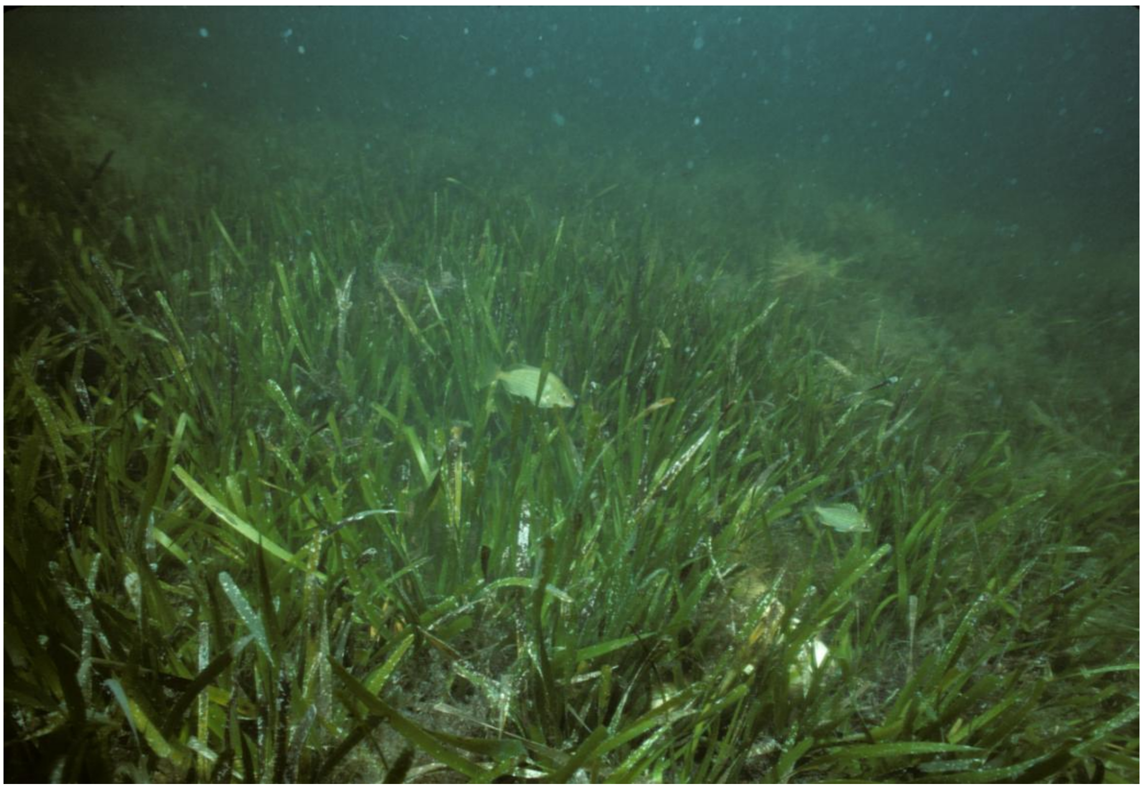
Tracking Long-Term Trends in Seagrass Cover and Condition in Texas Coastal Waters

Victoria M. Congdon and Kenneth H. Dunton[1]



[1]The University of Texas at Austin Marine Science Institute
750 Channel View Drive, Port Aransas, TX 78373
Email: ken.dunton@mail.utexas.edu
Phone: (361) 749-6744

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Principal Investigator

Kenneth H. Dunton
University of Texas at Austin Marine Science Institute
750 Channel View Drive, Port Aransas, TX 78373
Phone: (361) 749-6744
Fax: (361) 749-6777
E-mail: ken.dunton@utexas.edu

Submitted by
Victoria M. Congdon
Kenneth H. Dunton

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PROJECT SUMMARY

This report details the results of the Texas Seagrass Monitoring Plan following the survey of 567 individual sampling stations during the summer and early fall of 2014 and 2015. Sampling station locations were chosen from seagrass meadows mapped from remotely sensed data obtained from the 2004/2007 NOAA Benthic Habitat Assessment. Stations were spatially distributed among three estuarine systems: the Mission-Aransas, Nueces, and Laguna Madre. These three estuarine systems contain about 94% of the seagrasses along the Texas coast. The 2014 and 2015 field sampling effort specifically implemented Tier 2 protocols, which are intended to provide rapid assessments of hydrography, seagrass areal coverage, species distributions and plant physiological conditions. The observational data obtained during the field survey was then illustrated using geographic information systems in order to evaluate spatial relationships in measured parameters. The Tier 2 sampling program successfully yielded spatial characteristics of seagrass habitat quality, identified regions exhibiting seagrass decline and changes in species composition, and thoroughly evaluated the validity of seagrass habitat described in the 2004/2007 NOAA Benthic Habitat Assessment.

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 implements a program for monitoring seagrass meadows in Texas coastal waters following protocols that evaluate seagrass condition based on landscape-scale dynamics. These protocols adhere to the hierarchical strategy for seagrass monitoring outlined by Neckles et al. (2011) and serve to establish quantitative relationships between physical and biotic parameters that ultimately control seagrass condition, distribution, persistence, and overall health. Our monitoring 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 2015 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. (2011). Tier-2 sampling was conducted July through November in 2014 and July through October in 2015. For statistical rigor, a repeated measures design with fixed sampling stations was implemented to maximize our ability to detect future change. Neckles et al. (2011) 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 coverage were included in 2014 and 2015 sampling efforts. The Mission-Aransas National Estuarine Research Reserve and Corpus Christi Bay regions are reported together as one region, Coastal Bend (CB), whereas Upper and Lower Laguna Madre are referred to as ULM and LLM, respectively.

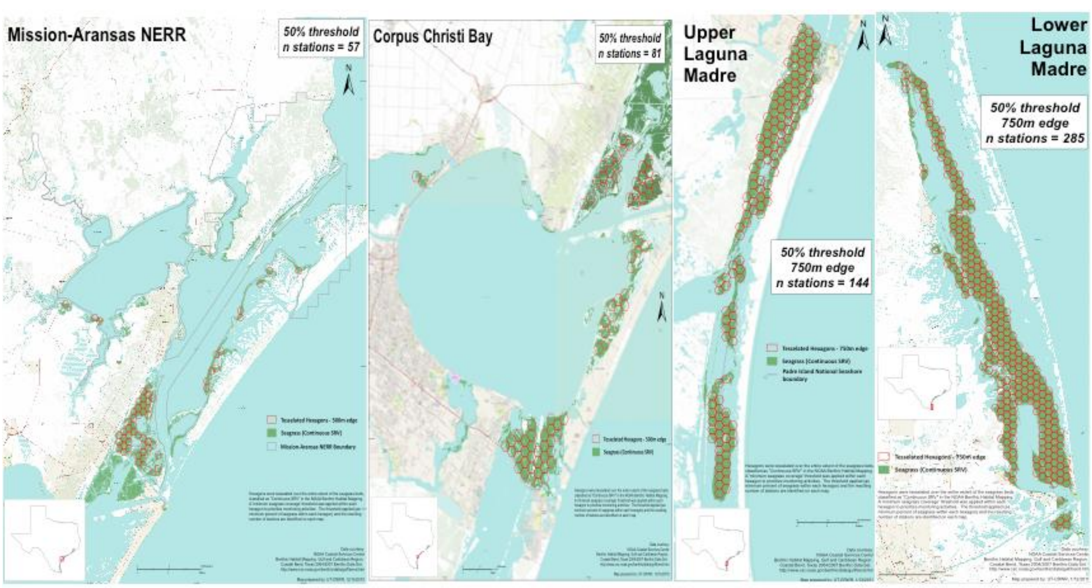

Figure 1. Tessellated boundaries of submerged vegetation delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

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 (See Appendix A.1). Water transparency was derived from measurements of photosynthetically active radiation (PAR) using two LI-COR spherical quantum scalar sensors attached to a lowering frame (See Appendix A.2). All sonde measurements and water samples were obtained prior to the deployment of benthic sampling equipment. In addition, Onset HOBO Conductivity Loggers (model U-24-002-C) were deployed in October 2014 near South Padre Island in Lower Laguna Madre (26°6'N, -97°11'W) and in Nine Mile Hole in Upper Laguna Madre (27°1'N, -97°25'W) in July 2015. Conductivity and temperature data were collected hourly and converted to salinity using HOBOware Pro software.

Seagrass Coverage

Species composition and areal coverage 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.).

Plant Tissue Condition

Seagrass leaf tissue was collected at every station containing a vegetated bottom. Upon removal, all tissue samples were immediately placed on ice in sealed plastic containers and transported to the University of Texas at Austin Marine Science Institute (UTMSI). Leaf tissue samples were then dried to a constant weight in a 60°C oven and homogenized using a mortar and pestle. Subsamples of leaf tissue were processed at UTMSI for determination of leaf tissue carbon content, nitrogen content, $\delta^{13}C$ and $\delta^{15}N$ (See Appendix A.3). All plant tissue analyses were limited to *Halodule wrightii* and *Thalassia testudinum*, as these species were the most prevalent and widely distributed among sample sites.

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

The Coastal Bend

Water Quality

2014. Stations within the CB had a depth of 54.6 ± 24.4 cm (mean ± standard deviation) and mean water temperature of 30.65 ± 2.06 °C (Table 1). Salinity values were hypersaline (42.7 ± 4.0; Table 1), where highest salinities were found behind Mustang Island and near Harbor Island. Mean dissolved oxygen concentrations were 7.03 ± 2.17 mg L^{-1} with a saturation of 117.96 ± 37.36% (Table 1). Highest and lowest dissolved oxygen concentrations were observed within Redfish Bay and East Flats, respectively. No stations experienced hypoxic conditions during sampling. The pH of the CB region was the second highest in 2014 (8.33 ± 0.39; Table 1) and none of the sampling stations had an acidic pH value. Generally greatest pH values corresponded with higher dissolved oxygen concentrations.

2015. The CB region stations exhibited an increased depth of 61.4 ± 26.3 cm and a mean water temperature of 30.86 ± 1.92 °C (Table 1). Salinity was relatively consistent among sampling stations in this region, with a mean of 36.6 ± 4.9 (Table 1) and decreased from 2014. However, some high salinity values (> 40) still remained and were documented in the southeastern portion of Redfish Bay, east Corpus Christi Bay and northeast of the JFK Causeway. Dissolved oxygen concentration in the CB region was 6.33 ± 2.25 mg L^{-1} with a saturation of 104.59 ± 39.22% (Table 1). Two stations revealed concentrations below 3 mg L^{-1}. The lowest dissolved oxygen concentrations were found in east Corpus Christi Bay and the southwest portion of Redfish Bay near Ingleside and Aransas Pass. The pH values were lowest in Redfish Bay and increased southwards into Corpus Christi Bay, with highest pH values north of JFK Causeway. Mean pH values for CB in 2015 were 8.15 ± 0.34 (Table 1).

Water Column Optical Properties

2014. CB stations were characterized by moderate water clarity with a mean downward attenuation coefficient (K_d) of 1.20 ± 0.66 m^{-1} (Table 2). Light attenuation was greatest in west CB, particularly near Ingleside and Aransas Pass. Average TSS and water column chlorophyll concentrations were 12.8 ± 13.0 mg L^{-1} and 4.69 ± 3.25 μg L^{-1}, respectively (Table 2). High TSS and water column chlorophyll concentrations were recorded near Harbor Island closest to the Aransas Ship Channel. Mean Secchi depth was variable (56.8 ± 26.3 cm; Table 2) but water transparency was good at most stations. Visibility at most stations was near the entire depth of the water column or within 3 cm of the vegetated or sediment surface, on average.

2015. The CB region stations were characterized by moderate water clarity with a mean downward attenuation coefficient (K_d) of 1.18 ± 1.03 m^{-1} (Table 2), which varied little from 2014. Light attenuation was greatest in west Corpus Christi Bay, behind Mustang Island, and Redfish Bay near Ingleside. High water column chlorophyll concentrations were documented in the southwest portion of Redfish Bay near Ingleside with moderate concentrations along the eastern banks of Redfish and Corpus Christi bays. High TSS concentrations were observed in the southeast portion of Redfish Bay. The highest attenuation values were generally recorded in locations with greater water column chlorophyll (4.77 ± 3.95 μg L^{-1}; Table 2) and TSS (15.5 ± 20.4 mg L^{-1}; Table 2) concentrations. Mean Secchi depth was variable (56.8 ± 26.3 cm; Table 2) but water transparency was good at most stations. Visibility at most stations was near the entire depth of the water column or within 5 cm of the vegetated or sediment surface, on average.

Seagrass Coverage and Species Distributions

2014. Approximately 29.2 ± 35.4% of the CB region is devoid of vegetation. The seagrass assemblage in CB was dominated by *Halodule wrightii* (36.3 ± 41.5%; Table 3, Figure 4a), followed by *Thalassia testudinum* (25.3 ± 40.5 %; Table 3, Figure 5a), *Syringodium filiforme* (6.4 ± 21.0%; Table 3, Figure 6a), *Halophila engelmannii* (1.5 ± 8.8%; Table 3, Figure 7a) and *Ruppia maritima* (1.3 ± 7.5%; Table 3, Figure 8a). Three sampling stations in CB were devoid of seagrass. Low coverage was observed near Harbor Island (Figure 9a). *H. wrightii* coverage was high and widely distributed, except for minimal coverage along the west side of Redfish Bay where *T. testudinum* dominated and established *T. testudinum* populations are likely excluding *H. wrightii* from expanding into this area. However, it should be noted that *H. wrightii* coverage was greatest in southeast Redfish Bay where *T. testudinum* was largely absent with the exception of one small area and in East Flats. Lastly, the CB region contained the greatest coverage of *H. engelmannii* with a few patches located in Redfish Bay, intermixed with *S. filiforme*. *T. testudinum* canopy height was greatest (35.1 ± 9.8 cm; Table 4), followed by *S. filiforme* (30.1 ± 13.1 cm; Table 4), followed by *H. wrightii* (16.4 ± 6.7 cm; Table 4), *R. maritima* (11.9 ± 5.4 cm; Table 4), and *H. engelmannii* (5.3 ± 2.0 cm; Table 4). The average canopy height was tall, likely attributed to the large amount of *T. testudinum* and *S. filiforme*.

2015. Total seagrass coverage in the CB region was 78.7 ± 23.3%. The seagrass assemblage in CB was dominated again by *H. wrightii* (35.9 ± 41.3%; Table 3, Figure

4b), followed by *T. testudinum* (22.8 ± 38.7 %; Table 3, Figure 5b), *S. filiforme* (7.1 ± 23.1%; Table 3, Figure 6b), *R. maritima* (3.9 ± 15.8%; Table 3, Figure 8b), and *H. engelmannii* (2.8 ± 14.8%; Table 3, Figure 7b). Vegetation was present at all stations in CB, with only moderate coverage in the southern regions of Redfish Bay (Figure 9b). *H. wrightii* and *T. testudinum* exhibited similar spatial distributions as previously documented in 2014. However, mean *H. wrightii* percent cover increased by roughly 2% and *T. testudinum* decreased by nearly 10%. *T. testudinum* appeared to lose coverage in southwest Redfish Bay outside Ingleside. Lastly, the CB region contained the greatest coverage of *H. engelmannii*, with a distinguished population located north of JFK Causeway, interspersed with *S. filiforme*, which increased in coverage from 2014. *S. filiforme* canopy height was tallest (28.3 ± 12.2 cm; Table 4), followed by *T. testudinum* (24.5 ± 9.4 cm; Table 4), *R. maritima* (19.7 ± 10.0 cm; Table 4), *H. wrightii* (18.0 ± 6.4 cm; Table 4), and *H. engelmannii* (5.6 ± 2.0 cm; Table 4). The average canopy height was taller in 2014 than in 2015 due to reduced *T. testudinum* and *S. filiforme* leaf heights in the CB region.

Elemental Tissue Composition

2014. H. wrightii C:N molar ratio was 21.3 ± 4.1 and highest in CB than any other region (Table 5). Mean $\delta^{13}C$ for *H. wrightii* was -10.5 ± 1.1‰ (Table 5). $\delta^{15}N$ was 2.0 ± 1.9‰ (Table 5; Figure 10) with the most enriched values (8.8‰) in Nueces Bay near Portland. *T. testudinum* C:N molar ratio was 13.8 ± 4.8 and lower in CB than LLM (Table 5). Mean *T. testudinum* carbon and nitrogen isotope signatures were -9.0 ± 1.0 ($\delta^{13}C$) and 3.0 ± 1.6‰ ($\delta^{15}N$), respectively (Table 5). The maximum $\delta^{15}N$ value was 7.1‰ and most enriched stations (5.0 to 7.1‰) were observed in the western side of Redfish Bay near Aransas Pass and Ingleside (Figure 11). Enriched $\delta^{15}N$ values in *H. wrightii* and *T. testudinum* tissue suggested that the nitrogen entering certain portions of CB is of anthropogenic origin.

The Upper Laguna Madre

Water Quality

2014. The ULM region had a mean depth of 81.7 ± 44.6 cm and an average water temperature of 31.32 ± 1.61 °C (Table 1). The entire region was characterized by extreme hypersaline conditions (50.2 ± 4.8; Table 1) where salinities greater than 50 were observed south of Bird Island Basin. Maximum salinities (50-82) were observed just south of Baffin Bay near Middle Ground extending towards the Land Cut. This area is near the southernmost portion of the Laguna Madre and lies at the greatest distance 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 lower mean dissolved oxygen concentration (5.68 ± 1.27 mg L^{-1}; Table 1) and saturation (100.42 ± 22.96%; Table 1) than CB; hypoxic conditions were observed at only one sampling station. Highest dissolved oxygen concentrations were found near JFK Causeway and Baffin Bay. Finally, ULM recorded a mean pH of 8.35 ± 0.20 (Table 1), with greatest values generally observed near the Corpus Christi Naval Air Station and lowest values just south of the Air Station and in a pocket within Nine Mile Hole.

2015. The ULM region stations had an increased depth of 84.7 ± 42.0 cm and an average water temperature of 31.33 ± 1.44 °C (Table 1). Hypersaline conditions (44.1 ± 5.3; Table 1) were characteristic of the whole region. Interestingly, the salinity regime remained under similar conditions as in 2014. Salinities greater than 40 were documented south of JFK Causeway, extending into Bird Island Basin and in Nine Mile Hole. However, maximum salinities (50-75) were observed just south of Baffin Bay near Middle Ground extending towards the Land Cut due to little freshwater input and tidal influence. A longer record of continuous salinity measurements obtained in southern ULM also reflected the hypersaline conditions that were captured during field sampling (Figure 2). Despite weekly and monthly fluctuations, salinity in this region remained relatively stable, hovering between 34 and 38, from July 2015 to November 2015. In December 2015, salinities increased and peaked at 49 in January 2016. Following January 2016, salinities decreased and were recorded at 36 in March 2016. The lack of freshwater input and limited tidal exchange facilitates hypersaline conditions in ULM. ULM had a mean dissolved oxygen concentration (5.98 ± 1.91 mg L^{-1}; Table 1) and saturation (101.79 ± 35.23%; Table 1), which increased from last year. Hypoxic conditions were observed at one sampling station, while one additional station recorded dissolved oxygen concentrations less than 3 mg L^{-1}. The highest dissolved oxygen concentrations were observed near Bird Island Basin and lowest concentrations were found near the mouth of Baffin Bay, extending south towards Middle Ground. Finally, ULM recorded a mean pH of 8.18 ± 0.35 (Table 1), with lowest values generally observed near Baffin Bay and highest values from Middle Ground south to Nine Mile Hole and the Land Cut.

Water Column Optical Properties

2014. Mean K_d was 1.41 ± 0.48 m^{-1} (Table 2) and greatest in the ULM region. High light attenuation values were recorded throughout much of ULM where greatest attenuation occurred in areas where water column chlorophyll concentrations were high. Both water column chlorophyll (15.08 ± 10.18 μg L^{-1}; Table 2) and TSS concentrations (21.4 ± 35.4 mg L^{-1}; Table 2) were greatest in the ULM region when compared to CB and LLM.

Highest water column chlorophyll concentrations were observed from JFK Causeway south to Baffin Bay, covering much of central ULM. Greatest TSS concentrations were documented in Nine Mile Hole and near the mouth of Baffin Bay. Mean Secchi depth was variable (52.8 ± 20.4 cm; Table 2), where visibility was roughly 60% of the water column, on average.

2015. The ULM stations exhibited a K_d of 1.40 ± 0.89 m^{-1} (Table 2), similar to mean 2014 observations. Although the mean downward attenuation coefficient was greatest in ULM, variability was greatest in this region. Higher light attenuation values were observed north of Baffin Bay and from Middle Ground south to Nine Mile Hole and the Land Cut. These areas generally coincided with concentrated pockets of water column chlorophyll levels and TSS concentrations. Water column chlorophyll concentration (4.20 ± 3.52 μg L^{-1}; Table 2) was lower in ULM than CB but TSS concentrations (18.8 ± 20.2 mg L^{-1}; Table 2) were greater. Mean TSS and water column chlorophyll concentrations were much lower in 2015 than 2014. Mean Secchi depth was variable (74.5 ± 34.6 cm; Table 2) but water transparency was high. At most stations, visibility was near the entire depth of the water column or within 10 cm of the vegetated or sediment surface, which is unusual for this region.

Seagrass Coverage and Species Distributions

2014. Bare substrate covered 33.9 ± 35.4% of the ULM region. *H. wrightii* (64.0 ± 42.6%; Table 3, Figure 4a) dominated the region, followed by *S. filiforme* (1.7 ± 11.6%; Table 3, Figure 6a), *R. maritima* (0.2 ± 3.8%; Table 3, Figure 8a), *H. engelmannii* (0.2 ± 3.8%; Table 3, Figure 7a), and was devoid of *T. testudinum*. Twenty-four sampling stations in this region had no vegetation present, with the vast majority of these located in Nine Mile Hole (Figure 9a). It is important to note that some of these sampling stations were dry with no overlying water and consisted of desiccated seagrasses. Seagrass coverage was lowest in the southern portion of ULM from Middle Ground south to Nine Mile Hole and the Land Cut. Other bare areas include the mouth of Baffin Bay and patches in central ULM. *H. wrightii* was found throughout ULM, but was largely absent south of Baffin Bay and north of JFK Causeway. Interestingly, modest *S. filiforme* coverage was found north of JFK Causeway as well. Furthermore, some areas west of the ICW in central ULM experienced a loss in *S. filiforme* with minimal recolonization by *H. wrightii*. *S. filiforme* canopy height was tallest (27.5 ± 10.4 cm; Table 4), followed by *R. maritima* (21.3 ± 14.1 cm; Table 4), *H. wrightii* (19.8 ± 9.9 cm; Table 4), and *H. engelmannii* (6.2 ± 1.2 cm; Table 4). Mean canopy height was shorter in ULM than the CB region.

2015. ULM total seagrass coverage was 72.3 ± 37.2%. The seagrass assemblage was again dominated by *H. wrightii* (68.4 ± 40.2%; Table 3, Figure 4b), followed by *S. filiforme* (3.7 ± 15.5%; Table 3, Figure 6b), *R. maritima* (0.2 ± 2.2%; Table 3, Figure 8b), *H. engelmannii* (0.4 ± 5.2%; Table 3, Figure 7b), with *T. testudinum absent*. Twelve sampling stations in this region had no vegetation present, which was a 50% reduction in the number of sampling stations observed in 2014. Seagrass coverage was lowest in the southern portion of ULM from Middle Ground south to Nine Mile Hole and the Land Cut (Figure 9b). *H. wrightii* was found throughout ULM, but was largely absent south of Baffin Bay and north of JFK Causeway. However, *H. wrightii* coverage slightly increased in these areas when compared to 2014 observations. Interestingly, the *S. filiforme* patch north of JFK Causeway expanded and patches were documented in central ULM. *S. filiforme* and *H. wrightii* coverage increased and appears to have expanded into the areas where ULM experienced a massive *S. filiforme* loss; however, some bare patches still remained. *S. filiforme* canopy height was again tallest (31.1 ± 11.0 cm; Table 4), followed by *H. wrightii* (20.0 ± 9.5 cm; Table 4), *R. maritima* (8.4 ± 8.5 cm; Table 4) and *H. engelmannii* (6.5 ± 2.4 cm; Table 4). Mean canopy height was shorter in ULM than the CB region. *H. wrightii* canopy height did not change much between 2014 and 2015, however, *S. filiforme* canopy height increased and *R. maritima* appreciably decreased.

Elemental Tissue Composition

2014. H. wrightii C:N molar ratio was 21.1 ± 2 (Table 5), with a minimum and maximum ratio of 16.1 and 27.0, respectively. Mean C:N ratios were relatively consistent throughout ULM. Mean *H. wrightii* carbon and nitrogen isotope signatures were -11.9 ± 1.4 ($\delta^{13}C$) and 1.5 ± 2.0‰ $\delta^{15}N$, respectively (Table 5). The maximum $\delta^{15}N$ signature was 4.1‰ and was the least enriched in all three regions. Mean $\delta^{15}N$ signatures were most enriched in the northern portion of LLM and decreased south towards the Land Cut (Figure 10).

The Lower Laguna Madre

Water Quality

2014. LLM stations exhibited a depth of 87.7 ± 33.3 cm and a mean water temperature of 25.83 ± 2.49 °C (Table 1). Salinity remained relatively stable among sampling stations in this region, with a mean of 28.1 ± 5.0 (Table 1). The majority of LLM was on the fresher side, with salinities as low as 13 in some areas. Lowest salinities were observed near the mouth of the Arroyo Colorado River, extending northward to Port Mansfield. Mean dissolved oxygen concentration in the LLM region was 7.79 ± 1.41 mg L^{-1} with a saturation of 111.71 ± 20.13% (Table 1). No stations revealed hypoxic conditions during sampling. The highest dissolved oxygen concentrations were found outside the mouth of the Arroyo Colorado River and near Port Mansfield. Mean pH values for this region were 8.32 ± 0.18 (Table 1) and were greatest where highest dissolved oxygen concentrations were observed.

2015. Mean water depth (91.4 ± 32.9 cm; Table 1) and water temperature (28.91 ± 1.44 °C; Table 1) increased in LLM from 2014. Greatest depths were observed in southern LLM, on average. Salinity remained relatively stable among sampling stations in this region, with a mean of 37.0 ± 4.2 (Table 1). Fresher values (< 25) were documented along the east side of LLM, just north of the Arroyo Colorado River. Higher salinities were restricted in the southern portion of the region near Brazos Santiago Pass. Mean salinity increased from 28 in 2014 to 37 in 2015. Continuous salinity data observations in southern LLM also showed a fresh 2014 to mid-2015. These reduced salinities were followed by increased salinities beginning summer 2015 (Figure 3). Salinities dropped to low 20s mid-November 2014, early January 2015, and late June-July 2015. Following July 2015, salinities increased from low 20s to high 40s in October 2015. Salinities dropped and were recorded at 34 in March 2016. Low salinities in 2014 to early 2015 were likely a result of increased and sustained rainfall in south Texas from January through May 2014 coupled with frequent and severe thunderstorms in fall 2014. Dissolved oxygen concentration in the LLM region was 6.97 ± 2.05 mg L^{-1} with a saturation of 110.57 ± 33.21% (Table 1). Three stations revealed concentrations below 3 mg L^{-1}. Lowest dissolved oxygen concentrations were found near the mouth of the Arroyo Colorado River. Mean pH values for LLM were 8.08 ± 0.26 (Table 1).

Water Column Optical Properties

2014. Mean K_d was 1.28 ± 0.99 m^{-1} (Table 2) across LLM stations. Light attenuation was comparable to CB and less than ULM, however, variability was greatest. Highest light attenuation values were observed to north and south of the Arroyo Colorado River, extending to the Laguna Atascosa National Wildlife Refuge and Laguna Vista. Water column chlorophyll (4.37 ± 5.44 µg L^{-1}; Table 2) was highest in closest proximity to the Laguna Atascosa National Wildlife Refuge. TSS concentrations (9.8 ± 9.3 mg L^{-1}; Table 2) were lowest in LLM in comparison to CB and ULM, where greater concentrations were generally restricted to the Laguna Atascosa National Wildlife Refuge. Mean Secchi depth was variable (73.9 ± 29.1 cm; Table 2) but water transparency was high at most stations where visibility was near the entire depth of the water column. Water transparency was greatest in LLM.

2015. Mean K_d (0.98 ± 0.48 m^{-1}; Table 2) decreased in 2015 compared to the mean downward attenuation coefficient recorded in 2014 (1.28 m^{-1}). Light attenuation and variability was the least in LLM compared to both CB and ULM in 2015. Higher light attenuation values were observed near the Laguna Atascosa National Wildlife Refuge. These areas generally coincided with greater chlorophyll levels and TSS concentrations. Water column chlorophyll (4.95 ± 6.18 μg L^{-1}; Table 2) was highest in LLM relative to CB and ULM but TSS concentrations (12.8 ± 8.8 mg L^{-1}; Table 2) were lowest of all three regions. Mean Secchi depth was variable (78.9 ± 28.4 cm; Table 2) but water transparency was high. At most stations, visibility was near the entire depth of the water column or within 12 cm of the vegetated or sediment surface.

Seagrass Coverage and Species Distributions

2014. Approximately 41.2 ± 40.7% of LLM is bare. *H. wrightii* dominated the seagrass assemblage in LLM (38.5 ± 42.8%; Table 3, Figure 4a), followed by *T. testudinum (*18.4 ± 34.3%; Table 3, Figure 5a*)*, *S. filiforme* (1.7 ± 10.3%; Table 3, Figure 6a), *H. engelmannii* (0.1 ± 1.3%; Table 3, Figure 7a), and *R. maritima* (0.1 ± 3.0%; Table 3, Figure 8a). Nineteen sampling stations in this region had no vegetation present, however, a large number of stations were documented to contain < 1% coverage. Seagrasses were largely absent south of the Laguna Atascosa National Wildlife Refuge and southeast of the spoil islands in the center of LLM (Figure 9a). *H. wrightii* dominated from the northernmost section of LLM to just south of the Arroyo Colorado River, with greatest coverage near the mouth of the river and to the north towards Port Mansfield. *T. testudinum* presence was confined to the southernmost region of LLM and just outside the Laguna Atascosa National Wildlife Refuge. *S. filiforme* canopy height was tallest (26.2 ± 10.8 cm; Table 4), followed by *T. testudinum* (19.6 ± 8.4 cm; Table 4), *H. wrightii* (16.4 ± 7.3 cm; Table 4), *R. maritima* (11.5 ± 2.9 cm; Table 4), and *H. engelmannii* (4.9 ± 2.6 cm; Table 4). Mean canopy height was shortest in LLM compared to ULM and CB regions.

2015. Mean bare coverage increased from 41% in 2014 to 47.9 ± 41.3% in 2015. *H. wrightii* dominated the seagrass assemblage in LLM (30.5 ± 40.5%; Table 3, Figure 4b), followed by *T. testudinum (*19.6 ± 34.9%; Table 3, Figure 5b*)*, *S. filiforme* (1.7 ± 9.9%; Table 3, Figure 6b), *H. engelmannii* (0.3 ± 2.6%; Table 3, Figure 7b), and very little presence of *R. maritima* (0 ± 0.2%; Table 3, Figure 8b). Twenty-one sampling stations in this region had no vegetation present. Seagrasses were absent along the eastern side of LLM, behind Padre Island, and southeast of the spoil islands in the center of LLM (Figure 9b). *H. wrightii* dominated from the northernmost section of LLM to just south of the Arroyo Colorado River. From here, *T. testudinum* coverage began and was greatest in the southernmost region of LLM and just outside the Laguna Atascosa National Wildlife

Refuge. *S. filiforme* canopy height remained tallest (26.5 ± 9.6 cm; Table 4), followed by *T. testudinum* (19.4 ± 8.1 cm; Table 4), *R. maritima* (13.9 ± 5.6 cm; Table 4), *H. wrightii* (13.8 ± 7.2 cm; Table 4), and *H. engelmannii* (4.6 ± 1.0 cm; Table 4). The greatest difference in mean canopy height between 2014 and 2015 (approximately 3.0 cm reduction) was observed in *H. wrightii*.

Elemental Tissue Composition

2014. Mean C:N molar ratio for *H. wrightii* was 18.0 ± 2.2 and the lowest of all three regions (Table 5). $\delta^{13}C$ and $\delta^{15}N$ signatures for *H. wrightii* were -9.9 ± 1.5‰ and 3.4 ± 2.6‰, respectively (Table 5). The maximum *H. wrightii* $\delta^{15}N$ value in LLM was 10.1‰. Enriched $\delta^{15}N$ signatures were found near the Arroyo Colorado River and extended northward (Figure 10). *T. testudinum* C:N molar ratio (17.7 ± 2.2) was highest in LLM (Table 5). Mean *T. testudinum* $\delta^{13}C$ was nearly identical to CB (-9.0 ± 1.0) but differed in mean $\delta^{15}N$ (2.8 ± 1.3‰; Table 5). The maximum *T. testudinum* $\delta^{15}N$ value in LLM was 5.8‰ and located near Laguna Vista. *T. testudinum* $\delta^{15}N$ tissue at stations located within this area ranged from 2.4 to 5.8‰ (Figure 12). Enriched $\delta^{15}N$ values (5.8‰) were also observed near the city of South Padre Island (Figure 12). It should also be noted that stations with enriched $\delta^{15}N$ signatures also had fleshy macroalgal species present.

DISCUSSION

The Coastal Bend

Stations characterized by high light attenuations in the CB region correlated to areas with increased TSS and water column chlorophyll. Despite lower water transparency, seagrass coverage was moderate to high in these areas and overall, high throughout the CB. These areas were generally high in both dissolved oxygen and pH. The greatest *H. engelmannii* percent cover was observed north of JFK Causeway, west of the ICW, interspersed with *S. filiforme. H. wrightii* coverage was observed east of the ICW, north of JFK Causeway. In south Redfish Bay, *T. testudinum* dominated the west portion and *H. wrightii* the east. Salinities were greater in east CB than west and this difference may explain seagrass distribution in the CB region, however, this requires further investigation. Something to note is that δ^{15}N *T. testudinum* values were more enriched than *H. wrightii* in CB. Interestingly, *T. testudinum* lies closer to populated areas such as Aransas Pass and Ingleside, where these areas corresponded with most enriched δ^{15}N signatures and treatment facilities. Overall, the mixed assemblage of seagrasses cover approximately 79% of the bay floor in CB and communities appear to be relatively stable.

The 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. Despite reduced water clarity, seagrass coverage was high, particularly from JFK Causeway south to Baffin Bay. Low seagrass coverage was observed near Bird Island Basin as well as from Middle Ground south to Nine Mile Hole and the Land cut. Nine Mile Hole experienced prolonged hypsersaline conditions, which may have attributed to a decline in *H. wrightii* in this area. The decreased seagrass cover near Bird Island Basin resulted from *S. filiforme* decline that was likely caused by increased salinities. 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 72% of the bay floor in ULM. Seagrass beds in portions of this region experienced a shift from *S. filiforme* to *H. wrightii*. ULM also experienced a decline in seagrass coverage in the southern portion of the region, near Nine Mile Hole to the Land Cut; however, recent observations imply that *H. wrightii* is rebounding in this area.

The Lower Laguna Madre

Overall, water quality in the LLM region improved from 2014 to 2015. Despite a slight increase in chlorophyll and total suspended solids concentrations, light attenuation decreased considerably and water clarity improved making LLM a more suitable habitat for seagrasses. However, the largest changes in both water quality and seagrass distribution were documented in the areas surrounding the Laguna Atascosa National Wildlife Refuge and spoil islands southwest of the refuge. Field observations indicated that seagrasses adjacent to these locations were buried under layers of sediment. It may be possible that the origin of these sediments was from the Arroyo Colorado River or dredging activities occurring near these areas. Light attenuation, water column chlorophyll and total suspended solids concentrations were highest and it is possible that the Laguna Atascosa National Wildlife Refuge may be influenced by fluctuating hydrologic contributions of the Arroyo Colorado River. Although these observations are a brief snapshot of water quality conditions, they do provide important information in identifying possible stressors of seagrass loss in the LLM. Additional research is needed in order to fully ascertain the nature of this relationship.

Impaired water column optical properties may not be the only explanation for seagrass loss in the LLM. Salinity plays an important role in controlling seagrass distribution and species composition in Texas bays and estuaries. The hypersaline conditions characteristic of the ULM during times of insufficient precipitation and drought resulted in a massive *S. filiforme* decline. Salinities were sustained above 55, well above the documented physiological threshold of this species. Continuous salinity data obtained from Nine Mole Hole show relatively stable salinity conditions (34-38) from July to November 2015. During this timeframe, temperatures decreased from 30 °C to 23 °C and continued to decrease to 10 °C by January 2016. At 25 °C salinities began to increase (> 45) until decreasing to 36 in March 2016. Since the ULM, particularly Nine Mile Hole, is relatively shallow, seasonal temperatures and climate play an important role in governing salinity. As was previously discussed, a large portion of the ULM is precariously located a great distance away from any significant freshwater or oceanic source. The limited exchange occurring within ULM coupled with seasonal and climatic events thus subjects this region to hypersaline conditions.

Conversely, portions of the LLM experience both freshwater (Arroyo Colorado River) and oceanic (Mansfield and Brazos Santiago passes) exchange. The Arroyo Colorado River is the primary riverine discharge into the LLM. These episodic fluxes of freshwater can decrease salinities to near brackish conditions. Depending on the duration of these fresh conditions, some seagrass species are not physiologically capable of tolerating these extreme conditions and may die. The decrease in *H. wrightii* coverage observed around the Arroyo Colorado River from 2014 to 2015 might be a result of increased freshwater into the system. For this reason, we intend to deploy a conductivity logger in close proximity to Arroyo Colorado River and the Laguna Atascosa National Wildlife Refuge to provide a finer resolution of the salinity regime in the LLM region.

The logger deployed in southern LLM captured salinities in the low 20s for duration of nearly eight months. Salinities remained low for much of spring and early summer 2015 until temperatures began to warm above 30 °C. Salinity lagged warming temperatures and finally peaked (> 40) in October 2015. Long-term salinity monitoring is critical in understanding its control on seagrass distribution and species composition. Monitoring provides the tools necessary to identify spatial and temporal patterns in temperature and salinity, making punctuated rain or drought events easier to tease out.

Lastly, nutrients from certain nitrogen sources may impact seagrass distribution in localized areas. Since seagrasses integrate the overlying water column, we can infer from enriched $\delta^{15}N$ signatures in *H. wrightii* and *T. testudinum* tissue that the nitrogen source is of anthropogenic origin. These enriched signatures appear to be confined to the Arroyo Colorado River, Laguna Vista, and South Padre Island areas. Interestingly, wastewater outfalls are located in conjunction with $\delta^{15}N$ enriched seagrass tissue. Highest $\delta^{15}N$ values are in closest proximity to wastewater treatment facilities and become more depleted with distance. These “plumes” appear to spread southwest of the point source, which may possibly be explained by prevailing southeast winds during summer. Increased nitrogen can decrease seagrass coverage by impairing water quality and promoting the growth of micro- and macroalgae species that can outcompete seagrasses. Further research is needed to better understand anthropogenic nitrogen sources into the LLM.

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

		Depth (cm)		Temperature (°C)		Salinity		Dissolved Oxygen (mg L^{-1})		Dissolved Oxygen (%)		pH	
		2014	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
CB													
	Mean	54.6	61.4	30.65	30.86	42.7	36.6	7.03	6.33	117.96	104.59	8.33	8.15
	Standard Deviation	24.4	26.3	2.06	1.92	4.0	4.9	2.17	2.25	37.36	39.22	0.39	0.34
ULM													
	Mean	81.7	84.7	31.32	31.33	50.2	44.1	5.68	5.98	100.42	101.79	8.35	8.18
	Standard Deviation	44.6	42.0	1.61	1.44	4.8	5.3	1.27	1.91	22.96	35.23	0.20	0.35
LLM													
	Mean	87.7	91.4	25.83	28.91	28.1	37.0	7.79	6.97	111.71	110.57	8.32	8.08
	Standard Deviation	33.3	32.9	2.49	1.44	5.0	4.2	1.41	2.05	20.13	33.21	0.18	0.26

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 ($mg\ L^{-1}$)	
		2014	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
CB									
	Mean	1.20	1.18	51.5	56.8	4.69	4.77	12.8	15.5
	Standard Deviation	0.66	1.03	22.0	26.3	3.25	3.95	13.0	20.4
ULM									
	Mean	1.41	1.40	52.8	74.5	15.08	4.20	21.4	18.8
	Standard Deviation	0.48	0.89	20.4	34.6	10.18	3.52	35.4	20.2
LLM									
	Mean	1.28	0.98	73.9	78.9	4.37	4.95	9.8	12.8
	Standard Deviation	0.99	0.48	29.1	28.4	5.44	6.18	9.3	8.8

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

		H. wrightii (% cover)		*T. testudinum* (% cover)		*S. filiforme* (% cover)		*R. maritima* (% cover)		*H. engelmannii* (% cover)		Bare (% cover)	
		2014	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
CB													
	Mean	36.3	35.9	25.3	22.8	6.4	7.1	1.3	3.9	1.5	2.8	29.2	27.5
	Std. Dev.	41.5	41.3	40.5	38.7	21.0	23.1	7.5	15.8	8.8	14.8	35.4	35.3
ULM													
	Mean	64.0	68.4	0	0	1.7	3.7	0.2	0.2	0.2	0.4	33.9	27.3
	Std. Dev.	42.6	40.2	0	0	11.6	15.5	3.8	2.2	3.8	5.2	35.4	38.7
LLM													
	Mean	38.5	30.5	18.4	19.6	1.7	1.7	0.1	0	0.1	0.3	41.2	47.9
	Std. Dev.	42.8	40.5	34.3	34.9	10.3	9.9	3.0	0.2	1.3	2.6	40.7	41.3

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)	
		2014	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**	**2014**	**2015**
CB											
	Mean	16.4	18.0	35.1	24.5	30.1	28.3	11.9	19.7	5.3	5.6
	Std. Dev.	6.7	6.4	9.8	9.4	13.1	12.2	5.4	10.0	2.0	2.0
ULM											
	Mean	19.8	20.0	0	0	27.5	31.1	21.3	8.4	6.2	6.5
	Std. Dev.	9.9	9.5	0	0	10.4	11.0	14.1	8.5	1.2	2.4
LLM											
	Mean	16.4	13.8	19.6	19.4	26.2	26.5	11.5	13.9	4.9	4.6
	Std. Dev.	7.3	7.2	8.4	8.1	10.8	9.6	2.9	5.6	2.6	1.0

Table 5. Summary of plant tissue condition by species and region in 2014.

		H. wrightii			*T. testudinum*		
		C:N	**$\delta^{13}C$** (‰)	**$\delta^{15}N$** (‰)	**C:N**	**$\delta^{13}C$** (‰)	**$\delta^{15}N$** (‰)
CB							
	Mean	21.3	-10.5	2.0	13.8	-9.0	3.0
	Std. Dev.	4.1	1.1	1.9	4.8	1.0	1.6
ULM							
	Mean	21.1	-11.9	1.5			
	Std. Dev.	2.7	1.4	2.0			
LLM							
	Mean	18.0	-9.9	3.4	17.7	-9.0	2.8
	Std. Dev.	2.2	1.5	2.6	2.2	1.0	1.3

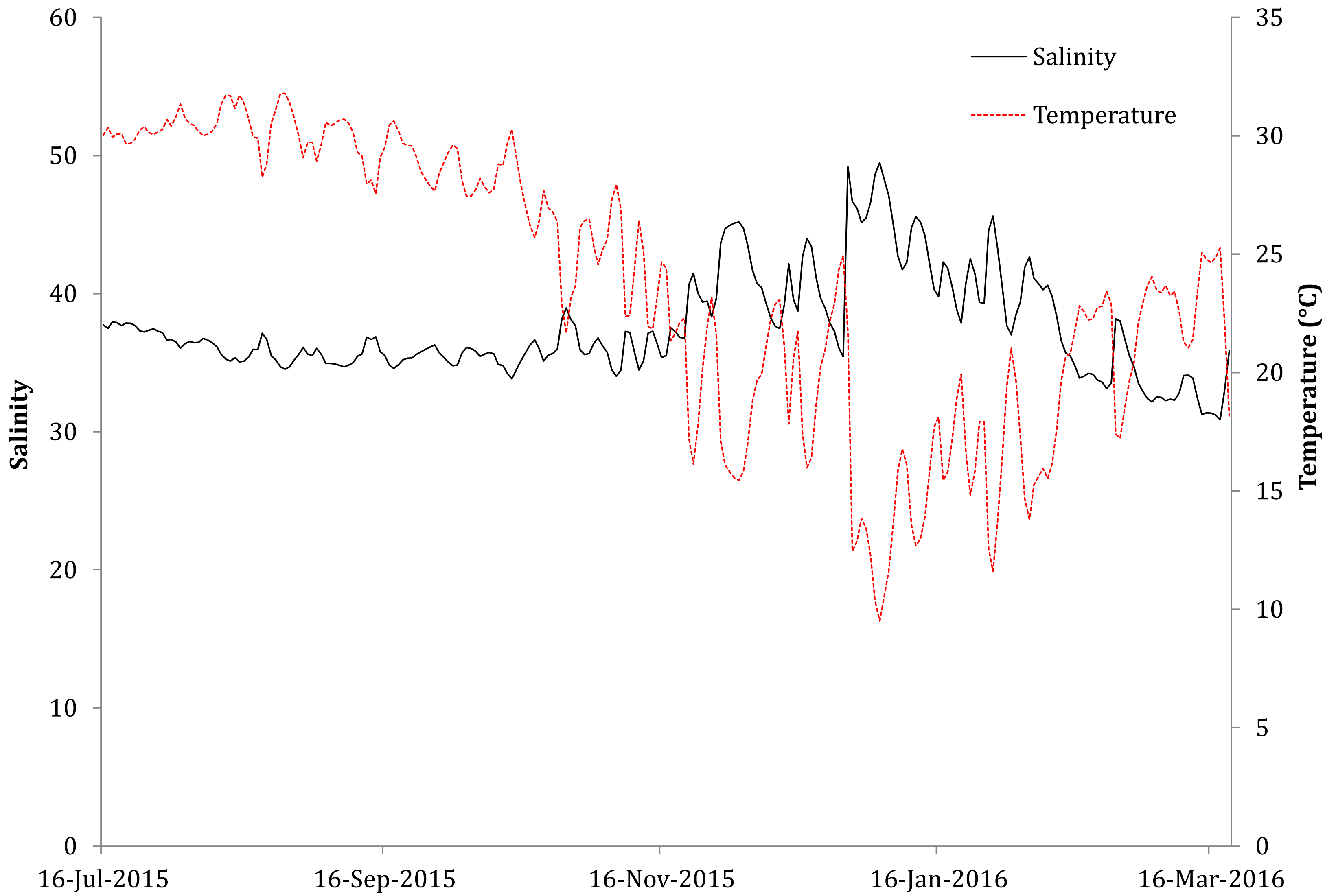

Figure 2. Mean daily salinity measurements from July 2015 to March 2016 for southern Upper Laguna Madre.

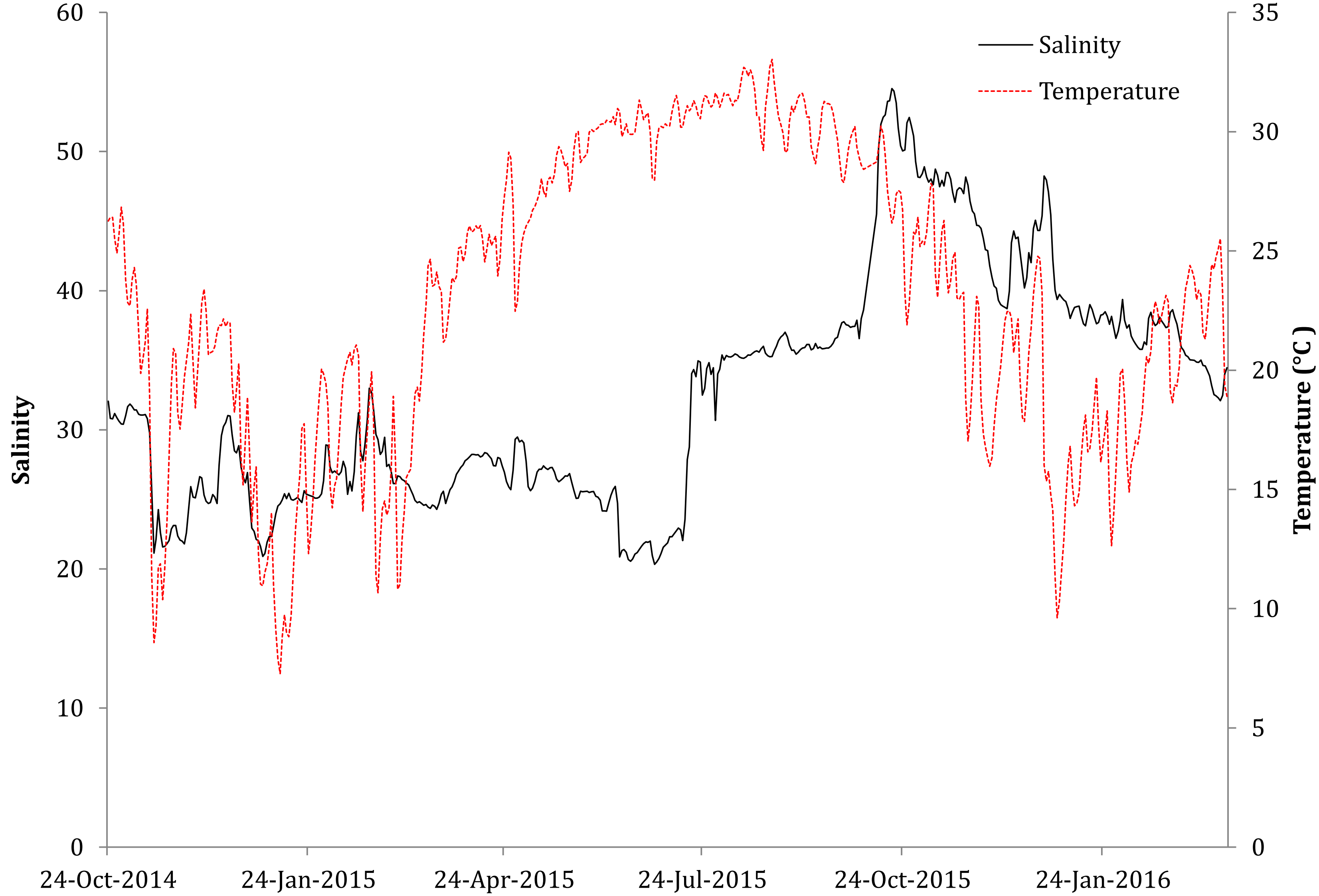

Figure 3. Mean daily salinity measurements from October 2014 to March 2016 for southern Lower Laguna Madre.

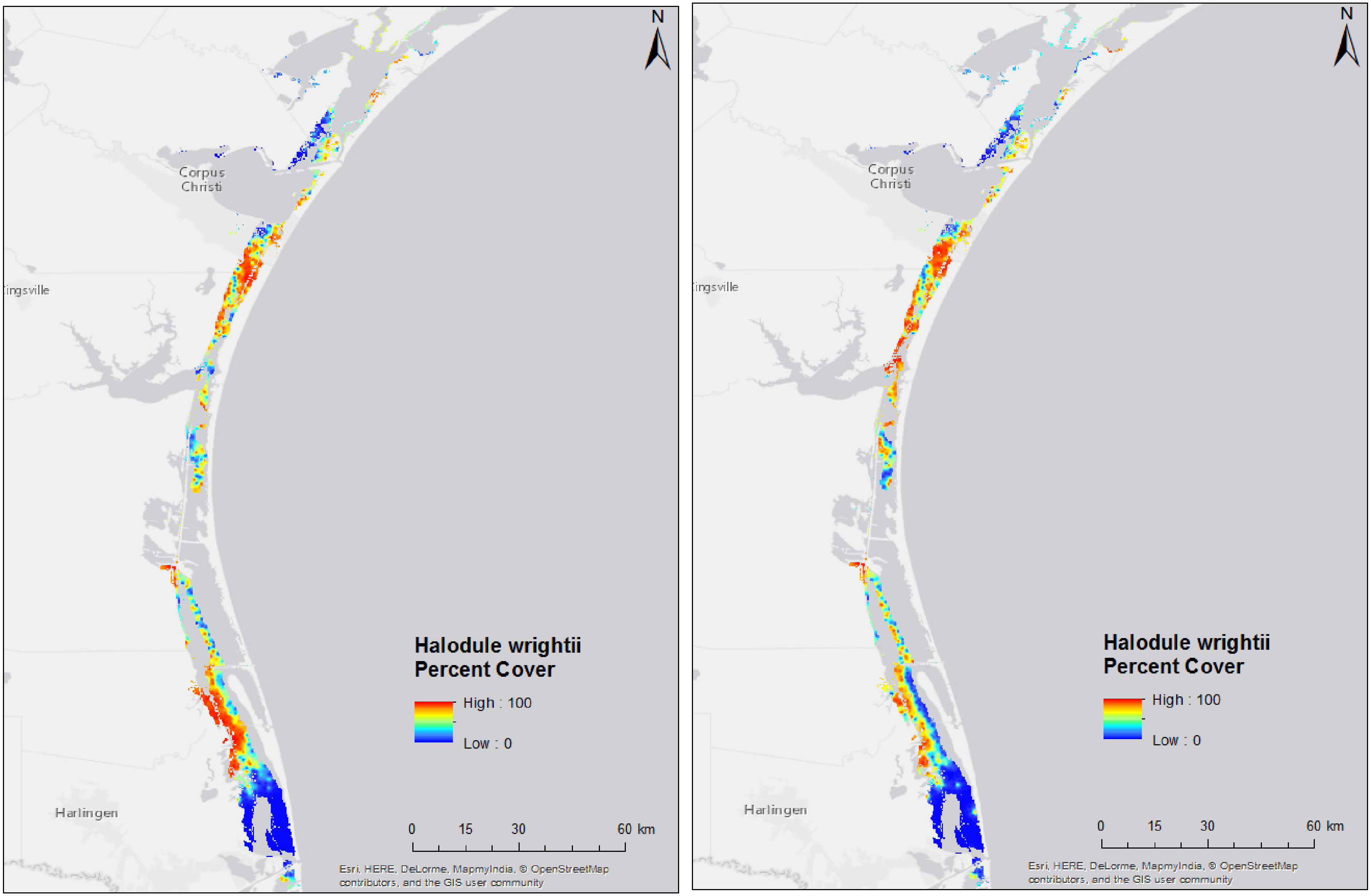

Figure 4. Spatial representations of percent cover for *H. wrightii* for a) 2014, b) 2015. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

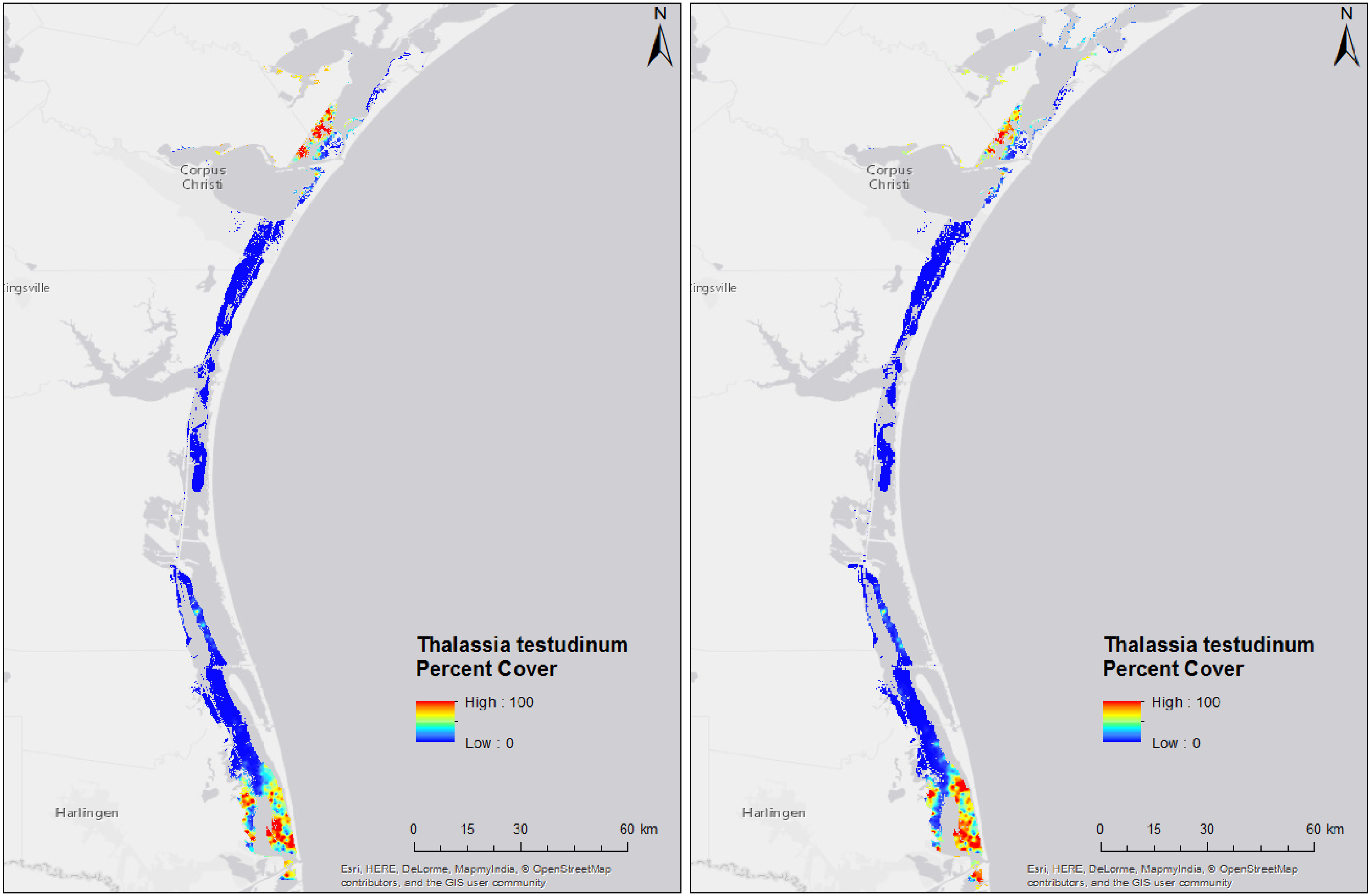

Figure 5. Spatial representations of percent cover for *T. testudinum* for a) 2014, b) 2015. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

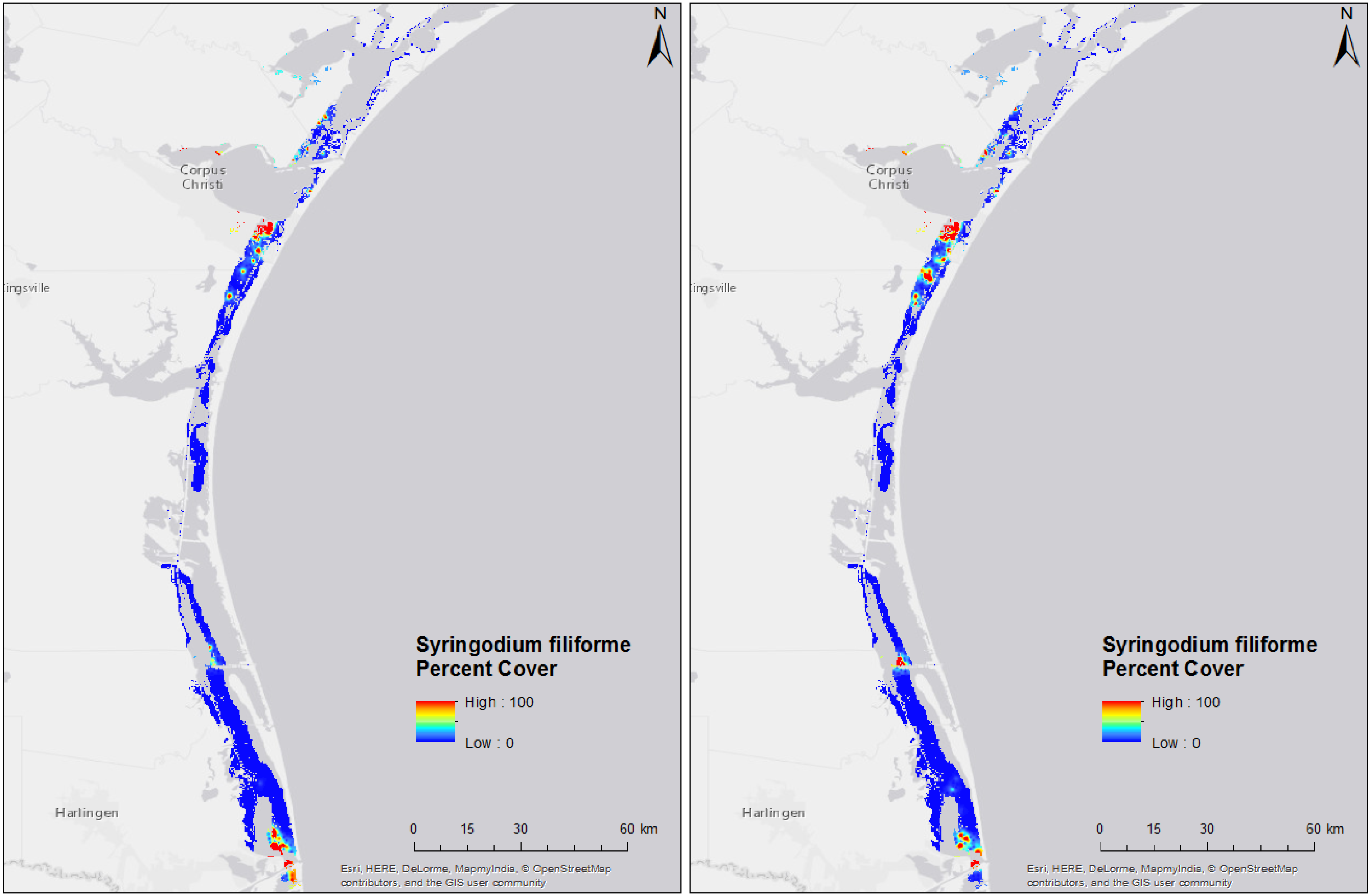

Figure 6. Spatial representations of percent cover for *S. filiforme* for a) 2014, b) 2015. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

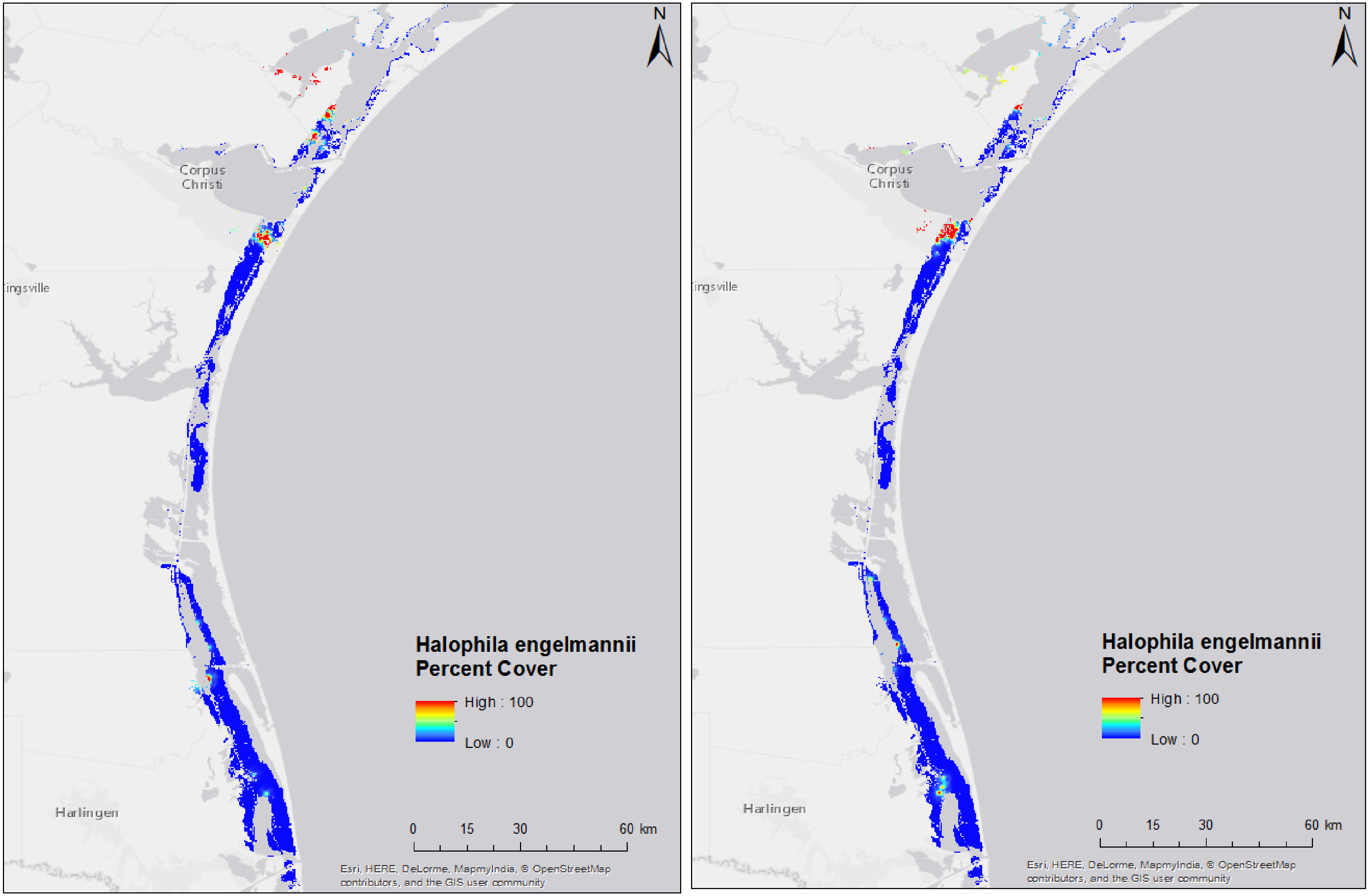

Figure 7. Spatial representations of percent cover for *H. engelmannii* for a) 2014, b) 2015. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

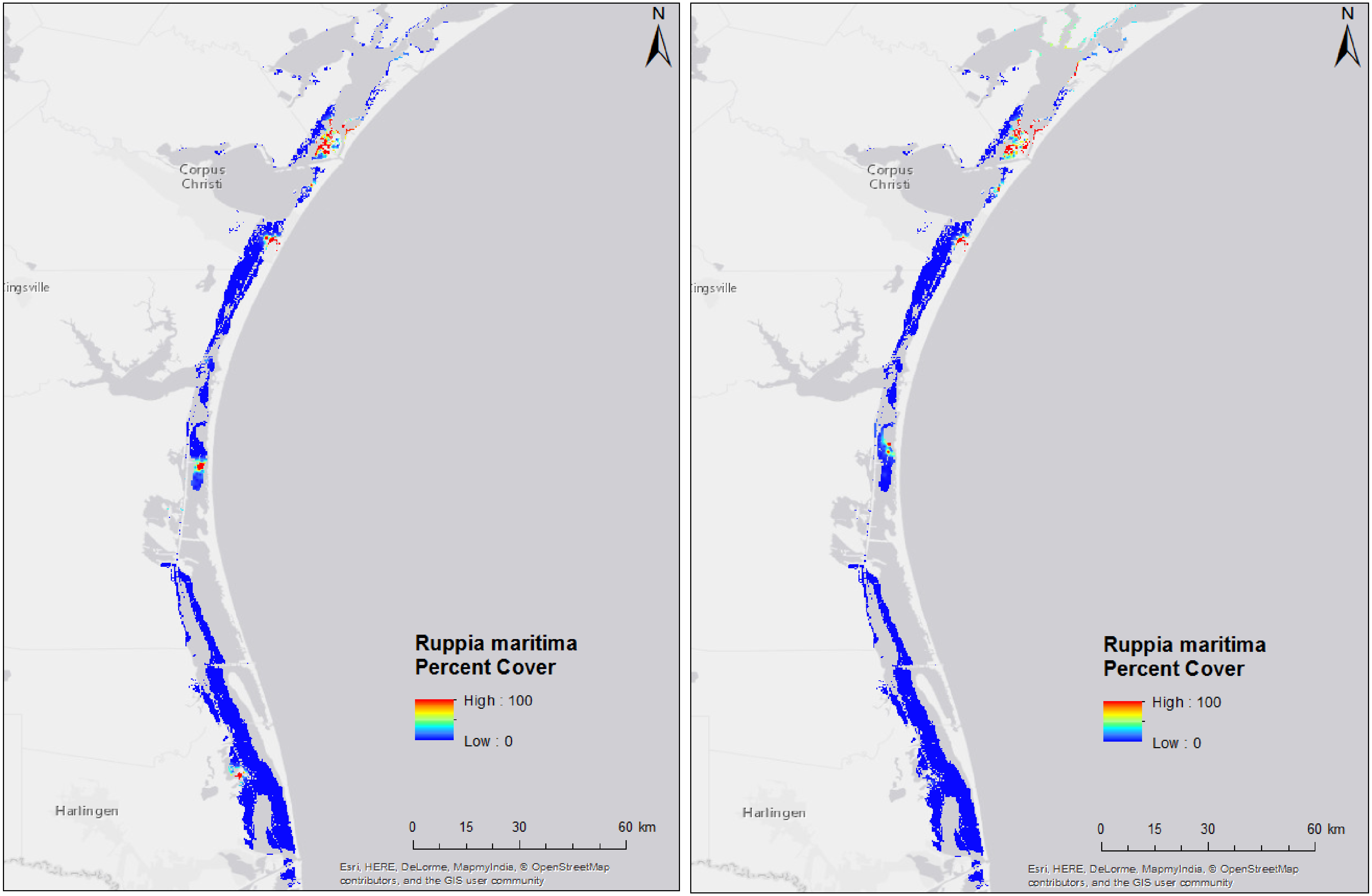

Figure 8. Spatial representations of percent cover for *R. maritima* for a) 2014, b) 2015. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

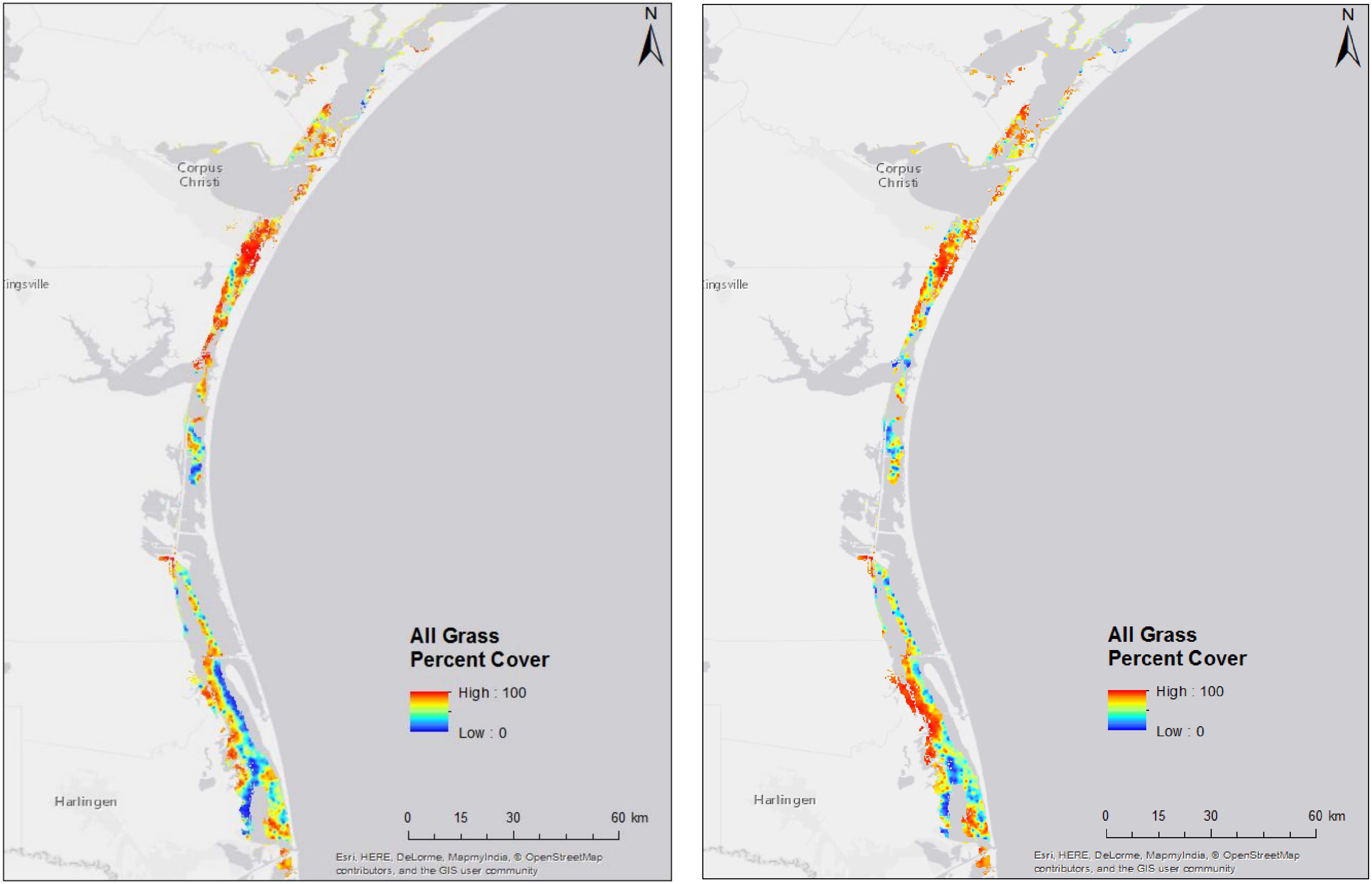

Figure 9. Spatial representations of percent cover for all seagrass species for a) 2014, b) 2015. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

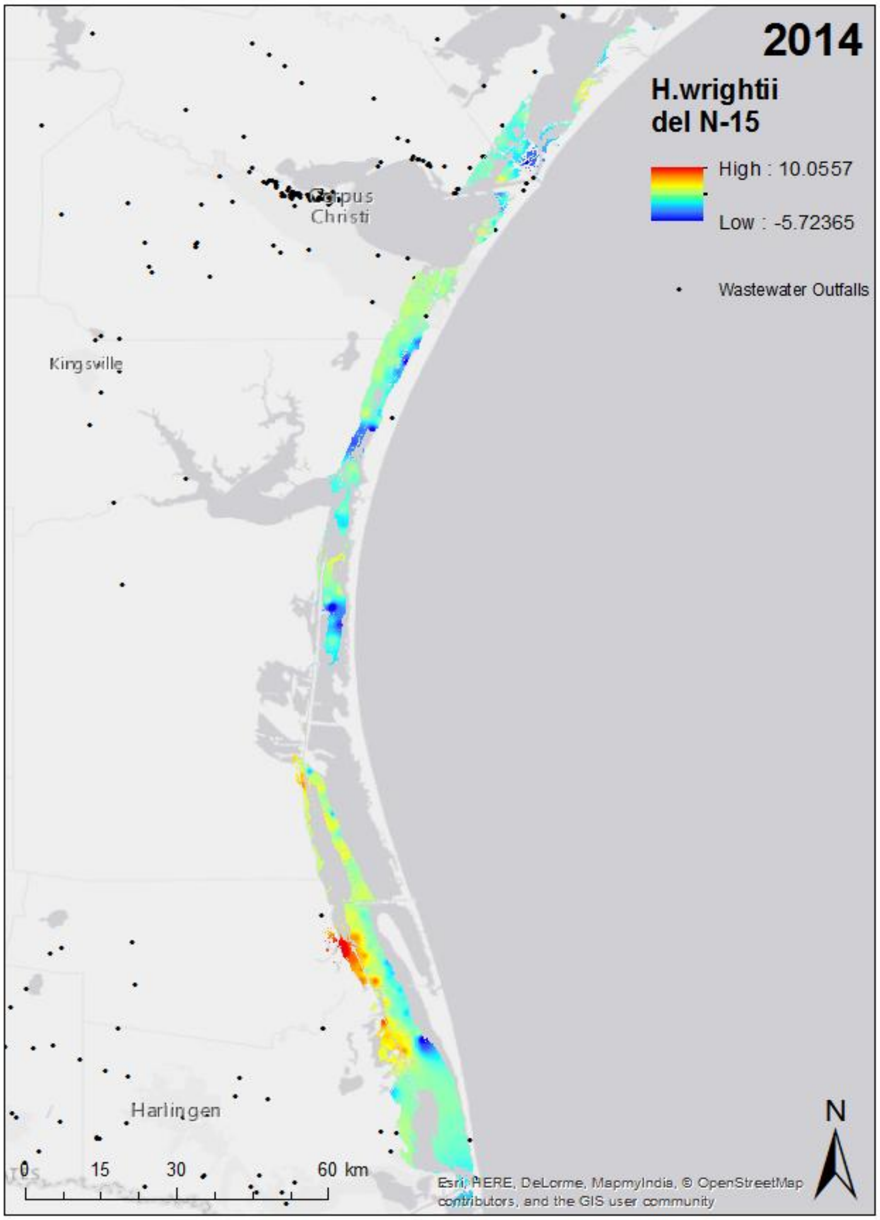

Figure 10. Spatial representations of $\delta^{15}N$ for *H. wrightii* for 2014. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

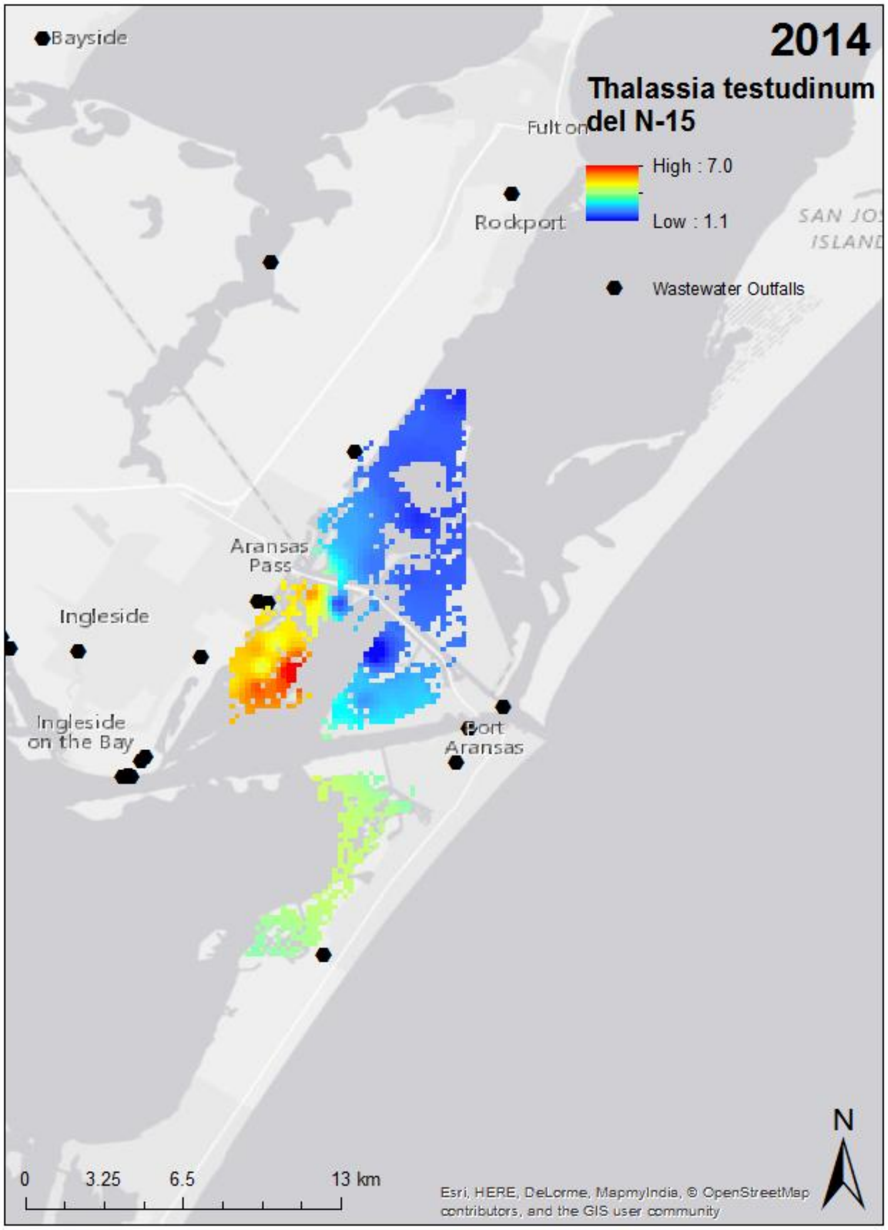

Figure 11. Spatial representations of $\delta^{15}N$ for *T. testudinum* for 2014 in the Coastal Bend. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

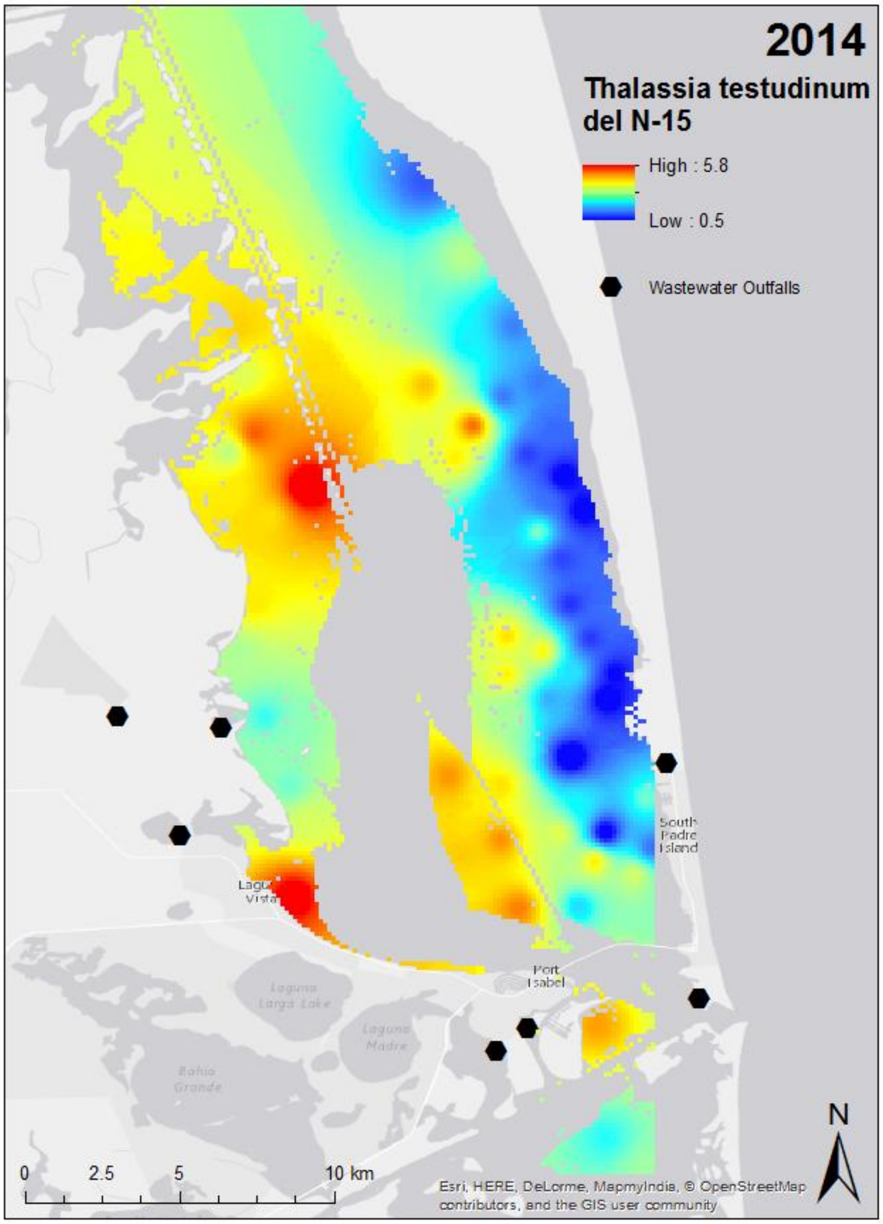

Figure 12. Spatial representations of $\delta^{15}N$ for *T. testudinum* for 2014 in the Lower Laguna Madre. The spatial data interpolation is limited to the boundaries of seagrass habitat delineated during the 2004/2007 NOAA Benthic Habitat Assessment.

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APPENDIX: METHODS

A.1 Total Suspended Solids

Developed by: Kenneth Dunton and Kimberly Jackson
Adapted from: EPA METHOD #: 160.2
Approved by: TPWD (2010)

1.0 Scope and Application

This method is applicable to drinking, surface, and saline waters, domestic and industrial wastes. The practical range of the determination is 4 mg/L to 20,000 mg/L.

2.0 Summary of Method

A well-mixed sample is filtered through a glass fiber filter, and the residue retained on the filter is dried to constant weight at 103-105°C. The filtrate from this method may be used for Residue, Filterable. Residue, and Non-Filterable. These are defined as those solids which are retained by a glass fiber filter and dried to constant weight at 103-105°C.

3.0 Sample Handling and Preservation

Non-representative particulates such as leaves, sticks, fish, and lumps of fecal matter should be excluded from the sample if it is determined that their inclusion is not desired in the final result. Preservation of the sample is not practical; analysis should begin as soon as possible. Refrigeration or icing to 4°C, to minimize microbiological decomposition of solids, is recommended.

4.0 Interferences

Filtration apparatus, filter material, pre-washing, post-washing, and drying temperature are specified because these variables have been shown to affect the results. Samples high in Filterable Residue (dissolved solids), such as saline waters, brines and some wastes, may be subject to a positive interference. Care must be taken in selecting the filtering apparatus so that washing of the filter and any dissolved solids in the filter (7.5) minimizes this potential interference.

5.0 Procedure

1) Place the glass fiber filter (i.e., Glass fiber filter discs, without organic binder, such as Millipore AP-40, Reeves Angel 934-AH, Gelman type A/E, or equivalent Our lab uses 47 mm GF/F 0.7 micron retention on the membrane filter apparatus. NOTE: Because of the physical nature of glass fiber filters, the absolute pore size cannot be controlled or measured. Terms such as "pore size", collection efficiencies and effective retention are used to define this property in glass fiber filters.

2) Dry new filters at 60C in oven prior to use.

3) Weigh filter immediately before use. After weighing, handle the filter or crucible/filter with forceps or tongs only.

4) For a 47 mm diameter filter, filter 100 mL of sample. If weight of captured residue is less than 1.0 mg, the sample volume must be increased to provide at least 1.0 mg of residue. If other filter diameters are used, start with a sample volume equal to 7 mL/cm of filter area and collect at least a weight of residue proportional to the 1.0 mg stated above. Note: If filtering clear pristine water, start with 1L. If filtering turbid water start with 100 m.

NOTE: If during filtration of this initial volume the filtration rate drops rapidly, or if filtration time exceeds 5 to 10 minutes, the following scheme is recommended: Use an unweighed glass fiber filter of choice affixed in the filter assembly. Add a known volume of sample to the filter funnel and record the time elapsed after selected volumes have passed through the filter. Twenty- five mL increments for timing are suggested. Continue to record the time and volume increments until filtration rate drops rapidly. Add additional sample if the filter funnel volume is inadequate to reach a reduced rate. Plot the observed time versus volume filtered. Select the proper filtration volume as that just short of the time a significant change in filtration rate occurred.

5) Assemble the filtering apparatus and begin suction.

6) Shake the sample vigorously and quantitatively transfer the predetermined sample volume selected to the filter using a graduated cylinder. Pour into funnel.

7) Remove all traces of water by continuing to apply vacuum after sample has passed through.

8) With suction on, wash the graduated cylinder, filter, non-filterable residue and filter funnel wall with three portions of distilled water allowing complete drainage between washing. Remove all traces of water by continuing to apply vacuum after water has passed through.

NOTE: Total volume of distilled rinse water used should equal no less than 50mls following complete filtration of sample volume.

9) Carefully remove the filter from the filter support.
10) Dry at least one hour at 103-105°C. Overnight insures accurate filter weight.
11) Cool in a desiccator and weigh.
12) Repeat the drying cycle until a constant weight is obtained (weight loss is less than 0.5 mg).

6.0 Calculations

Calculate non-filterable residue as follows, where: A = weight of filter (or filter and crucible) + residue in mg B = weight of filter (or filter and crucible) in mg C = mL of sample filtered

1000*(A-B)*1000/C=TSS mg/L

<u>A.2 Percent Surface Irradiance and Light Attenuation</u>
Developed by: Kenneth Dunton and Kimberly Jackson
Last Revised: December 2009
Approved by: EPA (2002) and TPWD (2010)

Field Measurements

Measurements of percent surface irradiance (% SI) and the diffuse light attenuation coefficient (*k*) are made from simultaneous measurements of surface (ambient) and underwater irradiance. Measurements of photosynthetically active radiation (PAR = ca. 400 to 700 nm wavelength) are collected on the surface using an LI-190SA quantum-sensor that provides input to a LI-COR datalogger (LI-COR Inc., Lincoln, Nebraska, USA). Underwater measurements are made using a LI-192SA or LI-193SA sensor. Measurements of % SI and *k* are based on three or more replicate determinations of instantaneous PAR collected by surface and underwater sensors and recorded by the datalogger. Care is taken to reduce extraneous sources of reflected light (from boats or clothing).

Light attenuation will be calculated using the transformed Beer Lambert equation:

$Kd = -[\ln(Iz/I0)]/z$

where *k* is the attenuation coefficient (m-1) and Iz and I0 are irradiance (μmol photons m-2 sec-1) at depth z (m) and at the surface, respectively.

Percent surface irradiance available at the seagrass canopy will be calculated as follows:

$\% SI = (Iz/I0) \times 100$

where Iz and I0 are irradiance (μmol photons m-2 sec-1) at depth z (m) and at the surface, respectively.

A.3 Seagrass Tissue Nutrient and Isotopic Analysis

Developed by: Kenneth Dunton, Kimberly Jackson, Christopher Wilson, Karen Bishop and Sang Rul Park
Last updated: December 2009
Approved by: EPA (2002) and TPWD (2010)

Tissue C:N Content, $\delta^{13}C$ and $\delta^{15}N$

Newly formed leaves (the youngest leaf in a shoot bundle) are gently scraped and rinsed in tap water to remove algal and faunal epiphytes. The rinsed tissue samples are then dried to a constant weight at 60 °C and homogenized by grinding to a fine powder using a mortar and pestle. Tissue samples are analyzed for carbon and nitrogen concentrations and isotopic values using either a Carlo Erba 2500 elemental analyzer coupled to a Finnigan MAT DELTAplus Isotope Ratio Mass Spectrometer 23 (UTMSI; precision 0.3 ‰).