Scarborough Marsh Phragmites Salinity Study
Scarborough, Maine USA

Friends of Scarborough Marsh

Prepared For

Friends of the Scarborough Marsh (FOSM)
PO Box 7049
Scarborough, ME 04070
https://www.scarboroughmarsh.org/

Prepared By

Steven R. Pinette, Consulting Hydrogeologist (ret.) and FOSM Chair
Anthony J. DeVecchis, BS, University of Southern Maine

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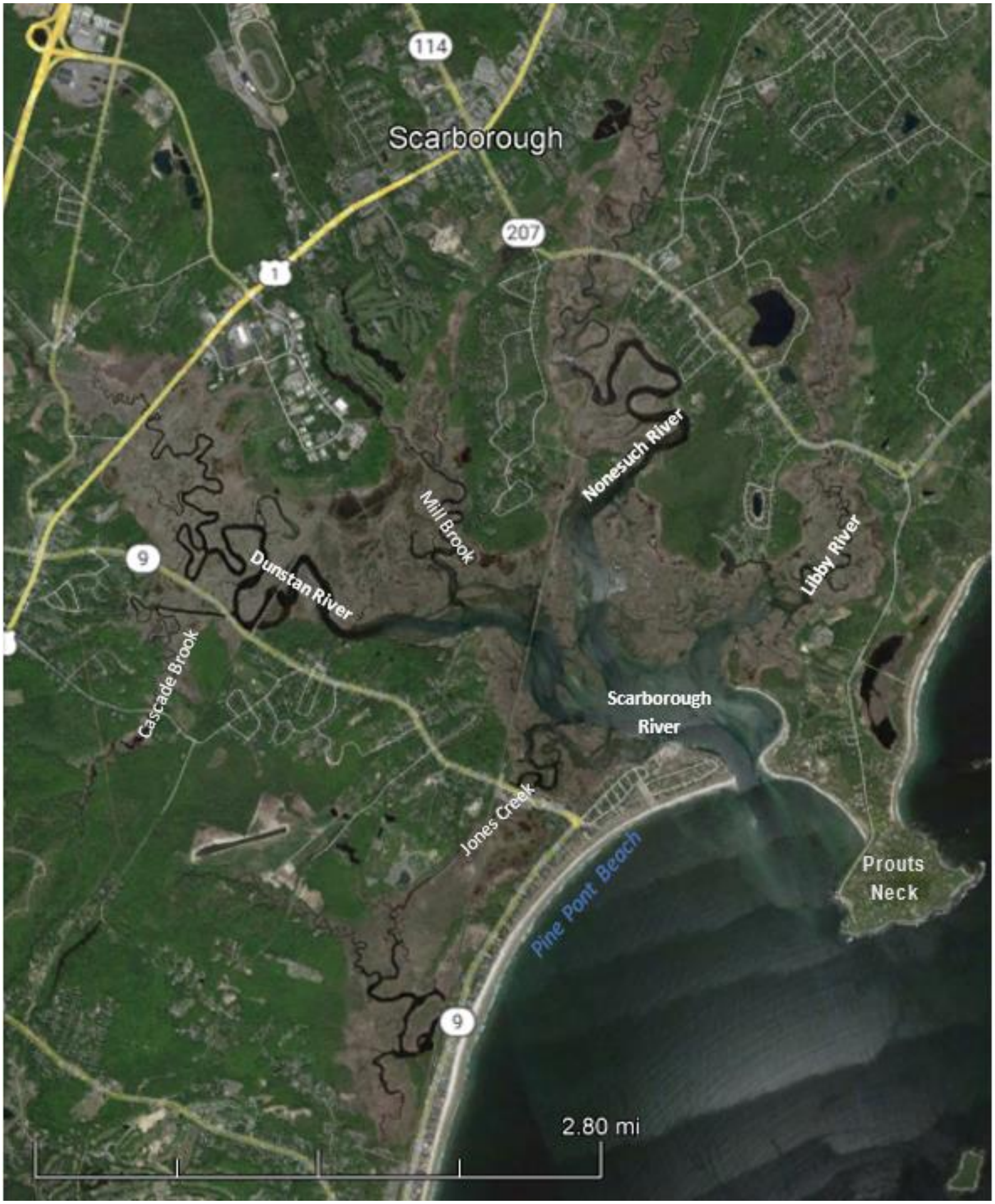

Google Earth imagery (5/2012) showing Scarborough Marsh (**light brown areas**) with its major tributaries labelled.

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EXECUTIVE SUMMARY

Study Background and Purpose

In 2018 Friends of Scarborough Marsh (FOSM) funded a study by Normandeau Associates, Inc. (Normandeau, 2019) to identify significant occurrences of the invasive plant *Phragmites* ssp. *australis* (Phragmites) on the Scarborough Marsh. This subspecies of Phragmites is an aggressive invasive plant that was introduced to North America from Europe, and it has out-completed 11 native North American Phragmites lineages and spread aggressively throughout eastern and southeastern coastal North America, beginning around mid-20thcentury (Saltonstall, 2002). Invasive Phragmites has been reported in many different classes of tidal marsh in North America and elsewhere, but low-salinity tidal wetlands (salinities less than 5 parts per thousand[1] [ppt]) and created or restored tidal wetlands appear to be those most susceptible to its colonization (Chambers *et al.*, 2003).

The Normandeau survey identified 111 Phragmites stands covering an area of approximately 134 acres (approximately 4.4% of the Scarborough Marsh) and 54 diffuse/small stands. Normandeau posited that tidal restrictions and influx of stormwater from adjacent commercial and residential developments (i.e., conditions that cause decrease in soil/peat porewater salinity) were likely the principal factors contributing to growth of these dense Phragmites stands.

As part of an effort to better understand the cause(s) of the Phragmites invasion problem in the Scarborough Marsh, one of the current study's authors (Pinette) conducted a site reconnaissance (July 2019) in one of the more prominent Phragmites stands (site DR-A in this study) which is located directly north of Route 1 and east of the Dunstan River. A key observation noted during this site visit was the presence of a deep freshwater pool (depths to approximately 4 ft) along the eastern margin of the marsh adjacent to the mouth of a northeasterly-trending natural drainage ravine. This observation provided the impetus for conducting the current study.

[1] For reference, the salinity of flood tide water (i.e., the source water flooding the marsh plain) measured in two Scarborough Marsh tributary rivers were: Libby River directly downstream of Black Point Road – two highest salinities measured in May 2019 were 21 ppt on 5/8/2019 and 24 ppt on 5/15/2019 (Underwood, 2019, unpublished data); Nonesuch River at Seavey Landing – salinity of 26 ppt (6/2/2022; this study)

FOSM approved funding in 2020 for field research to characterize the salinity of shallow groundwater and shallow soil porewater in several areas of the Scarborough Marsh where extensive Phragmites stands dominate the marsh vegetation and where stormwater conveyance structures (e.g., roadway ditches, culverts and outfall pipes/channels) discharge stormwater to the marsh fringe and the high-marsh plain.

The broad objectives of this study were to:

- Characterize the salinity of shallow groundwater below three dense Phragmites stands in the Dunstan River, Nonesuch River and Libby River sub-watersheds that are downgradient from concentrated stormwater discharges.
- Using specific conductance[2] of porewater in the shallow soil as a proxy for salinity, evaluate the distribution of porewater salinity in the shallow soils in and around seven large Phragmites stands that are downgradient from concentrated stormwater sources in the Dunstan River, Nonesuch River and Libby River sub-watersheds (total of 11 study sites). Three of the sites (DR-A, DR-B and MR-A) are in the Dunstan River sub-watershed, five sites (LR-A through LR-E) are in one large Phragmites stand in the Libby River sub-watershed, and three sites (NR-A, NR-B and NR-C) are in the Nonesuch River sub-watershed. Three of these sites (DR-A, NR-B and LR-B) were also part of the groundwater study.

Ground Water

Ground water level measurements collected from eight monitoring wells in August, September and October 2020 (three rounds of monitoring) showed shallow groundwater within 0.5 ft of the marsh surface. The salinity of shallow groundwater collected in the monitoring wells on these three dates ranged between 0 and 13 ppt. The Dunstan River site (porewater site DR-A) had the lowest groundwater salinities of 2 to 3 ppt on these three dates. Shallow groundwater salinity at the Libby River site (porewater site LR-B) ranged from 0 ppt to 3 ppt. The Nonesuch River site (porewater site NR-B) had the highest salinities of 11 to 13 ppt. We did not observe differences in Phragmites plant appearance, plant height or plant density (number of stems per area) among the three sites.

Porewater

Between November 2020 and June 2021 we measured porewater specific conductance and recorded the dominant marsh plant species for 291 survey points at 11 study sites, in 7 Phragmites stands. Phragmites was the dominant plant species adjacent to the marsh fringe at

[2] *Specific conductance* is the ability of a substance to conduct electricity, and specific conductance of water increases as salinity increases. We use *salinity* (based on specific conductance v. salinity calibration discussed in **Section 2.2.2**) for discussions addressing descriptive statistics (i.e., range, mean and median) and *specific conductance* for discussions related to comparative statistics (i.e., comparing study sites and plant species for significant differences).

all the study sites. Subordinate clusters of narrow-leaf cattail, *Typha angustifolia* (cattail), occurred in depressions within the Phragmites stands. We designated the conspicuous boundary between the areas dominated by Phragmites and those dominated by either short-form *Spartina ssp.* a*lterniflora* [*Spartina alterniflora*] or *Spartina ssp. patens* [*Spartina patens*; present only at site DR-B) as the Phragmites 'front' after which Phragmites clusters may have been present but it was not the dominant species. **Figure ES-1** below presents photographs of the four dominant plants encountered in the study.

Conversion of the specific conductance data collected at 291 survey points yielded equivalent porewater salinities for the entire study ranging from 0 ppt to 13 ppt with a mean and median of 6 ppt.

Figure ES-1 Photos of the four dominant plant species encountered in the study areas

Phragmites *(Phragmites australis)*	**Narrow-leaf cattail (*Typha angustifolia)***
	
Spartina patens showing the typical 'cowlick' pattern.	***Spartina alterniflora*** on riverbank
	

Sub-watershed Comparisons – Statistical testing using Dunn's Test found that specific conductance data for the Nonesuch River sub-watershed are significantly different (lower; probability [p] ≤ 0.05) compared to the data for both the Dunstan River and Libby River sub-watersheds, whereas data from the Dunstan River and Libby Rivers sub-watersheds are not significantly different.

Comparisons by Dominant Plant Species (Entire Study) – Statistical testing shows that Phragmites specific conductance data are significantly different (lower; $p \leq 0.05$) compared to the data for both cattail and Spartina (undifferentiated by sub-species). Porewater data for cattail and Spartina are not significantly different.

Study Site Comparisons (undifferentiated by plant species) - Statistical testing of the specific conductance data among the 11 porewater study sites (ignoring dominant plant species) shows significant differences for 24 site-site pairs. All study sites are significantly different from at least two other sites. On the low end, site DR-A (in Dunstan River sub-watershed) is significantly different from only two sites, whereas on the upper end site NR-A (in Nonesuch River sub-watershed) is significantly different from six sites.

Study Site Comparisons (differentiated by plants species) – Within the same plant species, statistical pairwise site comparisons (10 sites with cattail data, 11 sites with Phragmites data and 10 sites with Spartina data) show significant differences for 10 cattail site pairs, 18 Phragmites site pairs and 17 Spartina site pairs. The median specific conductance values for most of these site pairs generally differ by a factor of two or more. Other interesting observations include:

- The median specific conductance for short-form *Spartina alterniflora* (a low-marsh plant) at site DR-A (in Dunstan River sub-watershed) is almost twice that of *Spartina patens*[3] (a high-marsh plant) at site DR-B, suggesting that either stormwater dilution of tidal flux is significantly greater for DR-B or that the areas dominated by *Spartina alterniflora* at site DR-A are at lower elevations (i.e., subjected to more frequent tidal flooding) than those dominated by *Spartina patens* in site DR-B.
- Median specific conductances for all three plant species at site NR-A (in Nonesuch River sub-watershed) are uniformly lower than those at site NR-B, although both sites border the same small tributary creek to the Nonesuch River. This suggests that dilution of tidal flux with stormwater is greater for site NR-A, that NR-A lies at higher elevations than site NR-B, or both. Greater influx of stormwater in site NR-A is plausible, considering that a freshwater wetland directly west of NR-A and a half-mile section of Black Point Road both drain into NR-A, whereas NR-B receives runoff from a relatively short section of road ditch and the adjacent residential property.

Specific Conductance versus Distance-from-Marsh-Fringe – The salinity profile of soil porewater in the high-marsh region of a healthy salt marsh typically shows a positive salinity

[3] DR-A had short-form *Spartina alterniflora* beyond the Phragmites front facing the Dunstan River, whereas DR-B had *Spartina patens* in the same relative position.

gradient with salinity increasing in the high-marsh with distance from the marsh fringe in the direction of the high-marsh/low-marsh boundary (explained in Silvestri, 2005). Part of our analyses focused on examining survey transects oriented perpendicular to the marsh fringe in the Phragmites stands to determine if a high-marsh salinity gradient as described exists or whether influx of stormwater and growth of Phragmites disrupts this phenomenon.

We categorized the transects used for this evaluation as either 'source' transects which are directly downgradient for the stormwater source, or 'off-gradient' transects which are distant (but within the same Phragmites stand) from the stormwater source. Both transect types run perpendicular to the marsh fringe. Source transect DR-A, its off-gradient transect T-1/DR-A and source transect MR-A in the Dunstan River sub-watershed are the only transects that show strong, statistically significant positive linear relationships between distance-from-marsh-fringe and porewater specific conductance (i.e., support a high-marsh salinity gradient.

These results suggest that, depending on site macro- and micro-topography, stormwater discharge can affect the porewater salinities on the high-marsh over lateral distances on the order of 200 meters away from the runoff source[4] and cause irregular pooling of runoff on the marsh plain that may mask the characteristic high-marsh salinity gradient. This pooling notion appears consistent with relatively large dimensions of the Phragmites stands studied relative to the associated stormwater point-sources at the study sites.

Marsh-Fringe Reference Sites - In June 2022, we conducted a reconnaissance survey in four locations (total of 10 survey points) in the Dunstan River, Libby River and Nonesuch River sub-watersheds to characterize the porewater specific conductance in areas of the high-marsh adjacent to the marsh fringe that are covered with *Spartina patens* and where evidence of anthropogenic alteration and stormwater inputs (i.e., from roads, streets and commercial/residential developments) is absent. With one exception[5], the marsh fringe in these areas consisted of a mixture of shrubs, salt-marsh grasses, rushes and/or sedges with adjoining mature forest on the upland side of the fringe. These porewater survey points are within 1 to 9 meters of the marsh fringe.

The mean and median porewater specific conductances are higher at the marsh-fringe reference sites compared to Phragmites study sites for cattails, Phragmites, Spartina (undifferentiated), *Spartina patens* and *Spartina alterniflora*. Statistical testing shows that specific conductance data collected at the marsh-fringe reference sites are significantly

[4] Local macro- and micro-topography likely also affect the extent and configuration of these runoff-impacted areas.
[5] One survey point in the Nonesuch River sub-watershed is adjacent to a low soil scarp adjoining a residential property bordered with shrubbery.

different (higher) compared to each of the dominant plant species found at the 11 Phragmites study sites.

Broad conclusions of the Porewater Study

1. The three dominant plants species (cattail, Phragmites, Spartina) show broad overlap in porewater salinities. This suggests that while Phragmites initially exploits low-salinity regions of the marsh fringe that have been impacted by tidal restrictions and/or influx of stormwater from anthropogenic sources, it can spread and flourish into high-salinity regimes normally dominated by native salt-marsh plants such as short-form *Spartina alterniflora* and *Spartina patens.*
2. Based on six source transects at six Phragmites study sites, specific conductance data for only two source transects (DR-A and MR-A) within Phragmites stands showed statistically significant linear relationships that support a characteristic high-marsh positive salinity gradient (i.e., salinity increasing from the marsh fringe toward the high-marsh/low-marsh boundary).
3. Based on the available survey data, we found no broad distribution pattern (e.g., isosurfaces[6]) for specific conductance values within the dense Phragmites stands at the 11 study sites. However, this may be an artifact of the reconnaissance nature of this study. A denser sampling pattern/grid of the high-marsh plain would be necessary to assess the distribution of specific conductance/salinity within Phragmites stands in a more meaningful way.

Recommendations for Further Work

1. Preliminary examination of the locations of stormwater discharge structures in the Town of Scarborough using the Town's geographic information system (https://webapps2.cgis-solutions.com/scarboroughAdvanced/; drainage utilities layer) shows that many of the large Phragmites stands mapped by Normandeau (2019) are adjacent to or downgradient from stormwater drainage structures (e.g., culverts, road ditches, outfall pipes). A more comprehensive analysis of the Town's stormwater discharges in relation to the locations of mapped Phragmites stands will be necessary to assess the potential impact of these stormwater structures on the Scarborough Marsh's Phragmites problem. This assessment should include an engineering study to estimate the annual volume of stormwater that currently discharges to the marsh and projections for future discharges in anticipation of climate-change induced increases in Maine's annual precipitation.

[6] An *isosurface* is a surface in 2- or 3-dimensional space that represents points of constant value or a range of values (e.g., specific conductance, elevation, pressure, temperature, velocity, density) within a volume of space. The area between two adjacent topographic contour lines on a map is an example of an isosurface.

2. A dense survey grid in one or more of the Phragmites stands studied for this project would be useful to study the distribution of porewater specific conductance/salinity further. More comprehensive porewater analyses (e.g., major cations and anions, dissolved oxygen and sulfur, nutrients and biochemical analytes related to plant/root respiration) and measurement of soil hydraulic conductivity at some of these sites will help advance theories regarding Phragmites propagation and its survival in high-salinity regimes.

3. The Phragmites stands evaluated in this study represent only a fraction of the Phragmites problem identified by Normandeau (2019). Moreover, data documenting the extent of stormwater impacts (i.e., reduction in porewater/root zone salinity) elsewhere in the marsh are lacking, as are data documenting the health of marsh plants near the marsh fringe, and in the high-marsh and low-marsh regions of the Scarborough Marsh. We cannot fully assess the health of the marsh without these data and other data such as hydrologic monitoring and modeling. As an interim measure that focuses on plant ecology, we recommend using remote sensing techniques that rely on crop reflectance and other properties to: (1) map the key plant communities and their habitats throughout the marsh; (2) once mapped, identify areas in which these plants are stressed using both ground-based and remote-sensing techniques to understand the nature of the stress(es); and (3) develop a remote-sensing technique (with ground-truthing) to map the porewater salinity of the rooting zone throughout the marsh.

Recommendations for Municipal Stormwater Management

While Phragmites eradication efforts using conventional methods such as cutting and herbicide application have proven relatively ineffective on the Scarborough Marsh and elsewhere in North America, relocating existing and future stormwater discharges away from the high-marsh plain directly into marsh creeks and rivers (e.g., using pipes or small ditches/runnels cut into the marsh surface) and enhancing tidal flooding into the affected areas may help limit the spread of Phragmites stands beyond their current geographic footprints. This strategy would likely require modifications to the Town of Scarborough's existing municipal stormwater discharge plan as well as a permit(s) from the Maine Department of Environmental Protection (DEP) to discharge stormwater directly into the marsh rivers and creeks (i.e., into *Waters of the State*). FOSM proposes to begin discussions with the Town and DEP to explore the feasibility of developing such a strategy.

1 INTRODUCTION

1.1 Study Background and Purpose

Friends of Scarborough Marsh (FOSM) conducted research in 2020 and 2021 to characterize the salinity of shallow groundwater and shallow soil porewater in several areas of the Scarborough Marsh where dense monotypic stands of non-native *Phragmites* ssp. *australis* (Phragmites) reed beds occur downgradient from concentrated discharges of stormwater flow onto the high-marsh plain.

Our initial hypotheses were:

1) Phragmites stands in areas impacted by concentrated stormwater discharge are characterized by lower salinity porewater in the shallow soils and shallow groundwater compared to the adjacent areas where the native salt-marsh plant species such as *Spartina ssp. patens*[7] (*Spartina patens*) and *Spartina ssp. alterniflora*[8] (*Spartina alterniflora*) dominate the high-marsh and low-marsh regions, respectively.
2) Phragmites does not tolerate elevated porewater salinities favorable to *Spartina alterniflora*, i.e., there is no overlap between the salinity ranges of the two plants.

Saltonstall (2002) identified Phragmites *haplotype M*[9] with a likely Eurasian affiliation as the aggressive invasive plant that has out-competed 11 native North American Phragmites lineages and spread aggressively throughout eastern and southeastern coastal North America, beginning around mid-20thcentury. In a laboratory study of three Phragmites lineages, Vasquez *et al.* (2005) note that invasive haplotype M is viable at higher salinities than two native haplotypes, which may help explain how it can propagate into higher salinity regimes associated with the high-marsh regions of tidal marshes.

Non-native Phragmites has been reported in many different classes of tidal marsh in North America and elsewhere. Low-salinity tidal wetlands (salinities less than 5 parts per thousand [ppt]) and created or restored tidal wetlands appear to be those most susceptible to its colonization (Chambers *et al.*, 2003). Human alteration of salt marshes, such as tidal restrictions that reduce saltwater flooding of a marsh and concentrated drainage of freshwater from storm runoff and spring meltwater, reduce the salinity of marsh soils and can create favorable conditions for Phragmites growth (e.g., Burdick *et al.*, 2001; Geedicke *et al.*, 2018). Burdick *et al.* (1999) found that invasive Phragmites can exploit seasonal variations in salinity to establish

[7] *Spartina patens* common name: saltmeadow cordgrass
[8] *Spartina alterniflora* common name: smooth cordgrass
[9] A haplotype is a physical grouping of genomic variants (or polymorphisms) that tend to be inherited together. A specific haplotype typically reflects a unique combination of variants that reside near each other on a chromosome (https://www.genome.gov/genetics-glossary/haplotype).

itself early in the growing season during periods when higher precipitation and meltwater naturally decrease marsh salinities. Addition of nutrients has also been shown to substantially increase above-ground Phragmites biomass and its expansion potential in controlled (experimental) disturbances on a Rhode Island salt marsh (Minchinton *et al.*, 2003).

Although Phragmites was not present in their study of four salt marshes in Venice, Italy, Silvestri *et al*. (2005) concluded that, although important, soil salinity alone does not explain the distribution and zonation of salt marsh plant species. They suggest that subsurface factors such as soil permeability and groundwater flow also exert control on halophyte (salt-tolerant plants) zonation, perhaps due to their influence on oxygen availability for aerobic respiration.

Recent research (Bernal *et al*., 2017) also suggests that Phragmites has the potential to change soil organic matter dynamics and lead to loss of the salt-marsh soil carbon pool that is sequestered at depth under the native salt-marsh vegetation. This salt-marsh carbon pool is part of what climate-change scientists term *blue carbon*, or the carbon stored in the coastal and marine ecosystems of the world. Chmura *et al.* (2003) report that tidal wetlands represent about 1-2% of the estimated carbon sink in the conterminous United States, which is significant considering that salt marshes in the US cover approximately 3.8 million acres (Burns and Gordon, 2021) or approximately 0.2% of the estimated 2.2 billion acres of land with non-urban land uses (derived from Bigelow and Borchers, 2017) that have the potential to sequester carbon[10].

In summary, physical disturbance of the high-marsh surface, salinity reduction (of the marsh soil porewater and shallow groundwater) and influx of nutrient-laden runoff are development-related factors that, separately or together, may promote non-native Phragmites growth in salt marshes.

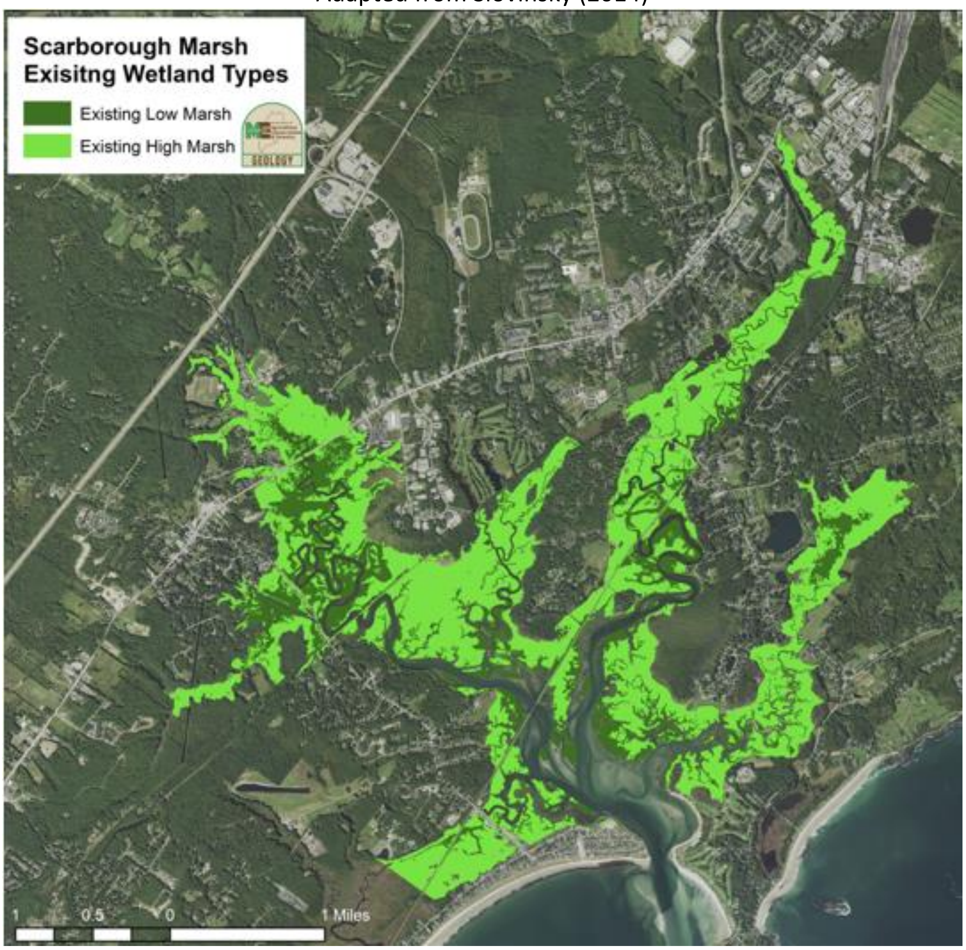
1.2 Historical Occurrence of Phragmites in the Scarborough Marsh

Invasion by non-native Phragmites poses several environmental problems for the Scarborough Marsh and other coastal salt marshes. As an aggressive invasive plant, it can rapidly overtake native salt marsh plant species and change the salt-marsh habitat, ecology and hydrology. Phragmites growth in the Scarborough Marsh generally occurs in the high-marsh regions along the areas bordering the upland fringe which is dominated by non-halophytes.

[10] Non-urban land uses with carbon sequestration potential include grassland, pasture, rangeland, cropland, forests, wetlands, tundra, unproductive woodland, parks and wildlife areas.

Scarborough Marsh covers an area of approximately 3,070 acres[11] characterized as salt marsh dominated by halophytes. Approximately 78% of this area is considered high marsh (lower salinity regime) which is inundated infrequently during periods of extreme high tide and storm surge associated with coastal storms. The remaining 22% is characterized as low marsh (higher salinity regime) which is flooded during each tidal cycle (percentages derived from MGS and SMRPC, 2010). **Figure 1.2-1** adapted from Slovinsky (2014) depicts the low-marsh and high-marsh zones of the Scarborough Marsh.

Figure 1.2-1 Distribution of the low-marsh and high-marsh zones in the Scarborough Marsh. Adapted from Slovinsky (2014)



Based on anecdotal reports, Phragmites appeared along Route 1 in the Dunstan River sub-watershed[12] of the Scarborough Marsh around the late 1970s to early 1980s (Maine Audubon

[11] This 3,070-acre salt marsh area is based on Normandeau (2019) calculations using geographic information system (GIS) tools and analyses of the Scarborough Marsh. Normandeau's landward boundary for the salt marsh is the 2015 Highest Annual Tide (HAT) layer from the Maine Geological Survey.

[12] For ease of reference, we have divided the Scarborough Marsh into the following six sub-watersheds based on the major tributary river/creek/brook that flows through the area: Cascade Brook, Dunstan River, Jones Creek, Libby River, Nonesuch River and Scarborough River.

Society, 1999). By 1998 when Maine Audubon conducted its comprehensive study of the Scarborough Marsh ecosystem, 54 Phragmites stands covered on the order of 50 acres, or approximately 1.6% of the Scarborough Marsh (Maine Audubon Society, 1999). Audubon reported that about 40% of this area occurred in the Dunstan River sub-watershed north of Route 1.

Between 2003 and 2013 Friends of Scarborough Marsh (FOSM) and collaborators conducted marsh restoration projects in several regions of the marsh to eradicate the larger Phragmites stands identified in the Maine Audubon report with the goal of re-establishing native salt-marsh halophytes. The initial phase of these restoration efforts focused on improving marsh hydrologic function and increasing porewater salinity of the shallow marsh soils as close as practicable to pre-development conditions favorable to proliferation of native halophytes like *Spartina patens* and *Spartina alterniflora*. The second restoration phase, beginning in 2010, involved mowing dense Phragmites stands to ground level and spray application of the herbicide Rodeo to these areas. The areas treated by either hydrologic restoration or mowing/herbicide application are listed in **Appendix A**. While both treatment regimens achieved some short-term success at controlling this invasive plant, dense Phragmites stands currently occupy many of the areas that were treated by mowing/herbicides. However, it is important to note that quantitative evaluation to compare the pre-treatment Phragmites coverage to long-term post-treatment conditions is lacking.

In 2018 FOSM contracted Normandeau Associates, Inc. to map the significant occurrences of Phragmites in the Scarborough Marsh and recommend options for controlling this invasive plant species (Normandeau, 2019). The project identified 111 Phragmites stands covering approximately 134 acres (approximately 4.4% of the Scarborough Marsh) and 54 diffuse/small stands. Normandeau posited that tidal restrictions and influx of stormwater from adjacent commercial and residential developments (i.e., conditions that cause decrease in soil porewater salinity) are likely the principal factors contributing to growth of these dense Phragmites stands. Smaller isolated occurrences of Phragmites were also documented on elevated marsh micro-topography (e.g., hay roads, small berms and mounds) that appear to be relics of marsh plain modifications related to historical salt marsh haying and disturbances from marsh mowing/spraying equipment associated with the referenced marsh restoration efforts. **Figure 1.2-2** adapted from Normandeau (2019) depicts Normandeau's Phragmites study area, the locations of the major Phragmites stands identified in the study and the general locations of the six major sub-watersheds of the Scarborough Marsh. The largest concentrations of Phragmites occur in the Dunstan River and Libby River sub-watersheds.

Normandeau identified several methods to control the spread of Phragmites including hydrologic modifications such as adding more large-diameter culvert capacity or bridges where feasible (e.g., under Route 1 to enhance tidal flow into the upper Dunstan River sub-watershed) to improve tidal flushing into the affected areas, application of herbicide as had been done previously, and burning. Based on municipal and environmental considerations, FOSM determined that herbicide application and burning are unfeasible for controlling invasive Phragmites, leaving enhancement of tidal flushing and control of stormwater drainage onto the marsh plain as the remaining Phragmites mitigation options.

Major tidal restrictions in Dunstan River, Libby River and Jones Creek will require infrastructure alterations beneath Route 1, Eastern Trail, Black Point Road and Pine Point Road. However, hydrologic monitoring and modeling to understand the scope of the problem and the potential solutions will be necessary before these infrastructure-based solutions can be designed and implemented.

Examination of the Town of Scarborough's GIS layer titled 'Drainage Utilities' shows that numerous large Phragmites stands identified by Normandeau are directly adjacent or downgradient from areas where roadway ditches and culverts, drainage swales/gullies and stormwater control structures (e.g., detention pond outfalls, street underdrain pipes) discharge runoff onto the high-marsh plain. Mindful of Silvestro *et al.*'s. (2005) conclusion that salinity is likely only one important factor influencing halophyte growth, we set out to study the salinity regimes of several large Phragmites stands receiving stormwater discharges from these drainage structures.

1.3 Study Goals

The goals of this study were threefold:

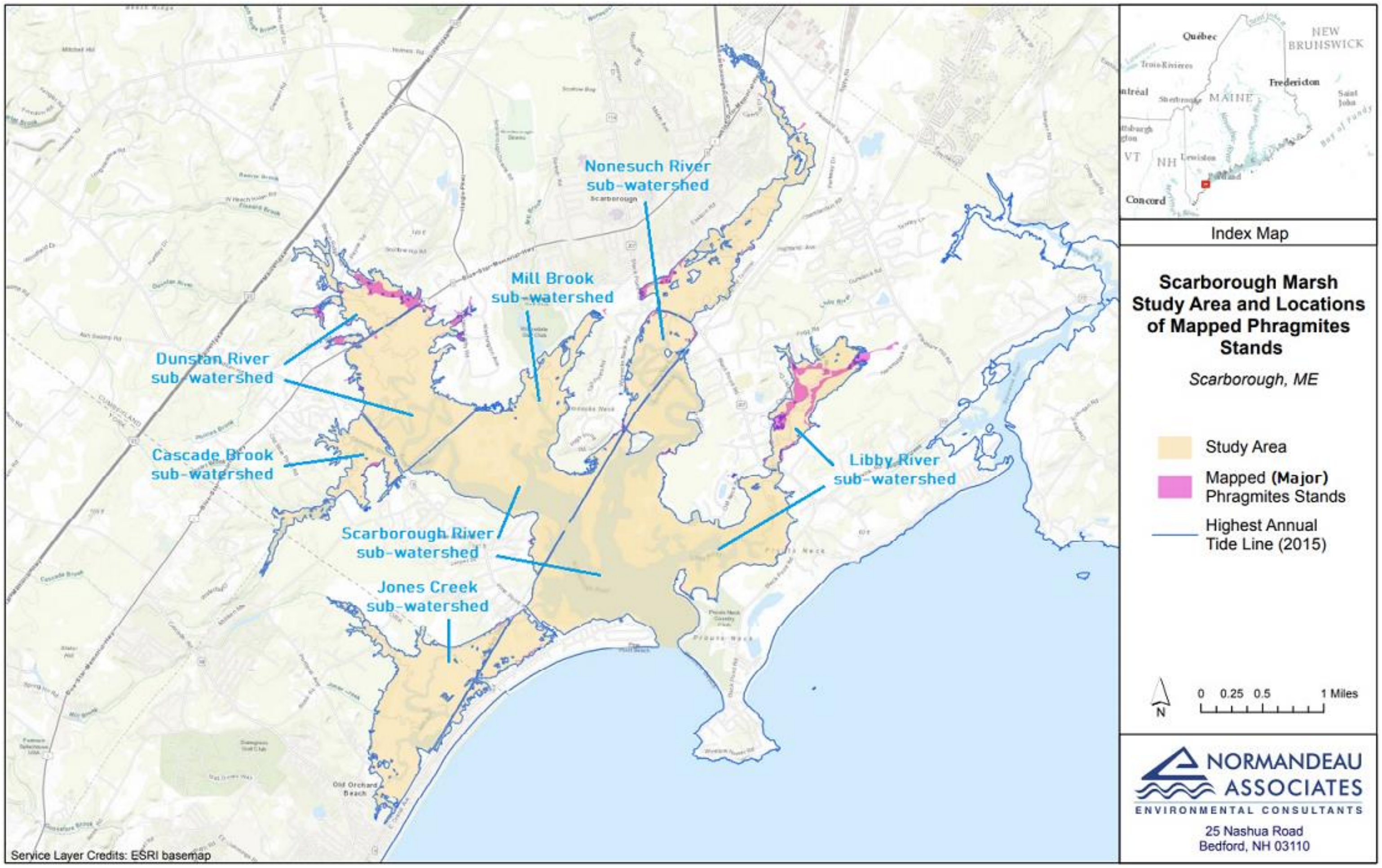
1. Characterize the salinity of shallow groundwater (depth of 1-9 feet) below dense Phragmites stands that are downgradient from three concentrated stormwater discharges.
2. Using the specific conductivity as a proxy for salinity[13], characterize the porewater specific conductivity of the shallow organic soils (depth of 0 - 6 inches) in and around seven large Phragmites stands that are downgradient from concentrated runoff sources. Since conductivity is a measure of electrical potential, its value will increase with rising salinity due to the charged nature of the ions present in the salts being measured with salinity. The strong connection between salinity and electrical

[13] The practice of using soil electrical conductivity as a proxy for soil salinity surveys covering large areas is common in agriculture and soil science. For example, Yang *et al*. (2019) used electrical conductivity of topsoil samples (electrical conductivity measurements made in the laboratory) to identify salt-affected areas in agricultural regions of the Heihe River Basin in northwestern China.

conductivity coupled with wide availability of instruments to measure conductivity make electrical conductivity a good proxy for salinity (Yang *et al.*, 2019).

3. Evaluate the potential effects of stormwater discharge and subsequent growth of Phragmites on the positive salinity gradient observed by researchers between the high-marsh region of a healthy salt marsh and the high marsh/low-marsh boundary (i.e., salinity increases away from the marsh fringe toward the high-marsh/low-marsh boundary).

Figure 1.2-2 Normandeau's (2019) Phragmites study area, locations of the major Phragmites stands identified and general locations of the six sub-watersheds of the Scarborough Marsh. Adapted from Normandeau (2019)



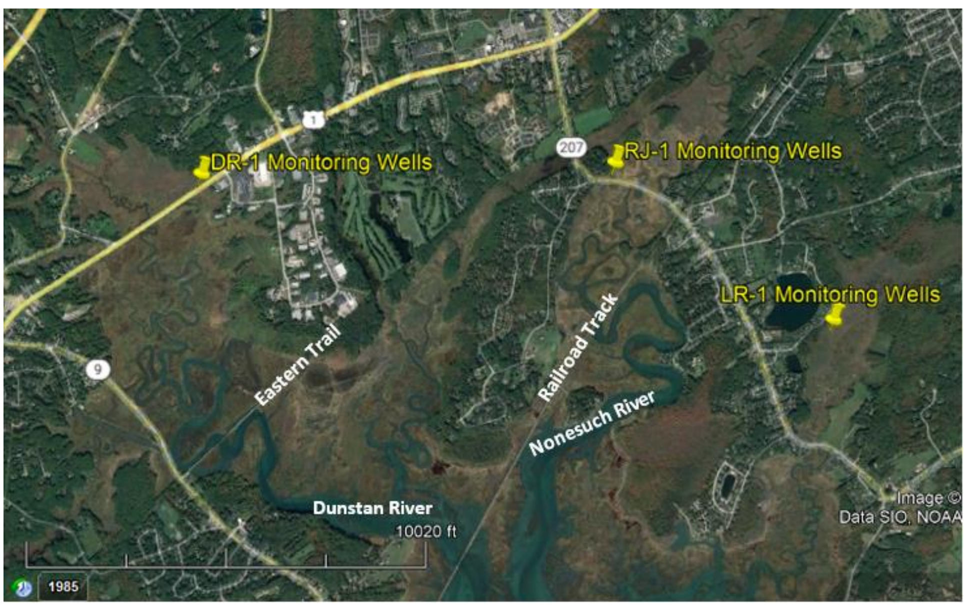
2 METHODS

2.1 Groundwater Salinity Evaluation

2.1.1 Site Selection

In August 2020, we installed groundwater monitoring wells in three Phragmites stands to monitor groundwater salinity. Downgradient orientation from stormwater discharges related to road ditches, piped outfalls or drainage swales/gullies and easy site access were the key factors we used to guide site selection. The three groundwater monitoring locations shown in **Figure 2.1.1-1** are in the Dunstan River (site DR-1), Libby River (site LR-1) and Nonesuch River (site RJ-1) sub-watersheds of the Scarborough Marsh. Refer to **Figure 1.2-2** above for the locations of these sub-watersheds. The Dunstan and Libby River sites are in the Scarborough Marsh Wildlife Management Area on property owned by the State of Maine and managed by the Department of Inland Fisheries and Wildlife. The Nonesuch River site is on private land.

Figure 2.1.1-1 Locations of groundwater monitoring sites on Google Earth 1985 imagery. DM-1is in Dunstan River sub-watershed; RJ-1 is in Nonesuch River sub-watershed; LR-1 is in Libby River sub-watershed.



Major sources of stormwater runoff for the Dunstan River site (DR-1) include a shallow ravine that captures runoff from several residential and commercial developments, parking lots and streets. A long section of Route 1 also drains into this area. Runoff sources for the Nonesuch River (RJ-1) site include one residential property and a short section of road ditch along Black Point Road. The Libby River site (LR-1) receives runoff from several sources including piped outfalls for underdrains along Clearwater Drive and stormwater detention basins.

2.1.2 Monitoring Wells

Monitoring wells are labelled as follows: Dunstan River sub-watershed wells are designated DR-1S and DR-1M; wells in the Libby River sub-watershed are designated LR-1S, LR-1M and LR-1D; wells in the Nonesuch River sub-watershed wells are designated RJ-1S and RJ-1M. The S, M and D suffixes indicate shallow depth, intermediate depth and deep wells, respectively.

Each monitoring well consists of solid 3/4-inch diameter Schedule 40 PVC pipe with the bottom 0.5-ft section perforated with eight 1/8-inch diameter drillholes to allow groundwater from the adjacent saturated soil to flow into the well. A solid PVC end cap is affixed to the bottom end of each monitoring well to minimize intrusion of fine organic soil into the well during installation.

We installed the monitoring wells at the desired depths by applying hand pressure. Well depths ranged from 3.0 to 9.1 ft below the marsh surface, and the perforated section (hereafter, the *screen*) of each well is in direct contact with the native soil encountered at depth (i.e., the screen interval is not encased in a filter medium such a textile filter or filter sand). We installed a bentonite clay surface seal around each monitoring well from the marsh surface down to a depth of 0.5 ft.

Groundwater sampling occurred on the following dates: August 28, 2020; September 21, 2020; and October 14, 2020. For each monitoring event we measured depth to the groundwater surface in the wells with a 1/2-inch diameter copper tubing endcap, (aka 'plopper') taped to a metal measuring tape. Sample collection relied on dedicated bailers (i.e., one bailer dedicated to one well for each sampling event) constructed from 1-ft sections of 1/2-inch diameter copper pipe with a copper end cap. Clean polyester twine attached to the top portion of the bailer was used to lower and retrieve the bailer during sample collection. We evacuated the equivalent of one volume of standing water from each well prior to collecting a groundwater sample for salinity testing. After each sampling event, we decontaminated the bailers by rinsing with copious amounts of deionized water and refitted each bailer with new twine.

We used a VEE-GEE STX-3 refractometer with a range of 0-100 parts per thousand (ppt) to measure the salinity of each groundwater sample. VEE-GEE reports an accuracy of 1.0 ppt for this model. Refractometer calibration checks with a 35-ppt refractometer calibration solution (vendor: Aqua Craft Products) occurred before sampling at each of the three monitoring sites. Following salinity measurement for each monitoring well sample, we rinsed the refractometer with deionized water to minimize the potential for contaminating subsequent samples.

2.1.2 Soil Borings to Understand Marsh Stratigraphy

We used a standard metal soil screw-auger (with 6-inch auger section) to collect marsh soil samples down to the depth of the deeper(est) monitoring well at each of the three locations.

We collected consecutive soil samples at 6-inch depth intervals within the same borehole or adjacent boreholes, depending on site conditions.

Description of the organic soil samples is generally based on the classification system of Von Post (1921) as presented in the Alaska Department of Transportation and Public Building's *Guide to Description and Classification of Peat and Organic Soil* (Alaska DOT, 2007). Organic soil texture in this classification ranges from *fibric* (relatively undecomposed plant matter with less than 67% plant fibers[14]) through *hemic* (intermediate decomposition with 33 - 67% fiber content) and *sapric* (highly decomposed with less than 33% fiber). Fiber refers to relatively undecomposed plant and root fragments. At depth the matrix for these fibers is humus, which is highly decomposed dark brown organic material with a very fine-grained amorphous texture. Humus may also contain variable amounts of silt/fine sand.

Appendix B presents subsurface soil information for each of the three monitoring sites along with monitoring well diagrams showing depths of well placement , depth and stratigraphic[15] position of the well screen and depth of the shallow groundwater table in each well on 8/28/2020.

2.2 Evaluation of Electrical Conductivity in Shallow Soil Porewater

2.2.1 Phragmites Site Selections, Site Nomenclature and Site Descriptions

We selected seven large Phragmites stands in the following sub-watersheds to study the porewater salinity of the shallow marsh soil: Dunstan River (three stands/sites: DR-A, DR-B and MR-A); Libby River (one stand, sub-divided into five sites: LR-A, LR-B, LR-C, LR-D and LR-E); Nonesuch River (three stands/sites: NR-A, NR-B and NR-C). Except for study site NR-C[16], these Phragmites stands are downgradient from concentrated stormwater discharges originating from stormwater conveyances including roadway ditches and culverts, detention/retention basin outflows and natural or created drainage channels (including a natural ravine and several low-profile gullies/swales).

At each site we surveyed at least one transect oriented perpendicular to the marsh fringe and measured the electrical conductivity of the shallow soil across the Phragmites stand and a short distance beyond the abrupt Phragmites 'front' where Spartina (either subspecies *Spartina alterniflora* or *Spartina patens*) is the dominant plant species. We sub-divided the Libby River

[14] *Fiber* refers to plant and root fragments.

[15] *Stratigraphic* is an adjective for *stratigraphy* which refers to the order and relative position of soil and bedrock layers (i.e., strata/stratum) in the subsurface.

[16] Site NR-C is on the order of 100 ft directly south of Black Point Road. Although it may be impacted by diffuse stormwater runoff from the roadway, no stormwater conveyance structures, such as ditches and culverts, discharge into this area of the Scarborough Marsh.

Phragmites stand into five sites to accommodate multiple runoff sources and the large areas between them. At each site except site LR-B[17], we designated transects that are oriented perpendicular to the marsh fringe as either 'source' transects (i.e., directly downgradient from a runoff source) or 'off-gradient' transects (i.e., within the same Phragmites stand as a source transect, but laterally distant from the source transect). Both the source and off-gradient transects originate from the marsh fringe. We designated other transects that are oriented parallel or obliquely to the marsh fringe as 'filler' transects; the intended purpose of these was to help delineate a potential low-salinity runoff zone on the high-marsh plain.

The source transects include DR-A, DR-B and MR-A (Dunstan River sub-watershed); LR-A and LR-B (Libby River sub-watershed); and NR-A and NR-B (Nonesuch River sub-watershed). Off-gradient transects include T-1a/DR-A (at site DR-A in Dunstan River sub-watershed), LR-C and LR-E (at sites LR-C and LR-E in the Libby River sub-watershed) and NR-C (at site NR-C in the Nonesuch River sub-watershed). More detailed descriptions of these sites, transects and runoff sources are presented below.

Figure 2.2.1-1 shows the general locations of the seven Phragmites stands included in this study. Detailed site maps showing the transect locations and electrical conductivity information for the survey points are in **Appendix C**.

- **Dunstan River Sub-Watershed Sites** - Site DR-A is downgradient from a shallow ravine (refer to **Figure 2.2.1-2**) located to the northeast. The ravine drains the surrounding woodlands, residential and commercial properties, parking lots, streets and a section of Route 1. Source transect DR-A is directly downgradient from this ravine. Site DR-B is downgradient from a gully that drains the commercial and industrial properties and streets located directly east. Site MR-A is downgradient from a culvert that drains a section of Milliken Road and Route 1. **Figure 2.2.1-3** shows the general locations of these three sites on a Google Earth aerial map background.

[17] Site LR-B in the Libby River sub-watershed is a constellation of eight survey points used to characterize the porewater specific conductance near groundwater monitoring site LR-1 in an area dominated by Phragmites.

Figure 2.2.1-1 Google Earth 1985 imagery showing general locations of porewater salinity monitoring sites. Gray inset covers the area shown in Figure 2.2.1-2

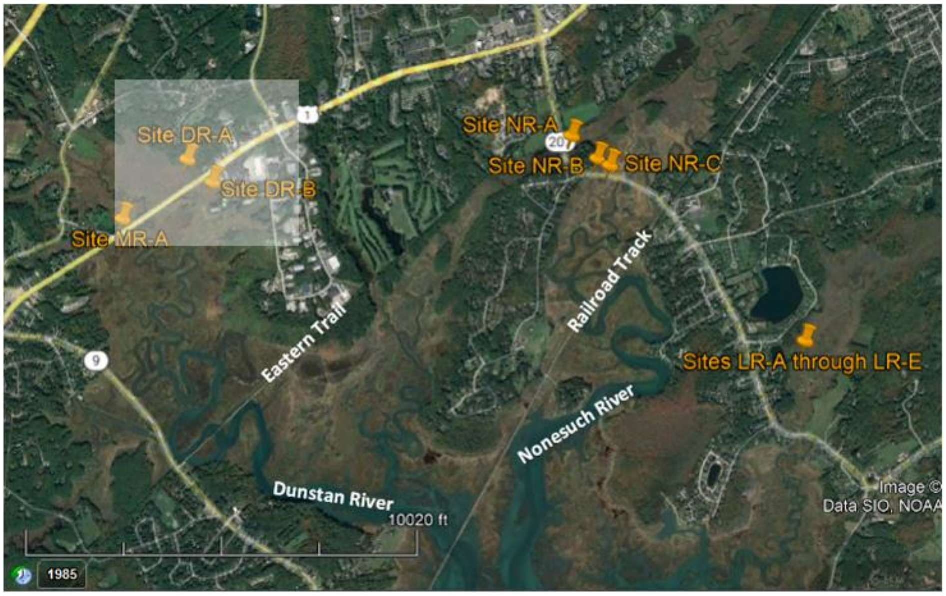


Figure 2.2.1-2 LIDAR hill-shade overlay map showing the ravine, drainage gullies and detention ponds near site DR-A and drainage gully near site DR-B. Refer to Figure 2.2.1-1 inset for the general location of this figure (Source: Maine Geological Survey web map viewer; unanotated image downloaded 11/16/2022)

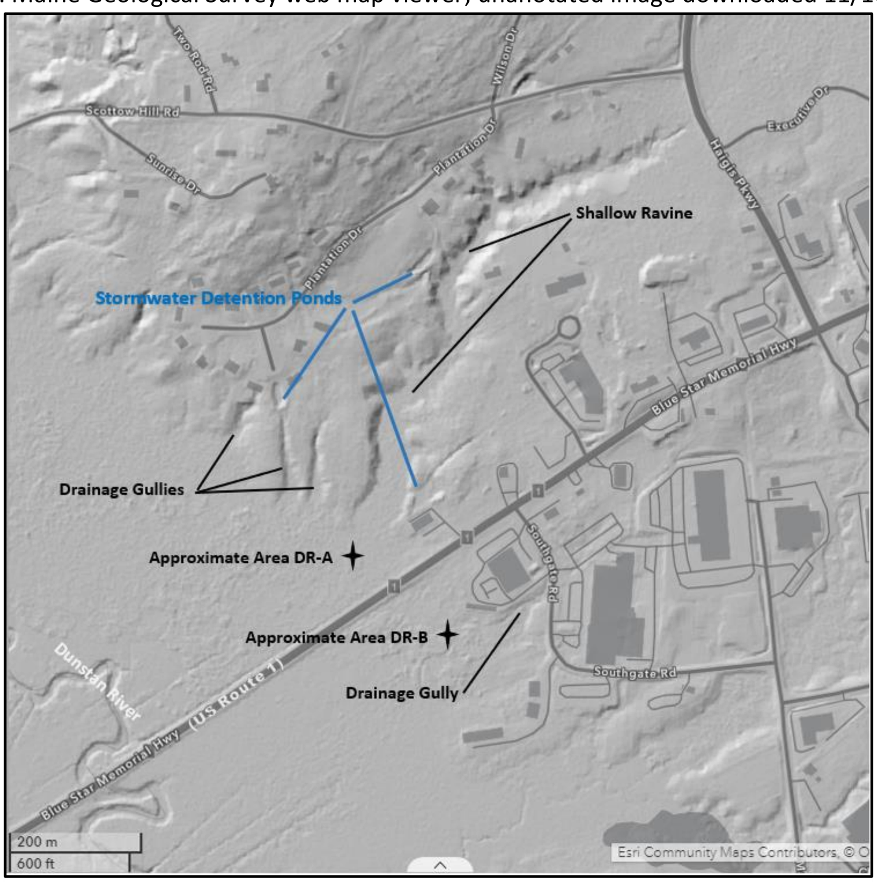
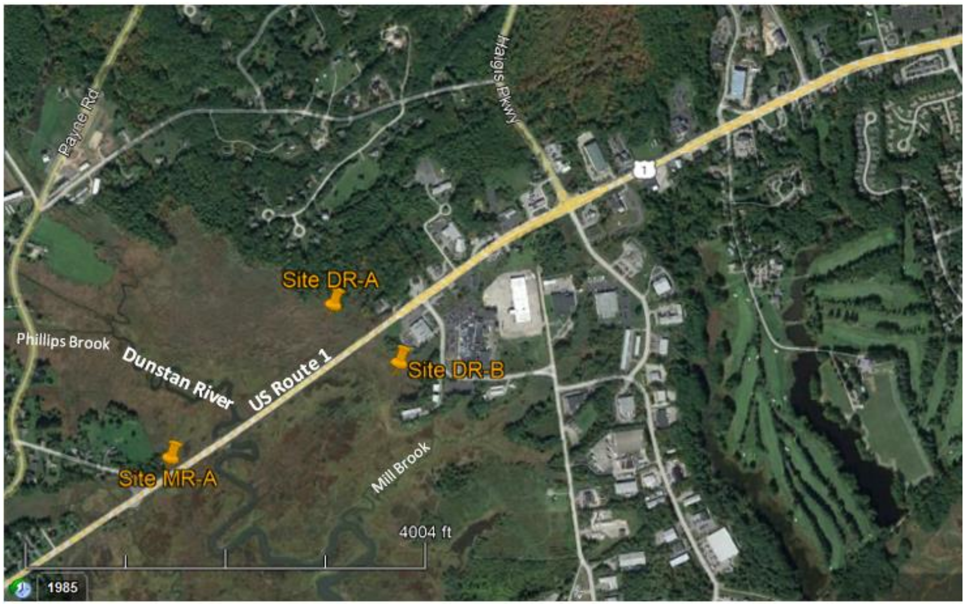


Figure 2.2.1-3 Google Earth 1985 imagery showing general locations of porewater study sites in the Dunstan River sub-watershed



Libby River Sub-Watershed Sites - Site LR-A is directly southeast and downgradient from underdrain outfalls that drain a quarter-mile section of Clearwater Drive and the adjacent residential properties (refer to **Figure 2.2.1-4**). Site LR-B is a constellation of eight survey points used to characterize porewater specific conductance around groundwater monitoring site LR-1 in an area dominated by Phragmites; it is not directly downgradient from a source of concentrated stormwater discharge. Site LR-C includes off-gradient transect LR-C. Site LR-D is directly downgradient from a stormwater detention basin near 25 Clearwater Drive, and it includes source transect LR-D. Site LR-E consists of two closely spaced parallel transects; we combined data from short sections of each transect to create off-gradient transect LR-E.

Nonesuch River Sub-Watershed Sites - Site NR-A drains a half-mile section of Black Point Road to the north (refer to **Figure 2.2-5**). Site NR-B receives runoff from a residential property and a short section of Black Point Road. Site NR-C consists of two parallel transects (T-north/NR-C and T-south/NR-C) which run between the forested marsh upland fringe and a non-outlet marsh-plain ditch oriented perpendicular to each transect. We designated the combination of these two transects as off-gradient transect NR-C.

We used both the source and off-gradient transects to examine the electrical conductivity profiles of the Phragmites stands with distance from the marsh fringe and to assess whether a statistically significant difference exists between paired source and off-gradient transects (discussed below in Section 3.2.4). As discussed earlier, the high-marsh region of a healthy salt marsh generally displays a positive salinity gradient with salinity increasing away from the marsh fringe toward the high-marsh/low-marsh boundary. As discussed in Section 1.3, one of our ancillary goals was to understand if discharge of runoff and subsequent growth of Phragmites alter this condition.

Figure 2.2.1-4 Google Earth 1985 imagery showing locations of porewater study sites in the Libby River sub-watershed

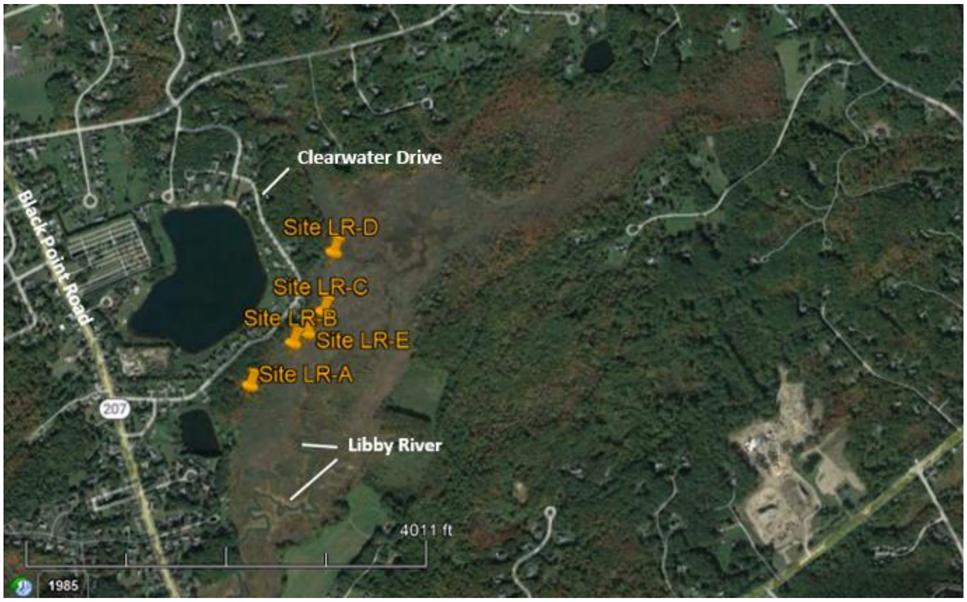
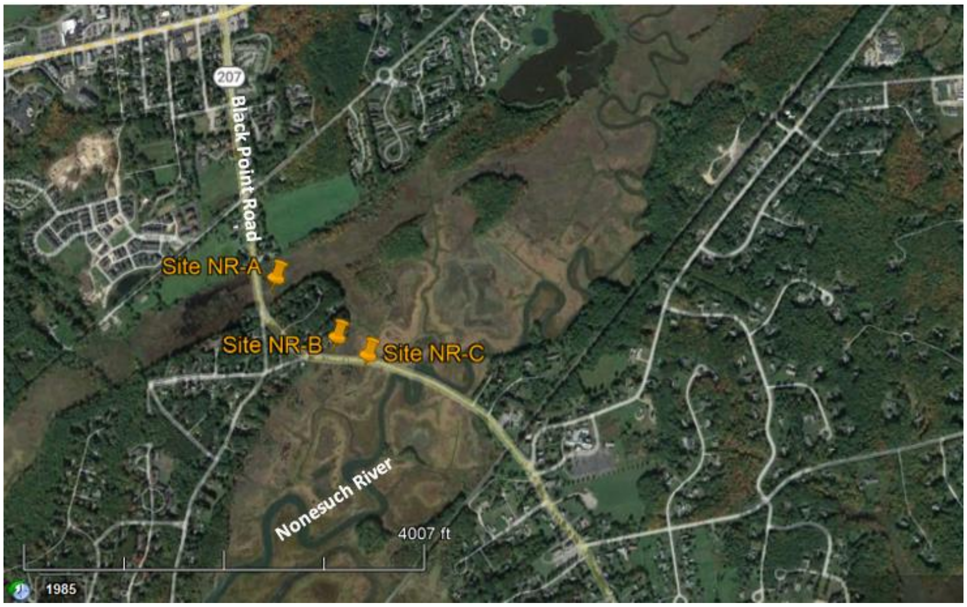


Figure 2.2.1-5 Google Earth 1985 imagery showing locations of study sites in the Nonesuch River sub-watershed



2.2.2 Marsh-Fringe Reference Sites

In June 2022, we conducted a reconnaissance survey in four locations (total of 10 survey points) in the Dunstan River, Libby River and Nonesuch River sub-watersheds to characterize the porewater specific conductance in continuous bands of *Spartina patens* along the marsh fringe where evidence of anthropogenic alteration and stormwater inputs (i.e., from roads, streets and commercial/residential developments) are absent. With one exception[18], the marsh fringe in these areas consisted of a mixture of shrubs, salt-marsh grasses, rushes and/or sedges with adjoining mature forest on the upland side of the fringe. These porewater survey points are within 1 to 9 meters of the marsh fringe in areas where *Spartina patens* was the only plant present. **Figures 2.2.2-1A** through **2.2.2-1C** show the general locations of these marsh-fringe reference sites (reference sites).

2.2.3 Field Measurements

Phragmites Sites – As discussed above in **Section 2.2.1**, we oriented the initial survey transects in each Phragmites stand roughly perpendicular to the marsh fringe and added filler transects to increase sampling density based on preliminary examination of the field data and to delineate the breadth of potential low-salinity runoff zones proximal to the source transects. Except for sites LR-E and NR-C[19] which were surveyed at 5-meter intervals, survey point spacing

[18] Station 25 in the Nonesuch River sub-watershed is adjacent to a low soil scarp adjoining a residential property bordered with shrubbery.

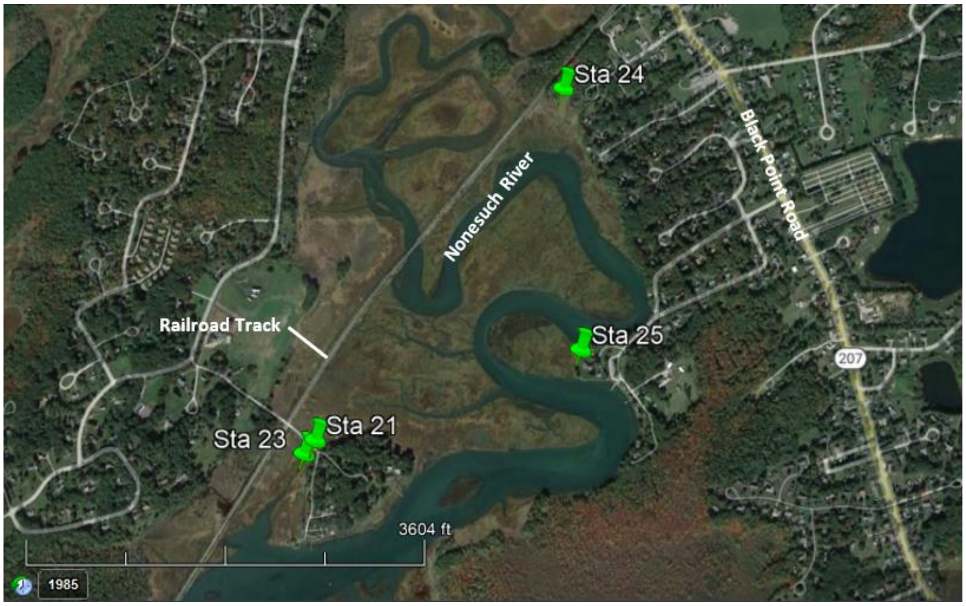
[19] Sites LR-E and NR-C were surveyed in conjunction with A. DeVecchis' Undergraduate Research Opportunities Program (UROP) project research at the University of Southern Maine in 2020.

was approximately 20 meters along the transects, with extra points added to accommodate notable changes in dominant plant species, marsh pools and creeks (including dry channels).

Figure 2.2.2-1A Google Earth 1985 imagery showing locations of the Dunstan River marsh-fringe reference sites

Figure 2.2.2B Google Earth 1985 imagery showing general locations of Libby River marsh-fringe reference sites

Figure 2.2.2-1C Google Earth 1985 imagery showing general locations of marsh-fringe reference sites



Marsh-Fringe Reference Sites – As discussed in **Section 2.2.2**, the marsh-fringe reference site survey points are within 1 to 9 meters of the marsh fringe (measured approximately perpendicular to the fringe) in tracts of *Spartina patens* (i.e., it was the only plant present).

Electrical Conductivity Measurements – We used an Aquaterr EC-350 portable soil probe to measure the soil moisture (%), temperature (^{o}F), and electrical conductivity (microsiemens (µS)/cm; proxy for salinity) of the shallow soil surrounding the probe at all survey sites.

At each survey point, we inserted the Aquaterr metal probe tip into the soil to a depth of approximately six inches and allowed it to equilibrate with the soil environment for at least one minute before collecting data for the target parameters. We encountered four instances (two survey points at site DR-A and two at the marsh-fringe reference sites) where electrical conductivity exceeded the 2,000 µS/cm measurement limit of the instrument. For these four locations we used 2,000 µS/cm as the default electrical conductivity value.

We used a Garmin GPSmap 62s unit to determine the geographic coordinates for each survey point. We also noted the dominant plant species at the survey points. Using the temperature recorded for the shallow soil at each point we converted electrical conductivity measurements to <u>specific conductance</u>, or electrical conductivity standardized to 25°C, based on the following equation:

*specific conductance = electrical conductivity / (1 + (0.02 * (soil temperature - 25)))* where specific conductance and electrical conductivity units are microsiemens (µS)/cm and soil temperature is in degrees Celsius.

Although we relied on specific conductance to assess salinity-based relationships among the study sites and among the dominant plants species at each site, we also calibrated specific conductance to known water salinities (salinities measured using the refractometer discussed above in **Section 2.2.1**) determined for tap water (from a drilled bedrock well) amended with serial aliquots[20] of brackish water collected from the Dunstan River during flood tide. **Table 2.2.3-1** summarizes these specific conductance and salinity data, and **Figure 2.2.3-1** presents a linear regression plot of the data (specific conductance v. salinity).

The regression equation for the trendline plotted through the data presented in **Table 2.2.3-1** is

$$y = 0.0065x - 0.8787$$

where *y* is salinity and *x* is specific conductance. Based on an r-squared value of 0.9794, the regression equation explains approximately 98% of the variability in the salinity values, indicating that the linear relationship between specific conductance and salinity is very strong. For the discussions that follow in **Sections 3.2** and **4.0**, where appropriate we present both specific conductance and salinity, with salinity calculated using the regression equation presented above.

We plotted specific conductance and dominant plant species on Google Earth base maps shown in **Appendix C**. **Appendix D** presents the porewater specific conductance data for the survey points. Phragmites was the dominant plant species adjacent to the marsh fringe at all the study sites. Subordinate clusters of narrow-leaf cattail, *Typha angustifolia*, were present in depressions within the Phragmites stands. As discussed earlier, we designated the conspicuous boundary between the areas dominated by Phragmites and those dominated by Spartina (generally short-form *Spartina alterniflora* except for site DR-B where *Spartina patens* was dominant) as the Phragmites 'front' after which Phragmites clusters may have been present but the plant was not the dominant species. **Figure 2.2.2-2** presents photographs of the four dominant plants encountered in the study.

[20] The aliquots of brackish water ranged from 97 to 127 ml.

Table 2.2.2-1 Salinity and specific conductance data for various surface water samples

Specific Conductance (µs/cm)	Salinity (ppt)
93	0
323	1
654	3
825	5
1115	6
1421	7
1457	9
1549	10
1732	11
1858	11
2179	13

Figure 2.2.3-1 Scatterplot for the salinity versus specific conductance data presented in Table 2.2.3-1

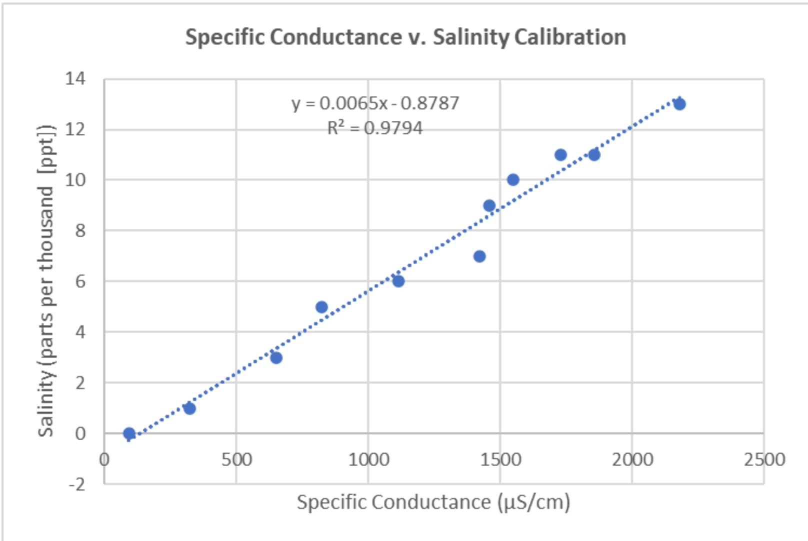


Figure 2.2.2-2 Photos of the four dominant plant species encountered in the study areas

Phragmites *(Phragmites australis)*

Narrow-leaf cattail (*Typha angustifolia)*

Spartina patens showing the typical 'cowlick' pattern.

Spartina alterniflora on riverbank

3 STUDY RESULTS AND DISCUSSION

3.1 Marsh Stratigraphy and Groundwater

3.1.1 Marsh Stratigraphy at Groundwater Monitoring Sites

Groundwater in the pore spaces (i.e., porewater) of the shallow soil layers on a salt marsh provides water and minerals to the roots of the halophytes that grow on the marsh surface. Information about the groundwater levels in these soil layers is important for understanding the relative position and movement of groundwater beneath each site. Refer to **Appendix B** for the soil boring logs and the vertical position of groundwater in the underlying soil units at each boring location.

Boring DM-1 in the Dunstan River Sub-Watershed – Soil boring DM-1 reached a depth of 4.5 ft below the marsh surface. The soil stratigraphy at this location consists of a surface layer[21] of fibric soil approximately 1.5 ft thick, over 1.0 ft of hemic soil, over 0.5 ft of fibric soil to a depth of 3.0 ft. The remainder of the boring encountered very fine sand with a trace amount of plant and root fragments. Orange-brown mottles (small patches discolored from oxidation) in the lower 0.5 ft (depth interval: 4.0 - 4.5 ft) of the boring indicate the soil at this depth alternated between saturated and unsaturated conditions[22] before becoming fully saturated under the submerged conditions required for deposition of the overlying sand and organic soil.

The screen section in monitoring well DM-1S rests at 2.6 - 3.1 ft below the marsh surface in the upper part of the very fine sand unit. The screen in well DM-1M is at 3.4 - 3.9 ft below grade in the very fine sand unit.

Boring LR-1 in the Libby River Sub-Watershed – Soil boring LR-1 reached a depth of 9.1 ft below the marsh surface. The stratigraphy at this location is predominantly fibric soil to the bottom of the boring. Three variably textured mineral soil units encountered at the following depths were likely deposited during periods of brief sea-level rise and/or increased wave energy that rendered conditions unfavorable for development of salt-marsh soils.

- 4.0 - 4.5 ft: silty, very fine sand
- 6.0 - 7.5 ft: organic silt
- 8.5 - 9.1: silty, very fine sand

The screen in monitoring well LR-1S rests at 2.5 - 3.0 ft below grade in the upper fibric soil unit. The screen in well LR-1M is in fibric soil at 5.5 - 6.0 ft below grade. The screen in well LR-1D is at

[21] We have assumed that the soil layers beneath the marsh surface are horizontal or nearly so.

[22] Unsaturated conditions allow atmospheric oxygen to react with the metallic ions in fine-grained soils (i.e., silts and clays) to create metal oxides (e.g., iron oxides). These discolored areas generally occur as irregular pods adjacent to soil fractures.

8.6 - 9.1 ft below grade in lower fibric soil unit, which also has millimeter-scale laminae of silty, very fine sand.

Boring RJ-1 in the Nonesuch River Sub-Watershed – Soil boring RJ-1 reached a depth of 4.0 ft below the marsh surface. The soil stratigraphy at this location consists of a 1.5 ft thick surface layer of fibric soil over 0.5 ft of hemic soil. Very fine sand is present at 2.0 - 3.5 ft below grade. Although 1 ft shallower than the very fine sand bed observed in DM-1 (depth of very fine sand in DM-1 is 3.0 - 4.5+ ft), it is plausible that these two sandy units were deposited contemporaneously in a beach environment during a period of elevated sea-level. Additional analyses, e.g., age-dating using foraminifera and pollen in the soil, would be necessary to explore this theory. The remainder of the boring encountered fibric soil.

The screen in monitoring well RJ-1S lies at 1.5 - 2.0 ft below the marsh surface in the thin hemic soil unit. The screen in well RJ-1M rests in the lower portion of the underlying very find sand unit at 2.9 - 3.4 ft below grade.

3.1.2 Groundwater Levels

Table 3.1.2-1 presents groundwater levels for the seven monitoring wells involved in this study. The soil and monitoring well logs presented in **Appendix B** depict these groundwater levels in graphical format to aid in understanding the hydraulic relationships among/between the stratigraphic units at each site. Groundwater levels show higher variability at site LR-1 and less variability at sites DR-1 and RJ-1.

The shallow groundwater table at all three sites was within the upper fibric soil layer. Groundwater depths were greater (i.e., the groundwater table was lower) for the August 28, 2020 monitoring event compared to the subsequent September or October events when evapotranspiration is expected to be less. A lower rate of evapotranspiration in late summer/early fall allows a greater portion of rainfall to recharge the shallow soil aquifer, thereby raising the groundwater table closer to ground surface. Groundwater levels in September and October were similar for the individual wells.

Groundwater levels on 8/28/2020 ranged between 1.3 and 2.6 ft below grade in DR-1S and DR-1M, which is unexpected since both well screens occupy similar depths in the same stratigraphic unit. Depth to groundwater was 0.3 ft in both RJ-1S and RJ-1M for this monitoring event, which suggests that the very fine sand unit in contact with the RJ-1M well screen has a good hydraulic connection with the overlying fibric soil that surrounds the RJ-1S well screen. Groundwater levels in LR-1S, LR-1M and LR-1D were 0.4, 2.0 ft and 8.5 ft below grade, respectively, for the same date.

Table 3.1.2-1 Groundwater levels in monitoring wells in Scarborough Marsh

Monitoring Well	Groundwater Depth (ft below grade)		
	8/28/2020	9/21/2020	10/14/202
DR-1 S	1.3	0.4	0.4
DR-1 M	2.6	0.6	0.5
LR-1 S	0.4	0.2	0.3
LR-1 M	4.2	0.4	0.5
LR-1 D	8.5	7.9	7.8
RJ-1 S	0.2	0.0	0.0
RJ-1 M	0.2	0.1	0.0

Although none of the monitoring wells has a bentonite clay seal to hydraulically isolate its screen from the overlying and underlying aquifer regions, it is noteworthy that groundwater levels in wells LR-1S, LR-1M and LR-1D differ by several feet, suggesting the soils surrounding each screen are hydraulically isolated from the others by low-permeability layers (e.g., silty fine sand or clay/silt beds). Moreover, the lower groundwater levels observed in the two deeper wells at this site suggest that the shallow soil aquifer is *recharging* the underlying aquifers units (i.e., where shallow groundwater moves deeper into the aquifer) which is counter to the notion that the Libby River valley should be associated with regional groundwater *discharge* (i.e., upward movement of groundwater into the shallower aquifer region)[23]. This recharge relationship persists for all three monitoring events.

3.1.3 Salinity of Groundwater

Groundwater salinities measured in monitoring wells at sites LR-1 and RJ-1 were higher in October 2020 compared to those measured in August and September (**Table 3.1.3-1**), whereas groundwater salinities measured in the two monitoring wells at site DR-1 showed relatively little change. Salinity data for the three monitoring dates are lower than the May 2019 salinities measured in the Libby River (refer to **Figure 3.1.3-1**).

Groundwater salinities for the three monitoring rounds ranged between 0 ppt for LR-1M and LR-1D on 8/28/2021 and 9/21/2021 to 13 ppt in monitoring well RJ-1S on 10/14/2021. Salinities were generally higher in shallow monitoring wells LR-1S and RJ-1S compared to their deeper counterparts. The salinity of water puddled on the marsh surface on 10/14/2021 following two inches of rainfall on the previous day was 1 ppt near site DM-1 in the Dunstan River sub-watershed and 6 ppt near site RJ-1 on the Nonesuch River sub-watershed. These values are

[23] Aquifer recharge (i.e., associated with downward movement of groundwater at depth through the soil layers) generally occurs in the upland regions of a watershed, whereas aquifer discharge occurs in the lowland regions of the watershed proximal to wetlands and water bodies such as streams, rivers, lakes and the marine shoreline.

consistent with salinities measured in the shallow monitoring wells at each site on the same day.

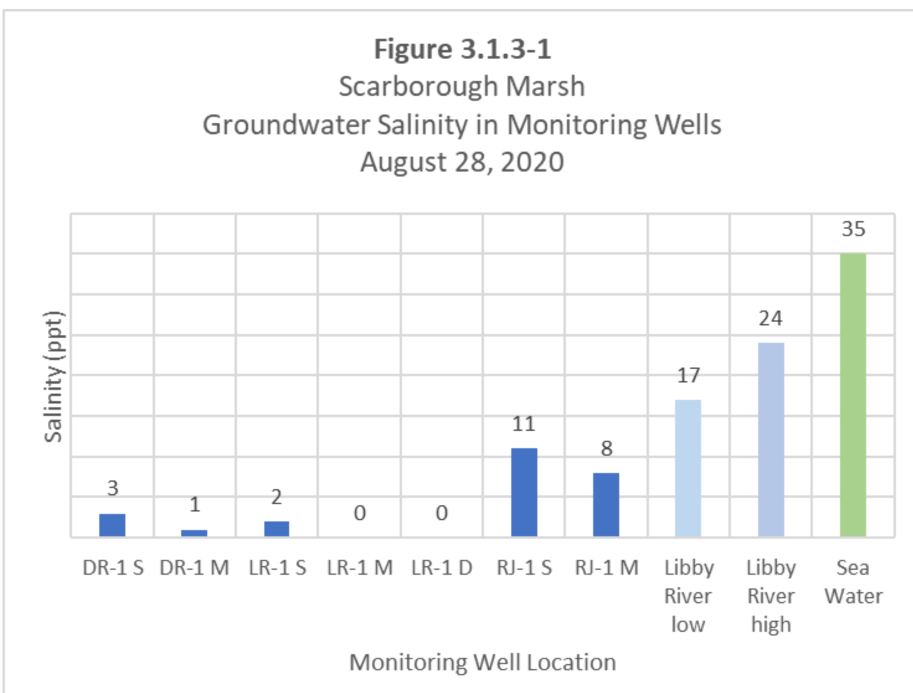
Salinities measured in the shallow peat aquifer at all three sites are lower than the 20-ppt level viewed by some researchers (Burdick and Dionne, 1994; Chambers, 1997) as the upper limit for salinity conditions that support Phragmites growth.

Table 3.1.3-1 Groundwater salinity in monitoring wells, Scarborough Marsh

Mon. Well	Well Bottom below grade (ft)	Salinity in parts per thousand(ppt) *		
		8/28/2020	9/21/2020	10-14-2020
DR-1 S	3.1	**2 - 3**	**3**	**2**
DR-1 M	3.9	**0 - 1**	**3**	**3**
LR-1 S	2.0	**2**	**5**	**7**
LR-1 M	3.4	**0**	**0**	**2-3**
LR-1 D	3.0	**0**	**0**	**1**
RJ-1 S	6.0	**11**	**11**	**13**
RJ-1 M	9.1	**8**	**7 - 8**	**10**

Note

* For reference, the salinity of the Libby River measured during the flood tide adjacent to Black Point Road in May 2019 ranged between 17 ppt and 24 ppt (Underwood, 2019, unpublished data)



Note

Libby River salinities were the two highest measured during flood tide in May 2019 near Black Point Road (Underwood, 2019, upublished data).

3.2 Specific Conductance of Porewater in Shallow Soils

This section discusses porewater specific conductance and dominant plant species data for 291 survey points[24] at 11 Phragmites study sites and 10 survey points at the *Spartina patens* marsh-fringe reference sites in the Scarborough Marsh. We present the data and discussion of the results for the Phragmites sites in five sections as follows:

- **Section 3.2.1** - Descriptive statistics for porewater specific conductance for the 11 Phragmites study sites, 3 sub-watersheds, and 3 dominant plant species. Readers with only marginal interest in these basic statistics may wish to focus on the two **Statistical Comparisons** discussions (one for sub-watersheds and one for plants species) in this section.
- **Section 3.2.2** - Descriptive statistics for porewater specific conductance at each study site by plant species. Readers with only marginal interest in these basic statistics may wish to skip this section.
- **Section 3.2.3** - Phragmites study site comparisons for statistically significant differences in porewater specific conductance.
- **Section 3.2.4** - Relationship of soil porewater specific conductance and distance from marsh fringe for both source and off-gradient transects at the Phragmites study sites.
- **Section 3.2.5** – Porewater specific conductance data for *Spartina patens* at the marsh-fringe reference sites and comparison of these to the aggregated data for each dominant plant species (i.e., porewater data for each dominant plant species aggregated for all 11 Phragmites study sites).

Appendix D presents porewater specific conductance data for the Phragmites study sites and the marsh-fringe reference sites. **Appendix E** shows data for the statistical analyses discussed in this section.

3.2.1 Descriptive and Comparative Statistics for the All Phragmites Study Sites[25], Each Sub-Watershed and Each Dominant Plant Species

Soil porewater specific conductance data, dominant plant species and transect orientations for each porewater study site are depicted on site maps in **Appendix C** and compiled in table format in **Appendix D**. We also measured the specific conductance of standing water pooled directly downgradient from the drainage ravine in area DR-A in the Dunstan River sub-watershed to establish a reference range for specific conductance of late-spring to fall runoff

[24] This number includes 72 survey points from A. DeVecchis' 2020 UROP project
[25] Excluding the marsh-fringe reference sites

into this area of the Scarborough Marsh when salinity introduced from winter de-icing salt is expected to be minimal.

Table 3.2.1-1 presents a summary of important descriptive statistics for porewater specific conductance (equivalent salinities in brackets) for the entire study, three sub-watersheds, three dominant plant species, and ten water-pool survey points associated with the drainage ravine at site DR-A. **Figure 3.2.1-1** presents boxplots[26] of the specific conductance for these same data. **Figures 3.2.1-2** through **3.2.1-4** are histograms showing the distribution of specific conductance for the entire study, sub-watersheds and dominant plant species, respectively.

Table 3.2.1-1 Phragmites summary specific conductance statistics for the entire study, dominant plant species and sub-watersheds. Specific conductance (µS/cm) values are unbracketed; salinities [ppt] are in brackets

Category	No. of Points	Min-Max	Mean/Median	Standard Deviation	Normal Distribution?
Entire Study	291	35-2203 **[0-13]**	984/991 **[6/6]**	542 **[3]**	No
Dunstan River Sub-Watershed	92	69-2178 **[0-13]**	1068/1086 **[6/6]**	642 **[3]**	No
Libby River Sub-Watershed	121	35-2203 **[0-13]**	1008/1016 **[6/6]**	487 **[2]**	Yes
Nonsuch River Sub-watershed	78	52-1920 **[0-12]**	847/861 **[5/5]**	470 **[2]**	No
DR-A standing water	10	26-247 **[0-1]**	123/113 **[0/0]**	78 **[0]**	Yes
Cattails	58	99-2146 **[0-13]**	1149/1161 **[7/7]**	485 **[2]**	Yes
Phragmites	159	35-2169 **[0-13]**	842/744 **[6/4]**	534 **[3]**	No
Spartina	74	232-2203 **[0-13]**	1157/1115 **[7/6]**	520 **[3]**	No
Spartina alterniflora	62	232–2203 **[1-13]**	1175/1091 **[7/6]**	559 **[3]**	No
Spartina patens	12	712–1401 **[4-8]**	1063/1140 **[6/7]**	220 **[1]**	Yes

[26] Refresher on Box-and-Whisker Plots (boxplots) and Quartiles - Quartiles divide a numerical data set into four quarters. The first quartile (or lower quartile), **Q1,** separates the lowest 25% of data from the highest 75%. The second or middle quartile, **Q2,** is also the median, and it divides the data values into two equal parts. The third quartile (or the upper quartile), **Q3,** separates the highest 25% of data from the lowest 75%. The upper and lower ends of the 'whiskers' in a boxplot represent the maximum and minimum values.

The box represents the two inner quartiles (**Q2 + Q3** = 50% of the data) and the data range which the box encompasses is the **inner-quartile range**. The horizontal line inside the box represents the **median** value, and 'X' in the middle of each boxes represents the **mean** value.

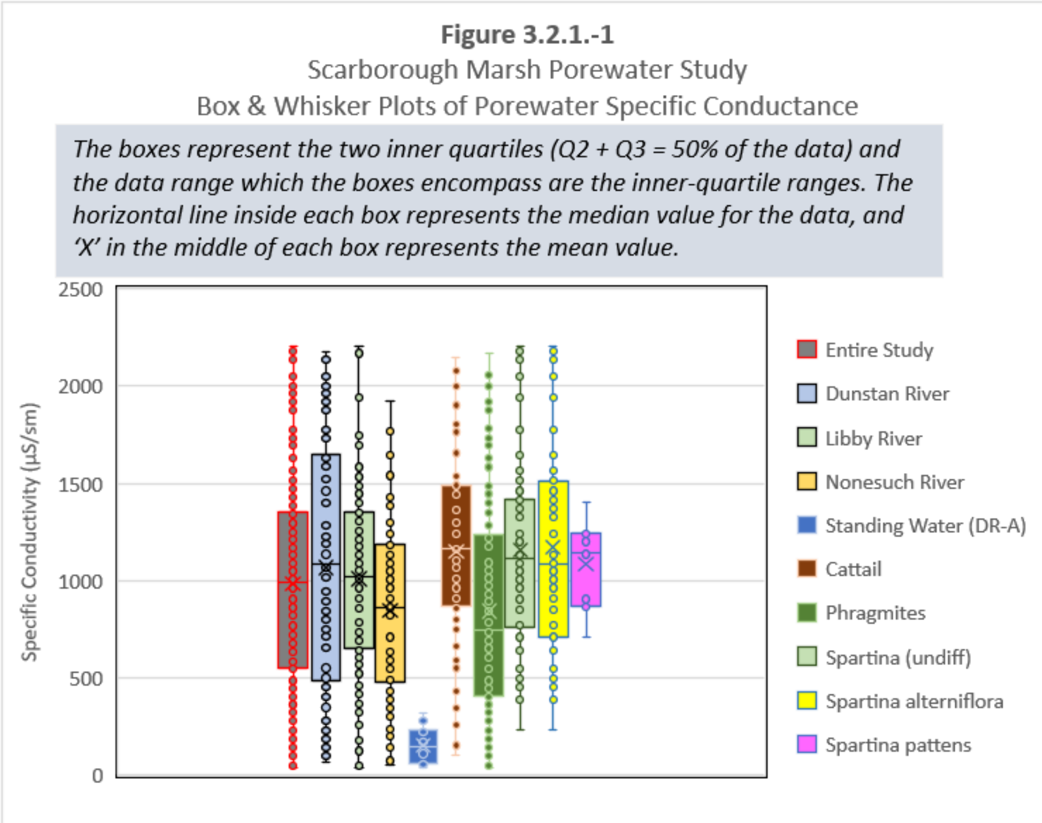


Figure 3.2.1.-1
Scarborough Marsh Porewater Study
Box & Whisker Plots of Porewater Specific Conductance
The boxes represent the two inner quartiles (Q2 + Q3 = 50% of the data) and the data range which the boxes encompass are the inner-quartile ranges. The horizontal line inside each box represents the median value for the data, and 'X' in the middle of each box represents the mean value.
Specific Conductivity (µS/sm)
2500
2000
1500
1000
500
0
Entire Study
Dunstan River
Libby River
Nonesuch River
Standing Water (DR-A)
Cattail
Phragmites
Spartina (undiff)
Spartina alterniflora
Spartina pattens

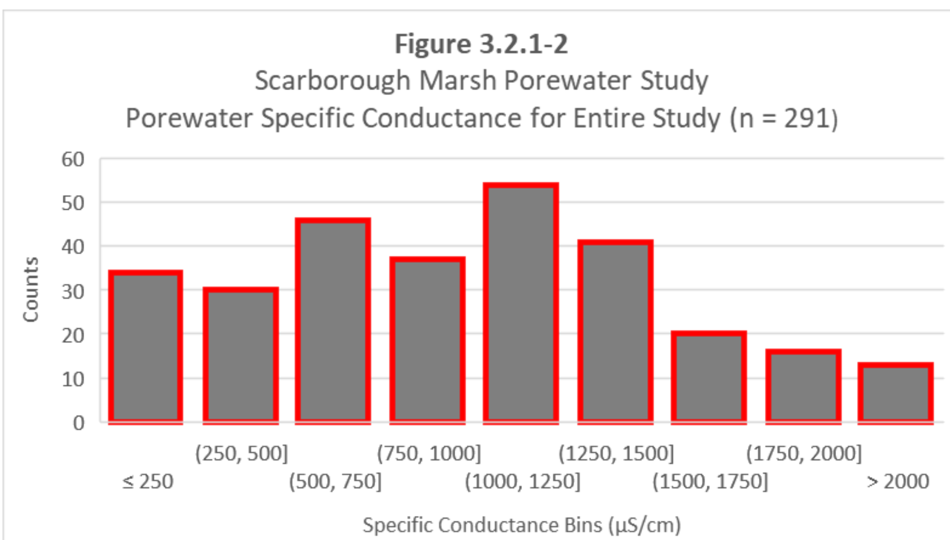
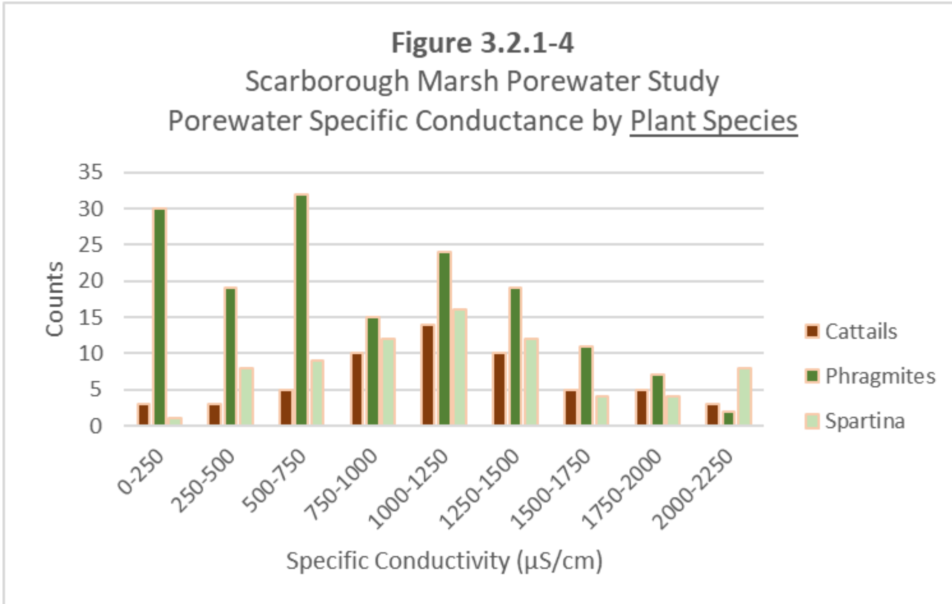


Figure 3.2.1-2
Scarborough Marsh Porewater Study
Porewater Specific Conductance for Entire Study (n = 291)
Counts
60
50
40
30
20
10
0
≤ 250
(250, 500]
(500, 750]
(750, 1000]
(1000, 1250]
(1250, 1500]
(1500, 1750]
(1750, 2000]
> 2000
Specific Conductance Bins (µS/cm)



Entire Study – Porewater specific conductance for the entire Phragmites study ranged from 35 µS/cm [*0 ppt*] to 2203 µS/cm [*13 ppt*] with a mean of 984 µS/cm [*6 ppt*] and a median of 991 µS/cm [*6 ppt*]. According to the Shapiro-Wilks normality test these data are non-normally distributed , meaning the data are not symmetrically distributed on both sides of the mean (refer to **Figure 3.2.1-2**).

Sub-watersheds – Porewater specific conductance data for each sub-watershed are summarized below (also refer to **Figure 3.2.1-3**).

Dunstan River sub-watershed – Porewater specific conductance for the 92 survey points in the Dunstan River sub-watershed ranged between 69 µS/cm [*0 ppt*] and 2178 µS/cm [*13 ppt*] with a mean of 1068 µS/cm [*6 ppt*] and a median of 1086 µS/cm [*6 ppt*]. According to the Shapiro-Wilks normality test these data are non-normally distributed.

Libby River Sub-Watershed – Porewater specific conductance for the 121 survey points in the Libby River sub-watershed ranged between 35 µS/cm [*0 ppt*] and 2203 µS/cm [*13 ppt*] with a mean of 1008 µS/cm [*6 ppt*] and a median of 1016 µS/cm [*6 ppt*]. According to the Shapiro-Wilks normality test these data are normally distributed.

Nonesuch River Sub-Watershed – Porewater specific conductance for the 78 survey points in the Nonesuch River sub-watershed ranged between 52 µS/cm [*0 ppt*] and 1920 µS/cm [*12 ppt*] with a mean of 847 µS/cm [*5 ppt*] and a median of 861 µS/cm [*5 ppt*]. Shapiro-Wilks normality test indicates that these data are non-normally distributed.

Statistical Comparisons - Because the data for two of the sub-watersheds are non-normally distributed, we used non-parametric[27] statistical tests to determine if there are statistically significant differences for specific conductance among the three sub-watersheds. The omnibus Kruskal-Wallis Test[28] determined that a significant difference(s) (probability [p] ≤ 0.05) exists among the data for the three sub-watersheds. To isolate which sub-watersheds are different, we used the post-hoc Dunn's Test pairwise multiple comparison procedure employing the Bonferroni Correction. The test results show that specific conductance data for the Nonesuch River sub-watershed are significantly different (lower; $p \leq 0.05$) compared to the data for both the Dunstan River and Libby River sub-watersheds. However, the data from the Dunstan River and Libby Rivers sub-watersheds are not significantly different. **Table 3.2.1-2** summarizes this information.

Table 3.2.1-2 Summary of pairwise sub-watershed specific conductance data comparisons using Dunn's Test with Bonferroni Correction

Sub-watershed pair	Significantly Different? p < 0.05
Dunstan v. Nonesuch	Yes
Libby v. Nonesuch	Yes
Dunstan v. Libby	No

Although the inner-quartile (i.e., the 'box' representing the central 50% of the values, or Q2 + Q3) ranges for the three sub-watersheds overlap substantially (refer to **Figure 3.2.1-1** above), note that the median specific conductance for the Dunstan River (1068 µS/cm [*6 ppt*]) and Libby River (1008 µS/cm [*6 ppt*]) sub-watersheds are 26% and 19%, respectively, greater than the median for the Nonesuch River sub-watershed (847 µS/cm [*5 ppt*]).

<u>**Standing Water (DR-A)**</u> – Specific conductance for 10 survey points in standing water near the mouth of the shallow ravine draining into site DR-A ranged from 26 µS/cm [*0 ppt*] to 247 µS/cm [*1 ppt*] with a mean of 123 µS/cm [*0 ppt*] and median of 113 µS/cm [*0 ppt*]. According to the Shapiro-Wilks normality test these data are normally distributed.

<u>**Dominant Plant Species**</u> – Porewater specific conductance data for each dominant plant species in the study are presented below.

Cattails – Porewater specific conductance for the 58 survey points dominated by cattails ranged between 99 µS/cm [*0 ppt*] and 2146 µS/cm [*13 ppt*] with a mean of 1149 µS/cm [*7*

[27] Non-parametric tests rely on statistical methods which do not make assumptions about the frequency distribution (e.g., such as a normal distribution) of variables being evaluated.

[28] Computed using the Real Statistics Package add-in for Microsoft Excel developed by Charles Zaiontz (www.real-statistics.com/free-download/real-statistics-resource-pack/)

ppt] and a median of 1161 µS/cm [*7 ppt*]. According to the Shapiro-Wilks normality test these data are normally distributed.

Phragmites – Porewater specific conductance for the 159 survey points dominated by Phragmites ranged between 35 µS/cm [*0 ppt*] and 2169 µS/cm [*13 ppt*] with a mean of 842 µS/cm [*6 ppt*]and a median of 744 µS/cm [*4 ppt*]. Shapiro-Wilks normality test indicates these data are non-normally distributed.

Spartina (undifferentiated) – Porewater specific conductance for the 74 survey points dominated by Spartina ranged between 232 µS/cm [*1 ppt*] and 2203 µS/cm [*13 ppt*] with a mean of 1157 µS/cm [*7 ppt*] and a median of 1115 µS/cm [*6 ppt*]. Shapiro-Wilks normality test shows that these data are also non-normally distributed.

Considering that short-form *Spartina alterniflora* is the dominant Spartina subspecies for all study sites except site DR-B, where *Spartina patens* is dominant, we also provide the statistics to address these Spartina subspecies.

Spartina alterniflora - Porewater specific conductance for the 62 survey points dominated by *Spartina alterniflora* ranged between 232 µS/cm [*1 ppt*] and 2203 µS/cm [*13 ppt*] with a mean of 1175 µS/cm [*7 ppt*] and a median of 1090 µS/cm [*6 ppt*]. According to the Shapiro-Wilks normality test these data are non-normally distributed.

Spartina patens - Porewater specific conductance for the 12 survey points dominated by *Spartina patens* ranged between 712 µS/cm [*4 ppt*] and 1401µS/cm [*8 ppt*] with a mean of 1063 µS/cm [*6 ppt*] and a median of 1140 µS/cm [*7 ppt*]. Shapiro-Wilks normality test classifies these data as normally distributed.

Statistical Comparisons - The Kruskal-Wallis Test identified a statistically significant difference ($p \leq 0.05$) for specific conductance among the three dominant plant species. Dunn's Test employing the Bonferroni Correction shows that Phragmites data are significantly different (lower; $p \leq 0.05$) compared to those for both cattail and Spartina (undifferentiated), whereas the data for cattail and Spartina are not significantly different. Although the inter-quartile ranges for the three dominant plant species overlap substantially (refer to **Figure 3.2.1-1** above), note that the median specific conductance for the cattails (1149 µS/cm [*7 ppt*]) and Spartina (1157 µS/cm [*7 ppt*]) are both approximately 36% greater than the median for Phragmites (847 µS/cm [*5 ppt*]).

The Kruskal-Wallis Test found no significant difference between *Spartina alterniflora* and *Spartina patens* data.

Table 3.2.1-3 summarizes these data.

Table 3.2.1-3 Summary of pairwise plant species comparisons based on specific conductance for the entire study using Dunn's Test

Comparison	Significantly Different? $p \leq 0.05$
Cattail v. Spartina	No
Cattail v. Phragmites	Yes
Phragmites v. Spartina	Yes
S. alterniflora v. *S. patens*	No

3.2.2 Descriptive and Comparative Statistics for Phragmites Study Sites by Plant Species

Table 3.2.2-1 below presents descriptive statistics for specific conductance for each study site according to the three dominant plant species. For clarity, we exclude the equivalent salinity values from this table.

<u>**Dunstan River Sites**</u> **- Figure 3.2.2-1A** presents boxplots for specific conductance data by study site and dominant plant species for the Dunstan River sub-watershed

Cattail Data – MR-A has the highest cattail specific conductance of 1555 µS/cm [*9 ppt*] followed by DR-A (1454 µS/cm [*9 ppt*]) and DR-B (1193 µS/cm [*7 ppt*]). DR-B has the smallest inner-quartile range of 532 µS/cm [*3 ppt*] followed by MR-A (1255 µS/cm [*7 ppt*]) and DR-A (1465 µS/cm [*9 ppt*]). DR-A, DR-B and MR-A data overlap and their first quartiles (Q1) are separated by 24 µS/cm (DR-A and MR-A) and 75 µS/cm (MR-A and DR-B).

Phragmites Data – MR-A has the highest Phragmites mean specific conductance of 1276 µS/cm [*7 ppt*] based on two data points (498 µS/cm [*2 ppt*] and 2055 µS/cm [*12 ppt*]) followed by DR-A (871 µS/cm [*5 ppt*]) and DR-B (754 µS/cm [*4 ppt*]). DR-A and DR-B have inner-quartile ranges of 1442 µS/cm [*8 ppt*] and 480 µS/cm [*2 ppt*], respectively, whereas MR-A's two survey points are insufficient to compute an inner-quartile range. The inner-quartile range for DR-A brackets the smaller DR-B inner-quartile range.

Spartina (undifferentiated) Data – DR-A has the highest mean Spartina specific conductance of 2030 µS/cm [*12 ppt*] followed by MR-A (2065 µS/cm [*13 ppt*] (single point) and DR-B (1063 µS/cm [*6 ppt*]). DR-A and DR-B have inner-quartile ranges of 235 µS/cm [*1 ppt*] and 373 µS/cm [*2 ppt*], respectively. With only one survey point, it is not possible to compute an inner-quartile range for MR-A. The inner-quartile range for DR-A brackets the single point value for MR-A, and neither overlaps with the inner-quartile range for DR-B. The separation between the inner-quartile ranges for DR-A and DR-B (i.e., Q1-DR-A-phrag minus Q3-DR-B-phrag) is 675 µS/cm [*4 ppt*].

The lower specific conductance values for DR-B are noteworthy because DR-A and MR-A have short-form *Spartina alterniflora* beyond the Phragmites front, whereas DR-B has *Spartina patens*. Higher specific conductance for areas dominated by *Spartina alterniflora* in DR-A and MR-A suggests that these areas are at lower marsh elevations that are more frequently flooded by tides than the areas dominated by *Spartina patens* at site DR-B. An elevation survey of the three sites would be necessary to explore this concept further.

Figure 3.2.2-1A

Scarborough Marsh

Box & Whisker Plots for Dunstan River Sites by Dominant Plant Species

The boxes represent the two inner quartiles (Q2 + Q3 = 50% of the data) and the data range which the boxes encompass are the inner-quartile ranges. The horizontal line inside each box represents the median value for the data, and 'X' in the middle of each box represents the mean value.

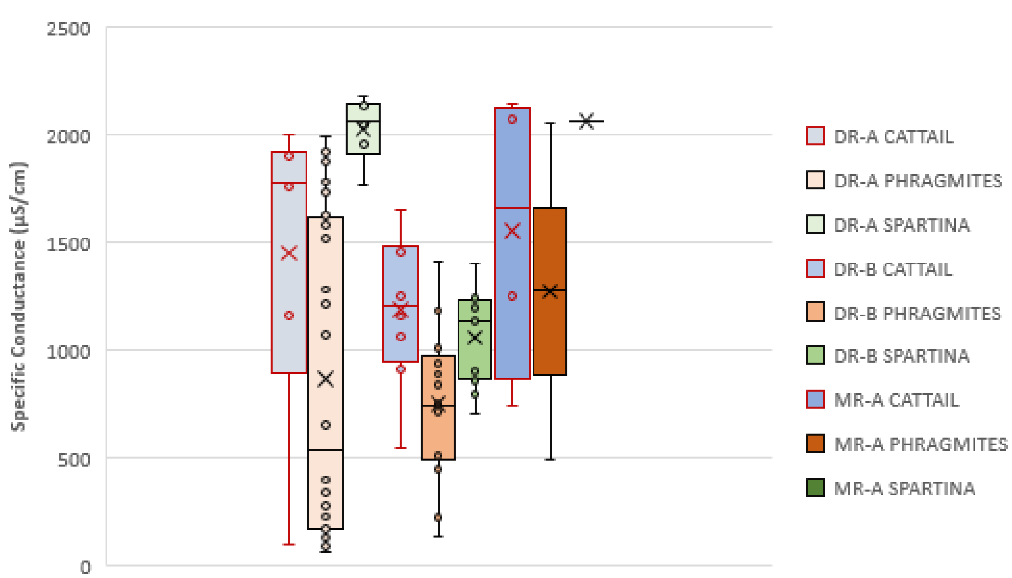


Table 3.2.2-1 Summary of descriptive statistics for each study site according to the dominant plant species

Marsh Lobe	Study Site	Specific Conductivity (µS/cm) Descriptive Statistics: survey point count / min-max / mean / median / normal?			
		Entire Study	**Cattail**	**Phragmites**	**Spartina**
N/A	**Entire Study**	291 / 35-2203 / 984 / 991 / no	58 / 99-2146 / 1149 / 1161 / yes	159 / 35-2169 / 842 / 744 / no	74 / 232-2203 / 1157 / 1115 / no
Dunstan River	**DR-A**	48 / 69-2178 / 1089 / 1253 / no	6 / 99-2001 / 1454 / 1778 / no	36 / 69-1998 /871 / 544 / no	6 / 1775-2178 / 2030 / 2063 /yes
	DR-B	37 / 142-1656 / 949 / 911 / yes	8 / 550-1656 / 1193 / 1206 / yes	17 / 142-1418 / 754 /746 / yes	12 / 712-1401 / 1063 / 1140 / yes
	MR-A	7 / 498-2146 / 1548 / 2055 / no	4 / 748-2146 / 1555 / 1663 / #	2 / 498-2055 / 1276 / 1276 / #	1 / 2065 / #
	Ravine mouth pooled runoff	10 / 26-247 / 123 / 113 / yes	n/a	n/a	n/a
Libby River	**LR-A**	14 / 47-2203 / 812 / 196 / yes	1 / 175 / #	10 / 47-1693 / 460 / 180 / no	3 / 2193-2202 / 2199 / 2200 / yes
	LR-B	8 / 571-1016 / 733 / 672 / no	0 / n/a	8 / 571-1016 / 733 / 672 / no	0 / n/a
	LR-C	9 / 878-1942 / 1389 / 1533 / yes	2 / 962-1568 / 1265 / 1265 / #	4 / 878-1745 / 1315 / 1319 / yes	3 / 1240-1942 / 1572 / 1533 / yes
	LR-D	36 / 697-2169 /1271 / 1208 / yes	13 / 869-1536 / 1169 / 1105 / yes	19 / 697-2169 / 1277 / 1212 / yes	4 / 1372-1946 /1574 / 1489 / yes
	LR-E	54 / 35-1514 / 860 / 778 / yes	5 / 258-1188 / 751 / 798 / yes	33 / 35-1487 / 763 / 701 / yes	16 / 552-1514 / 1094 / 1138 / yes
Nonesuch River	**NR-A**	31 / 52-1070 / 475 / 486 / yes	4 / 151-859 / 544 / 583 / yes	10 / 52-727 / 241 / 212 / no	17 / 232-1070 / 597 / 497 / no
	NR-B	29 / 219-1920 / 1141 / 1299 / yes	10 / 342-1805 / 1250 /1441 / yes	12 / 219-1920 /1058 / 1106 / yes	7 / 508-1647 / 1130 / 1096 / yes
	NR-C	18 / 561-1326 / 1013 / 1063 / yes	5 / 1078-1310 / 1169 / 11128 / yes	8 / 561-1184 / 868 /897 / yes	5 / 978-1326 / 1091 / 1048 / yes

Notes

# indicates inadequate data for Shapiro-Wilks Test to determine data distribution

N/A or n/a indicates 'not applicable'

normal?: Are the data normally distributed? (yes/no)

<u>Libby River Sites</u> – Figure 3.2.2-1B presents boxplots for specific conductance data by study site and dominant plant species for the Libby River sub-watershed.

Cattail Data – LR-C (two survey points) has the highest mean specific conductance of 1265 µS/cm [*7 ppt*] followed by LR-D (1169 µS/cm [*7 ppt*]), LR-E (751 µS/cm [*4 ppt*]) and LR-A (175 µS/cm [*0 ppt*]; 1 survey point). LR-B has no cattail data. LR-D and LR-E have inner-quartile ranges of 443 µS/cm [*2 ppt*] and 563 µS/cm [*3 ppt*], respectively. LR-A and LR-C have insufficient cattail data (1 and 2 survey points, respectively) to compute inner-quartile ranges.

Phragmites Data – LR-C has the highest mean specific conductance of 1315 µS/cm [*8 ppt*] followed by LR-D (1277 µS/cm [*7 ppt*]), LR-E (763 µS/cm [*4 ppt*]), LR-B (773 µS/cm [*4 ppt*]) and LR-A (460 µS/cm [*2 ppt*]). LR-B had the smallest inner-quartile range of 344 µS/cm [*1 ppt*] followed by LR-D (407 µS/cm [*2 ppt*]), LR-E (473 µS/cm [*2 ppt]*), LR-A (683 µS/cm [*4 ppt*]) and LR-C (784 µS/cm [*4 ppt*]). Inner quartile ranges for LR-A, LR-B and LR-E overlap, but are distinct (lower) compared to those for LR-C and LR-D, which also overlap.

Spartina (undifferentiated) Data – LR-A has the highest mean specific conductance of 2,199 µS/cm [*13 ppt*], followed by LR-D (1574 µS/cm [*9 ppt*]), LR-C (1572 µS/cm [*9 ppt*]) and LR-E (1094 µS/cm [*6 ppt*]). There are no Spartina data for LR-B. LR-A has the smallest inner-quartile range of 10 µS/cm [*0 ppt*] followed by LR-D (470 µS/cm [*2 ppt*]), LR-E (546 µS/cm [*3 ppt*]) and LR-C (702 µS/cm [*4 ppt*]). The inner-quartile range for LR-C overlaps with those for LR-D and LR-E, but inner-quartile ranges for LR-D and LR-E data do not overlap. The LR-A inner-quartile range does not overlap with the others.

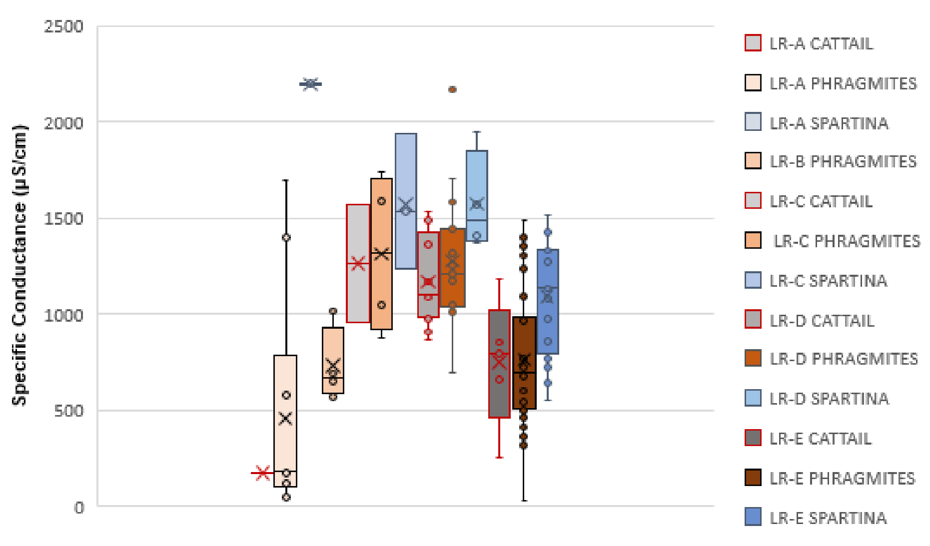
<u>Nonesuch River Sites</u> – **Figure 3.2.2-1C** presents boxplots for specific conductance data by study site and dominant plant species for the Nonesuch River sub-watershed.

Cattail Data – NR-B has the highest mean specific conductance of 1250 µS/cm [*7 ppt*] followed by NR-C (1169 µS/cm [*7 ppt*]) and NR-A (544 µS/cm [*3 ppt*]). NR-A has the smallest inner-quartile range of 534 µS/cm [*3 ppt*] followed by NR-C (563 µS/cm [*3 ppt*]) and NR-B (748 µS/cm [*4 ppt*]). The inner-quartile ranges for NR-A and NR-C overlap, and they overlap for NR-B and NR-C. However, there is no inner-quartile range overlap between NR-A and NR-B.

Phragmites Data – NR-B has the highest mean specific conductance of 1058 µS/cm [*6 ppt*] followed by NR-C (868 µS/cm [*5 ppt*]) and NR-A (241 µS/cm [*1 ppt*]). NR-A has the smallest inner-quartile range of 141 µS/cm [*0 ppt*], followed by NR-C with 563 µS/cm [*3 ppt*] and NR-B with 748 µS/cm [*4 ppt*]. The inner-quartile-ranges for NR-B and NR-C overlap, but neither overlaps with NR-A, which spans lower values.

Figure 3.2.2-1B
Scarborough Marsh
Box & Whisker Plots for Libby River Sites by Dominant Plant Species

The boxes represent the two inner quartiles (Q2 + Q3 = 50% of the data) and the data range which the boxes encompass are the inner-quartile ranges. The horizontal line inside each box represents the median value for the data, and 'X' in the middle of each box represents the mean value.



Spartina (undifferentiated) Data – NR-B has the highest mean specific conductance of 1130 µS/cm [*6 ppt*] followed by NR-C (1091 µS/cm [*6 ppt*]) and NR-A (597 µS/cm [*3 ppt*]). NR-A has the smallest inner-quartile range of 351 µS/cm [*1 ppt*], followed by NR-C with 546 µS/cm [*3 ppt*] and NR-B with 563 µS/cm [*3 ppt*]. Inner-quartile ranges for NR-B and NR-C overlap substantially. The inner-quartile ranges for NR-A and NR-B do not overlap, but NR-A and NR-C have a 13 µS/cm overlap.

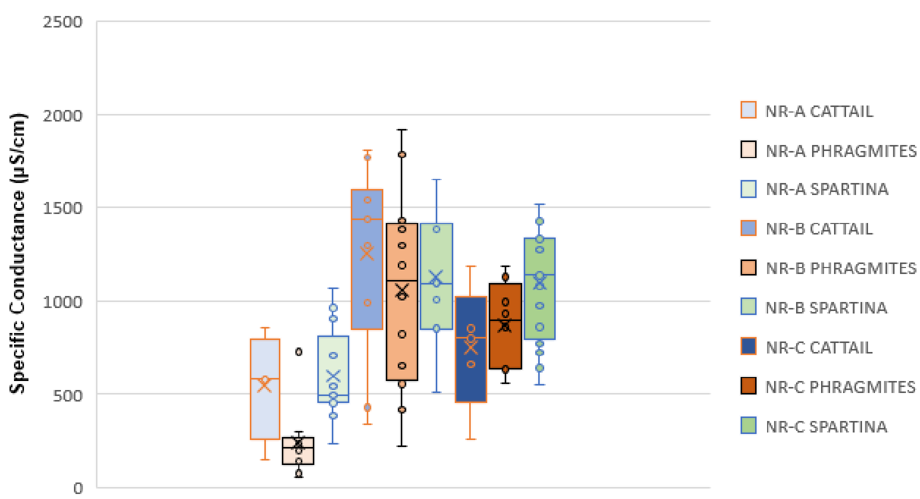
3.2.3 Phragmites Study Site Statistical Comparisons

In this section we discuss the results of two statistical pairwise comparisons among the study sites. The first set of comparisons relies on specific conductance data for each site, undifferentiated according to the dominant plant species. The second set of comparisons uses specific conductance values for each of the three dominant plant species partitioned by study site (e.g., NR-A Phragmites, LR- E Spartina, etc.).

Site Pairwise Comparisons (independent of dominant plants species) - Kruskal-Wallis Test results show a statistically significant difference among the study sites (ignoring dominant plant species). We used Dunn's Test pairwise multiple comparison procedure employing the Bonferroni Correction to determine which site pairs are significantly different. With 11 study sites, there are 55 possible pairwise comparisons[29]. Dunn's Test results show significant differences ($p \leq 0.05$) for 23 site-site pairs. All study sites are significantly different from at least two other sites. On the low end, site DR-A is significantly different from only two sites, whereas at the upper end site NR-A is significantly different from eight sites. **Table 3.2.3-1** shows the 23 significantly different pairwise comparisons among the 11 study sites.

Figure 3.2.2-1C
Scarborough Marsh
Box & Whisker Plots for Nonesuch River Sites by Dominant Plant Species

The boxes represent the two inner quartiles (Q2 + Q3 = 50% of the data) and the data range which the boxes encompass are the inner-quartile ranges. The horizontal line inside each box represents the median value for the data, and 'X' in the middle of each box represents the mean value.



Site Comparisons for Each Dominant Plant Species – As above, Kruskal-Wallis Test determined that some of the study sites within the same dominant plant species are significantly different. As before, we used Dunn's Test to isolate which site-plant species pairs are significantly different. With 10 sites having cattail data, 11 sites with Phragmites data (site LR-B had only Phragmites) and 10 sites with Spartina data, there are 45, 55 and 45 possible site pair comparisons, respectively.

[29] The formula for possible number (N) of pairwise comparisons is $N = k(k-1)/2$, where k is the number of conditions being compared. In this case *number of conditions = 11 study sites*.

Table 3.2.3-1 Summary of statistically significant different ($p < 0.05$) site pairs based on Dunn's Test. Site pairs that are significantly different [$p \leq 0.05$] are shaded and marked with an X.

SITES	DR-A	DR-B	MR-A	LR-A	LR-B	LR-C	LR-D	LR-E	NR-A	NR-B	NR-C
DR-A						X			X		
DR-B			X			X			X		
MR-A				X	X			X	X		
LR-A						X	X			X	
LR-B						X	X				
LR-C								X	X		X
LR-D								X	X		
LR-E									X	X	
NR-A										X	X
NR-B											
NR-C											

Dunn's Test results show significant differences ($p \leq 0.05$) for 10 cattail site pairs, 18 Phragmites site pairs and 17 Spartina site pairs. **Table 3.2.2-2** below summarizes these data according to dominant plant species.

Other important observations include:

- The median specific conductance for short-form *Spartina alterniflora* at site DR-A is almost twice that of *Spartina patens* at site DR-B, suggesting that either runoff dilution of tidal flux is significantly greater for DR-B, or that, as discussed in **Section 3.2.2**, areas dominated by *Spartina alterniflora* at site DR-A are at lower elevations (i.e., more frequently flooded during high tide) compared to area dominated by *Spartina patens*-dominated at site DR-B.
- Median specific conductances for all three plant species at site NR-A are uniformly lower than those at NR-B, although both sites border the same small tributary creek to the Nonesuch River. This suggests that dilution of tidal flux with stormwater is greater for site NR-A or that site NR-A is at a higher elevation (i.e., less frequently flooded during high tides). Greater influx of stormwater into site NR-A is plausible considering that the large freshwater wetland directly west of NR-A and drainage from a half-mile section of Black Point Road both discharge into NR-A, whereas NR-B receives runoff from a relatively short section of road ditch and the adjacent residential property.

One important observation to note from **Table 3.2.2-2** is that the median specific conductance values for most site pairs which are statistically different generally differ by a factor of two or more.

Table 3.2.3-2 The significantly different site pairs within each dominant plant species.
Median specific conductance (µS/cm) for each site in parentheses.

Cattail	**Phragmites**	**Spartina** (undifferentiated)
DR-A (1778) v. LR-A (#)	DR-A (544) v. LR-A (180)	DR-A (2063) v. DR-B (1140)
DR-A (1778) v. LR-E (798)	DR-A (544) v. LR-D (1212)	DR-A (2063) v. LR-E (1138)
DR-A (1778) v. NR-A (583)	DR-A (544) v. NR-A (212)	DR-A (2063) v. NR-A (497)
DR-B (1206) v. NR-A (583)	DR-B (746) v. LR-D (1212)	DR-A (2063) v. NR-B (1096)
MR-A (1663) v. NR-A (583)	DR-B (746) v. NR-A (212)	DR-A (2063) v. NR-C (1048)
MR-A (1663) v. LR-A (#)	LR-A (180) v. LR-C (1319)	DR-B (1140) v. LR-A (2200)
MR-A (163) v. LR-E (798)	LR-A (180) v. LR-D (1212)	DR-B (1140) v. NR-A (497)
LR-D (1208) v. NR-A (583)	LR-A (180) v. LR-E (701)	LR-A (2200) v. LR-E (1138)
LR-E (798) v. NR-B (1299)	LR-A (180) v. NR-B (1106)	LR-A (2200) v. NR-A (497)
NR-A(583) v. NR-B (1299)	LR-B (672) v. LR-D (1212)	LR-A (2200) v. NR-B (1096)
	LR-B (672) v. NR-A (212)	LR-A (2200) v. NR-C (1048)
	LR-C (1319) v. NR-A (212)	LR-C (1533) v. NR-A (497)
	LR-D (1212) v. LR-E (701)	LR-D (1489) v. NR-A (497)
	LR-D (1212) v. NR-A (212)	LR-E (1138) v. NR-A (497)
	LR-E (701) v. NR-A (212)	MR-A (#) v. NR-A (497)
	MR-A (1276) v. NR-A (212)	NR-A (497) v. NR-B (1096)
	NR-A (212) v. NR-B (1106)	NR-A (497) v. NR-C (1048)
	NR-A (212) v. NR-C (897)	

Note

# indicates not enough data to calculate median

Examination of **Figures 3.2.2-1A**, **3.2.2-1B** and **3.2.321C** in **Section 3.2.2** above shows that the inner-quartile ranges for the sites pairs which are significantly different either have small overlap or no overlap. The broad distribution of specific conductance values for each of the dominant plant species among the study sites is especially noteworthy. There is also broad overlap in specific conductance ranges between cattail and Phragmites; above 500 µS/cm the specific conductance ranges for cattail and Phragmites both overlap with the specific conductance range for Spartina (undifferentiated). Similar to what Silvestri *et al.* (2005) posited in their study of Italian salt marshes, it appears that salinity alone is not a strong predictor of halophyte zonation in areas of the Scarborough Marsh that have been impacted by concentrated discharges of runoff. Although Phragmites is generally viewed as a colonizer of low-salinity regions in altered salt marsh systems, the specific conductance data presented here indicate that it can propagate into the higher salinity regimes dominated by *Spartina alterniflora* and *Spartina Patens.*

3.2.4 Relationship of Porewater Specific Conductance and Distance from Marsh Fringe in the Phragmites Study Sites

As explained in Silvestri *et al.* (2005), research has shown that soil salinity in the low-marsh region of unaltered coastal salt marshes gradually increases with marsh surface elevation (i.e., away from the tidal creek or river), reaching a maximum just above the mean high water (MHW) level near the outer limit of the low-marsh region. At higher elevations in the high-marsh, soil porewater salinity tends to decrease toward the marsh fringe due to progressively less frequent tidal flooding and a commensurate reduction in salt input.

In this section we explore whether this high-marsh salinity gradient (i.e., lower salinity near the marsh fringe progressing to higher salinities in the direction of the high-marsh/low-marsh boundary) is also present in areas dominated by Phragmites for both the source and off-gradient transects.

Except for source transect DR-B which extends approximately 160 meters from the runoff source, we selected only survey points that are within 120 meters from the marsh fringe and considered only those survey points that were dominated by Phragmites or cattail for the linear regression analyses discussed below.

Table 3.2.4-1 lists the source transects and the associated off-gradient transects along with the horizontal distances separating both. The source and off-gradients transects used in the regression analyses are shown in **Appendix C-1** as red lines on their respective site maps. **Figures C-2A** through **Figure C-2K** in **Appendix C** are scatter plots of distance-from-marsh-fringe versus specific conductance for each transect along with pertinent linear regression data and p-value for level of statistical significance. We used Microsoft Excel to generate the scatterplots, trend lines, and linear regression equations shown in these figures and the Real-Statistics add-in for Excel to calculate the p-values for each transect. Results of the regression analyses used to calculate the p-values are presented in **Appendix E**. A p-value ≤ 0.05 is the benchmark to determine whether the regression trend-line projected through the data points for each transect yields a statistically significant linear relationship from which we can infer a specific conductance (salinity) gradient.

Source transect DR-A, its off-gradient transect T-1/DR-A, source transect DR-B, off-gradient transect LR-C and source transect MR-A are the only transects that show statistically significant ($p \leq 0.05$) linear relationships between distance-from-marsh-fringe and specific conductance. However, the low R-squared value of 0.38 for transect DR-B indicates that the regression model shown in **Figure 3.2.4-1b** explains less than 40% of the variability between these two variables; therefore, we omitted it from further discussion in this section. We also omitted transect LR-C from consideration because it appears unrepresentative of the broader local conditions since it is based on only three survey points covering a distance of 20 meters.

Table 3.2.4-1 Source transects and their off-gradient counterparts

Runoff Source Transect	Off-gradient Transect	Estimated Distance (m) from Source Transect
DR-A	T-1/DR-A	230
DR-B	None associated	na
LR-A	LR-E	225
LR-D	LR-C & LR-E	185 & 270
NR-A	none associated	—
NR-B	NR-C	50 (15 m of this is road embankment)

These regression results suggest that, depending on site macro- and micro-topography, stormwater discharge can affect the porewater salinities on the high-marsh over lateral distances on the order of 200 meters away from the runoff source[30] and cause irregular pooling of runoff on the marsh plain that may mask the characteristic high-marsh salinity gradient. This pooling notion appears consistent with relatively large dimensions of Phragmites stands relative to the associated stormwater point-sources at the study sites.

Positive slopes for regression lines for transects DR-A, T-1/DR-A and MR-A are consistent with a high-marsh salinity gradient, but source transects DR-A and MR-A have steeper regression line slopes (46.9 and 45.1, respectively) which suggest stronger salinity gradients compared to the slopes for off-gradient transect T-1/DR-A (slope = 13.7).

We used Microsoft Excel's *Slopestest* function to determine whether the regression lines for source transect DR-A and its off-gradient transect T-1/DR-A are statistically different. The analysis shows that DR-A and T-1/DR-A are significantly different ($p = 0.00253$), which is consistent with their regression line slopes differing by a factor of 3.4 and the notion that the salinity conditions of the source transect should be markedly different from its off-gradient transect 250 meters distant.

3.2.5 Marsh-Fringe Reference Sites

The principal objective of the marsh-fringe reference site (reference sites) surveys was to collect porewater specific conductance data near the marsh fringe in relatively unspoiled areas of the Scarborough Marsh (i.e., where evidence of excavation/erosion, invasive plants and concentrated stormwater discharge is absent) and compare these to the porewater data from

[30] Local macro- and micro-topography likely also affect the extent and configuration of these runoff-impacted areas.

the 11 stormwater-impacted study sites where Phragmites dominates the marsh fringe and the high-marsh.

Table 3.2.5-1 presents porewater specific conductance data for the 10 *Spartina patens* survey points at the reference sites. **Table 3.2.5-2** presents a summary of important descriptive statistics for specific conductance for these reference sites along with the same data for each dominant plant species encountered at the 11 Phragmites study sites. **Figure 3.2.5-1** is a boxplot of specific conductance for these same data.

Porewater specific conductance for the 10 *Spartina patens* reference survey points ranged between 1411 µS/cm [*8 ppt*] and 2293 µS/cm [*14 ppt*] with a mean of 1914 µS/cm [*12 ppt*] and a median of 1963 µS/cm [*12 ppt*]. According to the Shapiro-Wilks normality test these data are normally distributed.

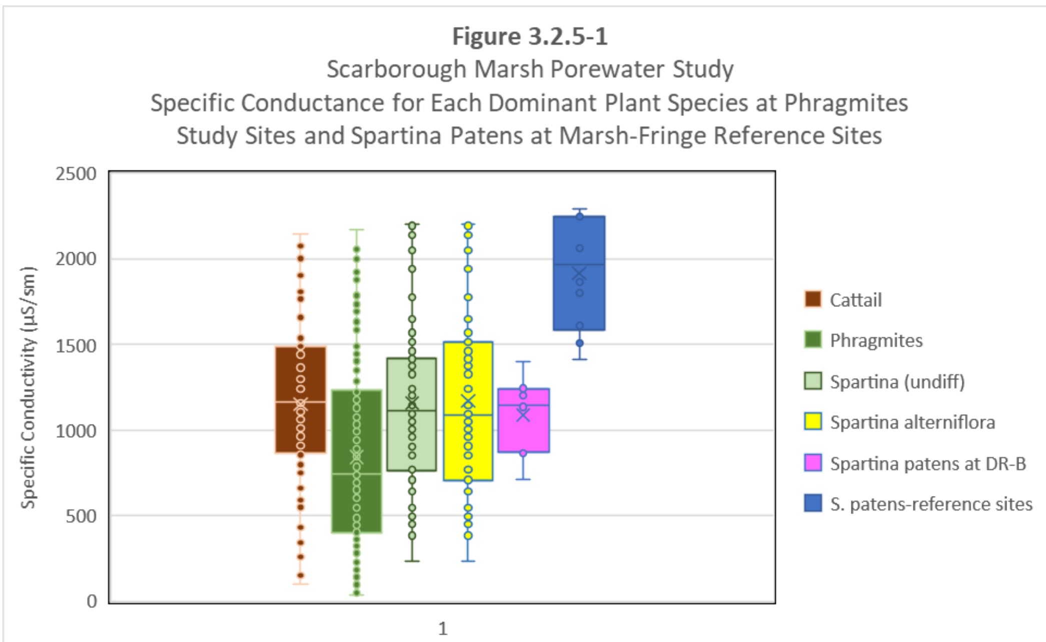
Comparison of these data for the reference sites to the data for dominant plant species from the 11 Phragmites study sites indicates that the mean and median porewater specific conductance are higher at the reference sites compared to Phragmites study site data for cattails, Phragmites, Spartina (undifferentiated), *Spartina patens* and *Spartina alterniflora*. Furthermore, the inner-quartile range for *Spartina patens* at the marsh-fringe reference sites brackets higher specific conductances compared to the inner-quartile range data for *Spartina patens* from Phragmites study site DR-B.

Table 3.2.5-1 Porewater specific conductance for *Spartina patens* at marsh-fringe reference sites

Survey Station (point)	Sub-Watershed	Distance from Marsh Fringe (meters)	Specific Conductance (µS/cm)
14	Dunstan River	6	1611
15		4.5	1505
16		6	2060
21	Nonesuch River	9	1411
22		3	1802
24		1.5	2253
25		4	2247
26	Libby River	1	1866
27		1	2095
28		1	2293

Table 3.2.5-2 Summary statistics for the *Spartina patens* survey points in the marsh-fringe reference sites and each dominant plant species encountered at the stormwater-impacted Phragmites study sites. Specific conductance (µS/cm) values are unbracketed; salinity [ppt] values are in brackets.

Category	No. of Points	Min-Max	Mean/Median	Normal Distribution
Cattails (Phragmites sites)	58	99-2146 **[0-13]**	1149/1161 **[7/7]**	Yes
Phragmites (Phragmites sites)	159	35-2169 **[0-13]**	842/744 **[6/4]**	No
Spartina (undifferentiated; Phragmites sites)	74	232-2203 **[0-13]**	1157/1115 **[7/6]**	No
S. alterniflora (Phragmites sites)	63	232–2203 **[1-13]**	1175/1090 **[7/6]**	No
S. patens (Phragmites sites)	12	712–1401 **[4-8]**	1063/1140 **[6/7]**	Yes
Marsh-fringe reference sites (*S. patens*)	10	1411-2293 **[8-14]**	1914/1963 **[12/12]**	Yes



Kruskal-Wallis Test results show a statistically significant difference (p ≤ 0.05) between the dominant plant porewater data from the Phragmites study sites and *Spartina patens* at the reference sites. Dunn's Test results show that the specific conductance data for the *Spartina patens* reference sites are significantly different (greater; p values ranging from 1.17E-07 to 2.76E-03) compared to the data for cattails, Phragmites and Spartina (including both subspecies) from the Phragmites study sites. **Table 3.2.5-3** summarizes this information. As shown in **Figure 3.2.5-1**, the inter-quartile ranges for the porewater data from the dominant plant species at Phragmites study sites do not overlap with inter-quartile range for the reference sites.

In summary, the marked differences between specific conductance data from the relatively unspoiled marsh-fringe reference sites and the 11 stormwater-impacted Phragmites study sites shows that concentrated stormwater influx onto the high-marsh plain significantly lowered porewater salinity beyond the Phragmites stands into the high-marsh region where native *Spartina patens* (site DR-B) and short-form *Spartina alterniflora* (at the other 10 sites) are present. With annual precipitation in Maine projected to increase on the order of 10 - 15% by the middle of the 21st century compared the late 20th century in conjunction with climate change (NCICS, 2022), existing stormwater loads discharged onto the marsh plain would also increase commensurately and exacerbate changes to the marsh ecology, including encroachment of invasive plants such as Phragmites.

Table 3.2.5-3 Summary of pairwise plant species specific conductance comparisons for the Phragmites study sites v. the marsh-fringe references sites using Dunn's Test

Comparison	Significant? P-value
Cattail v. *S. patens* (reference)	Yes; p = 7.68E-04
Phragmites v. *S. patens* (reference)	Yes; p = 1.17E-07
S. alterniflora v. *S. patens* (reference)	Yes; p = 5.82E-04
DR-B *S. patens* v. *S. patens* (reference)	Yes; p = 2.76E-03

4 SUMMARY

In early 2020, Friends of Scarborough Marsh (FOSM) approved funding for field research to characterize the salinity of groundwater and shallow soil porewater in several areas of the Scarborough Marsh where extensive Phragmites stands dominate the marsh vegetation and where stormwater conveyance structures such as ditches, culverts and pipes discharge runoff onto the marsh fringe and the high-marsh plain.

The goals of this study were threefold:

- Characterize the salinity of shallow groundwater below three dense Phragmites stands in the Dunstan River, Nonesuch River and Libby River sub-watersheds of the Scarborough Marsh which are downgradient from concentrated stormwater discharges.
- Use specific conductance of the shallow soil as a proxy for soil porewater salinity to evaluate the salinity distribution of the salt marsh soils in and around seven large Phragmites stands which are downgradient from concentrated stormwater sources in the Dunstan River, Nonesuch River and Libby River sub-watersheds. Three of these Phragmites stands were also part of the groundwater study.
- Evaluate the potential effects of stormwater discharge and subsequent growth of Phragmites on the positive salinity gradient observed by researchers between the high-marsh region of a healthy salt marsh and the high marsh/low-marsh boundary (i.e., salinity increases away from the marsh fringe toward the high-marsh/low-marsh boundary).

4.1 Groundwater

Shallow groundwater samples collected from eight monitoring wells in August, September and October 2020 (three rounds of monitoring) had salinities ranging from 2 to 10 ppt.

4.2 Soil Porewater Salinity at the Phragmites Study Sites

Between November 2020 and June 2021, we measured porewater specific conductance and recorded the dominant marsh plant species data for 291 survey points at 11 Phragmites study sites in 7 Phragmites stands in the Dunstan River, Libby River and Nonesuch River sub-watersheds. Based on these specific conductance data, porewater salinities for the entire study ranged from 0 ppt to 13 ppt with a mean and median of 6 ppt.

4.2.1 Sub-watershed Comparisons

Porewater salinities for the 92 survey points in the Dunstan River sub-watershed ranged between 0 ppt and 13 ppt with a mean and median of 6 ppt. Porewater salinities for the 121 survey points in the Libby River sub-watershed ranged between 0 ppt and 13 ppt with a mean and median of 6 ppt. Porewater salinities for the 78 survey points in the Nonesuch River sub-watershed ranged between 0 ppt and 11 ppt with a mean and median of 5 ppt.

Statistical testing shows that specific conductance and salinity data for the Nonesuch River sub-watershed sites are significantly different (lower; $p \le 0.05$) compared to the Dunstan River and Libby River sub-watershed sites, whereas data from the Dunstan River and Libby River sub-watersheds are not significantly different.

4.2.2 Comparisons by Dominant Plant Species

The three dominant plant species encountered in the study sites were: narrow-leaf cattail (*Typha angustifolia*), Phragmites (*Phragmites ssp. australis*) and Spartina (both *Spartina pat*ens and short-form *Spartina alterniflora*). Porewater salinities for the 58 survey points dominated by cattails ranged between 0 ppt and 13 ppt with a mean and median of 7 ppt. Porewater salinities for the 159 survey points dominated by Phragmites ranged between 0 ppt and 13 ppt with a mean of 5 ppt and a median of 4 ppt. Porewater salinities for the 74 survey points dominated by Spartina ranged between 1 ppt and 13 ppt with a mean of 7 ppt and a median of 6 ppt.

Statistical testing shows that Phragmites specific conductance data are significantly different (lower; $p \le 0.05$) compared to the data for both cattails and Spartina, whereas porewater data for cattail and Spartina (undifferentiated) are not significantly different, suggesting that freshwater intrusion from sources such as stormwater conveyances is a factor in controlling the occurrence of Phragmites.

4.2.3 Study Site Comparisons (undifferentiated by plant species)

Statistical comparison of the specific conductance data among the 11 Phragmites study sites (ignoring dominant plant species) shows significant differences ($p \le 0.05$) for 24 site-site pairs. All study sites were significantly different from at least two other sites. On the low end, site DR-A (in Dunstan River sub-watershed) is significantly different from only two sites, whereas on the upper end, site NR-A (in Nonesuch River sub-watershed) is significantly different (lower values) from six sites.

4.2.4 Study Site Comparisons (differentiated by plants species)

Within the same plant species, statistical pairwise site comparisons (10 sites with cattail data, 11 sites with Phragmites data and 10 sites with Spartina data) show significant differences ($p \le 0.05$) for 10 cattail site pairs, 18 Phragmites site pairs and 17 Spartina site pairs. The median specific conductance values for most of these significantly different site pairs generally differ by a factor of two or more.

Cattail Data – Specific conductance data for seven out of the ten sites with cattail data were significantly different from at least one site. On the high end, site DR-A is significantly different for four sites. Sites DR-B, LR-C and NR-C show no significant differences with any sites.

Phragmites Data – Specific conductance data for each of the 11 sites with Phragmites data were significantly different from at least one site. On the low end, sites MR-A and NR-C are significantly different from one site. On the high end, site NR-A is significantly different (has lower values) from nines sites.

Spartina (undifferentiated) Data – Specific conductance data for each of the tens sites with Spartina data were significantly different from at least one site. On the low end, sites LR-C and LR-D are significantly different from one site. On the high end, site NR-A is significantly different (has lower values) from 10 sites.

Other interesting observations include:

- The median specific conductance for short-form *Spartina alterniflora* adjacent to the Phragmites front at site DR-A is almost twice that of *Spartina patens* in the same relative position at site DR-B, suggesting that either runoff dilution of tidal flux is significantly greater for DR-B or that areas dominated by *Spartina alterniflora* at site DR-A are at lower elevations (i.e., subjected to more frequent tidal flooding) than areas dominated by *Spartina patens* at site DR-B.
- Median specific conductances for all three plant species at site NR-A are uniformly lower than those at NR-B, although both sites border the same small tributary creek to the Nonesuch River. This suggests that dilution of tidal flux with freshwater runoff is greater for site NR-A, that NR-A lies at higher elevations than NR-B (i.e., NR-A is inundated by tidal flow less frequently than NR-B), or both. Greater influx of runoff into site NR-A is plausible, considering that a freshwater wetland directly west of NR-A and stormwater from a half-mile section of Black Point Road both drain into site NR-A, whereas site NR-B receives runoff from a relatively short section of road ditch and the adjacent residential property (i.e., less runoff flows into NR-B).

4.2.5 Porewater Specific Conductance versus Distance-from-Marsh-Fringe

The salinity profile of the pore water in the high-marsh region of a healthy salt marsh typically shows a positive salinity gradient with salinity increasing away from the marsh fringe in the direction of the high-marsh/low-marsh boundary. Source transect DR-A, its off-gradient transect T-1/DR-A and source transect MR-A in the Dunstan River sub-watershed are the only transects that show strong, statistically significant ($p \leq 0.05$) positive linear relationships between distance-from-marsh-fringe and specific conductance (i.e., support a high-marsh salinity gradient).

4.2.6 Broad conclusions of the Phragmites porewater study

The three dominant plants species (cattail, Phragmites, Spartina) show broad overlap in porewater salinities. This suggests that while Phragmites may initially exploit low-salinity regions of the marsh fringe/high-marsh plain which have been impacted by tidal restrictions and/or influx of stormwater, after Phragmites becomes established, it can spread and flourish into high-salinity regimes normally dominated by native salt marsh plants such as short-form *Spartina alterniflora* and *Spartina patens.*

Chambers (1997) study of porewater chemistry in a Connecticut tidal marsh found Phragmites growing and flowering throughout a porewater salinity range from 12 to 30 ppt. Adams and Bate (1999) found Phragmites in a South African tidal marsh flooded by sea water with a salinity of 35 ppt. They and Burdick *et al.* (2001) suggest that Phragmites can tolerate surface waters high in salt, provided that the associated rhizosphere (the root system) receives freshwater dilution from groundwater originating from the surrounding uplands.

Based on six source transects at six study sites, specific conductance data for only two source transects (DR-A and MR-A) within the Phragmites-dominated areas showed statistically significant linear relationships that support a characteristic high-marsh salinity gradient with salinity increasing from the marsh fringe toward the high-marsh/low-marsh boundary.

We found no broad pattern in distribution of specific conductance values within the dense Phragmites stands (e.g., isosurfaces[31]) at the 11 Phragmites study sites, but this may be an artifact of the reconnaissance nature of this study. A denser sampling pattern (e.g., a survey array based on an orthogonal sampling grid (e.g., with 10 m by 10 m grid cells) of the impacted high-marsh plain would be necessary to assess the distribution of specific conductance/salinity within Phragmites stands in a more meaningful way.

4.3 Comparison to Unspoiled High-Marsh Regions of the Scarborough Marsh

Statistical comparison of porewater data from the Phragmites study sites and unspoiled marsh-fringe reference sites shows that porewater specific conductance and salinity data for *Spartina patens* at the reference sites are significantly different (higher) compared to the values measured for cattail, Phragmites and both Spartina subspecies at the Phragmites study sites.

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[31] Isosurface is a surface in 2- or 3-dimensional space that represents points of a constant value or a range of values (e.g., specific conductance, pressure, temperature, velocity, density) within a volume of space

In summary, the observations and conclusions of this study show that stormwater discharges to the salt marsh fringe and the high-marsh plain have adversely impacted the ecology of native salt-marsh plants over broad regions of the Scarborough Marsh and lowered marsh soil porewater salinities to levels that favor aggressive growth of invasive plants such as Phragmites. As development around the Scarborough Marsh continues to increase and Maine's projected annual precipitation increases because of climate change, this Phragmites problem will grow, eventually impacting a broader area of the marsh than the current estimate of 4.4% unless current stormwater management practices change for all developments and roadways proximal to the Scarborough Marsh.

5 RECOMMENDATIONS

5.1 Preliminary Recommendations for Municipal Stormwater Management

This study focused on seven Phragmites stands impacted by stormwater discharge out of the 111 large stands identified by Normandeau (2019). Preliminary examination of the locations of stormwater discharge structures in the Town of Scarborough using the Town's geographic information system (https://webapps2.cgis-solutions.com/scarboroughAdvanced/; drainage utilities layer) shows that large number of these large Phragmites stands occur adjacent to or downgradient from stormwater drainage structures such as culverts, road ditches and outfall pipes. A more comprehensive analysis of these Phragmites stands and nearby stormwater discharges will be necessary to determine how many Phragmites stands are potentially linked to stormwater discharges.

While eradication of existing Phragmites stands using conventional methods such as cutting and herbicide application has proven relatively ineffective on the Scarborough Marsh and elsewhere in North America, moving existing and future sources of stormwater discharge away from the marsh plain directly into the marsh creeks and rivers (e.g., using pipes or small ditches [runnels] cut into the marsh surface) may help limit the spread of large Phragmites stands beyond their current footprints. This strategy would likely require modifications to the Town's existing municipal stormwater discharge plan as well as a discharge permit(s) issued by the Maine Department of Environmental Protection (DEP) to discharge stormwater directly into the marsh rivers and creeks (i.e., into *Waters of the State*). FOSM proposes to begin discussions with the Town and DEP to explore the feasibility of implementing such a strategy. Where practical, another strategy could involve discharging stormwater onto permeable (e.g., sandy) upland soils for infiltration into groundwater using infiltration basins or shallow injection wells.

Increasing natural tidal flow by removing tidal restrictions to allow higher salinity waters to inundate areas compromised by stormwater and Phragmites growth is another strategy worth exploring. For example, increasing tidal flow north of the Eastern Trail and Route 1 would help raise the porewater and shallow groundwater salinities in study areas DR-A, DR-B and MR-A. Lowering the invert elevation of the three culverts draining the Libby River beneath Black Point Road to the elevation of the riverbed would allow the upper Libby River where study sites LR-A through LR-E are located to completely drain during the ebb tide, preventing upland freshwater drainage from pooling north of the road and diluting the salinity of the subsequent flood tide.

5.2 Recommendations for Additional Work

We offer two recommendations for future work to expand our understanding of the Phragmites/stormwater problem in the Scarborough Marsh.

1. Preliminary examination of the locations of stormwater discharge structures in the Town of Scarborough using the Town's geographic information system (GIS; https://webapps2.cgis-solutions.com/scarboroughAdvanced/ – drainage utilities layer) shows that many of the large Phragmites stands mapped by Normandeau (2019) are adjacent to or downgradient from stormwater drainage structures (e.g., culverts, road ditches, outfall pipes). A more comprehensive analysis of the Town's stormwater discharges in relation to the locations of mapped Phragmites stands will be necessary to assess the potential impact of these stormwater structures on the Scarborough Marsh's current and future Phragmites problem. This assessment should include an engineering study to estimate the annual volume of stormwater that currently discharges to the marsh and projections for future discharges in anticipation of climate-change induced increases in Maine's annual precipitation.
2. A dense survey grid in one or more of the Phragmites stands studied for this project would be useful to study the distribution of porewater specific conductance/salinity further. More comprehensive porewater analyses (e.g., major cations and anions, dissolved oxygen and sulfur, nutrients and biochemical analytes related to plant/root respiration) and measurement of soil hydraulic conductivity at some of these sites would help advance theories regarding Phragmites propagation and its survival in high-salinity regimes.
3. The Phragmites stands evaluated in this study represent only a fraction of the Phragmites problem identified by Normandeau (2019). Moreover, data documenting the extent of stormwater impacts (i.e., reduction in porewater/root zone salinity) elsewhere in the marsh are lacking, as are data documenting the health of marsh plants elsewhere near the marsh fringe, and in the high-marsh and low-marsh regions of the Scarborough Marsh. We cannot fully assess the health of the marsh without these data and other data such as hydrologic monitoring and modeling. As an interim measure that focuses on plant ecology, we recommend using remote sensing techniques that rely on crop reflectance and/or other properties to: (1) map the key plant communities and their habitats throughout the marsh, (2) once mapped, identify areas in which these plants are stressed using both ground-based and remote-sensing techniques to understand the nature of the stress(es), and (3) develop a remote-sensing technique (with ground-truthing) to map the porewater salinity of the rooting zone throughout the marsh.

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Friends of Scarborough Marsh (FOSM) provided the funding to procure the equipment and supplies used for this project. Dr. Joseph Staples from the University of Southern Maine initially proposed using soil specific conductance to study Scarborough Marsh plant/salinity distributions for A. DeVecchis' UROP project. Methods and ideas generated from that project enabled us to conduct the Phragmites porewater study upon which much of this project is based. FOSM provided an intern stipend to A. DeVecchis to conduct the porewater survey field work.

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APPENDIX A - SCARBOROUGH MARSH RESTORATION PROJECTS (2003 TO 2013)

(Data compiled by Steve Pinette on 1/13/2022 from available reports and documents)

A-1. PROJECTS FOCUSED ON RESTORING HYDROLOGIC FUNTION (refer to Figure A.1 for location map)

Cascade Brook (2003; 88 acres affected)

Treatments: Removal of peat piles and road spoils deposited on marsh surface following 500-year storm in 1996; lowering of water control structure near Pine Point Road; removing berms or parts of berms upstream from water-control structure; herbicide treatment of Phragmites stands.

Results: The tidal hydroperiod and flooding depths increased; Phragmites monocultures were replaced with diverse plant growth; some Phragmites regrowth occurred.

Middle Nonesuch River (2006; 250 acres affected)

Treatments: Ditch plugging and berm removal

Results: Raised groundwater table; increased extent of tidal flooding and hydroperiod; retained water in existing permanent pools; trend toward development of desirable salt marsh plant community; decreased extent of Phragmites.

Mill Brook (2004; 14 acres affected)

Treatments: ditch-plugging to restore pool habitat to pre-ditch conditions; excavating a new ditch and clearing out two existing ditches to minimize freshwater pooling in the northern portion of the marsh; herbicide treatment of Phragmites stands.

Results: Substantial pool habitat restored; increased hydroperiod near ditch plugs; amount of Phragmites decreased.

Seavey Landing (2002; 25 acres affected)

Treatments: Plugging man-made ditches to restore hydrology to the marsh surface; excavation of shallow panne areas on the marsh surface to promote permanent pool habitat.

Results: Increased extent of permanent pools; raised groundwater table.

A-2. MAINE DEPARTMENT OF TRANSPORTATION BRIDGE & CULVERT PROJECTS

Route 1 Over Dunstan River (2004)

Treatment: Replaced undersized culverts with four 8-ft diameter culverts to improve tidal flooding and hydroperiod in upper Dunstan River marsh.

Results: Unknown; no follow-up study to document post-construction effects.

Black Point Road over Libby River (2006)

Treatment: Added two 72-inch diameter culverts to supplement existing 60-inch culvert to improved tidal flooding and recovery of native plant species in upper Libby River marsh.

Results (1-year post-installation): Increased the tidal range (by 20%), hydroperiod and salinity upstream of Pine Point Road.

A-3. PHRAGMITES STANDS TREATED WITH HERBICIDES

Focused efforts targeting small areas

Cascade Brook

(2004): Phragmites treatment area unknown

Libby River

(2005): five Phragmites areas treated by NRCS

Mill Brook

(2004): 12 Phragmites patches treated

Larger scale efforts from 2010 to 2013 (total area treated = 98.5 acres)

Cascade Brook: 7.4 acres

Dunstan River: 39 acres

Jones Creek: 22 acres

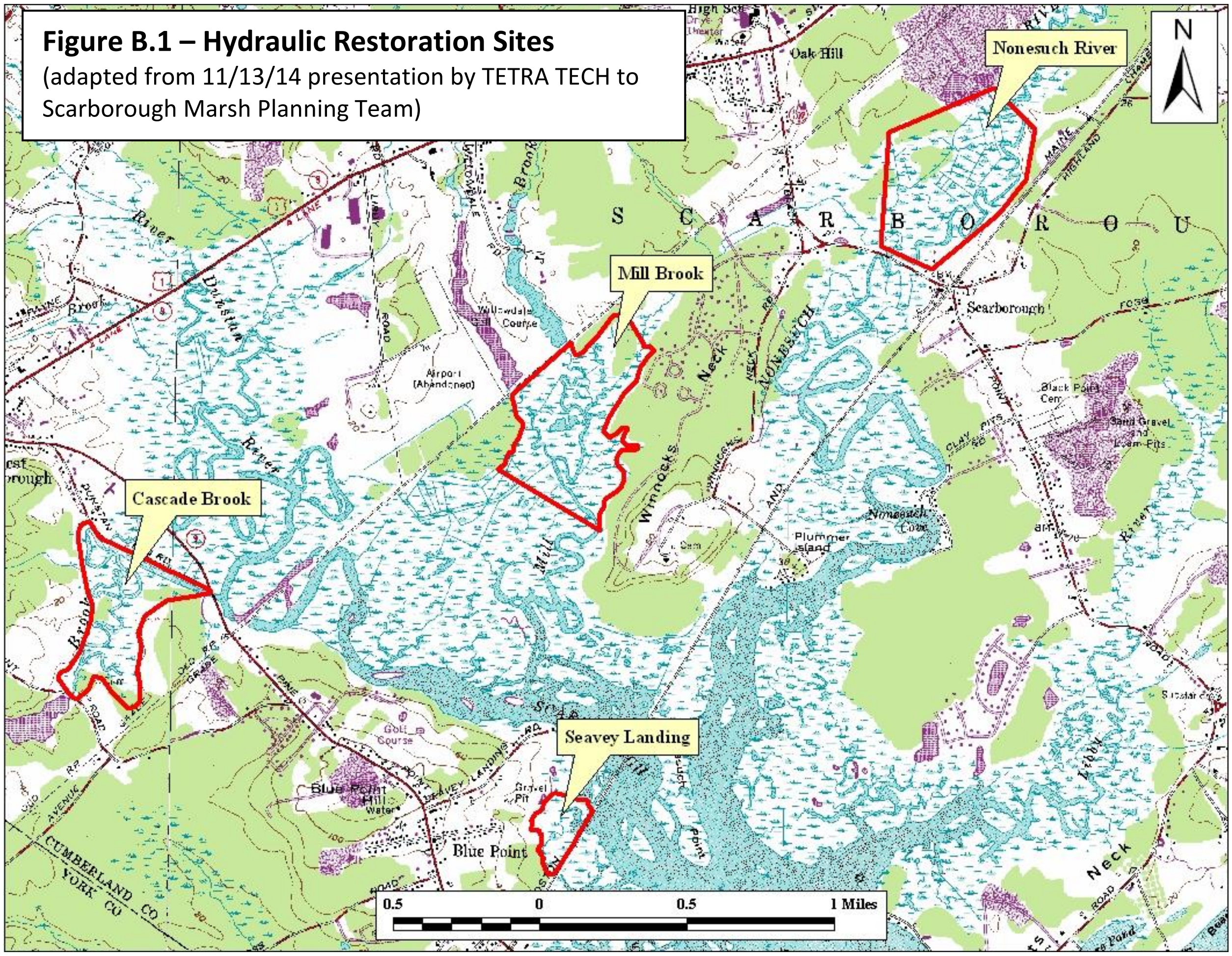
Libby River: 24 acres

Mill Brook: 0.7 acres

Nonesuch River: 5.4 acres

Note: No follow-up study exists to document post-2013 treatment efficacies.

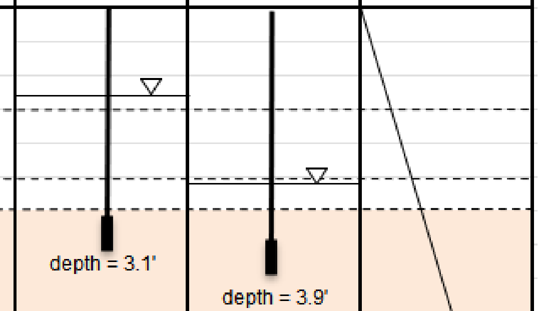
Figure B.1 – Hydraulic Restoration Sites
(adapted from 11/13/14 presentation by TETRA TECH to Scarborough Marsh Planning Team)



APPENDIX B - SOIL BORING LOGS AND MONITORING WELL DIAGRAMS

SOIL & MONITORING WELL LOG			
Project Name: FOAM Phragmites & Ground Water Salinity Study		**Boring ID**	**DM-1**
Location: Dunstan River Marsh		**Date (well installation)**	8/15/2020
FOSM Rep: S Pinette		**Total sampling depth**	4.5 ft.
		Shallow Ground Water Depth	1.27 ft. (on 8/28/2020)

Depth (ft)	**Sample interval (ft)**	**Description**	**Monitoring Well Diagram: DM-1S**	**DM-1M**	**BLANK**
0		Fibric peat (medium yellow brown) containing plant and root fragments with subordinate amounts (<25%) of dark yellow-brown amorphous humus and trace very fine sand.			
1					
		Hemic peat (dark yellow brown) containing greater than 50% amorphous humus with subordinate fibric material consisting of plant and root fragments; trace very fine sand.			
2					
		Fibric peat (dark yellow brown) in a matrix (+/-25%) of amorphorus humus			
3		Very fine sand (medium brownish gray) with trace of plant and root fragments.	depth = 3.1'		
4		~Orange-brown mottles (staining) in lower 0.5', indicating periodic exposure to air~		depth = 3.9'	
		Bottom of boring at 4.5 ft.			
5					
6					
7					
8					



Notes: (1) Monitoring well consists of 3/4-inch diameter Schedule 40 PVC with the bottom 6 inches perforated with 8 x 1/8-inch drilled holes; a PVC end-cap is installed at the bottom of the monitoring well. (2) Strata boundaries are approximate. The following symbol depicts depth to ground ground water in the monitoring well on August 28, 2021: ▽

SOIL & MONITORING WELL LOG	Boring ID	LR-1
Project Name: FOAM Phragmites & Ground Water Salinity Study	**Date (well installation)**	8/17/2020
Location: Dunstan River Marsh	**Total sampling depth**	9.0 ft.
FOSM Rep: S Pinette	**Shallow Ground Water Depth**	0.4 ft. (on 8/28/2020)

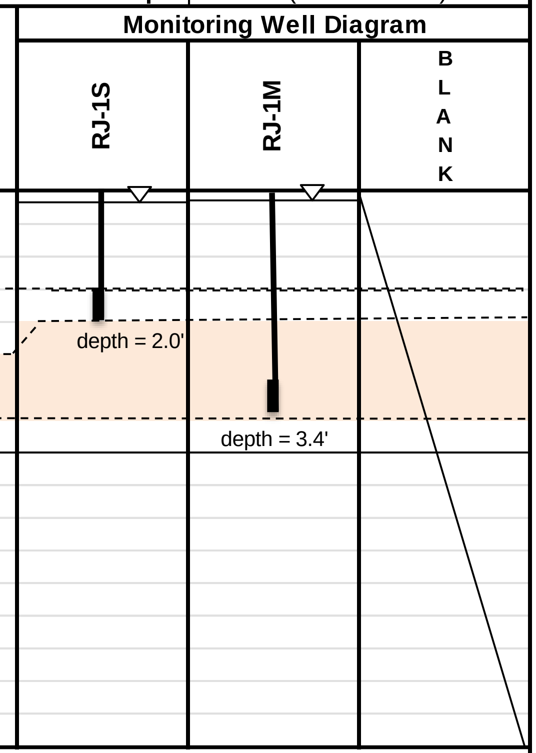
Depth (ft)	Sample interval (ft)	Description	Monitoring Well Diagram: LR-1S	LR-1M	LR-1D
0		Fibric peat (dark brown) containing plant and root fragments with subordinate amounts (<25%) of amorphous humus and trace very fine sand.	▽		
1		[color is dark yellow-brown between approx.1.5 - 3.5 ft.]			
2					
3			depth = 3.0		
4		Fibric peat and humus (dark brown) interbedded? with silty very fine sand (light gray)		▽	
5		Fibric peat (dark yellow-brown) with amorphous humus matrix			
6		Organic silty very fine sand (dark olive gray) interbedded? with fibric peat containing amorphous humus matrix		depth = 6.0'	
7		Fibric peat (dark brown) with amorphous humus matrix; trace very fine sand in 8 - 8.5' sample.			
8		Fibric peat (dark brown) with amorphous humus matrix interbeded? with mm-scale dark olive gray silty v.fine sand			▽
9		Bottom of boring at 9.1 ft.			depth =9.1'

Notes: (1) Monitoring well consists of 3/4-inch diameter Schedule 40 PVC with the bottom 6 inches perforated with 8 x 1/8-inch drilled holes; a PVC end-cap is installed at the bottom of the monitoring well. (2) Strata boundaries are approximate. The following symbol depicts depth to ground water in the monitoring well on August 28, 2021: ▽

SOIL & MONITORING WELL LOG		
Project Name: FOAM Phragmites & Ground Water Salinity Study	**Boring ID**	**RJ-1**
Location: Dunstan River Marsh	**Date (well installation)**	8/12/2020
FOSM Rep: S Pinette	**Total sampling depth**	4.0 ft.
	Shallow Ground Water Depth	0.2 ft. (on 8/28/2020)

Depth (ft)	Sample interval (ft)	Description
0		Fibric peat (light yellow brown) consisting of undecomposed plant and roots fragments with trace (<<5%) fine to medium sand in matrix
1		
		Hemic peat (dark brown) consisting of approx. equal portions fiber (plant/root frags) and amorphous humus matrix
2		
		Very fine sand (medium brownish gray) with trace plant and root fragments [color changes to light brownish gray around 3 ft]
3		
		Fibric peat (dark yellow-brown) with amorphous humus matrix (± 30%)
4		*Bottom of boring at 4.0 ft.*
5		
6		
7		
8		

Monitoring Well Diagram

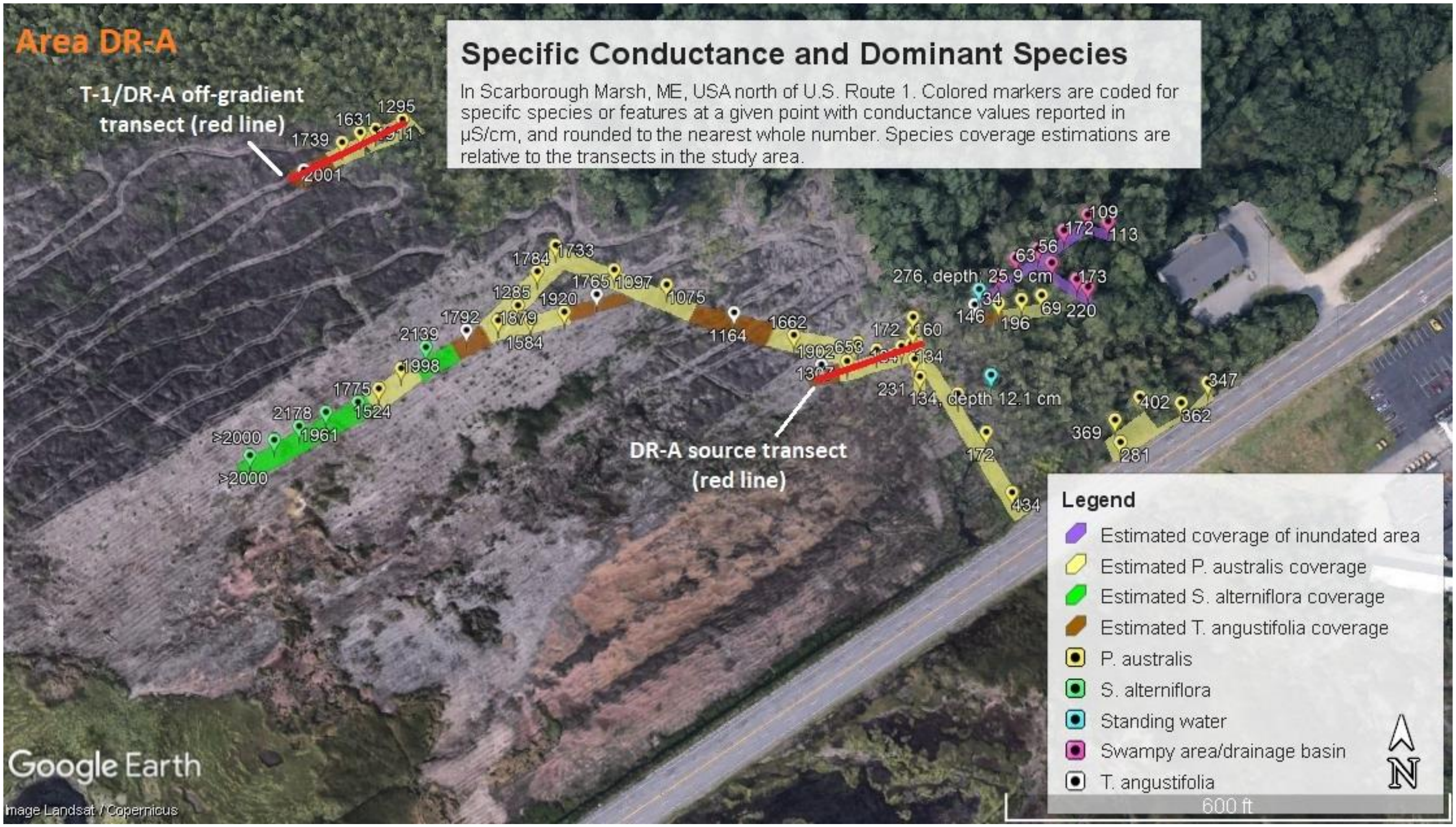


Notes: (1) Monitoring well consists of 3/4-inch diameter Schedule 40 PVC with the bottom 6 inches perforated with 8 x 1/8-inch drilled holes; a PVC end-cap is installed at the bottom of the monitoring well. (2) Strata boundaries are approximate. The following symbol depicts depth to ground water in the monitoring well on August 28, 2021: ▽

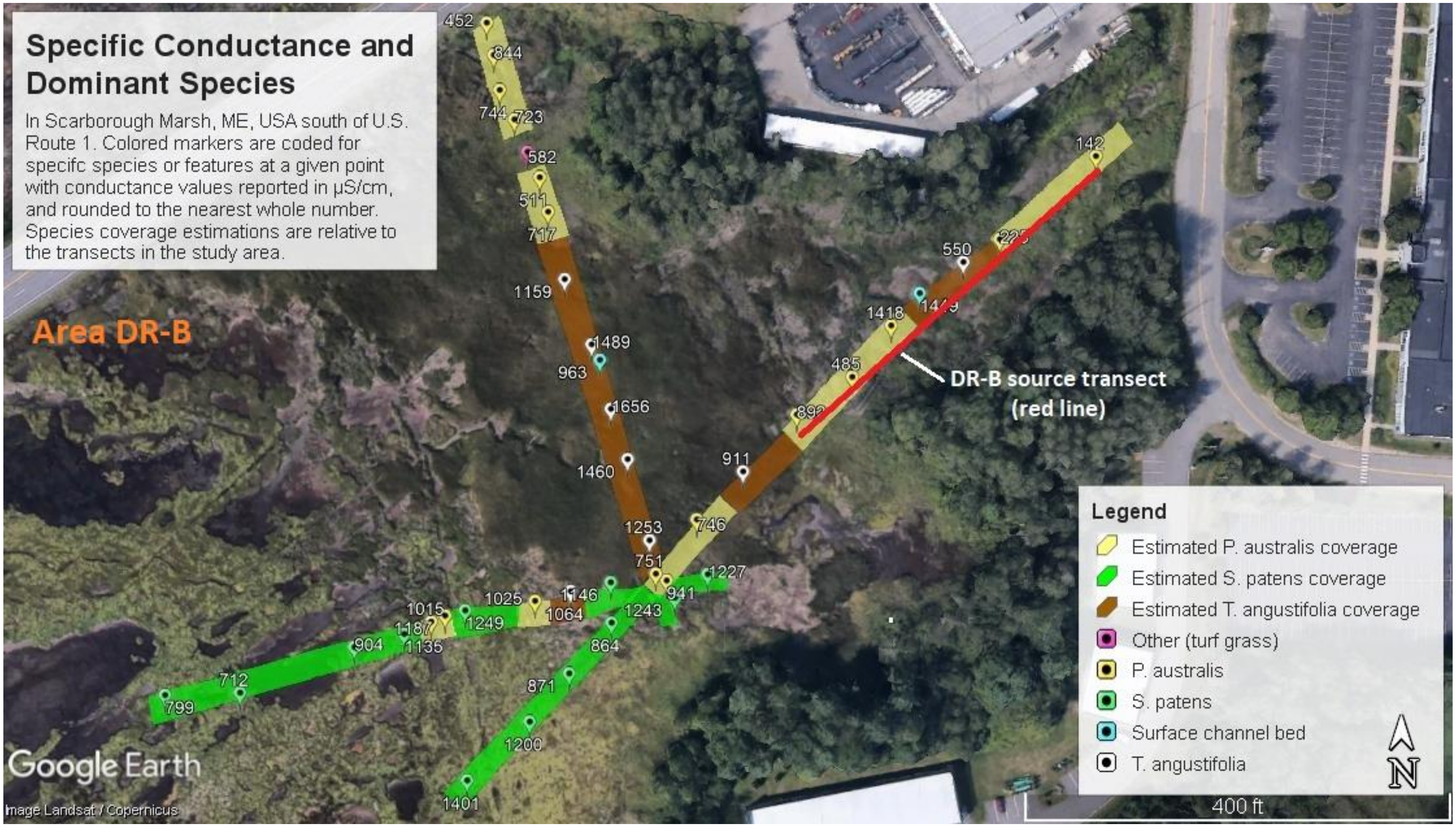
APPENDIX C - POREWATER SITE LOCATION MAPS AND MARSH-FRINGE DATA PLOTS

Appendix C-1. Location Maps for Porewater Study Sites

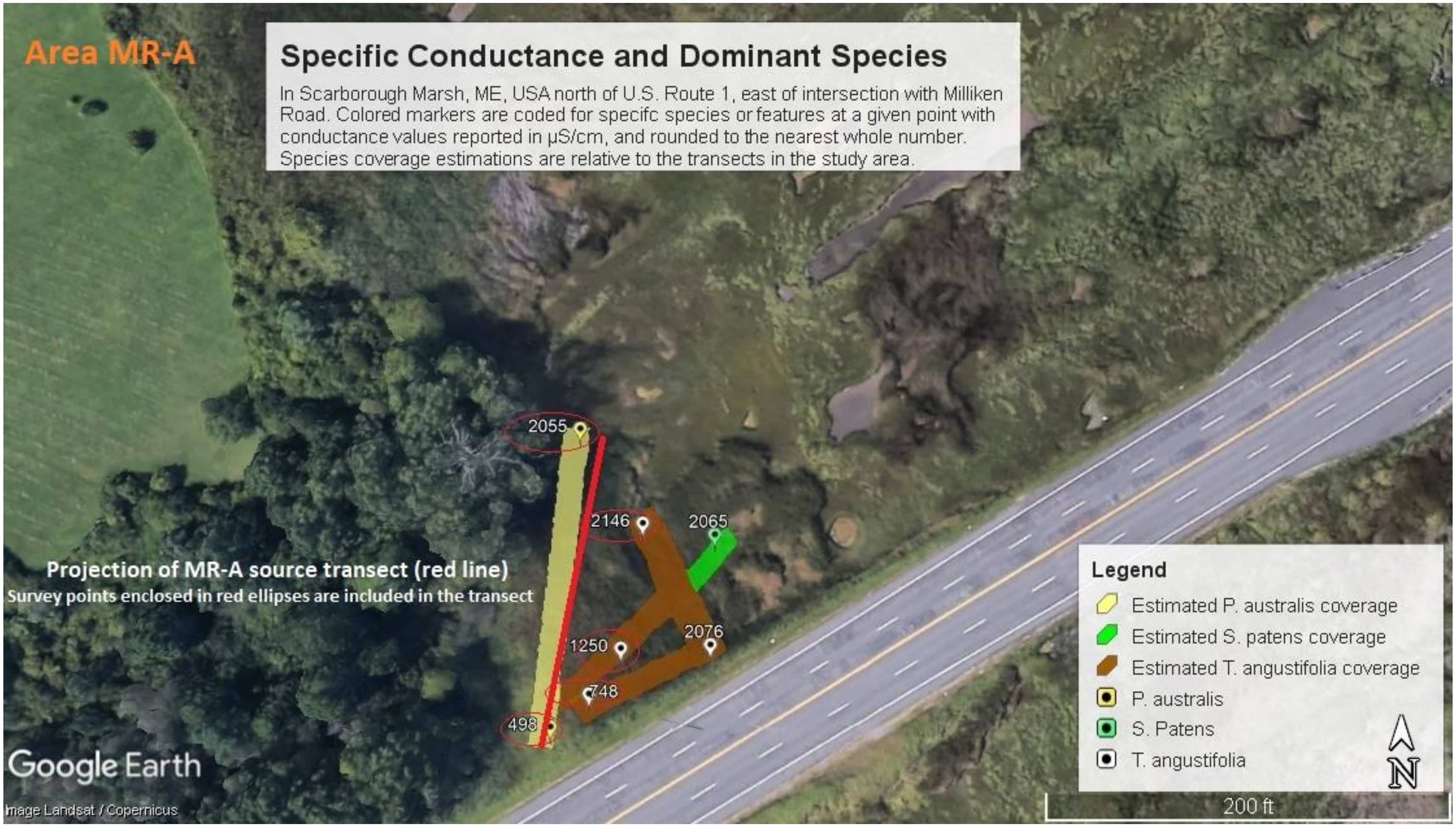
Site DR-A



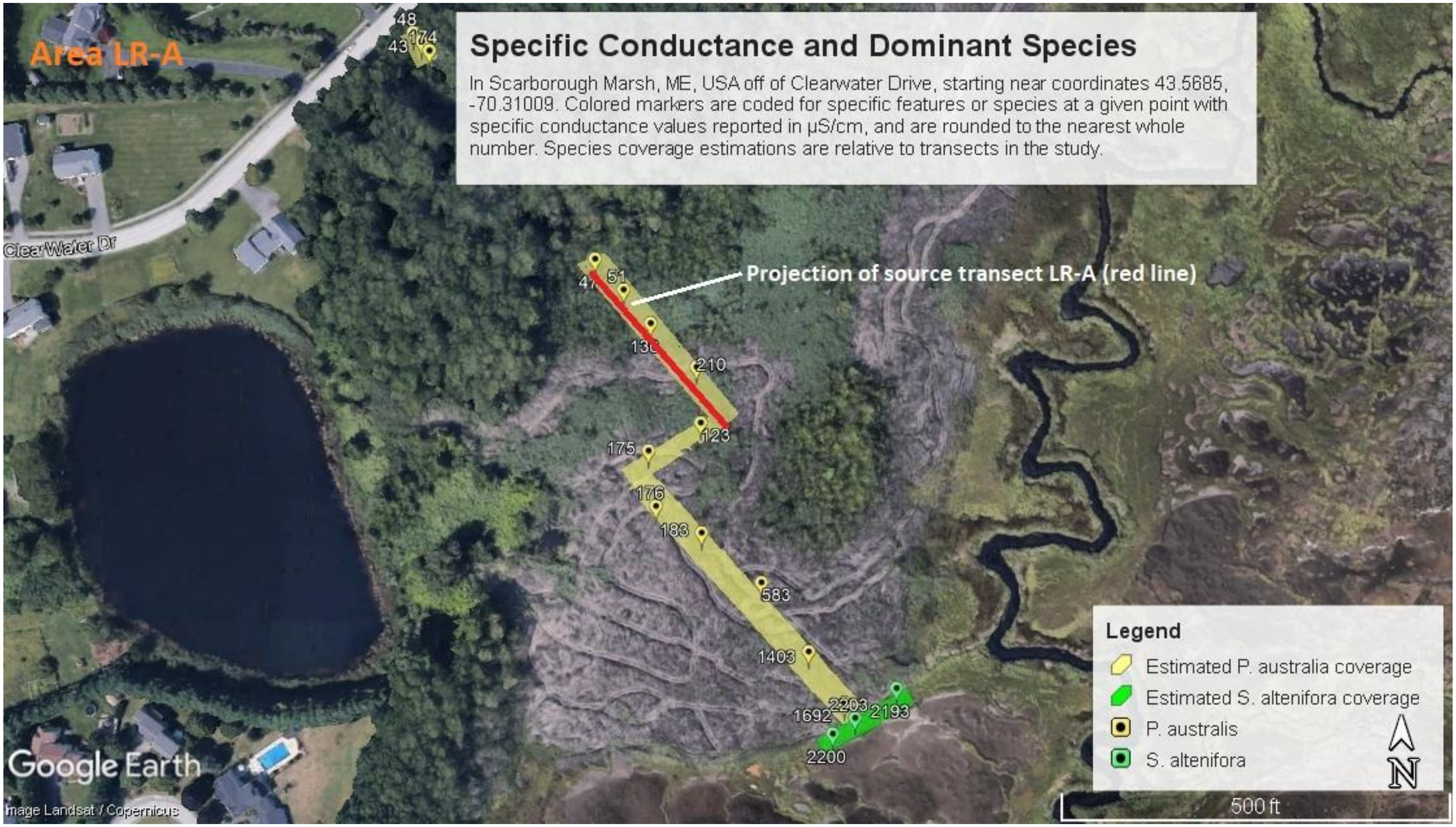
Site DR-B


Specific Conductance and Dominant Species
In Scarborough Marsh, ME, USA south of U.S. Route 1. Colored markers are coded for specifc species or features at a given point with conductance values reported in µS/cm, and rounded to the nearest whole number. Species coverage estimations are relative to the transects in the study area.
Area DR-B
DR-B source transect (red line)
Legend
Estimated P. australis coverage
Estimated S. patens coverage
Estimated T. angustifolia coverage
Other (turf grass)
P. australis
S. patens
Surface channel bed
T. angustifolia
N
400 ft
Google Earth
Image Landsat / Copernicus

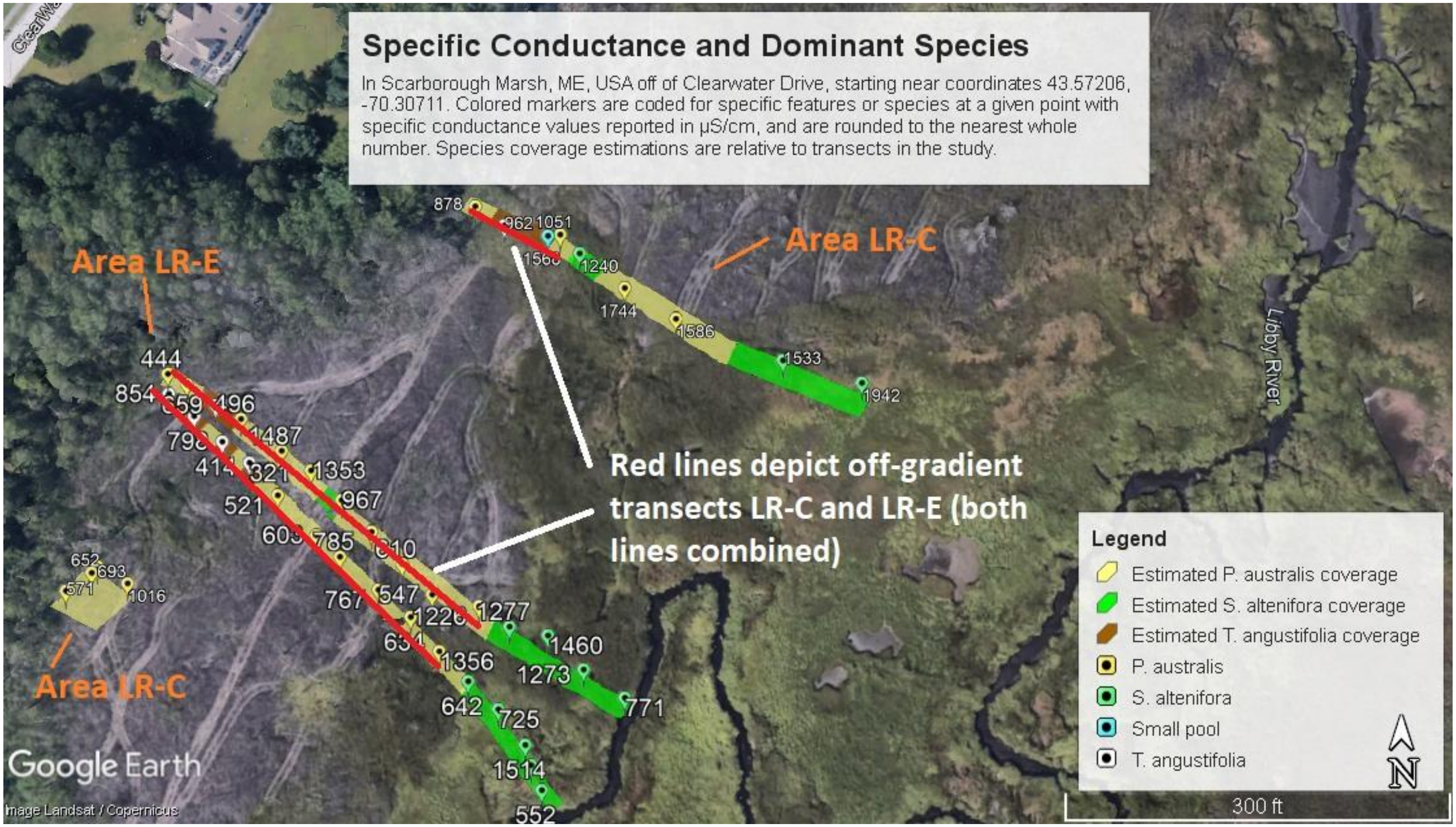
Site MR-A


Area MR-A
Specific Conductance and Dominant Species
In Scarborough Marsh, ME, USA north of U.S. Route 1, east of intersection with Milliken Road. Colored markers are coded for specifc species or features at a given point with conductance values reported in μS/cm, and rounded to the nearest whole number. Species coverage estimations are relative to the transects in the study area.
2055
2146
2065
1250
2076
748
498
Projection of MR-A source transect (red line)
Survey points enclosed in red ellipses are included in the transect
Legend
Estimated P. australis coverage
Estimated S. patens coverage
Estimated T. angustifolia coverage
P. australis
S. Patens
T. angustifolia
N
200 ft
Google Earth
Image Landsat / Copernicus

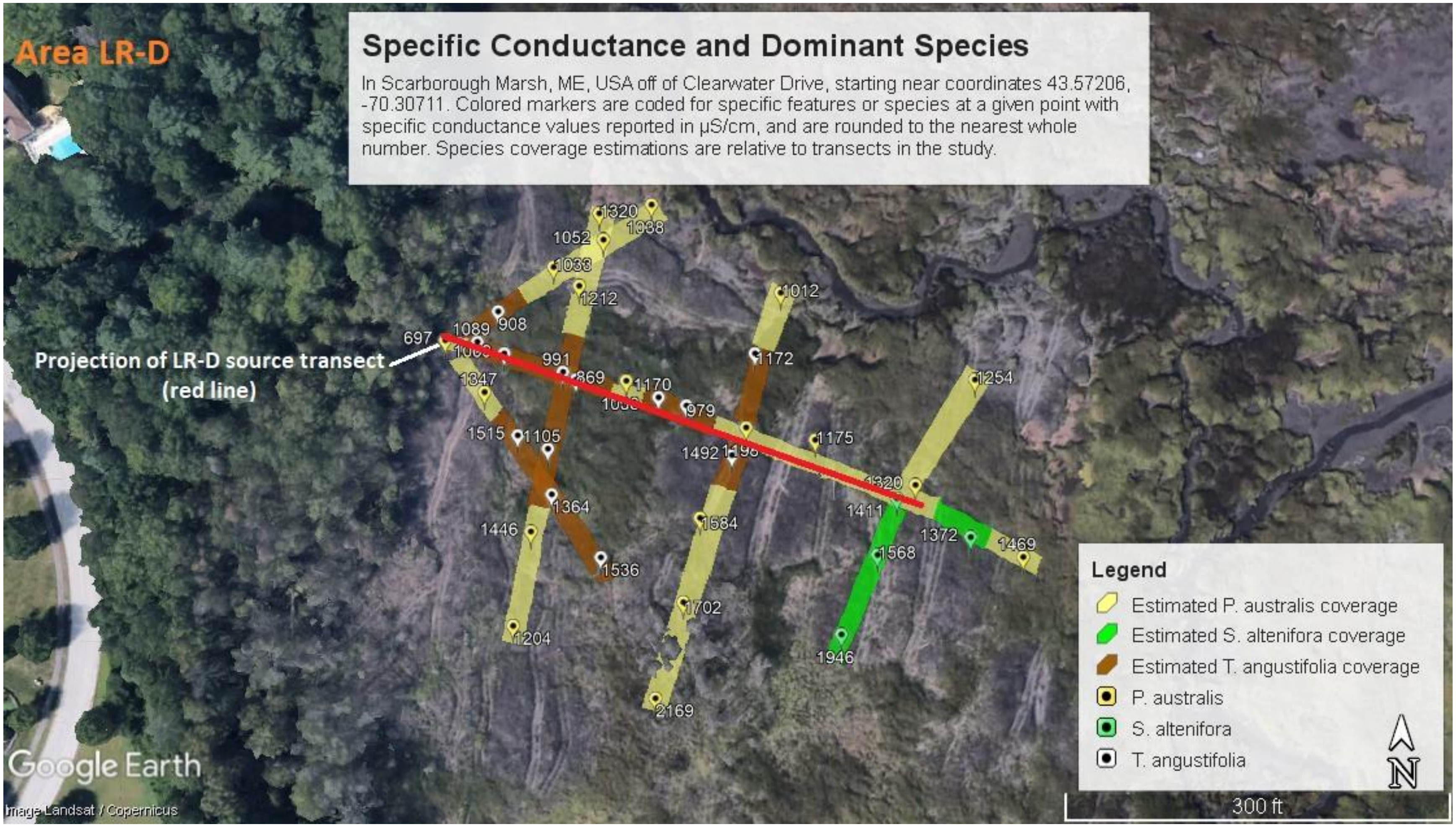
Site LR-A


Area LR-A
Specific Conductance and Dominant Species
In Scarborough Marsh, ME, USA off of Clearwater Drive, starting near coordinates 43.5685, -70.31009. Colored markers are coded for specific features or species at a given point with specific conductance values reported in µS/cm, and are rounded to the nearest whole number. Species coverage estimations are relative to transects in the study.
Projection of source transect LR-A (red line)
Clearwater Dr
48
43
174
51
210
123
175
176
183
583
1403
1692
2203
2193
2200
Legend
Estimated P. australia coverage
Estimated S. altenifora coverage
P. australis
S. altenifora
N
500 ft
Google Earth
Image Landsat / Copernicus

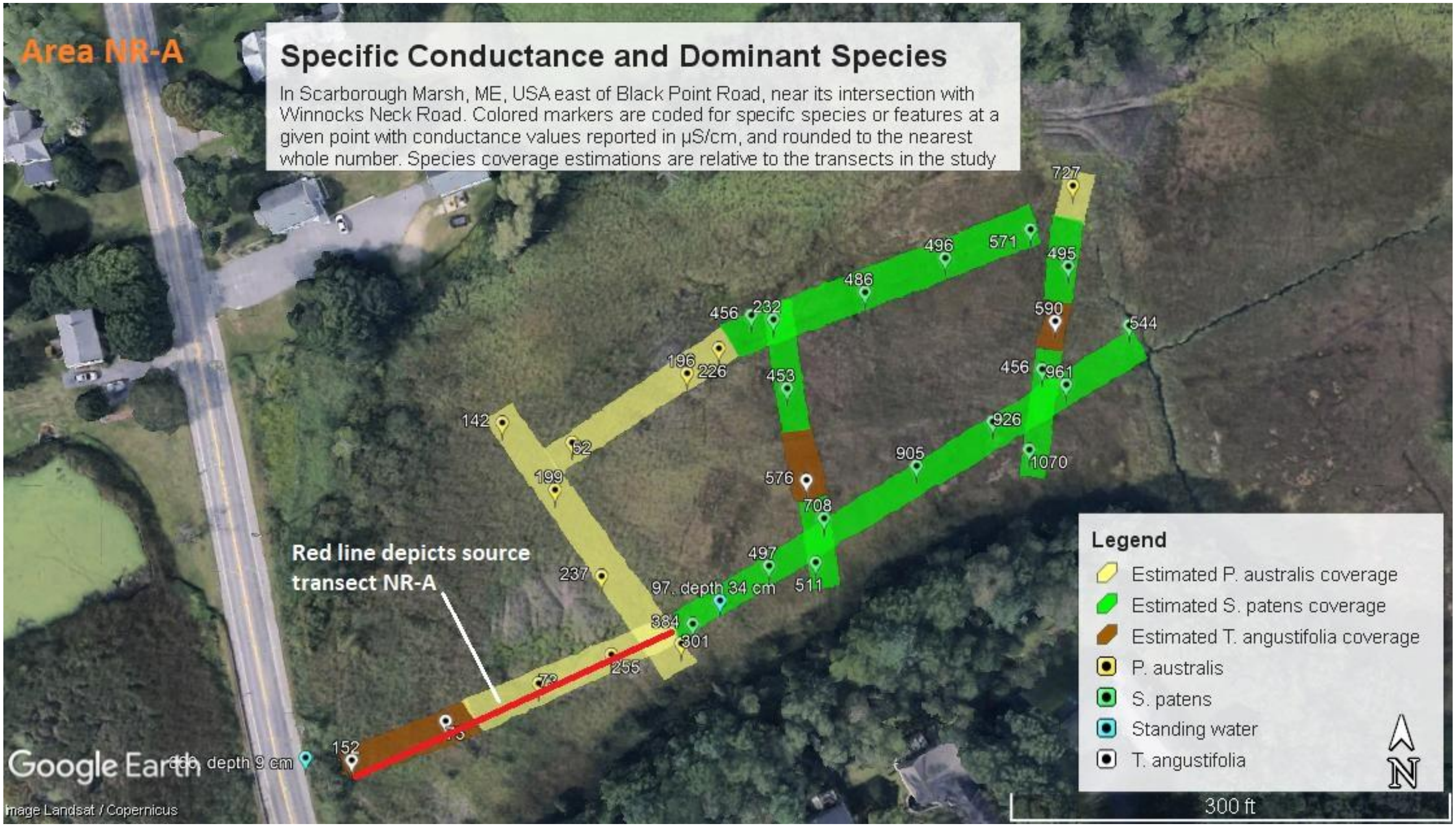
Sites LR-B, LR-C and LR-E



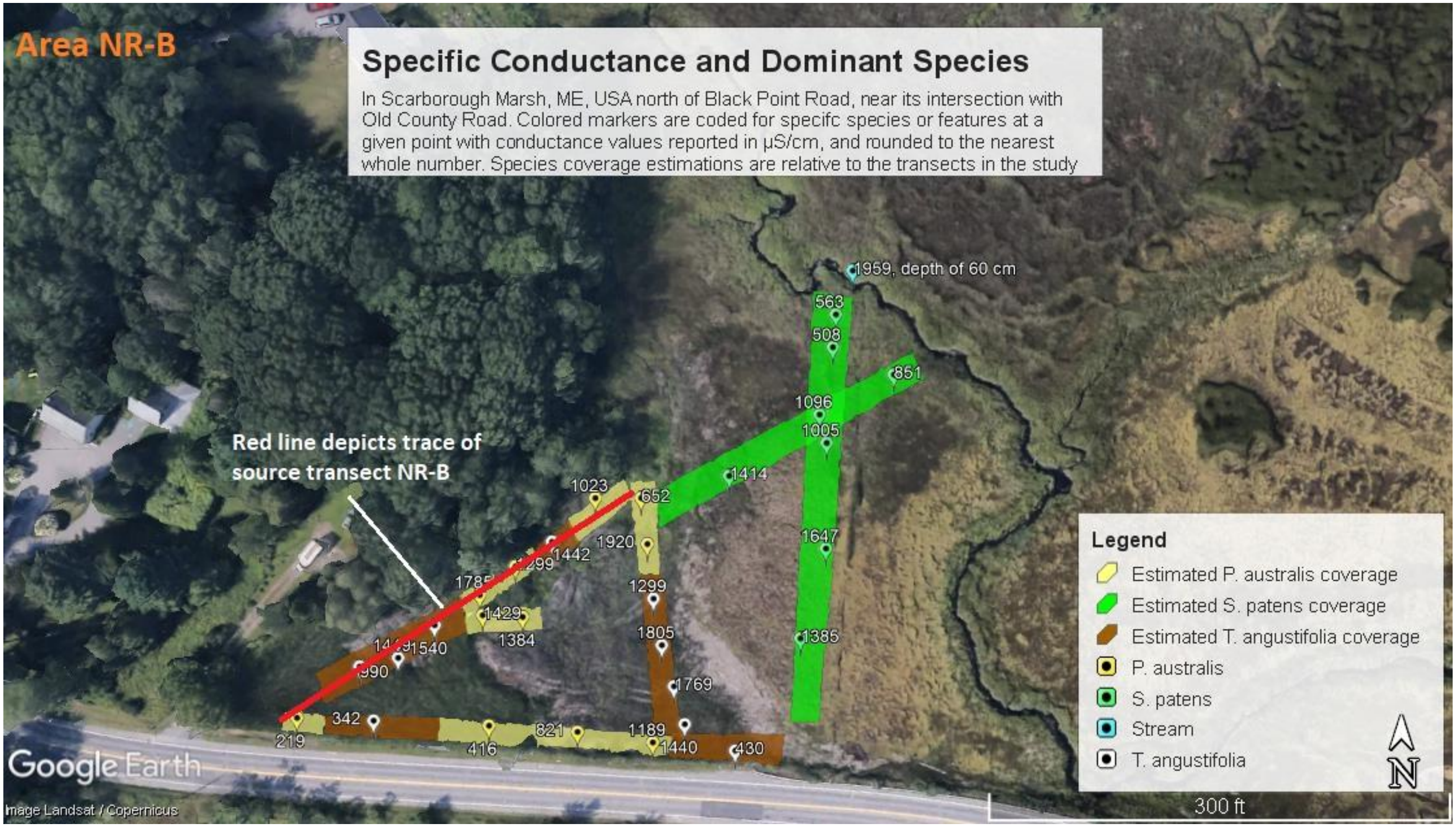
Site LR-D


Area LR-D
Specific Conductance and Dominant Species
In Scarborough Marsh, ME, USA off of Clearwater Drive, starting near coordinates 43.57206, -70.30711. Colored markers are coded for specific features or species at a given point with specific conductance values reported in µS/cm, and are rounded to the nearest whole number. Species coverage estimations are relative to transects in the study.
Projection of LR-D source transect (red line)
Legend
Estimated P. australis coverage
Estimated S. altenifora coverage
Estimated T. angustifolia coverage
P. australis
S. altenifora
T. angustifolia
300 ft
Google Earth
Image Landsat / Copernicus

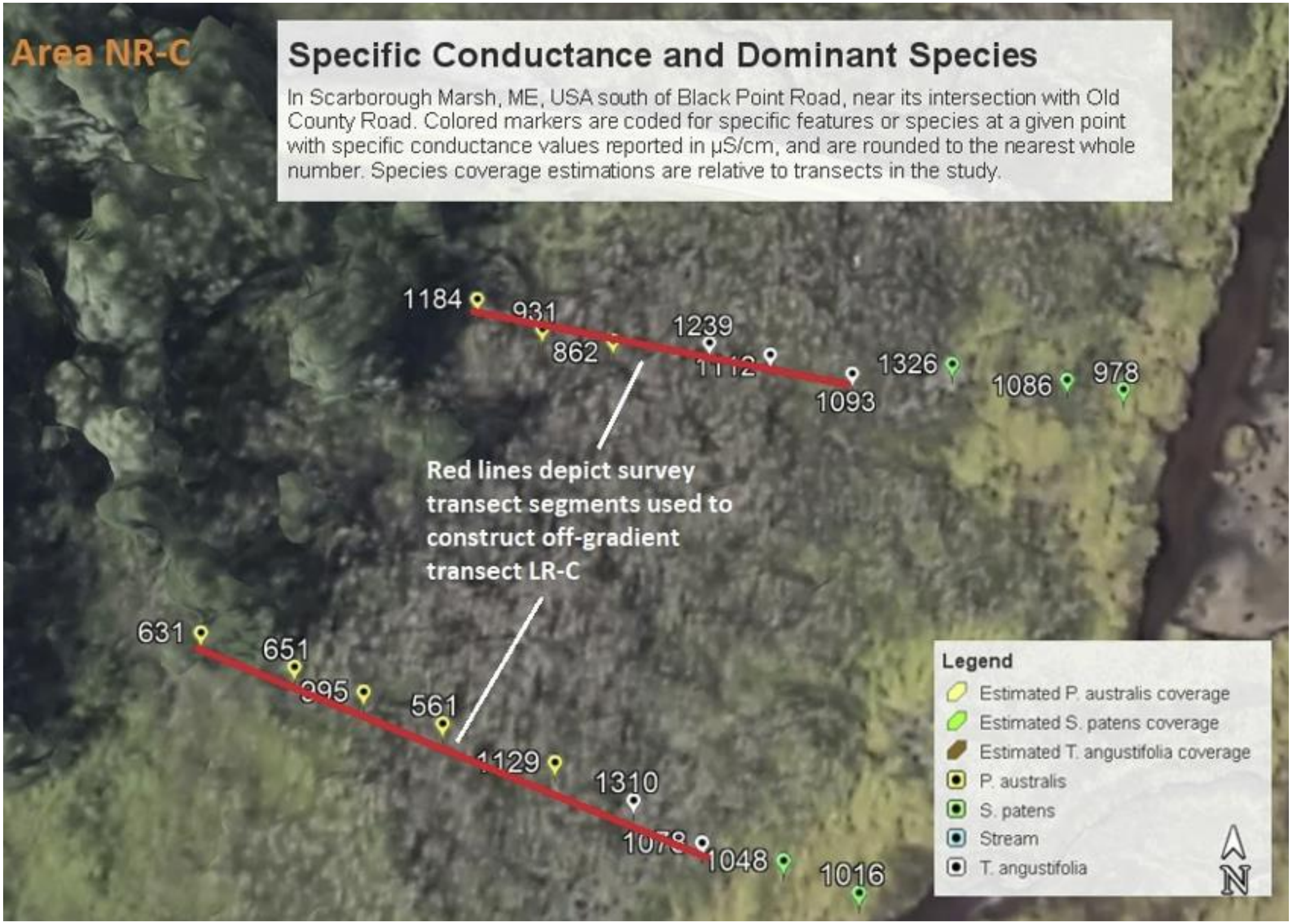
Site NR-A


Area NR-A
Specific Conductance and Dominant Species
In Scarborough Marsh, ME, USA east of Black Point Road, near its intersection with Winnocks Neck Road. Colored markers are coded for specifc species or features at a given point with conductance values reported in µS/cm, and rounded to the nearest whole number. Species coverage estimations are relative to the transects in the study
Red line depicts source transect NR-A
727
571
496
495
486
456
232
590
544
456
961
453
196
226
142
926
1070
905
576
708
199
497
237
511
97, depth 34 cm
384
301
255
152
Legend
Estimated P. australis coverage
Estimated S. patens coverage
Estimated T. angustifolia coverage
P. australis
S. patens
Standing water
T. angustifolia
N
300 ft
Google Earth
Image Landsat / Copernicus

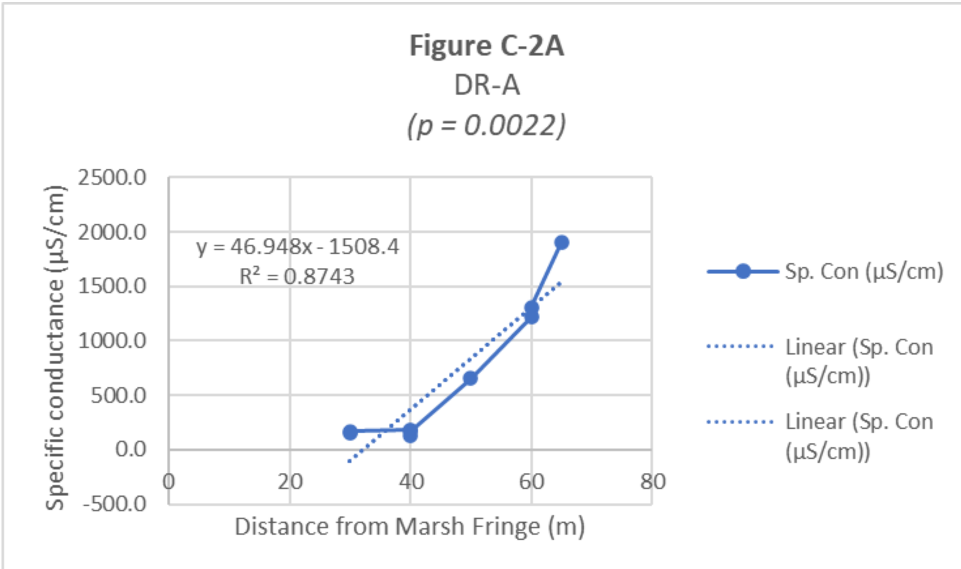
Site NR-B

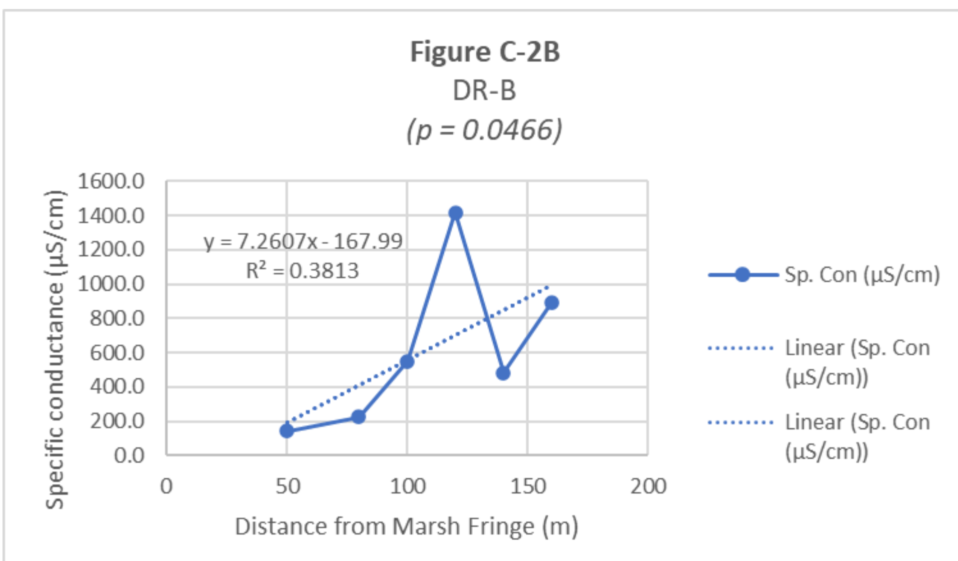

Area NR-B
Specific Conductance and Dominant Species
In Scarborough Marsh, ME, USA north of Black Point Road, near its intersection with Old County Road. Colored markers are coded for specifc species or features at a given point with conductance values reported in µS/cm, and rounded to the nearest whole number. Species coverage estimations are relative to the transects in the study
Red line depicts trace of source transect NR-B
1959, depth of 60 cm
563
508
851
1096
1005
1414
1023
652
1920
1442
1299
1785
1429
1384
1540
990
1299
1805
1769
1647
1385
342
219
416
821
1189
1440
430
Legend
Estimated P. australis coverage
Estimated S. patens coverage
Estimated T. angustifolia coverage
P. australis
S. patens
Stream
T. angustifolia
N
300 ft
Google Earth
Image Landsat / Copernicus

Site NR-C


Area NR-C
Specific Conductance and Dominant Species
In Scarborough Marsh, ME, USA south of Black Point Road, near its intersection with Old County Road. Colored markers are coded for specific features or species at a given point with specific conductance values reported in µS/cm, and are rounded to the nearest whole number. Species coverage estimations are relative to transects in the study.
1184
931
862
1239
1093
1326
1086
978
Red lines depict survey transect segments used to construct off-gradient transect LR-C
631
651
561
1310
1048
1016
Legend
Estimated P. australis coverage
Estimated S. patens coverage
Estimated T. angustifolia coverage
P. australis
S. patens
Stream
T. angustifolia
N

Appendix C-2. Plots of Distance-from-Marsh-Fringe versus Porewater Specific Conductance





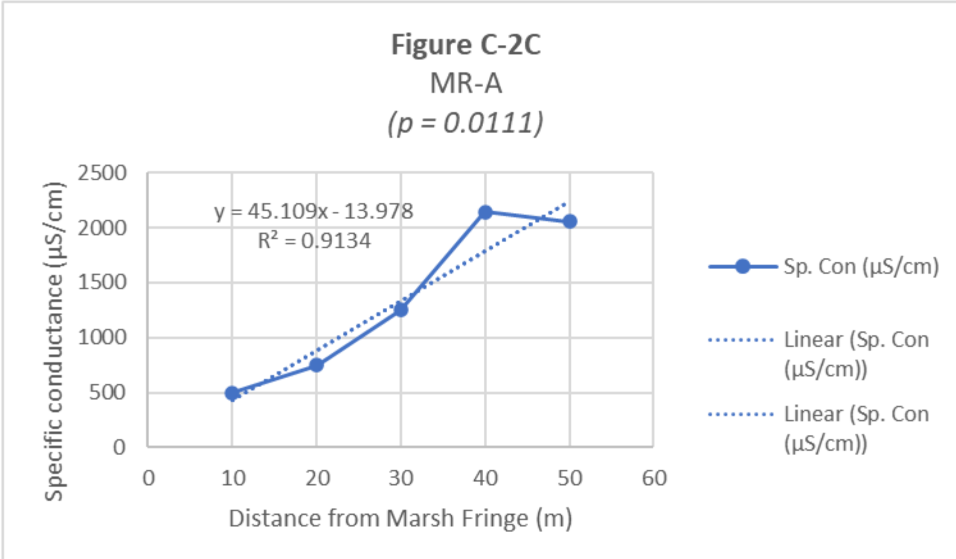


Figure C-2C
MR-A
(p = 0.0111)
y = 45.109x - 13.978
R² = 0.9134
Specific conductance (µS/cm)
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
Distance from Marsh Fringe (m)
Sp. Con (µS/cm)
Linear (Sp. Con (µS/cm))
Linear (Sp. Con (µS/cm))

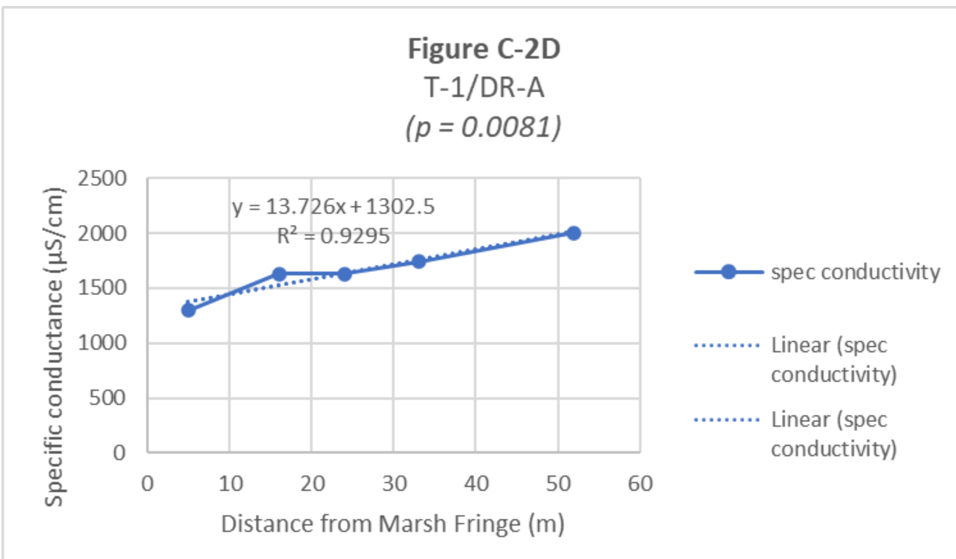


Figure C-2D
T-1/DR-A
(p = 0.0081)
y = 13.726x + 1302.5
R² = 0.9295
Specific conductance (µS/cm)
2500
2000
1500
1000
500
0
0
10
20
30
40
50
60
Distance from Marsh Fringe (m)
spec conductivity
Linear (spec conductivity)
Linear (spec conductivity)

Figure C-2E
LR-A
($p = 0.1578$)

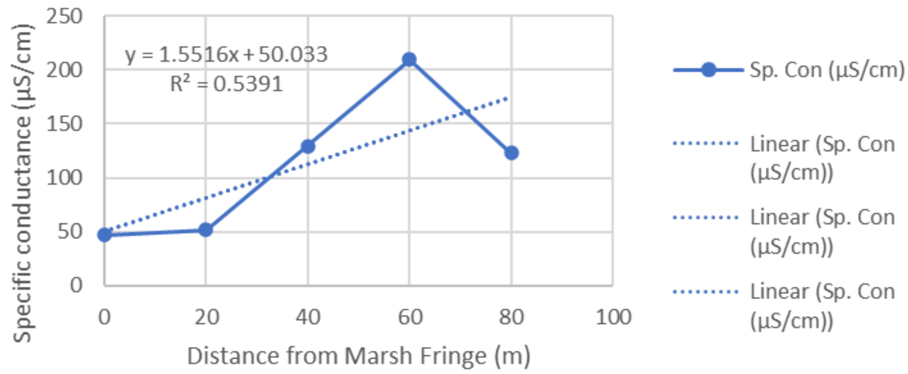
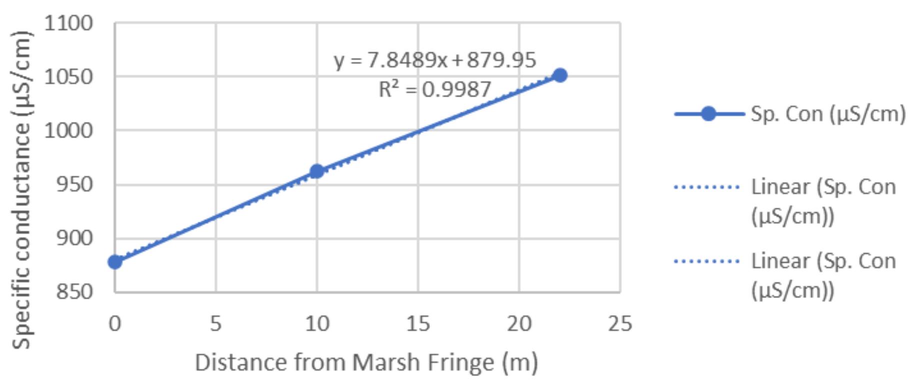


Figure C-2F
LR-C
($p = 0.0228$)



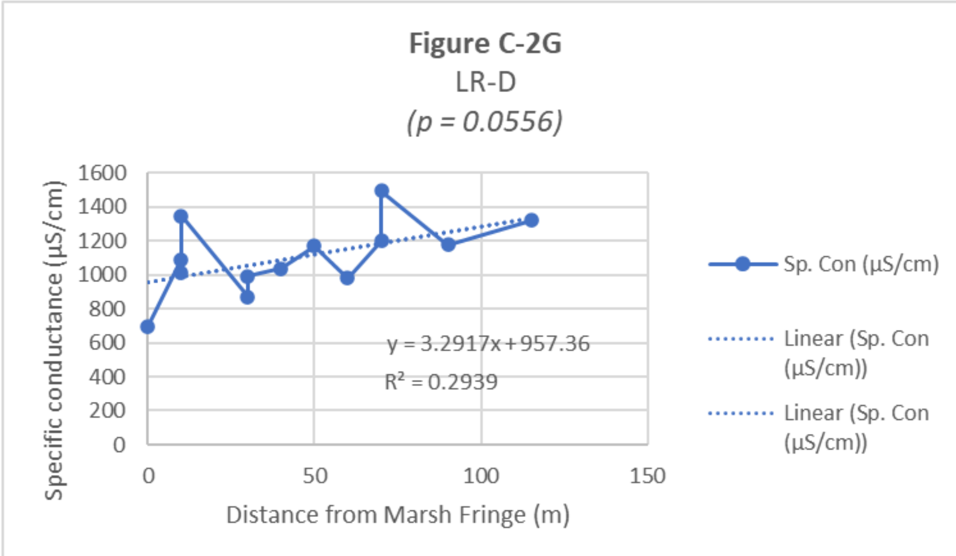


Figure C-2G
LR-D
(p = 0.0556)
Specific conductance (µS/cm)
1600
1400
1200
1000
800
600
400
200
0
0
50
100
150
Distance from Marsh Fringe (m)
y = 3.2917x + 957.36
R² = 0.2939
Sp. Con (µS/cm)
Linear (Sp. Con (µS/cm))
Linear (Sp. Con (µS/cm))

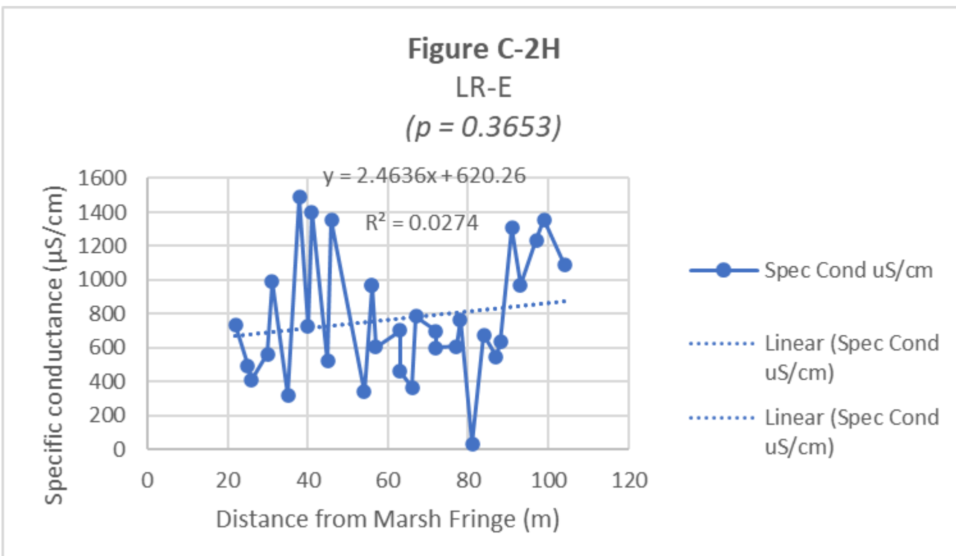


Figure C-2H
LR-E
(p = 0.3653)
Specific conductance (µS/cm)
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
Distance from Marsh Fringe (m)
y = 2.4636x + 620.26
R² = 0.0274
Spec Cond uS/cm
Linear (Spec Cond uS/cm)
Linear (Spec Cond uS/cm)

Figure C-2I
NR-A
(p = 0.0779)

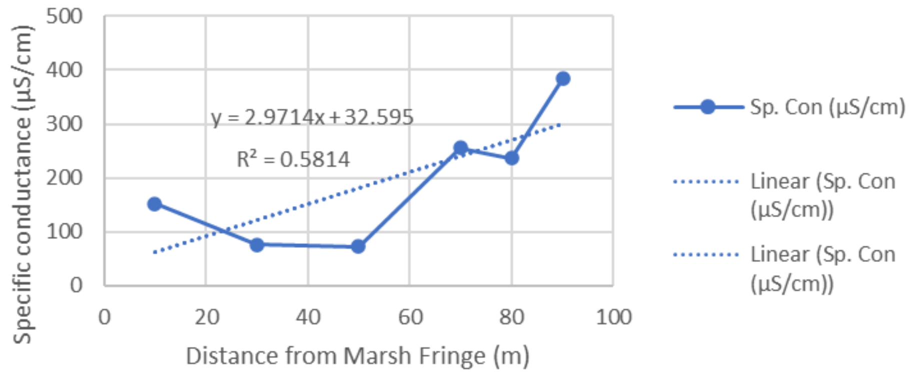
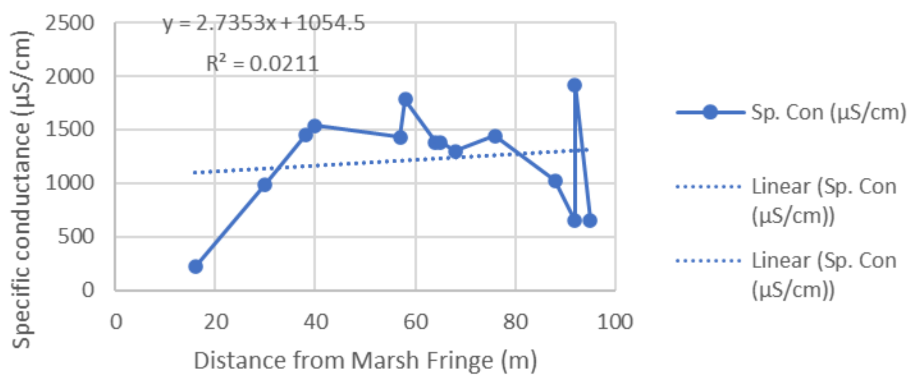


Figure C-2J
NR-B
(p = 0.6205)



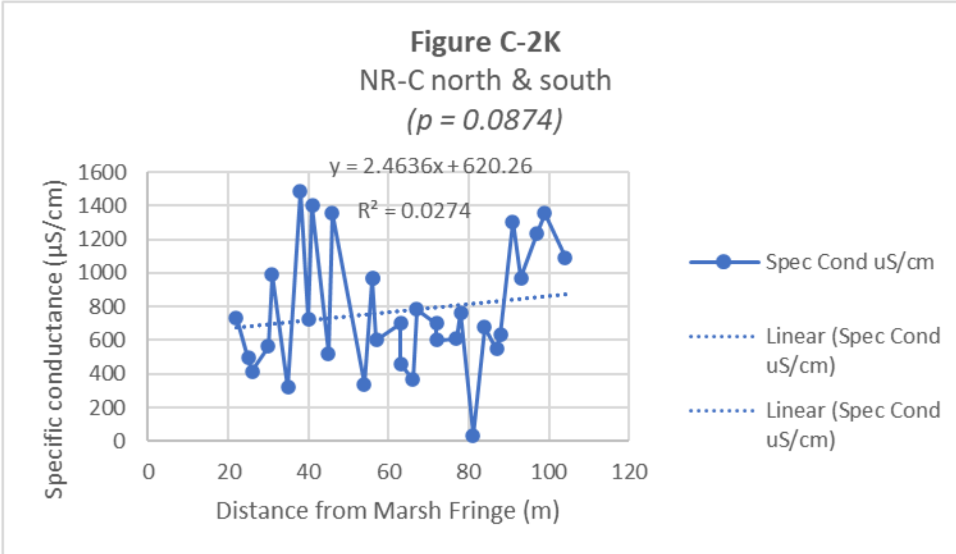


Figure C-2K
NR-C north & south
(p = 0.0874)
y = 2.4636x + 620.26
R² = 0.0274
1600
1400
1200
1000
800
600
400
200
0
0
20
40
60
80
100
120
Specific conductance (µS/cm)
Distance from Marsh Fringe (m)
Spec Cond uS/cm
Linear (Spec Cond uS/cm)
Linear (Spec Cond uS/cm)

APPENDIX D - SPECIFIC CONDUCTANCE DATA FOR POREWATER SURVEY POINTS

Phragmites Study Sites

Data sorted by area, then by survey point				
Survey Point (Phragmites study)	**Study Site**	**Survey Date**	**Specific Conductance (µs/cm)**	**Dominant Plant Type**
142	DR-A	5/18/2021	69	Phrag
143	DR-A	5/18/2021	196	Phrag
144	DR-A	5/18/2021	146	Phrag
146	DR-A	5/18/2021	99	Cattail
153	DR-A	5/19/2021	281	Phrag
154	DR-A	5/19/2021	369	Phrag
155	DR-A	5/19/2021	402	Phrag
156	DR-A	5/19/2021	362	Phrag
157	DR-A	5/19/2021	347	Phrag
311	DR-A	6/24/2021	134	Phrag
312	DR-A	6/29/2021	2,076	Spartina
313	DR-A	6/29/2021	2,050	Spartina
314	DR-A	6/29/2021	2,178	Spartina
315	DR-A	6/29/2021	1,961	Spartina
316	DR-A	6/29/2021	1,775	Spartina
317	DR-A	6/29/2021	1,524	Phrag
318	DR-A	6/29/2021	1,998	Phrag
319	DR-A	6/29/2021	2,139	Spartina
320	DR-A	6/29/2021	1,792	Cattail
321	DR-A	6/29/2021	1,879	Phrag
322	DR-A	6/29/2021	1,285	Phrag
323	DR-A	6/29/2021	1,784	Phrag
324	DR-A	6/29/2021	1,733	Phrag
325	DR-A	6/29/2021	1,584	Phrag
326	DR-A	6/29/2021	1,920	Phrag
327	DR-A	6/29/2021	1,765	Cattail
328	DR-A	6/29/2021	1,097	Phrag
329	DR-A	6/29/2021	1,075	Phrag
330	DR-A	6/29/2021	1,164	Cattail
331	DR-A	6/29/2021	1,662	Phrag
332	DR-A	6/29/2021	1,220	Phrag
333	DR-A	6/29/2021	184	Phrag
334	DR-A	6/29/2021	97	Phrag
335	DR-A	6/29/2021	172	Phrag
336	DR-A	6/29/2021	434	Phrag
337	DR-A	6/30/2021	1,295	Phrag

Survey Point (Phragmites study)	Study Site	Survey Date	Specific Conductance (µs/cm)	Dominant Plant Type
338	DR-A	6/30/2021	1,911	Phrag
339	DR-A	6/30/2021	1,631	Phrag
340	DR-A	6/30/2021	1,739	Phrag
341	DR-A	6/30/2021	2,001	Cattail
342	DR-A	6/30/2021	231	Phrag
343	DR-A	6/30/2021	134	Phrag
344	DR-A	6/30/2021	160	Phrag
345	DR-A	6/30/2021	172	Phrag
347	DR-A	6/30/2021	1,902	Cattail
348	DR-A	6/30/2021	1,307	Phrag
349	DR-A	6/30/2021	653	Phrag
350	DR-A	6/30/2021	176	Phrag
48	DR-B	3/12/2021	452	Phrag
49	DR-B	3/12/2021	844	Phrag
51	DR-B	3/12/2021	744	Phrag
52	DR-B	3/12/2021	723	Phrag
54	DR-B	3/12/2021	511	Phrag
118	DR-B	5/11/2021	226	Phrag
119	DR-B	5/11/2021	550	Cattail
121	DR-B	5/11/2021	1,418	Phrag
122	DR-B	5/12/2021	485	Phrag
123	DR-B	5/12/2021	892	Phrag
124	DR-B	5/12/2021	911	Cattail
125	DR-B	5/12/2021	746	Phrag
126	DR-B	5/12/2021	751	Phrag
127	DR-B	5/12/2021	864	Spartina
128	DR-B	5/12/2021	871	Spartina
129	DR-B	5/12/2021	1,200	Spartina
130	DR-B	5/12/2021	1,401	Spartina
131	DR-B	5/17/2021	717	Phrag
132	DR-B	5/17/2021	1,159	Cattail
133	DR-B	5/17/2021	1,489	Cattail
134	DR-B	5/18/2021	1,656	Cattail
135	DR-B	5/18/2021	1,460	Cattail
136	DR-B	5/18/2021	1,253	Cattail
137	DR-B	5/18/2021	1,243	Spartina
138	DR-B	5/18/2021	142	Phrag
159	DR-B	5/19/2021	1,227	Spartina
160	DR-B	5/19/2021	941	Phrag
161	DR-B	5/19/2021	1,146	Spartina
162	DR-B	5/19/2021	1,064	Cattail

Survey Point (Phragmites study)	Study Site	Survey Date	Specific Conductance (µs/cm)	Dominant Plant Type
163	DR-B	5/19/2021	1,025	Phrag
164	DR-B	5/19/2021	1,249	Spartina
165	DR-B	5/19/2021	1,187	Phrag
166	DR-B	5/19/2021	1,015	Phrag
167	DR-B	5/19/2021	1,135	Spartina
168	DR-B	5/19/2021	904	Spartina
169	DR-B	5/19/2021	712	Spartina
170	DR-B	5/19/2021	800	Spartina
297	LR-A	6/20/2021	47	Phrag
298	LR-A	6/20/2021	51	Phrag
299	LR-A	6/20/2021	130	Phrag
300	LR-A	6/20/2021	210	Phrag
301	LR-A	6/20/2021	123	Phrag
302	LR-A	6/20/2021	175	Cattail
303	LR-A	6/20/2021	176	Phrag
304	LR-A	6/20/2021	183	Phrag
305	LR-A	6/20/2021	583	Phrag
306	LR-A	6/20/2021	1,403	Phrag
307	LR-A	6/20/2021	1,693	Phrag
308	LR-A	6/20/2021	2,203	Spartina
309	LR-A	6/20/2021	2,193	Spartina
310	LR-A	6/20/2021	2,200	Spartina
293	LR-B	6/20/2021	652	Phrag
293	LR-B	6/20/2021	652	Phrag
294	LR-B	6/20/2021	693	Phrag
294	LR-B	6/20/2021	693	Phrag
295	LR-B	6/20/2021	1,016	Phrag
295	LR-B	6/20/2021	1,016	Phrag
296	LR-B	6/20/2021	571	Phrag
296	LR-B	6/20/2021	571	Phrag
246	LR-C	6/9/2021	878	Phrag
247	LR-C	6/9/2021	962	Cattail
248	LR-C	6/9/2021	1,568	Cattail
249	LR-C	6/9/2021	1,051	Phrag
250	LR-C	6/9/2021	1,240	Spartina
251	LR-C	6/9/2021	1,745	Phrag
252	LR-C	6/9/2021	1,586	Phrag
253	LR-C	6/9/2021	1,533	Spartina
254	LR-C	6/9/2021	1,942	Spartina
256	LR-D	6/11/2021	697	Phrag
257	LR-D	6/11/2021	1,089	Cattail

258	LR-D	6/11/2021	1,009	Cattail
259	LR-D	6/11/2021	869	Cattail
Survey Point (Phragmites study)	**Study Site**	**Survey Date**	**Specific Conductance (µs/cm)**	**Dominant Plant Type**
260	LR-D	6/11/2021	1,036	Phrag
261	LR-D	6/11/2021	1,170	Cattail
262	LR-D	6/11/2021	979	Cattail
263	LR-D	6/11/2021	1,198	Phrag
264	LR-D	6/11/2021	1,175	Phrag
265	LR-D	6/11/2021	1,411	Spartina
266	LR-D	6/11/2021	1,372	Spartina
267	LR-D	6/11/2021	1,469	Phrag
268	LR-D	6/11/2021	1,254	Phrag
269	LR-D	6/11/2021	1,320	Phrag
270	LR-D	6/11/2021	1,568	Spartina
271	LR-D	6/11/2021	1,946	Spartina
272	LR-D	6/17/2021	1,013	Phrag
273	LR-D	6/17/2021	1,172	Cattail
274	LR-D	6/17/2021	1,492	Cattail
275	LR-D	6/17/2021	1,584	Phrag
276	LR-D	6/17/2021	1,702	Phrag
277	LR-D	6/17/2021	2,169	Phrag
278	LR-D	6/18/2021	1,320	Phrag
279	LR-D	6/18/2021	1,212	Phrag
280	LR-D	6/18/2021	991	Cattail
281	LR-D	6/18/2021	1,105	Cattail
282	LR-D	6/18/2021	1,446	Phrag
283	LR-D	6/18/2021	1,204	Phrag
284	LR-D	6/18/2021	908	Cattail
285	LR-D	6/18/2021	1,033	Phrag
288	LR-D	6/18/2021	1,038	Phrag
289	LR-D	6/20/2021	1,347	Phrag
290	LR-D	6/20/2021	1,515	Cattail
291	LR-D	6/20/2021	1,364	Cattail
292	LR-D	6/20/2021	1,536	Cattail
286/287	LR-D	6/18/2021	1,052	Phrag
117	LR-E	4/18/2021	854	Cattail
43	LR-E	1/15/2021	258	Cattail
116	LR-E	4/18/2021	1,188	Cattail
No B297ID	LR-E	4/18/2021	798	Cattail
42	LR-E	1/15/2021	659	Cattail
45	LR-E	1/15/2021	444	Phrag
115	LR-E	4/18/2021	736	Phrag

114	LR-E	4/18/2021	414	Phrag
41	LR-E	1/15/2021	496	Phrag
113	LR-E	4/18/2021	565	Phrag
Survey Point (Phragmites study)	**Study Site**	**Survey Date**	**Specific Conductance (µs/cm)**	**Dominant Plant Type**
40	LR-E	1/15/2021	991	Phrag
112	LR-E	4/18/2021	321	Phrag
111	LR-E	4/18/2021	727	Phrag
39	LR-E	11/21/2020	1,487	Phrag
38	LR-E	11/21/2020	1,402	Phrag
110	LR-E	4/18/2021	521	Phrag
37	LR-E	11/21/2020	1,353	Phrag
109	LR-E	4/18/2021	339	Phrag
No ID	LR-E	4/18/2021	967	Phrag
108	LR-E	4/18/2021	603	Phrag
107	LR-E	4/18/2021	702	Phrag
106	LR-E	4/18/2021	785	Phrag
105	LR-E	4/18/2021	701	Phrag
104	LR-E	4/18/2021	767	Phrag
103	LR-E	4/18/2021	676	Phrag
102	LR-E	4/18/2021	634	Phrag
101	LR-E	4/18/2021	972	Phrag
100	LR-E	4/18/2021	1,356	Phrag
99	LR-E	11/21/2020	1,092	Phrag
34	LR-E	11/21/2020	967	Phrag
33	LR-E	11/21/2020	460	Phrag
32	LR-E	11/21/2020	366	Phrag
31	LR-E	11/21/2020	602	Phrag
30	LR-E	11/21/2020	610	Phrag
29	LR-E	11/21/2020	35	Phrag
28	LR-E	11/21/2020	547	Phrag
27	LR-E	11/21/2020	1,306	Phrag
26	LR-E	11/21/2020	1,236	Phrag
98	LR-E	4/18/2021	642	Spartina
97	LR-E	4/18/2021	861	Spartina
96	LR-E	4/18/2021	725	Spartina
95	LR-E	4/18/2021	975	Spartina
94	LR-E	4/18/2021	1,514	Spartina
93	LR-E	4/18/2021	1,342	Spartina
92	LR-E	4/18/2021	552	Spartina
35	LR-E	11/21/2020	1,332	Spartina
25	LR-E	11/21/2020	1,082	Spartina
24	LR-E	11/21/2020	1,277	Spartina

23	LR-E	11/21/2020	1,426	Spartina
22	LR-E	11/21/2020	1,460	Spartina
21	LR-E	11/21/2020	1,142	Spartina
20	LR-E	11/21/2020	1,273	Spartina
Survey Point (Phragmites study)	**Study Site**	**Survey Date**	**Specific Conductance (µs/cm)**	**Dominant Plant Type**
19	LR-E	11/21/2020	1,134	Spartina
18	LR-E	11/21/2020	771	Spartina
240	MR-A	6/7/2021	748	Cattail
241	MR-A	6/7/2021	1,250	Cattail
243	MR-A	6/7/2021	2,076	Cattail
244	MR-A	6/7/2021	2,146	Cattail
239	MR-A	6/7/2021	498	Phrag
245	MR-A	6/7/2021	2,055	Phrag
242	MR-A	6/7/2021	2,065	Spartina
202	NR-A	6/2/2021	860	Cattail
203	NR-A	6/2/2021	152	Cattail
220	NR-A	6/2/2021	576	Cattail
225	NR-A	6/4/2021	590	Cattail
205	NR-A	6/2/2021	73	Phrag
206	NR-A	6/2/2021	255	Phrag
215	NR-A	6/2/2021	301	Phrag
216	NR-A	6/2/2021	237	Phrag
217	NR-A	6/2/2021	199	Phrag
218	NR-A	6/2/2021	142	Phrag
227	NR-A	6/4/2021	727	Phrag
232	NR-A	6/4/2021	226	Phrag
233	NR-A	6/4/2021	196	Phrag
234	NR-A	6/4/2021	52	Phrag
207	NR-A	6/2/2021	384	Spartina
208	NR-A	6/2/2021	497	Spartina
209	NR-A	6/2/2021	708	Spartina
211	NR-A	6/2/2021	905	Spartina
212	NR-A	6/2/2021	926	Spartina
213	NR-A	6/2/2021	961	Spartina
214	NR-A	6/2/2021	544	Spartina
219	NR-A	6/2/2021	511	Spartina
221	NR-A	6/2/2021	453	Spartina
222	NR-A	6/2/2021	456	Spartina
223	NR-A	6/4/2021	1,070	Spartina
224	NR-A	6/4/2021	456	Spartina
226	NR-A	6/4/2021	495	Spartina
228	NR-A	6/4/2021	571	Spartina

229	NR-A	6/4/2021	496	Spartina
230	NR-A	6/4/2021	486	Spartina
231	NR-A	6/4/2021	232	Spartina
171	NR-B	5/26/2021	1,440	Cattail
172	NR-B	5/26/2021	1,769	Cattail
Survey Point (Phragmites study)	**Study Site**	**Survey Date**	**Specific Conductance (µs/cm)**	**Dominant Plant Type**
173	NR-B	5/26/2021	1,805	Cattail
174	NR-B	5/26/2021	1,299	Cattail
178	NR-B	5/26/2021	1,442	Cattail
183	NR-B	5/26/2021	1,540	Cattail
184	NR-B	5/26/2021	1,449	Cattail
185	NR-B	5/26/2021	990	Cattail
189	NR-B	5/26/2021	430	Cattail
193	NR-B	5/26/2021	342	Cattail
175	NR-B	5/26/2021	1,920	Phrag
176	NR-B	5/26/2021	652	Phrag
177	NR-B	5/26/2021	1,023	Phrag
179	NR-B	5/26/2021	1,299	Phrag
180	NR-B	5/26/2021	1,785	Phrag
181	NR-B	5/26/2021	1,429	Phrag
182	NR-B	5/26/2021	1,384	Phrag
190	NR-B	5/26/2021	1,189	Phrag
191	NR-B	5/26/2021	821	Phrag
192	NR-B	5/26/2021	416	Phrag
194	NR-B	5/26/2021	219	Phrag
195	NR-B	5/28/2021	552	Phrag
186	NR-B	5/26/2021	1,414	Spartina
187	NR-B	5/26/2021	1,096	Spartina
188	NR-B	5/26/2021	851	Spartina
196	NR-B	5/28/2021	1,385	Spartina
197	NR-B	5/28/2021	1,647	Spartina
198	NR-B	5/28/2021	1,005	Spartina
199	NR-B	5/28/2021	508	Spartina
69	NR-C north transect	4/9/2021	1,239	Cattail
68	NR-C north transect	4/9/2021	1,112	Cattail
67	NR-C north transect	4/9/2021	1,093	Cattail
72	NR-C north transect	4/9/2021	1,184	Phrag
71	NR-C north transect	4/9/2021	931	Phrag
70	NR-C north transect	4/9/2021	862	Phrag
66	NR-C north transect	4/9/2021	1,326	Spartina
65	NR-C north transect	4/9/2021	1,086	Spartina
64	NR-C north transect	4/9/2021	978	Spartina

85	NR-C south transect	4/11/2021	1,310	Cattail
84	NR-C south transect	4/11/2021	1,078	Cattail
90	NR-C south transect	4/11/2021	631	Phrag
89	NR-C south transect	4/11/2021	651	Phrag
88	NR-C south transect	4/11/2021	995	Phrag
87	NR-C south transect	4/11/2021	561	Phrag
Survey Point (Phragmites study)	**Study Site**	**Survey Date**	**Specific Conductance (µs/cm)**	**Dominant Plant Type**
86	NR-C south transect	4/11/2021	1,129	Phrag
83	NR-C south transect	4/11/2021	1,048	Spartina
82	NR-C south transect	4/11/2021	1,016	Spartina
			Total count	291

Marsh-Fringe Reference Sites

Survey Point (Reference Site)	Study Site (sub-watershed)	Survey Date	Specific Conductance (µs/cm)	Dominant Plant Type
14	Dunstan River	6/30/2022	1611	*Spartina patens*
15		6/30/2022	1505	*Spartina patens*
16		6/30/2022	2060	*Spartina patens*
21	Nonesuch River	7/5/2022	1411	*Spartina patens*
22		7/5/2022	1802	*Spartina patens*
24		7/5/2022	2253	*Spartina patens*
25		7/5/2022	2247	*Spartina patens*
26	Libby River	7/5/2022	1866	*Spartina patens*
27		7/5/2022	2095	*Spartina patens*
28		7/5/2022	2293	*Spartina patens*
			Total Count	10

APPENDIX E - STATISTICAL DATA

E-1. Statistical Data for Phragmites Study

E-2. Statistical Data for Marsh-Fringe Reference Sites

Appendix E-1. Summary Statistics for the Phragmites Porewater Study Sites

Basic Stats for Cattails_Entire Study			
		Shapiro-Wilk Test	
	Group 1		*Group 1*
Mean	1149	W-stat	0.983637
Standard I	64	p-value	0.621865
Median	1161	alpha	0.05
Mode	#N/A	normal	yes
Standard I	484.6927		
Sample V:	234927	d'Agostino-Pearson	
Kurtosis	-0.22		
Skewness	-0.18968	DA-stat	0.43693
Range	2047	p-value	1
Maximum	2146	alpha	0.05
Minimum	99	normal	yes
Sum	66660		
Count	58		
Geometri	998.7332		
Harmonic	747.1619		
AAD	376.9236		
MAD	300.0855		
IQR	603.2032		

Basic Stats for Phragmites_Entire Study			
		Shapiro-Wilk Test	
	Group 1		*Group 1*
Mean	842	W-stat	0.95942
Standard I	42.38265	p-value	0.000135
Median	744	alpha	0.05
Mode	651.6839	normal	no
Standard I	534.4249		
Sample V:	285609.9	d'Agostino-Pearson	
Kurtosis	-0.7522		
Skewness	0.385845	DA-stat	12.93136
Range	2134.261	p-value	0.001556
Maximum	2169	alpha	0.05
Minimum	35	normal	no
Sum	133946		
Count	159		
Geometri	625.4731		
Harmonic	373.2942		
AAD	451.5748		
MAD	439.5992		
IQR	820.1396		

Basic Stats for Spartina_Entire Study			
		Shapiro-Wilk Test	
	Group 1		*Group 1*
Mean	1157.071	W-stat	0.95136
Standard I	60.43825	p-value	0.006373
Median	1114.852	alpha	0.05
Mode	#N/A	normal	no
Standard I	519.9095		
Sample V:	270305.9	d'Agostino-Pearson	
Kurtosis	-0.54833		
Skewness	0.44683	DA-stat	3.925366
Range	1970.302	p-value	0.140481
Maximum	2202.719	alpha	0.05
Minimum	232.4176	normal	yes
Sum	85623.26		
Count	74		
Geometri	1034.882		
Harmonic	906.3774		
AAD	415.8301		
MAD	313.141		
IQR	635.4345		

Basic Stats_All Plants_Enitire Study			
		Shapiro-Wilk Test	
	Group 1		*Group 1*
Mean	984	W-stat	0.976814
Standard I	31.78121	p-value	0.000116
Median	991	alpha	0.05
Mode	651.6839	normal	no
Standard I	542.1469		
Sample V:	293923.2	d'Agostino-Pearson	
Kurtosis	-0.66483		
Skewness	0.228253	DA-stat	14.33991
Range	2167.719	p-value	0.000769
Maximum	2203	alpha	0.05
Minimum	35	normal	no
Sum	286229		
Count	291		
Geometri	780.4177		
Harmonic	497.2589		
AAD	445.9233		
MAD	409.9174		
IQR	793.3731		

STATS FOR SPARTINA ALTERNIFLORA				
			Shapiro-Wilk Test	
	Group 1			*Group 1*
Mean	1175.348		W-stat	0.943505
Standard I	71.01249		p-value	0.006573
Median	1090.852		alpha	0.05
Mode	#N/A		normal	no
Standard I	559.1529			
Sample Va	312652		d'Agostino-Pearson	
Kurtosis	-0.87886			
Skewness	0.348461		DA-stat	6.223833
Range	1970.302		p-value	0.044516
Maximum	2202.719		alpha	0.05
Minimum	232.4176		normal	no
Sum	72871.59			
Count	62			
Geometri	1033.762			
Harmonic	887.5334			
AAD	462.566			
MAD	402.9327			
IQR	788.149			

STATS FOR SPARTINA PATTENS				
			Shapiro-Wilk Test	
	Group 1			*Group 1*
Mean	1063		W-stat	0.918083
Standard I	64		p-value	0.27043
Median	1140		alpha	0.05
Mode	#N/A		normal	yes
Standard I	220.0903			
Sample Va	48439.76		d'Agostino-Pearson	
Kurtosis	-1.35368			
Skewness	-0.21533		DA-stat	2.040812
Range	689		p-value	0.360449
Maximum	1401		alpha	0.05
Minimum	712		normal	yes
Sum	12752			
Count	12			
Geometri	1040.691			
Harmonic	1018.056			
AAD	193.6834			
MAD	172.558			
IQR	361.2795			

Kruskal-Wallis Test			
	alterniflor	pattens	
median	1090.852	1140.405	
rank sum	2356	419	
count	62	12	74
r^2/n	89528	14630.08	104158.1
H-stat			0.206667
H-ties			0.206667
df			1
p-value			0.649393
alpha			0.05
sig			no

DUNN's TEST		alpha	0.05	0.05
group	*R-sum*	*size*	*R-mean*	*z-crit*
alterniflor	2356	62	38	
pattens	419	12	34.91667	
		74		1.959964

D TEST

group 1	*group 2*	*R-mean*	*std err*	*z-stat*	*R-crit*	*p-value*
alterniflor	pattens	3.083333	6.782429	0.454606	13.29332	0.649393

Basic statistics for each Phragmites study site by dominant plant species

DR-A ALL		*DR-A CATTAILS*	
Mean	1088.794051	Mean	1453.620608
Standard Error	111.4029685	Standard Error	296.1074689
Median	1252.589285	Median	1778.117647
Mode	#N/A	Mode	#N/A
Standard Deviation	771.8224065	Standard Deviation	725.3122078
Sample Variance	595709.8271	Sample Variance	526077.7988
Kurtosis	-1.73115422	Kurtosis	2.672410895
Skewness	-0.100463183	Skewness	-1.720269576
Range	2109.212684	Range	1901.934223
Minimum	68.63309353	Minimum	98.9010989
Maximum	2177.845777	Maximum	2000.835322
Sum	52262.11443	Sum	8721.723648
Count	48	Count	6

DR-A PHRAG		*DR-A SPARTINA*	
Mean	871.1563783	Mean	2029.793526
Standard Error	117.6657591	Standard Error	59.5342444
Median	543.5928099	Median	2063.119231
Mode	#N/A	Mode	#N/A
Standard Deviation	705.9945544	Standard Deviation	145.828521
Sample Variance	498428.3108	Sample Variance	21265.95754
Kurtosis	-1.67195497	Kurtosis	1.319643993
Skewness	0.293255036	Skewness	-1.18762117
Range	1929.467465	Range	403.2134243
Minimum	68.63309353	Minimum	1774.632353
Maximum	1998.100559	Maximum	2177.845777
Sum	31361.62962	Sum	12178.76116
Count	36	Count	6

DR-B all		*DR-B CATTAILS*	
Mean	948.9623037	Mean	1192.819479
Standard Error	57.53279539	Standard Error	125.9389155
Median	911.2852665	Median	1206.10333
Mode	#N/A	Mode	#N/A
Standard Deviation	349.958332	Standard Deviation	356.2090447
Sample Variance	122470.8342	Sample Variance	126884.8835
Kurtosis	-0.16506911	Kurtosis	0.137730361
Skewness	-0.236393094	Skewness	-0.613209853
Range	1514.40632	Range	1106.680952
Minimum	142.0353982	Minimum	549.7607656
Maximum	1656.441718	Maximum	1656.441718
Sum	35111.60524	Sum	9542.555835
Count	37	Count	8
DR-B PHRAG		*DR-B SPARTINA*	
Mean	753.9639124	Mean	1062.638574
Standard Error	79.30548879	Standard Error	63.53460825
Median	746.3076923	Median	1140.405436
Mode	#N/A	Mode	#N/A
Standard Deviation	326.984907	Standard Deviation	220.0903391
Sample Variance	106919.1294	Sample Variance	48439.75735
Kurtosis	0.137177303	Kurtosis	-1.353677893
Skewness	-0.034038379	Skewness	-0.215328211
Range	1275.810756	Range	688.7127068
Minimum	142.0353982	Minimum	712.2047244
Maximum	1417.846154	Maximum	1400.917431
Sum	12817.38651	Sum	12751.66289
Count	17	Count	12

MR-A ALL		*MR-A CATTAILS*	
Mean	1548.176126	Mean	1554.877992
Standard Error	266.8727069	Standard Error	337.3269128
Median	2054.651163	Median	1662.873418
Mode	#N/A	Mode	#N/A
Standard Deviation	706.0788143	Standard Deviation	674.6538257
Sample Variance	498547.2919	Sample Variance	455157.7845
Kurtosis	-1.690646463	Kurtosis	-3.382323675
Skewness	-0.707979121	Skewness	-0.447441468
Range	1647.68147	Range	1398.194665
Minimum	498.2984293	Minimum	747.7852349
Maximum	2145.979899	Maximum	2145.979899
Sum	10837.23288	Sum	6219.51197
Count	7	Count	4
MR-A PHRAG		*MR-A Spartina*	
Mean	1276.474796	Mean	2064.771323
Standard Error	778.1763667	Standard Error	0
Median	1276.474796	Median	2064.771323
Mode	#N/A	Mode	#N/A
Standard Deviation	1100.507572	Standard Deviation	#DIV/0!
Sample Variance	1211116.915	Sample Variance	#DIV/0!
Kurtosis	#DIV/0!	Kurtosis	#DIV/0!
Skewness	#DIV/0!	Skewness	#DIV/0!
Range	1556.352733	Range	0
Minimum	498.2984293	Minimum	2064.771323
Maximum	2054.651163	Maximum	2064.771323
Sum	2552.949592	Sum	2064.771323
Count	2	Count	1

LR-A All		LR-A cattail [one value]
		175
Mean	812.1442643	
Standard Error	241.5374123	
Median	196.3400952	
Mode	#N/A	
Standard Deviation	903.7502429	
Sample Variance	816764.5015	
Kurtosis	-1.355452848	
Skewness	0.772774711	
Range	2155.870092	
Minimum	46.84931507	
Maximum	2202.719407	
Sum	11370.0197	
Count	14	

LR-A phrag		*LR-A Spartina*	
Mean	459.903298	Mean	2198.584977
Standard Error	188.7041545	Standard Error	3.089448494
Median	179.6962596	Median	2200.494438
Mode	#N/A	Mode	#N/A
Standard Deviation	596.7349323	Standard Deviation	5.351081758
Sample Variance	356092.5794	Sample Variance	28.63407598
Kurtosis	1.170028775	Kurtosis	#DIV/0!
Skewness	1.596671097	Skewness	-1.401298162
Range	1646.034121	Range	10.17831944
Minimum	46.84931507	Minimum	2192.541087
Maximum	1692.883436	Maximum	2202.719407
Sum	4599.03298	Sum	6595.754931
Count	10	Count	3

LR-B PHRAG (NO OTHER PLANT)	
Mean	733.1360148
Standard Error	64.00444949
Median	672.379365
Mode	651.6839378
Standard Deviation	181.0319211
Sample Variance	32772.55644
Kurtosis	-0.31792898
Skewness	1.149591342
Range	445.1558472
Minimum	571.314741
Maximum	1016.470588
Sum	5865.088119
Count	8

LR-C ALL		*LR-C CATTAIL*	
Mean	1389.489538	Mean	1264.957155
Standard Error	123.8074135	Standard Error	302.6930036
Median	1533.050847	Median	1264.957155
Mode	#N/A	Mode	#N/A
Standard Deviation	371.4222406	Standard Deviation	428.0725509
Sample Variance	137954.4808	Sample Variance	183246.1088
Kurtosis	-1.369903304	Kurtosis	#DIV/0!
Skewness	-0.075874507	Skewness	#DIV/0!
Range	1064.080601	Range	605.3860071
Minimum	877.9069767	Minimum	962.2641509
Maximum	1941.987578	Maximum	1567.650158
Sum	12505.40585	Sum	2529.914309
Count	9	Count	2

LR-C PHRAG		*LR-C SPARTINA*	
Mean	1315.045544	Mean	1571.769787
Standard Error	207.9814397	Standard Error	203.491137
Median	1318.744962	Median	1533.050847
Mode	#N/A	Mode	#N/A
Standard Deviation	415.9628794	Standard Deviation	352.4569882
Sample Variance	173025.117	Sample Variance	124225.9285
Kurtosis	-4.492700426	Kurtosis	#DIV/0!
Skewness	-0.023896977	Skewness	0.488378912
Range	866.8782993	Range	701.7166417
Minimum	877.9069767	Minimum	1240.270936
Maximum	1744.785276	Maximum	1941.987578
Sum	5260.182176	Sum	4715.309361
Count	4	Count	3

LR-D ALL		*LR-D CATTAILS*	
Mean	1271.242607	Mean	1169.161155
Standard Error	50.18003723	Standard Error	64.97834637
Median	1207.814516	Median	1105.263158
Mode	#N/A	Mode	#N/A
Standard Deviation	301.0802234	Standard Deviation	234.2827596
Sample Variance	90649.3009	Sample Variance	54888.41145
Kurtosis	1.318961535	Kurtosis	-1.160104722
Skewness	0.865995457	Skewness	0.530284154
Range	1472.677771	Range	667.3726655
Minimum	696.5834428	Minimum	868.5483871
Maximum	2169.261214	Maximum	1535.921053
Sum	45764.73387	Sum	15199.09501
Count	36	Count	13
LR-D PHRAG		*LR-D SPARTINA*	
Mean	1277.261128	Mean	1574.419358
Standard Error	72.63410658	Standard Error	131.0056302
Median	1212	Median	1489.419271
Mode	#N/A	Mode	#N/A
Standard Deviation	316.6047304	Standard Deviation	262.0112603
Sample Variance	100238.5553	Sample Variance	68649.90053
Kurtosis	2.670775396	Kurtosis	1.731916824
Skewness	1.09040176	Skewness	1.44142876
Range	1472.677771	Range	574.074494
Minimum	696.5834428	Minimum	1372.382199
Maximum	2169.261214	Maximum	1946.456693
Sum	24267.96142	Sum	6297.677433
Count	19	Count	4

LR-E All		*LR-E Cattails*	
Mean	860.0925926	Mean	751.4
Standard Error	50.36159444	Standard Error	150.8806151
Median	778	Median	798
Mode	967	Mode	#N/A
Standard Deviation	370.080627	Standard Deviation	337.3793118
Sample Variance	136959.6705	Sample Variance	113824.8
Kurtosis	-0.908077202	Kurtosis	1.241700382
Skewness	0.09096481	Skewness	-0.396008837
Range	1479	Range	930
Minimum	35	Minimum	258
Maximum	1514	Maximum	1188
Sum	46445	Sum	3757
Count	54	Count	5
LR-E Phragmites		*LR-E Spartina*	
Mean	763.030303	Mean	1094.25
Standard Error	62.62116263	Standard Error	76.79282193
Median	701	Median	1138
Mode	967	Mode	#N/A
Standard Deviation	359.7311917	Standard Deviation	307.1712877
Sample Variance	129406.5303	Sample Variance	94354.2
Kurtosis	-0.450016163	Kurtosis	-1.122268797
Skewness	0.43838558	Skewness	-0.395430354
Range	1452	Range	962
Minimum	35	Minimum	552
Maximum	1487	Maximum	1514
Sum	25180	Sum	17508
Count	33	Count	16

NR-A All		*NR-A Cattails*	
Mean	475.3189268	Mean	544.4100964
Standard Error	49.29828367	Standard Error	146.2819439
Median	486.0244233	Median	583.125
Mode	#N/A	Mode	#N/A
Standard Deviation	274.481227	Standard Deviation	292.5638878
Sample Variance	75339.94396	Sample Variance	85593.62844
Kurtosis	-0.508116117	Kurtosis	1.827175316
Skewness	0.463944452	Skewness	-0.77485588
Range	1018.415851	Range	708.0832988
Minimum	51.5060241	Minimum	151.6535433
Maximum	1069.921875	Maximum	859.7368421
Sum	14734.88673	Sum	2177.640385
Count	31	Count	4
NR-A PHRAG		*NR-A SPARTINA*	
Mean	240.7117415	Mean	597.0664077
Standard Error	59.43206052	Standard Error	56.36151828
Median	212.3609227	Median	496.7696629
Mode	#N/A	Mode	#N/A
Standard Deviation	187.9406773	Standard Deviation	232.3844931
Sample Variance	35321.69817	Sample Variance	54002.55263
Kurtosis	5.820360652	Kurtosis	-0.227547698
Skewness	2.145147577	Skewness	0.834768399
Range	675.4170528	Range	837.5042926
Minimum	51.5060241	Minimum	232.4175824
Maximum	726.9230769	Maximum	1069.921875
Sum	2407.117415	Sum	10150.12893
Count	10	Count	17

NR-B ALL		*NR-B CATTAILS*	
Mean	1141.47215	Mean	1250.492212
Standard Error	90.32599231	Standard Error	161.3213593
Median	1298.905609	Median	1441.001742
Mode	#N/A	Mode	#N/A
Standard Deviation	486.4203549	Standard Deviation	510.1429306
Sample Variance	236604.7617	Sample Variance	260245.8096
Kurtosis	-0.940782781	Kurtosis	-0.088672521
Skewness	-0.34842734	Skewness	-1.010290159
Range	1700.99693	Range	1463.482823
Minimum	218.9189189	Minimum	341.5662651
Maximum	1919.915849	Maximum	1805.049088
Sum	33102.69235	Sum	12504.92212
Count	29	Count	10

NR-B PHRAG		*NR-B SPARTINA*	
Mean	1057.548248	Mean	1129.598752
Standard Error	155.3069518	Standard Error	145.9361325
Median	1106.282444	Median	1095.704698
Mode	#N/A	Mode	#N/A
Standard Deviation	537.9990624	Standard Deviation	386.110714
Sample Variance	289442.9912	Sample Variance	149081.4834
Kurtosis	-0.974882165	Kurtosis	-0.407774735
Skewness	0.046673091	Skewness	-0.343319747
Range	1700.99693	Range	1138.767099
Minimum	218.9189189	Minimum	508.4254144
Maximum	1919.915849	Maximum	1647.192513
Sum	12690.57897	Sum	7907.191265
Count	12	Count	7

NR-C All		*NR-C Cattail*	
Mean	1012.777778	Mean	1166.4
Standard Error	51.74362109	Standard Error	45.85477074
Median	1063	Median	1112
Mode	#N/A	Mode	#N/A
Standard Deviation	219.5295922	Standard Deviation	102.5343845
Sample Variance	48193.24183	Sample Variance	10513.3
Kurtosis	0.064153291	Kurtosis	-1.758951456
Skewness	-0.762276978	Skewness	0.810386889
Range	765	Range	232
Minimum	561	Minimum	1078
Maximum	1326	Maximum	1310
Sum	18230	Sum	5832
Count	18	Count	5

NR-C Phragmites		*NR-C Spartina*	
Mean	868	Mean	1090.8
Standard Error	82.98214094	Standard Error	61.43809893
Median	896.5	Median	1048
Mode	#N/A	Mode	#N/A
Standard Deviation	234.7089383	Standard Deviation	137.3797656
Sample Variance	55088.28571	Sample Variance	18873.2
Kurtosis	-1.607499241	Kurtosis	3.428881809
Skewness	-0.012264376	Skewness	1.780376539
Range	623	Range	348
Minimum	561	Minimum	978
Maximum	1184	Maximum	1326
Sum	6944	Sum	5454
Count	8	Count	5

Sub-Watershed Comparisons (ignoring plant species)

Test sub-watershed comparisons

Kruskal-Wallis Test

	DR	LR	NR	
median	1086	1016	861	
rank sum	14371	18319	9796	
count	92	121	78	291
r^2/n	2244843.924	2773436.041	1230277.128	6248557.093
H-stat				6.439922813
H-ties				6.439930653
df				2
p-value				0.039956444
alpha				0.05
sig				yes

DUNN's TEST

group	*R-sum*	*size*	*R-mean*	*z-crit*		
			alpha	0.05	0.016666667	
DR	*14371*	*92*	*156.2065217*			
LR	18319	121	151.3966942			
NR	9796	78	125.5897436			
		291		1.959963985		

D TEST

group 1	*group 2*	*R-mean*	*std err*	*z-stat*	*R-crit*	*p-value*
DR	LR	4.809827524	11.63992644	0.413218034	22.8138366	0.679446876
DR	NR	30.61677815	12.95180444	2.363900589	25.38507025	0.018083664
LR	NR	25.80695063	12.21894147	2.112044704	23.94868521	0.034682615

Entire Study – Comparing plant species

ENTIRE STUDY -COMPARING PLANT SPECIES				
Kruskal-Wallis Test				
	Cattails	Phrag	Spartina (undifferentiated)	
median	1161	744	1115	
rank sum	10094	19774	12618	
count	58	159	74	291
r^2/n	1756704.069	2459189.157	2151539.514	6367432.74
H-stat				23.22789715
H-ties				23.22792543
df				2
p-value				9.03899E-06
alpha				0.05
sig				yes

DUNN's TEST		alpha	0.05	0.016667
group	*R-sum*	*size*	*R-mean*	*z-crit*
Cattails	10094	58	174.0345	
Phrag	19774	159	124.3648	
Spartina (ı	12618	74	170.5135	
		291		1.959964

D TEST						
group 1	*group 2*	*R-mean*	*std err*	*z-stat*	*R-crit*	*p-value*
Cattails	Phrag	49.6697	12.90816	3.847931	25.29953	0.000119
Cattails	Spartina (ı	3.520969	14.75721	0.238593	28.92359	0.811421
Phrag	Spartina (ı	46.14873	11.84161	3.897169	23.20912	9.73E-05

Site Comparisons *ignoring plant species* (statistically significant differences highlighted)

SITE-SITE COMPARISONS (IGNORING PLANT SPECIES)

Kruskal-Wallis Test

	DR-A	DR-B	LR-A	LR-B	LR-C	LR-D	LR-E	MR-A	NR-A	NR-B	NR-C	
median	1253	911	196	672	1320	1105	778	2055	486	1299	1063	
rank sum	7558	5306	1552	832	6646	2357	6932	1507	1979	5046	2771	
count	48	37	14	8	32	13	54	7	31	29	18	291
r^2/n	*1190070*	*760909.1*	*172050.3*	*86528*	*1380291*	*427342.2*	*889863.4*	*324435.6*	*126336.8*	*878004*	*426580.1*	6662411
H-stat												64.88556
H-ties												64.88564
df												10
p-value												4.26E-10
alpha												0.05
sig												yes

Dunn's Test results sorted by p-value

group 1	group 2	R-mean	std err	z-stat	R-crit	p-value
LR-C	NR-A	143.8488	21.20613	6.783358	41.56326	1.17E-11
NR-A	NR-B	110.1613	21.73916	5.067412	42.60798	4.03E-07
DR-A	NR-A	93.61962	19.38917	4.82845	38.00207	1.38E-06
MR-A	NR-A	151.447	35.21348	4.300825	69.01716	1.7E-05
LR-C	LR-E	79.31713	18.7726	4.225155	36.79362	2.39E-05
LR-D	NR-A	117.469	27.80487	4.224763	54.49654	2.39E-05
DR-B	NR-A	79.5667	20.48895	3.883395	40.15761	0.000103
NR-A	NR-C	90.10573	24.93607	3.61347	48.8738	0.000302
LR-A	LR-C	96.83036	26.96416	3.591076	52.84879	0.000329
LR-E	NR-A	64.53166	18.96177	3.403252	37.16438	0.000666
DR-B	LR-C	64.28209	20.31401	3.164421	39.81473	0.001554
LR-B	**LR-C**	**103.6875**	**33.26267**	3.117234	65.19363	0.001826
LR-A	MR-A	104.4286	38.95324	2.68087	76.34696	0.007343
DR-A	LR-C	50.22917	19.20421	2.615529	37.63956	0.008909
LR-E	MR-A	86.91534	33.80384	2.571168	66.25431	0.010136
LR-B	MR-A	111.2857	43.55105	2.555293	85.35849	0.01061
LR-E	NR-B	45.62963	19.3727	2.355357	37.9698	0.018505
LR-A	**NR-B**	**63**	**27**	2.305717	53.67429	0.021126
LR-A	LR-D	70.45055	32.41106	2.173658	63.52451	0.029731
LR-C	NR-C	53.74306	24.79253	2.167712	48.59246	0.030181
LR-B	NR-B	70	33.605	2.083023	65.86459	0.037249
DR-B	MR-A	71.88031	34.68355	2.072461	67.9785	0.038222
LR-B	**LR-D**	**77.30769**	**37.8129**	2.044479	74.11193	0.040906
LR-D	LR-E	52.93732	25.99656	2.03632	50.95232	0.041718
DR-A	LR-A	46.60119	25.55985	1.823219	50.09638	0.06827
DR-A	LR-E	29.08796	16.69282	1.742544	32.71732	0.081413

data continue ↓

Site comparisons for the same plant species (statistically significant differences highlighted)

CATTAIL

Kruskal-Wallis Test

	DR-A CATTAIL	DR-B CATTAIL	LR-A CATTAIL	LR-C CATTAIL	LR-D CATTAIL	LR-E CATTAIL	MR-A CATTAIL	NR-A CATTAIL	NR-B CATTAIL	NR-C CATTAIL	
median	1778	1206	175	1265	1105	798	1663	583	1441	1112	
rank sum	246	249	3	67	385	72	161	33	345	150	
count	6	8	1	2	13	5	4	4	10	5	58
r^2/n	10086	7750.125	9	2244.5	11401.92308	1036.8	6480.25	272.25	11902.5	4500	55683.34808
H-stat											18.26597806
H-ties											18.26597806
df											9
p-value											0.032210155
alpha											0.05
sig	DUNN's Test results										yes

Sorted by p-value

D TEST

group 1	group 2	R-mean	std err	z-stat	R-crit	p-value	
DR-A CATTAIL	NR-A CATTAIL	32.75	10.90043322	3.004467743	21.36445653	0.00266046	
MR-A CATTAIL	NR-A CATTAIL	32	11.94082633	2.679881537	23.40358954	0.007364822	
NR-A CATTAIL	NR-B CATTAIL	26.25	9.99041207	2.627519247	19.58084785	0.008600998	
DR-A CATTAIL	LR-E CATTAIL	26.6	10.22551276	2.601336543	20.04163672	0.009286131	
LR-E CATTAIL	MR-A CATTAIL	25.85	11.3280625	2.281943625	22.20259451	0.022492669	
LR-D CATTAIL	NR-A CATTAIL	21.36538462	9.655442201	2.212781576	18.92431897	0.026912708	
DR-B CATTAIL	NR-A CATTAIL	22.875	10.34105894	2.212055857	20.26810308	0.026962806	
LR-E CATTAIL	NR-B CATTAIL	20.1	9.2493243	2.173131717	18.12834251	0.029770405	
DR-A CATTAIL	LR-A CATTAIL	38	18.2399135	2.083343213	35.74957354	0.03721995	
LR-A CATTAIL	MR-A CATTAIL	37.25	18.88010417	1.972976403	37.00432419	0.048498251	
NR-A CATTAIL	NR-C CATTAIL	21.75	11.3280625	1.920010593	22.20259451	0.054856561	
LR-A CATTAIL	NR-B CATTAIL	31.5	17.71110763	1.778544892	34.71313307	0.075314406	
DR-B CATTAIL	LR-E CATTAIL	16.725	9.627001956	1.737300987	18.86857711	0.082334057	
LR-C CATTAIL	NR-A CATTAIL	25.25	14.6244658	1.726558791	28.66342627	0.084246932	
LR-D CATTAIL	LR-E CATTAIL	15.21538462	8.886463344	1.712197983	17.4171481	0.086860189	
DR-B CATTAIL	LR-A CATTAIL	28.125	17.91123949	1.570243088	35.10538432	0.116358569	
LR-A CATTAIL	LR-D CATTAIL	26.61538462	17.52434204	1.518766556	34.34707926	0.128821267	
LR-A CATTAIL	LR-C CATTAIL	30.5	20.68211788	1.474703905	40.53620617	0.140292166	data continues
LR-E CATTAIL	NR-C CATTAIL	15.6	10.68019975	1.460646839	20.93280685	0.144112385	

PHRAGMITES

Kruskal-Wallis Test

	DR-A PHRAGMITES	DR-B PHRAGMITE	LR-A PHRAGMITES	LR-B PHRAGMITES	LR-C PHRAGMITE	LR-D PHRAGMITES	LR-E PHRAGMITES	MR-A PHR	NR-A PHR	NR-B PHR	NR-C PHRAGMITES	
median	544	746	180	672	1319	1212	701	1277	212	1106	897	
rank sum	2827	1291	424	584	487	2278	2489	207	268	1188	677	
count	**36**	**17**	**10**	**8**	**4**	**19**	**33**	**2**	**10**	**12**	**8**	159
r^2/n	221998.0278	98040.05882	17977.6	42632	59292.25	273120.2105	187730.9394	21424.5	7182.4	117612	57291.13	1104301
H-stat												40.89675
H-ties												40.89706
df												10
p-value												1.18E-05
alpha												0.05
sig												yes

D TEST

group 1	group 2	R-mean	std err	z-stat	R-crit	p-value
LR-D PHRAGMITES	NR-A PHRAGMITES	93.09473684	17.98823316	5.175312995	35.25628914	2.27529E-07
LR-A PHRAGMITES	LR-D PHRAGMITES	77.49473684	17.98823316	4.308079406	35.25628914	1.64678E-05
NR-A PHRAGMITES	NR-B PHRAGMITES	72.2	19.71455721	3.662268406	38.63982209	0.000249992
LR-C PHRAGMITES	NR-A PHRAGMITES	94.95	27.23957529	3.485737167	53.38858652	0.000490783
LR-D PHRAGMITES	LR-E PHRAGMITES	44.47049442	13.25971566	3.353804528	25.98856514	0.000797086
DR-A PHRAGMITES	LR-D PHRAGMITES	41.36695906	13.05628446	3.168356142	25.58984732	0.001533036
DR-A PHRAGMITES	NR-A PHRAGMITES	51.72777778	16.45864111	3.142894814	32.2583438	0.001672859
LR-E PHRAGMITES	NR-A PHRAGMITES	48.62424242	16.62048021	2.925561825	32.57554262	0.003438348
LR-A PHRAGMITES	LR-C PHRAGMITES	79.35	27.23957529	2.913041013	53.38858652	0.003579276
LR-A PHRAGMITES	NR-B PHRAGMITES	56.6	19.71455721	2.870974956	38.63982209	0.004092079
DR-B PHRAGMITES	LR-D PHRAGMITES	43.95356037	15.37150175	2.859418753	30.12758983	0.004244181
DR-B PHRAGMITES	NR-A PHRAGMITES	49.14117647	18.34947872	2.678069346	35.96431743	0.007404789
NR-A PHRAGMITES	NR-C PHRAGMITES	57.825	21.84024816	2.647634751	42.80609982	0.008105705
LR-B PHRAGMITES	LR-D PHRAGMITES	46.89473684	19.40556974	2.416560682	38.03421778	0.015667914
DR-A PHRAGMITES	LR-A PHRAGMITES	36.12777778	16.45864111	2.195064437	32.2583438	0.028158976
MR-A PHRAGMITES	NR-A PHRAGMITES	76.7	35.66497591	2.150569236	69.90206828	0.031510216
LR-B PHRAGMITES	NR-A PHRAGMITES	46.2	21.84024816	2.115360579	42.80609982	0.034399227
LR-A PHRAGMITES	LR-E PHRAGMITES	33.02424242	16.62048021	1.986960786	32.57554262	0.046926743
LR-A PHRAGMITES	NR-C PHRAGMITES	42.225	21.84024816	1.933357152	42.80609982	0.053192216
LR-C PHRAGMITES	LR-E PHRAGMITES	46.32575758	24.37699713	1.900388195	47.77803643	0.057382195
DR-B PHRAGMITES	LR-A PHRAGMITES	33.54117647	18.34947872	1.827908955	35.96431743	0.067563217

Data continue ↓

SPRATINA (undifferentiated)

Kruskal-Wallis Test

	DR-A SPAI	DR-B SPAI	LR-A SPAR	LR-C SPAR	LR-D SPAR	LR-E SPAR	MR-A SPA	NR-A SPAI	NR-B SPAI	NR-C SPARTINA	
median	*2063*	*1140*	*2200*	*1533*	*1489*	*1138*	*2065*	*497*	*1096*	*1048*	
rank sum	406	419	*219*	*168*	*233*	*599*	*68*	*213*	*270*	*180*	
count	6	12	3	3	4	16	1	17	7	5	74
r^2/n	27473	14630	15987	9408	13572	22425	4624	2669	10414	6480	127682.1
H-stat											51.06943
H-ties											51.06943
df											9
p-value											6.78E-08
alpha											0.05
sig											yes

Dunn's Test results sorted by p-value

group 1	*group 2*	*R-mean*	***std err***	***z-stat***	***R-crit***	***p-value***
DR-A SPAI	NR-A SPAI	55.13725	10.21221	5.399151	20.01556	6.7E-08
LR-A SPAR	NR-A SPAI	60.47059	13.46746	4.490125	26.39574	7.12E-06
LR-D SPAR	NR-A SPAI	45.72059	11.95119	3.82561	23.4239	0.00013
LR-E SPAR	NR-A SPAI	24.90809	7.490803	3.325156	14.6817	0.000884
LR-C SPAR	NR-A SPAI	43.47059	13.46746	3.227823	26.39574	0.001247
DR-A SPAI	DR-B SPAI	32.75	*10.75291*	*3.045688*	*21.07531*	*0.002321*
DR-A SPAI	LR-E SPAR	30.22917	10.29512	2.93626	20.17807	0.003322
DR-B SPAI	NR-A SPAI	22.38725	8.108486	2.760966	15.89234	0.005763
DR-B SPAI	LR-A SPAR	38.08333	13.88194	2.743372	27.20811	0.006081
NR-A SPAI	NR-B SPAI	26.04202	9.658018	2.696414	18.92937	0.007009
LR-A SPAR	LR-E SPAR	35.5625	13.53044	2.628332	26.51918	0.00858
MR-A SPA	NR-A SPAI	55.47059	22.1293	2.506658	43.37263	0.012188
DR-A SPAI	NR-B SPAI	29.09524	11.96473	2.431751	23.45044	0.015026
DR-A SPAI	NR-C SPAI	31.66667	13.02242	2.431704	25.52347	0.015028
LR-A SPAR	NR-C SPAI	37	15.70563	2.355844	30.78246	0.018481
LR-A SPAR	NR-B SPAI	34.42857	14.84042	2.319919	29.08669	0.020345
NR-A SPAI	NR-C SPAI	23.47059	10.94102	2.145192	21.444	0.031937
DR-B SPAI	LR-D SPAR	23.33333	12.41639	1.879237	24.33567	0.060212
LR-D SPAR	LR-E SPAR	20.8125	12.02212	1.731185	23.56291	0.083419
LR-D SPAR	NR-C SPAI	22.25	14.42654	1.542297	28.27549	0.123002

data continue

Appendix E-2. Summary Statistics for Marsh-Fringe Reference Sites

Descriptive Statistics			Shapiro-Wilk Test		
Specific Conductance (µS/cm)			*Specific Conductance (µS/cm)*		
Mean	*1914*		W-stat	*0.914200657*	
Standard Error	*102.7837023*		*p-value*	0.311108994	
Median	1963		alpha	0.05	
Mode	#N/A		normal	yes	
Standard Deviation	325.0306058				
Sample Variance	105644.8947		d'Agostino-Pearson		
Kurtosis	-1.435832001				
Skewness	-0.349615571		DA-stat	1.961452548	
Range	882		p-value	0.375038619	
Maximum	2293		alpha	0	
Minimum	1411		normal	yes	
Sum	19142				
Count	10				
Geometric Mean	1888.136137				
Harmonic Mean	1861.18177				
AAD	275.3322172				
MAD	287.3917063				
IQR	550.5328327				

For Marsh-Fringe Reference Sites to Phragmites Study Sites Comparisons

DUNN's TEST			alpha	0.05
group	*R-sum*	*size*	*R-mean*	*z-crit*
Entire study cattails	10147	58	174.9482759	
Entire study phragmites	19851	159	124.8490566	
Entire study alterniflora	10737	62	173.1774194	
DR-B patens	1964	12	163.6666667	
Patens reference site	2752	10	275.2	
		301		1.959963985

D TEST

group 1	*group 2*	*R-mean*	*std err*	*z-stat*	*R-crit*	*p-value*
Entire study cattails	Entire study phragmites	50.09921926	13.35098062	3.752474871	26.16744117	0.000175097
Entire study cattails	Entire study alterniflora	1.770856507	15.89925002	0.111379877	31.16195743	0.911315117
Entire study cattails	DR-B patens	11.2816092	27.60198132	0.408724615	54.09888928	0.682741767
Entire study cattails	Patens reference site	100.2517241	29.801376	3.363996486	58.40962365	0.000768225
Entire study phragmites	Entire study alterniflora	48.32836275	13.03159539	3.708553044	25.54145762	0.000208447
Entire study phragmites	DR-B patens	38.81761006	26.05581892	1.489786607	51.06846667	0.136280354
Entire study phragmites	Patens reference site	150.3509434	28.37531213	5.298653375	55.61458983	1.1666E-07
Entire study alterniflora	DR-B patens	9.510752688	27.44891924	0.34648915	53.79889313	0.728975137
Entire study alterniflora	Patens reference site	102.0225806	29.65966632	3.439775065	58.13187779	0.000582198
DR-B patens	Patens reference site	111.5333333	37.26632565	2.992871752	73.04065612	0.002763659

Results of Pairwise Comparisons

(Significantly different pairs involving the reference sites have yellow highlight; significant differences with gray highlight do not pertain to the reference sites and were presented previously in **Appendix E-1**)

DUNN's TEST			alpha	0.05		
group	*R-sum*	*size*	*R-mean*	*z-crit*		
Entire study cattails	10147	58	174.9482759			
Entire study phragmites	19851	159	124.8490566			
Entire study alterniflora	10737	62	173.1774194			
DR-B patens	1964	12	163.6666667			
Patens reference site	2752	10	275.2			
		301		1.959963985		
D TEST						
group 1	*group 2*	*R-mean*	*std err*	*z-stat*	*R-crit*	*p-value*
Entire study cattails	Entire study phragmites	50.09921926	13.35098062	3.752474871	26.16744117	0.000175097
Entire study cattails	Entire study alterniflora	1.770856507	15.89925002	0.111379877	31.16195743	0.911315117
Entire study cattails	DR-B patens	11.2816092	27.60198132	0.408724615	54.09888928	0.682741767
Entire study cattails	Patens reference site	100.2517241	29.801376	3.363996486	58.40962365	0.000768225
Entire study phragmites	Entire study alterniflora	48.32836275	13.03159539	3.708553044	25.54145762	0.000208447
Entire study phragmites	DR-B patens	38.81761006	26.05581892	1.489786607	51.06846667	0.136280354
Entire study phragmites	Patens reference site	150.3509434	28.37531213	5.298653375	55.61458983	1.1666E-07
Entire study alterniflora	DR-B patens	9.510752688	27.44891924	0.34648915	53.79889313	0.728975137
Entire study alterniflora	Patens reference site	102.0225806	29.65966632	3.439775065	58.13187779	0.000582198
DR-B patens	Patens reference site	111.5333333	37.26632565	2.992871752	73.04065612	0.002763659