October 22, 2021

Jordan,

I am attaching a copy of your report with suggested edits and many comments/questions by me. I have added an Executive Summary and Purpose of the Study. (In the Word version, my edits are marked as revisions). Also attaching the Appendices, which could probably use captions.

As you will see, the report raised many questions for me. The biggest question is where to go from here – or perhaps to let this marsh continue without intervention while we move on to look at other marshes.

I would appreciate an opportunity to discuss the report and my questions in person -- perhaps by zoom again or when we meet at Frost Fish Creek. I do not think it makes sense to address all the questions I raise in revisions to the report -- that would be a major effort.

I realize that you came into this project in the middle without much local background and that portions of the report were drafted by different people. Consequently, there is some inconsistency in naming areas of the marsh, which makes reading the report harder. It would have been nice to start with an overview map that indicated a consistent breakdown and naming of the areas of the system for use throughout the report. I do not know if it makes sense to revise the report along that line at this point.

I guess my main concern is what recommendations come out of the report, and how that should be presented to the CCF Board and the Chatham public.

Please let me know what you think when you get back to work and have a chance to review the attachments.

-- *Gerry*

Cockle Cove and Bucks Creek Salt Marsh System
Site Assessment Report
Association to Preserve Cape Cod
October 2021

Oversight and Report Development: April Wobst and Jordan Mora
Field Data Collection: Carl Depuy and Adrianne Lovuolo
Contracted by the CCF Salt Marsh Task Force: Gerry Stahl, Chair

Executive Summary:

During Summer 2021, APCC undertook a site assessment of the Cockle Cove and Bucks Creek salt-marsh system under contract with the Salt Marsh Task Force of the Chatham Conservation Foundation (CCF).

The assessment included:

1) A review of the area's agricultural history and data from past studies, and ranking of the ecological value and restoration feasibility of different sections of the marsh according to standardized criteria adapted to Cape Cod.
2) Water testing for several possible pollutants.
3) Measurement of tidal flow to specific areas of the marsh.
4) Soil sample collection and texture analysis.
5) Vegetation surveys to document extent of invasive phragmites versus healthy marsh plants.

Primary findings were:

- Most areas of the marsh are healthy.
- The two areas suffering from excessive phragmites are likely to improve over time with sea-level rise.
- A major cause of water pollution is probably from septic leakage into the ground water, which will be addressed as the Town completes sewering local homes.
- A secondary source of poor water quality may be runoff from the roads surrounding the marsh, which could be addressed by the Town installing drains at strategic locations around the marsh.
- Monitoring of the marsh should be conducted periodically in the future based on the baseline data of this assessment in order to track changes to water quality, tidal flushing, extent of invasives and maintenance of general marsh health.

Purpose of the Study:

The Cockle Cove and Bucks Creek tidal system has been well-studied over the last twenty years, but due to its complicated hydrology and poor water quality, it remains a site targeted for monitoring, restoration and stormwater management improvement. The purpose of the monitoring undertaken by APCC in 2021 was to better understand the following contributing factors and provide recommendations for improved management strategies:

a) The sources of pollutants impacting water quality.
b) The general hydrology of the system, including a recently restored area of the marsh north of Cranberry Lane and the area west of a collapsed culvert on Ridgevale Road.
c) The extent and diversity of the salt marsh plant species, including the non-native variety of *Phragmites australis.*

To accomplish these goals, APCC employed the following monitoring methods:

1) A GIS-based ranking of the various sections of the large system for potential restoration according to ecological value and feasibility.
2) Water-quality monitoring consisting of cyanobacteria, bacteria (*Enterococcus*), and nutrient (total nitrogen and total phosphorus) sampling.
3) Assessment of tidal hydrology and salinity fluctuations.
4) Soil sampling and texture analysis.
5) Salt marsh vegetation surveys including a delineation of *Phragmites* extent and a rapid assessment of salt marsh integrity.

Background & Rationale:

The Cockle Cove and Bucks Creek system is located on the south side of Chatham and is hydrologically connected to tidal exchange with Nantucket Sound near Ridgevale Beach. The Cockle Cove salt marsh covers roughly 35 acres. The Cockle Cove Creek extends from Route 28 near Sam Ryder Road and the Chatham Transfer Station to the southern end of Ridgevale Road, where it connects to the Bucks Creek system. The Bucks Creek (including Sulphur Springs) salt marsh is roughly 67 acres in area. Bucks Creek runs from an active cranberry bog north of Cranberry Lane to Ridgevale Beach.

Based upon the 2018-2020 Massachusetts Integrated List of Waters for the Clean Water Act (the "Integrated List"), the Bucks Creek system falls under the impaired category due to high levels of three pollutants: *Enterococcus*, fecal coliform, and total nitrogen (DEP 2021). Additionally, the Integrated List included Cockle Cove Creek as impaired for only bacteria, namely *Enterococcus* and fecal coliform (DEP 2021). Several previous studies investigated the origin of these pollutants, but the bulk of those studies were completed over fifteen years ago (Howes et al. 2003, Howes et al. 2006, CZM 2005). During the years since these determinations, the Ridgevale Beach has been closed to swimming and/or shellfish on numerous occasions due to bacteria concentrations reaching levels above EPA safety standards (130 cfu/100 ml in saltwater; EPA 2012).

Even though Cockle Cove Creek receives discharge from the Wastewater Treatment Facility at its headwaters, the Massachusetts Estuaries Project (MEP) reports completed in 2003 and 2006 suggested that the salt marsh surrounding Cockle Cove Creek was efficiently denitrifying the inorganic form of nitrogen known as nitrate and exporting organic forms (less biologically active), such as particulate organic nitrogen (Howes et al. 2003, Howes et al. 2006). Although neighbors have complained of macroalgae accumulation on the salt marsh platform (Nate Wordell, personal communications, July 2021), the results from isotopic analysis in the MEP report suggest that the algae likely enter the salt marsh system during flood tides (Howes et al. 2006). Thus, Cockle Cove was not considered threatened or impaired by high nitrogen levels.

Conversely, the findings from the 2003 MEP report showed habitat impairment in Bucks Creek caused by nitrogen concentrations that exceeded total maximum daily loads (TMDLs). Septic systems were found to contribute 77% of the overall unattenuated watershed nitrogen load, meaning that the majority of the nitrogen enters this system through the groundwater from residential septic systems (Howes et al. 2003). The impact of the active cranberry bog upstream of Bucks Creek was not considered a major influence on the nitrogen problem although Star Bog (located just downstream of the active cranberry bog) shows signs of degradation due to eutrophication (e.g., overabundance of duckweed during peak summer months).

Based on the findings from these earlier studies and the ongoing closures at Ridgevale Beach, the APCC, with input from Chatham Conservation Foundation and other partners, focused monitoring efforts on *Enterococcus* in the Cockle Cove Creek and total nitrogen as well as total phosphorus in Bucks Creek. The goal was to provide an updated baseline of these pollutants in order to inform decision-making of potential management strategies. Furthermore, the bacteria sampling protocol and site selection were designed to help distinguish the most likely sources of *Enterococcus* in order to prioritize areas for potential stormwater management projects.

In addition to the poor water quality, Cockle Cove and Bucks Creek have been the focus of monitoring and study in the more recent past due to tidal restrictions caused by undersized or collapsed culverts (Ramsey 2009). In 2011, following an engineer survey and hydrologic model completed by Applied Coastal Research and Engineering, Inc. (Ramsey 2009), the 18-inch undersized culvert on Cranberry Lane was replaced with a 3 ft x 4 ft box culvert to improve tidal flushing upstream and reduce the cover and density of the non-native variety of *Phragmites*. In the context of this assessment, the marsh downstream (south) of the 2011 box culvert is considered a “reference” marsh for purposes of comparison with the health of the “study” target marsh upstream (north) of the culvert. Although post-construction monitoring completed by the Division of Ecological Restoration showed improvements in tidal flushing in 2012, the stand of *Phragmites* still remains upstream of the culvert. APCC deployed water level loggers on the north and south sides of the Cranberry Lane culvert to compare the tidal hydroperiod upstream to the southern reference area.

More recently, results from a GIS-based assessment of Chatham Conservation Foundation lands, completed by APCC in February 2020, highlighted two failed culverts within this large combined tidal system – one where Route 28 crosses Cockle Cove Creek and a second beneath Ridgevale Road which once connected Cockle Cove and Bucks Creek (Stahl and Horsley 2020). *Phragmites* currently dominates the plant community to the west of the collapsed Ridgevale Road culvert. Due to safety and access concerns at the Route 28 culvert, APCC chose to focus additional hydrology modeling at the Ridgevale Road site.

Methods:

1. Desktop Assessment

To expand upon the existing GIS-based map assessment and analysis completed by APCC for the Chatham Conservation Foundation in early 2020, APCC completed a comprehensive desktop assessment of the Cockle Cove Bucks Creek site. This assessment included review of current and historical maps, review of the project area for overlap with key resource areas, and ranking of the ecological value and feasibility of restoration according to three different criteria matrices designed for Cape Cod salt marshes.

a. Historical Review

Current and historical maps of the project area were reviewed to better understand changes in development and land use around the site that has influenced the condition and health of the system.

b. GIS-based Restoration Ranking Analysis

For the desktop ranking of the site, the salt marsh complex was divided into five areas (Figure 4) based on creek boundaries and areas of restricted or limited tidal flow: 1) Cockle Cove Creek west of the Ridgevale Road restriction; 2) Cockle Cove Creek north of the Route 28 restriction; 3) all of Cockle Cove Creek upstream of the historic pedestrian bridge; 4) Bucks Creek north of the restored Cranberry Lane restriction including the upstream active and inactive bogs; and 5) eastern Bucks Creek from the outlet with Nantucket Sound to Barn Hill Road to the east. Division in this manner allows for assessment and scoring of the ecological value of these subsections of this large marsh complex and assessment of the potential for restoration in these areas.

Each of these five areas was then ranked according to: 1) APCC's 11 criteria for scoring restoration projects across Cape Cod according to their ecological value and feasibility; 2) the five existing eligibility criteria used for ranking in the Cape Cod Water Resource Restoration Project (CCWRRP) Final Watershed Plan and Areawide Environmental Impact Statement (NRCS, 2006); and 3) the 5 secondary criteria developed by APCC and the Cape Cod Conservation District in 2020 for ranking of salt marsh projects for the CCWRRP update. Table 1 summarizes the ranking criteria. A full description of the criteria and scoring for each is available upon request from the APCC.

Table 1: APCC and CCWRRP Ranking Criteria used to assess and score the ecological value and restoration potential for Cockle Cove and Bucks Creek.

#	APCC Ranking Criteria	CCWRRP 2006 Eligibility Ranking Criteria	CCWRRP 2020 Secondary Ranking Criteria

1	Holistic Nature of Project	Size of upstream affected area	New: Resilience to SLR (SLAMM)
2	Water Quality Based on TMDL Categories	Is the upstream affected area contiguous to protected open space (ownership)?	New: Potential for salt marsh migration
3	Water Quality Based on Shellfish Growing Area Designations	Does this tidal channel support a shellfish resource area?	New: Potential to improve water quality (nutrient and/or bacteria impairment of connected waterbody)
4	Area for potential restoration	Is the channel or system part of an anadromous fish pathway?	New: Low lying properties impacted
5	Support sensitive resources	Does the affected area include Priority Habitat of Rare Species or Estimated Habitat of Rare Wildlife?	New: Extent of Restriction
6	Human use benefits		
7	Habitat Connectivity and Linkage to Other Protected Areas		
8	Resilience to Sea Level Rise		
9	Resilience to Erosion		
10	Local Support (community or partner)		
11	Town Priority		

2. Water Quality

a. *Nutrients*

Water samples were collected at each station every other week at or within one hour of low tide (generally between 8am and 11am) beginning in July 2021 and ending in mid-September. Care was taken not to walk in the creek before sampling to avoid stirring up detritus and substrate, and bottles were inserted into the flow upstream of sampler's physical location. Sample bottles (120 ml polypropylene container) were pre-rinsed with site water three times before filling to slightly below the curve on the top of the bottle. Samples were stored in a cooler with ice packs. Samples were delivered to the Center for Coastal Studies Water Quality Laboratory for analysis directly following each sampling event in most cases; otherwise, they were frozen within eight hours and delivered within a few days of sampling. A duplicate was taken on each sampling event at a rotating location. See Figure 1 for site locations and sampling design.

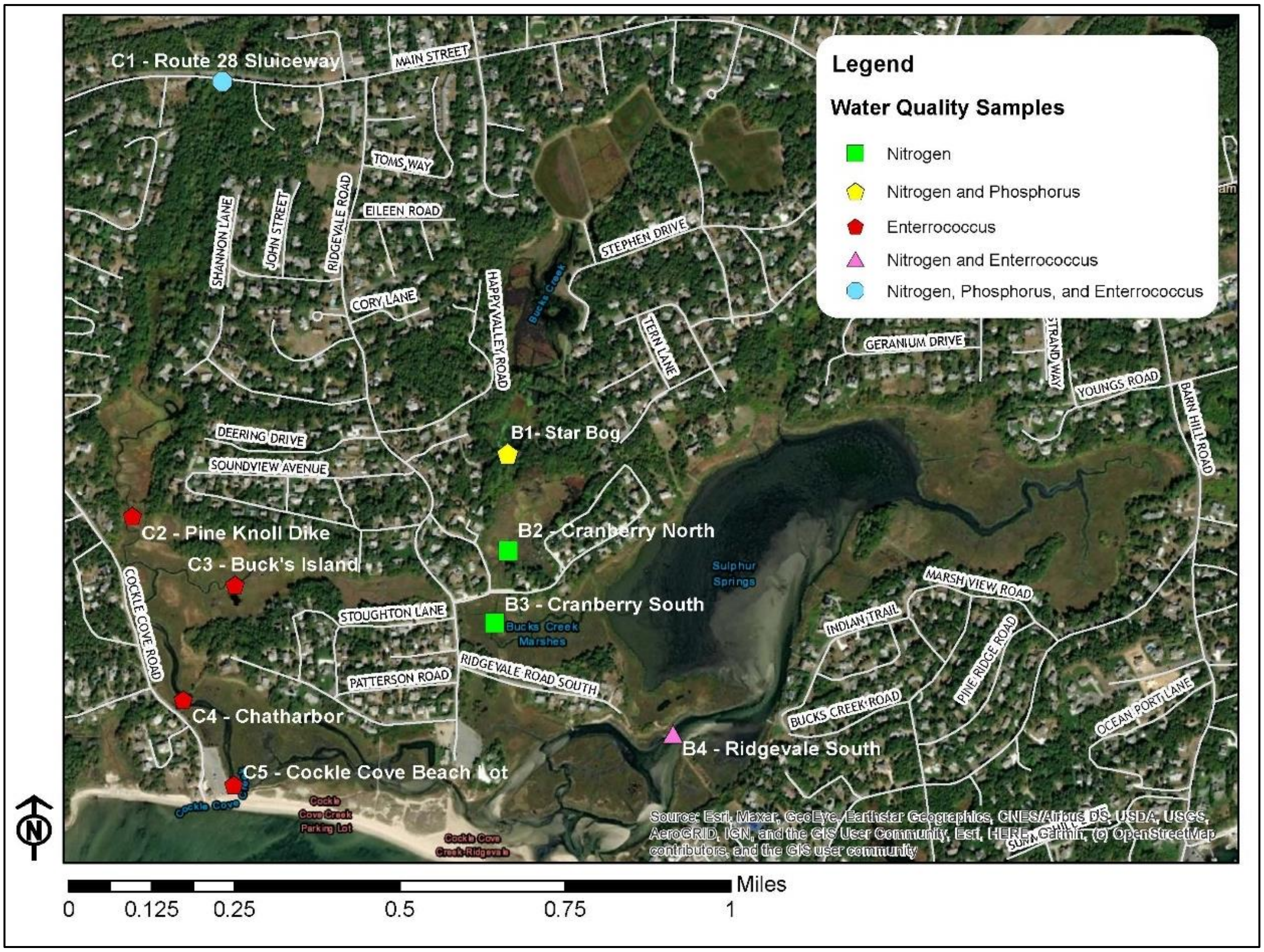


Figure 1: Map of water quality sites and sampling design.

b. Bacteria

Bacteria samples were collected every other week at or within one hour of low tide, with the exception of the wet weather events on 8/5 and 10/4 which occurred closer to high tide in order to collect a rainwater sample at Route 28 (C1). Samples were analyzed for *Enterococcus* at the Barnstable County Laboratory. All low tide samples were collected in the morning (8am – 11am) and delivered to the lab between noon and 2pm. Nitrile gloves were worn on top of rubber gloves while sampling. Sample bottles were filled to approximately the 100ml line. See Figure 1 for the site locations and sampling design.

c. ***Cyanobacteria***

At each sampling event, two samples were collected from the shore, one using a 50-micron (µm) mesh plankton net and one using a 1-meter tube. Field observations included completion of a field data sheet with information on weather, visual appearance of pond surface, water temperature, etc. Photographs were taken of the pond's shoreline. Sampling was conducted on a regular schedule, every other week throughout the monitoring season to allow tracking of cyanobacteria over time.

On the same day as sample collection, the sample was processed and analyzed following APCC's cyanobacteria screening protocol. The protocol involves identifying cyanobacterium types (genera) and percent dominance of each type of cyanobacteria. After freezing samples for the purposes of lysing cells, samples were thawed and analyzed for cyanobacteria pigments (phycocyanin) and non-cyanobacteria algal pigments (chlorophyll-a) using a fluorometer. Measurement of chlorophyll-a is done in order to express cyanobacteria results as a ratio of cyanobacteria pigments to algal pigments, an indicator of the progression of overall algal growth over time. All resulting data were recorded and stored on APCC's online server and findings were interpreted by APCC cyanobacteria program staff and interns.

3. Assessment of Tidal Hydrology and Salinity

In summer of 2021, time-series monitoring of water level, temperature, and conductivity in the stream was conducted using Solinst Levelogger LTC data loggers. The purpose of the time-series monitoring was to compare pre- and post-restoration changes around Cranberry Lane and assess the extent of restriction of tidal flow to Cockle Cove Creek west of the Ridgevale Road culvert. The expectation is that the Cranberry Lane culvert replacement would improve upstream tidal flow resulting in a tidal regime and salinity concentrations similar to that of the reference marsh.

A total of four water level loggers were deployed at the following locations: north of Cranberry Lane in the restored study marsh, south of Cranberry Lane in the reference marsh, immediately west of the Ridgevale Road culvert, and south of Pine Knoll Road closer to Cockle Cove Creek (see Figure 2). Water level loggers (non-vented pressure transducers) were deployed at low tide and placed at locations where they would ideally remain submerged in the stream throughout the low tide. A barometric pressure logger (Solinst Barologger) was also placed on site to convert the water level logger pressure data to relative water depth. The barometric pressure logger was attached to a tree directly off Ridgevale Road central in location to the monitored sites. All loggers were set to record at 10-minute intervals and were left in place for roughly 6-weeks to capture a full lunar cycle. The water level loggers were protected with a biofouling screen attached to the unit to prevent clogging with silt or muck. The water level loggers were deployed inside a PVC tube and secured to a metal fence post using zip ties to prevent movement or loss of the equipment. The metal fence post was driven into the creek one to two feet deep until stable.

The elevation of the top of the protective PVC housing was measured in meters using the Trimble Geo7x with a survey rod and R2 rover to maximize vertical accuracy (NAVD88 datum). Due to an offset setting on the device, all elevation data was recorded at an offset of 0.9m. The water level data provided in the results section of this report includes the relative readings (with offset) in meters as well as the corrected data (subtract 0.9m from the reference elevation reading) converted to feet.

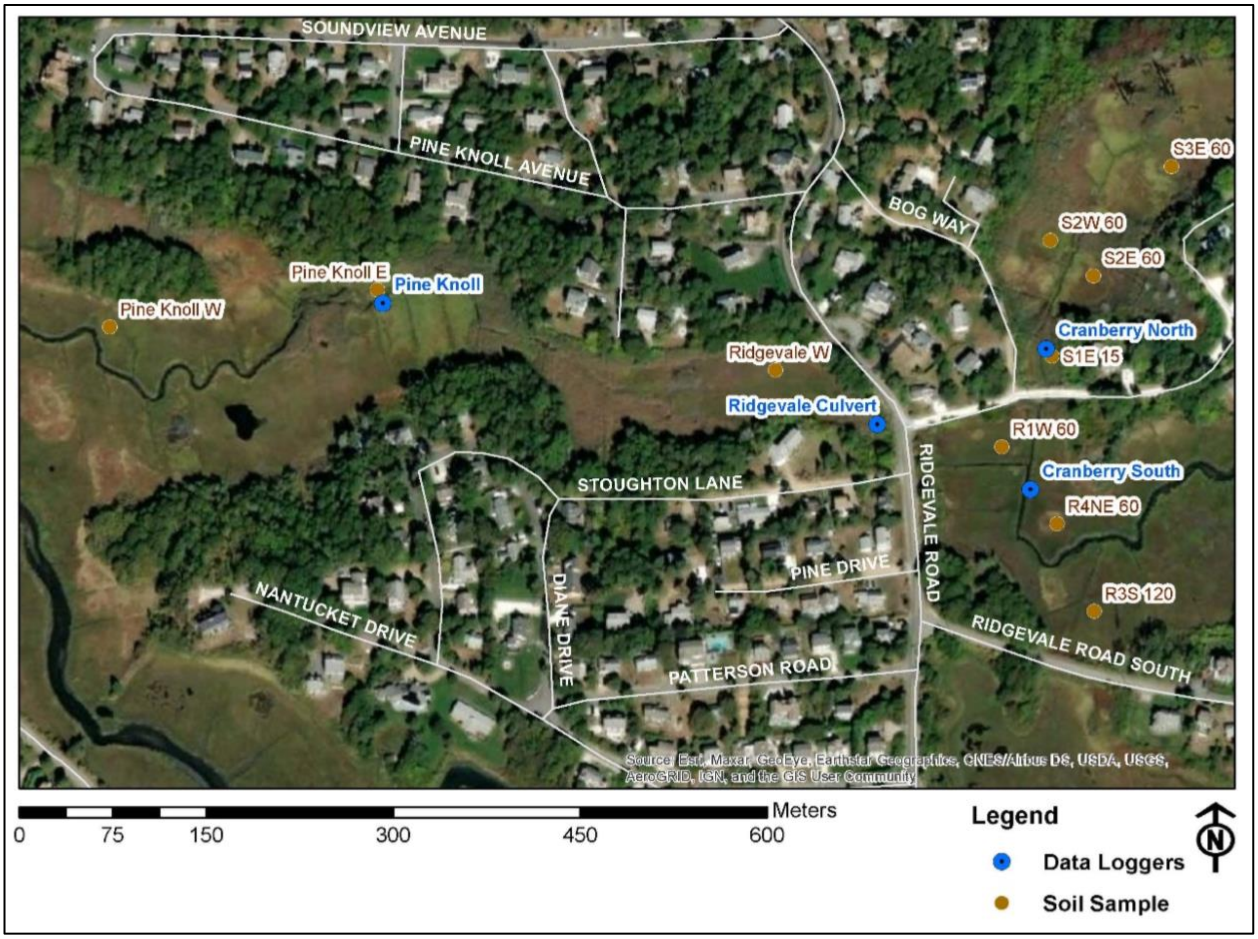


Figure 2: Map of the water level and salinity logger placement and soil sample sites (not shown: Barn Hill soil samples).

Data loggers were deployed on July 6, 2021, and redeployed after conducting a field data check on July 16, 2021, to confirm all loggers were functioning properly. After retrieving the loggers on August 19, 2021, data were downloaded and corrected for changes in atmospheric pressure using Solinst Levelogger software version 4.5.3. Salinity was generated from the time-series logger output by first converting conductivity data (µS/cm) to temperature adjusted specific conductivity (mS/cm) and then calculating salinity in grams per liter (ppt).

4. Soil Sampling

Soil samples were collected on July 20th, 2021, using a metal hand auger (see Figure 3). The auger had a 1-foot boring spade. All samples were pulled by turning the hand auger in a clockwise circle while applying pressure to the handles until the top of the spade was level with the soil surface. The hand auger was then pushed back and forth to help loosen any attached roots or soil to get a better sample.

A total of 12 soil samples were collected in four different locations within the Cockle Cove/Bucks Creek marsh system. Soil samples were extracted from the middle of the marsh along existing vegetation transects where possible (e.g., Bucks Creek Cranberry Lane reference and study marsh locations). Three reference soil samples were collected in the reference side of Bucks Creek south of Cranberry Lane, five samples were collected on the north side of Cranberry Lane (restored study area), two samples were collected in the Cockle Cove marsh west of Ridgevale Road, and one sample was collected in the Bucks Creek marsh west of Barn Hill Road (Figure 2; note Barn Hill location not shown).

Figure 3: Photos of the auger used to collect soil samples.

5. Vegetation

APCC completed vegetation monitoring using methodology that is regionally standardized to allow for consistent data comparison and restoration assessment throughout Cape Cod and the New England region (Carlisle et al. 2002, Neckles et al. 2013, Kutcher 2019). This included transect-quadrat (or permanent plot) surveys of vegetation north and south of Cranberry Lane at pre-existing transects set up prior to replacement of the culvert in 2011, and rapid assessment transects added in 2021 to assess the health and condition of the Cockle Cove marsh west of Ridgevale Road and Bucks Creek marsh west of Barn Hill Road. Vegetation sampling is important for long-term monitoring because plant presence and health reflect a wide array of stressors (e.g., salinity, hydrology, and substrate) over a period of time.

a. Quadrat Survey

Transect-quadrat sampling was completed according to protocols detailed in *A Volunteer Handbook for Monitoring New England Salt Marshes* (Carlisle et al. 2002) and comply with methodology recommended by the scientific community on salt marsh restoration monitoring (Neckles et al. 2002).

APCC visited the site in July of 2021 to relocate the ten transects established in 2010 for pre-restoration and post-restoration monitoring of the Cranberry Lane salt marsh. This included four study transects north of Cranberry Lane in the restored marsh. The restored marsh transects span east to west across the full extent of the marsh. Additionally, there were six shorter transects on either side of the creek south of Cranberry Lane in the reference marsh. APCC put in new wooden stakes where markers were lost. Previous monitoring by APCC included pre-restoration sampling in 2010 and post-restoration sampling in 2012 and 2014. The methodology employed for 2021 monitoring is the same vegetation sampling methodology used in 2010, 2012 and 2014 to allow for comparison of data across years. A photo of each transect was taken from the creek edge marking looking toward the upland.

Vegetation sampling occurred within one-meter-square quadrats located at regular 60 ft intervals along the length of a 300 ft transect. Where space was limited, the interval between quadrats was reduced to 15 ft or 30 ft as necessary. All plant species and percent cover of each species were recorded within the 1 m^2 quadrats. Plants were surveyed at each quadrat once during the peak growing season (July-August). The non-native variety of *Phragmites australis* (common reed) is an invasive species that is opportunistic and out-competes native species. In plots containing *Phragmites*, the heights of the 10 tallest stems were measured and recorded. During sampling APCC also identified potential native *Phragmites australis*, ssp. *americanus* (American reed) and documented the location of these patches with GPS points.

After transect-quadrat vegetation sampling was completed in August of 2021, APCC mapped all transect ends and quadrat markers for geographic coordinates and elevation using APCC's Trimble Geo7x. Elevation was recorded in meters relative to Mean Sea Level NAVD88. Due to an offset setting on the device, all elevation measurements contain a 0.9 m offset.

Vegetation data was analyzed according to the methods described in *A Volunteer Handbook for Monitoring New England Salt Marshes* (Carlisle et al. 2002). Data was sorted by species and corresponding percent cover measurements were totaled by species to get total plot cover for the reference and study marsh. Total plot cover was then normalized to calculate annual percent cover for individual species and major subclasses of vegetation (halophytes, non-halophytes, invasives including *Phragmites* and *Typha*, and other cover including dead, bare ground, or open water) for the reference and study marshes. Average annual *Phragmites* height (cm) was calculated for the study marsh. No *Phragmites* patches were detected or monitored in the reference marsh.

b. Phragmites Mapping

In 2021, in addition to transect-quadrat sampling, APCC mapped the location and extent of *Phragmites* patches in each of the major marsh areas: north of Cranberry Lane, south of Cranberry Lane, along Cockle Cove Creek west of Ridgevale Road, and in the Bucks Creek marsh west of Barn Hill Road. This ground-truthed field mapping was not previously done and the GPS documentation was used to compare against delineations derived from aerial imagery completed by Jeff Mason of Friends of Chatham Waterways in 2018.

Mapping of the *Phragmites* boundaries was completed using APCC's handheld Trimble Geo7x GPS unit. The boundaries were delineated by walking the marsh edge of *Phragmites* patches to create polygons or lines to be finalized in ArcGIS (version 10.8.1). For the purpose of field mapping, the exact edges of these patches were defined using "the 50% rule" whereby the mapped line is based on visual determination of areas with 50% or greater coverage of *Phragmites*. This mapping method results in omission of some more sparsely covered areas of *Phragmites*, but in an area with mixed plant community it provides more consistent and efficient results than trying to map and capture all individual plants and stems of *Phragmites*. During this mapping effort several patches of native *Phragmites* were also identified and mapped along with one larger panne with limited salt marsh vegetation.

c. Rapid Assessment Monitoring

In 2021, APCC employed the Salt Marsh Rapid Assessment Method ("MarshRAM", Kutcher 2019) to assess the health and condition of vegetation in the Cockle Cove Creek marsh west of Ridgevale Road as well as the Bucks Creek marsh west of Barn Hill Road. Three transects were established along Cockle Cove Creek and two transects in the Bucks Creek marsh. APCC did not include a rapid assessment in the Bucks Creek marsh system nearer Ridgevale Road because this area was already being monitored utilizing the more detailed and data-rich transect-quadrat method. APCC determined that the transect information collected in this eastern area of Bucks Creek was adequate for evaluating current plant community structure and changes in marsh vegetation.

Starting locations for the transects were determined by using a stratified random sampling methodology. Random starting locations were chosen in each stratified section using an online random number generator. A random number was generated between 0-500 feet and another random number was generated between 500-1,000 feet. A field tape measure was used to determine the starting location for each transect based on the random number generated for each section. All rapid assessment transects were marked with two wooden stakes: at the beginning of the transect on the creek edge and at the upland edge of each transect. The upper, lower, and mid-point location (and elevation) of each rapid assessment transect was documented using a Trimble Geo7x. However, there was an offset of 0.9m set on the device, so all readings reflect NAVD88 plus 0.9m.

The rapid assessment methodology followed the procedures outlined in Kutcher (2019) and included walking transects that were set up in the field. The number of steps within each plant community type (e.g., short-form *Spartina alterniflora*) was documented on a rapid assessment data sheet. Marsh Community Composition (i.e., percent cover of each community type) and the Index of Marsh Integrity was calculated from the data collected in the field according to Kutcher (2019). The Index of Marsh Integrity was calculated by multiplying the number of steps in each community type with a coefficient of community integrity which was then divided by the total number of steps taken in each transect. Scores range from 0 to 10 where 10 represents a marsh with no observed disturbance and 0 indicates multiple disturbances and extreme degradation.

Results:

1. Desktop Assessment

a. Historical Review

As part of the GIS-based analysis, the land-use history of the Cockle Cove/Bucks Creeks area was developed. The historical study uncovered how anthropogenic modifications have significantly altered this already highly dynamic coastal zone. Major influences upon the landscape occurring since the late 19^{th} century have principally been for the purposes of agriculture and erosion control. For example, cranberry farming was responsible for transforming the naturally winding flow of creeks in the salt marshes into straight ditches connecting at 90° angles. In combination with the installation of dams and dikes, the farmer controlled both the artificial timing and velocity of inundation and flow through the system. The summary of the history for Cockle Cove/Bucks Creek is divided by each focal area of the project site.

Lower Cockle Cove Creek/Beach: For the purpose of this historical report, this area is defined as beginning at the deteriorated dike just south of the intersection of Cockle Cove Road and Chatharbor Lane, continuing south to Cockle Cove beach and following the creek eastward towards Ridgevale Beach. Until the 1970's, Cockle Cove creek was directly connected to Nantucket Sound near the location of the present-day Cockle Cove Beach parking lot, and a substantial zone of tidal flats and sand bars extended south (Appendix A, Appendix B). Washover events during winter storms were common, and the landscape of the tidal zone of the near-shore area was constantly in flux. There is no evidence that the area south of Chatharbor dike was ever farmed for cranberries.

To combat erosion at the site of a field of radio towers (now Forest Beach Conservation Area), groin fields and jetties were installed in the 1950's, primarily on the shore west of the Mill creek outlet (Howes et al. 2003). Coastal sediment transportation in this area is in the west to east direction, meaning that the groins accomplished their goal of accreting sediment and stabilizing the shoreline on Forest beach, but also contributed to the downdrift (eastern) beaches being starved of sediment input (Howes et al. 2003). That modification, in combination with storms and nourishment initiatives taken by the Town of Chatham, permanently closed the direct Cockle Cove outlet to Nantucket Sound.

Pine Knoll Ave/Mid Cockle Cove Creek/Buck's Island: This area includes all salt marsh bound by Cockle Cove Road on the west, Chatharbor dike to the south, the degraded dike that lies west of the property on 145 Pine Knoll Avenue (referred to as Pine Knoll dike), and the dike near the south end of Whiteman Avenue to the east. Cranberry irrigation, as well as mosquito control ditching, have left a grid over the majority of the marsh that is still faintly visible on satellite photos. This area was farmed by the United Cape Cod Cranberry Co. (Appendix C) until the great hurricane of 1938 (Nate Wordell, personal communications, July 2021). Lastly, there are two drainage easements (see Appendix D) off Pine Knoll Ave that are now storm drains which discharge into this section of the marsh.

Ridgevale Rd culvert and western marsh: This section of marsh lies between two restrictions: a dike to the west (visible in Appendix A) and Ridgevale Rd to the east. While the western dike was an artificial deposit from cranberry farming, the land mass under Ridgevale Road is natural (Appendix A). No plans could be found of this marsh area, but based on town records this area was taken through eminent domain to extend Ridgevale Road and build the beach landing in 1949 (Appendix B). After this point, what had been called Ridgevale Road became Ridgevale South, as it is known today.

Cranberry Ln North/Star Bog: Cranberry Lane North refers to the marsh north of the culvert on Cranberry Lane (Appendix E). It is "downriver" from Star Bog (Appendix F). The connection between the two was stronger until the late 1970's, when cranberry bog owner, Richard Rich, installed a new flume to replace a failing one, and raised the adjoining road on the south side of

Star Bog by three or four feet (Affidavit as to Adverse Possession, Appendix G). The purpose of raising the road was to control flooding for the purpose of cranberry farming on the owner's three main bogs (referred to as Upper, Middle, and Lower in Appendix G) upstream of Star Bog. After the hurricane of 1938, Star Bog was primarily used for flood control and a source of sand and fill as the storm caused significant damage to the crop in Star Bog.

b. GIS-based Restoration Ranking Analysis

All five subareas of Cockle Cove and Bucks Creek (Figure 4) ranked moderate to high (>35pts) according to APCC's 11 criteria with the highest score for the eastern Bucks Creek marsh and entire Cockle Cove Creek marsh (Table 2). These high scores relative to scores for other potential restoration projects and sites ranked by APCC across Cape Cod indicate the high value of this marsh complex and support the need to protect, preserve and restore this area. This high score is largely driven by the high scores received due to potential to improve impaired waters (bacteria or nutrient impairment) through restoration, the large area(s) of the marsh, overlap with sensitive resources along the coast (Biomap Core habitat, NHESP priority species habitat, and shellfish habitat), protection of the area by the town and Chatham Conservation Foundation ensuring long-term preservation of the marsh, resilience to sea level rise and erosion, and local support and interest from the Foundation to protect, preserve and restore this marsh complex.

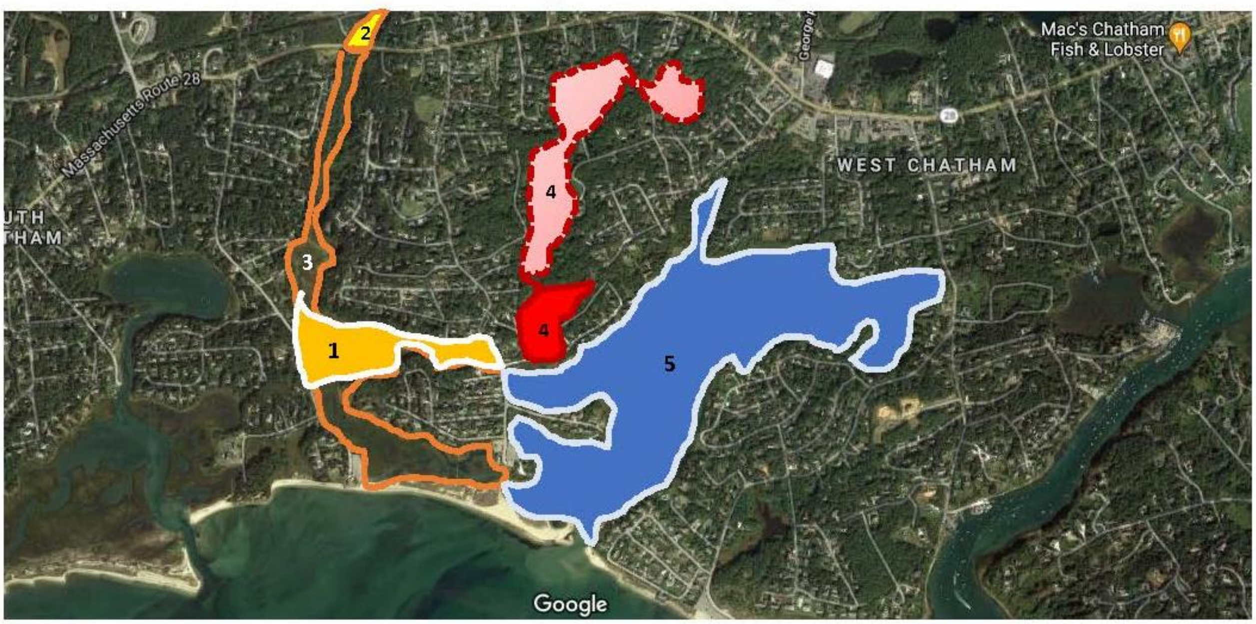


Figure 4: This map depicts the five subsections of Cockle Cove-Bucks Creek marsh system used for the GIS-based desktop assessment and restoration ranking. The five subsections are as follows: 1) Ridgevale Road restriction west to Cockle Cove Drive, 2) Cockle Creek north of Route 28, 3) Cockle Cove Creek and marshes west of Ridgevale Road, 4) Bucks Creek north of Cranberry Lane (dashed line indicates area of Star Bog and active cranberry farming), and 5) Bucks Creek (and Sulphur Springs).

Table 2: APCC restoration ranking criteria and scoring for Cockle Cove-Bucks Creek salt marshes.

Study ID	Description	Holistic Nature of Project	Water Quality	Water Quality Based on Shellfish Designation	Area Restored	Sensitive Resources	Human Use Benefits	Linkage Protected Area	Resilience to SLR	Resilience to Erosion	Local Support	Town Priority	Ecological Value Score	Feasibility Score	Total Score
1	Cockle Cove Creek west of Ridgevale Road and south of Pine Knoll Road	1	4	1	3	1	0	5	3	5	5	1	**29**	**6**	**35**
2	Rt 28 tidal restriction of Cockle Cove Creek	2	4	1	1	0	0	5	6	5	5	1	**30**	**6**	**36**
3	Cockle Cove Creek and marshes	2	4	2	5	2	1	3	6	NA	5	3	**33**	**8**	**41**
4	Bucks Creek north of Cranberry Lane	1	4	1	4	0	0	5	2	5	5	1	**28**	**6**	**34**
5	Bucks Creek marshes to the east (Sulphur Springs)	1	4	2	5	3	1	3	6	NA	5	3	**33**	**8**	**41**

Table 3: Cape Cod Waters Resource Restoration Project (CCWRRP) ranking criteria (2006 & 2020 version) and scoring for the Cockle Cove-Bucks Creek salt marshes.

			Eligibility Score (2006 CCWRRP)					Secondary Criteria Score (2020 CCWRRP)					
Study ID	**Description**	**Upstream Area**	**Contiguous open space**	**Shellfish Resource**	**Anadromous Fish Passage**	**Priority Habitat**	**TOTAL**	**Resilience to SLR Score**	**Migration Score**	**TMDL**	**Low lying property**	**Extent of Restriction**	**TOTAL**
1	Cockle Cove Creek west of Ridgevale Road and south of Pine Knoll Road	7	1	1	0	1	**10**	4	0	6	0	6	**16.0**
2	Rt 28 tidal restriction of Cockle Cove Creek	3	1	0	0	0	**4**	6	0	6	6	6	**24.0**
3	Cockle Cove Creek and marshes	10	1	1	0	1	**13**	4	2	6	0	0	**12.0**
4	Bucks Creek north of Cranberry Lane	5 or 10	1	1	0	0	**7 or 12**	6	0	6	3	0	**15.0**
5	Bucks Creek marshes to the east (Sulphur Springs)	10	1	1	0	1	**13**	4	0	6	0	0	**10.0**

The Bucks Creek and Cockle Cove Creek systems and marshes as a whole, except the wetland area located north of Route 28 (section labeled "2" in Figure 4), ranked moderately high ($\geq$10pts) in restoration priority according to the 2006 CCWRRP eligibility criteria (Table 3). Similar to the APCC criteria scoring, the high ranking is due to the large marsh areas, protection status of the marsh, and linkage to key resources including shellfish beds, and priority habitat for rare species. The marshes scored low for restoration potential on the secondary ranking criteria (2020 CCWRRP) as there is no clear restriction of tidal flow, minimal to no anticipated gains from salt marsh migration, and already moderate to high resilience to sea level rise (50% loss of salt marsh from sea level rise is not reached until 2070). However, the poor water quality in both areas is of concern considering the large resource area that could be protected. Efforts to improve water quality is likely the best area of focus for the systems as a whole.

Ridgevale Road Culvert: The Ridgevale Road culvert restriction had a moderate eligibility score according to the CCWRRP criteria due to high acreage for restoration. Additionally, this area has moderate to high resilience to the impacts of sea level rise with 50% loss of salt marsh not seen until 2070. However, the site had a low to medium secondary criteria score as there was no marsh migration potential and two low-lying properties identified as potentially impacted by sea level rise by 2070. Thus, while the current culvert is half the width of the adjacent stream to the east providing potential for restoration of flow and improvement to water quality, this potential negative impact of residential flooding results in lower scoring. Further study is warranted to determine the potential improvements from culvert widening relative to impacts on abutting properties.

Route 28 Culvert: The area located north of the Route 28 culvert restriction ranked higher for restoration potential than the other areas, according to the 2020 CCWRRP criteria, because: 1) the location is near the headwaters of the system providing greater resilience to sea level rise, 2) there are no low-lying residences or businesses adjacent to the wetland area, and 3) the current culvert restriction is a relatively narrow pipe with low flow so refitting the passage with a larger diameter culvert would improve tidal flow upstream. However, the Route 28 tidal restriction of Cockle Cove scored low for its eligibility score due to low acreage north of the restriction. This is not a recommended restoration site because the small area of potentially restored marsh would provide limited resource benefits.

Cranberry Lane Culvert: The Cranberry Lane area scored moderate to high for the eligibility score according to the CCWRRP criteria. The ranking corresponds with the potential for large acres of restored marsh if connected to the upstream ponds and bogs. The area had a moderate score for the secondary criteria since 1) the restored culvert has effectively eliminated the restriction, 2) the area is not likely to lose much salt marsh due to sea level rise by 2070, and 3) there was no observed potential for salt marsh migration by 2070. The moderate secondary score also factors in that there is potential for some low-lying properties surrounding the existing marsh to be impacted by sea level rise by 2070. The lack of marsh migration in the upstream area is likely due to the previously observed higher elevation. Restoration of connectivity to the upstream area (ponds and bogs) and reduction in elevation might change this potential for migration and restoration but any reduction in elevation in the existing salt marsh area or upstream could potentially lead to impacts on low-lying properties. Further elevation study and modeling would be required.

The maps used for this ranking are available in Appendix H. Appendix H shows the overlap of the marsh complex with key resources (marine beaches, impaired water bodies, Biomap Core habitat, NHESP priority species habitat, shellfish growing and suitability areas), the Town or Chatham Conservation Foundation protected land area, potential flooding of key roadway crossings currently restricting tidal under the intermediate-high sea level rise scenario of 3-4 ft, shoreline change showing erosion of the coastline with limited to no impact on the marsh, and the Massachusetts Office of Coastal Zone Management Sea-Level Affecting Marshes Model (SLAMM) showing anticipated shifts in wetland resources by 2070 under the intermediate-high sea level rise scenario of 4.5 ft. This latter map indicates that by 2070 with this 4.5-foot scenario of sea level rise, we would anticipate significant loss of low and high marsh across the complex. The lost marsh would likely transition to more coastal tidal flat or beach habitat with limited salt marsh migration. There would be limited migration north in Cockle Cove Creek and no anticipated marsh migration in Bucks Creek due to the prohibitive elevation gain caused by the historical and active cranberry farming.

2. Water Quality

a. Nutrients

Results from the water sampling of total nitrogen and total phosphorus indicate that Star Bog contains very high nutrient concentrations during the weeks with peak summer temperatures (Tables 4 and 5). Anecdotally, the field researchers also noted extremely high abundance of floating duckweed during these sampling events, corroborating the high nutrient availability. Since the nutrient levels rise and fall sharply prior to and after the peak summer period, the shift is likely related to organic forms of nitrogen and phosphorus. Organic species of nitrogen and phosphorus (dissolved and particulate) are most prevalent in the summer when primary productivity and bacterial respiration respond to increased temperatures and solar intensity.

Table 4: Total nitrogen results from water samples collected at Bucks Creek. Gray cells with italics indicate where duplicate samples have been averaged together.

Site ID	**Site Description**	**Total Nitrogen (µM)**					
		7/15	7/29	8/12	8/30	9/13	Average
B1	Star bog	*105.5*	860.0	948.0	1020.0	*126.5*	612.0
B2	Cranberry Ln North	51.4	*31.3*	40.5	27.1	71.1	44.3
B3	Cranberry Ln South	56.5	56.2	*157.0*	83.2	76.0	85.8
B4	Ridgevale Rd South	33.8	33.3	37.7	*38.5*	37.3	36.1

Table 5: Total phosphorus results from samples collected at Bucks Creek. Gray cells with italics indicate where duplicate samples have been averaged together.

Site ID	Site Description	Total Phosphorus (µM)					
		7/15	7/29	8/12	8/30	9/13	Average
B1	Star bog	*7.6*	78	71.7	107	*5.6*	54.0
B2	Cranberry Ln North	4.1	*6.5*	9.32	8.7	4.15	6.6
B3	Cranberry Ln South	4.42	6.58	*13.3*	15.2	6.03	9.1
B4	Ridgevale Rd South	1.65	1.98	2.4	*2.5*	2.4	2.2

Although the nutrient levels were extremely high in Star Bog, the concentrations found in the creek north of Cranberry Lane (recently restored area of marsh) were not elevated, compared to Ridgevale Road South, suggesting that there is little to no impact or connection between Star Bog and the lower salt marsh. Furthermore, the nutrient concentrations were actually higher on the southern (reference) side of Cranberry Lane which indicates that the infiltrating groundwater at low tide acts as the major source of nitrogen and phosphorus, more so than the upstream surface water of the estuary. These findings are consistent with MEP report which concluded that the major contributing source of nitrogen in the Bucks Creek estuary was leaching septic systems (Howes et al. 2003). Because of its proximity to the Nantucket Sound, Ridgevale Road South provided a reference station to the stations further inland.

b. Bacteria

The results from the water samples collected along Cockle Cove Creek and at Ridgevale Road South suggest that the major source of bacteria in the system is the Route 28 sluiceway (Table 6). Although the APCC team was only able to collect two samples at this location (C1) due to the relatively dry weather during the sampling period (samples could only be collected at the sluiceway while the roadway was actively draining rainwater), both samples were consistently much higher than those collected in Cockle Cove Creek. These findings are generally consistent with those from the CZM study which suggested that bacteria seemed to primarily enter the marsh system with stormwater runoff from Route 28 and Cockle Cove Road (CZM 2005).

Table 6: Enterococcus results from water samples collected along Cockle Cove Creek and Route 28. NS: no sample.

Site ID	Site Description	Enterococcus (cfu/100ml)					
		8/5	8/12	8/30	9/13	9/27	10/4
C1	Route 28 Sluiceway	>24000	NS	NS	NS	NS	8200

C2	Pine Knoll Dike	505	1800	250	350	175	NS
C3	Buck's Island	370	2200	230	750	210	NS
C4	Chatharbor	20	1000	270	600	290	NS
C5	Cockle Cove Beach Lot	<10	300	230	365	400	NS
B4	Ridgevale Rd South	10	<10	<10	30	10	NS

The fact that the bacteria levels are higher during or following rainfall (Figure 5) provides further evidence that stormwater runoff is the main contributor of bacteria into the system. Therefore, implementing better stormwater management of the roadways and surrounding drainage easements would be the best solution to improve water quality.

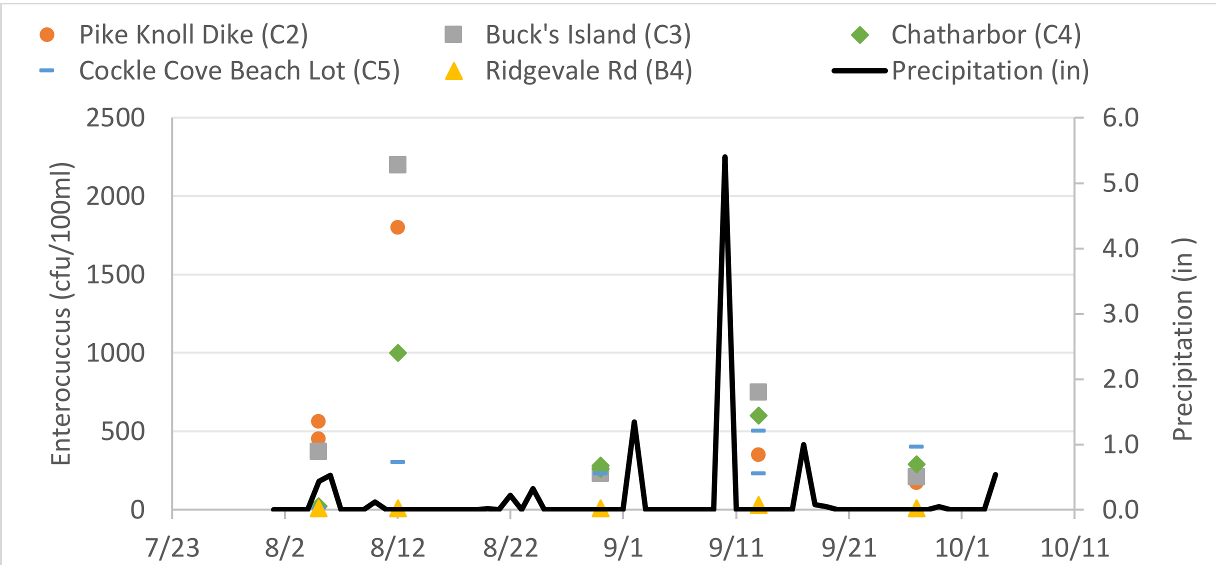


Figure 5: Chatham rainfall and Enterococcus concentrations at Cockle Cove Creek. Rainfall data from the Community Collaborative Rain, Hail, & Snow Network (CoCoRaHS: www.cocorahs.org).

c. Cyanobacteria

Star Bog was sampled for cyanobacteria on a biweekly schedule from June through September 2021. The results from the fluorometer analysis and microscope counts indicate that Star Bog did not experience any cyanobacteria blooms throughout the season (Table 7). Phycocyanin (the pigment produced by freshwater cyanobacteria) concentrations remained low throughout the sampling period and a relatively small number of *Microcystis* and *Oscillatoria*, two of the potential bloom forming species, were observed.

Table 7: Cyanobacteria results for samples collected at Star Bog.

Sample Date	Pond Temp (F)	Air Temp (F)	Fluor Date	Fluorometer Results (mixed raw sample)			Colony Count	Dominant Genus	Human Threat Level Status
				PC (ug/L)	*CHLA (ug/L)*	*Ratio*	*colonies/mL*		
6/16/2021	66.6	61.6	6/17/2021	8.63	2.33	3.70	2	Other	Low
6/30/2021	76.3	72.7	7/1/2021	26.03	1.26	20.15	0	NA	Low
7/14/2021	67.6	64.1	7/15/2021	0.00	2.06	0.00	6	Microcystis	Low
7/30/2021	67.8	63.3	8/2/2021	6.45	1.20	5.40	12	Oscillatoria	Low
8/12/2021	75.6	75.0	8/13/2021	10.65	1.44	7.41	0	NA	Low
8/25/2021	81.8	84.8	8/26/2021	18.23	1.67	9.75	0	NA	Low
9/8/2021	65.3	64.9	9/9/2021	7.31	2.66	2.87	0	NA	Low
9/22/2021	66.4	65.1	9/23/2021	11.61	2.30	5.03	4	Oscillatoria	Low

3. Tidal Hydrology and Salinity

Figure 6 shows the results from the water level loggers deployed at four different locations within the Cockle Cove and Bucks Creek system. The station with the greatest tidal range was located at Cranberry Lane South in the reference marsh area whereas the station with the smallest tidal range was located at Ridgevale Road West (Table 8). The other two stations, Cranberry Lane North and Pine Knoll East, showed very similar tidal ranges even during spring tides. The phenomenon whereby one flood tide is higher than the second within a 24-hour period is known as the diurnal inequality.

Table 8: Maximum elevation, minimum elevation, average elevation, and tidal range derived from water level logger data for each of the four stations.

	Relative Water Level (m, NAVD88 + 0.9m)				Corrected Water Level (ft, NAVD88)			
	Max	Min	Range	Average	Max	Min	Range	Average
Cranberry Lane - South (Reference)	1.97	0.87	1.10	1.16	3.52	-0.09	3.61	0.87
Cranberry Lane - North (Restored)	1.90	1.00	0.91	1.22	3.29	0.31	2.98	1.05
Pine Knoll East	1.90	1.04	0.86	1.23	3.28	0.45	2.83	1.10
Ridgevale Road West	1.84	1.29	0.54	1.37	3.08	1.29	1.79	1.56

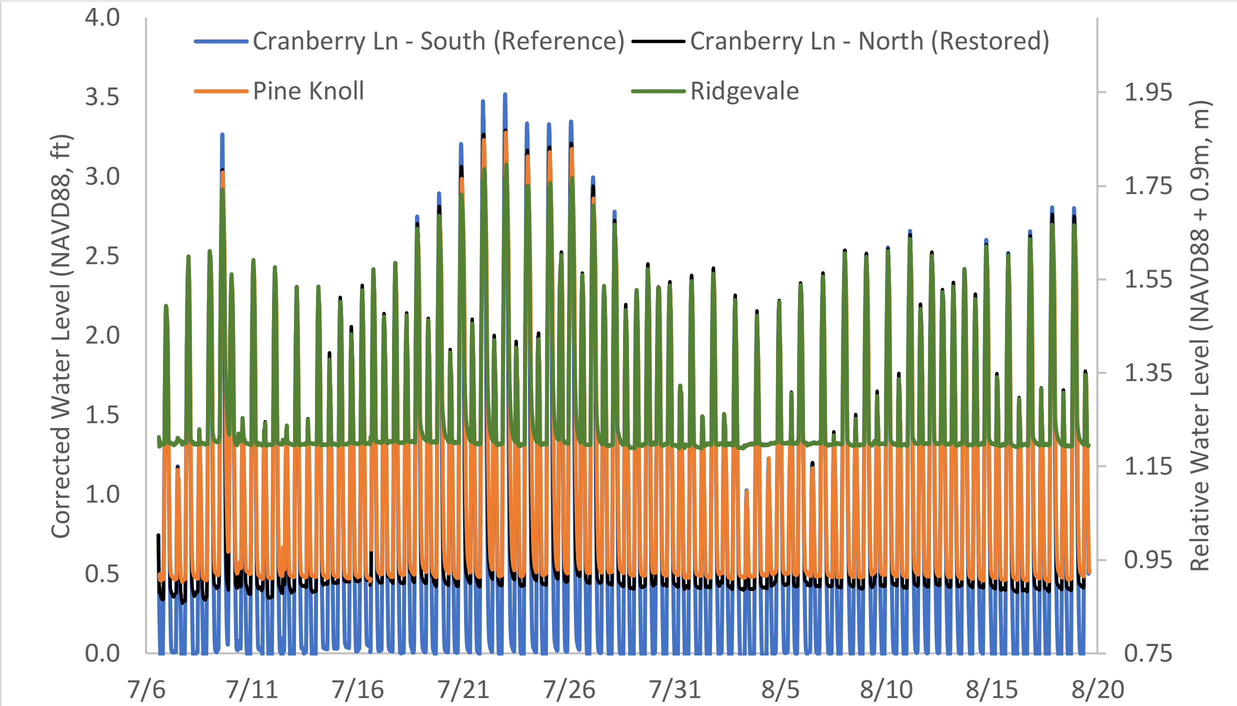


Figure 6: Water level data from four stations within the Cockle Cove and Bucks Creek marsh system. Because there was an offset during elevation data collection, the data have been corrected to NAVD88 in feet (to compare against earlier monitoring efforts). The relative water level data is also provided in meters in order to make comparisons across the other parameters collected as part of this study.

Upon closer inspection of the restored and reference areas surrounding Cranberry Lane, the impact of the culvert is more pronounced (Figure 7). The culvert at the Cranberry Lane crossing was replaced from an 18-inch pipe to a 3 ft x 4 ft diameter box culvert in 2011 to improve tidal flow to the upstream portion of Bucks Creek. While the 2011 culvert does improve the tidal range upstream (compared to Figure 1, Ramsey 2009), the restored area still receives an attenuated (reduced) tide during spring tide. Additionally, during spring tides, the upstream marsh area does not drain as quickly as the reference area of the marsh with an approximate 30-minute to hour-long delay in the subsiding upstream water level.

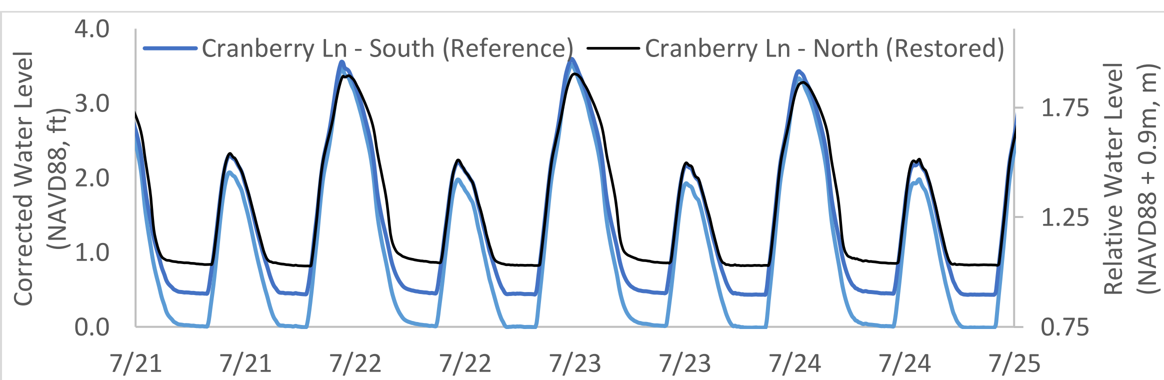


Figure 7: Water level data spanning four days from the restored and reference areas surrounding Cranberry Lane.

The Pine Knoll and Ridgevale water loggers also reflect an interesting hydrologic relationship between the Cockle Cove channel and the impaired marsh area west of Ridgevale Road (Figure 8). The elevation difference between the two loggers can be clearly seen in the data results. As the tide retreats, the Ridgevale logger is no longer submerged at roughly a full foot higher in elevation than the Pine Knoll logger. This change in elevation across the salt marsh is mostly likely a result of human-induced modifications during the historical cranberry farming and the building of Ridgevale Road.

Also, the water level at Ridgevale West does not reach the same peak height as at the station at Pine Knoll. The reason for this difference in peak tidal height is unclear and requires further investigation but may be related to the old cranberry dike restricting the flooding high tide and/or a change in groundwater pressure at Ridgevale. During spring tides (high of the diurnal pattern), it appears that the water level at Ridgevale West may be driven more by the groundwater table than by the tide in Cockle Cove Creek. The threshold for this shift to groundwater influence appears to be approximately 2 ft above mean sea level (NAVD88). The groundwater table at Ridgevale West is likely affected earlier than Pine Knoll because of its proximity to Bucks Creek. Ridgevale West also drains earlier and faster than the outgoing tide at Pine Knoll, which may mean that the change in groundwater pressure from the tide receding at Bucks Creek impacts the Ridgevale marsh sooner than the tide turning in Cockle Cove. Due to this complicated hydrological interaction, this area requires further study to understand how replacing the failed culvert might impact the salt marsh platform elevation and hydroperiod in this area of the marsh system.

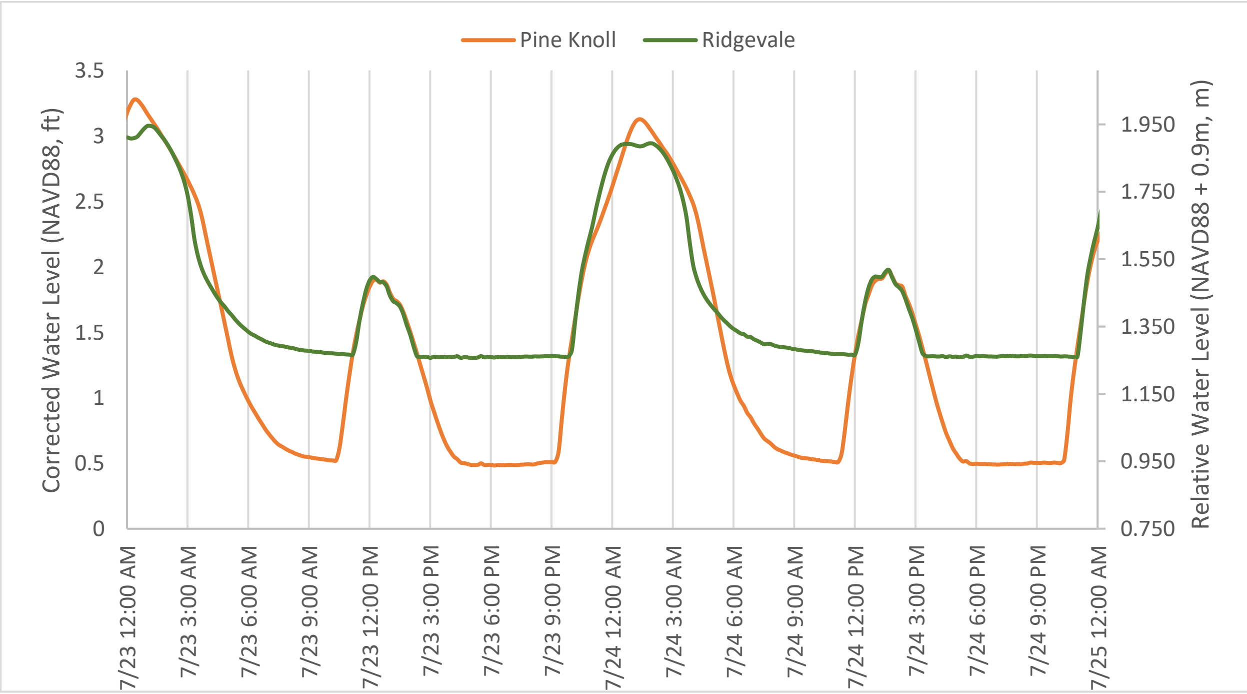


Figure 8: Pine Knoll East and Ridgevale West water level data spanning two full tidal cycles.

The variation in salinity from the loggers also shows the impact of the tides across the four stations (Table 9). At Cranberry Lane the restored area of the marsh retains higher salinity levels at low tide especially during spring tidal cycles (Figure 9). Since the salinity never reaches zero during low tides (i.e., the logger is always partially submerged in saltwater), it is likely that there is some standing water in the main channel during low tides. Conversely, the area of the creek where the reference logger was placed appears to completely drain during low tide. The slow drain and residual water in the upstream (restored) area results in higher salinity causing the average salinity in the creek channel to be approximately 2 ppt greater than the downstream (reference) area (Table 9).

Table 9: Maximum, minimum, average, and range in salinity concentration at the four monitoring stations.

	Salinity (ppt)			
	Max	Min	Range	Average
Cranberry Lane - South (Reference)	32.1	0.0	32.0	15.7
Cranberry Lane - North (Restored)	30.9	2.7	28.3	13.4
Pine Knoll East	32.1	2.8	29.3	11.4
Ridgevale Road West	32.2	0.0	32.2	11.7

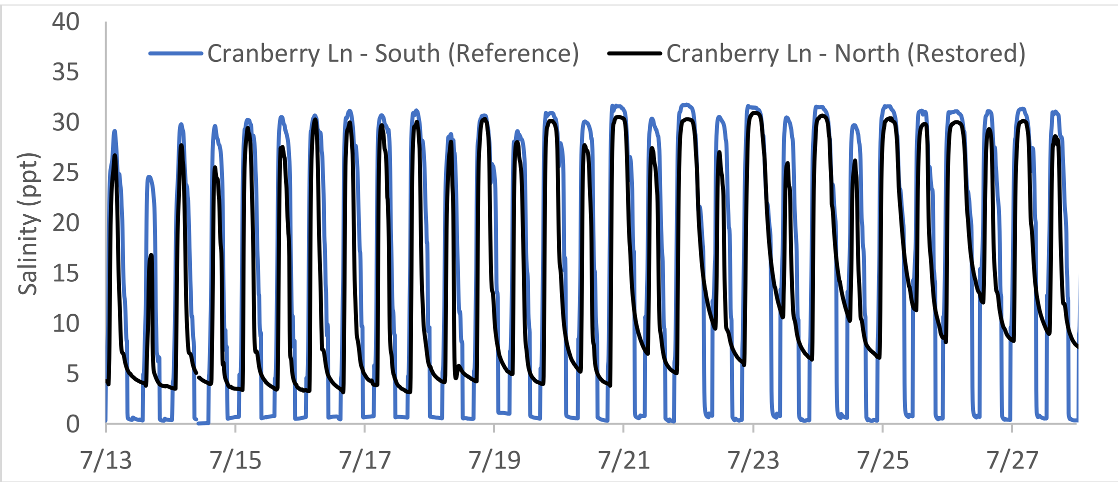


Figure 9: Salinity data collected from automated data loggers within the tidal creek north and south of Cranberry Lane. The time series shows the impact of a neap tide (7/13 – 7/20) and spring tide (7/21 – 7/28) on salinity concentrations in the restored (north) and reference (south) areas surrounding Cranberry Lane.

The salinity results from Ridgevale West show a different pattern for spring and neap tides. During neap tides, the salinity follows a regular oscillating pattern whereby the salinity reaches a high of 32 ppt during higher flood tides and a low of roughly 10 ppt during the smaller flood tides (see Figure 10). However, during spring tides the salinity readings remain higher for longer such that the salinity rarely drops below 20 ppt within one full diurnal cycle, or 24-hour period (see Figure 11). Although the tide drains quickly (as discussed above), the salinity does not fall with the water level and rebounds to roughly 23 ppt with the next flood tide. The marsh only reaches the low tide baseline of 5-10 ppt after a full 24-hour tidal cycle. This further suggests that the water level West of Ridgevale Road is driven by groundwater pressure changes to a greater extent than surface water flooding. Lastly, storm impacts, as seen in the drop in barometric pressure on July 9th in Figure 12, clearly impact the salinity concentrations within the Ridgevale West marsh by forcing up the water level and causing high salinity water to inundate the marsh for an extended period of time.

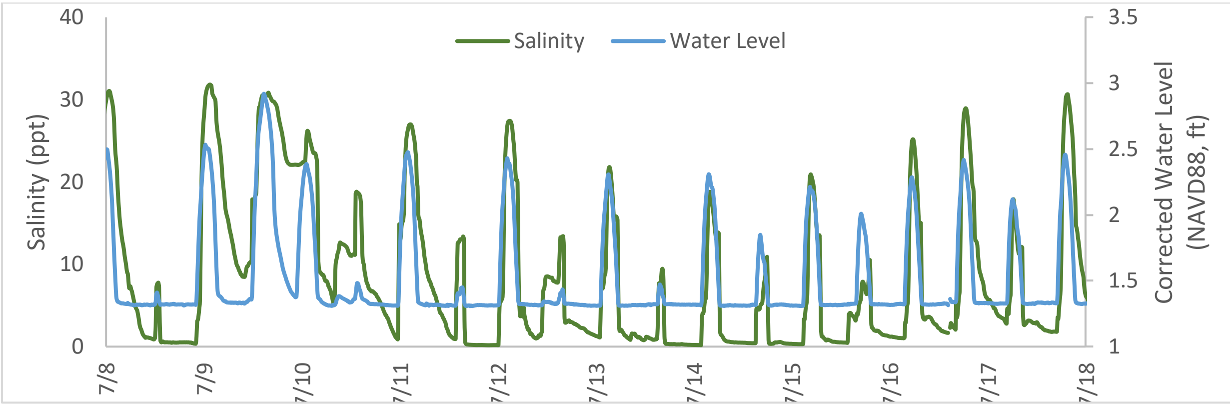


Figure 10: Salinity and water level during a neap tide at the marsh located on the western side of Ridgevale Road.

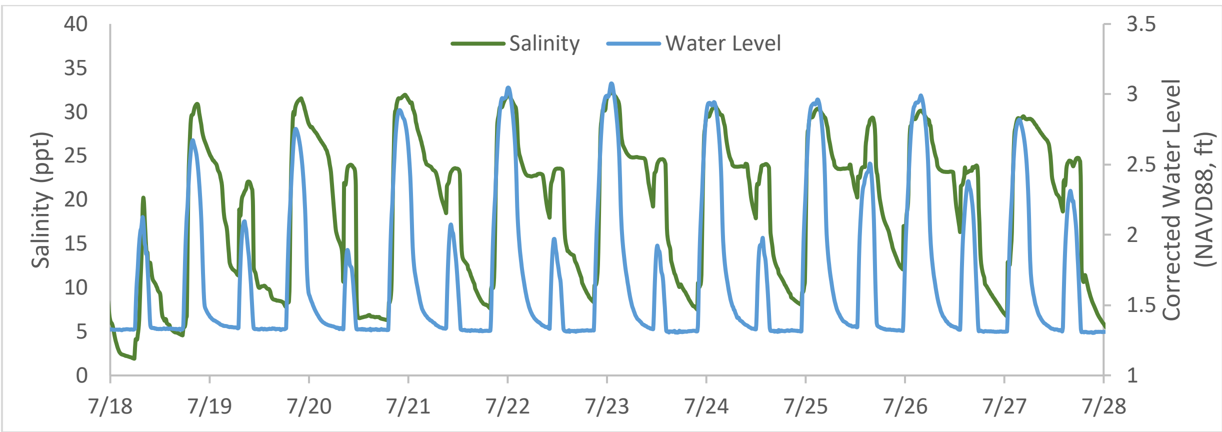


Figure 11: Salinity and water level during a spring tide at the marsh located on the western side of Ridgevale Road.

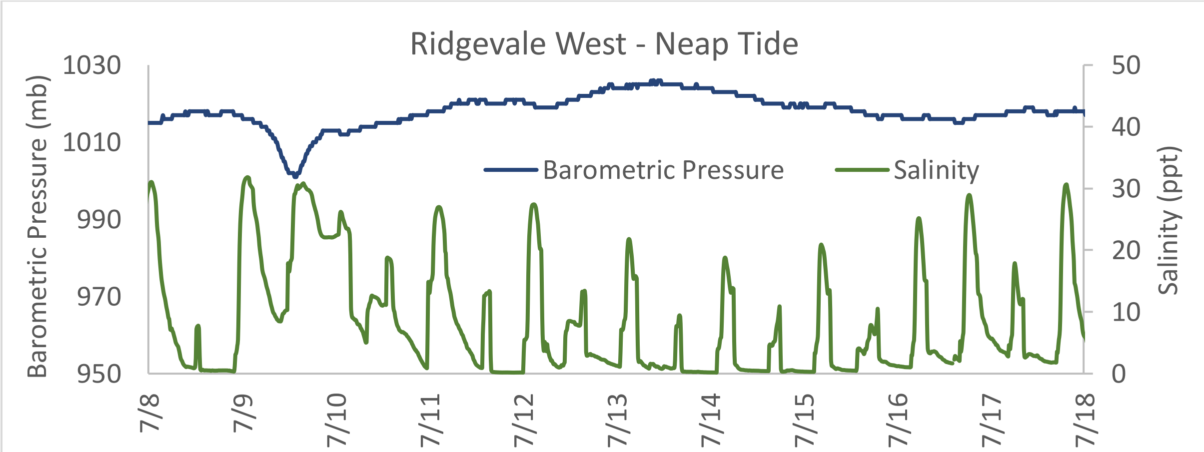


Figure 12: Storm impacts the water level and salinity concentrations west of Ridgevale Road. Barometric pressure data provided by the Waquoit Bay National Estuarine Research Reserve (www.nerrsdata.org).

4. Soil Sampling

The soil samples taken in the reference marsh south of Cranberry Lane were composed primarily of peat (Figure 13).

It was noticeable easier to get the auger into the study marsh side north of Cranberry Lane indicating that the peat layer is less compact or developed. There was more sand and mud under a layer of marsh peat.

Figure 13: Images of Cranberry Lane reference marsh soil samples (left to right): Sample R1W-60 and sample R3S-120. No image was taken of R4NE-60.

Figure 14: Images of Cranberry Lane restored study marsh soil (left to right, top row to bottom row): samples S1E-15, S2E-60, S2W-60, S3W-60. No images shown for S3W-120 and S3E.

The samples taken in the restored area of marsh were largely composed of peat, mud, and sand (Figure 14).
The marsh west of Ridgevale Road was very unstable to walk on indicating a less developed peat subsurface. Sample collection was attempted at the central part of the small marsh surrounded by *Phragmites*. However, due to the small layer of peat floating on an unstable, watery substrate, soil extraction was not possible.

Figure 15: Images of Cockle Cove Creek marsh south of Pine Knoll (left to right): sample from western edge of cockle cove, and sample from east near data logger deployment location.

The Cockle Cove Creek salt marsh south of Pine Knoll Road was firm to walk on with a very well-developed peat layer. Samples taken both at the western edge of the marsh and the eastern section near the location of the water level logger deployment were both composed of 100% peat indicative of a healthy marsh soil (Figure 15). The soil sample taken in Bucks Creek marsh west of Barn Hill Road was also composed of 100% peat (Figure 16).

Figure 16: Image of soil sample taken in Bucks Creek reference marsh west of Barn Hill Road.

Table 10 summarizes the soil types of each of the major marsh areas sampled. The marsh surrounding Cockle Cove Creek south of Pine Knoll and the Bucks Creek reference marsh west of Barn Hill Road had the most stable soils with 100% peat. The reference marsh soils south of Cranberry Lane were also largely composed of peat with some finer mud. This limited sampling in the unrestricted reference marsh suggests a healthy marsh condition due to the high peat content in the soils. The restored study marsh north of Cranberry Lane also contained varying levels of peat mixed with sand. This noticeable inclusion of sand is indicative of former cranberry bog farming in this location. Addition of sand as part of the farming process is likely a contributing factor to higher elevation and dryer soils in this area and might play a part in differences in vegetation, salinity and tidal flow measured in this area.

The area west of Ridgevale Road as well as some sections of the marsh north of Cranberry Lane contained very wet mud with more limited peat development. This loss of peat is indicative of degradation of the marsh resulting from long-term tidal flow restriction.

Table 10: Summary of soil sample locations and soil descriptions.

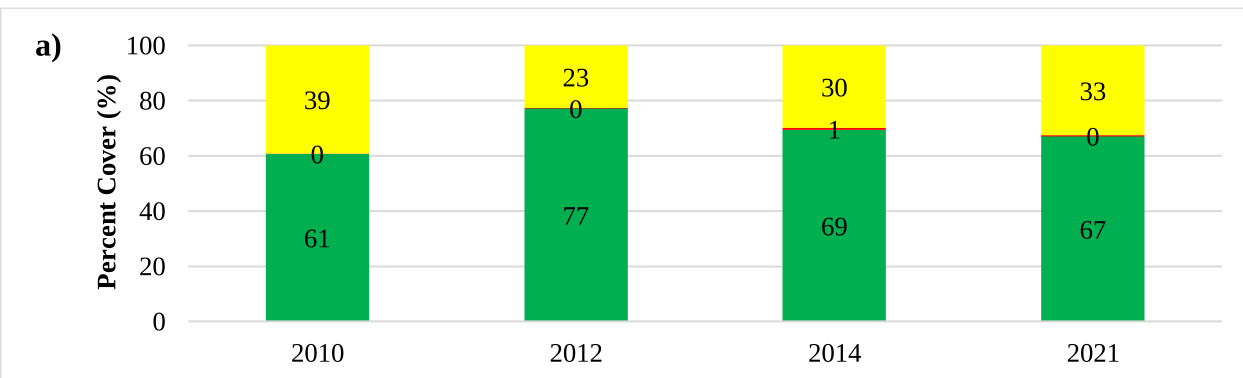
Location	**Sample ID**	**Soil Description**
Cranberry Lane Reference Marsh	R1W-60	95% peat, 5% mud/sand
Cranberry Lane Reference Marsh	R3S-120	100% peat
Cranberry Lane Reference Marsh	R4NE-60	50% peat, 50% mud
Cranberry Lane Study (Restored) Marsh	S1E-15	100% peat with sand
Cranberry Lane Study (Restored) Marsh	S2E-60	60% peat, 40% mud/sand
Cranberry Lane Study (Restored) Marsh	S2W-60	40% peat, 40% sand
Cranberry Lane Study (Restored) Marsh	S3W-120	80% peat, 15% gray sand
Cranberry Lane Study (Restored) Marsh	S3E	Wet. Very little peat
Cockle Cove Marsh West of Ridgevale Road	n/a	Wet. Very little peat
Cockle Cove Marsh South of Pine Knoll	West	100% peat
Cockle Cove Marsh South of Pine Knoll	East (near logger)	100% peat
Reference Marsh West of Barn Hill Road	Barn Hill	100% peat

5. Vegetation

a. Quadrat Sampling

Following the 2011 restoration of tidal flow to the upstream marsh north of Cranberry Lane, the expectation was that there would be a reduction in cover of the salt-intolerant invasive species *Phragmites* and non-halophytes coinciding with an increase in cover of halophytes. The resultant shift in the vegetation would, in theory, more closely resemble that of the reference marsh. At the same time, the increase in tidal flow and salinity in the study marsh would be expected to stunt the growth of *Phragmites* and limit its height.

The data from the 2012 transect-quadrant monitoring show the vegetation following an early response to the restoration as predicted, but subsequent years of monitoring show the restored area reverting back to the vegetation composition seen before restoration (Figure 17). Interestingly, the reference marsh also shows a similar increase in halophytes (namely *Spartina alterniflora*) in 2012 which suggests that other environmental factors (e.g., precipitation) may be the primary driver influencing these changes. In the restored marsh, the *Phragmites* cover remains largely unchanged, and the halophytes continue to be outcompeted. Additionally, the average height of the *Phragmites* increases over time following the restoration with the tallest stem heights in 2021 (Figure 18). Since the tidal flow restoration does not appear to have impacted the percent cover or growth pattern of *Phragmites*, there must be other factors influencing its survival. Possible explanations for the resistance of *Phragmites* concern the depth of the groundwater table and leaching of nutrients. *Phragmites* has been known to have extensive rhizomes (or root systems) which allows it to reach deep into the groundwater table for freshwater and nutrients.



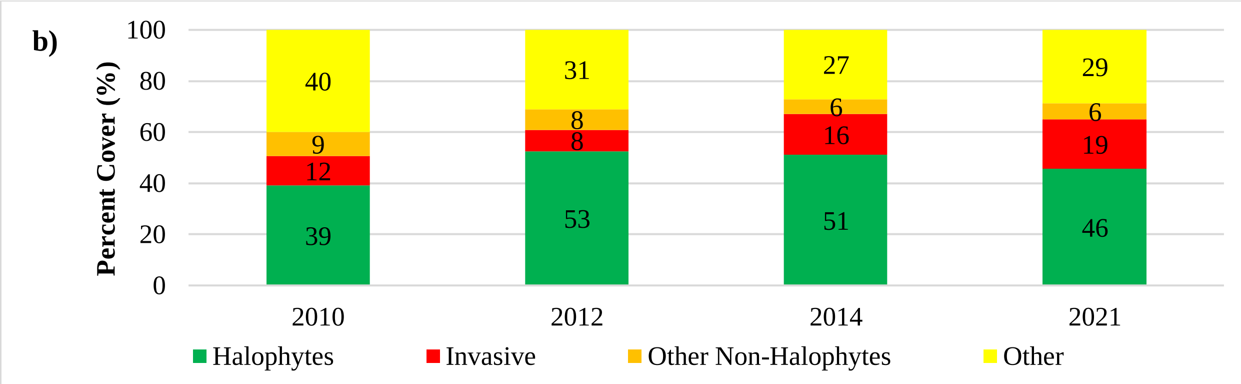


Figure 17: Results from the vegetation quadrat survey in the a) reference and b) restored area of the Bucks Creek marsh (south and north of Cranberry Lane, respectively). The culvert restriction was removed in 2011.

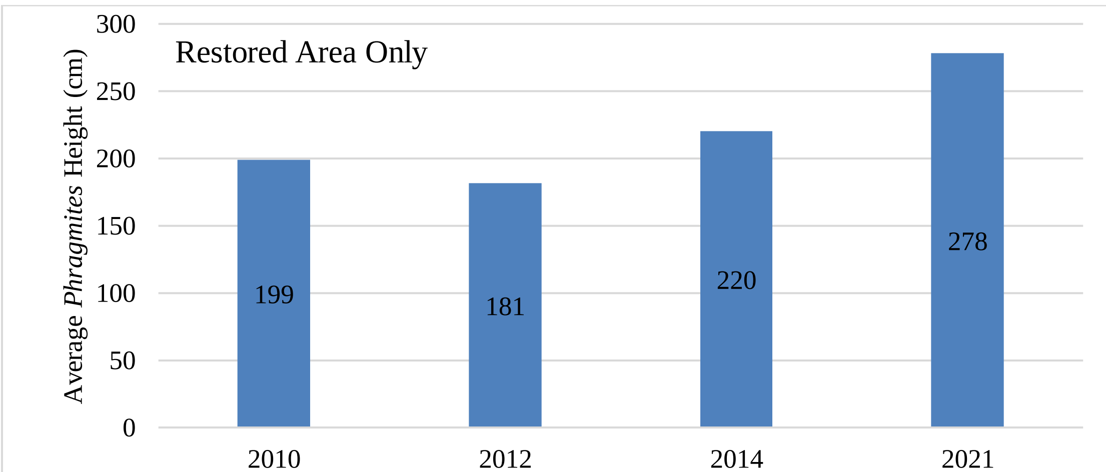


Figure 18: Average height of *Phragmites australis* (the non-native variety) surveyed within vegetation quadrats in the restored area of marsh (north of Cranberry Lane).

Based on the elevation measurements obtained at each of the vegetation quadrat plots, the restored marsh has an average platform elevation of 1.50m (NAVD88 + 0.9m) whereas the reference marsh plots had an average elevation of 1.32m (NAVD88 + 0.9m) (see Figure 19). This elevation difference of roughly 20 cm, on average, may also contribute to the resilience of the *Phragmites* stand against the restored tidal flow. As noted in the soil sample results, the change in elevation may be a result of adding sand during the historical cranberry bog operations.

b. Phragmites mapping

Although the results from the quadrat monitoring indicate the growth and expansion of *Phragmites* north of Cranberry Lane, the results from the *Phragmites* mapping effort seem to indicate that the cover of *Phragmites* has retreated some since 2018 (Figure 20). These combined results suggest that the area of *Phragmites* does fluctuate on an interannual basis depending on climate and other environmental factors. That said, it is important to emphasize the differences in methodologies employed by APCC and Jeff Mason. APCC mapping in 2021 was completed in the field allowing for more accurate identification of species but does not include mapping all areas of *Phragmites* where sparsely vegetated. Methodology employed by Jeff Mason in 2018 utilized drone footage and aerial imagery to identify and map *Phragmites* patches with no on-the-ground inspections.

Based on the comparison of the two sets of data and in field observation in 2021, it was noted that some of the 2018 data may include sections of tall form *Spartina alterniflora* on the fringe of *Phragmites* patches resulting in an over-estimate of the size of *Phragmites* patches in some areas (e.g., Figure 21 and Figure 22). Therefore, the two datasets alone may not be directly comparable when seeking to examine change in the extent of *Phragmites* over this time period. These data should be reviewed in tandem with other vegetation data to understand the extent and changes in *Phragmites* at this site over time.

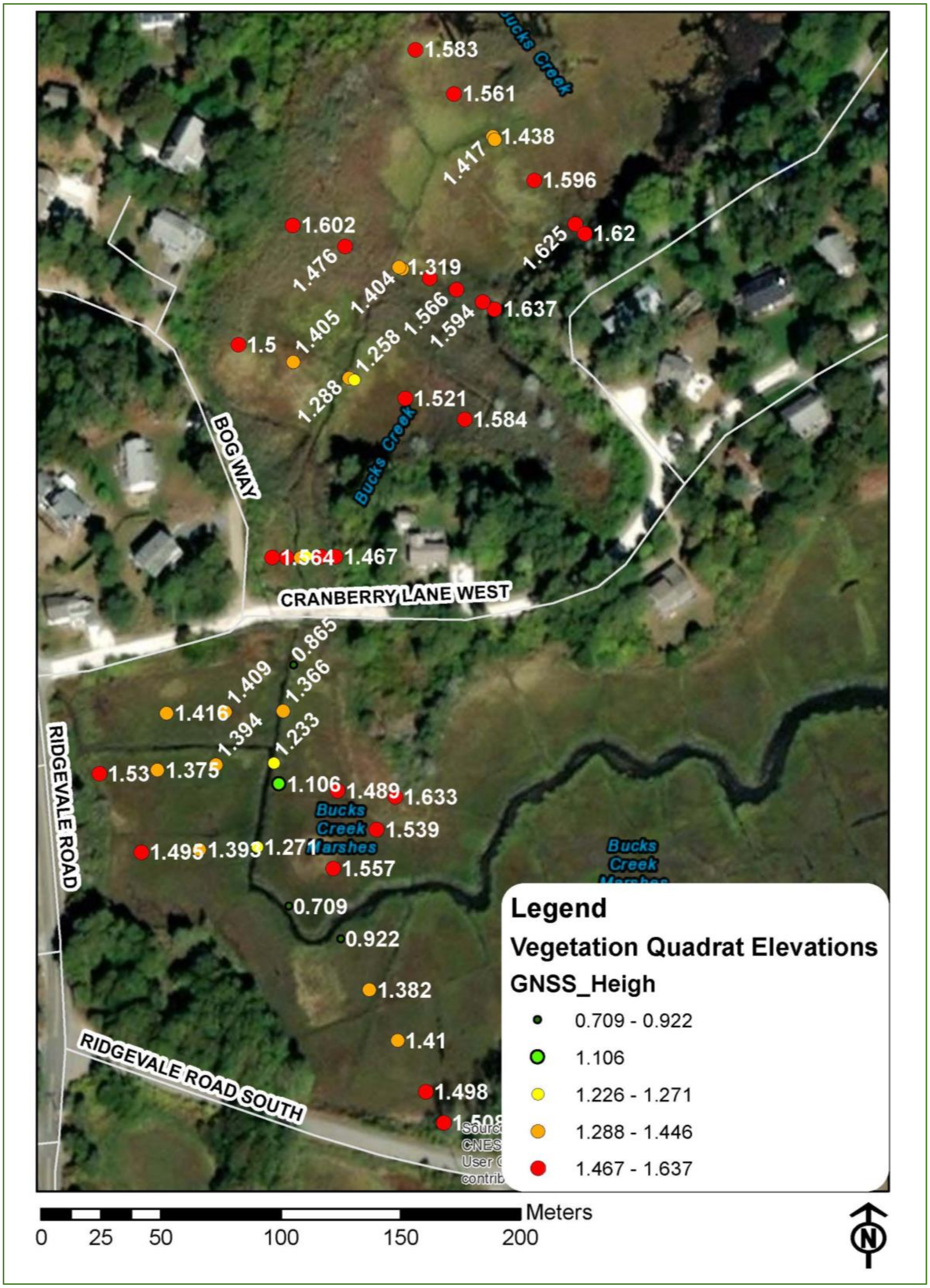


Figure 19: Map displaying the location and elevation (including 0.9m offset) of the quadrats on Bucks Creek north and south of Cranberry Lane.

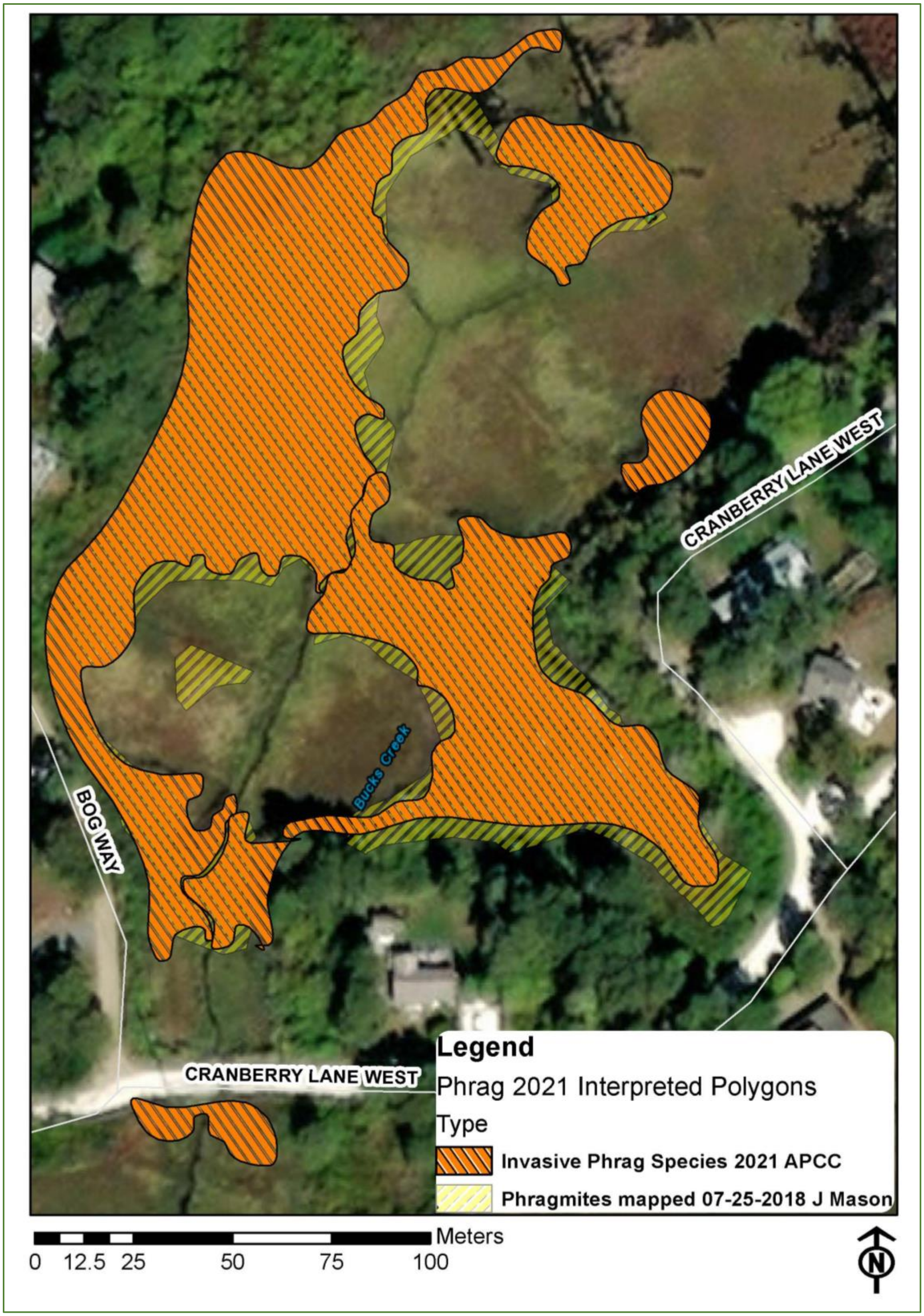


Figure 20: Extent of non-native *Phragmites australis*. Note that 2021 survey was delineated in the field using a handheld GPS whereas the 2018 extent was delineated based on aerial photography.

c. Rapid Assessment Monitoring

The results from the salt marsh rapid assessment method demonstrated that the various areas of marsh are similar in their moderate resiliency to sea level rise. All of the transects averaged similar Marsh Integrity Scores between 5-6 (highest possible score = 10) except for the marsh transect located on the north side of the Pine Knoll area which scored higher at nearly 9 (Table 11). The Pine Knoll area contains the highest diversity of plants including some native *Phragmites* as well as native high marsh plants (includes flooding-intolerant species such as *Distichlis spicata*, *Spartina patens*, and *Juncus gerardii*). Based on research described in Kutcher (2019), the presence of high marsh plant species demonstrates relatively low vulnerability to recent sea level rise. Conversely, the salt marsh areas bordering Ridgevale Road and Sulphur Springs (or Bucks Creek) are dominated by short-form *Spartina alterniflora* which is a more flood-tolerant species and endures in areas adjusting to increased inundation. The lack of high marsh plants in Bucks Creek indicates that these marsh areas are already struggling to keep up with sea level rise.

Table 11: Scoring results from the salt marsh rapid assessment method (Kutcher 2019). The scale for the Marsh Integrity Score is 0 to 10, where 10 is no disturbance (high integrity) and 0 is highly disturbed (low integrity).

	Community Composition (Percent Cover)															
Marsh Area/Transect	Salt Shrub	Brackish Marsh Native	Phragmites	Meadow High Marsh	Mixed High Marsh	Spartina alterniflora high marsh	Dieoff Bare Depression	Low Marsh	Dieback/Denuded Peat	Natural Panne	Natural Pool	Natural Creek	Ditch	Bare Sediments	Total Cover	Marsh Integrity Score
Ridgevale					13	88									100	5.25
Pine Knoll - South		16	22			53	4	6							100	5.36
Pine Knoll - North	9	38		31		18		4							100	8.94
Sulfur Springs - South		5				73		22							100	5.91
Sulfur Springs - North				8	5	74	3	10							100	5.66

See Figures 21 and 22 for the location and elevation of the rapid assessment transects as well as the extent of *Phragmites* in 2021 and 2018.

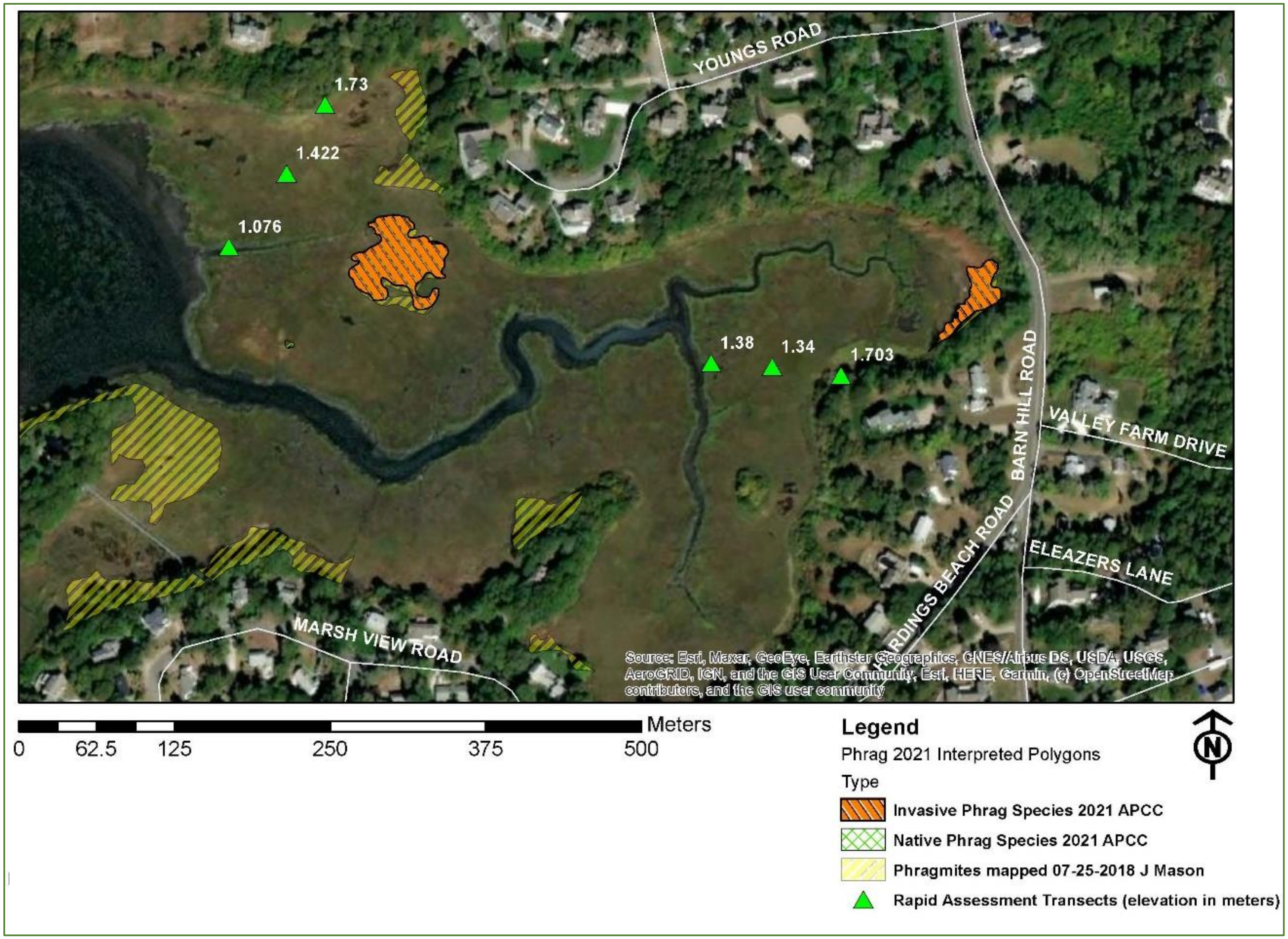


Figure 21: Map detailing the location of the rapid assessment method transects near Barn Hill Road. Elevation data of the transect endpoints and midpoints are provided in NAVD88 (m) and offset by +0.9m. Note there was a difference in methods for determining the *Phragmites* extent across years; 2021 survey was delineated in the field using a handheld GPS whereas the 2018 extent was delineated based on aerial photography.

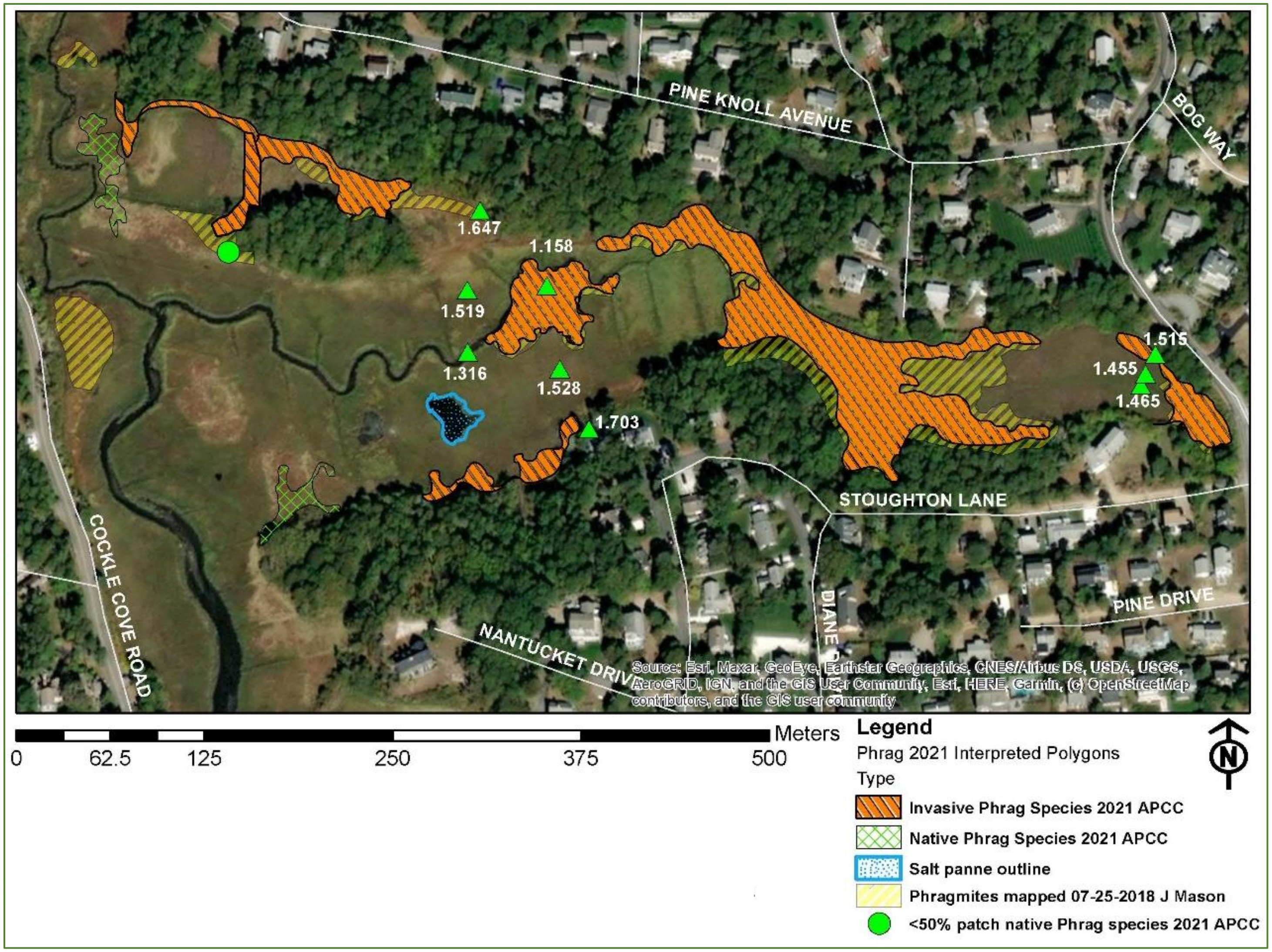


Figure 22: Map detailing the location of the rapid assessment method transects near Pine Knoll Road. Elevation data of the transect endpoints and midpoints are provided in NAVD88 (m) and offset by +0.9m. Note there was a difference in methods for determining the *Phragmites* extent across years; 2021 survey was delineated in the field using a handheld GPS whereas the 2018 extent was delineated based on aerial photography.

Summary & Recommendations:

The tidally restricted marsh areas located west of Ridgevale Road and north of Cranberry Lane (sections labeled “1” and “4” in Figure 4) received moderate scores for the restoration ranking criteria due to moderate resilience to sea level rise and connection to impaired water bodies which could benefit from restoration. However, all areas of the Cockle Cove and Bucks Creek marsh complex ranked low for potential salt marsh migration due to high elevation of the surrounding landscape. Despite the limited migration pathways, the moderate or high scores received by both the Cockle Cove Creek marsh west of Ridgevale Road and the marsh north of Cranberry Lane supports the need to preserve and restore these areas.

The anticipated potential to restore the active and inactive bogs north of Cranberry Lane to salt marsh or for future salt marsh migration is not supported by this assessment. Based on site elevation and sea level rise modeling and scenarios, restoration of Star Bog and the active bogs north of Cranberry Lane is unlikely to provide a route for marsh migration. However, if the bogs are abandoned in the future these might still present opportunity for restoration to freshwater wetlands. Additionally, although the northern side of Cranberry Lane did not show elevated nutrient levels, it’s possible that the *Phragmites* stand persists in this area due to rare overflows of high nutrient concentrations from the neighboring Star Bog. Thus, restoration of Star Bog to a more functional freshwater wetland might help reduce *Phragmites*.

While surrounding nutrient levels may be one contributing factor to the persistence of *Phragmites* upstream of Cranberry Lane, the second likely driver is the higher elevation of the restored salt marsh area. This higher elevation is a remnant of the past cranberry farming operations during the mid-1900s and continues to impact the salt marsh function and plant diversity today. While actions could be taken to lower the elevation, this artificially elevated marsh might provide increased resilience to sea level rise in the future by supplying an area for salt marsh migration with rising seas. Based on the rapid assessment transects, there is already a trend towards higher percent cover of *Spartina alterniflora* in Bucks Creek marshes which resulted in a moderate score for condition and health of those areas. The loss of high marsh plant species in Bucks Creek suggests that the overall system might already be impacted by sea level rise. This is further evidence that the persistence of high elevation areas like north of Cranberry Lane might be useful to maintain high marsh plants in this system long-term. In conclusion, APCC does not recommend changing the elevation of the restored marsh area north of Cranberry Lane.

Additionally, APCC recommends further study of the hydrology and elevation in the marsh west of Ridgevale Road. The soil samples and anecdotal observation of this marsh is consistent with this finding of an area that is wet and does not drain well. As was determined from historical review, the patch of marsh which currently supports a robust stand of non-native *Phragmites* was the location of a former dike. This higher elevation may be contributing to persistence of *Phragmites* as well as degrading the marsh through impeded drainage. *Spartina alterniflora* continues to dominate in the center of the marsh (between the dike and Ridgevale Road) due to the high salinity levels which persist throughout the entire spring tidal cycle. The discovery that the water level is controlled by both tides (from Cockle Cove Creek) and groundwater pressure (from Bucks Creek) is an odd one and warrants further investigation. While perhaps not necessary to have a large-scale tidal restoration by replacing the collapsed culvert with an enlarged one (as was done at Cranberry Lane), there is potential to restore additional flow and increase drainage through replacement of the culvert in-kind. There's also the possibility that the roadway may be compromised if left unstudied. This location should be further reviewed by the Town and the Chatham Conservation Foundation for culvert replacement and dike removal.

Lastly, APCC recommends further stormwater assessment of lower Cockle Cove Road, Route 28, Ridgevale Road, and Ridgevale Road South to determine extent of drainage area, calculate pollutant loadings, and determine stormwater management options (concept designs) for consideration by the Town. Since sampling was limited at the sluiceway on Route 28, additional wet weather sampling at this site is critical to determining the pollutant load of *Enterococcus* coming from this roadway. More sampling is also needed along Cockle Cove Road, as the data showed elevated bacteria levels along Cockle Cove Creek following rainstorm events.

Literature Cited:

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Howes, B., D. White, and R. Samimy. November 2006. "MEP Technical Memorandum Final: Cockle Cove Salt Marsh Nitrogen Threshold." Massachusetts Department of Environmental Protection and University of Massachusetts Dartmouth School of Marine Science and Technology.

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Neckles, H.A., M. Dionne, D.M. Burdick, C.T. Roman, R. Buchsbaum, E. Hutchins. 2002. “A monitoring protocol to assess tidal restoration of salt marshes on local and regional scales.” *Restoration Ecology* 10:3, 556-563.

Neckles, H.A., G.R. Guntenspergen, W.G. Shriver, N.P. Danz, W.A. Weist, J.L. Nagel, and J.H. Olker. 2013. “Identification of Metrics to Monitor Salt Marsh Integrity on National Wildlife Refuges in Relation to Conservation and Management Objectives.” United States Geological Survey.

Natural Resources Conservation Service (NRCS). 2006. “Final Watershed Plan – Areawide Environmental Impact Statement.” United States Department of Agriculture.

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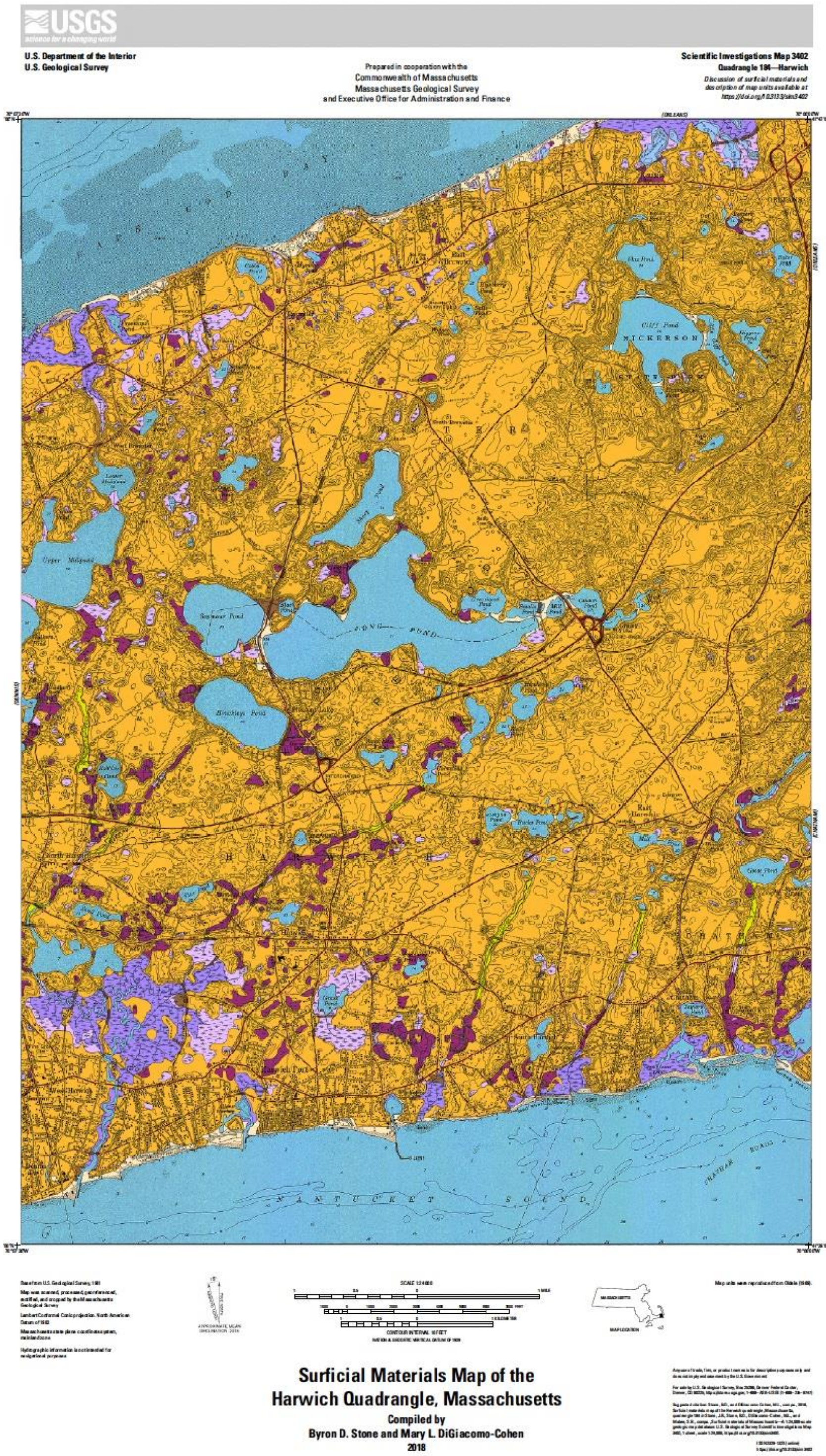
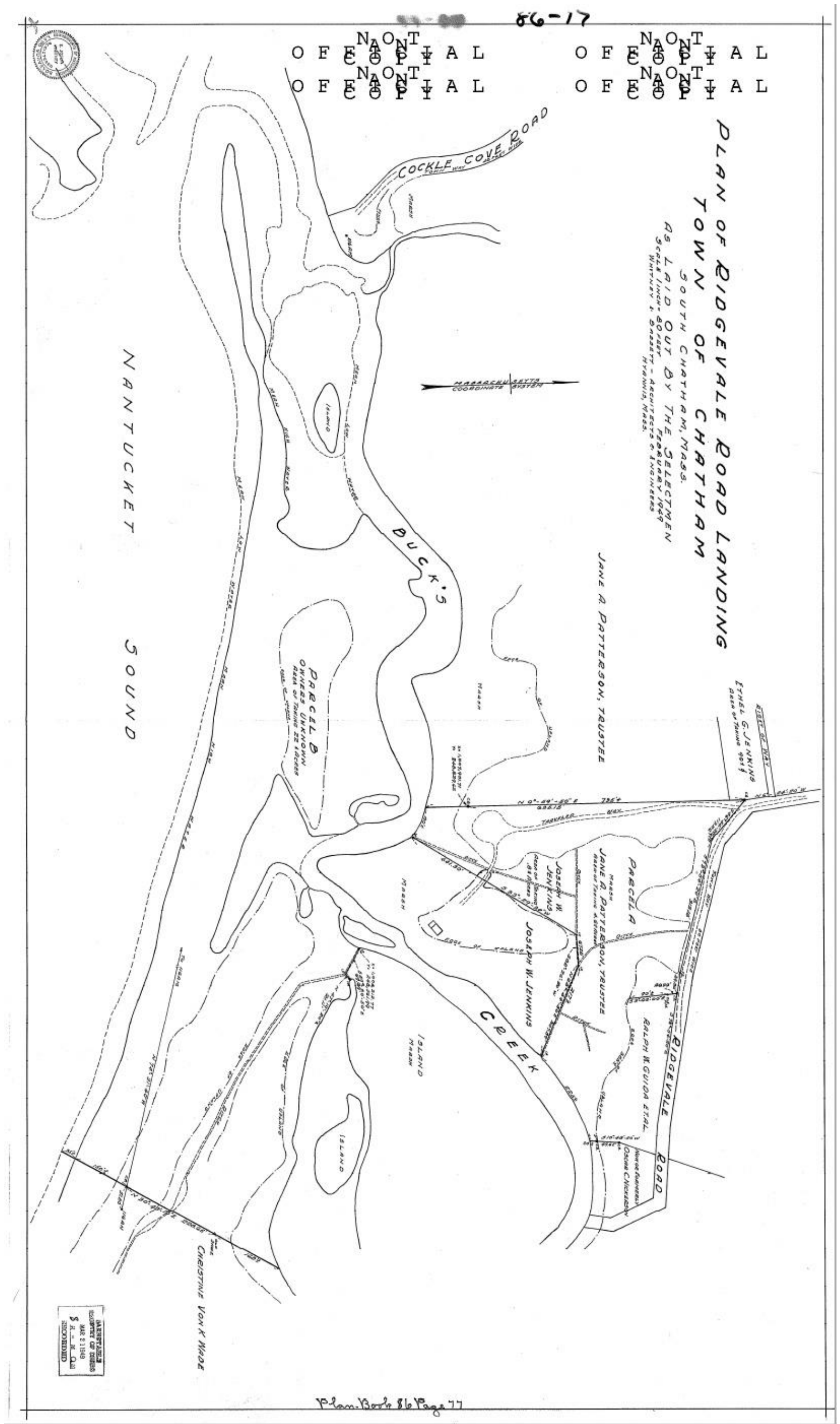
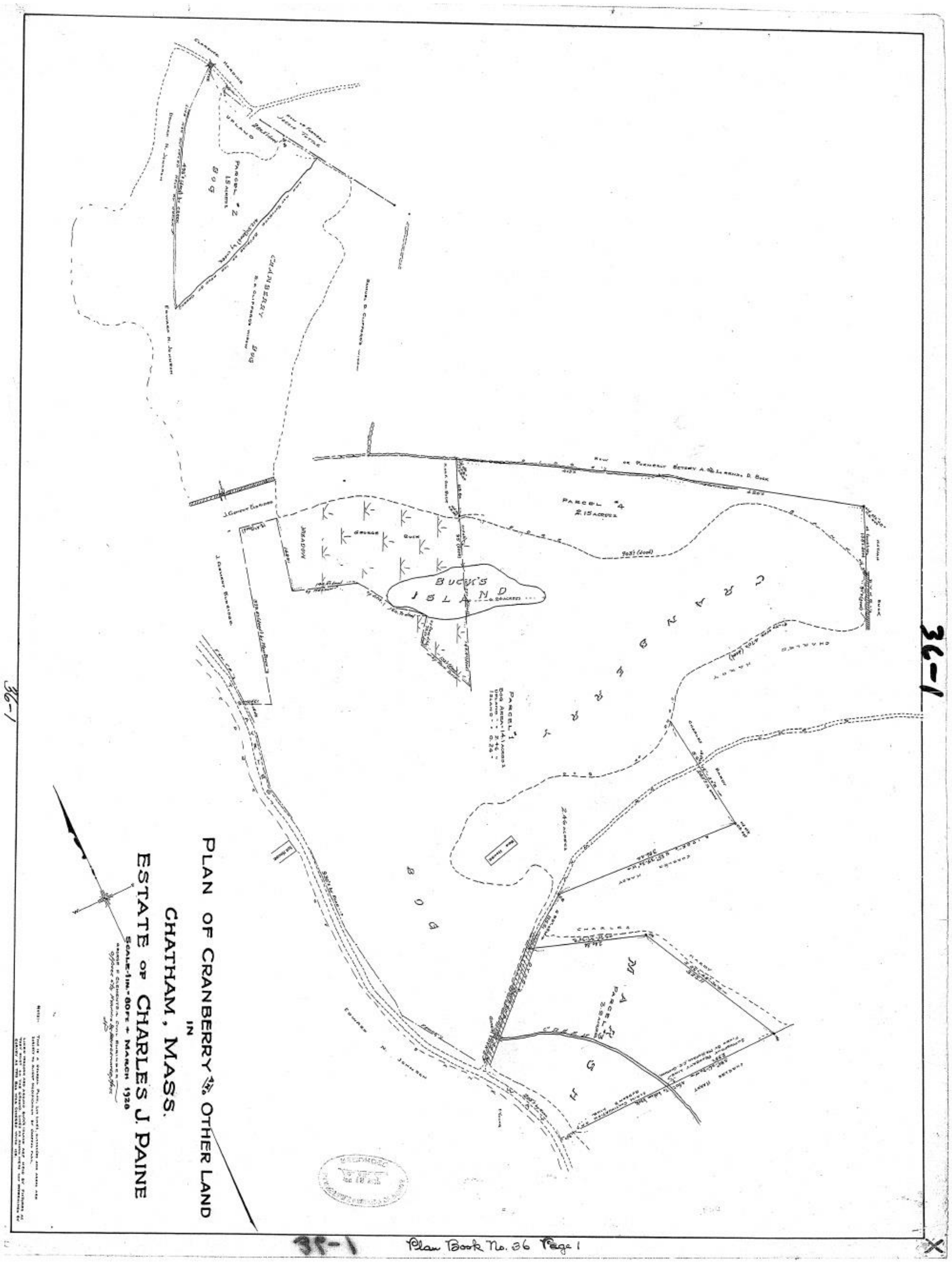
Appendix A


USGS
U.S. Department of the Interior
U.S. Geological Survey
Prepared in cooperation with the
Commonwealth of Massachusetts
Massachusetts Geological Survey
and Executive Office for Administration and Finance
Scientific Investigations Map 3402
Quadrangle 194—Harwich
Surficial Materials Map of the
Harwich Quadrangle, Massachusetts
Compiled by
Byron D. Stone and Mary L. DiGiacomo-Cohen
2018

Appendix B

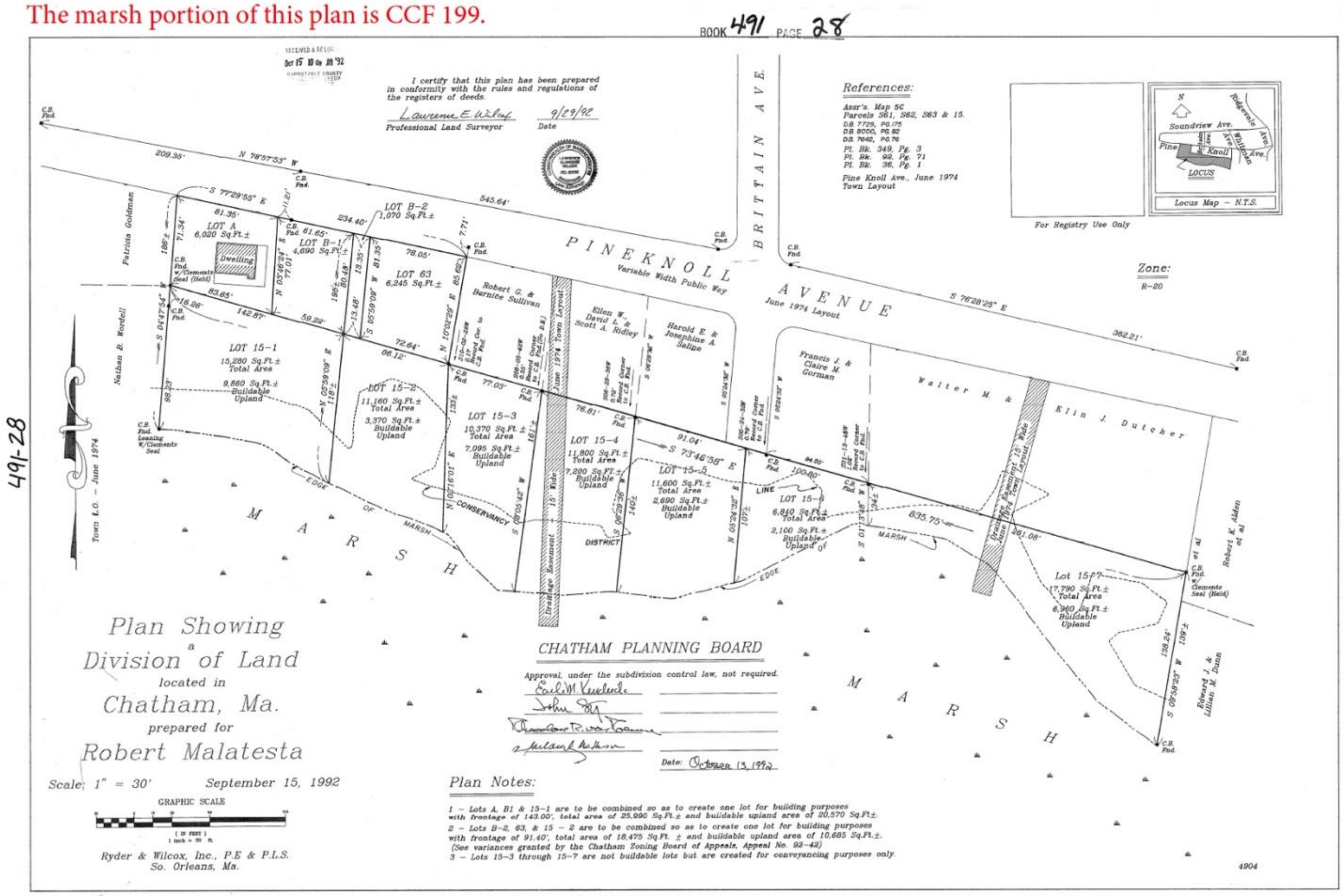

86-77
NOT AN OFFICIAL COPY
PLAN OF RIDGEVALE ROAD LANDING
TOWN OF CHATHAM
SOUTH CHATHAM, MASS.
AS LAID OUT BY THE SELECTMEN
COCKLE COVE ROAD
NANTUCKET SOUND
BUCK'S CREEK
JANE A. PATTERSON, TRUSTEE
PARCEL A
PARCEL B
JOSIAH W. JENKINS
RALPH W. GUIDA ET AL
RIDGEVALE ROAD
ISLAND
CHRISTINE VON K WADE
Plan Book 86 Page 77

Appendix C

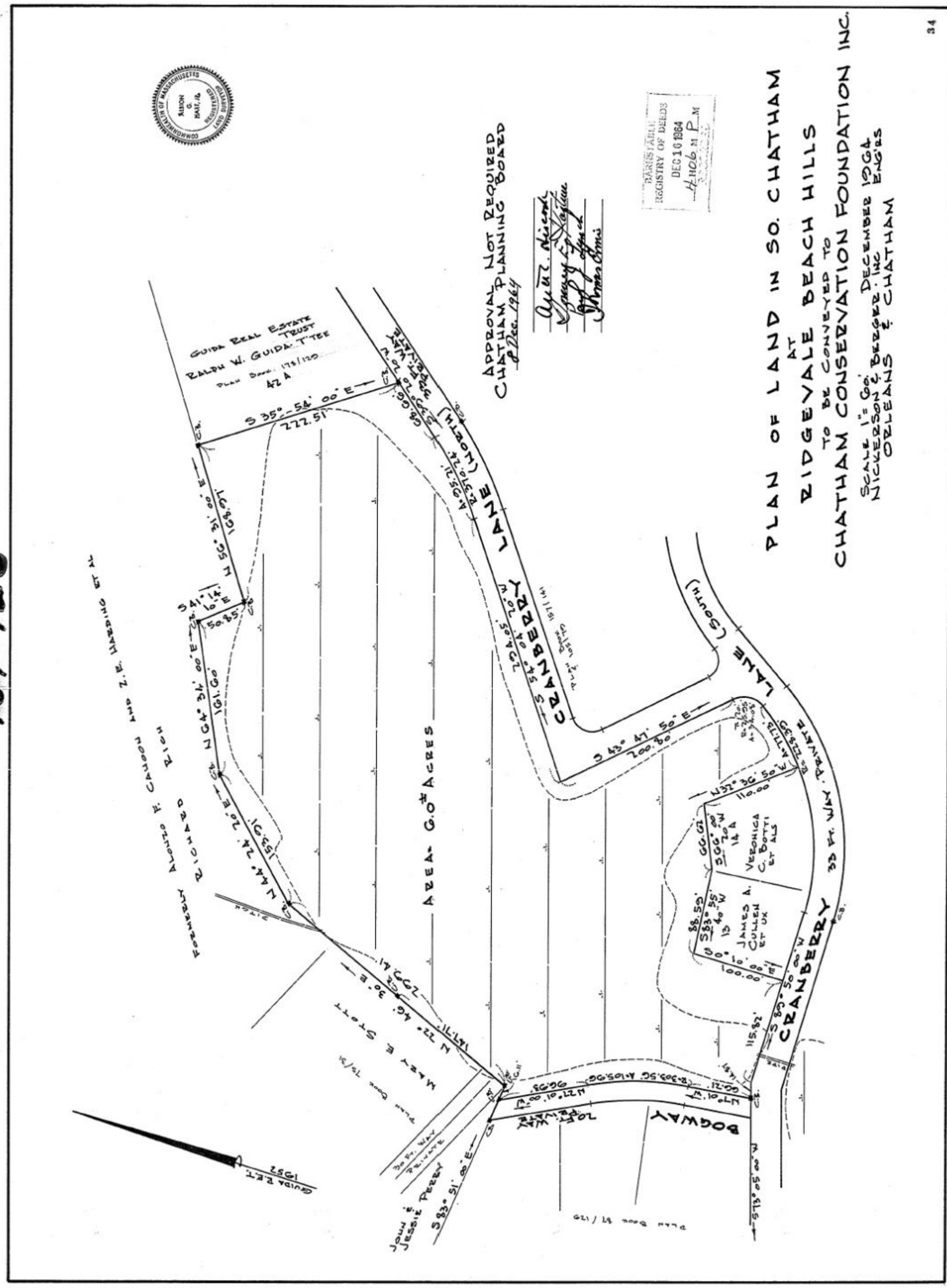

PLAN OF CRANBERRY & OTHER LAND
IN
CHATHAM, MASS.
ESTATE OF CHARLES J. PAINE
SCALE-1IN.=80FT. MARCH 1926
BUCK'S ISLAND
CRANBERRY
BOG
36-1
Plan Book No. 36 Page 1

Appendix D

The marsh portion of this plan is CCF 199.

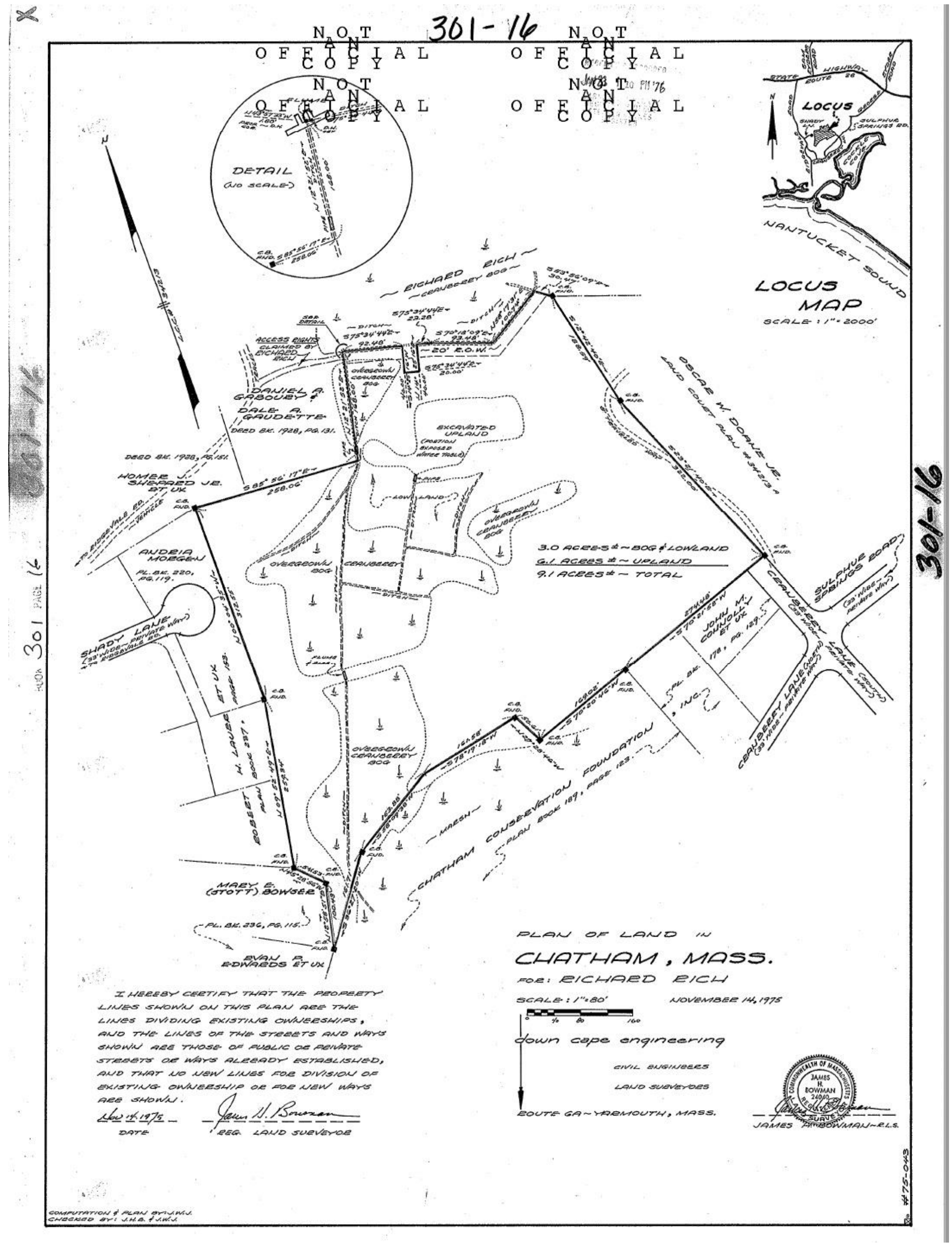


Appendix E



189-123
PLAN OF LAND IN SO. CHATHAM
AT
RIDGEVALE BEACH HILLS
TO BE CONVEYED TO
CHATHAM CONSERVATION FOUNDATION INC.
APPROVAL NOT REQUIRED
CHATHAM PLANNING BOARD
AREA 6.0± ACRES
CRANBERRY LANE
BOGWAY
Plan Book 189 Page 123

Appendix F


301-16
NOT AN OFFICIAL COPY
DETAIL (NO SCALE)
LOCUS MAP
SCALE: 1"=2000'
NANTUCKET SOUND
RICHARD RICH ~ CRANBERRY BOG
DANIEL A. GABOURY & DALE A. GAUDETTE
DEED BK. 1928, PG. 131.
HOMER J. SHEPARD JR. ET UX
ANDRIA MOEGEN
PL. BK. 220, PG. 119.
SHADY LANE
EXCAVATED UPLAND
OVERGROWN CRANBERRY BOG
3.0 ACRES ± ~ BOG & LOWLAND
6.1 ACRES ± ~ UPLAND
9.1 ACRES ± ~ TOTAL
OSCAR W. DOANE JR.
JOHN M. CONNOLLY ET UX
SULPHUR SPRINGS ROAD
CRANBERRY LANE
CHATHAM CONSERVATION FOUNDATION, INC.
PLAN BOOK 189, PAGE 123.
ROBERT H. LAUBE ET UX
MARY E. (STOTT) BOWSER
EVAN P. EDWARDS ET UX
PLAN OF LAND IN
CHATHAM, MASS.
FOR: RICHARD RICH
SCALE: 1"=80'
NOVEMBER 14, 1975
down cape engineering
CIVIL ENGINEERS
LAND SURVEYORS
ROUTE 6A ~ YARMOUTH, MASS.
I HEREBY CERTIFY THAT THE PROPERTY LINES SHOWN ON THIS PLAN ARE THE LINES DIVIDING EXISTING OWNERSHIPS, AND THE LINES OF THE STREETS AND WAYS SHOWN ARE THOSE OF PUBLIC OR PRIVATE STREETS OR WAYS ALREADY ESTABLISHED, AND THAT NO NEW LINES FOR DIVISION OF EXISTING OWNERSHIP OR FOR NEW WAYS ARE SHOWN.
Nov 14 1975
DATE
REG. LAND SURVEYOR
JAMES H. BOWMAN ~ R.L.S.
COMPUTATION & PLAN BY: J.W.J.
CHECKED BY: J.H.B. & J.W.J.

BK11750 PG168 75659
10-08-1998 @ 08:42

COMMONWEALTH OF MASSACHUSETTS

Barnstable, ss: September 23, 1998

AFFIDAVIT AS TO ADVERSE POSSESSION

RICHARD F. RICH, a/k/a Richard Rich, of 58 Portanimicut Road, South Orleans, Barnstable County, Massachusetts, being first duly sworn, deposes and says as follows:

1. The Affiant was born in Malden, Massachusetts on February 27, 1907 and moved to Tonset Road, Orleans, Massachusetts in the 1930s and has resided in Orleans, Massachusetts until the present day.

2. On November 28, 1947 I purchased the "Star Bog" from Cape Cod Food Products, Inc. and a copy of that Deed is recorded at the Barnstable County Registry of Deeds in Book 692, Page 026. The "Star Bog" is more particularly shown on the plan of land previously referred to and recorded at Barnstable in Book 301, Page 16.

3. Affiant, at the time of the purchase of the Star Bog, owned abutting bogs which are shown on a plan of land entitled "Plan of Land in Chatham, Mass made for Richard Rich, Scale 1" = 80', March 30, 1979, Down Cape Engineering" a copy of said plan being recorded Barnstable County Registry of Deeds in Plan Book 337, Page 16. The bogs shown on that plan, identified as the Upper, Middle and Lower bogs, were purchased by Affiant in the 1930s, see deeds referred to as Title Deeds in Deed from Richard F. Rich to Andrew A. O'Brien dated September 3, 1987 and recorded at Barnstable in Book 5281, Page 35.

4. Being the owner of the abutting parcel since the 1930s, your Affiant was intimately familiar with the Star Bog. Affiant worked the Upper, Lower and Middle bogs on a regular basis, from year to year. Affiant had a working partnership with Grafton Howes, former Selectman of Dennis, on the cranberry business during many of those years. There was constant sanding and cultivating of berries through the years. At the time of the purchase of the three bogs, the cement flume, located in the southwesterly corner of the parcel (shown on plan 337/16) was in disrepair. Affiant rebuilt the flume in the 1930s and maintained it on a regular basis through the 1970s, the flume being the way I controlled the level of water on the bogs.

off Shady Lane, Chatham M.R. Bk 7018 Pg 346

12. During my ownership, in the mid 1960's on one specific occasion I allowed Oscar Doane to remove clay and fill as he wanted to fill in an old bog located to the South East on his property. This worked to our mutual benefit as I wanted additional holding areas for water.

13. During all of the time that said parcel of land as shown on Plan Book 301 Page 16 was owned by Affiant, Affiant's use of said land was open, visible, notorious, continuous, peaceable, exclusive and adverse to all of the world and all of the world recognized no title superior to mine during all of that period, and no other person, during said period, used or enjoyed same or exercised any exclusive acts of ownership over same and your Affiant never encountered any hostile claim or interference from any source whatsoever.

14. The boundaries of said parcel of land have been established either by monument on the ground or by acquisition and general reputation during all of said period and there has never been any dispute or controversy with respect to the correct locations thereof.

15. Affiant certifies and stipulates that this affidavit is made of my own personal knowledge.

WITNESS my hand and seal this 23rd day of September, 1998.

Richard F. Rich
RICHARD F. RICH

COMMONWEALTH OF MASSACHUSETTS

Barnstable, ss: September 23, 1998

Then personally appeared the above named RICHARD F. RICH and acknowledged the foregoing to be true and to the best of his knowledge and believe and acknowledged the foregoing to be his free act and deed before me.

Herbert F. Robert
NOTARY PUBLIC
My commission expires: 12-28-2002

5. Affiant accessed the bogs originally over the parcel identified on the plan as "W. Vernon Whiteley" as well as over the road shown on the plan leading from Route 28. In addition, I accessed the bog over land shown on the plan as "Homer J. Shephard, et ux" on a regular basis, for purposes of maintaining the flume.

6. The flume is shown on said plan as adjacent to the land shown in Plan Book 301, Page 16.

7. During Affiant's ownership of the Upper, Middle and Lower bogs, Elnathan Eldredge of South Orleans owned the Star Bog, so-called. Elnathan Eldredge worked the bog on a regular basis. Affiant tried to purchase the bog from Elnathan Eldredge after the 1938 hurricane in order to improve my flood control, however he chose to continue to work the bog. At that particular point in time, Elnathan Eldredge had 10 or 15 people working for him, harvesting and maintaining the Star Bog and other bogs. I have very distinct recollections of Elnathan Eldredge's employees putting in new vines to replace those damaged by the 1938 hurricane.

8. Eventually, Elnathan Eldredge sold the Star Bog to Coleman Winchester. During Coleman Winchester's ownership of the bog, he did little in terms of maintenance and the flume, in particular, deteriorated. Winchester eventually sold the bog to Cape Cod Food Products, Inc. who, as previously set forth, conveyed the property to Richard Rich, et ux, in 1947.

9. Affiant's primary motivation for purchasing the Star Bog was to control the water levels by way of the flume to my remaining bogs shown on Plan Book 337, Page 16 as well as to have available a constant supply of sand.

10. In 1978 I rebuilt and made the "flume and pipe" taller which is delineated on the plan recorded at Barnstable in Plan Book 301, Page 16, said "flume and pipe" being on the line of the ditch separating two separate bog areas. Also, shortly thereafter, I raised the road over the flume (i.e. dike) some three or four feet. This permitted me to hold water on the Star Bog in large areas (shown with hatch marks and beyond) and, when required by farming needs, I could pump this water on to the Upper, Middle and Lower bogs or release the water and it would eventually drain into the Atlantic Ocean.

11. From the time of my purchase of the Star Bog, and throughout my ownership, I maintained the flume, flooded and unflooded the Star Bog area, built roads and dikes, all for the purposes of the cultivation of cranberries, which took place, during my ownership, primarily on the Upper, Middle and Lower bogs.

ATTORNEY'S CERTIFICATE

I, Herbert Franklin Roberts, Attorney-at-Law, in compliance with Massachusetts General Laws, Chapter 183 Section 5-B certify that the facts stated in this Affidavit are relevant to the title to certain land being more particularly referred to in said affidavit and that this affidavit will be of benefit and assistance in clarifying the chain of title and location of same.

WITNESS my hand and seal on this the 23rd day of September, 1998.

HERBERT FRANKLIN ROBERTS

COMMONWEALTH OF MASSACHUSETTS

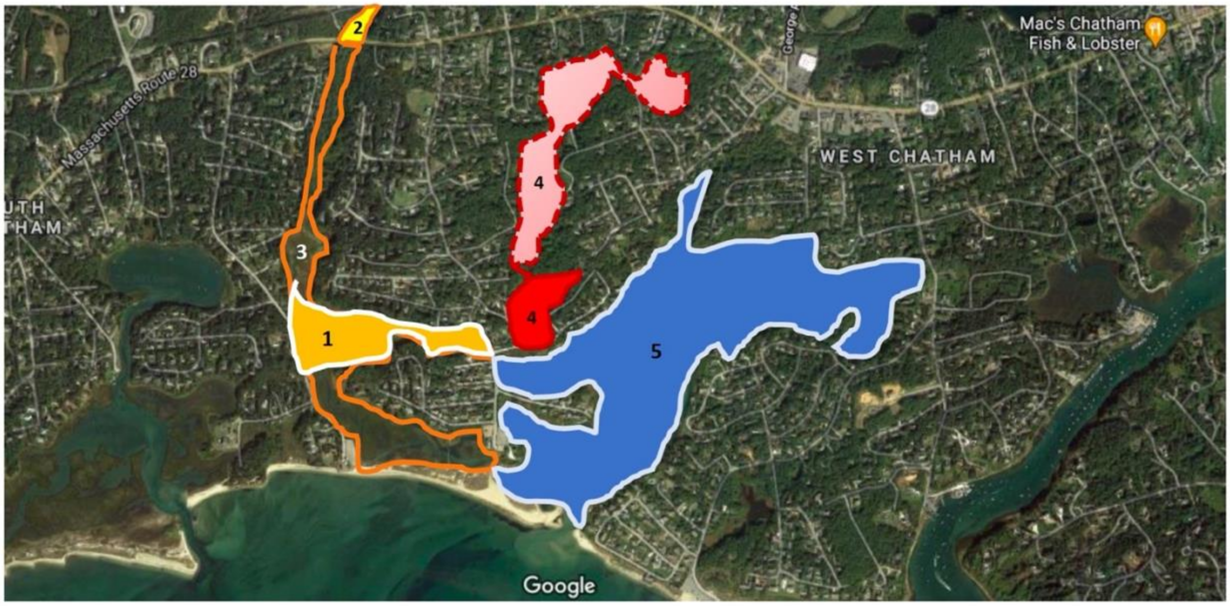
Barnstable, ss: September 23, 1998

Then personally appeared the above named Herbert Franklin Roberts and acknowledged the same to be his free act and deed, before me.

Carol C. Potrzeba
NOTARY PUBLIC
My commission expires: 1-29-2004

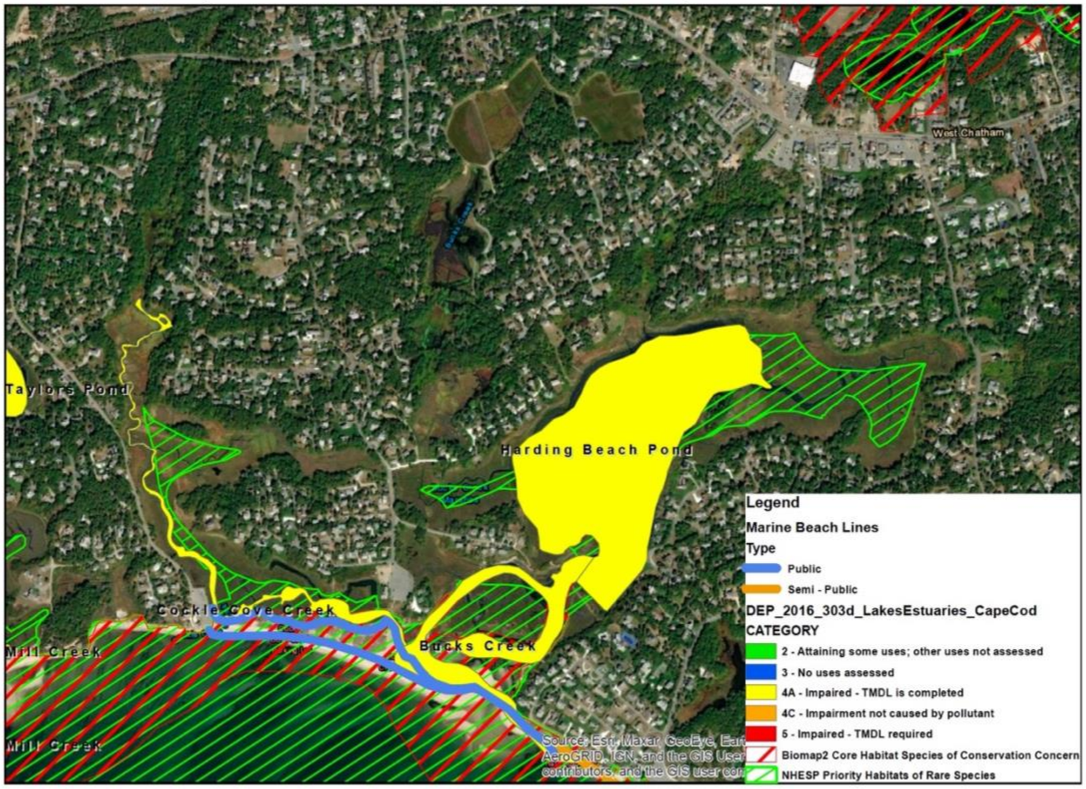
Appendix H

GIS Desktop Assessment Area Map

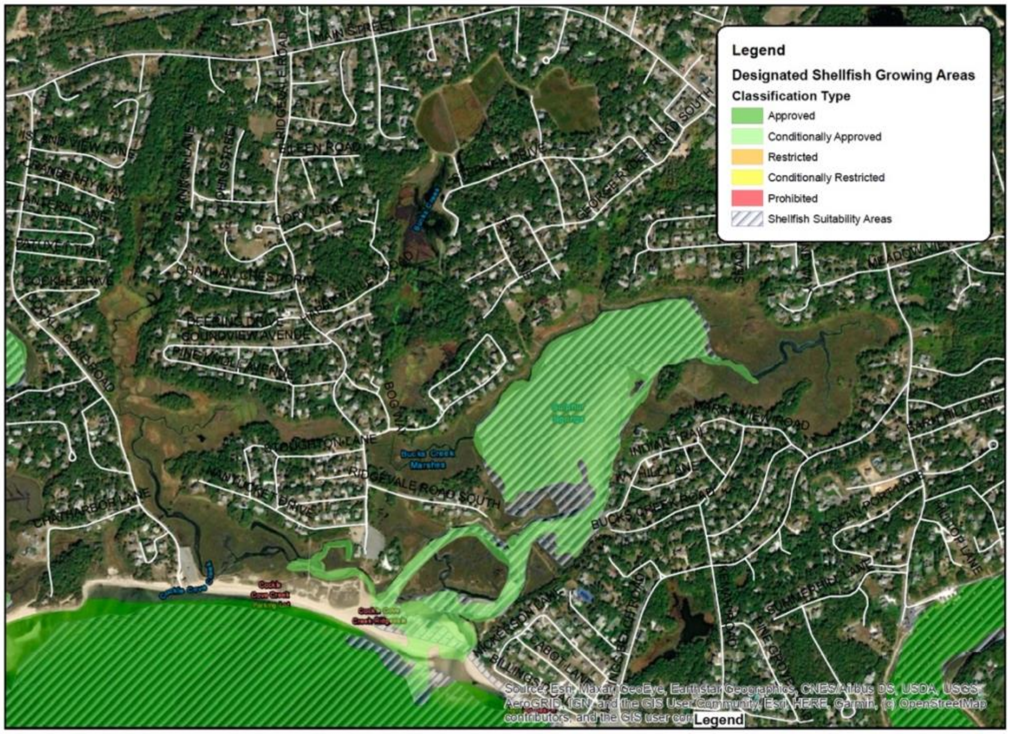


The assessment area map shows the five subsections of the Cockle Cove Bucks Creek Marsh system used for the GIS desktop assessment and ranking. The following is a description and numbering of the five areas: 1) Ridgevale Road restriction west to Cockle Cove Drive, 2) Cockle Cove Creek north of Route 28, 3) All of Cockle Cove creek west of Ridgevale Road and the footbridge to Ridgevale Beach, 4) Bucks Creek north of Cranberry Lane restriction with and without the ponds and bogs, and 5) eastern Bucks Creek.

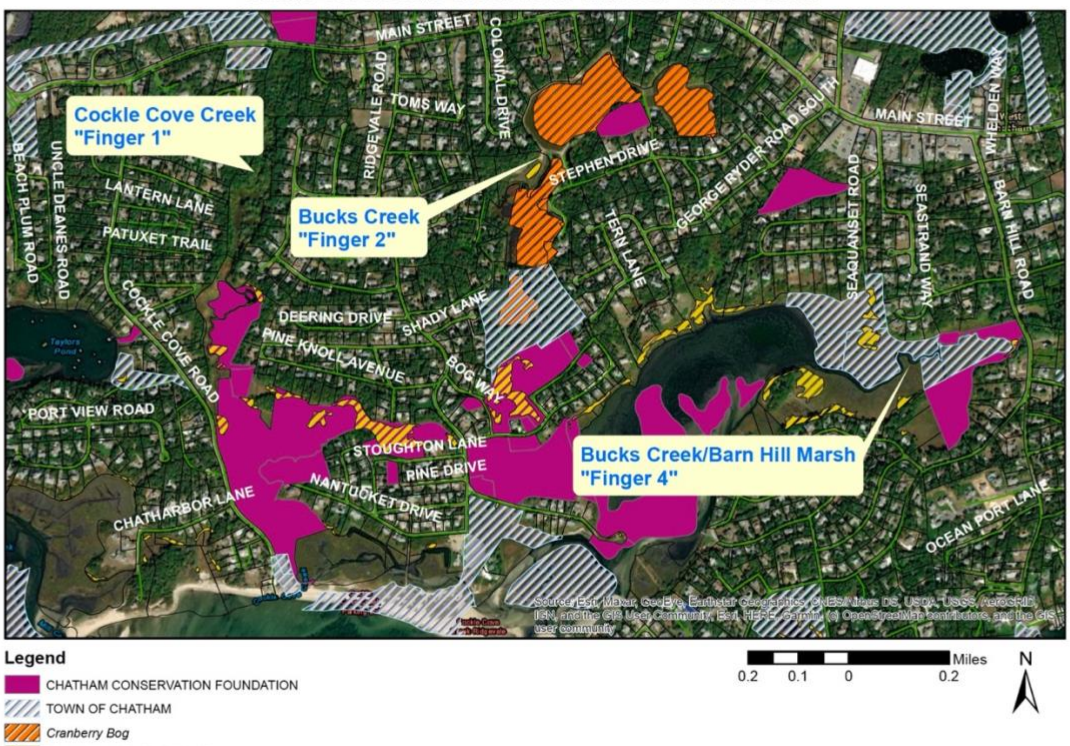
Marine beaches, Impaired water bodies, Biomap core habitat, and NHESP Priority Species Habitat



Areas of concern in Cockle Cove/Bucks Creeks - Shellfish

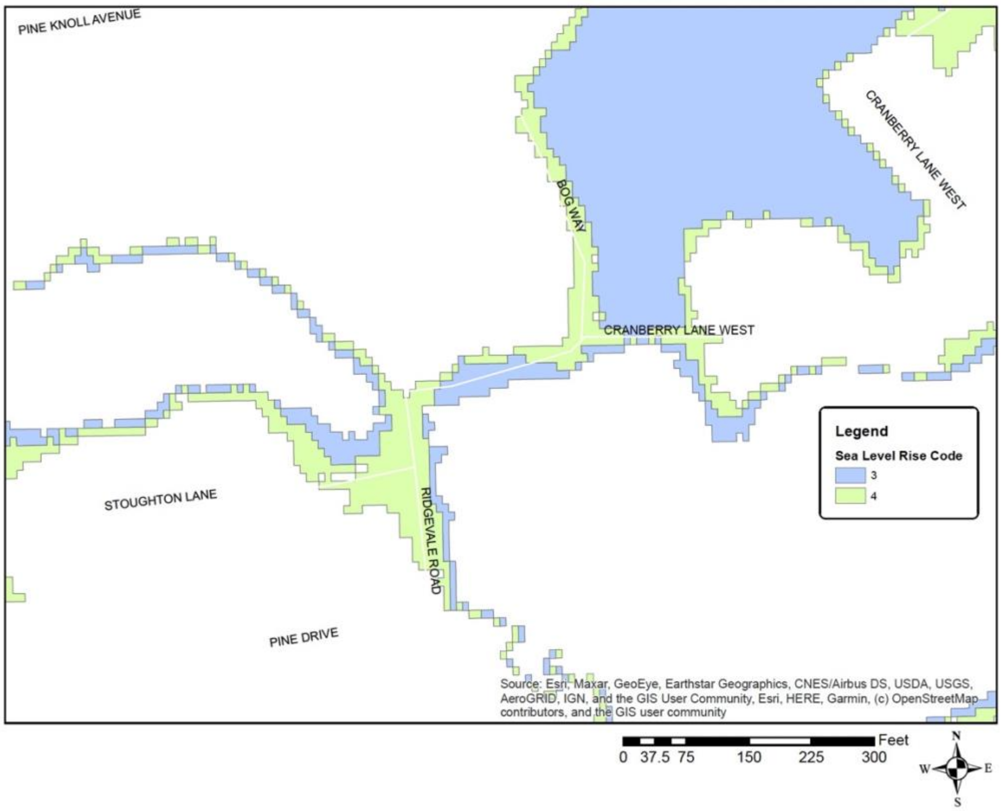


Cockle Cove/Bucks Creek Town- and CCF-Owned Land

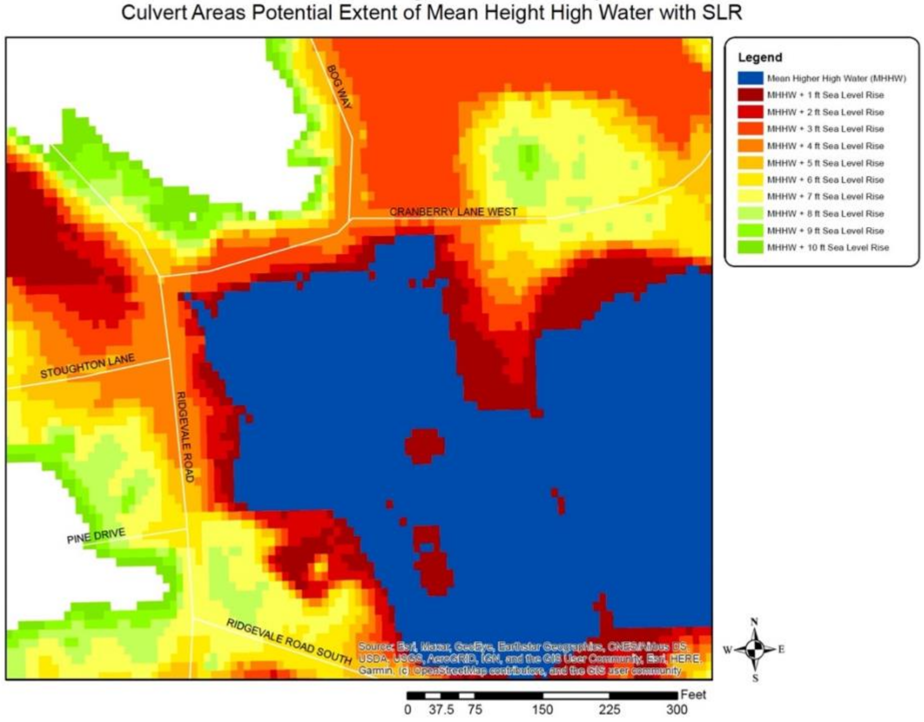


*Note: Ownership parcel, Bog, and Phragmites data are from 2018, 2019, and 2018 respectively.

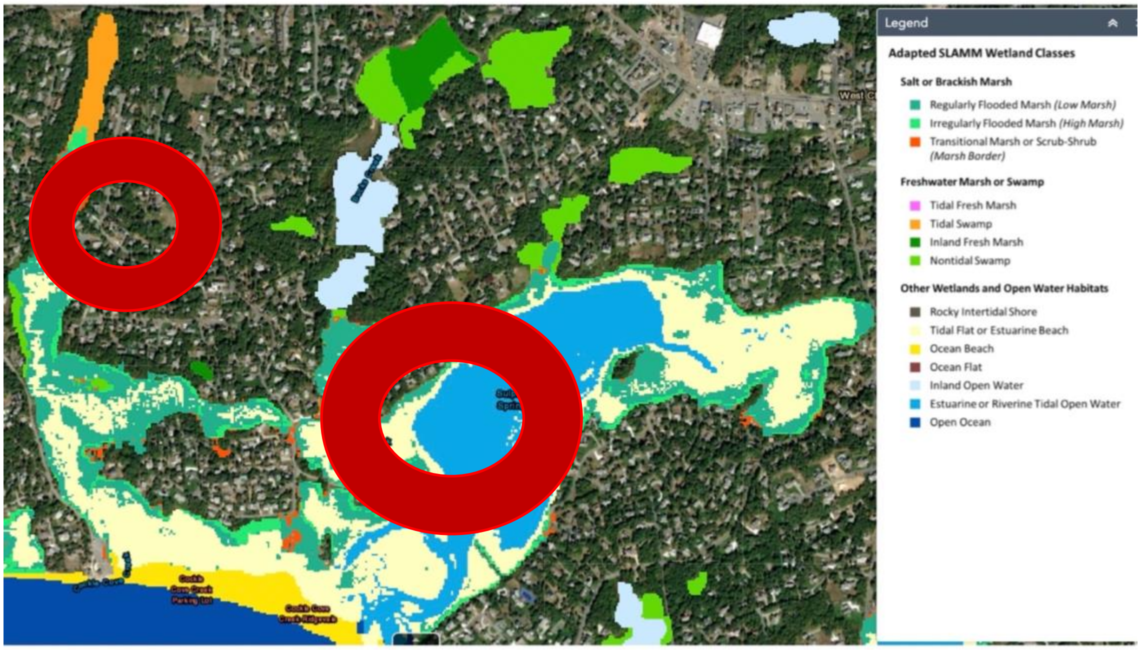
Sea Level Rise: Ridgevale Rd/Cranberry Ln
Culvert areas inundated during high tides at 3 and 4 feet SLR



Sea Level Rise: Ridgevale Rd/Cranberry Ln
Culvert Areas Potential Extent of Mean Height High Water with SLR



MA Office of Coastal Zone Management Sea Level Affecting Marshes Model (SLAMM)



Map showing salt marsh loss under an intermediate-high sea level rise scenario (4.5ft) in 2070 and little to no salt marsh migration potential north of Cranberry Lane due to high elevation of the pond and bogs