

Summer 8-1-2021

Spatial and Seasonal Patterns of Above- and Belowground Vegetation Biomass and Potential Drivers in the Pascagoula River Delta, MS

Evan Grimes

Follow this and additional works at: https://aquila.usm.edu/masters_theses



Part of the [Biology Commons](#), and the [Marine Biology Commons](#)

Recommended Citation

Grimes, Evan, "Spatial and Seasonal Patterns of Above- and Belowground Vegetation Biomass and Potential Drivers in the Pascagoula River Delta, MS" (2021). *Master's Theses*. 849.
https://aquila.usm.edu/masters_theses/849

This Masters Thesis is brought to you for free and open access by The Aquila Digital Community. It has been accepted for inclusion in Master's Theses by an authorized administrator of The Aquila Digital Community. For more information, please contact Joshua.Cromwell@usm.edu.

SPATIAL AND SEASONAL PATTERNS OF ABOVE- AND BELOWGROUND
VEGETATION BIOMASS AND POTENTIAL DRIVERS IN THE PASCAGOULA
RIVER DELTA, MS

by

Evan Scott Grimes

A Thesis
Submitted to the Graduate School,
the College of Arts and Sciences
and the School of Ocean Science and Engineering
at The University of Southern Mississippi
in Partial Fulfillment of the Requirements
for the Degree of Master of Science

Approved by:

Dr. Wei Wu, Committee Chair

Dr. Patrick Biber

Dr. Glenn Suir

August 2021

COPYRIGHT BY

Evan Scott Grimes

2021

Published by the Graduate School



ABSTRACT

Coastal wetlands provide a valuable wealth of services to the greater coastal ecosystem and human communities. However, threats such as sea level rise and conservation projects, such as freshwater diversions, have the potential to alter coastal wetlands in different ways. In this thesis, I describe the effects of inundation and nitrogen on vegetation productivity using a field-sampling approach and an *in situ* controlled mesocosm experiment, called a marsh organ. The West Channel of the Pascagoula River contained significantly higher belowground biomass than the East Channel, which is more anthropogenically modified. Vertical distribution of belowground biomass did not strongly vary between seasons or channels. Elevation was significantly correlated to aboveground biomass, and NO_x was correlated to belowground biomass. Both relationships were nonlinear and complex. In the marsh organ, *Sagittaria lancifolia* end-of-season biomass responded in a quadratic fashion, similar to coastal sedge and grass species in previous studies. My findings are valuable to understanding the status and resilience of the lower Pascagoula River, as well as the ability of *S. lancifolia* (a dominant fresh-brackish water marsh species) to respond to changing hydrological regimes, potentially including freshwater diversion.

ACKNOWLEDGMENTS

I'd like to thank my lab members for all the help and support throughout the field and lab work of my project. Dr. Hailong Huang (for assistance with boating, marsh organ construction, and field work), Devin Jen, Kodi Feldpausch, Olivia Cola, and Mackenzie Holifield (for field work), Lisa Janowsky (for lab sample processing help), and Dr. Wei Wu (for support, writing, and statistical teaching). Special thanks to the US Army Corps of Engineers for soil chemistry analysis. I would not be able to complete this work without my committee members, Dr. Patrick Biber and Dr. Glenn Suir, as well as the funding from the Coastal Sciences Department.

DEDICATION

To my extremely supportive parents, family, and friends for reassuring me when times were rough or great and my loving girlfriend Brittany Maldonado for being there for me through all of it.

TABLE OF CONTENTS

ABSTRACT ii

ACKNOWLEDGMENTS iii

DEDICATION iv

LIST OF TABLES viii

LIST OF ILLUSTRATIONS ix

CHAPTER I - SPATIAL AND SEASONAL PATTERNS OF ABOVE- AND
BELOWGROUND BIOMASS IN THE LOWER PASCAGOULA RIVER DELTA IN
MISSISSIPPI 1

 1.1 Introduction 1

 1.1.2 Objectives and Hypotheses 6

 1.2 Methods 7

 1.2.1 Sampling Locations 7

 1.2.2 Field Work 8

 1.2.3 Laboratory Work 9

 1.2.4 Remote Sensing Data 10

 1.2.5 Soil Chemistry Data 11

 1.2.6 Statistical Modeling 11

 1.3 Results 12

 1.3.1 Summary 12

1.3.2 Spatial and Seasonal Patterns of Above- and Belowground Biomass and Ratio of Below- Aboveground Biomass.....	12
1.3.3 Spatial and Seasonal Vertical Distribution of Belowground Biomass	16
1.3.4 Live Biomass Relations to Inundation and Inorganic Nitrogen.....	20
1.3.5 Marsh Transects	21
1.4 Discussion	23
1.5 Conclusion	25
 CHAPTER II - EVALUATING THE RESPONSE OF <i>SAGITTARIA LANCIFOLIA</i> TO COMBINED INUNDATION AND NITROGEN ADDITION USING A MARSH ORGAN	
ORGAN	26
2.1 Introduction.....	26
2.1.1 Objectives and Hypotheses	28
2.2 Methods.....	29
2.2.1 Study Site.....	29
2.2.2 Marsh Organ Design	31
2.2.3 Monitoring and Biomass Collection	33
2.2.4 Statistical Analyses	34
2.3 Results.....	34
2.4 Discussion	43
2.5 Conclusion	46

CHAPTER III - IMPACTS, SCALABILITY, AND SUGGESTIONS FOR FUTURE

RESEARCH..... 47

APPENDIX A – Supplemental Data for the Thesis..... 51

LITERATURE CITED 59

LIST OF TABLES

Table 1.1 Summaries of collected aboveground and belowground biomass from the Pascagoula River delta in each season..... 13

Table 1.2 Two-way ANOVA tables of live belowground and aboveground biomass, and B:A ratio with channel and season as main factors 13

Table 1.3 Tukey HSD test results of pairwise comparisons of channel and season as factors..... 14

Table 1.4 GAM results with p-values relating soil chemistry values to aboveground and belowground biomass in each season 20

Table 2.1 Mixed-Effects Model results for leaf count, longest leaf length, leaf width, and stem width..... 40

Table 2.2 Linear regression of end-of-season live biomass with respect to percent inundation time 43

Table A.1 Soil chemistry data from Pascagoula River sampling sites, December 2020.. 51

Table A.2 Live aboveground biomass organized by site and species..... 55

LIST OF ILLUSTRATIONS

Figure 1.1 Typical marsh platform vegetation from north to south in the lower Pascagoula River..... 4

Figure 1.2 Sampling sites in the lower Pascagoula River delta..... 9

Figure 1.3 Average \pm S.D. belowground biomass between east and west channels for each sampling season..... 14

Figure 1.4 Average seasonal belowground biomass (g/m^2) in the West and East Channel 15

Figure 1.5 Average \pm S.D. of aboveground biomass between East and West Channels for each sampling season..... 16

Figure 1.6 Average \pm S.D. belowground biomass in the West and East Channels in summer, fall, and winter 17

Figure 1.7 Linear regression of belowground biomass with respect to depth across seasons and sites 18

Figure 1.8 Posterior distributions of Bayesian multilevel model 19

Figure 1.9 Biomass relationships to environmental factors..... 21

Figure 1.10 Belowground biomass patterns along the three marsh transects for each season sampled..... 22

Figure 1.11 Aboveground biomass patterns along the three marsh transects for each season sampled..... 22

Figure 2.1 Marsh organ placement 30

Figure 2.2 Marsh organ experimental site 30

Figure 2.3 Marsh organ diagram..... 32

Figure 2.4 Percent Time inundated for the six rows in the marsh organ 36

Figure 2.5 Comparison of overall vegetation characteristics between inundation rows
with and without nitrate additions..... 38

Figure 2.6 Average vegetation characteristics per row during the summer and fall 2020 39

Figure 2.7 Above and belowground biomass of *Sagittaria lancifolia* after one growing
season 42

Figure 2.8 Photo of the marsh organ site pre-construction in mid-July 2020..... 44

CHAPTER I - SPATIAL AND SEASONAL PATTERNS OF ABOVE- AND
BELOWGROUND BIOMASS IN THE LOWER PASCAGOULA RIVER DELTA IN
MISSISSIPPI

1.1 Introduction

Coastal wetlands provide a valuable wealth of services to the greater coastal ecosystem and human communities. Wetlands are highly valued and recognized for their productive benefits including erosion prevention, storm buffering, carbon sequestration, and habitat for recreational and commercial fish nursery (Barbier et al., 2013; Costanza et al., 1997; Mitsch & Gosselink, 2000). They provide important habitat for various migrating birds and reptiles as well as unique assemblages of plants. However, coastal wetlands are highly vulnerable to sea level rise (SLR) and natural and anthropogenic stressors (Turner, 1997). They are disappearing at high rates in the northern Gulf of Mexico (NGOM) (Couvillion et al., 2017; Jankowski et al., 2017; Shirley & Battaglia, 2006; Wu et al., 2017). Understanding the dynamics of coastal wetland vegetation is valuable in assessing overall community health and resilience to potential impacts of future climates.

Freshwater input and SLR can alter the depths and duration of inundation on coastal wetlands, and impact their ability to maintain healthy vegetation and elevation (Wu et al., 2020). Disturbances to wetlands can also increase erosion and decrease their resilience to wave activity and storms (Silliman et al., 2019). Freshwater diversions can also change the salinity and nutrient dynamics of these coastal wetlands. Understanding spatial variability of productivity of coastal wetland vegetation, and how dominant vegetation species allocate biomass between above- and belowground fractions are key to

determining vegetation dynamics related to these key drivers (SLR and freshwater diversions). A better understanding of the dynamics of above- and belowground biomass in these coastal wetlands is important for elucidating their abilities for maintaining a resilient coast. Studying biomass allocation will help us better understand the abilities of the marsh vegetation to capture and store carbon, mediate greenhouse gases, and accrete marshland to mitigate effects of future SLR (Tripathee & Schäfer, 2015).

Coastal wetlands also experience seasonal variations, another factor that must be considered when studying wetland response to natural and anthropogenic stressors. No studies have examined at the seasonal variability of biomass in the lower Pascagoula River. Plant responses to seasonal shifts and will include gradual physiological changes in photosynthesis, osmo- and thermoregulation, which will affect primary productivity and growth rates, often resulting in altered morphology over weeks to months.

The Pascagoula River system is a prominent drainage in southeast Mississippi beginning in George County with the combination of the Leaf River and Chickasawhay River, and discharging into Pascagoula Bay and Mississippi Sound in coastal Jackson County. The river is the largest undammed river drainage by volume in the lower 48 United States and is minimally impacted anthropogenically (Dynesius & Nilsson, 1994). Its channels are used by local and commercial fishermen and for public recreation. Its wetland ecosystem is utilized by a handful of vulnerable and tracked species including Gulf Sturgeon (*Acipenser oxyrinchus desotoi*), Mississippi Diamondback Terrapin (*Malachlemys terrapin pileata*), Yellow-blotched Map Turtle (*Graptemys flavimaculata*), Pascagoula Map Turtle (*Graptemys gibbonsi*), Painted Devil Crayfish (*Lacunicambarus ludovicianus*), and Mississippi Sandhill Crane (*Grus canadensis pulla*). The lower

Pascagoula River (south of Interstate 10, centered around N 30.41°, W 88.60°) can be characterized by dynamic hydrological extremes, including north-south salinity gradients (0-25 ppt) and regular tidal influence. Vegetation consists of Black Needlerush (*Juncus roemerianus*), Saltmeadow Hay (*Spartina patens*), and Saltmarsh Cordgrass (*Spartina alterniflora*) in more saline regimes. Based on in-field observations, in the fresher portions of the lower Pascagoula, Three-square Bulrush (*Schoenoplectus pungens*), Soft-stemmed Bulrush (*Schoenoplectus tabernaemontani*), Broadleaf Arrowhead (*Sagittaria lancifolia*), Broadleaf Cattail (*Typha latifolia*), and Common Reed (*Phragmites australis* spp.) replace the aforementioned dominant saltmarsh species (Figure 1.1).

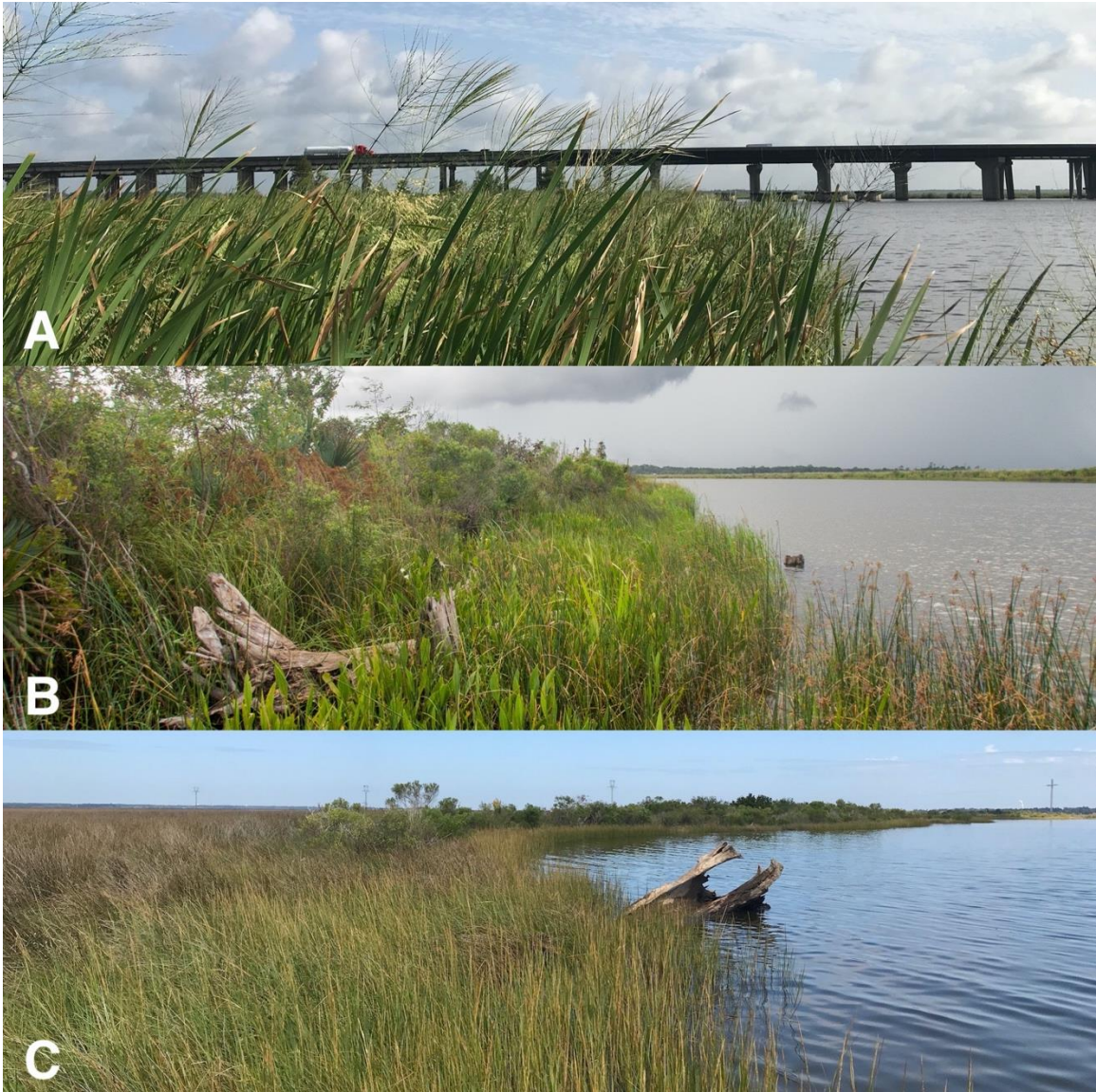


Figure 1.1 *Typical marsh platform vegetation from north to south in the lower Pascagoula River*

“A”: *Zizaniopsis miliacea*, *Typha latifolia*, *Phragmites australis*; “B”: *Sagittaria lancifolia*, *Schoenoplectus tabernaemontani*, various shrubby plants; “C”: *Spartina alterniflora*, *Juncus roemerianus*.

While the Pascagoula River has been the subject of multiple studies of species such as the Gulf Sturgeon and endemic map turtles, very few studies exist to assess the allocation of above- or belowground biomass of vegetation (Wu et al. 2020). Healthy marsh ecosystems can be more resilient to changes in salinity, water levels, and storm

events, and can keep pace with less extreme SLR, and species shifts can occur in the wetlands if diversity allows it (Schile et al., 2014; Watson & Byrne, 2009). Although aerial photography and modeling suggest resilience of the lower Pascagoula to SLR rate up to 10 mm/yr. (Wu et al., 2020), overall wetland losses were observed from 1955-2014 (Waldron et al., 2021). This land loss further emphasizes the vulnerability of marshes in the NGOM, and the importance of analyzing plant productivity in the area.

Wetland health is dependent on vegetation health. One way to assess vegetation health is through analysis of biomass and allocation of biomass to above- and belowground portions along the environmental gradient. Biomass quantity and partitioning can be affected by a myriad of factors such as season, inundation, and nutrients. Allocation of biomass between above- and belowground has important implications for stability of coastal wetlands, both contributing to accretion of wetland platforms and therefore stability of wetlands (Kirwan et al., 2010; Morris et al., 2016; Wu et al., 2020). Above- and belowground biomass can contribute to marsh platform accretion through sediment trapping and organic matter deposition. Nutrient addition to marsh vegetation tends to result in decreased belowground biomass, and varying aboveground biomass effects depending on species (Langley et al., 2013). Live belowground biomass tends to aggregate near the surface of saturated soils in coastal marshes due to proximity to oxygenated soils richer in nutrients, and allocation may vary due to specific biology and spatiality of the wetland plants. Live, green aboveground biomass changes throughout the year with higher quantities present in warmer months and lower quantities present in colder months. Patterns of biomass production can vary throughout the year in the NGOM (Darby & Turner, 2008a). Generally, peak biomass for

plants in the coastal marshes of the Gulf of Mexico is observed from June to October, barring any extreme meteorological or hydrological events (Hopkinson et al., 1978, 1980; Thomas et al., 2019). Even so, studies characterizing biomass in the NGOM generally have taken place in coastal Louisiana where wetland loss is highest in the US (Blum & Roberts, 2009; Couvillion et al., 2017).

1.1.2 Objectives and Hypotheses

This study aims to:

- 1) Characterize spatial and seasonal variability of above- and belowground biomass;
- 2) Study vertical distribution of belowground biomass and biomass allocation between above- and belowground; and
- 3) Relate live biomass and ratio of below- to above-ground biomass to inundation and soil nutrient availability (inorganic nitrogen content in soil pore water).

The hypotheses tested include:

- 1) Coastal wetlands in the East Channel contain higher live aboveground biomass but lower live belowground biomass than in the more pristine West Channel, therefore the ratio of below- to aboveground biomass is lower in the East Channel than in the West Channel.
- 2) Seasonal variability of live aboveground biomass is larger than that of live belowground biomass. The higher aboveground biomass occurs in summer and fall.
- 3) Live belowground biomass decreases with depth in both channels and all seasons, and the rate of decrease was the largest in the West Channel during the summer period.

- 4) Live above- and belowground biomass and the ratio of below- to aboveground biomass is related to inundation levels and soil inorganic nitrogen content.

1.2 Methods

The study area is the Pascagoula River delta, a tidally influenced coastal wetland with freshwater input in southeastern Mississippi. I sampled above- and belowground biomass in fall (2019), summer (2020), and winter (2020/21) along elevation and salinity gradients. Each sample included duplicate collections of aboveground biomass from a 15x15 cm quadrat and belowground biomass from a 30-cm long core extractor with 10-cm diameter. I separated biomass into live and dead material. I dried sorted biomass using an oven for three days at 70 degrees Celsius. Resulting dry biomass was analyzed to compare east and West Channel allocation across seasons, total biomass between channels, and above- below, and below-above ratios related to a variety of variables such as elevation, salinity, and soil inorganic nitrogen.

1.2.1 Sampling Locations

I collected vegetative biomass from the lower Pascagoula River where 35% of coastal wetlands of Mississippi Gulf Coast are located (MDEQ 2001, Wu et al. 2020). The Pascagoula River is the largest undammed river (by volume) in the continental US with an average streamflow of 3511 m³/s from 1994 to 2007 (<https://waterdata.usgs.gov/nwis>). An undammed river with natural flows provides an ideal field laboratory that mimics the rivers before dam construction or after freshwater diversion project construction intended to restore natural freshwater flows.

1.2.2 Field Work

I sampled biomass along a gradient of water levels and salinity in both main channels - East and West channels. The lower West Channel is more pristine compared to the East Channel that abounds a shipbuilding yard and is continuously dredged for maritime transportation. Disturbed areas in the East Channel are also less dense in benthic and epifaunal prevalence than undisturbed areas in the West Channel (Partyka & Peterson, 2008). I used a refractometer at each sample location to record point observations of salinity in parts per thousand (ppt). I chose six sites, also called latitudinal sites, with approximately equidistant separation from south to north using a handheld Trimble GPS (Figure 1.2) in each of the two channels. To capture spatial variability of biomass from the water edge into marshes, I sampled three marsh transects approximately perpendicular to the water edge in the West Channel (Figure 1.2, yellow points). Each perpendicular transect, called transect a site, consisted of three points that were running upslope from the water edge approximately 10 meters apart, called transect points. In selecting specific collection areas, I tossed a 15x15cm quadrat in a haphazard fashion at each chosen site. Above-ground biomass was clipped at the point of vegetation emergence from the sediment and stored in in labeled bags. Below-ground biomass was collected using a 30 cm long, 10 cm diameter sediment core extractor. I separated each of the cores on-site at 5 cm intervals using a ruler and handsaw, subsections were subsequently placed into separate plastic bags. All the sample collections were stored in a cooler. I took duplicate sediment cores and duplicate aboveground biomass samples. I sampled the areas in different seasons, fall (November), summer (August) 2020, and winter (December 2020) (Figure 1.2). All sediment/belowground samples were

transported to the USM Gulf Coast Research Laboratory and stored at -18°C and aboveground biomass stored at 4°C in refrigerators until further processing.

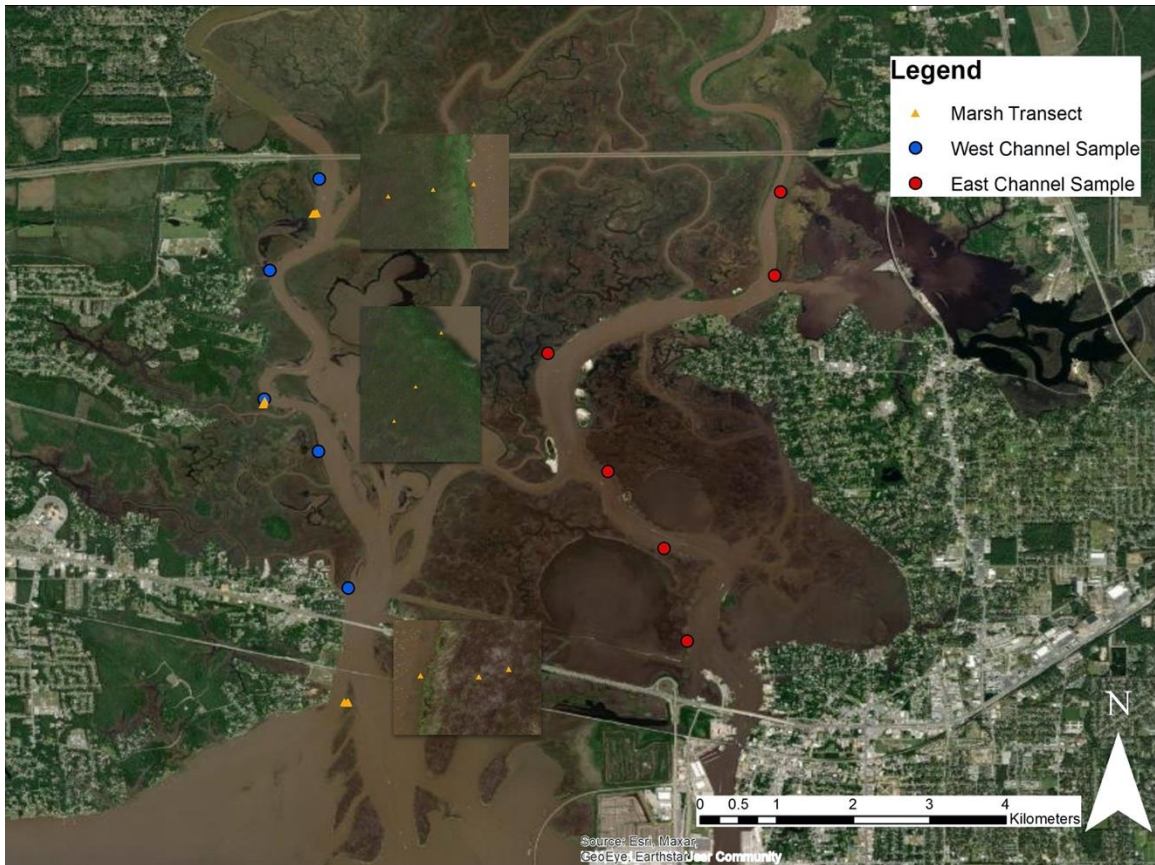


Figure 1.2 *Sampling sites in the lower Pascagoula River delta*

Each point consisted of duplicate above- and below-ground biomass sampling. Red and blue points are latitudinal sites in the East and West Channel respectively. The yellow triangle represent inland marsh transects and each point on the inset map is a transect site where biomass was collected.

1.2.3 Laboratory Work

To obtain below-ground biomass measurements after harvest, I cleaned and sorted collected samples by hand. I first filtered the soil core samples through a 1 mm mesh to remove inorganic matter under running water. I placed washed roots back into their respective bags and stored at 4°C . Washed roots were then separated into live and dead

biomass. Color, turgidity, and buoyancy were all characteristics I used to identify live biomass. Biomass that sank into the water, was duller in color, or was soft (loss of turgidity) was considered dead. I placed the roots into pre-weighed aluminum trays. I then dried the roots in an oven at 70 °C (~ 3 to 5 days) until constant weight (Wu et al., 2020). Samples were weighed again to obtain dry weight. All the samples were processed and dried within two months of their initial collection.

Using the collected aboveground biomass, I identified all plant species present in a quadrat to the lowest taxonomic levels, ideally genus or species when monotypic characters (flowers) were present. Depending on time of collection, these characters may not have been present in the material collected. Some plant matter was not able to be identified below family level due to lack of identifiable characteristics.

After I identified the above-ground vegetation to the lowest taxonomic group, I separated live and dead biomass based on presence of green coloration. Sections with green coloration were grouped in the live biomass of the given taxa. Aluminum tins were labeled with the date, location, and identified species or taxa. I then dried all biomass under the same conditions as the below-ground samples and recorded the weights of the dried samples.

1.2.4 Remote Sensing Data

I gathered LiDAR data from the Mississippi Automated Resource Information System (MARIS; <https://www.maris.state.ms.us/HTML/DATA/Elevation.html#gsc.tab=0>), which was collected for coastal Mississippi in 2015. The data has point spacing of 0.7 m and is classified into 4-foot pixel raster DEM of bare-earth surface. The vertical datum is

NAVD88 and uses NAD83 2011 for the horizontal datum. I extracted point elevation at each of my collection sites from the GPS coordinates collected in the field.

1.2.5 Soil Chemistry Data

Triplicate belowground core samples were collected in addition to the standard duplicate biomass cores in winter 2020 by staff from the US Army Corps of Engineers, Engineer Research and Development Center (ERDC). Cores were sectioned into three levels (0-10cm, 10-20cm, 20-30cm). Researchers at the ERDC Environmental Laboratory processed the cores and collected a variety of soil variables, including salinity, pH, inorganic nitrogen (NO_x and NH_4^+), loss on ignition, bulk density, phosphate content, and multiple active bacterial enzymes (Table A.1).

1.2.6 Statistical Modeling

I applied a two-way ANOVA to analyze the aboveground biomass, belowground biomass, and below- to aboveground biomass ratios using season and channel as the factors (H1 & H2). Belowground biomass across depths and aboveground biomass across taxonomic levels were totaled for each replicate at each site and averaged between the duplicate samples collected. I used the Tukey HSD test for post-hoc analysis of pairwise comparisons. I then applied a Bayesian multilevel model to examine the vertical distribution of belowground biomass (H3). I used a generalized additive model (GAM) to investigate nonlinear relations between productivity and inundation (elevation) and soil inorganic nitrogen (H4).

1.3 Results

1.3.1 Summary

I determined the West Channel had significantly higher belowground biomass than the East Channel in most seasons. Winter had moderately higher belowground biomass when compared to the fall season. Aboveground biomass did not vary between channels or seasons. Belowground biomass declined with depth, and the distribution of belowground biomass varied moderately between channels but very little between seasons. I found a significant correlation between elevation and aboveground biomass, and a significant correlation of NO_x and belowground biomass.

1.3.2 Spatial and Seasonal Patterns of Above- and Belowground Biomass and Ratio of Below- Aboveground Biomass

Highest aboveground biomass material was collected in the fall and the highest belowground biomass material was collected in the winter (Table 1.1). There were significant effects of channel, season, and interaction of the two factors in above- and belowground biomass (Table 1.2). Tukey HSD tests highlighted 1363.86 grams more belowground biomass in the West Channel than the east ($p < 0.001$), and 1040.24 grams more biomass in the winter when compared to the fall ($p < 0.03$) (Table 1.3). No significant effects of channel and season on live aboveground biomass production. Below-aboveground biomass ratios were also not significantly different between channels and among seasons. The interaction, however, was significant for belowground biomass as well as the ratio of below-aboveground biomass. Belowground biomass in winter was significantly higher than either fall or summer in the West Channel and biomass in winter in the East Channel (Figure 1.3).

Table 1.1 *Summaries of collected aboveground and belowground biomass from the Pascagoula River delta in each season*

<i>Biomass Summaries</i>				
Sample	Season	Min (g/m ²)	Mean (g/m ²)	Max (g/m ²)
Aboveground	Summer	152.4	1268.1	4169.6
	Fall	372.9	1514.0	4922.9
	Winter	373.6	1075.8	2186.7
Belowground	Summer	1082.0	4855.0	14320.0
	Fall	897.6	3187.2	8420.6
	Winter	376.2	5031.2	16561.7

Table 1.2 *Two-way ANOVA tables of live belowground and aboveground biomass, and B:A ratio with channel and season as main factors*

<i>Belowground</i>					
Predictor	<i>Df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>p</i>
Channel	1	60907934	60907934	19.939	0.000
Season	2	23848566	11924283	3.904	0.032
Channel:Season	2	31236543	16068272	5.260	0.012
Residuals	29	82476256	3054676		

<i>Aboveground</i>					
Predictor	<i>Df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>p</i>
Channel	1	41598	41598	0.344	0.563
Season	2	278431	139216	1.150	0.332
Channel:Season	2	457106	228553	1.888	0.171
Residuals	27	3268167	121043		

<i>BA Ratio</i>					
Predictor	<i>Df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>p</i>
Channel	1	224.8	224.78	2.462	0.128
Season	2	222.2	111.12	1.217	0.312
Channel:Season	2	554.7	277.34	3.037	0.065
Residuals	27	2465.4	91.31		

Table 1.3 Tukey HSD test results of pairwise comparisons of channel and season as factors

Significant interactions reported.

Belowground Tukey HSD Results

Predictor	difference	lower	upper	p
West-East	1363.859	737.05	1990.668	0.000
Summer-Fall	543.21	-380.61	1467.029	0.327
Winter-Fall	1040.237	116.418	1964.056	0.025
Winter-Summer	497.026	-426.793	1420.845	0.389
West: Winter-West:Fall	2019.7399	326.51201	3712.9678	0.013
West: Winter-West:Summer	1758.4711	65.24326	3451.699	0.038
West: Winter-East:Winter	2733.327	1112.18472	4354.4693	0.000

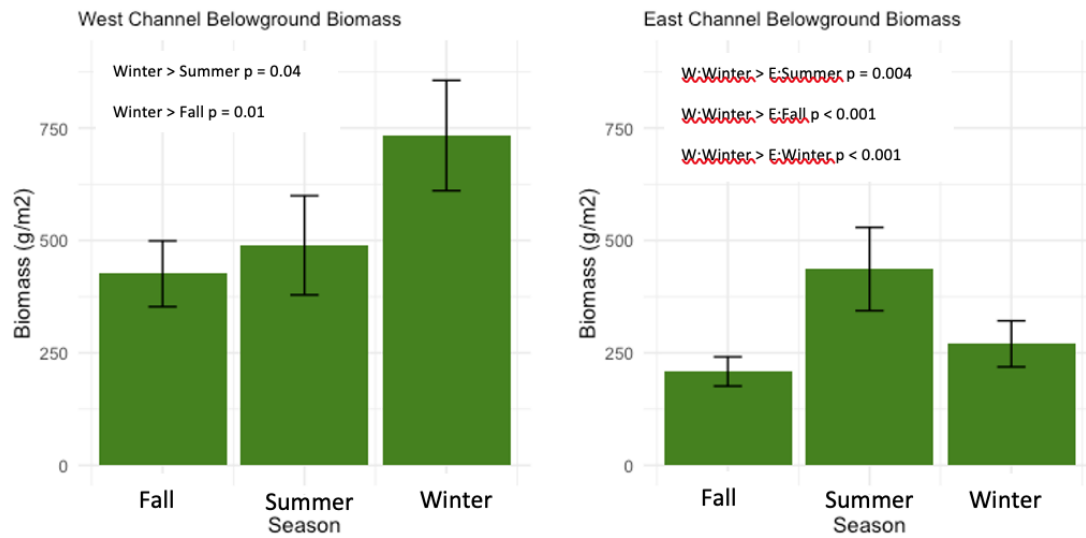


Figure 1.3 Average \pm S.D. belowground biomass between east and west channels for each sampling season

While summer was nearly equal in both channels, fall and winter biomass was significantly higher in the West Channel.

Winter samples at each site contained more belowground biomass than summer or fall in the West Channel (Figure 1.4). The East Channel showed less clear of a trend, with fall appearing to have the least biomass, but also the least variation in biomass across sites. Aboveground biomass did not strongly vary among seasons or channels (Figure 1.5).

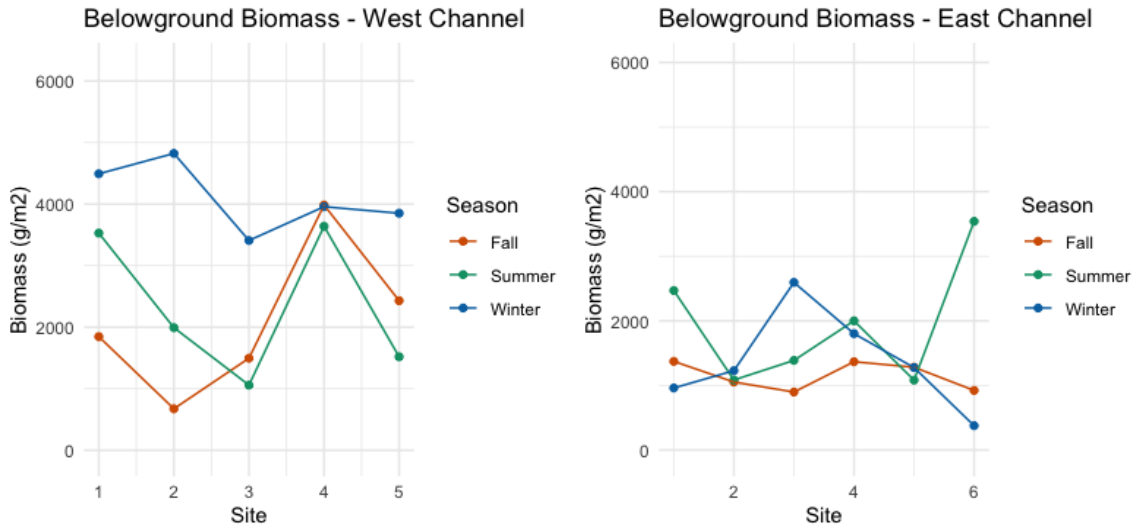


Figure 1.4 Average seasonal belowground biomass (g/m^2) in the West and East Channel

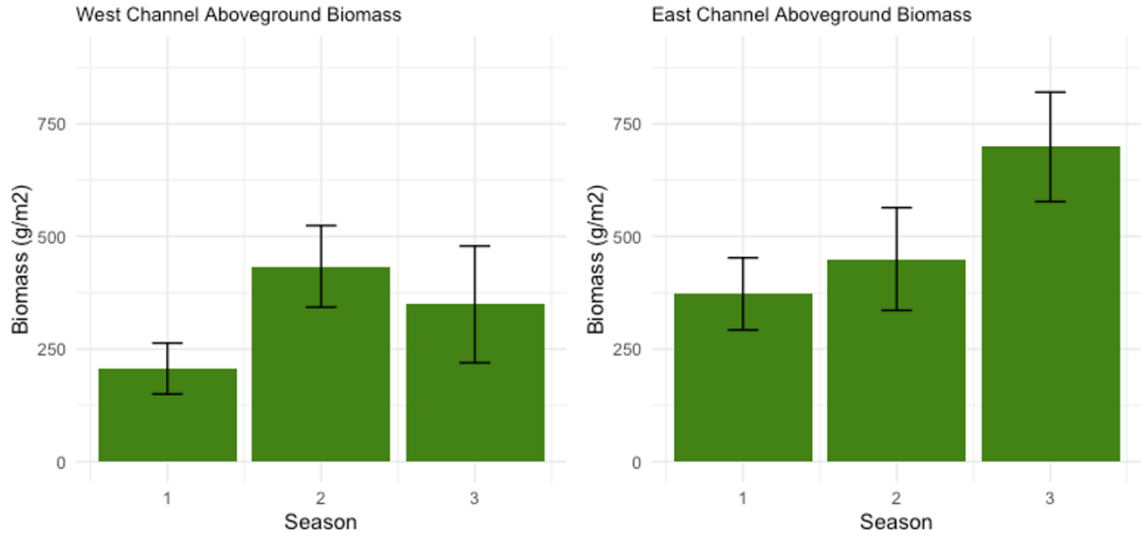


Figure 1.5 Average \pm S.D. of aboveground biomass between East and West Channels for each sampling season

1.3.3 Spatial and Seasonal Vertical Distribution of Belowground Biomass

Belowground biomass showed variation in vertical distribution among seasons and between East and West Channels (Figure 1.6). The uppermost level (0-5 cm) during the summer in the East Channel had higher biomass than the lower depths; the West Channel contained higher levels of belowground biomass in most depth levels (Figure 1.7).

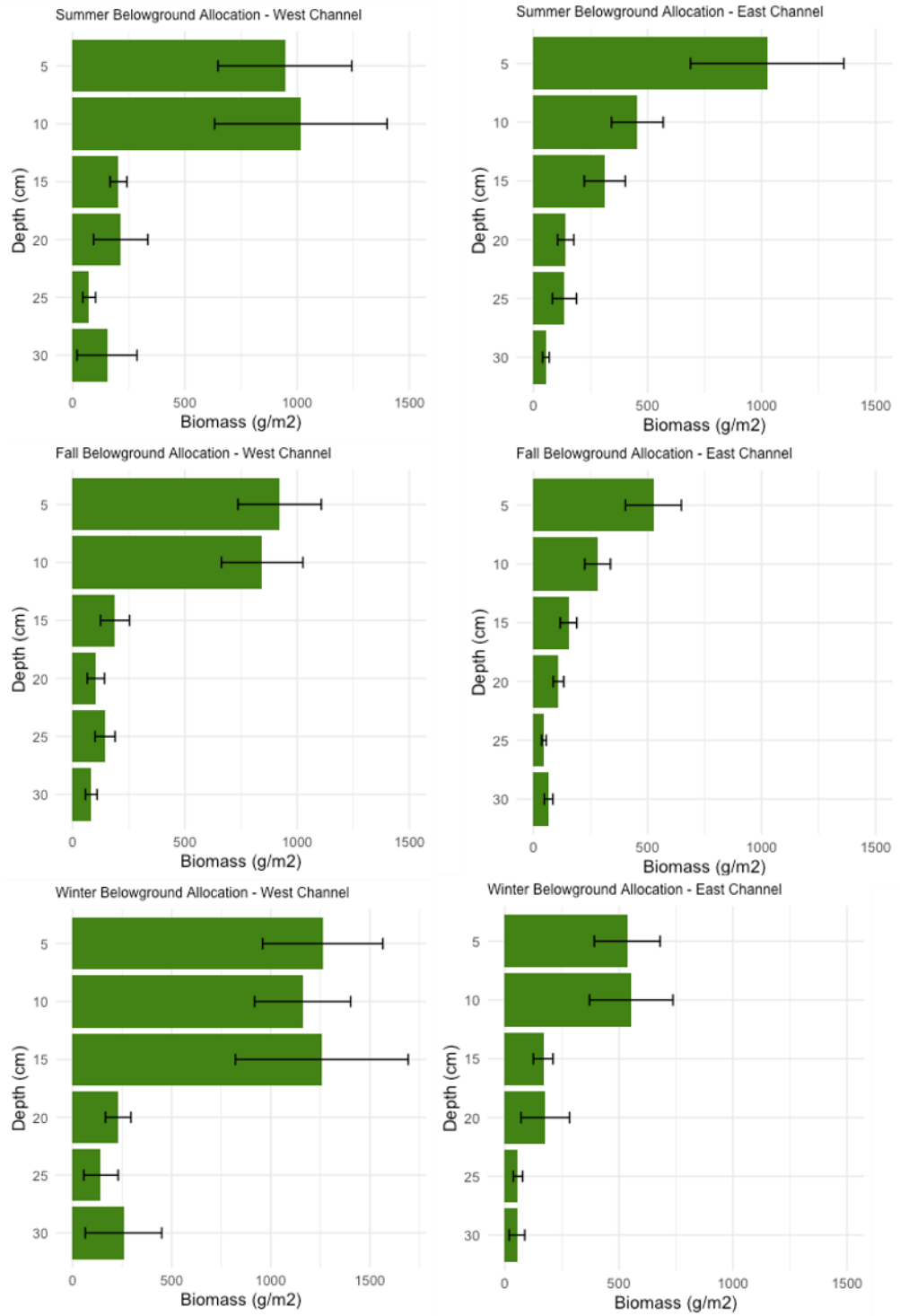


Figure 1.6 Average \pm S.D. belowground biomass in the West and East Channels in summer, fall, and winter

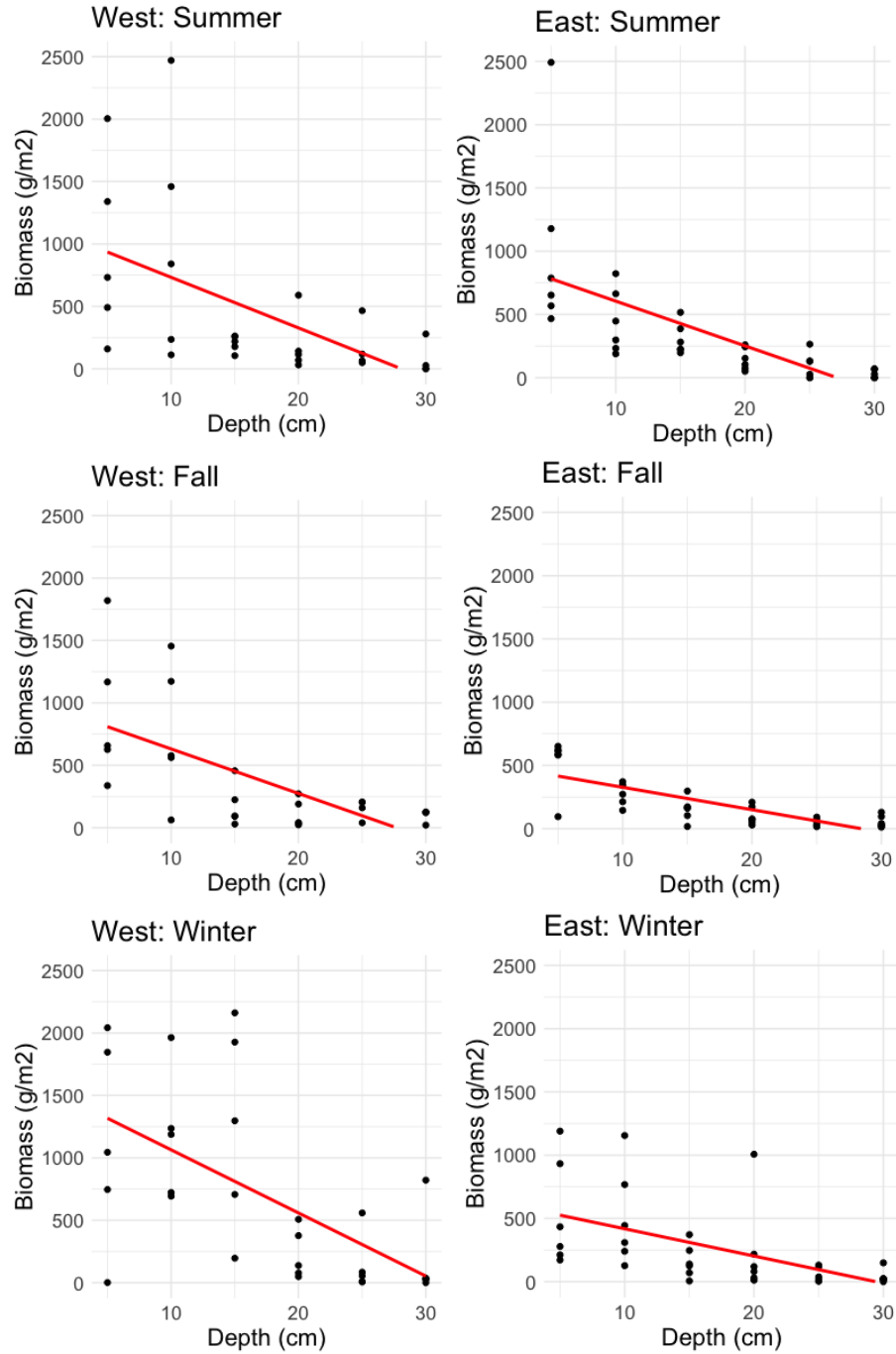


Figure 1.7 Linear regression of belowground biomass with respect to depth across seasons and sites

The second depth level (6-10 cm) averaged more biomass in the West Channel than the East Channel across all seasons sampled (Figure 1.6). Biomass deeper than 10

cm from the soil surface was larger in the West Channel than in the East Channel during the winter season. Across all channels and seasons, most of the biomass was allocated within the first 10 cm of depth.

Posterior distributions after Bayesian multilevel modeling showed an obvious negative trend for biomass with depth (Figure 1.8; A). Each channel showed biomass decreasing with depth, normal for estuarine marshes in the NGOM (Darby & Turner, 2008a). The model showed a strong difference in channels (86.5%) although not beyond the 95% credible interval. The West Channel exhibited a more uniform distribution of belowground biomass. Differences between fall and winter seasons in both channels were low (Figure 1.8; B). These differences include 0 in the posterior distributions, but the medians of the differences in both channels were negative.

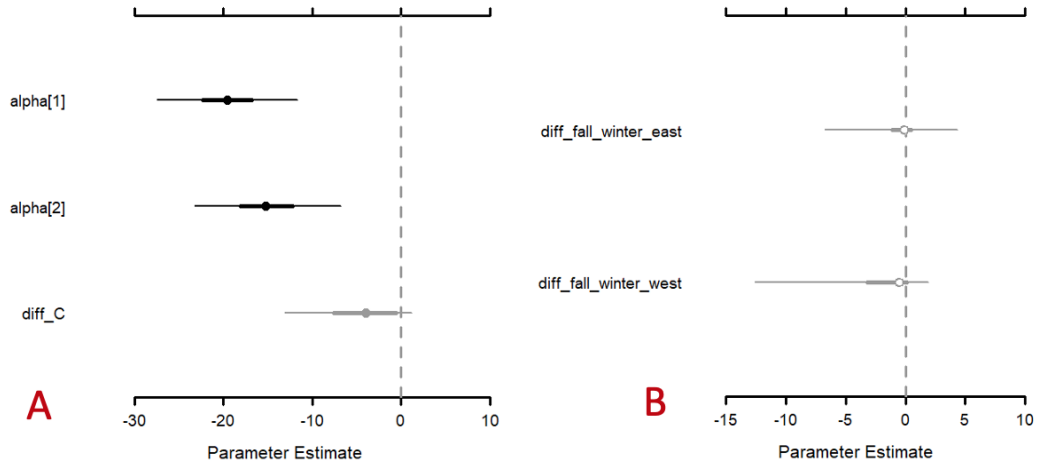


Figure 1.8 *Posterior distributions of Bayesian multilevel model*

East Channel (alpha[1]), West Channel (alpha[2]), and difference between channels (A); posterior distributions of the difference between fall and winter in the east and West Channel (B). The thin line surrounding the median point represents the 95% credible interval.

1.3.4 Live Biomass Relations to Inundation and Inorganic Nitrogen

The GAM predicted significant correlations of fall aboveground biomass with elevation and fall belowground biomass with NO_x (Table 1.4). The relationship between aboveground biomass and elevation was nonlinear, with three distinct optima along the elevation range (Figure 1.9; A). Correlation of belowground biomass in the fall with NO_x was less clear, showing relatively consistent biomass with the NO_x until N was 2.5 mg/kg, where biomass steeply decreased and subsequently increased around 3.5 mg/kg N (Figure 1.9; B).

Table 1.4 *GAM results with p-values relating soil chemistry values to aboveground and belowground biomass in each season*

GAM						
	pH	Salinity	NO _x	NH ₄	Elevation	
Winter Above	0.901	0.398	0.963	1.000	0.139	
Fall Above	0.206	0.481	0.475	0.503	0.005	
Summer Above	0.465	0.493	0.351	1.000	0.579	
Winter Below	0.440	0.639	0.682	0.139	0.687	
Fall Below	0.286	0.417	0.046	1.000	0.387	
Summer Below	0.974	0.738	0.069	1.000	0.531	

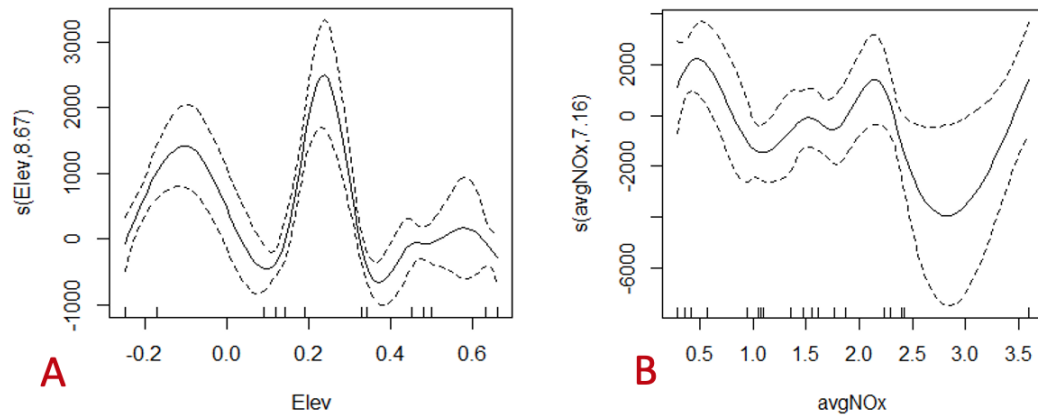


Figure 1.9 *Biomass relationships to environmental factors.*

Relationship of fall aboveground biomass to elevation (A); relationship of fall belowground biomass to NO_x (B). Y-axis is biomass in g/m^2

1.3.5 Marsh Transects

While the largest belowground biomass occurred primarily at the most inland transect points (Figure 1.10), the largest aboveground biomass mostly occurred at the middle site 2 (Figure 1.10). Marsh transects showed a slightly increasing trend for belowground biomass further in the marsh except fall and winter in Site 1 (southernmost) and fall in Site 3 (northernmost) (Figure 1.10). In Site 2, winter was higher in biomass along the first two transect points, whereas biomass in summer was higher than in the other seasons at the third transect point across each site. Belowground biomass appeared to increase consistently as the transect progressed inland, with the exception of fall and winter in Site 2 and fall in Site 3 (Figure 1.10). Biomass at the third point (most inland) was highest in the summer across each of the three transects. Aboveground biomass in

summer and fall was greater than in winter except for Site 3, where measurements were very similar at transect points 1 and 3 across seasons (Figure 1.11).

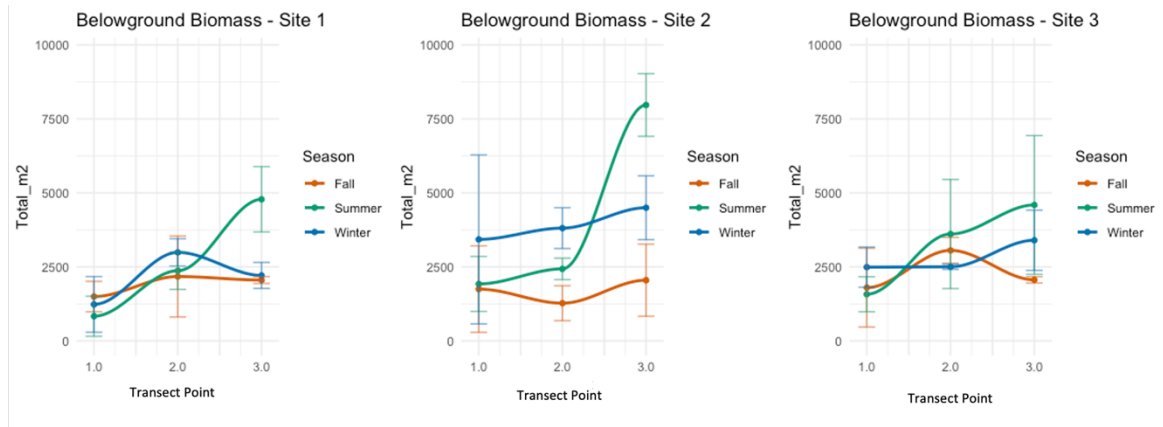


Figure 1.10 *Belowground biomass patterns along the three marsh transects for each season sampled*

Along the x-axis are the transect points, 1 being closest to the water, 3 being furthest upslope. Standard error bars reflect duplicate sample variation.

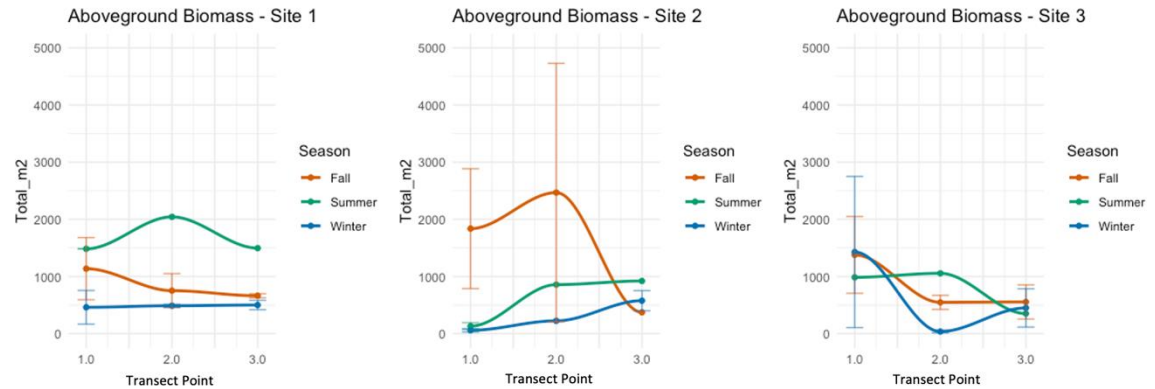


Figure 1.11 *Aboveground biomass patterns along the three marsh transects for each season sampled*

Along the x-axis are the transect points, 1 being closest to the water, 3 being furthest upslope

1.4 Discussion

I observed higher levels of belowground biomass in the western channel of the Pascagoula River, a prediction that was not surprising to me given the history of the two channels. Increased channelization and nutrient loading may be causing a response in the plants to allocate lower amounts of energy to root mass development, as limiting nutrients may be more readily available in the East Channel. Commercial boat traffic is more active in the East Channel due to its dredging for larger vessels, and any non-point sources of nutrients upriver from commercial and agricultural runoff may further deposit nutrients to the marshes in the lower eastern channel.

I found that belowground biomass was usually most concentrated in the first 10 cm of sediment, similar to the findings of previous studies in Louisiana (Turner et al., 2004). Belowground biomass slightly increased in the winter season in both channels, and slightly more in the western channel. This may be due to translocation of aboveground biomass to below surface to better conserve energy during the cold months for regrowth in the next growing season, common at high latitudes but also in northern Gulf of Mexico (Connor & Chmura, 2000; Darby & Turner, 2008a; Gallagher, 1983). Belowground biomass was higher in the West Channel during the winter as well, and the increase in live biomass to deeper depths at these sites may indicate an action by the plants to extract scarcer nutrients (Langley et al., 2013).

While belowground biomass showed patterns of variation between seasons and channels, aboveground biomass patterns were not so clear. Variation between seasons

was low for both channels. The lack of seasonal difference in the live above-ground biomass sampled from Summer, Fall, and Winter is consistent with a Louisiana marsh with a similar climate as my sites in Mississippi (Darby and Turner 2008). Darby and Turner found that their samples collected in December were not as different to fall samples as they were when collected later in the winter. Larger seasonal variability would likely be evident when sampling is conducted in January or February instead of December after more live biomass dies off during the colder season. I would suggest greater gaps in seasonal sampling in future efforts to elucidate this potential variability in the Pascagoula River delta. Belowground biomass relations to NO_x were somewhat unclear. Biomass remained relatively consistent until it decreased with NO_x levels in excess of 2.5 mg/kg. Live biomass was weakly related to inorganic nitrogen, which is similar to prior results for aboveground biomass variation in a Louisiana saltmarsh but contradicts belowground biomass results from the same study (Darby & Turner, 2008b). Nitrogen does indeed have effects on belowground biomass production in mesocosm experimentation (Langley et al., 2013), although my results were not as clear as to nitrogen's effects in the Pascagoula River. I may attribute these results to the collection date of soil chemistry samples (December 2020) where nitrogen levels may be lower, and relationships may be clearer if further sampling is done during peak green biomass season (summer) in the future for comparison, which coincides with increased agricultural activity and runoff. However, my results indicate that Nitrogen may not be a strong factor in biomass productivity in this system.

1.5 Conclusion

I found significant variation in belowground biomass between channels. Winter biomass, the peak season for belowground biomass, was higher in the West Channel than the East Channel. Aboveground biomass did not vary between channel or season. Due to the variation of aboveground biomass between sites, below-aboveground ratios did not vary significantly between seasons or channels. Vertical distribution of belowground biomass did not strongly vary between seasons or channels. Additionally, I found a strong relationship of fall aboveground biomass with elevation. The multiple peaks in biomass with elevation may reflect different dominant species in the vegetation community along the elevation gradients. Belowground biomass was significantly related to NO_x , but the relationship is nonlinear and complex in this wetland ecosystem.

CHAPTER II - EVALUATING THE RESPONSE OF *SAGITTARIA LANCIFOLIA* TO
COMBINED INUNDATION AND NITROGEN ADDITION USING A MARSH
ORGAN

2.1 Introduction

In coastal wetlands, rising sea level can confound the potential benefits of freshwater diversion. The combined effects of freshwater diversion and SLR will change the sediment, salinity, and nutrient dynamics. Understanding how dominant vegetation species respond to the increased inundation is key to predict landscape dynamics resulting from hydrological and sediment diversions, combined with accelerating SLR. However, critical gaps in this understanding arise from relatively limited data available in microtidal estuaries compared to macrotidal estuaries (Janousek et al., 2016; Kirwan et al., 2012; Langley et al., 2013). Difficulties arise when considering the spatial scale for such studies, especially in field experiments where other variables (salinity, soil nutrients) may confound the results of inundation impacts. Coastal wetlands also experience seasonal and interannual variations, another factor that should be considered when planning such field experiments. Multiyear studies that include periodical sampling or vegetation measurements are key to capturing such temporal variability. Plant responses to these various factors include rapid physiological changes over seconds to hours in photosynthesis, osmo- and thermoregulation, which will affect primary productivity and growth rates over days and weeks, often resulting in altered morphological expression over the course of weeks to months.

Inundation-productivity relationships have been studied in a variety of coastal marsh species such as *Spartina alterniflora*, *Spartina patens*, *Juncus roemerianus*, and *Schoenoplectus americanus* (Kirwan et al., 2012; Langley et al., 2013; Li et al., 2018; Morris, 2007; Snedden et al., 2015). Some studies focusing on *S. alterniflora* found a hump-shaped, or parabolic relationship between inundation and productivity, characterizing an optimum inundation period/level for the vegetative growth of this species (Kirwan et al., 2012; Morris, 2007). In another study, *Spartina patens* and *S. alterniflora* responded negatively to increased inundation in southeast Louisiana (Snedden et al., 2015). *S. americanus* was more productive than *S. alterniflora* at lower elevations and higher inundation periods, reflective of a species of higher flood tolerance.

While multiple species of brackish- and saltmarsh plants have had inundation-productivity relationships described using mesocosm analysis, freshwater and other deltaic species have not been studied adequately in the southeastern US. *Sagittaria lancifolia* is a common species found in freshwater wetlands of the northern Gulf of Mexico. While multiple species of arrowhead (*Sagittaria sp.*) grow in the southeastern United States, *S. lancifolia* is expanding its range, while *Sagittaria platyphylla* and *Sagittaria latifolia* are disappearing (Visser et al., 1999). This may be due to the adaptation of *S. lancifolia* to oligohaline (salinity 0-5 ppt) habitats, and more robust below-ground root and tuber growth compared to other congenics (Martin & Shaffer, 2005). *S. lancifolia* is expected to replace more salt-adapted species such as *Spartina patens* and *Juncus roemerianus* as freshwater diversion projects alter the salinity regimes of coastal Louisiana marshes to a fresher ecosystem. However, our understanding on how *S. lancifolia* will be affected by inundation is still limited.

Tidal range and SLR affect coastal saltmarsh species such as *Spartina alterniflora*, and *Juncus roemarianus* differently than more freshwater oriented species such as *Sagittaria lancifolia*. Marsh organ mesocosm studies have been used to predict their inundation-productivity relationships of these saltmarsh species, and responses vary based on species and geographic region. In this chapter I aim to characterize the inundation-productivity relationship of *Sagittaria lancifolia* in the Pascagoula River using a marsh organ *in situ* mesocosm (Langley et al., 2013; Morris, 2007; Snedden et al., 2015). This species-experimental design combination is novel and is valuable to the understanding of fresh-brackish wetland vegetation responses to altered hydrological regimes.

2.1.1 Objectives and Hypotheses

This study aims to:

- 1) Assess the responses of *Sagittaria lancifolia* to inundation and nutrient supplement;
- 2) Understand *S. lancifolia* biomass production with respect to various inundation periods

The hypotheses tested include:

- 1) *Sagittaria lancifolia* will respond negatively to too much or too little inundation (there is an optimum inundation period);
- 2) Morphological responses of the plants in the marsh organ will vary between treatments of percent inundation time;

- 3) Nutrient addition will affect the productivity and morphology of *S. lancifolia* in a marsh organ experiment

2.2 Methods

I constructed a marsh organ to study *Sagittaria lancifolia*'s responses to varying levels of inundation. The marsh organ was situated in a tidally influenced brackish coastal marsh (salinity 0-7 ppt, mean 2.3 ppt) to facilitate both low to no salinity and tidal inundation. I measured a variety of vegetation traits one to two times monthly, including leaf count, longest green leaf length, stem width, leaf width at widest point, and presence or absence of reproductive structures during the growing season. End-of-season plants were collected to quantify above- and belowground biomass.

2.2.1 Study Site

The marsh organ experimental site was chosen to be in the eastern channel of the lower Pascagoula River (Figure 2.1). An ideal site possessed both low salinity (to support the habitat requirements for the desired study species) and tidal influence (to provide variation in inundation times for marsh organ levels). This selected site just south of Interstate 10 has a small salinity range that is fresher than the mouth of the river (0-7 ppt as compared to 10-25 ppt) to support growth of *Sagittaria lancifolia*. The organ was constructed and placed at N 30.434°, W -88.559° in the eastern channel (Figure 2.2).



Figure 2.1 *Marsh organ placement*

Map showing the location of the *Sagittaria lancifolia* marsh organ (red circle) in the Pascagoula River delta and the state of Mississippi (left).



Figure 2.2 *Marsh organ experimental site*

North-facing view from the chosen site for the marsh organ, east margin of the East Channel of the lower Pascagoula River (left). The PVC pipe houses the HOBO water logger to record water level. Marsh organ after construction in July 2020 (right).

The marsh platform at the site, while small, was enough to support the dimensions of the organ (Figure 2.2). The low-marsh edge contains mixtures of *Spartina alterniflora* (10%), *Schoenoplectus tabernaemontani* (5%), and *Sagittaria lancifolia* (85%). Further upslope, the mid-marsh is primarily filled with *Juncus roemerianus*. Old, dead *Taxodium discitichum* and *Pinus sp.* spot the high marsh, which likely perished during saltwater intrusions from previous large storm events, such as Hurricane Katrina. A pair of HOBO water logger (HOBO U20L-04, Onset Computer Corporation) were used to measure the water levels since November 2019 with one sitting on the water bottom and second being suspended above the high water to record compensational atmospheric pressure. Data obtained were used to aid in the design of the marsh organ levels and to incorporate percent inundation time for the duration of the organ experiment.

2.2.2 Marsh Organ Design

The marsh organ design includes six different elevation levels (rows) with 8 replicate pipes in each row (Figure 2.3). Each row had an estimated inundation level of 100%, 80%, 60%, 40%, 20%, and 5% based on the recorded water levels from July to November 2019 using the HOBO logger on site and a nearby NOAA tidal gauge (<https://tidesandcurrents.noaa.gov/ports/ports.html?id=8741533>), with consideration of precipitation, storm surges, and seasonal changes of water levels.

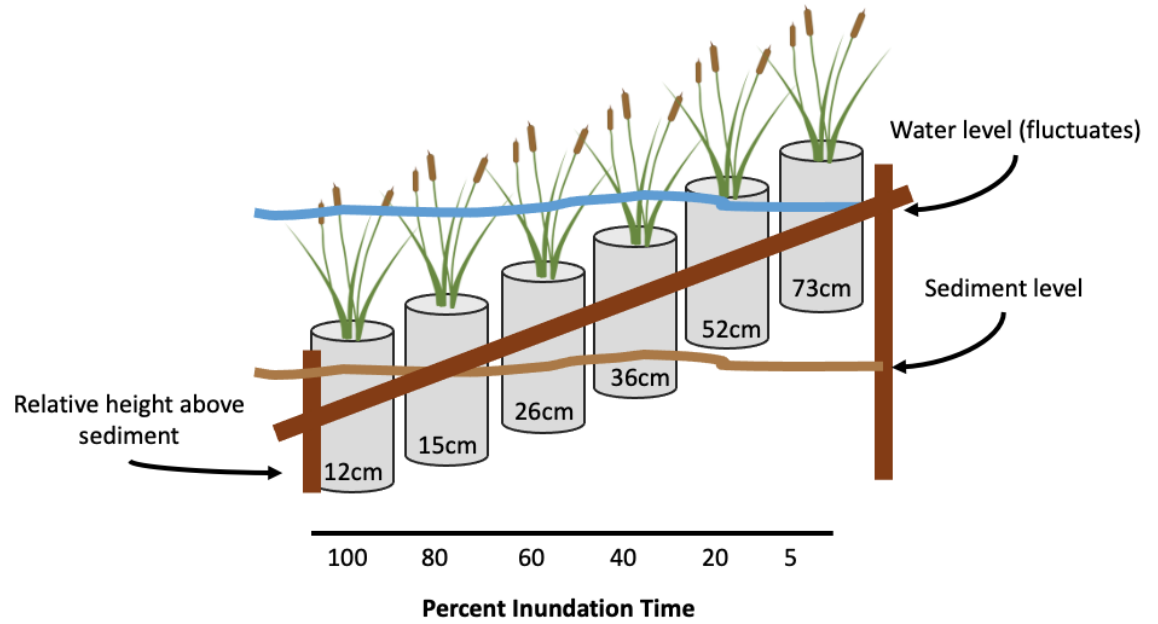


Figure 2.3 *Marsh organ diagram*

Side-view diagram of layout of the marsh organ mesocosm with heights above the sediment surface and the estimated percent inundation time upon construction.

Marsh organ construction was completed in July 2020 with the assistance of Dr. Hailong Huang. I used 15 cm (6 in) diameter PVC pipes at a standard length of 61 cm (24 in). I screwed pipes together according to their respective estimated heights in a matrix in the field. Rows one through four were pushed into the sediment, and we capped the bottoms of the two highest rows with nylon meshing to contain the sediment but allow natural vertical water flow for the higher rows (rows five and six). A wooden frame was constructed around the pipe matrix for stability against river flow, tides, and storm surges. I added and packed local sediment to each pipe to ensure plants would grow at the top opening of the pipe and not subside into the pipe. I then collected *Sagittaria lancifolia* individuals from locations nearby and transplanted one plant into each of the PVC pipes

of the marsh organ in July 2020. We also considered settling of sediment and added extra sediment to the tops of the pipes to account for any gradual compaction.

I measured plant traits at the time of transplanting and then let them acclimate to the new environment for one month before beginning nitrogen addition treatment. In each row, four randomly chosen plants received repeated nitrogen supplements and four did not. I visited the marsh organ on July 14th, July 31st, August 17th, September 4th, September 30th, October 14th, and November 11th in 2020. Based on the method from a similarly designed experiment, I had planned to supplement each of the designated N-enriched pots with 25 grams per m² (0.37 g per pot) at each visit (Langley et al., 2013). I did not make a nutrient supplement solution due to time constraints and facility logistics at the time (lack of access to lab due to COVID-19 related regulations). Instead, I poured 45.5 grams of solid pellets of calcium nitrate directly into the respective pots and buried them with 5 cm of available topsoil within each pipe. This value is about 150x higher than the previous study to and resulted in a trial to examine the effects of large amounts of extraneous nitrogen input on the plants. I began adding supplements on September 4th and at each of the two subsequent visits until the plants were collected on November 11.

2.2.3 Monitoring and Biomass Collection

I conducted plant growth and morphological measurements every two-four weeks, including leaf counts, longest green leaf length, width at widest point, stem width, and presence-absence of reproductive structures. I ignored leaves that were fully senesced at the time of measurement in the leaf counts. Since each stem of *S. lancifolia* terminates in only one leaf, leaf count is equal to stem count. At the conclusion of one growing season, I sampled half of the plants by removing above- and below-ground biomass from a

random selection of control and nutrient-added pipes. Biomass was separated into live and dead material and dried in an oven at 70° C for three days. To obtain below-ground biomass measurements after harvest, I cleaned and sorted collected samples by hand. Samples were filtered through a 1 mm mesh to remove inorganic matter under running water. I placed washed roots back into their respective bags and stored at them 4 °C.

Washed roots were separated into live and dead biomass. Color, turgidity, and buoyancy were all characteristics I used to identify live biomass. Biomass that sank into the water, was dull in coloration, or was soft (loss of turgidity) was considered dead. I placed the roots into pre-weighed aluminum trays. I then dried the roots in an oven at 70 °C (~ 3 to 5 days) until constant weight (Wu et al., 2020). Samples were weighed again to obtain dry weight.

2.2.4 Statistical Analyses

To derive effects of inundation and nutrient addition on plant measurements, I applied a linear mixed-effects model with marsh organ row, presence or absence of nutrient addition, initial condition, and time since planting as fixed factors, and individual plant as the random factor. To account for the nonlinear effect of inundation on belowground, aboveground, and below-above ratios on harvested live biomass at end of growing season, I also applied a quadratic term of marsh organ rows as the fixed factor. I used linear regression with inundation and squared inundation as covariates.

2.3 Results

At the end of the 2020 growing season (November), water levels in each marsh organ row had percent inundation times that varied slightly from the 2019 estimated percentages. Rows 1 and 2 (the lowest elevations) were inundated for the same amount of

time, 99.5%. Rows 3, 4, and 5 were inundated 95.2%, 85.7%, and 55.3% of the time respectively. The highest and driest row 6 was inundated for only 16.6% of the time (Figure 2.4). Inundation times in 2020 varied from the predicted 2019 levels likely due to multiple storm surges during the fall hurricane season.

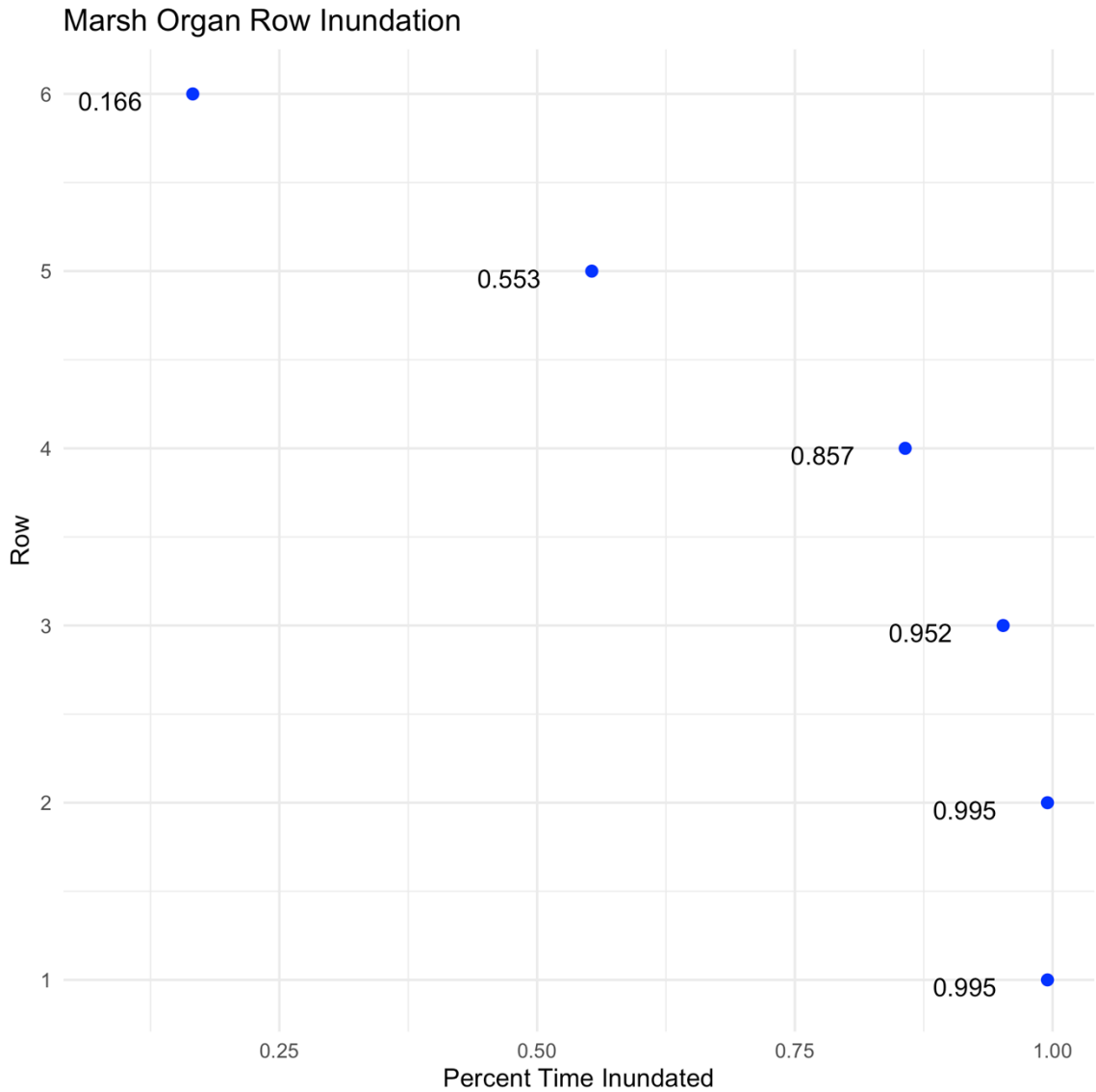


Figure 2.4 *Percent Time inundated for the six rows in the marsh organ*

Percentage of time inundated for the six rows in the marsh organ, calculated from on-site water logger data from July 2020 to November 2020. Row six was the highest elevation.

Aboveground morphological characteristics showed no differences between nutrient treatments plants and control plants (Figure 2.5; Table 2.1). At the end of the 2020 growing season, leaf counts were higher in dry rows (5 and 6) and lower in

inundated rows (1 and 2). The inverse was true for leaf length; on average, the leaves in Row 6 were the shortest while they were the longest in Row 1. Stem width and leaf width were both highest in Row 4 at the end of the growing season, whereas all other rows widths were similarly low (Figure 2.6, Table 2.1). The initial condition of the plant significantly affected the measured metrics (except leaf width). After plotting the trends over time, I saw a general trend of longer but fewer leaves in higher inundation (Figure 2.6). Only the effect of inundation on leaf length was significant (Table 2.1). The linear mixed effects model predicted a significant negative effect of added nutrients on both leaf length and stem width, but a slightly positive significant effect on leaf count. Higher rows (decreased inundation) significantly decreased leaf length.

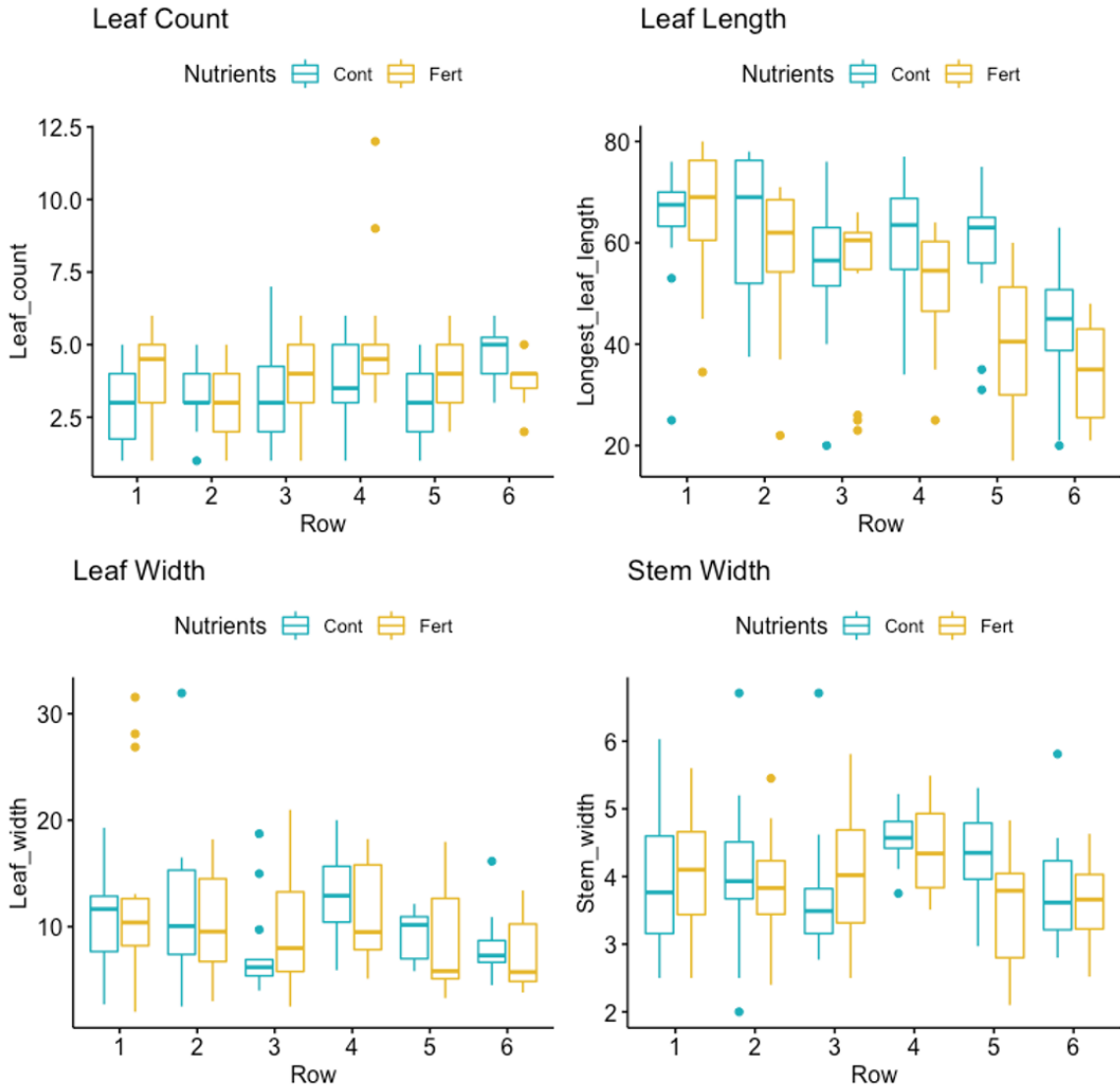


Figure 2.5 Comparison of overall vegetation characteristics between inundation rows with and without nitrate additions

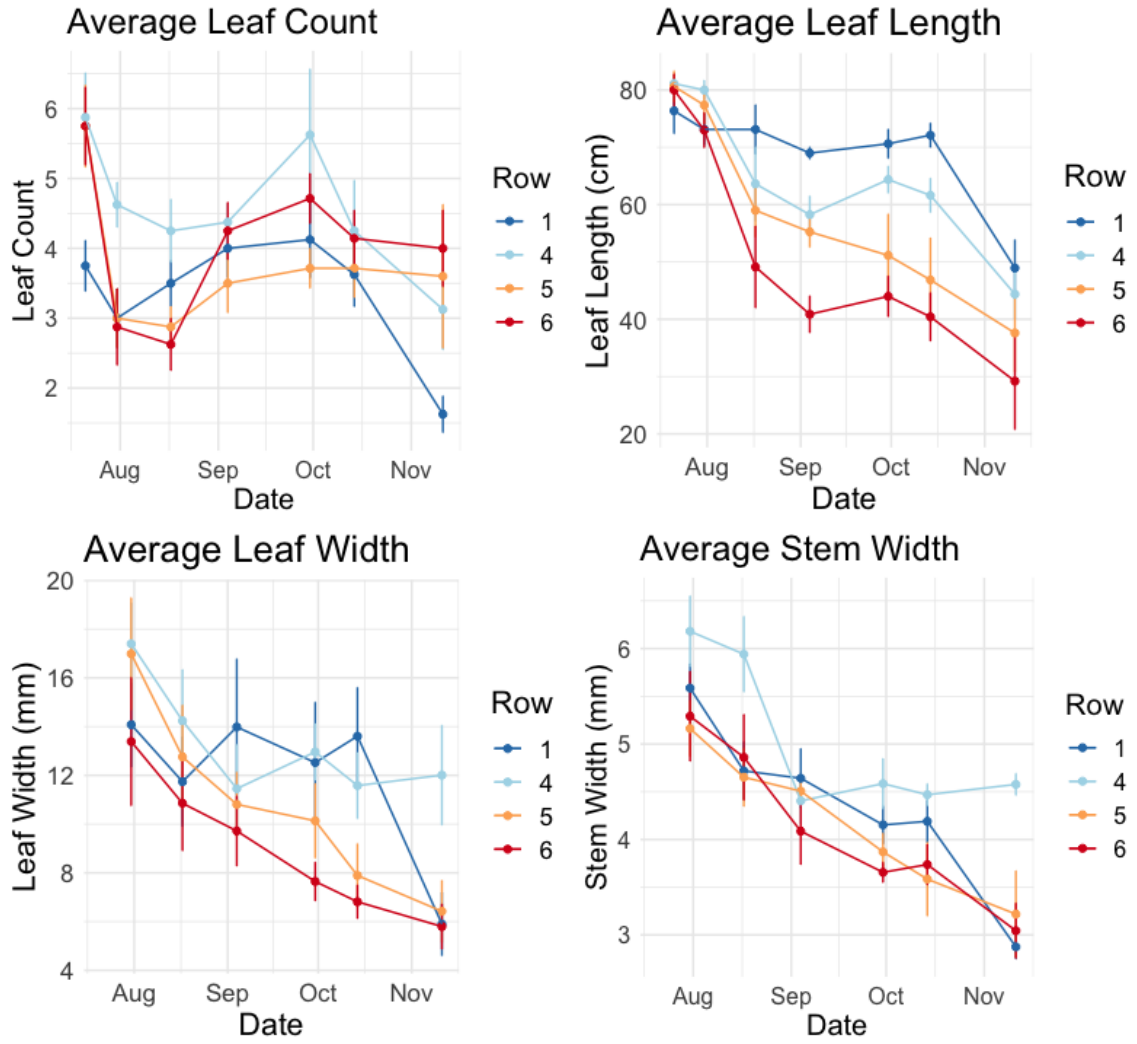


Figure 2.6 Average vegetation characteristics per row during the summer and fall 2020

Table 2.1 *Mixed-Effects Model results for leaf count, longest leaf length, leaf width, and stem width*

<i>Leaf Count</i>					
Random Effect					
~ 1 Individual	Intercept	Residual			
Standard Deviation	0.51	1.318			
Fixed Effects	Value	Standard Error	<i>t</i>	<i>p</i>	
Intercept	2.82	0.392	7.196	< 0.0001	
Pre_cond	0.151	0.075	2.029	0.049	
Time	-0.007	0.003	-2.855	0.005	
Nutrient	0.765	0.218	4.516	< 0.001	
Row	0.0375	0.07	0.533	0.597	

<i>Leaf Length</i>					
Random Effect					
~ 1 Individual	Intercept	Residual			
Standard Deviation	4.207	11.818			
Fixed Effects	Value	Standard Error	<i>t</i>	<i>p</i>	
Intercept	66.333	8.626	7.69	< 0.0001	
Pre_cond	0.277	0.106	2.614	0.013	
Time	-0.236	0.023	-10.311	< 0.0001	
Nutrient	-4.877	1.906	-2.558	0.011	
Row	-4.006	0.555	-7.219	< 0.0001	

<i>Leaf Width</i>					
Random Effect					
~ 1 Individual	Intercept	Residual			
Standard Deviation	3.681	4.044			
Fixed Effects	Value	Standard Error	<i>t</i>	<i>p</i>	
Intercept	15.228	5.391	2.825	0.007	
Pre_cond	0.039	0.067	0.591	0.557	

Time	-0.087	0.008	-10.553	< 0.0001
Nutrient	0.807	0.189	1.024	0.307
Row	-0.625	0.346	-1.81	0.077

Stem Width

Random Effect				
~ 1 Individual	Intercept	Residual		
Standard Deviation	0.517	0.685		
Fixed Effects	Value	Standard Error	<i>t</i>	<i>p</i>
Intercept	3.871	0.787	4.921	< 0.0001
Pre_cond	0.027	0.01	2.735	0.009
Time	-0.021	0.001	-15.091	< 0.0001
Nutrient	-0.274	0.129	-3.658	0.035
Row	-0.076	0.05	-1.81	0.131

After harvesting, both aboveground and belowground biomass displayed a hump-shaped relation with inundation levels/rows showing an optimum inundation time existed for live biomass of *Sagittaria lancifolia* (Figure 2.7). As such, I included a quadratic term of rows in the mixed effects models for biomass (Table 2.2). The biomass in Row 4 (inundated 86% of the time) was highest for both aboveground vegetation and belowground root mass. Rows 3 and 5 (inundated 95% and 55%) were similar in above- and belowground biomass and were the second-highest levels for belowground biomass. While aboveground biomass was lower in Row 6 than Row 1, the opposite was true for belowground biomass. Nutrient addition only had a significant positive effect on leaf count and a significant negative effect on leaf length. The quadratic term for percent inundation time was a significant effect on both belowground and aboveground production but had no significant effect on the below-above ratio (Table 2.2)

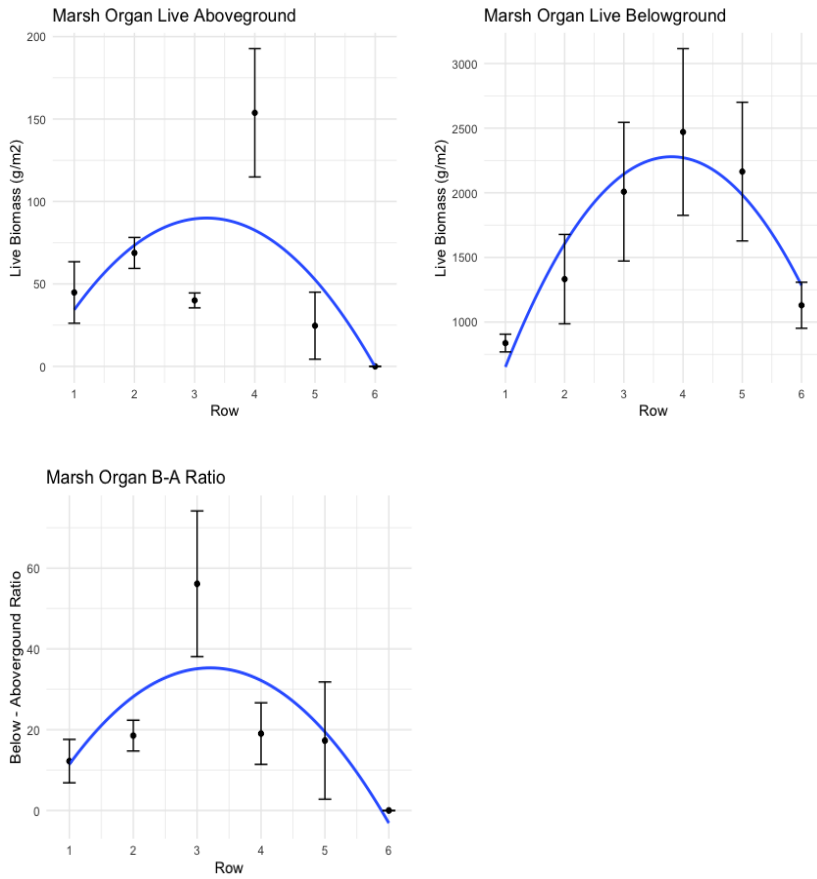


Figure 2.7 Above and belowground biomass of *Sagittaria lancifolia* after one growing season

Standardized to g/m². Blue line is a fitted quadratic model

Table 2.2 *Linear regression of end-of-season live biomass with respect to percent inundation time*

<i>Marsh Organ Belowground Biomass</i>					
Predictor	<i>Df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>p</i>
Percent Inundation	1	117741	117741	0.140	0.712
Perc_inund^2	1	5729176	5729176	6.795	0.016
Residuals	23	19390959	843085		
<i>Marsh Organ Aboveground Biomass</i>					
Predictor	<i>Df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>p</i>
Percent Inundation	1	19198	19198	6.304	0.020
Perc_inund^2	1	3258	3258	1.070	0.312
Residuals	23	70047	3046		
<i>Below-Above Ratio</i>					
Predictor	<i>Df</i>	Sum of Squares	Mean Square	<i>F</i>	<i>p</i>
Percent Inundation	1	319	319.2	0.398	0.538
Perc_inund^2	1	6	5.7	0.007	0.934
Residuals	14	11229	802.1		

The applied quadratic model predicted a marsh organ plant's maximum biomass to be 2453.72 g/m² belowground and 71.44 g/m² aboveground in Row 4. This row in the marsh organ was closest to these optimal inundation times for both above- and belowground biomass at the end of the growing season.

2.4 Discussion

Sagittaria lancifolia productivity, based on aboveground and belowground biomass, displayed an obvious parabolic response to inundation during one growing season in a marsh organ. The species' resilience to varying hydrologic characteristics,

including salinity, inundation, and nutrification is not unlike previous findings (Kenow et al., 2018; Martin & Shaffer, 2005; Pezeshki et al., 1987). The plants withstood alterations in salinity due to multiple fall storms (i.e., Hurricane Zeta) similarly to the findings of Martin and Schaffer (2005). Recorded surface water salinity during visits to the marsh organ site ranged from 0-7 ppt, and the abundance of *S. lancifolia* seemed unabated by mild variations in salinity (Figure 2.8).



Figure 2.8 *Photo of the marsh organ site pre-construction in mid-July 2020*

Sagittaria lancifolia is the dominant vegetation.

The most inundated rows in the marsh organ exhibited the longest leaves after the first few weeks. This may be a response by the plant to allocate energy towards vertical growth to reach above the water level to be able to continue gas exchange and

photosynthesis. The average leaf length of row 1, the most inundated row, is especially divergent when compared to row 6, the driest row. Although the most inundated leaves were longer (vertical direction), the biomass of those plants (3-dimension metric) was lower compared to the middle rows of the marsh organ, whose biomass plant was near the optimum of the inundation-productivity relationship. This shows a tradeoff of growth between vertical and horizontal directions. When the inundation level becomes higher, growth is optimized in the vertical direction, but at the large expense of horizontal growth (widths of all stems and leaves) therefore the biomass was not as great.

In situ S. lancifolia at the study site mostly grew at the lowest marsh organ level, which was between 0 and 12 cm above the site sediment surface level, or at site sediment surface level. This suggests more suitable *S. lancifolia* habitat may occur further north in the channel with fresher waters or further upslope from the water's edge with high elevation where productivity may be greater, similar to that of the optimum biomass levels in Row 4 (36 cm above site sediment surface level). Marsh organ experimentation and comparison to natural-growing *S. lancifolia* along the salinity gradient of the lower Pascagoula River could provide clearer patterns to this species' growth and productivity relative to salinity and elevation gradients.

Although nutrient addition can affect biomass allocation in various wetland species (Ket et al., 2011; Langley et al., 2013), my study did not note any trend for the effect of nitrate additions to marsh organ pots. This was likely due to the form and amount in which the nutrients were added as solid pellets. I also added a very high amount of nitrate ($\sim 3000 \text{ g/m}^2$) for the size of the area each plant was in. Though the pellets were applied in a concentrated manner and buried below 5 cm of sediment,

diffusion of the nutrients with the rising tide likely homogenized the nitrogen addition effects along the entire organ, affecting both nutrient amended and control plants similarly. Close proximity of the plants in the organ likely exacerbated this bias and made comparisons among treatments less meaningful. Ability to manipulate pellets into liquid solution was not possible due to facility restrictions during the Covid-19 pandemic. Future studies should consider techniques with different control and amended organs separated by some distance to reduce intermixing on the tide when the nutrients diffuse into the surrounding water, as well as applications of more appropriate nitrogen concentrations.

2.5 Conclusion

Sagittaria lancifolia responds similarly to other brackish or saltmarsh sedge and grass species tested in marsh organs previously (Kirwan & Guntenspergen, 2015; Langley et al., 2013; Morris, 2007; Snedden et al., 2015). Inundation-productivity relationships for above- and belowground biomass can be described using a quadratic function. This knowledge is valuable in the understanding of this fresh-brackish water coastal marsh species' responses to changing hydrological regimes, potentially including freshwater diversion. I encourage further study and experimental development to parse out the effects on aboveground morphology and the effects of various nutrient additions (e.g., nitrogen and phosphorus), perhaps in more extreme scenarios (e.g., wider tide ranges, inundation above leaf height limits).

CHAPTER III - IMPACTS, SCALABILITY, AND SUGGESTIONS FOR FUTURE RESEARCH

In my previous two chapters, I described the effects of inundation and nitrogen on vegetation productivity using a field-sampling approach and an *in situ* controlled mesocosm experiment. Belowground biomass in the West Channel was significantly greater than in the East Channel when compared in the winter, the season of peak belowground biomass. Vertical distribution of belowground biomass was greatest in the upper 10 cm of sediment depth. The distribution of aboveground biomass varied moderately between channels, but seasonal differences were small.

I found similar inundation effects on vegetation at two different scales in the Pascagoula River delta. Across the whole lower delta, inundation played a role in aboveground biomass with multiple optima strongly correlated to the fall sampling period. There existed multiple peaks of green biomass in relation to inundation, which may suggest an optimum for different species or groups of species that fill niches along the marsh elevation gradient (Brewer & Grace, 1990; Ewanchuk & Bertness, 2004; Rasser et al., 2013). I noted similar effects of inundation on *Sagittaria lancifolia* in my field mesocosm experiment, with aboveground, belowground, and the below-above ratio responding to inundation quadratically. *S. lancifolia* responded similarly to sedge and grass species studied in marsh organs previously (Kirwan & Guntenspergen, 2015; Langley et al., 2013; Morris, 2007).

Since *S. lancifolia* is a primarily freshwater wetland species, its response to inundation is of interest with respect to future sea level rise (SLR) in the Pascagoula River delta. The species was most prevalent in my northernmost sites in both channels

where salinity was lower (4, 5 and 6; see Appendix 2). Its habitat preference along this salinity range (latitudinal band) may serve as an interesting site to monitor for long-term SLR effects. Since the species only withstands low amounts of salinity (< 7 ppt), its spatial distribution may begin migrating upslope and upriver as its current distribution becomes more inundated and saltier over time. Long-term biomass monitoring of the species or aerial remote-sensing surveys of its coverage may be valuable in tracking species-specific coverage changes every decade.

S. lancifolia is present in Louisiana near freshwater diversion projects, and its response to inundation has applications to management efforts for that state's coastal marshes. Marsh vegetation should not shift much in areas where *S. lancifolia* is dominant, as it proved tolerant to increased levels of inundation over a growing season in my study. The pulsation strategy of Mississippi River freshwater diversion efforts (Caernarvon Freshwater Diversion Project 2003, lacoast.gov) to mimic seasonal flood periods should not reduce overall biomass of *S. lancifolia* dominated marshes directly downstream of diversion outputs. Its distribution may increase by replacing salt-tolerant species where salinity decreases after freshwater diversion outputs. If possible, monitoring of coverage of this species in LA restoration areas could corroborate the mechanistic findings of my study and the species resilience in those marshes. Therefore, this marsh species will likely respond differently in the future to effects of SLR in Mississippi, and effects of freshwater diversion in Louisiana.

Nitrogen's impact was less clear across two study approaches. For the Pascagoula Delta system, NO_x present in sediment only significantly related to the belowground biomass in the fall, but the relation is nonlinear and complex. This may be due to

variability in species biomass production at each season. Belowground biomass remained relatively consistent with increasing NO_x content, until a point where biomass greatly decreased with values greater than 2.5 mg/kg before it increased again when NO_x exceeded 3.8 mg/kg. Future studies focusing on seasonal collection of soil chemistry and vegetation biomass would likely clarify some of the relationships across the Pascagoula Delta.

Nitrogen's impact in my marsh organ approach was less clear due to the application method, where high N enrichment was experienced by both control and fertilized plants. Due to this treatment bias, any measured relationship to biomass and morphology makes the scalability of this environmental character difficult. In the marsh organ, future reapplication of inorganic nitrogen with more refined techniques and level of nitrogen input would likely produce cleaner results with clearer relationship between the study species and the application of nutrients.

Although marsh organ construction and design are difficult, the result of this and previous studies prove the technique to be valuable for the fine-scale evaluation of a species response to inundation. In future studies, I'd suggest simplification of the design. Wood and hardware (screws, bolts, brackets, braces) made up for about half of the total cost of the organ, and bulk acquisition of pipes would be more cost-efficient as well. I'd have liked to try utilization of longer PVC pipes based on prior estimations of water level at the given site. Water should be monitored for at least a year to account for seasonal variability in mean tide height and amplitudes. Pipes should then be measured and cut based on the required height above sediment level, where the pipes are then pushed into the sediment (1-2 meters) for stability. This will ensure that 1) there is no need for the

extra effort of building a complicated frame around the organ, and 2) that the sediment will not be able to wash out from the bottoms of the pipes and allow for expedited subsidence.

APPENDIX A – Supplemental Data for the Thesis

Table A.1 *Soil chemistry data from Pascagoula River sampling sites, December 2020*

Sample	Depth (cm)	Bulk Density (g/cm³)	Moisture Content (%)	Soil pH	Soil Conductivity (μS)
PE1 0-10	0-10	1.26	26.21	7.88	4730.00
PE1 10-20	10-20	0.85	28.72	5.98	6073.00
PE1 20-30	20-30	0.56	31.50	6.12	5838.00
PE2 0-10	0-10	0.64	51.40	6.74	4573.00
PE2 10-20	10-20	0.33	65.30	6.35	5000.00
PE2 20-30	20-30	0.29	69.80	6.56	5126.00
PE3 0-10	0-10	0.97	26.94	7.29	2664.00
PE3 10-20	10-20	1.01	26.81	7.44	2608.00
PE3 20-30	20-30	0.75	25.60	6.75	2175.00
PE4 0-10	0-10	0.55	50.88	6.84	3428.00
PE4 10-20	10-20	0.43	59.19	4.94	4559.00
PE4 20-30	20-30	0.31	64.94	5.50	3885.00
PE5 0-10	0-10	0.47	54.76	6.86	2590.00
PE5 10-20	10-20	0.50	49.51	7.11	1832.00
PE5 20-30	20-30	0.49	49.99	7.23	2107.00
PE6 0-10	0-10	0.86	34.19	7.24	1499.00
PE6 10-20	10-20	0.69	37.63	7.30	1471.00
PE6 20-30	20-30	0.43	45.21	7.18	1734.00
PW-1.1 0-10	0-10	0.76	39.06	7.41	1134.00
PW-1.1 10-20	10-20	0.88	35.78	6.70	1580.00
PW-1.1 20-30	20-30	0.95	30.83	6.52	1196.00
PW2 0-10	0-10	0.66	41.45	7.41	1861.00
PW2 10-20	10-20	0.94	33.31	7.22	1916.00
PW2 20-30	20-30	0.92	42.92	7.23	1417.00
PW3 (PWT 2-1)	0-10	0.47	49.64	7.51	2750.00
PW3 (PWT 2-1)	10-20	0.49	59.17	7.35	3503.00
PW3 (PWT 2-1)	20-30	0.37	61.06	7.10	3385.00
PW4 0-10	0-10	0.48	50.05	7.23	2159.00
PW4 10-20	10-20	0.31	63.01	5.51	3471.00
PW4 20-30	20-30	0.34	60.18	5.02	3258.00
PW5 0-10	0-10	0.72	41.43	7.39	3451.00
PW5 10-20	10-20	0.95	31.35	7.13	3768.00
PW5 20-30	20-30	0.63	29.44	7.04	3130.00
PWT 1-1 0-10	0-10	0.65	47.51	6.33	3713.00
PWT 1-1 10-20	10-20	0.70	44.92	6.62	4026.00

PWT 1-1 20-30	20-30	0.53	41.84	6.65	3484.00
PWT 1-2 0-10	0-10	0.38	67.01	6.90	5023.00
PWT 1-2 10-20	10-20	0.48	58.42	6.28	3639.00
PWT 1-2 20-30	20-30	0.39	62.04	7.08	4707.00
PWT 1-3 0-10	0-10	0.57	57.31	7.01	4872.00
PWT 1-3 10-20	10-20	0.32	66.06	7.36	5933.00
PWT 1-3 20-30	20-30	0.20	68.12	7.10	5732.00
PWT 2-2 0-10	0-10	0.36	61.79	7.47	3663.00
PWT 2-2 10-20	10-20	0.25	71.45	7.24	5024.00
PWT 2-2 20-30	20-30	0.28	68.11	7.01	4191.00
PWT 2-3 0-10	0-10	0.28	71.77	7.32	3353.00
PWT 2-3 10-20	10-20	0.29	69.43	6.69	3509.00
PWT 2-3 20-30	20-30	0.15	73.89	6.40	3555.00
PWT 3-1 0-10	0-10	0.73	40.33	6.28	1431.00
PWT 3-1 10-20	10-20	0.54	51.16	6.57	1898.00
PWT 3-1 20-30	20-30	0.50	56.21	6.44	2209.00
PWT 3-2 0-10	0-10	0.23	72.84	6.86	2630.00
PWT 3-2 10-20	10-20	0.31	67.31	6.44	2770.00
PWT 3-2 20-30	20-30	0.24	71.09	5.98	2565.00
PWT 3-3 0-10	0-10	0.19	76.26	6.90	1837.00
PWT 3-3 10-20	10-20	0.21	73.70	6.03	2409.00
PWT 3-3 20-30	20-30	0.18	77.82	6.17	2037.00

Sample	Soil Salinity	Loss on Ignition	SRP	NOx	NH4+
	(ppt)	(%)	(mg/kg dry weight)		
PE1 0-10	2.54	1.89	0.00	0.94	5.81
PE1 10-20	3.31	1.84	0.00	1.08	2.17
PE1 20-30	3.18	3.48	0.00	1.13	6.25
PE2 0-10	2.45	8.50	0.00	1.80	2.55
PE2 10-20	3.02	16.34	0.00	2.50	0.00
PE2 20-30	2.79	17.77	0.00	2.91	0.00
PE3 0-10	1.38	1.28	0.00	1.10	1.36
PE3 10-20	1.35	0.59	0.00	1.32	1.43
PE3 20-30	1.12	0.50	0.00	0.87	1.52
PE4 0-10	1.8	8.11	0.00	1.77	0.00
PE4 10-20	2.44	23.00	0.00	2.10	0.00
PE4 20-30	2.06	18.43	0.00	1.41	0.00
PE5 0-10	1.34	6.97	0.00	3.48	3.14
PE5 10-20	0.93	7.28	0.00	1.70	1.45
PE5 20-30	1.08	8.25	0.00	2.10	1.24

PE6 0-10	0.76	2.89	0.00	0.79	0.00
PE6 10-20	0.74	3.95	0.00	0.00	1.33
PE6 20-30	0.88	7.73	0.00	2.05	0.00
PW-1.1 0-10	0.56	3.47	0.00	0.00	1.08
PW-1.1 10-20	0.8	3.25	0.00	0.27	1.35
PW-1.1 20-30	0.6	2.08	0.00	0.99	1.11
PW2 0-10	0.95	3.46	0.00	0.64	0.00
PW2 10-20	0.98	2.66	0.00	0.40	0.00
PW2 20-30	0.71	3.15	0.00	0.65	0.00
PW3 (PWT 2-1)	1.43	5.07	0.00	2.03	2.62
PW3 (PWT 2-1)	1.85	7.35	0.00	1.27	0.00
PW3 (PWT 2-1)	1.78	9.38	0.00	1.35	2.58
PW4 0-10	1.11	6.45	0.00	1.76	3.17
PW4 10-20	1.83	11.61	0.00	1.04	2.69
PW4 20-30	1.71	11.21	0.00	2.82	3.35
PW5 0-10	1.82	4.16	0.00	1.63	3.42
PW5 10-20	2	2.28	0.00	1.47	1.72
PW5 20-30	1.64	2.41	0.00	1.33	2.28
PWT 1-1 0-10	1.97	5.02	0.00	1.53	0.00
PWT 1-1 10-20	2.14	4.53	0.00	1.27	0.00
PWT 1-1 20-30	1.84	3.88	0.00	1.27	1.65
PWT 1-2 0-10	2.71	8.45	0.00	2.17	1.54
PWT 1-2 10-20	1.93	9.70	0.00	2.37	0.00
PWT 1-2 20-30	2.53	11.18	0.00	2.16	1.38
PWT 1-3 0-10	2.62	10.45	0.00	1.65	0.00
PWT 1-3 10-20	3.23	13.15	0.00	1.66	0.00
PWT 1-3 20-30	3.12	14.11	0.00	1.54	0.00
PWT 2-2 0-10	1.94	8.41	0.00	1.04	5.69
PWT 2-2 10-20	2.71	13.73	0.00	1.06	5.21
PWT 2-2 20-30	2.23	13.56	0.00	1.13	0.00
PWT 2-3 0-10	1.76	13.17	0.00	6.90	0.00
PWT 2-3 10-20	1.85	15.74	0.00	3.89	1.87
PWT 2-3 20-30	1.88	21.14	0.00	0.00	1.88
PWT 3-1 0-10	0.72	3.66	0.00	0.84	0.00
PWT 3-1 10-20	0.97	5.93	0.00	0.00	1.44
PWT 3-1 20-30	1.14	7.15	0.00	0.00	2.03
PWT 3-2 0-10	1.37	16.84	0.00	0.00	1.90
PWT 3-2 10-20	1.44	14.44	0.00	0.00	2.04
PWT 3-2 20-30	1.33	17.37	0.00	1.08	5.10
PWT 3-3 0-10	0.94	20.01	0.00	1.80	0.00
PWT 3-3 10-20	1.25	19.05	0.00	2.28	3.48
PWT 3-3 20-30	1.04	25.35	0.00	2.82	0.00

Table A.1 (continued)

Sample	Beta-Glucosidase (B-gluc)	N-acetyl-glucosaminidase (NAG)	Phosphatase (Phos)	Winter Surface Water Salinity (ppt)	Elevation (m)
Enzyme Activity (nmol/gdw/h)					
PE1 0-10	400.5151	504.40	400.19	1	0.33
PE1 10-20	494.277	339.59	632.23	1	0.33
PE1 20-30	1054.031	576.68	408.25	1	0.33
PE2 0-10	1016.014	675.48	1561.02	3	0.50
PE2 10-20	1736.609	1417.96	1283.84	3	0.50
PE2 20-30	1750.274	1330.91	2266.15	3	0.50
PE3 0-10	136.0916	167.40	203.57	2	0.45
PE3 10-20	103.9657	110.14	154.40	2	0.45
PE3 20-30	67.89227	84.57	133.52	2	0.45
PE4 0-10	3638.037	1361.28	1901.43	1	0.14
PE4 10-20	4226.773	1905.82	2118.33	1	0.14
PE4 20-30	5626.771	1496.61	2290.94	1	0.14
PE5 0-10	3049.359	1187.09	814.15	0	-0.25
PE5 10-20	4809.422	938.85	744.17	0	-0.25
PE5 20-30	4253.988	1077.46	891.60	0	-0.25
PE6 0-10	1018.587	503.46	443.91	0	0.12
PE6 10-20	3421.891	642.23	708.81	0	0.12
PE6 20-30	2806.654	649.32	1006.18	0	0.12
PW-1.1 0-10	3633.625	712.12	844.10	0	NA
PW-1.1 10-20	1710.712	598.97	608.21	0	NA
PW-1.1 20-30	2954.753	523.75	444.50	0	NA
PW2 0-10	9128.415	1271.59	1169.63	0	0.12
PW2 10-20	3979.939	689.11	836.34	0	0.12
PW2 20-30	2631.88	614.34	757.85	0	0.12
PW3 (PWT 2-1)	1054.462	886.65	881.49	0	-0.17
PW3 (PWT 2-1)	2293.022	1240.14	914.43	0	-0.17
PW3 (PWT 2-1)	5749.37	1541.35	2288.13	0	-0.17
PW4 0-10	8343.588	1802.40	1103.62	1	0.09
PW4 10-20	3315.175	1186.75	1989.05	1	0.09
PW4 20-30	3400.527	1183.56	1706.78	1	0.09
PW5 0-10	722.7745	561.81	542.55	1	NA
PW5 10-20	2407.865	564.32	393.02	1	NA
PW5 20-30	388.8248	229.64	327.10	1	NA

PWT 1-1 0-10	4111.68	741.77	1397.24	1	NA
PWT 1-1 10-20	4054.008	536.38	590.36	1	NA
PWT 1-1 20-30	3491.405	771.78	526.69	1	NA
PWT 1-2 0-10	4400.345	2878.01	3248.61	NA	0.63
PWT 1-2 10-20	1985.166	1405.66	2245.79	NA	0.63
PWT 1-2 20-30	2405.27	1057.93	2256.77	NA	0.63
PWT 1-3 0-10	5462.665	2433.02	2291.59	NA	0.34
PWT 1-3 10-20	2821.023	2342.80	2078.90	NA	0.34
PWT 1-3 20-30	2558.114	1835.28	1788.56	NA	0.34
PWT 2-2 0-10	5415.58	2107.15	1898.42	NA	0.19
PWT 2-2 10-20	10824.04	3252.95	3286.91	NA	0.19
PWT 2-2 20-30	12898.03	3026.97	2544.84	NA	0.19
PWT 2-3 0-10	2935.676	2464.19	1549.14	NA	0.33
PWT 2-3 10-20	7101.094	5188.89	4068.77	NA	0.33
PWT 2-3 20-30	8948.717	4903.59	4803.95	NA	0.33
PWT 3-1 0-10	4463.589	993.68	1754.23	0	NA
PWT 3-1 10-20	6733.868	845.09	2911.05	0	NA
PWT 3-1 20-30	10011.95	1570.80	3921.58	0	NA
PWT 3-2 0-10	14502.23	3710.93	5018.78	NA	0.66
PWT 3-2 10-20	10251.47	3257.04	4544.89	NA	0.66
PWT 3-2 20-30	7689.707	3468.70	3987.59	NA	0.66
PWT 3-3 0-10	12829.65	4679.73	5759.98	NA	0.48
PWT 3-3 10-20	8177.614	3730.04	4962.35	NA	0.48
PWT 3-3 20-30	8528.644	3832.73	5041.77	NA	0.48

Table A.2 *Live aboveground biomass organized by site and species*

Channel	Season	Site	Species	Live Biomass (g/m ²)
East	Summer	1	<i>Juncus roemerianus</i>	915.33
East	Summer	1	<i>Spartina alterniflora</i>	1098.67
East	Summer	2	<i>Spartina alterniflora</i>	94.22
East	Summer	2	<i>Spartina patens</i>	82.67
East	Summer	3	<i>Juncus roemerianus</i>	1157.93
East	Summer	3	<i>Salvinia sp.</i>	1.33
East	Summer	3	<i>Spartina alterniflora</i>	503.41
East	Summer	4	<i>Juncus roemerianus</i>	587.11
East	Summer	4	Other	8.00
East	Summer	4	<i>Sagittaria lancifolia</i>	505.78
East	Summer	4	<i>Salvinia sp.</i>	10.22

East	Summer	4	<i>Spartina alterniflora</i>	373.33
East	Summer	5	<i>Juncus roemerianus</i>	375.33
East	Summer	5	Other	77.78
East	Summer	5	<i>Salvinia sp.</i>	0.44
East	Summer	5	<i>Schoenoplectus tabernaemonani</i>	538.67
East	Summer	5	<i>Spartina alterniflora</i>	21.78
East	Summer	6	Other	0.89
East	Summer	6	<i>Sagittaria lancifolia</i>	1342.67
East	Summer	6	<i>Spartina alterniflora</i>	304.00
East	Fall	1	<i>Spartina alterniflora</i>	414.22
East	Fall	1	<i>Spartina patens</i>	221.33
East	Fall	2	<i>Juncus roemerianus</i>	872.44
East	Fall	2	Other	20.22
East	Fall	3	<i>Spartina alterniflora</i>	793.78
East	Fall	4	<i>Juncus roemerianus</i>	531.33
East	Fall	4	<i>Spartina alterniflora</i>	171.11
East	Fall	5	<i>Juncus roemerianus</i>	176.89
East	Fall	5	Other	29.33
East	Fall	5	<i>Sagittaria lancifolia</i>	79.11
East	Fall	5	<i>Spartina alterniflora</i>	562.44
East	Fall	6	<i>Fuireneae</i>	330.00
East	Fall	6	<i>Sagittaria lancifolia</i>	51.11
East	Fall	6	<i>Spartina alterniflora</i>	34.67
East	Winter	1	<i>Juncus roemerianus</i>	293.11
East	Winter	1	<i>Spartina alterniflora</i>	631.78
East	Winter	2	<i>Juncus roemerianus</i>	649.78
East	Winter	2	Other	1.33
East	Winter	2	<i>Spartina alterniflora</i>	656.89
East	Winter	3	<i>Spartina alterniflora</i>	969.11
East	Winter	4	<i>Juncus roemerianus</i>	680.67
East	Winter	4	<i>Spartina alterniflora</i>	7.33
East	Winter	4	<i>Spartina patens</i>	16.00
East	Winter	5	<i>Phragmites sp.</i>	1795.11
East	Winter	5	<i>Spartina alterniflora</i>	563.33
East	Winter	6	<i>Phragmites sp.</i>	328.44
East	Winter	6	<i>Spartina alterniflora</i>	340.44
West	Summer	1	<i>Juncus roemerianus</i>	205.04

West	Summer	1	<i>Schoenoplectus tabernaemonani</i>	647.11
West	Summer	1	<i>Spartina alterniflora</i>	698.22
West	Summer	2	<i>Juncus roemerianus</i>	77.78
West	Summer	2	Other	63.56
West	Summer	2	<i>Sagittaria lancifolia</i>	213.33
West	Summer	2	<i>Spartina alterniflora</i>	277.78
West	Summer	2	<i>Spartina patens</i>	101.78
West	Summer	3	<i>Juncus roemerianus</i>	11.56
West	Summer	3	<i>Sagittaria lancifolia</i>	1466.67
West	Summer	4	<i>Juncus roemerianus</i>	76.74
West	Summer	4	Other	12.44
West	Summer	4	<i>Sagittaria lancifolia</i>	272.30
West	Summer	4	<i>Salvinia sp.</i>	8.67
West	Summer	4	<i>Spartina alterniflora</i>	824.59
West	Summer	5	Other	12.00
West	Summer	5	<i>Sagittaria lancifolia</i>	40.89
West	Summer	5	<i>Salvinia sp.</i>	431.78
West	Summer	5	<i>Typha latifolia</i>	554.22
West	Summer	5	<i>Zizaniopsis miliacea</i>	664.67
West	Fall	1	<i>Juncus roemerianus</i>	887.56
West	Fall	1	<i>Schoenoplectus sp.</i>	1052.00
West	Fall	1	<i>Spartina alterniflora</i>	79.56
West	Fall	2	<i>Juncus roemerianus</i>	147.56
West	Fall	2	Other	16.00
West	Fall	2	<i>Sagittaria lancifolia</i>	80.00
West	Fall	2	Seagrass	16.89
West	Fall	2	<i>Spartina alterniflora</i>	220.22
West	Fall	3	Cyperaceae	95.56
West	Fall	3	<i>Juncus roemerianus</i>	22.22
West	Fall	3	Other	10.22
West	Fall	3	<i>Sagittaria lancifolia</i>	80.89
West	Fall	3	<i>Schoenoplectus sp.</i>	316.00
West	Fall	3	<i>Spartina alterniflora</i>	29.78
West	Fall	3	<i>Spartina patens</i>	37.78
West	Fall	4	<i>Juncus roemerianus</i>	484.89
West	Fall	4	<i>Sagittaria lancifolia</i>	216.00
West	Fall	4	<i>Spartina alterniflora</i>	152.89

West	Fall	5	Other	297.33
West	Fall	5	<i>Sagittaria lancifolia</i>	20.00
West	Winter	1	<i>Juncus roemerianus</i>	865.11
West	Winter	1	<i>Spartina alterniflora</i>	170.22
West	Winter	1	<i>Spartina patens</i>	127.11
West	Winter	2	<i>Juncus roemerianus</i>	362.67
West	Winter	2	Other	15.56
West	Winter	2	<i>Spartina alterniflora</i>	40.00
West	Winter	3	<i>Juncus roemerianus</i>	14.89
West	Winter	3	<i>Schoenoplectus sp.</i>	43.78
West	Winter	4	<i>Alternanthera philoxeroides</i>	28.00
West	Winter	4	<i>Juncus roemerianus</i>	1048.22
West	Winter	5	<i>Alternanthera philoxeroides</i>	373.56
West	Winter	5	<i>Zizaniopsis miliacea</i>	276.44

LITERATURE CITED

- Barbier, E. B., Georgiou, I. Y., Enchelmeyer, B., & Reed, D. J. (2013). The Value of Wetlands in Protecting Southeast Louisiana from Hurricane Storm Surges. *PLOS ONE*, 8(3), e58715. <https://doi.org/10.1371/journal.pone.0058715>
- Blum, M. D., & Roberts, H. H. (2009). Drowning of the Mississippi Delta due to insufficient sediment supply and global sea-level rise. *Nature Geoscience*, 2(7), 488–491.
- Brewer, J. S., & Grace, J. B. (1990). Plant community structure in an oligohaline tidal marsh. *Vegetatio*, 90(2), 93–107.
- Connor, R., & Chmura, G. L. (2000). Dynamics of above-and belowground organic matter in a high latitude macrotidal saltmarsh. *Marine Ecology Progress Series*, 204, 101–110.
- Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387(6630), 253–260. <https://doi.org/10.1038/387253a0>
- Couvillion, B. R., Beck, H., Schoolmaster, D., & Fischer, M. (2017). *Land area change in coastal Louisiana (1932 to 2016)* (Report No. 3381; Scientific Investigations Map). USGS Publications Warehouse. <https://doi.org/10.3133/sim3381>
- Darby, F. A., & Turner, R. E. (2008a). Below- and Aboveground *Spartina alterniflora* Production in a Louisiana Salt Marsh. *Estuaries and Coasts*, 31(1), 223–231. <https://doi.org/10.1007/s12237-007-9014-7>

- Darby, F. A., & Turner, R. E. (2008b). Below- and Aboveground Biomass of *Spartina alterniflora*: Response to Nutrient Addition in a Louisiana Salt Marsh. *Estuaries and Coasts*, *31*(2), 326–334. <https://doi.org/10.1007/s12237-008-9037-8>
- Dynesius, M., & Nilsson, C. (1994). Fragmentation and flow regulation of river systems in the northern third of the world. *Science*, *266*(5186), 753–762.
- Ewanchuk, P. J., & Bertness, M. D. (2004). Structure and organization of a northern New England salt marsh plant community: *Northern New England salt marsh plant communities*. *Journal of Ecology*, *92*(1), 72–85. <https://doi.org/10.1111/j.1365-2745.2004.00838.x>
- Gallagher, J. L. (1983). Seasonal patterns in recoverable underground reserves in *Spartina alterniflora* Loisel. *American Journal of Botany*, *70*(2), 212–215.
- Hopkinson, C. S., Gosselink, J. G., & Parrando, R. T. (1978). Aboveground Production of Seven Marsh Plant Species in Coastal Louisiana. *Ecology*, *59*(4), 760–769. <https://doi.org/10.2307/1938780>
- Hopkinson, C. S., Gosselink, J. G., & Parrando, R. T. (1980). Production of Coastal Louisiana Marsh Plants Calculated from Phenometric Techniques. *Ecology*, *61*(5), 1091–1098. <https://doi.org/10.2307/1936828>
- Jankowski, K. L., Törnqvist, T. E., & Fernandes, A. M. (2017). Vulnerability of Louisiana’s coastal wetlands to present-day rates of relative sea-level rise. *Nature Communications*, *8*(1), 1–7.
- Janousek, C., Buffington, K., Thorne, K., Guntenspergen, G., Takekawa, J., & Dugger, B. (2016). Potential effects of sea-level rise on plant productivity: Species-

- specific responses in northeast Pacific tidal marshes. *Marine Ecology Progress Series*, 548, 111–125. <https://doi.org/10.3354/meps11683>
- Kenow, K. P., Gray, B. R., & Lyon, J. E. (2018). Flooding tolerance of *Sagittaria latifolia* and *Sagittaria rigida* under controlled laboratory conditions: Flooding tolerance of *Sagittaria* under laboratory conditions. *River Research and Applications*, 34(8), 1024–1031. <https://doi.org/10.1002/rra.3337>
- Ket, W. A., Schubauer-Berigan, J. P., & Craft, C. B. (2011). Effects of five years of nitrogen and phosphorus additions on a *Zizaniopsis miliacea* tidal freshwater marsh. *Aquatic Botany*, 95(1), 17–23. <https://doi.org/10.1016/j.aquabot.2011.03.003>
- Kirwan, M. L., Christian, R. R., Blum, L. K., & Brinson, M. M. (2012). On the Relationship Between Sea Level and *Spartina alterniflora* Production. *Ecosystems*, 15(1), 140–147. <https://doi.org/10.1007/s10021-011-9498-7>
- Kirwan, M. L., & Guntenspergen, G. R. (2015). Response of plant productivity to experimental flooding in a stable and a submerging marsh. *Ecosystems*, 18(5), 903–913.
- Kirwan, M. L., Guntenspergen, G. R., D’Alpaos, A., Morris, J. T., Mudd, S. M., & Temmerman, S. (2010). Limits on the adaptability of coastal marshes to rising sea level. *Geophysical Research Letters*, 37(23).
- Langley, A. J., Mozdzer, T. J., Shepard, K. A., Hagerty, S. B., & Patrick Megonigal, J. (2013). Tidal marsh plant responses to elevated CO₂, nitrogen fertilization, and sea level rise. *Global Change Biology*, 19(5), 1495–1503. <https://doi.org/10.1111/gcb.12147>

- Li, R., Yu, Q., Wang, Y., Wang, Z. B., Gao, S., & Flemming, B. (2018). The relationship between inundation duration and *Spartina alterniflora* growth along the Jiangsu coast, China. *Estuarine, Coastal and Shelf Science*, 213, 305–313.
<https://doi.org/10.1016/j.ecss.2018.08.027>
- Martin, S. B., & Shaffer, G. P. (2005). *Sagittaria* Biomass Partitioning Relative to Salinity, Hydrologic Regime, and Substrate Type: Implications for Plant Distribution Patterns in Coastal Louisiana, United States. *Journal of Coastal Research*, 211, 167–174. <https://doi.org/10.2112/02110.1>
- Mitsch, W. J., & Gosselink, J. G. (2000). The value of wetlands: Importance of scale and landscape setting. *Ecological Economics*, 35(1), 25–33.
[https://doi.org/10.1016/S0921-8009\(00\)00165-8](https://doi.org/10.1016/S0921-8009(00)00165-8)
- Morris, J. T. (2007). Estimating net primary production of salt marsh macrophytes. In *Principles and standards for measuring primary production* (pp. 106–119).
- Morris, J. T., Barber, D. C., Callaway, J. C., Chambers, R., Hagen, S. C., Hopkinson, C. S., Johnson, B. J., Megonigal, P., Neubauer, S. C., Troxler, T., & Wigand, C. (2016). Contributions of organic and inorganic matter to sediment volume and accretion in tidal wetlands at steady state. *Earth's Future*, 4(4), 110–121.
<https://doi.org/10.1002/2015EF000334>
- Partyka, M. L., & Peterson, M. S. (2008). Habitat quality and salt-marsh species assemblages along an anthropogenic estuarine landscape. *Journal of Coastal Research*, 24(6 (246)), 1570–1581.

- Pezeshki, S., DeLaune, R., & Patrick Jr, W. (1987). Effects of flooding and salinity on photosynthesis of *Sagittaria lancifolia*. *Marine Ecology Progress Series. Oldendorf*, 41(1), 87–91.
- Rasser, M. K., Fowler, N. L., & Dunton, K. H. (2013). Elevation and Plant Community Distribution in a Microtidal Salt Marsh of the Western Gulf of Mexico. *Wetlands*, 33(4), 575–583. <https://doi.org/10.1007/s13157-013-0398-9>
- Schile, L. M., Callaway, J. C., Morris, J. T., Stralberg, D., Parker, V. T., & Kelly, M. (2014). Modeling Tidal Marsh Distribution with Sea-Level Rise: Evaluating the Role of Vegetation, Sediment, and Upland Habitat in Marsh Resiliency. *PLOS ONE*, 9(2), e88760. <https://doi.org/10.1371/journal.pone.0088760>
- Shirley, L. J., & Battaglia, L. L. (2006). Assessing vegetation change in coastal landscapes of the northern Gulf of Mexico. *Wetlands*, 26(4), 1057–1070. [https://doi.org/10.1672/0277-5212\(2006\)26\[1057:AVCICL\]2.0.CO;2](https://doi.org/10.1672/0277-5212(2006)26[1057:AVCICL]2.0.CO;2)
- Silliman, B. R., He, Q., Angelini, C., Smith, C. S., Kirwan, M. L., Daleo, P., Renzi, J. J., Butler, J., Osborne, T. Z., & Nifong, J. C. (2019). Field experiments and meta-analysis reveal wetland vegetation as a crucial element in the coastal protection paradigm. *Current Biology*, 29(11), 1800–1806.
- Snedden, G. A., Cretini, K., & Patton, B. (2015). Inundation and salinity impacts to above- and belowground productivity in *Spartina patens* and *Spartina alterniflora* in the Mississippi River deltaic plain: Implications for using river diversions as restoration tools. *Ecological Engineering*, 81, 133–139. <https://doi.org/10.1016/j.ecoleng.2015.04.035>

- Thomas, N., Simard, M., Castañeda-Moya, E., Byrd, K., Windham-Myers, L., Bevington, A., & Twilley, R. R. (2019). High-resolution mapping of biomass and distribution of marsh and forested wetlands in southeastern coastal Louisiana. *International Journal of Applied Earth Observation and Geoinformation*, *80*, 257–267.
<https://doi.org/10.1016/j.jag.2019.03.013>
- Tripathee, R., & Schäfer, K. V. R. (2015). Above- and Belowground Biomass Allocation in Four Dominant Salt Marsh Species of the Eastern United States. *Wetlands*, *35*(1), 21–30. <https://doi.org/10.1007/s13157-014-0589-z>
- Turner, R. E. (1997). Wetland Loss in the Northern Gulf of Mexico: Multiple Working Hypotheses. *Estuaries*, *20*(1), 1. <https://doi.org/10.2307/1352716>
- Turner, R. E., Swenson, E. M., Milan, C. S., & OSWALD, T. A. (2004). Below-ground biomass in healthy and impaired salt marshes. *Ecological Research*, *19*(1), 29–35.
- Visser, J. M., Sasser, C. E., Chabreck, R. H., & Linscombe, R. (1999). Long-term vegetation change in Louisiana tidal marshes, 1968–1992. *Wetlands*, *19*(1), 168–175.
- Waldron, M. C., Carter, G. A., & Biber, P. D. (2021). Using Aerial Imagery to Determine the Effects of Sea-Level Rise on Fluvial Marshes at the Mouth of the Pascagoula River (Mississippi, USA). *Journal of Coastal Research*, *37*(2), 389–407.
<https://doi.org/10.2112/JCOASTRES-D-20-00037.1>
- Watson, E. B., & Byrne, R. (2009). Abundance and diversity of tidal marsh plants along the salinity gradient of the San Francisco Estuary: Implications for global change ecology. *Plant Ecology*, *205*(1), 113. <https://doi.org/10.1007/s11258-009-9602-7>

Wu, W., Biber, P., & Bethel, M. (2017). Thresholds of sea-level rise rate and sea-level rise acceleration rate in a vulnerable coastal wetland. *Ecology and Evolution*, 7(24), 10890–10903. <https://doi.org/10.1002/ece3.3550>

Wu, W., Biber, P., Mishra, D. R., & Ghosh, S. (2020). Sea-level rise thresholds for stability of salt marshes in a riverine versus a marine dominated estuary. *Science of The Total Environment*, 718, 137181. <https://doi.org/10.1016/j.scitotenv.2020.137181>