



Drainage impacts on the productivity of wetland species *Spartina alterniflora* and *Salicornia pacifica*

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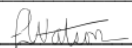
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Drainage Impacts on the Productivity of Wetland Species *Spartina alterniflora* and *Salicornia pacifica*

A Thesis

Submitted to the Faculty

of

Drexel University

by

Kylie Margaret Cherneskie

in partial fulfillment of the requirements for the degree

of

Master of Science

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ABSTRACT

Drainage Impacts on the Productivity of Wetland Species *Spartina alterniflora* and *Salicornia pacifica*

Kylie Cherneskie

Elizabeth Watson, Ph.D.

Coastal wetlands display ecohydrological zonation such that vertical differences in groundwater levels over tidal cycles are large in the tall form *Spartina alterniflora* zone, intermediate in the short form *Spartina alterniflora* zone, and modest in the upper marsh zone. It is unclear how this variable level of tidal drainage directly impacts biotic and abiotic factors in coastal wetland ecosystems, which included above and belowground biomass, porewater pH, salinity, ammonium concentration, sulfide concentration, soil redox potential, NEE, photosynthesis rate, respiration rate, and methane flux. To determine the impacts of drainage levels, simulated tides in mesocosms with varying degrees of drainage were created with *Spartina alterniflora*, the salt marsh coastal ecosystem dominant species on the United States Atlantic Coast, and *Salicornia pacifica*, the Pacific Coast dominant. We measured biomass production and photosynthesis as measures of plant health, and we supplemented these measures with those of soil and porewater characteristics to help interpret patterns of productivity. As based on the four degrees of drainage, we found the greatest plant production in soils with intermediate drainage levels, with production values that were 13.7% higher for *S. alterniflora* and 57.7% higher for *S. pacifica* in the intermediate levels than the outer two levels. Understanding how drainage impacts plant species is important for predicting wetland resilience to sea level rise, as increasing water levels alter ecohydrologic zonation.

1. INTRODUCTION

Coastal wetlands are ecosystems of vital importance because they provide ecosystem services such as the maintenance of fisheries, shoreline protection, storm surge buffering, water quality maintenance, nutrient recycling, preservation of biodiversity, climate regulation, carbon sequestration, and sediment retention (Brouwer et al. 1999; Blankespoor et al. 2014). The ecological, economical, and coastal protection functions are important for numerous bird and invertebrate species, as well as for the local coastal communities (Barbier et al. 2011). According to Schuerch et al. (2018), the ecosystem services provided by coastal wetlands are valued at up to US\$194,000 ha⁻¹ yr⁻¹

Salt marshes are coastal wetland areas characterized by intertidal grasses and succulents and regular seawater flooding (Silliman et al. 2014). Salt marshes are areas of high productivity, and they protect coastal zones through their ability to grow in elevation by trapping sediments and accreting biomass (Cahoon 1994; Fagherazzi et al. 2020; Liu et al. 2021). Coastal wetlands, such as salt marshes, are especially vulnerable to submergence and lateral erosion caused by sea level rise (Nyman 1993; Kirwan 2012; Krause et al. 2020). Submergence and lateral erosion have been causing widespread wetland loss on a global scale (Schuerch et al. 2018; Alldred 2020; Sweet 2020). The vertical development of wetland plants has been shown to lag behind sea-level rise, creating an elevation deficit (Fagherazzi et al. 2019; Cahoon et al. 2019). The wetland gradually becomes lower relative to the local sea level, thus increasing the depth, frequency, and duration of flooding (Raposa et al. 2016; Cahoon et al. 2019). Salt marsh drowning occurs when the surface elevation does not increase at a rate that is the same or equal to the rate of sea level rise (FitzGerald 2008; Rodriguez 2017; Phillips 2018). Salt marshes in the Northeastern United States (U.S.) are disappearing due to symptoms associated with sea level

rise at rates of approximately 5-10% per decade (Hartig et al., 2002; Watson et al., 2017; Krause et al. 2021), and are projected to decline by 10% to 45% in area by 2100 (Krause et al. 2021). Within the context of rapid wetland loss due to over inundation, further research is needed to better understand the relationship between tidal flooding, drainage, and plant productivity.

Previous tidal mesocosm studies have focused on the relationships between flooding and plant production (Padgett and Brown 1999; Spalding and Hester 2007; Woo and Takekawa 2012; Sharpe and Baldwin 2012; Miller and Long 2015; Watson et al. 2017; Jones 2018). The relationship between flooding and plant growth is generally thought to be parabolic, or hump-shaped, with flooding optima that vary by species (e.g., Morris et al., 2002; Krause et al. 2008), and which often interacts with salinity (e.g., Woo and Takekawa 2012). Although some mesocosm studies have identified such a parabolic relationship (e.g., Woo and Takekawa 2012; Watson et al., 2016; Peng et al., 2018), many, perhaps most, studies have found that plant productivity declines linearly with flooding among salt marsh plants (Voss et al., 2013; Watson et al. 2017; Lie et al. 2020; Hanson et al. 2016; Voss et al. 2013; Payne et al. 2019). Alternative conclusions may explain these differing results. First, wetland taxa may not actually need frequent inundation, and may grow better under less inundated conditions (Neckles et al. 1990). A second, and more methodological explanation, is that the relationship between flooding and plant growth may have become parabolic in the experiments where it appeared linear if a wider distribution of inundation regimes was tested. Regardless of the response, one shortcoming among these types of experiments is that generally they focus on the effect of surface flooding. In these experiments, plants are exposed to different depths and/or lengths of surface flooding, and pots are allowed to drain mostly or completely at "low tide." However, in the field, the root zone of salt marsh soils is often continuously flooded to depths that are, or very near, the surface

(Montalto et al. 2006; Wilson et al. 2015). Thus, this category of studies both does not realistically produce conditions experienced in the field under natural conditions and does not ascertain how marsh plant growth responds to root zone flooding.

Studying conditions that better emulate conditions in the field is especially crucial as recent research into groundwater hydrology patterns in salt marshes has revealed what an important role hydrology plays in structuring ecological zonation (Moffett et al. 2012; Wilson et al. 2015; Xin et al. 2022). Differences in net groundwater flow direction and root zone drainage are critical factors controlling ecological productivity. Along the Atlantic Coast of the U.S., this ecohydrological zonation causes large vertical differences in groundwater levels in the tall form *Spartina alterniflora* zone, intermediate vertical differences in the short form *Spartina alterniflora* zone, and modest differences in the upper marsh zone (Wilson et al. 2015). In addition, the tall form *Spartina alterniflora* zone is characterized by net downward flow and drained conditions, while the short-form *Spartina alterniflora* and upper marsh zones are characterized by periods of upward water movement (Wilson et al. 2015). Along the Pacific Coast, although groundwater hydrology has been less studied, it is known that wetland elevation and the tidal cycles have a strong influence on the positioning of *S. pacifica* within the tidal frame (Mahall and Park 1976; Moffet 2012). While there have been numerous studies on the effects of surface flooding on coastal wetlands (Ramsey 1995; Hartig et al. 2002; Kearney et al. 2002; Smith 2009; Watson 2017), to our knowledge the effects of this poor soil drainage have not been studied experimentally.

Plant survival, growth, and productivity are influenced by flooding and drainage because of plant responses to anoxic soil conditions. Root growth is an energy-dependent process that requires oxygen, and under flooded conditions, root functioning is also affected because oxygen

is required as an electron acceptor for oxidative phosphorylation (Pezeshki et al. 2001). Harmful byproducts of anaerobic respiration include hydrogen sulfide (H_2S) which can reduce the growth of vegetation (Koch et al. 1990). Sulfide concentrations can become very high in sites that experience long daily tidal inundation (Alldred et al. 2020), and elevated sulfide levels can be toxic to marsh plants (Krause et al. 2019). Previous studies have shown that the presence of high H_2S concentrations in flooded marshes reduces plant productivity (Portnoy and Giblin 1997; Mendelsohn and Kuhn 2003). We hypothesize that continuous soil flooding will have more negative effects on plant growth and will be associated with higher soil sulfide levels.

In addition to interactions between soil drainage and anoxia, drainage may also affect several soil parameters less directly, such as porewater salinity, pH, and soil nutrient levels, which can also impact the growth and productivity of coastal plants. Porewater salinity is known to affect vegetation distribution and productivity in coastal marsh ecosystems, and pH affects many chemical and biological processes in water such as carbonate formation and productivity (Morris and Haskin 1990; Soetaert et al 2007). The concentration of nitrogen in the soil impacts plant growth, as nitrogen is a vital nutrient that coastal wetland plants need to grow (Güsewell and Koerselman 2002). Both oxidized N forms (nitrate, NO_3^-) and reduced forms (ammonium, NH_4^+) can relieve nutrient limitation and increase primary production (Bowen et al. 2020). Each of these biological impacts on wetland plants can influence plant growth in situations where drainage is poor.

We were also interested in the effects of flooding on methane emissions and carbon accumulation. The flooding of coastal marshes may alter carbon cycling, including fluxes of the greenhouse gases (GHGs), carbon dioxide (CO_2) and methane (CH_4). When studying CO_2 fluxes and plant zonation, it has been shown that reduced net carbon uptake can occur in zones of

the marsh where areas are flooded (Whiting and Chanton 2001; Moseman-Valtierra et al. 2016; Abdul-Aziz 2018). Inundation is generally considered a primary controller of methane emissions, with higher emissions in flooded areas (Bubier and Moore 1994; Mitsch et al. 2013; Zou et al. 2022). Further, we might expect that poorly drained conditions would promote methane emissions, as prolonged surface flooding has been consistently found to increase methane emissions when compared with intermittent flooding (Altor and Mitsch 2008; Ding et al. 2010; Mitsch 2017). However, with the varied ability of salt marsh plants, especially *Spartina alterniflora*, to oxygenate its rhizosphere, we might expect methane emissions to covary among plant species and among biomass levels (Bertness 1991).

The goal of this work is to assess how drainage affects coastal wetlands, as sea level rise and hydrologic modifications to tidal marshes are compounding to contribute to excessive root zone flooding. To address this goal, *Spartina alterniflora*, which is found on the U.S. Atlantic Coast, and *Salicornia pacifica*, found on the Pacific Coast, were propagated in mesocosms with simulated tides where the high tide level was held constant, but where soils experienced varied levels of drainage. In the present paper we sought to determine how soil flooding and drainage impact the growth and productivity of coastal wetland plants. We sought to determine if there are significant differences in biomass and photosynthetic uptake of carbon dioxide between the flooding treatments, and if specific abiotic factors, such as respiration rates, methane rates, porewater salinity, pH, sulfate, and/or ammonium are affected by soil flooding. Although many studies have focused on the impacts between flooding and plant growth among salt marsh plants, we took a different approach by manipulating the level of drainage plants are experiencing at low tide to better understand the role of ecohydrologic zonation in structuring plant growth.

2. METHODS

2.1 STUDY PLANTS

This experiment was conducted using two ecosystem-dominant salt marsh species *Spartina alterniflora* and *Salicornia pacifica*. *S. alterniflora* is commonly called smooth cordgrass and it is a facultative halophyte in the family Gramineae that dominates intertidal salt marshes on the Atlantic and Gulf Coast marshes (Wang 2006; Morris et al. 2002). It is a perennial grass species characterized by tall, smooth, hollow stems that bear leaves (Hessini 2009; McKee and Patrick 1988). *S. pacifica* is commonly known as pickleweed and is distributed across the Pacific Coast of North America (Noto and Shurin 2017). This species is a perennial low-growing succulent halophyte that grows as erect shrubs (Zedler 2012). Both species are salt-tolerant plants that can withstand flooding. These plants were chosen for this study so we could assess the ecosystem-dominant plant from the Atlantic Coast, *S. alterniflora*, and the ecosystem-dominant plant from Pacific Coast, *S. pacifica*.

2.2 EXPERIMENTAL DESIGN

Mesocosms were used to quantify the effects of the varying treatments on the coastal wetland plant growth and soil conditions. The mesocosm soil was prepared by combining 25% marsh soil that was collected from the Tuckerton Peninsula, New Jersey (39.5388°, -74.3254°), 25% multipurpose sand (Lowe's, Philadelphia, PA, USA), and 50% mushroom compost (Primex Garden Center, Glenside, PA, USA). Soils were screened at 2-mm to remove shell hash and coarse organic matter, homogenized with a cement mixer, and added to plant pots. The *S. alterniflora* plants were contained in pots that were made from cylindrical PVC pipes that were 20-cm long x 10-cm in diameter and were screened at the bottom to allow for water exchange.

The *S. pacifica* plants were contained in 20-cm long square (7.6 x 7.6-cm) treepots, also screened at the bottom. *S. alterniflora* was collected from the field bare roots in May (Payne et al. 2019), and 3-5 culms were added to each pot. *S. pacifica* was obtained in May as seedlings in 5.7 x 5.7 x 8.3-cm plant pots from Native West Nursery, San Diego, CA.

We conducted a 2 x 4 factorial experiment where two types of plants were exposed to four different drainage treatments, replicated 8 times, with a total of 64 experimental units (Fig. 1). Pots were placed in 150 L tidal mesocosms constructed from stock tanks and painted white with Plastic Drip multipurpose rubber coating to reduce water temperature artifacts (Fig. 1). Simulated tides were created using tubing to pump water between the experimental tank and a reservoir, using timers to create a once daily three-hour high tide (at which time the plant pots were all completely submerged), and 21-hour low tide. Inside four sperate tanks there were four drainage treatments: where the low tide water level was never drained (0-cm), and where the low tide water levels were drained to 5-cm, 10-cm, and 20-cm below the surface of the plant pot (Fig. 2). The tidal regime chosen for this study was a recreation of conditions on the Pacific Coast, where plants experience one high tide per day due to the mixed tidal regime. The plants were propagated outdoors receiving natural precipitation. Plants were propogated in freshwater for one week, transitioned to 10 ppt salinity for one week, and finally changed over to 20 ppt salinity for the remainder of the experiment. Saline conditions were created utilizing *Instant Ocean* (Spectrum Brands, Blacksburg, VA, USA). Plants were propagated for 12 weeks from 13 May 2021 to 3 August 2021.

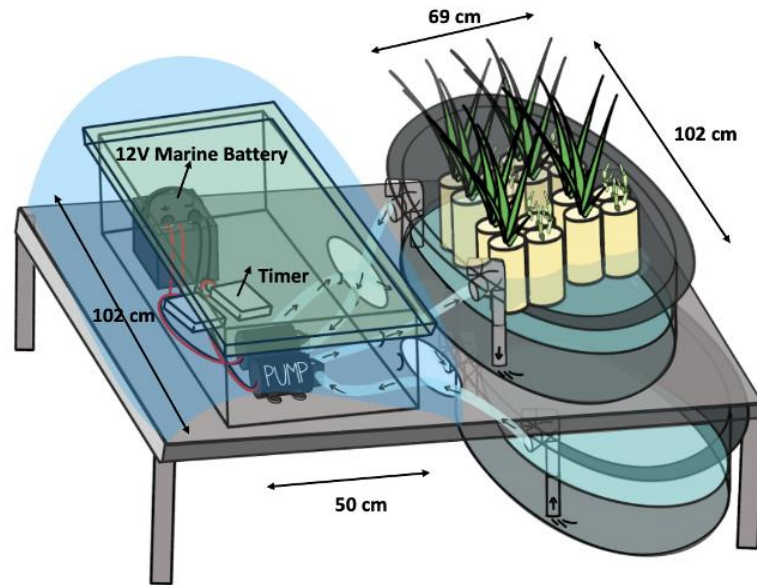


Figure 1. A diagram of the experimental setup. The image depicts the pots in the mesocosm, and how the water that is pumped in and out of the mesocosm is stored in the reservoir below the table. The pumping system was powered by a marine battery, and the timer controlled the high and low tides each day.

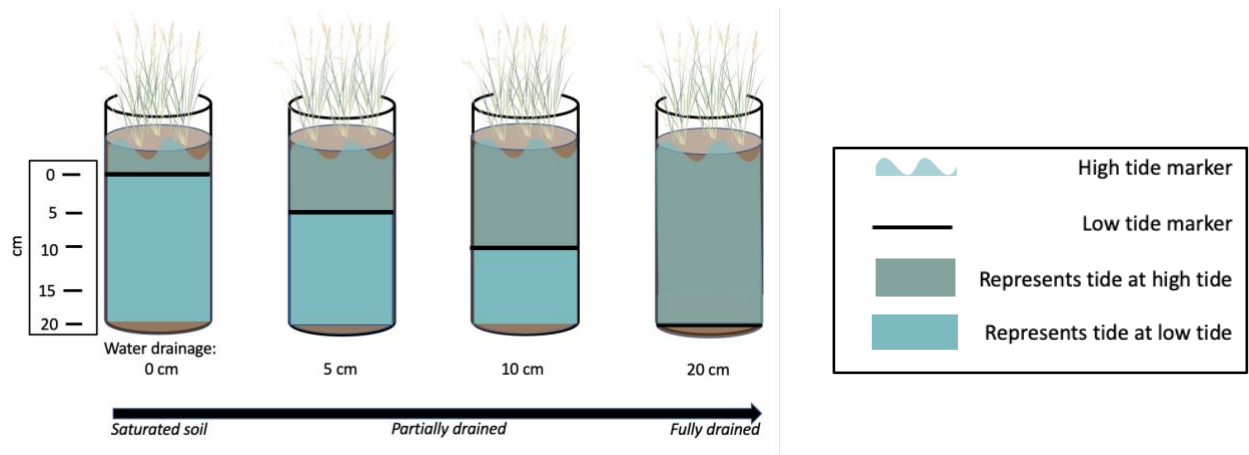


Figure 2. Experimental design depicting the four levels of drainage used in this plant growth experiment. Treatment 0-cm represents the treatment that was never drained. Treatments 5-cm, 10-cm, and 20-cm represent the treatments that were drained to depths of 5, 10, and 20 cm below the top of the plant pot for 21 hours daily during "low tide." The wavy line represents the water level at high tide, and the solid line represents the water level at low tide.

2.3 BIOMASS

To measure the productivity of the wetland species' *Spartina alterniflora* and *Salicornia pacifica*, the aboveground and belowground biomass of each treatment was measured.

Aboveground and belowground biomass was harvested at the end of week 12. Stalks growing from the soil were cut, plants were washed over a 2 mm sieve, dried at 60°C, and weighed.

Belowground biomass was separated from the soil by hand, rinsed over a sieve, dried at 60°C, and then weighed. Biomass values were scaled to a square meter through multiplication by a constant.

2.4 POREWATER SALINITY AND PH

Measurements on the abiotic effects of soil drainage included porewater salinity and pH. Porewater was collected with a push point sampler on 7 August 2021 (PPX36, MHE, East Tawas, MI, USA) at a depth of 20-cm. Samples for pH and salinity were frozen for later analysis. Samples were analyzed for salinity and pH using a calibrated YSI meter (Star A325 pH/Conductivity Portable Multiparameter Meter, Thermo Scientific Orion).

2.5 AMMONIUM, AND HYDROGEN SULFIDE

Measurements on the chemical effects of soil drainage included porewater ammonium and hydrogen sulfide. Porewater was collected with a push point sampler (PPX36, MHE, East Tawas, MI, USA) on 7 August 2021 at a depth of 20-cm. Samples for ammonium were frozen for later analysis. Subsamples (2 mL) were fixed with 0.22% zinc acetate solution, and frozen, for later analysis of hydrogen sulfide. UV-vis spectrophotometry was used for measurements of porewater ammonium using the indophenol blue method (Grasshoff et al. 1999) and hydrogen

sulfide measurements using the methylene blue method (Cline 1969). Sulfide samples were run alongside blanks, which were used to identify the detection limit. All samples below the detection limit were assigned a sulfide concentration of zero for the purposes of data analysis.

2.6 SOIL REDOX POTENTIAL

Redox potential measurements were taken at depths of 5-cm and 15-cm for the *Spartina alterniflora* soils, and depths of 3-cm and 9-cm for *Spartina pacifica* soils to reflect the size of the pots using a YSI meter (Bench-Top pH/mV Meter, Sper Scientific).

2.7 CARBON DIOXIDE AND METHANE EXCHANGE

Carbon dioxide and methane fluxes were measured to calculate the photosynthesis, respiration, and net ecosystem exchange (NEE) rates of the plants. The fluxes were measured in the field on 7 August 2021 from 10 a.m. to 4 p.m. (Eastern Standard Time), using an LGR ultra-portable greenhouse gas analyzer via cavity ring-down spectroscopy (ABB-Los Gatos Research, San Jose, CA, USA). We staggered the measures so that variations in photosynthesis and respiration rates throughout the day would be captured (i.e., we measured pots in the order 0-5-10-20, rather than for instance measuring all the 0 pots, then all the 5 pots, etc). Plant pots were encapsulated in a chamber (clear for NEE or opaque for respiration), and the change in concentration of gases in the head space of the chamber was measured using the LGR analyzer. Carbon dioxide and methane flux measurements were repeated in both light and dark conditions to obtain the rates of NEE, photosynthesis, and respiration using a static chamber (Moseman-Valtierra et al. 2016). Gas fluxes were calculated from linear rates of change in gas concentrations in each chamber over time using the ideal gas law, the field measured air temperature and atmospheric pressure (Abdul-Aziz et al. 2018). Positive fluxes were defined as

those in which gas concentrations increased over time within the chamber, and negative fluxes as those in which concentrations decreased (Nakano et al. 2004).

Photosynthesis rates were obtained by measuring the carbon dioxide concentration as a function of time in the light and dark conditions, and then subtracting the dark measurement from the light measurement. Respiration rates were obtained by measuring the carbon dioxide concentration as a function of time in the dark conditions. Finally, net ecosystem exchange is a measurement of both photosynthesis and respiration combined, and it was measured through the light measurements (Waring and Running 2007).

2.8 STATISTICAL TESTS AND DATA VISUALIZATION

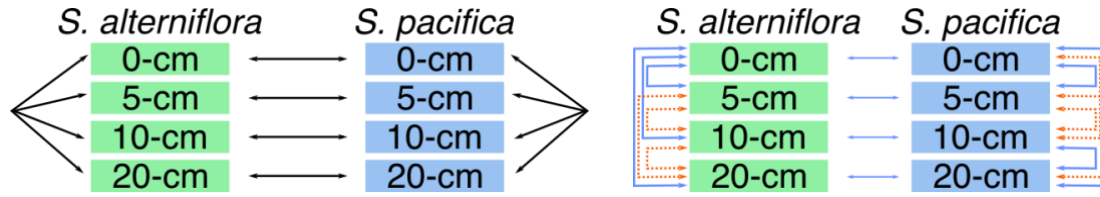
All statistical analyses were performed in R 4.2.3 (R Core Team 2023). Bar graphs and scatter plots were made using the package ggplot2 (v. 3.4.2; Wickham 2005). The graphs are grouped by treatment according to each species and are presented in the order 0-cm, 5-cm, 10-cm, and 20-cm based on the drainage treatment level. Error bars represent the standard error of the mean.

The responses of the study plants *Spartina* and *Salicornia* to drainage were analyzed using permutational multivariate ANOVA (perMANOVAs; Anderson 2001), utilizing the R package vegan (v. 2.6-4; Oksanen 2022). The dependent variables included above and belowground biomass, porewater pH, salinity, ammonium concentration, sulfide concentration, soil redox potential, NEE, photosynthesis rate, respiration rate, and methane flux. We partitioned the variability and obtained F-statistics on matrices of Euclidean distances calculated from the original raw data. *P*-values were calculated using 10,000 random permutations of the appropriate exchangeable units. Where variables were missing, the means of a treatment group factor were

added to the matrix. Redox was rank transformed prior to analysis to remove negative values.

Because the interaction term was significant, we conducted contrast tests using the same function (adonis2) (Fig. 3), with a Bonferroni correction applied for the number of contrasts ($0.05/16 = 0.0031$).

Figure 3. A pictorial version of the perMANOVA post-hoc contrast tests, at left and their results at right. Solid blue lines reflect statistically significant differences at the $p < 0.0031$ level (to account for the 16 contrast tests). Dotted orange lines are non-significant differences.



Because the results of the contrasts did not reveal strong groupings, we conducted follow-up two-way ANOVAs to identify the factors contributing to significant differences between the species and drainage levels. ANOVAs were performed on rank transformed data to account for the non-normal error structure. ANOVAs were run in base R using the aov command. Follow up least-square means comparisons tests were completed on main effects and interactions, where appropriate using package lsmeans using the tukey or sidak methods for p value adjustments as appropriate (v. 2.30-0; Lenth 2018).

A principal component analysis (PCA) was used for dimension reduction to examine variability between treatments and plant species, as well as to determine species and treatment grouping patterns with respect to the dependent variables. The component matrix was created through the correlations of the item with each component. The packages used for the PCA include cor (v, 0.4.4; Kuhn et al. 2021), ggcorrplot (v.0.1.4; Kassambara 2022), factoextra (v1.0.7; Kassambara 2020). To perform the PCA, the data was first normalized, a correlation matrix was computed

and visualized. Visualization of the PCA was constructed as a biplot of the first vs. second principal components. A Kaiser-Meyer-Olkin (KMO) test was used to determine how suited the data is for factor analysis, utilizing the EFAtools package (v. 0.4.4; Steiner et al. 2023). A Bartlett's test of sphericity was used to test for significant correlations among at least some of the variables, utilizing the psych package (v. 2.3.3; Revelle 2023).

As many of the measured variables varied in response to the drainage treatments in a multi-dimensional way, we constructed loess curves (span=0.40) to describe the relationship between treatment and the response variables of above and belowground biomass, porewater salinity, porewater pH, porewater ammonium and sulfide concentration, NEE, and redox potential. A loess curve is a nonparametric method for smoothing a series of data and was used because of the non-linear structure of the relationship between drainage and response variables. The wetland ecology literature was used to generate hypotheses about the relationship between drainage and response variables, and these curves were used to compare differences between hypothesized and observed relationships.

3. RESULTS

A two-way perMANOVA revealed a significant effect of drainage, species, and a significant interaction between drainage and species on the multivariate dataset considering all the response variables (biomass, porewater pH, ammonium, salinity, and sulfide concentration, soil redox, and rates of photosynthesis, respiration, net ecosystem exchange, and methane efflux) (Fig. 4). Post-hoc contrast tests (Fig. 3; Supplemental Material) revealed that there were significant differences for *S. alterniflora* between the 0 and 5-cm treatments, between the 0 and 10-cm treatments, and between the 0 and 20-cm treatments. For *S. pacifica*, there were

significant differences between the 0 and 5-cm treatment, significant differences between the 10-cm and 20-cm treatments, and significant differences between the 0 and 20-cm treatment. There were significant differences between *S. alterniflora* and *S. pacifica*, for all four drainage treatments.

Table 1. Results of the perMANOVA test

	Sum of squares	df	r^2	F	p
species	58594	1	0.24791	35.223	<1e-06 ***
drainage	61818	3	0.26155	12.387	<1e-06 ***
species x drainage	22787	3	0.09641	4.566	<1e-06 ***
residual	93156	56	0.39414		
total	236354	63	1.00000		

For aboveground biomass, the two-way ANOVA indicated that there were no significant differences between the four drainage treatment levels; however, there was a significant difference in plant production values between the two species. *S. alterniflora* produced more above ($F= 26.321$ $p= 3.75e-06$; table 3) and belowground plant biomass than *S. pacifica* ($F= 236.014$; $p=< 2e-16$; table 2). Considering belowground biomass, there was a significant interaction between species and drainage, such that for *S. pacifica* there were no significant difference between drainage treatments, but for *S. alterniflora* the 0-cm drainage treatment had significantly less biomass than the 5-cm and 20-cm treatments ($t=-3.500$, $p= 0.0193$; $t=-3.440$ $p=0.00229$; table S5).

Table 2. Summary of two-way ANOVA for effects of drainage treatment and species. The tests were performed to identify drivers of the significant differences found between treatments and species, and the tests were conducted on rank transformed data to remedy non-normal error structures.

	<u>Species</u>		<u>Drainage</u>		<u>Species x drainage</u>	
	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>	<i>F</i>	<i>p</i>
Productivity						
aboveground biomass	26.321	3.75e-06 ***	1.743	0.169	1.519	0.220
belowground biomass	238.716	< 2e-16 ***	2.545	0.06521	5.274	0.00283 **
photosynthetic uptake	64.32	7.16e-11 ***	15.82	1.44e-07***	14.44	4.38e-07***
respiration	0.009	0.9253	19.504	8.8e-09***	3.029	0.0368 *
net ecosystem exchange	66.00	4.84e-11 ***	27.397	4.90e-11***	6.872	0.000506***
Porewater						
salinity	0.656	0.421	10.897	9.68e-06 ***	1.823	0.153
pH	0.582	0.4486	5.737	0.0017 **	3.011	0.0376 *
ammonium	14.23	0.000393 ***	28.212	3.01e-11***	9.949	2.35e-05***
Redox sensitive factors						
methane emissions	67.15	3.70e-11 ***	24.840	2.38e-10***	9.412	3.93e-05***
sulfide concentration	0.021	0.88641	13.660	8.45e-07***	4.384	0.00768**
soil redox	132.94	<2e-16 ***	2.530	0.0664	1.367	0.2622

significance codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Follow-up ANOVA tests on the rank transformed data revealed significant interactions between species and drainage treatment for seven of the additional nine variables, including: photosynthetic uptake, respiration, net ecosystem exchange, pH, ammonium concentration, methane emissions, and sulfide concentrations. For these variables, we do not interpret the main effects, as they can be misleading, but present the results of contrast tests. Two variables did not have significant interactions between species and drainage treatments: salinity and soil redox. Salinity lacked any significant interaction with plant species. Salinity was only affected by the drainage treatment, such that salinity for the 0-cm treatment was lower than the 10-cm and 20-cm treatments (table S9). Redox was affected by only plant species, such that soil redox was lower from *S. pacifica* than for *S. alterniflora* (table S14).

Considering variables reflecting productivity, including photosynthesis, respiration, and net ecosystem exchange, we found a few differences between species, and within each plant species, we found differences by drainage level (Supplemental Material). We did not formally compare pairs that differed by both species and drainage level. Photosynthetic uptake of carbon dioxide was found to be greater for *S. alterniflora* than *S. pacifica* at the 10-cm ($t=9.029$; $p<0.0001$; table S6) and 20-cm drainage treatments ($t=4.773$; $p=0.0003$; table S6). There were no differences in respiration between species. Net ecosystem exchange was greater in *S. pacifica* than for *S. alterniflora* ($t=4.824$; $p=0.0003$; table S8) at the 5-cm drainage treatment. For *S. alterniflora*, there was greater photosynthetic uptake of CO₂ at the 5-cm treatment than the 0-cm ($t=3.912$; $p=0.0057$; S6) or 10-cm treatment ($t=5.525$; $p<0.0001$; table S6), and greater photosynthetic uptake of CO₂ at the 10-cm than 20-cm treatment ($t=-3.223$; $p=0.0412$; table S6). For *S. pacifica*, there was greater photosynthetic uptake of CO₂ at 5-cm than 0-cm ($t=5.216$; $p=0.0001$; table S6). Considering respiration, there were lower respiration rates for *S. alterniflora* at the 5-cm drainage treatment than the 10-cm ($t= 3.445$; $p=0.0226$; table S7), and 20-cm drainage treatments ($t= 5.045$; $p=0.0001$; table S7). For *S. pacifica* there was greater respiration at the 20-cm drainage treatment than the 0-cm ($t= 4.480$; $p=0.0009$; table S7), 5-cm ($t= 5.572$; $p<0.0001$; table S7), or 10-cm treatments ($t= 5.365$; $p<0.0001$; table S7). Considering NEE for *S. alterniflora*, there were more positive values for NEE for the 0-cm treatment than the 10-cm ($t=7.438$; $p<0.0001$; table S8) or 20-cm ($t= 4.747$; $p=0.0004$; table S8) drainage treatments. Also, there were more positive values for NEE for the 5-cm treatment than the 20-cm drainage treatment ($t= 3.935$; $p=0.0053$; table S8). For *S. pacifica*, there more negative values of NEE for the 20-cm treatment than for the 0-cm ($t=5.611$; $p<0.0001$; table S8), 5-cm ($t= 6.575$; $p<0.0001$; table S8), or 10-cm ($t= 6.499$; $p<0.0001$; table S8) drainage treatment.

Two porewater variables - pH and ammonium concentration - had significant interactions between species and drainage treatment. For *S. alterniflora*, porewater pH was significantly lower in the 0-cm treatment than the 20-cm treatment ($t=3.939$, $p=0.0053$; table S10), and this was the only significant difference found for pH. For porewater ammonium, concentrations were higher for *S. pacifica* than *S. alterniflora*, but only for the 5-cm ($t=3.703$; $p=0.0108$; table S11) and 10-cm ($t=4.703$; $p=0.0004$; table S11) drainage treatments. Considering *S. alterniflora*, porewater ammonium concentrations were higher in the 0-cm treatment than the 5-cm ($t=7.555$; $p<0.0001$; table S11) and 10-cm treatments ($t=5.290$; $p=0.0001$; table S11). Also, ammonium concentrations were higher in the 20-cm treatment than the 5-cm ($t=6.279$; $p<0.0001$) and 10-cm treatments ($t=4.013$; $p=0.0042$; table S11). For *S. pacifica*, porewater ammonium was higher in the 0-cm treatment than the 5-cm ($t=5.405$; $p<0.0001$; table S11) or 20-cm ($t=5.244$; $p=0.0001$; table S11) treatments. Also, porewater ammonium was higher in the 10-cm treatment than the 5-cm treatment ($t=3.266$; $p=0.0368$; table S11).

Overall soil redox varied by plant species, more oxygenated conditions associated with *S. alterniflora*. Considering other variables reflecting redox, including methane emissions, and porewater sulfide levels, we found a few differences between species for methane, and within each plant species, we found differences by drainage level (Supplemental Material). Methane emissions were greater for *S. pacifica* than *S. alterniflora* at the 0-cm ($t=7.826$; $p<0.0001$) and 5-cm ($t=5.370$; $p<0.0001$) drainage treatments. There were no differences in porewater sulfide levels by drainage treatment. For *S. alterniflora*, there were greater methane emissions at the 10-cm treatment than the 0-cm ($t=6.362$; $p<0.0001$; table S12), 5-cm ($t=7.304$; $p<0.0001$; table S12), or 20-cm treatments ($t=4.606$; $p=0.0006$; table S12). For *S. pacifica*, there were greater methane emissions for the 0-cm treatment than the 5-cm ($t=3.398$, $p=0.0258$; table S12), or 20-

cm ($t=4.797$, $p=0.0003$; table S12) treatments. There were also greater methane emissions at the 10-cm treatment than the 5-cm ($t=3.856$; $p=0.0068$; table S12) or 20-cm treatments ($t=5.255$; $p=0.0001$; table S12). For *S. alterniflora*, there were higher sulfide concentrations at the 0-cm treatment than the 20-cm treatment ($t=4.420$, $p=0.0011$; table S13). For *S. pacifica*, there were higher porewater sulfide concentrations at the 0-cm treatment than for the 5-cm ($t=3.807$; $p=0.0079$; table S13), 10-cm ($t=5.711$, $p < 0.0001$; table S13), or 20-cm ($t=3.693$; $p=0.0111$; table S13) treatments.

The correlation matrix revealed some clustering in redox sensitive soil and porewater characteristics (Fig. 5). Methane fluxes were negatively correlated with soil redox measures, i.e., high methane fluxes were under reducing conditions ($r = -0.57$), and there was a modest positive correlation between methane fluxes and porewater sulfide ($r = 0.24$). There was a negative relationship between sulfide level and soil redox ($r = -0.29$).

In contrast, there is evidence that plant productivity played an important role in mediating soil properties. Redox potential is strongly different between the two species, and there was a strong positive relationship observed between belowground biomass and soil redox i.e., more plant growth was associated with more oxygenated soil conditions ($r = 0.62$), and belowground biomass was also negatively correlated with photosynthesis rate ($r = -0.52$), and NEE ($r = -0.63$; i.e., lower levels of belowground biomass were associated with greater photosynthesis rates and NEE). Also, there was a modest negative correlation between belowground biomass and methane fluxes ($r = -0.35$). Aboveground biomass exhibited similar negative correlations between photosynthesis rate ($r = -0.47$), and NEE ($r = -0.38$).

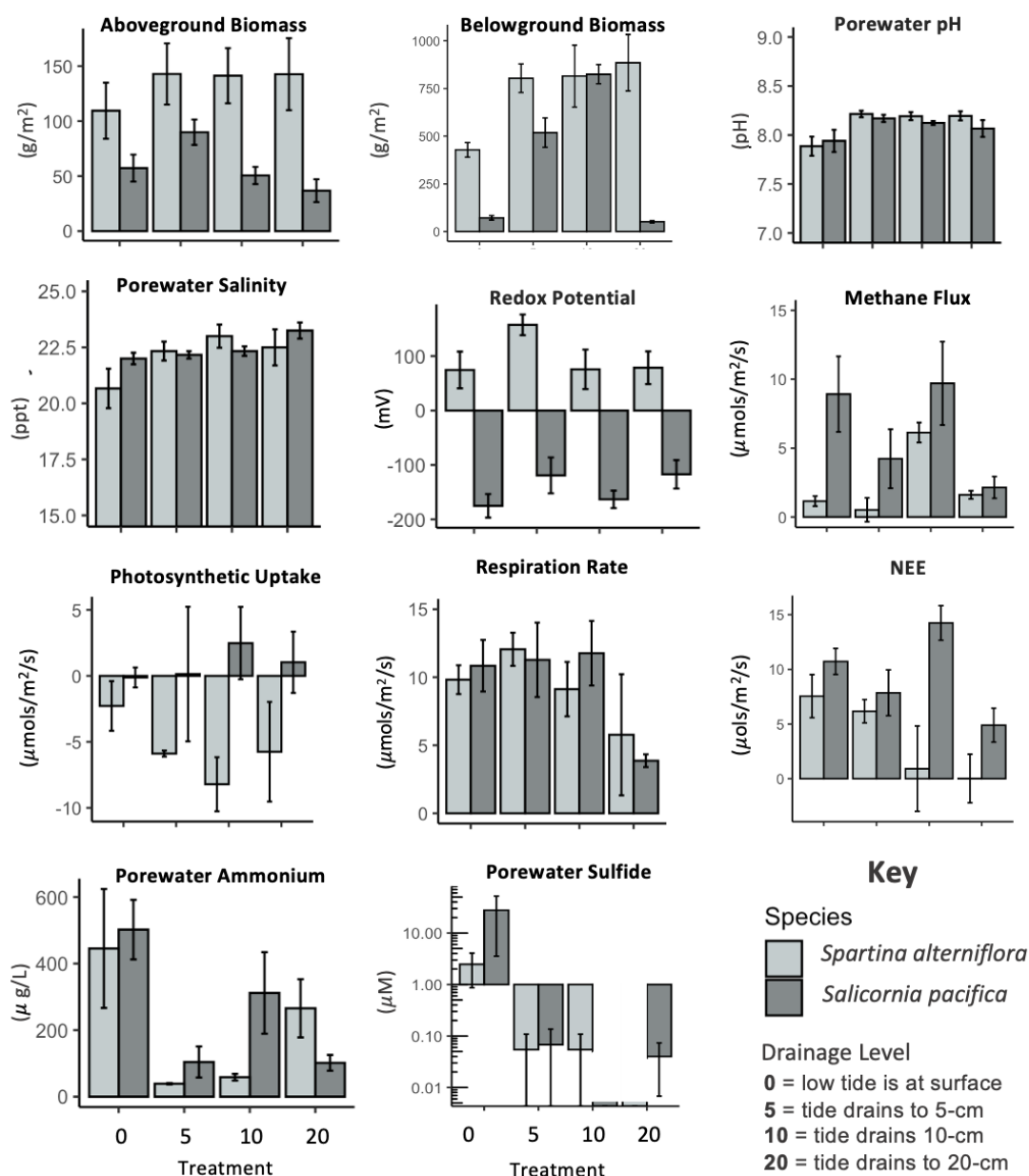


Figure 4. The effects of the drainage levels on the biotic and abiotic factors. (A) Aboveground biomass measured in g/m² (B) belowground biomass measured in g/m² (C) porewater pH (D) porewater salinity measured in ppt (E) soil redox measured in mV (F) methane flux measured in μmols/m²/s (G) rate of photosynthetic uptake of carbon dioxide measured in μmols/m²/s (H) rate of the release of carbon dioxide through respiration measured in μmols/m²/s (I) net ecosystem exchange as a measurement of total exchanged carbon dioxide measured in μmols/m²/s (J) porewater ammonium concentration measured in g/L and (K) porewater sulfide concentration measured in μM.

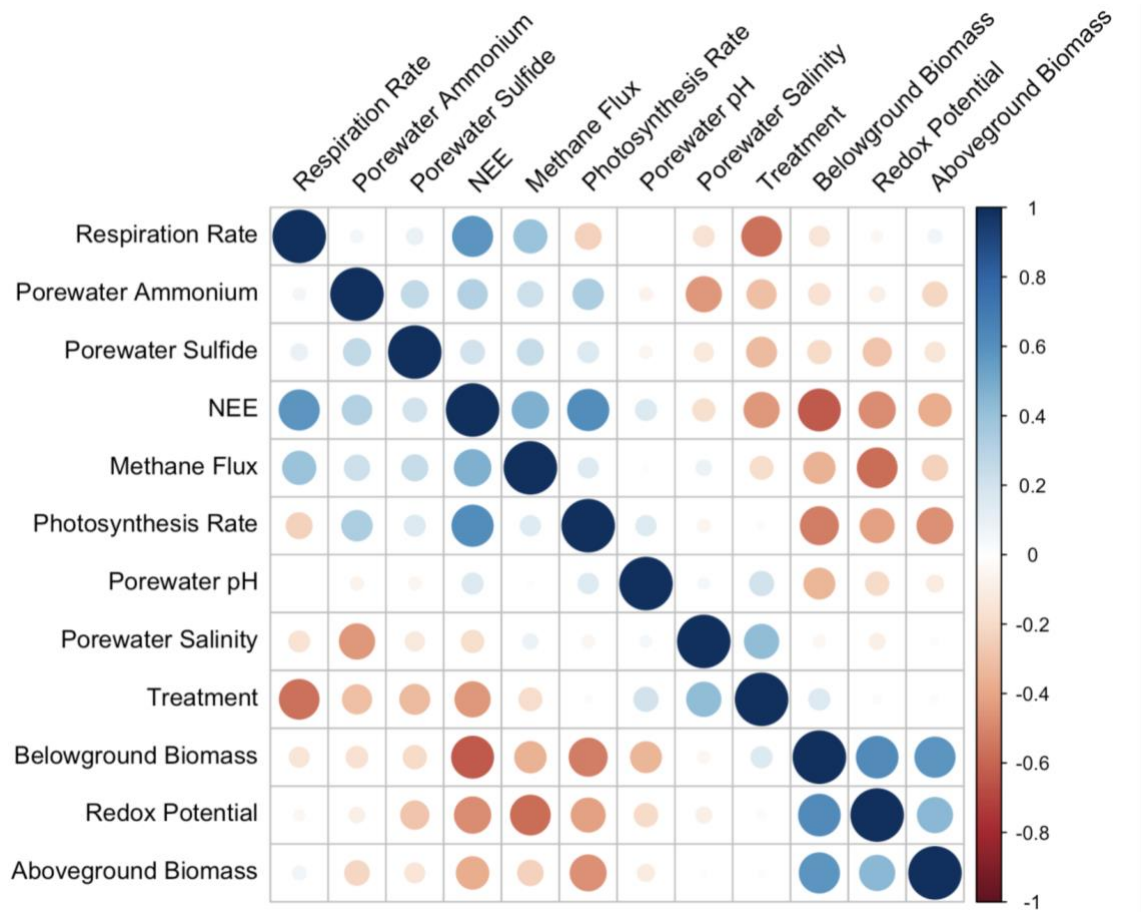


Figure 5. Correlation matrix of all abiotic and biotic variables considered in our analysis. The variables included in this correlation matrix were belowground biomass, photosynthesis rate, methane flux, NEE, porewater sulfide, respiration rate, porewater ammonium, aboveground biomass, redox potential, porewater pH, treatment group, and porewater salinity, and drainage level. The matrix depicts the correlation between all the possible pairs of factors. The key indicates that the closer the correlation value is to 1 or red, the more positively correlated the two variables are, and the closer the value is to -1 or blue, the more negatively correlated the variables are.

There were relationships between some porewater characteristics and various drivers.

There was a slight negative relationship between porewater pH and redox ($r = -0.20$), and a minimal positive relationship between pH and NEE ($r = 0.16$). There were few other modest positive relationships between other variables such as ammonium concentration and photosynthesis rate ($r = 0.33$).

The output of the PCA indicated that the first principal component explained 34% of the total variance, implying that more than 25% of the data in the set of 13 variables can be represented by the first principal component. The loading from the PCA output indicates that the first principal component had higher correlation between variables associated with biomass measures such as NEE, photosynthesis rate, methane flux, and redox potential. The second principal component, which explained 14% percent of the data, had higher correlations values between variables more associated with drainage such as respiration rate, porewater salinity, porewater ammonium porewater pH. The four-dimension solution explained 74% of the total variance. The overall Kaiser-Meyer-Olkin (KMO) measure was 0.576 with 10 out of the 12-factor individual KMO measures greater than 0.5, classifications of 'middling' to 'meritorious' according to Kaiser (1974). Bartlett's test of sphericity was statistically significant ($p < 0.0001$), indicating that the data was factorizable. The biplot of the PCA indicates that the treatment that there is some significant clustering by both species and drainage and reflected in the outputs of the perMANOVA and ANOVA tests.

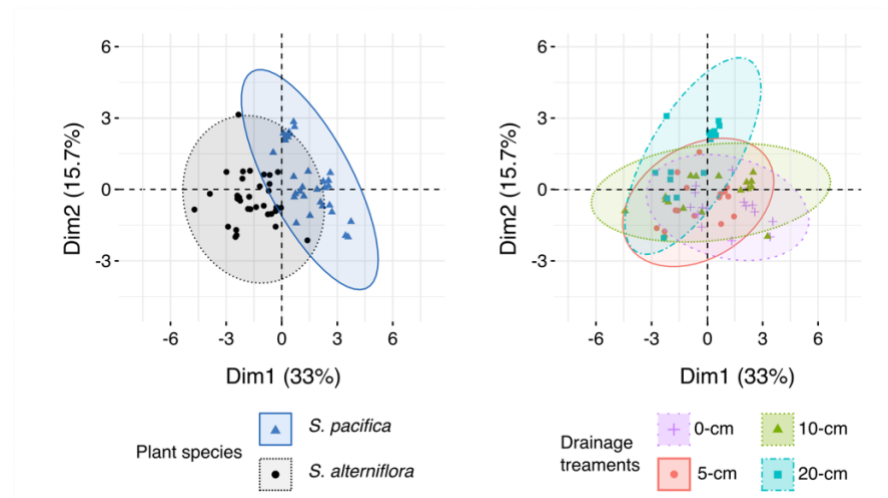


Figure 6. Biplot of dimension 1 verses dimension 2 of a principal components analysis conducted on measured response variables. These included above and belowground biomass, pH, salinity, ammonium concentration, sulfide concentration, redox potential, NEE, photosynthesis

rate, respiration rate, and methane flux. The clustering by species is shown at left and by drainage treatment at right.

4. DISCUSSION

In this paper we showed that coastal salt marshes can be influenced by the level of soil drainage and that species type was a primary indicator of the major impacts. The measurements of above and belowground biomass, porewater pH, ammonium, and sulfide, as well as the gas fluxes which included photosynthesis, respiration, and methane flux, were all significantly impacted by the level of drainage and the species type. This finding indicates that both the drainage level of the soil and the species type are interacting to produce the alterations that we observed in the biotic and abiotic factors in this study. Overall, the treatments with the intermediate amount of drainage (treatments 5-cm and 10-cm) had the highest plant productivity for both *S. alterniflora* and *S. pacifica* (Fig. 3). Both aboveground and belowground biomass displayed results that were consistent with our hypotheses, displaying a parabolic curve (Fig. 6). It is possible that the growth of the plants increased due to less drainage in treatment 5-cm, but as soil drainage decreased past 5-cm, there were negative impacts on productivity. We found a loosely parabolic relationship between plant growth as a function of drainage, similar to that reported by Kirwan and Guntenspergen (2012).

This study could support the view that there is an optimal soil flooding level for coastal wetland productivity, as indicated by the plant productivity in the varying drainage levels (Fig. 7). An observation made pertaining to marsh inundation and coastal wetland loss is that the productivity of coastal wetlands often declines beyond a specific threshold of hydrologic stress (Stagg et al. 2019). In our study, the hydraulic stress is represented by soil saturation due to lack

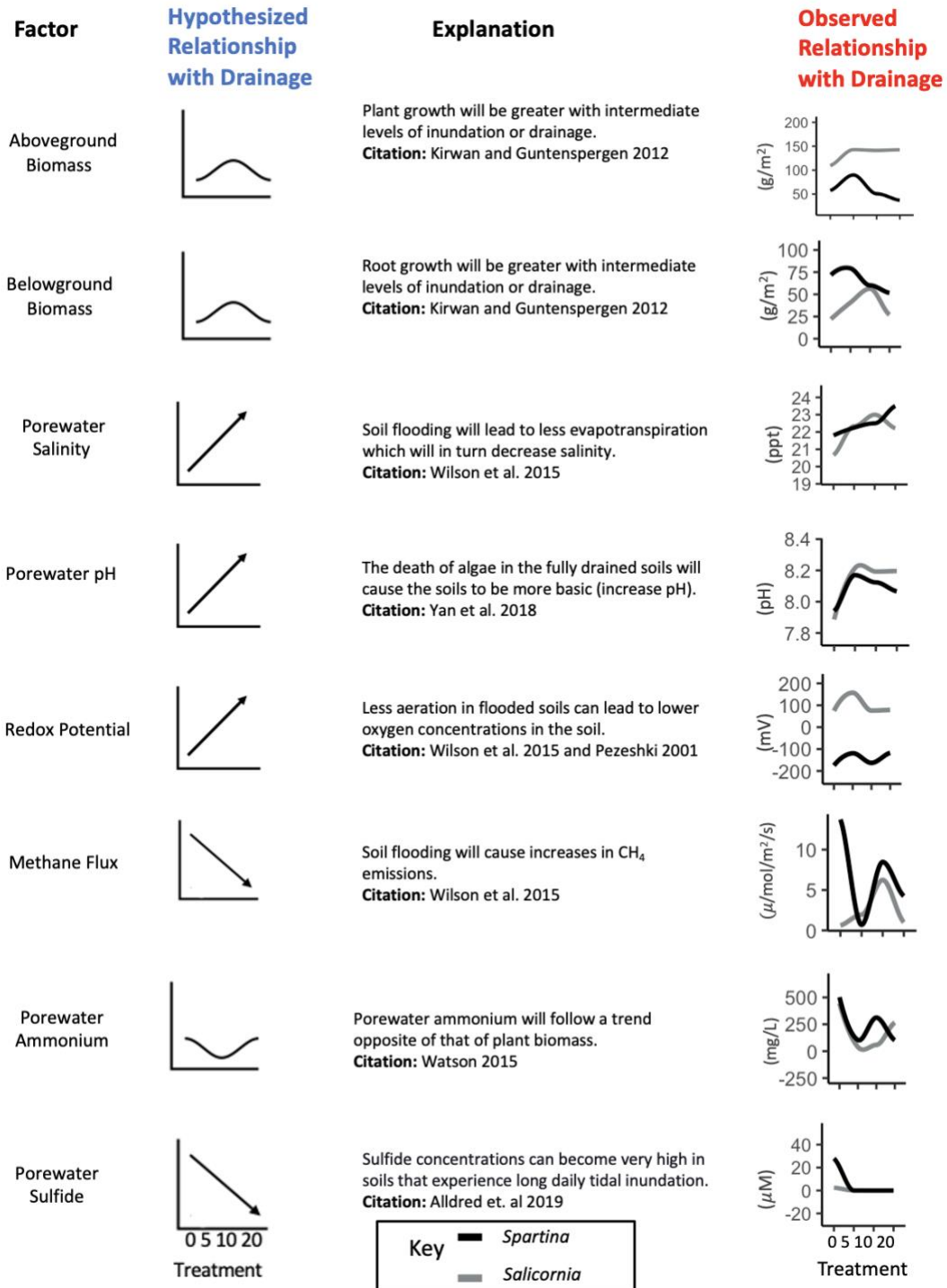


Figure 7. The hypothesized and observed relationships between drainage impacts on the factors. An explanation of how soil drainage may alter such abiotic factors, as well as references to peer-reviewed publications that have studied a particular factor associated with wetland flooding was also included. The observed relationships are in a plot with loess curves to visualize the trends of the results.

of drainage, and the threshold of hydraulic stress could be demonstrated as the decline in plant biomass that occurred from treatment 5-cm to 0-cm. Our results indicate that a threshold is present when soil drainage decreases past 5-cm (Fig. 4). Furthermore, our study plants were likely limited by hypoxia as drainage decreased (Morris et al. 2002 and Zhu et al. 2019), which could indicate that there is an optimum marsh elevation for coastal wetland productivity as seen in other studies (McKee and Patrick 1988; Morris et. al. 2002).

This study revealed that some main differences between *S. alterniflora*, the U.S. Atlantic Coast dominant species, and *S. pacifica*, the U.S. Pacific Coast dominant species include plant growth rate differences (Class 1997). *S. alterniflora* grew more than *S. pacifica* under our experimental conditions. This result relates back to the plant species' ecological zonation. *S. alterniflora* dominates the low marsh which is inundated more often and thus, could be better equipped to handle the increased inundation (Stagg et al. 2019). Moreover, *S. alterniflora* exhibited belowground biomass results closer to what we hypothesized to see. A study that looked at feedbacks between inundation and root production proved that root growth was highest at a distinct optimum elevation. It is likely that the conditions in our study were closer to the optimum elevation of *S. alterniflora* (Kirwan and Guntenspergen 2012). However, the high temperatures most likely impacted the growth of both species, especially *S. pacifica*, as the study took place in the Mid-Atlantic, far away from the source area of the plants which was from New Hampshire for *S. alterniflora* and San Diego for *S. pacifica*.

Generally, we saw the lowest porewater salinity values in the most inundated treatment and the highest porewater salinity values in the most drained treatment, with minimal differences between the plant species (Fig. 6). This result has also been reported for other salt marsh plant mesocosms (Wigand et al., 2016). Various explanations may account for these patterns. Salt can

accumulate due to evapotranspiration to levels that are significantly stressful to salt marsh plants (Shen et al., 2018), and salinity concentration through evaporation likely plays a role in the concentration of salinity in the treatments that were better drained. In the field, salt marsh soil salinities are related to tidal flooding, evapotranspiration, and soil hydraulic conductivity. Most studies of northeastern U.S. salt marshes have described patterns of higher salinity at low elevations and adjacent to marsh shorelines (Moore et al. 2011; McKinney et al. 2019), suggesting that tidal flooding, as a vector for salt, plays the most important role in shaping salinity patterns. However, in the southeast U.S., a simulation of salt dynamics suggests that salt often concentrates just above the high tide line (Shen et al. 2018), where salinities accumulate, creating salt marsh pannes. At this position, the soils are not flooded regularly, therefore not flushed from the system, but rather concentrated through evapotranspiration. Above the high tide mark, soils are not as regularly flooded, and rainfall contributes to flushing salts (Shen et al., 2018). The salinities in our mesocosms raise the question of whether salt is less likely to concentrate in soils that are continuously flooded, as are found on the upper marsh platform (e.g., Montalto et al., 2016) and also likely experience lower rates of evapotranspiration due to stressed plants.

Both pH levels and redox have also been shown to decrease during prolonged flooding (Pezeshki 2001). Poorly drained soils associated with flooding can lead to less aerated soils (Xin et al 2010), and a lower redox potential (Wilson et al 2015). The pH in mesocosms may be related to productivity patterns, where low pH reflects increased respiration (high CO₂ production), and high pH reflects CO₂ consumption. Here, we found the highest pH levels in intermediate treatments with lower pH found in the stagnant pots (0 cm), and somewhat lower

pH found also in the best drained plant pots (20cm), which may be reflect patterns of root respiration or water column productivity in the tanks.

We found differences between species and differences between drainage level for measurements of photosynthesis, respiration, and net ecosystem exchange under varying drainage levels (table 3). This observation indicates that the patterns of greenhouse gas exchange in our study reflects both environmental conditions and plant growth patterns. The treatment that was fully saturated at all times, treatment 0-cm, exhibited reductions in photosynthetic uptake and respiration which in turn contributed to the reductions in plant biomass. Differences in the elevation of the marsh has been shown to have an influence on photosynthesis and respiration rates of salt marshes (Watson 2015; Wigand 2009), this phenomenon can be related to our study in the way of soil saturation. The treatments that did not receive any degree of drainage and were saturated always did not have the opportunity to become oxygenated enough (Gleason 1981) and could not complete its ideal photosynthesis and respiration performance due to root oxygen-deficiency (Pezeshki 2001).

Methane emissions were greater from *S. pacifica* than *S. alterniflora*, and redox was much more negative in *S. pacifica*, which highlights the important ability of *S. alterniflora* to oxygenate its rhizosphere (DeLaune 1983) and mitigate methane emissions (Yang et al. 2020). We also found higher methane emissions from our experimental pots than generally found from salt marsh soils (Bartlett et al. 1985), which may be related to the soil composition. Although we expected high methane emissions from the more stagnant treatments (0-cm), we did not observe this pattern, although the stagnant treatment was associated with elevated sulfide levels. Together, these factors suggest the ability of the marsh plants to oxygenate their rhizosphere is perhaps more significant than inundation patterns in methane emissions. Our

experiment would have been stronger in this regard if we had maintained and sampled mesocosms pots lacking plants.

Although our results set a baseline of what future experiments might detect, our lack of 'control,' or unvegetated pots, our attempt to grow a perennial plant (*S. pacifica*) from essentially the seedling size in just a few weeks, the source area of our plants being from far outside (San Diego, CA and the Great Bay, NH) the environmental conditions where they were propagated (Philadelphia, PA), and the moderate environmental salinities we tested, does leave open the possibility that future studies might better refine the impacts of soil drainage on salt marsh plant growth and ecosystem function. Successful aspects of our experiment include the propagation of plants outdoors which limited the impacts of the summer high temperatures often found in greenhouses, and the strong comparison between two very different plant species which allowed for a better understanding of the interaction between environmental conditions and plant functional traits.

Understanding the importance of soil drainage in promoting wetland resilience to sea-level rise is essential in making predictions about the future of coastal wetlands (Cahoon 2020; Guimond et al. 2021). Furthermore, hydrologic alterations can be conducted to manipulate soil flooding. This could include the installation of tidal channels to promote surface and subsurface drainage (Besterman et al. 2022; Watson et al. 2022), which is a climate change adaptation strategy that has been implemented across the northeastern U.S. (Wigand et al. 2017; Weiss et al. 2021). In relation to tidal channel installation, our study suggests that enhancing drainage only modestly may enhance the ability of plants to survive, as we found that growth was enhanced at intermediate and not fully drained conditions. Alternatively, some scientists have advocated for tidal restrictions to promote the survival of tidal wetlands (Sadat-Noori et al. 2021). This method

recreates past tidal regimes using tide gates ("Smart Gates") and has been successfully demonstrated as a method to protect wetlands from submergence. With respect to such an adaptation strategy, our study suggests that reducing the low tide elevation may have important consequences for plant growth and marsh function. In addition to changes in hydrology, marsh sediment additions also alter drainage through altered hydraulic conductivity (Wilburn et al., submitted). Thus, the study of soil drainage is important in the context of coastal climate adaptation.

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7. APPENDIX

SUPPLEMENTAL MATERIAL

Table S1. Results of perMANOVA pairwise post-hoc tests for *S. alterniflora*. Pairwise comparisons for *S. alterniflora*. All *p* values less than 0.0031 are highlighted.

Treatment	0-cm	5-cm	10-cm	20-cm
0-cm	–	$F=11.986$ $p=2e-04$	$F=6.3216$ $p=2e-04$	$F=4.9211$ $p=0.0035$
5-cm	$F=11.986$ $p=2e-04$	–	$F=0.2305$ $p=0.7812$	$F=1.7735$ $p=0.1778$
10-cm	$F=6.3216$ $p=2e-04$	$F=0.2305$ $p=0.7812$	–	$F=0.8316$ $p=0.3907$
20-cm	$F=4.9211$ $p=0.0035$	$F=1.7735$ $p=0.1778$	$F=0.8316$ $p=0.3907$	–

Table S2. Results of perMANOVA pairwise post-hoc tests for *S. pacifica*. Pairwise comparisons for *S. pacifica*. All *p* values less than 0.0031 are highlighted.

Treatment	0-cm	5-cm	10-cm	20-cm
0-cm	–	$F=33.212$ $p=6e-04$	$F=4.6637$ $p=0.0227$	$F=37.783$ $p=2e-04$
5-cm	$F=33.212$ $p=6e-04$	–	$F=6.658$ $p=0.0045$	$F=1.4586$ $p=0.2397$
10-cm	$F=4.6637$ $p=0.0227$	$F=6.658$ $p=0.0045$	–	$F=7.1548$ $p=0.0029$
20-cm	$F=37.783$ $p=2e-04$	$F=1.4586$ $p=0.2397$	$F=7.1548$ $p=0.0029$	–

Table S3. Results of perMANOVA pairwise post-hoc tests. Pairwise comparisons between *S. pacifica* and *S. alterniflora*, only considering the same drainage treatments. All *p* values less than 0.0031 are highlighted.

Comparison		
0-cm	<i>S. alterniflora</i> - <i>S. pacifica</i>	$F=8.6081$ $p=2e-04$
5-cm	<i>S. alterniflora</i> - <i>S. pacifica</i>	$F=74.457$ $p=4e-04$
10-cm	<i>S. alterniflora</i> - <i>S. pacifica</i>	$F=20.499$ $p=4e-04$
20-cm	<i>S. alterniflora</i> - <i>S. pacifica</i>	$F=25.133$ $p=2e-04$

Post-hoc contrast tests for the significant main or interactions identified by two-way ANOVAs

Table S4. Aboveground biomass contrast tests to assess the significant main effect of the species. Confidence level used: 0.95 P value adjustment: sidak method for 4 estimates.

Species	lsmean	SE	df	lower.CL	upper.CL
<i>S. alterniflora</i>	42.4	2.72	56	36.1	48.6
<i>S. pacifica</i>	22.6	2.72	56	16.4	28.9

Summary: *S. alterniflora* > *S. pacifica*

Table S5. Belowground biomass contrast tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	19.00	4.14	56	4.587	0.0006
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	32.00	4.14	56	7.725	<.0001
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	35.50	4.14	56	8.570	<.0001
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	41.50	4.14	56	10.019	<.0001
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	-14.50	4.14	56	-3.500	0.0193
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	-12.25	4.14	56	-2.957	0.0803
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-14.25	4.14	56	-3.440	0.0229
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	2.25	4.14	56	0.543	0.9993
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	0.25	4.14	56	0.060	1.0000
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-2.00	4.14	56	-0.483	0.9997
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	-1.50	4.14	56	-0.362	1.0000
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	4.25	4.14	56	1.026	0.9684
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	8.25	4.14	56	1.992	0.4965
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	5.75	4.14	56	1.388	0.8588
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	9.75	4.14	56	2.354	0.2842
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	4.00	4.14	56	0.966	0.9774

Summary:

0-cm *S. alterniflora* > 0-cm *S. pacifica*
5-cm *S. alterniflora* > 5-cm *S. pacifica*
10-cm *S. alterniflora* > 10-cm *S. pacifica*
20-cm *S. alterniflora* > 20-cm *S. pacifica*

0-cm *S. alterniflora* < 5-cm *S. alterniflora*
0-cm *S. alterniflora* < 20-cm *S. alterniflora*

Table S6. Photosynthesis contrast tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	-9.00	5.08	56	-1.771	0.6414
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	-2.38	5.08	56	-0.467	0.9998
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	-45.88	5.08	56	-9.029	<.0001
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	-24.25	5.08	56	-4.773	0.0003
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	19.88	5.08	56	3.912	0.0057
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	28.12	5.08	56	5.535	<.0001
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	11.75	5.08	56	2.313	0.3053
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	8.25	5.08	56	1.624	0.7342
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-8.12	5.08	56	-1.599	0.7488
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-16.38	5.08	56	-3.223	0.0412
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	26.50	5.08	56	5.216	0.0001
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-8.75	5.08	56	-1.722	0.6731
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	-3.50	5.08	56	-0.689	0.9970
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-35.25	5.08	56	-6.938	<.0001
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	-30.00	5.08	56	-5.904	<.0001
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	5.25	5.08	56	1.033	0.9672

Summary:

10-cm *S. alterniflora* < 10-cm *S. pacifica*
20-cm *S. alterniflora* < 20-cm *S. pacifica*

0-cm *S. alterniflora* > 5-cm *S. alterniflora*
0-cm *S. alterniflora* > 10-cm *S. alterniflora*
10-cm *S. alterniflora* < 20-cm *S. alterniflora*

0-cm *S. pacifica* > 5-cm *S. pacifica*
5-cm *S. pacifica* < 10-cm *S. pacifica*
5-cm *S. pacifica* < 20-cm *S. pacifica*

Table S7. Respiration contrast tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	-4.75	6.64	56	-0.715	0.9962
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	8.00	6.64	56	1.205	0.9272
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	-13.50	6.64	56	-2.033	0.4698
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	11.50	6.64	56	1.732	0.6669
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	-20.00	6.64	56	-3.012	0.0703
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	2.88	6.64	56	0.433	0.9999
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	13.50	6.64	56	2.033	0.4698
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	22.88	6.64	56	3.445	0.0226
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	33.50	6.64	56	5.045	0.0001
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	10.62	6.64	56	1.600	0.7482
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	-7.25	6.64	56	-1.092	0.9559
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-5.88	6.64	56	-0.885	0.9863
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	29.75	6.64	56	4.480	0.0009
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	1.38	6.64	56	0.207	1.0000
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	37.00	6.64	56	5.572	<.0001
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	35.62	6.64	56	5.365	<.0001

Summary: 5-cm *S. alterniflora* > 10-cm *S. alterniflora*
5-cm *S. alterniflora* > 20-cm *S. alterniflora*

0-cm *S. pacifica* > 20-cm *S. pacifica*
5-cm *S. pacifica* > 20-cm *S. pacifica*
10-cm *S. pacifica* > 20-cm *S. pacifica*

Table S8. Net ecosystem exchange contrast post-hoc tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	-8.875	4.92	56	-1.802	0.6211
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	-23.750	4.92	56	-4.824	0.0003
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	0.375	4.92	56	0.076	1.0000
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	-10.750	4.92	56	-2.183	0.3772
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	10.125	4.92	56	2.056	0.4550
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	36.625	4.92	56	7.438	<.0001
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	23.375	4.92	56	4.747	0.0004
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	13.250	4.92	56	2.691	0.1469
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	19.375	4.92	56	3.935	0.0053
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	6.125	4.92	56	1.244	0.9148
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	-4.750	4.92	56	-0.965	0.9775
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-4.375	4.92	56	-0.889	0.9860
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	27.625	4.92	56	5.611	<.0001
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	0.375	4.92	56	0.076	1.0000
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	32.375	4.92	56	6.575	<.0001
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	32.000	4.92	56	6.499	<.0001

Summary: 5-cm *S. alterniflora* < 5-cm *S. pacifica*

0-cm *S. alterniflora* > 10-cm *S. alterniflora*
0-cm *S. alterniflora* > 20-cm *S. alterniflora*
5-cm *S. alterniflora* > 20-cm *S. alterniflora*

0-cm *S. pacifica* > 20-cm *S. pacifica*
5-cm *S. pacifica* > 20-cm *S. pacifica*
10-cm *S. pacifica* > 20-cm *S. pacifica*

Table S9. Salinity contrast tests to assess the significant main effect of the drainage treatment. Confidence level used: 0.95 P value adjustment: sidak method for 4 estimates.

Treatment	lsmean	SE	df	lower.CL	upper.CL
0-cm	15.4	3.74	56	5.78	25.0
5-cm	31.5	3.74	56	21.87	41.1
10-cm	40.9	3.74	56	31.28	50.5
20-cm	42.2	3.74	56	32.56	51.8

Summary: 0-cm < 10-cm
0-cm < 20-cm

Table S10. pH contrast tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	-4.12	8.11	56	-0.509	0.9996
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	-16.06	8.11	56	-1.981	0.5036
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	-8.88	8.11	56	-1.094	0.9554
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	16.69	8.11	56	2.058	0.4540
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	-13.50	8.11	56	-1.665	0.7091
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	-10.38	8.11	56	-1.279	0.9026
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-31.94	8.11	56	-3.939	0.0053
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	3.12	8.11	56	0.385	0.9999
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-18.44	8.11	56	-2.274	0.3260
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-21.56	8.11	56	-2.659	0.1572
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	-25.44	8.11	56	-3.137	0.0515
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-15.12	8.11	56	-1.865	0.5797
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	-11.12	8.11	56	-1.372	0.8659
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	10.31	8.11	56	1.272	0.9053
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	14.31	8.11	56	1.765	0.6455
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	4.00	8.11	56	0.493	0.9997

Summary: 0-cm *S. alterniflora* < 20-cm *S. alterniflora*

Table S11. Ammonium concentration contrast tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	-8.438	5.44	56	-1.552	0.7756
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	-20.125	5.44	56	-3.703	0.0108
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	-25.562	5.44	56	-4.703	0.0004
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	13.125	5.44	56	2.415	0.2546
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	41.062	5.44	56	7.555	<.0001
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	28.750	5.44	56	5.290	0.0001
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	6.938	5.44	56	1.276	0.9037
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	-12.312	5.44	56	-2.265	0.3306
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-34.125	5.44	56	-6.279	<.0001
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-21.812	5.44	56	-4.013	0.0042
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	29.375	5.44	56	5.405	<.0001
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	11.625	5.44	56	2.139	0.4037
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	28.500	5.44	56	5.244	0.0001
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-17.750	5.44	56	-3.266	0.0368
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	-0.875	5.44	56	-0.161	1.0000
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	16.875	5.44	56	3.105	0.0558

Summary:

5-cm *S. alterniflora* < 5-cm *S. pacifica*
10-cm *S. alterniflora* < 10-cm *S. pacifica*

0-cm *S. alterniflora* > 5-cm *S. alterniflora*
0-cm *S. alterniflora* > 10-cm *S. alterniflora*
5-cm *S. alterniflora* < 20-cm *S. alterniflora*
10-cm *S. alterniflora* < 20-cm *S. alterniflora*

0-cm *S. pacifica* > 5-cm *S. pacifica*
0-cm *S. pacifica* > 20-cm *S. pacifica*
5-cm *S. pacifica* < 10-cm *S. pacifica*

Table S12. Methane emissions contrast tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	-38.44	4.91	56	-7.826	<.0001
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	-26.38	4.91	56	-5.370	<.0001
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	-9.44	4.91	56	-1.921	0.5425
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	-6.25	4.91	56	-1.272	0.9051
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	4.62	4.91	56	0.942	0.9804
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	-31.25	4.91	56	-6.362	<.0001
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	8.62	4.91	56	-1.756	0.6513
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	-35.88	4.91	56	-7.304	<.0001
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	-13.25	4.91	56	-2.698	0.1448
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	22.62	4.91	56	4.606	0.0006
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	16.69	4.91	56	3.398	0.0258
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-2.25	4.91	56	-0.458	0.9998
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	23.56	4.91	56	4.797	0.0003
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	-18.94	4.91	56	-3.856	0.0068
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	6.88	4.91	56	1.400	0.8536
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	25.81	4.91	56	5.255	0.0001

Summary:

0-cm *S. alterniflora* < 0-cm *S. pacifica*
5-cm *S. alterniflora* < 5-cm *S. pacifica*

0-cm *S. alterniflora* < 10-cm *S. alterniflora*
5-cm *S. alterniflora* < 10-cm *S. alterniflora*
10-cm *S. alterniflora* > 20-cm *S. alterniflora*

0-cm *S. pacifica* > 5-cm *S. pacifica*
0-cm *S. pacifica* > 20-cm *S. pacifica*
5-cm *S. pacifica* < 10-cm *S. pacifica*
10-cm *S. pacifica* > 20-cm *S. pacifica*

Table S13. Sulfide concentration tests to assess the significant interaction found between species and drainage treatment. Confidence level used: 0.95 P value adjustment: tukey method for comparing a family of 8 estimates.

Contrasts		estimate	SE	df	t ratio	p value
0-cm <i>S. alterniflora</i>	0-cm <i>S. pacifica</i>	-8.44	6.53	56	-1.291	0.8982
5-cm <i>S. alterniflora</i>	5-cm <i>S. pacifica</i>	2.06	6.53	56	0.316	1.0000
10-cm <i>S. alterniflora</i>	10-cm <i>S. pacifica</i>	17.69	6.53	56	2.707	0.1419
20-cm <i>S. alterniflora</i>	20-cm <i>S. pacifica</i>	-13.19	6.53	56	-2.019	0.4791
0-cm <i>S. alterniflora</i>	5-cm <i>S. alterniflora</i>	14.38	6.53	56	2.200	0.3673
0-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	11.19	6.53	56	1.712	0.6793
0-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	28.88	6.53	56	4.420	0.0011
5-cm <i>S. alterniflora</i>	10-cm <i>S. alterniflora</i>	-3.19	6.53	56	-0.488	0.9997
5-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	14.50	6.53	56	2.219	0.3563
10-cm <i>S. alterniflora</i>	20-cm <i>S. alterniflora</i>	17.69	6.53	56	2.707	0.1419
0-cm <i>S. pacifica</i>	5-cm <i>S. pacifica</i>	24.88	6.53	56	3.807	0.0079
0-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	37.31	6.53	56	5.711	<.0001
0-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	24.12	6.53	56	3.693	0.0111
5-cm <i>S. pacifica</i>	10-cm <i>S. pacifica</i>	12.44	6.53	56	1.904	0.5542
5-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	-0.75	6.53	56	-0.115	1.0000
10-cm <i>S. pacifica</i>	20-cm <i>S. pacifica</i>	-13.19	6.53	56	-2.019	0.4791

Summary: 0-cm *S. alterniflora* > 20-cm *S. alterniflora*

0-cm *S. pacifica* > 5-cm *S. pacifica*

0-cm *S. pacifica* > 10-cm *S. pacifica*

0-cm *S. pacifica* > 20-cm *S. pacifica*

Table S14. redox contrast tests to assess the significant main effect of the species. Confidence level used: 0.95 P value adjustment: sidak method for 4 estimates.

Species	lsmean	SE	df	lower.CL	upper.CL
<i>S. alterniflora</i>	47.5	1.84	56	43.3	51.8
<i>S. pacifica</i>	17.5	1.84	56	13.2	21.7

Summary: *S. alterniflora* > *S. pacifica*

8. VITA

KYLIE CHERNESKIE
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EDUCATION

Bachelor of Science in Biology *cum laude* May 2021
Minors in Biostatistics and Environmental Studies
Ursinus College, Collegeville, PA
Honors: Academic Dean's List, Academic Scholarship

Master of Science Degree in Environmental Science Jun. 2023
Drexel University, Philadelphia PA
Honors: Dean's Fellowship Academic Scholarship

SPECIAL HONORS

Arthur Wallach Memorial Award, Drexel University, Philadelphia, PA 2023

- The award goes to the graduate student in Environmental Science for excellence in the preparation and completion of a Master's thesis or Master's research project, as determined by the Department Head and Graduate Committee.

Beta Beta Beta Biological Honor Society, Ursinus College, Collegeville, PA 2018-2019

- This society functions as an honor and professional society for students of the biological sciences. Its activities are designed to stimulate interest, scholarly attainment, and investigation in the biological sciences, and to promote the dissemination of information and new interpretations among students of the life sciences.

W.W. Smith Scholar Ursinus College, Collegeville, PA 2019-2021

- Scholars were chosen by the W.W. Smith Charitable Trust on the basis of merit and contributions to their school community.

Whitman's Honor Society Member Ursinus College, Collegeville, PA 2020-2021

- Members were admitted based on students who maintain high academic levels as well as make significant contributions to leadership and service both on and off-campus.

Centennial Conference Athletic Academic Honor Roll 2019 and 2020

- To be nominated a student-athlete must attain a cumulative grade point average of 3.40 or higher.

RESEARCH EXPERIENCE

UNDERGRADUATE

Agroecology, Ursinus College, Collegeville, PA 2019-2021

- Investigated and researched forage diversity and soil health for the

Forage Diversity Project (Fall 2019 and Spring 2020)

- Performed particulate organic matter extraction, carbon dioxide burst, and active carbon measurements to test for soil health and documented all findings.
- Developed my own project, as well as created a mock grant proposal, the project asked the two question (Fall 2021 and spring 2021):
 - How does the addition of nitrogen impact the biomass of the soil microbial community?
 - How does the addition of nitrogen influence the fungal to bacteria ratio of the microbial community?

GRADUATE

Master's Thesis with Beth Watson, Wetland Biology Drexel University

Jan. 2022-Present

- Title of the project is "Drainage Impacts on the Productivity of Wetland Species *Spartina alterniflora* and *Salicornia pacifica*"
- The goal of the project is to assess how the drainage of water affects coastal plants in a time of increased sea level rise.
- We created simulated tides in mesocosms how varying amounts of soil flooding affects wetland plants.

Research Assistantship

Sep. 2022-Jan. 2023

Wetland Ecology, Academy of Natural Sciences in Philadelphia, Drexel University

Worked on a soil project called the Elkhorn Marsh Sediment Project.

- Conducted LIO measurements, redox measurements, pH, and salinity and nutrient measurements.

TEACHING EXPERIENCE

Teaching Assistant

- Microbiology for Health Professionals Lab (Professor Laura Duwel, Drexel University) Sept. 2021-Dec. 2021
- Essential Biology Lab (Professor Monica Togna, Drexel University) Jan.- Mar. 2022
 - Taught an additional recitation once a week.
- Ecology of the Pine Barrens Lab (Professor Dane Ward, Drexel University) Mar.- Jun. 2022
- Essential Biology Lab (Professor Monica Togna, Drexel University) Jan.- Mar. 2023
- Essential Biology Lab (Professor Meshagae Brown, Drexel University) April.- Jun. 2023

LEADERSHIP EXPERIENCE

President, Newman Society, Ursinus College, Collegeville, PA

2018-2021

- Organized group meetings and special campus events.
- Met with local parish pastor each week for a bible discussion.

Energy Fellow, Sustainability Fellowship, Ursinus College, Collegeville, PA

Fall 2019- Spring 2020

- Helped to assess the college's greenhouse gas emissions (GHGs) and energy use.
- Analyzed the college's data on emissions, converted it into graphs and charts that can be read by the public, and gained experience in communicating about GHGs

with various stakeholders.

Waste Fellow, Sustainability Fellowship, Ursinus College, Collegeville, PA Fall 2020-Spring 2021

- Leader on campus for sustainability education; advocate for more sustainable campus procedures.
- Student coordinator of Sustainable Move-out at the end of the spring semester- an operation that stops unnecessary items from going into landfills at the end of the school year.
 - Organized the Move-out and worked the entirety of the Move-out days.
- Lead and performed a social media-based campaign about what can and cannot be recycled on campus.