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Halinity in Tidal Soils of the Connecticut River

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Halinity in Tidal Soils of the Connecticut River

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This work is dedicated to Janine René.

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Chapter 1: Introduction

An Overview of Soil Salinity and Halinity

Recent coastal soil mapping in Rhode Island and Connecticut by the United States Department of Agriculture- Natural Resources Conservation Service (NRCS) and cooperators has shown a need for better definition of soils affected by ocean salts. Much work has been done to identify and classify saline soils that typically occur in arid climates such as the western United States. High salinity in these regions, often resulting from long term agricultural irrigation, is a major concern for land productivity. Consequently, salinity classes have been developed to categorize these arid soils accordingly, based on productivity or lack thereof (USDA-NRCS Soil Survey Staff 1993). In contrast, NRCS currently does not clearly identify soils influenced by ocean-derived salts. As a result soil salinity classes that accurately represent the coastal, subaqueous, salt marsh or other tidally influenced soils have not yet been established. Because the dominant anions in the sea are halides- specifically chloride (primarily sodium chloride, NaCl), soils affected by these salts will be referred to as "haline" to differentiate from the more general term "saline".

Salinity and Halinity Classification Systems

There have been many attempts at generating salinity, halinity, and chlorinity classes in the past by other agencies for various purposes using a range of methods. For example, in 1979 under the United States Fish and Wildlife Service (USFWS), soil halinity classes were published by wetland scientists mainly for ecological classification (Cowardin et al. 1979). The USFWS system is different in that the values are based on soil pore water while historically similar classes used water column samples with a given biotic composition (Ekman 1953; Mead 1966; Den Hartog 1974). Notice the system's use of the terms "salinity" and "halinity" to differentiate inland from ocean affected wetlands. Thus, these halinity classes are used solely in marine and estuarine habitats (Cowardin et al. 1979). A more comprehensive history of salinity and halinity classification systems is detailed in Chapter 3.

Measuring Halinity

Of the many historic classification systems for salinity and halinity, most are a classification of aquatic biota using water rather than soil samples (Ekman 1953; Mead 1966; Den Hartog 1974). The aforementioned USFWS system however is based on soil pore water, which is one of the laboratory methods for measuring electrical conductivity (EC) that is explored in this study (Cowardin et al. 1979). These methods are used in this study because EC is the most precise way to measure halinity without completing a full chemical analysis (Clesceri et al. 1998). The other EC methods originate from coastal soil mapping projects in Rhode Island and Connecticut. This method involves measuring EC with a conductivity meter from a 1 part soil to 5 parts deionized water by volume mixture ($EC_{1:5vol}$) in dS m^{-1}, equivalent to mmhos cm^{-1}, which brings readings within the range of most hand-held conductivity meters. An in-depth comparison of the lab methods for EC is detailed in Chapter 2.

Study Area: The Connecticut River Estuary

The Connecticut River is the largest river in New England with a length of 660 km, a basin area of about 28,500 square km, and an average discharge of just under 570 cubic m s^{-1} (CRWC, 2011; Dreyer and Caplis, 2001; Meade, 1966). The river provides approximately 70 percent of the freshwater input to Long Island Sound, which extends perpendicular to the mouth of the river into the Atlantic Ocean. Although the river's watershed extends from southern Connecticut through four states into Canada, the tidal influence only reaches about 58 km from the mouth of the river. The Connecticut River is ecologically and economically important to the states it passes through as it provides valuable habitat, recreational areas, and jobs to the over two million people living in the 400 municipalities within the watershed (Dreyer and Caplis 2001). In fact, the river is so locally important that there is an entire class dedicated to it at the University of Massachusetts at Amherst entitled "Under the Connecticut". Additionally, the mouth of the Connecticut River is considered an Estuary of National Importance by the National Oceanic and Atmospheric Administration and an Estuary of International Importance by Ramsar (NOAA, Ocean Service Staff 2013; Ramsar Standing Committee 2013). These areas are important to our seafood industry because the nutrients from coastal wetlands directly or indirectly nourish many edible fish and shellfish species (Warren and Fell 1995). Some of the federally endangered species that the waterway hosts include the piping plover, short nose sturgeon, puritan tiger beetle, dwarf wedgemussle, small whorled pogonia, Northeastern bulrush, and Jesup's milk-vetch (CRWC, 2011).

The Connecticut River valley (Figure 1.1) was formed during the Mesozoic Era (250 to 65 million years ago) when it was rifted apart as the Atlantic Ocean formed. The traprock to the west of the river forces groundwater to flow in a south easterly direction in the Hartford to Middletown area. Moving downstream, Paleozoic metamorphic rocks drive the river to the east. This project mainly deals with an area from the mouth of the river in Old Lyme and Old Saybrook to the end of the salt water wedge in Essex/Lyme, or the last approximately 18 km of the river before it empties into the Sound (Meade 1966).

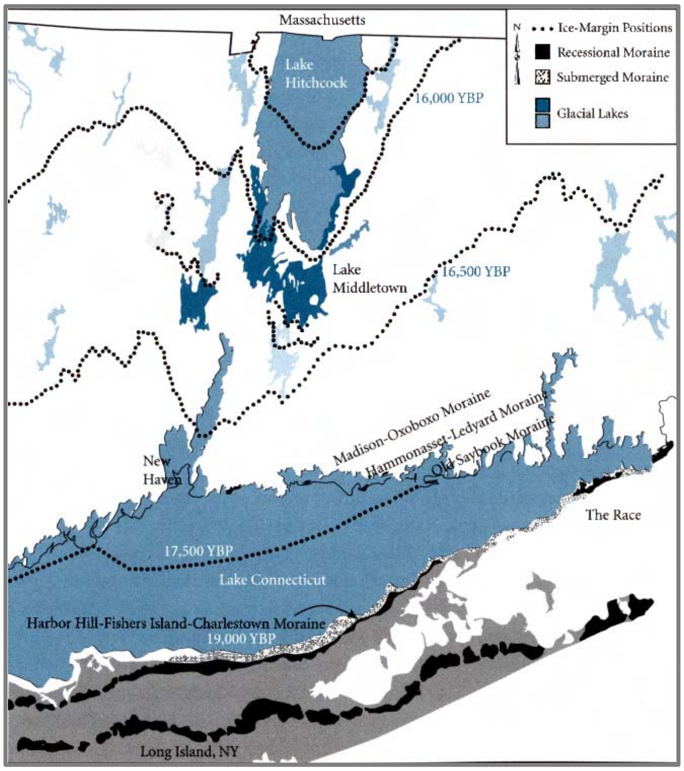


Figure1.1: Glacial map of the CT River valley (Dreyer and Caplis 2001)

The estuary of the Connecticut River was chosen for this study for multiple reasons. There has been copious data collection in and around this river throughout its recent history. For example there was an extensive study from 1934 to 1939 by the U.S. Geological Survey (USGS) in cooperation with the Connecticut State Water Commission and the Works Progress Administration for Connecticut exploring the movement of the salt wedge depending on river discharge, tide and wind. About 180,000 samples of river water were analyzed by titration for chlorinity to reveal temporal and spatial halinity patterns (Mead 1966). A publication by the Connecticut College Arboretum also discusses these halinity patterns which depend on river discharge. To quantify the river's physical and chemical factors, there are currently USGS tidal gauges installed at the mouth of the river in Old Lyme as well as upstream in Essex. Data are available in real-time, including water temperature, specific conductance, and salinity (USGS 2012). As with any field-based research, having a multitude of access points is important. The river provides many potential sample sites with the array of wildlife areas and local boat launches. For example, Great Island Wildlife Management Area is the largest continuous undeveloped marsh in the study area and is a representative of a preserved area in the study. Hence, the Connecticut River has been well studied and monitored and is an ideal location for researching soil halinity.

Soil Response to Global Warming and Sea Level Rise

Scientists have been aware of peat accumulation, or accretion, over time in coastal marshes since as early as 1858 (Orson et al. 1987). Recently, the issue of the rate of sea level rise surpassing the marsh accretion rate and producing a net loss of tidal wetlands has been particularly pertinent. Through analysis of soil core samples, sea level rise has been proven to facilitate tidal marsh development over former fresh water marshes. By studying halophytic vegetation and pollen that have been preserved in tidal marsh samples and through the identification of sand lenses deposited during known storm events, scientists can determine precisely how the marsh vegetation developed (Roman et al. 1984; Orson et al.1987). Other methods for calculating accretion rates include the use of a marker horizon such as clay and aluminum glitter and using Pb-210 as a tracer (Stumpf 1983). There have also been studies where the clay type present in a soil horizon has been used to distinguish between saltwater and freshwater derived sediments (vermiculite for salt or illite for upland) because of known salt water weathering reactions

(Hill and Shearin 1970). Thus, much can be learned about the formation of marsh landscapes through inspection of their soil.

Marsh accretion rates can be quite variable by location depending on several factors. A review study (Neubauer 2008) containing soils data from the U.S. Eastern Seaboard from Maine to Georgia, the Gulf Coast, and one site in Belgium found that accretion rates can vary by halinity; fresh water marshes were found to accrete more on average than brackish and salt marshes. Neubauer (2008) also found that fresh marsh accretion is generally affected by both organic matter and mineral soils, while salt marshes are mainly influenced by organic matter. In fact, in the Northeastern U.S., the organic material component of tidal marsh soils is the only portion which significantly contributes to marsh accretion. In a study in Delaware, it was found that normal tidal flooding does not account for the supply of sediment needed to build tidal marshes, but instead it is deposited from larger storm events (Stumpf 1983). There may also be anthropogenic effects on marshes due to sediment from upland sources within the watershed. This type of sedimentation may cause a positive feedback loop by altering the marsh hydrology to slow water velocity, allowing additional sedimentation to occur (Zedler 2001). The simplified formula for net vertical accretion is given as:

net accretion = surface deposition + subsurface production – erosion – decomposition

by Reed (1995). These values are all locally variable and related to marsh hydrology. Generally this rate is lower in haline areas because of increased decomposition in coastal zones (Neubuaer 2007). While actual accretion rates for CT range from 1.1 mm (Orson et al. 1987) to 1 cm year^{-1} (Anisfeld et al. 1999), the definite rate of sea level rise has long since been a topic of dispute among scientists.

According to a study in 1993 (Warren and Niering), sea level rise was at least 2-2.5 mm $year^{-1}$ in Southern New England since 1938. The investigators also found that some accretion rates are slower than this rate by up to about half, which leads to a net loss of marsh (Warren and Niering 1993). A similar study conducted in Newport, RI in 1998, found that the historic annual mean sea level rise rate was approximately 0.25 mm $year^{-1}$ –or an order of magnitude less than the 1993 study (Boothroyd and Calabro 1998). Gornitz et al. (1982) reported values for sea level rise varying from 1 to 3 mm per year, while Hill and Shearin (1970) found that in Connecticut, the sea level has risen as much as 10 m in the last 7,000 to 11,000 years, or about 0.9 to 1.4 mm $year^{-1}$, with an equivalent accretion rate since 3000 years ago. More recent sea level rise models give spatially variable figures. For example Yin et al. (2009) predicted a more rapid and dynamical sea level rise in the Northeast US, with New York City experiencing a 15 to 21cm increase this century, or 1.5 to 2.1 mm $year^{-1}$. In brief, like accretion, sea level rise is a highly variable, site specific value.

In some areas, accretion cannot keep up with sea level rise because of disturbance, subsidence, or erosion. For example, Louisiana loses up to 130 km^2 $year^{-1}$ of land, in part because of the subsidence of the Mississippi River Delta sediments and disruption from large storms (Gagliano 1981; USGS 1995; Baldwin and Mendelssohn 1998). In some areas, sea level rise and salt water intrusion leads to a decrease in marsh productivity and may have an overall detrimental effect on vegetation because of plants' negative physiological response to increased soil halinity. Because of the variability in long and short-term sea level rise predictions though, it is difficult to know exactly what marsh accretion rate is necessary to overcome the effects of global climate change.

On the macro-scale of climate change, tidal marshes offer valuable carbon sequestration. Organic swamp and marsh soils are known to hold up to three times the amount of carbon as vegetation, or as much as 100 Mg ha^{-1} carbon, mainly in the upper 30-45 cm. Similarly subaqueous soils were found to hold 35 percent more carbon than their subaerial counterparts along the Maine coast (Jesperen et al. 2007). One study estimated the global sequestration rate to be 210 g carbon dioxide m^{-1} annually or 42.6 Tg carbon $year^{-1}$ by tidal haline wetlands (Chmura et al. 2003). Organic matter may be deposited from the same sources as mineral soils or accumulate from local vegetation. Salt marsh organic carbon deposition depends on tidal range, local geomorphology, successional age of the wetland, the marsh to open water ratio, and freshwater inputs. Conversely, carbon exports mostly tend to leave these systems in the form of dissolved compounds (Odum 1988).

Halinity in Relation to Mapping Subaqueous Soils

The NRCS currently uses an $EC_{1:5vol}$ of 0.2 dS m^{-1} to differentiate between fresh (classified as *frasi*) and coastal subaqueous soils in the *Keys to Soil Taxonomy 11th Edition* (USDA-NRCS Soil Survey Staff 2010). This value was agreed upon by NRCS, URI, Pennsylvania State University (PSU), and University of Maryland (UMD) soil scientists (Stolt 2011). The break is derived from data contributed by University of Rhode Island (URI) and UMD subaqueous soil graduate dissertations dealing with salt water subaqueous soils (Bradley 2001; Balduff 2007; Salisbury 2009; Stolt 2011).

Since the 1999 redefinition of soil upper limits to include up to 2.5 m of water (USDA-NRCS Soil Survey Staff 2010), coastal soil mapping by the scientists in Rhode Island, Connecticut, Massachusetts, New York, Texas, New Hampshire, Delaware, Maryland, Florida, Maine, and New Jersey have shown that soils found in these areas require different salinity methods and interpretations than upland soils. The subaqueous soils in these studies have water tables at or above the soil surface and may be located in fresh, estuarine, and salt water environments. Some subaqueous interpretations such as shellfish productivity, eelgrass restoration for aquatic habitat, heavy metal content potential, mooring sites, acid sulfate soils, and the use of dredged material have already been explored based on soil characteristics such as texture, landscape position, and chemistry by both NRCS staff and graduate students from the University of Rhode Island (URI) (Salisbury 2009; Bradley 2001; Bradley and Stolt 2005; Surabian 2007). The research has resulted in copious data concerning many subaqueous soil characteristics including $EC_{1:5vol}$. Resource managers from agencies such as National Oceanic and Atmospheric Administration, Chesapeake Bay Program, MD Coastal Bays Program, Egg Harbor, NJ, U.S. Army Corps of Engineers, MD-Department of Natural Resources, Assateague Island National Park, DE Sierra Club, and U.S. Environmental Protection Agency have also created subaqueous soil interpretations for managing coastal areas that include nutrient reduction, benthic preservation, waterfowl nurseries and spawning areas, horseshoe crab habitat, and shellfish stocking among others (King 2005; Erich et al. 2010). Although halinity may significantly affect many land uses and is known as one of the most important driving factors behind coastal ecology, these data have not yet been compiled or categorized (Wenner and Riekerk 2011).

Project Objectives

The purpose of this project is to establish methods for soil halinity classes that are useful for diverse soil interpretations for tidal marsh and subaqueous soils. Because of tidal flooding these soils are unsuitable for building or traditional agriculture without modification, so land uses will mainly deal with ecological and recreational functions. Of the many potential land use interpretations for tidal marsh soils, the most obvious is for wildlife habitat. The three main vegetation bands of Northeastern tidal marshes (*Juncus gerardi, Spartina patens,* and *Spartina alterniflora*) are quite productive in terms of biomass (Warren and Fell 1995). The stratified sampling scheme will reflect the distinct vegetative patterns in salt marshes. The project will result in soil halinity data to assist in the protection and management of recreational marsh and beach areas. Also, because the contents of a water body reflect what happens within its watershed, the findings may also influence local and regional watershed protection programs.

This project will generate methods for soil halinity classes, having appropriate breaks to represent distinct ecological communities, as well as preliminary Ecological Site Descriptions by recognizing vegetation patterns due to salt content in the soil, and a comparison of EC methods used for halinity measurement. Ecological Site Descriptions, or ESDs are models developed by NRCS to correlate vegetation with soil type and predict outcomes from natural processes and different land management techniques (USDA-NRCS 2013). Related soil series descriptions will also be updated with halinity ranges to increase accuracy of existing soil maps. Chapter 2 will detail the EC methods comparison, while Chapter 3 will provide the results of soil analyses and halinity class generation methods. Each chapter includes an introduction including relevant background information, field, lab, and data analysis methods, written and graphical results and discussion, and the final conclusions and recommendations of the findings.

Chapter 2: Comparison of Electrical Conductivity Methods to Determine Soil Halinity

Abstract

Soil halinity, or salinity caused by ocean-derived salt deposition, is an important soil characteristic that can influence land ecology and limit use. Though the ecological effects of soil halinity have been studied extensively, the USDA- Natural Resources Conservation Service (NRCS) has not yet standardized a measurement for the parameter. This study compared three methods for measuring electrical conductivity (EC) as a measurement of soil halinity: EC in 1 part soil and 5 parts deionized water by volume ($EC_{1:5vol}$), EC of extracted soil pore water ($EC_{porewater}$), and EC of extracted soil pore water diluted by 5 parts deionized water ($EC_{1:5porewater}$). The research reveals that all three methods show almost equivalent accuracies and thus, the author recommends the use of $EC_{1:5vol}$ for simplicity of procedure and minimal equipment requirements.

Introduction

Several recent projects dealing with coastal soils have been undertaken by the NRCS National Cooperative Soil Survey (NCSS). However, there are no finalized standard methods for determining electrical conductivity (EC) in tidally influenced soils. The saturated paste method has been long accepted as the standard method for determining salinity in arid inland areas, but salinity in ocean-influenced soils has different chemistry and results in different soil interpretations. Salinity derived from ocean salts is referred to herein as *halinity*. Within the NCSS there is currently a proposed draft method for measuring EC using a one part soil to five parts deionized water by volume mixture, $EC_{1:5vol}$. This method is intended to be used in coastal soils influenced by ocean salts such as in tidal marshes and subaqueous settings. The NCSS draft $EC_{1:5vol}$ and optional pore water ($EC_{porewater}$) method along with one additional method will be tested and compared. Ultimately the data from this study will be used to develop halinity classes for coastal ecological management and planning purposes.

Halinity Variation

In estuarine systems, the halinity of soil is highly variable spatially and temporally. Values of EC fluctuate depending on numerous factors such as: timing and height of tides, amount of recent precipitation and insolation (both local and within the watershed), ground water flow, local topography, river and creek morphology, vegetation transpiration, and depth of the soil sample (USDA U.S. Salinity Lab 1954; Hill and Shearin 1970; Ammann 2000; Silvistri et al. 2004; Upchurch 2012). As a general rule, halinity decreases with increasing fresh water inputs and distance from the sea, and it increases with frequency and duration of ocean water flooding. So, on a landscape scale one would expect to find higher EC values in low marsh areas as compared with areas farther inland.

Freshwater inputs to these systems vary seasonally in temperate climates as snowmelt occurs in the spring (Figure 2.1). This increased discharge flushes the salt water down the estuary as well as down the soil profile. Likewise, soil EC values are likely to drop in situations where there is a large amount of groundwater flow. Consequently halinity, in combination with temperature and soil color could be used to verify the infiltration of oxygenated ground water (aeric soil indicator) in haline soils (USDA-NRCS Soil Survey Staff 2010).

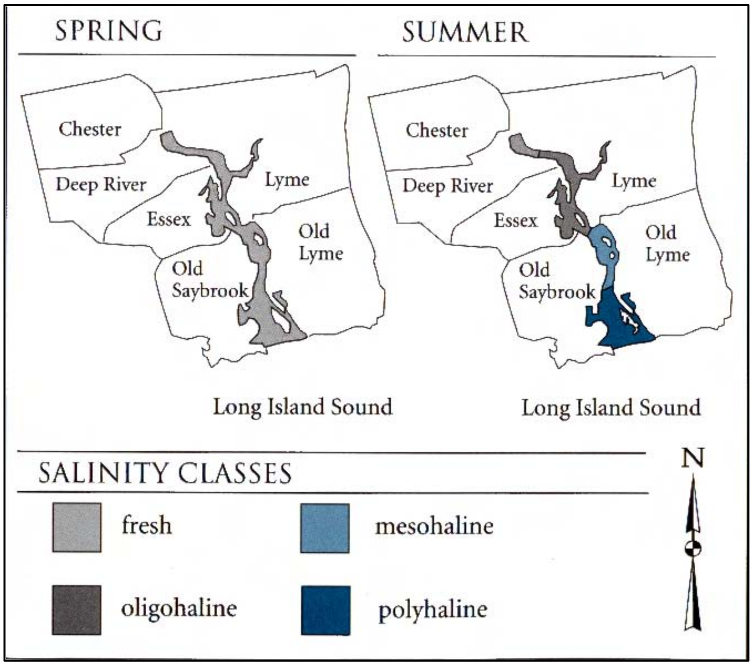


Figure 2.1: Seasonal variation of salinity in the CT River (Dreyer and Caplis 2001)

A study in the 1930s revealed that at the mouth of the Connecticut River, halinity levels peak from July to October and that the salt wedge stays within the lower 13 km of the river except for those summer months (Mead 1966). During this time of year, small tidal marsh depressions known as *pannes* collect sea water which evaporates after the tide goes out, leaving behind salts. These salts accumulate over time, especially in warmer seasons, and can cause a halinity that is higher than that of ocean water (Tiner 1987). Thus, areas with lower annual precipitation are more likely to have increased halinities, giving some estuaries a reversed gradient to the ocean, e.g. the Suez Canal (Dahl 1956).

The highest daily halinity for a given site occurs when water is changing from flowing into to flowing out of the river due to tides. There is an approximate two hour lag in tides between the upper (above the Saybrook Bridge) and lower parts of the Connecticut River (Meade 1966). For these reasons, a more complex sampling scheme is required for determining the EC of coastal versus upland soils. Vegetation in salt marshes is highly indicative of the soil salt content and flooding regime (Miller and Egler 1950; Hill and Shearin 1970; Olff et al. 1988; Ammann 2000; Warren et al. 2002; Upchurch 2012). So, stratifying the sampling by vegetation is a way to reflect both the average and extreme halinities of a given ecological community on the marsh.

Anthropogenic Effects

Humans have affected salt marshes ever since Native Americans used them to hunt and forage, and European settlers harvested the grasses for hay and bedding (Ammann 2000). These anthropogenic interferences have indisputably had an influence on tidal marsh soil halinity. Salts may concentrate in soil materials in situations where these systems have been filled, drained, or channeled (Hill and Shearin 1970). These practices became common after the Civil War when soldiers brought malaria to New England. In the 1940s, the U.S. government encouraged the channeling of marshes in order to drain them for mosquito control and put citizens to work during the Great Depression. Ditchers were paid by the foot, so there are often very tight gridded patterns in the affected estuarine marshes. In 1985, ditching practices were abandoned in favor of a more natural approach in which *Fundulus* habitat was created to encourage predation of the pests. Even before the insect control era, farmers who owned tidal marsh plots used ditches to remove standing water in order to employ the marshes for hay and pasture land. Flood gates were also utilized to control water and generate energy from tidal mills as early as the 1700s (Rozsa 1995). By the 1930s, it was evident that tidal gates did not allow ocean water to replenish salts and thus EC values have decreased in salt marshes with these structures (Hill and Shearin 1970). Most of these tidal gates and ditches remain on the landscape today and over time these collective human influences have affected the halinity, and therefore vegetation, throughout the New England coast.

Halinity Chemistry

There have been many attempts at generating halinity classes in the past, but one of the most well-known and regarded systems is the USFWS's "Classification of Wetlands and Deepwater Habitats of the US" (Cowardin et al. 1979), Table 2.1.

Table 2.1: USFWS Classification of Wetlands and Deep Water Habitats of the US (Cowardin et al. 1979)

Coastal Modifiers	Inland Modifiers	Salinity (ppt)	Approximate specific conductance (μ Mhos at 25°C)
Fresh	*Fresh*	<0.5	<800
Oligohaline	*Oligosaline*	0.5-5	800-8,000
Mesohaline	*Mesosaline*	5-18	8,000-30,000
Polyhaline	*Polysaline*	18-30	30,000-45,000
Mixohaline	*Mixosaline*	0.5-30	800-45,000
Euhaline	*Eusaline*	30-40	45,000-60,000
Hyperhaline	*Hypersaline*	>40	>60,000

This system differentiates soil halinity (salts derived from the ocean) from salinity (salts accumulated over the land). The salinity of inland water is caused by the presence of calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and potassium (K^{+}) cations and carbonate (CO_3^{2-}), sulfate (SO_4^{2-}), and chloride (Cl^{-}) anions. In contrast, the dominant anions in the ocean are *halides*- a majority of which are sodium chloride (NaCl), hence the term *halinity* (Cowardin et al. 1979).

The only way to directly measure either salinity or halinity is to complete a full chemical analysis, which is costly and time consuming. As a result, soil halinity is most often measured by secondary means. Conductivity is defined as the amount of current produced by a known voltage between two probes at a fixed distance (LaMotte Staff 2011). Because the halinity of a solution reflects the ion content, it is measured indirectly by taking the EC of a sample often in dS m^{-1} which is equivalent to mmhos cm^{-1} at 25°C (USDA-NRCS Soil Survey Staff 1993). A mho (equivalent to 1 Siemen) is the reciprocal of ohms which are a measure of resistance (USDA U.S. Salinity Lab 1954). One ohm is the resistance value through which one volt will maintain a current of one ampere (A), or volts/ampere, so one mho is the conductivity value for one ampere per volt, which can be further broken down to $(s^3*A^2)/(kg*m^2)$, where s is time in seconds (Rowlett 2005).

Other physical characteristics such as density, refractive index, and sound speed are also used to calculate halinity (Table 2.2), but because conductivity is the most precise way (±0.0002 practical salinity units (psu)) to physically relate the ion content, it has become the standard method (Clesceri et al. 1998).

Table 2.2: Comparison of Precision of Halinity Measurements

(Clesceri et al. 1998)

Property	Precision of Measurement	Precision of Halinity
Conductivity	±0. 0002 psu	±0.0002
Density	$\pm 3*10^{-6}$ g cm^{-3}	±0.004
Sound Speed	±0.02 m s^{-1}	±0.01

Elevated conductivity values represent a larger current as a result of a higher concentration of ions in solution. Water has a greater potential to hold ions with increasing temperature, so the reading must either be taken at the accepted standard temperature (25°C) or adjusted accordingly (LaMotte Staff 2011). There is an approximate two percent EC increase $°C^{-1}$, but some authors have found a more non-linear relationship (USDA U.S. Salinity Lab 1954). Within the environmental temperature range of typical field and lab conditions in this study, the relationship is very close to linear. Most brands of EC probes cite Weyl's (1964) conversion equation for their built-in temperature adjustment functions:

$$\text{Log}(K_8) = 0.57627 + 0.892 \log(\%Cl^-) - 10^{-4T} [88.3 + 0.55T + 0.0107T^2 - \% Cl^- (0.145 - 0.002T + 0.0002T^2]$$

where T = 25- the temperature (°C). Once measured and corrected for temperature, EC can be converted to total dissolved solids (TDS) or salinity (in this case halinity). The measurements can also be converted to salts (from µmhos cm^{-1} to mg L^{-1}) by multiplying by a conversion factor of 0.64 (SWAT Lab 2011).

Various methods for sampling for EC have been tested, with varying accuracies. For example, in New Hampshire electromagnetic induction (EMI) was used to measure EC in an estuary which resulted in an R^2 value of about 0.5 when correlated with manual soil pore water readings (Moore et al. 2010). Currently, the NCSS uses the saturated paste method as a standard for measuring EC of terrestrial soils for salinity (USDA-NRCS Soil Survey Staff 1993). EC can also be rapidly measured by using a 1:1 or 1:5 soil to water slurry using an EC probe, however the higher the water ratio, the less representative the extracted solution will be to *in situ* conditions. Thus, the most representative EC method is to take a soil pore water extract from a sample (USDA U.S. Salinity Lab 1954). Both 1:5 slurry and soil pore water extract readings were compared in this study. An additional method using 1 part vacuum-filtered pore water to 5 parts deionized water solution reading was also examined in order to determine the effects of filtration on EC.

Acid-sulfate reactions occurring in salt marsh soils have the capability to affect halinity readings. In tidal marsh soils, pH is often a balance between the neutralizing effects of carbonates derived from shell fragments and ocean water and the acidifying sulfides which are byproducts of anaerobic bacteria reduction reactions. When exposed to air, sulfide materials oxidize to make sulfate salts which can skew soil halinity readings if samples are not immediately tested or frozen to prevent this reaction (Hill and Shearin

1970; Fanning et al. 2010). Sulfide materials may be detected by smell ("rotten egg-like" sulfurous scent) or by incubation pH analysis.

Objectives

The purpose of this investigation was to evaluate the proposed NCSS methods for measuring EC in soils containing ocean-derived salts plus one additional method. The three EC methods tested here were:

1. $EC_{1:5vol}$- EC in a 1 part soil to 5 parts deionized water by volume solution
2. $EC_{porewater}$- EC in a filtered soil pore water extract
3. $EC_{1:5porewater}$- EC in a 1 part filtered soil pore water to 5 parts deionized water solution; this method was added to determine the effect of filtration on EC readings.

EC methods will be henceforth referenced in this order. The most effective method for measuring EC will be recommended for use as a standard by the NCSS. These values will also ultimately be used to develop halinity classes that reflect distinct ecological sites in coastal regions.

Methods

Project Area

This project mainly involves soils sampled from an area at the mouth of the Connecticut River in Old Lyme/Old Saybrook, CT to the end of the salt water wedge in Essex/Lyme, CT or the last approximately 18 km of the river before it empties into the Long Island Sound. The study area is a relatively flat to undulating coastal lowland region consisting mainly of marine deposits, organic peat, glacial outwash, and till materials. The NRCS tidal marsh soil series include Pacatuck, Westbrook, Ipswich, Sandyhook, and Matunuck. These soils formed in drowned coastal areas when the sea level rose after the last continental glacier retreated (Hill and Shearin 1970). Land uses in the project area are a

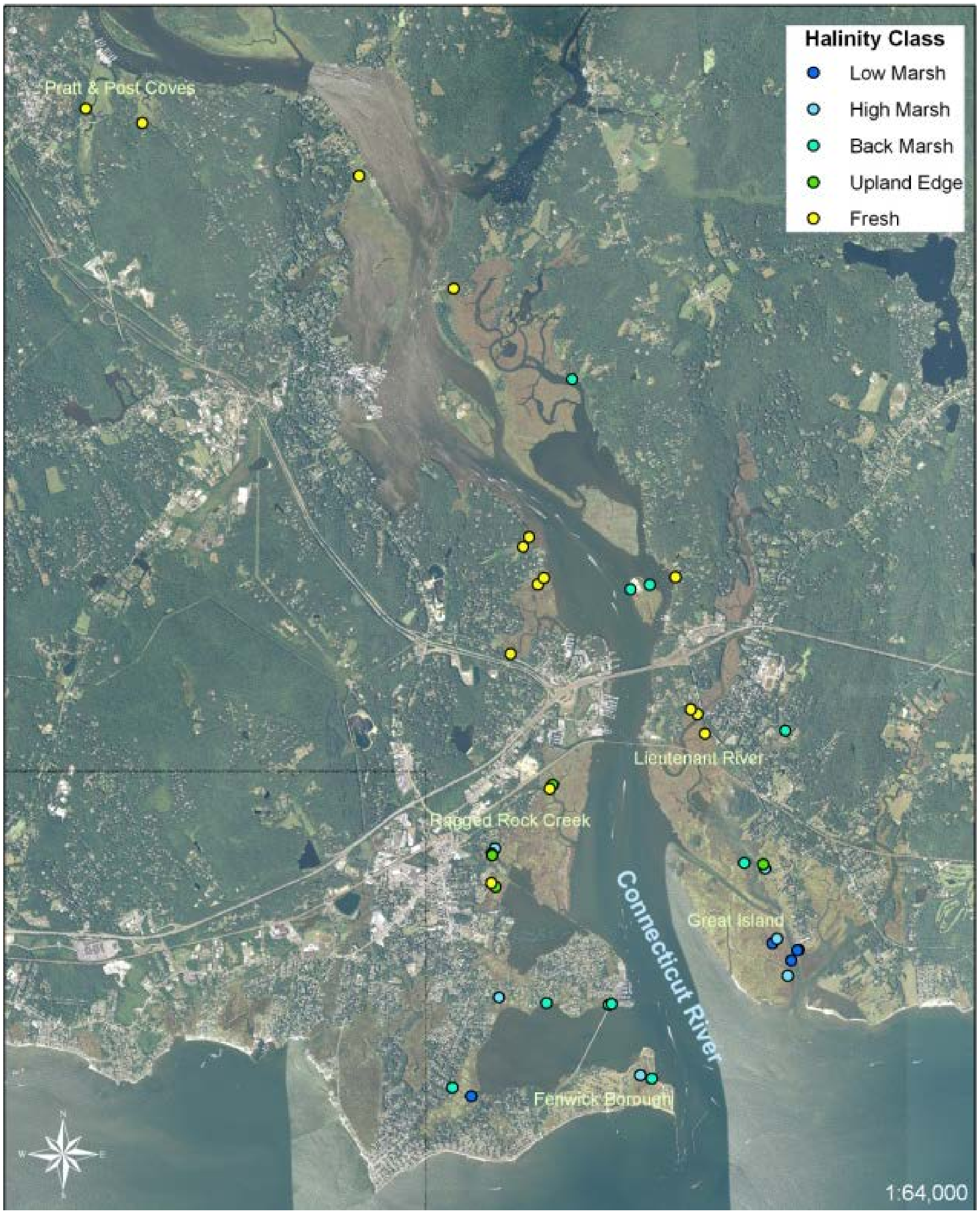


Figure 2.2: Map of sample sites by class
(Imagery from the 2010 National Agriculture Imagery Program)

combination of state, Nature Conservancy, and local land trusts and recreational areas intermixed with commercial and residential zones along the shoreline.

Vegetation varies, in order from open water to back marsh, from aquatic plants such as widgeon grass (*Ruppia maritima*) to low marsh smooth cord grass (*Spartina alterniflora*), salt meadow cord grass (*Spartina patens*), blackgrass (*Juncus gerardii*), spikegrass (*Distichlis spictata*), and high tide bush (*Iva frutescens*). Salt pannes within the marsh contain higher halinities because of evaporative processes and are home to such species as stunted smooth cord grass, which has a higher halinity tolerance (Warren and Fell 1995). In the brackish to fresh water counterparts to these habitats, species such as cattails (*Typha spp*.), bulrush (*Bulboschoennus*/*Shoenoplectus spp*.), and wild rice (*Ziziania aquatica*) also exist (Barrett 1989).

Field Sampling

Five important ecological bands were defined after a review of the literature. Sampling was stratified vertically by soil horizon and across the landscape by the following vegetative units into (in decreasing order of halinity): *Spartina alterniflora*, *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii*, *Bolboschoenus* and *Schoenoplectus* species, *Iva frutescens* and *Panicum virgatum*, and *Typha* and *Phragmites* species. Samples were taken in these strata to represent catenas that demonstrate the spatial variation in halinity. Soil samples were collected using small hand-dug pits, Macaulay peat sampler for soft or fluid soils, and standard bucket and Dutch augers in sandy materials. All samples were taken within two hours of low tide according to the closest NOAA tide predictions (NOAA CO-OPS Staff 2011). Horizons were delineated and sampled from each layer to a depth of approximately 1.3 m, including one sample for lab analysis and one bulk density sample of a known volume. Each pedon was classified and described using standard soil survey procedures (USDA-NRCS Soil Survey Staff 1993) and entered into the National Soils Information System, NASIS. Every sample location was described on worksheets (vegetation, landscape position etc., see Appendix I for example field sheet), photographed and recorded on-site using a GPS unit, to be later uploaded to a GIS program for mapping. In the initial phase of sampling, approximately 100 samples from 21 sites were extracted in marshes along the river in the fall of 2011. Lab analyses for these samples were completed the following winter. Results were used to determine whether an adequate number of samples had been taken, and the number of new sites required for each category. Sample size was calculated as:

$$(n = t^2 * s^2 / (\text{mean} * 0.15)^2,$$

where n is the sample size, t is the t-score, and s is the standard deviation (Freese 1962). Twenty new sites were sampled in the spring of 2012 as determined by the statistical analysis. In all, a total of 41 sites (218 samples) were sampled.

Laboratory Analysis

All soils were kept frozen until the time of analysis to prevent oxidation. Samples were determined to be either organic or mineral soil layers based on notes within their respective field description sheets. This process was used to divide the individual samples into mineral (including A, Bw, C, Cg, etc.) and organic samples (Oa, Oe, Oi) by horizon texture in the field, later to be verified by lab analyses.

EC was measured with an Oakton ECTestr11 conductivity meter. If the value was over range, as in a few of the low marsh pore water samples, the Oakton CON6 conductivity meter was used because of its capabilities to read a higher range of values. $EC_{porewater}$ was measured after pore water extraction via vacuum pump filtration through Whatson number 42 paper filters (Figure 2.3). This filter size was chosen because it retains most mineral and organic soil material, but allows salt ions to pass into the liquid sample (Wysocki 2011). $EC_{1:5pore\ water}$ readings were also taken in pore water samples diluted by five parts deionized water.

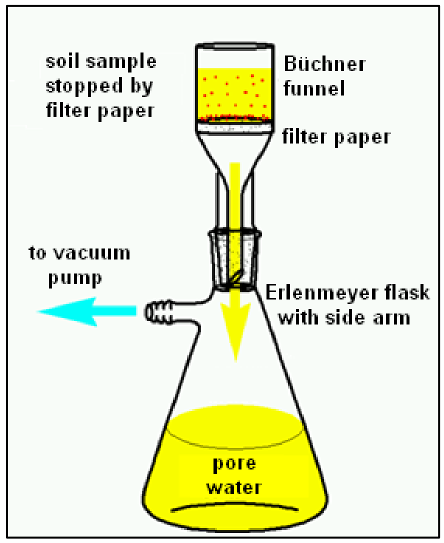


Figure 2.3: Pore water extraction (Adopted from Lersch 2007)

Bulk density samples were oven dried overnight at 110°C and weighed. To determine the bulk density, recorded sample volumes were divided by their dry weights and reported as g cm^{-3}. Other laboratory analyses include particle size density, percent organic carbon, coarse fragments, and moisture by weight, pH by 1:1 soil to deionized water slurry mixtures using an Oakton pHTestr 30 pH probe for mineral soils and percent mineral materials, pyrophosphate colors, and pH for organic soils. All methods are described and available online in the *Soil Survey Lab Manual* (USDA-NRCS Soil Survey Staff 1993).

Data Analysis

Soil descriptions were classified using the eleventh edition of *Keys to Soil Taxonomy* (USDA-NRCS Soil Survey Staff 2010), and added to the NRCS National Soils Information System (NASIS). $EC_{1:5vol}$ values were compared to $EC_{porewater}$ and $EC_{1:5porewater}$ and graphed against each other and other parameters such as pH and bulk density to see how strongly they correlate using either JMP 2010 (SAS Institute Inc.) or Excel 2007 (Microsoft) software. Additionally, current halinity ranges of coastal benchmark soils were evaluated against field data.

Results and Discussion

EC Method Comparison

$EC_{1:5vol}$ did not yield a conductivity that represents a linear shift of the $EC_{porewater}$ values. Figure 2.4 displays the disparity among the raw EC values. Although the values are represented on different scales below, the three sets of EC data had similar overall distributions (Figure 2.5). However, the $EC_{1:5vol}$ values had the fewest number of outliers. A Shapiro-Wilk goodness of fit test showed that raw data of all three methods provided results that were not normally distributed ($W= 0.8187$, $p< 0.0001$; $W=0.5974$, $p< 0.0001$; $W= 0.7049$, $p< 0.0001$). Logarithmic transformations of the EC values (Figure 2.6) also did not produce normal distributions ($W= 0.9392$, $p< 0.0001$; $W=0.9828$, $p= 0.0101$; $W= 0.9602$, $p< 0.0001$). Untransformed data was used because it was more normal.

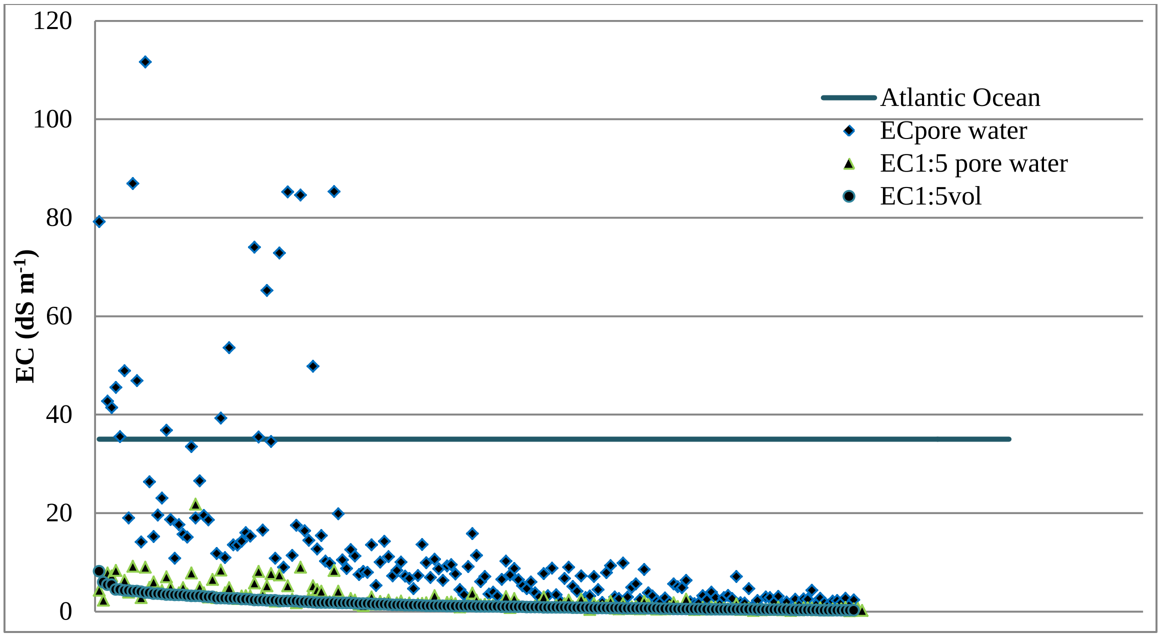


Figure 2.4: EC values by method; each point represents one soil horizon value

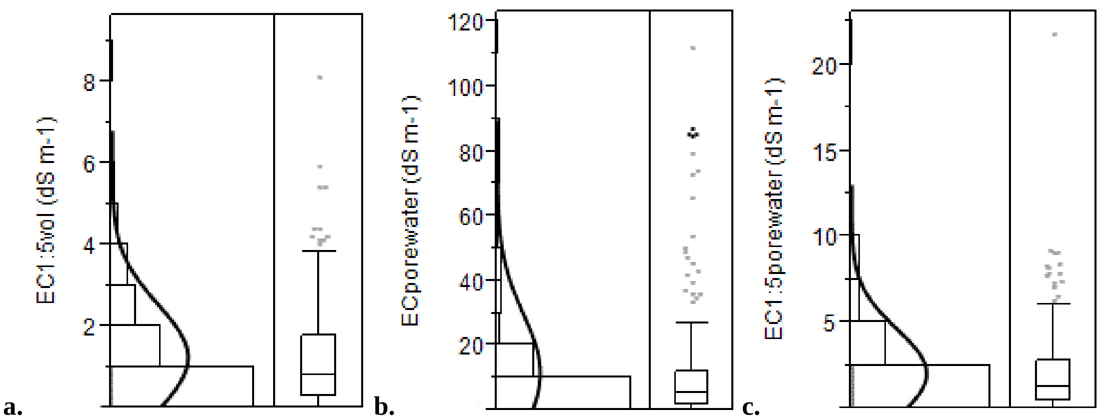


Figure 2.5: EC data distributions for a) $EC_{1:5vol}$, b) $EC_{porewater}$, and c) $EC_{1:5porewater}$ values; The fitted normal curve is represented below by a black line.

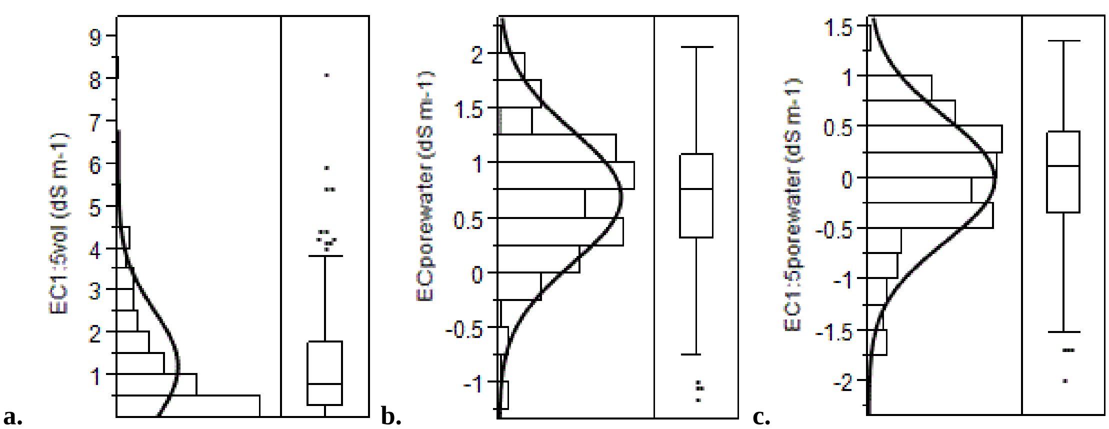
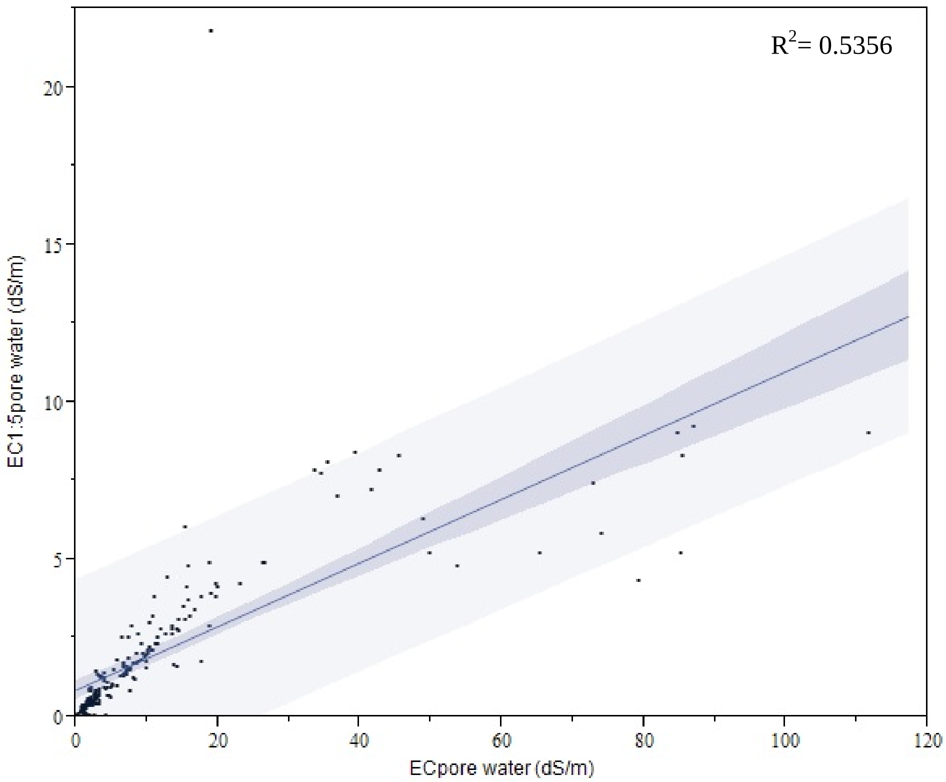
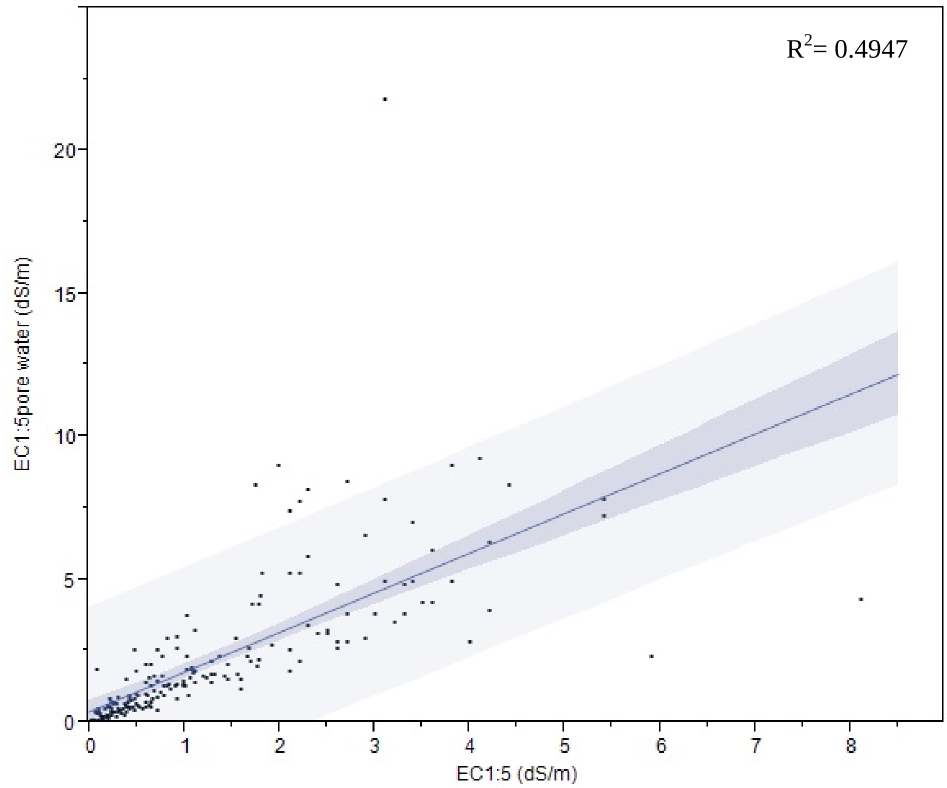


Figure 2.6: Log_{10} EC data distributions for of a) $EC_{1:5vol}$, b) $EC_{porewater}$, and c) $EC_{1:5porewater}$ values

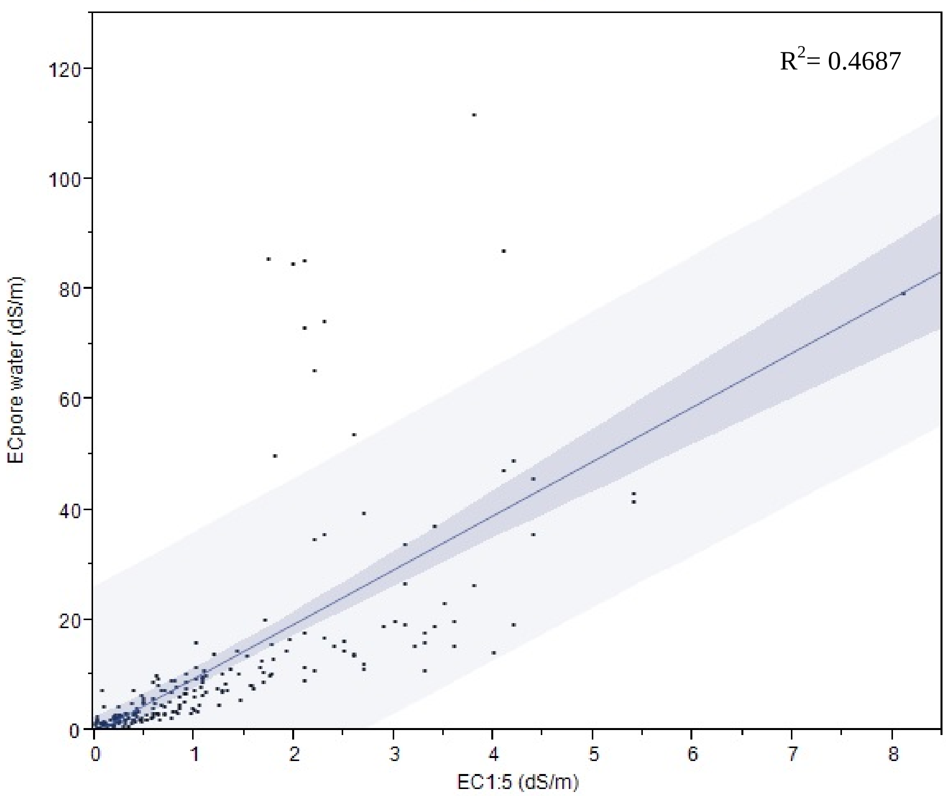
Coefficients of determination (R^2) between all combinations of EC methods were similar and ranged from 0.4687 to 0.5356 (Table 2.7). Of the three EC methods, the best linear relationship was between $EC_{porewater}$ and $EC_{1:5porewater}$ values (R^2= 0.5356). The next best R^2 value was between $EC_{1:5vol}$ and $EC_{1:5porewater}$ (0.4947), followed by $EC_{1:5vol}$ and $EC_{porewater}$ (R^2= 0.4687). Scatter plots of these data combinations are displayed in Figure 2.7. Note the differences in scales of the axes due to the different dilutions.



a.



b.



c.

Figure 2.7: EC method scatter plots displaying a) $EC_{porewater}$ and $EC_{1:5porewater}$, b) $EC_{1:5vol}$ and $EC_{1:5porewater}$, and c) $EC_{porewater}$ and $EC_{1:5vol}$; Inner shading represents confidence of fit, outer shading represents confidence of prediction

Table 2.3: R^2 Values of EC Method Linear Regression			
	$EC_{1:5vol}$	**$EC_{porewater}$**	**$EC_{1:5porewater}$**
$EC_{1:5vol}$	-	0.4687	0.4947
$EC_{porewater}$	0.4687	-	0.5356
$EC_{1:5porewater}$	0.4947	0.5356	-

R^2 values from linear regressions of EC values show each method's relation to the others (Table 2.3). According to Siegle (2013), these R^2 values are all significant (d_f= 213, α= 0.05). These results may have implications for using one method to predict the other, but about half of the variance for each pair is yet unexplained.

EC values are also significant within most halinity classes. In all three combinations of data, back marsh values had the highest R^2 (0.9003, 0.8299, and 0.8449) and low marsh (0.6753, 0.0294, and 0.0029) and high marsh (0.0646, 0.2558, and 0.0415) had the lowest values. These data also have implications for use of different methods for different ranges of EC values.

In Figures 2.8 and 2.9, while there is no difference between general horizon type, the average EC values between all mineral (n= 46) and all organic (n=170) horizons were found to be significantly different (F= 4.0938; p= 0.04).

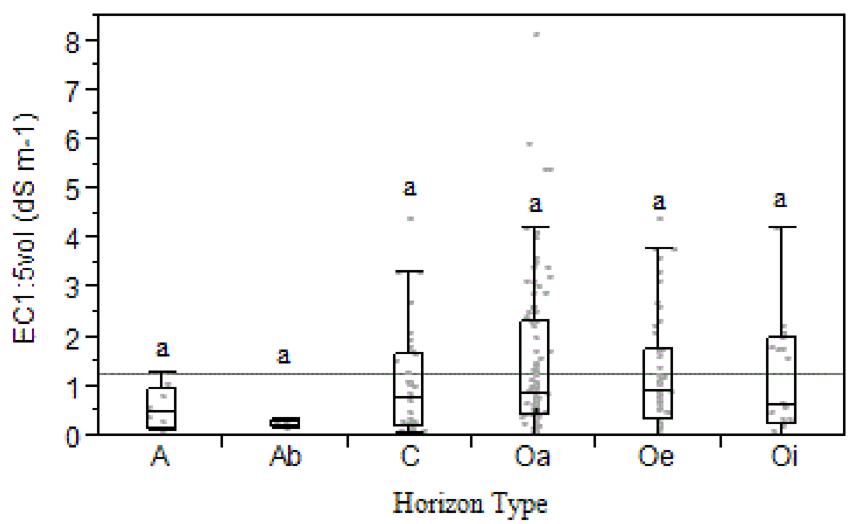


Figure 2.8: Comparison of EC values by soil horizon type (F= 1.5614, p= 0.1724); Box plots topped by the same letter are not significantly different at p= 0.05 (F=4.0938, p= 0.0443)

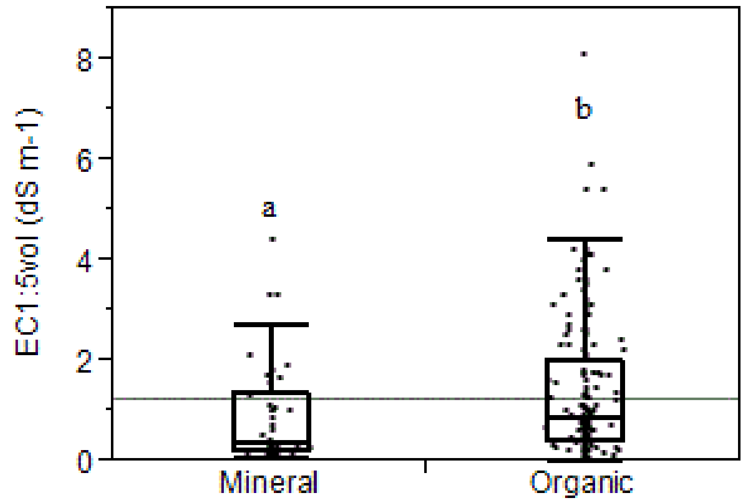


Figure 2.9: EC values for mineral and organic soil horizons; Box plots topped by the same letter are not significantly different at p= 0.05 (F=4.0938, p= 0.0443)

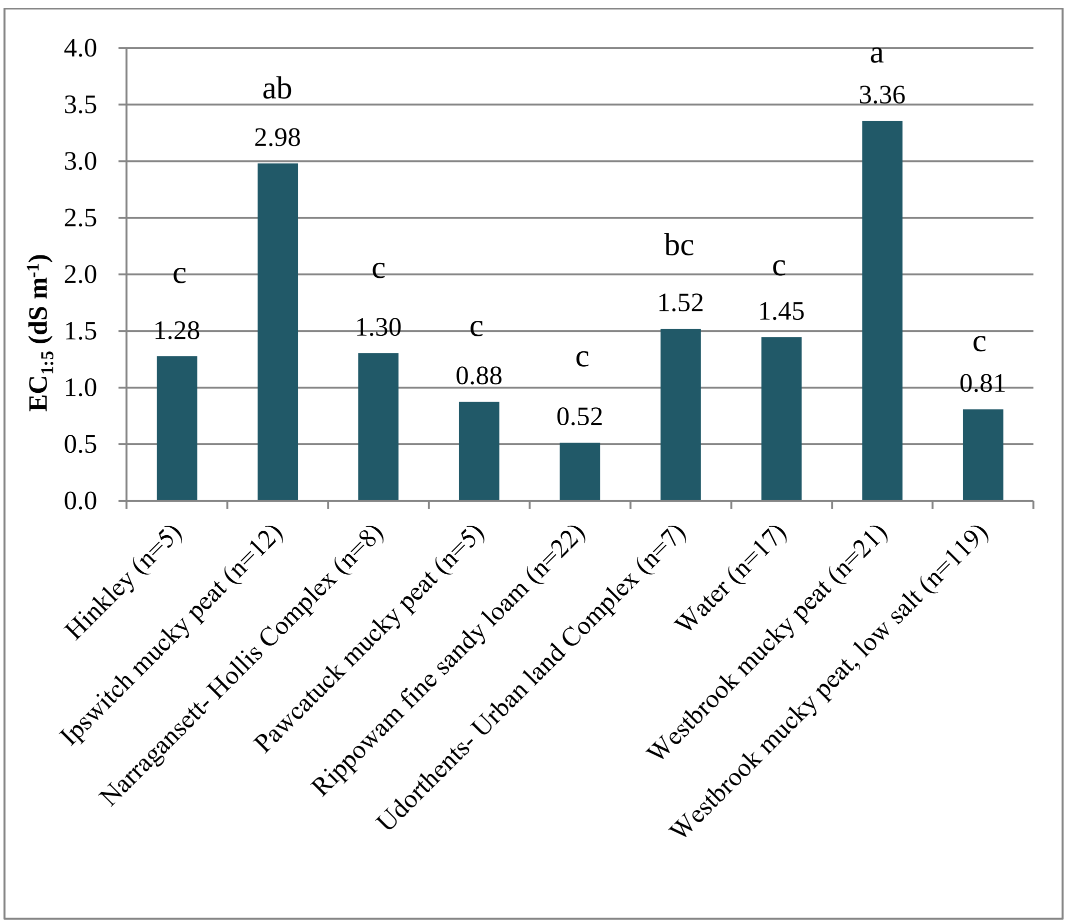


Figure 2.10: EC values by soil map unit; values represent means; Each letter indicates a significantly different class (F= 21.5926, p<0.0001)

The $EC_{1:5vol}$ values were compared to their respective soil map units (Figure 2.10), which can potentially be used to update soil series descriptions and map unit descriptions to reflect average halinity conditions. These data may prove particularly useful in differentiating similar map units such as 'Westbrook muck peat' and 'Westbrook mucky peat, low salt' which may be designated as haline or otherwise.

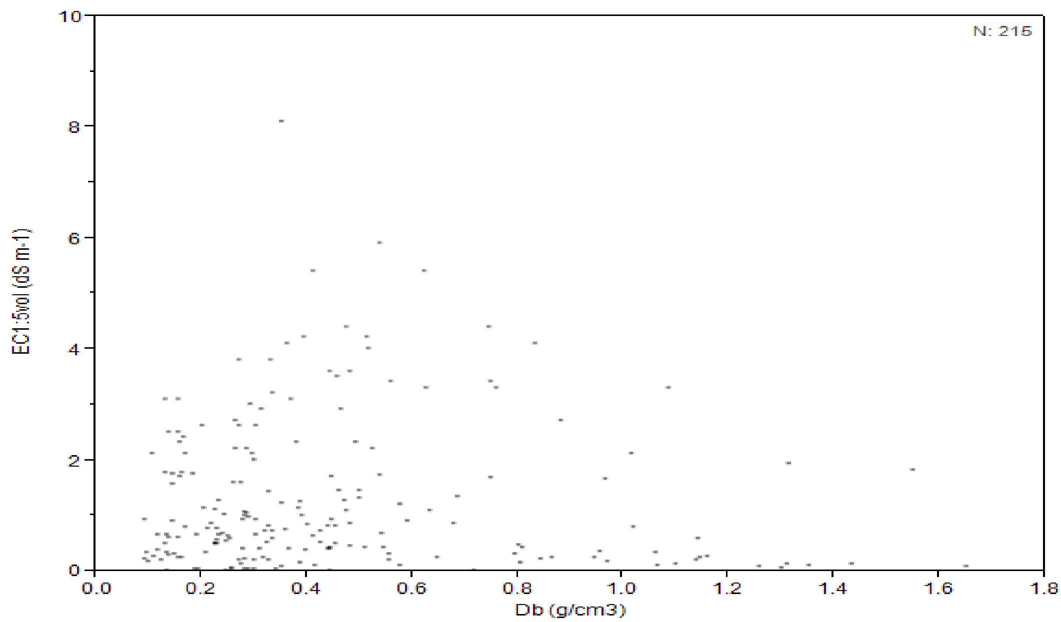


Figure 2.11: EC values by bulk density (R^2= 0.0015)

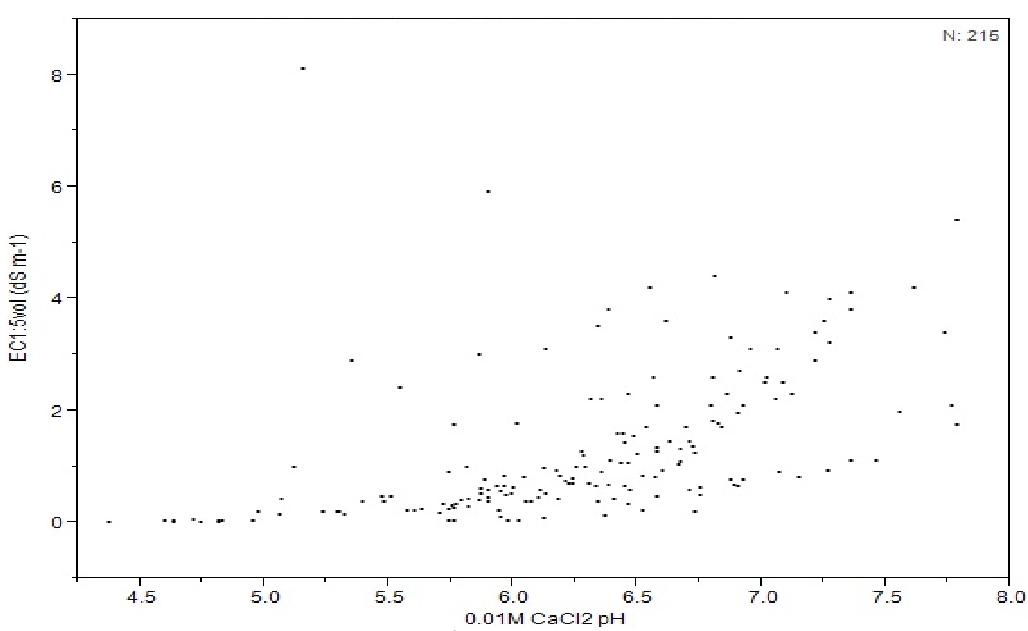


Figure 2.12: EC values by $CaCl_2$ pH (R^2= 0.2604)

Most other factors have seemingly no relation to EC, such as bulk density and calcium chloride pH as shown in Figures 2.11 and 2.12. The two "outlier" points to the right of the cluster in the $CaCl_2$ pH graph are from a *Juncus gerardii* site and are also outliers for their $EC_{1:5vol}$ halinity class (see Chapter 3 for detailed halinity class data).

Conclusions

EC Correlations

All three EC methods produced non-normally distributed data that were similar in their correlations to each other (R^2= 0.69 to 0.73). Similar distributions resulted when the data were logarithmically transformed. The most obvious factor that may affect these measurements is the use of a filter to remove the mineral and organic soil components in the $EC_{porewater}$ and $EC_{1:5porewater}$ methods. The $EC_{1:5vol}$ readings were conversely taken directly from a soil dilution, and therefore contain not only the targeted salts, but also mineral and organic soil materials. These materials may increase EC values by conducting additional current. Contrary to this logic however, the two pore water methods differed from each other nearly as much as they differed from the $EC_{1:5vol}$ method. The organic layers did produce statistically higher EC values than mineral layers. This difference may be due to the ability of organic materials to adsorb ions (salts), rather than from the organic molecules themselves.

Other potential factors contributing to the difference between $EC_{1:5vol}$ the $EC_{1:5porewater}$ include slight changes in temperature, although the EC meters adjust for this. $EC_{1:5vol}$ did have a significant positive correlation with $CaCl_2$ pH (d_f= 214, R^2= 0.2604)

(Siegle 2013). However, mineral texture, bulk density, percent moisture, and all other factors measured in this study did not significantly affect EC.

Recommendations

Despite their differences in execution, the results were similar among all three EC methods. Thus, the simplest procedure is recommended. This is the $EC_{1:5vol}$ method which is easily repeated in the field or lab with as little equipment as: a graduated cylinder, beaker, deionized water, spatula, and EC probe. The pore water methods involve more equipment, time, and a larger soil sample than $EC_{1:5vol}$. The process of filtering adds additional risks that are not present in the simple volumetric method. For example the filters may not always establish suction onto the Buchner funnel and soil particles may occasionally leak into the Erlenmeyer flask. Ultimately, it is recommended that the NRCS NCSS pursue use of the $EC_{1:5vol}$ method so that the EC method for measuring halinity in coastal soils may be standardized for the country. Also, because mineral and organic horizons were found to have significantly different EC readings, it is recommended that the effects of soil organic matter content on EC be further evaluated.

Chapter 3: Development of Soil Halinity Classes for Connecticut Tidal Marshes

Abstract

The amount of salts in a soil can determine much about its capabilities and ecology. This paper uses measurements of electrical conductivity of soil samples stratified by ecological community to correlate soil halinity to vegetative community. These methods are recommended for use in other estuaries for purposes of ecological classification, soil mapping and general land/habitat management.

Introduction

Although there is extensive research involving the measurement of salinity in arid, inland soils, the NRCS does not currently classify the salinity of coastal soils. Soil EC is, however, used to generally classify subaqueous soils as fresh (“frasi”, <0.2 dS m^{-1}) or saltwater (USDA-NRCS Soil Survey Staff 2010). The following research was intended to apply these methods to soils within the Connecticut River estuary with the intention of ultimately generating *halinity* classes that reflect unique ecological communities in tidally influenced soils. Note the term *halinity* is used here to differentiate salt-affected coastal soils from saline inland soils. Natural thresholds in tidal marsh vegetation will be used to delineate coastal soils and to develop Ecological Site Descriptions for these areas (USDA-NRCS 2013).

Existing Classifications

Modern salinity and halinity classification systems are used for a variety of purposes such as determining habitat type (Cowardin et al. 1979) and accessing site suitability for agriculture (USDA-NRCS Soil Survey Staff 1993). In contrast, early classification systems were mainly used by marine biologists to categorize water chemistry, rather than soil, and typically were based on the (usually benthic) aquatic organisms present in the various zones of estuaries. Dahl (1956) and Den Hartog (1974) each give detailed reports of these systems including the Redeke, Valikangas, Redeke-Valikangas, Remane, Ekman, and Venice systems which were created in 1922, 1933, 1933, 1934, 1953, and 1958, respectively. As the examples in Table 3.1 reveal, the thresholds are highly variable by method and location.

Table 3.1: Summary of Fresh Water Limits

Maximum Fresh Water Salinity (ppt)	Classification System	Method	Location
0.1	Redeke, 1922*	Benthos-based water sampling	North Sea Baltic area
0.2- 0.5	Redeke-Valikangas, 1933**	Mixed biology water samples	North Sea Baltic area
3.0	Remane, 1934**	Mixed biology water samples	North Sea and Bay of Kiel
0.1-5.0	Day, 1951**	Mixed biology water samples	South Africa
0.5	Ekman, 1953**	Mixed biology water samples	Baltic Sea area
5.0	Dahl, 1956**	Mixed biology water samples	North Sea Baltic area
0.5	ASLO Venice System, 1958**	Mixed biology water samples	Mixed International
0.5	Classification of Wetlands & Deep Water Habitat, 1979***	Soil pore water	United States
1.0†	USDA-NRCS Soil Survey Staff 1993****	Soil saturated paste	United States

† Converted from dS m^{-1} assuming all NaCl ions

(*Hartog 1974, **Dahl 1956, ***Cowardin et al. 1979, ** USDA-NRCS Soil Survey Staff 1993)**

Redeke's preliminary system was based on benthic biological community composition with approximated salinity figures. The terminology used is based from limnologist Einar Naumann's early 1920s work. It is important to note that the limits in Redeke's classification are meant to represent average salinities, rather than actual values

(Den Hartog 1974). Soon following, Valikangas based his system on the plankton distribution in the Gulf of Finland in his 1926 study. Valikangas acknowledged that the 'mesohaline' class could be further broken into α and β sections if necessary. The system was regarded as a confirmation of Redeke's classes, with some deviations in the final 1933 version. Neither system has ever been widely utilized in the US because the data collection took place in Northern Europe and consequently may not reflect conditions found in North America. Ekman's terms also use repetitious suffixes for each threshold, which were quickly abandoned by other marine biologists (Dahl 1956).

These early systems were later tested by French scientists working in the Mediterranean who found them to be 'too static' because some sites could be classified into more than one category depending on the tide. The methods also caused confusion when data from plankton and benthic biota were directly compared because of the differences in habitat (Den Hartog 1974). Thus the Venice system, a modified version of the Redeke-Valikangas system, was created at the meeting of the *Societas Internationalis Limnologiae* in Italy in 1958 (ASLO 1958; Den Hartog 1974). The resulting shift in the lower limit of the mesohaline break was intended to accommodate representative areas in southern Europe and South Africa. Later, Remane said it to be a compromise at the meeting during which the system originated (Den Hartog 1974).

Dahl (1956) generated his own water classification system, reticent of the older systems called "Ecological Salinity Boundaries in Poikilohaline Waters." All of the previous systems classified biota, rather than the water, so Dahl focused instead on the physical and chemical water properties. He separated estuaries from brackish water environments by the stability of the water exchange, halinity, temperature, and alkalinity.

He determined that areas dependant on the interchange of water with the sea for halinity (estuaries) should be called ‘poikilohaline’, while ‘homiohaline’ should refer to water that is either fresh or the ocean itself. The terms are mostly borrowed from Redeke and Valikangas, except ‘metahaline’ which is derived from a study in Texas by Hedgepeth in 1951. Like others, Dahl (1956) set his boundaries from copious species data and concluded that the term ‘brackish’ should denote the presence of brackish species, not just the absence of salt water species. Because of the vertical gradient, he came to the conclusion that it is better to go with a higher limit (0.5 ppt) for non-marine halinities, and that this limit would be somewhat higher in warmer areas because of the increased capacity for water to suspend ions. Dahl notes that some important sub-classes may be generated for specific locales when the larger inclusions do not provide a sufficient amount of detail (Dahl 1956).

More than twenty years after the Venice system and all its subsequent modifications, the USFWS published its inventory classification system for wetlands. This more modern system classifies inland and coastal wetlands separately, using salinity and halinity to respectively differentiate the salt content (Cowardin et al. 1979). The biggest drawback of this version is that the same values are used for both sets of h/salinity modifiers. This may deemphasize the difference between the two modifiers because the values clearly were not derived from separate field measurements.

In a way, the research presented here is reminiscent of early systems in that the sampling locations are based on biota. The general consensus from most of the authors of these salinity classes is that there are no obvious sharp limits in these natural systems, but zones with less gradual ecological transition do occur (Dahl 1956; Cowardin et al. 1979).

Salinity-vegetation correlations are documented in specific geologic locations and may not necessarily be valid in other areas. Thus, although this research may be suitable for the Connecticut River, and perhaps even other areas in Connecticut and New England, it may not be directly applicable to every estuary. Nevertheless, the general concepts, methods, and sampling scheme can be repeated for site-specific halinity classes that may be more appropriate for any given estuarine system.

Coastal Vegetation and Ecology

In tidal ecosystems, energy is primarily derived from macrophytes, benthic macroalgae, phytoplankton, and upland-originated organic matter which must be broken down for ecosystem use. Important consumers which facilitate this process are crustaceans, polychaetes, mollusks, and adult insects. Because of the unique plants and soil conditions in coastal wetlands, the decomposition rate in marshes is moderate. Plants tend to have increased levels of resistant materials such as cellulose, hemicelluloses and lignin as well as higher concentrations of inorganic ash. These crude fibers along with toxic substances such as cinamic acids also make marsh plants less palatable to detritivores. The low nitrogen content in salt marshes further diminishes the breakdown rate. In anaerobic conditions, decomposition typically occurs either by fermentation or by sulfur reduction. So generally, the higher halinity and more saturation, the more sulfur gases are emitted. If sulfate levels are high, sulfate-reducing bacteria may out-compete methanogenic bacteria. Similarly, if sulfur is depleted deeper in the soil, methanogens may dominate this zone, resulting in an inverse methane-sulfate relationship in soil pore water. Thus, because of the compounded processes which result in reduced rates of plant decomposition, salt marshes tend to have a surface litter layer present throughout the year (Odum 1988).

Soil halinity is likely the most important natural factor affecting coastal plant growth (Hill and Shearin 1970; Tiner 1987; Odum 1988). It affects the diversity, reproduction, biomass, primary production, and photosynthesis in vascular plants (Odum 1988). In general, halinity decreases with distance from the open ocean and with amount of incoming fresh water from sources such as rivers, streams, and groundwater. Tides fuel the ecosystem by delivering salts, sediments, oxygen, and organic matter. This added energy creates marsh productivity of up to 1000 g m^{-2} which breaks down to ultimately fuel our shellfish and finfish populations (Warren and Fell 1995).

Because much of vascular plant energy is used to respond to the stress of high salt and sulfide content and low oxygen content of coastal soils, many of these plants are perennial graminoids (grasses, sedges, and rushes). These plants have extensive rhizome systems which serve in asexual reproduction, and they tend to replace plants that require additional energy for seed dispersal. Although the productivity of individual plants is lower in these systems, the overall biological yield is compensated for by an algae mat that typically occurs on lower mudflats. In addition, the soil quality is increased from aeration caused by salt marsh crabs as well as from amplified amounts of phosphorus from tidal inputs, which is a limiting nutrient in upland landscapes (Odum 1988). The resulting productivity rivals our most efficient terrestrial agricultural land.

In addition to fish spawning and nursery habitat, there are many species of waterfowl, wading shore birds, and furbearers which overwinter, feed, and nest in salt marshes. Nationwide, 71 percent of the commercial fish value is derived from species dependent on the organic exports, smaller fish (such as mummichogs), and habitat that coastal wetlands provide (Ammann 2000). Additionally, some other tidal marsh ecological services include temporary flood water storage, wave action buffering, erosion prevention, storm surge protection, and water quality improvement (Tiner 1987; Ammann 2000). For these reasons, research in these ecosystems is valuable and necessary.

Salt marshes are said to have very little seasonal variation in vegetation, with highly pronounced zonation, totaling in all about 30-40 vascular plant species. Within each ecological band, there is low species diversity and little habitat overlap because each zone is nearly homogeneous (Odum 1988). Thus these areas are well suited for a stratified sampling scheme. Traversing seaward from high marsh to low marsh, a typical estuarine salt marsh vegetation belting pattern on the United States eastern seaboard consists of *Juncus gerardi*, *Spartina patens* (with intermittent pannes of stunted *Spartina alterniflora* often bordered by forbs), and *Spartina alterniflora*. The areas with higher frequencies and durations of flooding tend to have increased saturation, sulfides, and halinity and lower reduction-oxidation reaction (redox) potential, favoring more open vegetation (Warren and Niering 1993). The distinct vegetation pattern in salt marshes reflects the effects of salt content in the soil and as such makes a logical break for halinity classes. For example, the dividing line between the low and high marsh is the mean high tide, which often corresponds with the change from *Spartina alterniflora* (which corresponds with the 'low marsh' class) to *Spartina patens* ('high marsh' here) (Odum 1988).

Salt stress in plants is physiologically close to stress caused by drought. As previously stated, energy in plants is diverted from normal production in high-salt environments. For example, in these environments, *Spartina alterniflora* uses energy to synthesize nitrogen solutes to aid in salt tolerance rather than for primary production or reproduction. In Louisiana, a study focusing on *Spartina alterniflora* meant to represent the US Gulf Coast found that salt application resulted in a rapid (within 24 hour) and statistically significant reduction in leaf conductance and a net loss in photosynthesis because of stomatal closure (Pezeshki et al. 1986). Energy is also spent on reducing the toxicity of sulfates by using rhizomes to bring oxygen to the soil. This action generates phosphorus-iron and phosphorus-aluminum complexes which slightly reduces the abundant free phosphorus content of the soil. This mechanism also takes up ammonium, which must compete with its competitive inhibitor sodium (Odum 1988).

The two main mechanisms that plants employ to deal with increased soil salt content are tolerance and avoidance. Tolerance involves maintaining cell strength and minimizing disruptions to metabolism by adjusting osmotic solutes or changing tissue elasticity and. Tolerance in many plants is observed by salt excretion through leaf tissue. Avoidance in plants includes increased stomatal and cuticular resistance and adaptations in leaf morphology and orientation (Touchette et al. 2009). In order for water to move into plants from the soil, decreased water potential (Ψ) gradients must be established. Ψ decreases from 0 Pascals with increased halinity. Thus, plants in turn must lower their internal Ψ by increasing the concentration of ions to continue to take up water through an osmotic gradient (Flowers et al. 1977).

Objectives

The purpose of this study was to generate methods for measuring soil halinity thresholds that represent the ecological zonation in the Connecticut River estuary. These will be used to generate ecological land use interpretations for wildlife habitat and recreational purposes. Ultimately soil mapping will be updated to reflect these classes via existing soil map unit descriptions, soil series descriptions, and soil survey geospatial data. The resulting data will also create soil-plant relationship information which will act as a starting point for the generation of Ecological Site Descriptions (ESDs) for tidal marshes in the Northeast. These ESDs will act as a guide for land owners to manage soil and vegetation use to obtain desired states (USDA-NRCS 2013).

Methods

Project Area

This project mainly involves soil sampled from the area from the mouth of the Connecticut River in Old Lyme/Old Saybrook to the end of the salt water wedge in Essex and Lyme, or the last approximate 18 km of the river before it empties into the Long Island Sound. The highest halinity due to tides occurs when water is changing from flowing in to flowing out of the river. There is an approximate two hour tidal lag between the upper (above the Saybrook Bridge) and lower parts of the river (Meade 1966).

This is a relatively flat to undulating coastal lowland area consisting mainly of marine deposits, organic peat, glacial outwash, and till materials. The NRCS tidal marsh soil series include Pacatuck, Westbrook, Ipswich, Sandyhook, and Matunuck. Subaqueous soils include Anguilla, Billington, Fort Neck, Marshneck, Massapog,

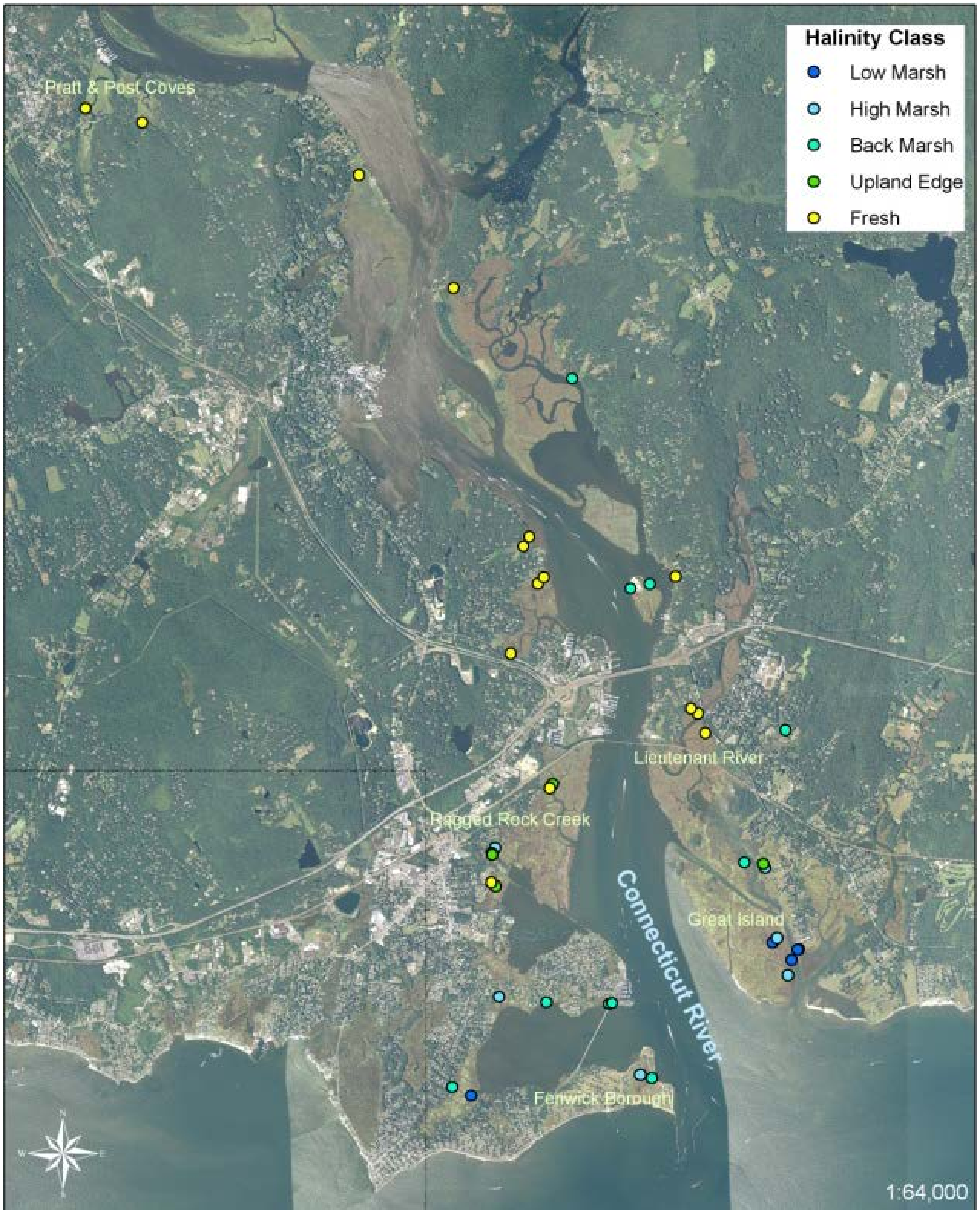


Figure 3.1: Map of sample sites (Imagery from the 2010 National Agriculture Imagery Program)

Nagunt, Napatree, Pishagqua, and Rhodesfolly. These soils formed in drowned coastal areas when the sea level rose after the last continental glacier retreated (Hill and Shearin 1970). Land uses in the project area are a combination of nature preserves and recreational areas intermixed with commercial and residential zones along the shoreline. Most other areas have undergone commercial and residential development that is now mostly impervious. Recreational areas include boat launches along either side of the river; for example, one at Town Landing Road in Old Lyme, CT.

Vegetation included aquatic plants such as widgeon grass (*Ruppia maritima*) to the low marsh smooth cord grass (*Spartina alterniflora*), salt meadow cord grass (*Spartina patens*), blackgrass (*Juncus gerardii*), spikegrass (*Distichlis spictata*), and high tide bush (*Iva fruscens*) traversing from open water to back marsh. Small depressions (pannes) within the marsh contain higher halinities because of evaporative processes and are home to such species as stunted smooth cord grass, which have higher halinity tolerance (Warren and Fell 1995). In brackish to fresh water habitats cattails, bulrush, and wild rice (*Typha*, *Schoenoplectus* and *Bolboschoenus*, and *Zizania* genus) also exist along the river.

Field Sampling

Sampling was stratified vertically by soil horizon and horizontally across the landscape by vegetative unit into (in decreasing order of halinity): 1) *Spartina alterniflora*; 2)*Spartina patens, Distichlis spicata*, and *Juncus gerardii*; 3) *Bolboschoenus* and *Schoenoplectus* species; 4) I*va frutescens* and *Panicum vergatum*; and 5) *Typha* and *Phragmites* species. These 5 ecological communities were identified after an extensive literature review. Samples were taken in these strata to represent catenas that demonstrate the spatial variation in halinity. After previous sampling was examined, a preliminary sampling took place in Barn Island in Stonington, Connecticut, where NRCS tidal and subaqueous soil data already exist. Laboratory EC tests confirmed that samples taken at sites with more salt-tolerant plants (*Spartina alterniflora*) had higher ECs than those closer to upland areas. Soil samples were collected using small hand-dug pits, Macaulay peat sampler for soft or fluid soils, and bucket and Dutch augers in sandy materials. Bulk density samples were taken by either cutting lengths of Macaulay auger (fluid) samples or extracting cubes of known volume out of firmer material. All samples were taken within two hours of low tide according to the closest NOAA tide predictions (NOAA CO-OPS Staff 2011).

Horizons were delineated and sampled from each soil layer to a depth of approximately 1.3 m. Each pedon was classified and described using standard soil survey procedures (USDA-NRCS Soil Survey Staff 1993) and entered into the National Soils Information System, NASIS. Every sample location was described on worksheets (vegetation, landscape position etc., see Appendix I for example field sheet), photographed and recorded on-site using a GPS unit, to be uploaded later using a GIS program for mapping. In the initial phase of sampling, approximately 100 samples from 21 sites were obtained along the Connecticut River in the fall of 2011 (Figure 3.1). Lab analyses for these samples were completed the following winter. Results were used to determine whether an adequate number of samples had been taken and the number of new sites required for each category was determined from the calculated n-value. Sample size was calculated as:

$$n = t^2 * s^2 / (\text{avg} * 0.15)^2,$$

where t is the t-score, and s is the standard deviation. This equation was used to determine the number of new sites required to be within 15% of the mean (Freese 1962).

Twenty new sites were sampled in the spring of 2012. In all, a total of 41 sites (218 samples) were sampled.

Laboratory Analysis

All soils were kept frozen until the time of analysis to prevent oxidation. Samples were determined to be either organic or mineral based from notes within their respective field description sheets. This process was used to divide the individual samples into mineral (including A, Bw, C, Cg, etc.) and organic samples (Oa, Oe, Oi) by horizon texture in the field, later to be verified by lab analyses.

Bulk density samples were oven dried overnight at 110° C and weighed. To determine the bulk density, recorded sample volumes were divided by their dry weights and reported as g cm^{-3}. Other laboratory analyses include particle size density, percent organic carbon, coarse fragments, and moisture by weight, pH by 1:1 soil to deionized water slurry mixtures using an Oakton pHTestr 30 pH probe for mineral soils and percent mineral materials, pyrophosphate colors, and pH for organic soils. All methods are described and available online in the *Soil Survey Lab Manual* (USDA-NRCS Soil Survey Staff 1993). In all samples, EC was measured with an Oakton ECTestr11 conductivity meter using one part soil sample solution to five parts distilled water by volume ($EC_{1:5vol}$).

Data Analysis

The soil descriptions were categorized and classified using the eleventh edition of *Keys to Soil Taxonomy* (USDA-NRCS Soil Survey Staff 2010), and entered into NASIS. Unequal ANOVA and Tukey-Kramer tests were used to differentiate soil types and vegetation categories. Linear regression was used to determine relationships between the soil parameters. The software used includes JMP 2010 (SAS Institute Inc.) and Excel 2007 (Microsoft).

Results and Discussion

According to a Shapiro-Wilk test, the distribution of the $EC_{1:5vol}$ data was not normal (W= 0.8187; p <0.0001. Figure 3.2 shows that they were skewed to the low values. This phenomenon is due to the sampling scheme which divided samples into five soil halinity classes based on vegetation with decreasing salt tolerances. As a result, the data contain more low values than high. In the distribution graph in Figure 3.2, the line indicates a normal continuous fit while dots over the box plot represent outliers. A majority of the sample sites were in the fresh, upland edge, and back marsh classes, so the data are skewed towards the smaller EC values.

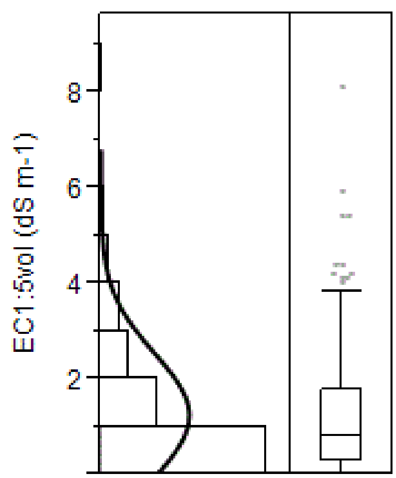


Figure 3.2: Distribution of $EC_{1:5vol}$ data

Of the five preliminary halinity vegetative classes used for sampling in this project (Table 3.2) which were defined based on the literature review, four were significantly different based on $EC_{1:5vol}$ (Figure 3.3). The upland edge class overlapped the back marsh and fresh classes too much to be a significantly different category. This lack of separation between classes was expected due to overlapping salt tolerances of the respective vegetation types (F= 62.4; p< 0.0001). Thus, the data indicate four halinity classes for the Connecticut River estuary rather than the five that were generated from the literature review. Table 3.2 and Figure 3.3 provide summary data and box plots of these classes.

Table 3.2: Preliminary Halinity Class Summary

	Low Marsh	**High Marsh**	**Back Marsh**	**Upland Edge**	**Fresh**
Species	*Spartina alterniflora*	*Spartina patens, Distichlis spicata, & Juncus gerardii*	*Bolboschoenus maritimus & Schoenoplectus robustus*	*Iva frutescens & Panicum virgatum*	*Typha x glauca & Phragmites australis*
Common Name	smooth cordgrass	saltmeadow cordgrass, saltgrass, blackgrass	salt marsh bullrush	marsh elder, switchgrass	hybrid cattail, common reed
n	19	30	68	22	77
Mean $EC_{1:5vol}$ (dS m^{-1})	3.49	2.56	1.07	0.71	0.51
Median	3.40	2.30	0.96	0.68	0.38
s	0.99	1.61	0.93	0.35	0.44
95% CI for mean	3.01-3.97	1.96-3.17	0.84-1.29	0.55-0.87	0.41-0.60
Class	a	b	c	cd	d

In the box plots in Figure 3.3, no outliers occur below the average values. This pattern occurs because although plants may survive in the upper limits of their halinity and flooding tolerances, they are limited at the lower end by competition of more efficient marsh vegetation (Miller and Egler 1950; Olff et al. 1988; Silvestri et al. 2004). The same pattern occurs when the vegetation is analyzed by species.

The vegetation distributions by species are shown in Figures 3.4- 3.9. According to an ANOVA and Tukey-Kramer test, *Phragmites autralis* had a significantly higher average EC value than either of the other 'fresh' species, *Carex stricta* or *Typha* species (p-values 0.0004, and 0.0007 respectively). *Typha* had a higher mean EC than *Carex* (p-value 0.0372) when the two 'fresh' species were compared with one another. Upland

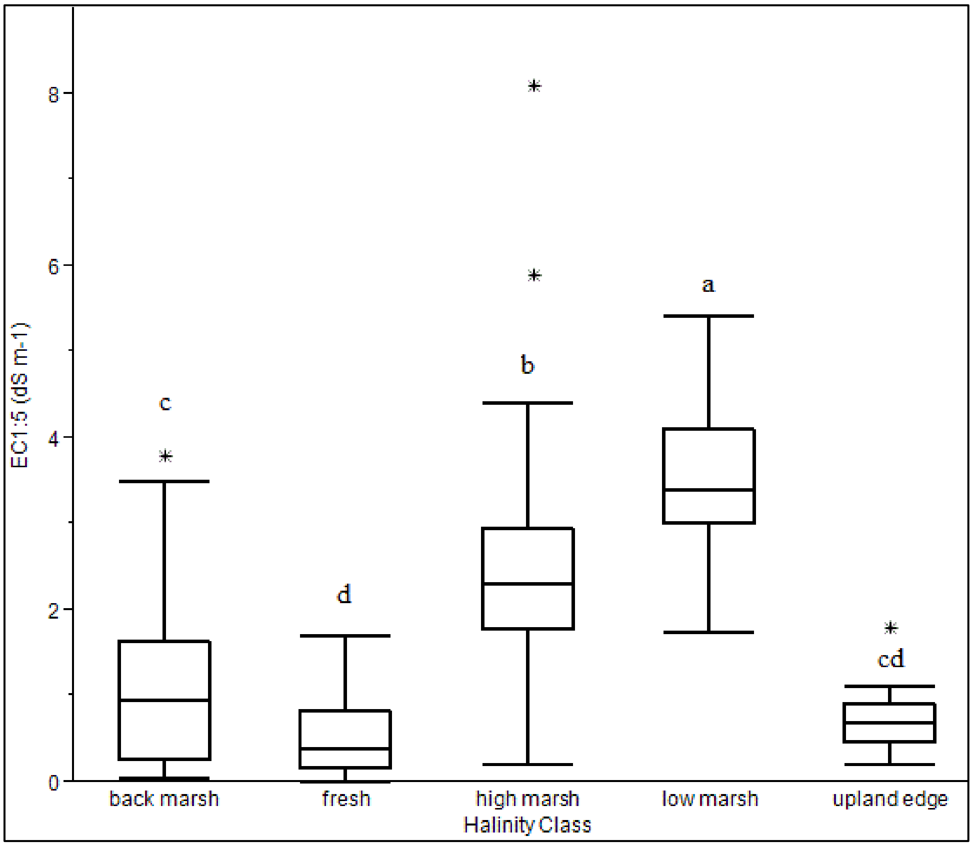


Figure 3.3: Box plot of halinity classes; letters indicate significantly different classes

edge species *Iva frutescens* and *Panicum virgatum* proved to have statistically similar EC values (p-value 0.2362). The back marsh species exhibited two statistically different groups due to varying species salt tolerance in the *Schoenoplectus* and *Bolboschoenus* genera. *Juncus gerardii* had significantly higher ECs ($\bar{x} = 4.94$) than both *Distichlis spicata* ($\bar{x} = 2.44$; $p = 0.0017$) and *Spartina patens* ($\bar{x} = 1.95$; $p < 0.001$) within the high marsh. This result is likely due to sampling *Juncus gerardii* stands mainly in panne areas on the marsh. The short form of *Spartina alterniflora* ($\bar{x} = 2.74$) had a statistically lower average EC value than the tall form ($\bar{x} = 3.76$, $p = 0.0453$). This phenomenon is probably an artifact of sampling timing for the one short form site (5 soil horizons), as indicated by water data as an increase in the Connecticut River gage height at Essex, CT two days before sampling followed by decrease in water salinity by the sample date, 3 November 2011 (USGS 2012).

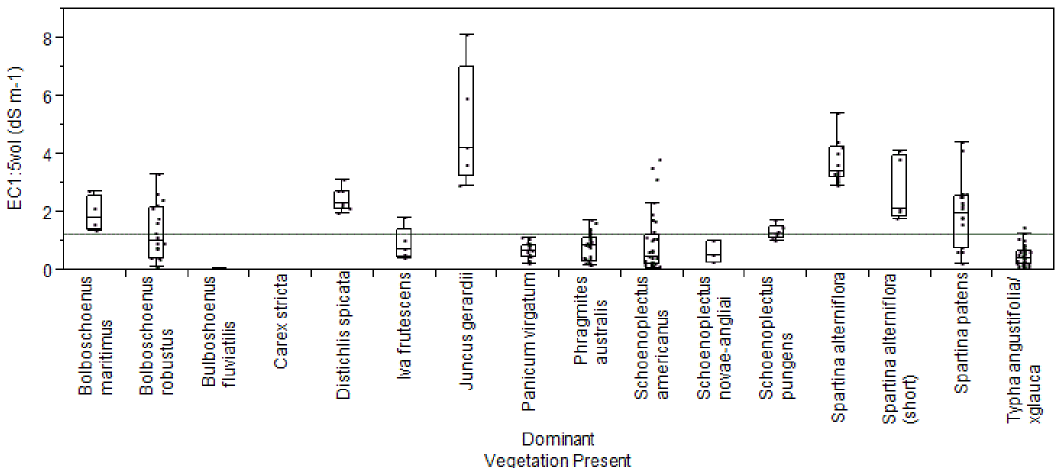


Figure 3.4 EC distributions for all species

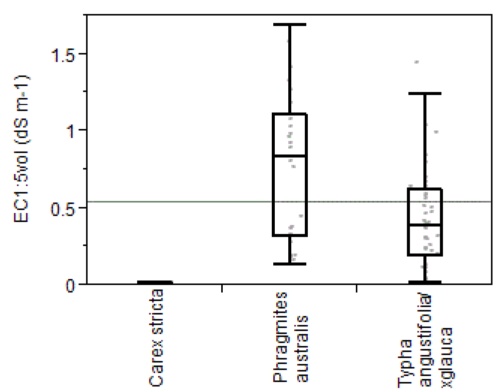


Figure 3.5 EC distributions for fresh species

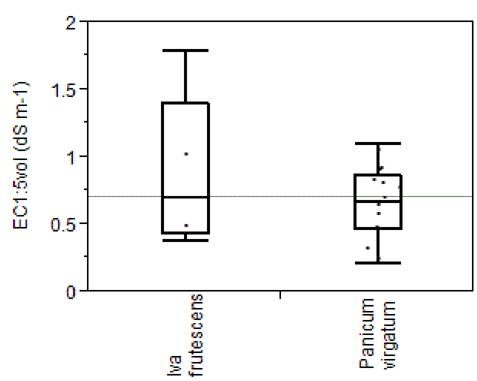


Figure 3.6 EC distributions for upland edge species

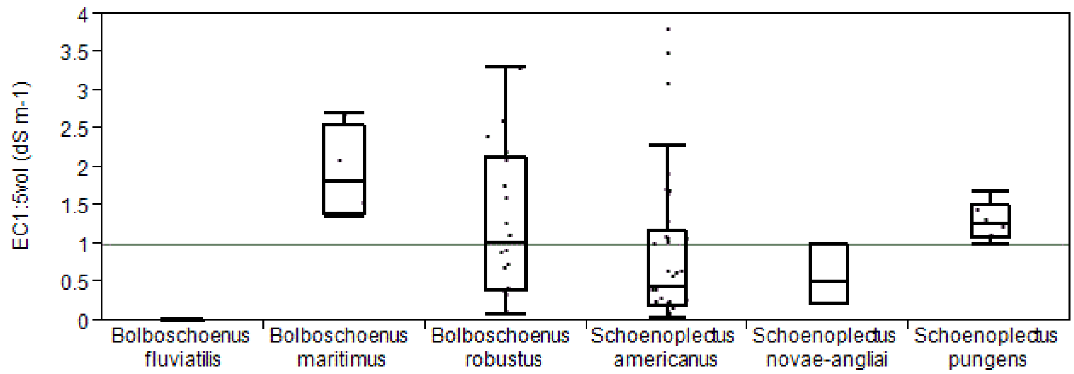


Figure 3.7 EC distributions for back marsh species

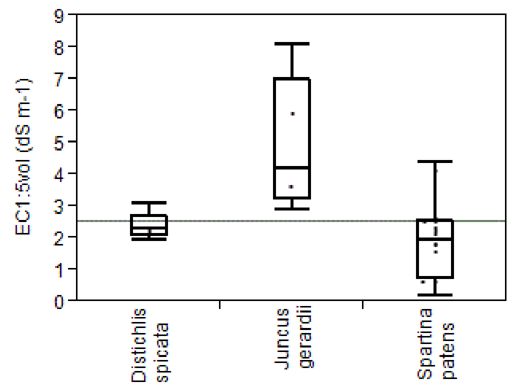


Figure 3.8 EC distributions for high marsh species

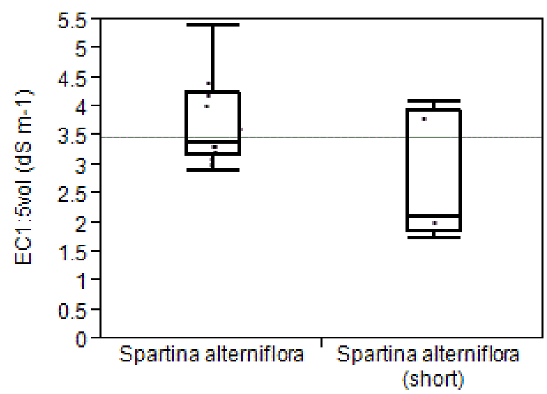


Figure 3.9: EC distributions for low marsh species

Fitting nature to a model

As with numerous other fields in environmental science, soil science directs researchers to place artificial numeric limits around natural gradations. Thus, it is not realistic to expect unambiguous classes of any given parameter in a system of constant flux. A plant's salt tolerance reflects the conditions it must survive in; consequently, plants must grow in an area with a lower halinity than its maximum tolerance. However, plants with higher tolerances may grow in areas with lower halinities as long as other plants do not out-compete them for resources. Plants which have high salt tolerance must have a mechanism to exclude or tolerate the salts in the soil, and are less efficient than plants that use less of their energy to contend with salt stress (Odum 1988). Presumably, this is why all of the outliers were on the higher end of the halinity ranges- because the species were outcompeted at lower halinities.

Conclusions

This study confirmed that sampling by vegetation type is a promising method for determining the boundaries of halinity classes for tidal marsh species. The back marsh and fresh community ranges in average $EC_{1:5vol}$ values were not mutually exclusive because of overlapping plant salt tolerances. As a result, it is suggested that back marsh and fresh halinity classes be combined. Conversely, the high marsh and low marsh classes were significantly different from the other classes (Table 3.2) and thus make a substantial foundation for determining regional soil halinity classes.

Sampling and classifying methods examined here are recommended for future similar studies, especially for attempts to expand this and similar research to regional and national scales. Further sampling is recommended before any soil halinity classification system is extrapolated to areas other than the Connecticut River.

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Appendix I

Example of Field Description Form

U.S. DEPARTMENT OF AGRICULTURE
NATURAL RESOURCES CONSERVATION SERVC E

HISTOSOL DESCRIPTION

NRCS - SOI - 036
9-96

Series ____________ Observer(s) ____________

State ____________ County ____________ Date ______ ______ No. ____________

Classification ____________

Location ____________ Est. M.A. Soil Temp. ____________

Method of Examining Soil ____________

N. Veg. or Crop ____________

Microrelief ____________ Slope ____________

Physiography ____________

Size of Area ____________

Distance to Adjoining Mineral Soil ____________

Depth to Water Table ____________ Depth to Permafrost ____________

Evidence of Subsidence ____________

Additional Notes ____________

Schematic Cross Section of Site

Layer or Horizon	Depth	Botanical Origin of Fiber	Fiber Content %		Color			Sodium Pyrophosphate Color Test	Mineral Content % 1/	Structure	Reaction		Consistence	Boundary	Roots
			Undisturbed	Rubbed	Broken Face	Rubbed	Pressed				H_2O	0.01M $CaCl_2$			

Remarks:

Note if present: other kinds of horizons or strata too thin to separate such as layers of charcoal; evidences of salinity or alkalinity; volume of logs, stumps, and other coarse woody fragments; worms; layer of water below the soil; evidence of change in kind of vegetation; evidence of irreversible drying; marked changes in pH on drying; iron sulfate mottles (straw colored); carbonates; other relevant features.

1/ State soil texture class for mineral horizons.

Appendix II

Site Data

Pedon ID	Location	Sample Date	Dominant Vegetation	Classification
2011CT007001	Old Saybrook	10/4/2011	*Distichlis spicata*	Typic Sulfihemists
2011CT007002	Old Saybrook	10/4/2011	*Bolboschoenus maritimus*	Thapto-Histic Sulfaquents
2011CT011007	Old Lyme	10/4/2011	*Spartina patens*	Typic Sulfihemists
2011CT011008	Old Lyme	10/4/2011	*Spartina alterniflora*	Terric Sulfihemists
2011CT011009	Lt. River	10/21/2011	*Typha angustifolia/ xglauca*	Terric Sulfisaprists
2011CT011010	Lt. River	10/21/2011	*Typha angustifolia/ xglauca*	Terric Sulfisaprists
2011CT011011	Old Lyme	10/21/2011	*Spartina patens*	Typic Sulfisaprists
2011CT011012	Old Lyme	10/21/2011	*Iva frutescens*	Sulfic Endoaquents
2011CT011013	Great Island	11/3/2011	*Spartina alterniflora (short)*	Typic Sulfisaprists
2011CT011014	Great Island	11/3/2011	*Juncus gerardii*	Typic Sulfisaprists
2011CT011015	Great Island	11/3/2011	*Bulboschoenus robustus*	Terric Sulfihemists
2011CT011016	Great Island	11/4/2011	*Spartina alterniflora*	Terric Sulfisaprists
2011CT011017	Great Island	11/4/2011	*Distichlis spicata*	Terric Sulfihemists
2011CT007003	Ragged Rock	11/17/2011	*Spartina patens* (panne)	Typic Sulfihemists
2011CT007004	Ragged Rock	11/17/2011	*Schoenoplectus americanus*	Typic Sulfihemists
2011CT007005	Ragged Rock	11/17/2011	*Panicum virgatum*	Typic Sulfihemists
2011CT007006	Ragged Rock	11/17/2011	*Panicum virgatum*	Typic Sulfihemists
2011CT007007	Ragged Rock	11/17/2011	*Typha angustifolia*	Typic Sulfisaprists
2011CT007008	Ragged Rock	12/2/2011	*Panicum virgatum*	Terric Sulfisaprists
2011CT007009	Ragged Rock	12/2/2011	*Phragmites australis*	Typic Sulfisaprists
2011CT007010	Ayer's Point	12/2/2011	*Phragmites australis*	Typic Sulfisaprists
2012CT007001	Ayer's Point	3/14/2012	*Typha angustifolia/ xglauca*	Typic Sulfisaprists

2012CT007002	Otter Cove	3/14/2012	*Phragmites australis*	Typic Sulfisaprists
2012CT007003	Otter Cove	3/14/2012	*Phragmites australis*	Typic Sulfisaprists
2012CT007004	Ayer's Point	3/14/2012	*Typha angustifolia/ xglauca*	Typic Sulfisaprists
2012CT007005	Pettipaug	3/15/2012	*Typha angustifolia/ xglauca*	Histic Sulfaquents
2012CT007006	Post Cove	3/15/2012	*Carex stricta*	Typic Haplohemists
2012CT007007	Pratt Cove	3/15/2012	*Bulboshoenus fluviatilis*	Sapric Haplohemists
2012CT011001	Lt. River	3/16/2012	*Typha angustifolia/ xglauca*	Terric Sulfisaprists
2012CT011002	Pilgram's Landing	3/16/2012	*Phragmites australis*	Typic Sulfihemists
2012CT011003	Ely's Ferry Rd.	3/16/2012	*Typha angustifolia/ xglauca*	Typic Sulfisaprists
2012CT011004	Calves Island	5/30/2012	*Schoenoplectus americanus*	Thapto-Histic Fluvaquents
2012CT011005	Calves Island	5/30/2012	*Schoenoplectus americanus*	Thapto-Histic Fluvaquents
2012CT007008	Saybrook Point	6/14/2012	*Schoenoplectus pungens*	Typic Sulfisaprists
2012CT007009	Saybrook Point	6/14/2012	*Spartina patens*	Typic Sulfisaprists
2012CT007010	Saybrook Point	7/12/2012	*Schoenoplectus americanus*	Terric Sulfihemists
2012CT007011	Saybrook Point	7/12/2012	*Schoenoplectus americanus*	Histic Sulfaquents
2012CT007012	Saybrook Point	7/12/2012	*Bolboschoenus robustus*	Terric Sulfisaprists
2012CT011006	Duck Pond Cemetary	7/13/2012	*Bolboschoenus robustus*	Typic Sulfisaprists
2012CT011006	Duck Pond Cemetary	7/13/2012	*Bolboschoenus robustus*	Typic Sulfisaprists
2012CT011007	Dickens Launch	7/13/2012	*Schoenoplectus novae-angliai*	Typic Fluvaquents
2012CT007013	Saybrook Point	8/9/2012	*Spartina alterniflora*	Histic Sulfaquents

Appendix III

Soil Horizon Data

Pedon ID	Horizon	Depth (cm)		EC (dS/m)			Texture		pH		D_{bulk} (g cm^{-3})	% OC	% H_2O
		Top	Bottom	EC_{pw}	$EC_{1:5vol}$	$EC_{1:5pw}$	Field	PSA	1:1	0.01*M* $CaCl_2$			
2011CT007001	Oi	0	13	9.00	2.1	-	peat	-	-	6.92	0.1685	-	-
2011CT007001	Oe	13	37	11.80	2.7	2.80	mk peat	-	-	6.91	0.2649	-	-
2011CT007001	Oi'	37	47	16.40	1.96	-	peat	-	-	6.90	-	-	-
2011CT007001	Oe'	47	75	-	-	21.80	mk peat	-	-	-	0.2968	-	-
2011CT007001	Oa	75	120	19.00	3.1	2.90	muck	-	-	6.95	0.1318	-	-
2011CT007002	Cg1	0	37	13.50	1.53	3.80	lfs	-	7.45	-	-	-	46.29
2011CT007002	Cg2	37	47	10.90	2.70	2.50	sil	mkSiL	7.60	-	-	6.49	-
2011CT007002	Oib	47	65	11.40	2.10	2.30	peat	-	-	6.58	-	-	-
2011CT007002	Oeb	65	85	11.10	1.36	4.10	mk peat	-	-	6.72	-	-	-
2011CT011007	Oi	0	20	15.40	1.77	4.80	peat	-	-	6.01	0.1284	-	-
2011CT011007	Oe1	20	56	13.60	2.60	-	mk peat	-	-	6.80	0.2714	-	-
2011CT011007	Oe2	56	78	15.50	4.40	-	mk peat	-	-	6.81	0.4744	-	-
2011CT011007	Oa	78	125	46.90	4.10	6.00	muck	-	-	7.10	0.3615	-	-
2011CT011008	Oa1	0	50	15.20	3.60	6.30	muck	-	-	7.25	0.4799	-	-
2011CT011008	Oa2	50	80	48.90	4.20	7.00	muck	-	-	7.61	0.3936	-	-
2011CT011008	Oa3	80	110	36.80	3.40	-	muck	-	-	7.73	0.7496	-	-
2011CT011008	Cg	110	125	10.80	3.30	0.89	sil	-	7.51	-	1.0853	-	-
2011CT011009	Oa1	0	28	1.80	0.51	1.29	muck	-	-	6.13	0.3239	-	-

2011CT011009	Oa2	28	65	3.50	0.99	1.50	muck	-	-	6.29	0.3903	-	-
2011CT011009	Oa3	65	116	5.30	1.45	-	muck	-	-	6.71	0.4619	-	-
2011CT011009	Cg	116	130	4.60	0.85	0.07	mk sil	mkSi	6.53	-	0.6778	9.57	58.70
2011CT011010	Oa1	0	10	4.20	0.09	0.40	muck	-	-	5.95	0.4162	-	-
2011CT011010	Oa2	10	40	3.10	0.70	0.36	muck	-	-	6.24	0.3193	-	-
2011CT011010	Cg1	40	60	1.29	0.30	0.54	mk sil	mkSi	6.52	-	0.5538	10.28	55.21
2011CT011010	Oab	60	74	1.52	0.41	0.11	muck	-	-	6.40	0.8085	-	-
2011CT011010	Cg2	74	92	1.37	0.20	0.16	mk sil	mkSi	6.58	-	0.8421	8.41	47.83
2011CT011010	Cg3	92	130	1.04	0.14	5.20	mk sil	mkSi	6.54	-	0.8034	6.00	42.62
2011CT011011	Oi	0	32	49.80	1.81	5.20	peat	-	-	6.80	1.5517	-	-
2011CT011011	Oe1	32	55	65.20	2.20	5.20	mk peat	-	-	7.05	0.5232	-	-
2011CT011011	Oe2	55	68	85.20	2.10	5.80	mk peat	-	-	6.79	0.2961	-	-
2011CT011011	Oa	68	130	74.00	2.30	1.48	muck	-	-	6.86	0.1581	-	-
2011CT011012	A (O)	0	5	7.10	0.38	3.70	mk sl	muck	6.27	6.34	-	60.52	76.82
2011CT011012	Ap	5	31	15.80	1.02	4.40	mk CoSL	mkSiL	5.55	-	-	6.25	24.78
2011CT011012	Bw	31	42	12.70	1.79	2.50	CoSL	CoSL	4.96	-	-	1.95	18.30
2011CT011012	BC	42	80	7.20	0.70	1.79	CoSL	LCoS	5.22	-	-	1.98	16.69
2011CT011012	C	80	100	5.60	0.49	7.40	gr CoS	CoS	4.98	-	-	0.09	15.71
2011CT011013	Oi1	0	13	72.80	2.1	8.30	peat	-	-	7.76	0.1055	-	-
2011CT011013	Oi2	13	20	85.30	1.74	9.00	peat	-	-	7.78	0.1824	-	-
2011CT011013	Oa1	20	44	84.60	1.98	9.00	muck	-	-	7.55	0.2976	-	-
2011CT011013	Oe	44	59	111.60	3.8	9.20	mk peat	-	-	7.36	0.2717	-	-

2011CT011013	Oa2	59	130	86.90	4.1	3.90	muck	-	-	7.36	0.8318	-	-
2011CT011014	Oi	0	10	19.00	4.2	4.20	peat	-	-	6.55	0.5116	-	-
2011CT011014	Oe	10	31	19.60	3.6	2.30	mk peat	-	-	6.61	0.4416	-	-
2011CT011014	Oa1	31	59	OR	5.90	6.50	muck	-	-	5.90	0.5389	-	-
2011CT011014	Oa2	59	80	OR	2.90	4.30	muck	-	-	5.35	0.4644	-	-
2011CT011014	Oa3	80	130	79.20	8.10	1.85	muck	-	-	5.15	0.3503	-	-
2011CT011015	Oi	0	13	7.20	0.08	1.77	peat	-	-	6.12	0.3512	-	-
2011CT011015	Oe1	13	25	9.90	1.11	4.80	mk peat	-	-	7.36	0.2026	-	-
2011CT011015	Oe2	25	97	15.70	3.30	1.77	mk peat	-	-	6.87	0.7586	-	-
2011CT011015	Cg	97	130	17.50	2.10	7.80	mk sil	mkSi	7.31	-	1.0149	6.34	48.11
2011CT011016	Oe	0	36	33.50	3.10	7.80	mk peat	-	-	7.06	0.1536	-	-
2011CT011016	Oa1	36	90	42.70	5.40	7.20	muck	-	-	7.78	0.4096	-	-
2011CT011016	Oa2	90	98	41.40	5.40	8.30	muck	-	-	7.78	0.6209	-	-
2011CT011016	Cg	98	130	45.50	4.40	7.70	mk sil	mkSi	7.45	-	0.7445	7.08	56.67
2011CT011017	Oi	0	19	34.50	2.20	8.10	peat	-	-	6.31	0.2837	-	-
2011CT011017	Oe	19	76	35.40	2.30	8.40	mk peat	-	-	7.12	0.3788	-	-
2011CT011017	Cg	76	130	39.30	2.70	0.50	lvfs	-	7.32	-	0.8816	7.92	54.40
2011CT007003	Oi1	0	20	1.77	0.21	0.96	peat	-	-	5.57	0.0907	-	-
2011CT007003	Oi2	20	32	5.60	0.59	1.58	peat	-	-	6.71	0.1374	-	-
2011CT007003	Oa	32	56	6.70	0.76	2.30	muck	-	-	6.92	0.2277	-	-
2011CT007003	Oe	56	130	9.00	0.76	0.65	mk peat	-	-	6.87	0.2099	-	-
2011CT007004	Oi1	0	10	4.30	0.24	1.23	peat	-	-	5.74	0.1538	-	-

2011CT007004	Oi2	10	30	7.90	0.64	2.00	peat	-	-	6.45	0.2327	-	-
2011CT007004	Oe	30	59	8.50	0.58	1.56	mk peat	-	-	6.47	0.3350	-	-
2011CT007004	Oa	59	87	9.80	0.62	2.00	muck	-	-	6.75	0.2484	-	78.52
2011CT007004	Oe'	87	130	9.30	0.64	1.56	mk peat	-	-	6.90	0.1907	-	-
2011CT007005	Oe	0	18	7.60	1.06	2.50	mk peat	-	-	6.46	0.2822	-	-
2011CT007005	Oi	18	42	6.30	0.47	2.60	peat	-	-	6.58	0.2291	-	-
2011CT007005	Oe'1	42	64	8.70	0.91	2.90	mk peat	-	-	7.07	0.4455	-	-
2011CT007005	Oe'2	64	77	7.70	0.81	3.00	mk peat	-	-	7.15	0.4411	-	-
2011CT007005	Oe'3	77	98	10.20	0.92	3.20	mk peat	-	-	7.26	0.3041	-	-
2011CT007005	Oe'4	98	130	10.60	1.1	0.69	mk peat	-	-	7.46	0.2239	-	-
2011CT007006	Oi1	0	5	2.50	0.25	0.41	peat	-	-	5.76	0.1093	-	-
2011CT007006	Oi2	5	23	2.90	0.32	0.96	peat	-	-	6.46	0.0965	-	-
2011CT007006	Oe	23	54	5.00	0.48	1.60	mkpeat	-	-	6.75	0.2250	-	-
2011CT007006	Oa	54	81	7.10	0.67	0.81	muck	-	-	6.89	0.2382	-	-
2011CT007006	Oe'	81	130	2.70	0.21	0.22	mk peat	-	-	6.52	0.2815	-	-
2011CT007007	Oe1	0	20	0.76	0.19	0.18	mk peat	-	-	6.73	0.1235	-	-
2011CT007007	Oe2	20	35	0.80	0.12	0.06	mk peat	-	-	6.37	0.2730	-	-
2011CT007007	Oa1	35	62	0.18	0.04	0.04	muck	-	-	6.02	0.2576	-	-
2011CT007007	Oa2	62	75	0.10	0.02	0.06	muck	-	-	5.74	0.2558	-	-
2011CT007007	Oi1	75	98	0.20	0.02	0.07	peat	-	-	5.76	0.1939	-	-
2011CT007007	Oi2	98	130	0.19	0.02	0.81	peat	-	-	5.98	0.1853	-	-
2011CT007008	Oe1	0	6	1.94	0.47	0.82	mk peat	-	-	5.47	0.1318	-	-

2011CT007008	Oe2	6	40	1.85	0.65	1.31	mk peat	-	-	6.33	0.1163	-	-
2011CT007008	Oa1	40	64	2.90	0.83	1.45	muck	-	-	6.19	0.3995	-	-
2011CT007008	Oa2	64	81	2.80	0.70	1.23	muck	-	-	6.22	0.3336	-	-
2011CT007008	OA (A)	81	110	3.40	0.78	1.40	muck	mk LCoS	7.46	6.24	1.0204	8.48	48.23
2011CT007008	A	110	130	3.80	0.58	-	mk fs	mkFSL	7.28	-	1.1425	8.00	43.82
2011CT007009	Oa1	0	14	3.10	0.96	-	muck	-	-	6.12	0.2879	-	-
2011CT007009	Oa2	14	31	5.20	0.89	-	muck	-	-	6.35	0.5921	-	-
2011CT007009	Oe	31	44	6.00	0.84	-	mk peat	-	-	6.52	0.4826	-	-
2011CT007009	O'a1	44	63	6.30	1.08	-	muck	-	-	6.67	0.6313	-	-
2011CT007009	O'a2	63	69	3.40	1.03	-	muck	-	-	6.66	0.2862	-	-
2011CT007009	O'a3	69	115	7.20	1.33	-	muck	-	-	6.58	0.6860	-	-
2011CT007009	Oe'	115	130	8.70	1.69	0.31	mk peat	-	-	6.69	0.1569	-	-
2011CT007010	Oi	0	16	0.61	0.33	0.93	peat	-	-	5.77	0.1335	-	-
2011CT007010	Oa1	16	31	2.00	0.77	1.12	muck	-	-	5.88	0.1691	-	-
2011CT007010	Oa2	31	50	3.80	0.84	1.27	muck	-	-	5.96	0.2189	-	-
2011CT007010	Oe	50	80	3.20	0.81	1.24	mk peat	-	-	6.04	0.4525	-	-
2011CT007010	O'a	80	130	3.90	0.98	0.43	muck	-	-	5.81	0.2815	-	-
2012CT007001	Oa1	0	22	1.88	0.30	0.65	muck	-	-	5.75	0.1489	-	83.81
2012CT007001	Oa2	22	45	4.64	0.37	0.91	muck	-	-	6.05	0.3975	-	72.64
2012CT007001	Oa3	45	62	3.90	0.42	1.06	muck	-	-	6.18	0.4418	-	69.90
2012CT007001	Oa4	62	79	4.40	0.67	-	muck	-	-	6.38	0.5415	-	67.54
2012CT007001	Oe	79	115	8.78	0.80	-	mk peat	-	-	6.57	0.3284	-	76.87

2012CT007001	O'a5	115	130	4.60	1.24	0.15	muck	-	-	6.73	0.3863	-	71.08
2012CT007002	Oe	0	25	0.75	0.18	0.13	mk peat		-	5.29	0.2985	-	73.48
2012CT007002	Oa1	25	40	0.81	0.14	0.15	muck	-	-	5.32	0.3879	-	71.78
2012CT007002	Oa2	40	67	0.60	0.19	0.15	muck	-	-	5.30	0.2703	-	81.27
2012CT007002	Oa3	67	90	0.74	0.19	0.23	muck	-	-	5.23	0.3283	-	85.54
2012CT007002	Oa4	90	130	1.08	0.37	0.22	muck	-	-	5.39	0.1154	-	89.64
2012CT007003	Oa1	0	30	0.77	0.17	0.17	muck	-	-	5.70	0.0974	-	88.76
2012CT007003	Oe	30	70	0.62	0.28	0.37	mk peat	-	-	5.82	0.1376	-	84.75
2012CT007003	Oa'2	70	90	1.79	0.38	0.49	muck	-	-	6.07	0.3111	-	73.67
2012CT007003	Oa'3	90	130	1.69	0.45	0.34	muck	-	-	6.10	0.8027	-	47.18
2012CT007004	Oe	0	32	1.40	0.24	0.38	mk peat	-	-	5.63	0.1629	-	81.70
2012CT007004	Oa1	32	64	1.54	0.47	0.43	muck	-	-	5.51	0.2263	-	77.43
2012CT007004	Oa2	64	85	2.10	0.56	0.68	muck	-	-	5.95	0.2288	-	82.38
2012CT007004	Oa3	85	130	2.90	0.64	0.08	muck	-	-	5.96	0.3006	-	77.41
2012CT007005	Oa	0	21	0.32	0.05	0.13	muck	-	-	4.71	-	-	-
2012CT007005	A	21	36	0.63	0.12	0.25	mk fsl	-	5.77	-	1.3114	-	33.10
2012CT007005	Cg1	36	51	1.33	0.23	0.34	mk fsl	-	5.85	-	0.6452	-	57.16
2012CT007005	Cg2	51	81	1.42	0.26	0.39	mk fsl	-	6.05	-	1.1617	-	41.62
2012CT007005	Cg3	81	130	1.92	0.31	0.03	mk fsl	-	6.02	-	1.0605	-	39.60
2012CT007006	Oa1	0	16	1.71	0.02	0.05	muck	-	-	4.95	0.3004	-	76.78
2012CT007006	Oa2	16	32	1.70	0.02	0.02	muck	-	-	4.63	0.2892	-	78.55
2012CT007006	Oe1	32	63	1.10	0.01	0.02	mk peat	-	-	4.81	0.1319	-	86.51

2012CT007006	Oe2	63	130	1.00	0.01	0.05	mk peat	-	-	4.74	0.2473	-	82.26
2012CT007007	Oe	0	19	2.44	0.03	0.05	mk peat	-	-	4.83	-	-	-
2012CT007007	Oe	19	42	1.55	0.02	0.02	mk peat	-	-	4.60	0.2811	-	79.18
2012CT007007	Oa/A	42	56	0.09	0.03	0.01	muck	-	5.33	4.81	0.3401	-	71.44
2012CT007007	Oe	56	82	0.09	0.01	0.02	mk peat	-	-	4.63	0.7162	-	59.78
2012CT007007	Oa	82	130	0.07	0.01	0.54	muck	-	-	4.37	0.4423	-	66.63
2012CT011001	Oa1	0	15	2.40	0.59	0.51	muck	-	-	5.90	-	-	-
2012CT011001	Oa2	15	43	2.60	0.64	0.51	muck	-	-	5.93	0.1353	-	90.11
2012CT011001	Oa3	43	65	1.93	0.52	0.59	muck	-	-	5.99	0.2451	-	79.92
2012CT011001	Oa4	65	80	2.90	0.62	0.67	muck	-	-	6.00	0.4104	-	79.82
2012CT011001	Oa5	80	108	3.10	0.58	0.90	muck	-	-	6.11	0.2517	-	80.73
2012CT011001	Cg	108	130	4.40	1.04	0.80	ml sl	-	6.74	-	-	-	-
2012CT011002	Oe	0	33	7.40	0.92	1.16	mk peat	-	-	6.17	0.0918	-	92.58
2012CT011002	Oa1	33	46	8.15	1.58	1.61	muck	-	-	6.42	0.2587	-	82.04
2012CT011002	Oa2	46	79	14.24	1.42	1.68	muck	-	-	6.45	0.3256	-	77.63
2012CT011002	OA	79	98	6.70	1.27	1.62	muck		6.54	6.27	0.4712	-	65.66
2012CT011002	Oe'	98	130	13.61	1.19	0.43	mkpeat	-	-	6.28	0.5768	-	63.27
2012CT011003	Oa	0	18	2.81	0.32	0.37	muck	-	-	5.72	0.2067	-	80.96
2012CT011003	Oe	18	42	2.22	0.22	0.50	mk peat	-	-	5.60	0.3151	-	76.35
2012CT011003	Oa'1	42	56	3.26	0.4	0.55	muck	-	-	5.79	0.2764	-	80.48
2012CT011003	Oa'2	56	71	1.70	0.38	0.62	muck	-	-	5.90	0.3651	-	75.46
2012CT011003	Oa'3	71	130	4.80	0.48	0.51	muck	-	-	5.97	0.4536	-	73.39

2012CT011004	Cg	0	9	2.35	0.19	0.33	s	-	6.47	-	1.1395	-	22.04
2012CT011004	CA	9	13	0.98	0.09	0.30	mk fsl	-	5.53	-	0.5780	-	51.15
2012CT011004	AC	13	18	1.03	0.11	0.28	mksil	-	6.10	-	1.1010	-	20.51
2012CT011004	Cg'	18	22	0.86	0.08	0.36	ls	-	6.27	-	1.2600	-	27.58
2012CT011004	Cg"	22	25	0.98	0.09	0.45	ls	-	6.16	-	1.3550	-	26.69
2012CT011004	2Ab	25	33	1.75	0.15	0.60	mk sil	-	5.98	5.06	0.9710	-	43.41
2012CT011004	2Oa1	33	45	2.08	0.19	0.82	muck	-	-	4.97	0.5570	-	52.38
2012CT011004	2Oa2	45	71	2.83	0.41	0.85	muck	-	-	5.07	0.5461	-	66.99
2012CT011004	2Ab'	71	86	3.06	0.30	0.65	mkfsl	-	5.69	-	0.7954	-	55.51
2012CT011004	2AC	86	99	2.50	0.27	0.71	mkls	-	5.99	-	-	-	-
2012CT011004	2Cg'''	99	120	2.53	0.25	0.46	s	-	5.99	-	-	-	-
2012CT011005	Cg1	0	17	1.46	0.09	0.36	s	-	4.81	-	1.0640	-	22.53
2012CT011005	Cg2	17	33	1.09	0.05	0.34	s	-	5.47	-	1.3020	-	21.99
2012CT011005	Cg3	33	49	1.09	0.08	0.47	lfs	-	6.47	-	1.6529	-	27.88
2012CT011005	Oa	49	61	2.06	0.22	0.70	muck	-	-	5.94	0.9454	-	50.28
2012CT011005	Ab	61	66	2.65	0.23	0.68	mksl		6.52	-	1.1460	-	40.68
2012CT011005	Oa'	66	80	2.83	0.40	0.76	muck	-	-	5.86	0.4434	-	69.83
2012CT011005	Oa"	80	100	3.18	0.44	1.28	muck	-	-	5.90	0.4819	-	69.52
2012CT007008	Oa1	0	16	6.06	1.00	1.40	muck	-	-	5.12	0.2441	-	75.14
2012CT007008	Oa2	16	26	6.89	1.11	1.53	muck	-	-	6.39	0.3830	-	66.52
2012CT007008	Oe	26	34	7.31	1.22	1.68	mk peat	-	-	6.50	0.3530	-	70.12
2012CT007008	Oa'	34	75	8.32	1.31	2.00	muck	-	-	6.67	0.4983	-	66.12

2012CT007008	Oa"	75	90	10.00	1.44	2.10	muck	-	-	6.63	0.5001	-	66.73
2012CT007008	Oa"'	90	130	10.45	1.69	0.90	muck	-	-	6.84	0.4464	-	68.57
2012CT007009	Oi1	0	16	4.85	0.60	1.68	peat	-	-	5.87	0.1538	-	86.07
2012CT007009	Oi2	16	33	7.93	1.55	2.20	peat	-	-	6.48	0.1450	-	86.01
2012CT007009	Oe	33	54	10.19	1.77	2.80	mk peat	-	-	6.82	0.1620	-	82.72
2012CT007009	Oa1	54	66	13.54	2.60	3.10	muck	-	-	7.02	0.3011	-	77.98
2012CT007009	Oa2	66	103	14.26	2.50	3.20	muck	-	-	7.01	0.1554	-	87.49
2012CT007009	Oa3	103	130	15.97	2.50	4.9	muck	-	-	7.08	0.1383	-	89.42
2012CT007010	Oa1	0	8	26.50	3.10	3.4	muck	-	-	6.13	0.3700	-	66.96
2012CT007010	Oa2	8	19	16.53	2.30	1.82	muck	-	-	6.46	0.4930	-	60.26
2012CT007010	Oe	19	40	9.22	1.07	1.81	mk peat	-	-	6.43	0.4760	-	61.09
2012CT007010	Cg1	40	55	9.12	1.02	1.72	ls	-	6.58	-	-	-	-
2012CT007010	Cg2	55	70	8.68	1.08	1.88	s	-	6.79	-	-	-	-
2012CT007010	Cg3	70	79	9.49	1.07	2.3	sil	-	6.90	-	-	-	-
2012CT007010	Cg4	79	101	11.39	1.01	4.9	gr ls	-	6.31	-	-	-	-
2012CT007011	Oe	0	10	26.30	3.80	4.2	mk peat	-	-	6.38	0.3310	-	74.72
2012CT007011	Oa1	10	21	23.00	3.50	4.1	muck	-	-	6.34	0.4570	-	60.26
2012CT007011	Oa2	21	36	19.85	1.71		muck	-	-	6.53	0.5380	-	57.76
2012CT007011	Cg1	36	62			2.1	vfsl	-		-	-	-	-
2012CT007011	C/O	62	83	10.04	1.28	2.3	muck/vfs l/mksil	-	5.26	-	-	-	-
2012CT007011	Cg1	83	90	11.22	1.65	2.6	mk sil	-	7.33	-	0.9680	-	52.04
2012CT007011	Cg2	90	98	12.56	1.68	2.7	mk sil	-	7.33	-	0.7480	-	52.81

2012CT007011	Cg3	98	130	14.41	1.92	3.1	mk sl	-	7.31	-	1.3150	-	37.21
2012CT007012	Oa1	0	20	15.29	2.40	1.93	muck	-	-	5.54	0.1660	-	80.09
2012CT007012	Oe	20	36	9.8	1.75	1.27	mk peat	-	-	5.76	0.1440	-	84.74
2012CT007012	Oa'1	36	62	6.5	0.90	0.5	muck	-	-	5.74	0.1440	-	83.61
2012CT007012	Oa'2	62	93	2.6	0.38	0.43	muck	-	-	5.48	0.4410	-	72.28
2012CT007012	Ab	93	103	2.2	0.34	0.23	mk fsl	-	5.38	-	0.9550	-	46.83
2012CT007012	C	103	130	1.2	0.11	2.6	fsl	-	5.11	-	1.4330	-	28.69
2012CT011006	Oa1	0	8	13.43	2.6	2.1	muck	-	-	6.56	0.2010	-	80.05
2012CT011006	Oa2	8	21	10.78	2.2	1.47	muck	-	-	6.35	0.2630	-	78.19
2012CT011006	Oe	21	32	7.46	1.59	1.35	mk peat	-	-	6.44	0.2740	-	79.63
2012CT011006	Oa'3	32	50	7.14	1.27	1.31	muck	-	-	6.58	0.2322	-	83.69
2012CT011006	Oa'4	50	70	6.50	0.92	1.01	muck	-	-	6.60	0.2780	-	80.05
2012CT011006	Oa'5	70	82	5.06	0.74	0.85	muck	-	-	6.21	0.3590	-	73.12
2012CT011006	Oa'6	82	92	4.13	0.7	0.48	muck	-	-	6.30	0.4250	-	70.18
2012CT011006	Oa'7	92	130	2.44	0.42	1.45	muck	-	-	5.82	0.5090	-	69.23
2012CT011007	Oa	0	7	7.10	0.99	0.55	muck	-	-	6.25	-	-	-
2012CT011007	Oe	7	20	2.74	0.51	0.36	mk peat	-	-	5.87	0.4250	-	67.50
2012CT011007	C	20	52	1.75	0.23	3.80	sil	-	6.31	-	0.8650	-	49.96
2012CT007013	Oa1	0	11	19.5	3.0	2.90	muck	-	-	5.86	0.2918	-	72.61
2012CT007013	Oa1	11	27	18.6	2.9	3.50	muck	-	-	7.21	0.3127	-	68.46
2012CT007013	Oa3	27	39	15.1	3.2	3.80	muck	-	-	7.27	0.3355	-	70.50
2012CT007013	Cg	39	74	17.6	3.3	4.90	mk sil	-	7.30	-	0.6252	-	57.90

2012CT007013	Oa'1	74	103	18.7	3.4	2.80	muck	-	-	7.21	0.5580	-	65.76
2012CT007013	Oa'2	103	130	14.1	4.0	-	muck	-	-	7.27	0.5156	-	65.86

Key to Abbreviations

Column Headings	Textures and Texture Modifiers	
EC_{pw}- Electrical Conductivity of a pore water sample	Peat- peat; i.e. 75 percent or more rubbed fibers	LVFS- loamy very fine sand
$EC_{1:5vol}$- Electrical Conductivity of a one part soil sample to five parts deionized water by volume solution	Muck- muck; i.e. less than 17 percent rubbed fibers	FS- fine sand
$EC_{1:5pw}$- Electrical Conductivity of a one part pore water to five parts deionized water by volume solution	Mk peat- mucky peat; i.e. 17 to 75 percent rubbed fibers	VFSL- very fine sandy loam
PSA- Particle Size Analysis	Mk- “mucky” modifier; >10% organic matter and <17% fibers	Ls- loamy sand
1:1 pH- pH of a one part soil to one part deionized water by volume solution	Gr- “gravelly” modifier; 15 to 35% gravels	S- sand
0.1*M* $CaCl_2$ pH- pH of a 0.1M calcium chloride and soil solution	LFS- loamy fine sand	Si- silt
D_{bulk}- bulk density	SiL- silt loam	LCoS- loamy coarse sand
%OC- percent organic carbon by weight	SL- sandy loam	
%H_2O- percent moisture by weight	CoSL- coarse sandy loam	

(USDA-NRCS Soil Survey Staff 2002)