Farmers in the Marsh: Lessons from History and Case Studies for the Future

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ABSTRACT

Salt marshes across coastal New England are undergoing rapid change characterized by increased areas of saturation resulting in shifts in vegetation communities, large areas of vegetation dieback, and increases in shallow standing water. In the early 2000s, gently sloped leading edges of salt marshes ("low marsh" dominated by *Spartina alterniflora* and flooded daily) began to be lost from Maine to Connecticut. More marsh edges are now "cliff-faced" with steep, vertical edges often characterized by peat calving. In many places, the "high marsh" (the irregularly flooded marsh platform normally dominated by *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii,* as well as forbs) has been overtaken by short- (<0.10 m) to intermediate- (>0.60m – 1.0 m) form *S. alterniflora*, bare patches, and large areas of shallow standing water. The marsh platform between the ubiquitous ditches has subsided. In extreme cases, the marsh has 'collapsed' and now holds shallow water in a mega-pool with the only vegetation occurring along the ditch margins, in a "waffle-maple syrup" pattern. Elsewhere, the mega-pool becomes large and amorphous or interlocking in a jig-saw puzzle fashion suggestive of northern patterned fens with strings and flarks. While a few researchers have documented traits and trajectories of "natural" pools, the relatively sudden appearance and geographic extent of these changes suggests large-scale drivers. At the same time, research into historical salt marsh alterations for farming purposes dating as far back as the 1600s with large corporate works in the 1800s, has led this team to realize that remnant infrastructure from past agriculture coupled with accelerated sea-level rise is driving wide-scale salt marsh degradation. Tidal marsh obligate birds, such as the saltmarsh sparrow, which nest in narrow portions of "high marsh", are at increasing peril from the loss of marsh elevation due to subsidence trajectories exacerbated by a heretofore largely unrecognized historical agricultural infrastructure. With species extinction modelled at 2050 and a metonic cycle shifting toward increasing tide ranges in 2024, it is imperative to halt subsidence trajectories by re-balancing marsh hydrology to optimize vegetation, accretion, and elevation gain. Obligate wildlife species and their habitats can then be supported over the long-term through the development of strategic management plans for each salt marsh system. Following a review of the historical literature, which documents the breadth of standardized farming practices, we identify these features on several sites, then present a four-step process to restore hydrologic function using innovative restoration practices at two case studies located in Rhode Island and Massachusetts, USA.

Keywords: salt hay farm, ditch, embankment, mega-pool, standing water, high marsh.

Salt marshes across coastal New England are undergoing rapid change characterized by increased areas of saturation resulting in shifts in vegetation communities (Warren and Niering 1993; Donnelly and Bertness 2001), large areas of vegetation dieback, and increases in shallow standing water (Smith 2009, 2015; Raposa et al. 2017; Watson et al. 2017). In many places, the "high marsh" (the irregularly flooded marsh platform normally dominated by *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii,* as well as forbs) has been overtaken by short- to intermediate-form *S. alterniflora*, bare patches, and large areas of shallow standing water. The marsh platform between the ubiquitous ditches has subsided (Vincent et al. 2014; Burdick et al. *in press*). In extreme cases, the marsh has 'collapsed' and now holds shallow water, and the only vegetation occurs along the ditch margins (Watson et al. 2017). While a few researchers have documented traits and trajectories of "natural" pools (Adamowicz and Roman 2005; Wilson et al. 2014), the relatively sudden appearance and geographic extent of shallow pools and other marsh changes suggests a large-scale driver. Research into historical salt marsh alterations for farming purposes dating as far back as the 1600s, with large corporate works in the 1800s (e.g., Massachusetts 1834: An Act to Incorporate the Broad Marsh Diking Company in Ipswich), has led this team to realize that remnant infrastructure from past agriculture coupled with accelerated sea level rise (Boon 2012) is driving wide-scale

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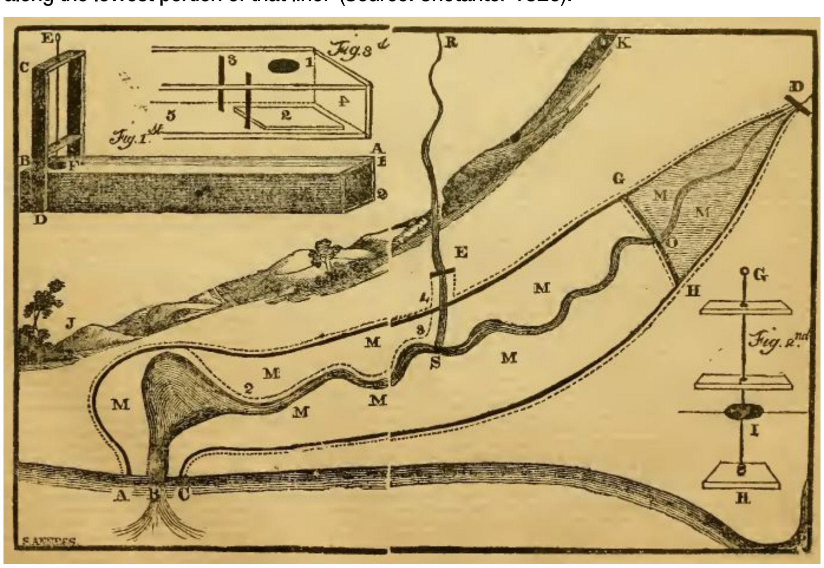
FIGURE 1. Aerial of Great Marsh, MA (April 2016) showing large number of small ditches. Little Pine Island is below the date bar. (Google Earth image accessed April 1, 2020.)

FIGURE 2. The diagram depicts plans to build a simple tide gate with instructions on how to isolate a salt marsh with agricultural embankments Figure 1st (upper left): A: Tide trunk open end; B: trunk closed end; C, D: a frame attached to the trunk, intended to hold an iron rod (E) perpendicular to the trunk; E: an iron rod that attached on its end to a valve that floats on an incoming tide and closes the trunk aperture; F: an aperture on the top of the trunk. Figure 2nd (lower right): G: Detail of iron rod as it passes through the external frame; H: valve that attaches to iron rod by a hook. The valve may be coated with cork to increase buoyancy; I: trunk aperture. Figure 3rd (upper left) interior view of the trunk: 1: aperture; 2: valve lying at the bottom; 3: two perpendicular rods passing through the trunk and intended to confine the valve in its place instead of the rod described above. Central figure: A-C: embankment along the Potomac River shore sufficient to exclude highest tide; B: tide trunk placed at Chotank Creek's mouth; D: dam for the purpose of turning the water from above into the marginal ditches; E: a mound used to turn waters of stream R-S into the marginal ditch (dotted line) to the river at A; G-H: embankment to exclude tide: J,K: ridge of hills known as "Black Castle"; M: marshes; O: tide trunk; R,E,S: stream; A,E,G,D,H,C: margin of the marsh; dotted lines G-D, D-H, H-C denote marginal ditches. Dotted line 2-3-4 represents an embankment that follows the creek with a tide trunk along the lowest portion of that line. (Source: Chotanter 1820).



salt marsh degradation. We present a review of farming practice in marshes along the Eastern Seaboard and then propose a four-step approach to correct tidal hydrology, stimulate marsh revegetation and rebuilding elevation to increase marsh resilience to accelerating sea level rise. One of our goals is to provide enhanced habitat for tidal marsh obligate birds, such as the saltmarsh sparrow, which are at increasing peril from nest flooding and extinction (Gjerdrum et al. 2008).

Since 2017, five fundamental points began to reshape how the authors perceive salt marsh condition, underlying causes, ramifications for wildlife, and even marsh semantics in the 21st Century:

1. Hawes' (1986) paper detailed the ways in which different generations of farmers altered salt marshes. The mosquito ditching from the Works Progress Administration in the 1930s was not the only ditching pattern to be found.
2. Beginning first in southern New England, salt marshes were showing signs of degradation related to excessive inundation.
3. The farming infrastructure identified by Hawes is still present on salt marshes and is highly correlated with incidences of marsh degradation.
4. Patterns of marsh degradation also indicate loss of saltmarsh sparrow nesting habitat.
5. Shifting patterns in salt marsh vegetation communities make traditional terms such as "high marsh" and "low marsh" confusing at best and misleading or incorrect at worst.

NUMBER 1: FARMERS IN THE MARSH

Staddles, circles of wooden posts driven into the high marsh platform, are one of the most iconic images of New England salt marshes. They were used by farmers to stack salt hay harvested from the immediate area; multiple staddles were present and common on most salt marshes. Martin Johnson Heade painted the haystacks atop the staddles during the second half of the 19th Century, decades before Monet painted his famous haystack series. Besides the staddles, the most commonly recognized remnant from salt hay farming are shallow, often closely spaced ditches (Sebold 1998; Figure 1).

Edward Hawes, an historian rather than a salt marsh ecologist, described a much more complicated series of alterations and their evolution over 200 years of early American agriculture (Hawes 1986). That this knowledge (see also Smith et al. 1989) was published in journals related to history rather than ecology or estuarine science may be an explanation for why it never caught the attention of coastal scientists until now. Table 1 lists different techniques used by farmers from the 1600s to late 1800s in order to alter site hydrology and salinity. These "improvements", including ditches and embankments, could increase vegetation yields 3-4 times and allow farmers to move from subsistence farming to marketing their excess. Methods that freshened hay beds close to the upland edge allowed the growth of brackish tolerant or freshwater plants such as timothy (aka "herds grass," *Phleum pratense*) and mangelwurzel (a root crop for livestock, *Beta vulgaris*). Smith et al. (1989) cites a farmer extolling the "black arts" which were merely the addition of manure (aka compost) to his tidally restricted salt meadows. John Adams (1771) recorded a "recipe for making manure" which included directions for using soil obtained from salt marsh ditches to add to dung and other material as a soil amendment. Schematics of salt marsh cross-sections in the most prestigious articles and texts (Miller and Egler 1950; Redfield 1965, 1972; Niering and Warren 1980; Smith et al. 1989) overlooked these physical alterations (ditches and particularly embankments) and may also be cause for similar neglect by generations of coastal ecologists.

Fortunately, the Farmers Journal (Chotanter 1820) brings to light the layout of ditches and embankments. While requiring some study, Figure 2 from that article depicts a method for enclosing an area of salt marsh with embankments to control tidal flooding. An internal network of ditches and a water control structure (aka "trunk") regulated levels of soil saturation. While embankments and unusual ditching patterns can often be found in New England salt marshes, it was this article that made sense of the layout of these remnant features as we see them today. This was an infrastructure system that was promulgated along the U.S. East Coast at least as far south as the Carolinas where trunks are still known from rice farming. And like Japanese rice farming, the salt marsh system of embankments was applied in a terraced fashion with each landward hay bed cultivating progressively fresher and more valuable grasses and crops. Indeed, in many locations, ditches extend through adjacent uplands although they can be obscured by regrown forest. The

TABLE 1. Agricultural and other alterations used on salt marshes (Chotanter 1820; Sheppard 1823; Clift 1862; Hawes 1986; Sebold 1992; Wolfe 1996; Adamowicz and Roman 2002; Mora and Burdick 2013)

	I 1600s Folk	II 1700s Folk	III Late 1700s Folk	1790's-1860s Folk/ Improvers	Post-1860's Improvers	Early-1900s	Mid-Late-1900s	2000s
Ditching & Maintenance	6-8" deep	X	X			X	X	X
Embankments		For S. patens	Enclosing 6-20 Ac					
Reclamation Embankments & Dikes				X	X			
Water Control Structures		Loose clapper gate		Trunk				
Perimeter Ditches				X	X	X		
Roads				"Corduroy" road			Modern road bed	X
Ditch Plugs							X	X
OMWM							X	X
Wildlife Impoundments							X	

FIGURE 3. Remnant embankment at Old Town Hill, Newbury, Massachusetts. (Photo credit: G. Wilson.)

FIGURE 4. *Spartina patens* thatch with algae: 2010, Wells, Maine, USA. Notice bare ground visible below thatch layer. (Photo credit: S.C. Adamowicz.)

advent of Google Earth and other websites with historical aerial imagery, tax maps, deeds and other records have been vital tools in our current efforts to identify this farming infrastructure on salt marshes from Maine to the Carolinas. An important caveat, however, is that most of the embankments seen in U.S. salt marshes today are not the comparatively massive constructions common to Nova Scotia (Smith et al. 1989) that currently carry roads and highways, but are much more subtle features (Figure 3).

NUMBER 2: PATTERNS OF SALT MARSH DEGRADATION

While salt marshes in southern New England were already undergoing loss of *S. patens* circa 2000 (Donnelly and Bertness 2001), signs of saturation and plant loss were brought to light in the 2012-2014 Rhode Island salt marsh assessment (Ekberg et al. 2017; Raposa et al. 2017). Early signs may have been occurring about the same time in Maine. Figure 4 shows an unidentified dark alga growing on *Spartina patens* thatch in 2010. When the alga was present, the *S. patens* thatch bases rotted causing them to be easily torn away (Adamowicz, pers. obs.). Following the appearance of this alga, *Spartina alterniflora* was observed to increase in density on the marsh platform (Figures 5), while *S. patens* often decreased (Figure 6). As soil saturation increased, all vegetation died off creating large areas of shallow standing water. Root collapse following plant death (DeLaune et al. 1994; Turner et al. 2004) lowered marsh surface elevation and reinforced the trajectory to shallowly impounded water and vegetation loss.

Mega-pool trajectories. In southern New England and areas with abundant grid ditching, the marsh platform between ditches has lost both elevation and vegetation. The pattern is clear from aerial imagery (e.g. Google Earth). In cases where vegetation is present, mainly on ditch maintenance embankments ("levees"), the pattern is reminiscent of waffles filled with maple syrup, where the "waffle/marsh ridges" support vegetation and the now lower marsh platform is covered in shallow standing water ("maple syrup") (Figure 7a). Raposa et al. (2017) noted that the occurrence of large areas of standing water were associated with "higher than normal" tides. Water was flooding the marsh surface, as it does during spring and storm tides, but was not able to drain sufficiently, thus beginning the mega-pool trajectory. In areas without intensive ditching, the pattern of vegetation to standing water can be more amorphous (Figure 7b).

A further pattern of mega-pools forms particularly along the upland margins of salt marshes. The standing water is often deeper, more typical of natural salt marsh pools (Adamowicz and Roman 2002). However, the pools occur in groups of tightly fitting clusters, reminiscent of jigsaw puzzle pieces or patterned fens (Madsen 1987). In patterned fens, saturation from groundwater causes the loss of vegetation and the iconic pattern of strings and flarks. The direction of groundwater flow is reflected in the pattern of strings, which are perpendicular to subsurface flow. Wilson (2010) demonstrated that groundwater flow may be responsible for elongated "necks" on pools in Maine; it is highly suggestive that the same may be true in these jigsaw pools in salt marshes (Figure 7c). Unlike patterned fens, which occupy much/most of the wetland in which they occur, the salt marsh jigsaw pools usually occur in scattered locations against an upland edge.

FIGURE 5. Encroachment of *S. alterniflora* into "high marsh" showing algae on thatch; 2010, Wells, ME, USA. (Photo credit: S.C. Adamowicz.)

NUMBER 3: FARMING INFRASTRUCTURE AND ASSOCIATION WITH CURRENT DEGRADATION FEATURES

Widespread marsh degradation was first noted in southern New England by Smith (2009) who documented dieback of *S. patens* over large areas in Wellfleet, MA and attributed this to sea-level rise. A different pattern of increased marsh saturation and vegetation conversion to shallow standing water emerged in Rhode Island. In their 2012-2013 salt marsh assessments, accelerated sea-level rise was highlighted as a potential stressor on Rhode Island marshes (Cole Ekberg et al. 2017). Rhode Island marsh accretion rates were determined to be 1.8mm/yr compared to the 5.2mm/yr of sea-level rise (Raposa et al. 2017). The micro-tides of Rhode Island and the relatively low position of salt marsh platforms in the tidal range also were seen as contributing factors. However, during a 2017 meeting of Great Marsh (Massachusetts) stakeholders, Hunt Durey (MA Division of Ecological Restoration, pers. comm.) pointed with alarm to the number of mega-pools converting what was once high quality *S. patens* "high marsh" into shallow surface water features. It was at that time that Geoffrey Wilson and Susan Adamowicz noted that many of the mega-pools were associated with human-made features such as historic roads. Further examination of historical documents (Shepard 1823; Clift 1862; Hawes 1986) led to the realization that the unusual ditching pattern in northern New England (compared to mosquito grid ditching prominent in marshes to the south) was indeed a part of the agricultural infrastructure. Investigation of current and historic aerial imagery and other online documents slowly

FIGURE 6. Decrease in *Spartina patens* (left axis) and increase in *Spartina alterniflora*, bare ground and wrack (right axis) indicate increased saturation at permanent plots in Wells, Maine (S. Adamowicz, unpublished data).

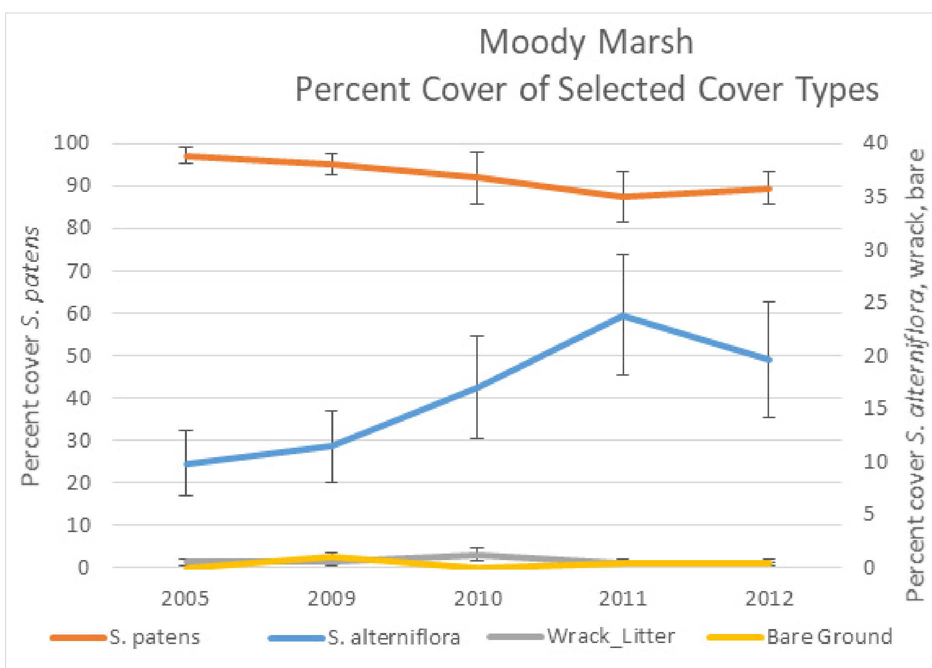
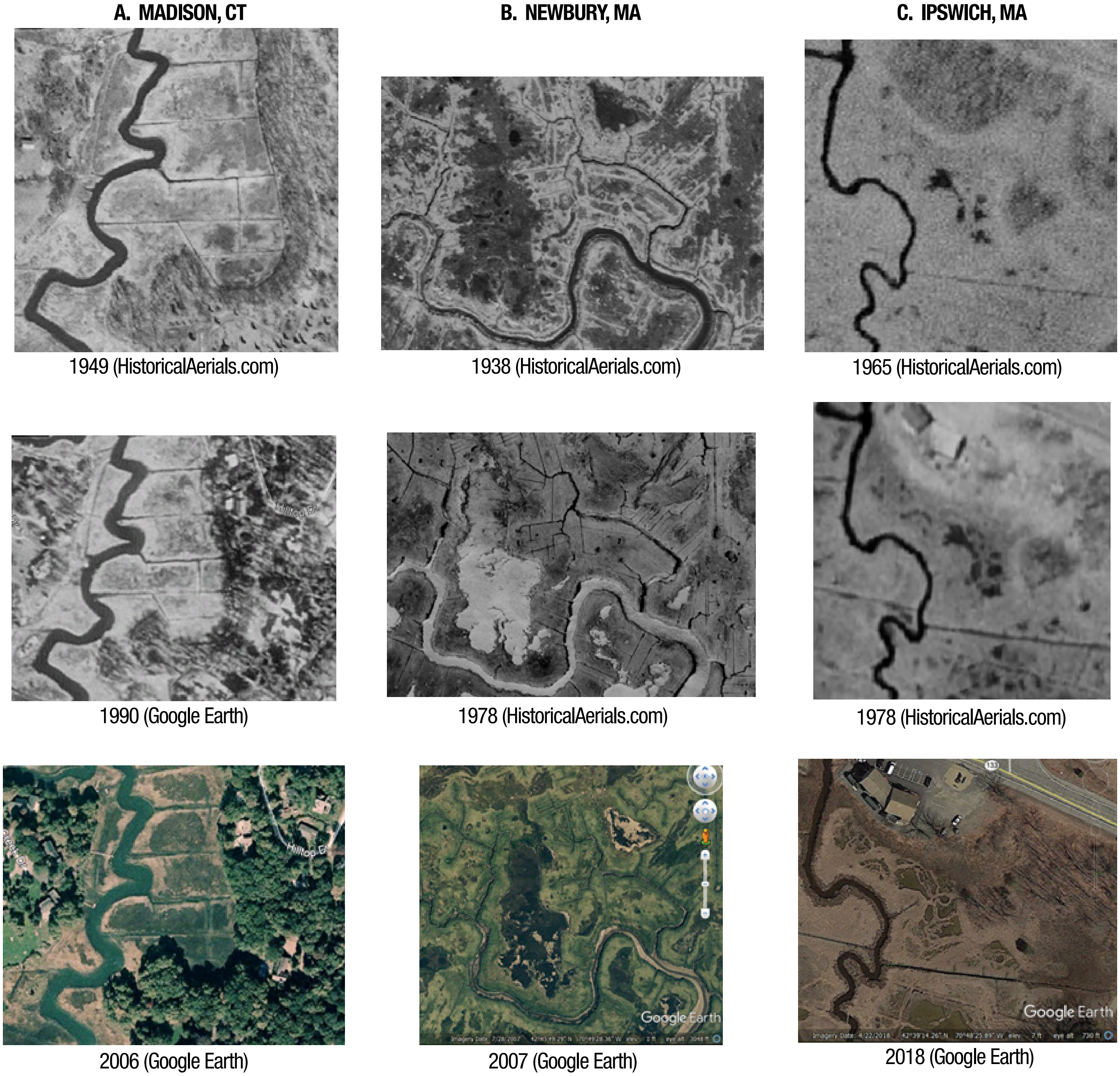


FIGURE 7. A time series showing development of A) "waffle-maple syrup" mega-pools, B) amorphous mega-pools, and C) "jig-saw puzzle" pools. (All Google Earth images were accessed on April 14, 2020.)



revealed the extensiveness of this infrastructure. And while the agricultural features are more subtle in more southern New England states (perhaps due to higher rates of decomposition and subsequent alterations for mosquito control), they are nonetheless still present. Furthermore, zones of supersaturated marsh and mega-pools can be predicted based on the layout of the agricultural embankments and old ditch signatures.

Salt marsh and reclamation embankments are mapped for several New England sites in Figure 8. *Salt marsh embankments* generally were constructed with a single borrow ditch. Within the area enclosed by a salt marsh embankment, interior drainage ditches typically drained into the borrow ditch and thence to a trunk outlet or an open tidal channel (Clift 1862). *Reclamation embankments* typically were larger to prevent tidal flooding and on occasion were fortified with upland soil spread over the top. Associated borrow ditches often were on both sides of reclamation embankments, and were double- or triple-wide. Reclamation enclosures usually had an internal drainage ditch system that tipped “backward” towards the upland and into a “marginal ditch.” The marginal ditch (aka “perimeter ditch” in more modern terminology) conducted water out of the reclamation enclosure through the trunk to the main tidal channel. The marginal ditch also drained groundwater from the adjacent upland (Clift 1862).

In the twentieth century, the excavation of mosquito control ditches covered much of the East Coast (Bourne and Cottam 1950). The dug blocks were sometimes placed as “turf dams” along the sides of the ditches (Miller and Egler 1950). Mosquito ditches had to be maintained, however. Tracked vehicles straddling a ditch would use a V-shaped plow (i.e. scavel plow; Figure 9) to remove debris and sediments from a ditch and slosh them onto the marsh surface. The machine treads then would compact the material in place. This resulted in modest embankments on both sides.

In the second series of images in Figure 7, we identify areas that are saturated or contain shallow standing water not associated with natural pools. While in a sense driven by natural processes of spring tides and storm floods, the underlying structures of embankments and collapsed drainage ditches are what trap water on the marsh surface and lead to mega-pool formation. A visual signature here is the line that one can see as the embankments curtail the expansion of mega-pools on at least one side. Without these impediments to flow, flooding waters would simply drain on ebb tides.

NUMBER 4: PATTERNS OF MARSH DEGRADATION ALSO INDICATE LOSS OF SALTMARSH SPARROW NESTING HABITAT

The saltmarsh sparrow (SALS) is an obligate salt marsh species, nesting from Maine to Virginia and overwintering from North Carolina to Florida. Female SALS build their nests just a few centimeters off the marsh surface, preferring *S. patens* with cowlick growth and thatch. This bird species has been suffering an average 9% decline in population size since 1998 (Correll et al. 2017). The primary cause has been identified as nest flooding, at least in New England (Ruskin et al. 2017). The timing of increased marsh inundation/saturation and loss of traditional “high marsh” habitat observed throughout the Northeast has led the authors to speculate that the sparrows may also be suffering due to marsh drainage issues.

FIGURE 8. Embankment types: A) two farmer’s embankments from ~1700s in Newbury, MA; B) reclamation embankment in Newbury, MA; C) diking company embankment in Wells, ME. (All images are Google Earth, accessed April 14, 2020).

A.

B.

C.

NUMBER 5: MARSH VEGETATION COMMUNITY NOMENCLATURE NEEDS TO REFLECT ACTUAL FIELD CONDITIONS

Historically, foundational papers by salt marsh ecologists have defined "low marsh" as that area of marsh that floods regularly (daily) and is occupied by tall form *Spartina alterniflora* (Miller and Egler 1950; Niering and Warren 1980; Nixon 1982; Bertness 1999). This combination of hydrology and vegetation was seen to occur along ditches/creeks and the main tidal channel or embayment interface. On the other hand, "high marsh" was defined as that portion of the marsh that floods less frequently (or "irregularly flooded"; Federal Geographic Data Committee 2013) and typically is occupied by *S. patens, Distichlis spicata, Juncus gerardii*, stunted *S. alterniflora* and several forb species (Chapman 1938; Redfield 1972; Miller and Egler 1950; Niering and Warren 1980; Bertness 1999). High marsh habitat was closely associated with the flat marsh "plain" or platform.

Marsh cross-sectional schematics from classic papers (Miller and Egler 1950; Redfield 1965, 1972; Niering and Warren 1980) were necessarily simplified versions of what existed in the field. In general, elevation was given as a proxy for inundation. Even Smith et al. (1989), despite their focus on significant farming alterations to the marsh surface, did not include embankments or ditches in their cross-sectional diagram. The omission has meant that at least two generations of ecologists have failed to recognize these important features and their potentially catastrophic impacts to normal marsh hydrology.

Additionally, over the last 10 years (at least), salt marsh surface vegetation and morphology has been changing. The sloping "low marsh" habitat along marsh fronts has been eroding into steep cliff-like banks (Deegan 2012) throughout New England (pers. observation); although, some banks, or scarps are expected, from a theoretical perspective (Fagharazzi et al. 2006). At the same time, *S. alterniflora* has been advancing upon the marsh platform and increasing in height from <10 cm for short-form, to an intermediate height up to 60 cm. *Flooding frequency* on the high marsh, however, has not increased to the twice daily regime of the classic "low marsh" definition, but *inundation* has increased due to standing water (Raposa 2017; Watson et al. 2017). The authors contend that referring to such locations as "low marsh" is both misleading and incorrect. During this time of shifting vegetation and tidal flooding patterns, the current use of "low" and "high marsh" do not accurately describe conditions in the field. Instead, we urge careful description of place, vegetation, flooding and inundation without short-handed referencing. For example, rather than noting presence of "high marsh" vegetation, we recommend listing vegetation by species (*D. spicata, J. gerardii*, *S. alterniflora*, *S. patens*, etc.), and providing actual height of *S. alterniflora* rather than short-, intermediate- or tall- modifiers. Similarly for hydrology, recording actual rather than presumed tidal flooding frequency *as well as* inundation provides a more accurate site description. The old rubric of elevation as an indicator of inundation simply does not hold because subtle barriers to hydrology have formed mega-pools. The aim, here, is to provide a more diagnostic description of actual site conditions.

MOVING FORWARD: THE NEED FOR INNOVATIVE RESTORATION TECHNIQUES AND COLLABORATIVES

The authors have piloted innovative salt marsh restoration techniques at Rachel Carson National Wildlife Refuge (Wells, ME) and Parker River National Wildlife Refuge (Newburyport, MA). Save The Bay/Narragansett Bay (Save The Bay, Inc.) developed the use of runnels in Rhode Island (W. Ferguson, pers. comm.). While initially designed to address intensely ditched sites (ditch remediation; see Burdick et al. 2020) or areas that are supersaturated or have standing water (ditch plug removal, runneling), awareness of the lingering farming infrastructure has spurred the authors to discard limited remedies and instead propose a comprehensive approach to marsh restoration – one that focuses on immediate, interim, and long-term marsh health and includes creation of saltmarsh sparrow habitat. Two case studies below exemplify these points:

FIGURE 9. Scavel plow clearing debris from a mosquito control ditch circa 1940-1950s. Mechanized ditching patterns are ubiquitous from Massachusetts southward, often overlay previous agricultural ditching patterns, may not adhere to tideshed boundaries or original marsh slope, and develop highly compacted embankments on both sides of ditches. (Photo credit CT DEEP.)

CASE STUDY 1: OLD TOWN HILL, NEWBURY, MA (~80 AC; 42.775226, -70.862025")

Owned and managed by The Trustees of Reservations, this salt marsh lies in the upper part of the tidal range and is heavily ditched. After examining a series of historic aerial images and with field verification, Geoffrey Wilson determined there were 219 farmer's ditches and 51 agricultural embankments (Figure 10). A 1907 map of the area shows that virtually the entire property and surrounding landscape was cleared (The Trustees of Reservations 2007). The Hill was open with a watch house and a large elm growing on top that was used for navigation. Currently most of the marsh is on a subsidence trajectory. Large areas of marsh platform are saturated and support stunted (30 cm) *S. alterniflora* and *Distichlis spicata*; *S. patens* grows best on the many embankments.

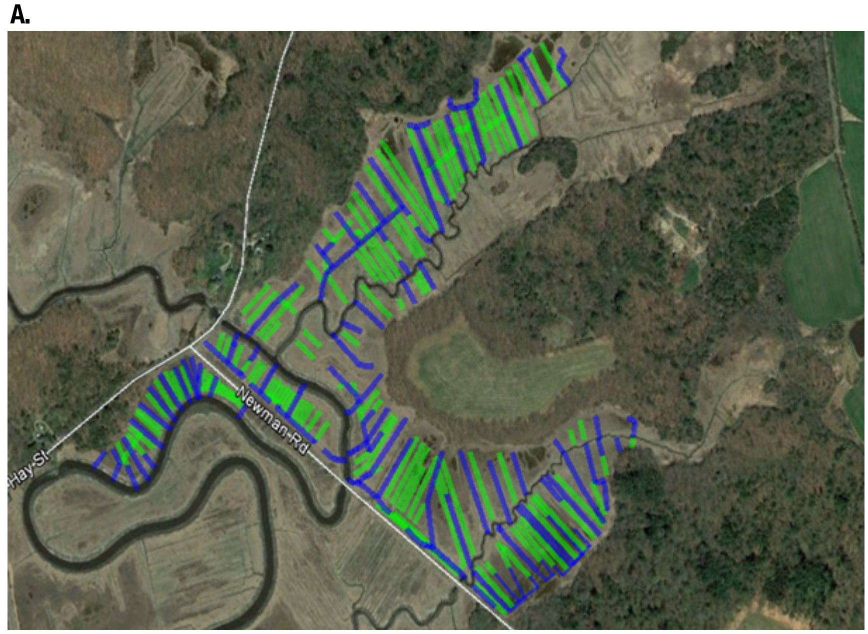
Wilson's restoration design relies on identifying tidesheds and primary drainage channels in the field. These will be re-emphasized by using ditch remediation (Burdick et al. 2019) to "heal" auxiliary ditches from the bottom up. Nine blocked ditches will be cleared to reestablish primary channel drainage. Collapsed ditches will be opened as runnels and used to clear shallow impounded surface water (mega-pools) so that vegetation can recolonize. Any peat removed in runnel creation will be placed so as to create slightly higher microtopography suitable for potential saltmarsh sparrow nesting. These methods correspond to Tiers 1 and 2 noted below (under Timeline). Importantly, each Tier creates small- to large-scale SALS nesting habitat.

CASE STUDY 2: JACOBS POINT, WARREN RI (~35 AC; 41.712234, -17.288328)

Jacobs Point is managed by the Warren Land Conservation Trust and lies west of the East Bay Bicycle Path (a former railroad line) and just north of the Rhode Island Audubon Claire D. McIntosh Wildlife Refuge (Figure 11). This site is crossed by a 1915 road that is currently used as a footpath. An extensive patch of invasive *Phragmites australis* was controlled partially in 2010 through the replacement of three collapsed culverts under the footpath by partners including Save The Bay, U.S.D.A. Natural Resources Conservation Service, and the Town of Warren. Patches of *Phragmites* south of the footpath and north along the bike path were sprayed with herbicide in 2010-12. Save The Bay/Narragansett Bay and RI Department of Environmental Management/ Mosquito Abatement installed runnels (i.e. 2012 hand dug and 2015-16 excavated with low ground pressure excavator) in areas both north and south of the footpath and adjacent to the bike path. The runnels were used to remove shallow standing water and relieve waterlogging in small tidesheds isolated by embankments. Near the bike path, the standing water, in turn, had been facilitating expansion of invasive *Phragmites* and vegetation die-off toward the marsh interior. In this case, it is believed that much of the standing freshwater was stormwater runoff from two upslope developments

FIGURE 10. Old Town Hill Reservation, Newbury, MA. A) 219 primary (blue) and secondary (green) ditches. B) 51 embankments (red) identified. (Google Earth accessed April 2018.)

A.



B.

where impervious surface increased from ~1% in 1972 to over 20% in 2011 (W. Ferguson, unpublished data).

In 2017 the Saltmarsh Sparrow Research Initiative (SALSri; https://www.salsri.org/) began a multi-year field study of saltmarsh sparrow breeding ecology and survivorship at Jacobs Point. Following runnel creation near the bike path noted above, the runnel not only reduced standing water and waterlogging, but also restored connectivity and unimpeded tidal exchange resulting in higher quality salt marsh conditions that saltmarsh sparrows prefer (W. Ferguson, pers. comm.). In 2017-2019, one female located to the area and built a total of 4 nests (Steven Reinert, pers. comm.). Further study is required to provide more details of SALS recruitment to the restored marsh section, but even this initial case shows promise.

COLLABORATION: SMARTEAMS APPROACH

Recognizing the success when avian researchers and wildlife managers organized under Saltmarsh Habitat and Avian Research Project ("SHARP"; tidalmarshbirds.org) and the need to increase efficiency and effectiveness during the next 10 years, we propose a similar collaborative approach for salt marsh researchers, restoration practitioners, managers and landowners under the Salt Marsh Adaptation and Resiliency Teams ("SMARTeams"). Thus, instead of working project by project (or site by site), groups of project advocates ("Field Teams") can work collectively, achieving economies of scale in restoration design, permitting, project management, monitoring, and outreach.

SMARTeams, as proposed, have three support elements to assist Field Teams: 1) a Design Review Team, 2) a Technical Support Team, and 3) an Education, Outreach and Training Team (Figure 12). In this way, salt marsh restoration project number and acreage can be increased while maintaining high standards across the board. Under the direction of the Design Review Team and in consultation with U.S. Fish and Wildlife Service, SHARP, and Atlantic Coast Joint Ventures' "Saltmarsh Sparrow Business Plan," each restoration project can include measures that enhance saltmarsh sparrow nesting success for current and future generations. With consistent monitoring and adaptive management frameworks, lessons learned can be quickly propagated across the entire region.

The role of the Technical Support Team is to provide services too complex or expensive for single projects or small organizations. The SMARTeams approach, using portfolios of Field Teams and multiple projects, makes it highly desirable and possible to track projects through a web-based portal that might include a story map, project narrative, and summary results. Standardized monitoring protocols can be shared and data could be stored in a central location to facilitate access, analyses, and archiving. Specialty expert input (e.g. from a tidal hydrologist, historian, marine geologist, among others) would provide vital and targeted information to increase project success. Finally, as insights and lessons learned accrue, decision support tools could be developed to increase the ease and accuracy of site diagnosis and restoration design for additional and future restoration Field Teams.

The Education, Outreach and Training Team's role is to communicate internally with SMARTeams participants and externally with those interested in participating in salt marsh restoration and with the public. In addition to the story map noted above, a web presence

FIGURE 11. Jacob's Point, Warren, RI, with runnels (light green), larger cleared channels (light blue), ditches (pink), embankments (red), stonewall embankments (purple), road/footpath (white), possible historic channel (dark blue) (Google Earth accessed May 19, 2020). All delineations were based on aerial signatures and need to be field verified.

should include news updates, class and training session notices, project and people profiles, reference material and research findings among other materials. Training sessions will be offered to project proponents and regulators to increase understanding of current site conditions at local salt marshes as well as the purpose and outcome of innovative restoration techniques. There is also the possibility of offering training to restoration practitioners so that these new techniques can be applied and executed properly.

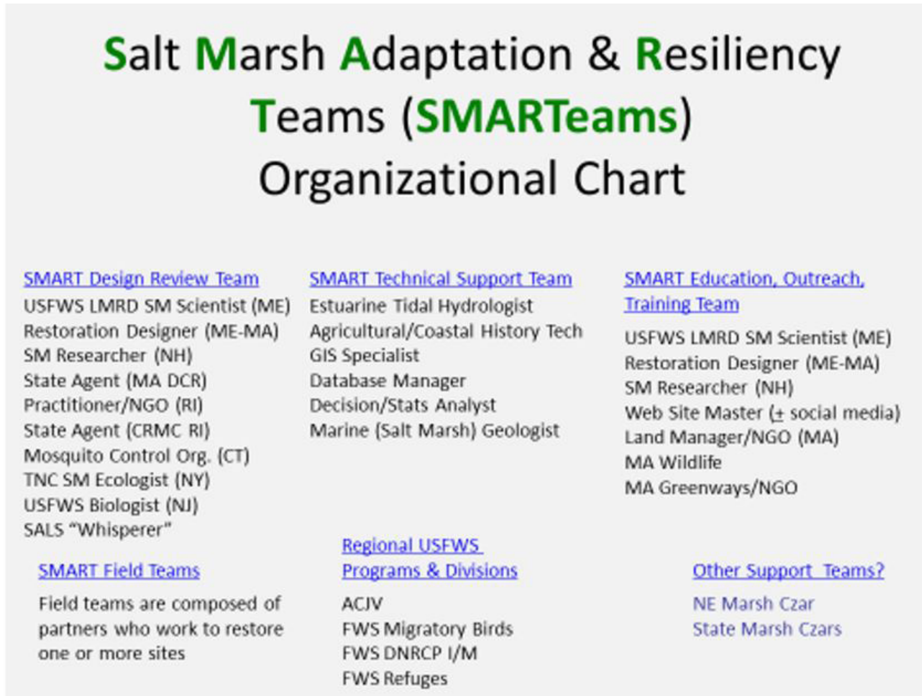
A 10-YEAR TIMELINE

Given the necessity to stabilize saltmarsh sparrow populations and the opportunity of a period of relatively lower astronomical tidal ranges in the Metonic cycle, the next 10 years will be perhaps the last best opportunity to restore northeastern salt marshes. We propose a 4-tiered approach to restoration efforts within the sparrow's nesting range. The four tiers can be remembered by HOTT: 1) Halt subsidence trajectories, 2) Optimize accretion/ elevation gain, 3) Tune marsh hydrology and vegetation to support obligate wildlife species, and 4) Tend to our coastal marshes over the long-term through the development of strategic management plans for each salt marsh system.

Tier 1's goal is to restore tidal flow and ebb to sites with ditch plugs or naturally blocked ditches. This would immediately halt the saturation subsidence trajectory and provide plants an opportunity to grow. Sediments removed from plugged ditches or runnels would be repurposed to create saltmarsh sparrow nesting microhabitat by placing the sediments over live plants over 4 by 8 foot 'islands' (32 square feet). This step provides safer nesting habitat after 2 to 3 years for new adults. This step provides safer nesting locations for new adults. Runnels can be used at this point to connect areas of shallow standing water through an embankment to a tidal channel/ditch. Ditch remediation used in this phase starts the "healing" process in auxiliary ditches and reinforces flow to primary ditches/creeks.

Tier 2's purpose is to optimize elevation gain by promoting growth of *S. alterniflora* belowground biomass on the marsh platform where prior saturation/inundation caused subsidence. This is done by adjusting the root zone saturation depth to optimal levels such as shown by Morris and colleagues (2002, 2013). Runnels are also a primary tool in this phase. Again, material excavated for this tier is to be used for

FIGURE 12. Salt Marsh Adaptation and Resiliency Teams (SMARTeams) draft organization chart.



additional nesting microhabitat. The nesting microhabitats "buy time" for saltmarsh sparrows by creating areas that are less prone to flooding compared to the rest of the marsh while *S. alterniflora* is building overall elevation.

Tier 3 involves further adjusting hydrologic conditions to favor *S. patens* growth and to create more expansive areas of successful nesting habitat, while Tier 4's goal is to create a long-term strategic management and monitoring plans for each salt marsh system. These plans will identify important stakeholders, current and future potential funding sources, management and restoration history and milestones for future managers and biologists. Systematic monitoring of hydrology (water level recorders), vegetation (abundance by species) and elevation change (real-time kinematic survey tools) on an annual basis will ensure a capacity for adaptive management and an ability to analyze data across project sites. Permitting for long-term maintenance enables rapid responses that could waylay more complicated situations. In this way, the legacy of the SMARTeams includes not only restored marshes and increased quality nesting sites for saltmarsh sparrows, but also prepares for their continuation in future decades.

We believe it is possible to restore significant high quality salt marsh acreage across the saltmarsh sparrow breeding range by working with NGOs, state and local agencies, and the U.S. Fish and Wildlife Service's National Wildlife Refuges. While time passes even as this article is written, there are hopeful signs in the organization of Field Teams in Massachusetts, Rhode Island, and Maine. ■

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