransas Bay	626	626	649	654	954	838
San Antonio Bay	1,016	1,017	1,009	1,006	2,618	2,378
Matagorda Bay	783	785	786	775	1,021	738
East-Matagorda	406	406	414	405	568	389
Galveston Bay	2,053	2,052	1,985	1,991	2,514	1,599
Sabine Lake	3,058	3,068	3,088	3,394	2,486	175
Lake Calcasieu	3,481	3,476	3,448	4,381	3,297	207
Vermilion-Cote Blanche Bays	6,025	5,861	6,260	6,028	4,655	2,662
Terrebonne-Timbalier Bays	10,861	10,802	10,954	11,187	8,199	7,419
Barataria Bay	10,793	10,673	11,165	10,823	7,649	4,623
Breton-Chandeleur Sounds	11,755	11,559	12,380	13,166	9,218	3,242
Lake Borgne	3,244	3,249	3,455	3,754	3,028	1,279
West Mississippi Sound	696	703	710	682	986	142
East Missisippi Sound	732	745	743	729	1,266	53
Mobile Bay	645	671	688	662	612	32
Perdido Bay	188	189	193	186	121	16
Apalachicola Bay	457	457	457	453	258	11
Suwanee Sound	442	442	442	445	402	383
Cedar Key	179	178	179	183	572	572
Tampa Bay	552	550	549	572	203	139
Charlotte Harbor	529	529	538	516	153	141

Appendix Table 7. The amount of marsh edge (m) per ha of total estuarine area in different estuaries of the northern Gulf of Mexico based on the data in Appendix Tables 1-6. Edge in the NWI data is shown for a combination of Regularly Flooded (RF) and Irregularly Flooded (IRR) wetlands and between water and only Regularly Flooded wetlands.

	C-CAP				NWI	
Estuary	**1996**	**2001**	**2006**	**2010**	**RF and IRR**	**only RF**
Lower Laguna Madre	4	4	4	4	2	1
Upper Laguna Madre	1	1	1	2	1	0
Corpus Christi Bay	4	4	4	4	5	4
Aransas Bay	9	9	9	9	13	12
San Antonio Bay	12	12	12	12	34	31
Matagorda Bay	6	6	6	6	9	6
East-Matagorda	13	13	13	13	20	14
Galveston Bay	9	9	9	9	13	8
Sabine Lake	25	25	25	28	24	2
Lake Calcasieu	28	28	27	35	29	2
Vermilion-Cote Blanche Bays	16	16	17	17	13	8
Terrebonne-Timbalier Bays	37	37	37	38	28	25
Barataria Bay	42	41	43	42	31	19
Breton-Chandeleur Sounds	19	18	20	21	15	5
Lake Borgne	10	10	10	11	10	4
West Mississippi Sound	4	4	4	4	6	1
East Missisippi Sound	9	9	9	9	15	1
Mobile Bay	5	6	6	6	5	0
Perdido Bay	13	13	13	12	8	1
Apalachicola Bay	6	6	6	6	4	0
Suwanee Sound	10	10	10	10	9	8
Cedar Key	4	4	4	4	13	13
Tampa Bay	6	6	5	6	2	1
Charlotte Harbor	7	7	7	6	2	2

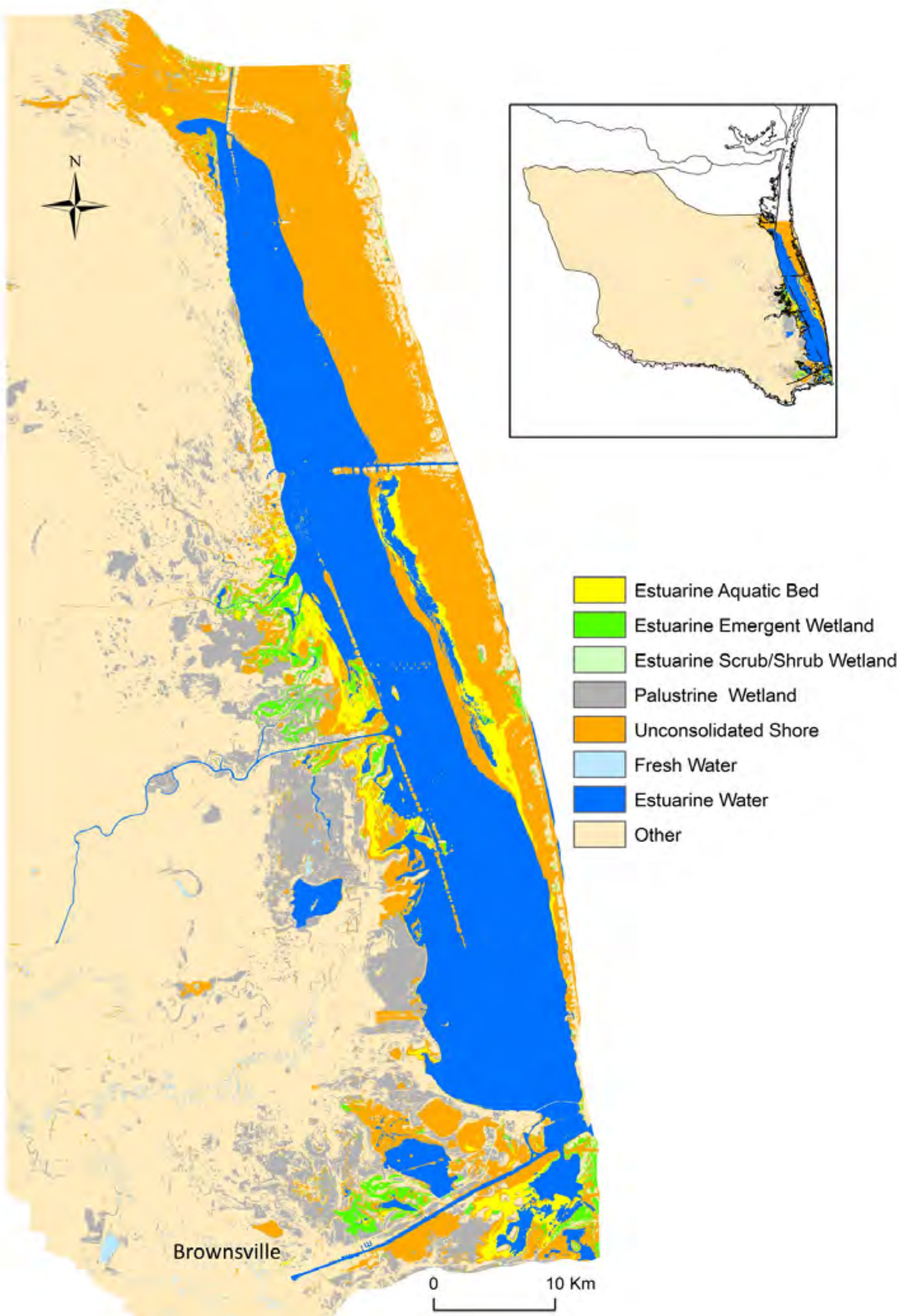
Appendix Table 8. The amount of marsh edge (m) per ha of estuarine marsh in different estuaries of the northern Gulf of Mexico based on the data in Appendix Tables 1-6. Edge in the NWI data is shown for a combination of Regularly Flooded (RF) and Irregularly Flooded (IRR) wetlands and between water and only Regularly Flooded wetlands.

	C-CAP				NWI	
Estuary	**1996**	**2001**	**2006**	**2010**	**RF and IRR**	**only RF**
Lower Laguna Madre	61	61	58	64	53	177
Upper Laguna Madre	29	29	34	38	59	221
Corpus Christi Bay	36	36	38	40	86	102
Aransas Bay	37	37	37	38	100	137
San Antonio Bay	49	49	48	49	263	347
Matagorda Bay	36	36	35	36	70	97
East-Matagorda	30	30	29	30	59	126
Galveston Bay	37	37	35	35	84	158
Sabine Lake	42	42	42	48	45	89
Lake Calcasieu	50	50	48	69	54	77
Vermilion-Cote Blanche Bays	55	54	58	55	43	57
Terrebonne-Timbalier Bays	118	118	120	134	84	87
Barataria Bay	107	107	112	113	75	91
Breton-Chandeleur Sounds	88	88	95	110	75	83
Lake Borgne	60	60	64	74	80	109
West Mississippi Sound	59	59	60	59	125	79
East Missisippi Sound	48	49	49	48	99	228
Mobile Bay	73	75	76	75	99	66
Perdido Bay	105	106	105	105	128	78
Apalachicola Bay	65	64	64	64	37	18
Suwanee Sound	39	39	39	39	45	44
Cedar Key	15	15	15	15	59	59
Tampa Bay	221	223	222	231	107	104
Charlotte Harbor	135	138	137	134	49	73

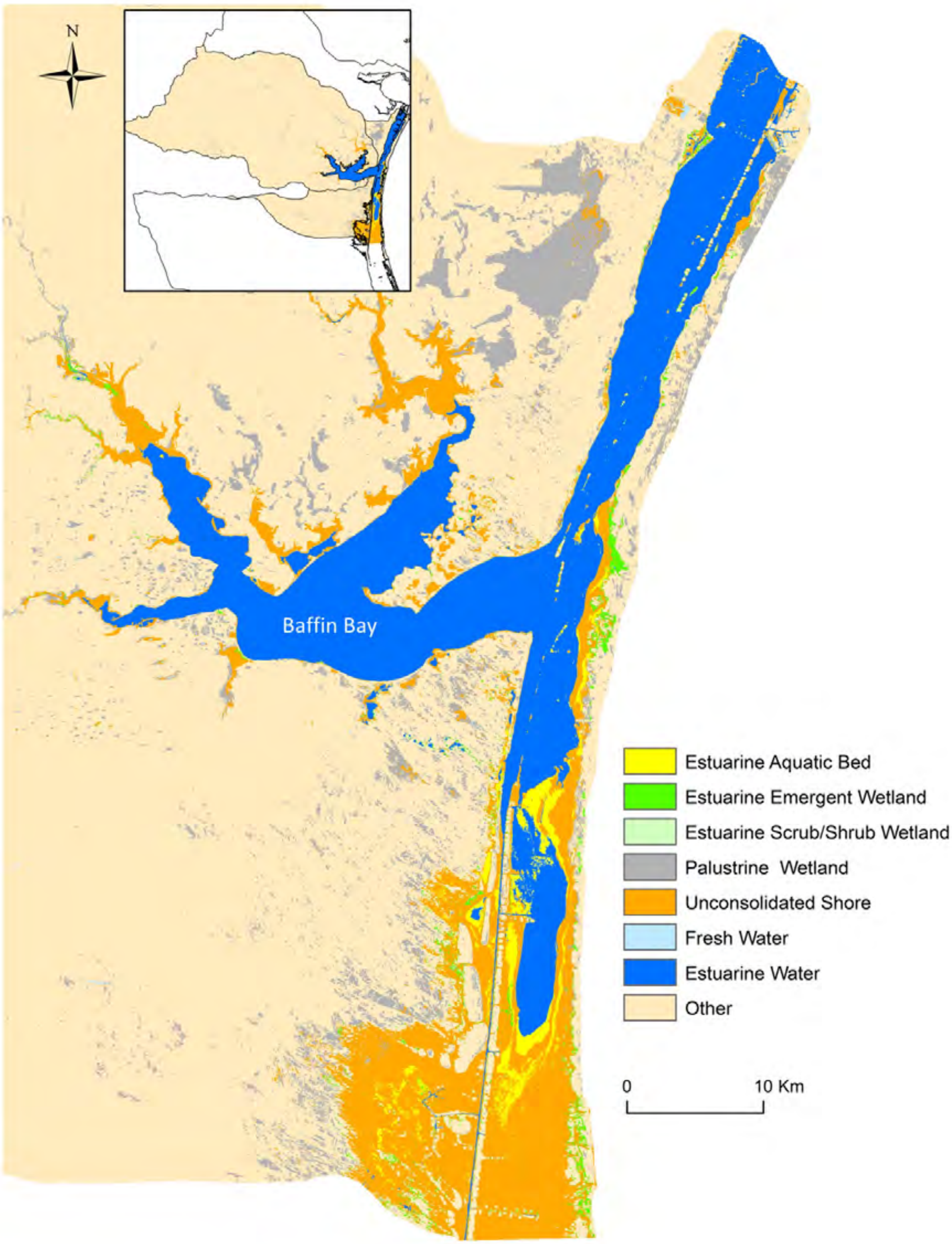
Appendix Table 9. Flooding of the marsh edge in 2013 at 57 *Spartina alterniflora* marshes in 13 estuaries. Marsh locations are shown in Appendix figures. Flooding estimates are based on the mean edge elevation from 10 measurements in each marsh and data from nearby tide gauges. NOAA tide gauges are identified by their station number in parentheses. Water level gauges in Louisiana were located at Coastwide Reference Monitoring System (CRMS) sites. Sites in grey are created marshes in Galveston Bay, TX.

Estuary	Study site	Lat (DD)	Long (DD)	Tide gauge used	Edge Flooding	Date Sampled
Aransas Bay	Copano Bay near TCOON gage	28.117	-97.049	TCOON Copano Bay gauge	94.3%	6/13/13
Aransas Bay	Rockport	27.981	-96.972	NOAA Rockport (8774770)	96.2%	6/13/13
Aransas Bay	Rockport II - South off ICWW	27.979	-97.079	NOAA Rockport (8774770)	89.0%	6/13/13
San Antonio Bay	San Antonio Bay North Seadrift	28.410	-96.733	Seadrift, TX (8773037)	97.8%	6/12/13
San Antonio Bay	San Antonio Bay North VBC	28.418	-96.750	Seadrift, TX (8773037)	96.8%	6/12/13
San Antonio Bay	San Antonio Bay South	28.394	-96.706	Seadrift, TX (8773037)	97.1%	6/12/13
San Antonio Bay	ANWR - East near boat ramp	28.230	-96.797	TCOON AWR (87742301)	93.8%	6/12/13
San Antonio Bay	ANWR - West	28.223	-96.805	TCOON AWR (87742301)	88.2%	6/12/13
Matagorda Bay	Lavaca Bay (Chocolate Bay)	28.587	-96.613	8773259 Port Lavaca, TX	85.0%	6/11/13
Galveston Bay	Rollover pass	29.517	-94.525	Rollover (8770971)	81.6%	6/20/13
Galveston Bay	Elmgrove Point	29.463	-94.686	Eagle Point (8771013)	77.2%	6/20/13
Galveston Bay	Cedar Point	29.666	-94.924	Eagle Point (8771013)	87.5%	6/12/13
Galveston Bay	Hog Island	29.694	-94.981	Eagle Point (8771013)	83.7%	6/12/13
Galveston Bay	Greens Lake	29.273	-94.986	Pier 21 (8771450)	51.3%	6/13/13
Galveston Bay	Jamaica Beach GISP Natural	29.197	-94.975	Sportsmans Road Gauge	85.7%	6/21/13
Galveston Bay	Jones Lake	29.315	-94.936	Pier 21 (8771450)	74.8%	6/13/13
Galveston Bay	Jumbile Cove Natural Marsh	29.196	-94.989	Sportsmans Road Gauge	61.6%	6/21/13
Galveston Bay	Marsh Point	29.524	-94.573	Rollover (8770971)	86.8%	6/20/13
Galveston Bay	Mud Island	29.080	-95.142	San Luis Pass (8771972)	75.6%	6/25/13
Galveston Bay	Nick's Lake, Christmas Bay	29.026	-95.236	Nicks Lake (87721781)	69.1%	6/11/13
Galveston Bay	San Leon	29.476	-94.956	Eagle Point (8771013)	84.4%	6/20/13
Galveston Bay	Smith Point	29.543	-94.775	Eagle Point (8771013)	93.2%	6/24/13
Galveston Bay	Sportsmans Road	29.255	-94.917	Sportsmans Road Gauge	82.1%	7/31/13
Galveston Bay	Virginia Point Railroad Bridge	29.303	-94.899	San Luis Pass (8771972)	83.9%	6/13/13
Galveston Bay	Delehide Cove	29.229	-94.946	Sportsmans Road Gauge	92.0%	6/21/13
Galveston Bay	Demonstration Marsh	29.652	-94.959	Eagle Point (8771013)	54.7%	6/12/13
Galveston Bay	GISP ARRA Mounds	29.196	-94.978	Sportsmans Road Gauge	85.5%	6/21/13
Galveston Bay	GISP Terraces	29.197	-94.977	Sportsmans Road Gauge	79.5%	6/21/13
Galveston Bay	Jumbile Cove created marsh I	29.196	-94.990	Sportsmans Road Gauge	91.4%	6/21/13
Galveston Bay	Jumbile Cove created marsh II	29.193	-94.990	Sportsmans Road Gauge	96.4%	6/21/13
Galveston Bay	Jumbile Cove created marsh III	29.186	-94.997	Sportsmans Road Gauge	95.1%	6/21/13
Galveston Bay	Mason Marsh	29.325	-94.923	Sportsmans Road Gauge	68.2%	6/13/13
Galveston Bay	Minello Marsh	29.320	-94.918	Sportsmans Road Gauge	84.9%	6/13/13
Sabine Lake	Sabine Pass N	29.720	-93.852	Sabine Pass North (8770570)	74.7%	6/3/13
Terrebonne-Timbalier Bays	Port Fourchon	29.117	-90.219	Port Fourchon (8762075)	71.7%	6/5/13
Terrebonne-Timbalier Bays	CRMS 292, near Port Fouchon	29.139	-90.227	CRMS 292	70.9%	6/5/13
Terrebonne-Timbalier Bays	CRMS 397, Timbalier Bay	29.351	-90.260	CRMS 397	88.0%	6/5/13
Terrebonne-Timbalier Bays	CRMS 978, Timbalier Bay	29.323	-90.293	CRMS 978	83.8%	6/5/13
Terrebonne-Timbalier Bays	CRMS 319, Timbalier Bay	29.324	-90.326	CRMS 319	86.4%	6/5/13
Barataria Bay	CRMS 181, East Barataria Bay	29.335	-89.695	CRMS 181	77.5%	6/4/13
Barataria Bay	CRMS 179, East Barataria Bay	29.398	-89.697	CRMS 179	82.3%	6/4/13
Barataria Bay	CRMS 172, East Barataria Bay	29.318	-89.734	CRMS 172	77.0%	6/4/13
Barataria Bay	CRMS 174, East Barataria Bay	29.399	-89.766	CRMS 174	84.9%	6/4/13
Barataria Bay	CRMS 171, East Barataria Bay	29.324	-89.792	CRMS 171	88.9%	6/4/13
Barataria Bay	CRMS 176, East Barataria Bay	29.414	-89.795	CRMS 176	90.3%	6/4/13
Barataria Bay	Barataria Bay Pass E of Grand Isle	29.281	-89.974	Grand Isle (8761724)	82.1%	6/4/13
Barataria Bay	CRMS 178, Central Barataria Bay	29.288	-90.043	CRMS 178	87.7%	6/4/13
Lake Borgne	CRMS 4548, Lake Borgne	29.862	-89.670	CRMS 4548	59.5%	6/6/13
Breton-Chandeleur Sounds	CRMS 4551, near Lake Borgne	29.853	-86.606	CRMS 4551	68.6%	6/6/13
Breton-Chandeleur Sounds	Shell Beach, near Lake Borgne	29.860	-89.675	Shell Beach (8761305)	57.4%	6/6/13
West Mississippi Sound	Bay St. Louis	30.341	-89.363	Bay Waveland (8747437)	89.4%	6/6/13
Mobile Bay	Weeks Bay	30.411	-87.835	Weeks Bay (8732828)	85.3%	6/7/13
Mobile Bay	East Fowl River, Mobil Bay	30.461	-88.102	East Fowl River (8735523)	85.3%	6/7/13
Apalachicola Bay	Apalachicola Bay, by NOAA Gauge	29.717	-84.988	Apalachicola (8728690)	96.9%	6/8/13
Apalachicola Bay	Lafayette Park	29.712	-85.018	Apalachicola (8728690)	90.1%	6/8/13
Apalachicola Bay	Sheepshead Bayou	29.673	-85.084	Pilot's Cove (DEP 872-8732)	82.5%	6/8/13
Suwanee Sound	Cedar Key	29.139	-83.055	Cedar Key (8727520)	70.5%	6/9/13

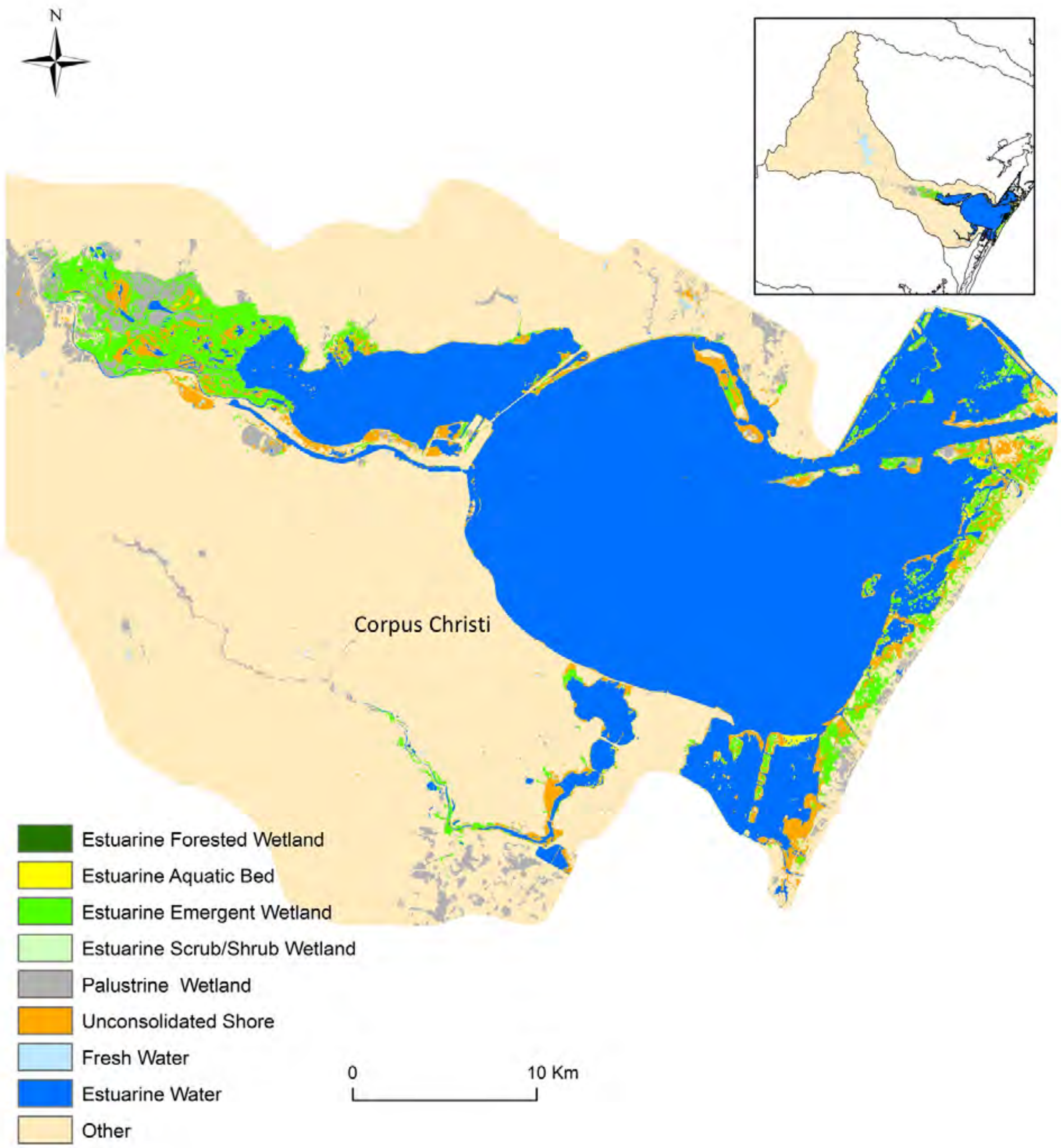
Appendix Figures



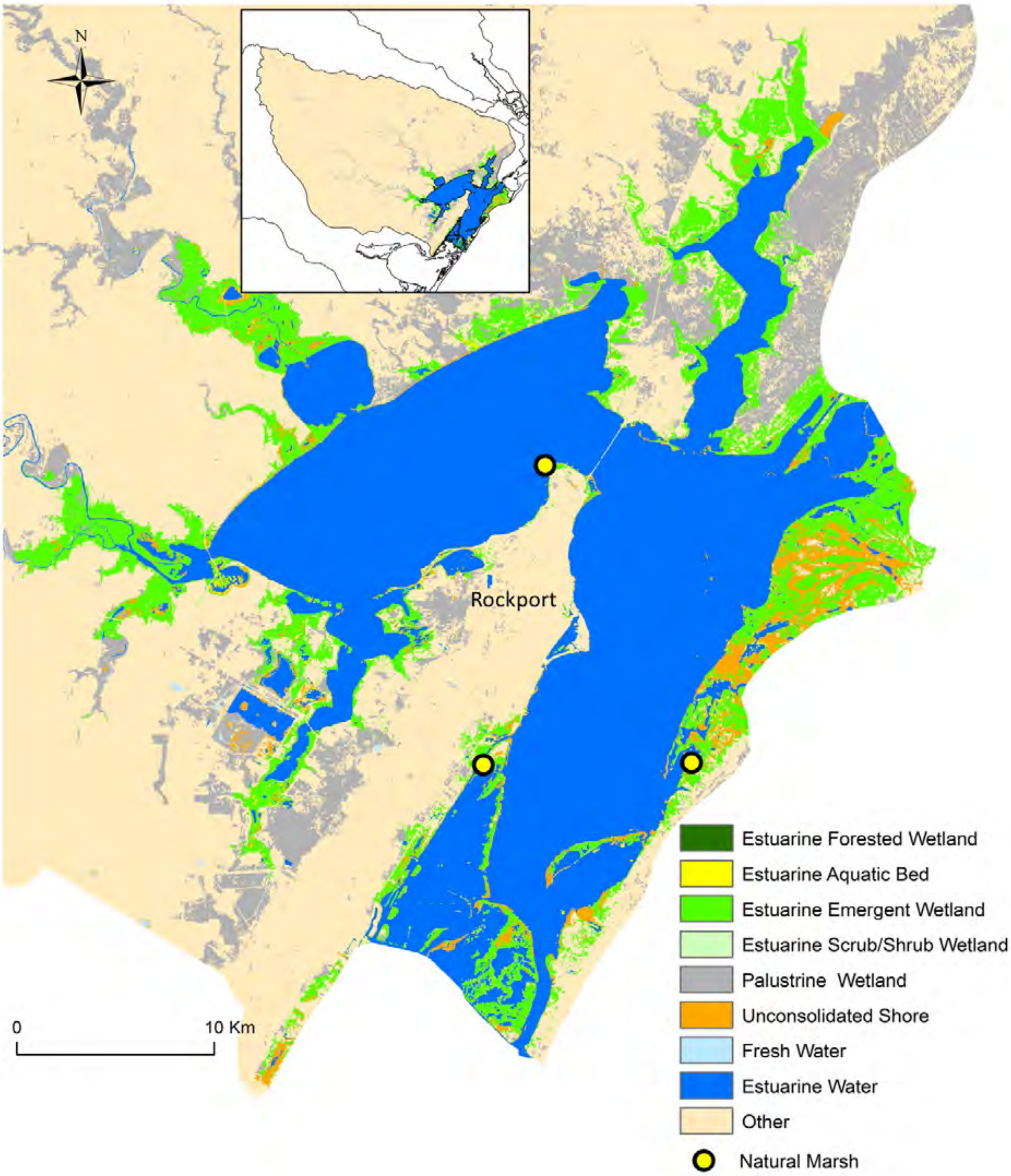
Appendix Figure 1. Fishery habitat in Lower Laguna Madre, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2.



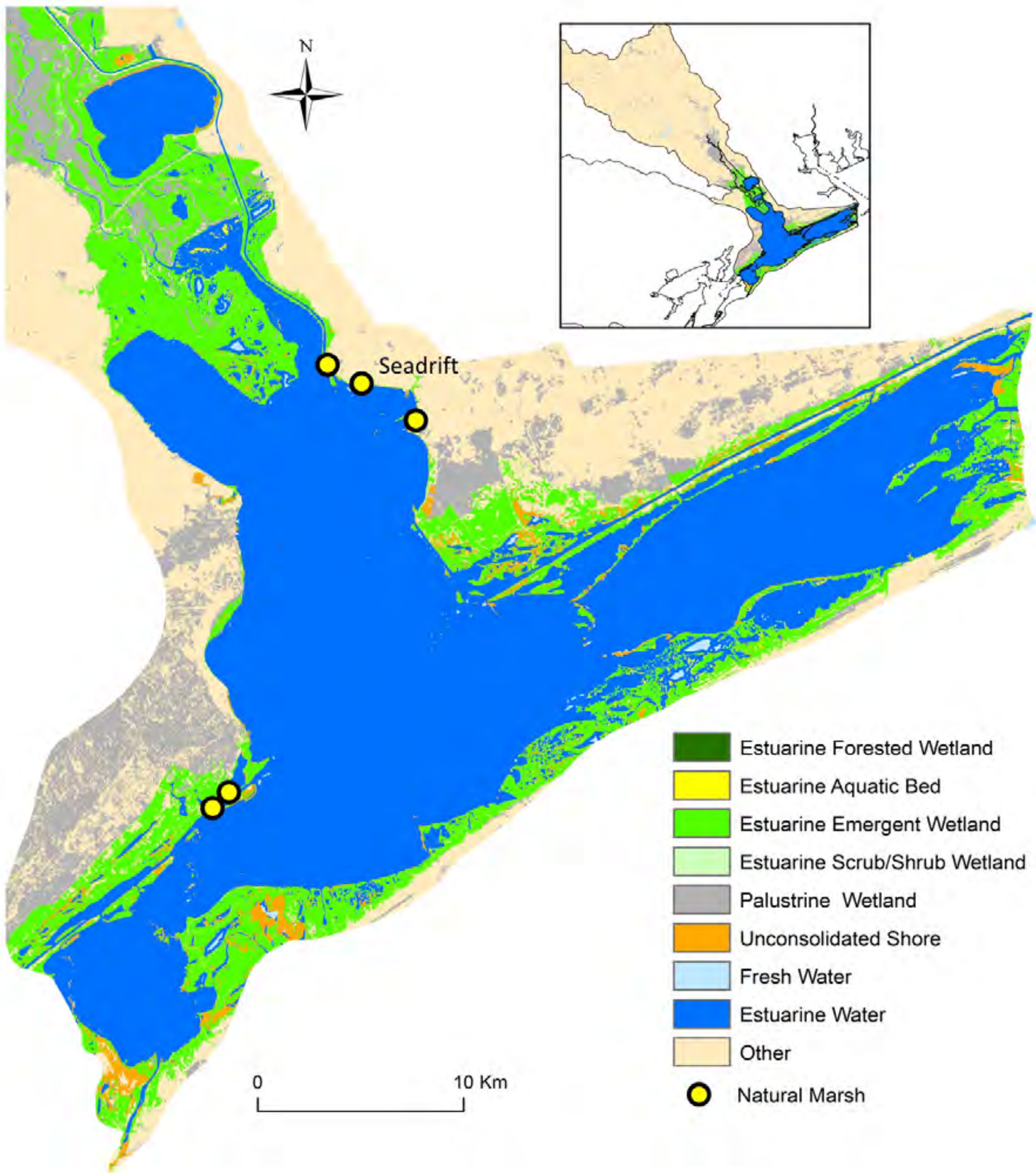
Appendix Figure 2. Fishery habitat in Upper Laguna Madre, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2.



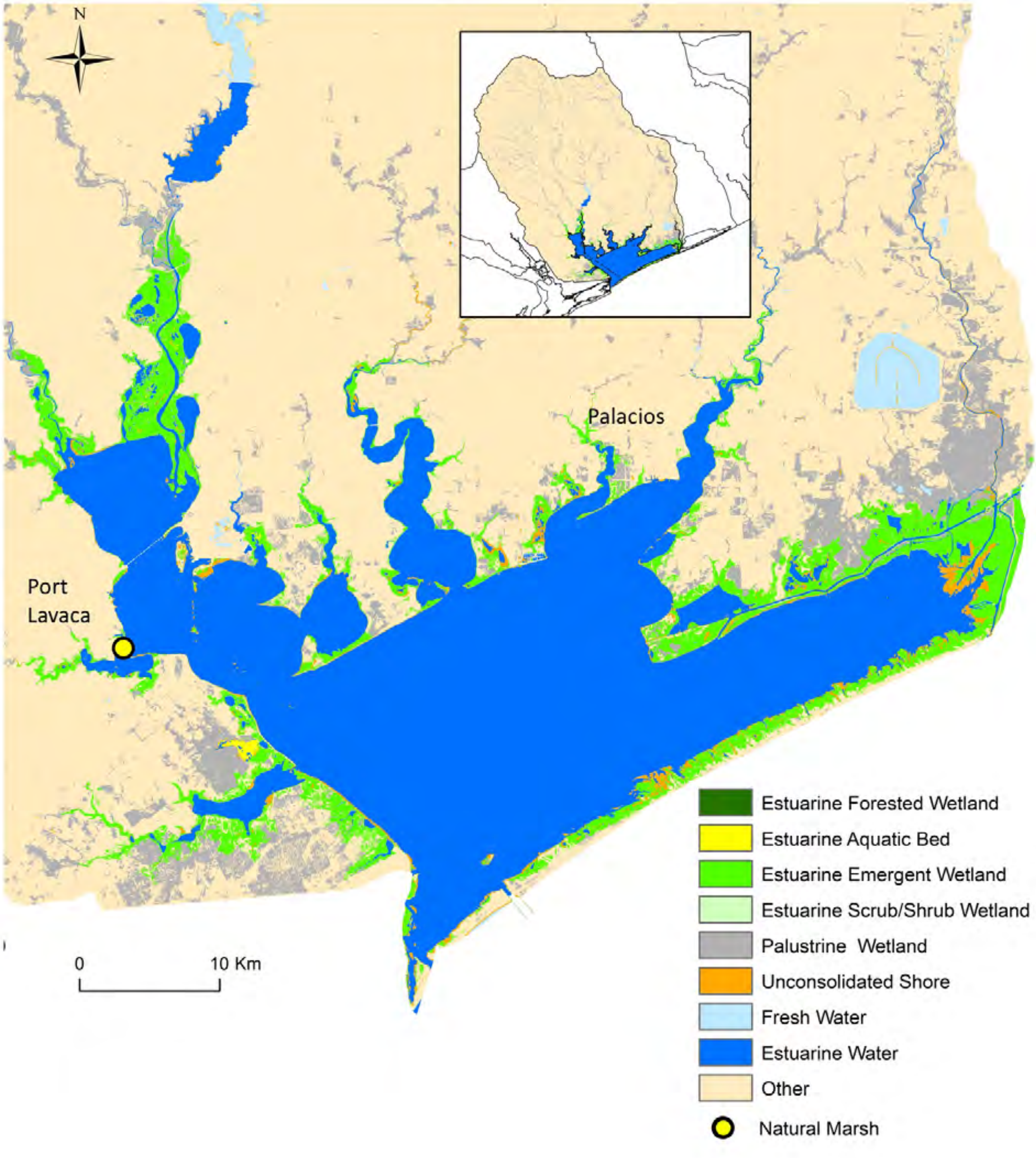
Appendix Figure 3. Fishery habitat in Corpus Christi Bay, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2.



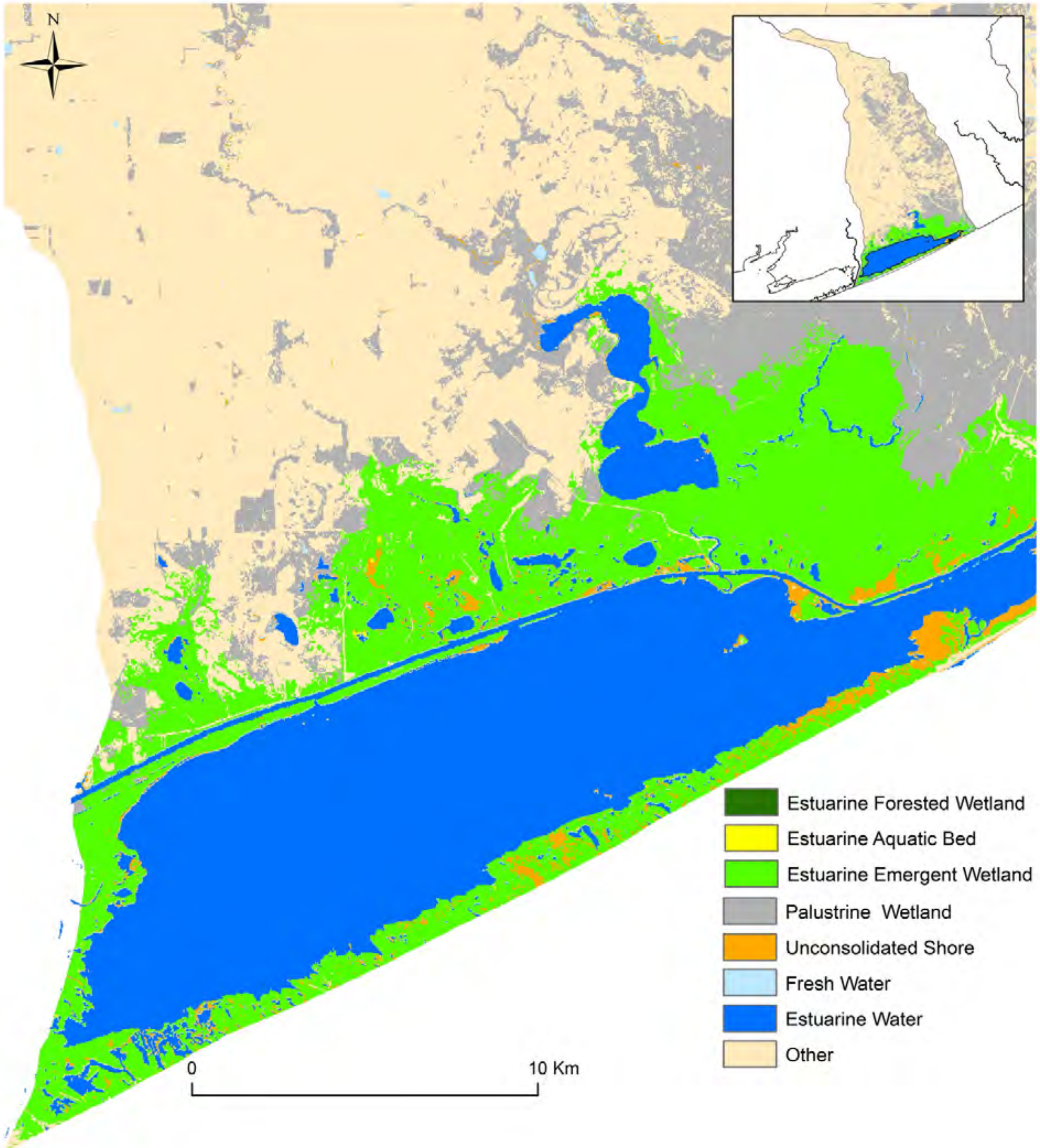
Appendix Figure 4. Fishery habitat in Aransas Bay, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2. Locations also are shown where elevation and inundation were measured for natural marshes.



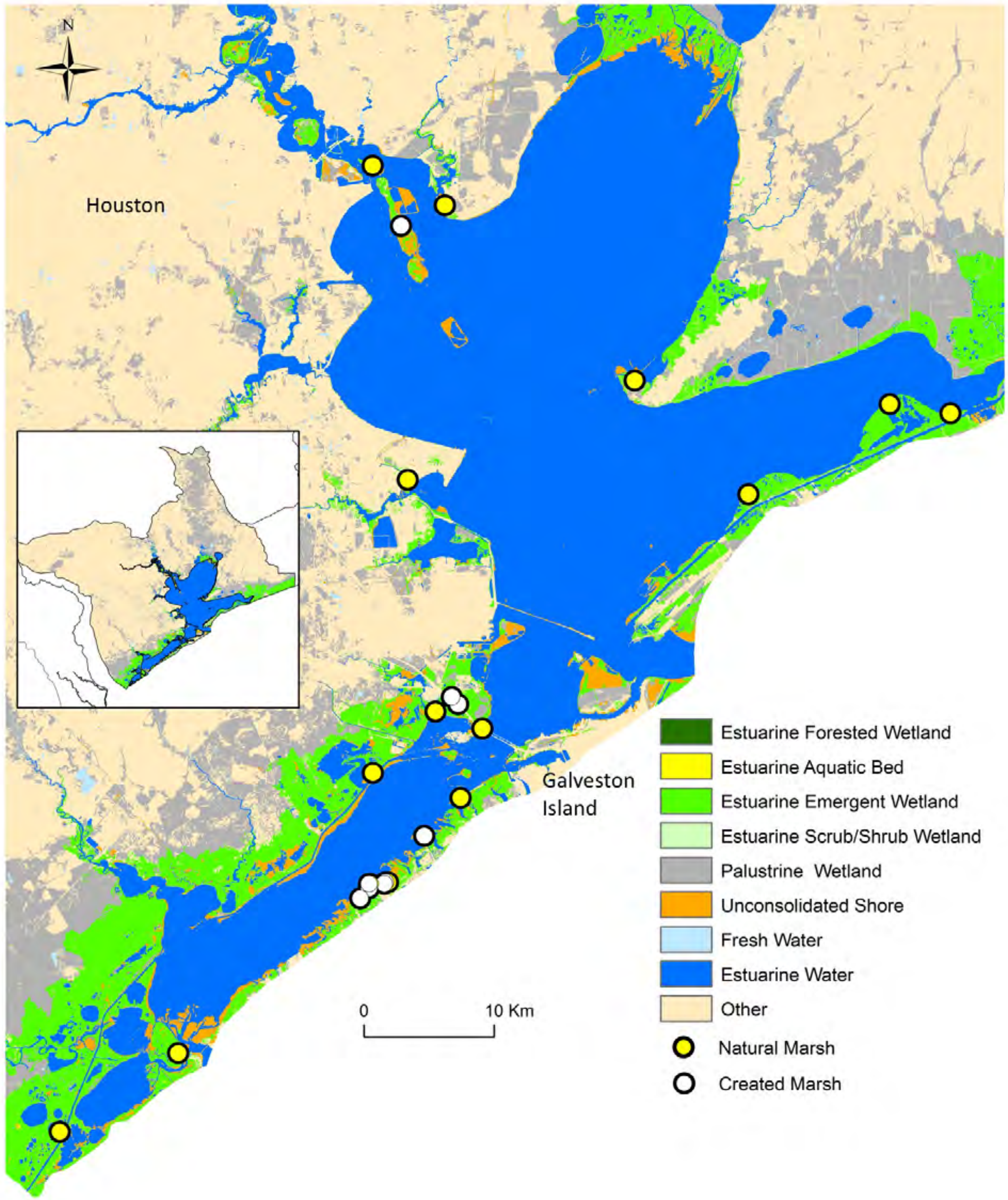
Appendix Figure 5. Fishery habitat in San Antonio Bay, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2. Locations also are shown where elevation and inundation were measured for natural marshes.



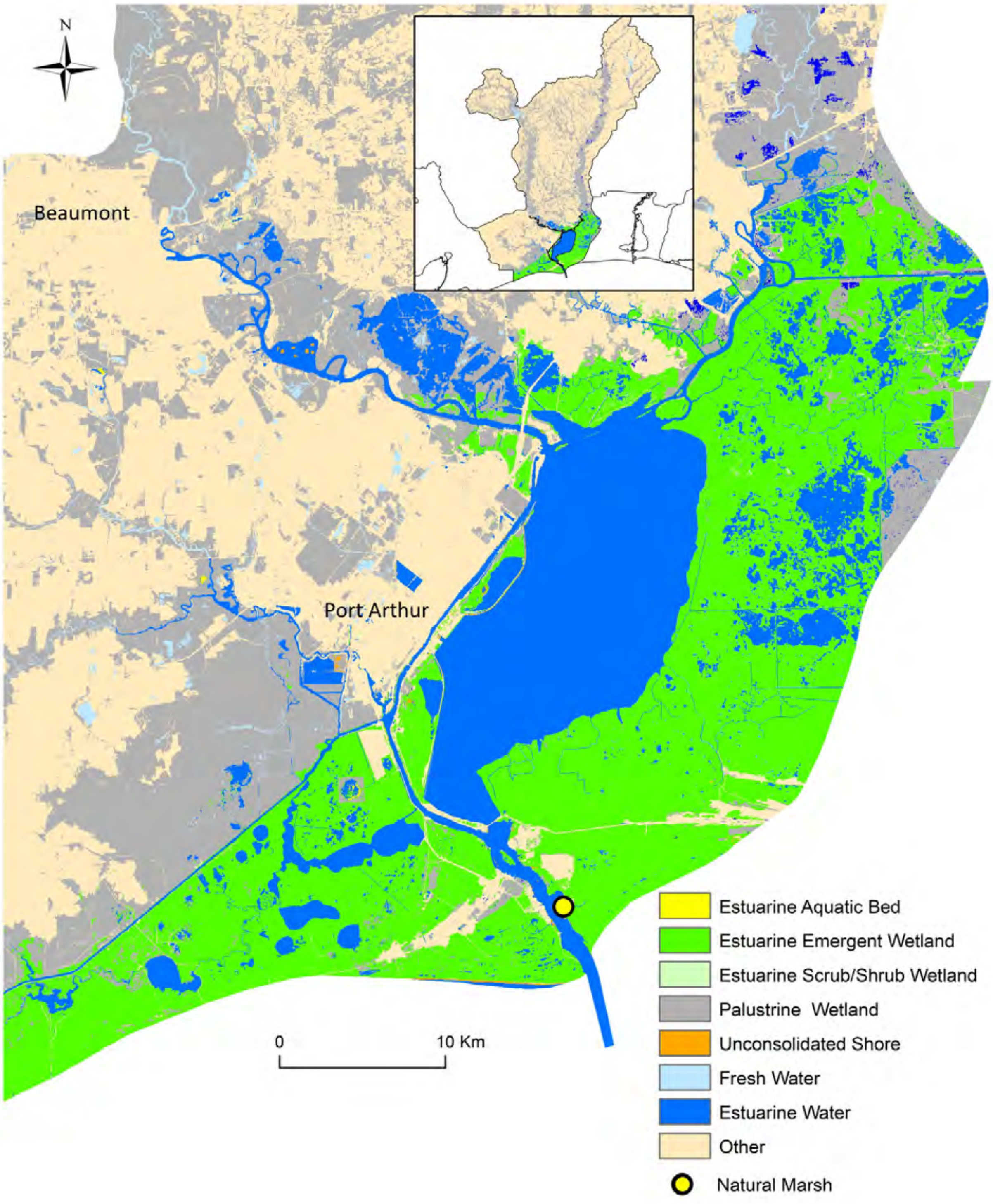
Appendix Figure 6. Fishery habitat in Matagorda Bay, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2. The location also is shown where elevation and inundation were measured for a natural marsh.



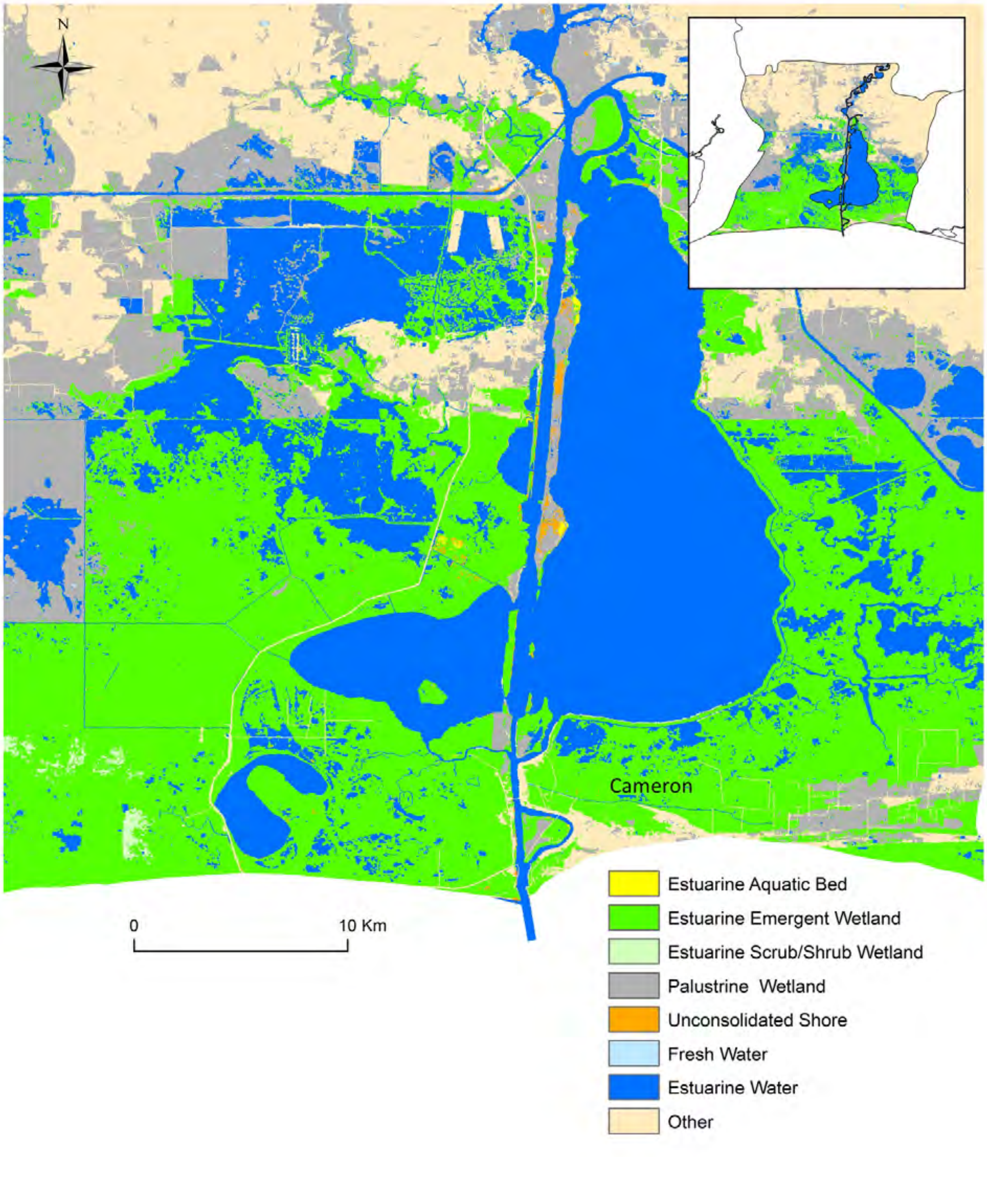
Appendix Figure 7. Fishery habitat in East Matagorda Bay, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2.



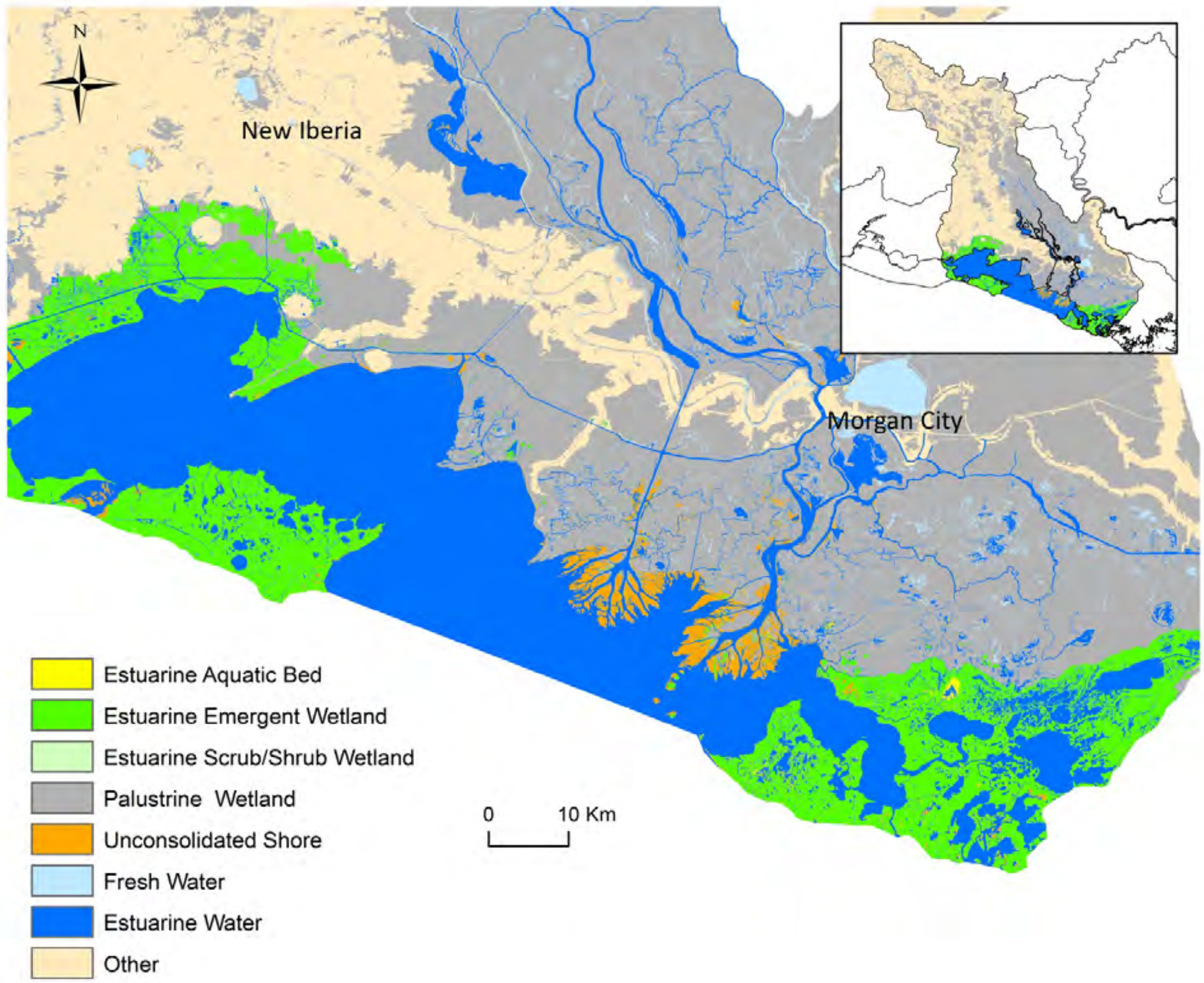
Appendix Figure 8. Fishery habitat in Galveston Bay, Texas based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2. Locations also are shown where elevation and inundation were measured for natural and created marshes.



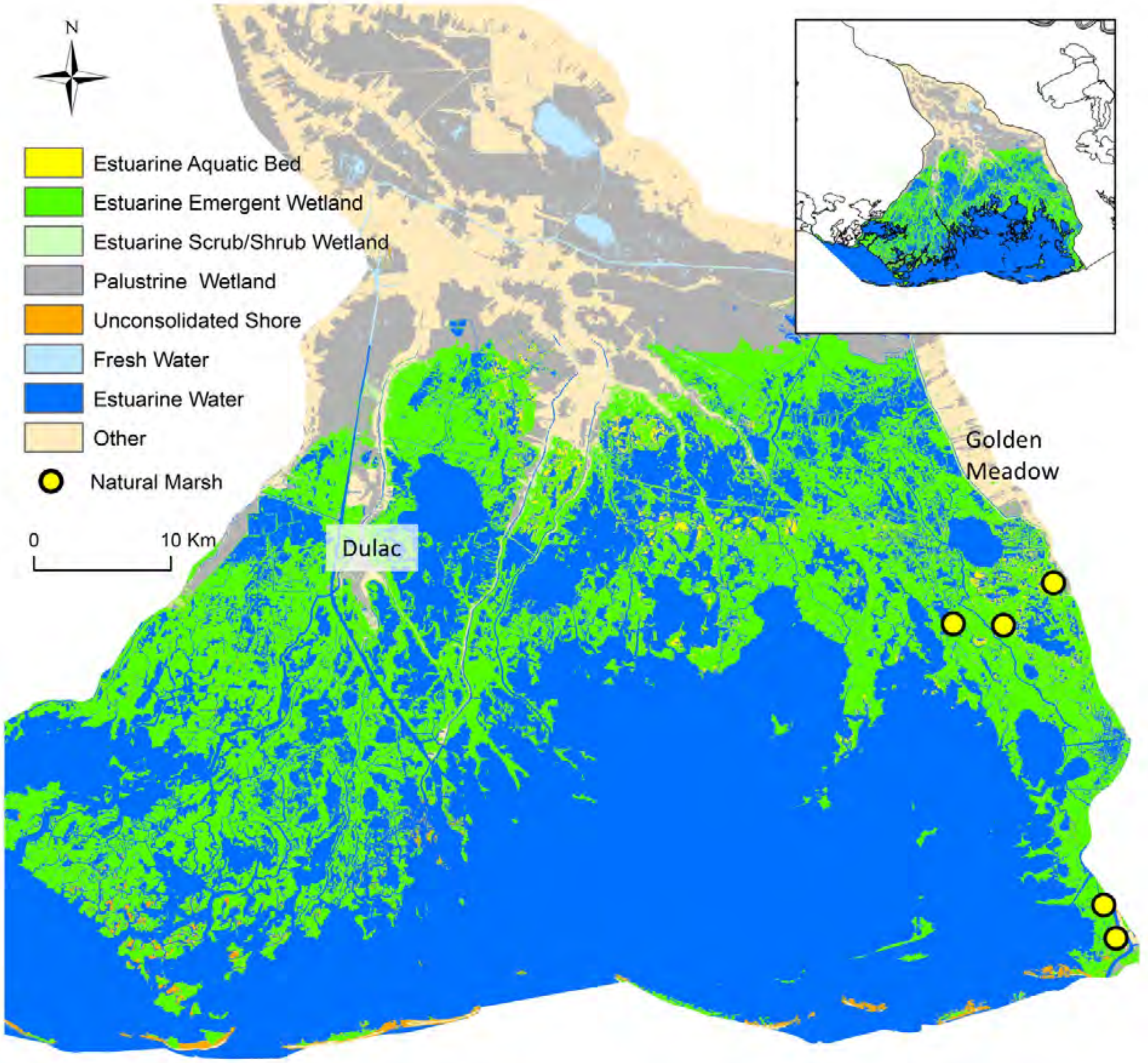
Appendix Figure 9. Fishery habitat in Sabine Lake on the Texas/Louisiana border based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2. The location also is shown where elevation and inundation were measured for a natural marsh.



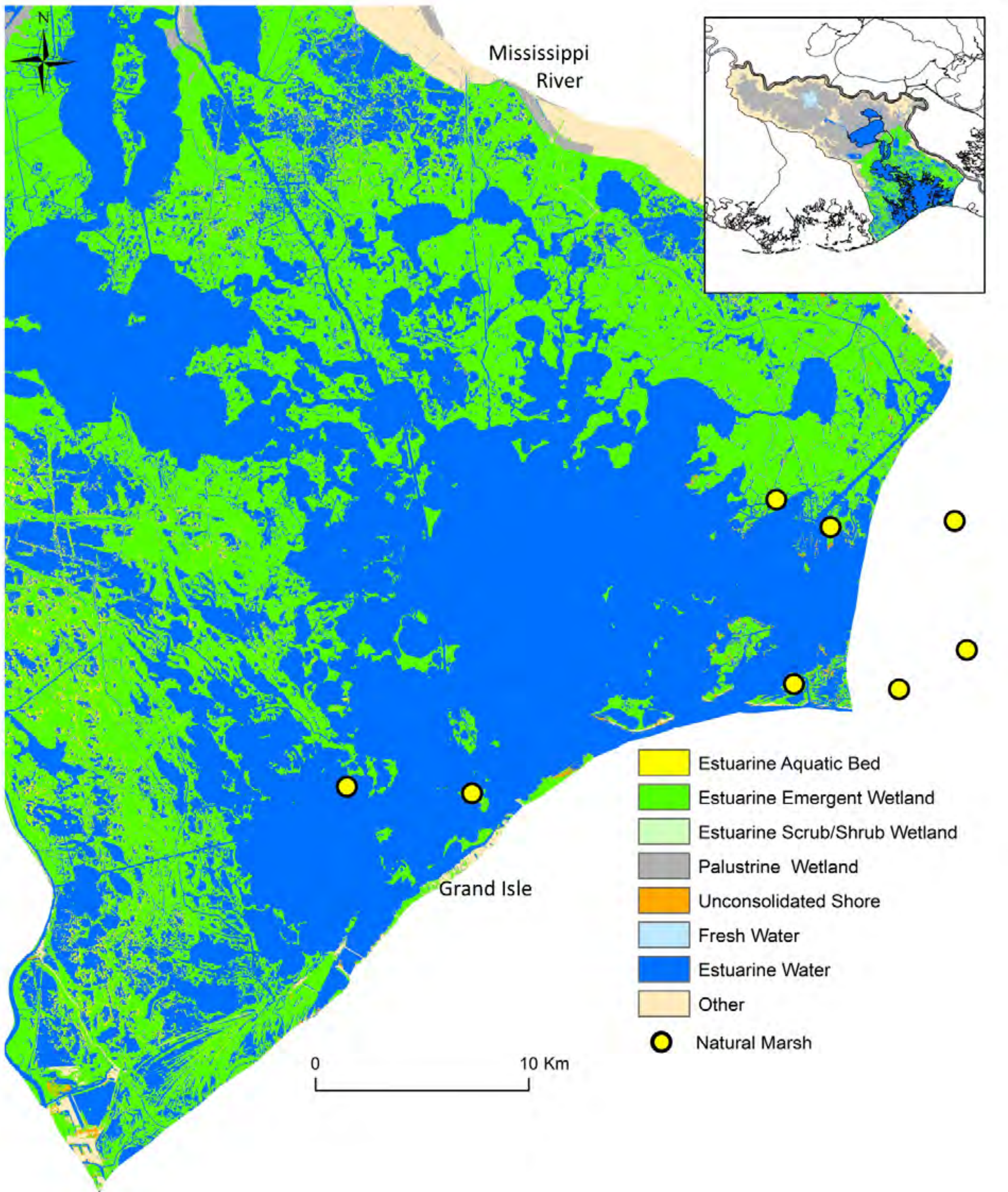
Appendix Figure 10. Fishery habitat in Lake Calcasieu, Louisiana based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2.



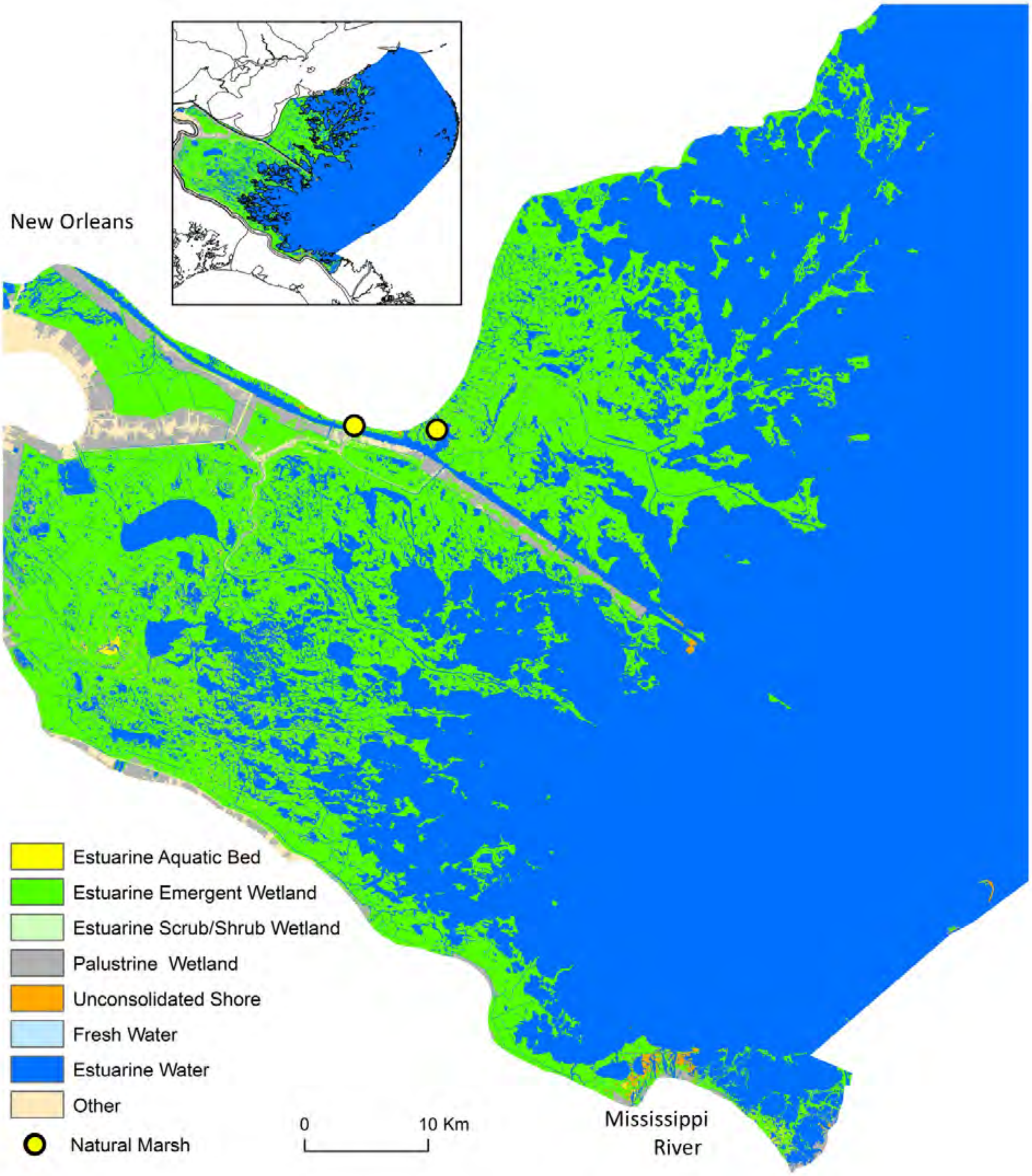
Appendix Figure 11. Fishery habitat in Vermilion-Cote Blanche Bays, Louisiana based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2.



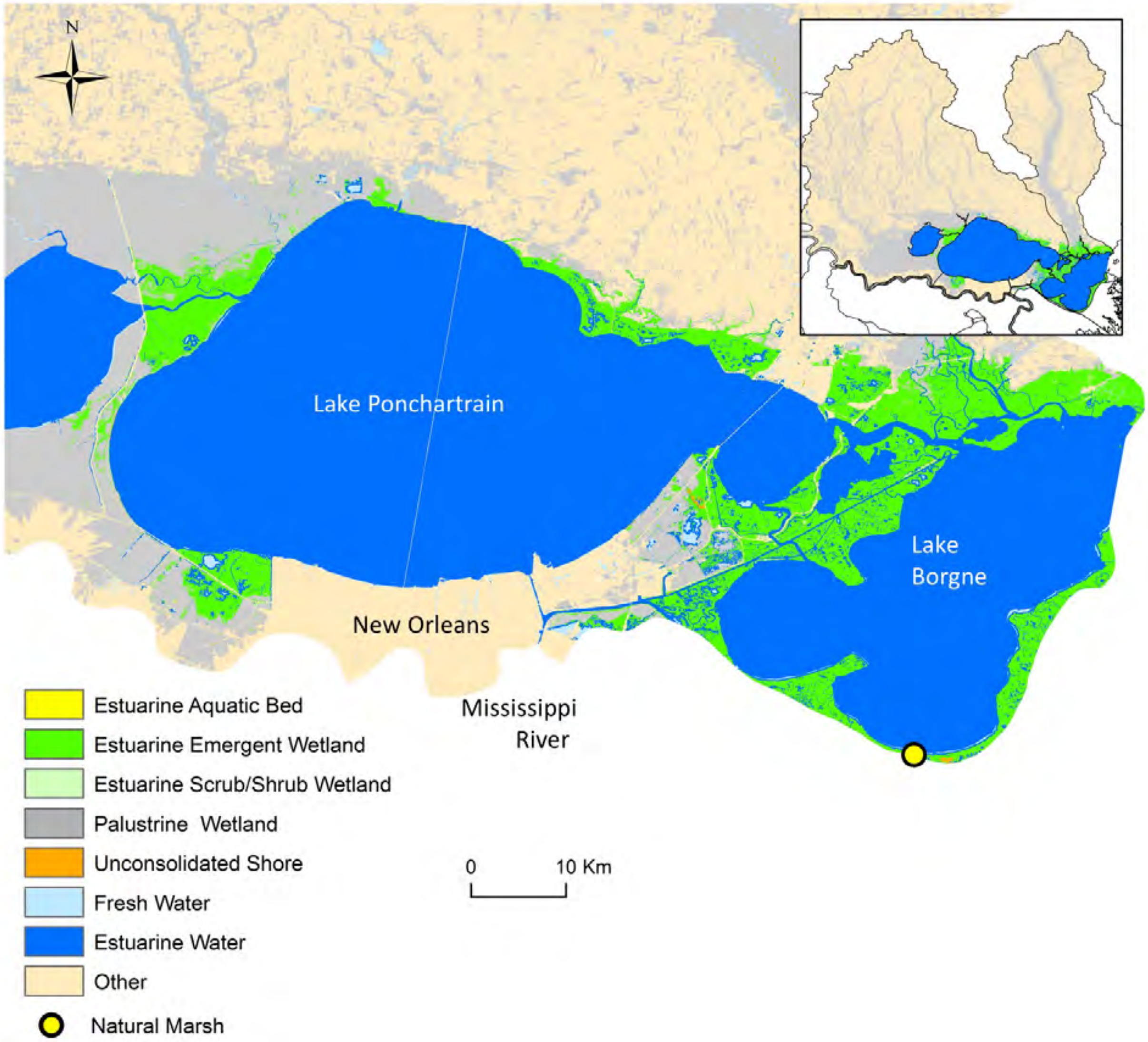
Appendix Figure 12. Fishery habitat in Terrebonne-Timbalier Bays, Louisiana based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2. Locations also are shown where elevation and inundation were measured for natural marshes.



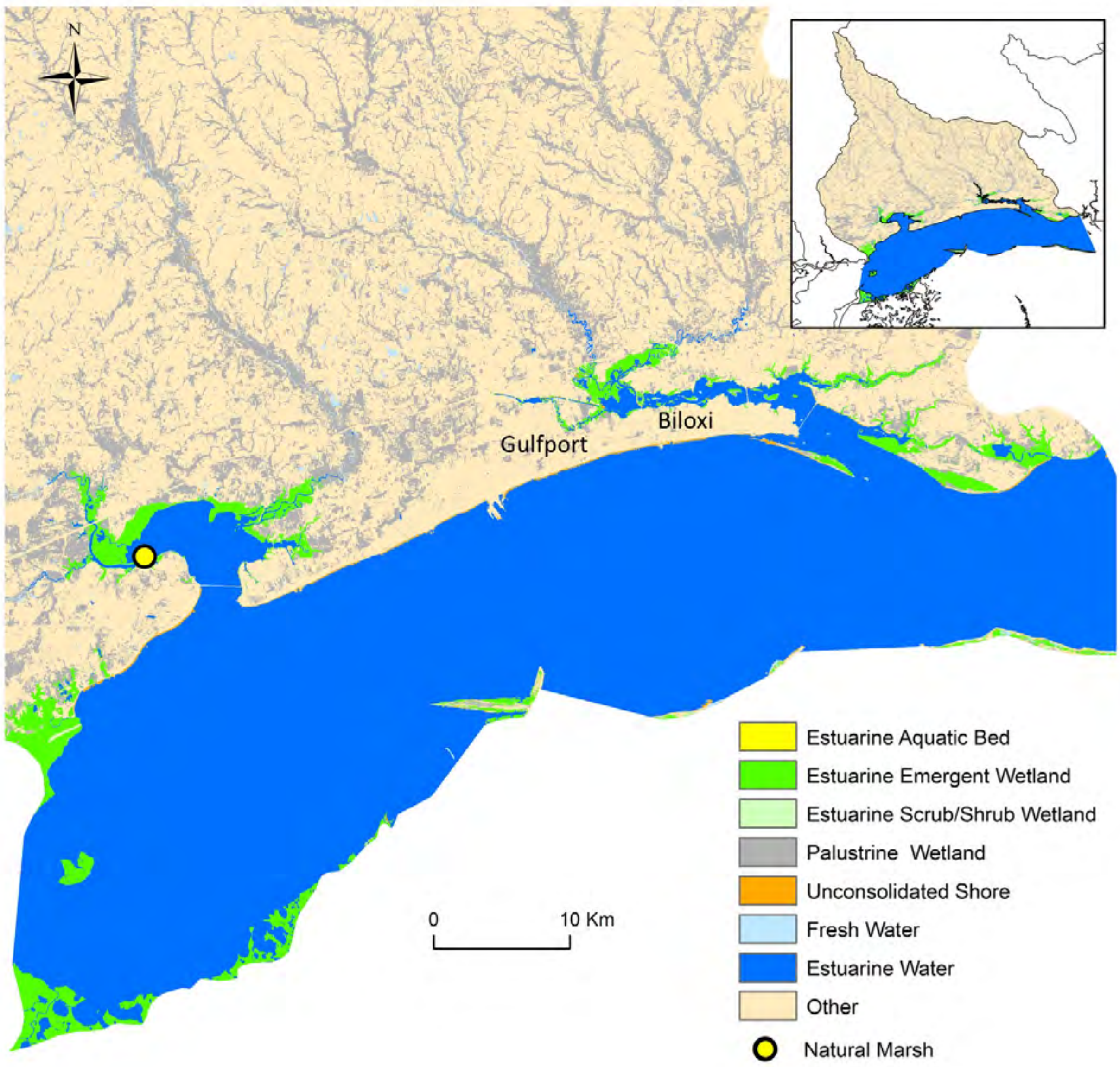
Appendix Figure 13. Fishery habitat in Barataria Bay, Louisiana based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 2. Locations also are shown where elevation and inundation were measured for natural marshes.



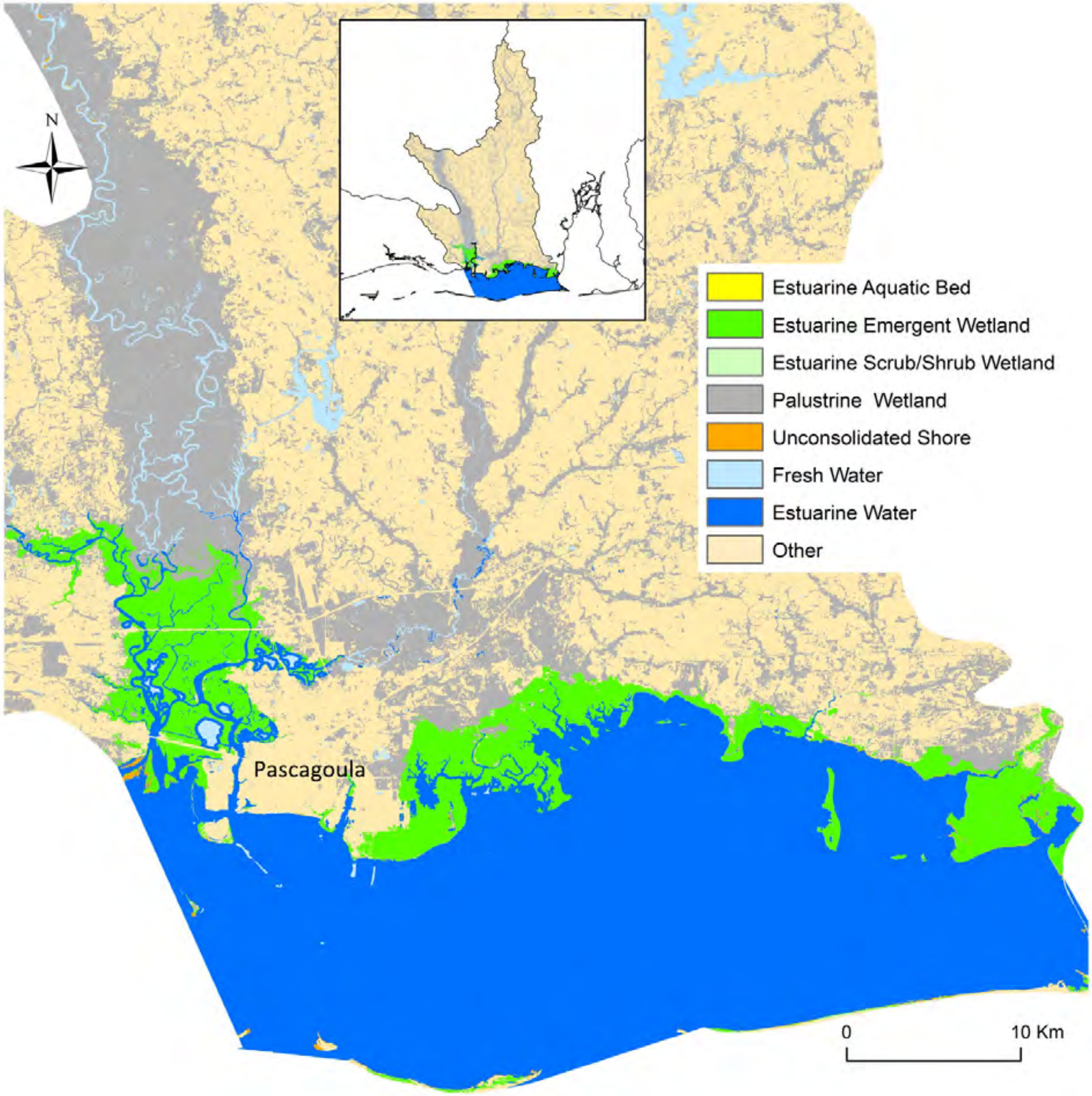
Appendix Figure 14. Fishery habitat in Breton-Chandeleur Sounds, Louisiana based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3. Locations also are shown where elevation and inundation were measured for natural marshes.



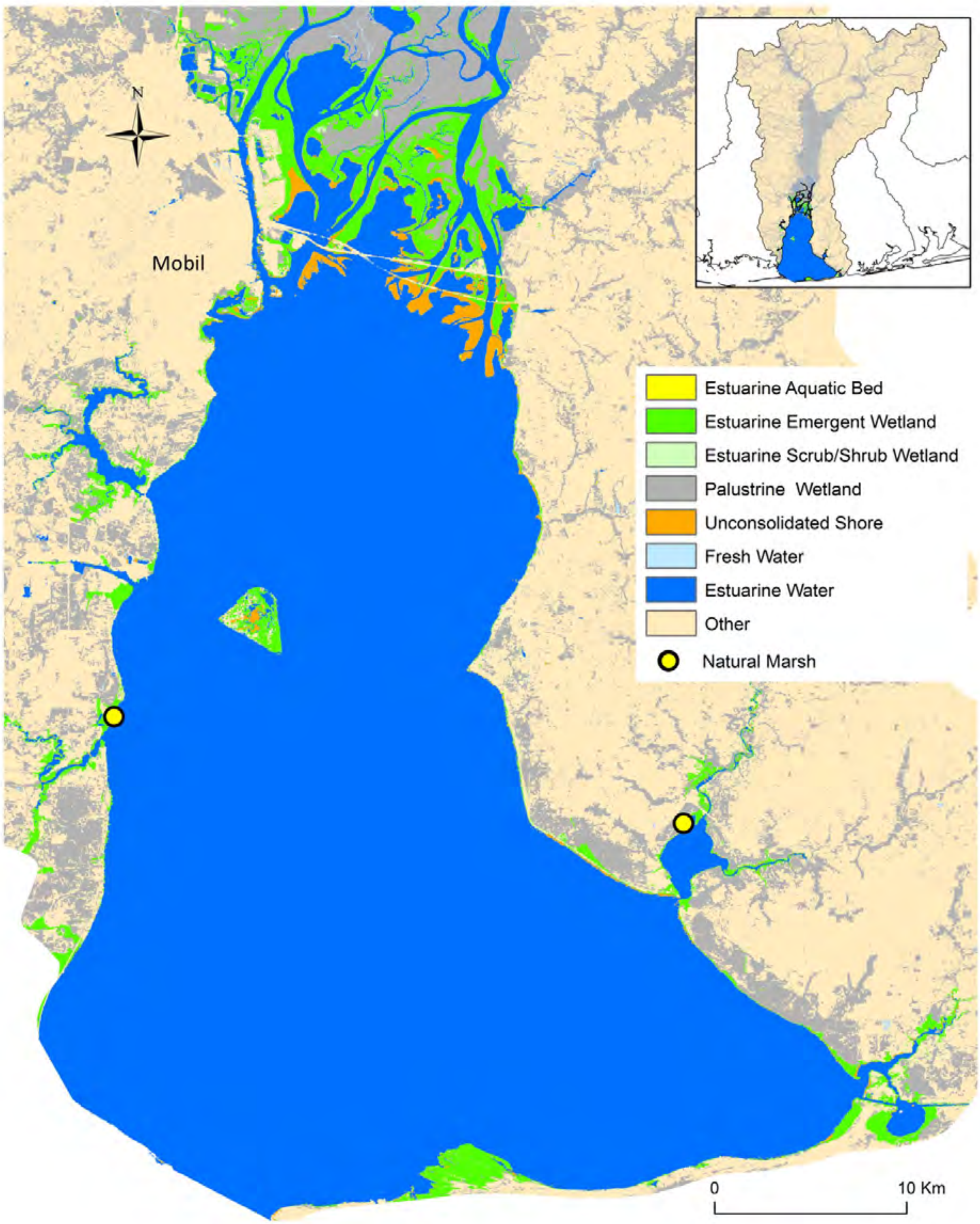
Appendix Figure 15. Fishery habitat in Lake Borgne, Louisiana based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3. The location also is shown where elevation and inundation were measured for a natural marsh.



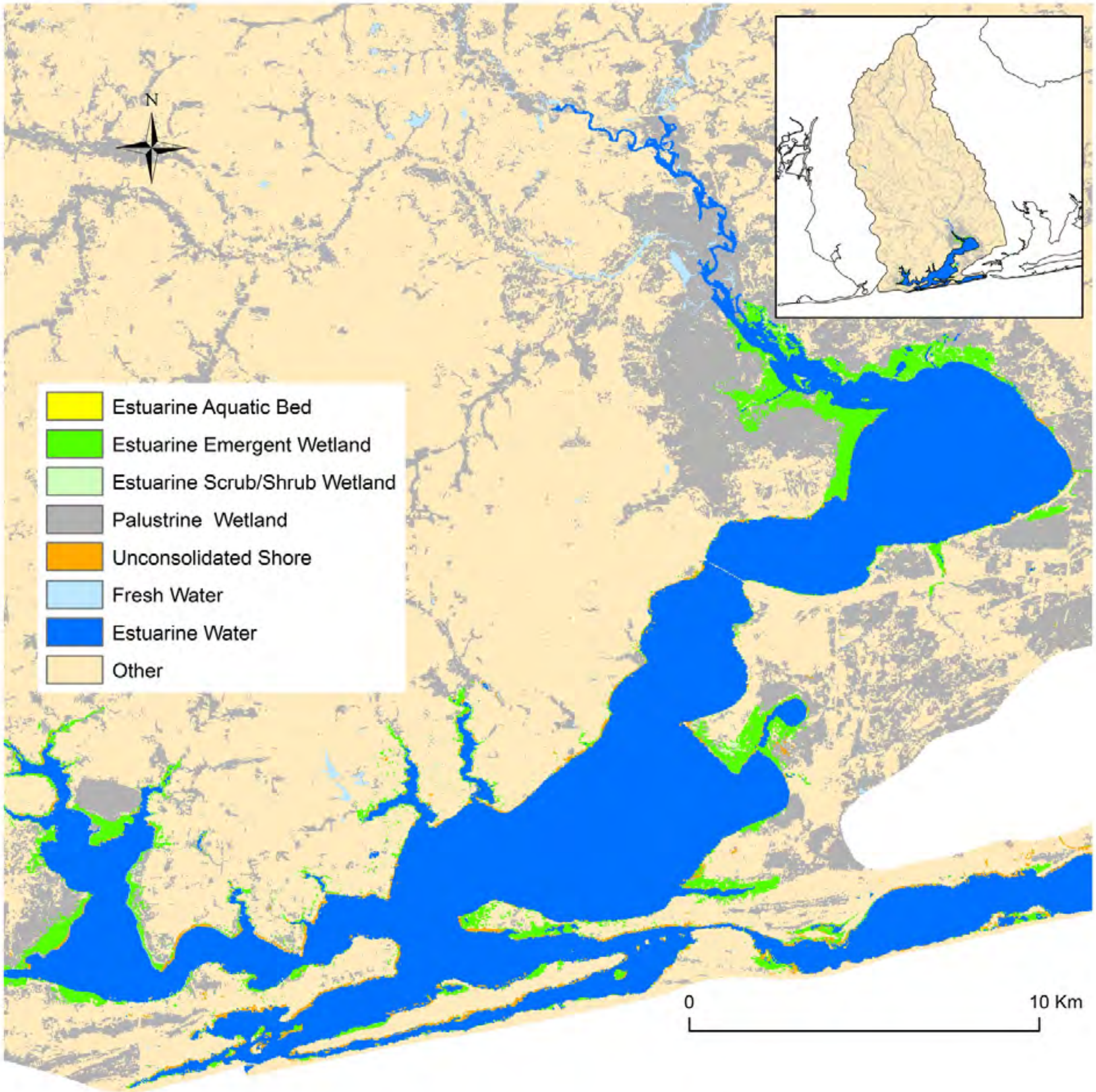
Appendix Figure 16. Fishery habitat in West Mississippi Sound based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3. The location also is shown where elevation and inundation were measured for a natural marsh.



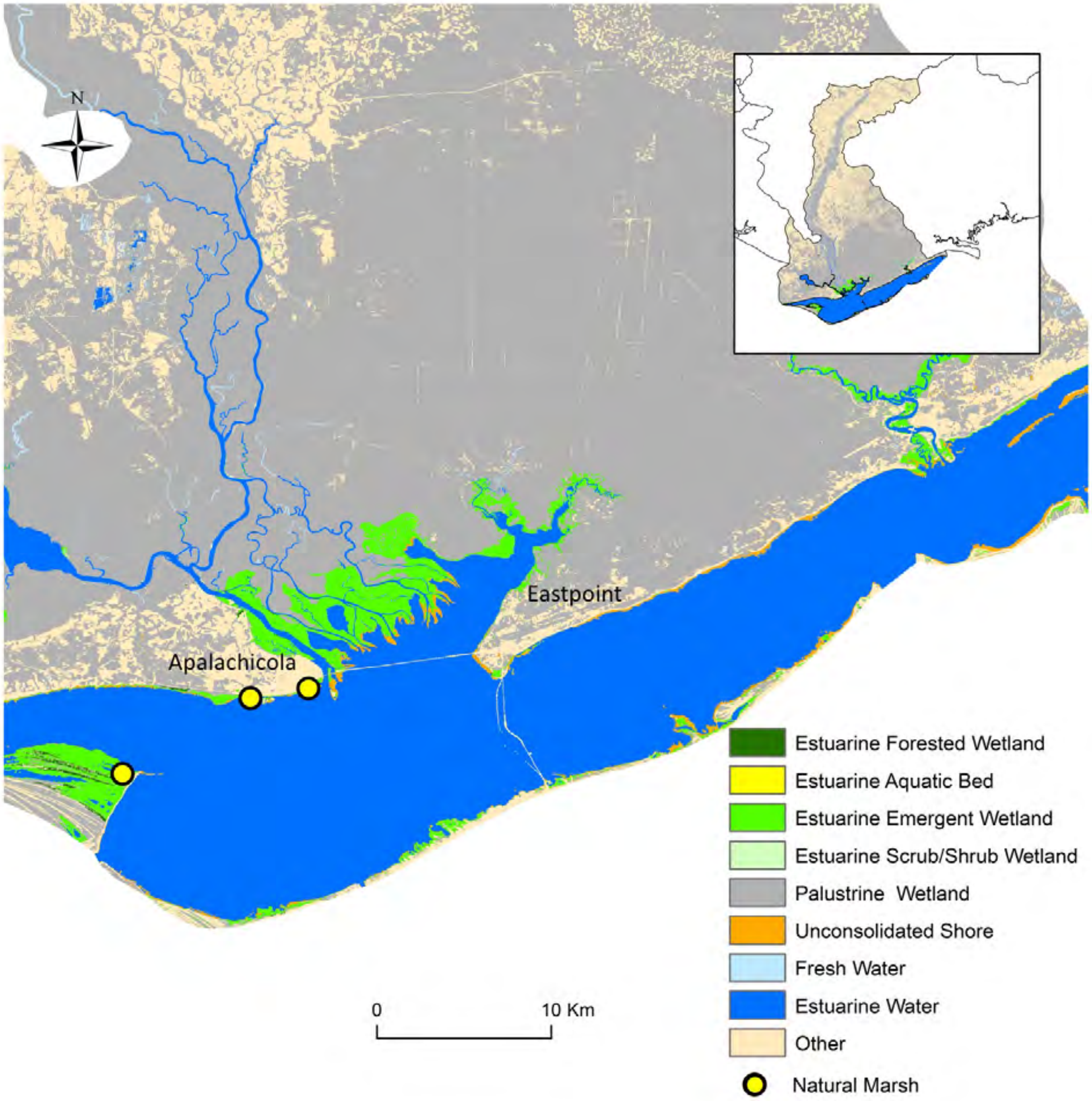
Appendix Figure 17. Fishery habitat in East Missisippi Sound based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3.



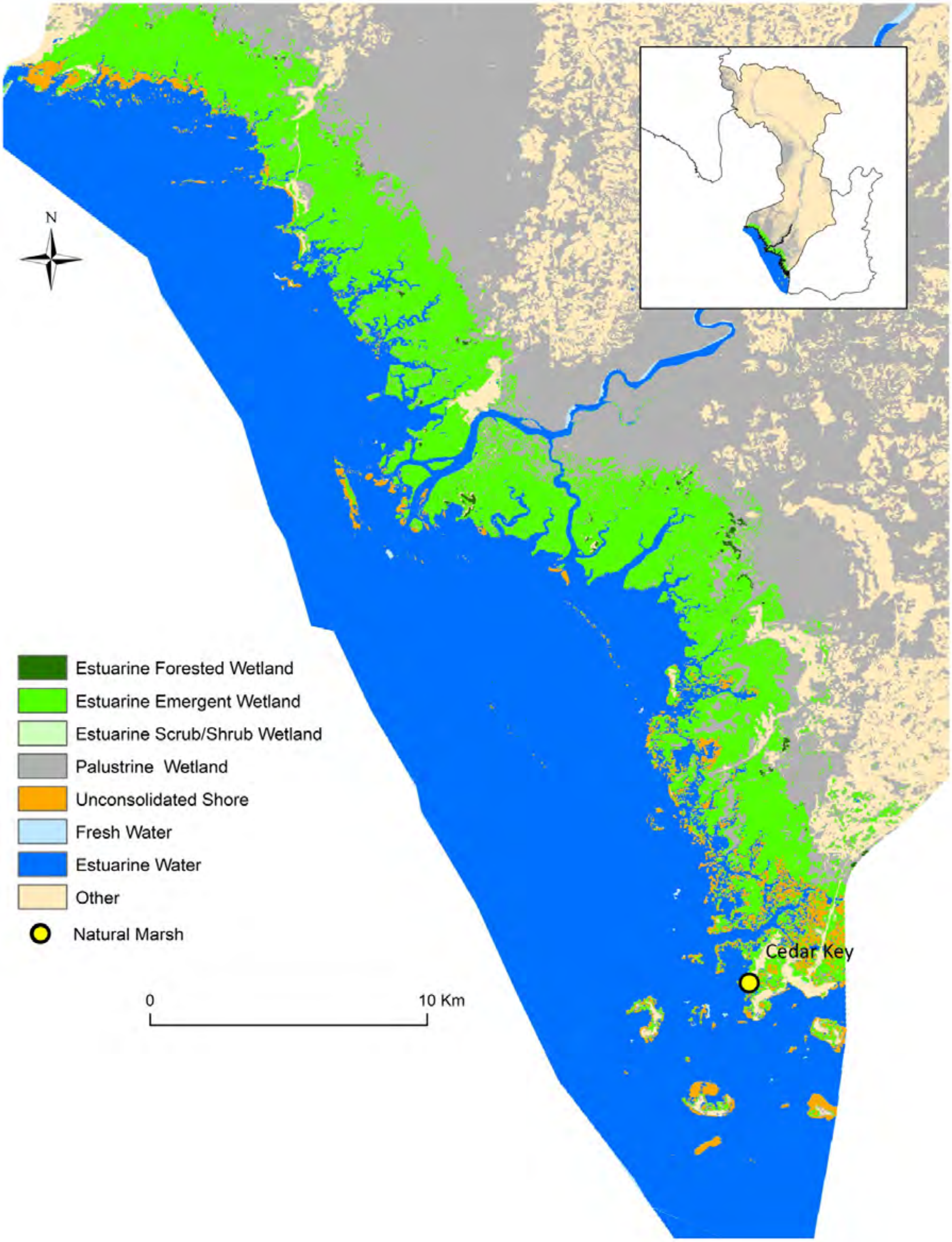
Appendix Figure 18. Fishery habitat in Mobile Bay, Alabama based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3. Locations also are shown where elevation and inundation were measured for natural marshes.



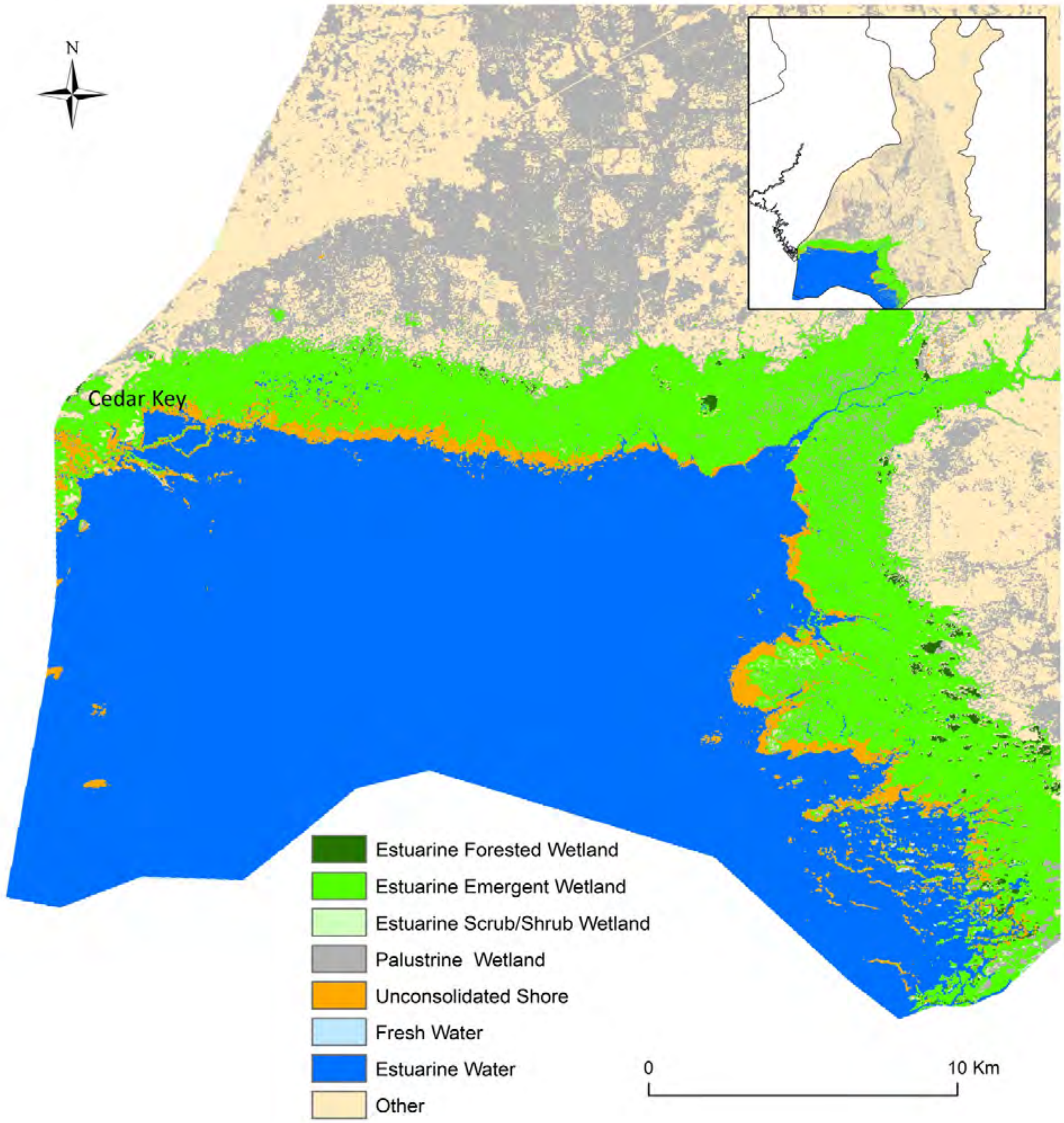
Appendix Figure 19. Fishery habitat in Perdido Bay, Florida based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3.



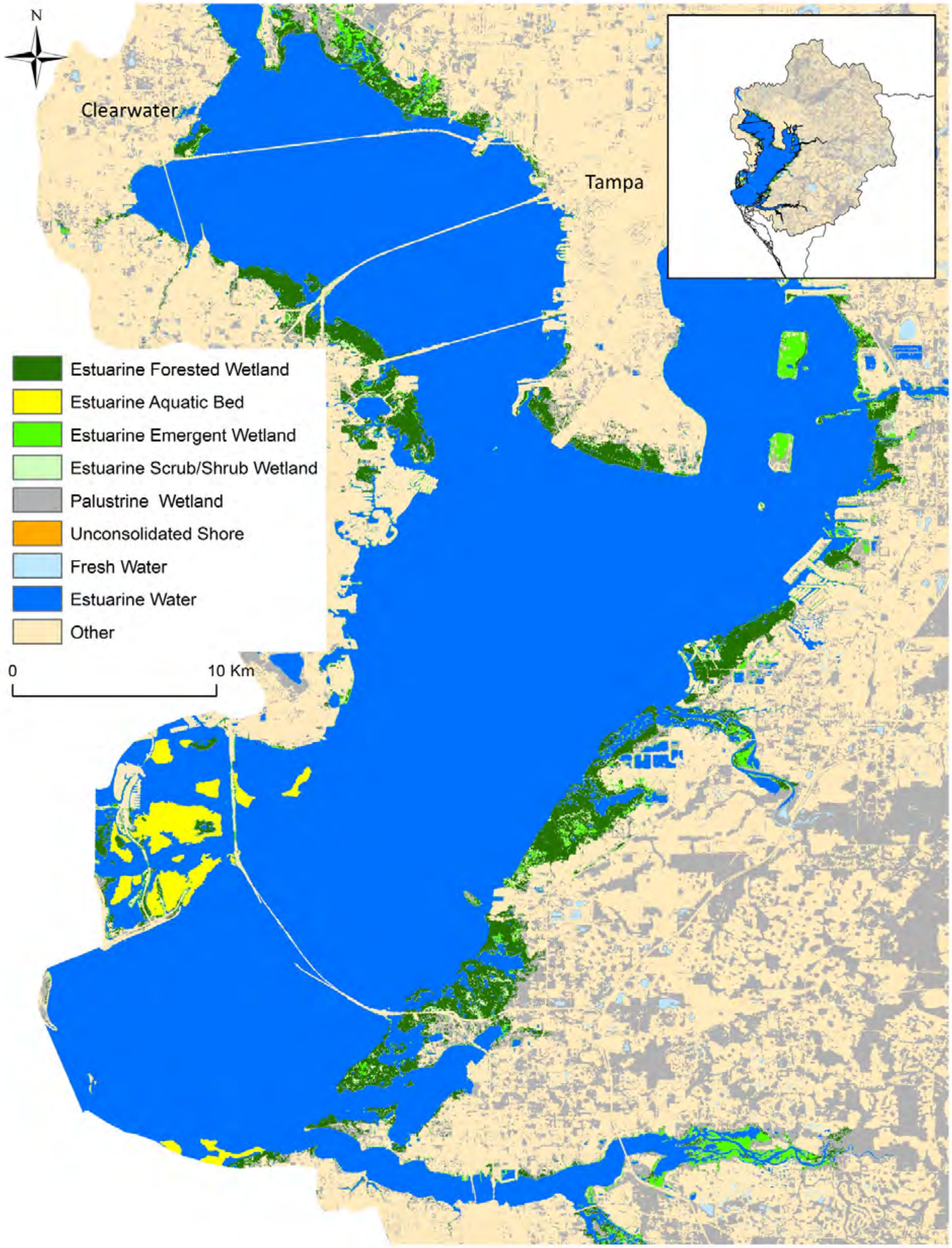
Appendix Figure 20. Fishery habitat in Apalachicola Bay, Florida based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3. Locations also are shown where elevation and inundation were measured for natural marshes.



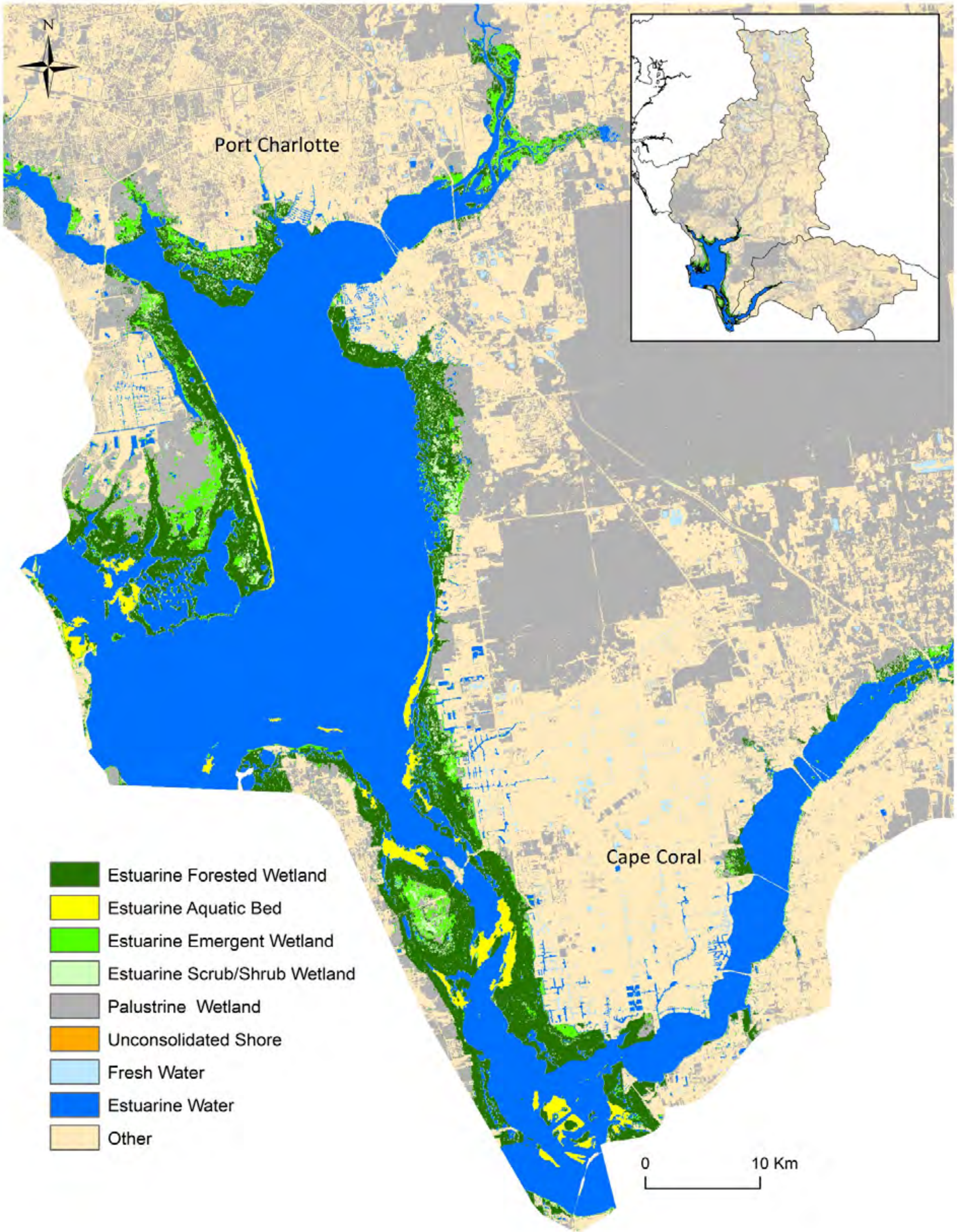
Appendix Figure 21. Fishery habitat in Suwanee Sound, Florida based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3. The location also is shown where elevation and inundation were measured for a natural marsh.



Appendix Figure 22. Fishery habitat in Cedar Key, Florida based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3.



Appendix Figure 23. Fishery habitat in Tampa Bay, Florida based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3.



Appendix Figure 24. Fishery habitat in Charlotte Harbor, Florida based on 2006 C-CAP data. Inset shows the entire Estuarine Drainage Area. The location of this EDA in relation to the northern Gulf of Mexico is shown in Figure 3.