A Globally Rare Coastal Salt Pond Marsh System at Odiorne Point State Park, Rye, New Hampshire

Article *in* Rhodora · January 2013

DOI: 10.3119/12-09

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RHODORA, Vol. 115, No. 961, pp. 1–27, 2013

DOI: 10.3119/12-09; first published online: January 22, 2013.

A GLOBALLY RARE COASTAL SALT POND MARSH SYSTEM AT ODIORNE POINT STATE PARK, RYE, NEW HAMPSHIRE

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abstract. Vegetation patterns in the coastal salt pond marsh system at Odiorne Point State Park in Rye, New Hampshire, the state's only viable example, are described based on recent surveys and historical data. Four natural communities occur within the system: coastal salt pond flat, coastal salt pond emergent marsh, coastal salt pond meadow marsh, and highbush blueberry–winterberry shrub thicket. The first three communities are newly described in New Hampshire and the northeastern US coastline. A total of 69 native or naturalized vascular plant taxa from 54 genera and 33 families have been documented in the system at Odiorne Point between 1967 and 2011. The families best represented were Cyperaceae (10 taxa), Poaceae (9 taxa), and Asteraceae (6 taxa); the largest genera were *Eleocharis* (4 taxa), *Hypericum* (4 taxa), and *Agrostis* (3 taxa). In 2011, only 35 of the 69 plant taxa were documented; a difference that can be attributed, at least partially, to the variable nature of hydrologic and salinity influences on the system. Of the 69 plant taxa, three are rare in New Hampshire and five are both non-native and invasive in the state and region. The uncertainty of the nativity status of *Typha angustifolia*, the dominant species in the marsh, has significant implications for future management decisions. Measurement of surface and pore water salinity in late summer of 2011 revealed essentially fresh water conditions at the surface (1.1 ± 0.5 ppt SE), whereas pore water occurring 10 cm and 40 cm below the soil surface was mesohaline (5.8 ± 1.8 and 8.1 ± 1.8 ppt SE, respectively). Mean pore water salinity differed significantly among the natural communities examined, suggesting that hydrology and salinity influence species composition and distribution within coastal salt pond marsh systems. This globally rare system, distributed from Maine to New Jersey, shares similar dominant species across its range, although some of the state rare species it supports differ along a latitudinal gradient.

Key Words: coastal salt pond marsh system, globally rare, natural communities, hydrology and salinity gradients, vascular flora, rare plant taxa, non-native plants, *Typha angustifolia*, surface and pore water salinity, oligohaline, mesohaline, electromagnetic induction, Odiorne Point State Park, New Hampshire

Coastal salt pond marshes are estuarine systems typically separated from the ocean by barrier beaches. Many of these marshes occur along the edges of semi-permanently or permanently flooded coastal salt ponds. In several examples along the northeastern US coastline, either storm waves or significant influxes of fresh water into ponds create openings through beaches, allowing for more frequent salt water inflow. The openings may be temporary or semi-permanent (Harshberger 1909). Water in these marshes is typically brackish (0.5–30 ppt) but can fluctuate dramatically between fresh ($<$ 0.5 ppt) and saline ($>$ 30 ppt) in response to precipitation, evaporation, and sea water overwash, breaching, and seepage (Anderson et al. 2006; Carpelan 1957; Jarecki and Walkey 2006). For example, the salinity in Georgica Pond (a former fresh water pond covering 1.73 km^2) in Hampton, NY, jumped to 26 ppt four days after the barrier beach was breached (Bokuniewicz et al. 2011). Vegetation patterns in coastal salt pond marshes are inherently variable because of temporal and spatial variability in hydrology and salinity (NatureServe 2011).

The single viable coastal salt pond marsh system occurring in New Hampshire is at Odiorne Point State Park, hereafter referred to as the "Park" (Figure 1). This 2.4 ha wetland along the coast in Rye (N 43°03′00.7″, W 70°43′09.0″) is semi-permanently saturated at its higher elevations and seasonally to semi-permanently flooded in lower elevations. The marsh system supports fresh water shrubs and meadow marsh species near its upper margin, and emergent marsh and aquatic species tolerant of wetter, more saline conditions in lower elevations. During drier periods of the growing season, exposed flats at lower elevations support annuals and herbaceous perennials.

Natural communities within coastal salt pond marshes are poorly documented (NatureServe 2011). A goal of this study was to conduct research and floristic surveys to describe the natural communities within this system at the Park. The relationship

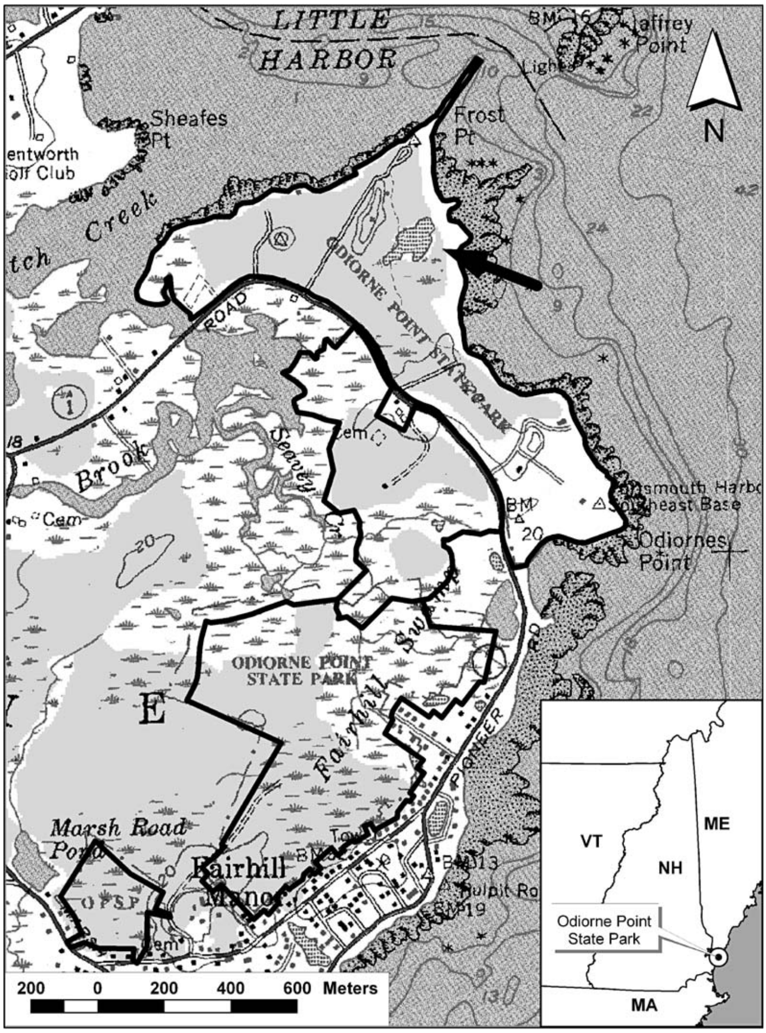

Figure 1. Location of the coastal salt pond marsh system (see arrow) at Odiorne Point State Park in Rye, New Hampshire. The thick black lines delineate the Park's boundary.

between vegetation, hydrology, and salinity patterns was examined. We also reviewed the classification and description of coastal salt pond marshes elsewhere in the northeastern US to help confirm our classification and compare differences among states.

SITE DESCRIPTION

The Park's lithology is classified as felsic, with relatively slow-weathering rock composed of base-poor silicates. The bedrock is Rye Formation, characterized by schists, gneisses, quartzites, and amphibolites (Billings 1956; Lyons et al. 1997). Depth to bedrock is typically over 0.5 m, although small areas of exposed bedrock occur in the marsh. The uppermost layer of the marsh's soil is Pawcatuck mucky peat (Kelsea and Gove 1986), an estuarine soil type most often associated with tidal marshes. This dark peat overlies a thin layer of gravelly silt loam mixed with small quantities of coarse sand.

Shortly after deglaciation and the associated marine submergence of our present coastline (ca. 12,640 YBP), isostatic recovery of the Earth's crust in the Gulf of Maine led to sea level minima at 60 m below present levels around 11,400 YBP (Bloom 1963). Then, the shoreline lay several kilometers east of the Park; mean sea level of the Atlantic Ocean now lies less than 40 m from the seaward edge of the coastal salt pond marsh at its nearest point. Since these events, the ocean has come to shape the marsh's nature by periodic intrusion of salt water over the narrow sand and cobble berm. The central portion of the berm rises 4.2 m above current mean sea level; the north end drops to 3.1 m and the southwest end is slightly higher (3.6 m above mean sea level). These lower ends show evidence of storm-wave overwash, based on the presence of several dry channels on the berm's landward side. The upper edge of the coastal salt pond marsh transitions to upland shrubland on the backside of the berm at approximately 1.9 m above mean sea level. During storms that generate large waves, the height of the central portion of the berm typically increases as coarse sediments move landward, piling on top of the ridge while the seaward-facing slope steepens. Strong storms such as the Halloween nor'easter of 1991 have significantly changed the height, slope, and overall shape of the berm over the years (Marilyn Gilmour, Seacoast Science Center, NH, pers. comm.).

Beginning early in the 17th century, a long history of human land use has had a profound effect on the flora, fauna, and natural communities in the Park. Because of its strategic location adjacent to Little Harbor at the mouth of the Piscataqua River, European colonists built a settlement and fortification at Odiorne Point in 1623. Since then, these lands have been used for a number of purposes, including farming, homesteads, grave sites, life-saving stations, and additional military installations. Close to the coastal salt pond marsh system, a farm house was converted into a hotel in 1868. In 1870, the building was enlarged and renamed the Sagamore Hotel. The hotel was lost to fire in 1872 and never rebuilt (Steed 1992).

MATERIALS AND METHODS

The following landscape data sources were examined to inform field surveys: aerial photographs, National Wetland Inventory maps, surficial and bedrock geology maps (Lyons et al. 1997), Natural Resource Conservation Service soil survey maps, and US Geological Survey (USGS) topographic quadrangles. The New Hampshire Natural Heritage Bureau database provided information on rare plant taxa known to occur in the coastal salt pond marsh system.

Floristic surveys were conducted by the authors in 1997 (June 24, 26, and October 2), 2010 (July 16), and 2011 (August 23, September 9, and October 10). The survey methodology for the 1997 and 2010 field work followed a specific protocol. Within each natural community type, an experienced botanist developed a list of all vascular plant taxa by searching intensively until no additional taxa were found within a 10-minute interval, or until small areas were completely traversed. In portions of natural communities that had not been completely searched, at the point when 10 minutes had passed with no additional taxa located, the remaining areas were surveyed at a higher rate of travel. This technique has been found to be effective in locating a minimum of 92% of the taxa actually present (Nichols et al. 1998).

During surveys in 1997 and 2010, natural community data were collected in relevé plots placed at representative locations in each community type. Determination of community type was based on inspection of differences in physical conditions and plant species composition, structure, and cover (Sperduto and Nichols 2011). At each relevé, all plant species were determined, percent cover was estimated for all plant species in each stratum, and physical site characteristics were noted. Vascular plant taxonomy, nomenclature, and nativity status have been updated to follow Haines (2011).

The primary goal of the 2011 fieldwork was to re-locate three state-listed (state endangered or threatened) plant species that were previously documented from the system in wet, low flats and ponded areas. An attempt was made to observe as much of the system as possible; however, the flats and open-water areas received a disproportionally high level of scrutiny. A secondary goal was to prepare a vegetation map of the system, showing boundaries of the types based on dominant species or clearly identifiable physical zones (e.g., transition to upland and open water). Within each of these delineated types, all vascular plant species were noted and their relative abundance was scored as uncommon, common, or abundant. All transitions between vegetation types were traversed and mapped, and the interior portion (i.e., away from the transition) of each area was examined by walking a meandering route. Voucher specimens were collected for state-listed species and for species requiring additional examination, and were deposited at the Hodgdon Herbarium (NHA) at the University of New Hampshire.

In addition to our fieldwork, earlier survey work (Straus 1973) was considered as supporting documentation for species composition in natural community determinations. Straus conducted surveys between 1967 and 1972, mapping 14 upland and wetland cover types within the Park and documenting vascular plant species within each type. As part of this work, Straus surveyed the coastal salt pond marsh, documenting 28 plant species and delineating two habitat types within the system: 1) barrier pond and marsh and 2) shrubby border of marsh.

For surveys in 1997, 2010, and 2011, Garmin 12 and 76CS Global Positioning System (GPS) units were used to gather locational information for relevé plots, rare plant populations, and invasive plant species. The estimated accuracy of the data based on satellite configuration was generally within 7 m. Field data and site locations for rare plant populations, exemplary natural communities, and the exemplary wetland system have been catalogued and incorporated into the New Hampshire Natural Heritage Bureau databases.

In 2011, pore water apparent conductivity (EC_a) was measured on two days in late August and early September using electromagnetic induction (EMI) techniques with a Geonics model EM38 (Geonics Limited, Mississauga, ON, Canada) paired with a Juniper Systems Allegro hand-held data collector and Garmin 76CS GPS unit with CSI wireless differential antenna. Apparent conductivity measurements (EC_a) integrate values over the effective penetration range of the instrument, which in this case is approximately 0.5–0.7 m. Researchers collected geo-referenced EC_a data continuously while walking meandering transects through the entirety of the coastal salt pond marsh system. Resulting conductivity data (mS/s) were converted to salinity (ppt) using an algorithm derived from prior work along New Hampshire's seacoast (Moore et al. 2011). A salinity contour map was then generated in ArcGIS 10.2 (ESRI, Redlands, CA) using the inverse distance weighted raster interpolation function in ArcToolbox to illustrate soil pore water data obtained using EMI. When plotted, EC_a measurements are particularly valuable for visualizing detailed salinity patterns on a landscape scale.

The EM38 unit was calibrated on-site each day. In addition, direct measures of pore water salinity were conducted by means of the sipper technique (Portnoy and Valiela 1997) at 12 locations in the marsh, using a hand-held refractometer as a quality control for comparison to EM38 results. Subsurface pore water was sampled at two depths (10 cm and 40 cm). Direct salinity measurements as well as those calculated from EC_a are reported as means $\pm$ 1 standard error (SE).

Pore water salinity values derived from EC_a data were plotted spatially in ArcGIS. Natural community boundaries (mapped separately using a handheld GPS) were then projected over the salinity data. Data occurring within the boundaries of three of the four community types (coastal salt pond flat, coastal salt pond emergent marsh, and coastal salt pond meadow marsh) were then selected in Arc, grouped by habitat, and exported to JMP® 9.9.0 for statistical analysis and to verify their classification. The fourth community type, highbush blueberry–winterberry shrub thicket, was excluded from this analysis due to its small size and discontinuous pattern adjacent to upland habitat. Data were analyzed using a non-parametric test (Kruskal-Wallis) to compare salinity across natural communities because the data were not normally distributed. A Tukey's HSD (α = 0.05) was used to determine differences between pore water salinity means within each plant community.

A baseline elevation survey was conducted on February 13, 2012 by the New Hampshire Forest and Lands Survey Office. Height above mean sea level was measured for both the higher-elevation edge of the coastal salt pond marsh and along eight transects across the berm separating the marsh from the Atlantic Ocean.

The initial reference benchmark was a brass National Geodetic Survey disk established on Odiorne Point in 1943. As this benchmark was not in the immediate vicinity of the marsh, several control hubs were set on the seaward side of the marsh's cobble berm to establish a vertical and horizontal elevation correlation to the 1943 benchmark. Sokkia Stratus GPS tripod units were used simultaneously at both the initial reference benchmark and the control hubs. Once the control hubs were linked to the NH State Plane coordinate system (NAD83) and the elevations relative to NAVD88, a Topcon Total Station Electronic Distance Measurer (Topcon Corp., Tokyo, Japan) was used at the hubs to collect baseline elevations. Accuracy of elevation data was ± 3 cm.

RESULTS

Sixty-nine plant taxa from 54 genera and 33 families were documented from the coastal salt pond marsh during surveys by the authors in 1997, 2010, and 2011 and by Straus (1973) between 1967 and 1972 (see Appendix). The families best represented were Cyperaceae (10 taxa), Poaceae (9 taxa), and Asteraceae (6 taxa); the largest genera were *Eleocharis* (4 taxa), *Hypericum* (4 taxa), and *Agrostis* (3 taxa). Three rare plant species have been documented in the marsh in 2010 and/or 2011 (New Hampshire Natural Heritage Bureau 2011): *Chenopodium rubrum* var. *rubrum* (state endangered), *Eleocharis parvula* (state threatened), and *E. uniglumis* (state threatened). A fourth species rare in the state, *Zannichellia palustris* L., has not been noted as occurring in the coastal salt pond marsh in nearly 40 years (Straus 1973). Because specimens are unknown, it is not included in the list of species in the Appendix and the record remains unsubstantiated unless it is rediscovered in the Park or a voucher specimen is located. Five of the 69 plant taxa were non-native, each one invasive in New Hampshire and the region (Mehrhoff et al. 2003): *Celastrus orbiculatus*, *Frangula alnus*, *Lythrum salicaria*, *Phragmites australis* var. *australis*, and *Solanum dulcamara*. It is unclear if *Typha angustifolia*, a species that dominates the marsh, is native here or not (see Discussion). If non-native, it would be considered an invasive species as well.

Four types of natural communities were documented in the coastal salt pond marsh system: coastal salt pond flat, coastal salt pond emergent marsh, coastal salt pond meadow marsh, and highbush blueberry–winterberry shrub thicket. The first three types are rare and newly defined. All four natural communities are described below.

1. Coastal Salt Pond Flat

The coastal salt pond flat occurs adjacent to the emergent marsh community (see below) but in lower-lying areas that are seasonally to semi-permanently flooded. The flat is vegetated by scattered rhizomatous perennials near the emergent marsh. On lower ground, annuals emerge from the seedbank as normally inundated areas become exposed during drought. Characteristic species are *Eleocharis flavescens* var. *olivacea*, *E. parvula*, and *E. uniglumis*. *Bolboschoenus maritimus* subsp. *paludosus* and *Schoenoplectus pungens* var. *pungens* occur in low cover. Because the low flat is often ponded, aquatic species such as *Lemna minor* that are tolerant of brackish conditions and drawdown are usually present here. *Zannichellia palustris*, a rare aquatic species in the state, was listed in this habitat by Straus (1973).

2. Coastal Salt Pond Emergent Marsh

Situated between the flat and meadow marsh communities, the coastal salt pond emergent marsh is saturated to semi-permanently flooded with seasonably variable water levels. Water levels in shallower portions of the emergent marsh range from a few to several centimeters for most of the growing season. Later in the growing season, the soil surface may be exposed and stay that way for the remainder of the summer. Deeper sections of the emergent marsh have 0.5 m or more of standing water. Soils in this area are exposed only during drier periods. Species composition in a given area depends on factors such as salinity, water depth, and amplitude of water-level fluctuations. Characteristic perennial emergent species, typically spongy-tissued or aerenchymatous, are *Bolboschoenus maritimus* subsp. *paludosus*, *Schoenoplectus pungens* var. *pungens*, *S. tabernaemontani*, *Sparganium* sp., and *Typha angustifolia*. Other plant taxa include *Hypericum* spp., *Juncus canadensis*, *Lysimachia terrestris*, *Lythrum salicaria*, *Phragmites australis* var. *australis*, *Scutellaria galericulata*, *Solanum dulcamara*, *Thelypteris palustris* var. *pubescens*, and *Triadenum virginicum*. Floating aquatic species intermixed with the dominant emergent vegetation include *Lemna minor* and *Nymphaea odorata*.

3. Coastal Salt Pond Meadow Marsh

On higher ground adjacent to the emergent marsh community described above, the coastal salt pond meadow marsh is semi-permanently saturated to seasonally flooded. Flooding typically occurs during the spring or high-runoff and precipitation events, but in most years, the water table remains at or below the surface for much of the growing season. Characteristic species include *Agrostis stolonifera*, *Solidago sempervirens*, *Spartina pectinata*, and *Symphyotrichum novi-belgii*. Associated species are *Bidens connata*, *B. frondosa*, *Carex hormathodes*, *Chenopodium rubrum* var. *rubrum*, *Hypericum* spp., *Iris versicolor*, *Juncus canadensis*, *Lycopus uniflorus*, *Lysimachia terrestris*, *Lythrum hyssopifolia*, *L. salicaria*, *Scirpus cyperinus*, *Thelypteris palustris* var. *pubescens*, and *Triadenum virginicum*.

4. Highbush Blueberry–Winterberry Shrub Thicket

In addition to the three preceding rare natural community types, a narrow and discontinuous band of highbush blueberry–winterberry shrub thicket occurs in the coastal salt pond marsh system. It is found along the upper edge of the coastal salt pond meadow marsh. This community type has been previously classified and described by the New Hampshire Natural Heritage Bureau (Sperduto and Nichols 2011). It is a common and widespread community that occurs in small, open basins, closed sand plain basins, and seasonally flooded zones within larger wetlands in central and southern New Hampshire. Characteristic vegetation in this example includes *Ilex verticillata*, *Lyonia ligustrina* var. *ligustrina*, *Myrica gale*, *Spiraea alba* var. *latifolia*, *Toxicodendron radicans*, *Vaccinium corymbosum*, *Viburnum dentatum* var. *lucidum*, *Acer rubrum* seedlings and saplings, and herbs such as *Hypericum* spp., *Lycopus uniflorus*, *Lysimachia terrestris*, *Onoclea sensibilis*, *Osmunda regalis* var. *spectabilis*, *Osmundastrum cinnamomeum*, and *Thelypteris palustris* var. *pubescens*. *Celastrus orbiculatus* and *Frangula alnus*, two invasive species in New England, also occur here. Adjacent to the highbush blueberry–winterberry shrub thicket, a small example of a maritime shrub thicket (a rare upland community type in New Hampshire) occurs on higher portions of the berm between the coastal salt pond marsh system and the maritime cobble beach on the other side.

Surface water salinity measurements obtained using a hand-held refractometer at 12 sampling locations (Figure 2) revealed that ponded water at the site was weakly oligohaline (1.1 $\pm$ 0.5 ppt SE). These findings were in contrast to those for mesohaline pore water sampled at these same locations at depths of 10 and 40 cm, which were 5.8 $\pm$ 1.8 and 8.1 $\pm$ 1.8 ppt, respectively.

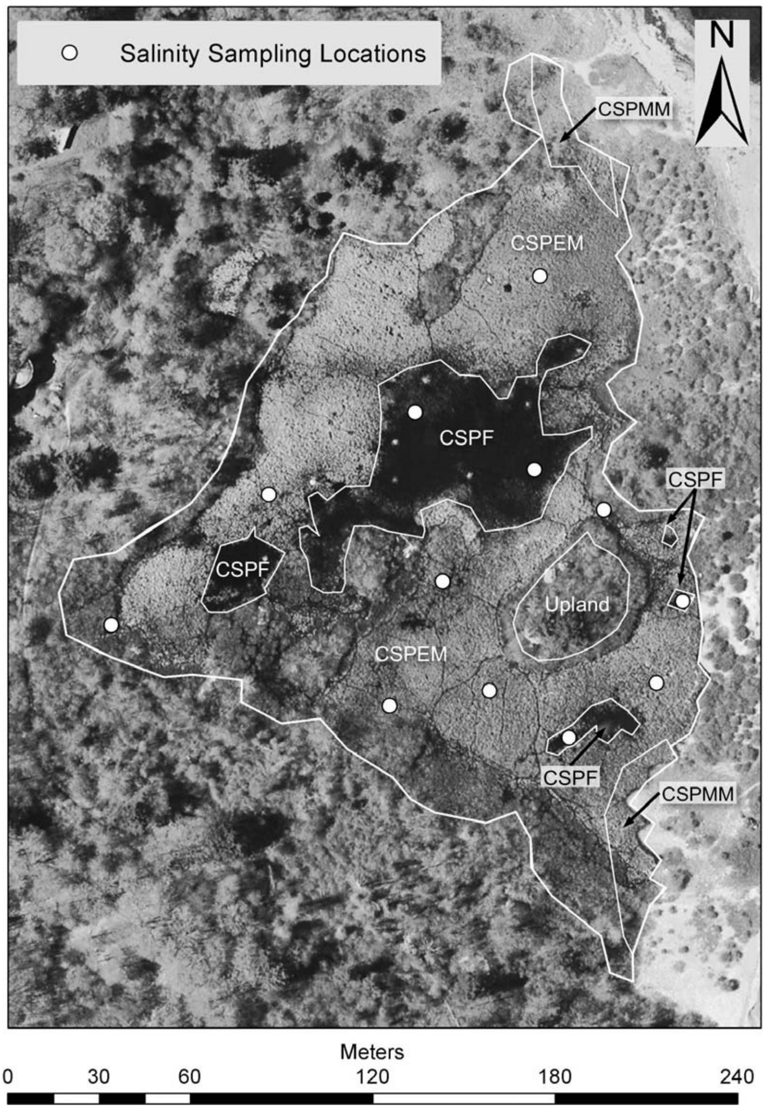

Figure 2. Designation of natural community types including coastal salt pond flat (CSPF), coastal salt pond emergent marsh (CSPEM), and coastal salt pond meadow marsh (CSPMM) with locations of 12 discrete surface and pore water salinity sampling plots. Odiorne Point State Park, Rye, New Hampshire.

When additional salinity data were collected over the site as a whole using electromagnetic induction, we found that mean pore water salinity was relatively variable across the site, with significantly different means between each of the natural communities examined (Figure 3). Our resulting salinity contour map (Figure 4) illustrates a somewhat concentric pattern that suggests a pore water salinity gradient from land to sea. Pockets of higher pore water salinity are centered within areas classified as coastal salt pond flat (10.6 $\pm$ 0.3 ppt), particularly those closest to the sea. Lowest pore water salinity was noted for the coastal salt pond meadow marsh (0.4 $\pm$ 0.1 ppt), whereas the coastal salt pond emergent marsh possessed an intermediate range of salinity (4.1 $\pm$ 0.1 ppt; Figure 3).

DISCUSSION

In New Hampshire, the coastal salt pond marsh system is known only from a single, viable site at the Park (Figure 5). As with other examples in the northeastern US, the slopes of the wetland basin are gentle, lengthening hydrology and salinity gradients (NatureServe 2011). Vegetation composition is highly variable, not only spatially but also temporally (Harshberger 1909). Out of 69 native or naturalized vascular plant taxa documented as occurring in the coastal salt pond marsh, only 35 were observed in 2011. This is likely the result of the temporally variable nature of the hydrologic and salinity patterns governing the system. Much of the ponded area that exists early in the growing season draws down later in the summer, exposing mud flats in low areas. Water levels can also rapidly rise after a storm. For example, areas in the marsh that were merely saturated just prior to the arrival of tropical storm Irene (August 28, 2011) were fairly deeply covered by fresh water when revisited after the storm's departure. Many of the plant species occurring in the coastal salt pond marsh system can be found in fresh ($<$ 0.5 ppt), oligohaline (0.5–5 ppt), or mesohaline (5–18 ppt) wetlands, but when growing together, they generally indicate brackish conditions. Other plant species, found only in fresh water habitats, are restricted here to higher ground along the wetland's upper edge where plant diversity is highest.

Like many habitats along the seacoast of New Hampshire, the coastal salt pond marsh system maintains elements of its native flora (93% of plant species are native) but it has been impacted by the spread of invasive species. *Phragmites australis* var. *australis*, in

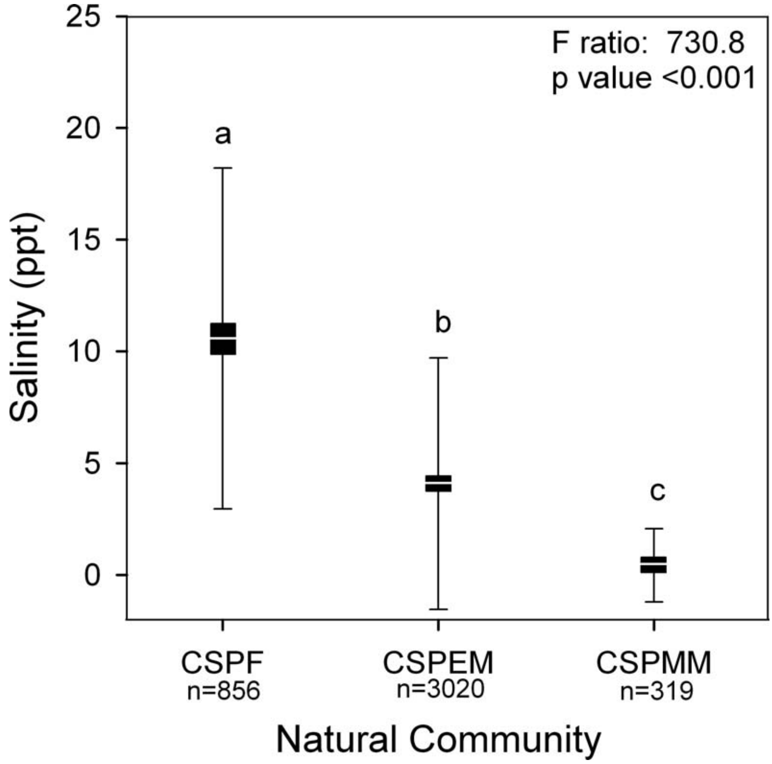

Figure 3. Comparison of soil salinity (derived from relationship with EC_a) across natural communities: CSPF = coastal salt pond flat, CSPEM = coastal salt pond emergent marsh, CSPMM = coastal salt pond meadow marsh. Box and whisker plots show the mean (white line in box center), 99% confidence intervals (box edges), and standard deviation $\pm$ 1 (whiskers). Results of a Kruskal-Wallis test are shown in the upper right. The means of "a", "b", and "c" are significantly different according to a Tukey's HSD, α = 0.05. Sample sizes are denoted beneath the natural community labels.

particular, threatens to outcompete native, rare plant species and to impact the viability of this globally rare system because of its competitive ability in oligohaline and mesohaline environments (Moore et al. 2009; Sperduto 2011; Sperduto and Nichols 2011). Another species that occurs in the coastal salt pond marsh, *Agrostis stolonifera*, has frequently been considered non-native to North America. Still, as Haines (2011) noted, more recent research (Harvey 2007) suggests some northern occurrences in salt marshes and lake shores may be native. It is here considered native.

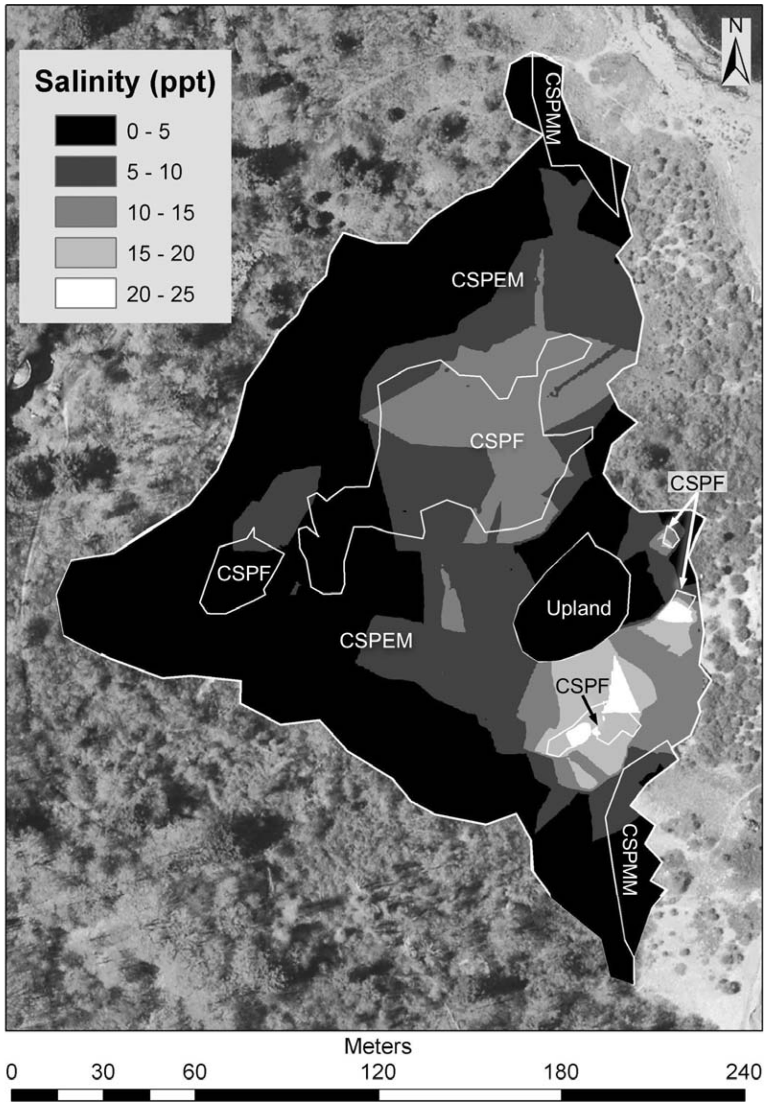

Figure 4. Salinity contour map of data obtained by electromagnetic induction. CSPF = coastal salt pond flat, CSPEM = coastal salt pond emergent marsh, CSPMM = coastal salt pond meadow marsh.

Figure 5. Coastal salt pond marsh (background left); maritime cobble beach (foreground center); maritime shrub thicket (background center); and intertidal zone and Atlantic Ocean (right). Odiorne Point State Park, Rye, New Hampshire.

Typha angustifolia dominates the coastal salt pond marsh at the Park. This species is considered non-native in recently published floras and plant atlases (Haines 2011; Kartesz 2011). However, there is a growing body of evidence indicating this taxon occurred on the northeast coast of North America prior to European settlement, and that it has since spread in a way similar to the native *T. latifolia* as a result of its ability to colonize and dominate disturbed areas (Distler 2010; Farrell et al. 2010; Pederson et al. 2005; Rippke et al. 2010; Shih and Finkelstein 2008). Still, it remains unclear if *T. angustifolia* is native here or not. Additional research is required to distinguish native occurrences from exotic haplotypes that may now exist even in populations of "native" species (M. Distler, State Univ. New York, pers. comm.). In addition, hybridization between native and exotic haplotypes may confound the issue and, coupled with increased human-related disturbance to wetlands, may be contributing to an increase in the invasive ability of *T. angustifolia* (e.g., the distribution of *T. angustifolia* has rapidly expanded since Europeans first arrived;

Rippke et al. 2010; Shih and Finkelstein 2008). An understanding of the status of *T. angustifolia* in this marsh (and elsewhere) could have a significant impact on future management decisions.

The types and distributions of natural communities in the coastal salt pond marsh system are determined by the hydrology of the site, which is dominated by regular fresh water inputs from precipitation and runoff. However, it is also evident from our EC_a data and from the presence of storm water overwash channels that sea water does enter the system and influences plant community composition. For example, the salinity pattern depicted in Figure 4 indicates the coastal salt pond flat soils closest to the berm store the highest salt concentrations. These soils also support the greatest number of salt-tolerant species. However, the absence of true halophytes in the coastal salt pond flat suggests recent saltwater intrusion has been limited, especially in comparison to fresh water inputs. If a significant increase in salinity were to occur as a result of sea water overwash during a storm, or by intrusion through porous berm sediments, it would have a prolonged effect on plant species composition (Harshberger 1909). The salinity data and field observations illustrate, at a level of detail not previously reported, that hydrology and pore water salinity influence the characteristic flora of this coastal salt pond marsh.

The coastal salt pond marsh system in New Hampshire corresponds to NatureServe's globally rare Atlantic coastal plain northern salt pond marsh system (NatureServe 2011; L. Sneddon, Senior Regional Ecologist with NatureServe, pers. comm.). The distribution of the system is limited to the northeastern Atlantic Coast from Maine to New Jersey. Ponded water ranges from fresh to saline but is usually brackish (Anderson et al. 2006). Sea water incursion occurs periodically by overwash during storm surges and, as postulated with the system at the Park, possibly by salt water seepage through the barrier beach. Characteristic species associated with the Atlantic coastal plain northern salt pond marsh system are *Bolboschoenus maritimus* subsp. *paludosus*, *Eleocharis parvula*, *E. uniglumis*, *Hibiscus moscheutos* L. subsp. *moscheutos*, *Ruppia maritima* L., *Schoenoplectus pungens* var. *pungens*, *Spartina patens* (Aiton) Muhl., *Typha angustifolia*, and *Zannichellia palustris*.

Coastal salt pond marshes in other maritime New England states, as well as New York and New Jersey, are all rare and broadly described at the natural community level in state classifications. Coastal salt pond marshes in Maine are defined within the brackish tidal marsh community (Gawler and Cutko 2010). Ten kilometers off the coast of Rye, NH, four small coastal salt pond marshes occur on three islands on the Maine side of the Isles of Shoals (i.e., Appledore, Duck, and Smuttynose Islands; Nichols and Nichols 2008). These marshes are similarly separated from the intertidal rocky shore by cobble ridges that are periodically overwashed by sea water. Vegetation composition varies among the marshes due to differences in hydrology and salinity. Common meadow marsh species occurring on higher ground include *Agrostis stolonifera*, *Bidens cernua* L., *Calystegia sepium*, *Elymus repens* (L.) Gould, *E. virginicus* L., *Impatiens capensis* Meerb., *Lycopus americanus* Muhl. *ex* W.P.C. Barton, *L. uniflorus*, *Lythrum hyssopifolia*, *L. salicaria*, *Persicaria maculosa* S.F. Gray, *P. pensylvanica* (L.) G. Maza, *P. punctata* (Elliott) Small, *Rumex crispus* L. subsp. *crispus*, and *Solanum dulcamara*. Scattered shrubs include *Ilex verticillata*, *Sambucus nigra* L. subsp. *canadensis* (L.) R. Bolli, and *Toxicodendron radicans*. Common taxa in emergent marsh zones are *Schoenoplectus pungens* var. *pungens*, *Typha angustifolia*, *T. latifolia*, and to a lesser extent, *Lythrum salicaria*. Taxa on exposed, saturated flats include *Eleocharis obtusa* (Willd.) J.A. Schultes, *E. uniglumis*, *Lemna minor*, *Ludwigia palustris* (L.) Elliott, *Nasturtium officinale* Aiton f., and *Ranunculus cymbalaria* Pursh. *Cyperus erythrorhizos* Muhl., a rare species occurring in three of the four coastal salt pond marshes on these islands, is found in Maine only on the Shoals (Nichols and Nichols 2008). Coastal salt pond marshes are known only from a few other locations in Maine (A. Cutko, Maine Natural Areas Program, pers. comm.).

Coastal salt pond marshes in Massachusetts mostly occur along Buzzard's Bay, Cape Cod, and the islands (Natural Heritage and Endangered Species Program 2011). There, this community includes just the marsh vegetation surrounding permanently flooded coastal salt ponds. Characteristic meadow marsh species are *Cyperus filicinus* Vahl, *Juncus canadensis*, *Panicum virgatum* L., *Scirpus cyperinus*, and *Spartina pectinata*. Typical emergent marsh species include *Cladium mariscoides* (Muhl.) Torr., *Phragmites australis* var. *australis*, *Schoenoplectus americanus* (Pers.) Volkart *ex* Schinz & R. Keller, *S. pungens* var. *pungens*, and *Typha angustifolia*. Species found on exposed flats are *Elatine minima* (Nutt.) Fisch. & C.A. Mey., *Limosella australis* R. Br., *Lindernia dubia* (L.) Pennell, *Ptilimnium capillaceum* (Michx.) Raf., and *Ranunculus cymbalaria*. Rare species in Massachusetts that can occur in these marshes are

Crassula aquatica (L.) Schönland, *Hydrocotyle verticillata* Thunb., *Setaria parviflora* (Poir.) Kerguelen, and *Suaeda calceoliformis* (Hook.) Moq.

In Rhode Island, this community is more broadly defined and is called coastal salt pond (Enser and Lundgren 2006). This community type includes permanently flooded coastal brackish ponds and their associated marshes. Ocean water periodically enters the ponds during storms or when significant additions of fresh water breach the beach, allowing for more regular inflow of ocean water. Meadow marsh species include *Eleocharis rostellata* (Torr.) Torr., *Hibiscus moscheutos* subsp. *moscheutos*, *Pluchea odorata* (L.) Cass. var. *succulenta* (Fernald) Cronquist, and *Spartina pectinata*. Frequent emergent marsh species are *Bolboschoenus robustus* (Pursh) Sojak, *Phragmites australis* var. *australis*, *Schoenoplectus pungens* var. *pungens*, and *Typha angustifolia*. Mud flat species include *Eleocharis parvula*, *Limosella australis*, and *Zannichellia palustris*.

In Connecticut, coastal salt pond marshes are not defined in the existing preliminary vegetation classification (Metzler and Barrett 2006). A few extant occurrences exist, however, and support many of the oligohaline species listed for Massachusetts and Rhode Island, intermixed with fresh water species (K. Metzler, Dept. of Environmental Protection, pers. comm.). *Typha angustifolia* is common in the emergent marsh; *Cladium mariscoides* often occurs in fresh to oligohaline settings. *Bolboschoenus robustus* and the invasive *Phragmites australis* var. *australis* also occur here. *Panicum virgatum* and *Spartina pectinata* are typical in meadow marsh zones (Miller and Egler 1950). Sparsely vegetated communities on unconsolidated substrates, including those on mud flats, have not been defined in the state (Metzler and Barrett 2006). However, *Eleocharis parvula* and *Zannichellia palustris* have been documented from these marshes in shallow water areas and on flats; algae can be abundant in deeper water. Rare plants associated with the flats and shallow water areas are *Hydrocotyle umbellata* L., *Leptochloa fusca* (L.) Kunth subsp. *fascicularis* (Lam.) N. Snow, and *Myriophyllum pinnatum* (Walter) Britton, Sterns & Poggenb. (K. Metzler, pers. comm.). Coastal salt pond marshes in Connecticut currently occur in Old Lyme, East Lyme, and Groton. A few historical marshes occurred to the west in the Bridgeport-Stratford area and elsewhere but are now overrun by *Phragmites australis* var. *australis* or have been substantially modified, largely from filling. Some of the ponds associated with these marshes were likely breached at times, until closed by storms (K. Metzler, pers. comm.; A. Whelchel, The Nature Conservancy, pers. comm.). As in most other maritime New England states, the distribution and status of coastal salt pond marshes in Connecticut remains understudied.

In New York, Edinger et al. (2002) describe this system as a pond shore marsh microhabitat of the coastal salt pond community that likely will be treated as a separate community (coastal salt pond shore) in a future version of the state community classification. The pond shore can support several narrow vegetation zones along a hydrologic gradient: intertidal mudflat, low salt marsh, high salt marsh, salt panne, brackish meadow, and salt shrub. Species associated with the pond shore include *Baccharis halimifolia* L., *Chenopodium* spp., *Distichlis spicata* (L.) Greene, *Eleocharis parvula*, *Hibiscus moscheutos*, *Iva frutescens* L., *Panicum virgatum*, *Phragmites australis* var. *australis*, *Pluchea odorata* var. *succulenta*, *Ptilimnium capillaceum*, *Schoenoplectus americanus*, *Spartina alterniflora* Loisel., and *S. patens*.

In New Jersey, NatureServe's Atlantic coastal plain northern salt pond marsh system reaches the southern limit of its range at Cape May. The vegetation classification in New Jersey (Breden et al. 2001) does not specifically classify coastal salt pond marsh communities. However, four broadly described community types occur, in part, within this system and are here described along a hydrologic gradient from permanently flooded to irregularly flooded. The first, *Stuckenia pectinata–Zannichellia palustris–*(*Ruppia maritima*) permanently flooded tidal herbaceous community, occurs in shallow brackish settings. Characteristic species include *Ruppia maritima*, *Stuckenia pectinata* (L.) Boerner, and *Zannichellia palustris*. Although brackish tidal flats have not been described in New Jersey, the *Typha angustifolia–Hibiscus moscheutos* herbaceous community occurs in saturated to semi-permanently flooded brackish settings at higher elevations than flats exposed during dry periods and permanently flooded ponded areas. Frequent associates of *Typha angustifolia*, often the most common species, are *Hibiscus moscheutos*, *Lilaeopsis chinensis* (L.) Kuntze, *Phragmites australis* var. *australis*, *Pluchea odorata* var. *succulenta*, *Pontederia cordata* L., *Schoenoplectus americanus*, *S. pungens*, and *Spartina cynosuroides* (L.) Roth. The *Panicum virgatum–Carex silicea* herbaceous community occurs in irregularly flooded brackish settings at higher elevations than *Typha angustifolia* emergent marshes. Characteristic species are *Carex silicea* Olney, *Panicum virgatum*, and *Spartina patens*.

Although detailed vascular plant species descriptions are generally lacking across the range of this understudied system, some broad biogeographic patterns associated with latitudinal gradients are here described. Based on current data, coastal salt pond marshes in Maine and New Hampshire lack species reaching the southern limit of their range; however, *Cyperus erythrorhizos* reaches the northern limit of its range in these marshes on the Isles of Shoals in Maine (Nichols and Nichols 2008). *Ptilimnium capillaceum*, *Schoenoplectus americanus*, and *Setaria parviflora* occur in this system in Massachusetts and reach the northern limit of their range in saline and brackish marshes in this state (Haines 2011; Kartesz 2011). *Hydrocotyle verticillata* also reaches the northern limit of its range in Massachusetts in fresh water settings and coastal salt pond marshes. *Fimbristylis castanea* (Michx.) Vahl reaches the northern limit of its range in this system in New Jersey and New York.

NatureServe's system is described as inherently highly variable, both biotically and abiotically, and likely to contain different natural communities distributed along hydrology and salinity gradients that further study would discern. This assertion applies to the rare natural communities we documented and described after surveys within the coastal salt pond marsh system at the Park.

Future research needs. Research needs and other proposed undertakings associated with coastal salt pond marshes exist at two scales, the site and regional level. In the example at Odiorne Point State Park, these needs and actions include installing water level monitoring wells to more accurately understand hydrology; refining salinity mapping; using ground-penetrating radar across the cobble berm to determine if salt water is seeping through the coarse sediments; collecting additional relevé data to refine natural community and soil descriptions; checking for evidence of overwash after storms; writing a management plan and implementing management actions; and publishing research findings.

A regional need is to conduct vegetation surveys in other coastal salt pond marshes along the northeastern Atlantic Coast to refine global status, identify floristic differences, and describe natural communities within the shrub thicket, meadow marsh, emergent marsh, and exposed flat zones. For coastal salt pond marshes that lie adjacent to permanently flooded ponds, vegetation sampling of the aquatic bed communities is required, and comparison between sites is needed as well.

ACKNOWLEDGMENTS. Thanks to Ben Kimball, Joann Hoy, Sara Cairns, and anonymous reviewers for their critical comments. Lenny Lord (Rockingham County Conservation District) participated in the 2011 botanical fieldwork and provided useful input on vegetation mapping. Ken Metzler contributed information on the distribution, status, and composition of coastal salt pond marshes in Connecticut. Janet Sullivan provided access to Albion Hodgdon Herbarium (NHA) at the University of New Hampshire and Emily Wood provided access to Gray Herbarium (GH) at Harvard University. Ron Duddy and Oscar Johnson from the NH Division of Forests and Lands' Survey Office conducted an elevational survey at the site. Lesley Sneddon, a Senior Regional Ecologist with NatureServe, provided feedback on the global status and distribution of the coastal salt pond marsh system.

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APPENDIX

COMPREHENSIVE LIST OF VASCULAR PLANT TAXA RECORDED IN THE COASTAL SALT POND MARSH SYSTEM, RYE, NEW HAMPSHIRE

A comprehensive list of 69 vascular plant taxa documented in the coastal salt pond marsh system is presented below. This list was compiled from surveys made by the authors in 1997, 2010, and 2011 and from reliable literature sources (Straus 1973). Taxonomy, nomenclature, and nativity status follow Haines (2011). Status: N = native taxon; R = native and state rare taxon; I = non-native invasive taxon, following Mehrhoff et al. (2003). Estimated frequency (Freq.) in natural communities where taxon is most associated (and for the system to a lesser extent) uses the following categories: 1 = historical or extant and rare; 2 = uncommon; 3 = occasional; 4 = common. Natural Community = community type where the taxon is most likely to occur: flat (F); emergent marsh (EM); meadow marsh (MM); shrub thicket (ST); these are listed from wetter to drier types (i.e., from flat to shrub thicket) when more than one type is listed for a species. Note: Because *Agrostis stolonifera* and *Typha angustifolia* may be native in this type of habitat in the northeastern US, they are here considered to be native. ** = state endangered species; * = state threatened species; Hodgdon Herbarium (NHA) unique accession numbers for state listed species are presented with the taxon name.

Taxon	Status	Freq.	Natural Community
ADOXACEAE			
Viburnum dentatum L. var. *lucidum* Aiton	N	1–2	ST
AMARANTHACEAE			
***Chenopodium rubrum* L. var. *rubrum*; accession # NHA-63032	R	2	MM
ANACARDIACEAE			
Toxicodendron radicans (L.) Kuntze	N	2–3	ST
AQUIFOLIACEAE			
Ilex verticillata (L.) A. Gray	N	2	ST
ARACEAE			
Lemna minor L.	N	2	F
ASTERACEAE			
Ambrosia artemisiifolia L.	N	1	MM
Bidens connata Muhl. *ex* Willd.	N	2	MM
Bidens frondosa L.	N	2	MM
Erechtites hieraciifolius (L.) Raf. *ex* DC.	N	2	MM
Solidago sempervirens L.	N	2–3	MM
Symphyotrichum novi-belgii (L.) G.L. Nesom	N	2–3	MM
CELASTRACEAE			
Celastrus orbiculatus Thunb.	I	1	ST

Appendix. Continued.

Taxon	Status	Freq.	Natural Community
CONVOLVULACEAE			
Calystegia sepium (L.) R. Br. subsp. *americana* (Sims) Brummitt	N	2	MM; ST
CORNACEAE			
Swida amomum (P. Mill.) Small	N	1	ST
CYPERACEAE			
Bolboschoenus maritimus (L.) Palla subsp. *paludosus* (A. Nelson) T. Koyama	N	2	F; EM
Carex hormathodes Fernald	N	1	MM
Carex lurida Wahlenb.	N	2	MM
Eleocharis acicularis (L.) Roemer & J.A. Schultes	N	1	MM
Eleocharis flavescens (Poir.) Urban var. *olivacea* (Torr.) Gleason	N	3	F; EM
**Eleocharis parvula* (Roemer & J.A. Schultes) Link *ex* Bluff, Nees & Schauer; accession # NHA-63033	R	2	F; EM
**Eleocharis uniglumis* (Link) J.A. Schultes; accession # NHA-63107	R	2	F; EM
Schoenoplectus pungens (Vahl) Palla var. *pungens*	N	2	F; EM
Schoenoplectus tabernaemontani (K.C. Gmel.) Palla	N	3–4	F; EM
Scirpus cyperinus (L.) Kunth	N	1	MM
ERICACEAE			
Gaylussacia baccata (Wangenh.) K. Koch	N	1	ST
Lyonia ligustrina (L.) DC. var. *ligustrina*	N	1	ST
Vaccinium corymbosum L.	N	2	ST
HALORAGACEAE			
Proserpinaca palustris L.	N	1	EM
HYPERICACEAE			
Hypericum boreale (Britton) E.P. Bicknell	N	1–2	EM; MM
Hypericum canadense L.	N	1–2	EM; MM
Hypericum gentianoides (L.) Britton, Sterns & Poggenb.	N	1	MM
Hypericum mutilum L.	N	1–2	EM; MM
Triadenum virginicum (L.) Raf.	N	2	EM; MM

Appendix. Continued.

Taxon	Status	Freq.	Natural Community
IRIDACEAE			
Iris versicolor L.	N	1–2	MM
JUNCACEAE			
Juncus canadensis J. Gay *ex* Laharpe	N	1–2	EM; MM
LAMIACEAE			
Lycopus uniflorus Michx.	N	2	MM; ST
Scutellaria galericulata L.	N	1	EM
LYTHRACEAE			
Lythrum hyssopifolia L.	N	1	MM
Lythrum salicaria L.	I	1–2	EM; MM
MYRICACEAE			
Myrica gale L.	N	2	MM; ST
MYRSINACEAE			
Lysimachia terrestris (L.) Britton, Sterns & Poggenb.	N	2	EM; MM; ST
NYMPHAEACEAE			
Nymphaea odorata Aiton	N	1	F
ONOCLEACEAE			
Onoclea sensibilis L.	N	1–2	MM; ST
OROBANCHACEAE			
Agalinis paupercula (A. Gray) Britton var. *borealis* Pennell	N	1	MM
OSMUNDACEAE			
Osmunda regalis L. var. *spectabilis* (Willd.) A. Gray	N	1	ST
Osmundastrum cinnamomeum (L.) C. Presl	N	1	ST
PLANTAGINACEAE			
Plantago maritima L. subsp. *juncoides* (Lam.) Hultén	N	1	MM
POACEAE			
Agrostis hyemalis (Walter) Britton, Sterns & Poggenb.	N	1–2	MM
Agrostis perennans (Walter) Tuckerman	N	1–2	MM
Agrostis stolonifera L.	N	2	MM
Anthoxanthum nitens (Weber) Y. Schouten & Veldkamp subsp. *nitens*	N	1	MM

Appendix. Continued.

Taxon	Status	Freq.	Natural Community
Calamagrostis canadensis (Michx.) P. Beauv. var. *canadensis*	N	1–2	MM
Dichanthelium acuminatum (Sw.) Gould & C.A. Clark subsp. *fasciculatum* (Torr.) Freckmann & Lelong	N	1	MM
Dichanthelium acuminatum (Sw.) Gould & C.A. Clark subsp. *implicatum* (Scribn.) Freckmann & Lelong	N	1	MM
Phragmites australis (Cav.) Trin. *ex* Steud. var. *australis*	I	3–4	EM; MM
Spartina pectinata Link	N	3	MM
RHAMNACEAE			
Frangula alnus P. Mill.	I	1	ST
ROSACEAE			
Aronia melanocarpa (Michx.) Elliott	N	1	ST
Spiraea alba Du Roi var. *latifolia* (Aiton) Dippel	N	1–2	MM; ST
RUBIACEAE			
Cephalanthus occidentalis L.	N	1	MM; ST
Galium palustre L.	N	1–2	EM; MM
SAPINDACEAE			
Acer rubrum L.	N	1–2	ST
SOLANACEAE			
Solanum dulcamara L.	I	1–2	EM; MM
THELYPTERIDACEAE			
Thelypteris palustris Schott var. *pubescens* (G. Lawson) Fernald	N	3	EM; MM; ST
TYPHACEAE			
Sparganium sp.	N	2	F
Typha angustifolia L.	N	4	EM
Typha latifolia L.	N	1	EM
VIOLACEAE			
Viola lanceolata L. subsp. *lanceolata*	N	1–2	MM
Viola sagittata Aiton var. *ovata* (Nutt.) Torr. & A. Gray	N	1–2	MM