Case Study: Nag Marsh (West), Prudence Island, RI

Habitat Description

A component of the Narragansett Bay National Estuarine Research Reserve, this approximately 34 acre back-barrier salt marsh has displayed an alarming shift in vegetation community over the past decade. Originally a mix of upper and lower marsh components, there has been a gradual displacement of *Spartina patens* by *Spartina alterniflora* in recent years.

The overall condition of tidal salt marsh within the State of Rhode Island is considered poor (as evidenced by the frequent and wide-spread formation of anoxic pools deteriorating high marsh) with an overall high degree of threat (rank=3). Threats to the unique vegetation communities (e.g. low salt marsh, high salt marsh, salt panne, salt scrub) that comprise this habitat include: habitat shifting and alteration, invasive non-native /alien species, household sewage and urban waste water, housing and urban areas, and recreational activities (RI DEM 2015).

Assessment Period

The team considered an array of time frames for this assessment and opted for an end period of 2050. They felt this would give an appropriate long-term view for making current and near-term management decisions and current models predicting the expected change in environmental conditions were available for this end date. The assumed change in environmental condition for the assessment period included an increase in temperature and precipitation, with a general shift toward greater winter precipitation and more frequent extreme precipitation events (*see* Supplemental Material), as well as a two foot increase in sea level.

Site Stressors and Characteristics Summary

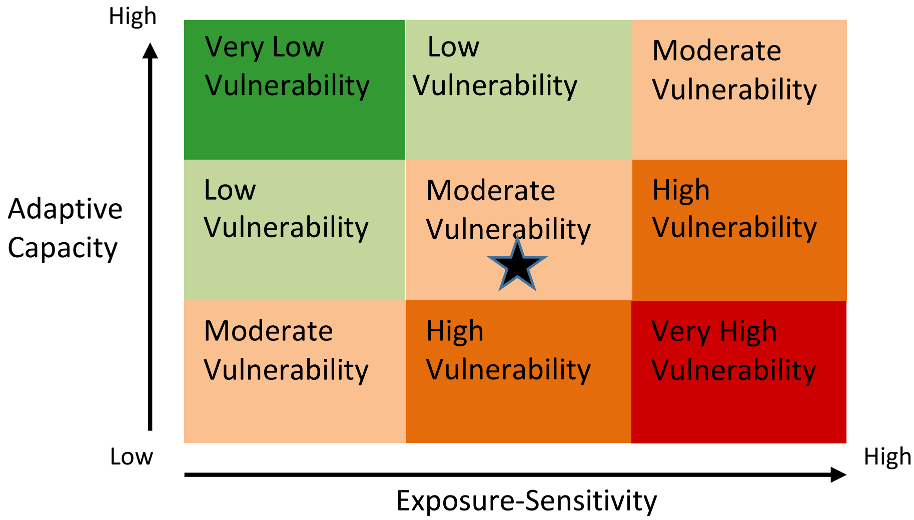
- Almost completely enclosed, "trapped" between a modest dune on the seaward side and a secondary road and higher elevation upland inland
- Barrier dune
- Red maple swamp in southwest containing trapped wet with fresh water; some *Phragmites australis* here
- Historic ditches, many of which are filled in now
- Some patches of dieback, now revegetating
- All protected land, including adjacent properties (discounting the public roadway that comprising a portion of the marsh boundary)
- Monitoring on-going since 2002

Final Scores:
Exposure-sensitivity = 35.5
Adaptive Capacity = 9.0
Certainty = 2.2

Scoring Summary

MODERATE exposure-sensitivity,
MODERATE adaptive capacity,
MODERATE overall vulnerability.

Overall Vulnerability



Nag Marsh (West) is located in a rural and natural setting relatively free from the influence of nutrient and pollutant exposure via groundwater or stormwater inputs. At mid-bay, it has a slightly higher elevation relative to marshes located further south and is somewhat protected from extreme storm events situated as it is behind a modest dune. The presence and influence of non-native invasive species is not yet extreme and is anticipated to remain somewhat constant. The moderate exposure-sensitivity score reflects the relatively un-impacted condition of this site and greater presumed resiliency associated with its geomorphic setting.

The moderate adaptive capacity score reflects this site's protected status and some limited capacity to migrate into unobstructed adjacent protected wetland areas (some areas are too steep to allow for migration) as well as the institutional capacity to both continue monitoring efforts and react to some extent to changing conditions as necessary. However the score also reflects the lack of potential management actions possible given the isolated location and access constraints for many potential manipulations given its island setting.

The overall vulnerability score is based on the relationship table above in which moderate scores for both exposure-sensitivity and adaptive capacity situate this site in one of three possible bins for moderate vulnerability. This moderate score suggests that while the site is not extremely vulnerable to non-climate stressors and the anticipated change in climate condition, neither does it have sufficient adaptive capacity components that would fully mitigate expected changes in environmental condition. Given the already degraded condition at this site, as evidenced by assigned scores for current condition and climate/non-climate stressor interactions, Nag Marsh (West) will likely experience a continued decline in condition in future decades.

Assigned Scores

The assessment team collaborated to create and review a list of reference materials which they incorporated into a resource document designed to capture relevant information from assorted data sets, white papers and published journal articles. To simplify the scoring process, this resource document was then converted into a bulleted list of anticipated species and/or habitat responses to the anticipated change in condition. The notes provided below reflect both general discussion content from the bulleted list which, together with the original resource document and the CCVATCH Guidance document as necessary were used as the primary source of considerations when discussing score assignment (at left) as well as more specific discussion points and considerations related to this site, if applicable (at right). Inserted grey boxes reflect the outcome of early team discussions regarding specific site characteristics that would influence score assignment; if none exist, then scores were assigned consistently for all sites.

Direct Climate Effects	
Current Condition: • Range shifts, altered species composition • ↓ forb communities • ↓ high marsh • ↑ die-back • Declines in salt marsh extent since 1860s; loss rate over 40 years = 17.3% • Loss through: shoreline erosion, reduced bay head region (back-barrier lagoons & estuaries), widening & headward expansion of tidal channels (+ formation/expansion of interior ponds) *Sites vary based on: presence/absence or extent of die-back areas; ratio of high/low marsh (or percent of transitional marsh communities); and/or extent of vegetation loss*	• ↑ die back • A lot of short form *Spartina alterniflora* present Assigned Score: 5 Certainty: 4
Increase in CO_2: • No expected change to C4 plants but ↑ biomass in C3 plants (*Scirpus*, *Phrag*) • Root %N ↓ and C/N ↑ in *Scirpus* could decrease decomposition and increase peat formation *Individual site response does not vary: Score = 0; Certainty = 4*	Assigned Score: 0 Certainty: 4
Increase in Temperature: • Δ competitive interactions • ↑ marsh decomposition rates • ↓ organic matter accretion • ↓ forb pannes **Note:** Although it was agreed that vegetation community composition (specifically the presence/absence and extent of forb panne communities) could be reflected in a differential response between sites, the variation in marsh communities across the state is very modest and would likely not support different scoring.	

Individual site response does not vary: Score = 2; Certainty = 3	Assigned Score: 2 Certainty: 3
Change in Precipitation: • Seasonal Δ timing/duration influences salinity through salt H_2O intrusion • Changes in groundwater flow/level can impact marsh elevation • Δ precipitation = ↓ productivity • C4 better competitors with frequent/more severe drought • ↓ precipitation and drought have no significant impact on *S. patens* • Dieback ↑ during drought? *Sites vary based on: relative groundwater levels (potentially, although site specific data is not available); species composition (maybe)*	Assigned Score: 2 Certainty: 3
Change in Sea Level: • Effects species distribution (shift to more salt tolerant species) • ↓ high marsh • ↓ low sediment marshes • ↑ inundation reduces below-ground biomass of *S. alterniflora* • ↑ inundation drives vegetation loss (elevation as proxy for inundation accounts for 96% of var. in loss rates); elevation threshold for *S. patens* = 0.51mNAVD88 *Sites vary based on: change in tidal range (using relative elevation as proxy)*	• Losing high marsh (indicated through long-term monitoring) Assigned Score: 2 Certainty: 4
Change in Extreme Climate Events: • ↑ extreme disturbance favors species that are 'colonizers' • Δ upland/marsh interface • ↑ compression of marsh surface due to weight of storm surges • Δ plant communities • ↑ debris *Sites vary based on: differences in geomorphology (e.g. presence/absence of dunes, orientation relative to dominant wind direction, degree of fetch); proximity to rivers prone to flooding; adjacent land use*	• Barrier dune may be compromised Assigned Score: 2 Certainty: 1

Invasive / Nuisance Species	
Current Condition: • Many exotic grazers and predators are present and increasing (interactions with natives vary ±) • Many anthropogenic impacts making things worse (e.g. eutrophication, overfishing, shoreline development)	• Some *Phragmites australis* • High numbers of fiddler crabs

• Range expansion by native plants, animals occurring (impacts debated ±) *Sites vary based on: presence/absence/proximity of Phragmites; presence/abundance of crab herbivores (if/when data available); presence/absence/proximity of others (e.g. perennial pepperweed, purple loosestrife)*	Assigned Score: 3 Certainty: 2.5
Increase in CO_2: • ↑ could enhance fitness of many marsh invasives (e.g. *Phragmites*) as well as some natives (e.g. poison ivy) • *Phragmites* does better with salt stress with ↑ CO_2 and ↑ temperature • Reduction in %N of *Scirpus* shoots results in an increase in green tissue C/N (may effect herbivore preferences and feeding rates); not true of C4 grasses (*S. patens, D. spicata*) **Note:** Response of *Phragmites* to both elevated CO_2 and temperature should only be considered once (do not double-count impact under both stressors *Individual site response varies only by presence/absence/proximity of invasives: If absent – Score = 0; Certainty = 1*	• Low *Phragmites* #s here but likely will benefit Assigned Score: 1 Certainty: 4
Increase in Temperature: • ↑ temperature and CO_2 may make *Phragmites* more tolerant of salt stress • C4 plants more resistant to *Phragmites* encroachment • ↑ temperature may encourage range expansion of southern species (animals quicker, plants) • Impacts of both natural and facilitated expansion debated • Facilitates *Phragmites* encroachment (with elevated CO_2) *Individual site response varies only by presence/absence/proximity of invasives: If absent – Score = 0; Certainty = 1*	• Likely longer season and better winter survival of crabs Assigned Score: 2 Certainty: 1
Change in Precipitation: • May cause species, currently limited by seasonal flooding, to spread • Plants and animals vulnerable to flooding may experience negative impacts • Multiple stressors (abiotic + biotic) may act synergistically with ↑ precipitation *Individual site response varies only by presence/absence/proximity of invasives: If absent – Score = 0; Certainty = 1*	Assigned Score: 1 Certainty: 1
Change in Sea Level: • Rising SL may accelerate loss of some natives (e.g. salt sensitive species) • Salt sensitive species may move inland if possible • Multiple stressors may act synergistically with SL ↑ • ↑ salt will kill *Phragmites* • SLR = ↑ fiddler crabs	

Note: Although site specific responses may in fact vary, the relative cost/ benefit associated with invasive/nuisance species (e.g. reduced *Phragmites*, increased crabs) is simply too complex without additional information with which to make that determination. *Individual site response varies only by presence/absence/proximity of invasives: If absent – Score = 0; Certainty = 1*	Assigned Score: 3 Certainty: 2
Increase in Extreme Climate Events: • Variable impacts on species, disease, vectors, etc. • Range expansion likely • More disturbances could ↑ vulnerability to invasion *Individual site response varies only by presence/absence/proximity of invasives: If absent – Score = 0; Certainty = 1*	Assigned Score: 0 Certainty: 1

Nutrients	
Current Condition: • High nutrient levels cause ↑ aboveground and ↓ belowground biomass; accelerates organic matter decomposition; marsh geomorphic stability is lost • ↑ N bad for high marsh - ↑ N favors *S. alterniflora* and *Phragmites* at expense of *S. patens* • ↑ N may allow marshes to accrete faster than sea level rise • N loading may reduce soil accretion in highly organic marshes (by ↓ allocation to roots); species composition shift to species that produce less below ground biomass *Sites vary based on: nutrient input source/levels (use adjacent land use as proxy / estimator); vegetation composition; relative position in Bay (upper vs lower); other nutrient sources*	• No/low human influence • Lot's of data Assigned Score: 0 Certainty: 4
Increase in CO_2: • Changes to vegetation communities (e.g. *Phragmites* promotion) affects N pools • Changes to structure/function of microbial N transformers • C3 species ↑ aboveground prod. with N + CO_2 (but not each alone) • ↑ C4 growth under high N (above- and below-ground) but response ↓ with increasing CO_2 *Individual site response does not vary: Score = 0; Certainty = 0.5*	Assigned Score: 0 Certainty: 0.5
Increase in Temperature: • Warming ↑ aboveground for *S. alterniflora*, but not high marsh plants • Stem height ↑ for both low + high marsh with warming	

• Warming ↑ decomposition for *S. patens* • ↑ temperature = ↑ nutrient cycling *Individual site response does not vary: Score = 0; Certainty = 2*	Assigned Score: 0 Certainty: 2
Change in Precipitation: • Drought decreased decomposition for native high marsh • Drought ↑ total biomass for *S. alterniflora* and *S. patens* • Changes in water levels could influence nutrient availability/circulation • ↑ in wet deposition of nutrients *Sites vary based on: potential for nutrient input via surface and groundwater (using adjacent land use [and slope] as proxy])*	• Very low upland sources, only estuarine (negligible • Monitoring since 2002* Assigned Score: 0 Certainty: 3
Change in Sea Level: • With ↑ N, marshes may keep up with sea level rise • Other factors (like climate, nutrients, predation) impact marshes abilities to survive SLR • SLR and high N load may degrade marshes by cooperatively contributing to ↑ hydrogen sulfide concentration (↑ decomposition) **Note:** Reference documents are not as definitive as the first and third bullets suggest. All factors that influence growth rate may influence ability to survive SLR. Fertilization may alter community composition and increase turf building capacity. Negative feedback associated with increased decomposition (and lower accretion rates) may result in greater drowning potential. *Sites vary based on: frequency/duration of inundation (with elevation as proxy) if nutrient sources (i.e. from adjacent land use, relative position in Bay) are thought to influence site*	Assigned Score: 0 Certainty: 3
Increase in Extreme Climate Events: • May cause more frequent combined sewer overflows **Note:** General knowledge also suggests storm related flooding and run-off as source. *Sites vary based on: expected influence and proximity of overflow locations (e.g. upper vs. lower Bay); other sources (using adjacent land use as proxy); slope; geomorphology*	Assigned Score: 0 Certainty: 3

Sedimentation	
Current Condition: • Salt marshes in RI are not keeping pace with SLR; low suspended sediment in Narragansett Bay	• Dune is the main source (< 5' high)

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- ↑ ditching in marshes = ↓ sedimentation
- Height and width of barrier is related to sedimentation rate in back barrier system
- ↓ sediment supply may exacerbate marsh loss but unlikely sole driver
- With ↑ sediment of 1-2 orders of magnitude, marsh can form in < 100 years

Sites vary based on: extent of ditching; river/streams inputs (or presence/ absence of river/streams as estimator); presence/absence of dunes

</td><td>Assigned Score: 2
Certainty: 3</td></tr>
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Increase in CO_2:

- Sediment trapping ↑ in C3 plants with ↑ N <u>and</u> ↑ CO_2

Individual site response does not vary: Score = 0; Certainty = 2

</td><td>Assigned Score: 0
Certainty: 2</td></tr>
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Increase in Temperature:

No impact of increase on sediment supply anticipated. All sites = no score.

</td><td>Assigned Score: -
Certainty: -</td></tr>
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Change in Precipitation:

- ↑ precipitation may increase sediment supply from uplands/streams

Sites vary based on: adjacent land use; presence/absence of streams

</td><td>Assigned Score: 0
Certainty: 3</td></tr>
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Change in Sea Level:

- Accretion rates across Narragansett Bay are not keeping pace with SLR
- ↑ inundation period may increase sediment deposition
- In vegetated marshes with high sediment loads, marshes may sustain elevation with SLR
- Narragansett Bay marshes rely primarily on <u>organic</u> accretion – ratios are site-specific
- Non-tidally restricted marshes may <u>not</u> drown

Note: Although the degree of tidal restriction and sediment load may influence sites, it is not possible to predict relative response to these factors.

Individual site response does not vary: Score = -1; Certainty = 1.5

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Certainty: 2</td></tr>
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Increase in Extreme Climate Events:

- Summer storms a major factor in defining short-term variability in sedimentation rates

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- Overwash is possible as well as dune blowout

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• Storm events dominate accretion/sedimentation rates at certain marshes. Mostly riverine systems and those subject to storm overwash *Sites vary based on: expected influence and proximity of overflow locations (e.g. upper vs. lower Bay); other sources (using adjacent land use as proxy); slope;*	Assigned Score: -2 Certainty: 2

Erosion	
Current Condition: • Look up annual erosion rates from CRMC for each marsh (http://crmr.ri.gov/maps/) • Edge vegetation has been denuded by overabundant marsh crabs • Vegetation loss leads to widening of creek banks and loss of marsh edge/area • Soil type and geographical setting are most important factors when comparing erosion rates among sites • Erosion continuously occurs (no critical threshold below which there is none) *Sites vary based on: erosion rates (using shoreline change maps as proxy for current rates); evidence of creek widening; soil type; geomorphic setting*	• Edge erosion ↑ with crabs • No/low wave exposure within marsh Assigned Score: 2 Certainty: 3
Increase in CO_2: • ↑ soil surface cover from ↑ plant production can reduce erosion rates **Note:** Although the decomposition of peat (and potential for increased erosion) could also be exacerbated by CO_2, levels of CO_2 across the state are assumed to be basically a constant and therefore no site specific variation in score for this impact is possible either. *Individual site response does not vary: Score = 3.9; Certainty = 3*	Assigned Score: 0 Certainty: 3
Increase in Temperature: • ↑ temperature = ↑ belowground decomposition = ↑ erosion (maybe) *Individual site response does not vary: Score = 3.9; Certainty = 3*	Assigned Score: 3.9 Certainty: 3
Change in Precipitation: • With increased rainfall, there may be an increase in erosion at riverine salt marsh systems **Note:** Acknowledging that variation between sites is possible, this metric presents a challenge as differences in stream flow rate, channel width/depth etc. are generally not known.	

Sites vary based on: proximity of rivers/streams influencing scouring levels	Assigned Score: 0 Certainty: 4
Change in Sea Level: • As marshes drown, wind-driven waves will erode unvegetated platforms • Platform marshes are more susceptible than ramp (fringe) marshes because they are expected to drown at once • ↑ SL of 30 cm will ↑ potential erosion on marsh surface by 50% (considered by authors as not significant) • Shoreline erosion with ↑ wind wave exposure (associated with ↑ depth, fetch, bottom shear stress) *Sites vary based on: type (e.g. platform, fringe); orientation to dominant wind direction; relative elevation; measured erosion rates (e.g. from shoreline change maps); percent vegetated cover*	• Protective value of dune may persist even with 2' rise Assigned Score: 2 Certainty: 2
Increase in Extreme Climate Events: • ↑ storms = more erosion of barrier beaches = ↑ threat to back barrier marshes • Violent storms and hurricanes contribute less than 1% to long-term salt marsh erosion rates **Note:** Given the somewhat contradictory statements of the two bullets, the choice was made to consider only the second for scoring purposes. *Individual site response does not vary: Score = 1.7; Certainty = 2*	Assigned Score: 1.7 Certainty: 2

Environmental Contaminants	
Current Condition: • There is a presumed tolerance to historic and persistent levels of exposure; however "cost" may be reduced ability to tolerate climatic stress • Certain legacy pollutants are decreasing, but other emerging contaminants are increasing and it is unknown how these 'new' contaminants will affect marsh growth • CC will stress communities through shifting them into non-optimal areas, ↓ resiliency, ↓ diversity, ↑ stress *Sites vary based on: proximity and source of exposure to both legacy and emerging contaminants; adjacent land use*	Assigned Score: 0 Certainty: 1
Increase in CO_2: • ↑ CO_2 can alter key ecosystem processes by altering contaminant mobility	

Note: There is insufficient information to determine the degree to which contaminant mobility is affected by CO_2 (and the degree to which contaminant uptake will alter ecosystem processes). No variation in score possible unless new information becomes available. *Individual site response does not vary: Score = 0; Certainty = 1*	Assigned Score: 0 Certainty: 1
Increase in Temperature: • May increase contaminant uptake and stress plant/animal community • May see ↑ use of pesticides / persistent organic pollutants (POPs) with ↑ temperature; ↑ temperature may alter uptake and physiological response • ↑may favor hardier species (more toxic species) that cause harmful algal blooms (HABs) **Note:** Although temperature is assumed to have some effect, there is no data available to determine if a 2° change is a sufficient trigger. No variation in score possible unless new information becomes available. *Individual site response does not vary: Score = 0; Certainty = 1*	Assigned Score: 0 Certainty: 1
Change in Precipitation: • ↑ precipitation = ↑ runoff = ↑ contaminants delivered to marshes • ↑ precipitation = ↑ wet deposition *Sites vary based on: presence/absence of contaminants; slope; presence and amount of stormwater and stream inputs; adjacent land use*	Assigned Score: 0 Certainty: 1
Change in Sea Level: • Changes to land use/land cover will alter runoff / flooding and delivery of contaminants • Changes bioavailability based on changes in salinity • Sea level affects infrastructure which alters contaminant delivery if infrastructure fails or is flooded *Sites vary based on: presence/absence of contaminants; contaminant delivery as function of flooding associated with SLR [potentially using elevation as proxy]*	Assigned Score: 0 Certainty: 1
Increase in Extreme Climate Events: • Can cause ↑ flooding of infrastructure / landfills, ↑ contaminant delivery *Sites vary based on: presence/absence of contaminants; contaminant delivery as function of coastal flooding potential*	Assigned Score: 0 Certainty: 2

Degree of Fragmentation	
• Many species (particularly plants) decrease with fragmentation • Fragmentation exacerbates vulnerability as harder to move and ↓ genetic diversity • Many mutualisms hindered by fragmentation • Edge effects	• Not a foreseeable problem Assigned Score: 2 Certainty: 2
Barriers to Migration	
• ↑ permeability = ↑ adaptability (through migration/range shift) • Relatively flat topography may result in ↑ shifts if barriers are at a greater distance (or absent) • Steep natural topography, but may still allow fringe marsh if erodable • Hardened, developed shoreline, more of an impediment • # and size of structures may ↑ in response to SLR	• Dirt roads bisects Nag W from Nag E • Freshwater slopes are steep Assigned Score: 1 Certainty: 2
Recovery / Regeneration	
• Speed of recovery / regeneration depends on severity of disturbance • Must be careful with restoration targets (i.e. is it likely that historic targets not going to be possible in future) • Where tidal exchange occurs through narrow inlets, tidal range restricted (and converse is true); may influence response	• This site has low tidal range and narrow inlet Assigned Score: 2 Certainty: 2
Diversity of Functional Groups	
• Dependent on disturbance level / stress • Biogeographical shifts of community already occurring and will continue • Changes to growing season will affect which species/groups are active when	Assigned Score: 0 Certainty: 4
Management Actions	
• Current marsh extent is a relic of historic land-use change; allow return to 'natural state'	• Not much we can do • This is an old "natural " marsh Assigned Score: 0 Certainty: 3
Institutional / Human Response	
• Decide if assisted migration is valid • Varied (depends on current/future management agency)	Assigned Score: 4 Certainty: 4

Research Needs

Certainty scores reflect the source of information considered when assigning sensitivity-exposure and adaptive capacity scores and ranges from zero (0; no direct or anecdotal evidence) to four (4; strong evidence, high consensus). Across all assessed sites within the state, overall certainty tended to be moderately higher at individual sites where local data sources were available or active management was being planned or applied.

Certainty score assignment associated with specific stressors (or stressor interactions) that are assigned an average score of less than two across sites indicates a general lack of evidence or consensus regarding habitat response. In the table below, circles indicate stressor / stressor interactions that fall within that category. Closed circles (●) indicate specific instances in which Nag Marsh also received low scores for those stressors and open circles (○) indicate higher than average certainty scores since more information about this specific site is known. X's indicate instances where the available information related to Nag Marsh was considered lacking and therefore were assigned less than the average certainty score. Cells in the table marked with ● or X's generally suggest that more research is needed to better understand habitat response at Nag Marsh.

	Current Condition	CO_2	Temp.	Precip.	Sea Level	Extreme Climate
Direct Effects						●
Invasive /Nuisance Sp.			X	X		X
Nutrients		●		○	○	○
Sedimentation						
Erosion						
Env. Contaminants	●	●	●	●	●	○
	Habitat Fragment.	**Barriers**	**Recovery /Regen.**	**Functional Groups**	**Management Actions**	**Inst./Human Response**
Adaptive Capacity						

Process and Facilitation

Numerous meetings were conducted over the course of a year to implement CCVATCH in the State of RI. The assessment team members varied somewhat, but a core group representing numerous state agencies (e.g. RI Coastal Resources Management Council, US Environmental Protection Agency, US Fish and Wildlife Service, Narragansett Bay National Estuarine Research Reserve, Audubon Society of RI, and Save The Bay) have consistently participated throughout the process. The process of applying CCVATCH in RI required the following general steps:

- Overview of tool & habitat selection
- Identification of experts, resources (e.g. published literature, available data sets, etc.) available
- Outreach to experts to solicit additional resource material
- Review of reference material & generation of resource document

- Create bulleted list from resource document to assist with scoring
- CCVATCH score assignment to selected sites

Team members were originally invited from a master list of attendees at a salt marsh conference recently held in the state. While this may have biased habitat selection toward salt marsh, specifically those marshes for which monitoring data were available, other habitats were identified as priorities for assessment such as tidal river/stream and submerged aquatic vegetation (SAV) for future efforts. Additional applications of CCVATCH to these habitats may take place in future, particularly if on-going efforts in other New England states develop resource documents that would aid in the process (*see* http://graham.umich.edu/activity/32984 for a project overview).

Climate Forecast

Temperatures in the Northeast increased by almost 2°F between 1895 and 2011 (0.16°F per decade) and precipitation increased more than 10%, approximately 5 inches (0.4 inches per decade; Horton et al, 2014). For the State of Rhode Island, a change in annual mean temperature of +3.6°F is expected by 2050 with comparable increases in annual precipitation levels, predominantly in the winter months (RCP8.5 scenario; Alder and Hostetler, 2013). Increased winter precipitation would mean more water available for runoff and evaporation. Rising temperatures would melt snow faster and earlier, likely increasing runoff and soil moisture in winter and early spring followed by reductions in soil moisture in the late summer and early fall, since warmer temperatures drive higher evaporation rates. The Northeast has experienced a greater recent increase in extreme precipitation than any other region in the United States, more than 70% increase in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) between 1958 and 2010 (Horton et al, 2014). Long-term rates of sea-level rise are 2.74 mm year-1 from 1930 to 2013 at the Newport, RI tide station; rates calculated from more current data over a shorter time scale suggest 4 mm year-1 increase in mean high water (MHW) from 1993 to 2014 (Boyd & Freedman, 2015). A two foot increase in sea level for 2050 and five foot increase by 2100 predicted using the NOAA High Rate sea level rise curve for this area has been adopted by the state to govern policy and management.

	Current (1950-2005) Temp (°C)		Predicted 2025-2049 Δ Temp (°C)		Current (1950-2005) Precip (mm/day)	Predicted 2025-2049 Δ Precip (mm/day)	Change in Evap. Deficit 2025-2049 (mm/mo)	Change in Runoff 2025-2049 (mm/mo)
	min	max	min	max				
Winter	-5.1	4.5	2.2	1.8	3.3	0.4	0.0	22.7
Spring	8.0	19.0	1.8	1.8	3.0	0.2	0.7	-12.6
Summer	14.7	25.3	2.1	2.2	3.0	0.2	7.1	-2.9
Fall	1.0	10.9	2.3	2.1	3.5	0.1	0.1	-0.5
Annual	4.6	14.9	2.1	2.0	3.2	0.3	2.0	1.7

*Data from USGS National Climate Change Viewer (RCP8.5 scenario; Mean Model output available Jan. 2016)

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