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David M. Burdick
Jackson Estuarine Laboratory, david.burdick@unh.edu

Chris Peter
Jackson Estuarine Laboratory

Gregg Moore
Jackson Estuarine Laboratory

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Prepared for:

CMA Engineers
35 Bow Street
Portsmouth, NH 03801

Prepared by:

David M. Burdick, Chris Peter and Gregg E. Moore
Jackson Estuarine Laboratory
University of New Hampshire
85 Adams Point Road
Durham, NH 03824
david.burdick@unh.edu
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Wetlands Evaluation

Philbrick's Pond is a lagoon type estuary that formed landward of barrier beach spits in North Hampton, NH. Its inlet was stabilized and restricted by the road that is now Route 1A or Ocean Boulevard. Water flow from the Gulf of Maine passes through a culvert running under Route 1A and into a small waterway and is further restricted as it runs through a clay pipe under an old trolley berm. The lagoon is characterized as a 29 acre tidal marsh. The overall drainage basin surrounding Philbrick's Pond is small, comprising about 680 acres, or a little more than one square mile.

The goal of the project is to evaluate the condition and hydrology of the two restrictions recognizing the conflicting needs for improved drainage from upstream flooding and limiting tidal flooding associated with extreme (i.e., storm surge) and normal flooding events due to sea level rise. The tidal marsh itself is a resource held in the public trust and therefore should be protected from any negative impacts associated with current conditions or predicted impacts due to future alternatives that may be chosen by the Town and its residents. Ditching of the marsh in the mid twentieth century rerouted drainage paths (e.g., Chapel Brook) and has resulted in large areas of vegetation loss between ditches in the past 60 years, as first reported by Short in 1984.

Philbrick's Pond was identified as having inadequate tidal exchange to support healthy marsh by the Soil Conservation Service in 1994 and this agency suggested both culverts needed to be replaced (SCS 1994). Current observations and modeling shows the large culvert under Route 1A does not impede water flow as much as the existing 30-inch culvert under the trolley berm. This round clay culvert constrains flow into the marsh during normal tidal fluctuations, and the restricted hydrology likely has negative impacts on salt marsh health (Burdick and Roman 2012). During the extreme "Mother's Day" storm in 2006, flow limitations due to the culvert exacerbated flood impacts to homes surrounding the marsh due to flow limitations on outgoing tides. The existing clay pipe also limits flow and flood levels into the marsh during storm surge conditions. If it is to be replaced, this trolley berm culvert needs an appropriately configured opening that optimally minimizes flood damage from both extreme precipitation events and storm surges, and that also improves marsh health through improved daily tidal inundation and draining.

The objectives of this report on the tidal marsh are threefold: 1) to evaluate the health of the tidal marsh by comparing existing and new data in Philbrick's Pond with conditions found in the Little River tidal marsh just to the south; 2) characterize the relative benefits to the tidal marsh for the hydraulic alternatives evaluated by the hydrologic modeling; and 3) recommend management actions to restore marsh health using small scale drainage improvements (also known as runneling).

Methods

Philbrick's Pond ("PP") Marsh and Little River ("LR") Marsh were both assessed as part of the NH Coastal Program's salt marsh monitoring program at the turn of the century, which involved collections of species composition and abundance of salt marsh plants along transects running from major tidal creeks to the upland edge at randomized locations. Using positions documented in the original database, we re-occupied four transects in each of the two marshes (Figure 1), and collected data in August from 0.5 m^2 plots at 1, 10, 50 feet and every 50 feet thereafter up to 200 feet. After 200 feet, 50 or 100 foot intervals were used to obtain seven plots per transect. This resulted in 29 plots at PP Marsh (Figure 2) and 28 at LR Marsh (Figure 3).

In addition to the vegetation, plot elevations were determined by real time kinematic geographic positioning system (Leica Viva GS14 GNSS RTK) and soil pore water was collected using stainless steel sippers with an inner diameter of 1 mm. Pore water salinity (temperature corrected refractive index) and chemical redox potential (ORP probe and millivolt reader) were measured in the field, whereas pH and sulfides (Cline 1969) were measured at the laboratory.

Data were entered into Excel spreadsheets and imported to JMP Statistical Software for analysis (JMP version 13). To examine soil differences between marshes, analysis of variance and covariance were used, with Tukey's post hoc test for significant effects ($P<0.05$).

Results of Wetland Surveys

Both marshes had severe tidal restrictions. Little River Marsh was restored to 75% of its potential tidal range in 2000 (Chmura et al. 2012), but the tidal restriction at PP Marsh remains to date. The average elevation of the marsh surface was found to be higher at LR Marsh (4.7 feet above NGVD) compared to PP Marsh (3.9 feet) – a difference of about 10 inches (Table 1). Even when unvegetated pools were removed from the data, PP Marsh remained 8 inches lower in elevation and the difference was highly significant.

Pore water salinity averaged 30 ppt in Philbrick's Pond Marsh, almost the strength of seawater (Table 1). In comparison, LR Marsh was about 32 ppt, the typical value for seawater in the Gulf of Maine. The difference in salinity between the two marshes was not statistically significant. Both marsh soils showed fairly neutral pH values, about 6.6 pH.

Redox potential, or Eh, is a measure of the ability of the soil constituents to accept electrons produced during chemical reactions. Eh ranges from fully oxidized (+700 millivolts) to severely reduced (-400 mV), with oxygen disappearing at about +400 mV. The chemical reduction of the soils was much more severe at PP Marsh (-305 mV) than LR Marsh (-119 mV), indicating more stressful conditions for life. Similarly, the plant toxin H_2S was 4-fold greater at PP marsh and these levels have been shown to stress marsh grasses as they interfere with nitrogen uptake, energy balance and salinity adaptation (Mendelssohn and Morris 2000). Both the Eh and sulfide concentration showed significant differences between the two sites, with PP Marsh having soil conditions indicative of greater flooding and impaired drainage.

Lower elevations, impeded drainage and more stressful conditions were reflected in the vegetation of Philbrick's Pond Marsh. In 2017, we found typical salt marsh plants (halophytes: *Spartina alterniflora*, *S. patens*, and others) covering about 55% of the plots and 40% bare sediment or dead grasses (Figure 4). Plant cover was similar to the original survey in 2002, with slightly less *S. alterniflora* (cordgrass) but more *S. patens* (salt hay). The most dramatic changes appear to have occurred sometime after the mid-twentieth century, but before 1984 when Dr. Short interpreted the large unvegetated areas still seen today as: "an area of dead saltwater hay (*Spartina patens*) covered by a thick mat of blue green algae."

In comparison, Little River Marsh showed a dramatic recovery from the large tidal restoration completed in 2000, based on data from 2003 and 2005 in addition to 2017 (Figure 5). Dead plants and bare ground were dominant at 60% cover in 2003, but decreased to 20% cover in 2017 while *S. patens* and *S. alterniflora* both increased, contributing to a total of 76% halophyte cover in 2017. With LR Marsh now largely restored (Chmura et al. 2012) it can serve as a reference marsh to compare conditions in Philbrick's Pond Marsh.

In 2017, our reference site at Little River Marsh was dominated by salt hay (38%) but also had a variety of other high marsh plants (halophytes) summing to 21% cover (Figure 6). In wetter areas (areas with greater flooding and/or less drainage), tall cordgrass was found to dominate the vegetation, contributing 17% cover. We found only 20% cover of dead and bare and 2% cover of invasive species, notably *Phragmites australis* (common reed). In sharp contrast, Philbrick's Pond Marsh showed 40% dead and bare (including the plots that fell within the large pools), likely due to stressful conditions. When compared to Little River Marsh, we found half as much salt hay, the high marsh dominant, and almost twice as much *S. alterniflora*, which is better adapted to the more stressful inundated conditions at Philbrick's Pond Marsh.

In summary, the lower elevations of Philbrick's Pond Marsh and impeded drainage has led to lower Eh and greater sulfides, all of which stress the vegetation and favor cordgrass over salt hay and other marsh plants typical of New Hampshire salt marshes. Many areas between ditches are too stressful for vegetation since extensive ditching took place 60 years ago. As a result, pools have replaced vegetation between ditches across large portions of the marsh.

Evaluation of Alternatives with respect to potential impacts to salt marsh

Several management alternatives were examined using hydrologic modeling for present day conditions and several sea level rise scenarios (see inset). They were chosen to capture the range of options for hydrologic management of the system to reduce flooding for residents and preserve the functions and values of the natural resources of the system.

Alternatives Evaluated

- No Action/No Change – pipes and channels remain as they are ("Existing Condition")
- SLAB – Remove cobble v-notch weir at DOT culvert and replace with 4 foot wide concrete slab at about elevation 2.0. Regrade channel bottom between trolley berm and DOT culvert.
- BOX – Remove 30 inch trolley berm culvert and replace with 30 inch high by 8 foot wide reinforced concrete box.
- CHANNEL and SLAB – Remove trolley berm in its entirety to maintain open channel flow. Replace v-notch weir with concrete slab, and regrade channel bottom.

Under the NO ACTION alternative, the Philbrick's Pond Marsh will continue on its path to complete degradation. The very small tides allow only a few inches of drainage every tide, leaving stagnant waters and stressful soil conditions that plants have difficulty surviving. With only intermittent flooding and no sediment sources, the marsh cannot perform its function of building through accretion and peat formation and so becomes lower relative to sea level as sea level rises.

Under the second alternative, SLAB, improved drainage is expected, leading to better growing conditions and a healthier marsh. Removal of the V-notch weir and channel re-grading will allow waters that are currently trapped behind the weir to drain, increasing the typical tidal range from less than 6 inches to 16 inches. Plant productivity and cover is likely to increase following implementation of this alternative. However, the flooding and sediment marshes need to build will still not be carried into the marsh under this alternative and the marsh will likely continue on its path to degradation once sea levels rise substantially (1-2 feet). This alternative will likely have no impact on flooding of homes and roads due to significant rainfall or storm surge events.

BOX is the third alternative, which is limited to replacing the trolley berm pipe with a box culvert alone (no replacement of V-notch weir with slab). Modeling indicates this alternative would not change the tidal flooding or drainage significantly compared to current conditions. The cross-sectional area of tidal exchange would increase from 5 to 20 square feet at the trolley berm, but the V-notch weir and shallow area in the channel would limit normal tides to existing conditions. The BOX alternative therefore, would be unlikely to increase the functions and values of the salt marsh unless it was combined with the removal of the V-notch weir (SLAB alternative).

The fourth alternative, CHANNEL AND SLAB would result in unrestricted tides from the landward side of Route 1A throughout the marsh. The culvert under Route 1A would still partially restrict the full range of tides. This solution would increase the normal tidal range to 1.4 feet (17 inches). Removing the trolley berm in its entirety and removing the v-notch weir at the Route 1A culvert would lower typical low tides by 0.9 feet from current levels and increase typical high tides by 0.1 feet. The current daily tidal fluctuation of 0.4 feet would increase to 1.4 feet. Flooding associated with significant rainfall events would be substantially reduced but not eliminated, and storm surges under assumed ranges of sea level rise would result in flooding conditions for homes and roads after 2050. Under current sea level conditions Philbrick Pond water levels during astronomical high tides would increase by about one foot. The greater flooding and flushing would likely bring substantial improvements to the health of the marsh.

Recommendations for marsh restoration activities beyond culvert replacement

Important changes in the hydrology of Philbrick's Pond Marsh occurred when natural drainages were replaced by ditches (sometime in the late 1950s according to USGS topographic maps). Hydrologic changes have led to impaired drainage and ponding, with loss of vegetation in areas surrounded by ditches. Since the turn of the last century, rising sea levels combined with altered hydrology, specifically old ditch systems, has led to patterns of vegetation loss in Rhode Island and Massachusetts salt marshes similar to those found at Philbrick's Pond (Raposa et al. 2015). The loss of vegetation from the large impounded areas was reported by Dr. Short in 1984 and has slowly continued to the present, as indicated by our quantitative vegetation survey.

Vegetation loss could be reversed, but only if tidal drainage is increased for the system. Once culvert or channel improvements are implemented for Philbrick's Pond, additional steps could be taken to hasten pant regrowth and reverse the pattern of marsh loss caused by impoundments associated with the old ditches. The increased drainage predicted from the hydraulic models would justify establishing a strategy to partially drain the impounded (ponded) areas between ditches using shallow drainage paths called runnels. Runnels are shallow drainages cut through unnatural impediments to drainage that allow the top six inches of sediment to drain. Runnels do not drain the peat deeply, unlike ditching which has led to loss of marsh elevation elsewhere (Burdick et al. 2017). Runnels have been used in Rhode Island, where low tidal ranges and rising sea levels have alarmed managers and the public (Ardito 2014; http://seagrant.gso.uri.edu/elevating-drowning-salt-marshes/). Runnels have also been tried in the Great Marsh of Massachusetts with documented success in reversing the expansion of the impoundments (Burdick et al. 2017).

Currently, there are over 20 impounded ponds in the southern portion of the marsh, 10 in the center and another 20 ponds in the northern section representing a significant opportunity to enhance restoration benefits. Several of these impounded areas could be partially drained by runneling and monitored to document plant response to the increased drainage above and beyond the increased drainage from the hydrologic improvements to the system. The addition of runneling to a restoration program for Philbrick's Pond Marsh represents a relatively low-cost strategy to enhance the benefits of restored hydrology. Furthermore, such a strategy is aligned with several current funding opportunities for developing innovative approaches to increasing coastal resilience in the State (e.g., NHDES Coastal Resiliency Grant).

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Tables and Figures

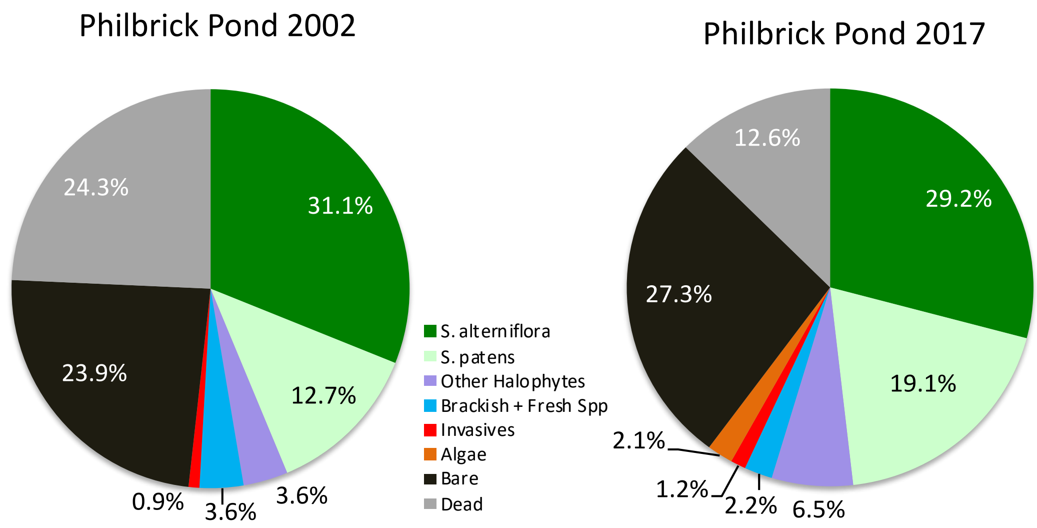
Table 1. Soil elevation and chemical characteristics in Philbrick's Pond Marsh and Little River Marsh. Values are Means (averages) and Standard Errors from 28 (PP) and 29 (LR) independent samples. P value is the probability that the difference between the two marshes is not real. Elevations were not normally distributed so Kruskal-Wallis test used.

	Little River		Philbrick Pond		
	Mean	SE	Mean	SE	p value
Elevation (ft NGVD29)					
All Plots	4.71	0.05	3.87	0.08	<0.01
High Marsh	4.73	0.03	4.02	0.05	<0.01
Pore water					
Salinity (ppt)	32.8	0.6	30.4	1.2	0.08
Redox (mV)	-119	26	-305	6	<0.01
pH	6.67	0.04	6.61	0.05	0.32
Sulfides (mM)	0.60	0.22	2.50	0.22	<0.01

Figure 1. Overview of Philbrick's Pond (upper right) and Little River (lower left); two back-barrier marshes along the Atlantic coast of New Hampshire.

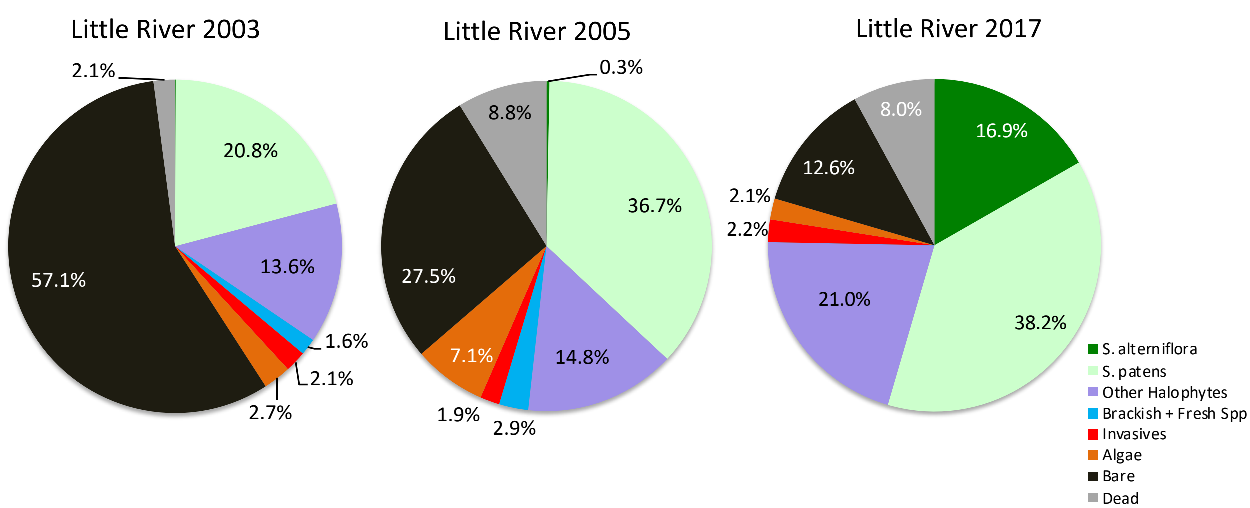
Figure 2. Stations along four transects in Philbrick's Pond sampled in 2017.

Figure 3. Stations along four transects in Little River Marsh Pond sampled in 2017.



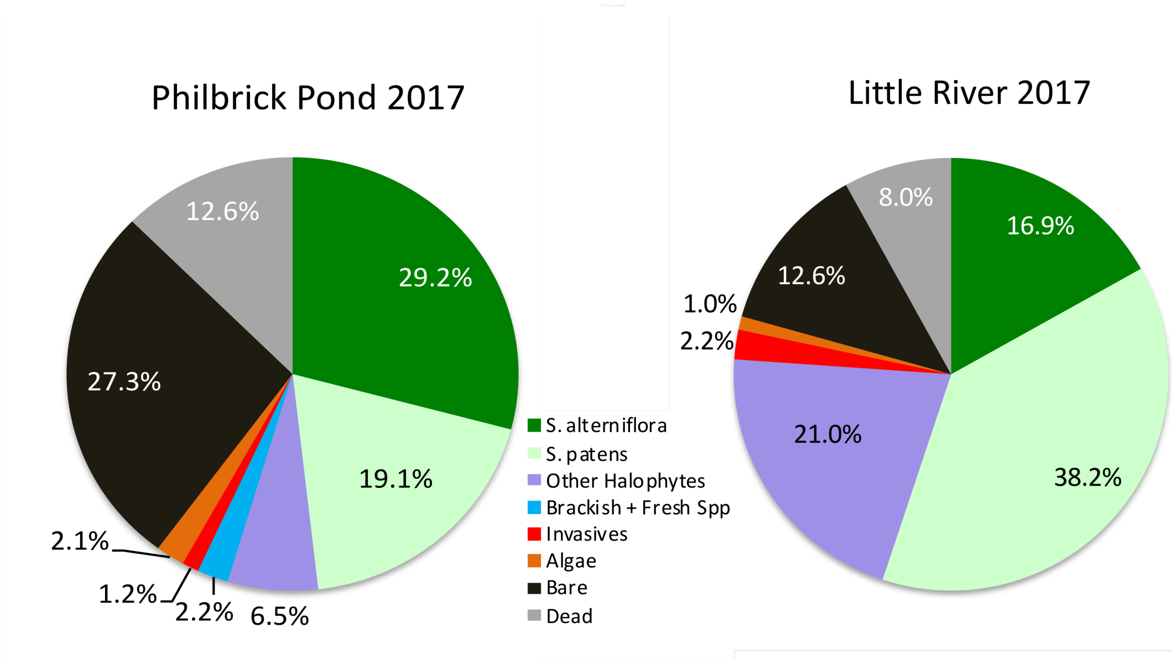
Notes: Other Halophytes = all halophytes except SA and SP. In 2002, monitoring done by NHCP, which measured open water as a category factored into 100% cover; assumed bare. 2002 n=52, 2017 n=29 due to different sampling intensity.

Figure 4. Vegetation cover averaged across four transects at Philbrick's Pond Marsh in 2002 and 2017.



Notes: Other Halophytes = all halophytes except SA and SP. In 2003 and 2005, monitoring done by NHCP, which measured open water as a category factored into 100% cover; assumed bare. 2003 n=131, 2005 n=140, 2017 n=28 due to to different sampling intensity and more transects in 2003 and 2005.

Figure 5. Vegetation cover averaged across four transects at Little River Marsh in 2017 compared with earlier results that combined more transects and closer plot spacing in 2003 and 2005. A large tidal restoration project was completed in 2000, resulting in loss of fresher plant species.



Note: Other Halophytes = all halophytes except SA and SP.

Figure 6. Vegetation cover averaged across four transects at Philbrick's Pond Marsh and Little River Marsh in 2017.