NERRS Science Collaborative Project:
Assessing how climate change will affect coastal habitats in the Northeast
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RI CLIMATE CHANGE VULNERABILITY ASSESSMENT

SALT MARSH HABITAT

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EXECUTIVE SUMMARY

A climate change vulnerability assessment of Rhode Island's salt marshes was conducted to support future adaptation and restoration planning for this critical habitat. Individual coastal planners and land managers may have a limited understanding of how climate change is likely to impact coastal wetland habitats and yet these same individuals have a definite need for this body of knowledge to support management decisions in the near term that will provide the greatest opportunity for climate change resilience into the future. This assessment was performed to provide information and decision support for a variety of stakeholders; primarily, coastal resource managers.

This project brought together representatives from multiple agencies to share their collective expertise and knowledge in a facilitated process utilizing the Climate Change Vulnerability Assessment Tool for Coastal Habitats (CCVATCH) to gauge site-specific vulnerabilities and potential adaptive capacity in each of fourteen salt marshes across the state. CCVATCH requires score assignment for the direct effect of CO_2, temperature, precipitation, sea level rise, and extreme climate events as well as the interactions of these climate stressors with a suite of existing non-climate stressors: invasive/nuisance species, nutrients, sedimentation, erosion, and environmental contaminants. The collective knowledge among the assessment team was augmented by a review of available literature and discussion/debate about the potential for future changes in habitat condition, given the presumed degree of exposure, associated with all of the above-listed stressors and stressor interactions.

Although sea level rise was considered the greatest driver of future change in habitat condition, the predicted change in seasonal precipitation also resulted in moderately high scores at multiple sites; suggesting a broad impact across the state. Other stressors (e.g. extreme climate events) and stressor interactions (e.g. temperature and invasive species) were considered less universally of concern and were believed to be more reliant on site-specific conditions or were influenced more strongly by existing current conditions. For example, the current presence of common reed (*Phragmites australis*) at or adjacent to a marsh strongly influenced future anticipated change in condition. Similarly, adaptive capacity potential was generally linked to specific site characteristics that would make any potential management actions relatively more or less practical and/or effective. For example, both the degree of fragmentation and the extent of existing barriers to migration are variable by location and would require very different strategies, equally challenging to implement, to overcome these limitations in adaptive potential.

Raw score assignment for both sensitivity-exposure and adaptive capacity provides the level of detail needed for adopting appropriate management strategies. Overall vulnerability scoring levels provide a 'snapshot' of the anticipated effect of a changing climate across the state. Both components of this assessment should be used to direct resources to ensure the most effective management actions are undertaken to improve resilience at specific sites. The majority of assessed salt marshes were assigned high overall vulnerability levels as the result of high sensitivity-exposure and moderate adaptive capacity level assignment at these locations. The exceptions include Winnapaug Pond, which was evaluated to be very highly vulnerable due to reduced adaptive capacity potential and a moderate overall vulnerability assignment at each of four locations. The four locations assigned moderate overall vulnerability levels included Ninigret, Nag West, and Providence Point due to reduced sensitivity-exposure levels and Barrington Beach due to higher adaptive

capacity score assignment. For Ninigret, it was the recent efforts to improve resiliency through thin-layer deposition that supported lower sensitivity-exposure score assignment at this location. Effectiveness monitoring, as outlined in the RI Coastal Wetland Restoration Strategy, should be implemented to ensure that the scoring assumptions associated with the implementation of specific management strategies were accurate and to inform future adaptation planning efforts.

Although site-specific knowledge and available resource material (e.g., monitoring data, reference documents) informed score assignment by a team of knowledgeable experts throughout the assessment, there remains a significant gap in knowledge related to the sensitivity of salt marsh habitat to the degree of anticipated change in stressor exposure. Specific identified research needs include, but are not limited to, nutrient and environmental contaminant availability and uptake associated with changing climate conditions. As additional research is implemented within the state or region that leads to a greater understanding of the potential impacts of these and other stressors and/or stressor interactions, that information should be used to re-assess the relevant stressors and modify score assignment as appropriate so that management decisions are made using the best available science.

The response of salt marsh habitat to changing climate conditions is generally more complex than an evaluation of sea level rise as a sole driver of change might indicate. This report provides insight into a variety of stressor impacts that may be realized in the relatively short term (i.e., by 2050). Although this assessment was performed on less than half of the individual salt marshes across the state, the collective knowledge captured from this assessment, and the description of site-specific responses described within this report can readily be transferred to other locations to inform management decisions. Effective adaptation and management plans should incorporate mitigation methods for the full suite of stressor impacts anticipated at each location. In addition, the implementation of other available state-wide mitigation strategies (e.g., land acquisition, policy change, restoration fund distribution) should take a broader landscape view to provide greater climate change resilience of salt marsh habitat across the state.

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Overview

This report summarizes the findings of a team of experts representing multiple partner agencies during the performance of a vulnerability assessment of Rhode Island (RI) salt marshes using the Climate Change Vulnerability Assessment Tool for Coastal Habitats (CCVATCH). Designed to evaluate individual assessment areas that are defined by habitat type, geographic extent and/or management unit, the tool utilizes an expert elicitation process to assign numerical scores. The assessment team members brought an array of knowledge from their perspective backgrounds of research, land management, and policy to allow for a more complete understanding of the potential impacts of climate change and adaptive capacities of the habitat given the relative level and source of vulnerabilities identified.

This report is intended to be used by RI coastal policy makers and land managers to better understand the main sources of vulnerability identified, recognize adaptive capacity limitations and potential, and consider comparative vulnerabilities in salt marsh habitat across the State of Rhode Island in support of future management decisions. Specifically, this report should be used in management planning, the prioritization of restoration and conservation efforts, for education and outreach, as guidance for policy and funding decisions, and to identify additional research and monitoring needs within the state.

ABOUT CCVATCH

CCVATCH was created by the National Estuarine Research Reserve (NERR) System to address the lack of available vulnerability assessment tools appropriate for application to coastal habitats and to provide a framework for incorporating local data and knowledge into the climate adaptation planning process. Although all habitats may be assessed using CCVATCH (i.e., it is not restricted for use on coastal habitats) it was designed to specifically incorporate sea level change in addition to other potential climate stressors (e.g., changes in CO_2 levels, precipitation, temperature, and extreme climate events). This assessment tool also incorporates the interaction of climate stressors with current or anticipated non-climate stressors (e.g., invasive/nuisance species, nutrients, sedimentation, erosion, and environmental contamination) to better understand the totality of anticipated habitat effects as the result of a change in climate condition. Elements of adaptive capacity, both inherent traits of the assessed system and external factors, which may collectively influence the ability of the habitat to adjust to changing conditions are also incorporated in the CCVATCH tool. Finally, the tool helps to fill a gap between science and management by requiring the assignment of a certainty score. Certainty scores indicate the level of agreement and general state of knowledge used to derive sensitivity-exposure and adaptive capacity scores. For additional tool detail, review the CCVATCH Guidance document, score sheet, case studies, and planning/application resources available on the CCVATCH website (www.ccvatch.com).

PROJECT SCOPE

The assessment of Rhode Island salt marshes was one of three assessments performed by the Northeast NERRs as part of a NERR Science Collaborative Science Transfer project entitled 'Assessing How Climate

Change Will Affect Coastal Habitats in the Northeast'. In addition to the RI assessment coordinated by the Narragansett Bay Reserve, the Wells (Maine) and Great Bay (New Hampshire) Reserves collaborated on the assessment of salt marsh sparrow habitat (e.g., high marsh) and Waquoit Bay (Massachusetts) assessed the vulnerability of cold water fisheries habitat to a changing climate. The project was designed to share the tasks of reviewing and compiling regional and site-specific data and information on climate effects on coastal habitats, developing meeting planning and resource documents, meeting facilitation, and the creation of outreach products among Reserves. Each Reserve also individually gained a better understanding of assessed habitats to help prioritize their land management and restoration actions.

PROCESS AND PRODUCTS

Numerous meetings were held in Rhode Island (RI) during the application of CCVATCH and the general process that the RI project team engaged in was used to develop a multi-day example of process agendas for future tool users; details will not be repeated here as all referenced documents displayed with active links are available for review on the CCVATCH website. The general sequence of steps for the application of CCVATCH in RI included:

- Select the habitat to be assessed from a suite of possible choices as well as the geographic extent of the habitat to be assessed. The assessment team elected to assess salt marsh and applied a stratified (e.g., north, central, south) random approach to ensure the maximum distribution of assessed sites. The fourteen sites assessed are displayed in Figure 1 (with two locations within Hundred Acre Cove).
- Determine the assessment time frame (the team selected an end date of 2050 as the most reasonable time frame on which to make management and policy decisions) and climate models to be applied to provide estimations of future change in climate conditions (see Appendix B).
- Identify and review available resource materials to inform scoring. These activities captured content for the Northeast Regional Resource Document: Salt Marsh Habitat.
- Apply scores to multiple assessment sites. Following initial assessments by the full team, the assessment team elected to

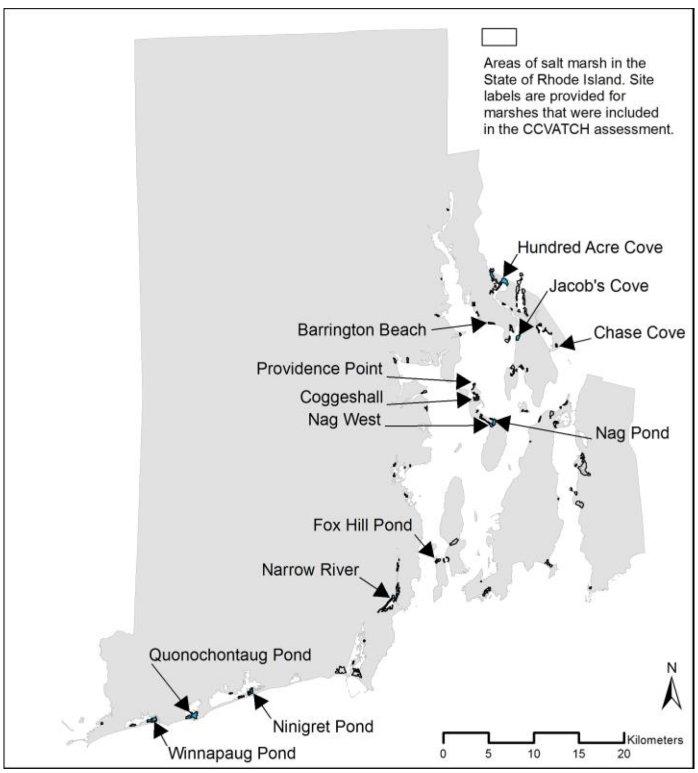

Figure 1: Location of assessed sites.

break into multiple smaller teams to assign scores to the greatest number of sites possible. This resulted in the commitment of extra effort to develop a scoring 'cheat sheet' that ensured all teams were basing their assessments on the same set of assumptions.

Site-specific assessment notes describing the current state of the habitat and site conditions believed to influence exposure to potential stressors as well as the general assumptions captured in the cheat sheet derived from team discussion of presumed sensitivity to climate and non-climate stressor interactions form the basis, together with assigned scores, of the reported results.

The CCVATCH website provides general guidance and facilitation materials such as the project-specific documentation described above. A series of RI case studies and captured research needs derived from low value certainty scores assigned during this project are also available for review on the CCVATCH website.

SCORE ASSIGNMENT

Scores were assigned based on general scoring levels (Table 1) and descriptive text available in each chapter of the CCVATCH Guidance document as well as the resource materials (e.g., data and reference documents) collected and reviewed by the assessment team members.

Numerous GIS layers were supplied by the project coordinator for each assessment site to assist with the evaluation of site characteristics that would potentially influence score assignment such as adjacent land use, orientation relative to prevailing winds, presence/absence of freshwater streams, etc. A list of GIS layers available to the assessment team are provided in the attached Appendix B. Also included in the appendix are estimated marsh platform elevations and shoreline change rates for individual sites that were used to inform score assignment for sea level rise and erosion, respectively.

OVERVIEW

Table 1: CCVATCH 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

Results

The following sections of this report, representing the bulk of this document, supply general inferences regarding the overall drivers of anticipated habitat change based on score assignment in each of the primary scoring categories (e.g., sensitivity-exposure and adaptive capacity), overall vulnerability scores calculated from primary scoring categories, and identified data gaps / research needs based on assigned certainty score values.

In general, the team's understanding of the potential of climate stressors and climate/non-climate stressor interactions to act as drivers of altered habitat condition and the degree to which these stressors variably effect salt marsh given different site-specific characteristics was derived from the collective expert knowledge of individual team members and an extensive review of available resource materials (e.g., data and reference documents). The team engaged in discussion/debate regarding both the mechanisms by which different assessment sites would vary in their response (e.g., presence/absence of freshwater inputs, relative elevations, etc.) and the degree to which the projected change in stressor level (i.e., exposure) was considered sufficient to trigger a response. A significant amount of effort was directed at capturing the consensus opinion of team members on which to base scoring; however, in many instances the average score best represented the team's collective response (i.e., score assignment 'somewhere between a 2 and a 5'). Summary statistics of scores are provided for both sensitivity-exposure and adaptive capacity scoring as an indication of the degree of variation in potential impact across all assessed sites and should be interpreted in the same way as general scoring levels (i.e., a mean score of 2 reflects a limited impact and a mean score of 5 reflects moderate impact).

Robustness Test

Although the majority of the RI assessment teams' effort was allocated to the assignment of scores at sites across the state as described above, the one exception was a repeat of scoring effort at a single location to determine the robustness of the tool to gauge relative vulnerabilities. The original intent had been to repeat this robustness test across several sites but that effort was not realized due to time constraints.

Three assessment team members indicated that current habitat and general site conditions at Winnapaug Pond were very well known to them; making this a suitable location for evaluating CCVATCH tool performance. In general, scores assigned by the two smaller teams were comparable (Table 2) and fell within the same general scoring levels (e.g., scores less than and equal to 2 indicate no change or limited impact and scores greater than 5 are indicative of limited persistence or complete habitat loss). However, there were some differences in score assignments.

Team notes suggest that scoring associated with invasive/nuisance species differed somewhat because Team 1 based their response only on the current lack of *Phragmites australis* at this location and Team 2 considered both the lack of *Phragmites australis* as well as the future potential, under higher temperatures and altered precipitation patterns, for a limited impact associated with crab burrowing if/when the marsh platform dries out – a condition more suitable for supporting high crab populations. It is likely that the difference in

RESULTS

Table 2: Robustness test: assigned scores by team.

Scoring Category	Score	Cert.	Score	Cert.
	Team 1		Team 2	
Direct Effects				
Current Condition	8	2	10	3
↑ CO_2	0	4	0	4
↑ Temperature	2	3	2	3
Δ Precipitation	2	2	2	1
Δ Sea Level	9	4	10	3
↑ Extreme Climate	0	2	2	2
Invasive/Nuisance Species				
Current Condition	0	3	1	2
↑ CO_2	0	3	0	2
↑ Temperature	0	3	2	2
Δ Precipitation	0	3	2	2
Δ Sea Level	0	2	-1	3
↑ Extreme Climate	0	2	0	3
Nutrients				
Current Condition	5	3	2	1
↑ CO_2	0	0.5	0	0.5
↑ Temperature	0	2	0	2
Δ Precipitation	7	2	-1	1.5
Δ Sea Level	7	2	0	3
↑ Extreme Climate	6	2	0	3
Sedimentation				
Current Condition	8	3	7.5	3.5
↑ CO_2	0	2	0	2
↑ Temperature	-	-	-	-
Δ Precipitation	0	3	0	3.5
Δ Sea Level	5	2	-1	1.5
↑ Extreme Climate	0	2	0	3
Erosion				
Current Condition	2	2	1	1
↑ CO_2	0	3	0	3
↑ Temperature	3.9	3	3.9	3
Δ Precipitation	2	2	0	2
Δ Sea Level	2	2	0	2
↑ Extreme Climate	1	2	1.7	2
Environmental Contaminants				
Current Condition	0	1	0	1
↑ CO_2	0	1	0	1
↑ Temperature	0	1	0	1
Δ Precipitation	0	1	0	1
Δ Sea Level	0	1	0	1
↑ Extreme Climate	0	1	0	2
Adaptive Capacity				
Fragmentation	0	3	0	4
Barriers to Migration	0	3	0	3
Recovery/Regeneration	2	1	0	3
Diversity of Funct. Groups	0	3	0	4
Management Actions	2	3	2	3
Inst./Human Response	2	3	2	2

interpretations was the presence on Team 2 of the lead author on a submitted, recently published paper on drivers of crab distributions (Raposa et al., 2018) who was better able to inform that scoring discussion.

The assessment scores associated with nutrients under various climate stressors also varied between teams. Although both teams acknowledge that high nutrient levels are currently possible and are derived from a variety of sources (e.g., residential wastewater, fertilizer and goose excrement from a nearby golf course) Team 1 based future estimation of potential nutrient impacts on the current level of nutrient loading; assuming no change in the level of nutrient input over time. By contrast, Team 2 assumed that the contribution of residential wastewater to nutrient loading had already been, and would continue to be, progressively more limited as a greater number of homes transition from seasonal use to year-round use with prerequisite requirements for sewer connections or upgraded septic design.

The final score assignment for which there was substantial disagreement between teams relates to the presumed future interaction of sedimentation and change in sea level. As barrier overwash potential is impeded by development at this location Team 1 assigned a score of 5; suggesting habitat persistence will be further limited by lack of sediment supply under conditions of elevated sea level. By contrast Team 2 acknowledged the limited accretion occurring at this site and anticipated that sedimentation may be somewhat enhanced in future due to rising sea levels. Although the notes were incomplete, the low score assignment was presumably associated with longer flooding residence time and alternate sediment sources as opposed to additional potential contributions of sediment from the adjacent dune.

For both teams the assigned scores for Winnapaug Pond resulted in an overall vulnerability level of very high, based

Table 3: Robustness test: score totals, levels and rankings.

	Team 1		Team 2	
Score Category	Score	Level	Score	Level
Exposure-Sensitivity	79.7	high	47.6	high
Adaptive Capacity	6.0	low	4.0	low
Certainty	1.90	-	2.07	-
Overall Vulnerability	-	v. high	-	v. high
Rank (exposure-sensitivity)		2		10

on a high level of sensitivity-exposure and a low level of adaptive capacity (Table 3). However, the relative ranking position (high to low) based solely on sensitivity-exposure scores was very different (2 of 14 versus 10 of 14). This difference is the result of derivative relationship table score output for the combination of current condition and sensitivity-exposure scores. For example, considering the assigned scores for sedimentation in which scores between teams are in general agreement (with the exception of the previously mentioned interaction of sedimentation and sea level), the Team 1 assigned scores of 8 and 5 and Team 2 assigned scores of 7.5 and -1 (for current condition and sum of sensitivity-exposure, respectively) result in relationship table outputs of 15 and 5.5 (see Appendix A in the CCVATCH Guidance Document or CCVATCH scoring worksheet). For nutrient scores the sum of relationship table outputs are equal to 25 for Team 1 and 0 for Team 2, respectively. It is the sum of relationship table output across all six sensitivity-exposure categories that is used to bin sensitivity-exposure levels into high, medium, and low levels.

The conversion of raw scores using the embedded relationship table within the CCVATCH scoring sheet assumes that (1) the current condition of a habitat will influence its overall vulnerability (i.e., degraded habitats are potentially more vulnerable to the effects of climate change) and (2) the influence of multiple climate change stressors (e.g., CO_2, temperature, precipitation) on habitat sensitivity is cumulative (i.e., habitats that are sensitive to a single climate change stressor (based on anticipated exposure levels) are likely to be less vulnerable than those which are sensitive to multiple climate change stressors (Plunket et al. 2015). Therefore, although the absolute scores and rankings do vary, this modest and incomplete test does suggest that the tool is robust; giving the same overall vulnerability levels derived from the assignment of scores by each of two teams. This robustness test also served to illustrate the importance of note taking during score assignment; specifically, the major issues debated, the rational for score assignment and all available information sources. This information provides insight regarding vulnerability assessment results and allows opportunities to reevaluate specific scoring assumptions at a later date.

Current Condition

In addition to the potential change in habitat condition associated with changing climate conditions, CCVATCH also requires score assignment for current condition as it relates to the direct effects of climate change and each individual climate/non-climate stressor interaction. The basic assumption is that a habitat which is already under stress will be more vulnerable to a change in climate condition than one which is at present unaffected. This relationship between current and future anticipated conditions is automatically incorporated into final score assignment via the previously mentioned relationship table which assumes a cumulative effect of current condition and collective sensitivity-exposure scores.

Table 4: Summary statistics of scores for current condition.

CURRENT CONDITION		
	Score	Cert.
Direct Climate Effects		
Min.	3.0	1.5
Max.	9.0	4.0
Mean	5.2	3.0
Median	5.0	2.8
Invasive / Nuisance Species		
Min.	0.5	2.0
Max.	7.5	4.0
Mean	3.3	3.0
Median	2.0	3.0
Nutrients		
Min.	0.0	1.5
Max.	5.0	4.0
Mean	2.4	2.5
Median	2.0	2.0
Sediment Supply		
Min.	1.0	1.0
Max.	7.8	3.5
Mean	4.4	2.8
Median	4.6	3.0
Erosion		
Min.	1.0	1.5
Max.	5.0	3.5
Mean	3.1	2.8
Median	2.0	3.0
Environmental Contamination		
Min.	0.0	1.0
Max.	1.0	4.0
Mean	0.1	1.4
Median	0.0	1.0

Assigned scores for current condition are provided in Table 2. Most sites were considered to have been already directly impacted by a change in climate conditions (when considering all climate stressors together) to a limited or moderate degree. Two sites (Quonochontaug and Winnapaug Ponds) were considered to be severely impacted. Indications of direct climate effect when assigning scores included the presence/absence of die-back areas, the ratio of high/low marsh (or percent of transitional marsh communities), and/or the extent of current vegetation loss which reflect the general anticipated response associated with changing climate conditions (e.g., altered species composition as the result of range shifts, a reduction in forb communities [Gedan & Bertness, 2009] and high marsh species, increased die-back associated with rising sea levels and the resulting change in inundation period/frequency).

Scores assigned for current condition of invasive/nuisance species reflect a variation in sites based on both the presence/absence/proximity of non-native invasive vegetation (e.g., common reed, perennial pepperweed, purple loosestrife) and presence/abundance of crab herbivores. With the exception of Hundred Acre Cove and Jacob's Cove which are severely impacted, and Coggeshall Marsh which was considered moderately impacted, most sites were assigned scores reflecting limited or no current impact.

The scoring of nutrient direct effects on the habitat was based primarily on potential nutrient input source/levels (using adjacent land use as a proxy or estimator), general vegetation composition (as high nutrient levels are believed to favor *Spartina alterniflora* and *Phragmites* over *Spartina patens*), and relative position in Narragansett Bay (e.g., upper vs. lower). Apart from the four sites located mid-Bay on Narragansett Bay National Estuarine Research Reserve (NBNERR) properties (e.g., Providence Point, Coggeshall

Marsh, Nag Pond, Nag Marsh) that are found on preserved lands in a rural setting known to have low nutrient input, all sites were considered to currently have limited to moderate impacts from nutrients. Generally, this impact is associated with adjacent land use in the form of proximate non-sewered residential, commercial (e.g., golf course), or agricultural lands.

Narragansett Bay is known to have very low suspended sediment levels and salt marshes in RI are not keeping pace with sea level rise. This is generally reflected in an average moderate impact score assignment. Sites do vary somewhat based on the extent of ditching (i.e., increased ditching results in lower sediment supply), inputs from rivers and streams, and the presence or absence of dunes. All sites were considered to range from limited (notably Nag West and Narrow River which have freshwater inputs) to severe impacts at Quonochontaug Pond which does not receive overwash sediment due to built infrastructure on the adjacent dune feature and Winnapaug Pond which suffers from extreme ditching and ditch spoil deposits on the marsh surface.

Annual erosion rates are available for each marsh based on shoreline change (Table B.2). Other indicators of potential erosion include evidence of creek widening, soil type, and geomorphic setting. Score assignment ranged from low to moderate impact based primarily on annual erosion rates and the extent of edge vegetation being denuded by overabundant marsh crabs. Sites considered to have higher impact were generally found in the mid- to upper-reaches of Narragansett Bay. Back barrier coastal marshes were assigned lower scores as they were assumed to be less impacted by erosion.

Although assessment team members were not terribly well-versed on the current impacts of environmental contaminants, they did review limited reference materials that suggested: (1) a tolerance to historic and persistent levels of exposure may have an associated 'cost' in reduced ability to tolerate climate stress [Stahl et al. 2013]; (2) emerging contaminants may be increasing and their effect on marsh growth is unknown; and, (3) climate change will shift marsh communities in some instances into non-optimal areas with potentially higher contaminant levels. In the absence of available data on contaminant presence and specific effect, the assessment team assigned scores indicating zero to low impact scores for all sites.

Sensitivity-exposure

As outlined in Glick *et al*. "Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment" (2011), vulnerability is a function of the level of exposure to changing climate conditions, the sensitivity of a given habitat to the anticipated level of exposure, and adaptive capacity (i.e., inherent traits and site characteristics capable of mitigating potential impacts). CCVATCH was designed to capture the exposure and sensitivity components with a single score assignment for each climate/non-climate stressor interaction. Summary statistics derived from assigned scores are provided in Tables 3 - 7.

Table 5: Summary statistics of scores for increase in CO_2.

INCREASE IN CO_2		
	Score	Cert.
Direct Climate Effects		
Min.	0.0	4.0
Max.	0.0	4.0
Mean	0.0	4.0
Median	0.0	4.0
Invasive / Nuisance Species		
Min.	0.0	2.0
Max.	7.5	4.0
Mean	2.6	3.0
Median	2.0	3.0
Nutrients		
Min.	0.0	0.5
Max.	0.0	1.0
Mean	0.0	0.5
Median	0.0	0.5
Sediment Supply		
Min.	0.0	2.0
Max.	0.0	2.0
Mean	0.0	2.0
Median	0.0	2.0
Erosion		
Min.	0.0	3.0
Max.	0.0	3.0
Mean	0.0	3.0
Median	0.0	3.0
Environmental Contamination		
Min.	0.0	1.0
Max.	0.0	1.0
Mean	0.0	1.0
Median	0.0	1.0

INCREASE IN CO_2

Although C3 plants such as *Scirpus* and *Phragmites* may experience an increase in biomass as the result of rising CO_2 and there is a potential for elevated C/N ratios which could decrease decomposition and increase peat formation, the direct effect of the presumed modest change in CO_2 levels were not considered sufficient to be a major driver of change in habitat condition (i.e., CO_2 levels are presumed to remain below the threshold that would drive significant vegetation community response). Variation in CO_2 levels across the state were also not considered by the assessment team to be sufficient to result in variation in individual site response. All sites therefore received a score indicative of no presumed impact.

Similarly, the effect of elevated CO_2 levels on nutrients, sediment supply, erosion rates, and environmental contaminant exposure, although presumably resulting in a modest change in vegetation communities (e.g., *Phragmites* promotion) which may in turn influence sediment trapping rates, soil surface cover, and contaminant uptake, these were generally considered to be both unproven at anticipated exposure levels and consistent across the state. An increase in CO_2 can also alter key ecosystem processes by altering contaminant mobility (Duvall et al. 2011) but the assessment team had insufficient information to determine the degree of this effect. All sites received scores reflecting no anticipated impact.

The exception to a presumed similarity in response to elevated CO_2 across sites occurred with score assignment for the interaction with invasive / nuisance species. Reviewed references suggest that an increase in CO_2 can enhance the fitness of many marsh invasives (e.g., *Phragmites*) and well as some native nuisance species (e.g., poison ivy) and that *Phragmites* is more resilient to salt stress under conditions of elevated temperature and CO_2 (Eller et al. 2014). In addition, the reduced percent nitrogen in *Scirpus* shoots associated with higher levels of CO_2 (and a subsequent increase in C/N) may alter herbivore preferences and feeding rates. Individual site score assignment was generally indicative of a presumed limited impact except where the current impact of invasive species was also scored as severe (e.g., Hundred Acre Cove, Coggeshall Marsh).

INCREASE IN TEMPERATURE

The direct effect of an increase in temperature was presumed to include a change in competitive interactions among species (Gedan & Bertness 2009), an increase in marsh decomposition rates and reduced organic matter accretion (Carey et al. 2015), and loss of forb panne communities (Gedan & Bertness 2009). Additionally, the effects of warming may result in increased aboveground biomass; greater stem height; increased nutrient cycling and contaminant uptake; greater use of pesticides; and a shift to more toxic species that cause HABs (see northeast regional resource document for salt marsh habitat). Although these effects would arguably be reflected in a differential response between sites, the variation in marsh community composition across the state is very modest and was considered insufficient to support different scoring. All sites received the same score for direct effect of change in temperature.

As previously indicated, the combined effect of an increase in both temperature and CO_2 may lead to greater salt stress tolerance in *Phragmites*. However, increased temperature has also been demonstrated to result in greater resistance in C4 plants (e.g., *S. patens*, *Distichlis spicata*) to *Phragmites* encroachment and is generally assumed to encourage range expansion of southern species. As the rapidity in relative response of these potential effects is unknown, score assignment did vary to reflect no presumed impact to severe impact based only on the difference in current presence (or absence) and/or proximity of invasive species.

For the remaining climate/non-climate stressor interactions, although numerous impacts are anticipated, the limited variation in marsh community composition across the state as well as uncertainty whether a two-degree change in temperature was sufficient to cause measurable change lead to the assumption that individual site response did not vary. Scores for all sites were the same for the influence of an increase in temperature on nutrients and environmental contaminants (0.0 = no impact) and erosion (3.9 = limited to moderate impact). No scores were assigned for the interaction of temperature and sediment supply as no information was available that suggested such an interaction between these stressors exists.

Table 6: Summary statistics of scores for increase in temperature.

INCREASE IN TEMPERATURE		
	Score	Cert.
Direct Climate Effects		
Min.	2.0	3.0
Max.	2.0	3.0
Mean	2.0	3.0
Median	2.0	3.0
Invasive / Nuisance Species		
Min.	0.0	1.0
Max.	7.5	3.0
Mean	2.5	2.0
Median	2.0	2.3
Nutrients		
Min.	0.0	2.0
Max.	0.0	2.0
Mean	0.0	2.0
Median	0.0	2.0
Sediment Supply		
Min.		
Max.		
Mean		
Median		
Erosion		
Min.	3.9	3.0
Max.	4.0	4.0
Mean	3.9	3.1
Median	3.9	3.0
Environmental Contamination		
Min.	0.0	1.0
Max.	0.0	1.0
Mean	0.0	1.0
Median	0.0	1.0

CHANGE IN PRECIPITATION

Although little change in the overall amount of precipitation is anticipated in Rhode Island, a shift in the timing/frequency of precipitation amounts results in a range of potential impacts from moderately detrimental to presumed benefit depending on site conditions. Changes in seasonal timing/duration of precipitation can influence salinity levels through salt water intrusion and groundwater flow/level and impact marsh elevation (Cahoon et al. 2006). C4 plants (e.g., *S. patens*, *Distichlis spicata*) are also considered to be better competitors under conditions of more frequent / severe drought which may influence community composition. Although specific site data were not available, sites were presumed to vary based on relative groundwater levels. Score assignment for direct effects of a change in precipitation was based entirely on expert knowledge of the site and ranged from no impact to moderate impact.

Table 7: Summary statistics of scores for change in precipitation.

CHANGE IN PRECIPITATION	Score	Cert.
Direct Climate Effects		
Min.	0.0	1.5
Max.	5.0	3.0
Mean	2.5	2.5
Median	2.0	2.5
Invasive / Nuisance Species		
Min.	0.0	1.0
Max.	5.0	3.0
Mean	1.9	2.0
Median	1.0	2.0
Nutrients		
Min.	0.0	1.0
Max.	5.0	3.0
Mean	2.1	1.9
Median	2.0	2.0
Sediment Supply		
Min.	-1.0	1.0
Max.	0.5	4.0
Mean	-0.1	3.1
Median	0.0	3.0
Erosion		
Min.	0.0	2.0
Max.	3.0	4.0
Mean	0.7	3.0
Median	0.0	3.0
Environmental Contamination		
Min.	0.0	1.0
Max.	1.0	4.0
Mean	0.1	1.3
Median	0.0	1.0

It was not clear from the literature to what extent a change in precipitation will influence the expansion of invasive/nuisance species although those vulnerable to flooding would presumably expand their range if reduced precipitation during the growing season is realized as anticipated. By contrast, the establishment of *Phragmites* which is intolerant of high salinity levels, may become restricted. The assessment team also recognized that multiple abiotic and biotic stressors could act synergistically with an increase in precipitation but it was not clear to what extent. Scores generally reflect no to moderate impact based on the presence and proximity of invasive species.

Reviewed reference materials suggest that drought can both increase total biomass for *S. alterniflora* and *S. patens* and decrease decomposition in native high marsh (Charles & Dukes 2009). A change in nutrient availability/circulation can also occur as the result of a change in water levels and increased wet deposition which are both associated with the timing and frequency of precipitation events. Sites were considered to vary based on their potential for nutrient input via surface and groundwater using adjacent land use and slope as a proxy for known nutrient sources. The average assigned score (ranging from 0 to 5) indicates that the team considered the impacts associated with the interaction of nutrients and precipitation would be limited.

Score assignment for sediment supply, erosion, and environmental contaminants and their interactions with a change in precipitation are also indicative of a presumed low impact. While salt marshes may receive a modest increase in sediment supply from uplands and streams during periods of heavy precipitation (reflected in the assignment of a negative score

Table 8: Summary statistics of scores for Increase in sea level.

CHANGE IN SEA LEVEL		
	Score	Cert.
Direct Climate Effects		
Min.	2.0	3.0
Max.	9.5	4.0
Mean	6.9	3.5
Median	7.3	3.5
Invasive / Nuisance Species		
Min.	-2.0	1.0
Max.	3.9	3.0
Mean	0.5	2.0
Median	0.8	2.0
Nutrients		
Min.	0.0	1.0
Max.	5.0	3.0
Mean	1.4	1.7
Median	0.0	1.5
Sediment Supply		
Min.	-1.0	1.5
Max.	5.0	3.0
Mean	0.0	2.1
Median	-1.0	2.0
Erosion		
Min.	1.0	2.0
Max.	5.0	3.5
Mean	3.6	2.6
Median	4.5	2.5
Environmental Contamination		
Min.	0.0	1.0
Max.	0.0	4.0
Mean	0.0	1.3
Median	0.0	1.0

[e.g., -1] at Chase Cove and Narrow River which have freshwater stream/riverine inputs) this was not presumed to have any impact at the majority of sites. Similarly, a change in the timing and intensity of precipitation events would presumably lead to greater erosion at riverine salt marsh systems. The assessment team, while acknowledging that a variation in erosion potential at individual sites was possible, considered the differences in erosion difficult to predict as data on stream flow rates, channel width/depth, etc. were not available. Score assignment was based on the presumed potential for increased scouring and ranged from no anticipated to limited impact. Except for the Narrow River site (score = 1), all locations were assigned a score of zero for the interaction of precipitation and environmental contaminants. The assessment team did consider that a change in precipitation could result in greater contaminant delivery to marshes through increased runoff and wet deposition and that specific site characteristics such as slope and the presence/amount of stormwater and stream inputs could influence the level of impact. However, the presence/proximity of contaminant sources was largely unknown, making differential score assignment impossible.

CHANGE IN SEA LEVEL

It is perhaps not surprising that, with two notable exceptions, all sites were assigned scores suggesting an anticipated moderate to severe impact as the direct effect of a change in sea level. An increase in sea level is expected to result in a shift to more flood-tolerant species and greater inundation periods can lead to a reduction in below-ground biomass of *S. alterniflora*. The RI team used relative elevation of assessed marshes as a proxy for change in tidal range to assign differential scores. The two sites anticipated to suffer only a limited impact from a change in sea level include Nag West and Nag Pond. These back-barrier sites are near one another, have potentially higher than average elevation capital, are largely surrounded by protected lands, and experience some degree of tidal restriction that was presumed to have some short-term benefit.

Higher salinity levels resulting from an increase in sea level is anticipated to reduce the extent of *Phragmites* which would be a benefit. However, higher sea levels may result in greater degradation from fiddler crabs which would result in some limited impact to the habitat. The relative cost/benefit associated with the interaction of invasive/nuisance species was considered too complex without additional information with which to make a determination of individual site responses. Score assignment ranged from -2 reflecting a benefit for sites with extensive *Phragmites* stands to 3.9 reflecting limited to moderate impact at Chase Cove, a location where *Phragmites* is currently limited but fiddler crab numbers are increasing.

The potential impacts of the interaction of rising sea levels and nutrient availability is complex. All factors that influence growth rate, such as increased nutrients, may influence the ability of a salt marsh to survive sea level rise. Fertilization may alter community composition and increase turf building however negative feedback associated with increased decomposition (and lower accretion rates) may result in greater drowning potential. Score assignment by site varied as a function of the anticipated frequency/duration of inundation (with elevation serving as proxy) when nutrient sources (i.e., from adjacent land use, relative position in the Bay) were thought to influence the site. Scores reflected a presumed difference between site characteristics ranging from no anticipated to moderate impact.

Although originally the assessment team had considered that it would not be possible to predict the relative response of sites to both the degree of tidal restriction (which influences drowning potential) and sediment deposition associated with increased inundation, score assignment for Quonochontaug and Winnapaug Ponds reflected an anticipated limited to moderate impact. All remaining sites were scored to suggest no impact (score = 0) or modest benefit (score = -1).

The assessment team considered the type of marsh (e.g., platform, fringe), orientation to dominant wind direction, relative elevation, measured erosion rates from shoreline change maps, and percent vegetated cover when applying differential scores for the interaction of erosion and change in sea level. The average of assigned scores (mean = 3.6) reflects an anticipated limited to moderate impact largely driven by the potential erosion of unvegetated platforms by wind-driven waves as marshes drown, although one reference suggests that a modest (e.g., 30 cm) increase in sea level results in a 50% increase in potential erosion on the marsh surface (Fagherazzi 2013) which is considered by the authors to be not significant.

As sea levels rise there will be a potential shift in land use adjacent to the coast and Bay and an increase in infrastructure flooding which will likely influence contaminant delivery. It is also possible that bioavailability of contaminants will be influenced by the change in salinity (Noyes et al. 2009). The assessment team, while acknowledging that these factors are site specific and should be varied based on flooding potential and contaminant sources, felt that insufficient data was available to support such a distinction between sites. All sites were assigned a score of zero, suggesting no anticipated impact.

INCREASE IN EXTREME CLIMATE EVENTS

More frequent extreme climate events (e.g., hurricanes, wildfire, ice storms, etc.) are anticipated. The potential direct impacts can include a change in plant communities as extreme disturbance favors colonizer species, a shift of the upland/marsh interface, some compression of the marsh surface associated with the weight of storm surge (Cahoon et al. 2006), and an increase in debris. Individual sites are presumed to differ based on geomorphology (e.g., presence/absence of dunes, orientation relative to dominant wind direction, degree of fetch), proximity to rivers prone to flooding, and adjacent land use. Assigned scores reflect a difference in site characteristics and range from no anticipated to moderate impact.

Table 9: Summary statistics of scores for increase in extreme climate events.

INCREASE IN EXTR. CLIMATE		
	Score	Cert.
Direct Climate Effects		
Min.	0.0	1.0
Max.	5.0	3.0
Mean	1.8	1.6
Median	2.0	1.5
Invasive / Nuisance Species		
Min.	0.0	1.0
Max.	1.0	3.0
Mean	0.2	2.1
Median	0.0	2.0
Nutrients		
Min.	0.0	0.5
Max.	3.0	3.0
Mean	0.9	1.5
Median	0.5	1.5
Sediment Supply		
Min.	-2.0	1.0
Max.	0.0	3.0
Mean	-0.7	2.2
Median	-1.0	2.0
Erosion		
Min.	1.0	2.0
Max.	1.8	2.0
Mean	1.6	2.0
Median	1.7	2.0
Environmental Contamination		
Min.	0.0	1.0
Max.	0.5	4.0
Mean	0.1	1.9
Median	0.0	2.0

An increase in extreme climate events may result in range expansion or increased vulnerability to invasion but the degree of impact varies by species, vector, etc. Although arguably the interaction of extreme climate events and invasive/nuisance species varies by site, insufficient information was available for the assessment team to make that distinction and all sites were assigned a score suggesting no or low anticipated impact.

General team member knowledge supports the assumption of a potential increase in nutrient availability caused by combined sewer overflow during storm events and instances of storm related flooding and run-off. Sites were expected to vary based on the expected influence and proximity of overflow locations (e.g., upper vs. lower Bay), other adjacent sources (using land use as proxy), slope, and geomorphology. Scores ranged from no anticipated impact to a moderate impact based on these criteria.

Summer storms are known to be a major factor in defining short-term variability in sedimentation rates (Roman et al. 1997) and, in marshes associated with riverine systems and subject to storm overwash, storm events can dominate accretion/erosion rates. Assessment team score assignment varied based on overwash potential and geomorphic setting (e.g., riverine vs. cove) and ranged from no anticipated impact to a score indicating some presumed benefit to the habitat (score = -2).

The literature was contradictory regarding the extent to which storms constitute a threat to back barrier marshes, but at least one source suggests that violent storms and hurricanes contribute very little (e.g., < 1%) to long-term salt marsh erosion rates (Leonardi et al. 2016). Score assignment varied very little by site at levels indicative of no anticipated to limited impact based on general geomorphology, measured erosion rates, and orientation to dominant winds.

Similar to the effect of sea level rise on environmental contaminants, an increase in extreme climate events is presumed to cause increased flooding of infrastructure/landfills, etc. leading to an increase in contaminant delivery. Although site potential varies based on the level on contaminant delivery as a function of coastal flooding potential during storm events, there was not sufficient information available to the assessment team to make that distinction among sites. In the absence of sufficient data to develop differential scoring at individual sites, assigned scores suggest no anticipated impact from the interaction of extreme climate events and environmental contaminants.

Adaptive Capacity

Adaptive capacity components are a mix of inherent traits and site-specific characteristics that may make a habitat more resilient (i.e., less vulnerable) to a change in climate. As the CCVATCH tool is designed to be applied to all habitats, the assignment of differential scores for some components of adaptive capacity at each site comprised of the same habitat is not as clear as it would be when applying the tool across multiple habitats. Scoring levels are also designed such that higher scores reflect a greater degree of adaptive capacity (suggesting a greater benefit to the habitat) as opposed to high scores for sensitivity-exposure which suggest a greater challenge to habitat persistence.

Table 10: Summary statistics of scores for adaptive capacity.

Adaptive Capacity		
	Score	Cert.
Degree of Fragmentation		
Min.	0.0	2.0
Max.	5.0	4.0
Mean	1.9	2.9
Median	2.0	3.0
Barriers to Migration		
Min.	0.0	2.0
Max.	4.0	3.5
Mean	1.6	2.7
Median	1.5	3.0
Recovery / Regeneration		
Min.	0.0	1.0
Max.	3.5	3.0
Mean	2.0	2.2
Median	2.0	2.0
Diversity of Functional Groups		
Min.	0.0	1.0
Max.	3.5	4.0
Mean	0.6	3.0
Median	0.0	3.5
Management Actions		
Min.	0.0	1.0
Max.	4.0	3.0
Mean	2.3	2.7
Median	2.0	3.0
Institutional / Human Response		
Min.	2.0	1.5
Max.	4.0	4.0
Mean	2.8	2.9
Median	2.0	3.0

DEGREE OF FRAGMENTATION

Many species, especially plants, experience a decrease in population size with greater fragmentation across the landscape. This primarily occurs as the result of an interruption in dispersal or movement (Sork et al. 2006; Thuiller et al. 2008) or by reduced genetic variation (Frankham et al. 2002; Leimu et al. 2010). Fragmentation may also lead to the disruption of biotic interactions such as plant-pollinator mutualisms and altered foraging behavior (Aquilar et al. 2006). In addition, 'edge effects' associated with different ratios of core to margin in habitat fragments, may influence within-fragment dynamics (Arroyo-Rodriguez & Mandujano, 2006; Jules & Shahani, 2003).

In this application of the CCVATCH tool, score assignment for the degree of fragmentation was generally applied based on the presence/absence of bisecting roads, footpaths, etc. and the relative degree of ditching at individual sites as opposed to the presumed effects associated with these site characteristics which were largely unknown for this habitat. A median score of 2 indicates that the assessment team believed that the degree of fragmentation would generally provide some modest impediment to habitat persistence at the site level.

BARRIERS TO MIGRATION

Adaptability is greater with increased landscape permeability which allows migration and/or range shifts and is presumably greatest when relatively flat topography is present. Even steep natural topography may allow some fringing marshes to develop if it is erodible. By contrast, the presence of hardened, developed shoreline which presents a barrier to migration will result in reduced potential for adaptation (e.g., greater vulnerability).

ADAPTIVE CAPACITY

Score assignments generally suggest that moderate to severe barriers to migration exist at assessed sites that would limit adaptive capacity potential. In some instances, the barriers are anthropogenic features that reflect past land use (e.g., stone walls) or those maintained to support current land use activities (e.g., golf courses, roadways). In others, barriers are natural features (e.g., forests, steep topography). Only at the two Hundred Acre Cove sites were barriers considered to present limited impediment to migration and therefore provide increased adaptive capacity of the marsh at these sites.

RECOVERY / REGENERATION FOLLOWING DISTURBANCE

Certain species are better adapted to exploiting disturbed sites than others, and this adaptive capacity component is more readily interpreted as a relative response across different habitat types. However, even during the application of CCVATCH to assess a single habitat type (i.e., multiple salt marshes) which is assumed to respond to disturbance in much the same way at different locations, there are some possible differences at individual sites that would influence score assignment. Although the severity of disturbance can dictate recovery time in salt marshes, the vegetation that comprise this habitat tends to become reestablished as opposed to replaced and yet pre- and post-disturbance vegetation composition may be altered to some extent.

Indicators of current, present-day disturbance (e.g., fill deposits, overwash fans) as well as the presumed influence of narrow vs. broad inlets (which effects tidal exchange) were most often used to determine recovery, and therefore adaptive capacity, potential at individual sites. Score assignment for most sites suggest a modest to severe impediment to habitat persistence as the capacity for recovery/regeneration following disturbance was not perceived to be sufficient to overcome climate change stressors.

DIVERSITY OF FUNCTIONAL GROUPS

Score assignment associated with the diversity of functional groups is also more readily interpreted when applying this tool to multiple habitats. The underlying assumption is that, when multiple representatives of individual functional groups exist, system resilience to environmental change is likely to be higher (Nystrom et al. 2008; Naeem 1998; Petchy & Gaston 2009). For a single habitat, in this case salt marsh, which does not differ greatly in composition from site to site score assignment for diversity of functional groups presents more of a challenge.

In general, salt marshes are not considered to have diverse representation in each functional group and this was reflected in the low score assignment across most sites suggesting a presumed modest to severe impediment to habitat persistence (i.e., low diversity will not provide added resiliency to climate change).

MANAGEMENT ACTIONS

Score assignment for management actions is generally derived from site specific knowledge to inform whether actions to mitigate climate stressors are possible but also assumes that sufficient resources would be available to perform the work. At some point in time, as the condition of the state's salt marshes become more critical, it will likely be necessary to revisit these scores as the effectiveness of specific management actions is evaluated through research and monitoring efforts and a greater appreciation of overall costs to implement specific actions becomes known. The types of management actions range from creating drainage channels to address surface ponding associated with spoil deposits on the marsh surface or restore tidal exchange, to wide-scale deposition to raise marsh platform elevations, to providing opportunities for marsh migration by recovering/restoring lands as human and upland vegetation communities retreat.

Score assignment ranges from zero at Nag West and Nag Pond, where the isolated and somewhat inaccessible location on Prudence Island is not believed to be conducive to wide-scale management activities, to a score of four at Ninigret and Quonochontaug Ponds which have been (in the case of Ninigret) or is slated to receive thin layer deposition of dredge material to offset the impacts associated with sea level rise. Other potential management actions identified at specific sites include: runnel digging (Barrington Beach); correction of tidal restrictions (Chase Cove, Winnapaug Pond), and the possible installation of a tide gate (Fox Hill). However, assigned scores ranging from 2 to 3.5 associated with these possible management actions suggest that they would, at best, partially offset climate stressors. For other sites, viable management actions were a bit more difficult to determine due to concerns about access, impact on species of concern, and cost vs. economic incentive at specific locations.

INSTITUTIONAL / HUMAN RESPONSE

The assignment of scores for institutional / human response takes into account the capacity of the land owner/management agency to conduct activities designed to improve site resilience as well as the potential for both adaptive and maladaptive human response (e.g., installation of hardened shoreline) permitted by current policy defined by the state and implemented by corporate entities such as commercial businesses, municipalities, land trusts, homeowner's associations, etc. as well as private property owners. Examples of institutional / human response that would improve salt marsh resilience include the management or procurement of adjacent lands to allow for migration, reduction in stormwater inputs, and the removal of existing barriers.

Most of the assessed sites were owned, in whole or in part, by the state or some other agency (e.g., Audubon Society of RI) that have clearly demonstrated the willingness and organizational capacity to perform adaptive management actions. Assigned scores (ranging from 2 to 4) suggest that many salt marshes will derive benefit from this organizational capacity and implied continuation of practices implemented to ensure the partial offset of climate stressors. However, in some instances such as at Barrington Beach and Fox Hill, additional support from adjacent property owners would be required to fully realize this adaptive capacity component.

Overall Vulnerability

Assigned scores for current condition, sensitivity-exposure, and adaptive capacity (Appendix A) are tallied and automatically assigned general scoring levels within the CCVATCH scoring worksheet. Assigned scoring levels are intended to reflect the same general degree of habitat response as indicated by raw score assignment to generate a broad-scale understanding of the implications of the anticipated response. Raw scores can and should be used to guide management decisions to ensure that the planned management actions, if any, best address all of the identified potential impacts attributed to the full suite of climate/non-climate stressor interactions and take into account the perceived increase in adaptive capacity associated with identified management actions when allocating resources.

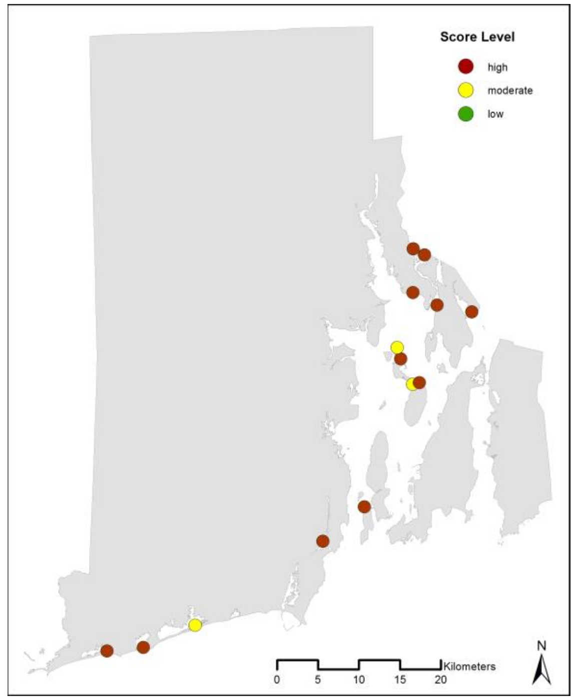

Figure 2: Sensitivity-exposure levels.

As indicated in Figure 2, the combined current condition and sensitivity-exposure scores generally suggest a high sensitivity-exposure level across all sites. Exceptions include moderate sensitive-exposure levels at Ninigret Pond, which has already received significant management effort to enhance elevations through thin-layer deposition to offset the effect of sea level rise, and Nag West and Providence Point on Prudence Island. These last two scored a bit lower due to reduced exposure levels associated with site characteristics (e.g., geomorphology, surrounded by preserved lands, etc.).

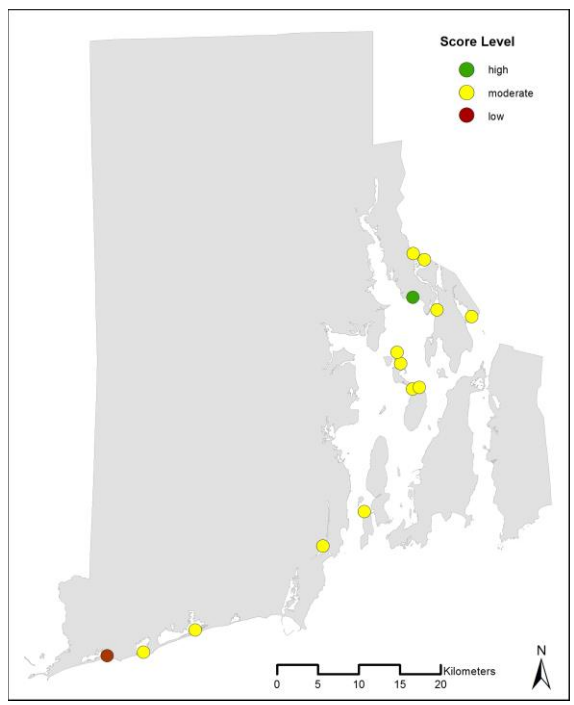

Figure 3: Adaptive capacity levels.

Figure 3 displays adaptive capacity levels for all assessed sites. Most sites were considered to have a moderate level of adaptive capacity, with two exceptions. Winnapaug Pond was considered to have a lower adaptive capacity potential because it is severely fragmented (i.e., extreme case of grid ditching with levees), has limited protection from land trusts, and offers severely limited opportunity for migration due to dense development and infrastructure. Barrington Beach, by contrast, received the only high adaptive capacity level assignment. This is partially attributed to some confusion by the assessment team as to how to break out the management action and institutional/human response components as well as an artifact of automated score adjustment (i.e., weighted for non-response) that occurs to provide an opportunity for comparison between sites. Regardless, opportunities for migration may exist at Barrington Beach assuming the current golf course changes its policy regarding depositing fill to prevent flooding and/or the land is acquired and protected for that purpose. This is similar in respect to the types of possible strategies available for improving resilience at sites that were assigned a moderate level of adaptive capacity.

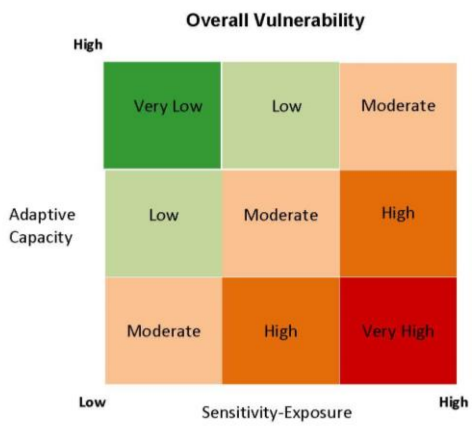

Figure 4: Relationship table for sensitivity-exposure and adaptive capacity.

Overall vulnerability levels are also automatically assigned in the CCVATCH scoring worksheet and they capture the relationship between sensitivity-exposure and adaptive capacity levels as illustrated in Figure 4. Habitats that experience high sensitivity-exposure levels and low adaptive capacity levels are very highly vulnerable whereas a habitat with a low degree of sensitivity-exposure and high adaptive capacity has low presumed vulnerability to climate change.

As previously mentioned, the raw scores provide the level of detail needed for adopting appropriate management strategies, and overall scoring levels provide a 'snapshot' of the anticipated effect of a changing climate. Figure 5 clearly indicates that most of the assessed sites were assigned high overall vulnerability levels. This is entirely the result of high sensitivity-exposure and moderate adaptive capacity level assignment at these locations. Assessed sites considered highly vulnerable should also be ranked to determine where, if possible, resources should be allocated in an attempt to 'boost' adaptive capacity to offset exposure. For instance, Fox Hill has an adjusted sensitivity-exposure score of 50.2 and an adaptive capacity score of 13.0 and the Hundred Acre Cove (MU 1&2) site with the same score for adaptive capacity received an adjusted sensitivity-exposure score of 76.6 which ranks among the highest scores assigned. If all else were equal (e.g., approximate extent of marsh habitat, community support), resources allocated at Fox Hill may result in greater,

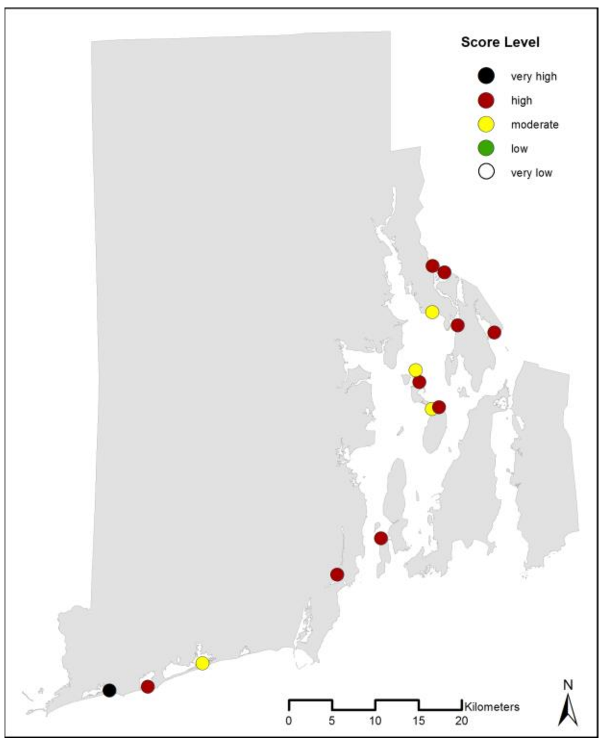

Figure 5: Overall vulnerability levels.

more sustainable benefit to the state's salt marsh habitat. In addition to Barrington Beach which, as previously suggested may not in fact have the high level of adaptive capacity indicated by the adjusted score, Ninigret Pond, Nag West and Providence Point were assigned moderate overall vulnerability scores for reasons already stated related to their lower presumed levels of exposure. Perhaps more surprisingly, there was only one site (Winnapaug Pond) that was assigned a very high vulnerability score. Prior to any attempt to mitigate climate effects at this location, scores should be reviewed to ensure that all sources of exposure to climate/non-climate stressors and challenges associated with low adaptive capacity scores has been adequately addressed.

IMPLICATIONS OF CERTAINTY SCORE ASSIGNMENT

A certainty score is also required for each assigned sensitivity-exposure and adaptive capacity score and indicates the basis of agreement for assigning the scores (Table 1). Information used to determine scores ranges from a general understanding of the underlying ecosystem processes, to on-site condition assessments, data derived from research and monitoring efforts, model outputs, and a study of peer-reviewed and grey literature. Certainty score assignments of two or lower is indicative of zero to medium certainty where only suggestive, inconclusive evidence or no direct evidence to support the assignment of sensitivity-exposure and adaptive capacity scores is available. In Table 11, closed circles indicate direct stressor effects or stressor interactions that fall within that category (certainty scores ≤ 2); dashed lines indicate no score assigned. The highest of these, a score of two, is most often based primarily on expert opinion and generally reflects the average (= 2.07) certainty score assigned across all assessed sites in RI. High and very high certainty (scores equal to 3 and 4, respectively) suggest that moderate or strong evidence is available to support sensitivity-exposure and adaptive capacity scores. In addition to using raw sensitivity-exposure and adaptive capacity scores to inform management actions, the certainty scores associated with each should also be reviewed and, if additional research has been implemented that would lead to a greater understanding of the potential impact, it should be used to re-assess relevant stressors and modify scores as appropriate so that decisions are made using the best available science.

The assignment of certainty scores in the range of 0.5 to 4 during this application of CCVATCH indicates that there are numerous data and research gaps that need to be addressed to improve our understanding of how salt marsh habitat will respond to this suite of climate and non-climate stressors. There is a clear need for

Table 11: Identified research needs.

	Current Condition	CO_2	Temp.	Precip.	Sea Level	Extreme Climate
Direct Effects						●
Invasive/Nuisance Species			●	●		
Nutrients		●	●	●	●	●
Sedimentation		●	---			
Erosion						●
Environmental Contaminants	●	●	●	●	●	●

more research on nutrient and environmental contaminant availability and uptake associated with changing climate conditions. For nutrient supply, species specific response will likely alter vegetation community composition but the relative change in aboveground versus belowground biomass which influences both marsh geomorphic stability as well as altered accretion and/or decomposition rates is also needed to inform management. The effect of legacy and emerging contaminants as well as changes in contaminant mobility as the result of climate change is also not well understood and should be a targeted focus for study.

Discussion

In general, the RI team assessment score assignments suggest that there are no strong geographic trends in anticipated salt marsh response to changing climate condition. Figures 7 through 11 display the relative scores across the geographic distribution of sites for each direct effect and climate/non-climate stressor interaction. Final score assignment for sensitivity-exposure (Table 9), which also incorporates current condition, ranges from 30 to 84.31 which indicates that site specific characteristics are responsible for differing exposure levels. These varying exposure levels are anticipated to result in moderate to high impact on salt marsh habitat by 2050. The direct effect of climate change has already resulted in moderate to severe impacts at most of the assessed sites, with sea level rise and change in precipitation anticipated to be the greatest stressors in future (Figure 7). At many sites the change in precipitation is expected to cause some limited impacts while sea level rise is expected to cause severe impacts sufficient to reduce habitat extent. For invasive/nuisance species, the anticipated change in CO_2 and temperature will moderately to severely impact areas which are currently extremely impacted (Figure 8); largely by enhancing the resiliency of *Phragmites* to higher salinity levels. Additional limited to moderate impact on invasive/nuisance species associated with a change in precipitation is also anticipated at some locations (e.g., Hundred Acre Cove [both locations], Jacob's Cove, Barrington Beach, and Narrow River). Nutrients are assumed to cause a range of current impacts from none to severe based primarily on available data and/or site characteristics. Nutrients are expected to cause limited to moderate impacts at various locations in future as the result of the anticipated change in precipitation, sea level, and frequency of extreme climate events with Narrow River receiving the highest score assignments for these stressors (Figure 9). Sediment supply was believed to be the cause of current limited to severe impacts across the state's salt marshes but, with the exception of Winnapaug and Quonochontaug Ponds which are anticipated to suffer additional impacts from the interaction of sediment supply and sea level rise, most sites were not expected to be impacted in future by a change in sediment supply and may even benefit a limited amount from sea level rise and an increase in extreme climate events (Figure 10). The current impact of erosion was presumed to be greatest (i.e., moderate impact) at many locations in the upper Bay (Figure 11). Surprisingly the anticipated increase in temperature (assigned the same moderate score at all sites) was considered to cause a greater impact than precipitation

Table 12: Final ranked scores for sensitivity-exposure with associated adaptive capacity and overall vulnerability ranking assignment.

Site	Exposure-Sensitivity Adj. Score	Exposure-Sensitivity Level	Adaptive Capacity Adj. Score	Adaptive Capacity Level	Overall Vulnerability Level
Providence Pt	30.00	moderate	11.0	moderate	Moderate Vulnerability
Nag West	36.72	moderate	9.0	moderate	Moderate Vulnerability
Ninigret	41.90	moderate	13.0	moderate	Moderate Vulnerability
Nag Pond	44.48	high	8.0	moderate	High Vulnerability
Coggeshall	50.17	high	8.5	moderate	High Vulnerability
Fox Hill	50.17	high	13.0	moderate	High Vulnerability
Quonochontaug	52.24	high	12.0	moderate	High Vulnerability
Chase Cove	59.48	high	10.0	moderate	High Vulnerability
Barrington Bch	59.48	high	16.5	high	Moderate Vulnerability
Winnapaug_Ave	64.66	high	5.0	low	Very High Vulnerability
Jacob's Cove	75.52	high	14.0	moderate	High Vulnerability
Narrow MU4	76.03	high	12.0	moderate	High Vulnerability
HAC MU1&2	76.55	high	13.0	moderate	High Vulnerability
HAC MU3	84.31	high	14.5	moderate	High Vulnerability

on erosion rates but less of an impact than the expected change in sea level, considered to result in a moderate impact at various locations. No figure was provided for environmental contamination scores as relative score assignment associated with current condition and climate stressors was not possible since little information was available on which to base differential scoring at individual sites.

As with sensitivity-exposure levels, adaptive capacity score assignments were largely based on specific individual site characteristics as opposed to generalized expectations regarding salt marsh response to changing climate conditions (Figure 12); although, in some instances, the direct effect of climate stressors, the interaction of climate / non-climate stressors, and adaptive capacity components were not anticipated to change between sites (e.g., CO_2 and nutrients, diversity of functional groups). Total adaptive capacity scores ranged from 5 to 16.5, indicating low to high levels of adaptive capacity were possible at individual sites. However, there were no sites that received consistently high scores which would indicate a full capacity to offset climate change stressors. Assigned adaptive management levels across the majority of assessed sites was moderate; suggesting that collective adaptive capacity components (e.g., degree of fragmentation, barriers to migration) constitute only modest impediments to habitat persistence under changing climate conditions. Even active management that is specifically planned and undertaken to facilitate resilience in select locations (e.g., Quonochontaug, Winnapaug, and Ninigret Ponds; Jacob's Cove; and Barrington Beach) was believed to be insufficient to fully offset climate change stressors and ensure complete habitat persistence into the future, although a partial offset was considered to be a reasonable expectation if applied management actions proved to be effective.

Vulnerability assessments utilizing the CCVATCH tool, which relies on expert elicitation for score assignment, assumes that sufficient information is available to fully evaluate the response of a habitat to changing climate conditions. While this was largely true in the application of this tool to salt marsh habitat across the State of RI, and site-specific knowledge informed score assignment by a team of knowledgeable experts comprised of researchers and land managers representing multiple agencies, it is also true that there remains a significant gap in knowledge related to the sensitivity of this habitat to the degree of anticipated change in stressor exposure. Overall vulnerability levels for assessed sites, and the raw scores from which the sensitivity-exposure and adaptive capacity levels were derived, can and should be used to direct resources to ensure the most effective management actions are undertaken to improve resilience at specific sites. Additional sites should also be assessed to provide the broadest basis for decision support in the allocation of resources. However, as new information becomes available that addresses research gaps and data needs, it should be used to reevaluate specific score assignments as appropriate. The treatment of project results as a 'living document', with new knowledge incorporated when it becomes available, will provide an ever-greater understanding of climate change impacts and serve as a lasting resource for prioritizing conservation, management, and restoration actions designed to ensure the persistence of RI's salt marsh habitat into the future.

COMPARISON WITH ALTERNATE VULNERABILITY INDEX FOR RI SALT MARSHES

A recently published paper documents the development and application of an alternate method to assess the vulnerability of RI's salt marshes to sea level rise (Ekberg et al. 2017). The authors evaluated several available metrics such as plant distributions and heights, elevation relative to mean high water (MHW) and tidal range, and predictions derived through SLAMM modeling as indicators of future vulnerability as well as for calibration and validation of this vulnerability index (Ekberg et al. 2017).

As with most vulnerability assessments, this effort was undertaken to support improved site-specific management actions; specifically, to target adaptation to sites based on their vulnerability and to match sites to appropriate interventions (Ekberg et al. 2017). Given the similar goals of these projects, one might expect that the assessment scores for the direct climate effect current condition, which reflects recent shifts in vegetation communities, would be similar to the vulnerability scores assigned by Ekberg et al. or, alternatively, that future anticipated conditions under elevated sea levels would compare favorably due to the strong influence of elevation relative to MHW incorporated in both assessments; but, that appears not to be the case. For the CCVATCH application, current condition associated with direct climate effects (primarily sea level rise) was largely based on indicators of degraded marsh condition across the entire marsh platform such as percentage of high versus low marsh and presence and extent of die-off depressions associated with drowning marshes and therefore directly attributable to recent (e.g., past 5 years) shifts in vegetation communities as opposed to past conditions assessed in the Ekberg et al. study (e.g., 1972-2011) captured along discreet transects which may or may not be indicative of conditions across the marsh. Future predicted impacts associated with sea level rise in the CCVATCH application are either assessed independently (e.g., direct effect) or are associated with the interaction of sea level rise on the suite of non-climate stressors incorporated in the tool (e.g., nutrients, sedimentation). In either instance, final score assignment also incorporates current condition as the CCVATCH tool is largely based on the premise that ecosystems already under stress are likely to have more rapid and acute reactions to climate change (Staudt et al. 2013).

Additionally, overall vulnerability determinations are not similar between the two assessments, which is not unexpected as these efforts were designed to evaluate vulnerabilities at different scales (i.e., single versus multiple stressors contributing to vulnerability). In the Ekberg et al. (2017) study the authors suggest that the derived vulnerability metrics can be used to target adaptation interventions to coastal wetlands that score as most vulnerable to sea level rise or, alternatively, to incorporate an ecological triage approach and apply conservation and adaptation actions to marshes within the low to moderate vulnerability range. By contrast, the CCVATCH application considers a suite of potential climate and non-climate stressors that should be taken into consideration when evaluating potential adaptation strategies. The supposition associated with applying the CCVATCH tool suggests that it would be inappropriate to consider only a single stressor (i.e., the vulnerability of a marsh to sea level rise) when making management decisions; rather, the effectiveness of applied adaptation strategies is greatly enhanced by considering and mitigating for multiple identified stressors.

IMPLICATIONS FOR POLICY AND MANAGEMENT

Clearly, it is most appropriate to evaluate salt marsh habitat at the site level when planning restoration or adaptation projects to ensure that all possible sources of vulnerability are addressed; particularly if the intent is to maximize resources utilized across the state to preserve and protect this valuable habitat into the future. All sources of current and anticipated future stressors need to be considered to ensure that efforts to resolve any particular direct climate stressor or stressor interaction is not undermined by the presence and persistence of other known or anticipated stressors in or adjacent to the managed site. Project permitting and funding allocation should require that all potential stressors are identified and, if it is not possible to fully address each, to identify mechanisms for minimizing stressor impacts within the project design.

A listing of specific strategies and approaches that can be applied to address identified site-specific stressors are readily available in the RI Coastal Wetland Restoration Strategy. However, it is worth noting that, in addition to actions specifically designed to mitigate stressors on and directly adjacent to the marsh platform (e.g., enhanced sediment accretion through thin-layer deposition, restored hydrology, facilitated transitions), the presence of multiple stressors may require that adaptation planning incorporates additional strategies designed to mitigate 'outside' stressors to enhance effectiveness. For example: the use of buffers or other stormwater management practices to reduce nutrient and pollutant inputs; restored fluvial delivery of sediments; restored shoreline vegetation to reduce erosion potential; and increased shoreline setbacks. For a site at which multiple potential stressors are identified, multiple potential adaptation/mitigation strategies will likely need to be employed to ensure continued habitat persistence.

The need for effectiveness monitoring of applied management strategies, as outlined in the RI Coastal Wetland Restoration Strategy, is also an essential mechanism for ensuring that future actions have the greatest possibility of success. The evidence for climate change and its effects on coastal habitats, particularly salt marsh, is already strong and will become more significant into the future. The State of RI, in taking a lead role in identifying research needs, actively adopting strategies for the prioritization of management actions and monitoring project effectiveness, contributes considerably to the body of knowledge required to most effectively address the current and future challenge of preserving valuable salt marsh habitat.

DISCUSSION

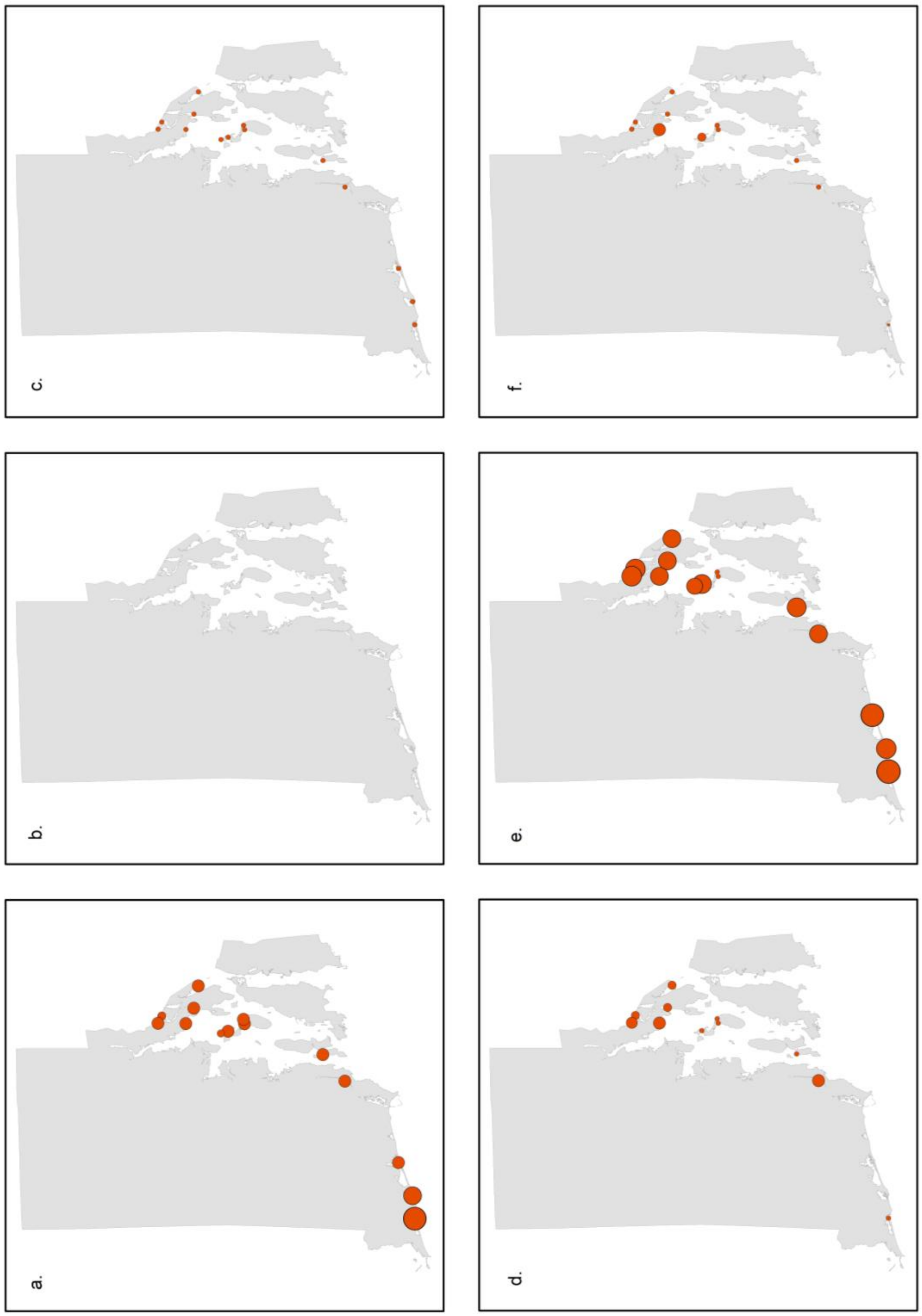

Figure 7: Relative scores for direct climate effect by climate stressor, applied to: (a) current condition, (b) increase in CO_2, (c) increase in temperature, (d) change in precipitation, (e) change in sea level, and (f) increase in extreme climate events.

Figure 8: Relative scores for invasive/nuisance species by climate stressor, applied to: (a) current condition, (b) increase in CO_2, (c) increase in temperature, (d) change in precipitation, (e) change in sea level, and (f) increase in extreme climate events.

Figure 9: Relative scores for nutrients by climate stressor, applied to: (a) current condition, (b) increase in CO_2, (c) increase in temperature, (d) change in precipitation, (e) change in sea level, and (f) increase in extreme climate events.

Figure 10: Relative scores for sedimentation by climate stressor, applied to: (a) current condition, (b) increase in CO_2, (c) increase in temperature, (d) change in precipitation, (e) change in sea level, and (f) increase in extreme climate events.

Figure 11: Relative scores for erosion by climate stressor, applied to: (a) current condition, (b) increase in CO_2, (c) increase in temperature, (d) change in precipitation, (e) change in sea level, and (f) increase in extreme climate events.

Figure 12: Relative scores for adaptive capacity by type, applied to: (a) degree of fragmentation, (b) barriers to migration, (c) recovery/regeneration following disturbance, (d) diversity of functional groups, (e) management actions, and (f) institutional / human response.

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Appendix A

Table A. 1: Assigned scores for current condition and sensitivity-exposure.

Habitat	Current	Cert.	CO2	Cert.	Temp	Cert.	Precip	Cert.	Sea Level	Cert.	Extr Clim	Cert.
Direct Climate Effects												
HAC MU1&2	3.5	1.5	0.0	4.0	2.0	3.0	3.5	3.0	8.0	3.5	2.0	1.5
HAC MU3	5.0	3.5	0.0	4.0	2.0	3.0	4.5	3.0	8.0	3.5	2.0	1.5
Quonnie	7.0	2.0	0.0	4.0	2.0	3.0	0.0	2.0	8.0	4.0	0.0	2.0
Ninigret	5.0	2.0	0.0	4.0	2.0	3.0	0.0	2.0	9.0	4.0	0.0	2.0
Narrow MU4	5.0	3.0	0.0	4.0	2.0	3.0	5.0	3.0	7.0	3.0	2.0	2.0
Jacob's Cove	5.0	4.0	0.0	4.0	2.0	3.0	3.5	3.0	7.0	3.5	2.0	1.5
Barrington Bch	5.0	4.0	0.0	4.0	2.0	3.0	5.0	3.0	7.0	3.5	5.0	3.0
Chase Cove	5.0	2.5	0.0	4.0	2.0	3.0	3.4	2.0	7.0	3.5	2.0	1.2
Coggeshall	5.0	4.0	0.0	4.0	2.0	3.0	2.0	2.0	7.5	3.5	3.3	1.2
Nag West	5.0	4.0	0.0	4.0	2.0	3.0	2.0	3.0	2.0	4.0	2.0	1.0
Fox Hill	5.0	2.0	0.0	4.0	2.0	3.0	2.0	2.0	7.5	3.0	2.0	1.0
Winnapaug_Ave	9.0	2.5	0.0	4.0	2.0	3.0	2.0	1.5	9.5	3.5	1.0	2.0
Nag Pond	5.0	2.5	0.0	4.0	2.0	3.0	2.0	3.0	2.0	4.0	2.0	1.0
Providence Pt	3.0	4.0	0.0	4.0	2.0	3.0	0.0	2.0	6.5	3.0	0.0	1.0
Invasive / Nuisance Species												
HAC MU1&2	7.5	3.0	7.5	3.5	7.5	2.5	3.5	2.0	1.0	2.0	0.0	3.0
HAC MU3	7.5	3.0	7.5	3.5	7.5	2.5	3.5	2.0	1.0	2.0	0.0	3.0
Quonnie	1.0	3.0	0.0	2.0	0.0	2.0	1.0	2.0	-2.0	2.0	0.0	2.0
Ninigret	2.0	3.0	2.0	2.0	2.0	2.0	2.0	2.0	-2.0	2.0	1.0	2.0
Narrow MU4	2.0	3.0	2.0	3.0	2.0	3.0	5.0	3.0	-2.0	3.0	1.0	3.0
Jacob's Cove	7.5	3.5	7.5	3.5	7.5	2.5	3.5	3.0	1.0	2.0	0.0	3.0
Barrington Bch	2.0	3.0	2.0	3.5	2.0	2.5	3.5	3.0	0.5	2.0	0.0	3.0
Chase Cove	2.0	2.0	1.6	2.2	1.0	1.0	1.0	1.0	3.9	2.0	0.2	1.4
Coggeshall	5.0	4.0	0.0	2.2	0.0	1.0	0.0	1.0	1.0	2.6	0.0	1.4
Nag West	3.0	2.5	1.0	4.0	2.0	1.0	1.0	1.0	3.0	2.0	0.0	1.0
Fox Hill	2.0	3.0	2.0	3.0	2.0	3.0	1.0	1.0	-1.0	1.0	0.0	1.0
Winnapaug_Ave	0.5	2.5	0.0	2.5	1.0	2.5	1.0	2.5	-0.5	2.5	0.0	2.5
Nag Pond	2.0	2.0	1.0	4.0	1.0	1.0	1.0	1.0	3.0	2.0	0.0	1.0
Providence Pt	2.0	4.0	2.0	3.0	0.0	2.0	0.0	3.0	0.0	2.0	0.0	2.0

Table A. 1: Assigned scores for current condition and sensitivity-exposure (*continued*).

Habitat	Current	Cert.	CO2	Cert.	Temp	Cert.	Precip	Cert.	Sea Level	Cert.	Extr Clim	Cert.
Nutrients (deficiency or excess)												
HAC MU1&2	5.0	2.0	0.0	0.5	0.0	2.0	3.0	2.0	0.0	1.0	0.5	0.5
HAC MU3	5.0	2.0	0.0	0.5	0.0	2.0	3.0	2.0	0.0	1.0	0.5	0.5
Quonnie	2.0	3.0	0.0	0.5	0.0	2.0	4.0	2.0	4.0	2.0	2.5	2.0
Ninigret	2.0	2.0	0.0	0.5	0.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0
Narrow MU4	5.0	2.0	0.0	0.5	0.0	2.0	5.0	2.5	5.0	2.5	3.0	1.0
Jacob's Cove	5.0	2.0	0.0	0.5	0.0	2.0	3.0	2.0	0.0	1.0	0.5	0.5
Barrington Bch	2.0	2.0	0.0	0.5	0.0	2.0	2.0	1.5	0.0	1.0	0.5	0.5
Chase Cove	2.0	2.0	0.0	0.5	0.0	2.0	1.7	1.0	3.7	1.0	0.2	2.0
Coggeshall	0.0	3.0	0.0	0.5	0.0	2.0	0.0	1.0	0.0	1.0	0.0	1.0
Nag West	0.0	4.0	0.0	0.5	0.0	2.0	0.0	3.0	0.0	3.0	0.0	3.0
Fox Hill	2.0	1.5	0.0	0.5	0.0	2.0	2.0	1.0	2.0	1.0	1.0	1.0
Winnapaug_Ave	3.5	2.0	0.0	0.5	0.0	2.0	3.0	1.8	3.5	2.5	3.0	2.5
Nag Pond	0.0	4.0	0.0	1.0	0.0	2.0	0.0	3.0	0.0	3.0	0.0	3.0
Providence Pt	0.0	3.0	0.0	0.5	0.0	2.0	0.0	2.0	0.0	2.0	0.0	2.0
Sedimentation												
HAC MU1&2	4.0	3.0	0.0	2.0			0.5	3.5	0.0	3.0	0.0	3.0
HAC MU3	4.0	3.0	0.0	2.0			0.5	3.5	0.0	3.0	0.0	3.0
Quonnie	7.0	3.0	0.0	2.0			0.0	3.0	5.0	2.0	-1.0	2.0
Ninigret	4.0	2.0	0.0	2.0			0.0	3.0	0.0	2.0	-2.0	2.0
Narrow MU4	1.0	1.0	0.0	2.0			-1.0	1.0	-1.0	1.5	-1.0	1.0
Jacob's Cove	5.0	3.5	0.0	2.0			0.0	3.5	0.0	3.0	-1.0	2.0
Barrington Bch	5.0	3.5	0.0	2.0			0.0	3.5	0.0	3.0	-1.0	2.0
Chase Cove	4.6	3.0	0.0	2.0			-1.0	3.0	-1.0	1.5	0.0	2.5
Coggeshall	5.0	3.0	0.0	2.0			0.0	3.0	-1.0	1.5	-1.0	2.5
Nag West	2.0	3.0	0.0	2.0			0.0	3.0	-1.0	2.0	-2.0	2.0
Fox Hill	5.0	3.0	0.0	2.0			0.0	3.0	-1.0	1.5	0.0	1.0
Winnapaug_Ave	7.8	3.3	0.0	2.0			0.0	3.3	2.0	1.8	0.0	2.5
Nag Pond	4.6	3.0	0.0	2.0			0.0	3.0	-1.0	2.0	0.0	2.0
Providence Pt	3.0	2.5	0.0	2.0			0.0	4.0	-1.0	1.5	-1.0	3.0

Table A. 1: Assigned scores for current condition and sensitivity-exposure (*continued*).

Habitat	Current	Cert.	CO2	Cert.	Temp	Cert.	Precip	Cert.	Sea Level	Cert.	Extr Clim	Cert.
Erosion												
HAC MU1&2	5.0	3.5	0.0	3.0	3.9	3.0	0.0	3.0	5.0	2.5	1.7	2.0
HAC MU3	5.0	3.5	0.0	3.0	3.9	3.0	0.0	3.0	5.0	2.5	1.7	2.0
Quonnie	2.0	2.0	0.0	3.0	3.9	3.0	1.0	2.0	2.0	2.0	1.0	2.0
Ninigret	1.0	2.0	0.0	3.0	3.9	3.0	1.0	2.0	2.0	2.0	1.0	2.0
Narrow MU4	2.0	2.0	0.0	3.0	3.9	3.0	3.0	2.0	4.0	3.0	1.7	2.0
Jacob's Cove	5.0	3.5	0.0	3.0	3.9	3.0	0.0	3.0	5.0	2.5	1.7	2.0
Barrington Bch	2.0	2.0	0.0	3.0	3.9	4.0	0.0	3.0	5.0	2.5	1.7	2.0
Chase Cove	5.0	3.0	0.0	3.0	3.9	3.0	2.0	3.0	5.0	3.5	1.8	2.0
Coggeshall	5.0	3.5	0.0	3.0	3.9	3.0	2.0	3.0	5.0	3.5	1.7	2.0
Nag West	2.0	3.0	0.0	3.0	3.9	3.0	0.0	4.0	2.0	2.0	1.7	2.0
Fox Hill	2.0	3.0	0.0	3.0	3.9	3.0	0.0	4.0	3.5	2.0	1.7	2.0
Winnapaug_Ave	1.5	1.5	0.0	3.0	3.9	3.0	1.0	2.0	1.0	2.0	1.4	2.0
Nag Pond	5.0	3.0	0.0	3.0	4.0	3.0	0.0	4.0	5.0	3.5	1.7	2.0
Providence Pt	1.0	3.0	0.0	3.0	3.9	3.0	0.0	4.0	1.0	3.0	1.7	2.0
Environmental Contamination												
HAC MU1&2	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.5	2.0
HAC MU3	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.5	2.0
Quonnie	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0
Ninigret	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0
Narrow MU4	1.0	3.0	0.0	1.0	0.0	1.0	1.0	2.0	0.0	2.0	0.0	2.0
Jacob's Cove	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.5	2.0
Barrington Bch	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.5	2.0
Chase Cove	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	2.0
Coggeshall	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	2.0
Nag West	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	2.0
Fox Hill	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	2.0
Winnapaug_Ave	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.5
Nag Pond	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	1.0	0.0	2.0
Providence Pt	0.0	4.0	0.0	1.0	0.0	1.0	0.0	4.0	0.0	4.0	0.0	4.0

Table A. 2: Assigned scores for adaptive capacity.

Habitat	Degree of fragmentation	Certainty	Barriers to migration	Certainty	Recovery / regeneration following disturbance	Certainty	Diversity of functional groups	Certainty	Management actions	Certainty	Institutional / Human response	Certainty
HAC MU1&2	2.0	3.5	4.0	3.5	2.0	3.0	2.0	1.0	1.0	1.0	2.0	1.5
HAC MU3	1.0	3.5	4.0	3.0	2.0	3.0	2.0	1.0	3.5	3.0	2.0	1.5
Quonnie	1.0	2.0	1.0	2.0	2.0	1.0	0.0	3.0	4.0	3.0	4.0	3.0
Ninigret	1.0	2.0	2.0	2.0	2.0	1.0	0.0	3.0	4.0	3.0	4.0	3.0
Narrow MU4	4.0	2.0	2.0	2.0	2.0	1.0	0.0	3.0	2.0	3.0	2.0	3.0
Jacob's Cove	2.0	3.0	1.0	3.0	2.0	3.0	3.5	1.0	3.5	2.0	2.0	2.0
Barrington Bch	2.0	3.0	2.0	3.0					3.5	3.0	3.5	3.0
Chase Cove	2.0	3.0	2.0	2.6	2.0	3.0	0.0	4.0	2.0	3.0	2.0	3.0
Coggeshall	1.0	3.0	0.0	3.5	3.5	2.0	0.0	4.0	2.0	3.0	2.0	4.0
Nag West	2.0	2.0	1.0	2.0	2.0	2.0	0.0	4.0	0.0	3.0	4.0	4.0
Fox Hill	5.0	3.0	1.0	2.0	2.0	2.0	0.0	4.0	3.0	2.0	2.0	2.0
Winnapaug_Ave	0.0	3.5	0.0	3.0	1.0	2.0	0.0	3.5	2.0	3.0	2.0	2.5
Nag Pond	2.0	3.0	1.0	3.0	2.0	2.0	0.0	4.0	0.0	3.0	3.0	4.0
Providence Pt	2.0	4.0	2.0	3.0	2.0	3.0	0.0	4.0	1.0	3.0	4.0	4.0

Table A. 3: Final assigned scores.

Habitat	Exposure-Sensitivity			Adaptive Capacity			Certainty	Overall Vulnerability Level
	Score	Adj. Score	Level	Score	Adj. Score	Level		
HAC MU1&2	74.0	76.6	high	13.0	13.0	moderate	2.01	High Vulnerability
HAC MU3	81.5	84.3	high	14.5	14.5	moderate	2.10	High Vulnerability
Quonnie	50.5	52.2	high	12.0	12.0	moderate	1.93	High Vulnerability
Ninigret	40.5	41.9	moderate	13.0	13.0	moderate	1.88	Moderate Vulnerability
Narrow MU4	73.5	76.0	high	12.0	12.0	moderate	2.04	High Vulnerability
Jacob's Cove	73.0	75.5	high	14.0	14.0	moderate	2.11	High Vulnerability
Barrington Bch	57.5	59.5	high	11.0	16.5	high	2.19	Moderate Vulnerability
Chase Cove	57.5	59.5	high	10.0	10.0	moderate	1.97	High Vulnerability
Coggeshall	48.5	50.2	high	8.5	8.5	moderate	2.10	High Vulnerability
Nag West	35.5	36.7	moderate	9.0	9.0	moderate	2.16	Moderate Vulnerability
Fox Hill	48.5	50.2	high	13.0	13.0	moderate	1.80	High Vulnerability
Winnapaug_Ave	62.5	64.7	high	5.0	5.0	low	2.05	Very High Vulnerability
Nag Pond	43.0	44.5	high	8.0	8.0	moderate	2.20	High Vulnerability
Providence Pt	29.0	30.0	moderate	11.0	11.0	moderate	2.24	Moderate Vulnerability

APPENDIX B

Appendix B

Resources supplied as handouts during team scoring sessions.

Table B. 1: Climate predictions for temperature.

Output from USGS National Climate Change Viewer (RCP8.5 scenario)

Temperature

	Current 1950-2005 Temp (°C)		Predicted 2025-2049 Δ Temp (°C)		Predicted 2050-2074 Δ Temp (°C)		Predicted 2075-2099 Δ Temp (°C)		
	min	max	min	max	min	max	min	max	
Winter	-7.0	2.5	2.4	1.8	4.4	3.4	6.1	4.8	J
	-6.1	3.6	2.3	1.9	3.9	3.2	5.7	4.7	F
	-2.1	7.5	2.0	1.8	3.4	3.2	4.7	4.4	M
Spring	2.8	13.5	1.8	1.7	3.2	3.1	4.8	4.6	A
	7.9	19.2	1.8	1.8	3.1	3.2	4.6	4.6	M
	13.2	24.2	1.8	1.9	3.3	3.5	4.6	4.9	J
Summer	16.5	27.1	2.0	2.1	3.6	3.8	5.1	5.3	J
	15.9	26.4	2.2	2.2	3.9	3.9	5.5	5.6	A
	11.7	22.4	2.1	2.2	3.8	3.8	5.5	5.4	S
Fall	5.9	16.8	2.2	2.1	3.7	3.6	5.3	5.1	O
	1.4	11.0	2.1	2.0	3.6	3.4	5.0	4.7	N
	-4.2	4.9	2.5	2.2	4.2	3.6	5.6	4.8	D
Winter	-5.1	4.5	2.2	1.8	3.9	3.3	5.5	4.6	
Spring	8.0	19.0	1.8	1.8	3.2	3.3	4.7	4.7	
Summer	14.7	25.3	2.1	2.2	3.8	3.8	5.4	5.4	
Fall	1.0	10.9	2.3	2.1	3.8	3.5	5.3	4.9	
Annual	4.6	14.9	2.1	2.0	3.7	3.5	5.3	4.9	

* RCP8.5 scenario is the most aggressive emissions scenario in which GHGs continue to rise unchecked through the end of the century leading to an equilavent radiative forcing of 8.5 Wm-2, about 1370 ppm CO2 equivalent.

For perspective, the current atmospheric CO2 level is about 400 ppm.

Table B. 2: Climate predictions for precipitation.

Output from USGS National Climate Change Viewer (RCP8.5 scenario)

Precipitation and Water Balance Modeling

	Current 1950-2005 Precip (mm/day)	Predicted 2025-2049 Δ Precip (mm/day)	Predicted 2050-2074 Δ Precip (mm/day)	Predicted 2075-2099 Δ Precip (mm/day)	Change in Evap. Deficit 2025-2049 (mm/mo)	Change in Evap. Deficit 2050-2074 (mm/mo)	Change in Evap. Deficit 2075-2099 (mm/mo)	Change in Runoff 2025-2049 (mm/mo)	Change in Runoff 2050-2074 (mm/mo)	Change in Runoff 2074-2099 (mm/mo)	
Winter	3.2	0.3	0.7	0.9	0.0	0.0	0.0	18.1	32.5	40.4	J
	3.2	0.3	0.5	0.7	0.0	0.0	0.0	24.5	39.4	48.9	F
	3.6	0.5	0.7	0.9	0.0	0.0	0.0	25.6	32.9	33.7	M
Spring	3.5	0.2	0.3	0.5	0.0	0.0	0.0	-9.2	-19.8	-23.2	A
	2.9	0.2	0.2	0.4	0.0	0.1	0.3	-18.8	-28.8	-30.9	M
	2.7	0.2	0.3	0.4	2.2	5.4	8.5	-9.7	-15.1	-16.7	J
Summer	2.5	0.2	0.1	0.2	9.3	23.8	39.3	-4.6	-7.8	-8.5	J
	3.2	0.3	0.2	0.2	8.5	22.3	37.2	-2.0	-4.3	-5.0	A
	3.2	0.1	0.1	0.0	3.5	8.1	14.3	-2.1	-4.7	-5.4	S
Fall	3.2	-0.1	0.1	0.1	0.4	1.1	2.5	-4.8	-7.3	-9.1	O
	3.8	0.2	0.5	0.5	0.0	0.0	0.0	-5.5	-8.5	-13.5	N
	3.6	0.3	0.5	0.8	0.0	0.0	0.0	8.8	13.1	12.6	D

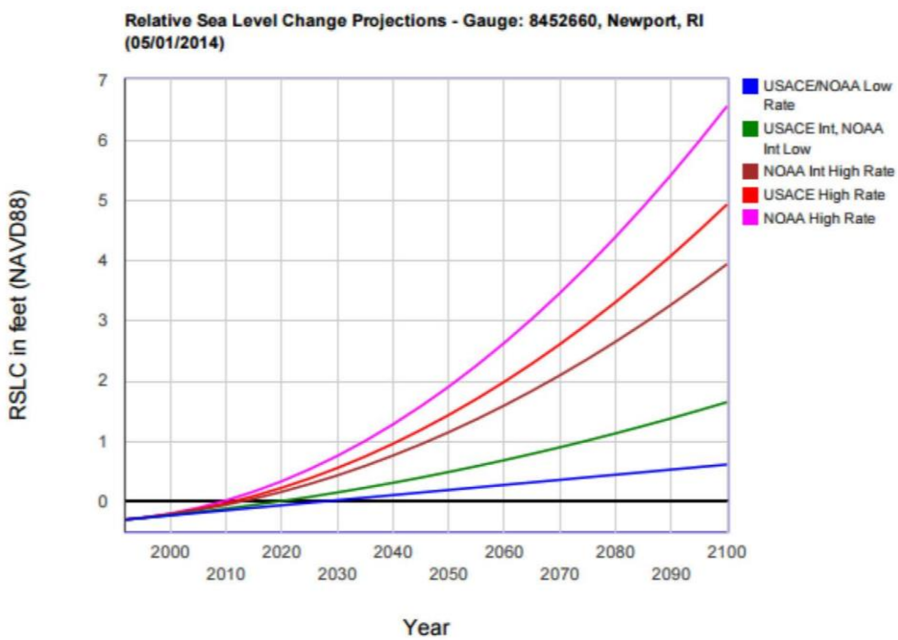
Winter	3.3	0.4	0.6	0.8	0.0	0.0	0.0	22.7	34.9	41.0
Spring	3.0	0.2	0.3	0.4	0.7	1.8	2.9	-12.6	-21.2	-23.6
Summer	3.0	0.2	0.1	0.1	7.1	18.1	30.3	-2.9	-5.6	-6.3
Fall	3.5	0.1	0.4	0.5	0.1	0.4	0.8	-0.5	-0.9	-3.3
Annual	3.2	0.3	0.4	0.5	2.0	5.1	8.4	1.7	1.8	1.9

Definitions:
Evaporative deficit, the difference between potential evapotranspiration (PET), which is the amount of evapotranspiration that would occur if unlimited water were available, and actual evapotranspiration (AET) which is what occurs when water is limited.

Runoff, the sum of direct runoff (DRO) that occurs from precipitation and snow melt and surplus runoff (RO) which occurs when soil moisture is at 100% capacity.

APPENDIX B

RI SLAMM Project Summary Report, Figure 3: Projected sea level rise curves for Newport, RI



Source: https://corpsclimate.us/ccaceslcurves.cfm

Figure B. 1: Climate predictions for sea level change.

Note: The RI assessment team used the 'worst case' scenario curve provided above, which is approximately 2 feet by the assessment end date of 2050.

APPENDIX B

Table B. 3: GIS layers identified as resources for assessing salt marshes in RI and incorporated into a series of maps provided for each assessment site.

File	Name	Description
saltmarsh12	Salt Marsh Habitats (2012)	Salt marsh habitats for the state of Rhode Island derived from high resolution (0.5m) imagery collecting during June 2012.
nbdegrade	Degraded Coastal Wetlands of Narragansett Bay	Internally degraded coastal wetland sites in Narragansett Bay delineated from 1996 true color aerial photography.
industry	Industrial Areas	Land designated for industrial purposes by municipalities
SLAMM15	Sea Level Affecting Marshes Model (SLAMM)	These data represent projected potential impacts to salt and brackish marsh under future scenarios of 1, 3, and 5 feet of sea-level rise as compared to the initial condition in 2010.
locCons14	Conservation Lands: Municipal and NGO	Non-State conservation lands are real property permanently protected from future development by recognized land protection organizations other than the State of Rhode Island.
staCons14	Conservation Lands: State of Rhode Island	Approximate edges of Conservation Lands protected by the State of Rhode Island through Fee Title Ownership, Conservation Easement, or Deed Restriction.
LUSTs12	Leaking Underground Storage Tanks (LUSTs)	Storage tanks and associated piping used for petroleum and certain hazardous substances that have experienced leaks as determined by RIDEM.
ripdes	RIPDES Sanitary Waste Sites	Rhode Island point discharge elimination system point locations for all sanitary waste sites where permits have been issued by RIDEM.
rivers_IWQMA12	Rivers and Streams: RI Integrated Water Quality Monitoring and Assessment Report 2012	Vector line data representing Rhode Island rivers and streams included in the State's Integrated Water Quality and Assessment Report required under provisions of the US Clean Water Act.
hardshore_shp	Hardened Shorelines in Narragansett Bay	Hardened shorelines (piers, jetties, etc) in Narragansett Bay
cerclis	Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS)	Superfund contamination sites; information for specific sites and current status available at http://www3.epa.gov/enviro/
ssurgo_RI	SSURGO	Soil survey spatial and tabular data (available from NRCS Soil Survey)

Note that, unless the source has otherwise been identified, these layers are all available for download on the RIGIS website (http://www.rigis.org/).

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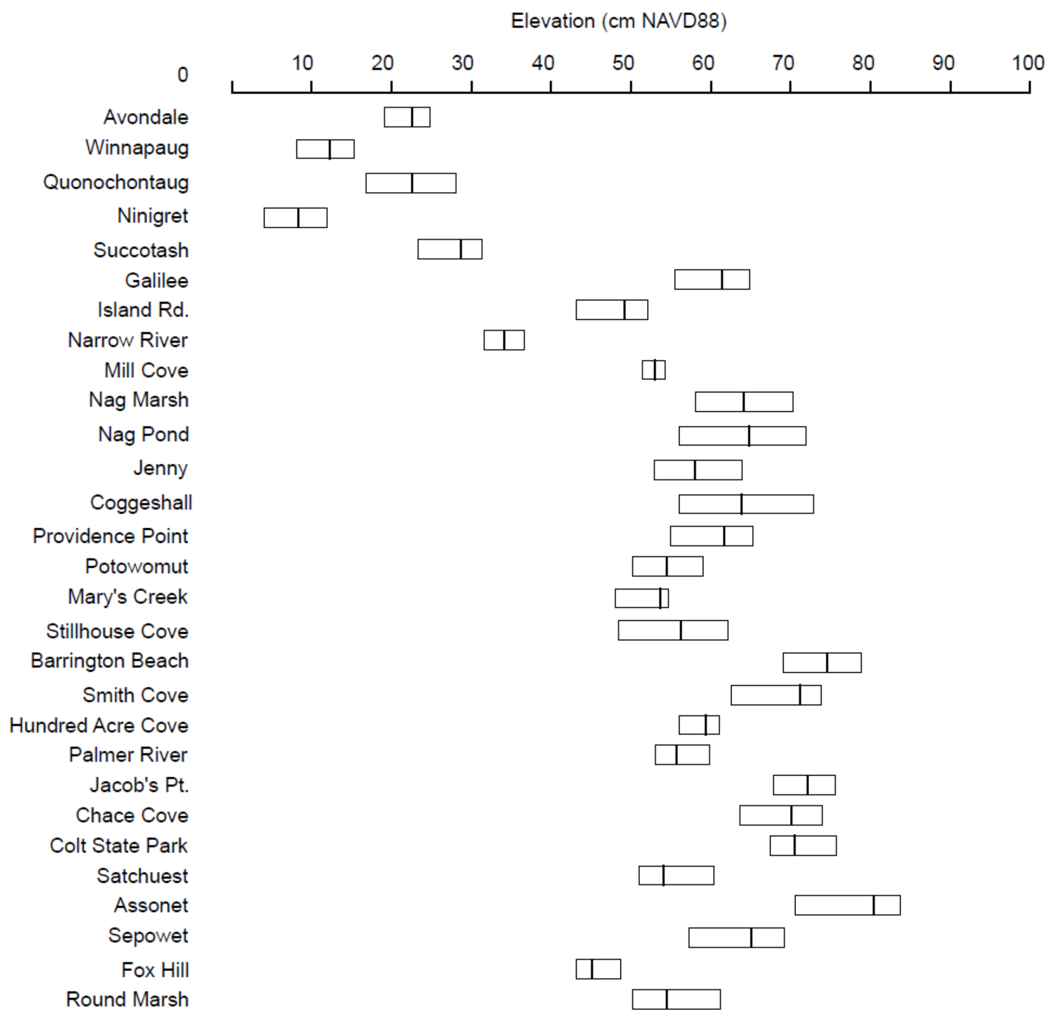

Figure B. 2: Marsh platform elevations relative to NAVD88.

APPENDIX B

Table B. 4: Measured rates of shoreline change extracted from shoreline change maps.

Shoreline Change 1939-2003

	End Point Rate (= est. edge erosion; m) at:				
	Shoreline Edge		**Cove / Channel**		
Site	**min**	**max**	**min**	**max**	**Shoreline Change Map Source**
Barrington Beach	-0.13	-0.5	n/a	n/a	Barrington_Bariington_Beach
Chase Cove	n/a	n/a	0.08	-0.03	Warren_Coggeshall
Coggeshall	0.04	-0.17	0.06	-0.09	Portsmouth_Prudence_Providence_Point
Colt State Park	0.17	-0.09	n/a	n/a	Bristol_Colt_State_Park
Fox Hill	-0.5	-0.71	0.01	-0.05	Jamestown_Beaverhead
HAC_N	n/a	n/a	n/a	n/a	N/A
HAC_SE	0.08	-0.67	n/a	n/a	Barrington_Hundred Acre Cove
HAC_SW	-0.12	-0.19	-0.1	n/a	Barrington_Hundred Acre Cove
Jacob's Point	-0.02	-0.14	n/a	n/a	Bristol_Jacobs_Point
Jenny's Creek	0.14	-0.26	n/a	n/a	Portsmouth_Prudence_Potter_Cove
Mary's Creek	0.03	-0.27	n/a	n/a	Warwick_Appomaug_Cove
Nag Pond	-0.04	-0.46	0.08	-0.18	Portsmouth_Prudence_Prudence_Neck
Nag West	0.06	-0.27	n/a	n/a	Portsmouth_Prudence_Prudence_Neck
Palmer River_N	-0.01	-0.31	n/a	n/a	Barrington_Palmer_River;
Palmer River_S	-0.07	-0.28	0	-0.06	Warren_Belcher_Cove
Potters Pond	-0.03	n/a	n/a	n/a	Portsmouth_Prudence_Potter_Cove
Providence Point	-0.02	-0.24	n/a	n/a	Portsmouth_Prudence_Providence_Point
Round East	n/a	n/a	n/a	n/a	N/A
Round West	-0.04	-0.12	n/a	n/a	Jamestown_Dutch_Island_Harbor
Sachuest	-0.04	-0.38	n/a	n/a	Middletown_Sachuest_Point
Sapowet	n/a	n/a	~ -0.03	~ -0.54	Tiverton_Sapowet_Point
Sapowet Point	~ -0.01	~ -0.44	0	-0.07	Tiverton_Sapowet_Point
Smith Cove	n/a	n/a	~ 0.05	~ -0.04	Barrington_Rumstick_Neck
Stillhouse Cove	0.18	-0.15	n/a	n/a	Cranston_Stillhouse_Cove

* Where rate of change is not displayed, estimates are included based on distance and a 64 year time span.

Note: Shoreline change maps are publicly available at http://www.crmc.ri.gov/maps/maps_shorechange.html.