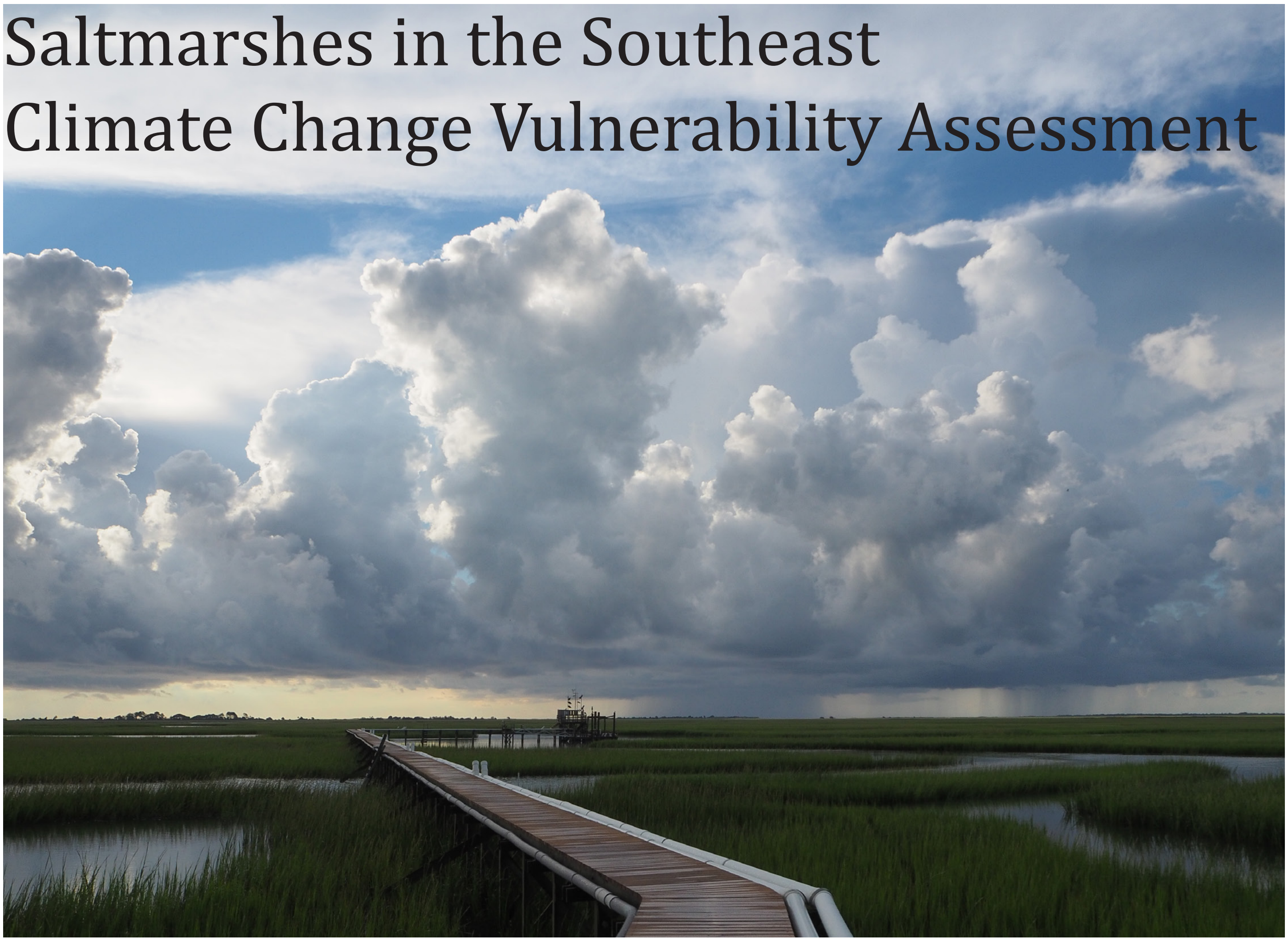
Saltmarshes in the Southeast
Climate Change Vulnerability Assessment



NERRS Science Collaborative Project:
Creating a shared understanding of the specific vulnerabilities of southeastern coastal habitats to climate change impacts

This report summarizes the findings of teams of experts representing multiple agencies who participated in a process to assess the vulnerabilities of intertidal marsh sites in North and South Carolina. This work was sponsered by the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center (NAI4NOS4190145).

Report prepared by: Jennifer Plunket, Stewardship Coordinator, North Inlet-Winyay Bay National Estuarine Research Reserve. jen@belle,baruch.sc.edu

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Introduction

Climate change will significantly affect the coastal zone through changes in sea level, storm severity and frequency, erosion and sediment supply, species range shifts, freshwater inflows, and water quality (Najjar et al. 2000, Rogers and McCarty 2000), potentially causing the degradation or loss of habitats that perform critical ecosystem services for coastal communities. In general, salt marshes in the southeast are already being impacted by changes in climate including sea level rise, increases in air and water temperature, changes in precipitation patterns, and an increase in storm event intensity. The North Inlet-Winyah Bay National Estuarine Research Reserve in South Carolina (NIWBNERR) and the North Carolina National Estuarine Research Reserve (NCNERR) are located in areas projected to experience differing levels of sea level rise, with varying species compositions, stressor conditions, and potential change responses, so it cannot be assumed that all southeastern marshes are equally vulnerable to the effects of climate change. Studies in North Inlet have found that although surface elevation of the intertidal marsh is increasing in pace with current mean relative sea level rise of 3.8 mm/yr, impacts of climate change on the ecological function of the marsh are evident. Interannual variations in abundance and growth in some fishes and shrimps and the timing of larval production within the estuary and larval ingress from offshore that have been related to changes in salinity and water temperature are attributed to changes in climate. In NC, sea level rise and its relationship to coastal hazards are primary concerns for the coastal management community. Sea level rise is projected to vary across the state, with a prediction of 0.09 and 0.24 m by 2045 based on a low greenhouse gas emission scenario (Science Panel, 2015).

Resource management and scientific communities are often tasked with assessing climate change impacts on conservation targets and with supporting the development of adaptation strategies to meet stakeholder and societal goals. A priority issue of the NIWBNERR, as described in the 2011-2016 Management Plan, is the impact of climate events on coastal ecosystems. The Reserve has set the goals of improving understanding of how climate events affect ecosystem functions and providing communities with information and skills to assist them in preparing for future impacts. Similarly, the NCNERR has identified assessing vulnerability of the Reserve's natural resources to inform management decision making as an objective within the coastal hazards resilience topical area of the 2016-2021 Management Plan. The process of completing a vulnerability assessment facilitates the compilation of locally-relevant ecological and climate data and best-available knowledge of future exposure to direct and indirect climate effects. Climate change vulnerability assessments can support decision making by providing managers with methods of identifying which habitats are likely to be most affected by projected changes in climate as well as insight as to why these habitats are likely to be vulnerable (Glick et al., 2011). Information on the expected impacts of climate change on coastal resources will lead to improved stewardship of these resources through implementation of habitat management actions, the refinement of local and state regulatory programs, and by informing policy discussions over the effectiveness of current regulatory programs.

The Climate Change Vulnerability Assessment Tool for Coastal Habitats (CCVATCH) is a decision support tool that improves understanding of the specific vulnerabilities of a habitat to climate change in order to inform current and potential management actions. Through this data assessment process, users of this tool determine the potential for applying adaptation strategies as well as the main sources of vulnerability, both of which are necessary to support increasingly challenging management decisions. This report summarizes the findings of teams of experts representing multiple agencies who participated in a CCVATCH process to assess the vulnerabilities of intertidal marsh sites in North and South Carolina.

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Background on the CCVATCH

The CCVATCH is a decision support tool that produces a vulnerability rating combining the elements of *sensitivity*, *exposure* and *adaptive capacity* consistent with nationally accepted guidance documents for assessing vulnerability to climate change (Glick et al., 2011)(Figure 1). A vulnerability assessment can be thought of an analysis of the range of potential outcomes, from a complete loss of a habitat to one that is likely to remain intact. Uncertainty is also incorporated into the CCVATCH scoring process. For more information on the CCVATCH development and process, please see Guidance Document at ccvatch.com.

The CCVATCH Process

Through a facilitated expert-elicitation process, users of the CCVATCH examine the existing information on how predicted changes in atmospheric CO_2, air and water temperature, precipitation, relative sea level, and the frequency and severity of large scale events such as storms and wildfires will directly impact the habitat and will interact with known non-climate habitat stressors. Stressors considered are invasive or nuisance species, nutrient enrichment, sedimentation and erosion, and biological and chemical contamination. Users begin the process with an assessment of the current conditions of the habitat with respect to any known current effects of climate change, and for each of the stressors. The current condition score is intended to capture the relative health of a habitat prior to the influence of additional stress from a changing climate at some future date. How individual habitat units respond to this future state will depend to some degree on whether the habitat is already compromised from non-climate stressors or, in the case of the direct climate effects, the degree to which climate change has already influenced the habitat (i.e. observed changes in phenology, reduced reproductive success, etc.). Assessors essentially answer a list of 42 questions about how severely they perceive each climate/stressor interaction will impact the function of the habitat, and 6 questions about adaptive capacity (Table 1). Numerical scores of 0 to 10 are assigned for each stressor (see Table 2 for score level descriptions). The direct effects of climate change on the habitat and the anticipated interactions of climate change with the non-climate stressors are then each scored from -2 (a positive impact) to 10. An overall vulnerability score for a defined habitat area is calculated (Figure 2).

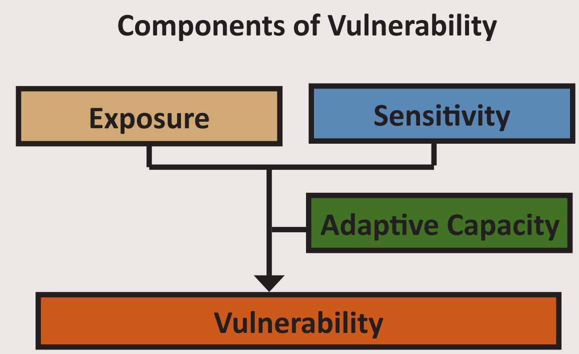

Figure 1. Exposure is the type, magnitude, and rate of climate change a species, habitat, or ecosystem is likely to experience. Sensitivity is the degree to which that system is or is likely to be affected by or responsive to those changes. Projected climate changes and a species or habitat's likely response to those changes determines the potential impact. Adaptive capacity refers to the ability of a species or system to accommodate or cope with climate change impacts with minimal disruption, and is both a factor of internal traits, such as the ability of a species to physically move in search of more favorable habitat conditions, and of external conditions, for example the existence of a structural barrier such as a seawalls that may limit the ability of that species or habitat to move. Vulnerability therefore is the degree of change that a species or system is projected to experience along with its likely response to those changes and the ability for the species or system to reduce or moderate those potential impacts.

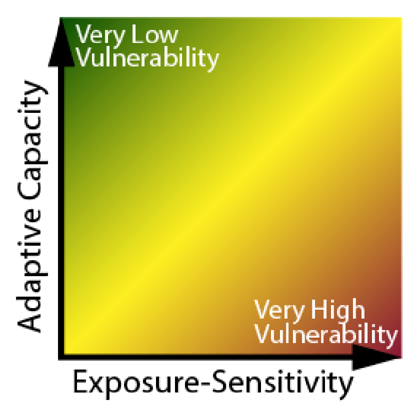

Figure 2. Overall vulnerability levels are based on levels assigned to sensitivity-exposure and adaptive capacity using a relationship table.

Methods

Assessment Questions

Table 1. The CCVATCH process can be broken down into a list of 42 questions for which the assessors provide individual scores.

Direct Climate Effects

1. Is the study area currently being directly impacted by climate changes?
2. Will the study area be directly impacted by an increase in CO_2?
3. Will the study area be directly impacted by predicted changes in temperature?
4. Will the study area be directly impacted by predicted changes in precipitation?
5. Will the study area be directly impacted by predicted changes in sea level?
6. Will the study area be directly impacted by extreme climate events?

Invasive/Nuisance Species

7. Is the study area currently impacted by invasive species?
8. Will invasive species impacts be exacerbated by an increase in CO_2?
9. Will invasive species impacts be exacerbated by predicted changes in temperature?
10. Will invasive species impacts be exacerbated by predicted changes in precipitation?
11. Will invasive species impacts be exacerbated by predicted changes in sea level?
12. Will invasive species impacts be exacerbated by extreme climate events?

Nutrients (deficiency or excess)

13. Is the study area currently impacted by nutrients?
14. Will nutrient impacts be exacerbated by an increase in CO_2?
15. Will nutrient impacts be exacerbated by predicted changes in temperature?
16. Will nutrient impacts be exacerbated by predicted changes in precipitation?
17. Will nutrient impacts be exacerbated by predicted changes in sea level?
18. Will nutrient impacts be exacerbated by extreme climate events?

Sedimentation (excess sediment supply)

19. Is the study area currently impacted by sedimentation?
20. Will sediment impacts be exacerbated by an increase in CO_2?
21. Will sediment impacts be exacerbated by predicted changes in temperature?
22. Will sediment impacts be exacerbated by predicted changes in precipitation?
23. Will sediment impacts be exacerbated by predicted changes in sea level?
24. Will sediment impacts be exacerbated by extreme climate events?

Erosion (loss of sediment or supply)

25. Is the study area currently impacted by erosion?
26. Will erosion impacts be exacerbated by an increase in CO_2?
27. Will erosion impacts be exacerbated by predicted changes in temperature?
28. Will erosion impacts be exacerbated by predicted changes in precipitation?
29. Will erosion impacts be exacerbated by predicted changes in sea level?
30. Will erosion impacts be exacerbated by extreme climate events?

Contamination

31. Is the study area currently impacted by contamination?
32. Will contamination impacts be exacerbated by an increase in CO_2?
33. Will contamination impacts be exacerbated by predicted changes in temperature?
34. Will contamination impacts be exacerbated by predicted changes in precipitation?
35. Will contamination impacts be exacerbated by predicted changes in sea level?
36. Will contamination impacts be exacerbated by extreme climate events?

Adaptive Capacity

37. Is the habitat in the study area fragmented?
38. Are there barriers to the potential migration of species in the study area?
39. Does the habitat type of the study area respond quickly following a major disturbance?
40. Is there a diversity of functional groups in the study area?
41. Do potential management strategies to increase resilience exist?
42. Are positive management strategies likely to be implemented?

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Scoring

Table 2. Score levels descriptions are provied as guidence for assigning scores for current condition, sensitivity-exposure, adaptive capacity, and certainty. Users of the tool may also elect to use intermediate scoring levels.

Current Condition

0	Habitat is not impacted by non-climate stressor
2	Habitat is currently impacted by non-climate stressor but to a limited degree (i.e. over a modest portion of its' extent or no significant influence on habitat structure/function)
5	Habitat is currently moderately impacted by non-climate stressor (i.e. evidence of stressor impact over a majority portion of its' extent or clear degradation of habitat structure/function)
10	Habitat is severely impacted by non-climate stressor

Sensitivity-Exposure

-2	Habitat may benefit; non-climate stressor impact is alleviated by a change in climate condition
0	No anticipated change in habitat structure, function or extent
2	Habitat will likely be impaired to a limited degree (i.e. over a modest portion of its' extent or no significant influence on habitat structure/function)
5	Habitat persistence will be limited (i.e. degradation of habitat structure/function sufficient to modify reproductive potential, reduced habitat extent)
10	Habitat will be lost

Adaptive Capacity

0	Severe impediments to habitat persistence or dispersal (e.g. barriers, fragmentation exist or innate community characteristics of the habitat are not sufficient to compensate for CC stressors or policy or management actions to offset CC stressors are not possible or are likely to be implemented
2	Modest impediments to habitat persistence or dispersal (e.g. barriers, fragmentation) exist or innate community characteristics of the habitat are sufficient to partially overcome CC stressors or appropriate policy or management actions may be taken to partially offset CC stressors
5	No impediment to habitat persistence or dispersal (e.g. barriers, fragmentation) exists or innate community characteristics of the habitat are sufficient to overcome CC stressors or appropriate policy or management actions may be taken to fully offset CC stressors

Certainty

0	No direct or anecdotal evidence is available to support the score, topic needs further investigation
1	Low: Inconclusive evidence (limited sources, extrapolations, inconsistent findings, poor documentation and/or methods not tested, etc.), disagreement or lack of opinions among experts, score base on anecdotal observations
2	Medium: Suggestive evidence (a few sources, limited consistency, models incomplete, methods emerging, etc.), competing schools of thought, score based mostly on expert opinion
3	High: Moderate evidence (several sources, some consistency, methods vary and/or documentation limited, etc.), medium consensus, general information can be applied to local habitats
4	Very High: Strong evidence (established theory, multiple sources, consistent results, well documented and accepted methods, etc.), high consensus, information for local habitats

Methods

Climate Predictions and Assesment Time Period

The assessment period time frame was decided to be 30 years, or approximately 2050, which provided a long enough time for changes in climate to be likely to have affected habitats, but is still within a realistic management action horizon. Assessment teams were provided with a general climate scenario including recent trends and changes predicted assuming the RCP 4.5 climate projections. Climate projections were obtained from the U.S. Geological Survey National Climate Change Viewer.

Generalized Climate Scenario for South Carolina

Recent trends

Sea Level

- Since 1921, the sea level at Charleston has risen by 1.3 inches per decade, nearly double the global sea level rise of 0.7 inches per decade.

Precipitation

- Annual precipitation has been below average during most years in the 2000s (12 of 16 years during 2000–2015).
- Since the start of the 21st century, the state has experienced a below normal number of extreme precipitation events.
- Record wettest 5-day period recoded at Georgetown County Airport with 23.5 inches (October 1–5, 2015)
- October monthly record for any station across the state 26.99 inches in 2015.

Predicted climate changes

Temperature

- Mean annual winter temperatures are expected to increase by 2-3^{0}F.
- The annual number of days below freezing will decrease from an average of 35 to 25 days/year.
- The annual number of days hotter than 95^{0}F will increase by approximately 20 days/year.
- Any increases in temperature will cause more rapid loss of soil moisture during dry spells, increasing the intensity of naturally occurring droughts in the future.

Precipitation

- Little change in average annual precipitation is projected over the 21st century.
- Average summer precipitation may increase slightly, but little change in winter precipitation is predicted.
- Precipitation extremes (2” in 48 hours) are predicted to increase in frequency.

Sea Level

- Some state-level estimates project a rise of 3.5 to 4 feet by 2069.

Extreme Climate Events

- Climate models project an increase in the number of the strongest (Category 4 and 5) hurricanes, accompanied by 20% more rainfall, by the end of the 21st century.

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Site Descriptions and Current Conditions

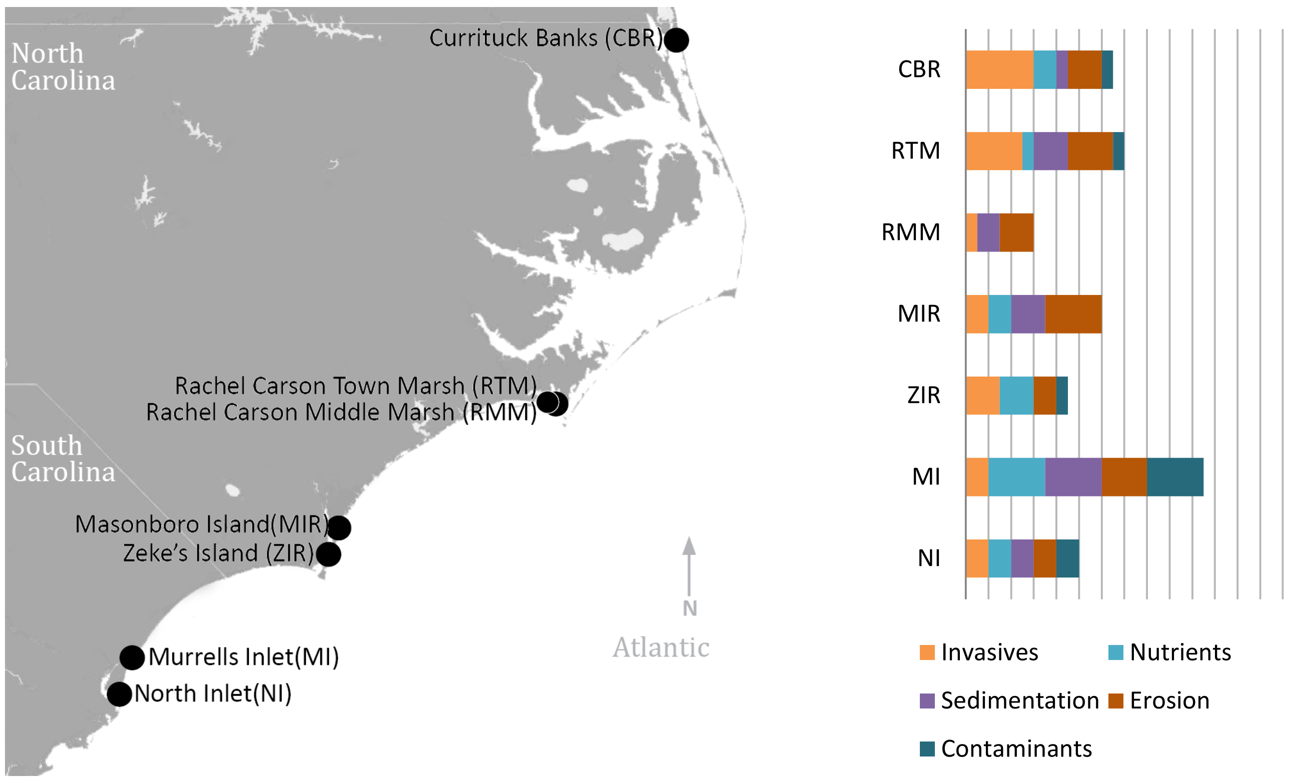

Figure 3. The assessment sites are located in areas projected to experience differing levels of sea level rise, with varying species compositions, stressor conditions, and potential change responses. The relative impacts of stressors on the current conditions are shown in the chart at right.

Currituck Banks Reserve, North Carolina

Currituck Banks Reserve (CBR) encompasses 965 acres in the northeastern corner of North Carolina in Currituck County on the Outer Banks. The site is ten miles south of the Virginia border and a mile north of the unincorporated village of Corolla. The Nature Conservancy and U.S. Fish and Wildlife Service properties bound Currituck Banks to the north, the Atlantic Ocean to the east, the Currituck Sound to the west, and private subdivisions of Corolla to the south. The habitat of focus for the CCVATCH study was the brackish coastal marsh which is primarily composed of giant cordgrass *Spartina cynosuroides*, black needlerush *Juncus roemerianus*, and cattails *Typha* spp.

In general, the Currituck Banks Reserve is primarily unaltered by development and has retained a protected contiguous beach to sound profile. Because of this, the brackish marsh has little to no barriers for landward migration; however it no longer receives sediment from over wash via the ocean. While the on-site infrastructure is limited to a small stretch of paved road in the southeastern corner of the Reserve, several factors affect the condition of the brackish marsh. These include invasive species such as feral hogs, the expansion of *Phragmites australis*, and the presence of free roaming horses. Feral hogs and horses have been known to damage marsh vegetation through consumption, trampling and/or uprooting. The expansion of *Phragmites* displaces native species and can result in a monoculture providing some loss in ecosystem services such as habitat value for native species. Erosion rates are variable throughout the marsh and existing SET data indicates sediment is available and perhaps keeping up with sea level rise. Additionally, feldspar markers also indicate that sediment is coming from the sound which is now the sole source of sediment accumulation. There is consensus that data gaps exist with respect to excess nutrients and contaminants that may exist, and how they are affecting the marsh with respects to plant growth and uptake, storage in sediments, and bioavailability in the water column.

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Rachel Carson Reserve, North Carolina

The Rachel Carson Reserve is located between the mouths of the Newport and North Rivers and directly across Taylor's Creek from the historic town of Beaufort in Carteret County. The main part of the site, just south of Beaufort, is a complex of islands which includes Carrot Island, Town Marsh, Bird Shoal, and Horse Island. The assessment covered two separate areas of the reserve, Middle Marsh (RMM) and Carrot Island/Town Marsh (RTM). Middle Marsh, separated from the rest of the site by the North River Channel, is almost two miles long and less than a mile wide. The Rachel Carson main islands have *Spartina alterniflora* salt marsh with fringing oyster reefs located throughout, including many transitional areas that are becoming marsh as sediment is deposited on tidal flats. Middle Marsh is a remote, highly fragmented marsh system that is a relic flood tide delta. Residential development in surrounding areas causes occasional high nutrient events from runoff and the site is located adjacent to a sewer wastewater outfall. Middle Marsh is less exposed to this given its different tidal currents and more remote location. The wild horse, a non-native species, has been documented to cause a disruption in marsh function at the main islands; horses are not found at Middle Marsh. The invasive marsh grass *Phragmites* is present. Erosion on main islands is occurring along marsh edges at a higher rate on the south side of the site and at a lower rate where there is less wave exposure on the north side of the islands.

Zeke's Island and Masonboro Island, North Carolina

Zeke's Island Reserve (ZIR) is 22 miles south of Wilmington, bounded by Federal Point to the north, Smith Island to the south, the Atlantic Ocean to the east, and the Cape Fear River to the west. The entire site is 1,635 acres and includes Zeke's Island, North Island, No Name Island, a beach barrier spit and extensive fringing marshes and tidal flats. While shoals and marshes have continued to appear and disappear within the basin, Zeke's, No Name, and North Islands have remained stable relative to the beach barrier spit, even though their shorelines periodically increase and erode.

The Masonboro Island Reserve (MIR) is located on the largest undisturbed barrier island along the southern part of the North Carolina coast, approximately five miles southeast of Wilmington, in the most populous part of the North Carolina coast. The Masonboro site is bounded by the Atlantic Ocean to the east, the Atlantic Intracoastal Waterway to the west, Masonboro Inlet to the north, and Carolina Beach Inlet to the south. Eighty-seven percent of the 8.4 mile long island is covered with marsh and tidal flats. The remaining portions are composed of beach uplands and dredge material islands. Masonboro Island is an essentially pristine barrier island and estuarine system.

The Masonboro Island and Zeke's Island Reserves have both been impacted by development in the watershed; however, the nature of these impacts differs. The MIR is directly affected by moderate residential development and shows some signs of the stormwater runoff impacts associated with rising impervious surface coverage and occasional wastewater pipe failures. The ZIR is located downstream of significant industrial development in a watershed that includes a large number of animal agriculture sites as well as approximately 20% of the state's human population. Both sites have some invasive species occurrences that are not causing significant loss of marsh function. At MIR, some areas of *Phragmites* could encroach on the saltmarsh but the salinity level should prevent major marsh loss. At ZIR, the invasive algae *Graciliaria vermiculophylla* creates large mats on mud flats that can become lodged against marsh edges, resulting in erosion, or can pile up on the marsh surface causing small patches to die off. Both sites have occasional high nutrient events, typically associated with rainfall. The MIR site is thought to have a sediment deficit based on preliminary surface elevation table data that indicates that deposition on the marsh surface is not greater than the expected sea level rise rate. The ZIR site appears to be accreting based on preliminary surface elevation table data that shows deposition that exceeds the expected sea level rise rate. Erosion occurs at both sites, but differs in its intensity and pattern. At MIR, erosion along marsh edges is widespread, although the reason for the erosion is not fully understood. At ZIR, edge erosion is localized and results from scouring by algal mats. Contaminants are not well understood at either site, as little to no monitoring of metals, hydrocarbons, or agricultural contaminants is currently being conducted. Due to its proximity to the ocean and the regular flushing of the lunar tides, MIR is likely to be exposed to lower amounts of contaminants. ZIR has far less flushing and is directly connected to the river, so contaminants are likely higher. At both sites, however, high levels of sediment disturbance may mobilize contaminants.

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North Inlet and Murrells Inlet, South Carolina

The North Inlet-Winyah Bay Reserve is located in Georgetown, South Carolina, approximately 60 miles north of Charleston, and consists of 18,900 acres of tidal marshes, waterways, former rice fields and forested uplands. North Inlet (NI) is an ocean dominated estuary surrounded by a small forested watershed that currently has little development. The focus of the assessment for this site was on the *Spartina alterniflora* salt marsh and it function as essential fish habitat.

Murrells Inlet (MI) is an ocean dominated estuary located in northeastern Georgetown County between Garden City Beach to the north-east and Huntington Beach to the south-west. Murrells Inlet was chosen for comparison with NI due to its close proximity and similarity to NI, with the main difference being in the extensive development surrounding MI and impacts to the waterways by dredging, filling and the construction of quarystone jetties at the mouth of the inlet in the late 1970's.

The Murrells Inlet marsh watershed has been impacted by development to a much greater extent than that of the North Inlet marsh. The presence of stormwater infrastructure (channels and ponds), impervious surfaces, and the removal of vegetation at the marsh edge may cause differences in erosion, sedimentation and nutrient and contaminant concentrations between the two sites. Upland erosion may be an important source of sediment in both marshes. The presence of channels and storm water ponds and the removal of marsh edge buffer vegetation in some areas of the MI watershed may affect sediment delivery compared to the NI watershed. Dredging has occurred in Murrells Inlet due to the infilling of channels, which may indicate a high sedimentation rate or may be from internal recycling of sediment. Erosion has been observed in the tidal channels of both marshes; however Murrells Inlet may have a greater impact from boat wake due to a greater number of boats and having more expansive wide channels. The presence of the jetties at the mouth of Murrells Inlet may be impacting erosion rates. There is generally not a large difference in PAH between the two marshes and atmospheric deposition of metals should be similar. Fecal coliform is currently a problem in Murrells Inlet where oyster beds are closed and fish kills have also occurred in the Murrells Inlet marsh. Sedimentation and erosion processes in Murrells Inlet may mobilize more contaminants. It has been observed that harmful algae have increased toxicity in North Inlet compared to that in Murrells Inlet. There are higher concentrations of nutrients in Murrells Inlet relative to North Inlet, resulting in more algal production in Murrells Inlet.

Figure 4. Examples of intertidal marsh habitats assessed. Top left: Currituck Banks, right: Rachel Carson Reserve, Bottom left:Masonboro Island, right: North Inlet.

Assessment Results

Overall Vulnerability

Overall vulnerability scores for the sites ranged from 'moderate' to 'very high' (Figure 5). All sites scored as 'high' in sensitivity-exposure (SE), but ranged from 'low' to 'high' in adaptive capacity (AC) (Table 3).

The CBR scored 'high' for both ES and AC, for an overall 'moderate' vulnerability score. Sea level rise and storms were the overall highest scoring climate-exposures, and invasive species and erosion were the highest scoring stressors at this site (Figure 6). The RMM and RTM sites both scored 'high' in SE. The sites differed in AC, with RMM scoring 'low' and RTM receiving a 'moderate' score, for an overall vulnerability assessed as 'very high' at RMM and 'high' at RTM. At RMM, the direct effects of sea level rise and the interaction of erosion with sea level rise and extreme climate received the highest scores. At RTM, the interaction of erosion and sea level and the direct effects of extreme climate events contributed the most to the SE score. The MIR and ZIR both had 'high' levels of SE and 'moderate' scores for AC, for overall 'high' vulnerability scores. Impacts from climate exposures of sea level rise and storms scored highest for both reserves. The direct effects of climate change and erosion were overall the highest scoring stressors for MIR, while invasive species and nutrients had the overall highest stressor scores at ZIR.

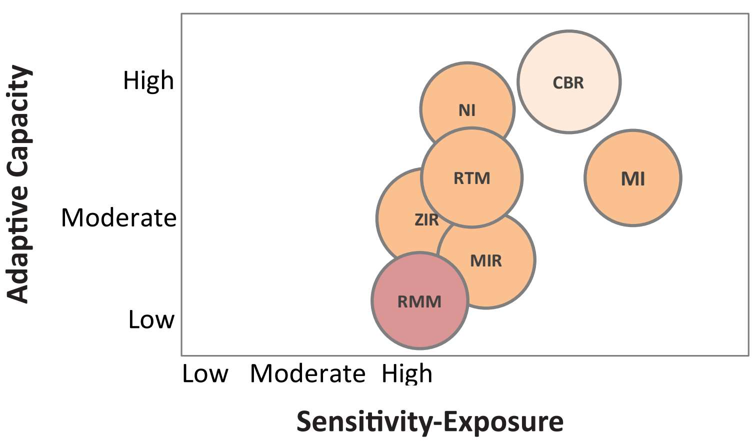

Figure 5. Overall vulnerability levels are based on levels assigned to sensitivity-exposure and adaptive capacity using a relationship table Overall vulnerability levels are based on the assumption that habitats having low sensitivity to predicted climate change exposure and high adaptive capacity will have less overall vulnerability and habitats that are highly sensitive to predicted climate change exposure and low adaptive capacity

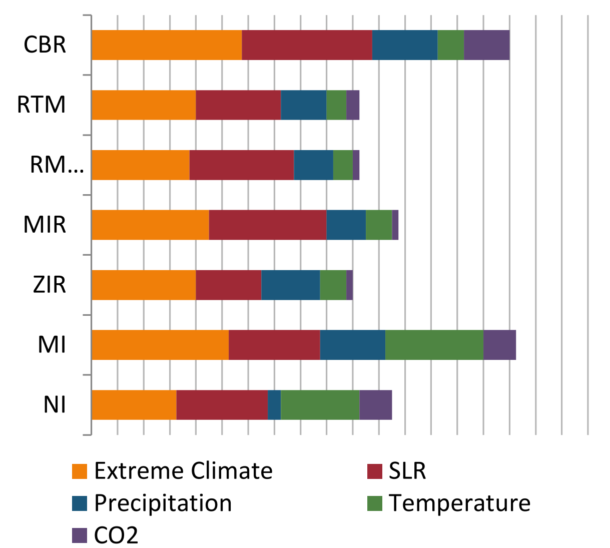

Figure 6. The relative contribution of each climate impact to the overall sensitiviyt-exposure score for each site shows that extreme climate events and sea level rise were considered to have the greatest potential for imact across sites.

Table 3.The scores for sensitivity-exposure (S-E), adaptive capacity (AC) and certainty and the associated level (low, moderat, high, very high) for each score are shown.

Site	SE score	SE level	AC score	AC level	Certainty	Overall level
CBR	82.0	High	20.0	High	1.64	Moderate
RTM	61.5	High	13.0	Moderate	1.69	High
RMM	50.5	High	4.0	Low	1.88	Very High
MIR	64.5	High	7.0	Moderate	1.81	High
ZIR	52.0	High	10.0	Moderate	1.67	High
MI	95.5	High	13	Moderate	1.9	High
NI	60.5	High	18	Moderate	2.0	High

Assessment Results

The assessment of North Inlet resulted in a 'high' SE score and a 'moderate' AC, for an overall 'high' vulnerability level. Murrells Inlet received a comparatively higher SE score and lower AC score, for an overall 'high' vulnerability level as well. The climate exposure impacts of rising sea level and an increase in the severity of storms were considered to have the greatest potential for impacts in North Inlet, while the current conditions and an increase in the severity of storms contributed the most to vulnerability for MI. For NI, invasive species and erosion ranked overall as the stressors of highest concern, and for MI the stressors of highest concern were erosion and contamination.

The results of this study demonstrate the balance between SE and AC. RMM was assessed as having the lowest ES of the sites, but also as having the lowest AC, which combined gave the site the highest vulnerability score. Conversely, the lowest scoring site for vulnerability was CBR, which was considered to have a high level of ES, but also the highest AC of the sites. The interaction of sea level rise and erosion contributed the most to vulnerability across sites. Invasive species were anticipated to impact habitats across all sites through interactions with all climate exposures. The potential effects of the interactions of contaminants with CO_2 and temperature had the highest uncertainty scores across sites (Table 4).

Table 4. Score levels (high, moderate, low, no effects, and positive effect) for each climate/exposure interaction for each site. Scores with 0 certainty are idicated by '?' scores with 3 or above ceratinty are indicated with '*'.

	CO_2							Temperature							Precipitation							Sea Level Rise							Extreme Events						
	NI	MI	ZIR	MIR	RMM	RTM	CBR	NI	MI	ZIR	MIR	RMM	RTM	CBR	NI	MI	ZIR	MIR	RMM	RTM	CBR	NI	MI	ZIR	MIR	RMM	RTM	CBR	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct														*							*	*	*		*	*					*	*	*		
Invasive	*	*						*	*																			*							
Nutrients			?	?											?	?					*	*	*		?										*
Sediment	*	*						*	*																	*									
Erosion	*	*			*	*		*	*						*	*	*	*	*	*		*	*		*	*	*	*	*	*		*	*	*	*
Contam.	*	*	?	?				*	*	?	?	?	?		*	*					?	*	*						*	*	*	*			

Vulnerability Score: high moderate low no effect positive effect *Certainty: * high ? needs further investigation*

Sensitivity-Exposure

<u>Direct Effects of Climate Change</u>

Direct climate effects are the ecophysiological responses of organisms and ecosystems to changes of CO_2, temperature, precipitation, sea level and extreme climate events, in the absence of ecological stressors. Not surprisingly, sea level rise (SLR) is predicted to have the greatest direct effect on the intertidal marsh habitats of all of the study sites (Figure 7). The direct effects of SLR received the highest scores (5) at NI, MI and MIR, and lower scores at CBR (2) and ZIR (2). Historically, intertidal marsh habitats have maintained elevation with SLR by accumulating organic matter and trapping inorganic sediment; however at high rates of SLR or under disturbed conditions, the dominant plant community may not be able to maintain an elevation that is within its range of tolerance. Morris et. al (2002) calculated that for estuaries with high sediment loading, such as those on the southeast coast of the United States, the limiting rate of relative SLR was predicted to be 1.2 cm/yr. The current rate of SLR at Springmaid Pier, the closest tide station to NI and MI, is 3.94 mm/yr, and is 3.04 mm/yr at the Beaufort tide station in NC. (NOAA Tides and Currents). Under an intermediate scenario, sea level is predicted to increase by 0.44m by 2050 at Springmaid pier and 0.47m at Beaufort (NOAA Sea Level Rise Viewer), which would result in rates exceeding the 1.2 cm/yr threshold. The marsh at MIR is not accreting at a rate higher than the current SLR and is not anticipated to keep up during the assessment period of 30 years, although the marsh at ZIR may be able to keep pace. Monitoring of the low marsh at both sites indicates that the low marsh/high marsh transition at MIR may already be moving upland. This is expected to continue and may result in an overall decrease in the number of acres of marsh at the site. At CBR, it has been determined through observation that swamp forest is being converted to marsh on nearby properties but it is not clear whether this is occurring on site and whether this conversion has a beneficial or negative impact.

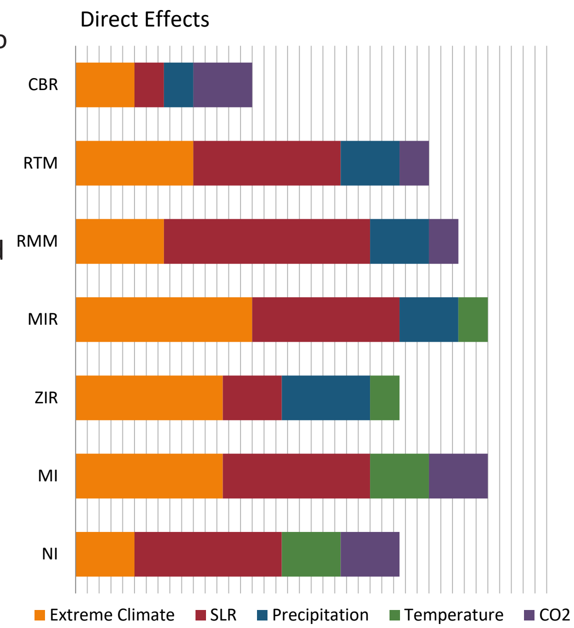

Figure 7. The contribution to total vulnerability of the direct effects of each climate change stressor at each site.

An increase in the severity of extreme weather events, primarily tropical storms, also contributed to the vulnerability scores across sites. Marsh habitats are highly dynamic and the study sites have in general responded well to major storms in the recent decades. For example, pre-and post-Hurricane Hugo (a category 4 storm) aerial photographs of North Inlet showed no change in the saltmarsh creek network or in the size or shape of sand bars within the creeks (Gardner et al, 1992). However, increased intensity of storms could result in loss of large areas of marsh at a site if there is significant erosion or smothering of marsh. Storms can also influence both surface and subsurface soil processes with the net outcome on soil elevation not always predictable solely from the observed effects of sediment deposition and erosion (Cahoon 2006). It was observed at RMM and RTM that although these marshes are generally resilient, several successive storms may be problematic for marsh recovery. During the NI and MI assessment, it was noted that there is the potential that marine debris may have a more adverse impact in MI due to the presence of dock and structures on the marsh edge, but there is no direct evidence that this would be the case. At CBR, it was noted that since 2011, heavy rain events such as Sandy, Irene and Matthew seem to have permanently changed water levels and marsh extent in some areas.

The direct effects of an increase in atmospheric CO_2 received scores ranging from 0 to 2, with a low certainty level of 1 across all sites. The primary direct effect of an increase in atmospheric CO_2 was considered to be its effects on C3 vs C4 competition in plants. While increased CO_2 would not adversely affect the dominant plant *Spartina alterniflora*, it might make other plants more competitive but not likely enough to overcome *Spartina*'s salinity tolerance advantage.

The direct effects of temperature received scores of 0 to 2 across sites, and precipitation received scores of 0 to 3. Shifts in species ranges due to changes in seasonal temperature and precipitation were of potential concern. At CBR, some indications point to a shift in native species ranges, which may occur with changes in temperature. For example, White ibis is now common year-round and Northern leopard frogs have been documented in the area where previously only Southern leopard frogs were found, however no overall species composition change is evident at CBR. Changing precipitation patterns and increased flashiness of rainfall may have adverse impacts on the saltmarsh if periods of lower salinity water occur frequently or are longer in duration. This has a higher potential to affect sites with higher volumes of stormwater input such as MI and ZIR.

Invasive Species

Invasive species considered were animals or plants whose introduction or spread would cause environmental, ecological, or economic damage. Both native species and exotic species not indigenous to the area can be considered invasive or nuisance species if they threaten local biodiversity. Nuisance species may also be species that cause periodic disruptions to the habitat if those disruptions are greater than the normal range of conditions. Pest species, such as plant parasites, were also considered within this stressor category.

Invasive species interactions with climate exposure contributed to the vulnerability scores at all sites (Figure 8). At NI and MI, the effects of increases in average air and water temperature were predicted to impact the habitats by increasing the range of species that may become invasive in these habitats. The number/duration of frosts or near freezing temperatures controls the northern distribution of most invasive species that may be an issue to this area, and the loss of cold water temperatures may result in more marine invasive species becoming established. Asian tiger shrimp *Penaeus monodon* and the Titan acorn barnacle *Megabalanus coccopoma* have been collected in NI and green porcelain crab *Petrolisthes armatus* has been found as far north as MI, but these species are not know to be established. The invasive red algae *Gracillaria vermiculophylla* is currently found in NI, but the amount of *Gracillaria* needs to be better assessed because it can transform the habitat by affecting infauna and biogeochemistry. Erosion at ZIR is primarily associated with scouring of marsh edges in select areas where mats of invasive *Gracilaria* build up. At MIR and ZIR, no species are currently recognized as being likely invaders with the temperature increase expected during the assessment time frame. Mangrove migration has been a concern in areas further south, but may be more restricted from this area by dispersal likelihood rather than temperature. It is possible that some invasive plants may be adversely affected by increased temperatures.

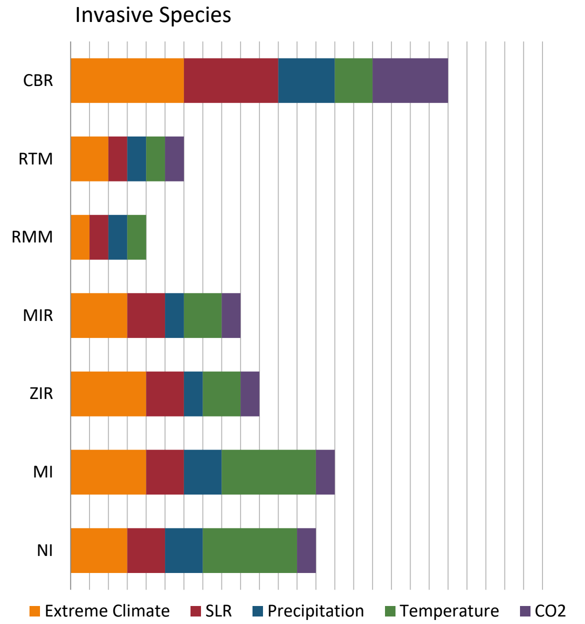

Figure 8. The contribution to total vulnerability of effects of each climate change stressor on invasive species at each site.

Precipitation may impact the ability of invasive species to colonize though spreading of propagule or seed during flood events, or through periods of drought causing stress and lowering the competitive ability of native species. At CBR, an increase in flooding may benefit the marsh by keeping horses out of some areas, reducing trampling and grazing impacts. Changes in precipitation patterns and a minor overall increase in the total annual precipitation amount or short duration fluctuations of salinity and water levels were not considered likely to benefit invading species or provide a competitive edge for invasive plants given the disturbance and salinity variations the dominant species *Spartina alterniflora* is adapted to thrive in at all of the sites.

An increase in the size or frequency of tropical storms (extreme events) may increase the introduction of propagules or colonizing species. Damage to the marsh from storms may open it up to opportunistic species, such as *Phragmites australis* which occurs in areas surrounding NI and MI, as well as MIR and CBR. Sediment movement from dredge spoil areas into the edge of the high marsh during storm events could also foster the spread of *Phragmites* at RMM and RTM. The effects of extended periods of drought on invasive species are not well understood for any of the sites. Invasive species impacts are thought to be more likely to occur and be problematic at the ZIR site than the MIR due to the nearby international port and the more direct connection to the river.

Nutrients

In the saltmarsh systems assessed, nitrogen is typically the limiting nutrient. If nitrogen availability changes significantly, shifts in species composition may occur. In most cases, excess nutrients cause loss of habitat function, although for some habitats a lack of nutrient input could be an ecological stressor. Assessors considered that climate changes can impact habitats both through creating an excess of nutrients and also though changing conditions in a way that limits nutrient input or cycling.

There were no anticipated interactions between an increase in CO_2 and nutrients at any of the sites except CBR within the 30 year assessment time frame (Figure 9). Ocean acidification may affect food web dynamics, carbon and nutrient cycling in the water column (Fabry et al. 2008) but it is unclear how the functioning of the intertidal marsh would be affected. Interactions between SLR and nutrients were also assessed as no effect at all sites except for ZIR and CBR. Upstream agricultural nutrient sources may become more connected to the assessed areas with increasing water levels.

Assessment Results

The affects of changes in precipitation on nutrients varied across sites from a positive affect at NI and MI, to no affect at MIR and RMM to a high affect at CBR. Nutrient delivery will get flashier if precipitation is flashier and there will be greater variability in nutrient loading. Stormwater runoff rates in MI are greater and the impacts of nutrient delivery due to precipitation would likely be greater than in NI, although there is uncertainty about impacts to the habitat. Nutrient loading may actually be beneficial for the marsh if it stimulates plant growth to build marsh vertically with sea level rise. An increase in algal production would also occur with an increase in nutrients, but it is not known if this would have an adverse impact on the overall function of the marsh habitat. Precipitation patterns shifting to flashier rain events and greater volumes of stormwater resulting from increased storm intensity may also result in delivery of higher levels of nutrients to the marsh habitats at both ZIR and MIR sites. Nutrient loading is recognized as being more of an issue at ZIR due to its lagoon-like configuration and upstream agricultural nutrient sources, while MIR receives a greater amount of flushing due to its proximity to two ocean inlets. Therefore, predicted changes in precipitation and storm patterns is likely to have a somewhat more significant impact at the ZIR. At CBR, agricultural areas upstream have potential to deliver nutrients and increases in residential development nearby may result in increased nutrients from lawn fertilizer throughout the watershed.

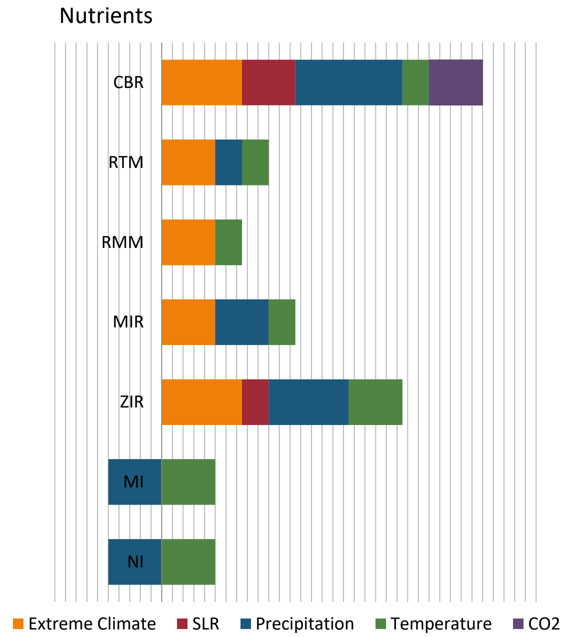

Figure 9. The contribution to total vulnerability of effects of each climate change stressor on nutrients at each site.

An increase in the frequency or intensity of tropical storms would possibly be an extreme version of precipitation loading impacts. This may be exacerbated in areas where there are major upstream nutrient sources (i.e. hog lagoons) that would breach and increase nutrients. For example, at CBR, compromised septic systems could result in a high probability of nutrients being introduced because of storms. While pulses of nutrients form storms could be greater than in normal runoff, nutrients may similarly be flushed out before they have in impact on the habitat function.

Erosion and Sedimentation

Erosion was defined as the wearing away of land due to processes such as wave action, tidal currents, and runoff. Sedimentation is the deposition of sediments which can be influenced by natural, climate, and human-induced changes to bathymetry; the timing and magnitude of river flows; inshore and offshore currents; and storm tracks, intensity, and duration. Sediment starvation was considered a separate process from erosion, for example were exceeding critical sea-level thresholds in sediment starved systems can lead to marsh drowning.

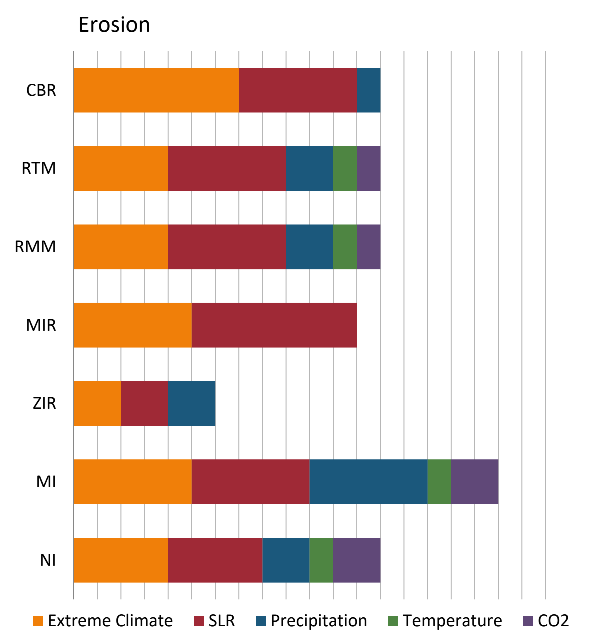

Figure 10. The contribution to total vulnerability of effects of each climate change stressor on erosion at each site.

Precipitation, sea level rise and an increase in intensity of tropical storms have the greatest potential to increase erosion at the sites assessed (Figure 10). At NI and MI, annual precipitation is already relatively high at 56 inches/yr, so an annual average increase may not affect erosion and sedimentation processes as much as an increase in the intensity of precipitation (flashiness) per event. Any effects of flashiness of precipitation would be greater in MI where the system has been impacted by changes to drainage in the watershed (i.e. storm water infrastructure). Higher water levels in the river as a result of flashier rainfall is likely to lead to increased erosion at ZIR, but could also result in more sediment being carried into the system though stormwater. It was consensus at CBR that changes in precipitation would not significantly impact erosion rates during the 30-year time.

SLR will increase wave action on the marsh platform and a larger tidal prism will increase erosion in NI and MI. SLR will result in increased erosion at MIR and ZIR, but has the potential to cause fairly extreme changes at MIR due to marsh die off from increased inundation times, from higher water levels causing more scouring of marsh edges as flow rates increase in tidal creeks, and from potential breeching of the barrier beach opening new channels and destroying large areas of current marsh. SLR could increase hydroperiod and wave impacts which would exacerbate erosion and more slumping would occur at CBR. The rate of SLR at RTM and RMM is thought to be higher than current sediment sources will keep up with.

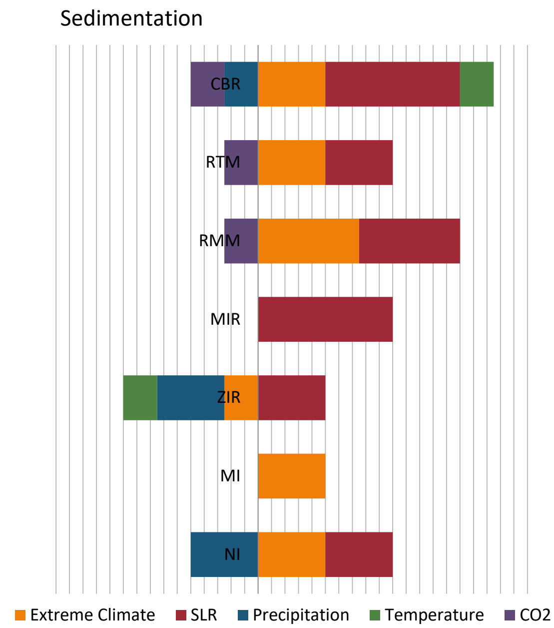

Figure 11. The contribution to total vulnerability of effects of each climate change stressor on sedimentation at each site.

Storms have the potential to cause many of the same impacts as SLR in a shortened temporal scale, particularly at MIR, due to its direct ocean exposure and the sediment deficit on the ocean beach resulting from the jetty at the northern end of the island. An increase in the strength or size of storms would create more erosion in NI, MI and CBR over the short term. For example at CBR it is known that 24 inches of rain in two days causes major erosion, after which the function of the marsh is not necessarily totally lost but select areas are lost to open water. On the other hand, extreme climate events may result in significant movement of sediments, including the potential for inlets to be opened in the barrier beaches and large pulses of sediments to be delivered to marshes. Recovery from these events would likely be rapid and may result in benefit to the marsh in terms of total area or function. It was noted at CBR that long-period southeasters deliver most sediments to the marsh. Not enough was known about sediment and storm dynamics at RTM to know if storm events were likely to benefit or adversely impact the functioning of the site.

Temperature may indirectly impact erosion if there is a reduced growth of plants that hold sediment, but plant growth may increase or other plants may replace existing canopy and preform the same stabilization function and increased decomposition could contribute to the organic matter available for marsh accretion. An increase in temperature could increase below ground decomposition and edge erosion, but this is not likely over 30-year time-frame. The loss of oyster reefs from acidification would lead to erosion of channel banks, but over the time span being considered it is not likely that conditions will get acidic enough to create this effect.

Contaminants

A contaminant was defined as any element or natural substance (e.g., metal or organic compound) whose concentration locally exceeds the background concentration, or any substance that does not naturally occur within the environment (e.g., synthetic chemicals such as DDT). Human sources of contaminants generally associated with industry, transportation, aquaculture, or agriculture were considered and include metals, petroleum hydrocarbons and pesticides. Toxins from harmful algal blooms (HABs) and fecal coliform (FCB) were also considered in this category, although their effects on the overall function of the sites was difficult to assess. Climate change may interact with contaminants by affecting the transport of as well as the reactivity of contaminants.

Contaminants in the watershed are less well studied than most other stressors. There is a lack of data on contaminants in the water column and in the sediments at all sites, as well as a lack of research on the effects of contaminants on local ecological systems, including saltmarshes. Many potential contaminants are not regularly monitored, but may be present, particularly at ZIR given the upstream development, industry, and agriculture. Contaminants were not considered to be present in large enough concentrations to become a problem at CB in the 30 year assessment time frame, unless a catastrophic event introduced contamination. Similarly at RMM and RTM, contaminants could be delivered from dredge spoil or though inundation of superfund sites, but these inputs were not predicted to be highly likely to occur (Figure 12).

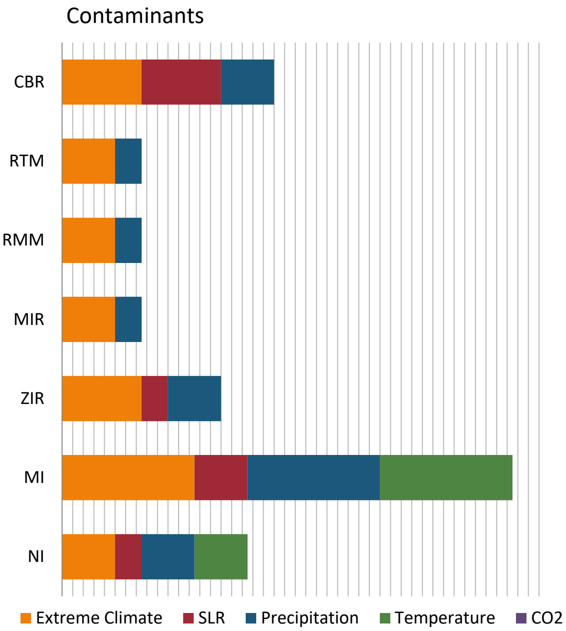

Figure 12. The contribution to total vulnerability of effects of each climate change stressor on contaminants at each site.

Division of Marine Fisheries fecal coliform (FCB) monitoring has limited shellfish harvesting in a small area of the southern back bay at MIR. FCB is currently a problem in MI, and two areas of NI where there are oyster harvesting restrictions. Harmful algal blooms (HABS) do not occur regularly at MIR or ZIR. Interestingly, it is known that there is greater toxicity of harmful algae in NI, but there have been more fish kills in MI. However it is not known how this may impact the function of the habitat over time. Increases in temperature in general increase the amount of bacterial contaminants such as vibrio, HABS, and other bacterial pathogens, but their effects on the habitat are less clear. Most of the work in this area has been on human health, but if one of the functions of habitat is considered to be providing food for humans, then it could be said that function will be affected. Increased temperature in the winter may increase negative impacts, but higher summer temperatures may decrease impacts, although no seasonality has been shown for example for *E.coli*. It is not known if there is a survival correlation with temperature.

An increase in the flashiness and intensity of precipitation events may cause a 'first flush effect' if long dry periods in between storm events cause an increase in contaminant loading. The data currently show that MI has a larger FCB problem than NI (in terms of areas closed to shellfish harvesting), possible due to wildlife and pets in the watershed, so the impact may be greater in MI. Also, greater sedimentation and erosion rates in MI may mobilize contaminants from the watershed. There is slightly more certainty about the negative effects of contaminants in MI based on evidence from fish kills.

Sea level rise and storm events may increase the redistribution of contaminants. Sanitary sewer overflows and flushing from developed uplands may increase the potential for contamination in MI during storm events. Increased tide height and storm surge may also mobilize headwater creeks for particle associated contaminants in areas that are not currently impacted by tidal flushing.

Sensitivity-Exposure Summary

Across all sites, erosion and the direct effects of climate change and invasive species were perceived as having the greatest potential to adversely impact these intertidal marsh areas. Nutrients and contamination received lower scores, but these were also areas of high uncertainty (see below). The assessment also indicated that the interaction of CO_2 and precipitation with sedimentation may actually benefit the study areas, mainly though increasing both the inorganic and organic sediment supplies to help marshes keep pace with rising sea levels.

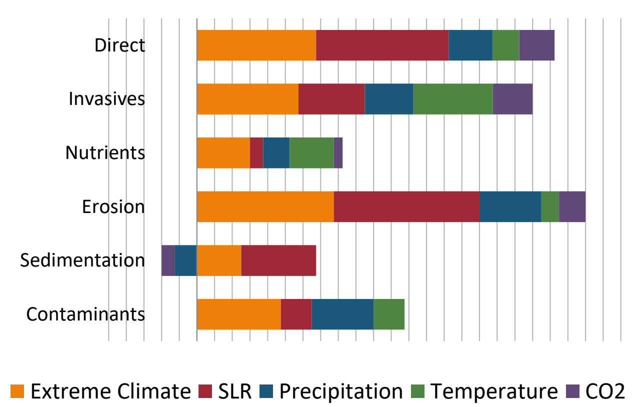

Figure 13. The contribution to total vulnerability of effects of each climate change stressor on contaminants at each site.

Assessment Results

Adaptive Capacity

Adaptive capacity is defined by the IPCC as, “the potential, capability, or ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (IPCC 2007). The elements of adaptive capacity that were assessed for each habitat were: degree of fragmentation, barriers to migration of habitat, potential for recovery following disturbance, the diversity of functional groups, potential management actions, and the anticipated institutional/ human response. For descriptions of these elements, please see the Guidance Document. Higher AC score indicate more potential for the element to provide adaptive capacity.

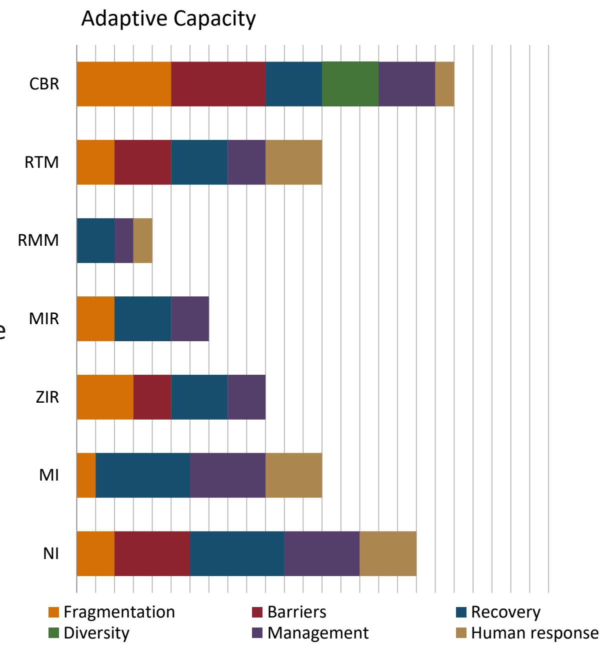

Figure 14. Adaptive capactity elements at each site.

Adaptive capacity (AC) scores ranged from ‘low’ to ‘high’ across sites. The sites with the highest AC scores were CBR and NI, and the RMM site scored the lowest (Figure 14). CBR was the only site that was perceived as having adaptive capacity potential for all six of the AC elements.

All sites except for RMM were considered to benefit from a relative lack of fragmentation. Fragmentation of intertidal marsh sites can include the presence of dredged channels as well as causeways that would impact water flow and increase edge effects. NI and MI are both relatively small in area and are not directly contiguous with other marsh areas along the coast, so may not have as great of a benefit in adaptive capacity from a lack of fragmentation, although NI is considered to be less fragmented than MI. MIR has somewhat less ability to adapt due to a greater degree of fragmentation, while the adaptive capacity of the marsh at the ZIR is somewhat higher due to less fragmentation. The degree of fragmentation at CBR is negligible due to the full cross section of barrier island protected and connections to other protected lands. The RMM was considered to be too highly fragmented to provide any adaptive capacity and was given a score of 0 for this element.

The marsh habitat of NI has the ability to migrate inland as it is bordered by protected land, while MI has little migration capacity because it is surrounded primarily by development. MIR is isolated from the mainland with stretches of the barrier island that are too narrow to provide for migration, and there is a greater slope in the area of the high marsh low marsh transition that may make migration of the low marsh impossible. Similar to NI, ZIR has some migration potential given its location adjacent to large tracts of protected lands. At CBR there is a high level of intactness and no man-made barriers to migration exist, so this site was given the highest AC score of 5 for this element.

The emergent marsh at all of these sites is dominated by *Spartina* species, which is adapted to an ongoing fluctuations in conditions, is successful in a wide variety of tidal and temperature regimes, and demonstrates a high degree of capacity to regenerate following disturbance. Therefore, regeneration capacity of these marsh habitats is considered to be high; however there is a lack of any species that could replace the function of *Spartina* in this habitat if for some reason there was a decline or loss of this plant. Less is known about the invertebrate and microbial communities’ roles and how diversity among these groups may support adaptive capacity in the face of climate change stressors. NI and MI were both given the highest AC score of 5 for recovery potential.

There are many theoretical management actions that could be taken in these marshes. Taking out barriers is tool that could be used in MI to allow marsh to migrate. There are no barriers that need to be removed in NI. Living shorelines and marsh restoration and creation are demonstrated management practices in this habitat type, although not specifically at the assessed sites. Sediment addition could be a possible management response to increasing sea level. Invasive species removal (primarily *Phagmites australis*) could also increase the adaptive capacity of the habitats.

Assessment Results

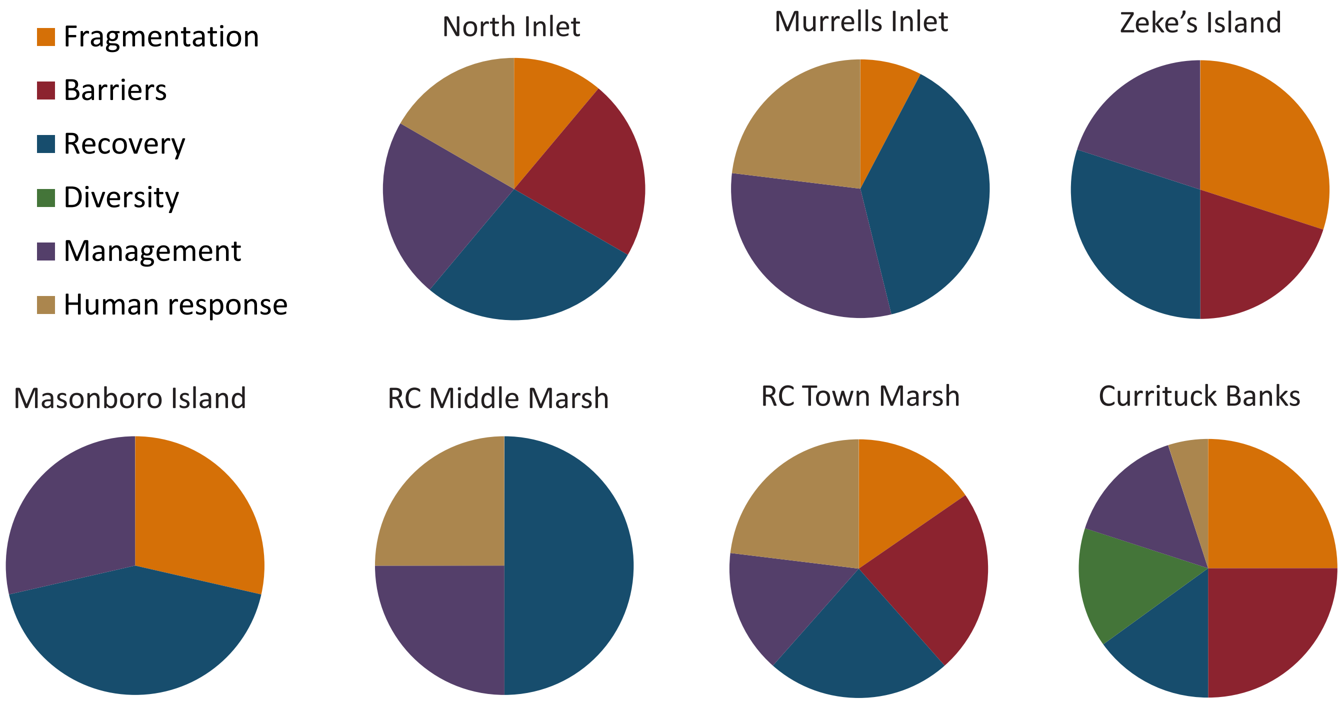

Figure 15. Proportion of total AC score contributed by each AC element.

MI and NI marshes received a similar score for the AC element of human response, but for different reasons. The community of Murrells Inlet has been engaged in the development of a watershed management plan, which may demonstrate a willingness to support management actions. The cultural and economic value of having shellfish beds open is a driver in this community. The removal of barriers such as causeways and limits on hardened structure may be more difficult to implement in this established community than other management actions such as overlay zones to reduce impervious surfaces. While MI has multiple stakeholder and jurisdictions that would need to work together to agree on management actions, NI has the adaptive advantage of being privately owned by a foundation. However, this means that there may be less resources available for management actions in NI. There is a greater potential for non-action management actions, such as allowing the marsh to migrate naturally, in NI. In both marsh habitats there is a noted university research presence, which may increase the effectiveness of management actions.

The institutional/human response to climate change stressors impacting the emergent marshes of the North Carolina sites is expected to be less than needed to significantly alter these impacts. Although the public that uses the sites regularly may have an interest in investing resources to address these impacts, it is anticipated that funds and political support for costly management actions that could address water level rise and storm impacts are likely to remain focused on areas of the coast that will be more directly affected in terms of economic losses, including highly developed barrier islands and municipalities proximal to the coast. However, the status of the sites as nature preserves and research reserves may result in access to some funding and support. At ZIR and MIR, natural process such as overwash and migration will be allowed to occur since these processes will not interfere with other human activities or property.

Assessment Results

Areas of Uncertainty

The basis and level of agreement among participants on assessment teams for current condition, sensitivity-exposure and adaptive capacity scores is recorded in the certainty score. The researchers and managers who participated in the assessments worked in, were familiar with and had a very good understand of the basic ecosystem processes that affect the functioning of the sites. However, at all sites there was a degree of uncertainty due to missing information about the current conditions of the site and ecosystem processes. There was also uncertainty over other input and controlling factors that may be entirely unknown at this time. Overall, NI and MI sites had the highest certainty scores, while ZIR had the lowest (Figure 16).

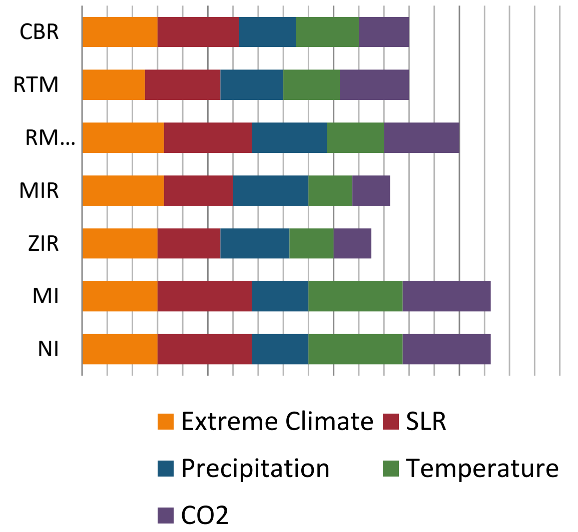

Figure 16. Total certainty scores for each site.

The highest amount of certainty (score=4) was given only to the direct effects of SLR at NI and MI. Overall, the effects of SLR on stressors received the highest certainty scores, while scores for the climate effects of temperature and CO_2 on stressors were the lowest. Interactions that received an average score of one across sites were the direct effects of CO_2, the interaction of CO_2 and nutrients, and the interactions of temperature and contaminants.

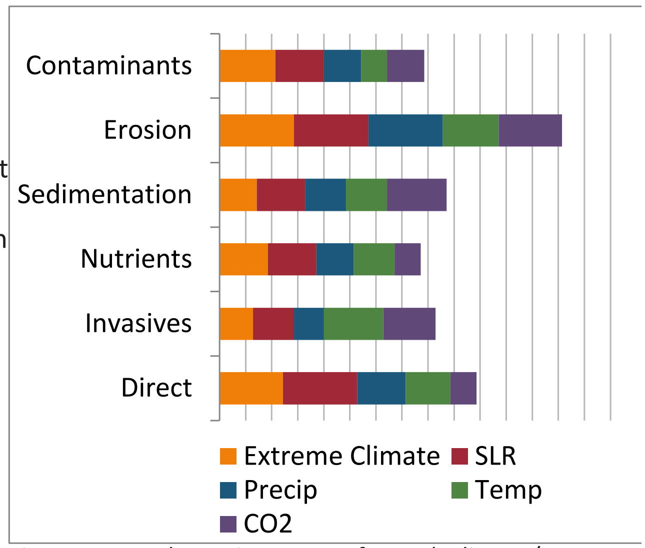

Figure 17. Total certainty scores for each climate/ SE interaction (higher bar indicates more certainty).

Contaminants were considered to be the least understood and studied stressor at the North Carolina sites. How contaminants, including combinations of contaminants, pulses of contaminants, and emerging contaminants, affect estuarine systems and emergent marshes in NC was acknowledged to be an important area of study, particularly for the Zeke's Island site given its direct connection with a major watershed with many upstream industrial and agricultural inputs.

The movement of sediments and associated impacts on marsh function was acknowledged as an ongoing monitoring need at NI, MI, ZIR and MIR. Sources of sediment and the contribution of upland erosion in both NI and MI systems are not well known.

The potential effects of a predicted increase in the intensity of precipitation events, or 'flashiness', on nutrient delivery and the resulting impacts to the marsh habitat are not well understood. While there is some certainty that there would be overall increased nutrients, there is uncertainty about impacts to the habitat. More nutrient loading may actually be beneficial for the marsh if it stimulates plant growth to build marsh vertically with sea level rise.

More information is needed in general on the effects of changes to precipitation patterns, storm intensity and sea level on invasive species. Monitoring for invasive species was also discussed as a need that would allow for implementation of rapid responses to new or expanding invasions facilitated by climate change stressors.

Assessment Results

Research Needs

The following topics either received low certainty scores during the CCVATCH assessment process or were generally discussed among project participants as being areas where further research was needed.

There is a lack of data on contaminants in the water column and sediments of the study areas, as well as a general lack of research on the effects of contaminants on local ecological systems, including saltmarshes.

Increased temperatures may increase the solubility of some contaminants or affect the biological cycling of sediment nutrients, which could result in the mobilization of contaminants such as metals. Increases in precipitation or in heavy precipitation events may also increase input and mobilization of contaminants from the watershed. Contaminants such as metals and plastics are not regularly monitored at any of the study sites, and the potential effects of specific contaminants on the function of the marsh in general are not known. An assessment of sediment and water column contaminants within reserves sites would provide baseline information for vulnerability assessments. Research is needed on how changes in temperature and precipitation affect known contaminants in marsh environments.

Reserve specific needs

- The identification of potential contaminant sources in each watershed from upstream development, industry and agriculture.
- Baseline assessments of microplastics in water and sediment at North Inlet.
- Monitoring of metals, hydrocarbons, and agricultural contaminants at Zekes Island and Masonboro Island.

Movement of sediments and associated impacts on marsh function is an ongoing monitoring need.

The marshes assessed were not in general considered to be currently sediment limited, however the effects of changes in precipitation and intensity of storms on sediment supply and distribution is not known. Marsh habitats that are meeting the projected rate of SLR at present may be impacted by changes in upland erosion from storm water runoff, tropical storms and surrounding land use changes. Landward migration of marshes may also affect sediment input from surrounding uplands. Detailed information on sediment sources was lacking for all of the marsh habitats assessed.

Reserve specific needs

- The quantification of the suspended sediment supply to Rachel Carson Middle Marsh.
- The quantification of sediment supply to North Inlet and sediment exchange with Winyah Bay.
- Assessment of the effects of stormwater infrastructure on sediment supply to Murrells Inlet.

Monitoring for invasive species would allow for implementation of rapid responses to invasions facilitated by climate change stressors.

Reserves have experienced and are vulnerable to invasions of both marine and terrestrial species. Invasive species population movement is being facilitated by shifts in climate, including increased winter temperatures (loss of freezing days) and changes to precipitation regimes. In addition, the likelyhood of a species being introduced to a new area through seeds, propagules, or movement of individuals through flooding or storms may be increased if the intensity or frequency of these events is increased by climate change. The surrounding distribution and movement of current known invasive species is not well known for many species that could become habitat stressors within the reserves. Increased mapping and monitoring of species both within and surrounding reserves would facilitate vulnerability assessments and adaptive management planning. Early detection of invasive species can also increase the effectiveness of species removal and restoration projects.

Reserve specific needs

- More study is needed on how invasives impact species diversity on site and how horse impacts will couple with plant changes at Currituck Banks and Rachel Carson Reserves.

- Marine invasive monitoring should be established at North Inlet.
- The distribution and habitat impacts of *Gracillaria* in North Inlet and Zekes Island.
- Monitoring and assessment of potential expansion of *Alternanthera philoxeroides* at Currituck Banks.
- The effects of upland colonization by *Phragmites australis* on the adjacent intertidal marshes of interest to all reserves.

The potential effects of a predicted increase in the intensity of precipitation events, or 'flashiness', on nutrient delivery and the resulting impacts to the marsh habitat are not well understood.

Nutrients are introduced to the intertidal marsh habitats through runoff from the surrounding uplands, especially through storm water runoff. An increase in the variability of precipitation may lead to a more pulsed input of nutrients to the marsh. While there is some certainty that there would be overall increased nutrients for the marshes assessed, there is uncertainty about impacts to the habitat. More nutrient loading may actually be beneficial for the marsh if it stimulates plant growth to build marsh vertically with sea level rise. The identification of upland sources of nutrients and research on specifically how nutrient pulses affect marsh habitat are needed.

Reserve specific needs

- Modeling of the effects of heavy precipitation and intermittent drought events on stormwater delivery of nutrients to the marsh in Murrells Inlet.

Management practices that would increase the adaptive capacity of intertidal marshes need to be identified, developed and tested.

Intertidal marshes have some intrinsic adaptive capacity to migrate horizontally and vertically with changes in sea level. However the increased rate of sea level rise coupled with non-climate stressors has likely reduced this capacity. The potential for increasing adaptive capacity of intertidal marshes through management practices such as thin layer deposition and facilitated migration has been proposed and assessed to a limited extent. Controlled experimental tests of marsh augmentation/restoration techniques would allow managers to better assess the likely success of employing these practices as an option to increase marsh resiliency.

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Sensitivity-Exposure Scores

	Site	Current	Cert.	CO2	Cert.	Temp.	Cert.	Precip.	Cert.	SLR	Cert.	Storms	Cert.
Direct Climate Effects	CBR	1.0	1.0	2.0	1.0	0.0	4.0	1.0	3.0	1.0	2.0	2.0	2.0
	RTM	0.0	1.0	1.0	1.0	0.0	2.0	2.0	2.0	5.0	2.0	4.0	2.0
	RMM	0.0	1.0	1.0	1.0	0.0	2.0	2.0	2.0	7.0	3.0	3.0	2.0
	MIR	1.0	2.0	0.0	1.0	1.0	1.0	2.0	2.0	5.0	3.0	6.0	3.0
	ZIR	0.0	2.0	0.0	1.0	1.0	1.0	3.0	2.0	2.0	2.0	5.0	3.0
	MI	2.0	2.0	2.0	1.0	2.0	1.0	0.0	1.0	5.0	4.0	5.0	2.0
	NI	2.0	2.0	2.0	1.0	2.0	1.0	0.0	1.0	5.0	4.0	2.0	2.0
Invasive Species	CBR	6.0	3.0	4.0	2.0	2.0	2.0	3.0	1.0	5.0	3.0	6.0	2.0
	RTM	5.0	3.0	1.0	2.0	1.0	2.0	1.0	1.0	1.0	2.0	2.0	1.0
	RMM	1.0	3.0	0.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0	1.0	2.0
	MIR	2.0	3.0	1.0	1.0	2.0	2.0	1.0	1.0	2.0	1.0	3.0	1.0
	ZIR	3.0	2.0	1.0	1.0	2.0	2.0	1.0	1.0	2.0	1.0	4.0	1.0
	MI	2.0	3.0	1.0	3.0	5.0	3.0	2.0	1.0	2.0	1.0	4.0	1.0
	NI	2.0	3.0	1.0	3.0	5.0	3.0	2.0	1.0	2.0	1.0	3.0	1.0
Nutrients	CBR	2.0	1.0	2.0	1.0	1.0	1.0	4.0	3.0	2.0	2.0	3.0	3.0
	RTM	1.0	1.0	0.0	2.0	1.0	2.0	1.0	1.0	0.0	2.0	2.0	2.0
	RMM	0.0	2.0	0.0	2.0	1.0	2.0	0.0	2.0	0.0	2.0	2.0	2.0
	MIR	2.0	3.0	0.0	0.0	1.0	1.0	2.0	2.0	0.0	0.0	2.0	2.0
	ZIR	3.0	3.0	0.0	0.0	2.0	1.0	3.0	2.0	1.0	1.0	3.0	2.0
	MI	5.0	1.0	0.0	1.0	2.0	2.0	-2.0	0.0	0.0	3.0	0.0	1.0
	NI	2.0	4.0	0.0	1.0	2.0	2.0	-2.0	0.0	0.0	3.0	0.0	1.0
Sedimentation	CBR	1.0	1.0	-1.0	2.0	1.0	1.0	-1.0	1.0	4.0	2.0	2.0	1.0
	RTM	3.0	2.0	-1.0	2.0	0.0	1.0	0.0	2.0	2.0	2.0	2.0	1.0
	RMM	2.0	2.0	-1.0	2.0	0.0	1.0	0.0	2.0	3.0	3.0	3.0	2.0
	MIR	3.0	2.0	0.0	2.0	0.0	1.0	0.0	2.0	4.0	2.0	0.0	1.0
	ZIR	0.0	2.0	0.0	2.0	-1.0	1.0	-2.0	2.0	2.0	2.0	-1.0	1.0
	MI	5.0	1.0	0.0	3.0	0.0	3.0	0.0	1.0	0.0	1.0	2.0	2.0
	NI	2.0	3.0	0.0	3.0	0.0	3.0	-2.0	1.0	2.0	1.0	2.0	2.0
Erosion	CBR	3.0	2.0	0.0	1.0	0.0	1.0	1.0	1.0	5.0	3.0	7.0	3.0
	RTM	4.0	3.0	1.0	3.0	1.0	2.0	2.0	3.0	5.0	3.0	4.0	3.0
	RMM	3.0	3.0	1.0	3.0	1.0	2.0	2.0	3.0	5.0	3.0	4.0	3.0
	MIR	5.0	3.0	0.0	2.0	0.0	2.0	0.0	4.0	7.0	3.0	5.0	3.0
	ZIR	2.0	2.0	0.0	2.0	0.0	2.0	2.0	3.0	2.0	2.0	2.0	2.0
	MI	4.0	3.0	2.0	3.0	1.0	3.0	5.0	3.0	5.0	3.0	5.0	3.0
	NI	2.0	3.0	2.0	3.0	1.0	3.0	2.0	3.0	4.0	3.0	4.0	3.0
Contamination	CBR	1.0	0.0	0.0	1.0	0.0	1.0	2.0	0.0	3.0	1.0	3.0	1.0
	RTM	1.0	2.0	0.0	1.0	0.0	0.0	1.0	1.0	0.0	1.0	2.0	1.0
	RMM	0.0	2.0	0.0	2.0	0.0	0.0	1.0	1.0	0.0	1.0	2.0	1.0
	MIR	0.0	1.0	0.0	0.0	0.0	0.0	1.0	1.0	0.0	2.0	2.0	3.0
	ZIR	1.0	1.0	0.0	0.0	0.0	0.0	2.0	1.0	1.0	2.0	3.0	3.0
	MI	5.0	3.0	0.0	3.0	5.0	3.0	5.0	3.0	2.0	3.0	5.0	3.0
	NI	2.0	2.0	0.0	3.0	2.0	3.0	2.0	3.0	1.0	3.0	2.0	3.0

Adaptive Capacity Scores

Site	Degree of frag.	Cert.	Barriers to migration	Cert.	Recovery after disturb.	Cert.	Diversity functional groups	Cert.	Mgmt options	Cert.	Human response	Cert.
CBR	5.0	4.0	5.0	4.0	3.0	3.0	3.0	1.0	3.0	3.0	1.0	3.0
RTM	2.0	3.0	3.0	2.0	3.0	3.0	0.0	4.0	2.0	3.0	3.0	2.0
RMM	0.0	3.0	0.0	3.0	2.0	3.0	0.0	4.0	1.0	3.0	1.0	2.0
MIR	2.0	3.0	0.0	3.0	3.0	3.0	0.0	4.0	2.0	2.0	0.0	3.0
ZIR	3.0	3.0	2.0	2.0	3.0	3.0	0.0	4.0	2.0	2.0	0.0	3.0
MI	1.0	1.0	0.0	3.0	5.0	3.0	0.0	3.0	4.0	3.0	3.0	2.0
NI	2.0	1.0	4.0	3.0	5.0	3.0	0.0	3.0	4.0	3.0	3.0	2.0

Overall Vulnerability Scores

Site	Sensitivity-Exposure			Adaptive Capacity			Overall Certainty	Overall Vulnerability Level
	Score	Adj. Score	Level	Score	Adj. Score	Level		
CBR	86.0	86.0	high	20.0	20.0	high	1.69	moderate vulnerability
RTM	61.5	61.5	high	13.0	13.0	moderate	1.69	high vulnerability
RMM	50.0	50.5	high	4.0	4.0	low	1.88	very high vulnerability
MIR	64.5	64.5	high	7.0	7.0	moderate	1.81	high vulnerability
ZIR	52.0	52.0	high	10.0	10.0	moderate	1.67	high vulnerability
MI	95.5	95.5	high	13.0	13.0	moderate	1.90	high vulnerability
NI	60.5	60.5	high	18.0	18.0	moderate	2.00	high vulnerability

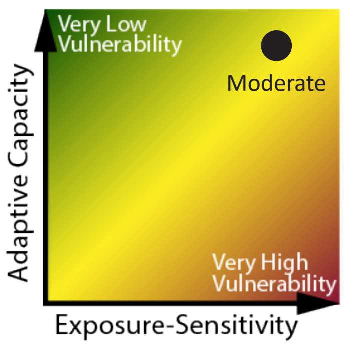
Currituck Banks Reserve, NC

Climate Chanage Vulnerability Assessment

Currituck Banks Reserve Brackish Marsh

The Currituck Banks Reserve spans from the oceanside beach to the brackish coastal marsh composed of giant cordgrass, black needlerush, and cattails. Invasive species such as feral hogs, the expansion of *Phragmites australis*, and the presence of free roaming horses affect the condition of the marsh. Erosion rates are variable throughout the marsh, but preliminary data indicates that a sediment from the sound is available and perhaps allowing the marsh to keep up with sea level rise.

Vulnerability to Climate Change



Vulnerability is a function of the sensitivity of a habitat to climate changes, its exposure to those changes, and its capacity to adapt to those changes. The Curritucks Bank Reserve brackish marsh scored HIGH in exposure-sensitivity and HIGH in adaptive capacity elements, for an overall vulnerability score of MODERATE.

Sources of Exposure-Sensitivity

- Increases in extreme climatic events delivering more precipitation may cause a loss of marsh area, however the ecosystem function of the remaining marsh will persist.
- Although there have been no significant changes in community composition, there are early signs of a shift in native species ranges. Seasonal species are now common year-round, and new species have been observed.
- Disturbance caused by increased inundation from sea level rise and extreme climate events could open previously intact areas to invasive species.
- The invasive marsh grass, *Phragmites*, is likely to have a competitive advantage over native marsh species and colonize susceptible open marsh areas more quickly.

Sources of Adaptive Capacity

- The degree of marsh fragmentation is negligible due to the full cross section of barrier island protected and connections to other protected lands.
- Marsh recovery due to extreme weather events is likely as the system is adapted to storms.
- The Reserve has protected the full barrier island profile from contiguous beach to sound, allowing the marsh to migrate landward with rising water levels.
- The marsh system is resilient to changes and fluctuations, but not necessarily able to out-compete invasive species due to low salinity.

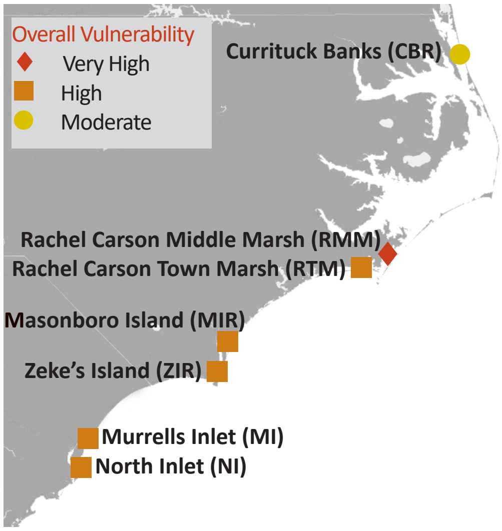
Recommendations

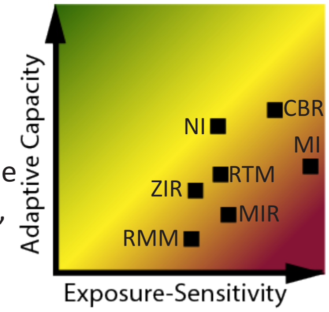
- Generally, not much information exists on how invasives impact species diversity on site and more study is needed on how horse impacts will couple with plant changes.
- Possible management actions include, prescribed fire, thin layer sedimentation, and replanting.

Currituck Banks Reserve

Climate Chanage Vulnerability Assessment

Regional Comparision





The results of this study demonstrate the balance between exposure sensitivity (ES) and adaptive capacity (AC). RMM was assessed as having the lowest ES of the sites, but also as having the lowest AC, which combined gave the site the highest vulnerability score. Conversely, the lowest scoring site for vulnerability was CBR, which was considered to have a high level of ES, but also the highest AC of the sites. The interaction of sea level rise and erosion contributed the most to vulnerability across sites. Invasive species were anticipated to impact habitats across all sites though interactions with all climate exposures. The potential effects of the interactions of contaminants with CO_2 and temperature had the highest uncertainty scores across sites.

	CO_2						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	no effect	no effect	low	low	low
Invasive	low *	low *	low	low	no effect	low	moderate
Nutrients	no effect	no effect	no effect ?	no effect ?	no effect	no effect	low
Sediment	no effect *	no effect *	no effect	no effect	positive effect	positive effect	positive effect
Erosion	low *	low *	no effect	no effect	low *	low *	no effect
Contam.	no effect *	no effect *	no effect ?	no effect ?	no effect	no effect	no effect

	Temperature						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	low	low	no effect	no effect	no effect *
Invasive	high *	high *	low	low	low	low	low
Nutrients	low	low	low	low	low	low	low
Sediment	no effect *	no effect *	positive effect	no effect	no effect	no effect	low
Erosion	low *	low *	no effect	no effect	low	low	no effect
Contam.	low *	high *	no effect ?	no effect ?	no effect ?	no effect ?	no effect

	Precipitation						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	no effect	no effect	moderate	low	low	low	low *
Invasive	low	low	low	low	low	low	moderate
Nutrients	positive effect ?	positive effect ?	moderate	low	no effect	low	moderate *
Sediment	positive effect	no effect	positive effect	no effect	no effect	no effect	positive effect
Erosion	low *	high *	low *	no effect *	low *	low *	low
Contam.	low *	high *	low	low	low	low	low ?

	Sea Level Rise						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	high *	high *	low	high *	high *	high	low
Invasive	low	low	low	low	low	low	high *
Nutrients	no effect *	no effect *	low	no effect ?	no effect	no effect	low
Sediment	low	no effect	low	moderate	moderate *	low	moderate
Erosion	moderate *	high *	low	high *	high *	high *	high *
Contam.	low *	low *	low	no effect	no effect	no effect	moderate

	Extreme Events						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	high	high *	high *	moderate *	moderate	low
Invasive	moderate	moderate	moderate	moderate	low	low	high
Nutrients	no effect	no effect	moderate	low	low	low	moderate *
Sediment	low	low	positive effect	no effect	moderate	low	low
Erosion	moderate *	high *	low	high *	moderate *	moderate *	high *
Contam.	low *	high *	moderate *	low *	low	low	moderate

Vulnerability Score: high moderate low no effect positive effect *Certainty: * high ? needs further investigation*

The **Climate Change Vulnerability Assessment Tool for Coastal Habitats** (CCVATCH) was created to help land managers develop conservation, management, and restoration strategies to proactively respond to the effects of climate change on protected lands. Through an expert elicitation process, the CCVATCH identifies sources of vulnerability, provides a greater understanding of the potential impacts of climate change alone and in relation to existing non-climate stressors, and identifies data gaps and research needs. Learn more at ccvatch.com.

Climate change impacts were evaluated for the year 2050 using the RCP 4.5 climate projection scenario (Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Air temperature and precipitation were calculated using the USGS National Climate Change Viewer and water level impacts were based on a sea level rise rate of 1 foot by 2050.

For More Information

Please contact Hope Sutton, Stewardship Coordinator, North Carolina Coastal Reserve and National Estuarine Research Reserve, suttonh@uncw.edu.

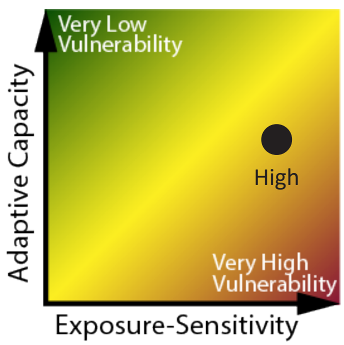
This work was sponsered by the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center (NAI4NOS4190145).

Masonboro Island Reserve, NC
Climate Change Vulnerability Assessment

Masonboro Island Reserve Saltmarsh

Masonboro Island is the largest undisturbed barrier island along the southern part of the North Carolina coast with extensive salt marshes comprised of *Spartina alterniflora*. Residential development in surrounding areas causes occasional high nutrient events from runoff and wastewater pipe failures. Invasive species are present, but have not caused the loss of marsh function and the salinity level should prevent major marsh loss from the invasive marsh grass *Phragmites*. Erosion is occurring along marsh edges and the marsh platform elevation is not keeping up with the rates of sea level rise, however mechanisms causing the loss along the marsh edge and surface are not fully understood.

Vulnerability to Climate Change



Vulnerability is a function of the sensitivity of a habitat to climate changes, its exposure to those changes, and its capacity to adapt to those changes. The Masonboro Island Reserve saltmarsh scored HIGH in exposure-sensitivity and MODERATE in adaptive capacity elements, for an overall vulnerability score of HIGH.

Sources of Exposure-Sensitivity

- Sea level rise may cause extreme loss of the marsh area due to longer inundation times, scouring of marsh edges due to higher flow and water levels, and new channels forming after future barrier island breaches and overwash.
- Storms have the potential to cause many of the same impacts as sea level rise, but over a shorter time due to the direct ocean exposure and sediment deficit caused by the jetty on the north end of the ocean beach.
- Increased storm intensity may cause a loss of large areas of marsh by increasing erosion or smothering of marsh with sediment.
- Changing precipitation patterns and increased flashiness of rainfall may lead to some weakening of the saltmarsh if periods of lower salinity water occur frequently or are longer in duration.

Sources of Adaptive Capacity

- The Masonboro site has somewhat less ability to adapt due to fragmentation, isolation from the mainland that prohibits habitat migration coupled with stretches of the barrier island that are too narrow to provide for migration, and steep slope between the high and low marsh that may make migration of the low marsh upslope impossible.
- Natural process such as overwash and barrier island migration will be allowed to occur since these processes will not interfere with other human activities or property.

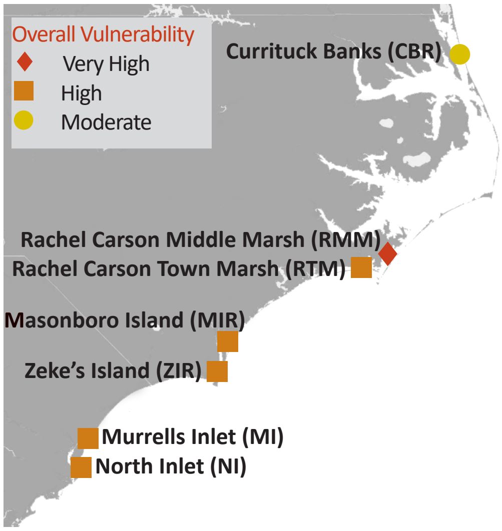
Recommendations

- Movement of sediments and associated impacts on marsh function is an ongoing monitoring need, particularly given the documented differences in the sediment supply between Masonboro Island and Zeke's Island.
- Research on how contaminants affect estuarine systems and emergent marshes in NC is needed.
- Monitoring for invasive species will allow for implementation of rapid responses to invasions facilitated by climate change stressors.

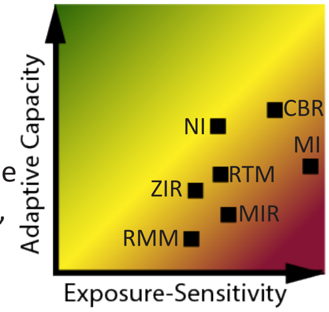
Masonboro Island Reserve is part of the North Carolina Coastal Reserve & National Estuarine Research Reserve

Masonboro Island Reserve
Climate Chanage Vulnerability Assessment

Regional Comparision



The results of this study demonstrate the balance between exposure sensitivity (ES) and adaptive capacity (AC). RMM was assessed as having the lowest ES of the sites, but also as having the lowest AC, which combined gave the site the highest vulnerability score. Conversely, the lowest scoring site for vulnerability was CBR, which was considered to have a high level of ES, but also the highest AC of the sites.



The interaction of sea level rise and erosion contributed the most to vulnerability across sites. Invasive species were anticipated to impact habitats across all sites though interactions with all climate exposures. The potential effects of the interactions of contaminants with CO_2 and temperature had the highest uncertainty scores across sites.

CO_2	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct							
Invasive	*	*					
Nutrients			?	?			
Sediment	*	*					
Erosion	*	*			*	*	
Contam.	*	*	?	?			

Temperature	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct							*
Invasive	*	*					
Nutrients							
Sediment	*	*					
Erosion	*	*					
Contam.	*	*	?	?	?	?	

Precipitation	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct							*
Invasive							
Nutrients	?	?					*
Sediment							
Erosion	*	*	*	*	*	*	
Contam.	*	*					?

Sea Level Rise	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	*	*		*	*		
Invasive							*
Nutrients	*	*		?			
Sediment					*		
Erosion	*	*		*	*	*	*
Contam.	*	*					

Extreme Events	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct			*	*	*		
Invasive							
Nutrients							*
Sediment							
Erosion	*	*		*	*	*	*
Contam.	*	*	*	*			

Vulnerability Score: high moderate low no effect positive effect *Certainty: * high ? needs further investigation*

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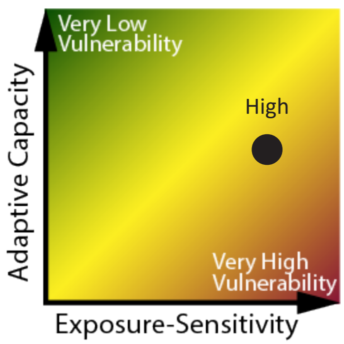
Murrells Inlet, SC

Climate Change Vulnerability Assessment

Murrells Inlet Saltmarsh

Murrells Inlet is an ocean dominated estuary located in northeastern Georgetown County. Extensive development surrounds the Murrells Inlet saltmarsh, and the waterways have been impacted by dredging, filling and the construction of quarystone jetties at the mouth of the inlet. The presence of channels and storm water ponds and the removal of marsh edge buffer vegetation in some areas of the Murrells Inlet watershed may affect sediment delivery. Erosion has been observed in the tidal channels, which may be possibly attributed to boat wake. Fecal coliform is currently a problem in Murrells Inlet where oyster beds are closed and fish kills have also occurred in the Murrells Inlet marsh.

Vulnerability to Climate Change



Vulnerability is a function of the sensitivity of a habitat to climate changes, its exposure to those changes, and its capacity to adapt to those changes. The Murrells Inlet saltmarsh scored HIGH in exposure-sensitivity and MODERATE in adaptive capacity elements, for an overall vulnerability score of HIGH.

Sources of Exposure-Sensitivity

- The marsh and oyster reefs may not be able to adjust vertically to the predicted accelerated rate in sea level rise.
- The surrounding development limits the potential for inland migration of marsh habitat.
- Marine invasive species may become established with increases in water temperature.
- The system has been impacted by changes to drainage in the watershed (i.e. storm water infrastructure), potentially making the marsh more vulnerable to the effects of increases in the intensity of precipitation such as increased erosion and nutrient delivery.

Sources of Adaptive Capacity

- The community of Murrells Inlet has demonstrated a willingness to take action to protect the inlet, for example by the development of a watershed management plan.
- Living shorelines and marsh restoration and creation are demonstrated management practices that could be implemented to increase resiliency.
- Salt marshes in general have a high recovery rate following disturbance.

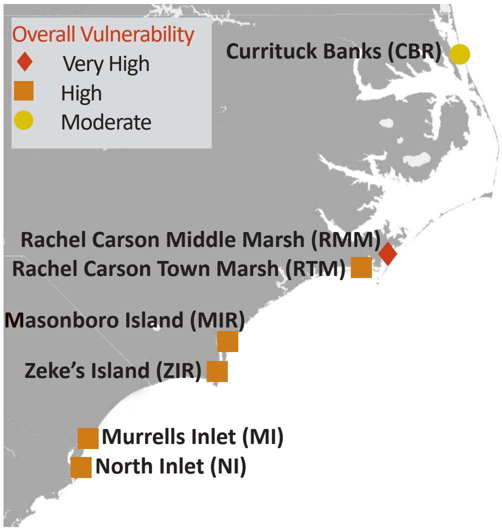
Recommendations

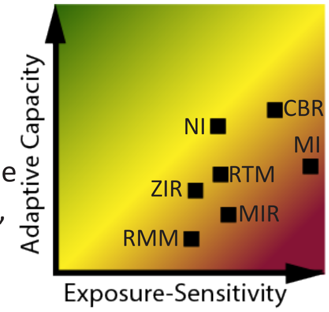
- The effects of a predicted increase in the intensity of precipitation events on storm water runoff rates, nutrient delivery and erosion and the resulting impacts to the marsh habitat are not well understood for this marsh.
- More information is needed in general on the effects of changes to precipitation patterns, storm intensity and sea level on invasive species. Early detection of marine invasive species would be facilitated through regular monitoring. Invasive species removal (primarily *Phagmites australis*) could also increase the adaptive capacity of the habitats.
- Limits on hardened structures at the marsh edge would allow for migration of marsh habitats

Murrells Inlet, SC

Climate Change Vulnerability Assessment

Regional Comparision





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CO_2	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	no effect	no effect	low	low	low
Invasive	low *	low *	low	low	no effect	low	moderate
Nutrients	no effect	no effect	no effect ?	no effect ?	no effect	no effect	low
Sediment	no effect *	no effect *	no effect	no effect	positive effect	positive effect	positive effect
Erosion	low *	low *	no effect	no effect	low *	low *	no effect
Contam.	no effect *	no effect *	no effect ?	no effect ?	no effect	no effect	no effect

Temperature	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	low	low	no effect	no effect	no effect *
Invasive	high *	high *	low	low	low	low	low
Nutrients	low	low	low	low	low	low	low
Sediment	no effect *	no effect *	positive effect	no effect	no effect	no effect	low
Erosion	low *	low *	no effect	no effect	low	low	no effect
Contam.	low *	high *	no effect ?	no effect ?	no effect ?	no effect ?	no effect

Precipitation	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	no effect	no effect	moderate	low	low	low	low *
Invasive	low	low	low	low	low	low	moderate
Nutrients	positive effect ?	positive effect ?	moderate	low	no effect	low	moderate *
Sediment	positive effect	no effect	positive effect	no effect	no effect	no effect	positive effect
Erosion	low *	high *	low *	no effect *	low *	low *	low
Contam.	low *	high *	low	low	low	low	low ?

Sea Level Rise	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	high *	high *	low	high *	high *	high	low
Invasive	low	low	low	low	low	low	high *
Nutrients	no effect *	no effect *	low	no effect ?	no effect	no effect	low
Sediment	low	no effect	low	moderate	moderate *	low	moderate
Erosion	moderate *	high *	low	high *	high *	high *	high *
Contam.	low *	low *	low	no effect	no effect	no effect	moderate

Extreme Events	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	high	high *	high *	moderate *	moderate	low
Invasive	moderate	moderate	moderate	moderate	low	low	high
Nutrients	no effect	no effect	moderate	low	low	low	moderate *
Sediment	low	low	positive effect	no effect	moderate	low	low
Erosion	moderate *	high *	low	high *	moderate *	moderate *	high *
Contam.	low *	high *	moderate *	low *	low	low	moderate

Vulnerability Score: high moderate low no effect positive effect *Certainty: * high ? needs further investigation*

The **Climate Change Vulnerability Assessment Tool for Coastal Habitats** (CCVATCH) was created to help land managers develop conservation, management, and restoration strategies to proactively respond to the effects of climate change on protected lands. Through an expert elicitation process, the CCVATCH identifies sources of vulnerability, provides a greater understanding of the potential impacts of climate change alone and in relation to existing non-climate stressors, and identifies data gaps and research needs. Learn more at ccvatch.com.

Climate change impacts were evaluated for the year 2050 using the RCP 4.5 climate projection scenario (Fifth Assessment Report of the Intergovernmental Panel on Climate Change). Air temperature and precipitation were calculated using the USGS National Climate Change Viewer and water level impacts were based on a sea level rise rate of 1 foot by 2050.

For More Information

Please contact Jennifer Plunket, Stewardship Coordinator, North Inlet-Winyah Bay National Estuarine Research Reserve, jen@belle.baruch.sc.edu

This work was sponsered by the National Estuarine Research Reserve System Science Collaborative, which supports collaborative research that addresses coastal management problems important to the reserves. The Science Collaborative is funded by the National Oceanic and Atmospheric Administration and managed by the University of Michigan Water Center (NAI4NOS4190145).

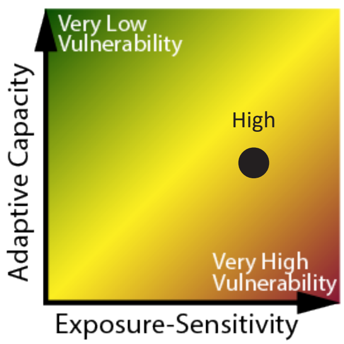
North Inlet, SC

Climate Change Vulnerability Assessment

North Inlet Saltmarsh

North Inlet is an ocean dominated estuary within the North Inlet-Winyah Bay National Estuarine Research Reserve, located in Georgetown, SC. The saltmarshes of North Inlet are surrounded by a small forested watershed that currently has little development. Water quality and habitat conditions are currently high. Erosion has been observed in the tidal channels and at the entrance to Winyah Bay. The invasive algae *Gracillaria vermiculophylla* has been observed, and marine invasives including *Penaesu monodon* have been collected within North Inlet.

Vulnerability to Climate Change



Vulnerability is a function of the sensitivity of a habitat to climate changes, its exposure to those changes, and its capacity to adapt to those changes. The North Inlet saltmarsh scored HIGH in exposure-sensitivity and MODERATE in adaptive capacity elements, for an overall vulnerability score of HIGH.

Sources of Exposure-Sensitivity

- The marsh may not be able to adjust vertically to an accelerated rate of sea level rise.
- Marine invasive species may become established with increases in water temperature.
- Sea level rise will increase wave action on the marsh platform and a larger tidal prism will increase erosion of the marsh.
- An increase in the intensity of tropical storms will increase shoreline erosion.

Sources of Adaptive Capacity

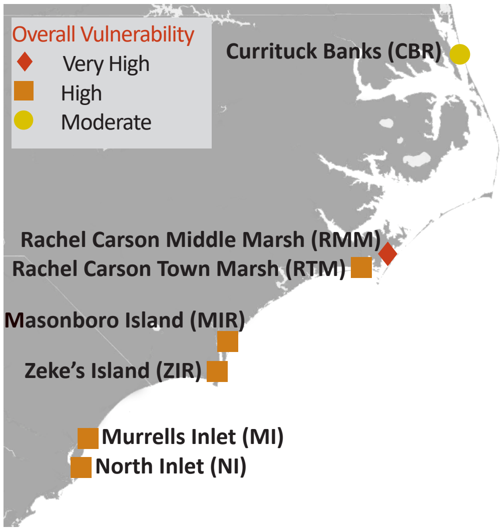
- Protected uplands surrounding the North Inlet marsh will allow for inland migration of the habitat.
- Salt marshes in general have a high recovery rate following disturbance.
- The high salinity of the system may inhibit establishment of invasives such as *Phragmites australis*
- The marsh habitat is un-fragmented by roads or ditching which can block species movement.
- There is a noted university research presence in North Inlet, which may increase the effectiveness of management actions.

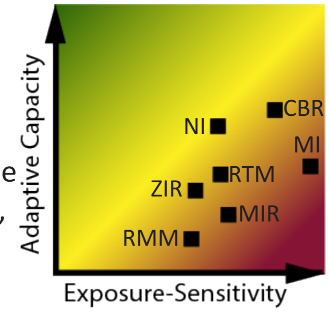
Recommendations

- The potential effects of a predicted increase in the intensity of precipitation events, or 'flasiness', on nutrient delivery and the resulting impacts to the marsh habitat are not well understood.
- More information is needed in general on the effects of changes to precipitation patterns, storm intensity and sea level on invasive species. Early detection of marine invasive species would be facilitated through regular monitoring. Invasive species removal (primarily *Phagmites australis*) could also increase the adaptive capacity of the habitats.
- Sediment addition could help to maintain marshes. Living shorelines may decrease erosion and nutrient input.

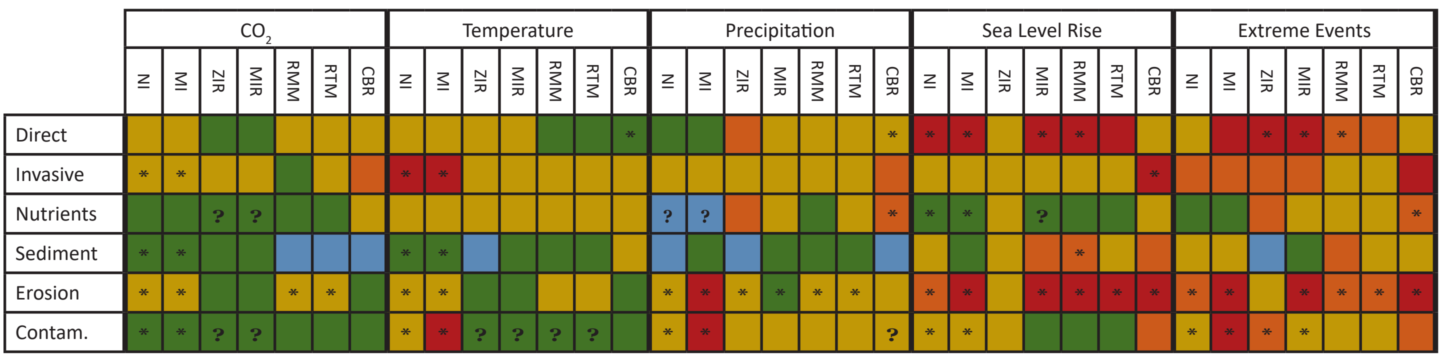
North Inlet, SC
Climate Chanage Vulnerability Assessment

Regional Comparision





The results of this study demonstrate the balance between exposure sensitivity (ES) and adaptive capacity (AC). RMM was assessed as having the lowest ES of the sites, but also as having the lowest AC, which combined gave the site the highest vulnerability score. Conversely, the lowest scoring site for vulnerability was CBR, which was considered to have a high level of ES, but also the highest AC of the sites. The interaction of sea level rise and erosion contributed the most to vulnerability across sites. Invasive species were anticipated to impact habitats across all sites though interactions with all climate exposures. The potential effects of the interactions of contaminants with CO_2 and temperature had the highest uncertainty scores across sites.



Vulnerability Score: high moderate low no effect positive effect *Certainty: * high ? needs further investigation*

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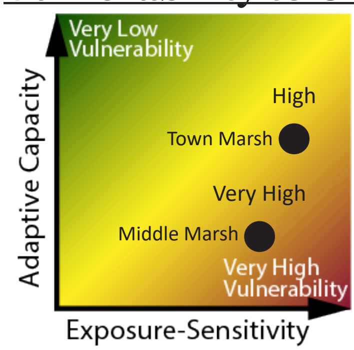
Rachel Carson Reserve, NC

Climate Change Vulnerability Assessment

Rachel Carson Reserve Saltmarsh

The main part of the Rachel Carson Reserve is a complex of the islands of Carrot Island, Town Marsh, Bird Shoal, and Horse Island, which have *Spartina alterniflora* saltmarsh with fringing oyster reefs located throughout. Middle Marsh is separated from the rest of the site by the North River Channel, and is a remote, highly fragmented marsh system that is a relic flood tide delta. The wild horse, a non-native species, has been documented to cause a disruption in marsh function at the main islands; however horses are not found at Middle Marsh.

Vulnerability to Climate Change



Vulnerability is a function of the sensitivity of a habitat to climate changes, its exposure to those changes, and its capacity to adapt to those changes. The Middle Marsh scored HIGH in exposure-sensitivity and LOW in adaptive capacity elements, for an overall vulnerability score of VERY HIGH. The Town Marsh complex scored HIGH in exposure-sensitivity and MODERATE in adaptive capacity elements, for an overall vulnerability score of HIGH.

Sources of Exposure-Sensitivity

- Marsh erosion is occurring, mostly along the perimeter of the main islands where there is exposure to boat, wind-driven, and inlet waves.
- It is unknown if marshes on the main islands will be able to keep up with sea level rise, but vertical migration may occur in areas that are fed by dredge spoil sediment.
- The lower marsh at Middle Marsh is not keeping up with sea level rise in some areas; the higher marsh is likely to have a better chance at keeping up with sea level rise.
- Changes in precipitation patterns and increased flashiness of rainfall are expected to result in wetter and drier periods which could affect soil salinity and overall marsh health. Droughts could cause an increase in marsh edge erosion.

Sources of Adaptive Capacity

- The main islands have a moderate ability to adapt to changing conditions given their location adjacent to dredge spoil cells, which helps to facilitate the transition of tidal flats to marsh.
- Middle Marsh marshes have less of an ability to adapt due to higher fragmentation and no opportunities for vertical migration.
- *Spartina alterniflora* is adapted to a wide variety of tidal and temperature regimes, and demonstrates a high degree of capacity to regenerate following disturbance.

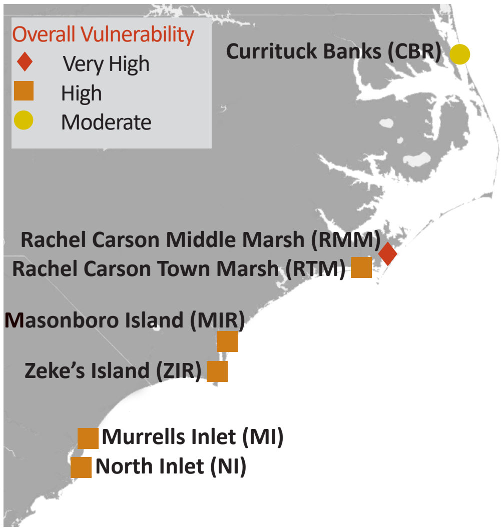
Recommendations

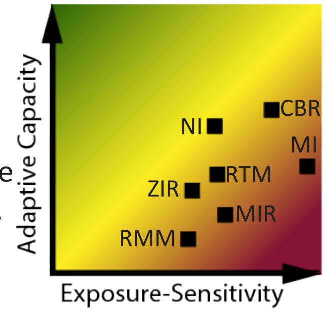
- Better understanding the interactions between various species (e.g. mussels, oysters, wild horses, etc.) and *Spartina* will help to more accurately assess adaptive capacity and vulnerability.
- Research is needed to quantify the suspended sediment supply to Middle Marsh.
- If proven effective, thin layer deposition might be a way to assist marshes in keeping up with rising water levels.
- Fringe oyster reef restoration to protect low marsh may be an effective management action in areas of lower wave energy.

Rachel Carson Reserve

Climate Chanage Vulnerability Assessment

Regional Comparision





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	CO_2						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	no effect	no effect	low	low	low
Invasive	low *	low *	low	low	no effect	low	moderate
Nutrients	no effect	no effect	no effect ?	no effect ?	no effect	no effect	low
Sediment	no effect *	no effect *	no effect	no effect	positive effect	positive effect	positive effect
Erosion	low *	low *	no effect	no effect	low *	low *	no effect
Contam.	no effect *	no effect *	no effect ?	no effect ?	no effect	no effect	no effect

	Temperature						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	low	low	no effect	no effect	no effect *
Invasive	high *	high *	low	low	low	low	low
Nutrients	low	low	low	low	low	low	low
Sediment	no effect *	no effect *	positive effect	no effect	no effect	no effect	low
Erosion	low *	low *	no effect	no effect	low	low	no effect
Contam.	low *	high *	no effect ?	no effect ?	no effect ?	no effect ?	no effect

	Precipitation						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	no effect	no effect	moderate	low	low	low	low *
Invasive	low	low	low	low	low	low	moderate
Nutrients	positive effect ?	positive effect ?	moderate	low	no effect	low	moderate *
Sediment	positive effect	no effect	positive effect	no effect	no effect	no effect	positive effect
Erosion	low *	high *	low *	no effect *	low *	low *	low
Contam.	low *	high *	low	low	low	low	low ?

	Sea Level Rise						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	high *	high *	low	high *	high *	high	low
Invasive	low	low	low	low	low	low	high *
Nutrients	no effect *	no effect *	low	no effect ?	no effect	no effect	low
Sediment	low	no effect	low	moderate	moderate *	low	moderate
Erosion	moderate *	high *	low	high *	high *	high *	high *
Contam.	low *	low *	low	no effect	no effect	no effect	moderate

	Extreme Events						
	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	high	high *	high *	moderate *	moderate	low
Invasive	moderate	moderate	moderate	moderate	low	low	high
Nutrients	no effect	no effect	moderate	low	low	low	moderate *
Sediment	low	low	positive effect	no effect	moderate	low	low
Erosion	moderate *	high *	low	high *	moderate *	moderate *	high *
Contam.	low *	high *	moderate *	low *	low	low	moderate

Vulnerability Score: high moderate low no effect positive effect *Certainty: * high ? needs further investigation*

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For More Information

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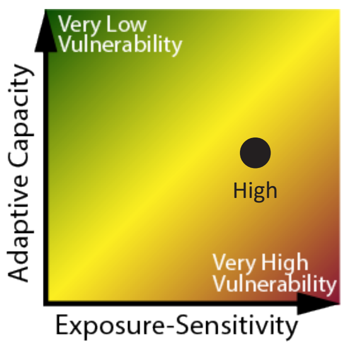
Zeke's Island Reserve, NC

Climate Change Vulnerability Assessment

Zeke's Island Reserve Saltmarsh

Zeke's Island Reserve is lagoon-like complex in the southern part of the North Carolina coast with fringing marshes and marsh islands comprised of *Spartina alterniflora*. Zeke's Island Reserve is located downstream of significant industrial development, in a watershed that includes a large number of animal agriculture sites and ~20% of the state's population. The invasive algal, *Graciliaria vermiculophylla*, creates large mats on mud flats that can be transported to the marsh, smothering marsh grass and eroding the marsh edge. The marsh platform appears to be accreting at rates exceeding expected sea level rise rates based on preliminary surface elevation table data.

Vulnerability to Climate Change



Vulnerability is a function of the sensitivity of a habitat to climate changes, its exposure to those changes, and its capacity to adapt to those changes. The Zeke's Island Reserve saltmarsh scored HIGH in exposure-sensitivity and MODERATE in adaptive capacity elements, for an overall vulnerability score of HIGH.

Sources of Exposure-Sensitivity

- Increased intensity of storms could result in loss of large areas of marsh, given the potential for significant movement of sediment that could lead to erosion or smothering of marsh.
- If high intensity storms occur and produce significant erosion or sediment changes, open areas could be rapidly colonized by non-native species introduced through stormwater or the international port because of the sites' direct connection with the river.

Sources of Adaptive Capacity

- Spartina alterniflora is adapted to a wide variety of tidal and temperature regimes, and demonstrates a high degree of capacity to regenerate following disturbance.
- The marsh at the Zeke's Island site is somewhat higher adaptive capacity due to less fragmentation and high migration potential given its location adjacent to large tracts of protected lands.
- Natural process such as overwash and migration will be allowed to occur since these processes will not interfere with other human activities or property.

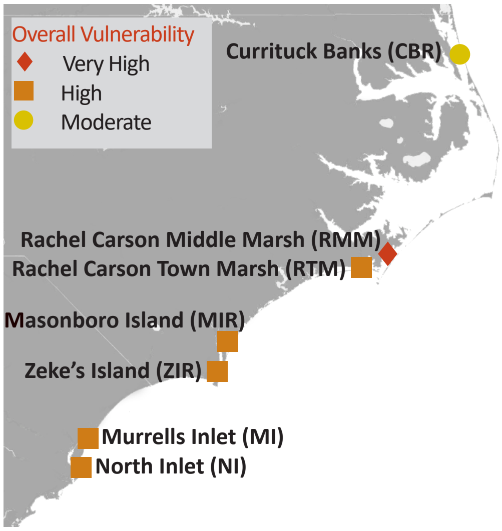
Recommendations

- Movement of sediments and associated impacts on marsh function is an ongoing monitoring need, particularly given the documented differences in the sediment supply between Masonboro Island and Zeke's Island.
- Research on how contaminants affect estuarine systems and emergent marshes in NC is needed given the direct connection of Zeke's Island with a major watershed with upstream industrial and agricultural inputs.
- Monitoring for invasive species will allow for implementation of rapid responses to invasions facilitated by climate change stressors.

Zeke's Island Reserve

Climate Chanage Vulnerability Assessment

Regional Comparision



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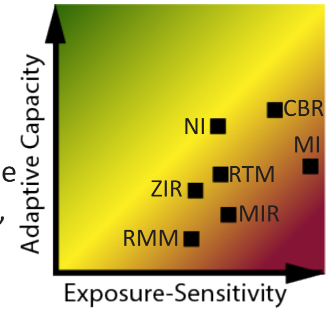

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CO_2	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	no effect	no effect	low	low	low
Invasive	low *	low *	low	low	no effect	low	moderate
Nutrients	no effect	no effect	no effect ?	no effect ?	no effect	no effect	low
Sediment	no effect *	no effect *	no effect	no effect	positive effect	positive effect	positive effect
Erosion	low *	low *	no effect	no effect	low *	low *	no effect
Contam.	no effect *	no effect *	no effect ?	no effect ?	no effect	no effect	no effect

Temperature	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	low	low	low	no effect	no effect	no effect *
Invasive	high *	high *	low	low	low	low	low
Nutrients	low	low	low	low	low	low	low
Sediment	no effect *	no effect *	positive effect	no effect	no effect	no effect	low
Erosion	low *	low *	no effect	no effect	low	low	no effect
Contam.	low *	high *	no effect ?	no effect ?	no effect ?	no effect ?	no effect

Precipitation	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	no effect	no effect	moderate	low	low	low	low *
Invasive	low	low	low	low	low	low	moderate
Nutrients	positive effect ?	positive effect ?	moderate	low	no effect	low	moderate *
Sediment	positive effect	no effect	positive effect	no effect	no effect	no effect	positive effect
Erosion	low *	high *	low *	no effect *	low *	low *	low
Contam.	low *	high *	low	low	low	low	low ?

Sea Level Rise	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	high *	high *	low	high *	high *	high	low
Invasive	low	low	low	low	low	low	high *
Nutrients	no effect *	no effect *	low	no effect ?	no effect	no effect	low
Sediment	low	no effect	low	moderate	moderate *	low	moderate
Erosion	moderate *	high *	low	high *	high *	high *	high *
Contam.	low *	low *	low	no effect	no effect	no effect	moderate

Extreme Events	NI	MI	ZIR	MIR	RMM	RTM	CBR
Direct	low	high	high *	high *	moderate *	moderate	low
Invasive	moderate	moderate	moderate	moderate	low	low	high
Nutrients	no effect	no effect	moderate	low	low	low	moderate *
Sediment	low	low	positive effect	no effect	moderate	low	low
Erosion	moderate *	high *	low	high *	moderate *	moderate *	high *
Contam.	low *	high *	moderate *	low *	low	low	moderate

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