Surface Elevation Table (SET) Inventory Gap Analysis

Spatially explicit recommendations for SET installation in the Northern Gulf of Mexico

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List of Acronyms

C-CAP: Coastal Change Analysis Program

CRMS: Coast Wide Reference Monitoring System

DEM: Digital Elevation Model

FLUCCS: Florida Land Use, Cover, and Classification System

GIS: Geographic Information System

NGO: Non-governmental organization

NGOM: Northern Gulf of Mexico

NOAA: National Oceanic and Atmospheric Administration

NWI: National Wetlands Inventory

SET: Surface Elevation Table

SLR: Sea Level Rise

USFWS: U.S. Fish and Wildlife Service

Abstract

Sediment elevation relative to sea level in coastal wetlands is a critically important factor in a variety of wetland conservation issues. Surface elevation tables (SETs) are mechanical levelling devices used to measure relative sediment elevation change in wetlands. SETs can be attached to deep and/or shallow benchmarks to capture elevation change relative to sea level, and are typically used in combination with marker horizons (MH) to measure vertical accretion, subsidence, and net elevation change at a very high resolution (±mm). The SET-MH approach plays an important role in developing coastal responses to sea level rise, disturbance, and management. This project follows up on a recent inventory of SET stations across all five Gulf states (TX, LA, MS, AL, and FL) in the northern Gulf of Mexico (NGOM), where 598 existing SET stations are identified. In order to better understand how SET stations can be utilized to characterize wetland vulnerability at local and regional scales, a gap analysis of the SET network is performed. This project involves a survey of scientists and land managers working on coastal wetland conservation issues, followed by a GIS-based gap analysis of the SET Inventory. This analysis identifies gaps in the SET Inventory, making spatially explicit recommendations for how the SET network can be strategically expanded to more effectively inform coastal wetland conservation and wetland response to sea level rise modeling.

Introduction

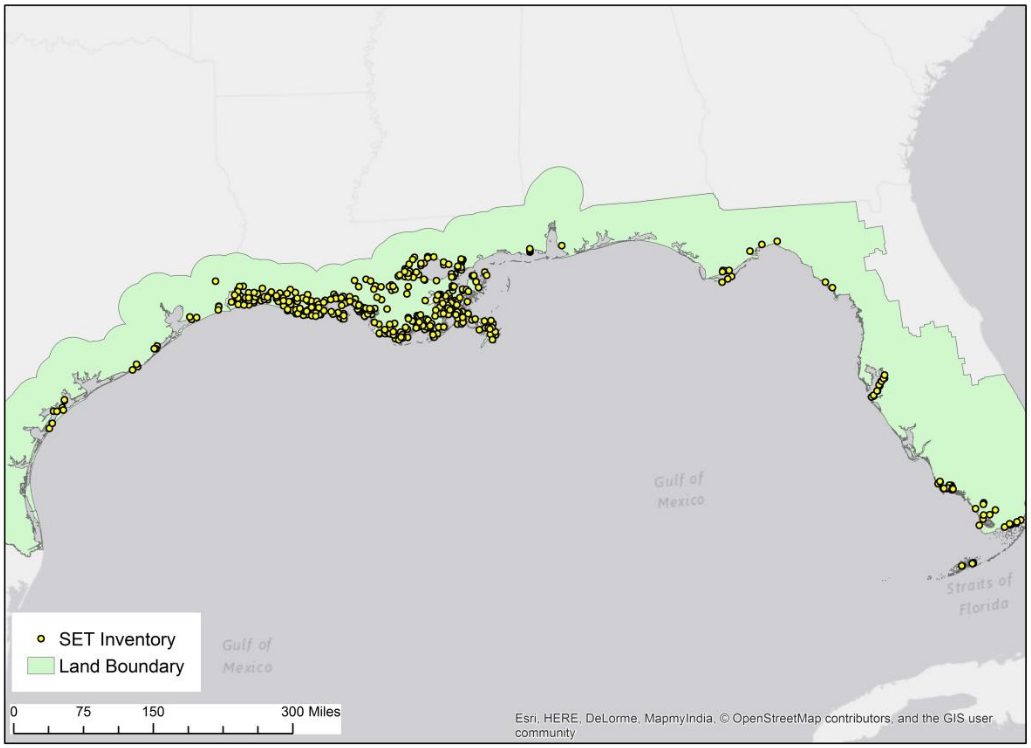
Surface Elevation Tables (SETs) are important tools in characterizing wetland vulnerability to sea level rise (SLR). A key factor of wetland vulnerability in the context of climate change is the extent to which the wetland surface can keep pace with SLR (Webb et al

2013). There are feedbacks driving wetland surface elevation change among allocthonous sediment inputs, plant growth, and inundation (Callaway et al 2013). A better understanding of the ecogeomorphic feedbacks driving this elevation change is of growing importance given the upward trend in sea level globally (Fitzgerald et al 2008). Morris et al (2002) use SETs to quantify and model the relationship between aboveground growth in salt marshes, and the elevation of the marsh platform relative to mean local sea level. Through the use of SETs they find that the elevation of the marsh platform is a function of the rate of aboveground growth and sediment-trapping by dominant macrophytes (Morris et al 2002). The accumulation of sediment is further supported by enhanced plant growth, a dual feedback that drives wetland sediment surface equilibrium with mean high water and mean sea level (Kirwan and Guntespergen 2009; Morris et al 2002). McKee (2011) employed SETs in two different mangrove environments in the Gulf of Mexico, finding that biotic processes are important controls on accretion and elevation change. These studies identify a high level of resiliency in coastal ecosystems regarding SLR, and the extent of this resiliency is critical to developing climate adaptation and mitigation strategies.

There is however a threshold to wetland adaptability in cases of too much inundation, or too little sediment input to the marsh (Kirwan et al 2010). Too much sediment accumulation and too little inundation will lead to a decline in wetland plant abundance due to competition with upland species (Callaway et al 2013). The SET is a critical tool used to quantify and characterize the direction and magnitude of vertical change of the wetland sediment surface (Cahoon et al 2002).

A recent inventory by researchers at the Northern Gulf of Mexico Sentinel Site Cooperative and USGS compiled data on all known SETs in the northern Gulf of Mexico (NGOM), covering an area from the Texas/Mexico border to the Florida Keys (See Figure 1).

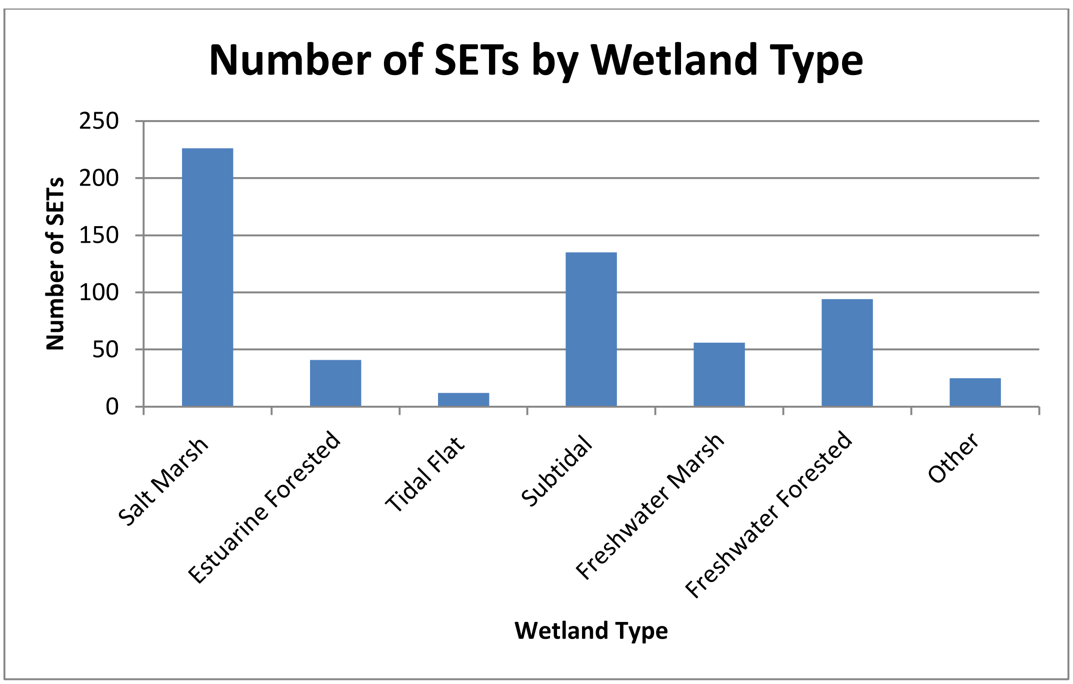
Figure 1: Inventory of SETs in the Northern Gulf of Mexico



The inventory found a total of 598 SETs across the NGOM, the majority (64%) of which are located in Louisiana. Furthermore, 76% of SETs are located in areas with high rates of sea level rise (>3.4mm/yr.), based on data derived from NOAA's National Water Level Observation Network. Louisiana also has some of the highest recorded rates of SLR in that region, thus contributing to the number of SETs in areas of high sea level change. 21.2% of SETs are located in areas with moderate SLR rates of 2.0-2.5 mm/yr., and 2.8% are in areas of low SLR with <1.8mm/yr. (NOAA 2016). SLR rates vary across the Gulf, with a range of 0-3 mm/yr. on the western coast of Florida, and 3-6 mm/yr. on the Texas Gulf coast (ibid).

Figure 2 shows the current distribution of SETs by wetland type across the NGOM, with the highest number located in salt marshes. Subtidal environments follow salt marshes terms of number of SETs, with 23% located in subtidal areas. Tidal flats have the lowest numbers of SETs, with 2% of stations located on those habitats.

Figure 2: SETs by Wetland Type



An ongoing project at the USGS and NGOM Sentinel Site Cooperative has compiled data on elevation, wetland type, temperature, and precipitation associated with the SET stations throughout NGOM. Gathering data on what is currently monitored with SETs is part of a broader attempt to create a regionally coordinated network, where regional-level inferences about wetland vulnerability to sea level rise can be drawn from site-specific SET observations (Webb et al 2013). The existing network of SETs in the NGOM is informal, the result of a variety of scientific projects and monitoring efforts (Cahoon et al 2006). A regional network of consistent and long term observations can help better inform the needs of scientists working on wetland and coastal vulnerability models, and land managers dealing with coastal wetlands (Webb et al 2013).

Project Goals and Scope

This project identifies spatially explicit gaps in the NGOM SET network, using a mixed methods approach to analyze the human and geospatial dimensions of the SET Inventory. The study area is the Unites States Gulf coast, extending from the Texas/Mexico border to Southern Florida. Building on the SET Inventory, this gap analysis uses important abiotic and biotic environmental gradients as suitability criteria to identify where priority zones are located on protected areas. The existence of a protected area is spatially defined by the U.S. Geological Survey's Protected Areas Database (USGS 2016). Information on the existence of gaps in the Inventory was explored through the implementation of a survey among stakeholders in coastal wetland conservation in the NGOM. The survey results help articulate what factors are missing and/or under-represented in wetland surface elevation monitoring, informing a spatially explicit analysis using Geographic Information Systems (GIS). Using the survey results to help define variables of interest that would indicate suitable SET locations, this project defines 4km^2 priority zones for additional SET monitoring, based on temperature, precipitation, elevation, land cover, and land ownership criteria.

This study finds spatially explicit gaps on publicly managed lands in the NGOM that can be filled with additional SET observations, contributing to better regional-scale data on wetland response to inundation and sea level rise. This report will first present the survey methods and results, followed by a discussion of the geospatial analysis methods. The results of the gap analysis are then presented, identifying areas suitable for SET network expansion.

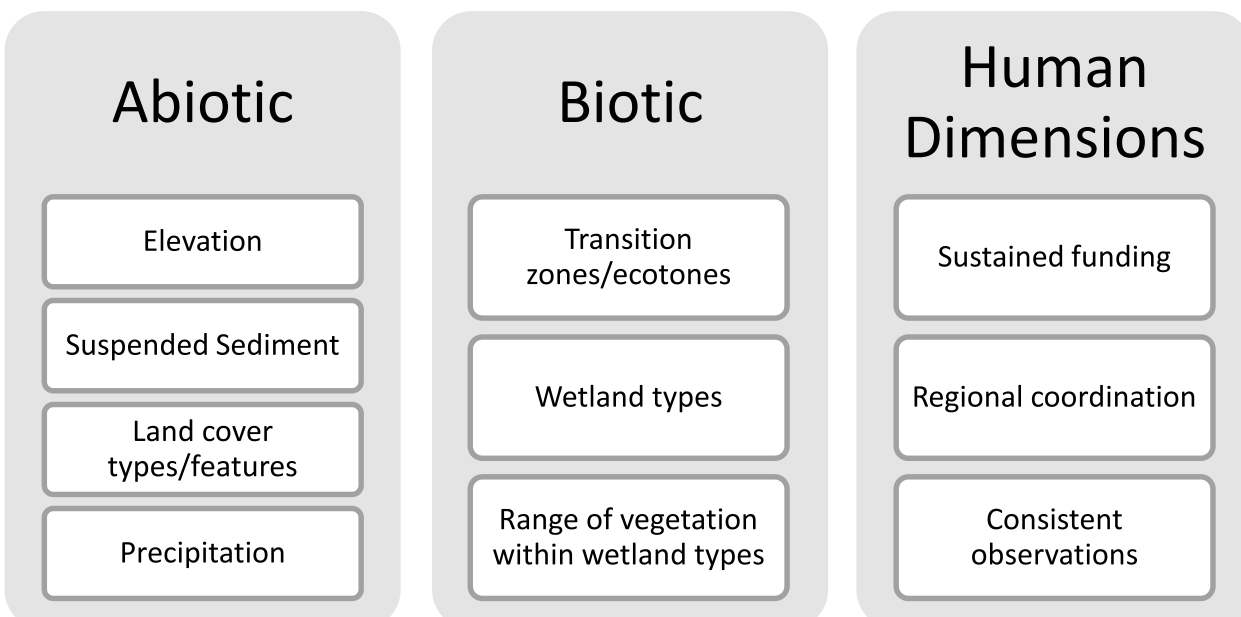
Survey Methods and Results

The methods utilized in this project were designed and vetted with help and support from experts at the U.S. Fish and Wildlife Service, the Northern Gulf of Mexico Sentinel Site Cooperative, U.S. Geological Survey, and other state, university, and NGO partners. These partners were crucial to the development of this project, providing advice, guidance, and data that helped shape the gap analysis. This project was developed in two parts: a survey of stakeholders in wetland conservation across NGOM, followed by a spatial analysis using GIS.

In order to evaluate the human dimensions of SET monitoring, a survey was designed to examine the needs and expectations of stakeholders in NGOM. Survey questions were written with the intent to illuminate how key stakeholders envision an ideal network of SETs in the Gulf that can provide comprehensive data for both wetland resilience modeling and land management activities. The survey design is non-probabilistic, using key informants instead of a random sample, because of the highly specialized nature of SET-based science (see Creswell 2014 for more on qualitative methods). Key stakeholders were selected to volunteer their participation in the survey based on their a) known involvement in SET-related science, or b) nature of work that would benefit from SET data. Survey respondents included scientists at universities, state and federal agencies, and NGOs. Survey questions were designed to encourage participants to articulate their opinion on how an ideal network of SETs would be distributed along spatial and environmental gradients. Examples of survey questions include: “*Are there gaps in the types of ecosystems or habitats represented by the current SET observation network? If so, list the ecosystem or habitat types that are in need of additional SET observation data:”* and “*How does the current network of SETs differ from an “ideal" network?”*

At a large scale, Mississippi, Alabama, and the Florida panhandle were the most frequently mentioned gaps in SET monitoring, with those areas cited in 17 of 27 survey responses. Key variables from the survey responses are displayed in Figure 3.

Figure 3: Survey Results



Elevation is the primary abiotic factor of interest, identified by 27% of respondents as needing more comprehensive SET coverage. Elevation is a driver of the distribution of vegetation and extent of the wetland, due to position in the tidal prism and accretionary dynamics (Cahoon et al 2006). Because of the site specific nature of many of the survey responses, identified variables driving environmental processes such as wetland transitions and vegetation zones are interpreted from the results. For example, instead of focusing on single responses concerning black needle rush (*Juncus roemerianus*) or marsh/mangrove transitions, temperature and precipitation are used as proxy variables driving changes in marsh type and marsh/mangrove migration. Suspended sediment is another critical variable that influences wetland morphology and resilience. Climatic variables, such as temperature and precipitation, drive many of the biotic factors listed in the survey, such as wetland ecotones, different wetland ecosystem types, and the range of vegetation within those ecosystems (Osland et al 2013; Osland et al 2014). Human dimensions identified in the survey include the need for sustained funding to support consistent SET observations over time. Because of the long time period necessary to establish reliable SET measurements (Cahoon et al 2002), sustained funding to support scientists to measure these devices is an important variable driving gaps in the network.

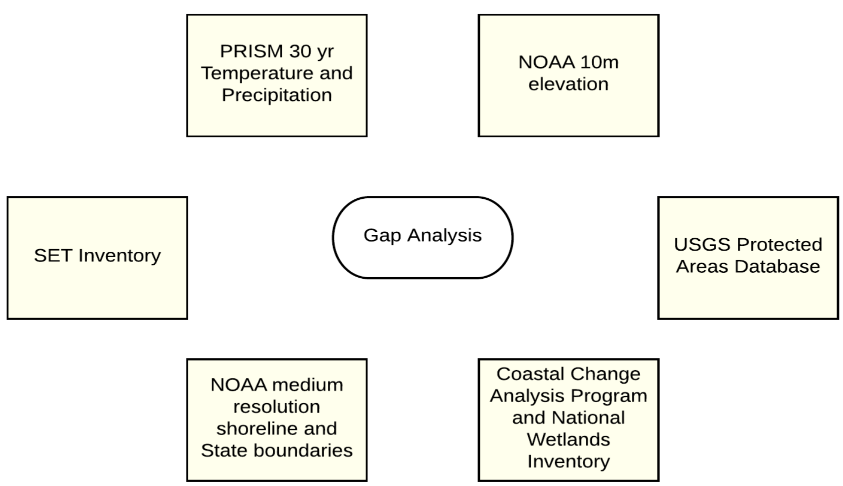
Gap Analysis Methods

The results of the survey provide guidance for the gap analysis regarding what variables to measure that will address the needs expressed by respondents. In order to identify spatially explicit areas for additional SET observations, an analysis is conducted using Geographic Information Systems (GIS). Layers of geospatial data are overlaid on top of one another, following the process outlined by Scott et al (1993). Scott et al (1993) develop a gap analysis methodology where datasets on vascular plant and vertebrate abundance are overlaid on land ownership data to better understand biodiversity management on public land. This methodology is transferable to wetland surface elevation because it enables the researcher to demonstrate where multiple criteria overlap regarding surface elevation monitoring. Using overlay techniques in ArcGIS, datasets representing elevation, temperature, wetland type, and protected area ownership are analyzed. Within these datasets, specific values are weighted inversely proportional in importance to the percentage of those variables covered in the SET inventory. In other words, those environmental variables in the spatial datasets *not* covered by SETs in the Inventory were given higher importance than those variables that were. Weights are calculated on a scale of 1 to 10, with 10 being the most important. For example, if 2% of SETs are located in a given .25m interval of elevation, that bin is categorized with a scale factor of 8, whereas a bin with 0% of SETs receives a scale factor of 10. Therefore, each .1 increment of value in a given dataset is assigned a value from 1 to 10 representing a scale factor.

Overlapping areas with shared scale factors (from temperature, precipitation, and elevation datasets) are written to output files, defining $4km^2$ priority zones for SET monitoring. These zones define areas of spatial priority for additional SET installation that would not only expand the network, but also provide useful information about environmental gradients of interest throughout the NGOM. Wetland types are determined using NOAA's coastal change analysis program (C-CAP), and the National Wetlands Inventory (NWI). In the case of Florida, the Florida Land Use, Cover, and Forms Classification System (FLUCCS) dataset is employed because of its fine-scale resolution (10m). These wetland types are then defined within public lands, using the USGS Protected Areas Database (PAD). An intersect function is applied to the PAD and Priority zones. This step identified potential locations suitable for addition SET monitoring are located on publicly managed lands. Coordinates are determined for the centroid of each pixel, allowing for navigation to these areas of interest by SET operators. Louisiana is not included in the final analysis because of the level of coordination already achieved by the Coast Wide Reference Monitoring System (CRMS, http://lacoast.gov/crms2/home.aspx), as well as suggestions by 15% of survey respondents that coastal Louisiana is already sufficiently monitored with SETs. Ongoing monitoring efforts in Louisiana's fragile coastal wetlands are strong at the time of this writing. Any region of the NGOM not displayed in the maps presented in this report does not contain areas deemed suitable for additional SET installation.

The survey results, summarized in Figure 2, provided details on which areas and what types of environmental variables would benefit from additional and/or more comprehensive SET observations. Figure 4 displays the different data sets used in the gap analysis, which the survey results helped identify.

Figure 4: Input GIS Datasets



The PRISM climate datasets, created at Oregon State University, contain absolute minimum recorded temperature values for 1981-2010 in 4km^2 pixels across the NGOM coastline; this variable determines the extent of mangrove ecosystems because of their frost intolerance, as well as the potential climatically appropriate areas for marsh-mangrove transitions (Osland et al 2013). PRISM also contains 30 year mean precipitation (mm) for the NGOM coast, which drives the potential for coverage of different foundational wetland plant communities (Osland et al 2014). NOAA 1/3 arc second (10m) elevation data are used to analyze how well the SET network is distributed across elevation gradients in coastal wetlands. The elevations of existing SETs are established in relation to local tidal datums, using information from NOAA's VDatum database.

Elevation

The elevation distribution of the existing SET Inventory is analyzed (See Figure 5), using NOAA tidal datum regions in order to determine the elevation of SETs relative to local mean higher high water (MHHW). Local tidal information provides fine-scale elevation measurements, which are necessary because the direction and magnitude of relative SLR, accretion, and subsidence are not uniform across wetlands (Lane et al 2006).

Figure 5: SET Elevation Relative to Local Tidal Datum

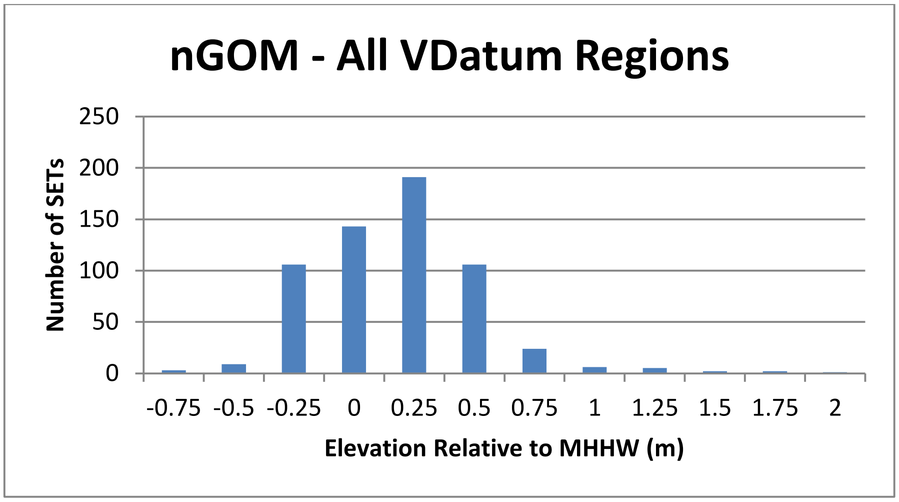


Figure 5 illustrates how the majority of SETs are clustered around .25m above MHHW. In an ideal network they would be distributed more evenly across each elevation bin, in order to provide the most comprehensive amount of information regarding elevation gradients in coastal wetlands. The distribution of SETs based on the local tidal datum is displayed in Figure 6. With the exception of the Louisiana and West Florida local tidal datums, it is clear from Figure 6 that the SET network throughout the NGOM is in need of more equal coverage of local elevation gradients, in order to help characterize wetland response to sea level rise more effectively in those areas. The spatial extent of the SET Inventory based on Vdatum region is mapped in Figure 7.

Figure 6: SETs by Local Tidal Datum

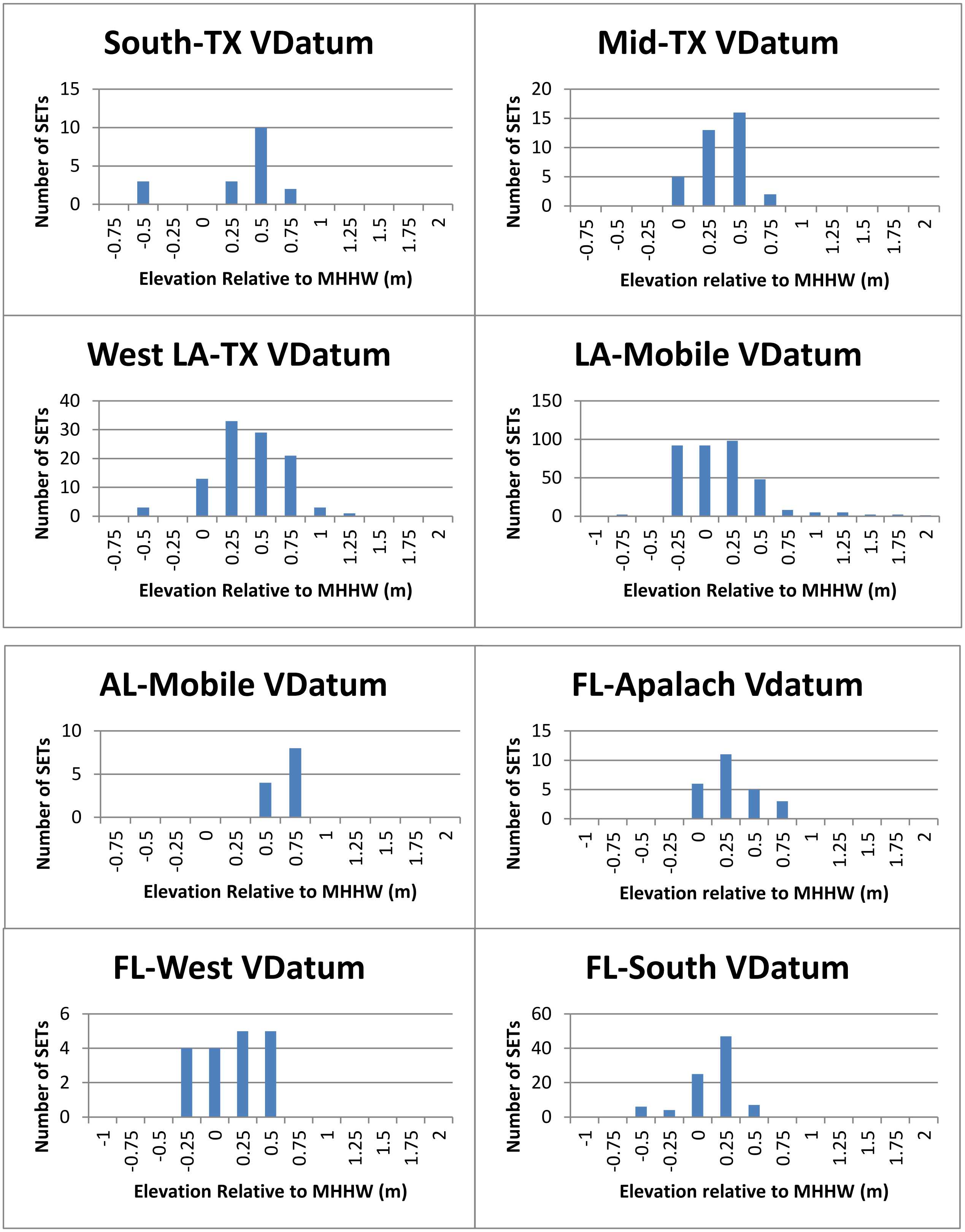


Figure 7: SETs by VDatum Region in the NGOM

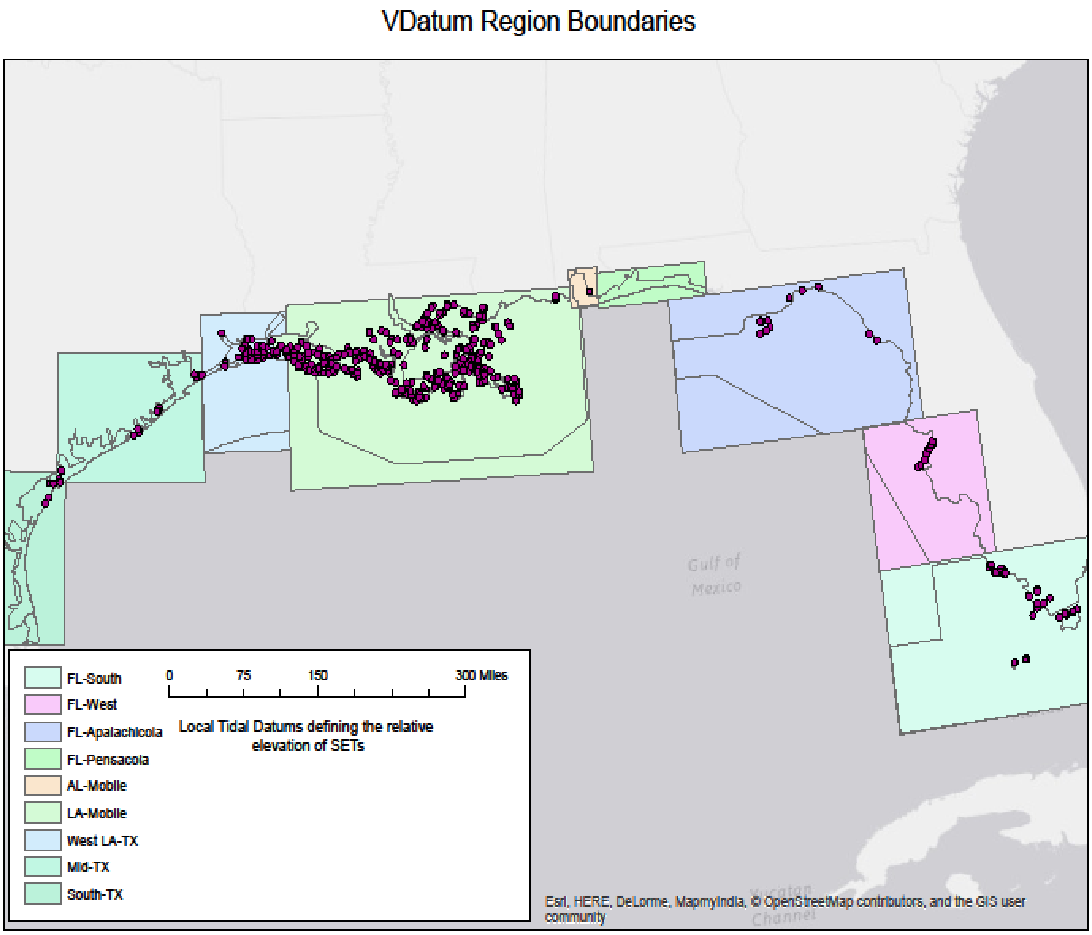
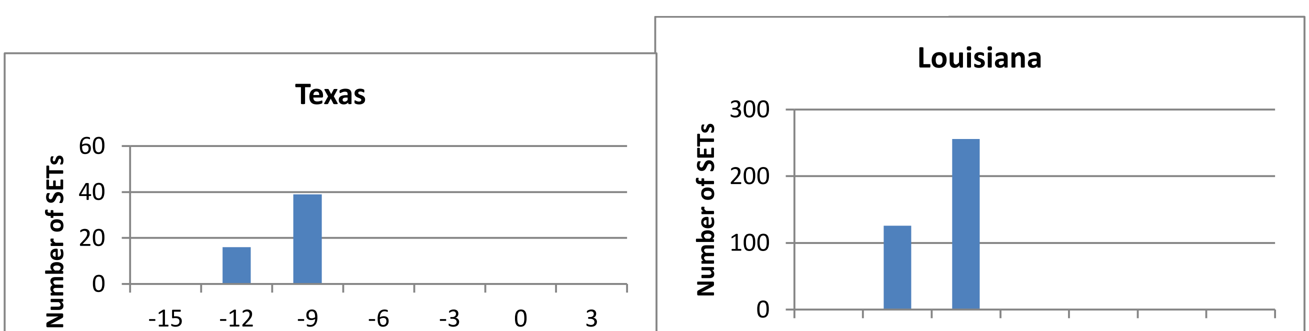


Figure 7 lays out the distribution of SETs relative to local tidal datum, providing visual insight into existing gaps in the SET Inventory. The southern and mid-Texas coast stands out as a region with inconsistent coverage of elevation gradients, as well as Mississippi, Alabama, the Florida Panhandle, and southern Florida. Additionally, the Florida-Pensacola tidal datum does not contain any inventoried SETs and therefore is not shown in Figure 6. Maps of the raw elevation data are shown in Appendix A, and are displayed at the scale of the data tiles produced by NOAA that were used as inputs for the gap analysis.

Temperature

Temperature is another important indicator of suitable SET monitoring zones, because of the significant effects of temperature change on the distribution and composition of tidal saline wetlands in temperate-tropical transition zones (Osland et al 2013). The distribution of SETs by temperature zone within each Gulf state is displayed in Figure 8. The frequency distribution uses 3 °C bins, based on Osland et al (2013), who studied the relationship between coastal wetland foundation species and temperature. Osland et al (2013) demonstrate a marsh-mangrove transition zone exists between -9 and -6 °C; however the SET Inventory contains no stations in that temperature category. This is a critical gap which is spatially prioritized in this study; Figure 9 shows where this transition zone is located on the Gulf Coast. Areas in this temperature zone are subject to significant change in wetland foundation species (Osland et al 2013), and SET monitoring will help scientists and land managers quantify the vertical response of these changing wetlands to sea level rise.

Figure 8: SETs by Minimum Recorded Temperature (°C) 1982-2010



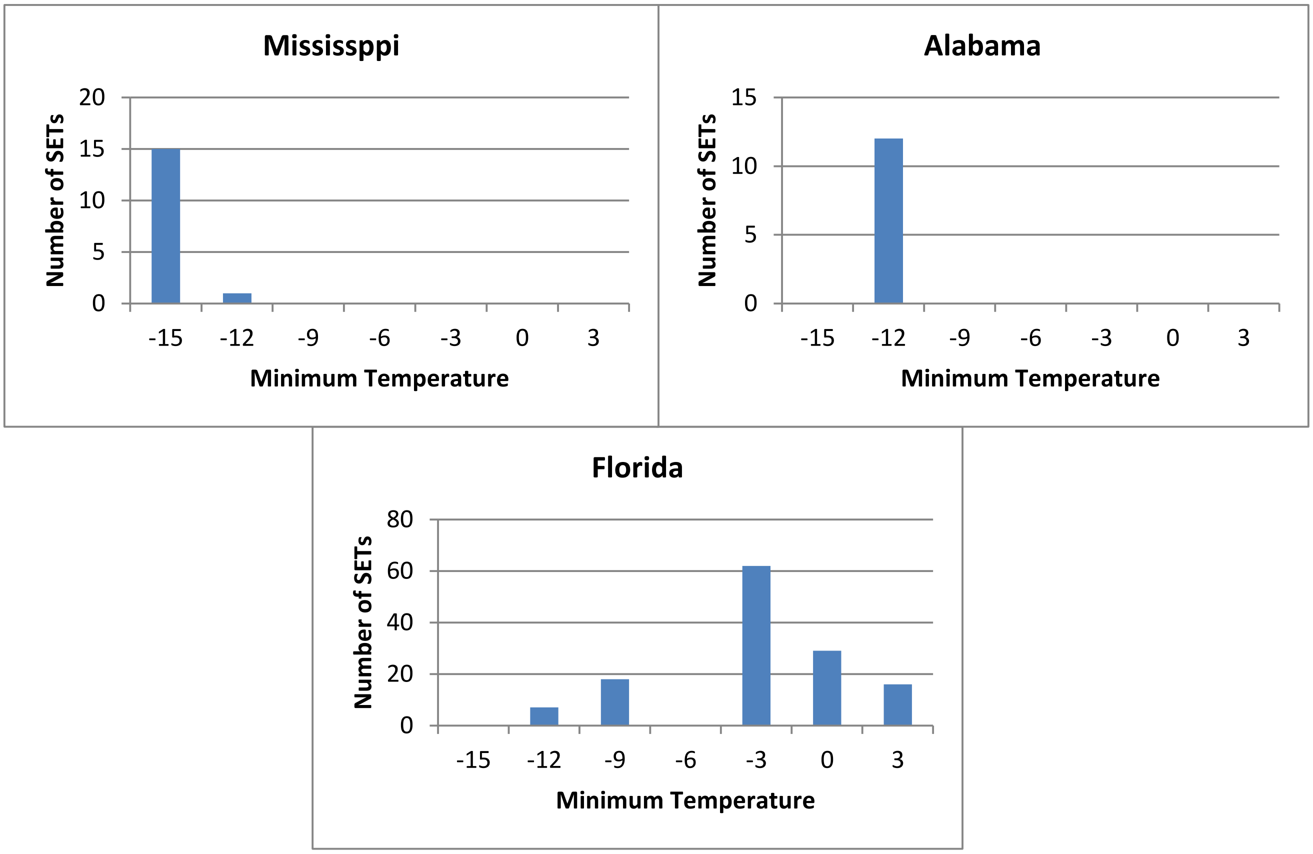


Figure 8 illustrates SET coverage of different temperature zones. While the central Gulf Coast does not cover a geographic extent large enough to capture a wide range of absolute minimum temperatures, Texas and Florida both span a relatively broad gradient, presenting further opportunities for SET installation. Figure 9 serves to visualize that spatial extent, and also displays the raw temperature data supporting the gap analysis.

Figure 9: Minimum Temperature (^{o}C, 1981-2010) Gradients in the NGOM

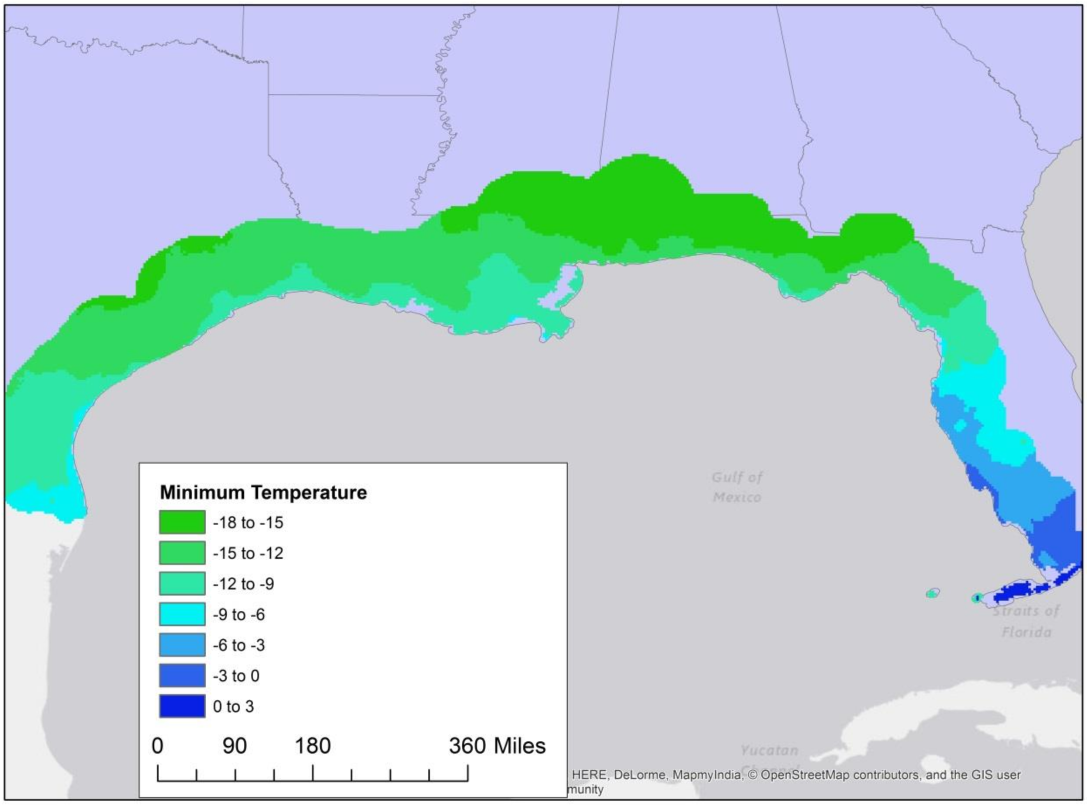
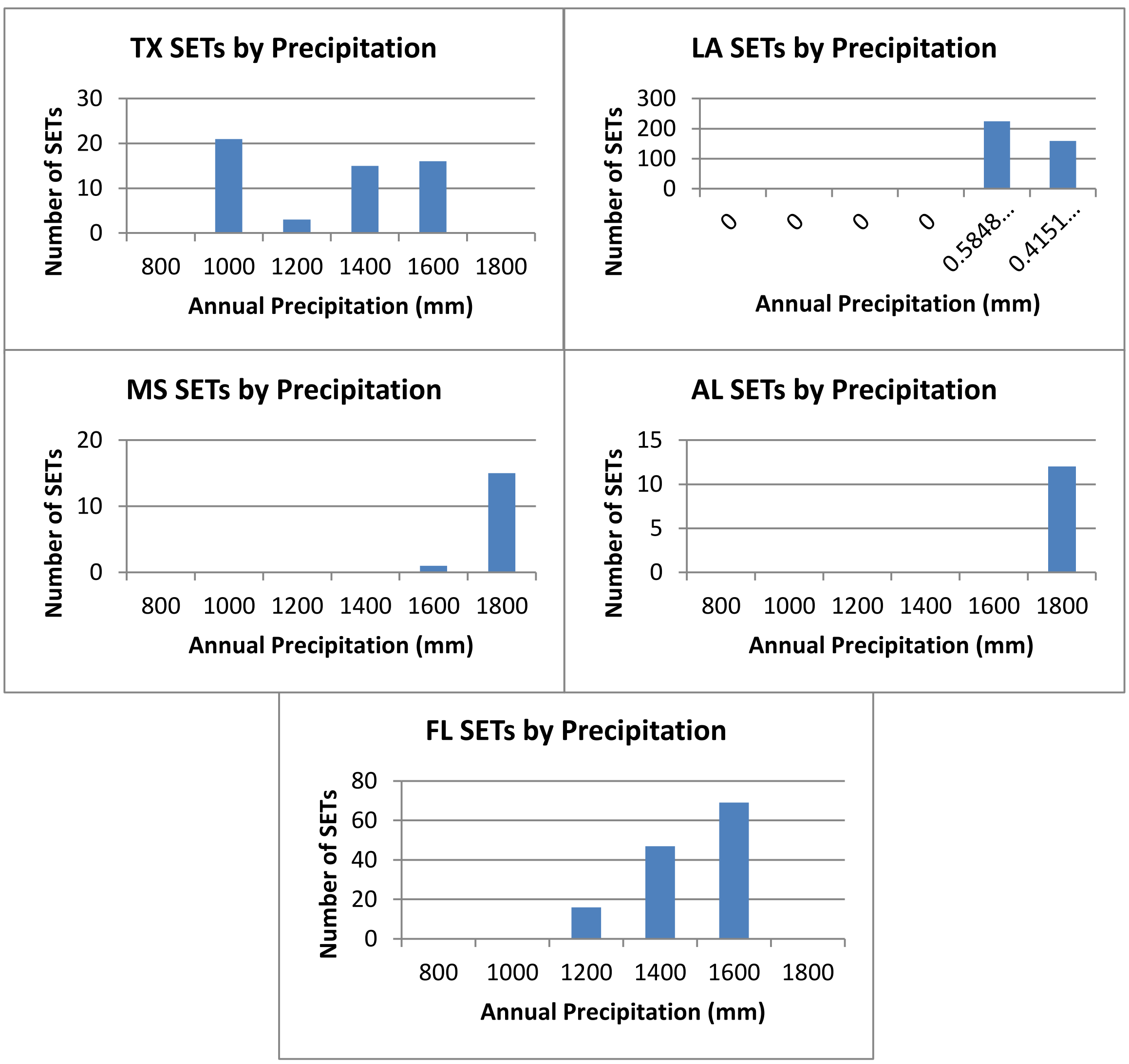


Figure 9 identifies areas where minimum temperatures indicate a potential wetland transition zone, particularly in the -9 to -6 degree areas located on the Florida and Texas coasts. These regions are highlighted in bright blue in Figure 9, and represent areas of important and potentially rapid change in the context of a warming climate that currently lack sufficient SET observations. Louisiana also contains some areas approaching the -9 degree level, which will continue to be monitored by existing stations there.

Precipitation

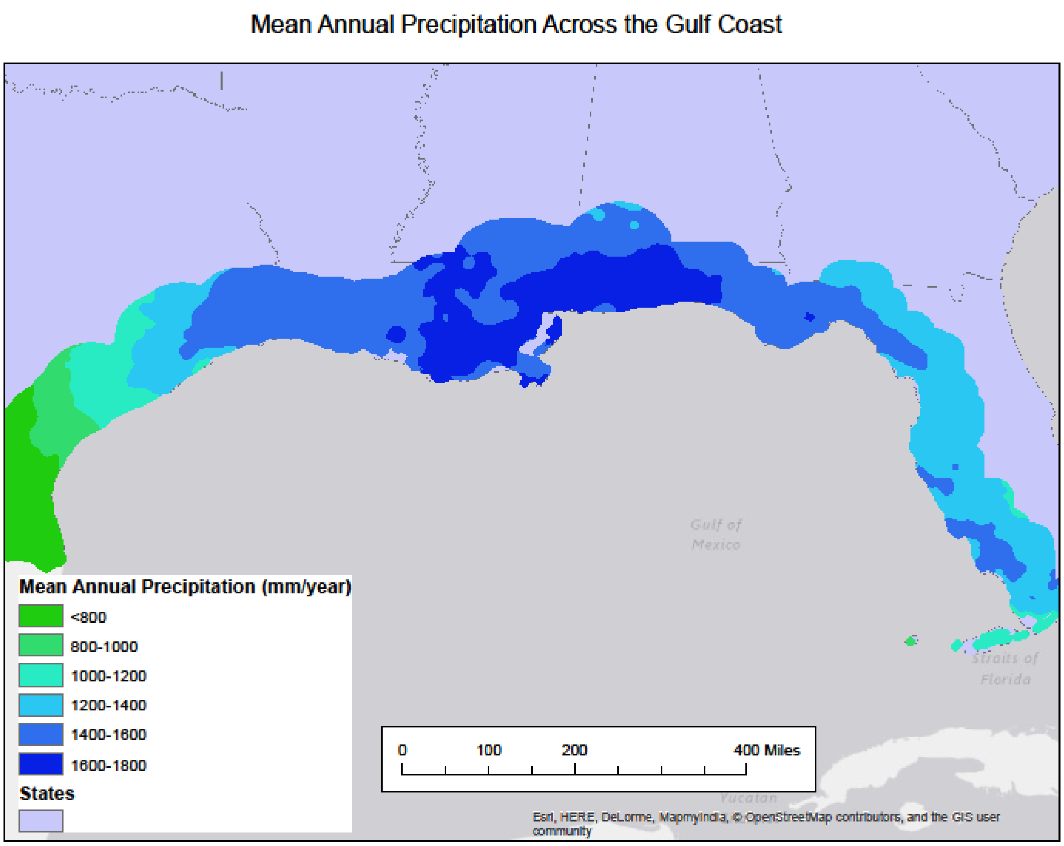
Precipitation is an important indicator of the potential coverage of wetland plants (Osland et al 2014). With too little precipitation, coastal wetlands may see a loss of wetland plant coverage and move toward tidal and/or salt flats. The ecogeomorphic response of tidal flats warrants further study, because of the loss in sediment trapping ability due to the reduction in aboveground biomass production. Precipitation associated with existing SET stations is shown in Figure 10.

Figure 10: Precipitation (mm/yr.) at SET stations



A wide range of precipitation levels is not expected in the central Gulf States, from central Louisiana to Alabama, because of the latitudinal concentration of these areas and similar amounts of annual precipitation recorded in the PRISM climate dataset (PRISM Climate Group 2015). See Figure 11 for a visualization of the distribution of mean annual precipitation throughout the Gulf coast.

Figure 11: Mean Annual Precipitation along the Gulf Coast



The bin of 1200-1400 mm/yr. is an important area of focus, because that part of the gradient is associated with increasingly rapid change in the potential percent coverage in wetland plants (Osland et al 2013). The majority of SETs are located in Louisiana, an area with >1400mm/year of precipitation. Texas in particular has a strong moist to dry gradient that will benefit from additional SET observations in the transition zones shown in Figure11.

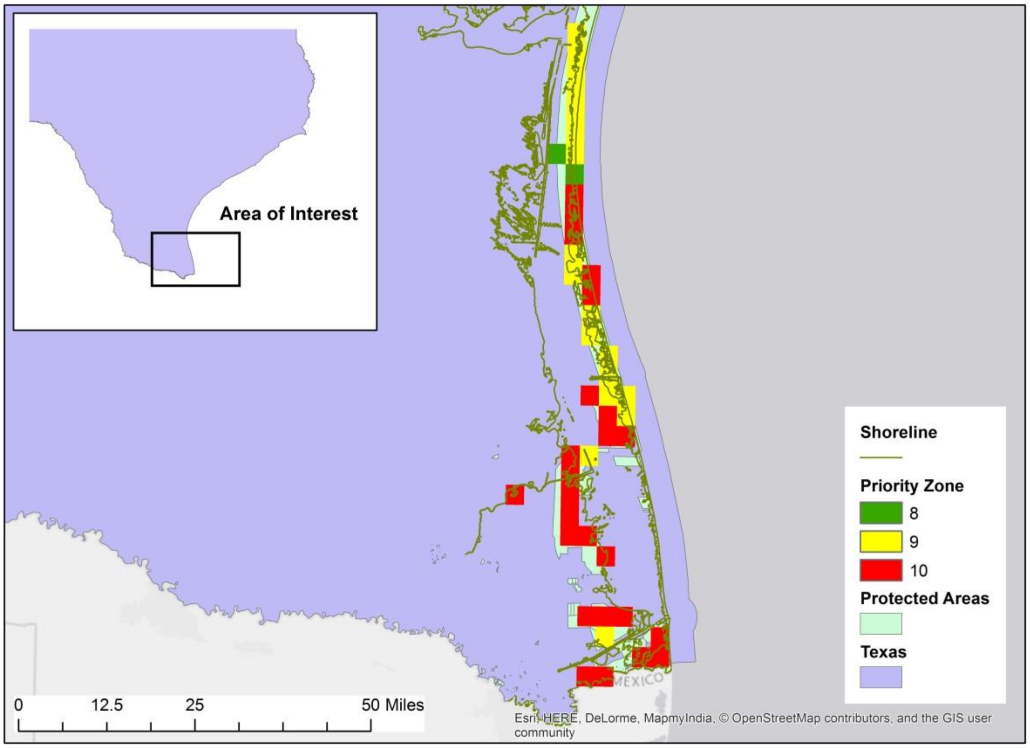
Results: Final Gap Analysis

Using data regarding temperature, precipitation, elevation, land ownership, and wetland type, a weighted overlay is conducted on coastal wetland areas in 4 of the 5 Gulf States. This section will present maps and figures, showing the priority zones developed in the gap analysis. These zones represent $4km^2$ areas, which is a result of the resolution of the input climate datasets. In order to provide site specific information to stakeholders in the Gulf, coordinates are calculated for the centroid of each priority zone. Pixels representing priority zones area classified on a numeric scale of 1-10, with 10 being of the most importance, and 1 being the lowest priority according to the suitability criteria. Maps are symbolized using a gradient of green, yellow, and red, with green pixels representing low priority zones, yellow as medium, and red as high priority zones. Maps are presented in sections starting with the western most areas in Texas and moving eastward. Texas and Florida are separated into smaller sub-regions due to their large geographic extent. The results of this gap analysis should be verified for accuracy on the ground by land managers and SET operators before planning new installations.

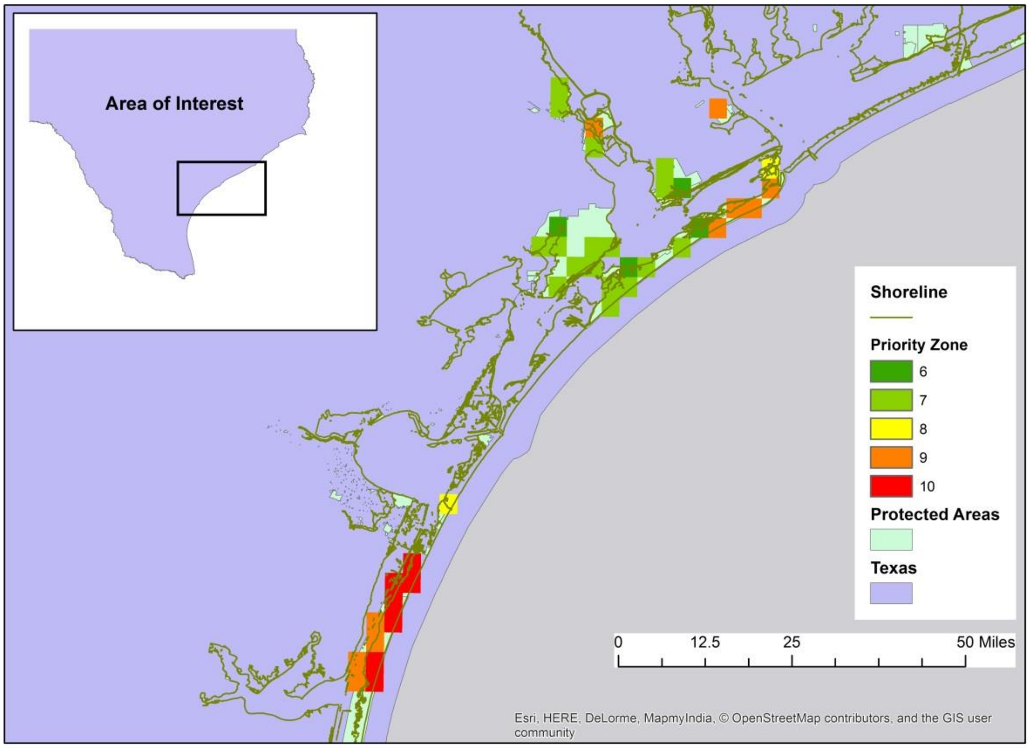
Texas

Maps of Texas are presented starting with the southernmost region in Figure 12a, then moving north and east along the Gulf Coast in Figures 12b-12d. See Appendix B for the coordinates and wetland type of the centroid for each priority zone.

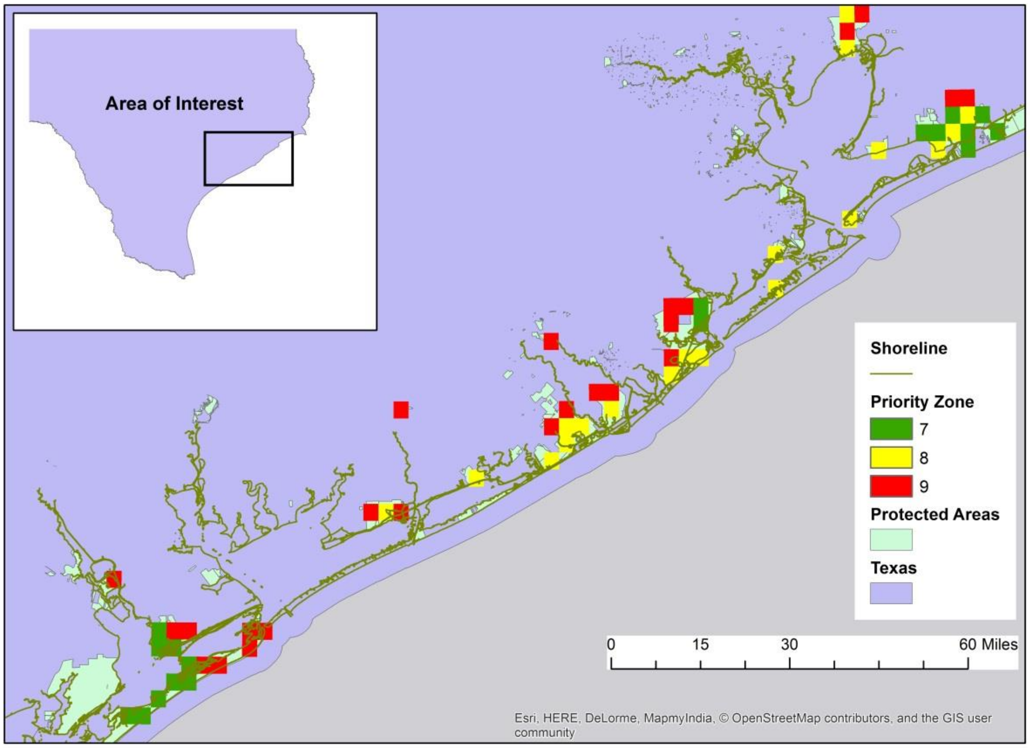
Figure 12A: Texas Priority Zones



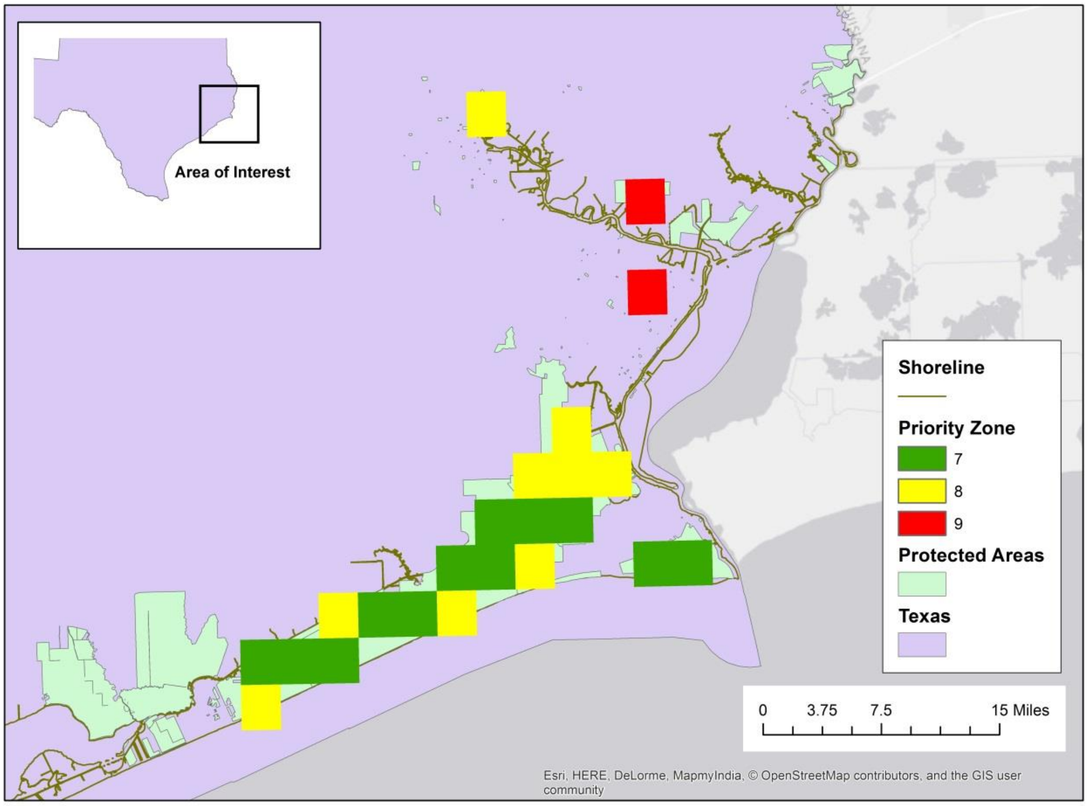
B) Texas Mid-Coast Priority Zones



C) Texas Upper-Mid-Coast Priority Zones



D) Easternmost Texas Coast

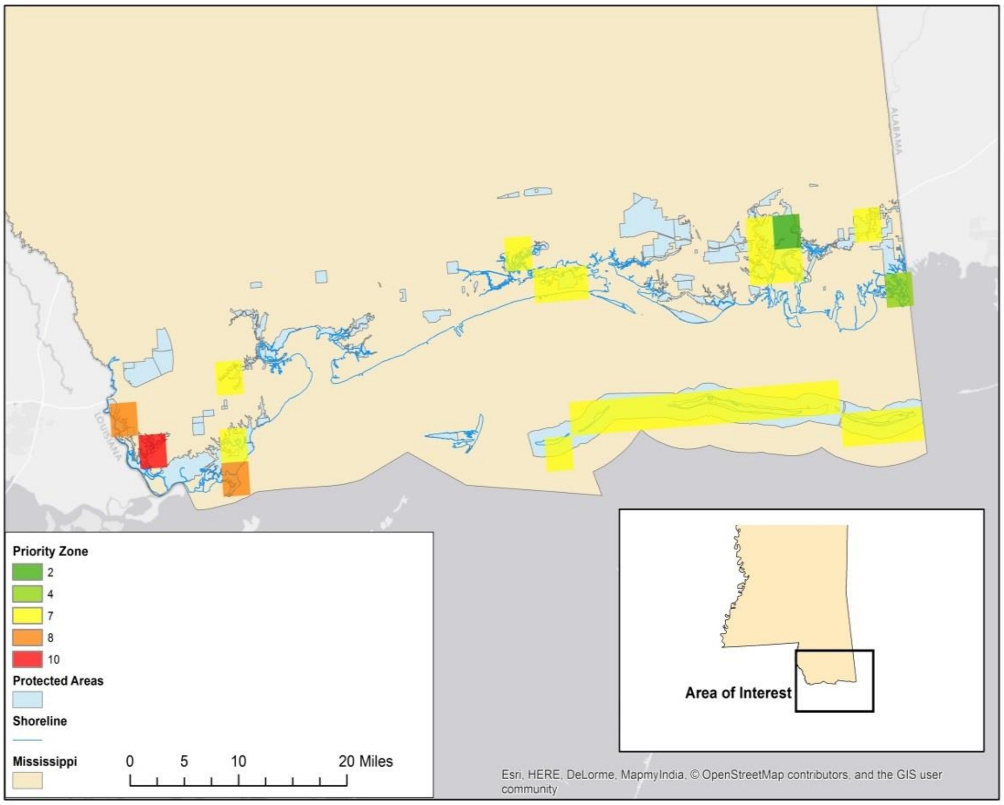


The results of the gap analysis show significant areas in the southern portions of the state that would be suitable for SET monitoring. This finding corroborates needs identified by stakeholders in the initial survey, as well as spatial gaps visible in the SET inventory. The high suitability of southern Texas speaks to the need for a greater number of SETs monitoring areas with low levels of precipitation (<1400mm/year), as well as the presence of wetland transitional areas due to the abiotic gradients incorporated in the overlay criteria. The coordinates specifying the location of the centroid of each priority zone are included in Appendix B. Notable publicly managed areas with high suitability are National Wildlife Refuges, such as Anahuac, Brazoria, San Bernard, Laguna Atascosa, and Lower Rio Grande Valley.

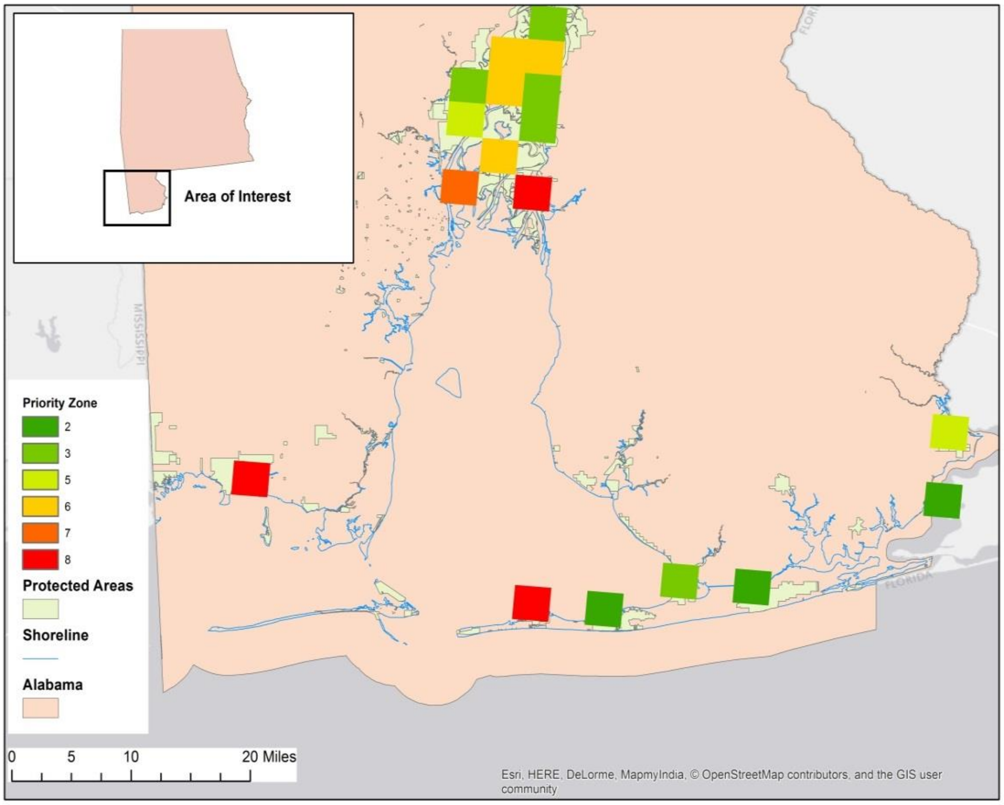
Alabama and Mississippi

The central Gulf Coast, excluding Louisiana, is a high priority region identified in the survey. Based on the frequency of survey responses to questions about specific gaps, 17 of 27 respondents cited spatial gaps in Mississippi, Alabama, and the Florida panhandle. These coastal areas have a low number of SETs recorded in the Inventory. They are more homogenous than the Texas coast and peninsular Florida in terms of precipitation and temperature, with annual rainfall not recorded below 1400mm/year and minimum recorded temperature not exceeding -9 °C (See Figures 9 and 11). The following maps display the suitable locations, based on the criteria used in this gap analysis. While the number of SETs in Mississippi and Alabama is small, it is important to note that they are clustered spatially at sites located at the Grand Bay and Weeks Bay National Estuarine Reserves, and the resolution of the Lidar data and geographic coordinates in the Inventory may not sufficiently capture their distribution across relevant biotic and abiotic gradients. For example, the SETs at Weeks Bay are strategically placed along an elevation gradient from an estuarine forested wetland, through a transitional zone and into a salt marsh ecosystem. Figures 13a and 13b show the priority zones in Alabama and Mississippi established in this gap analysis. As with all results in this report, specific sites should be verified for accuracy on the ground before making decisions on SET installations there.

Figure 13A: Priority Zones for Additional SET monitoring in Mississippi



B) Priority Zones in Alabama



The zone ranked with the highest priority in Mississippi is centered on the Hancock County Marsh Coastal Reserve, in the southeastern corner of the state. Other notable publicly managed areas include Gulf Islands National Seashore and Grand Bay National Estuarine Research Reserve. Mississippi contains a large area of moderately suitable wetlands, weighted as a 7 on a scale from 1 to 10. These areas warrant further consideration by parties interested in SET monitoring in Mississippi.

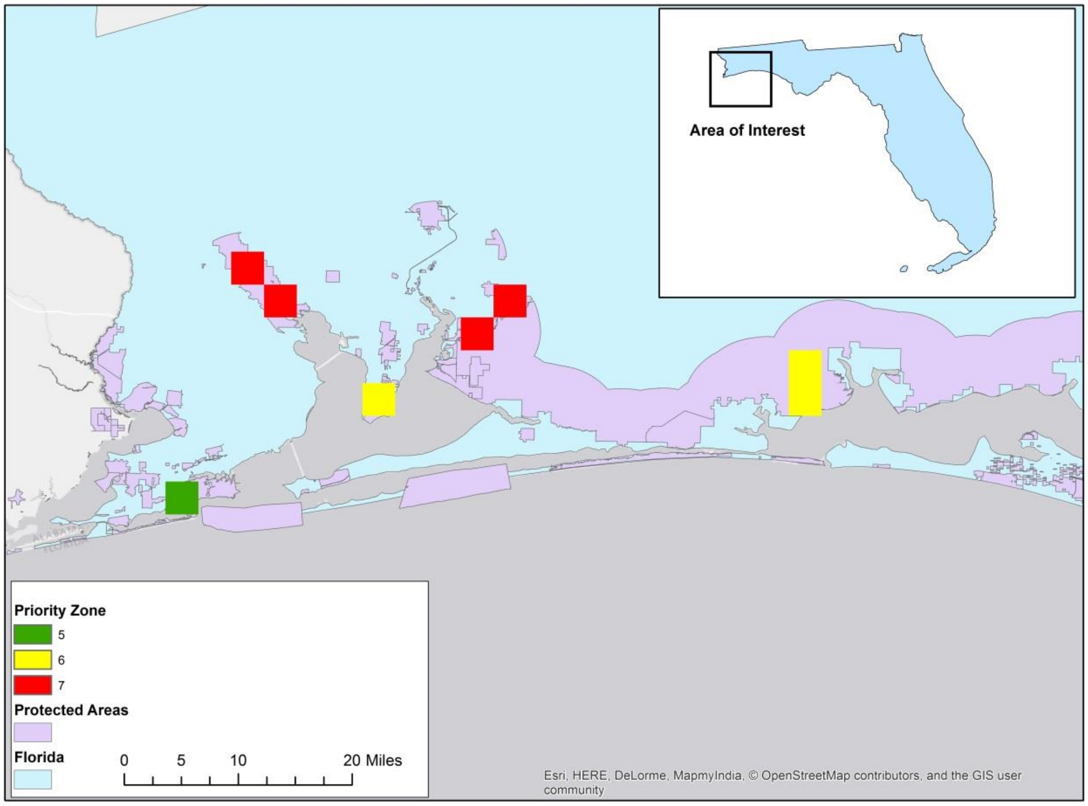
In Alabama, the highest priority zones are located in three separate areas, the W.L. Holland Wildlife Management Area, Bon Secour National Wildlife Refuge, and Grand Bay

Community Hunting Area. The large wetland areas on the northern edge of Mobile Bay provide lower suitability habitat for SET installation based on the holistic criteria, but actual suitability for individual projects may vary based on the research questions involved. Refer to Appendix B for the coordinates of the centroid for each priority zone.

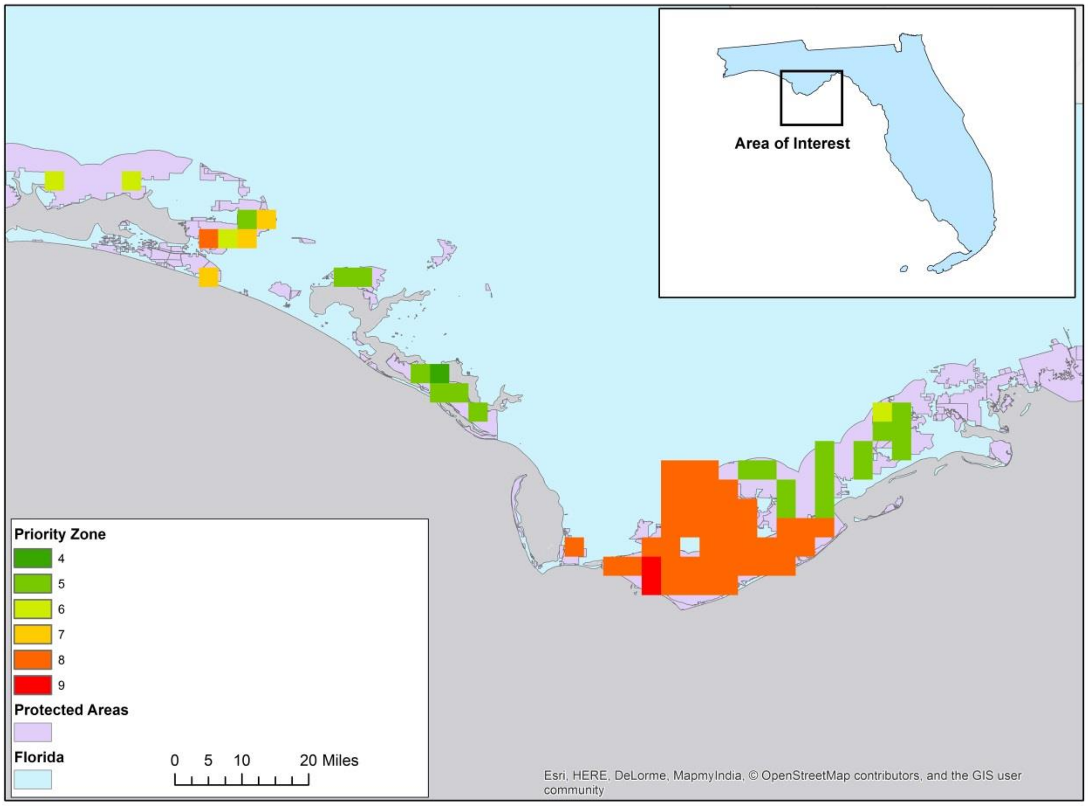
Florida

Figures 14a-14f present the gap analysis results for Florida. The maps are separated into distinct regions in order to better visualize the study areas. Due to the latitudinal area covered by Florida there are many zones identified with high suitability criteria, highlighting regions with environmental transition zones among factors such as precipitation and temperature. In the southern-most region of coastal Florida incorporated in this gap analysis, Ten Thousand Islands National Wildlife Refuge stands out as a suitable zone for SET installation. However, due to the ongoing work in Southern Florida noted in the survey, the western coast and panhandle regions of the state provide focal areas for this portion of the gap analysis. In particular, the "Big Bend" region north of Tampa, and the extent of the Florida panhandle from the Suwanee River and points west, are areas of interest because of the spatial gaps noted in the survey.

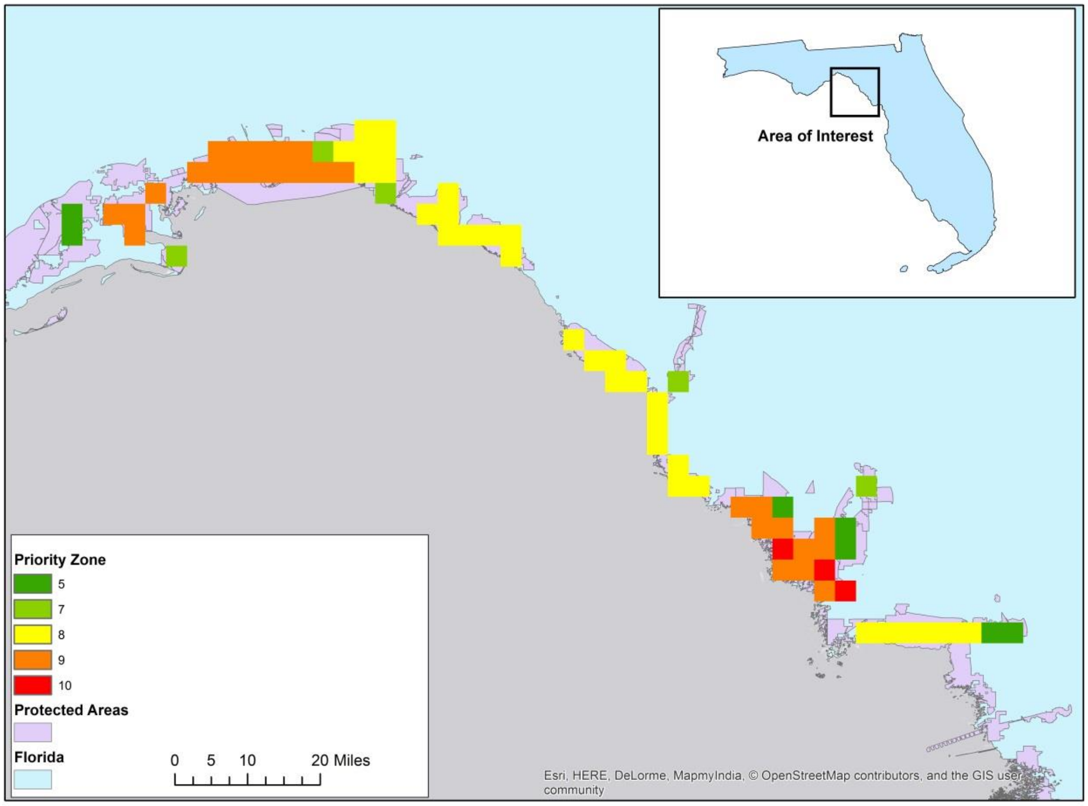
Figure 14A: Priority SET Monitoring Zones in Florida



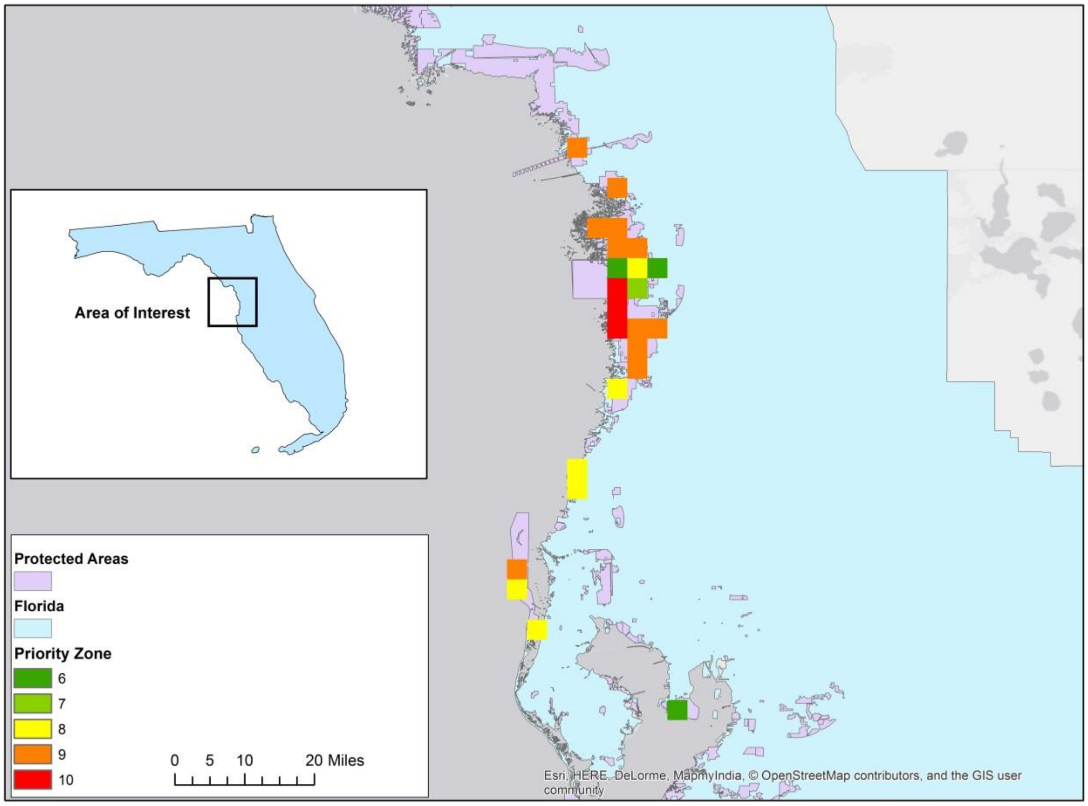
B) Florida Panhandle- Apalachicola



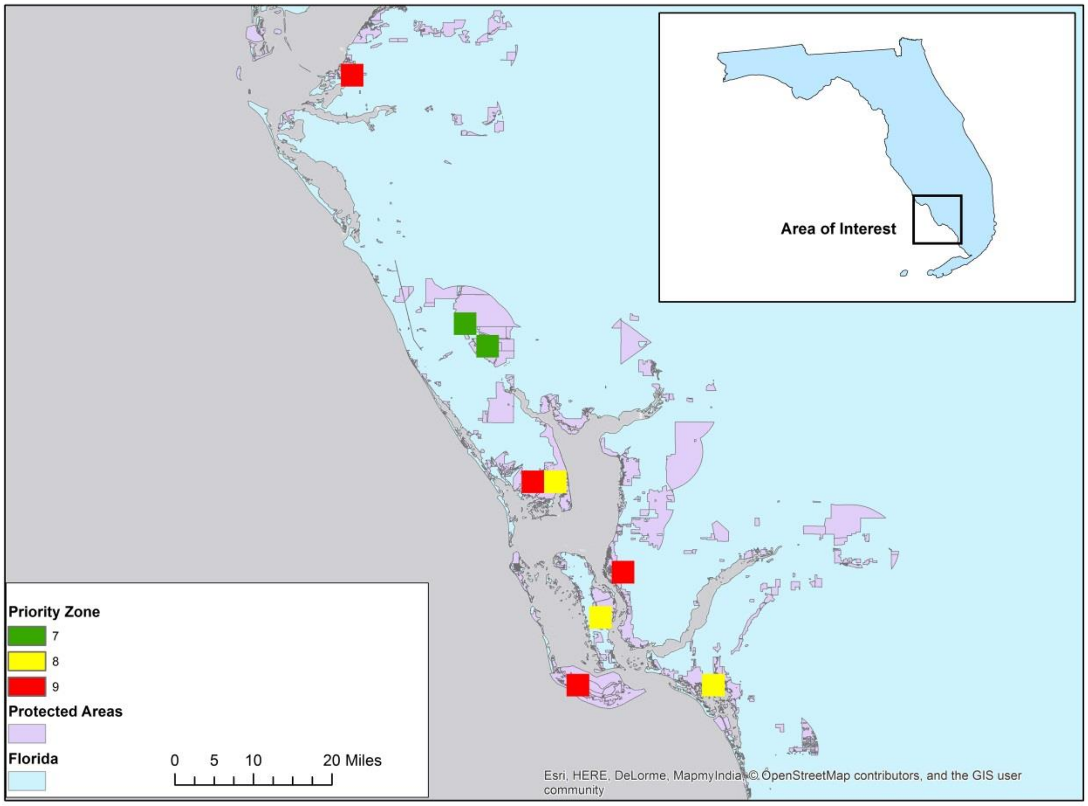
C) Western Florida Panhandle – Peninsular Florida



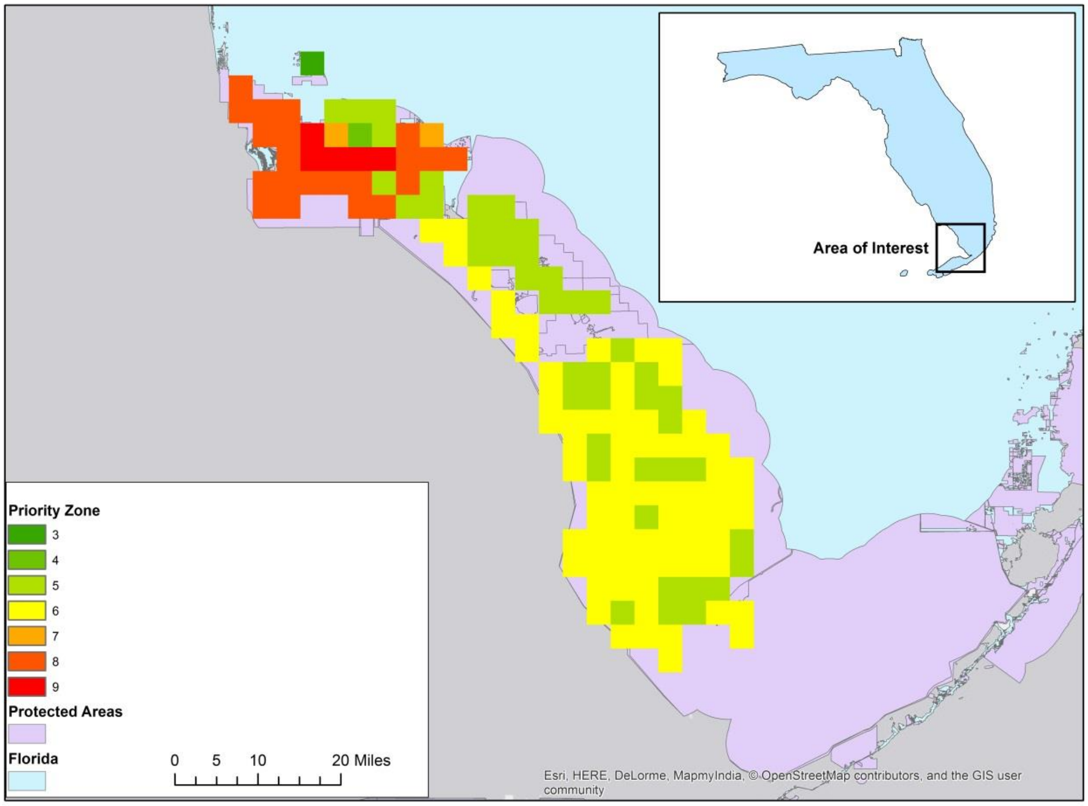
D) Florida West Coast



E) Florida West Coast-South



F) Southern Florida



In Figure 14a, the highest priority areas are located in two water management districts, the Yellow River and Lower Escambia. 14b shows where the highest priority areas overlap with St. Vincent National Wildlife Refuge and Apalachicola National Estuarine Reserve. This information will support the ongoing efforts in these public areas to monitor relative wetland sediment surface elevation. The region north of Tampa that extends into the eastern panhandle has two high priority areas of interest, the Lower Suwanee National Wildlife Refuge and Chassahowitzka National Wildlife Refuge (Figures 14c and 14d). In Figures 14e and 14f, Charlotte Harbor

Preserve State Park, J.N. Ding Darling National Wildlife Refuge, and Ten Thousand Islands National Wildlife Refuge all contain highly suitable areas for additional SET installation.

Discussion and Conclusion

The results presented in this report provide specific information on suitable locations for additional SET stations in the NGOM. These results identify how the SET Inventory can be more effectively expanded to better meet the needs of stakeholders in coastal wetland conservation. Due to the resolution of the input data and Gulf-wide scale of analysis, operators interested in using this gap analysis as a guide for SET installation should cross-check these results with ground observations to ensure accuracy. Recommended usage of the gap analysis is to define an area of interest, and use the coordinates provided in Appendix B to navigate to a priority zone. Once that zone is spatially identified and ground-truthed, other activities relevant to the particular study area and research questions can be addressed. Louisiana is not included in the body of this report, and SET operators interested in that state should refer to Appendix C for a map of priority zones using only temperature and precipitation variables.

The heterogeneity of coastal wetland types and their responses to different levels of inundation across the NGOM are important factors to understand in evaluating coastal vulnerability to SLR. Information from long term, consistent SET monitoring can help scientists and land managers better understand the response of coastal wetlands to SLR, in environments such as *Spartina alterniflora* dominated salt marshes and *Avicennia germinans* mangroves. Estuarine wetlands are dynamic and resilient ecosystems, providing wildlife habitat and numerous ecological services to coastal communities (Barbier et al 2011). This gap analysis provides 4km^2 priority zones for additional SET installation across the NGOM, in support of the U.S. Fish and Wildlife Service, the Northern Gulf of Mexico Sentinel Site Cooperative, the U.S. Geological Survey, and their partners.

<u>Appendix A: Elevation data used as input for the gap analysis</u>

Figure A: Southern Texas

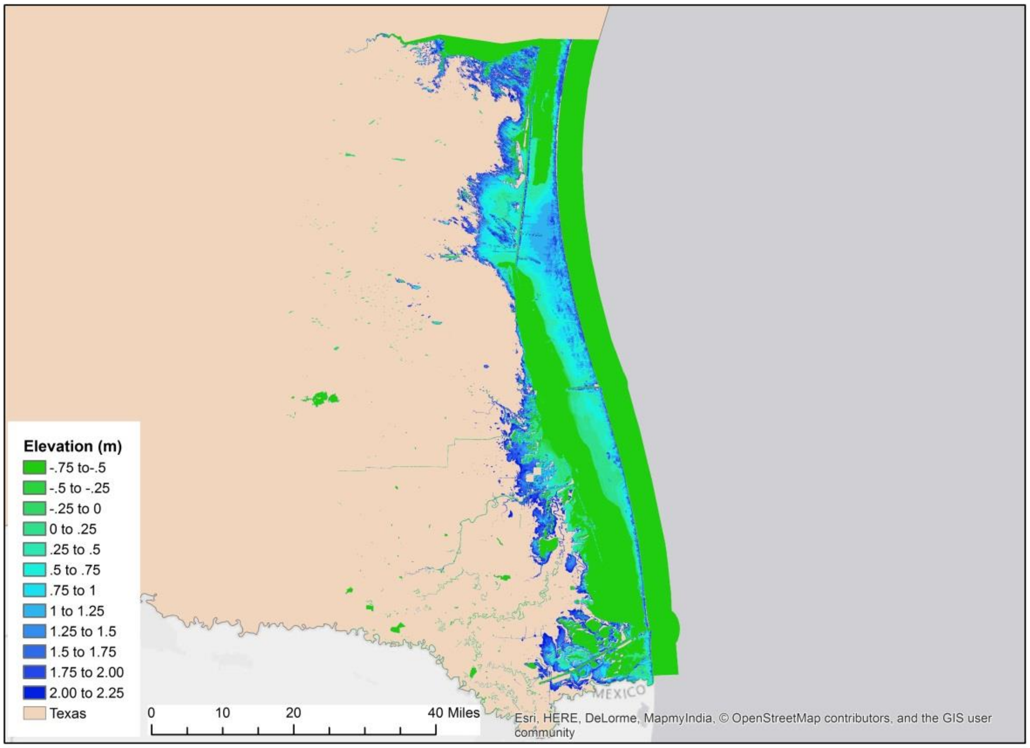


Figure B: Mid-Coast Texas

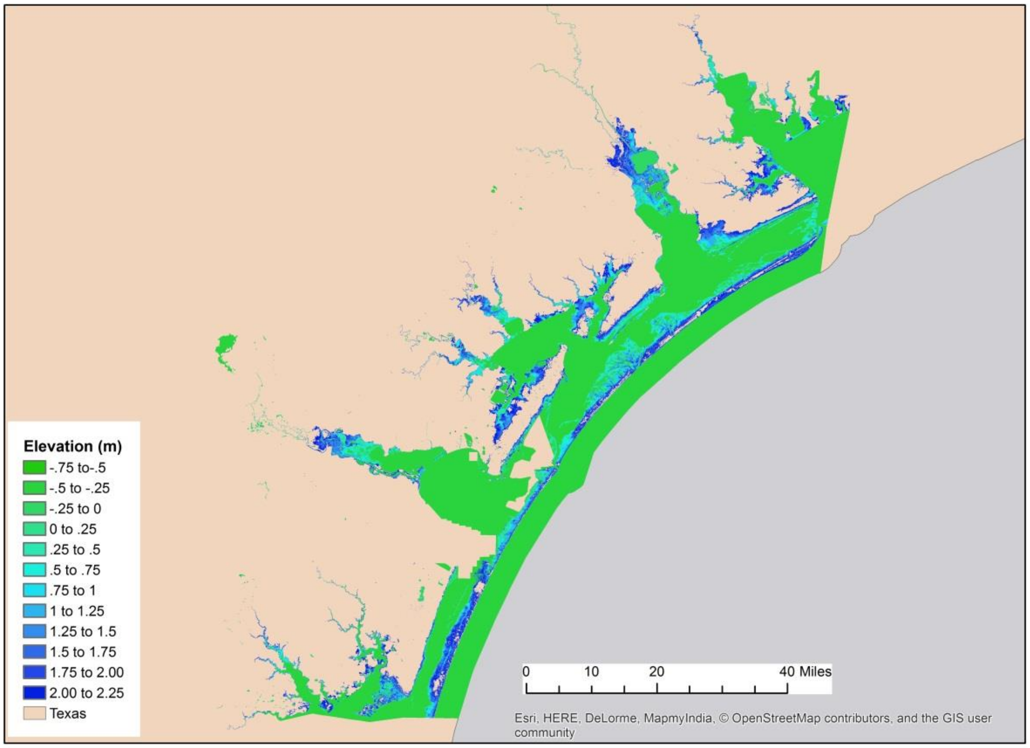


Figure C: Upper-Mid Coast Texas

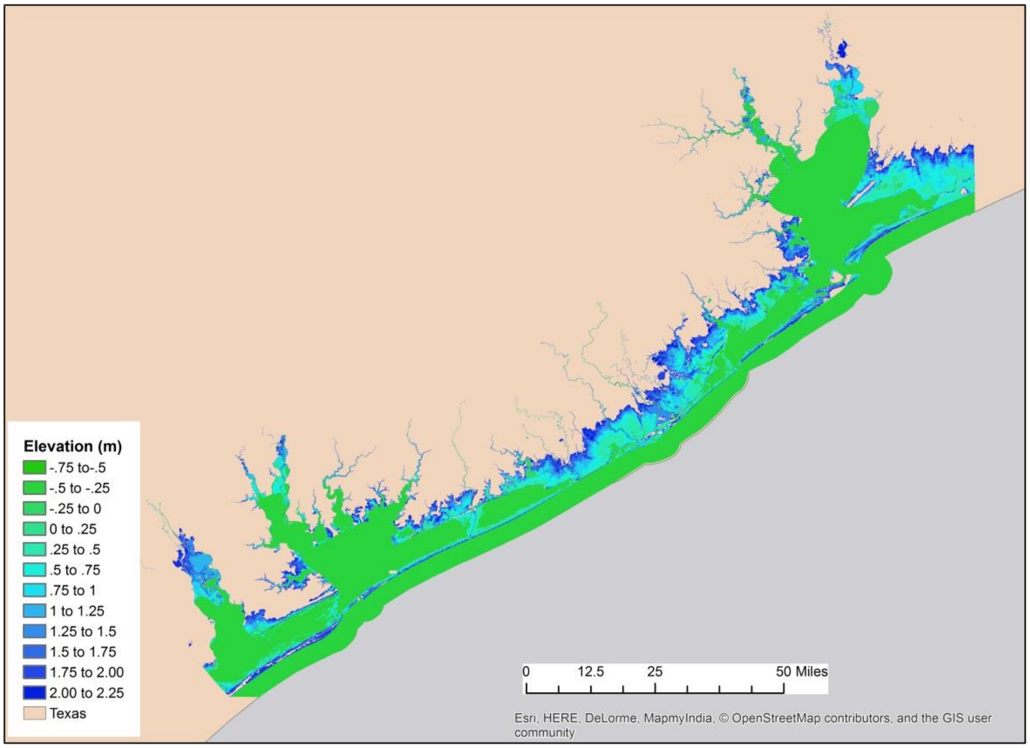


Figure D: Easternmost Texas Coast

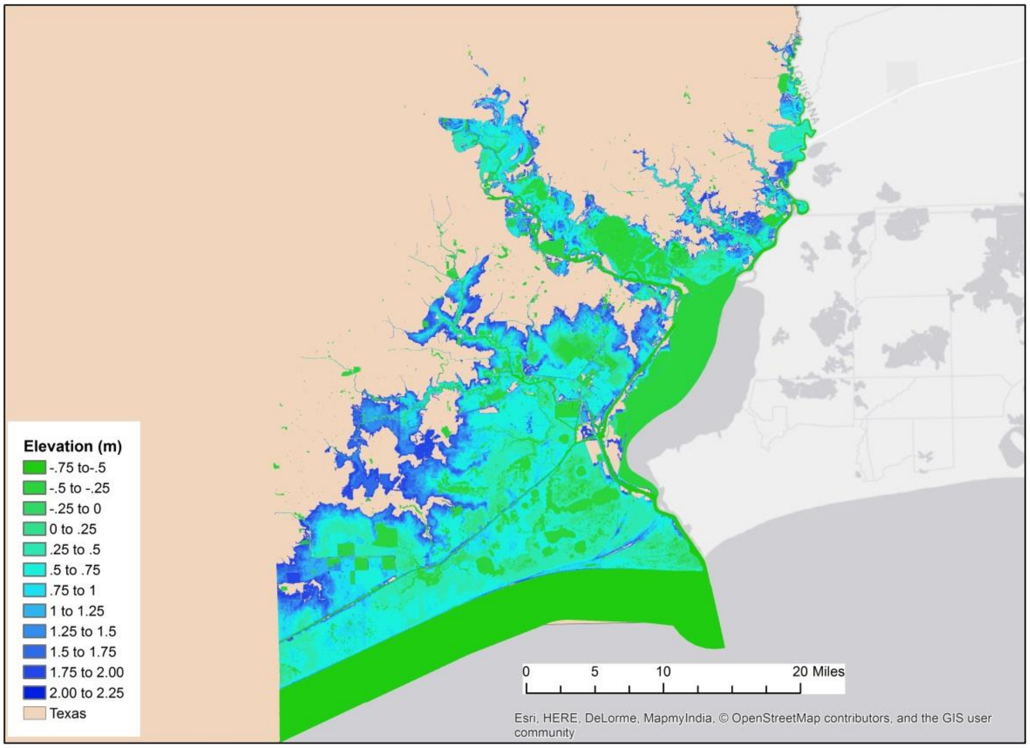


Figure E: Mississippi

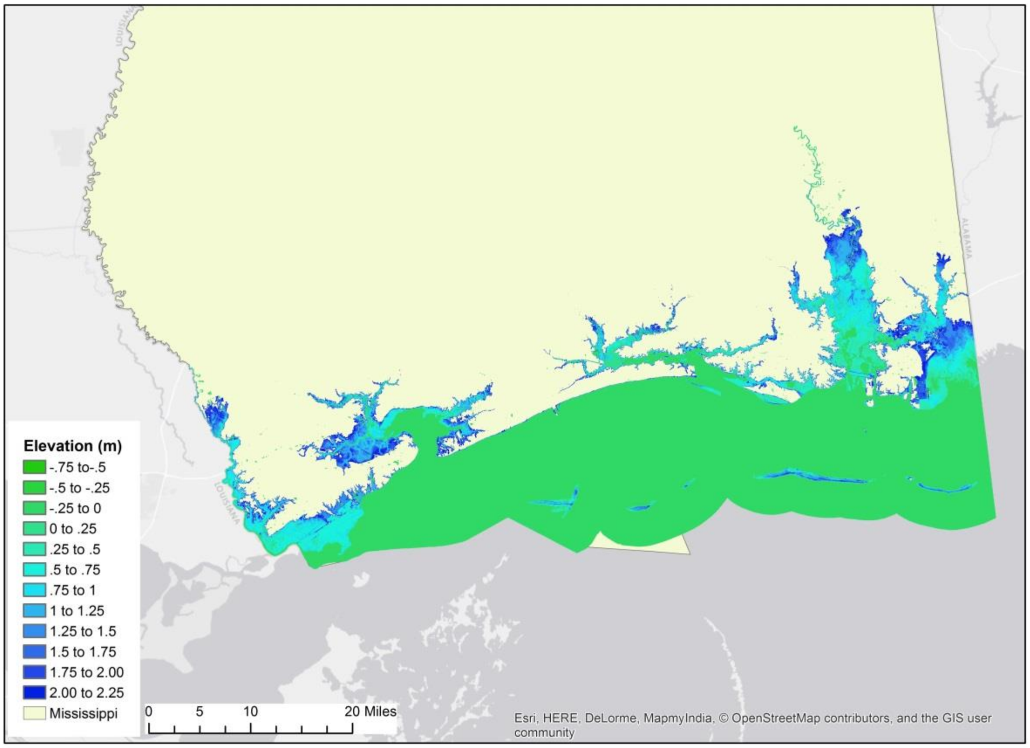


Figure F: Alabama-Florida

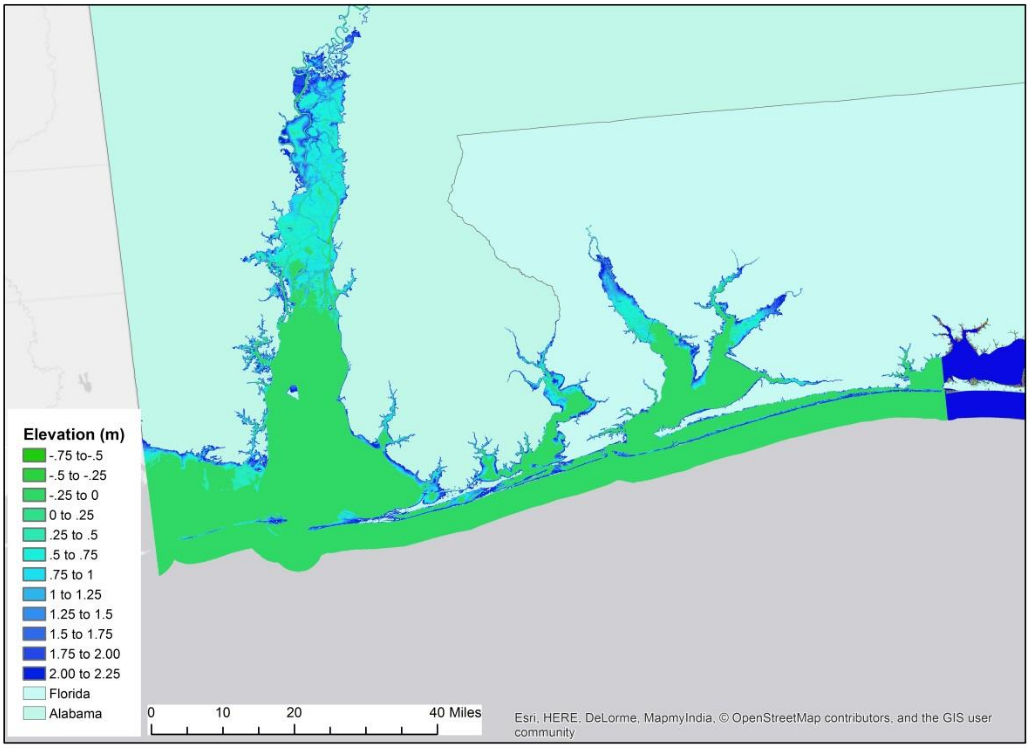


Figure G: Florida Panhandle- Apalachicola

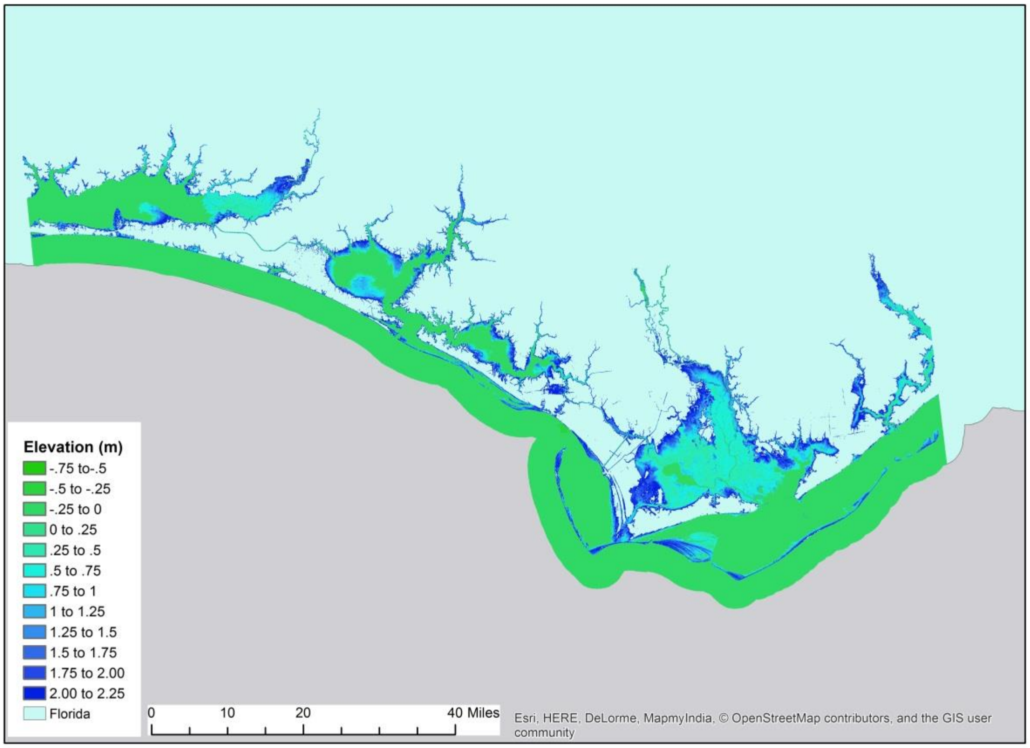


Figure H: Eastern Florida Panhandle- Peninsular Florida

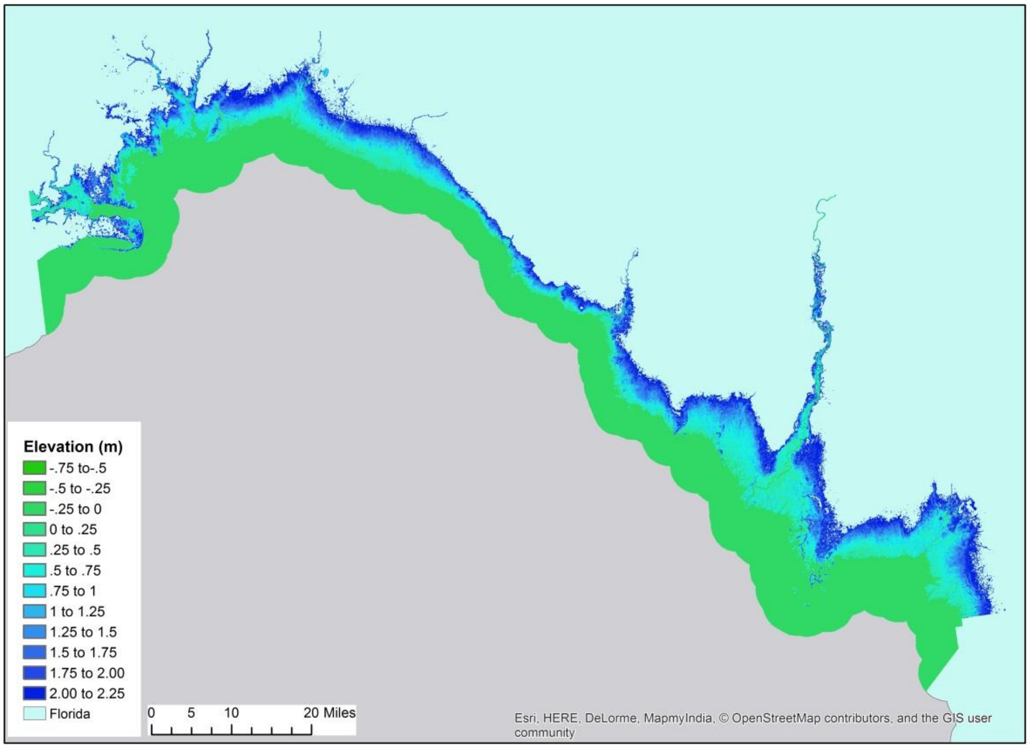


Figure I: West Coast Florida

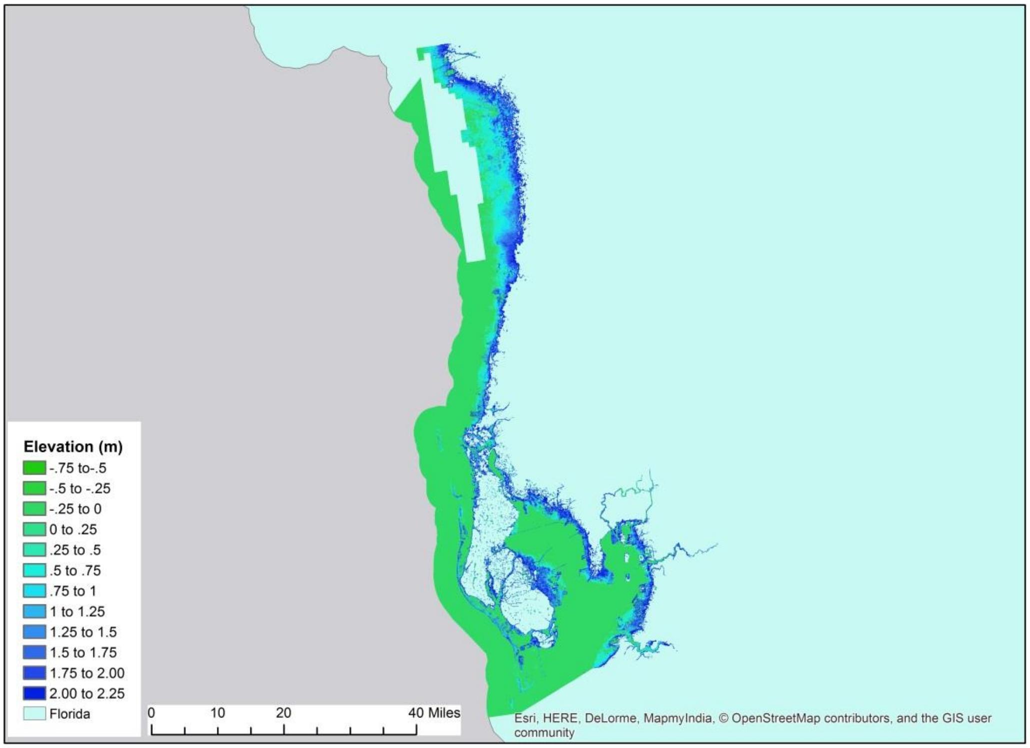


Figure J: South Western Florida

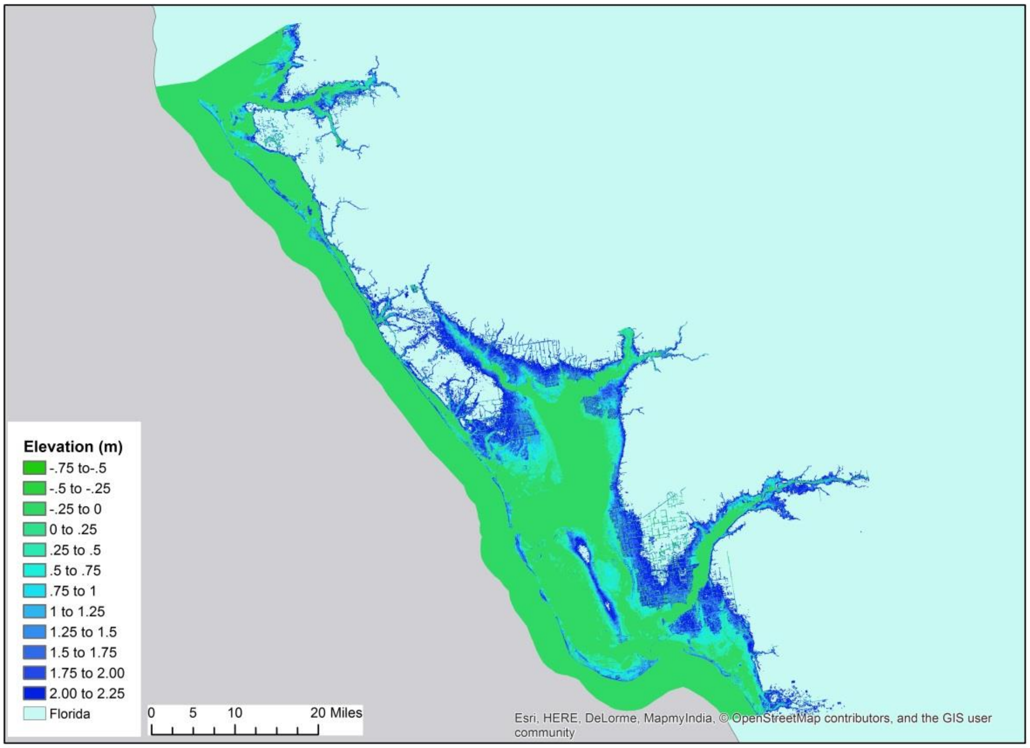
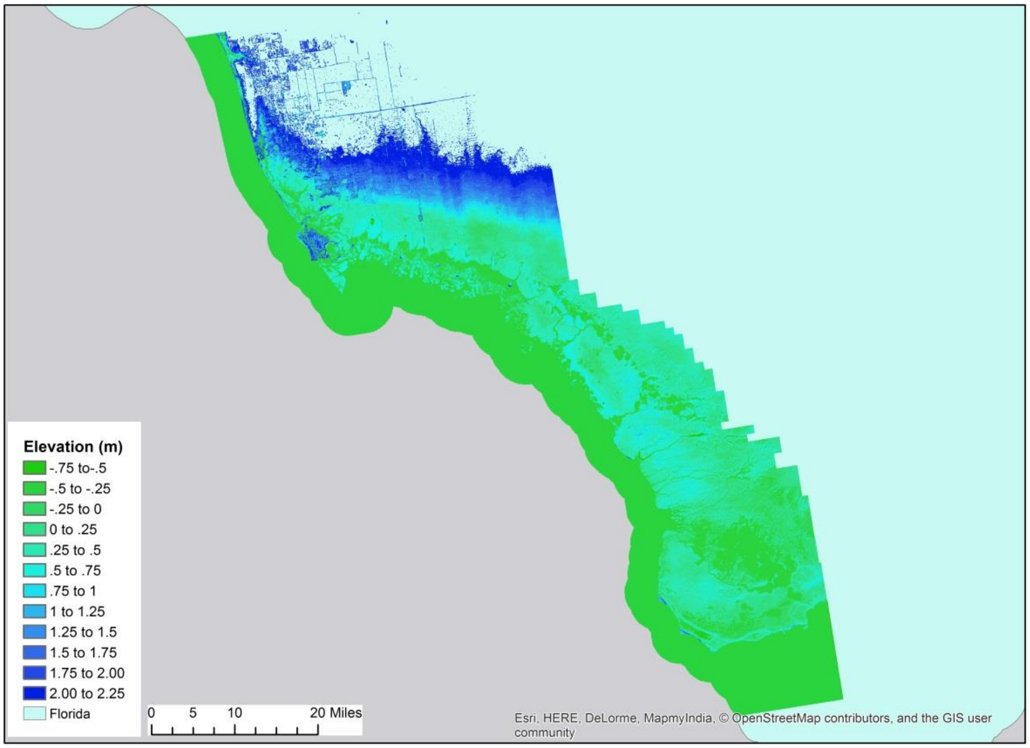


Figure K: Southern Florida



Appendix B: Coordinates and Approximate Wetland Type of Priority Zones

Texas, Mississippi, and Alabama were analyzed using the National Wetlands Inventory, from the U.S. Fish and Wildlife Service. Florida was analyzed using the Florida Land Use, Cover, and Classification System in order to achieve greater state level accuracy there. Similar wetland-related land cover datasets are not available for the other states. Louisiana is not included in this Appendix. Wetland type was established by the NWI or FLUCCS land cover type underlying the centroid of priority zone. If the zone did not directly intersect, and approximation was made based on the closest wetland type. NOAA C-CAP data is used to cross-check land cover types in Florida where FLUCCS data is unavailable. Coordinates are provided in decimal degrees.

A) Texas

X Coordinate	Y Coordinate	Unit Name	NWI Code	Wetland Type
-97.318045	25.940632	Lower Rio Grande Valley NWR	PEM1A	Palustrine Emergent
-97.186101	25.996188	Boca Chica State Park	E2USP	Intertidal Unconsolidated Shore
-97.297212	26.065632	Laguna Atascosa National Wildlife Refuge	E1UBL	Subtidal
-97.297212	26.065632	WRP Cameron, TX	E1UBL	Subtidal
-97.297212	26.190632	Laguna Atascosa National Wildlife Refuge	NoData	NoData
-97.373601	26.301743	Laguna Atascosa National Wildlife Refuge	PEM1A	Palustrine Emergent
-97.505545	26.315632	Las Palomas Wildlife Mgmt. Area	NoData	NoData
-97.283323	26.454521	Laguna Atascosa National Wildlife Refuge	E2USP	Intertidal Unconsolidated Shore
-97.338878	26.523965	Laguna Atascosa National Wildlife Refuge	E2AB1P	Intertidal Aquatic Bed
-97.338878	26.753132	Padre Island National Seashore	M2USM	Marine
-97.380545	26.898965	Padre Island National Seashore	E2AB1P	Intertidal Aquatic Bed
-97.338878	27.333032	Padre Island National Seashore	PEM1A	Palustrine Emergent
-97.280545	27.503866	Padre Island National Seashore	PEM1C	Palustrine Emergent

-96.61856	28.377227	WRP Calhoun TX	PEM1A, PEM1C	Palustrine Emergent
-96.535226	28.293894	Aransas National Wildlife Refuge	E2USM	Intertidal Unconsolidated Shore
-96.417171	28.363338	Conservation Easement: Aransas National Wildlife Refuge	E2EM1M	Salt Marsh
-96.80606	28.502227	Guadalupe Delta Wildlife Management Area	PEM1C	Palustrine Emergent
-96.097726	28.668894	Mad Island Macrosite Fee	PEMf	Palustrine Emergent
-96.014393	28.668894	Mad Island Wildlife Management Area	E2EM1P	Salt Marsh
-96.014393	28.918894	Riverside Park, Bay City, TX	PFO1A	Palustrine Forested
-95.597726	28.877227	San Bernard National Wildlife Refuge	L2USCh and Pss1A	Palustrine Scrub/Shrub and Lacustrine Unconsolidated Shore
-95.55606	28.918894	San Bernard National Wildlife Refuge	PSS1J	Palustrine Scrub/Shrub and Lacustrine Unconsolidated Shore
-95.451893	28.96056	Justine Hurst Wildlife Management Area (Approximate)	PEM, PFO	Palustrine Emergent and Forested
-95.264393	29.043894	Brazoria National Wildlife Refuge	E2EM1P	Salt Marsh
-95.250504	29.155005	Brazoria National Wildlife Refuge	PEM1A	Palustrine Emergent
-94.451893	29.668894	Anahuac National Wildlife Refuge	PUB/PAB, E2EM	Salt Marsh and Palustrine Aquatic
-94.764393	29.83556	Wallisville Lake	PFO1A	Palustrine Forested
-94.722726	29.877227	Wallisville Lake	PFO2T	Palustrine Forested
-95.597726	29.08556	San Bernard National Wildlife Refuge	PFO1A	Palustrine Forested

-95.597726	29.08556	WRP Brazoria, TX	PFO1A	Palustrine Forested
-93.925364	29.942907	Wesgroves Adult Park, City of Groves	NoData	NoData
-93.925364	30.02624	Lower Neches Wildlife Management Area	E1UBL	Subtidal

B) Mississippi

X Coordinate	Y Coordinate	Unit Name	NWI Code	Wetland Type
-89.450268	30.19509	Hancock County Marsh Coastal Reserve	E2EM1P	Estuarine and Marine Wetland
-88.950268	30.19509	Gulf Islands National Seashore	M1UBL	Estuarine and Marine Deepwater
-88.450268	30.19509	Gulf Islands National Seashore	M1UBL	Estuarine and Marine Deepwater
-89.575268	30.236757	Hancock County Marsh Coastal Reserve	E2EM1P	Estuarine and Marine Wetland
-89.450268	30.236757	Hancock County Marsh Coastal Reserve	E2EM1N	Estuarine and Marine Wetland
-88.721102	30.236757	Gulf Islands National Seashore	M1UBL	Estuarine and Marine Deepwater
-89.616935	30.278423	Hancock County Marsh Coastal Reserve	PSS1/2R	Freshwater Forested/Scrub Shrub
-89.450268	30.32009	Bayou Lacroix Coastal Reserve	PUBHh	Freshwater Pond
-88.929435	30.403423	Keesler Air Force Base	NoData	NoData
-88.603046	30.417312	Pascagoula River Coastal Reserve	E2EM1P	Estuarine and Marine Wetland
-88.991935	30.44509	Biloxi River Coastal Reserve	E2EM1P	Estuarine and Marine Wetland
-88.450268	30.44509	Grand Bay National Wildlife Refuge	R1UBV	Riverine

C) Alabama

X Coordinate	Y Coordinate	Unit Name	NWI Code	Wetland Type
-88.024384	30.724781	W.L. Holland Wildlife Management Area	E2EM1P	Salt Marsh
-87.9535898	30.718347	W.L. Holland Wildlife Management Area	PFO4B	Palustrine Forested
-88.278099	30.298084	Grand Bay Community Hunting Area	E2EM1P	Salt Marsh
-87.93681	30.258533	Bon Secour National Wildlife Refuge	E2EM1P	Salt Marsh

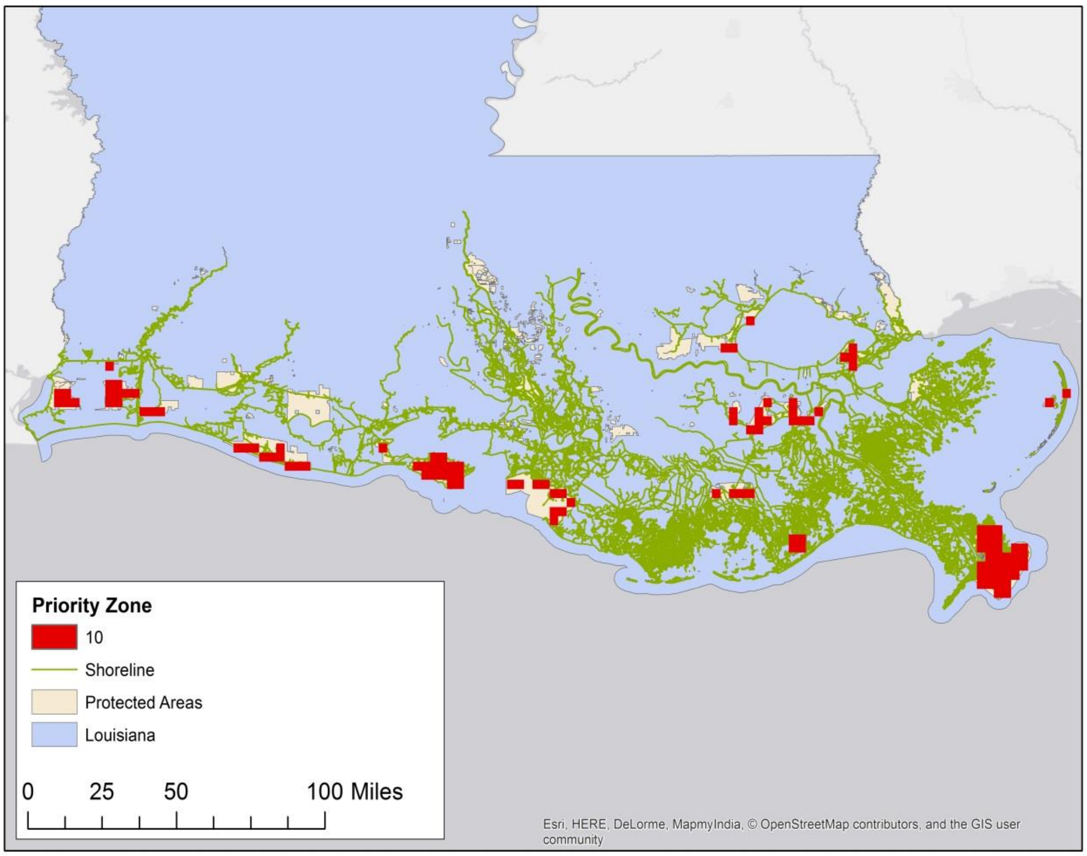
D) Florida

X Coordinate	Y Coordinate	Unit_Nm	FLUCCS Code	Wetland Type
-80.3262	25.270278	Crocodile Lake National Wildlife Refuge	5250	Mangrove Swamp
-80.254441	25.448518	Biscayne National Park	5000	Estuarine
-81.585693	25.945278	Ten Thousand Islands National Wildlife Refuge	5250	Mangrove Swamp
-82.639118	28.673801	Chassahowitzka National Wildlife Refuge	5000	Estuarine
-82.13656	26.461144	J. N. Ding Darling National Wildlife Refuge	5250	Mangrove Swamp
-82.13656	26.461144	J.N. Ding Darling Closing Order Boundary	5250	Mangrove Swamp
-82.053226	26.669477	Charlotte Harbor Preserve State Park	5240	Salt Marsh (Approximate)
-82.219893	26.836144	Charlotte Harbor Preserve State Park	5240	Salt Marsh (Approximate)
-82.553226	27.586144	Terra Ceia Preserve State Park	5250	Mangrove Swamp (Approximate)
-86.956184	30.552506	Eglin Air Force Base	5240	Salt Marsh (Approximate)

-87.206184	30.594173	Lower Escambia River Water Management Area	5240	Salt Marsh (Approximate)
-86.914517	30.594173	Yellow River Water Management Area	N/A	Palustrine Forested
-87.247851	30.63584	Lower Escambia River Water Management Area	N/A	Palustrine Forested
-85.114115	29.660045	St. Vincent National Wildlife Refuge	5240	Salt Marsh (Approximate)
-83.017933	29.267777	Lower Suwanee National Wildlife Refuge	N/A	Palustrine Forested
-83.0596	29.309444	Lower Suwanee National Wildlife Refuge	N/A	Palustrine Forested
-83.142933	29.351111	Lower Suwanee National Wildlife Refuge	5240	Salt Marsh

Appendix C: Gap Analysis in Louisiana using temperature and precipitation

This map was produced using the same methods described in the body of this report, except it does not account for elevation gradients. It is thus presented only as a supplementary material. The centroid of each priority zone is on average 1.67 km from existing SET stations, speaking to the comprehensiveness of monitoring in the CRMS network. The coordinates of each pixel, highlighted in red, are presented following the map.



X Coordinate	Y Coordinate	Unit Name	NWI Code	Wetland Type
-91.303677	29.353466	Atchafalaya Delta Wildlife Management Area	E1UBL5	Estuarine and Marine Deepwater
-91.296733	29.450688	Atchafalaya Delta Wildlife Management Area	R1UBV	Riverine
-91.380066	29.492355	Atchafalaya Delta Wildlife Management Area	R1UBV	Riverine

-91.862011	29.556244	Marsh Island Wildlife Refuge	E2EM1P5	Estuarine and Marine Wetland
-92.682149	29.627771	Rockefeller Wildlife Refuge	E2EM1Ph	Estuarine and Marine Wetland
-92.817566	29.659021	Rockefeller Wildlife Refuge	E2EM1N4	Estuarine and Marine Wetland
-92.150899	29.659021	State Wildlife Refuge	E2EM1P5	Estuarine and Marine Wetland
-89.147112	29.138819	Pass A Loutre Wildlife Management Area	R1UBV	Riverine
-90.130066	29.221521	Wisner Wildlife Management Area (includes Picciola Tract)	E1UBL4	Estuarine and Marine Deepwater
-91.234233	29.409021	Atchafalaya Delta Wildlife Management Area	E1UBL6	Estuarine and Marine Deepwater
-90.525899	29.450688	Pointe Aux Chenes Wildlife Management Area	E1UBL5	Estuarine and Marine Deepwater
-90.400899	29.450688	Pointe Aux Chenes Wildlife Management Area	E2EM1P5	Estuarine and Marine Wetland
-93.275899	29.825688	Sabine National Wildlife Refuge	E2EM1P5	Estuarine and Marine Wetland
-93.700899	29.884021	Sabine National Wildlife Refuge	E1UBL5	Estuarine and Marine Deepwater
-93.442566	29.909021	Sabine National Wildlife Refuge	PEM1Fh	Freshwater Emergent Wetland
-93.484233	30.034021	WRP_Cameron, LA (22023)	E1UBL5	Estuarine and Marine Deepwater
-90.317566	29.775688	Salvador Wildlife Management Area	PEM1F	Freshwater Emergent Wetland
-90.442566	29.804855	Paradis (Mitigation Bank)	PFO1Ad	Freshwater Forested/Shrub Wetland
-90.125899	29.809021	Jean Lafitte National Historical Park and Preserve	PEM1F	Freshwater Emergent Wetland
-90.275899	29.867355	Salvador Wildlife Management Area	L1AB4H	Lake

-88.900899	29.867355	Breton National Wildlife Refuge	E1UBL	Estuarine and Marine Deepwater
-88.817566	29.909021	Breton National Wildlife Refuge	M1UBL	Estuarine and Marine Deepwater
-88.817566	29.909021	Breton Wilderness Area	M1UBL	Estuarine and Marine Deepwater
-89.869649	30.075688	Bayou Sauvage National Wildlife Refuge	PEM1Ch	Freshwater Emergent Wetland
-90.463399	30.117355	Maurepas Swamp Wildlife Management Area	PFO2/1F	Freshwater Forested/Shrub Wetland
-90.359233	30.242355	Manchac Wildlife Management Area	PFO2/1T	Freshwater Forested/Shrub Wetland

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