

## **Vulnerability Assessment of Chase Garden Creek**

Year 1 Annual Report: March 2023 – January 2024

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Association to Preserve Cape Cod

*Project funded by the Lavori Sterling Foundation*



*Chase Garden Creek salt marsh, July 2023 (photo credit: APCC).*

### **Summary**

In November 2022, the Association to Preserve Cape Cod (APCC) began a five-year study of the Chase Garden Creek salt marsh system in Dennis and Yarmouth. The purpose of this multi-year project is to 1) evaluate the current status and future trajectory of the estuarine and coastal habitats with a particular focus on salt marsh health, 2) investigate impacts of various environmental and anthropogenic disturbances, 3) provide recommendations for protection and restoration of the vulnerable habitats, and 4) work with the relevant land managers to seek additional funding and permits towards restoration implementation. This report provides information collected by APCC during the first year of the study, from March 2023 to November 2023. Results from a GIS-based, landscape-scale assessment and a rapid field survey indicate that some areas of the marsh are degrading more rapidly than others and these areas are also at risk of deteriorating further with future sea level rise. These results will be used to inform subsequent monitoring and evaluation in Year 2.

Background (Task 1)

The Chase Garden Creek estuary on Cape Cod contains a vast, roughly 1,500-acre salt marsh system that extends into the towns of Dennis and Yarmouth on the north side of Cape Cod, Massachusetts (Figure 1). The headwaters of the creek and marsh begin in Dennis near Scargo Lake, and in Yarmouth near Tom Mathew’s Pond. The outlet for Chase Garden Creek is in Barnstable Harbor on Cape Cod Bay, just beyond Nobscusset Point and Chapin Beach in Dennis. Historic maps indicate that colonial settlements existed around Chase Garden Creek but do not indicate where or when there was agricultural activity on the marsh itself. Field visits and aerial imagery indicate the presence of agricultural/mosquito control ditches throughout the marsh. Additionally, manmade berms were observed along the upland edges of the marsh on the Dennis side of Chase Garden Creek.

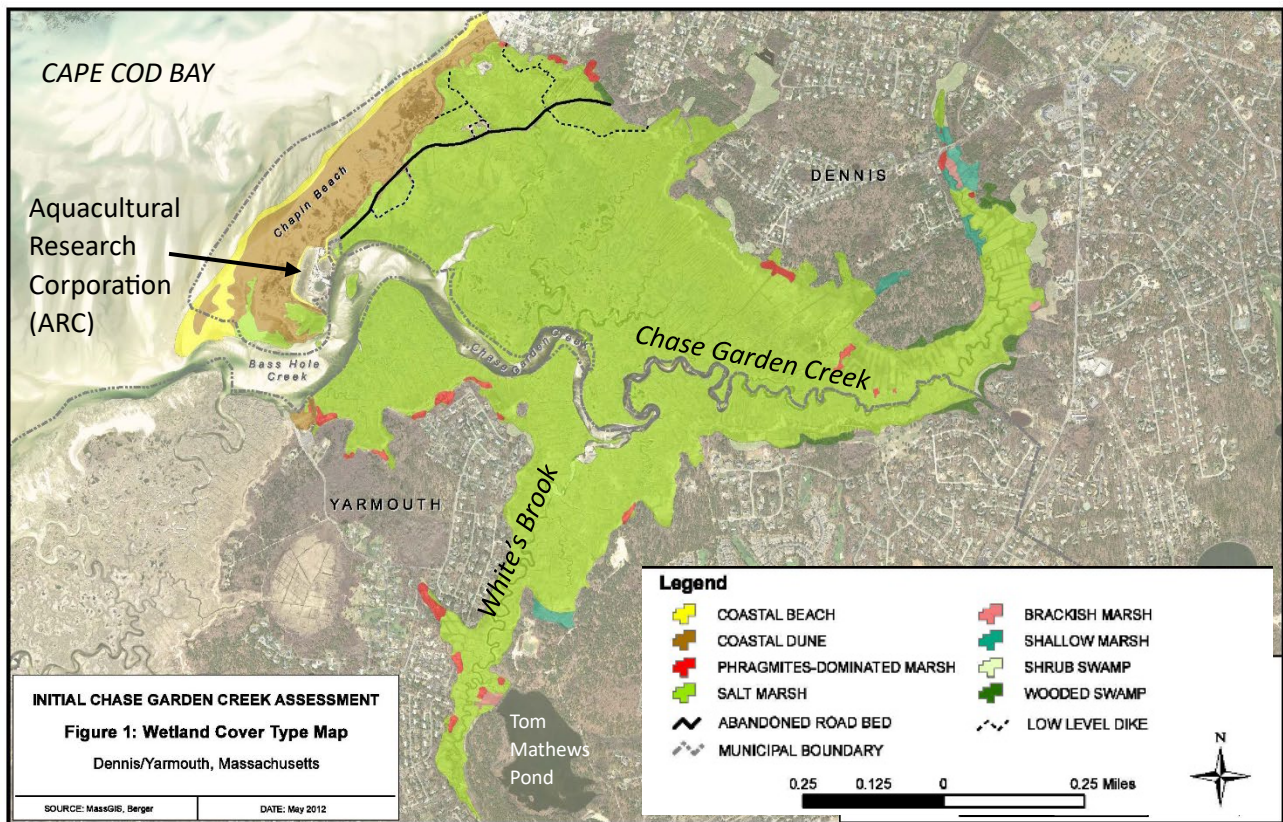


Figure 1: Map of Chase Garden Creek modified from Louis Berger Group (2012) showing major habitat types, municipal boundaries, and other important features.

The Chase Garden Creek system supports the local aquaculture industry (Aquacultural Research Corporation is located at the inlet; see Figure 1) and the marsh also provides essential habitat for commercially and recreationally significant fish species such as river herring, American eel, and striped bass. Furthermore, the estuary is home to several threatened or endangered fish, wildlife, and plant species including juvenile winter skate (*Leucoraja ocellata*), salt marsh sparrow

(*Ammodramus caudacutus*), diamondback terrapin (*Malaclemys terrapin*), and Mitchell's sedge (*Carex mitchelliana*) (Figure 2).

APCC reviewed previous studies to learn more about the site prior to the investigation in the marsh. A brief summary of the key findings from each of these studies is provided as background to this report. While there is currently ongoing water quality monitoring conducted by the Dennis Conservation Land Trust, no other monitoring programs are currently active at this site (see discussion on herring counts below).



Figure 2: Threatened or endangered species utilizing habitat in the Chase Garden Creek estuarine system. Top left: winter skate (*Leucoraja ocellata*). Top right: salt marsh sparrow (*Ammodramus caudacutus*). Bottom left: diamondback terrapin (*Malaclemys terrapin*). Bottom right: the Mitchell's sedge (*Carex mitchelliana*). Photo credits: Google, November 2023.

### *Sediment Dynamics*

The sediment transport appears very dynamic at Chase Garden Creek. Multiple surveys and reports have shown conflicting net transport directions at this site. In a comparison of sediment budget studies from 1964, 1966, and 1993, the area along the coast of Chapin Beach was highlighted as an area of conflict (Berman, 2011; Figure 3). The 1964 study identified a net westward transport of sediment from Chapin Beach into the Chase Garden Creek and Great Marshes estuaries. The 1966 study indicated that there is an approximate division in net transport direction and Chapin Beach acts as a sediment source for the coastline east of the beach and for the inner estuaries to the west. The 1993 study concluded that the net sediment transport along Chapin Beach was to the east. These studies and further analyses show that the system has changed significantly over the past 60+ years, and that both short-term and long-term trends may be unpredictable (Berman, 2011; Center for Coastal Studies, 2022).

While the overall sediment transport trends may change, the main issue is that Chapin Beach has been eroding and the channel bed of Chase Garden Creek is accumulating sand. The most recent direction of transport (from east to west) is consistent with the Center for Coastal Studies (CCS) Sediment Budget Report (Center for Coastal Studies, 2022), and some historic reporting from the Long Shore Sediment Transport report (Berman, 2011). Additionally, APCC reviewed aerial imagery over the past two decades and found that the point at the southwestern end of Chapin Beach has migrated eastward towards the channel of Chase Garden Creek.

The conflicting and changing reports of sediment transport along this coastline indicate that large-scale studies may not provide definitive conclusions about long-term sediment dynamics in this

area. More localized, site-specific assessments would provide a clearer picture of how these sediment dynamics impact the estuarine system as a whole, and in particular, how these shifting processes affect the sediment supply to the Chase Garden Creek salt marsh.

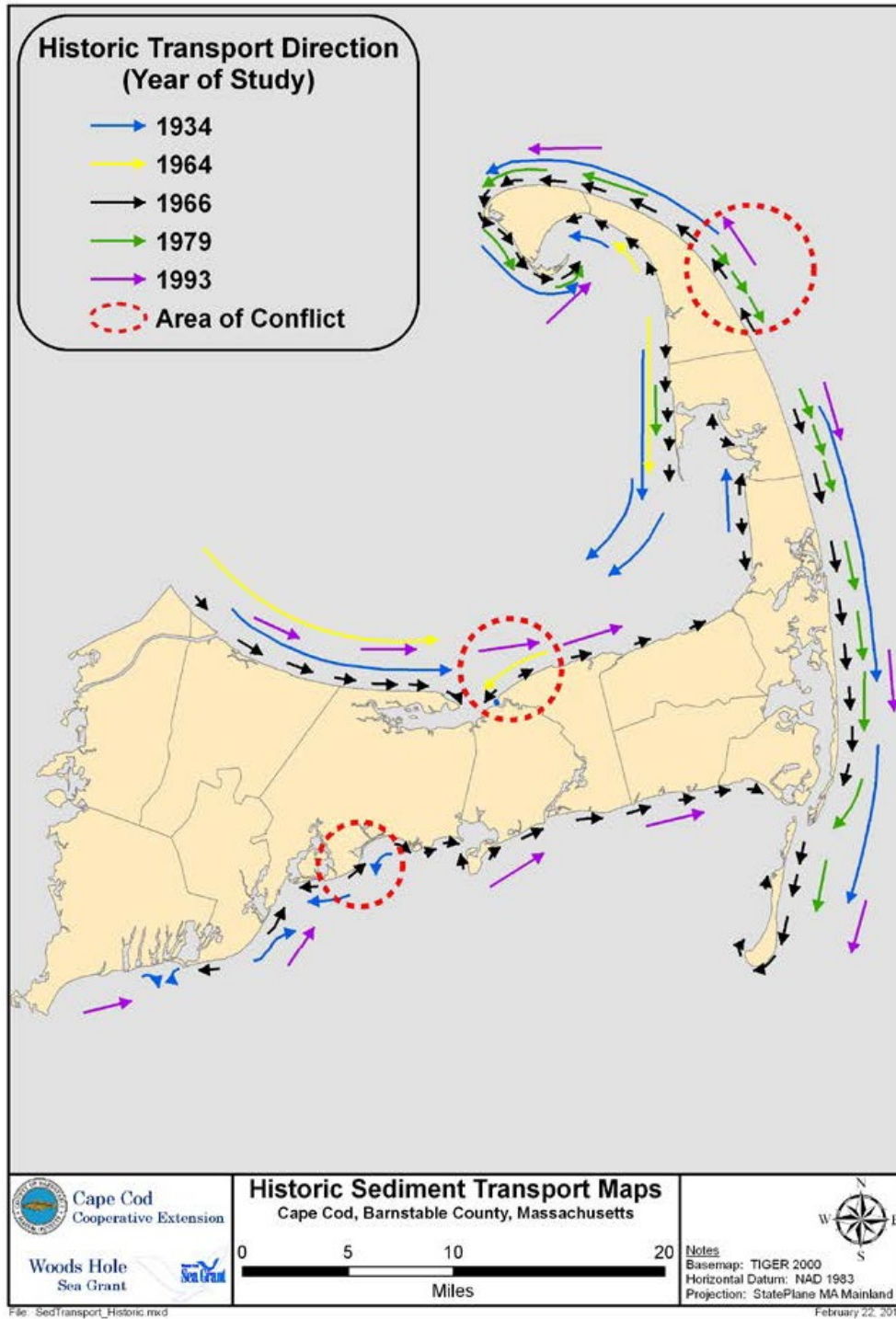


Figure 3: Map showing historic sediment transport from various studies over time and indicating areas where sediment transport direction has changed, referred to as “areas of conflict” (Berman, 2011).

*Tom Mathews Pond Fish Spawning Habitat*

The Massachusetts Division of Marine Fisheries (DMF) conducted a 2012-2013 analysis of the fish passage and water quality at Tom Mathews Pond, which drains to Chase Garden Creek via White’s Brook (Archer and Chase, 2022). This study indicated that water quality parameters were outside of the acceptable criteria range for river herring during the spawning period of May-September for temperature, pH, total nitrogen and phosphorous, and stream flow. During the same timeframe, the degraded state of the fish ladder, which was deemed impassable for migrating adults on several occasions during the spawning and nursery periods in 2012-2013, prompted the replacement of the fish ladder in 2014. APCC also conducted volunteer herring counts from 2014 to 2022, partnering with the pond’s landowner (Bass River Rod & Gun Club). While the herring run estimate was over 70,000 in 2014, estimates began to decline rapidly thereafter, despite the replacement of the fish ladder in 2014 (Figure 4). The continued decline of herring counts since 2014 indicated that water quality issues may be preventing herring migration to and from Tom Mathews Pond (Archer and Chase, 2022). Thus, Tom Mathews Pond was identified as an impaired habitat for river herring and American eel in 2022. Herring counts were discontinued in 2023 in order for planned restocking of river herring to “restart the run.” If restocking was in fact accomplished in 2023, volunteer herring counts may resume in 2024 to document whether restocking succeeds in restarting the run (J. Muramoto, personal communication from Bass River Rod & Gun Club).

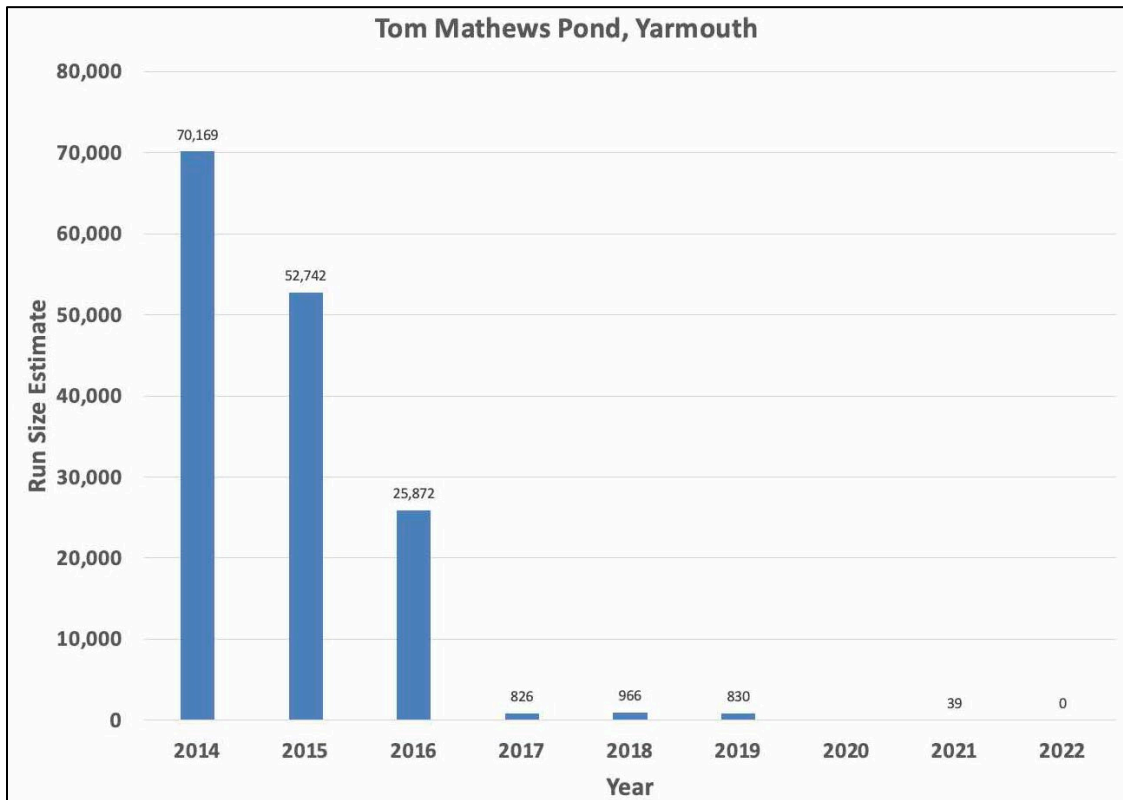


Figure 4: Estimated herring run sizes based on volunteer counts of river herring. Volunteers collected herring counts and the Division of Marine Fisheries calculated estimated run sizes. Data are from APCC’s Herring Monitoring Program for Tom Mathews Pond.

### *Salt Marsh Habitat*

In addition to providing essential habitat for commercially and recreationally significant shellfish and fish species, salt marshes also provide numerous other ecosystem services, or benefits, to humans. These services include flood and erosion protection from storms through wave attenuation and tide absorption, water quality improvements by filtering and removing harmful pollutants such as excess nutrients, and aesthetic benefits from scenic views. Because salt marshes can naturally adapt to sea level rise (accreting through sediment and organic matter accumulation over time), they also protect coastlines and sequester carbon, mitigating future climate change impacts. Historically, the average rate of sea level rise for New England was 2.5 millimeter per year (mm/year); however, in the last 19 years, the rate has accelerated to 4-6 mm/year (Watson et al., 2017). Thus, the services provided by salt marshes are only becoming more critical to the coastal community over time.

In reviewing the threats to the Chase Garden Creek salt marsh, APCC identified two potential tidal restrictions which are also highlighted in the Cape Cod Commission's Low-Lying Roads Project (Cape Cod Commission, 2021). Healthy salt marshes require frequent tidal flows of seawater to sustain salt marsh vegetation. These tidal restrictions reduce the flow of saltwater to the upstream marsh and can inhibit the marsh from migrating landward as sea level rises. In other words, the obstructed tidal flow from the road crossing limits the area of tidal inundation upstream and restricts where salt marsh plants can colonize and thrive in the future. The two areas which require further study regarding restricted tidal flow and inhibited landward migration are New Boston Road in Dennis and Route 6A in Yarmouth. The town of Dennis has started investigating design options for the New Boston Road and Route 6A is under the jurisdiction of the state agency, the MA Department of Transportation.

APCC also reviewed the study conducted by Louis Berger Group in 2011, which investigated whether the sedimentation at the mouth of Chase Garden Creek was significantly impeding tidal flow into the marsh. Using tide gauges at locations throughout the Chase Garden Creek system, they determined that the sandbars were not inhibiting the range of tidal flooding of the marsh in 2011 (Louis Berger Group, 2012). The consultants did not identify any other major restrictions in the marsh but did identify the presence of berms on the marsh platform. According to findings from this report, the sandbars provided shelter for coastal shellfish habitat from high wave action and currents, particularly at Gray's Beach, and do not limit the salt marsh habitat. While the study completed by the Louis Berger Group considered sedimentation, water levels, and general cover types in Chase Garden Creek, current research indicates that plant species composition and distribution are important metrics for assessing the resiliency of a marsh to sea level rise. Additionally, there have been no known analyses of vegetation change over time to reveal which sections of the marsh are most vulnerable to rising water levels.

### *Filling Information Gaps*

Based on this the review of previous work and discussions with local town staff and land managers, APCC found that the low-lying roads, water quality, and herring run components of the Chase

Garden Creek estuary were already under study and action plans were generally underway. However, it appeared that information and data gaps related to sediment dynamics and salt marsh integrity remained. APCC outlined plans to fill the gaps related to the stability of the salt marsh habitat. First, a GIS-based, landscape-scale assessment of the salt marsh was needed to better understand the impact of sea level rise on the sensitive habitat. APCC generated an unvegetated-to-vegetated-ratio (UVVR) for the entire marsh area from the head of tide to Gray's Beach. The UVVR assessment was proposed in an effort to better understand the areas of the marsh that are most vulnerable to sea level rise, and thus, may require restoration action to strengthen integrity and preserve habitat over time. This desktop assessment was followed by a rapid field assessment to take a closer look at the plant species composition and distribution. Finally, the two assessments were compared and evaluated to determine if both methods provided comparable results and to gauge each methods' strengths and weaknesses in predicting marsh stability.

### GIS-based Assessment (Task 2)

#### Methods

APCC completed a landscape-scale assessment of the Chase Garden Creek salt marsh using GIS-based mapping software. APCC applied an unvegetated to vegetated ratio (UVVR) analysis. This is a broad-scale method used to assess sea level rise vulnerability of each salt marsh tideshed, defined here as an area of marsh which floods and drains as one unit. The tideshed GIS layer used for the APCC analysis was obtained from a collaborative project led by the United States Geological Survey and MA Office of Coastal Zone Management (Ackerman et al., 2021; Figure 5).

The UVVR model is based on the work of Ganju and co-authors (2017) which found a strong relationship between UVVR and net sediment budgets in salt marshes across the United States. When a marsh has a low sediment supply (negative value or deficit in Figure 6a), the marsh does not accrete adequately over time to successfully adjust to sea level rise. Since the ratio of unvegetated area to vegetated is correlated to the sediment budget (low sediment supply corresponds to greater proportion of unvegetated marsh), this metric can be an effective predictor of marsh resilience over time (Figure 6; Ganju et al., 2017).



Figure 5: Aerial imagery of Chase Garden Creek showing the individual tidesheds obtained through the United States Geological Survey (Ackerman et al., 2021).

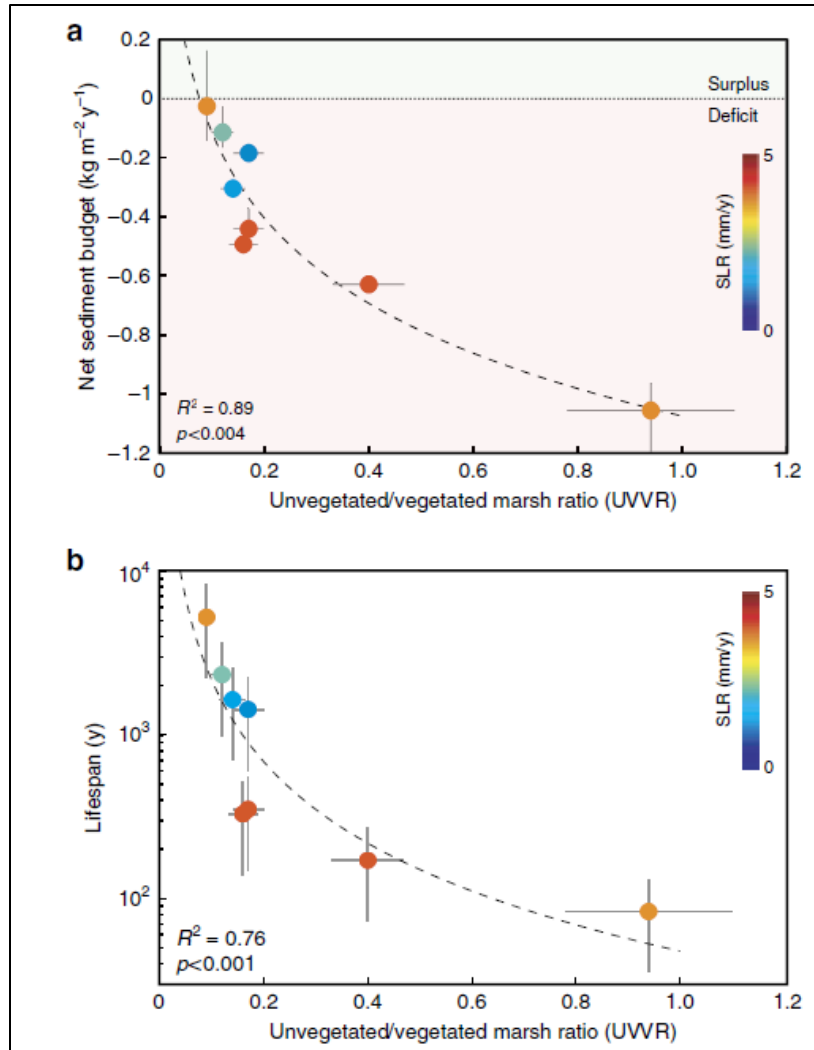


Figure 6: Data modeling results from Ganju et al. (2017) showing relationships between unvegetated to vegetated ratio and net sediment budget (a) and salt marsh lifespan (b).

In order to apply the UVVR method, APCC obtained National Agriculture Imagery Program (NAIP) imagery through the National Oceanic and Atmospheric Administration (NOAA) Data Access Viewer (<https://coast.noaa.gov/dataviewer/#/>). NAIP imagery is procured through the United States Department of Agriculture providing aerials during the “leaf-on” season. In Massachusetts, the imagery is generally available in October. APCC downloaded 2016 and 2021 NAIP imagery (raster files) for the entire area of Chase Garden Creek in March 2023.

Following methods developed by McKown and Burdick (2023) for other salt marsh restoration projects in New England, APCC generated Normalized Difference Vegetated Index (NDVI) imagery (Figure 7a) and, using training polygons selected within the nearby Barnstable Great Marsh, ran an automated classification “wizard” to distinguish vegetated and unvegetated area in the Chase Garden Creek marsh for the 2016 and 2021 imagery using ArcGIS Pro software (Figure 7b).

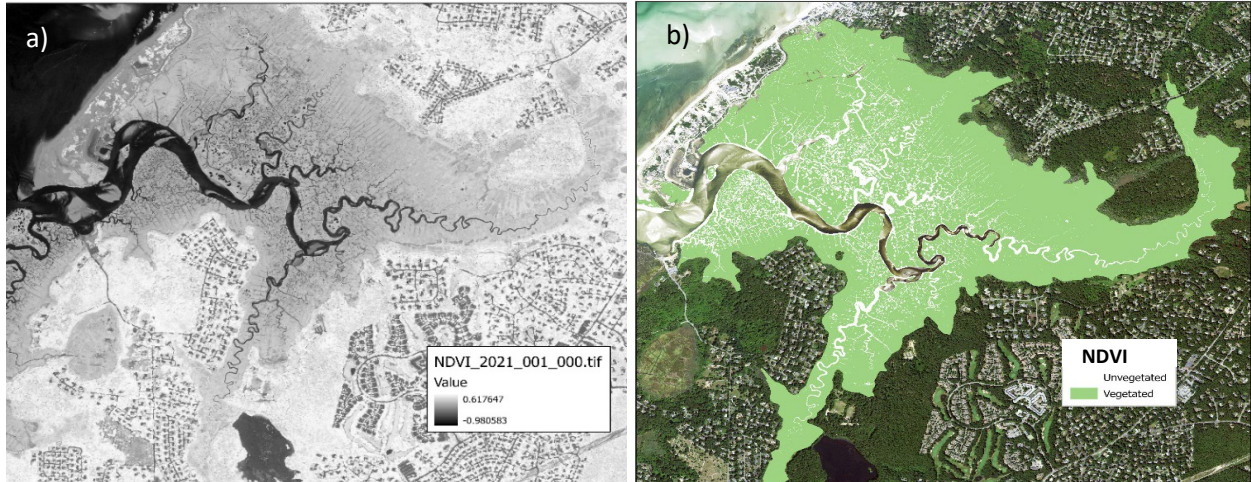


Figure 7: Images depicting Normalized Difference Vegetated Index (NDVI) generated from 2021 NAIP imagery (a) and results from automated classification wizard tool in ArcGIS Pro showing unvegetated (white) and vegetated (green) cover in Chase Garden Creek salt marsh (b).

Another part of the McKown and Burdick (2023) protocol involves generating an accuracy assessment of the unvegetated and vegetated classification. This is an important step to judge the accuracy of the ArcGIS Pro tool in discerning the different pixel assemblages between these two cover types. In order to complete this step, APCC utilized tools available in ArcGIS Pro to create randomized points for testing accuracy (Figure 8). Since ground-truthing the 2018 and 2021 field conditions was not an option, these points were analyzed using the NAIP and most recent aerial imagery (ortho-imagery downloaded from MassGIS). Each point was reviewed individually by APCC staff and placed in a cover type category (vegetated or unvegetated). After identifying the cover type, the tool provides a Confusion Matrix table (Table 1) including a Kappa Coefficient which can be used to assess the overall accuracy of the output. This step was completed for the 2016 and the 2021 imagery classifications.



Figure 8: Map of Chase Garden Creek salt marsh showing randomized accuracy assessment points generated by tool in ArcGIS Pro.

Table 1: How to interpret the Confusion Matrix provided by the Accuracy Assessment tool in ArcGIS Pro, table from McKown and Burdick (2023).

Class Value	Ground-truth Vegetated	Ground-truth Unvegetated	Total	User Accuracy	Kappa
Classified Vegetated	True Vegetated Points Classified as Vegetated	True Unvegetated Points Classified as Vegetated	Total Points Classified as Vegetated	Probability Classified Vegetated Points are True Vegetated	Overall Accuracy of Spatial Model (Kappa Value)
Classified Unvegetated	True Vegetated Points Classified as unvegetated	True Unvegetated Points Classified as Unvegetated	Total Points Classified as Unvegetated	Probability Classified Unvegetated Points are True Vegetated	
Total	Total True Vegetated Points	Total True Unvegetated Points	Total Accuracy Points		
Producer Accuracy	Probability True Vegetated Points were classified as Vegetated	Probability True Unvegetated Points were classified as Unvegetated			
Kappa					

### Findings

Based on their modeling, Ganju et al. (2017) determined that a UVVR of 0.13 was the critical threshold that predicted the longevity of a marsh with sea level rise. Anything above that ratio (greater proportion unvegetated) is in danger of drowning, but ratios below that threshold indicate a stable relationship between the sediment supply, elevation, and rate of sea level rise. The maps shown in Figure 9 of the 2016 and 2021 assessment show the calculated UVVR for the tidesheds along a color gradient. Tidesheds with a UVVR of less than 0.13 are highlighted with shades of green, indicating healthier and more stable areas of the marsh. Tidesheds with a UVVR of greater than 0.13 are highlighted with shades of red, indicating areas of marsh that are more at risk (i.e., these areas are more unvegetated or eroded). Yellow tidesheds are above 0.13 but are lower priority as these areas are still fairly well vegetated and may recover without human intervention.

The results from the accuracy assessment can be seen in Table 2. The Kappa coefficient was substantially better in 2016 than in 2021, but the average Kappa value across both years was still generally strong. The main factor that may have contributed to the low value for 2021 was the variation in georectification across the aerial and NAIP imagery. Slight differences in the stretching of images during the georectification process can cause misclassifications.

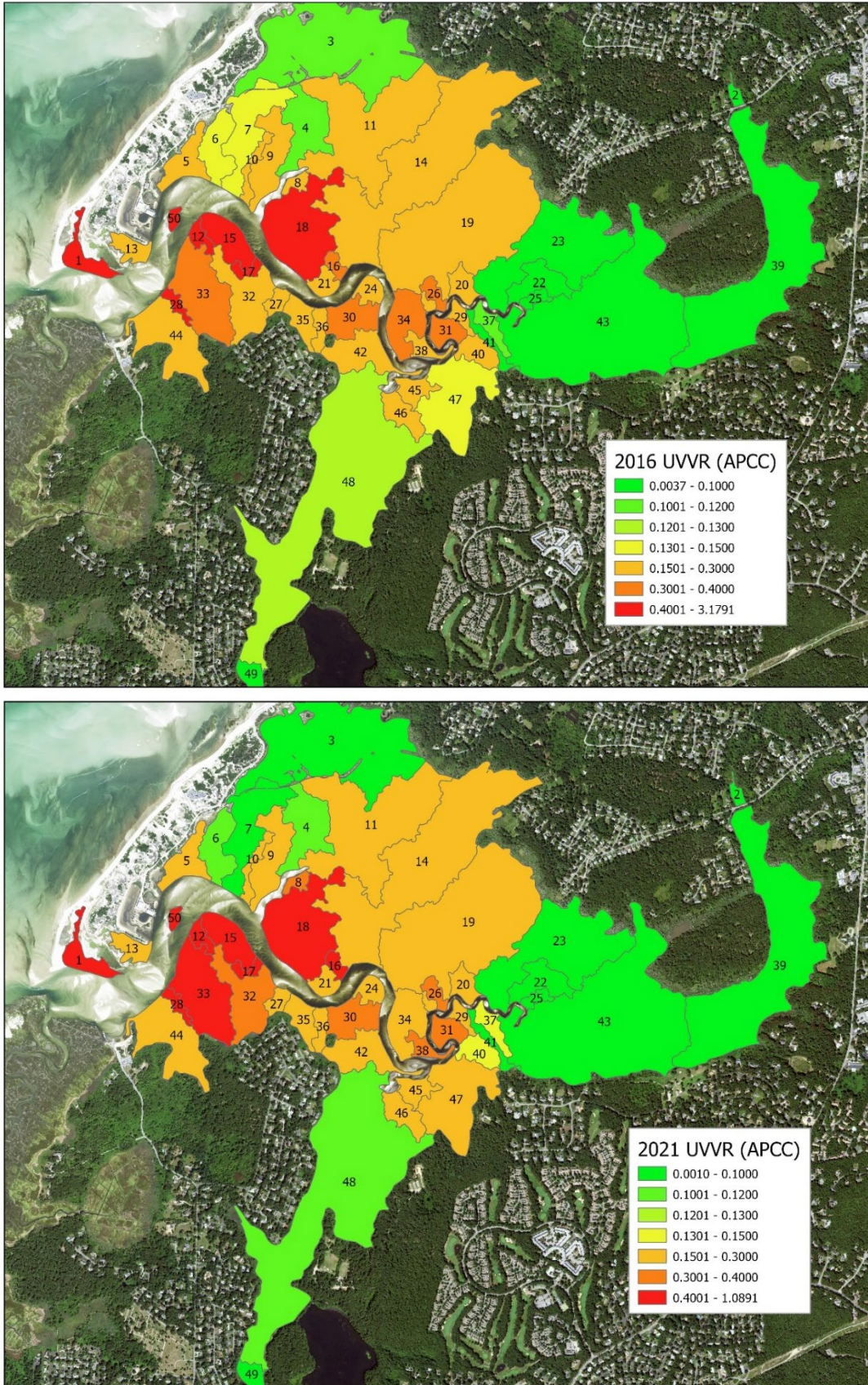


Figure 9: Mapped results from the UVVR analysis of Chase Garden Creek salt marsh for NAIP imagery from 2016 (a) and 2021 (b).

However, since the 2021 results were still considered moderate, based on interpretation of the kappa values (Table 3), and the 2016 results were very strong, APCC determined that the overall process was reliable, and they could be reasonably confident in the final results.

Table 2: Accuracy assessment results from the 2016 and 2021 NDVI imagery classification where C\_0 is the classification of vegetated cover, C\_1 is the classification of unvegetated cover.

2021 (APCC)					
ClassValue	C_0	C_1	Total	User Accuracy	Kappa
C_0	40	3	43	0.93	0.00
C_1	2	8	10	0.80	0.00
Total	42	11	53	0.00	0.00
Producer Accuracy	0.95	0.73	0.00	0.91	0.00
Kappa	0.00	0.00	0.00	0.00	<b>0.70</b>
2016 (APCC)					
C_0	41	1	42	0.98	0.00
C_1	0	10	10	1.00	0.00
Total	41	11	52	0.00	0.00
Producer Accuracy	1.00	0.91	0.00	0.98	0.00
Kappa	0.00	0.00	0.00	0.00	<b>0.94</b>
				<b>Average Kappa:</b>	<b>0.82</b>

Table 3: Interpretation of the Kappy Coefficient provided by McKown and Burdick (2023).

Interpretation of Kappa Coefficient		
Kappa Value	Level of Agreement	% Data is Reliable
0 - 0.20	None	0 - 4
0.21 - 0.39	Minimal	5 - 14
0.40 - 0.59	Weak	15 - 35
0.60 - 0.79	Moderate	35 - 63
0.80 - 0.90	Strong	64 - 81
0.90 - 1.0	Almost Perfect	82 - 100

By calculating the percent change in the ratio of UVVR between 2016 and 2021, APCC was able to determine the areas of the marsh which have experienced the most rapid change over that five-year period (Figure 10). These rapidly changing areas of the marsh showed degradation over time and provided a clear picture of which parts of the marsh are most vulnerable to sea level rise within the next twenty to fifty years. We refer to these degrading sections of the marsh as priority or target areas as they will require restoration action in order to build resilience and withstand future sea level rise. In other words, these areas of the marsh have experienced the most erosion of the tidal

creeks/ditches and pool formation on the marsh platform between 2016 and 2021. The priority or target areas were generally located at the edge of the main creek edge and at the lower end of the elevation gradient (i.e., closer to the mouth or inlet of the Chase Garden Creek).

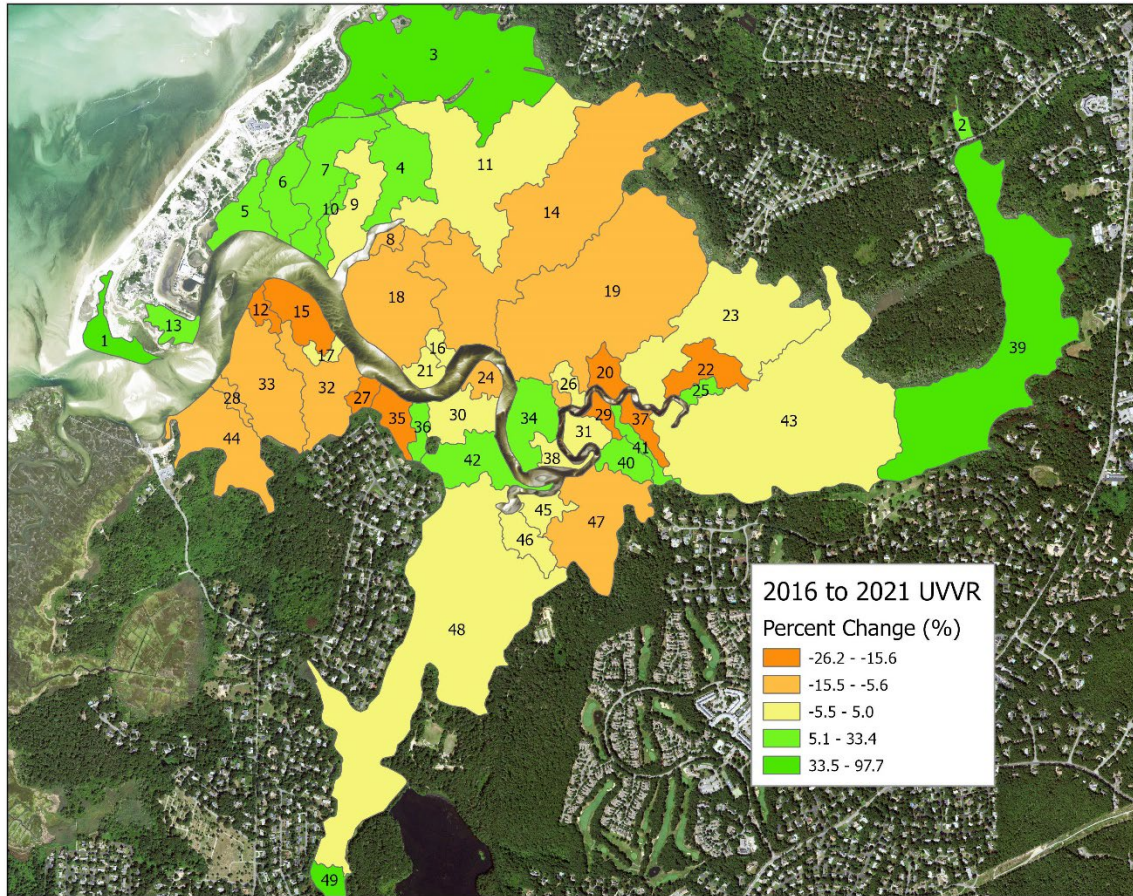


Figure 10: GIS-based map showing results of the percent change between the 2016 and 2021 unvegetated to vegetated ratio (UVVR).

### Rapid Field Assessment (Task 3)

#### Methods

APCC conducted a rapid field assessment of marsh vegetation at Chase Garden Creek in July 2023 to evaluate the marsh structure, or integrity, based on localized-scale plant community composition and distribution. The salt marsh rapid assessment method (MarshRAM) applied was developed by Kutcher et al. (2022) and involves walking the length of a transect (oriented perpendicular to the upland edge and running along the elevation gradient) and counting the number of steps taken in each major plant community (e.g., low marsh, high marsh, upland border, forb pannes, and dieback areas or pools). The number of steps in each zone is multiplied by a Coefficient of Community Integrity (CCI), whereby the plant communities which grow at higher elevations and/or indicate more natural features (i.e., natural creek vs. human-made ditch) receive higher CCI values than

bare or degraded communities (e.g., die-off patches or denuded peat). Then, the total sum of each product, from multiplying the CCI by the number of steps in that community, is divided by the total number of the tallied steps to calculate the Index of Marsh Integrity (IMI) score.

The upland starting points of the transects in Chase Garden Creek were randomly generated using ArcGIS Pro. Starting points were created in triplicate across the spectrum of risk as predicted by the UVVR results (low = green; medium = orange or yellow; high = red; Figure 11). In addition, transects were selected with closer spacing on the southern side of Chase Garden Creek for greater sample size within tidesheds. The southern extent was a more accessible area with high UVVR variability.

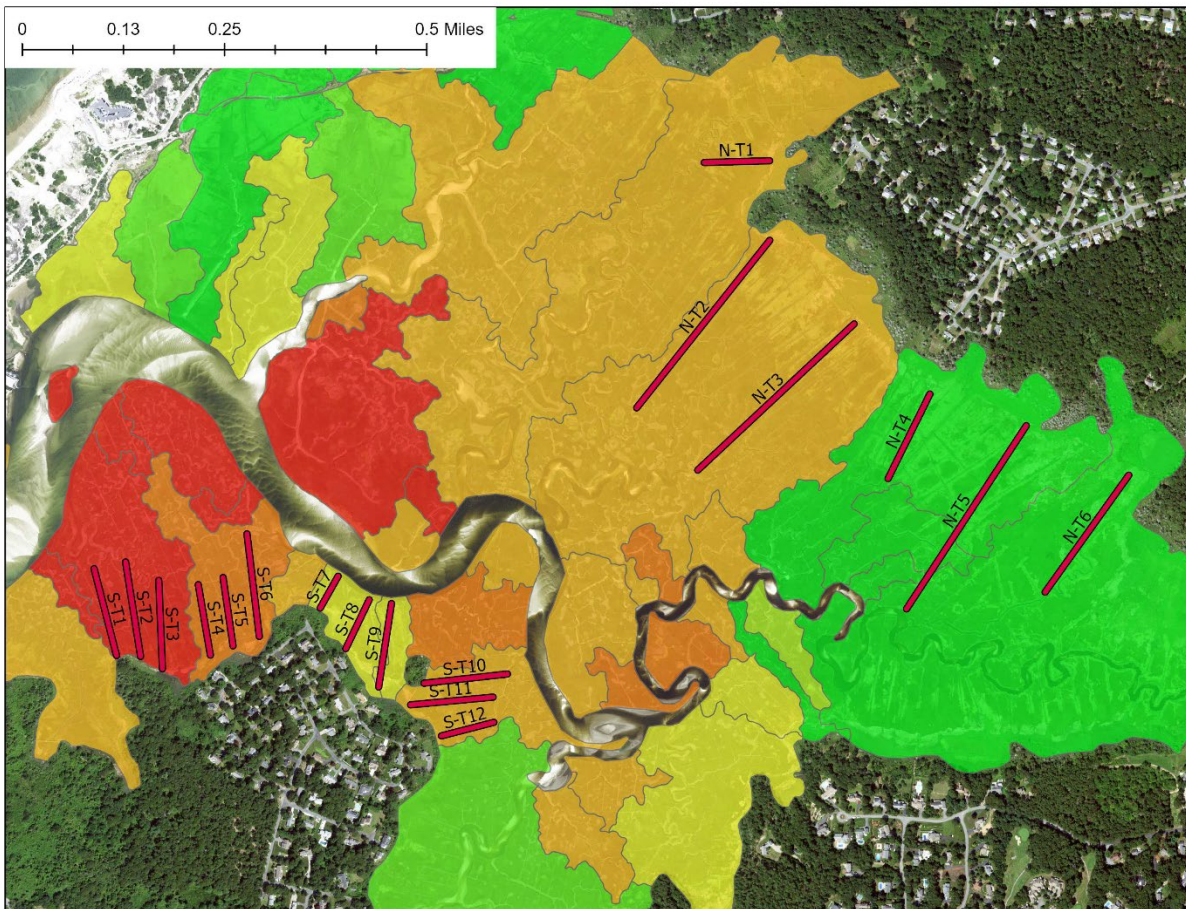


Figure 11: Location of the stratified randomized transects generated in ArcGIS and traversed in the field for the salt marsh rapid assessment method (MarshRAM) developed by Kutcher et al. (2022). These transects overlay the results from the 2021 UVVR assessment where red is higher unvegetated to vegetated area and green is higher vegetated to unvegetated area. Gray outlines depict boundaries of individual tidesheds.

## Findings

In reviewing the results from the MarshRAM study, it is critical to note that these transects were biased towards the marsh area nearest the upland because access and walkability became too difficult at the lower ends of the transect. Transects were traversed until the researchers

encountered a large, impassable creek (generally greater than 6ft wide and 6ft deep) that could not be circumvented. Due to the natural geomorphology of salt marshes, which are generally lowest in elevation at the major creek edge and highest at the upland edge, the area included in the survey represents the higher end of the elevation gradient of the marsh. The upland edge (and start of the transect) was considered where the slope of the marsh met the slope of the upland topography, or the point of slope inflection.

The plant species community results from the MarshRAM assessment conducted at the Chase Garden Creek salt marsh are provided in Figure 12. The most prevalent species community observed was “mixed high marsh” which included high marsh species, such as *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii*, combined with short-form *Spartina alterniflora*. The second most prevalent community was “*S. alterniflora* high marsh,” a monoculture of the short-form variety of this species. Finally, “low marsh,” or zones dominated by tall-form *S. alterniflora*, were observed frequently as well. These three community types are indicative of frequently inundated zones, probably flooded on a daily or twice daily basis. Where *S. alterniflora* grows to the taller variety, these areas of the marsh are well-drained during low tide. However, where *S. alterniflora* is stunted (short-form variety) this indicates that the soil, or peat, stays fully saturated even when the tide is low creating a low-oxygen environment which is more stressful for the plant as it has a harder time absorbing oxygen from the roots. Taken together, the overall results indicate that the marsh area nearest the upland, and therefore highest in elevation, was low in the marsh tidal range and flooded regularly.

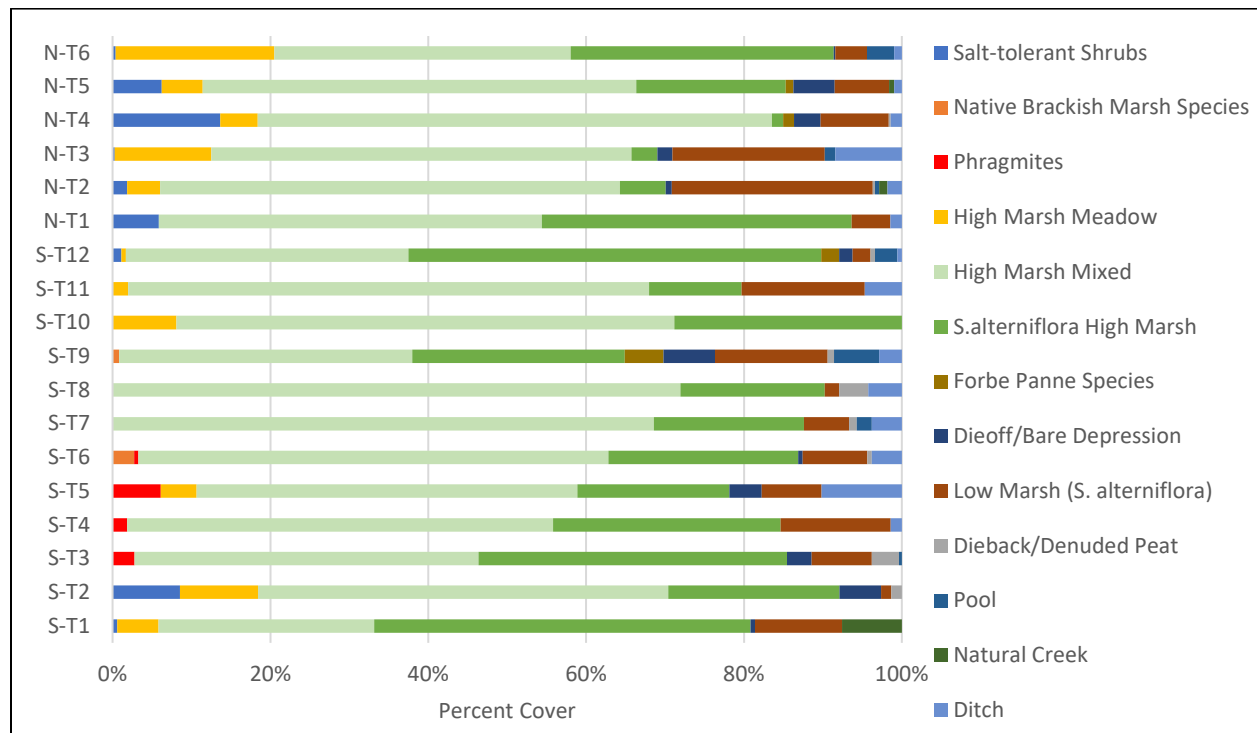


Figure 12: Results from the salt marsh rapid assessment method (MarshRAM) survey conducted at Chase Garden Creek showing the percentage of each plant community observed along each transect.

By comparing the different transects, several key distinctions can be seen across the various areas of marsh (Figure 12). First, the northern transects (N-T1 through N-T6) were comprised of more salt-tolerant shrubs, mainly *Iva frutescens*, and had greater percentages of “high marsh meadow” than the other areas of marsh. Second, the non-native variety of *Phragmites australis* was observed at the upper end of several of the southern transects (S-T3 through S-T6). *Phragmites australis* is common at the upland marsh edge where the fresher groundwater is accessible and saltwater flooding is more limited. Lastly, S-T7 through S-T9 were among the shortest transects due to the smaller width of marsh in this area and did not contain any higher marsh zone communities, such as “high marsh meadow” or “salt-tolerant shrubs.”

The community composition was converted to an Index of Marsh Integrity (IMI) score for each transect following standardized calculations developed by Kutcher et al. (2022) and described above. At Chase Garden Creek, the IMI scores varied across a scale of 5.75 (worst integrity) to 7.50 (best integrity). The transects with the highest scores were located on the northern section of the marsh while the lower scores were seen on the southern section. However, the scores did not always align with the results from the UVVR assessment; there were several moderate IMI scores in areas of high UVVR values. These findings suggest that there is considerable variability in vegetation types within these impaired tidesheds (Figure 13, Table 4).

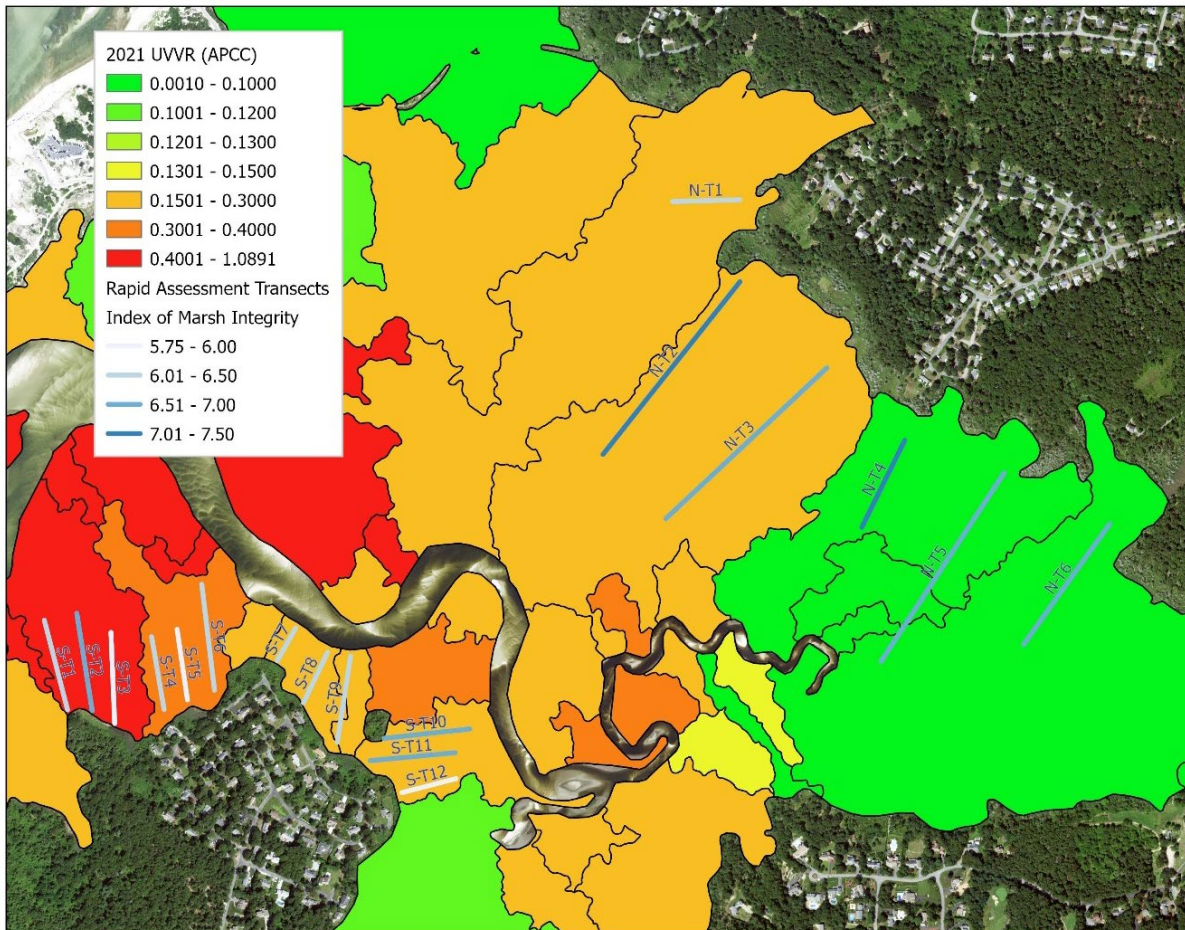


Figure 13: GIS-based map showing the results from the rapid assessment (MarshRAM) and UVVR assessments used to evaluate the vulnerability of the Chase Garden Creek salt marsh to sea level rise.

Table 4: Index of Marsh Integrity (IMI) score for each transect surveyed as part of the MarshRAM assessment as well as the UVVR for the corresponding tideshed.

TRANSECT ID	IMI SCORE	TIDESHED UVVR
N-T1	6.31	0.27
N-T2	7.15	0.22
N-T3	6.95	0.22
N-T4	7.20	0.05
N-T5	6.62	NA
N-T6	6.89	0.09
S-T1	6.37	0.40
S-T2	6.64	0.40
S-T3	5.75	0.40
S-T4	6.42	0.30
S-T5	5.83	0.30
S-T6	6.40	0.30
S-T7	6.40	0.19
S-T8	6.18	0.19
S-T9	6.03	NA
S-T10	6.67	0.23
S-T11	6.75	0.23
S-T12	5.84	0.23
<b>AVERAGE</b>	6.47	0.25

Note: N-T5 and S-T9 UVVR not included because transect crossed multiple tidesheds.

### Conclusions

Based on the results from the UVVR assessment, the areas of the marsh that are most at risk of disappearing with current rates of sea level rise are those bordering the main Chase Garden Creek channel near the inlet. By comparing the 2016 and 2021 results, these areas appear to be degrading more rapidly through pool formation and creek edge erosion relative to the rest of the marsh. In particular, the southern portion of the marsh where the marsh platform is narrowest, has high UVVR indicating that the rate of accretion has not kept up with sea level rise, and as a result, the elevation of the marsh is too low resulting in greater unvegetated area. In other words, the natural adaptation strategies needed to accrete in response to sea level rise are undermined or impaired. Since sea level rise is predicted to accelerate in the future (Sallenger et al., 2014; Kopp et al., 2016), these most seaward areas of the marsh are extremely vulnerable and will likely erode completely without any restorative intervention.

The results from the MarshRAM survey generally corroborate the findings from the UVVR assessment such that the areas of the marsh with higher UVVR generally had lower IMI scores and vice versa (Figure 14).

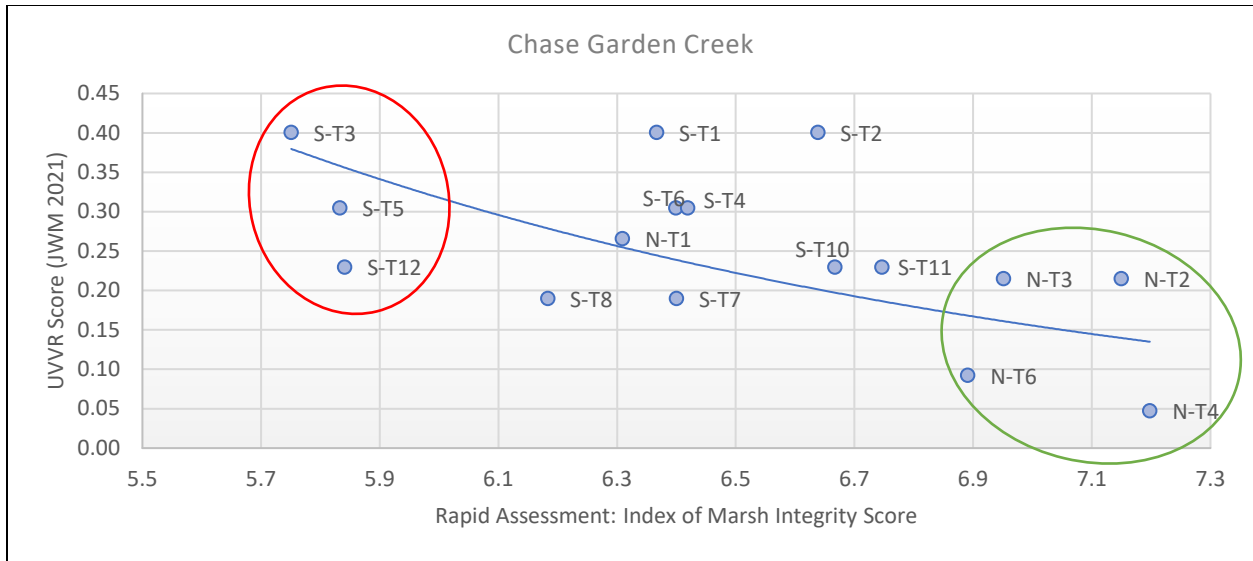


Figure 14: Index of Marsh Integrity (IMI) plotted against the UVVR score for the corresponding tideshed in Chase Garden Creek salt marsh. Note: N-T5 and S-T9 UVVR not included because transect crossed multiple tidesheds. The red circle indicates sites with correlated results of poor integrity or high vulnerability across methods. The green circle indicates sites with similar results of high integrity and low vulnerability across the two assessment methods.

However, the MarshRAM transects were biased towards the higher elevations of the marsh due to difficulty walking the lower zones of the marsh which were bisected by very large creeks (Figure 15). If the transects had run the full length of the marsh platform, these scores would likely have been lower (i.e., the proportion of habitats with lower CCI weights would have been greater). This walkability issue is a shortcoming of the MarshRAM protocol.

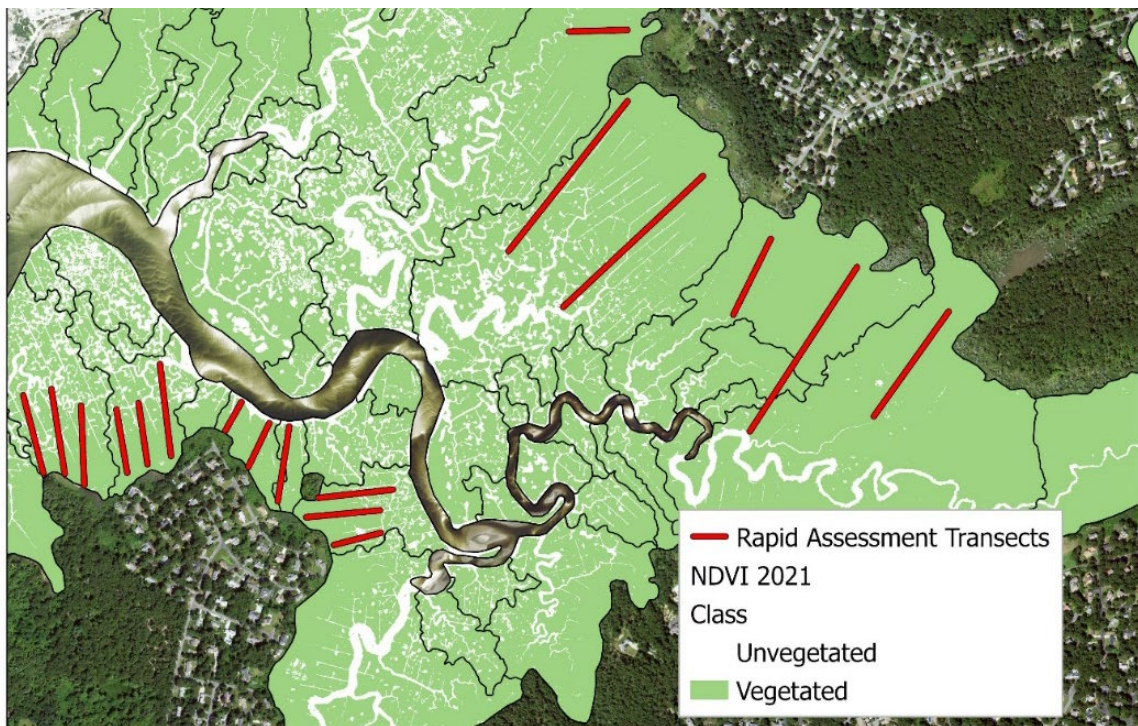


Figure 15: GIS-based image showing the bias towards vegetated areas (nearer the upland) in the location of transects included in the rapid assessment method (MarshRAM). Transects did not extend into areas with large creeks that could not be easily traversed. Unvegetated and vegetated area from 2021 NDVI classification.

One other caveat to the comparison across the two types of assessment was the variation in size among the tidesheds in the UVVR assessment. The tideshed layer was not generated by APCC but by an automated program developed by United States Geological Survey (Ackerman et al., 2021). APCC applied this tideshed layer to the marsh due to the size and complexity of the site. However, upon closer inspection over the course of the project, APCC noted several places where the tidesheds are a) too large, and/or b) do not accurately follow the contour of the flooding and drainage patterns in the marsh. If this experiment is repeated, APCC recommends manually digitizing the individual tidesheds at a smaller scale. If these changes were applied to future iterations of the MarshRAM and UVVR comparison, the correlation among the data would likely be much stronger.

### Implications

After reviewing the results and conclusions of the UVVR and MarshRAM assessments at Chase Garden Creek and comparing these with the scientific literature, APCC has developed a theory regarding what might be undermining the natural accretion mechanisms of the marsh, which are leading to low integrity scores at the seaward edge. Given the proximity to Cape Cod Bay, NobsCUSset Point, and Barnstable Harbor where research clearly shows active sediment movement, it is unlikely that the high priority areas of the Chase Garden Creek salt marsh are suffering from inadequate sediment supply. However, the marsh also clearly shows rapid degradation overtime, as seen by the increasing unvegetated area. Since the marsh is receiving sediment but not adequately gaining in elevation, there are likely other drivers causing subsidence which are counteracting any sediment accumulation yields.

Recent scientific research points to two different subsidence trajectories which are inhibiting marshes from gaining in elevation in response to the rising sea levels (Adamowicz et al., 2020). These two trajectories are referred to as “waterlogged subsidence trajectory” and “oxidative subsidence trajectory.” Both subsidence trajectories are caused by historic human land use practices that have manipulated the hydrology of the marsh, changing the soil chemistry and microbial processes.

The waterlogged subsidence trajectory occurs when areas of the marsh do not drain effectively, due to a reduction in the drainage rate and/or frequency of drainage. Soils that do not drain regularly stay fully saturated and stress plants which are physiologically



Figure 16: Image from Adamowicz et al. (2020) showing the impacts of historic embankments on salt marsh vegetation.

adapted to intermittent flooding. The resulting mortality of the plants leads to a scenario called “root collapse” whereby pore spaces in the roots, normally maintained by oxygen held in the root tissues, are lost producing a deflation in marsh elevation (DeLaune et al., 1994; Turner et al., 2004). This type of subsidence trajectory is often observed where man-made embankments (e.g., deposited ditching spoils, dikes, etc.) obstruct the outgoing tide (Figure 16). If the trajectory is not curtailed, large pools of water form on the marsh surface and expand over time (Watson et al., 2022, Figure 17).



Figure 17: Image from Watson et al. (2022) showing pools formed in various northeastern salt marshes of the USA due to the waterlogged subsidence trajectory.

The oxidative subsidence trajectory occurs when the marsh is over-drained which results in a lower groundwater table and accelerated soil decomposition (Vincent et al., 2013). Marsh soils, referred to as peat, contain high percentages of organic (or carbon-based) matter. When organic matter is exposed to oxygen, the rate of decomposition increases because microbial respiration is no longer constrained. In order for salt marshes to keep from decomposing, the groundwater table must be relatively close to the marsh surface even when the tide ebbs to provide anoxic, or low oxygen, conditions to limit decomposition. Deep and closely spaced man-made channels from humans ditching the marsh, a common agricultural practice for hundreds of years, has resulted in lower groundwater tables and increased decomposition rates in most of New England salt marshes (Burdick et al., 2020).

### Potential Restoration Techniques

In an attempt to reverse and eliminate subsidence trajectories from continuing to degrade New England salt marshes, wetland scientists have implemented various restoration strategies with promising results. First, runneling is the creation of small grooves in the marsh (generally  $\leq 30$  cm wide and deep) to drain standing water on the marsh surface. They are normally constructed using hand-digging and/or low-ground pressure excavators. Studies show that by implementing runnels, the vegetation recovers in these previously waterlogged areas within 3-5 years (Perry et al., 2021; Watson et al., 2022).

Second, ditch remediation is a method of filling ditches using natural salt marsh processes to restore groundwater table depths and reduce decomposition. Restoration practitioners mow salt marsh perennial grasses from one or both sides of the treatment ditch at the end of the growing season and fill the ditch with a 15–20 cm “hay” layer. The layer is lightly compacted and secured with fibrous twine and softwood stakes which will naturally biodegrade. This practice allows sediment and other particulates to accumulate in the ditch and research shows that plants will revegetate these areas within 3 years (Burdick et al., 2020).

Lastly, thin layer placement, as a means to boost salt marsh elevation, has been shown to successfully revitalize salt marsh habitats in Rhode Island (Rapososa et al., 2022). The goal is to quickly build elevation of the marsh surface and enhance declining high marsh plant species. To achieve this, restoration practitioners apply a layer (10–48 cm) of sandy material (can be dredged from a nearby harbor) on the marsh surface. The placed sediment has to be carefully graded by low ground-pressure bulldozers to target elevations.

APCC presented the assessment findings and potential restoration activities to local stakeholders, including town staff from Dennis and Yarmouth, the Cape Cod Commission, the Cape Cod Conservation District, the USDA Natural Resources Conservation Service (NRCS), the Aquacultural Research Corporation, the Dennis Conservation Land Trust, the Department of Fish and Game Division of Ecological Restoration, and Cape Cod Mosquito Control. The group concluded that any or all of the aforementioned restoration methods may be needed to rebuild salt marsh habitat at Chase Garden Creek, but more information is required in order to determine which strategies will be most applicable and feasible. More discussion and planning are also needed to determine the best target areas for these restoration strategy options. APCC will continue to gather information to help inform the decision-making process so these various techniques can be considered in a pragmatic and productive manner by the town, state, and federal funding and regulatory agencies as well as other local stakeholders and property owners.

### Next Steps

Throughout this first phase of the Chase Garden Creek project, APCC coordinated with key regional and local stakeholders in order to gather information, share findings of vulnerability assessments, and receive feedback on potential next steps for monitoring and restoration. Meetings were held in May and November 2023, bookending the growing season with an introduction and

follow up news on the project. For a full list of the stakeholders involved, please see the Acknowledgements section below.

Based on the results from the assessment and stakeholder feedback, APCC has begun planning for Year 2 of this project and proposes the following tasks:

- 1) **Sediment Study:** APCC plans to contract an engineering consultant to perform a sediment transport study on the shoal at the mouth of Chase Garden Creek. This information is necessary to better understand how the expanding sandbar is affecting sediment supply and tidal hydrology in the marsh upriver. It may also be a helpful first step to identifying whether dredging the area and using the materials for thin layer placement would be feasible without disturbing shellfish habitat. APCC anticipates securing a contract by summer 2024.
- 2) **Planning and Design:** APCC will seek out expert advice, conferences, and workshops on runneling and ditch remediation restoration techniques to support planning and inform future design scope of work. This task will also entail meeting with salt marsh scientists, regulators, and other key stakeholders onsite to gain perspective and discuss restoration options. The general timeline for this task is spring 2024 (April – June) with further site visits anticipated for summer of 2024.
- 3) **Monitoring:** APCC will continue to gather information through field observations. Additional data gathering may include completing more MarshRAM surveys, deploying continuous water level and salinity loggers, establishing and monitoring permanent vegetation plots, conducting high-accuracy elevation surveys, and/or installing sediment tables or accretion markers. A finalized monitoring plan will be developed by end of June 2024 informed by discussion with local stakeholders and experts with direct implementation experience in these new techniques.
- 4) **Communications:** APCC will communicate project updates and outcomes to the general public and will continue to coordinate with regional and local stakeholders on planning future restoration actions for the Chase Garden Creek. This task will be ongoing throughout the year with a public meeting planned for spring or early summer 2024.
- 5) **Reporting:** APCC will compile data and other information gathered into an annual report which will be shared with project funders and partners in February 2025.

### Acknowledgements:

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