Final Project Report

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Project Title: Interacting effects of invasive marsh grass and wave energy on shoreline stability and essential fish habitat

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ABSTRACT

Sea-level rise, coastal inundation, and shoreline hardening are leading to declines in coastal marsh ecosystems worldwide. North Carolina has over 16,945 km of estuarine shoreline, 87% of which is part of the Albemarle-Pamlico estuarine system (APES). Much of the estuarine shoreline in NC is eroding due primarily to a combination of storms, sea level rise, and low elevation. Wave energy is a major factor affecting shoreline change, especially over relatively short time scales, and can be highly variable in space and time. Invasive species may further exacerbate marsh habitat loss by displacing dominant native species and decreasing biodiversity. In particular, the invasive marsh grass, *Phragmites australis* (hereafter: *Phragmites*), can outcompete native marsh grasses resulting in large scale and often-expensive eradication efforts. The effects of *Phragmites* on the provision of marsh ecosystem services have been mixed, with studies showing positive, negative, or neutral effects. Additionally, marsh shorelines provide essential fish habitat (EFH) in the form of shallow detrital habitat (SDH) for juvenile blue crabs that recruit to the habitat following tropical storms, or through post-settlement secondary recruitment. SDH is comprised of eroding marsh peat layers, and occurs mostly along wave exposed shorelines. It is unknown if the presence of invasive *Phragmites* affects SDH formation, nor its effects on shoreline erosion. In this study, we examined **the interacting effects of invasive marsh grass distribution and wave energy on shoreline change rate and essential fish habitat (SDH) availability. Specifically, we (1) created a quantitative definition of SDH using basic soil characteristics, (2) quantified (a) shoreline change and (b) shallow detrital habitat presence as a function of (i) invasive species presence or absence and (ii) predicted wave energy; and (3) demonstrated the role of SDH as an essential fish habitat by measuring the spatial distribution and density of juvenile blue crabs across multiple habitats within the study area.** The results suggest that: (1) SDH was best defined as soil with a bulk density less than 0.57 g cm^{-3} and percent water weight greater that 54.5%. SDH was present at 89.5% of the surveyed locations. (2) *Phragmites* presence/absence had little effect on presence/absence of SDH or shoreline change. *Phragmites*-dominated shorelines did show greater loss post-hurricane Dorian than native marsh grass-dominated shorelines. (3) There was no statistically significant relationship between wave energy and SDH presence/absence. (4) Following Hurricane Dorian, *Phragmites*-dominated sites displayed greater loss than native marsh dominated sites. This is most likely due to the aboveground structure of *Phragmites*, which appeared to be more vulnerable to high winds, resulting in large stands being flattened. (5). SDH is the dominant shoreline habitat serving as EFH for juvenile blue crabs along the western shore of the APES. Small pockets of seagrass along the western shore of the APES contained the highest densities of early juveniles blue crabs measured in this study. The density of early juvenile blue crabs decreased with distance away from inlet sources of megalopae. Thus, seagrass beds near inlets are key nursery habitats for blue crabs. A list of additional products from this project are listed after the Tables and Figures below, and include: (1) Outreach, (2) Publications, (3) Students supported, (4) Additional leveraged research, and (5) Data Management.

INTRODUCTION

Rationale: North Carolina has over 16,945 km of estuarine shoreline, 87% of which is included in the Albemarle-Pamlico Estuarine System (APES; Riggs and Ames, 2003). These shorelines are dominated primarily by marsh habitats, which provide a number of ecosystem services, including supporting North Carolina's commercial and recreational fishing industry and providing shoreline stabilization in response to storms. Sea-level rise, coastal inundation, and shoreline hardening are leading to declines in coastal marsh ecosystems. Invasive species may further exacerbate marsh habitat loss by outcompeting native marsh species and reducing biodiversity. Information on shoreline change and the provision of essential fish habitat is needed to properly inform resource managers of current and anticipated changes to these important ecosystems, as well as provide predictive capabilities.

Shoreline Change: The factors that affect shoreline change are highly variable, consisting of a combination of factors related to shoreline topography and shape, near-shore hydrodynamics and bathymetry, habitat characteristics, and bio-geomorphic processes (Priestas et al., 2015; Eulie et al., 2016; Wu, 2019). The spatial and temporal scales over which shoreline change is measured can also affect the calculated rates of change. For example, Eulie et al. 2016 estimated shoreline change rate of -0.5 ± 0.07 m year^{-1} in the APES over relatively long (50 years) time scales, as well as short-term shoreline change rate (monthly to yearly), which can vary between 15.8 ± 7.5 to -19.3 ± 11.5 m year^{-1}. Factors such as wave energy can significantly affect shoreline change over relatively short time scales (Cowart et al., 2011, Eulie et al., 2016), whereas processes such as sea-level rise and subsidence affect shoreline change over much longer periods. Spatial factors such as shoreline topography, marsh composition and above-ground biomass, as well as near shore bathymetry can all affect shoreline change and can be highly variable over small spatial scales (Riggs and Ames, 2003). In this study, we quantified per capita shoreline change over the short-term time period (1-year) focusing on: (i) seasonal shifts in relation to crucial ecological and meteorological periods, and (ii) in response to hurricane Dorian. This aspect of the present study focused on four locations along the western shore of Pamlico Sound, NC: two located in Manns Harbor and two at Stumpy Point. Sites within each location were dominated by either native marsh grass or invasive, *Phragmites australis*, marsh grass.

Invasive marsh species: Fringing marsh species can have a profound effect on shoreline change by stabilizing sediment, dissipating wave energy, and trapping suspended sediment particles, thereby increasing accretion rates (Barbier et al., 2011). Invasive species may impede these functions by displacing dominant native species and decreasing biodiversity. The invasive marsh grass, *Phragmites australis* (hereafter: *Phragmites*) can outcompete native marsh grasses resulting in large scale and often-expensive eradication efforts (Martin and Blossey, 2013). Studies examining the effects of *Phragmites* presence on shoreline change have been mixed, displaying reduced shoreline erosion (Coops et al., 1996) due, in part, to the elevated growth rate and high above and belowground biomass (Windham, 2001), or neutral effects on erosion (Theuerkauf et al., 2017) . The effects of *Phragmites* on essential fish habitat (EFH) are also mixed, with some mildly negative (Able and Hagan, 2000; Jivoff and Able, 2003), yet mostly neutral effects on fish and invertebrate habitat (Posey et al., 2003; Long et al., 2011). Studies examining the effects on blue crabs specifically have also found mostly negligible differences between native marsh and *Phragmites* habitat in terms of crab abundance, feeding rates, and predation (Able and Hagan, 2000; Jivoff and Able, 2003; Long et al., 2011). The relationship between *Phragmites* and the presence of EFH such as shallow detrital habitat (SDH) is unknown.

Essential fish habitat: In North Carolina, the blue crab is one of the most economically important fishery species. Concern for the blue crab stock in North Carolina is due to reduced landings of hard blue crabs during 2007-2017, following record-high landings observed during 1996-1999. The most recent blue crab stock assessment for 2018 showed significant decreases in recruitment of juvenile and adult blue crabs to the population, indicating possible recruitment limitation (NCDMF, 2018). In the absence of tropical storms, the majority of post-larval blue crabs disperse through Oregon or Hatteras Inlets into the APES, after which they settle into near-inlet nursery habitats dominated primarily by seagrass (Etherington and Eggleston, 2000, 2003; Reyns et al., 2007; Eggleston et al., 2010). Following recruitment to seagrass habitat near inlets, post-settlement crabs often undergo density-dependent, pelagic dispersal across-sound and along an apparent migration corridor from Oregon Inlet to Stumpy Point (Reyns and Eggleston, 2004; Reyns et al., 2006; 2007) (Figure 1), and settling in near-shore nursery habitats dominated by SDH. In years with tropical storms, SDH may also serve as a primary settlement habitat for post-larval recruits carried by storm currents into the APES (Eggleston et al., 2010). SDH occurs along the erosional edge of marsh ecosystems and consists of finely ground peat material with embedded decomposing marsh stems and rhizomes (Etherington and Eggleston, 2000, 2003). While the utility of SDH as a nursery habitat has been documented, we still lack a quantitative definition of SDH. Moreover, we know little about the spatial distribution and areal cover of SDH, or the factors that drive these patterns. Lastly, information on how juvenile blue crabs are distributed among seagrass and SDH nursery habitats in the APES is extremely limited, and we suspect that the density of early juvenile blue crabs will vary significantly as a function of distance from inlet sources of megalopae.

Objectives: The overarching question addressed in this study is: What are the interacting effects of invasive marsh grass distribution and wave energy on shoreline change rate and essential fish habitat (SDH) availability. The s**pecific objectives were to: (1) create a quantitative definition of SDH using basic soil characteristics, (2) quantify (a) shoreline change and (b) shallow detrital habitat presence as a function of (i) invasive species presence or absence and (ii) predicted wave energy; and (3) demonstrate the role of SDH as an essential fish habitat by measuring the spatial distribution and density of juvenile blue crabs across multiple habitats within the study area.**

METHODS

To assess the effects of marsh species distribution and wave exposure on shoreline stability and essential fish habitat, we conducted (1) a comparison of sediment characteristics from sediment cores taken between sites with and without SDH, (2) characterization of marsh species composition and shoreline change using *in situ* surveys and unmanned aerial system (UAS) mapping, (3) an assessment of wave energy impact on western-sound shorelines over space and time using a wave exposure model, and (4) field sampling of early juvenile blue crab density among a range of habitat types and locations using kick-netting and suction sampling.

I. Study sites: This study focused on seagrass beds along the sound-side of the Outer Banks, from Oregon Inlet to Hatteras Inlet, as well as the dynamic shoreline along the western shore of Pamlico and Croatan Sounds, from Engelhard in the South to Manns Harbor in the North, including the western shore of Roanoke Island (Figure 1). Seagrass is most common in Pamlico Sound along the sound-side of the Outer Banks. The western shore locations were chosen due to their (i) relatively pristine nature and high proportion of unmodified shoreline (96%), (ii) known occurrence of *Spartina* and *Phragmites* dominated shorelines, (iii) importance as a major recruitment and settlement corridor for blue crabs, and (iv) high vulnerability to shoreline loss due to low elevation and risk of inundation.

II. SDH soil characteristics

Although the role of SDH as a nursery habitat for early blue crabs is well-established (Etherington and Eggleston, 2000; 2003; Reyns et al., 2006; 2007), it has not been well defined within a geologic framework. To accurately predict the spatial cover of SDH, we need an objective and quantifiable definition. Surface sediment cores were (0.00535 m^2) were taken from sites with known SDH presence and absence. Sites previously established to be both SDH and blue crab nursery habitats between Engelhard, Manns Harbor, and Stumpy Point, NC (Etherington and Eggleston, 2000; 2003; Voigt and Eggleston, unpubl. data) were used to establish known SDH presence locations. Surface sediment cores (n=12) were taken from these locations concurrently with a blue crab density study in the fall of 2018, thereby allowing us to directly correlate the sediment characteristics with blue crab abundance. Additionally cores from non-SDH sites (n=10) were also taken from within the study area. All cores were processed in the laboratory at NC State University for (a) percent water weight, (b) bulk density, and (c) percent organic weight. Percent water weight was the proportional difference in weight between wet and dried cores, where cores were dried for at least 74 hours at 65.5°C. Bulk density was quantified as the quotient of the dry weight over the volume of the core taken in the field. Percent organic weight was measured as the proportional mass lost after combustion of a homogenized subsample of the core combusted at 500°C for 5 hrs. Results were then analyzed using multiple logistic regression with accompanying Akaike Information Criterion (AIC; Akaike, 1974), where SDH presence or absence was the response variable and percent water weight, bulk density, and percent organic weight were the factors.

III. Marsh Surveys.

Field surveys of 170 km of marsh edge along the western shore of Pamlico Sound were performed in July 2019. Surveys took place every 4km along the shoreline (Figure 1). Areas of high human development or shoreline hardening were excluded from this survey. At all marsh survey locations, the following were measured: (a) SDH presence/absence, (b) percent cover of marsh vegetation, and (c) *Phragmites* presence/absence.

A. SDH presence/absence

Surface sediment cores were taken at every marsh survey location (Figure 1) in the summer of 2019 using a clear acrylic core (0.00535 m^2). Cores were taken in submerged habitat within the bounds of the marsh edge being surveyed for habitat characteristics. If the habitat was observed to be heterogenous, multiple cores were taken (Table 1). Core length and a basic description of whether the core appeared to contain SDH or not were recorded in the field. Cores were then processed in the laboratory for basic sediment parameters: (a) percent water weight, (b) bulk density, and (c) percent organic weight, using the same methodology as described above. Based on the results of soil parameter characterization of SDH (see results), each core was then classified as SDH based on how well the sediment parameters measured corresponded with the known SDH cores. This distinction was validated by comparing it to the observed descriptions taken in the field. Sites were then categorized as having continuous SDH if all cores were classified as SDH, patchy SDH if only some of the cores were classified as SDH, and absent SDH is none of the cores classified as SDH. Additionally, SDH presence/absence was then based on whether any of the cores taken at a site contained SDH.

B. Marsh vegetation

Fringing vegetation percent cover was quantified at all marsh survey points during the summer of 2019, and during the same period as the surface sediment cores were taken (Figure 1). Fringing vegetation was defined as the vegetation within 2 m of the vegetation edge and was quantified over a 20-m length of shoreline. When open, non-vegetated sections existed within the 2 x 20-m sampling area those were recorded as bare. These data were used to calculate *Phragmites* presence/absence, dominant cover type (dominant species + bare classification), and dominant marsh species (Table 1). Additionally, at each marsh survey point we recorded *Phragmites* presence/absence--this observation included all visible marsh within 10 m of shoreline on either side of the core location. Additionally, a data sheet was lost while in the field, so some survey sites are missing fringing vegetation marsh data, yet still have *Phragmites* presence/absence data (Table 1). We tested if *Phragmites* affected presence/absence of SDH with a two-sided Z-test of equal proportions, and tested if *Phragmites* influenced a category of SDH (e.g., continuous, patchy, or absent) with a G-test.

IV. Blue Crab Kick-netting survey

A total of 11 blue crab sampling sites were selected to expand upon the spatial cover of previous juvenile blue crab sampling efforts in this system (Figure 1) (Etherington and Eggleston, 2000; 2003; Reyns and Eggleston, 2004; Reyns et al., 2007), thereby providing fine-scale resolution of crab distribution and abundance in a diverse suite of putative nursery habitats, as well as helping to resolve the relationship between juvenile crab abundance and proximity to inlet sources of megalopae. Five sites were sampled along the western shore of Pamlico and Croatan Sounds (Figure 1). These sites were dominated by SDH, however, 3 sites also included ephemeral and patchy seagrass beds (*Ruppia maritima*). On the sound-side of the Outer Banks, a total of six sites were sampled (Figure 1). All Outer Banks (OBX) sites were dominated by a mixture of *Zostera marina, Halodule wrightii,* and *R. maritima* seagrass beds. It is important to note the dynamic, seasonal nature of seagrass in the APES, with percent cover of *Z. marina*, for example, peaking in May and dying off during summer and late fall (Field et al. 2020). Samples were collected between September 28th and October 6th, 2019. This period was chosen because it is in the middle of peak blue crab recruitment for Pamlico Sound, which ranges from August until the end of October (Etherington and Eggleston, 2000; 2003; Reyns et al., 2007; Eggleston et al., 2010). Sampling also occurred within the first quarter of the new moon to align with optimal post larval blue crab settlement and migration in Pamlico Sound (Mense et al. 1995, Etherington and Eggleston, 2000; 2003). Sampling of crabs was conducted using a kick-net with 500 um mesh and opening size of 27.5 cm by 47.5 cm. Kick-netting occurred within a 1.674 m^2 sampling ring (see Orth and Van Montfrans, 1987) to standardize the sampling area, and the kick-net swept the area within the ring for 6 minutes. Pilot studies found that net-sampling after 6 minutes rarely collected additional crabs. The sampling ring was tossed haphazardly into a continuous patch of the specified habitat. After kick-net sampling, the contents of the net were placed into a large sieve with 500 um mesh, and all crabs and megalopae were removed. All crabs removed were collected and frozen and transported to the laboratory at NC State for enumeration. In the laboratory, frozen crab samples were thawed and then separated into genus, enumerated, photographed, and carapace width measured using ImageJ 1.53 image analysis software (Schneider et al., 2012). We tested if blue crab density and various size-classes varied as a function of Habitat types and Locations (e.g., OBX-Seagrass, Western-Seagrass, and Western-SDH) with various ANOVA models, with seagrass shoot density and distance from inlet as covariates (Voigt et al., in review).

V. Wave exposure model

Representative wave energy (RWE) was calculated using a National Oceanic and Atmospheric Administration (NOAA) Wave Exposure Model (WEMo; Malhotra and Fonseca, 2007). RWE was calculated in WEMo using bathymetry data from NOAA's National Geophysical Data Center (NGDC), shoreline coverage data from NOAA's NGDC coastline database, and exceedance wind events (average top 5 % of wind speeds) from 2005–2012 from the NOAA National Data Buoy Center for the period of 2005–2012 from the Cape Hatteras Station (HCGN7) (Theuerkauf et al., 2017b). RWE was log transformed to meet the assumption of normal distribution and homogeneity of variance. The effect of wave exposure on SDH presence was analyzed using a logistic regression where the independent variable was log RWE and the response variable was either: (a) SDH presence/absence, or (b) categorical SDH cover such as continuous, patchy, or absent.

VI. High-resolution short-term UAS mapping

Short-term shoreline change was measured at four sites along the western shore of Croatan and Pamlico Sounds-two sites were dominated by *Phragmites* and two dominated by native species *Spartina alterniflora* and *Juncus roemerianus*, all with varying wave exposure (Figure 1). Each sites consisted of 1km long stretches of shoreline. Orthomosaic maps were georeferenced using permanent ground control points, GCPs, which were surveyed using an Emlid RTK GPS unit after every flight. UAS flights occurred seasonally, taking place three times a year for a period of approximately 1 year: November 2018-March 2019, March 2019-July 2019, and July 2019-September 2019. The July to September period was mapped to assess the impact of Hurricane Dorian on shoreline change, which occurred two weeks prior to the September flight date. Aerial photographs taken during flights were compiled and orthorectified using Agisoft Photoscan, and shorelines digitally traced using heads-up delineation whereby the shoreline was measured as the marsh vegetation edge (Seymour et al., 2018). Shoreline change was calculated as area lost or gained normalized by shoreline length and was partitioned by flight interval.

RESULTS

I. SDH soil characteristics

Percent water weight and bulk density had perfect separation between sediment cores with and without SDH, which precluded the need for logistic regression to converge when these factors were included (Figure 2a-b). Cores with SDH had bulk densities less than 0.57 g cm^{-3} and water weights greater than 54.5%. Percent organic matter was marginally different between cores with versus without SDH (Figure 2c, p-value = 0.053). Therefore, only percent water weight and bulk density are used to identify whether marsh survey cores are characterized as SDH. All cores met either both requirements or neither requirements, resulting in the predicted probabilities of being SDH as 100% or 0%.

II. SDH spatial coverage

A total of 38 sites (Figure 1) were sampled as part of the marsh survey, covering a range of marsh species compositions, sites with and without *Phragmites* presence (Figure 3), and wave exposures (Table 1, Figure 4). Of these sites, four had no SDH resulting in 89.5% of surveyed sites including at least partial SDH nursery habitat. Of the 34 sites which had SDH present, eight had patchy SDH, meaning that 1 or more of the cores taken at that site were SDH while others were not. This resulted in 68.4% of the surveyed area having continuous SDH, 21.1% of the area having patchy SDH, and 10.5% of the area having no SDH present (Figure 3, 4).

A. Phragmites presence/absence

Of the 38 sites sampled, *Phragmites* was present at 13 sites or 34.2% of the surveyed area (Table 1, Figure 3). *Phragmites* presence/absence is tightly linked to salinity, with *Phragmites* only occurring along the northern portion of the study area, beginning at site 38, where salinity begins to rapidly decline with an average salinity of 14.35 at sites 2-36 and average salinity of 3.51 at sites 38-80 (Table 1, Roelofts and Bumpus, 1953). *Phragmites* presence/absence had no effect on either SDH presence/absence, ($x^2 = 0.022$, df = 1, p-value = 0.88) or categorical SDH cover (G = 0.74, df = 2, p-value = 0.69; Figure 3).

B. Wave Exposure

Representative Wave Energy (RWE) was log transformed to meet the assumption of a normal distribution. RWE was highly variable across the survey area ranging from 3.17 – 701.5 J m^{-1}, with a median 4.63 J m^{-1}, and a mean of 33.47 J m^{-1} (Table 1, Figure 4). RWE did not significantly affect SDH presence/absence (p-value = 0.41) or SDH categorical cover (p-value = 0.95). However, there does appear to be a non-significant trend where sites where SDH is absent have a lower RWE than sites where SDH is present (Figures 4, 5a). This trend makes sense because wave energy erodes the marsh/peat layers, which produces SDH. Additionally, there appears to be a slight trend, which is supported by *in situ* observations, that sites with patchy SDH coverage tend to exist in sites with either higher than average RWE or lower than average RWE (Figures 4, 5), often resulting in greater quantities of sand or silt respectively (Voigt and Eggleston, unpubl. data).

III. Juvenile Blue Crab Distribution and Habitat Use

Mean crab densities were ~ 4-times higher in seagrass beds along the western shore of Croatan and Pamlico Sounds compared to seagrass along the eastern shore, or SDH along the western shore (Figure 6; SNK test). Juvenile blue crab size distribution, measured as arcsine transformed proportional frequencies, was compared across regions (east, west) by categorized size classes (recent settlers, J1-2, early recruits, J3-5, and late recruits, J6-10). There was no difference in proportional crab size-frequencies between east and west regions for any of the size classes ($F_{1,65} = 0.91$, p-value = 0.35; $F_{1,65} = 0.20$, p-value = 0.66; $F_{1,65} = 0.032$, p-value = 0.86, respectively). For OBX seagrass beds, crab density was strongly correlated with distance from the nearest inlet (p-value = 0.00041, $R^2 = 0.36$), with sites located near inlets having greater density of juvenile blue crabs than sites located farther from the source of megalopae (Figure 6a). For ephemeral seagrass located along the western shore, crab density was positively correlated with seagrass shoot density (p-value = 0.024, $R^2 = 0.54$), but did not differ across sites ($F_{2,6} = 3.645$, p-value = 0.092). SDH harbored similar blue crab densities across all sampled sites ($F_{4,22} = 1.79$, p-value = 0.17), with a slight, non-significant increase in density around Stumpy Point (Figure 6a).

IV. Shoreline Change

All four sites showed an average loss of shoreline from November 2018 to September 2019 (Figure 7). The data show some seasonality in the loss rates, with greater loss occurring in the November to March period compared to the March to July period. *Phragmites* presence/absence does not appear to influence loss rates. The only exception to this is the post-Hurricane, or July 2019 to September 2019 period in which *Phragmites* dominated sites had greater shoreline loss than native marsh-dominated sites (Figure 7). Wave exposure also had no strong effect on non-storm related shoreline change (Figure 8). Rather shoreline change appears site-specific. For example, the shoreline located at Manns Harbor had greater loss than the sites located at Stumpy Point, regardless of *Phragmites* presence/absence or wave exposure (Figure 8). This may be due to differences in shoreline loss characteristics such as elevation and shoreline orientation to major wind events. For example, shoreline loss at Manns Harbor appeared due to sand overwash smothering the marsh grass, resulting in a loss of marsh vegetation (Figure 9). Conversely, shoreline loss at Stumpy Point appeared due to erosion occurring at the marsh-water interface.

DISCUSSION

I. SDH Soil Characteristics

Characterization of SDH in this study as having a low bulk density and high percent water weight is not unexpected since the marsh peat material that makes up the bulk of its content tends to be very absorbent and often halves (or more) in size when compressed and the water is wrung out (Figure 10a). However, because these soil parameters are tightly linked to one another, there is concern that relying on just three parameters alone may tend over classify SDH in follow-up surveys. Therefore, we recommend using soil parameters in conjunction with visual observations. To be identified as SDH, we recommend that a core must contain recognizable marsh peat and detrital marsh roots, rhizomes, and shoots, and have a bulk density less than 0.57 g cm^{-3} and water weight greater than 54.5%.

II. SDH spatial coverage

Of the 38 sites covering approximately 170 km of marsh shoreline, 89.5% contained SDH (Table 1). This demonstrates how dominant and widespread SDH is on the western shore of Croatan and Pamlico Sounds. Considering that most SDH habitat extends approximately 10 m off the erosional marsh edge (Voigt and Eggleston, unpubl. data), this would account for approximately 1.52 km^2 of habitat within our study area. Surprisingly, we found no relationship between *Phragmites* presence or absence and SDH occurrence. This contradicts our initial pilot study results which found no co-occurrence of SDH and *Phragmites.* The inconsistency of these results may be due to the pilot study relying on *in situ* observations to determine SDH presence/absence, rather than data from sediment cores. Dense *Phragmites* patches often result in large areas of exposed and tightly packed root matter with little peat (Figure 10b). The characteristics of root matter in *Phragmites*-dominated shorelines varies from what is generally observed along shorelines dominated by native marsh grass (Figure 10c). In fact, while taking cores during the 2019 survey, it was often impossible to drive a core into the exposed *Phragmites*-dominated shorelines even when using a small hammer. These observations led us to originally assume that SDH was not occurring at *Phragmites*-dominated sites. However, when we took cores off the exposed berm in areas submerged under approximately 1 m of water, SDH was present. We hypothesize that this submerged, deeper SDH is actually the product of the peat mat established by the original native dominated marsh and that the invasive *Phragmites* has grown overtop resulting in the exposed berm formation.

Wave exposure also appeared to have no strong effect on SDH presence/absence. This may be partially due to the low sample size for SDH absence (n = 4). Sites with no SDH are generally located at the back of shallow bays, especially sites 6 and 12 (Figure 4), and correspond to low wave energy. Sites 64 and 66 have moderate wave energies, and are also located in the southern Albemarle/ northern Croatan sound and are therefore not susceptible to the large fetch of Pamlico Sound, resulting in less frequent large wave events. Furthermore, the Albemarle-Croatan Sound system provides a corridor by which sediment is flushed into the Pamlico Sound basin (Wells and Kim, 1989), potentially resulting in greater levels of sedimentation than sampling sites further south. Sites with patchy SDH cover have a similar trend-areas with low wave exposure (sites 14, 74, and 80) had relatively high silt deposits, whereas areas with high wave exposure (sites 8, 9, 32, and 68) had more sand deposits (Figure 4). These trends should be tested with a larger sample size than used in the present study.

III. Juvenile Blue Crab Distribution and Habitat Use

Patterns of early juvenile blue crab distribution and abundance identified in this study highlight the complex nature of nursery habitat use, and the role of region within the seascape, habitat type, and post-larval and early juvenile dispersal processes play in driving these patterns. Moreover, the combination of multiple dispersal processes and putative nursery habitat types appear to expand the nursery potential of the APES by promoting longitudinal cross-sound transport, as well as increasing latitudinal coverage through a “fanning-out” effect along the western shore, resulting in more uniform distribution of juveniles. These processes result in elevated crab density in western nursery habitats, despite their distance from the source of new recruits from Oregon and Hatteras Inlets. Blue crab distribution in SDH habitats was the most evenly distributed across sites, with slight spatial variation in mean crab density resulting in Stumpy Point displaying the highest density (Figure 6). This spatial variation in crab density is consistent with predictions of a key pelagic migration corridor between Oregon Inlet and Stumpy Point located on the western shore, and is driven by a combination of tide and wind (Reyns et al., 2006; 2007). While western seagrass beds host the highest density of crabs, they have limited spatial distribution and areal coverage. SDH serves as an alternative nursery habitat along the western shore when seagrass is not present, or when crab densities in seagrass beds along the OBX are too high (Reyns and Eggleston, 2004). Assuming that the proportional contribution of juvenile crabs to the spawning stock is similar across habitats, a unique dichotomy occurs where per capita crab abundance is greatest in western seagrass beds, making it the primary essential fishery habitat based on per capita measurements alone (see the Nursery Role Hypothesis framework: Beck et al., 2001). However, the relatively high areal extent of SDH and evenly-spaced distribution of crabs along the western shore of Pamlico Sound suggests that SDH serves as an "Effective Nursery Habitat" (*sensu* Dahlgren et al., 2006).

IV. Shoreline Change

When considering non-storm impacted shoreline change (November 2018 to July 2019), all four sampling sites located along the western shore of Croatan and Pamlico Sounds showed net shoreline loss, with only one site, *Phragmites*-dominated at Manns Harbor, showing net growth during the March to July time period. Changes in loss rates highlight the seasonal nature of shoreline change across our sites. The greatest loss across all sites was observed during the November to March period, which corresponds with strong Northeast wind systems and storms. The period from March to July showed relatively little change in shoreline loss or growth, which corresponds to the growing season for marsh grass.

There was no clear trend relating shoreline change to either *Phragmites* presence/absence or wave exposure. Rather, shoreline change was site specific. Both the *Phragmites* and the native marsh-dominated sites in Manns Harbor showed greater loss than the *Phragmites* and native marsh-dominated sites in Stumpy Point. This site variation may be due to differences in shoreline loss mechanisms whereby loss at Stumpy Point sites was attributed to erosional land loss, while loss at Manns Harbor was attributed to sand overwash. The Manns Harbor sites occur on the eastern facing portion of Croatan Sound, which acts as the primary outlet for Albemarle Sound in the north. We hypothesize that the sediment is accruing at these sites due to the flushing of sediment out of the Albemarle and into Pamlico Sound (Wells and Kim, 1989).

Hurricane Dorian resulted in shoreline loss across all sites. For storm impacted shoreline change, there does appear to be a relationship between *Phragmites* presence or absence. Post-hurricane, *Phragmites*-dominated shorelines demonstrated far greater loss than the shorelines dominated by native marsh species. We hypothesize that this increase in loss is due to the above ground structure of *Phragmites* not being as resilient to wind as native species. At several of the *Phragmites* dominated sites we found that the large stands of *Phragmites* had been flattened following the storm (Figure 10d). This damage appears to affect the above ground portion of the plant, and therefore may not have long-term effects on either shoreline change or *Phragmites* coverage.

V. Conclusions

1. *Phragmites* presence/absence had little effect on presence/absence of SDH or shoreline change. *Phragmites*-dominated shorelines did show greater loss post-hurricane Dorian than native marsh grass-dominated shorelines.
2. There was no statistically significant relationship between wave energy and SDH presence/absence, however, this may have been due to the fact that SDH appears to dominate this shoreline, and there was a relatively low sample size of sites without SDH. There does appear to be a trend with wave exposure and SDH whereby sites with low wave exposure located in embayments are dominated by silt, and sites with higher wave exposure located in northern Croatan Sound near the opening of Albemarle Sound tend to be dominated by sand. Additional surveys are needed to test this hypothesis.
3. There is a need to better understand sediment loads, particularly from Albemarle Sound into Pamlico Sound, and their effect on shoreline change and SDH formation. SDH was absent from cores taken in the northern portion of the study system and it was observed that the sediment in these areas was dominated by sand. Furthermore, northern sites at Manns Harbor showed increased levels of shoreline change due sand-overwash. These results hint at a large portion of sand being flushed from Albemarle into Croatan and Pamlico Sounds, potentially leading to loss of marsh habitat and increased shoreline loss.
4. Following Hurricane Dorian, *Phragmites*-dominated sites displayed greater loss than native marsh-dominated sites. This is most likely due to the aboveground structure of *Phragmites*, which appeared to be more vulnerable to high winds, resulting in large stands being flattened. This observation requires further investigation since it implies that *Phragmites*-dominated shorelines may not be as resilient to multiple, successive storm events compared to native marsh grass shorelines.
5. SDH is the dominant shoreline habitat serving as EFH for juvenile blue crabs on the western shore of the APES. Small pockets of seagrass along the western shore of the APES contained the highest densities of early juveniles blue crabs measured in this study. The density of early juvenile blue crabs decreased with distance away from inlet sources of megalopae. Thus, seagrass beds near inlets are key nursery habitats for blue crabs.

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TABLES AND FIGURES

Table 1. Marsh survey site characteristics including: water quality data (salinity, temperature, and dissolved oxygen, DO), the number of cores taken, *Phragmites* presence/absence, SDH categorized cover (Continuous = all cores contained SDH, Patchy= at least one core contained SDH), Representative Wave Energy (RWE), dominant cover type and corresponding percent cover, and dominant marsh species and corresponding percent cover. "the _____" in the Table means absent.

Site	Salinity (ppt)	Temp (ºC)	DO (mg/L)	# of Cores	*Phragmites* Presence	SDH Presence	RWE (J m^{-1})	Dominant Cover	Percentage	Dominant Species	Percentage
4	16.4	28.8	6.52	2	--	Patchy	5.70	*Spartina alternaflora*	55.30%	*Spartina alternaflora*	55.30%
6	16.1	29.8	7.20	2	--	--	3.64	*Spartina patens*	32.60%	*Spartina patens*	32.60%
8	*na*	*na*	*na*	2	--	Patchy	26.01	*Spartina alternaflora*	78.60%	*Spartina alternaflora*	78.60%
9	*na*	*na*	*na*	3	--	Patchy	19.72	*na*	*na*	*na*	*na*
10	15.9	30.8	6.59	1	--	Continuous	4.61	*Juncus roemerianus*	80.00%	*Juncus roemerianus*	80.00%
12	15.8	30.0	6.66	1	--	--	3.92	*Spartina patens*	70.00%	*Spartina patens*	70.00%
14	16.2	31.3	6.84	1	--	Continuous	10.85	*Spartina alternaflora*	52.26%	*Spartina alternaflora*	52.26%
16	15.6	30.3	6.93	1	--	Continuous	71.90	*Spartina patens*	53.36%	*Spartina patens*	53.36%
18	14.7	28.4	5.75	2	--	Continuous	5.47	*Spartina alternaflora*	49.00%	*Spartina alternaflora*	49.00%
20	13.1	30.5	6.10	1	--	Continuous	71.32	*Spartina patens*	43.50%	*Spartina patens*	43.50%
22	12.9	30.9	5.35	1	--	Continuous	4.32	*Juncus roemerianus*	95.00%	*Juncus roemerianus*	95.00%
24	11.4	31.4	5.43	1	--	Continuous	4.82	*Juncus roemerianus*	95.00%	*Juncus roemerianus*	95.00%
26	12.9	30.2	6.50	1	--	Continuous	4.01	*Spartina alternaflora*	87.44%	*Spartina alternaflora*	87.44%
28	13.1	30.8	6.75	2	--	Continuous	5.49	*Spartina patens*	56.50%	*Spartina patens*	56.50%
30	13.1	29.1	7.11	1	--	Continuous	3.81	*Juncus roemerianus*	60.00%	*Juncus roemerianus*	60.00%
32	13.3	28.3	5.62	2	--	Patchy	162.22	*Juncus roemerianus*	93.00%	*Juncus roemerianus*	93.00%
34	11.2	31.3	8.18	1	--	Continuous	4.20	*Spartina cynosuroides*	51.20%	*Spartina cynosuroides*	51.20%
36	15.2	27.9	5.61	2	--	Continuous	11.95	*Spartina patens*	68.66%	*Spartina patens*	68.66%
38	9.7	30.1	7.35	1	Present	Continuous	701.50	Bare	78.00%	*Phragmites australis*	20.00%
40	12.6	30.7	6.69	2	--	Continuous	4.07	*Spartina patens*	40.88%	*Spartina patens*	40.88%
42	5.0	29.8	7.50	3	--	Continuous	3.95	*Juncus roemerianus*	63.80%	*Juncus roemerianus*	63.80%
44	5.5	30.0	8.30	2	Present	Patchy	4.54	*Phragmites australis*	100.00%	*Phragmites australis*	100.00%
46	5.5	29.0	6.95	1	Present	Continuous	3.63	*Iva frutescens*	58.20%	*Iva frutescens*	58.20%
48	8.3	27.3	4.98	2	Present	Continuous	28.29	*Phragmites australis*	100.00%	*Phragmites australis*	100.00%
50	1.9	27.7	7.07	1	Present	Continuous	4.41	*na*	*na*	*na*	*na*
51	1.9	28.4	7.11	2	Present	Continuous	4.74	*na*	*na*	*na*	*na*
54	1.4	28.7	7.65	1	Present	Continuous	4.73	*Phragmites australis*	55.40%	*Phragmites australis*	55.40%
56	0.9	28.4	7.76	1	Present	Continuous	3.88	*Phragmites australis*	70.80%	*Phragmites australis*	70.80%
59	0.8	29.3	7.56	2	--	Continuous	4.50	*na*	*na*	*na*	*na*
64	0.8	28.3	8.11	1	Present	--	6.31	Bare	55.20%	*Phragmites australis*	26.40%
66	0.8	30.8	6.90	2	Present	--	4.97	Bare	48.64%	*Spartina patens*	25.84%
68	1.6	30.2	7.88	2	Present	Patchy	45.89	*Phragmites australis*	55.28%	*Phragmites australis*	55.28%
70	1.9	31.2	7.81	1	Present	Continuous	4.66	Bare	78.00%	*Phragmites australis*	22.00%
72	1.4	30.0	7.85	1	Present	Continuous	3.71	*Spartina alternaflora*	86.40%	*Spartina alternaflora*	86.40%
74	1.8	31.7	7.63	3	--	Patchy	3.17	*na*	*na*	*na*	*na*
76	2.1	28.7	7.56	2	--	Continuous	3.36	*Juncus roemerianus*	100.00%	*Juncus roemerianus*	100.00%
78	4.3	29.1	7.11	1	--	Continuous	4.05	Bare	36.24%	*Juncus roemerianus*	36.24%
80	1.9	29.5	7.30	2	--	Patchy	3.53	*Spartina alternaflora*	45.00%	*Spartina alternaflora*	45.00%

Figure 1. Sampling locations in the Albemarle-Pamlico Estuarine System. Green circles are marsh survey locations, yellow triangles are the unmanned aerial system (UAS) or drone mapping locations, and purple squares are the approximate site locations used for the juvenile blue crab kick-netting survey.

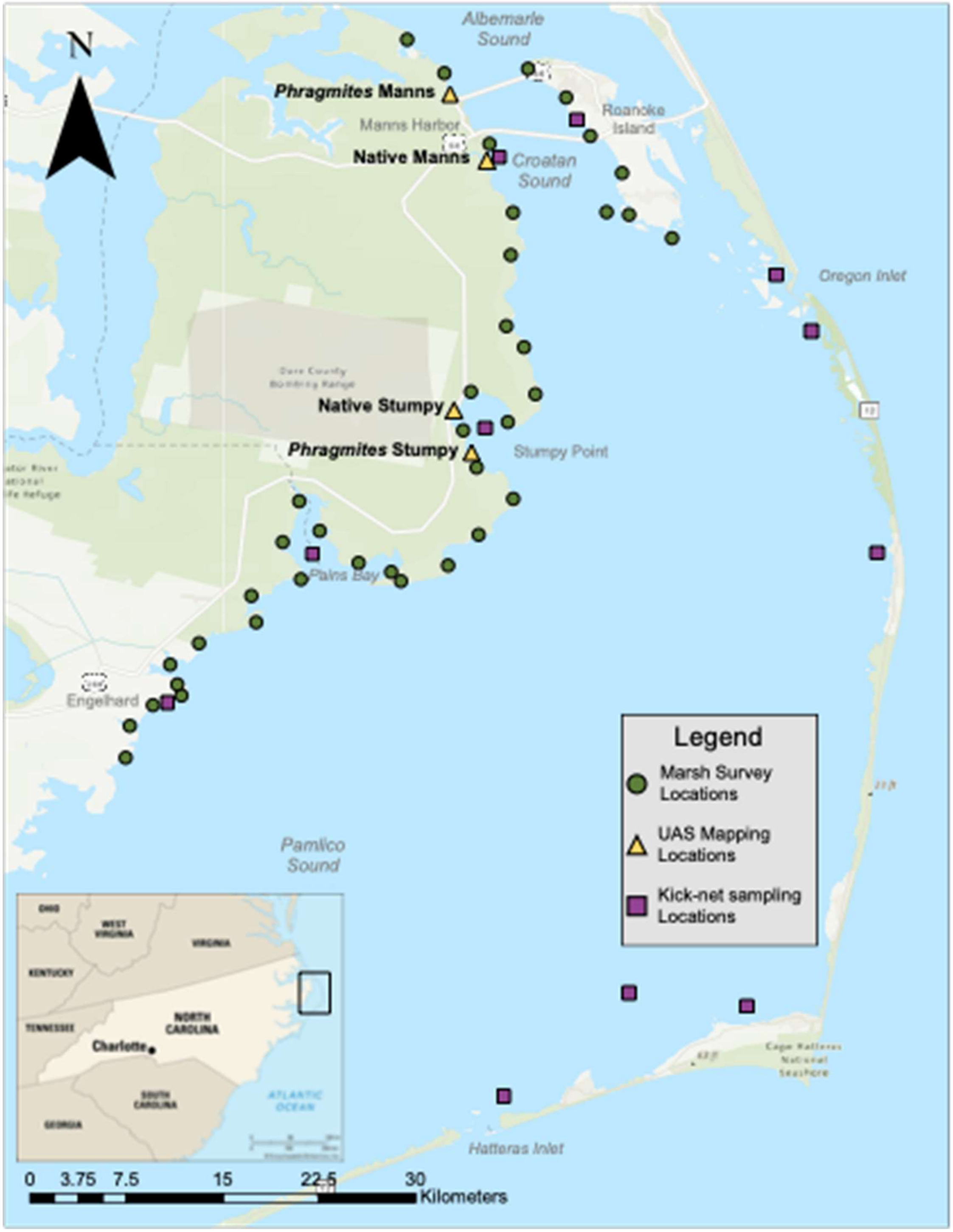


Figure 2. Box plots displaying differences in soil parameter characteristics: (a) bulk density, (b) percent water weight, and (c) percent organic matter, between sediment cores with and without SDH.

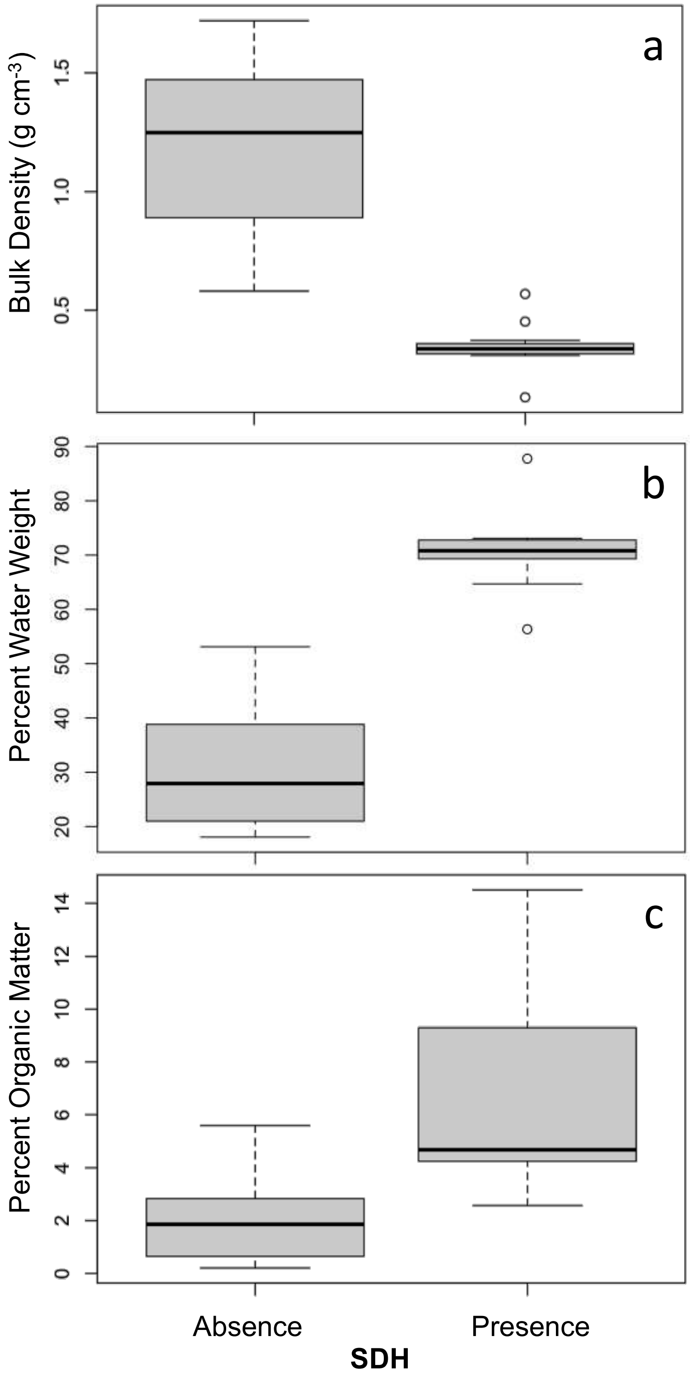


Figure 3. Marsh survey locations showing the relationship between SDH coverage and native marsh grass (circles), or invasive *Phragmites*-dominated (triangles) marshes. SDH coverage was categorized as either continuous (dark blue) if all cores taken at that site contained SDH, patchy (light blue) if at least one core taken at that site contained SDH, or absent (yellow) if none of the cores taken contained SDH. Map inserts display sites where SDH was absent.

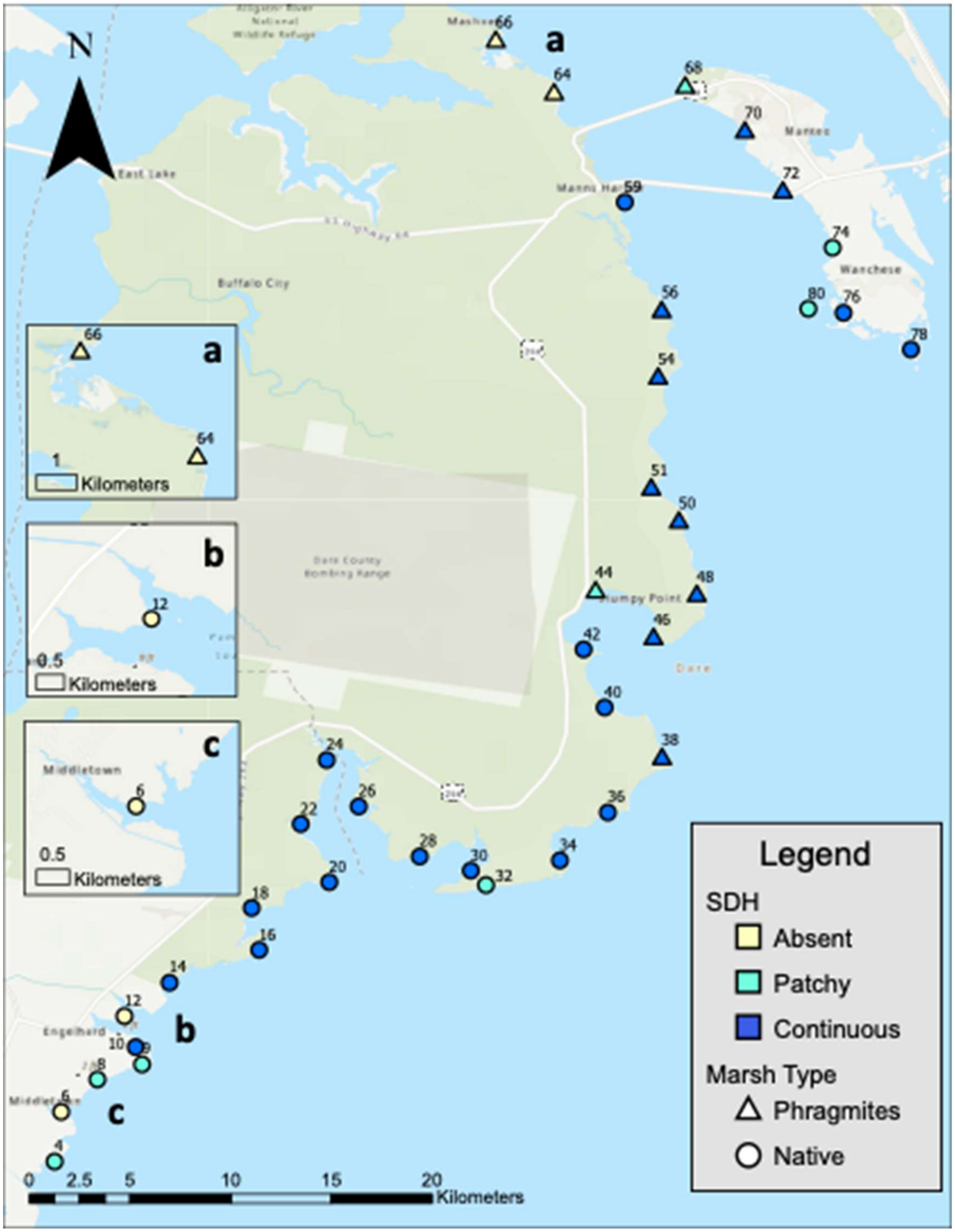


Figure 4. Marsh survey locations comparing the effect of Representative Wave Energy (RWE) on SDH coverage. RWE is illustrated by a color scheme whereby low RWE or wave exposure is purple and increases with warmer colors such as yellow. SDH is categorized as: continuous (circle) if all cores taken at that site contained SDH, patchy (diamond) if at least one core taken at that site contained SDH, or absent (triangle) if none of the cores taken contained SDH. Map inserts show sites where SDH was absent.

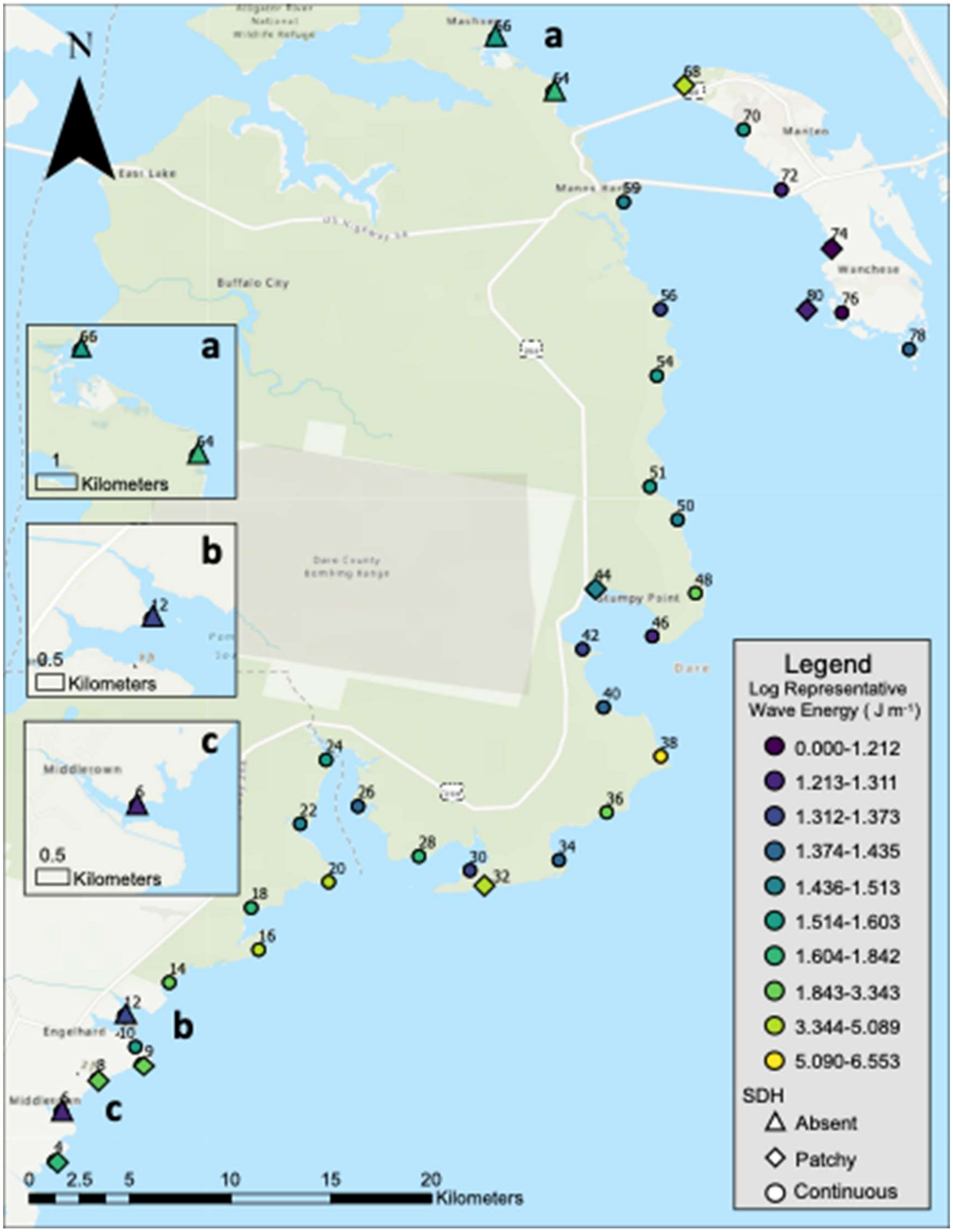


Figure 5. Box plots showing a comparison between log transformed Representative Wave Exposure (RWE) across marsh cores where SDH was categorized as (a) present or absent, or (b) Continuous, Patchy, or Absent.

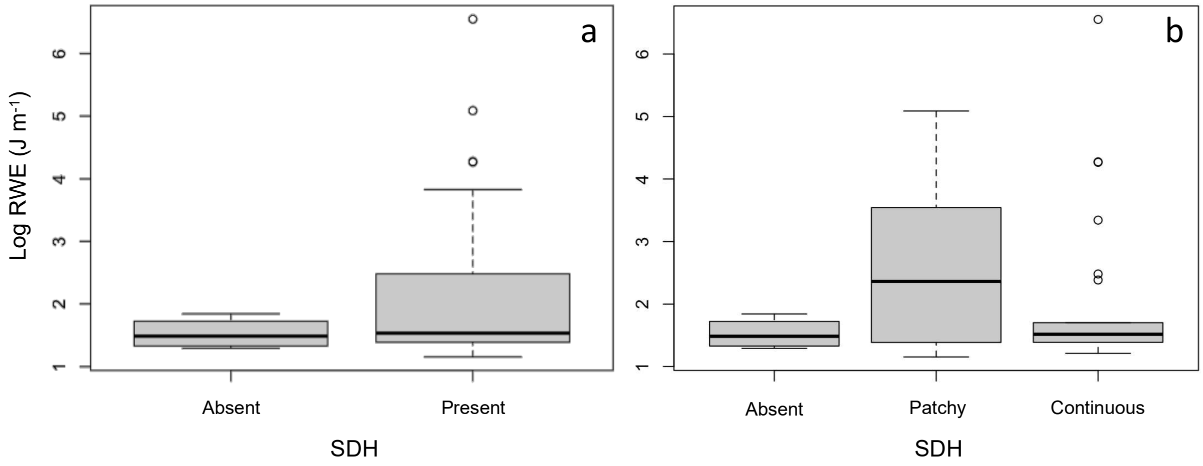


Figure 6. Juvenile blue crab kick-net survey results comparing crab density across habitat types: Eastern Seagrass (bright green), Western Seagrass (dark green), and SDH (light orange). (A) Spatial variation in crab density based on the circle size at every individual sampling location in Croatan and Pamlico Sounds. (B) Average juvenile blue crab density grouped by habitat type.

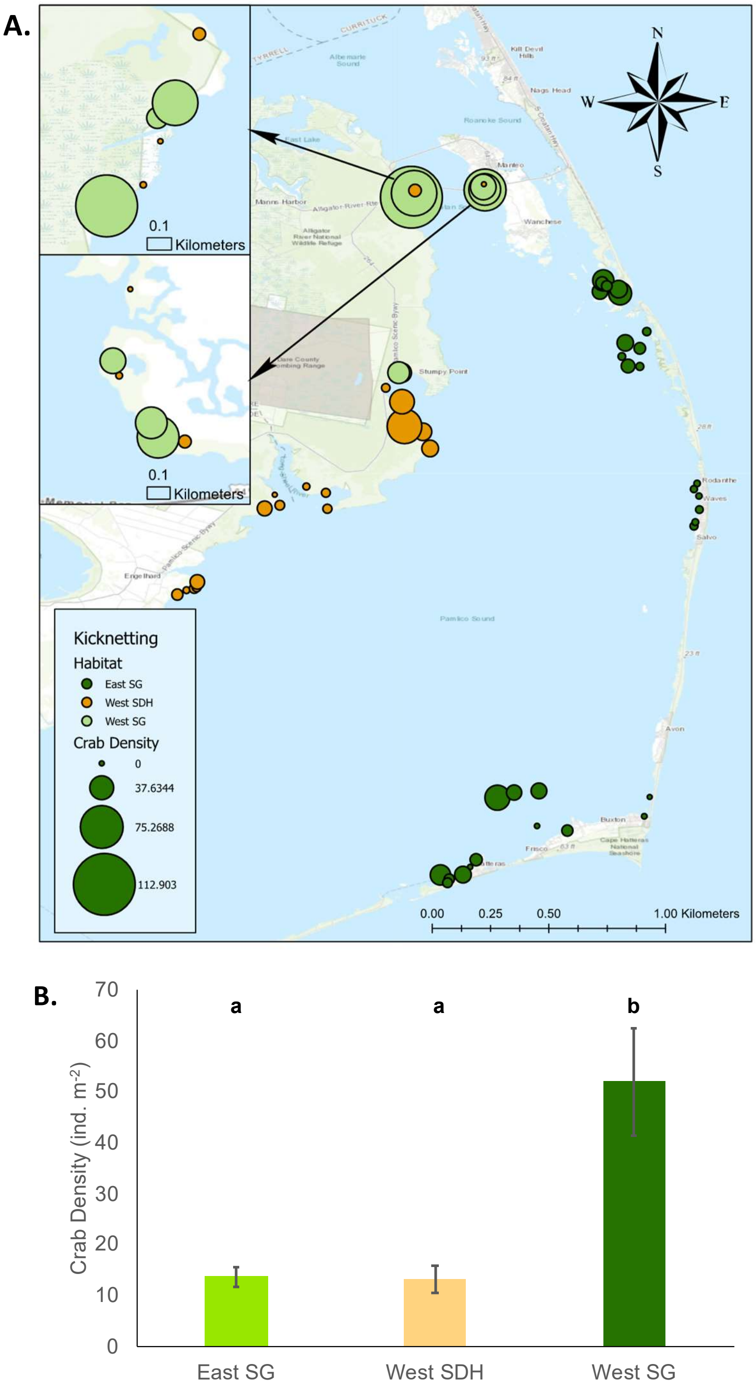


Figure 7. Shoreline change displayed as total change in area per capita shoreline length for four sites: two native marsh-grass site (dark colors) and two invasive *Phragmites*-dominated sites (light colors) located at either Stumpy Point (Blue) or Manns Harbor (Green). Shoreline change is plotted as function of UAS flight mapping periods along the x axis. Time-periods are as follows: Nov-March 2018, March-July 2019, Post-Dorian July-Sept 2019. N3 refers to a specific sampling site containing native marsh-grass at Stumpy Point. N4 refers to a specific sampling site containing native marsh-grass at Manns Harbor. P3 refers to a specific sampling site containing *Phragmites* sp. marsh-grass at Manns Harbor. P1 refers to a specific sampling site containing *Phragmites* sp. marsh-grass at Stumpy Point.

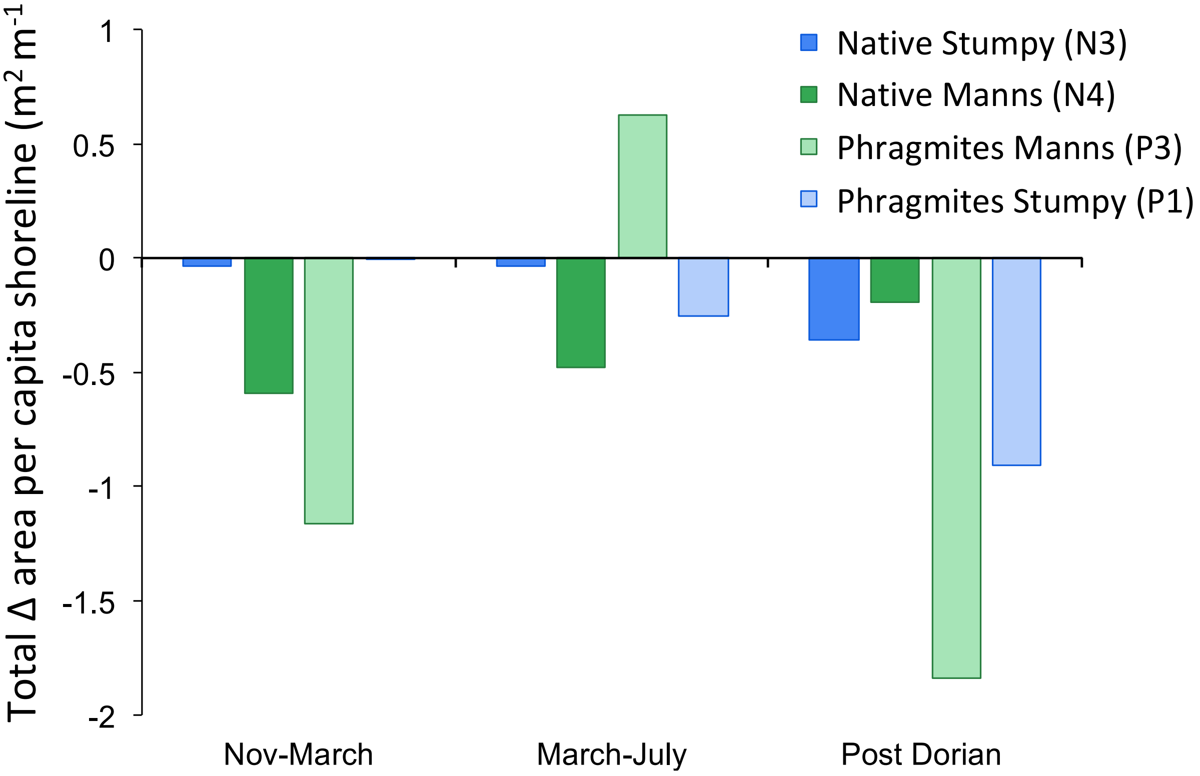


Figure 8. Shoreline change (total change in per capita shoreline length) as a function of Representative Wave Energy (RWE) calculated from WEMo using exceedance wind data from 2005-2012 (Theuerkauf et al., 2017b). Sites are classified as either Native marsh grass-dominated (square with dark color) or invasive *Phragmites*-dominated (diamond with 50% light color) and located at Stumpy Point (blue) or Manns Harbor (green).

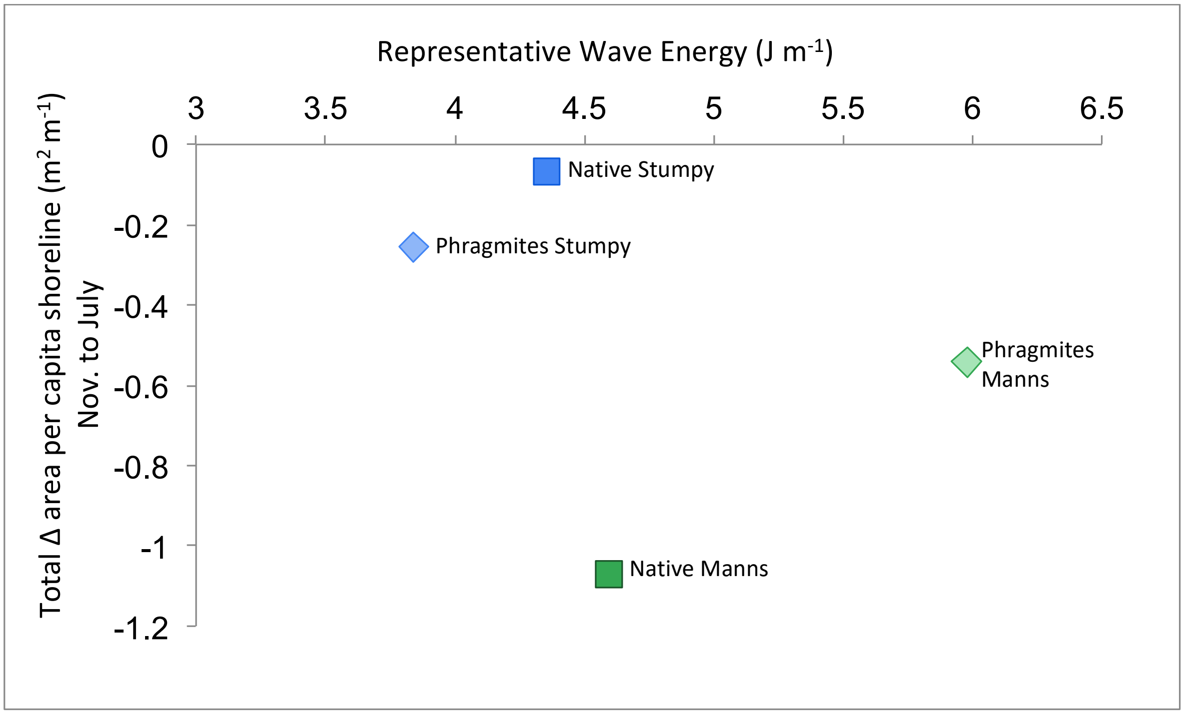
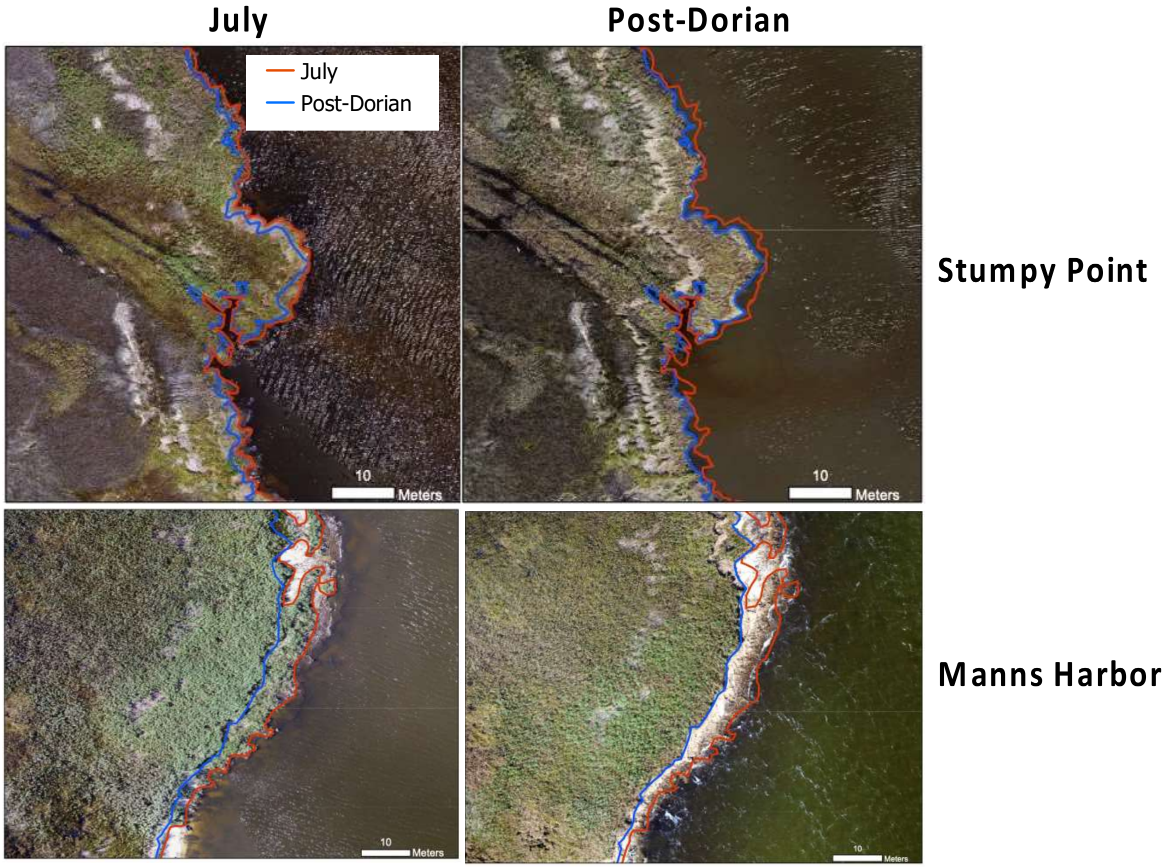


Figure 9. Illustrated differences in shoreline loss between the July 2019 flight (orange) and the September 2019 flight post Hurricane Dorian (blue). On the left are the orthomosaic aerial maps from July and Post-Dorian is on the right. The top panel shows the loss typical for Stumpy Point sites, where shoreline along the marsh-water interface is lost, whereas the bottom panel shows loss typical for Manns Harbor, where shoreline is lost due to sand overwash.



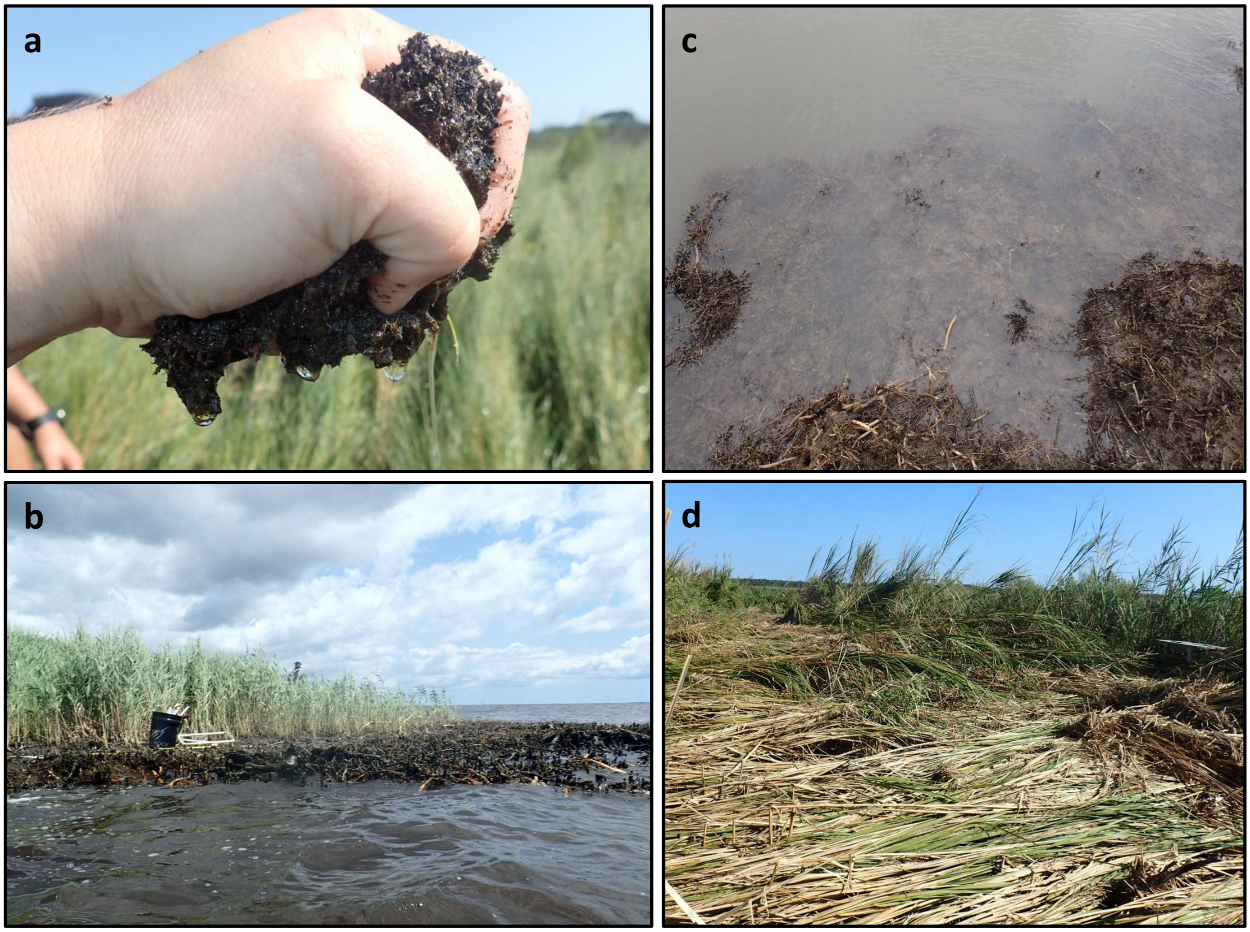


Figure 10. Photographic field observations displaying: (a) water retention capability of SDH shown as water dripping as peat mat is wrung out; (b) *Phragmites*-dominated shoreline showing the typical exposed berm with tight root mat and low peat content; (c) native marsh dominated shoreline showing typical SDH occurrence with high peat and detrital marsh content; and (d) *Phragmites*-dominated marsh section flattened by winds following Hurricane Dorian.

OUTREACH

Presentations:

Voigt E. and D. Eggleston. *Poster presentation*. Crabitat: Assessing effective nursery habitat of blue crabs in a large lagoonal estuary. Biennial Conference of the Coastal and Estuarine Research Federation (CERF). Nov. 2019

Voigt E. and D. Eggleston. *Poster presentation*. Crabitat: Assessing effective nursery habitat of blue crabs in a large lagoonal estuary. North Carolina Coastal Conference. Nov 2019 **Awarded 2nd place**

Branan C., **E. Voigt,** and D. Eggleston. *Oral presentation.* Sampling methods for marine debris in the Pamlico Sound. NCSU Applied Ecology Concentration (AEC) minor symposium. May 2020

Voigt E. *Oral presentation*. Crabitat. Science Tonight. NC Museum of Natural Sciences. November 2020.

Voigt E. and D. Eggleston. *Oral presentation*. Crabitat: Assessing habitat-specific variation in distribution and abundance of juvenile blue crabs in a large lagoonal estuary. Benthic Ecology Meeting. CANCELED DUE TO COVID April 2020

Durham A**., E. Voigt**, and D. Eggleston. *Poster presentation.* Crabitat: Assessing the effective nursery habitat for juvenile blue crabs. Ecological Society of America Meeting. August 2020

Voigt E. and D. Eggleston. *Oral presentation.* Crabitat: habitat-specific variation in distribution and abundance of juvenile blue crabs in a large lagoonal estuary. Western Society of Naturalists. Nov 2020

Voigt E. and D. Eggleston. *Oral presentation.* Nursery Habitat usage by juvenile blue crabs in a shallow, wind-driven estuary. Biennial Conference of the Coastal and Estuarine Research Federation (CERF). Nov 2021

Quackenbush A., **E.Voigt,** and D. Eggleston. *Oral presentation.* The use of drone in quantify large marine debris distribution in salt marshes. Biennial Conference of the Coastal and Estuarine Research Federation (CERF). Nov 2021. **Awarded top undergraduate oral presentation**

Smith L., **E. Voigt**, and D. Eggleston. *Poster presentation.* Microplastic Contamination in Juvenile Blue Crabs. Biennial Conference of the Coastal and Estuarine Research Federation (CERF). Nov 2021.

Grubb D., **E. Voigt**, and D. Eggleston. *Oral presentation.* North Carolina Blue Crab habitat: What is SDH? . NCSU Applied Ecology Concentration (AEC) minor symposium. Nov. 2021.

Publications:

E. P. Voigt, and L. Pharr. Crabitat: Juvenile Blue Crab Habitats in Pamlico Sound. North Carolina Sea Grant Coastwatch Currents. November, 2020.

E.P. Voigt and D.B. Eggleston. (2021) Spatial variation in nursery habitat use by juvenile blue crabs in a shallow, wind-driven estuary. Estuaries and Coast. *In review*

E.P. Voigt, A. Quakenbush, C. Branan, and D.B. Eggleston. (2022) The use of drones in quantifying large marine debris distribution in microtidal marshes. Marine Pollution Bulletin. *In prep*

E.P. Voigt and D.B. Eggleston. (2022) Interacting effects of invasive marsh grass and wave energy on shoreline stability and essential fish habitat. *In prep*

Other Outreach:

Social Media- Ms. Voigt posts to two professional science based social media accounts, one on twitter (handle: @epvoigt) and one on Instagram (handle: @estuarine.erin). In these posts, she shares information about the research funded by this fellowship, provides information about the day-to-day work of a research scientist, and provides science-based facts related to her dissertation research. Posts are frequently re-tweeted/reposted by NC State's CMAST, College of Sciences, College of Natural Resources, Department of Applied Ecology, and Division of Academic and Student Affairs official accounts, as well as APNEP and NC Sea Grant accounts. In addition, Ms. Voigt hosted an Instagram takeover of the NC State Graduate School account during the March UAS Flight fieldwork trip to highlight the diversity of careers NC State Graduate Students pursue.

Global Change Fellowship*:* As part of the Global Change Fellowship through the USGS Southeast Climate Adaptation Science Center, Ms. Voigt was featured in a scientific spotlight in which she discussed the research funded through this project, as well as its applicability to stakeholders. https://secasc.ncsu.edu/2019/12/06/researcher-spotlight-erin-voigt/

Additionally, Ms. Voigt created a video further detailing her research, which was also published by USGS Southeast Climate Adaptation Science Center, and can be found here: https://secasc.ncsu.edu/erin-voigt/

Or here:

https://www.youtube.com/watch?v=cbUhVq2dNeM&ab_channel=ErinVoigt

STUDENTS SUPPORTED:

1. **Erin Voigt**, PhD Student, NCSU/MEAS: The support through this fellowship has funded two of the four chapters of her dissertation research. The research undertaken through this fellowship has also helped Ms. Voigt acquire further funding through the Southeast Climate Adaptation Science Center- Global Change Fellows program, which was

awarded in the Summer of 2019. It has additionally spurred funding for a number of undergraduate research opportunities listed below.

2. **Aaron Durham,** undergraduate student and Doris Duke Conservation Scholar. Worked e as part of the Doris Duke Scholar program and based at CMAST during the summer of 2019. Participated in the July UAS Flight and the Marsh Surveys. He is currently working on the SDH sediment core definition and distribution study, which he will be presenting at the Ecological Society of America Conference in Utah in 2022.
3. **Leslie Smith,** undergraduate student and CMAST Coastal Fellow. Leslie worked with Aaron and Erin on the 2019 Marsh survey as part of her summer fellowship, and has been assisting with processing the sediment cores during the Spring 2020 semester. Additionally, in the Fall of 2021, Leslie was awarded an undergraduate research grant to start her own project studying microplastic contamination in juvenile crabs collected during the kick-netting portion of this study. Her poster presentation, given at the 2021 Coastal and Estuarine Research Foundation conference, is attached below.
4. **Carolina Branan,** undergraduate student and Undergraduate Student Experiential Learning Project based at CMAST. Caroline has been assisting with processing blue crab samples taken in conjunction with known SDH cores to better quantify what sediment characteristics are correlated with increased blue crab abundance. Caroline also conducted her own research project investigating sampling methodology for the marine debris project which was based on UAS maps collected for this study. She will be an author on the manuscript which will be submitted in Spring of 2022
5. **Alyssa Quackenbush,** undergraduate student, NCSU College of Natural Resources research enrichment grant, and Semester At CMAST studen. Alyssa is using the UAS aerial maps created as part of this project to measure marine debris and study the factors relating to debris dispersal throughout APES. Alyssa will be a co-author on the manuscript which will be submitted in the Spring of 2022. An abstract for the paper, as well as her presentation are included below.
6. **Kelan Gash,** undergraduate student and Semester at CMAST student. Kelan helped during the March 2019 UAS mapping trip as well as processing juvenile blue crab data.
7. **Dan Bowling**, graduate student. Dan and Erin worked together to create a UAS mapping protocol, which Dan has now extended into his own research using UAS to monitor intertidal oyster reefs.
8. **Davis Grubb**, undergraduate student and Applied Ecology Concentration Minor. Davis helped to process the SDH survey cores and presented his findings at the AEC minor symposium in 2021.

ADDITIONAL RESEARCH

The following projects used data derived and funded by this project.

The use of drones in quantifying large marine debris distribution in microtidal marshes.

E.P. Voigt, A. Quakenbush, C. Branan, and D.B. Eggleston

Abstract: Marine debris is a significant threat to humans and ecosystems because it can entangle organisms and leach harmful chemicals, which can biomagnify through food webs. While many studies have focused on debris found in the ocean and on beaches, few studies examine the amount of debris in other coastal habitats. Marshes provide many ecosystem services and are negatively affected by marine debris. Large debris smothers marshes and attempts to remove it can be more damaging due to trampling. The objectives of this study are to (1) test how effective drones are at locating marine debris in marshes; and (2) test for spatiotemporal variation of large marine debris along sites in Pamlico Sound, North Carolina, USA. This project uses unmanned aerial vehicles, or drones, as a non-invasive method of monitoring marsh debris. We completed synchronous ground and drone surveys of debris over a two-year period. Additionally, we surveyed various debris types in the field in order to calculate how debris size and area, and ground type affected the probability of debris being located in drone surveys. We found that large brightly colored debris located on wrack had the greatest likelihood of being located. Furthermore, the amount of debris varied significantly across sites and years but did not appear to correlate on any predictor variables. Ground surveys produced greater estimates of marine debris density and contained much smaller sized debris, while drone surveys mostly captured large debris. There was no relationship between marine debris density measured in ground surveys vs drone surveys of the same site. Drone surveys may be a good alternative for locating large debris, which is most likely to cause smothering damage, but are not accurate at predicting overall debris density. Furthermore, we hope that the efficacy data we gathered will provide key information to resource managers looking to implement drone surveys at their sites.

Link to NC Sea Grant funded research: The marine debris project was led by undergraduate student Alyssa Quackenbush, undergraduate student Carolina Branan assisted with methodology, and both students were mentored by Erin Voigt. The marine debris project used orthomosaic maps collected to measure shoreline change for this NC Sea Grant funded project.

Microplastic Contamination in Juvenile Blue Crabs.

Smith L., E. Voigt, and D. Eggleston.

Abstract: Microplastic ingestion is becoming an increasingly worrisome issue for popular fisheries. This may include North Carolina’s valuable commercial fishery, the blue crab (*Callinectes sapidus*). Adult blue crabs from other parts of the country were found to contain ingested microplastics, so North Carolina’s blue crabs may present a similar issue. Furthermore, more studies need to be conducted on different size classes of blue crabs to discover where in the lifecycle microplastic ingestion begins. In this study we look at microplastic contamination in juvenile (<20 mm) blue crabs. The methods of extracting microplastics from adult blue crabs is not applicable to juveniles of this size since they are too small to dissect. Therefore, the main objectives of our study are to both 1) discover an effective digestion and microplastic extraction process for juvenile blue crabs, and 2) measure the quantity of microplastics in crabs across multiple nursery habitats. We tested three digestion methods: two basic solutions (KOH 10% w.v. aq solution and NaOH 0.1 M), with and without heating, along with an oxidizing reaction (wet peroxide oxidation). Basic solutions were unable to break down blue crab exoskeletons even with increased temperature and agitation, but the wet peroxide oxidation digested the

majority of crab carapaces but left the microplastic unharmed. Using this method, we extracted evidence of microplastic ingestion in recently settled juvenile blue crabs, however these results were not distinguishable from microplastic levels found in control samples, which included no crab carapaces. This result points to the high level of microplastic contamination which can occur in a non-clean lab settings and should be taken as a warning to others attempting to do similar studies in the absence of laminar flow hoods or dust-free environments.

Link to NC Sea Grant funded research: The microplastic contamination project was led by undergraduate student Leslie Smith under the mentorship of Erin Voigt. The microplastic project used frozen blue crabs collected as part of the 2019 juvenile blue crab kick-netting survey which is part of this funded project.

DATA MANAGEMENT PLAN

We have completed the steps outlined in our project's initial data management plan with the exception of the following changes:

1. We used a DJI Phantom 4 Advanced UAS rather than a eBee by SenseFly, and Parrot Sequoia sensor
2. Marsh surveys were taken every 4 km rather than every 2 km
3. Fringing marsh species was recorder for a 20 x 2 m area
4. Only 4 out of 8 UAS sites have been analyzed the remaining 4 sites will be analyzed following Erin's maternity leave (Spring 2022)