A Long-Term Seagrass Monitoring Program for Corpus Christi Bay and Upper Laguna Madre

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Coastal Bend Bays & Estuaries Program
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Final Report to the Coastal Bend Bays and Estuaries Program

Seagrass Monitoring Project 1610

20 March 2018

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Texas Seagrass Monitoring CBBEP Contract No. 1610

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INTRODUCTION

In 1999, the Texas Parks and Wildlife Department (TPWD), along with the Texas General Land Office (TGLO) and the Texas Commission on Environmental Quality (TCEQ), drafted a Seagrass Conservation Plan that proposed, among other things, a seagrass habitat monitoring program (Pulich and Calnan, 1999). One of the main recommendations of this plan was to develop a coast wide monitoring program. In response, the Texas Seagrass Monitoring Plan (TSGMP) proposed a monitoring effort to detect changes in seagrass ecosystem conditions prior to actual seagrass mortality (Pulich et al., 2003). However, implementation of the plan required additional research to specifically identify the environmental parameters that elicit a seagrass stress response and the physiological or morphological variables that best reflect the impact of these environmental stressors.

Numerous researchers have related seagrass health to environmental stressors; however, these studies have not arrived at a consensus regarding the most effective habitat quality and seagrass condition indicators. Kirkman (1996) recommended biomass, productivity, and density for monitoring seagrass whereas other researchers focused on changes in seagrass distribution as a function of environmental stressors (Dennison et al., 1993, Livingston et al., 1998, Koch 2001, and Fourqurean et al., 2003). The consensus among these studies revealed that salinity, depth, light, nutrient concentrations, sediment characteristics, and temperature were among the most important variables that produced a response in a measured seagrass indicator. The relative influence of these environmental variables is likely a function of the seagrass species in question, the geographic location of the study, hydrography, methodology, and other factors specific to local climatology. Because no generalized approach can be extracted from previous research, careful analysis of regional seagrass ecosystems is necessary to develop an effective monitoring program for Texas.

Conservation efforts should seek to develop a conceptual model that outlines the linkages among seagrass ecosystem components and the role of indicators as predictive tools to assess the seagrass physiological response to stressors at various temporal and spatial scales. Tasks for this objective include the identification of stressors that arise from human-induced disturbances, which can result in seagrass loss or compromise plant physiological condition. For example, stressors that lead to higher water turbidity and light attenuation (e.g. dredging and shoreline erosion) are known to result in lower below-ground seagrass biomass and alterations to sediment nutrient concentrations. It is therefore necessary to evaluate long-term light measurements, the biomass of above- versus below-ground tissues and the concentrations of nutrients, sulfides, and dissolved oxygen in sediment porewater when examining the linkages between light attenuation and seagrass health.

This study is part of the Texas seagrass monitoring program, with specific focus on Corpus Christi Bay (CCB; Figure 1) and the Upper Laguna Madre (ULM; Figure 1), following protocols that evaluate seagrass condition based on landscape-scale dynamics. The program is based on a hierarchical strategy for seagrass monitoring outlined by Neckles et al. (2012) to establish the quantitative relationships between physical and biotic parameters that ultimately control seagrass condition, distribution, persistence, and overall health. This approach follows a broad template adopted by several federal and state agencies across the country, but which is uniquely designed for Texas (Dunton et al. 2011) and integrates plant condition indicators with landscape feature indicators to detect and interpret seagrass bed disturbances.

The objectives of this study were to (1) implement long-term monitoring to detect environmental changes with a focus on the ecological integrity of seagrass habitats, (2) provide insight to the ecological consequences of these changes, and (3) help decision makers (e.g. various state and federal agencies) determine if the observed change necessitates a revision of regulatory policy or management practices. We defined ecological integrity as the capacity of the seagrass system to support and maintain a balanced, integrated, and adaptive community of flora and fauna including its characteristic foundation seagrass species. Ecological integrity was assessed using a suite of condition indicators (physical, biological, hydrological, and chemical) measured annually on wide spatial scales.

The primary questions addressed in the 2017 annual Tier-2 surveys include:

1) What are the spatial and temporal patterns in the distribution of seagrasses over annual scales?
2) What are the characteristics of these plant communities, including their species composition and percent cover?
3) How are any changes in seagrass percent cover and species composition, related to measured characteristics of water quality?

METHODS

Sampling Summary

Tier-2 protocols, which are considered Rapid Assessment sampling methods, are adapted from Neckles et al. (2012). We conducted Tier-2 sampling from August to October 2017. Stations in Corpus Christi and Redfish Bays were sampled on 1, 2, and 22 August and then resampled following the arrival of Hurricane Harvey on 19, 20 September and 7, 8 October. Stations in Laguna Madre were sampled only once with the first visits made on 22, 24 August. The remaining stations were sampled on 2, 18, and 20 October. For statistical rigor, a repeated measures design with fixed sampling stations was implemented to maximize our ability to detect future change. Neckles et al. (2012) demonstrated that the Tier-2 approach, when all sampling stations are considered together within a regional system, results in > 99% probability that the bias in overall estimates will not interfere with detection of change.

Site Selection

The Tier-2 sampling program is intended to compliment ongoing remote sensing efforts. Sites were therefore selected from vegetation maps generated with aerial and satellite imagery during the 2004/2007 NOAA Benthic Habitat Assessment. The vegetation maps were then tessellated using polygons, and sample locations were randomly selected within each polygon (Figure 1). Only polygons containing > 50% seagrass cover were included in 2017 sampling efforts.

Water Quality

All sampling stations were located in the field using a handheld GPS device to within a 10 m radius of the pre-determined station coordinates. Upon arrival to a station, hydrographic measurements including water depth, conductivity, temperature, salinity, dissolved oxygen, chlorophyll fluorescence and pH were collected with a YSI 6920 data sonde. Water samples were obtained at each station for determination of Total Suspended Solid (TSS) concentration. Water transparency was derived from measurements of photosynthetically active radiation (PAR) using two LI-COR spherical quantum scalar sensors attached to a lowering frame. All sonde measurements and water samples were obtained prior to the deployment of benthic sampling equipment.

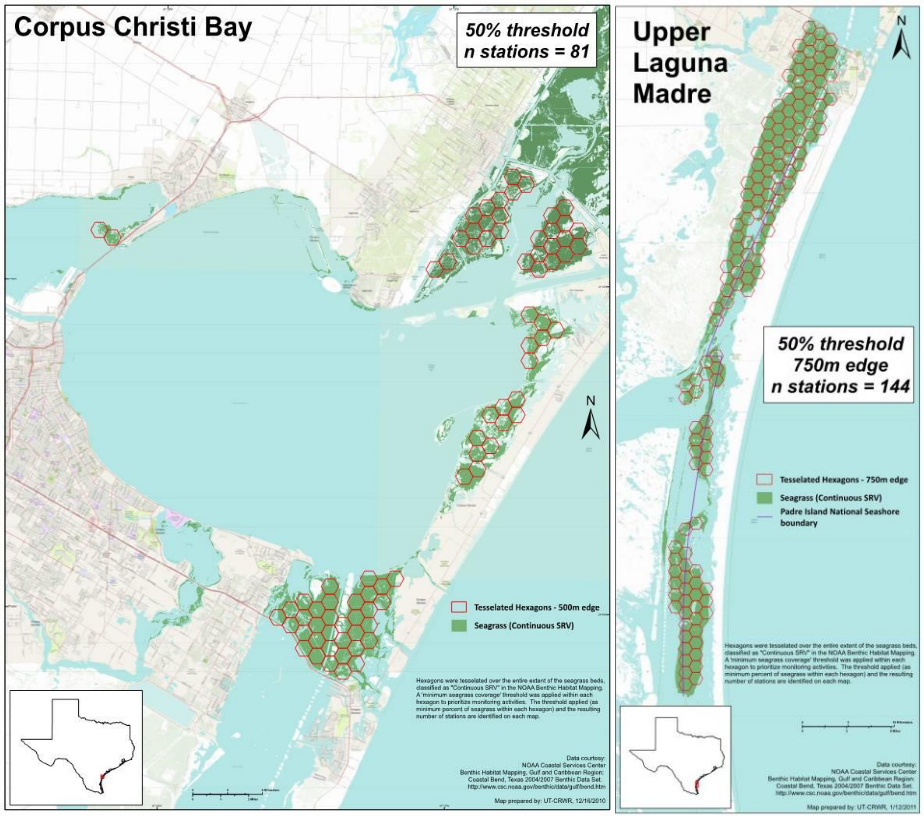

Figure 1. Tessellated boundaries of submerged vegetation delineated during the 2004/2007 NOAA Benthic Habitat Assessment where seagrass cover > 50%. Resulting stations (Upper Laguna Madre n = 144; Corpus Christi Bay n = 81) are identified in text on map. Stations outside the park boundary in Upper Laguna Madre are funded by CBBEP (n = 92) and are delineated by the light purple line on the map.

Seagrass Cover

Species composition and areal cover were obtained from four replicate quadrat samples per station at each of the four cardinal locations from the vessel. Percent cover of areal biomass was estimated by direct vertical observation of the seagrass canopy through the water using a 0.25 m^2 quadrat framer subdivided into 100 cells. Previous research has demonstrated that the probability of achieving a bias is less than 5% of the overall mean when using only four subsamples (Neckles, pers. comm.).

Spatial Data Analysis and Interpolation

ArcGIS software (Environmental Systems Research Institute) was used to manage, analyze, and display spatially referenced point samples and interpolate surfaces for all measured parameters. An inverse distance weighted method was used to assign a value to areas (cells) between sampling points. A total of 12 sampling stations were identified from a variable search radius to generate the value for a single unknown output cell (100 m^2). All data interpolation was spatially restricted to the geographic limits of the submerged vegetation map created during the 2004/2007 NOAA Benthic Habitat Assessment.

RESULTS

Water Quality

Corpus Christi Bay

The CCB region stations exhibited a depth of 68.1 ± 20.3 cm (mean ± standard deviation) and a mean water temperature of 31.3 ± 1.7 °C (Table 1). Salinity measurements were relatively consistent among sampling stations in this region, with a mean of 40.1 ± 2.4 (Table 1). The entire CCB region (Redfish Bay to the JFK Causeway) displayed hypersaline conditions (> 35). Dissolved oxygen concentrations in the CCB region were 5.1 ± 2.1 mg L^{-1} with a saturation of 84.5 ± 35.9% (Table 1). Dissolved oxygen concentrations below 3 mg L^{-1} were observed at thirteen stations, with hypoxic conditions (< 2 mg L^{-1}) at four stations. Hypoxic and low oxygen concentrations were documented within shallow water bodies, specifically in southeast Redfish Bay and East Flats. Mean pH values for CCB were 8.5 ± 0.2 (Table 1) with only two stations near the JFK Causeway that displayed values < 8.

Upper Laguna Madre

The ULM region stations had a mean depth of 104.0 ± 52.1 cm and an average water temperature of 29.2 ± 3.9 °C (Table 1). This region exhibited hypersaline conditions (41.5 ± 5.5; Table 1) between August and October. In August, maximum salinities (> 45) were observed south of the JFK Causeway to Bird Island Basin, and south of Baffin Bay to Nine Mile Hole. By October, salinities dropped to ~32-35 from Bird Island Basin to Baffin Bay. The southernmost portion of the ULM typically experiences hypersaline conditions because of restriction from any significant tidal inlet or freshwater source. As a result, these high salinity values are likely attributed to long water residence times with minimal flushing. ULM had a higher mean dissolved oxygen concentration (5.89 ± 1.48 mg L^{-1}; Table 1) and saturation (95.33 ± 26.39%; Table 1) than the CCB region. We only observed dissolved oxygen concentrations less than 3 mg L^{-1} at one station located in Nine Mile Hole. The highest dissolved oxygen concentrations were observed near Bird Island Basin, and lowest concentrations were found near the mouth of Baffin Bay, extending south to Nine Mile Hole which coincided with warmer water temperatures (33-37 °C). The ULM region was characterized with a mean pH of 8.32 ± 0.24 (Table 1), with highest values in Nine Mile Hole.

Table 1. Summary of water column hydrographic parameters by region.

		Depth (cm)	Temperature (°C)	Salinity	Dissolved Oxygen (mg L^{-1})	Dissolved Oxygen (%)	pH
CCB							
	Mean	68.1	31.26	40.1	5.06	84.49	8.50
	Std. Dev.	20.3	1.73	2.4	2.09	35.88	0.25
ULM							
	Mean	104.0	29.25	41.5	5.89	95.33	8.32
	Std. Dev.	52.1	3.92	5.5	1.48	26.39	0.24

Water Column Optical Properties

Corpus Christi Bay

The mean downward attenuation coefficient (K_d) was 1.03 ± 0.27 m^{-1} for the CCB region (Table 2). Light attenuation was greatest near Shamrock Cove. The highest attenuation values generally coincided with greater water column chlorophyll (10-14 μg L^{-1}). Chlorophyll concentrations were less variable (4.6 ± 2.8 μg L^{-1}; Table 2) than TSS (11.2 ± 6.8 mg L^{-1}; Table 2) measurements for the CCB region. Mean secchi depth varied among stations (67.5 ± 19.6 cm; Table 2) but overall, visibility at most stations was near the entire depth of the water column or within 1 cm of the vegetated or sediment surface, on average.

Upper Laguna Madre

The ULM stations were characterized by a mean K_d of 1.16 ± 0.59 m^{-1} (Table 2). The mean downward attenuation coefficient and variability were greater in ULM than in the CCB region. Higher light attenuation values were observed within Nine Mile Hole which generally coincided with greater chlorophyll levels and TSS concentrations (10-22 μg L^{-1}. and 15-100 mg L^{-1}, respectively). Water column chlorophyll (3.8 ± 3.3 μg L^{-1}; Table 2) was lower in the ULM than in the CCB region but TSS concentrations (16.0 ± 41.9 mg L^{-1}; Table 2) were greater and more variable. Highest water column chlorophyll and TSS concentrations were observed in Nine Mile Hole. Mean secchi depth was variable (100.3 ± 52.4 cm; Table 2) but water transparency was high. At most stations, visibility was near the entire depth of the water column or within 4 cm of the vegetated or sediment surface, on average.

Table 2. Summary of water transparency property indicators by region.

		K_d (m^{-1})	Secchi (cm)	Chlorophyll *a* ($\mu g\ L^{-1}$)	Total Suspended Solids ($mg\ L^{-1}$)
CCB					
	Mean	1.03	67.5	4.56	11.2
	Std. Dev.	0.27	19.6	2.75	6.8
ULM					
	Mean	1.16	100.3	3.82	16.0
	Std. Dev.	0.59	52.4	3.31	41.9

Seagrass Cover and Species Distributions

Corpus Christi Bay

Mean total seagrass cover in the CCB region was 65.3%. The seagrass assemblage in the CCB was dominated by *Halodule wrightii* (39.8 ± 42.4%; Table 3, Figure 2), followed by *Thalassia testudinum* (17.4 ± 36.5%; Table 3, Figure 3), *Syringodium filiforme* (7.3 ± 21.3%; Table 3, Figure 4), with minor contributions from *Ruppia maritima* (0.3 ± 2.9%; Table 3, Figure 5) and *Halophila engelmannii* (0.5 ± 3.1%; Table 3, Figure 6). Four stations (~ 5%) in the CCB did not have vegetation present. Low seagrass cover was observed in southern Redfish Bay near Ingleside and near the JFK Causeway (Figure 7). *Halodule wrightii* was most widely distributed within the CCB region relative to the other seagrass species. Minimal cover was observed in the southwest portion of Redfish Bay which was dominated by *Thalassia testudinum*. Established *Thalassia testudinum* populations are likely excluding *Halodule wrightii* from expanding into this area as *Thalassia testudinum* is a late successional species. Additionally, *Thalassia testudinum* has expanded into southeast Redfish Bay but colonization may be limited due to differences in water depth. However, it should be noted that *Halodule wrightii* populations dominated east Redfish Bay. Canopy height was greatest in *Thalassia testudinum* (34.5 ± 12.5 cm; Table 4), followed by *Syringodium filiforme* (23.0 ± 10.6 cm; Table 4), *Halodule wrightii* (18.0 ± 5.5 cm; Table 4), *Ruppia maritima* (11.4 ± 4.4 cm; Table 4) and *Halophila engelmannii* (5.1 ± 1.9 cm; Table 4).

Upper Laguna Madre

The ULM mean seagrass cover for all species was approximately 66.3%. The seagrass assemblage was again dominated by *Halodule wrightii* (60.1 ± 40.0%; Table 3, Figure 2), followed by *Syringodium filiforme* (6.2 ± 19.1%; Table 3, Figure 4), and *Halophila engelmannii* (0.2 ± 2.1%; Table 3, Figure 6). The ULM region was devoid of *Thalassia testudinum* and *Ruppia maritima* (Table 3, Figures 3 and 5). Eighteen sampling stations (~ 13%) were absent of vegetation. Seagrass cover was lowest in the deepest waters near Bird Island Basin and in the southernmost portion of Nine Mile Hole. *Halodule wrightii* was found throughout ULM, but was largely absent in south Nine Mile Hole and near the JFK Causeway. *Syringodium filiforme* continued to expand from the JFK Causeway south to Bird Island Basin. Highest canopy height values were observed in *Syringodium filiforme* (23.4 ± 8.6 cm; Table 4), followed by *Halodule wrightii* (20.6 ± 7.5 cm; Table 4) and *Halophila engelmannii* (7.4 ± 1.7 cm; Table 4). Mean canopy height was shorter in the ULM relative to the CCB region which may be explained by the absence of *Thalassia testudinum* in the ULM.

Table 3. Summary of plant areal cover by species and region.

		H. wrightii (% cover)	*T. testudinum* (% cover)	*S. filiforme* (% cover)	*R. maritima* (% cover)	*H. engelmannii* (% cover)	Bare (% cover)
CCB							
	Mean	39.8	17.4	7.3	0.3	0.5	34.7
	Std. Dev.	42.4	36.5	21.3	2.9	3.1	37.7
ULM							
	Mean	60.1	0	6.2	0	0.2	33.7
	Std. Dev.	40.0	0	19.1	0	2.1	38.1

Table 4. Summary of plant canopy height by species and region.

		H. wrightii (cm)	*T. testudinum* (cm)	*S. filiforme* (cm)	*R. maritima* (cm)	*H. engelmannii* (cm)
CCB						
	Mean	18.0	34.5	23.0	11.4	5.1
	Std. Dev.	5.5	12.5	10.6	4.4	1.9
ULM						
	Mean	20.1	0	23.4	0	7.4
	Std. Dev.	7.5	0	8.6	0	1.7

CONCLUSIONS

Corpus Christi Bay

Stations characterized by high light attenuations in the CCB correlated to areas with increased TSS and water column chlorophyll. We observed a large fish kill (predominantly drum species) in Redfish Bay while sampling in August 2017. Within this area, we documented low dissolved oxygen concentrations that were more than likely a result of little wind mixing, warm water temperatures, and shallow water depths. Although faunal communities were greatly affected, the seagrasses within this area appeared to withstand the hypoxic event. In south Redfish Bay, we observed greater presence of *Thalassia testudinum* in the west portion while *Halodule wrightii* dominated the area to the east (Harbor Island). The average depth is less in east Redfish Bay than in the west portion and this difference may explain seagrass distribution within the CCB region. Overall, the mixed assemblage of seagrasses covers approximately 65% of the bay floor in the CCB which declined from 79% in 2015.

Upper Laguna Madre

Overall, water quality in the ULM region was much less amenable to seagrasses. Light attenuation was greater, likely due to elevated chlorophyll and TSS in the water column, particularly in Nine Mile Hole. However, mean seagrass cover in the ULM was high, particularly from the JFK Causeway south to Baffin Bay. Low seagrass cover was observed near Bird Island Basin and Nine Mile Hole near the Land Cut. Although Nine Mile Hole experienced prolonged hypersaline conditions, *Halodule wrightii* cover appears to have increased in the northern portion of this area. However, high salinities may still control *Halodule wrightii* expansion into the southernmost region of Nine Mile Hole. Additionally, the increased salinities in the ULM may be limiting the recolonization of *Syringodium filiforme*. Due to minimal flushing and freshwater inflow, the ULM is susceptible to periods of hypersaline conditions during extended periods of aridity. Overall, seagrasses covered approximately 66% of the bay floor in the ULM which declined from 72% in 2015.

Impacts of Hurricane Harvey

Following our occupation of all stations in the Nueces and Mission Aransas estuaries by 22 August, this study area was hammered by Hurricane Harvey three days later. Harvey rapidly intensified into a category 4 hurricane (Saffir-Simpson Hurricane Wind Scale) before striking San Jose Island on August 25, 2017 (Figure 8). Maximum surface winds were recorded at 115 knots with highest recorded peak wind gusts of 130 knots (Blake &

Zelinsky 2018). The damages incurred by wind and disastrous flooding made Hurricane Harvey the second largest natural disaster in U.S. history.

Category 3 and 4 winds associated with the eyewall of Harvey were most prevalent in Redfish Bay (Figure 8 inset). Since we had just completed our 2017 Tier 2 sampling in the northern region of our study area, (which includes Redfish Bay), we had the unique opportunity to revisit the same stations directly after the storm. We present some of those interesting preliminary findings here in relation to the baseline data collected prior to Harvey's landfall.

Salinities measured in the Coastal Bend were substantially lower in September and October 2017 (mean=23.7, SD=7.9) than in July and August (mean=38.3, SD=3.6) (Figure 9). Reductions in seagrass blade length and percent cover corresponded with greater wind intensity, however, the magnitude of the response varied by species. After the passage of Hurricane Harvey, 7% of stations exhibited a complete loss of cover for *Halodule wrightii*. *Thalassia testudinum* was completely eradicated at 13% of stations, and 35% of stations displayed a > 50% reduction in cover. The Coastal Bend – which directly intercepted the path of Hurricane Harvey – lost ~20% of total seagrass area.

Seagrass beds, particularly *Thalassia testudinum*, in areas near the eyewall, and *Halodule wrightii* in the direct path of Hurricane Harvey experienced severe disturbance, with greater reductions in cover and blade length, and in some cases, the obliteration of *Thalassia testudinum* (Figure 10). We would like to note that the increase in cover at certain stations within Redfish Bay (Figure 10) is a result of seagrass patchiness in Texas. Maximum wind speeds corresponded to severe but localized effects of storm damage (Figure 8), with greater loss of *Thalassia testudinum* than *Halodule wrightii*. Extensive networks of islands may explain the difference in the degree of impact on cover and blade length between the species. *Halodule wrightii* dominates the shallow areas of east Redfish Bay (Fig. 2) which is protected by smaller islands vegetated with mangroves and assorted marsh plants. Although mangroves experienced severe defoliation (pers. obs.), *Halodule wrightii* seagrass communities appeared relatively unaffected by wind damage. It may be possible that the densely vegetated islands buffered the effects of Hurricane Harvey. It is also plausible that *Halodule wrightii* populations were able to recover quickly as we observed rapid growth rates in remnant *Thalassia testudinum* beds (unpub. data).

Hurricane Harvey ravaged some seagrass communities, yet others remained impervious to the fierce winds of the storm. Apart from the distinct impacts on the physical structure of seagrasses, these areas also experienced substantial erosion or burial (pers. obs.). Above- and belowground tissues of *Thalassia testudinum* were stripped and removed in some locations, leaving behind exposed roots and rhizomes, or broken and decayed material (pers. obs.). Alternatively, the winds eliminated aboveground tissues but left belowground biomass intact; these areas appeared cropped in appearance (~9 – 12 cm), with clean, horizontal cuts across the blade tissue. It is possible that the aboveground tissues were severed at the sediment surface during Hurricane Harvey and belowground stores were able to support the regeneration of leaf tissue. We observed elevated rates from September – November 2017 which may have been driven by higher nutrient loads from freshwater run-off. Therefore, shorter blade lengths of *Thalassia testudinum* may reflect the regrowth of leaf tissue supported by belowground stores following the storm.

The impacts of Hurricane Harvey to seagrass habitats were localized but severe. The synergistic effects of defoliation, erosion, and hyposalinity may prolong seagrass recovery because of the reduced transport of oxygen to respiring belowground tissues and the surrounding sediments. The loss of *Thalassia testudinum* may create space for the colonization of more opportunistic species such as *Halodule wrightii* and *Syringodium filiforme*. Reductions in seagrass cover could lead to cascading declines in epifaunal abundance and diversity which could propagate to the highest trophic levels.

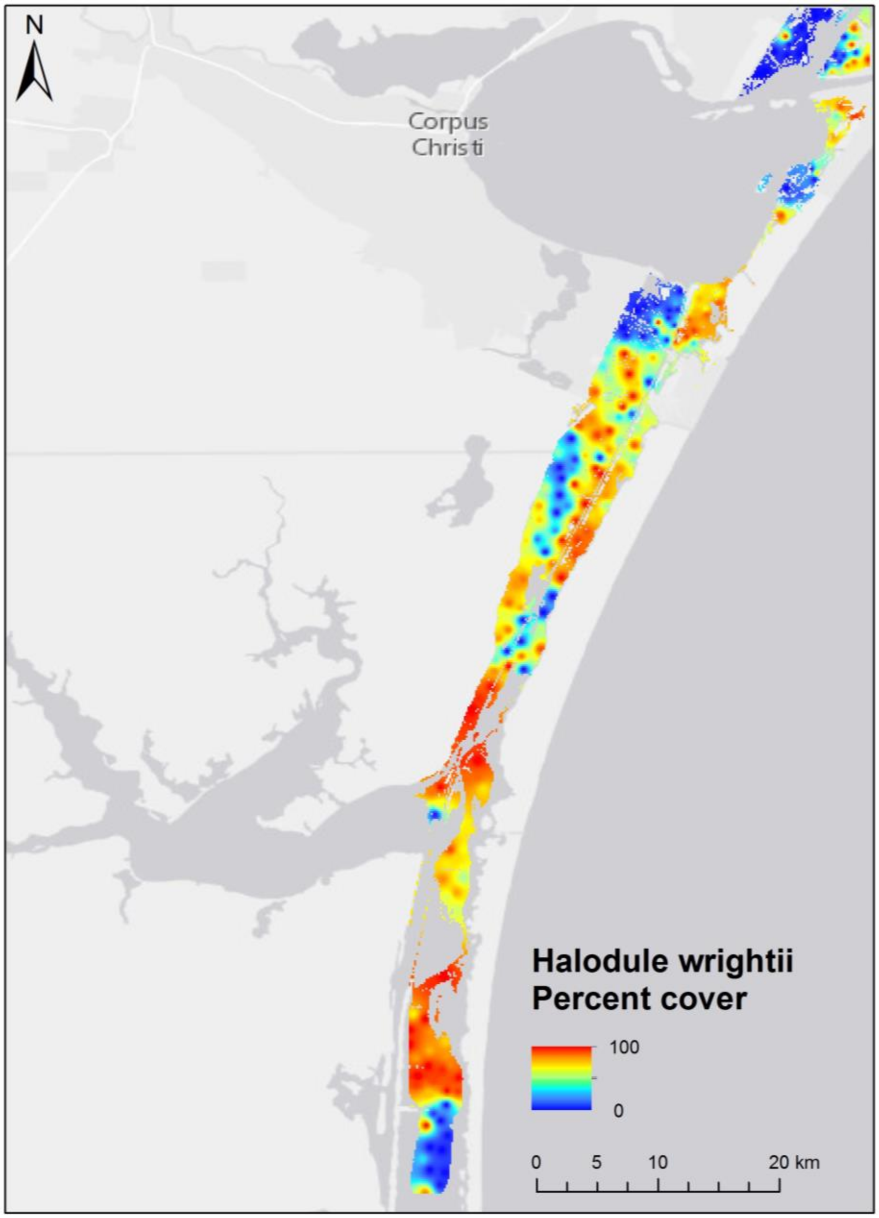

Figure 2. Spatial representations of percent cover for *Halodule wrightii* for 2017. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

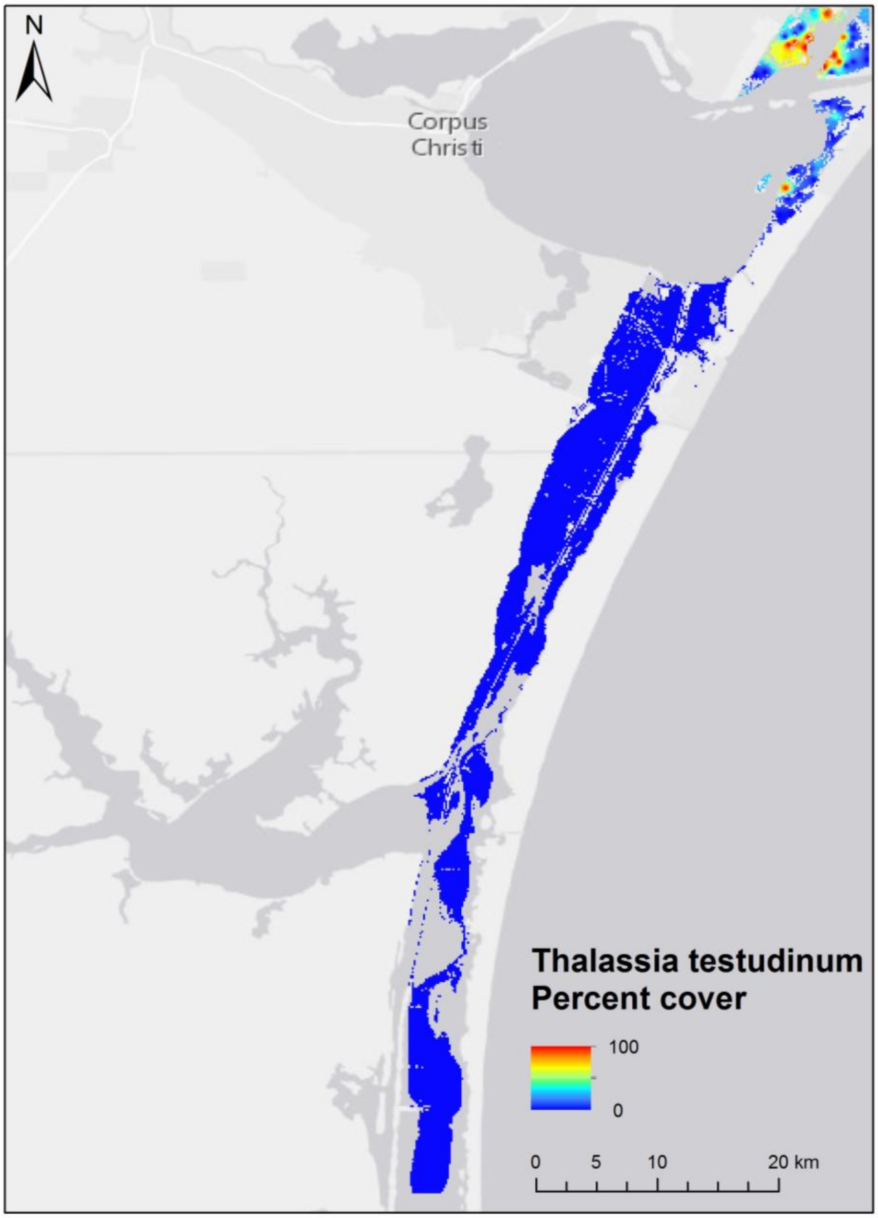

Figure 3. Spatial representations of percent cover for *Thalassia testudinum* for 2017. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

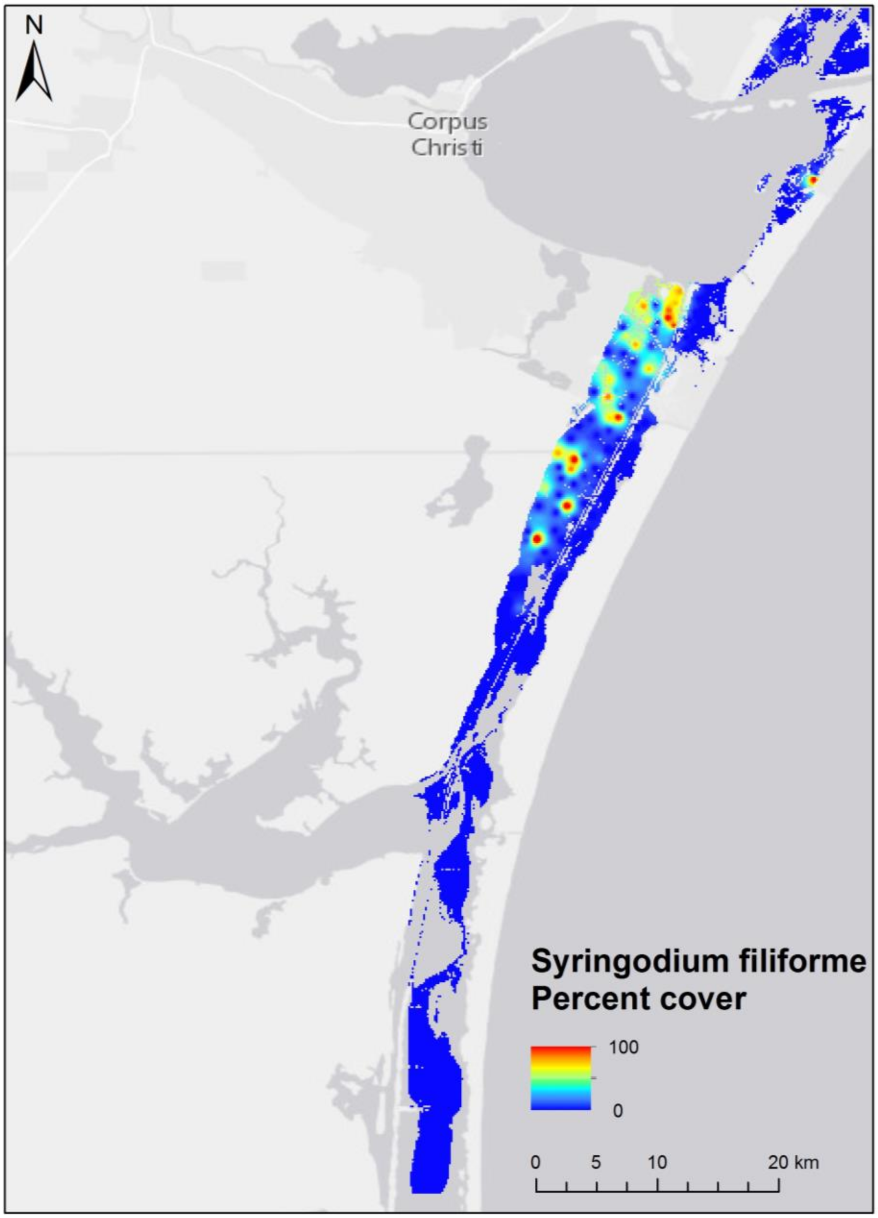

Figure 4. Spatial representations of percent cover for *Syringodium filiforme* for 2017. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

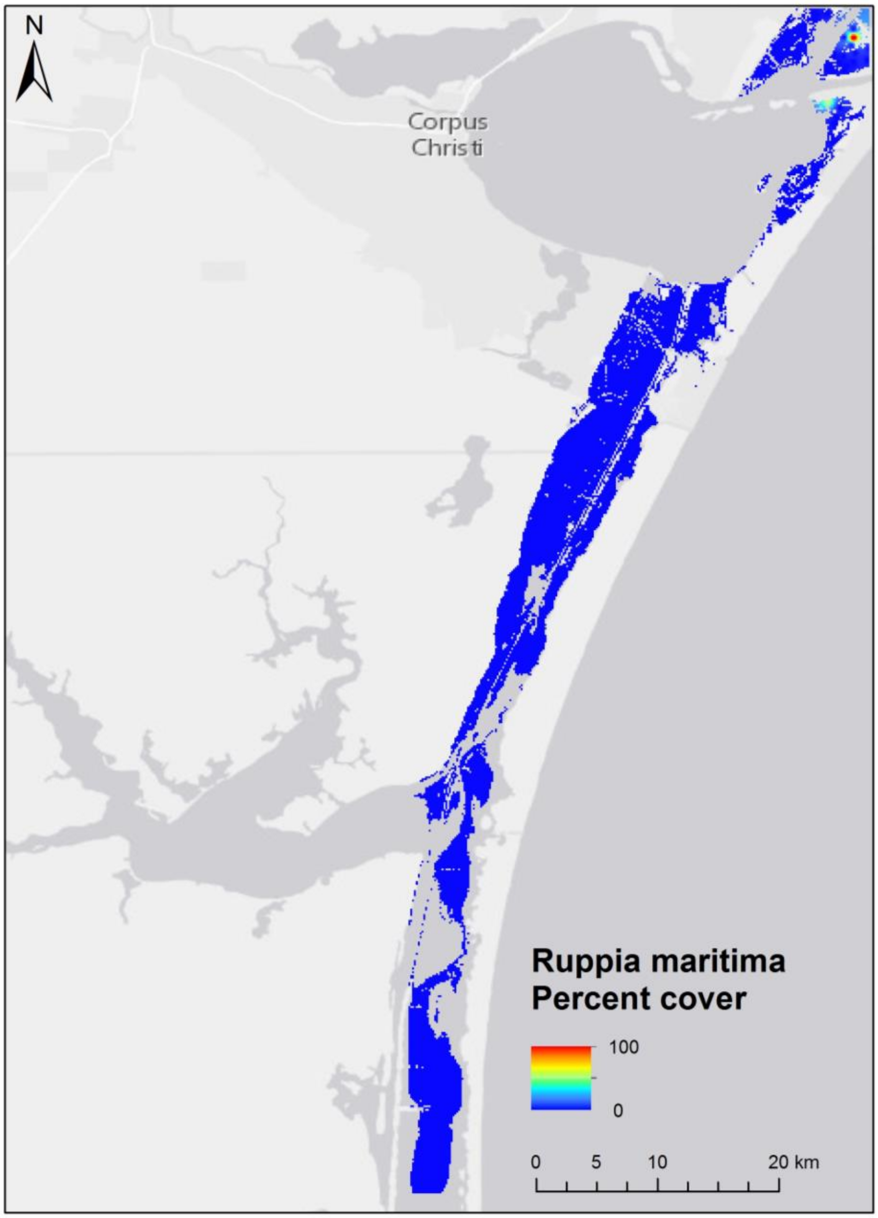

Figure 5. Spatial representations of percent cover for *Ruppia maritima* for 2017. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

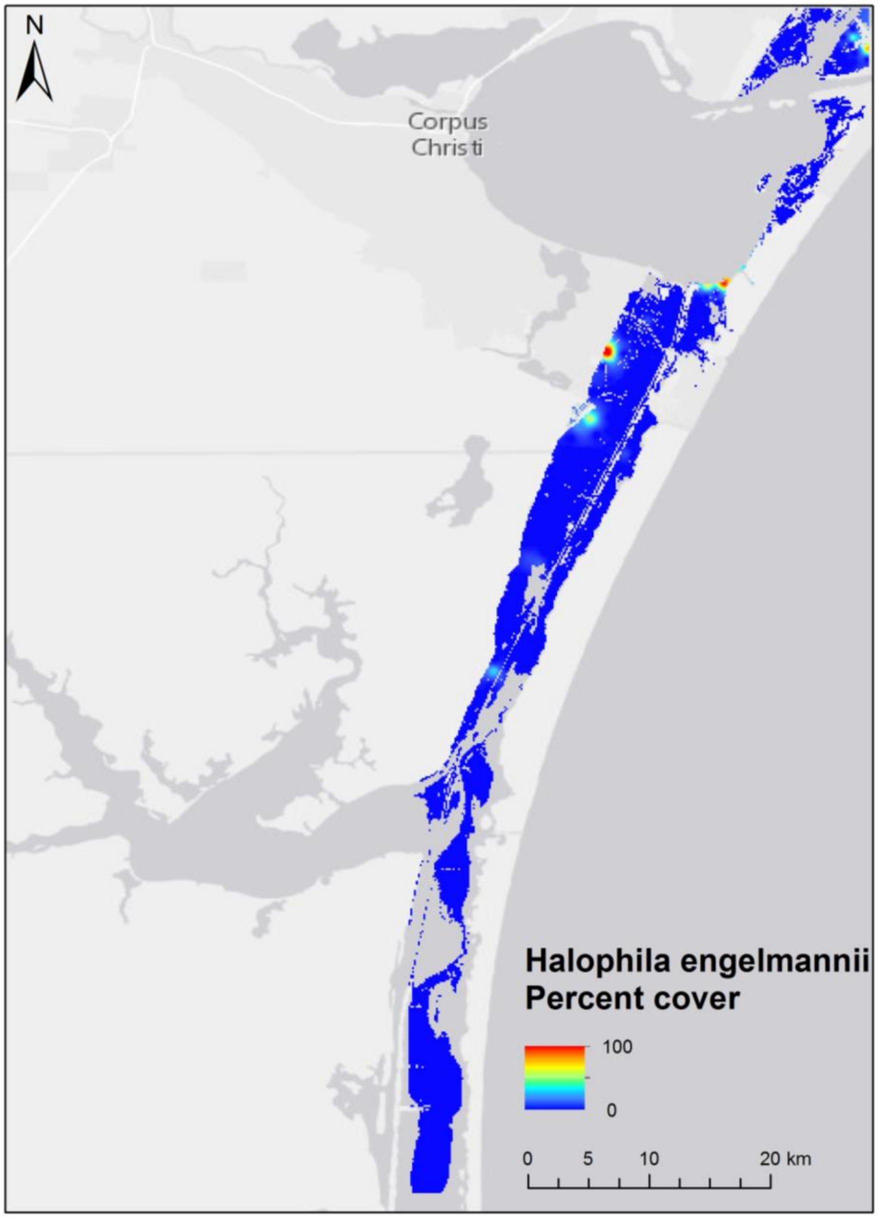

Figure 6. Spatial representations of percent cover for *Halophila engelmannii* for 2017. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

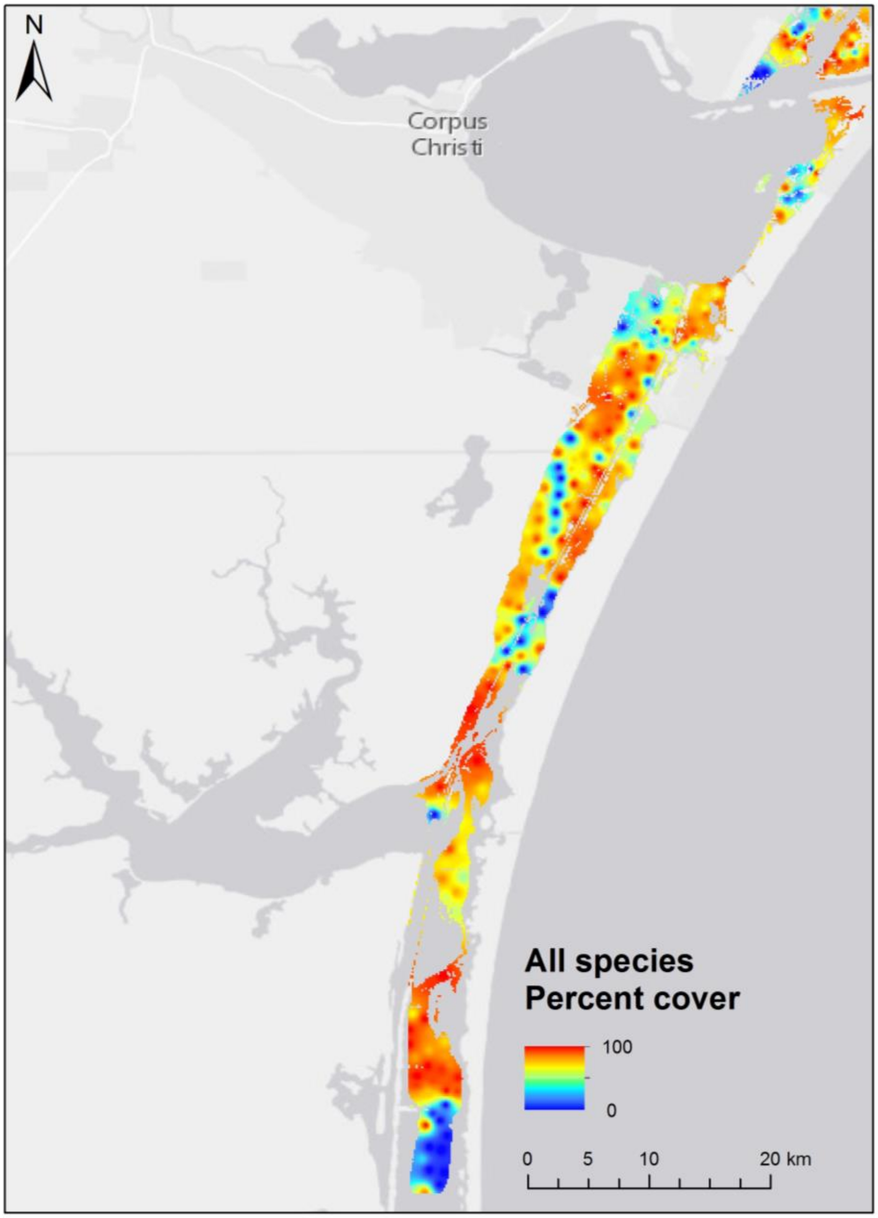

Figure 7. Spatial representations of percent cover for all seagrass species for 2017. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

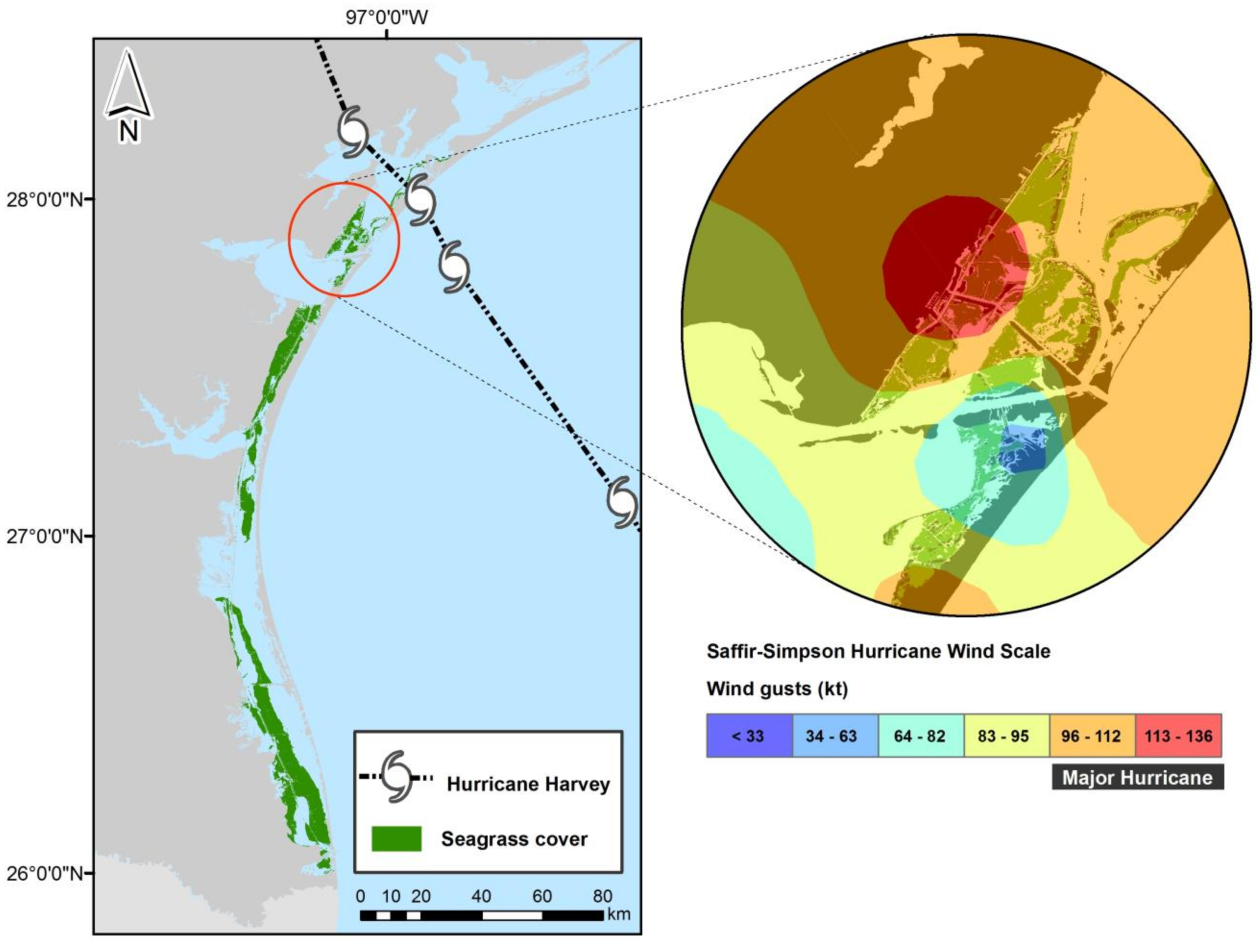

Figure 8. Hurricane Harvey made landfall on San Jose Island, Texas on August 25, 2017. Inset map shows interpolated peak 10-m wind gusts in Redfish Bay.

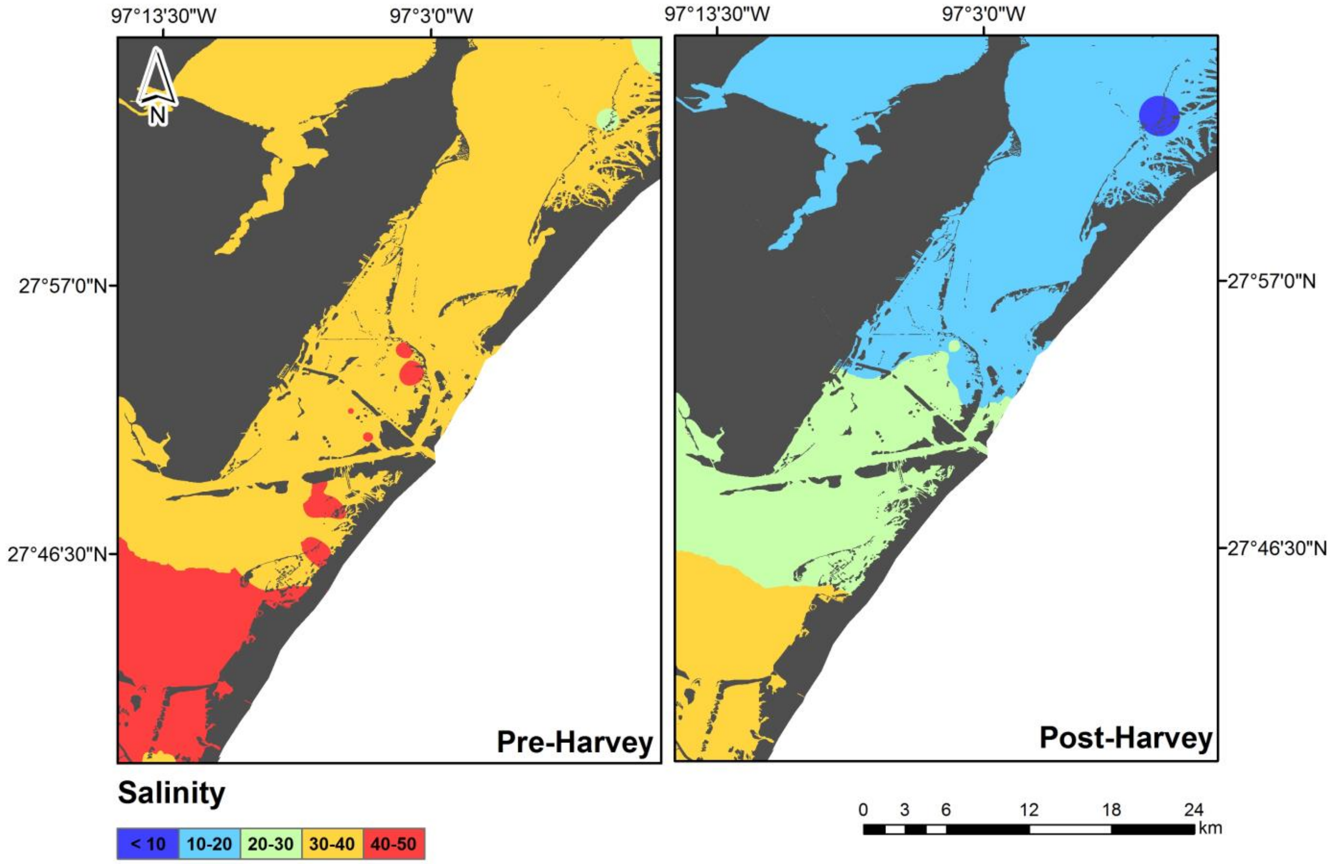

Figure 9. Salinity measurements reflecting the transition from hyper- to hypo-salinity conditions within the Coastal Bend as a result of Hurricane Harvey. Pre-storm measurements (left) were obtained in July and August 2017 and post-storm observations (right) were conducted in September and October 2017.

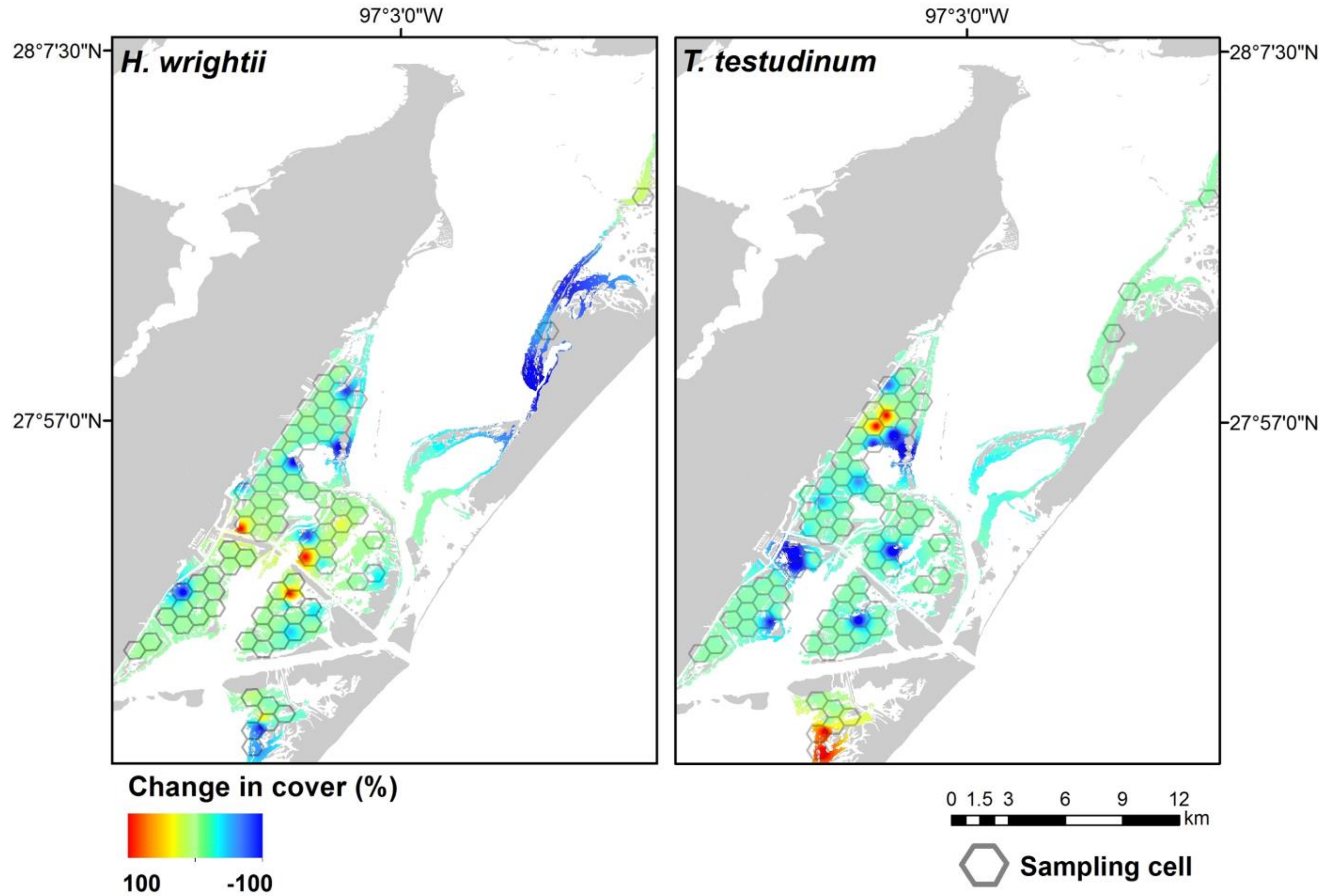

Figure 10. Percent change in cover of *Halodule wrightii* (left) and *Thalassia testudinum* (right) using pre- and post-storm measurements in Redfish Bay. One permanent station exists within each hexagon sampling cell (500m edge).

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