THE EFFECTS OF INCREASED NaCl SALINIZATION ON RIPARIAN PLANT PRODUCTIVITY AND DECOMPOSITION PROCESSES

by

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ABSTRACT

NaCl salinization in inland ecosystems is increasing globally due to anthropogenic activity and may alter organism abundances and ecosystem processes. Because sodium is an essential nutrient for heterotrophs but not required by autotrophs, this salinization can alter species abundance and performance. Riparia may be particularly sensitive to increases in salinization. Here, I examined the Sodium Subsidy-Stress Hypothesis, which states that deviations from an organism's optimal nutrient target can decrease abundance and performance, by studying the effects of NaCl salinization on plant chemistry, productivity, and decomposition rates in riparia. First, I selected three focal common riparian plants (water oak: *Quercus nigra*, cottonwood: *Populus deltoides*, and kale: *Brassica* sp.) to test the prediction that riparian plants will uptake and store sodium in their tissues. Plants received either 300ml low-level (0.05%) NaCl solution or just H_2O weekly. After three months, plants watered with NaCl solutions were ~2-3 times more enriched in sodium than controls but had no effects on productivity. The sodium-enriched plant tissues (leaves and stems) were then used to test the prediction that sodium-enriched plant tissues will decompose faster in riparia. These plant tissues along with artificial substrates (100% cellulose sponges either enriched in 0.05% NaCl or just H_2O) were placed in three and five inland riparia respectively in Texas and Louisiana. However, decomposition rates did not differ between sodium-enriched and control treated plant and artificial tissues for any species or tissue type at any of the locations. Lastly, I tested the impacts of a gradient of

NaCl addition on plant biochemistry and productivity in a common woody riparian species (water oak: *Q. nigra*). Oaks were watered with 0%, 0.05%, 0.1%, and 0.4% NaCl water solutions. After three months I found that oaks watered with higher NaCl solutions had higher tissues sodium concentrations and reduced leaf biomass and stem growth. Increases in NaCl salinization can lead to alterations in plant biochemistry as well as decreases in plant species abundances and productivity. Similar decomposition rates in sodium-enriched and non-enriched leaf litter suggest that either detrital communities in south-central United States may not be sodium-limited or detrital committees are not sensitive to differences in leaf litter sodium concentrations. Riparia are seeing increases in global salinization, which can alter dead organic matter quality and quantity.

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DEDICATION

To my wife Rebecca,

You have been my rock throughout this process. You provided the encouragement and motivation I needed these past two years.

I love you.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER 1

INTRODUCTION

1.1 Sodium Availability

Nutrient availability is heterogenous and impacts ecosystem processes and biodiversity (Stallard & Edmond, 1981; Williams & Fraústo da Silva, 1996). Nutrient availability controls organism abundance and activity and can ultimately impact population and community structure and ecosystem function (Filipiak et al., 2017; Williams & Fraústo da Silva, 1996). When essential nutrients are found at optimal levels, population abundances can increase and ecosystem processes are often positively impacted (Aumann & Emlen, 1965; Prather et al., 2018). However, decreased nutrient availability can reduce an organism's ability to perform essential physiological functions (Kaspari & Powers, 2016). When nutrients are available at levels lower than the requirements of organisms, organism behavior can be influenced in two main ways: 1) organisms may expend more energy to acquire these nutrients, or 2) they may decrease their activity or growth to conserve their energy (Belovsky & Jordan, 1981; Dudley et al., 2012). In both cases, organism abundances often decrease, and ecosystem processes slow down (Botkin et al., 1973; Odum et al., 1979).

Sodium is an essential nutrient that plays a major role in species abundance and activity (Schulkin, 1991). Like all other nutrients, sodium is unevenly dispersed across the

earth (Stallard & Edmond, 1981). Much of the sodium available in terrestrial ecosystems comes from NaCl found in ocean aerosols and forms a sharp decreasing gradient moving inland (Botkin et al., 1973; Kaspari et al., 2008; Stallard & Edmond, 1981). Terrestrial ecosystems typically lack larger concentrations of NaCl because ocean spray only reaches approximately 100km past coastlines, which creates a sharp decreasing sodium gradient moving inland from coastlines (Bravo & Harms, 2017; Kaspari et al., 2008; NADP, 2017). Much of the inland sodium comes from geological and animal processes via salt licks, urine, and NaCl enriched clay (Doughty et al., 2016; Dudley et al., 2012; Emmons & Stark, 1979). These dispersed sodium-rich pockets within a landscape of sodium limitation typically have local impacts on organismal activity and behavior and ecosystem functions. For instance, frugivorous bats in the Amazon rely on collpas, which are mineral rich clay deposits, to meet their sodium requirements and often congregate at these collpas (Bravo et al., 2010). Beyond natural sodium sources, anthropogenic activities are adding large quantities of sodium via NaCl to many ecosystems globally. Mining, agricultural practices (irrigation, fertilization, and animal excrement), and road salting are some of the main contributors of NaCl salinization in inland ecosystems (Kaushal et al., 2005; Rengasamy, 2006). These increases can alter organism abundance, community structure, and ecosystem processes (Aumann & Emlen, 1965; Jia et al., 2015; Kaspari, 2020).

1.2 Sodium Requirements for Organisms

1.2.1 Sodium in Animals

Sodium is considered an essential nutrient for all heterotrophs, influencing many physiological functions such as nerve signaling, muscle contractions, and osmoregulation (Geerling & Loewy, 2008; Kaspari et al., 2008; Schulkin, 1991; Weiss, 2008). Sodium

requirements vary among species, sex, and across phenology and ontogeny (Arms et al., 1974; Rothman et al., 2008). Females during reproductive stages often have the largest sodium demands (Belovsky & Jordan, 1981; Bravo et al., 2008; Ganguli et al., 1969). Because most inland ecosystems lack sufficient quantities of sodium to meet all animal requirements, sodium limitation for animals is evident in many terrestrial systems (Bravo & Harms, 2017; Kaspari et al., 2009; NADP, 2017). When animals are sodium-limited, they may expend large amounts of energy searching for sodium (Bravo et al., 2008; Dudley et al., 2012; Schulkin, 1991). When sodium availability increases in sodium-limited environments, organism abundances and activity can increase (Clay et al., 2014; Ganguli et al., 1969). Increases in environmental sodium concentrations can increase invertebrate abundances and activity (Clay et al., 2014; Prather et al., 2018; Welti et al., 2019). Low-level increases in NaCl salinization may benefit heterotroph populations and activity. Conversely, too much sodium may decrease individual organism health and eventually population abundances (Dahl & Heine, 1961; Haight & Weller, 1961).

1.2.2 Sodium in Plants

Unlike for heterotrophs, sodium is not an essential nutrient for most autotrophs, and sodium tolerance in plants is species-specific (Munns & Tester, 2008; Kronzucker et al., 2013). For many plants, even low-level additions of sodium can quickly become toxic (Parida & Das, 2005; Zhu, 2007). Sodium stress can alter plant physiology by inhibiting photosynthetic rates, reducing potassium absorption, disrupting essential enzyme activities, and interfering with osmoregulation, all of which can alter plant tissue biochemistry (Bazihizina et al., 2012; Blumwald et al., 2000). The effects of sodium toxicity in plants can lead to decreased growth or mortality (Munns & Termaat, 1986).

Although sodium is toxic to most plants, some plants have the ability to use sodium to replace potassium in a limited capacity when potassium availability is insufficient (Kronzucker et al., 2013; Maathuis, 2014; Wakeel et al., 2011). Certain plants, such as sugar beets and broccoli, are more productive when sodium is present in the soil (Wakeel et al., 2011). Because sodium tolerance in plants is species specific, increased soil salinization can impact plant species differently. A majority of research regarding the effects of sodium on plant productivity focuses on agricultural crops, leaving a large gap in knowledge on the impacts of sodium on plants in other ecosystems (Daei et al., 2009; Salachna et al., 2017). Large scale increases in salinization can negatively impact plant productivity on the ecosystem level. However, low-level salinization may lead to increased productivity in some plant species. Changes in global levels of sodium may lead to long-term decreases in plant productivity and ecosystem processes such as decomposition.

1.2.3 Optimal Nutrient Ranges in Organisms

All organisms have an optimal nutrient intake target, and any deviations from this optimal range can have adverse effects on the organism's physiological functions (Odum et al., 1979; Sterner and Elser, 2002; Raubenheimer et al., 2009). When sodium availability is below an organism's optimal range, that organism will not be able to perform essential functions such as osmoregulation (Geerling & Loewy, 2008). Sodium limitation across a community has the potential to alter ecosystem processes. The Sodium Ecosystem Respiration (SER) hypothesis posits that when sodium is limited, increases in sodium can positively impact animal activity and abundance (Kaspari et al., 2009). However, this hypothesis focuses on sodium only as a limiting nutrient and does not consider the effects of sodium when it is readily available. If nutrients are higher than an organism's optimal

range, that organism can experience stress or toxicity such as enzyme suppression or osmotic stress (Odum et al., 1979; Wichern et al., 2006). The Sodium Subsidy-Stress (SSS) hypothesis states that increases in sodium will increase organism activity (subsidize performance) to some optimum threshold, after which, increased access to sodium causes stress, and decreases performance, and can eventually become toxic (Odum et al., 1979; Entrekin et al., 2019). However, sodium requirements are species-specific and any given increase in salinization may alter sodium availability to be above or below a given species' optimum. Increasing salinization can have positive or negative impacts on ecosystems depending on background NaCl concentrations. Because heterotrophs require sodium for physiological functions, salinization in sodium-limited environments may increase activity and abundance of animals (Aumann & Emlen, 1965; Risch et al., 2016; Welti et al., 2019). Conversely, autotrophs typically do not require sodium and could face stress with an increase of salinization (Munns & Termaat, 1986; Blumwald et al., 1999). Together, overall community structure may change as plant abundance decrease and animal abundances increase. This change in community structure can alter which nutrients are limiting in ecosystems such as carbon, nitrogen, or phosphorous.

1.3 Riparian Ecosystems

The majority of research on how salinization impacts ecosystem processes comes from agricultural, (sub)tropical rainforests, and grassland systems (Clay et al., 2014; Dudley et al., 2012; Kaspari et al., 2014; Prather et al., 2018; Risch et al., 2016; Seastedt & Crossley, 1981; Welti et al., 2019). However, the impacts of salinization on ecosystems such as riparia, which may be particularly sensitive to NaCl salinization, have been largely overlooked. Riparian ecosystems influence freshwater quality and act as buffers between

terrestrial and aquatic ecosystems (Naiman et al., 1993). Riparian vegetation, especially long-lived woody plants, filter excess nutrients from the soil, shade streams, and provide nutrient inputs (Naiman et al., 1993). Due to anthropogenic activity, riparian ecosystems, and by extension aquatic ecosystems, are experiencing increased salinization (Kaushal et al., 2018). Increased terrestrial salinization can increase sodium concentrations in streams, raising mortality in aquatic biota and lowering overall water quality (Kaushal et al., 2005).

NaCl salinization may threaten stream systems through altering riparian processes. Three main pathways exist in which sodium can pass through riparia and ultimately enter a stream system: 1) terrestrial deposition of NaCl can runoff directly into a stream, 2) plants can absorb NaCl from the soil and sodium enriched dead organic matter can be deposited in both terrestrial and aquatic systems, and 3) decomposers can consume NaCl and increase nutrient cycling, which then leaches into the stream via the soil (Entrekin et al., 2019). Increases in aquatic salinization via pathways 2 and 3 are a direct result of altered terrestrial processes. Increased sodium can result in decreased plant productivity and may reduce a plant's ability to filter excess nutrients from the soil (Dosskey et al., 2010; Zhu, 2007). Sodium uptake by plants can also reduce overall biomass production and change tissue biochemistry, potentially changing decomposition processes by altering the quality and quantity of dead organic matter (Ayres et al., 2009; Ji et al., 2020). The second and third pathways have only recently been studied, leaving a large gap in knowledge concerning increases in NaCl and how it impacts riparian processes.

1.4 Decomposition and Nutrient Cycling

Nutrient exchange between riparian and freshwater systems are in part mediated by decomposition. The process of decomposition is essential for nutrient cycling, because

nutrients like, carbon (C), nitrogen (N), potassium (K), and phosphorous (P) that would otherwise be immobilized are mineralized. Through decomposition in riparia, previously immobilized nutrients are either made available for plant and animal uptake or leach through the soil and into streams or groundwater (Hättenschwiler et al., 2005; Parton et al., 2007). Aboveground systems (green food webs: based on living biomass) and belowground systems (brown food webs: based on dead biomass) are linked because plants depend on detrital communities to decompose dead organic matter and supply them with available forms of nutrients. In turn, detrital communities rely on plants to deposit organic matter that supplies these communities with nutrients for survival (Wardle, 2002). Decomposition is driven by microbes (largely fungi) and detritivores (mostly microinvertebrates) (Moore et al., 1988; Scheu & Setala, 2002; Hättenschwiler et al., 2005). Decomposition rates depend heavily on the nutritional value of dead organic matter, the biodiversity of the leaf litter, and the abundance of shredders in the detrital community (Hättenschwiler et al., 2005; Bruder et al., 2014).

With increases of global NaCl salinization, plant productivity and biochemistry may be altered. Experimental increases in soil sodium concentrations increase plant tissue sodium concentrations (Borer et al., 2019). Previous studies have demonstrated that plants in riparian areas under experimental sodium addition accumulate salts in their tissues (Gruntz, unpublished data). Plant tissue sodium concentrations differ among species, and generally level off over time after some threshold is reached (Welti et al., 2019). An increase of sodium in plant tissue can also lead to a change in food quantity and quality for detritivores, altering processes such as decomposition (Risch et al., 2016).

Increased sodium concentrations may reduce the overall quality and quantity of plant biomass, altering nutrient availability in detrital systems. Small changes in leaf litter biochemistry can decrease decomposition rates because detritovores and microbes specialize in consuming litter found in their local environments (Ayres et al., 2009; Ji et al., 2020). However, many studies have demonstrated that NaCl additions (0.05% - 1.5%) increase detritivore and microinvertebrate abundances and speed up decomposition processes (Clay et al., 2014; Kaspari et al., 2014; Jia et al., 2015; Welti et al., 2019). These studies added NaCl solutions directly onto litter and soil, acting as a subsidy for detritivores and microinvertebrates but potentially acting as a stressor for microbes. Microbes have been shown to be particularly sensitive to increases in sodium concentrations (Allison et al., 2013; Zhang et al., 2019). Risch et al. (2016) found that, in a coastal tropical rainforest, artificial substrate enriched with 5% NaCl solution decomposed faster than artificial substrates enriched with 0%, 0.5%, 1%, and 2.5% NaCl solutions. Using sodium-enriched plant tissue and substrates may limit a sodium stress effect and would test how sodium-enrichment of plants impacts decomposition processes, but studies using these methods are currently lacking.

To understand how salinization impacts decomposition rates (either as a subsidy or stressor) in sodium-limited riparia, I conducted a decomposition experiment using sodium-enriched plant tissues across a diversity of plant species and artificial leaves. I tested the hypothesis that sodium-enriched leaf and stem tissues will impact decomposition rates in riparian systems. Specifically, I predicted that sodium-enriched tissues will decompose faster in riparia than tissues that are not sodium-enriched. Three separate riparian plant species (*Quercus nigra*, *Populus deltoides*, and *Brassica* sp.) were enriched for three

months with either reverse osmosis (RO) water or a 0.05% NaCl solution to generate sodium-enriched plant tissues. Plant tissues were then collected and placed in five different riparia that spanned a gradient of sodium availability, along with artificial substrates, for 3 to 9 months to determine the decomposition rate.

1.5 Sodium Uptake in Riparian Plants

Plants have large impacts on ecosystem functions, especially in riparia, which act as a buffer between terrestrial and aquatic ecosystems (Naiman et al., 1993). Root systems absorb nutrients from the soil and help reduce excess nutrients like sodium from leaching further into the soil. Plants play an important role in water quality by limiting the amount of sodium that reaches a stream (Dosskey et al., 2002). Plants also provide habitat and structure to communities above- and belowground, and negative changes to their quality and quantity can decrease ecosystem processes such as nutrient cycling (Ayres et al., 2009; Dosskey et al., 2010). Soil nutrient concentrations like N, P, and K tend to increase plant productivity, while nutrients like sodium tend to decrease plant productivity (Marschner, 2011). Overall plant productivity depends on the concentrations of these nutrients because plants typically uptake nutrients in relation to the concentration of that nutrient in the surrounding soil (Maathuis, 2014). Because sodium is not an essential nutrient for autotrophs and can quickly become harmful (Parida & Das, 2005; Subbarao et al., 2003), increases in environmental sodium can negatively impact plants in riparia.

The majority of research has been on herbaceous plants, specifically crops (Daei et al., 2009; Salachna et al., 2017; Subbarao et al., 2003). However, long-lived woody plants are likely to have just as large or larger influence on communities and ecosystem functions. Water oak (*Quercus nigra*) is an abundant tree species in the Fagaceae family and is

common in riparian corridors and bottomlands in the southeastern United States (Vozzo et al., 1990). Woody plants, including water oaks, supply riparia with large quantities of dead organic matter, providing nutrients to the base of both green and brown food webs (Burton & Samuelson, 2005; Vozzo et al., 1990; Wallace et al., 1997). Woody plants also filter nutrients from the soil and influence water quality (Tabacchi et al., 1998). However, little research has focused on how sodium impacts these plants. Negative effects of salinization on riparian plants may decrease their ability to filter excess nutrients out of the soil, leading to increased leaching of these nutrients into stream systems (Kaushal et al., 2005; Cañedo-Argüelles et al., 2013). Salinization can also alter the quality and quantity of dead organic matter deposited in riparia and stream systems, altering nutrient inputs to these ecosystems. Understanding the impacts of increased salinization on long-lived woody plants, especially water oaks, can provide insight into overall changes in ecosystem functions and processes.

To understand how increased salinization impacts tissue sodium concentrations and productivity in water oaks, a greenhouse study was conducted by watering *Q. nigra* saplings with solutions of varying NaCl concentrations. Water oak saplings were watered with sodium-enriched water solutions (0%, 0.05%, 0.1%, and 0.4%) for 3 months. In doing so, I tested the hypothesis that increases in environmental NaCl will affect plant sodium tissue concentrations and productivity. Specifically, I predicted that 1) water oak saplings would uptake and store sodium in their tissues, 2) plant tissues (e.g., stem vs leaves) would contain different concentrations, and 3) sodium would follow a subsidy-stress curve where productivity increases then decreases with increasing sodium concentrations. Leaf and stem tissue sodium concentrations, leaf and stem mass, and stem diameter were measured.

CHAPTER 2

METHODS

2.1 Using Sodium-Enriched Plant Tissue to Test Decomposition

2.1.1 Growing Sodium-Enriched Plants

I tested the impacts of sodium-enriched plant tissues on decomposition rates in riparian ecosystems by first growing plants in a greenhouse under either elevated NaCl or just reverse osmosis (RO) water conditions. This experiment took place in the Louisiana Tech University greenhouse from December 2018 through August of 2019. Plants commonly found in the southeastern United States riparian areas (or close relatives) were chosen to determine how low-level increases of NaCl affect plant sodium uptake and decomposition rates. The plants chosen for this study were two woody species: water oak (*Quercus nigra)* and cottonwood *(Populus deltoides*) and an herbaceous species: ornamental kale *(Brassica* sp.). These species represent two major plant functional groups (woody and herbaceous). The kale was selected as the herbaceous plant because it is biologically similar to wild *Brassica* species, readily available, and grows well in a greenhouse setting (Liu et al., 2014). Kale and water oak seedlings were purchased from nearby nurseries (Lowes© and Arborgen©, respectively), and all individuals of each species came from the same stock. The cottonwoods were collected from cuttings on Louisiana Tech's campus. The cottonwood cuttings were coated in Hormodin 3 rooting

hormone (OHP Inc.) to promote root growth. The kale and water oak were already established, so they did not require growth hormones. All plants were placed in separate round plastic pots (16.5cm x 16.5cm) with ProMix General Purpose Growing Medium provided by the Louisiana Tech Greenhouse. Plants were first acclimated by watering with tap water for approximately 2 months until plants showed new growth.

Each plant (N=60, n=20 per plant species) was grown for approximately 3 months in the greenhouse but planting start dates were staggered in time due to seedling availability. Specifically, kale was grown from December 10 to April 10, cottonwood from April 17 to May 15, and water oaks from March 27 to August 22. Because the cottonwood came from cuttings, I watered them with tap water until they were established (growth of new shoots and leaves). For the experiment, the plants were watered weekly with either 300mL of RO water or NaCl amended water (0.05% NaCl by weight) (n=10 per treatment), which is considered a low NaCl concentration for irrigation water in agricultural practices (FAO, 1985). This amount of water provided plants with water proportional to Ruston, LA average weekly rainfall (U.S. Climate Data, 2017). RO water was used as a control to determine sodium levels in plants grown without exposure to NaCl additions.

To determine how sodium-enriched plant tissue impacts decomposition rates, I collected live leaves from plants after 3 months of watering. Leaves from each plant were collected, washed with RO water, dried for 48 hours at 60ºC, and weighed as a proxy for plant productivity. Ten 0.5g subsamples of dried leaf and stem tissue from each species and treatment were sent to the LSU Soil Testing and Plant Analysis Lab (STPAL) for chemical analysis using ICP mass spectrometry for Na, P, K, Ca, Mg, S, and LECO CN Analyzer for Total C and Total N (See LSU STPAL laboratory for method details).

I tested the null hypotheses that 1) there was no effect of NaCl treatment (0.05% NaCl vs. RO water as controls) on plant sodium concentrations, 2) no effect of tissue type (stem vs. leaves) on sodium concentrations, and 3) no interaction between treatment and tissue type on plant sodium concentrations, by conducting a Repeated Measures-ANOVA for each plant species. Tissue types was the within subject factor and treatment was the between subjects factor. Sodium concentration of cottonwood plant tissues did not meet the assumption of equal variances (Levene's, $p<0.05$), and were $\log_{10}(x)$ transformed prior to analysis. I examined the 95% confidence interval output model to determine significant differences between tissue type and treatment. Independent t-tests were used to test the null hypothesis of no difference in sodium concentration between soils watered with NaCl and RO water. Separate independent t-tests were conducted for soils from each plant species (kale, water oak, and cottonwood). To test how low-level sodium additions impact leaf productivity, independent t-tests were used to test the null hypothesis that leaf biomass did not differ between controls and NaCl treatments. Testing was completed using SPSS v.26 (IBM, 2019).

2.1.2 Decomposition of Sodium-Enriched Plant Tissue

To test the impacts of sodium-enriched plant tissues on decomposition rates in potentially sodium-limited riparia, a decomposition field experiment was conducted from February to October on four inland private ranches in central Texas and one site at Wafer Creek Ranch (32.58, -92.73) in Ruston, Louisiana (Figure 2-1). All the properties contain riparian corridors and streams that range from 5m to 10m across. The riparian corridors on the Burnet (S. TX-1), McLennan (N. TX-2), and Williamson (S. TX-2) County properties are forested, with juniper (*Juniperus ashei*), oaks (*Quercus virginiana, buckleyi*, and

macrocarpa), and elm (*Ulmus americana* and *crassifolia*) trees as the most abundant tree species. Switchgrasses (*Panicum virgatum*), cedar sedges (*Carex eburnea*), and Virginia wildrye (*Elymus virginicus*) are also common on these three properties. The property in Hill (N. TX-1) County was not heavily forested along the riparian corridor and mostly consisted of Texas wintergrass (*Nassella leucotricha*), bristlegrass (*Setaria vulpiseta*), and reeds (*Arundo donax*). Soils along the riparian corridors at sites N. TX-1 and N. TX-2 consisted of Tinn clays and Frio silty clays, respectively. Soils along the riparian corridors of both the S. TX-1 and the S. TX-2 sites consisted of Oakalla silty clay loams (Table 2-1). The riparian corridor at Wafer Creek Ranch (LA) is a shortleaf pine/oak-hickory forest dominated by *Pinus taeda*, *P. echinate, Quercus falcata, Q. alba*, and *Q. nigra*. Soils at the LA site were primarily a loamy sand Darley-Mahan soil type (Table 2-1).

Senesced leaves and woody stems from the plants (cottonwood, kale, and water oak) grown in the greenhouse under sodium-enrichment (0.05%) or RO water (Controls)

Table 2-1: List of the sites used for the decomposition experiment.

Site Name	County	GPS Coordinates	Initial Soil Sodium
Louisiana (LA)	Lincoln	32.58, -92.73	15.7 ± 8.4 ppm
North Texas 1 (N. TX-1)	Hill	31.90, -96.96	38.0 ± 3.1 ppm
North Texas 2 (N. TX-2)	McLennan	31.68, -97.41	68.5 ± 9.8 ppm
South Texas 1 (S. TX-1)	Burnet	30.83, -98.06	39.6 ± 4.7 ppm
South Texas 2 (S. TX-2)	Williamson	30.54, -97.77	51.0 ± 3.9 ppm

were used to conduct the decomposition experiment. Additionally, I used artificial leaves (100% cellulose sponges) enriched in NaCl or just RO water (controls) at each site to control for any variation due to differences in leaf chemistry and allow for a standard comparison with other studies (e.g., Risch et al., 2016). Specifically, ~1.5g of cellulose

sponges soaked in either 0.05% NaCl solution (0.5g NaCl L^{-1} RO water) or RO water (controls). Most prior research has directly sprayed saltwater onto plots and in the majority of studies in inland mesic environments, decomposition rates increase (Clay et al., 2015; Jia et al., 2015; Kaspari et al., 2009, 2014; Wichern et al., 2006). However, direct additions of NaCl may create sodium stress in some inland mesic detrital communities and reduce decomposition rates (Gruntz, *unpublished data)*. Experimental designs that focus only on direct additions of NaCl preclude understanding how sodium-driven changes in leaf litter quality may impact decomposition processes. To measure the decomposition rate of sodium-enriched versus unenriched substrates, dried leaf and stem tissue from the kale, water oaks, and cottonwood grown in the greenhouse experiment treated with either 0.05% NaCl or just RO water (controls) were placed in coarse mesh (0.5cm) litterbags to allow for micro- and macroinvertebrates to access the plant material (Ji et al., 2020). Each of the focal plant species produced different amounts of biomass during sodium-enrichment (or water controls) in the greenhouse. Consequently, each species was placed alone in a litterbag, and each species had a different initial mass: kale leaves: ~1.5g, water oak leaves: ~0.9g, water oak stems: ~1.15, and cottonwood stems: ~2.2g but quantities were roughly the same within species between treatments (Table 2.2). Cottonwood plants did not produce enough leaf tissue to be included in the decomposition experiment. Prior to placement in litterbags, each of the leaf and stem samples were dried for 48 hours at 60ºC and weighed before being placed in the litterbags so that mass loss could be determined upon final collection.

At each of the five sites, litterbags were placed in paired control and treatment blocks. Blocks consisted of a litterbag of each species and artificial substrates of a single treatment (either NaCl or controls) that were randomly placed around a central stake.

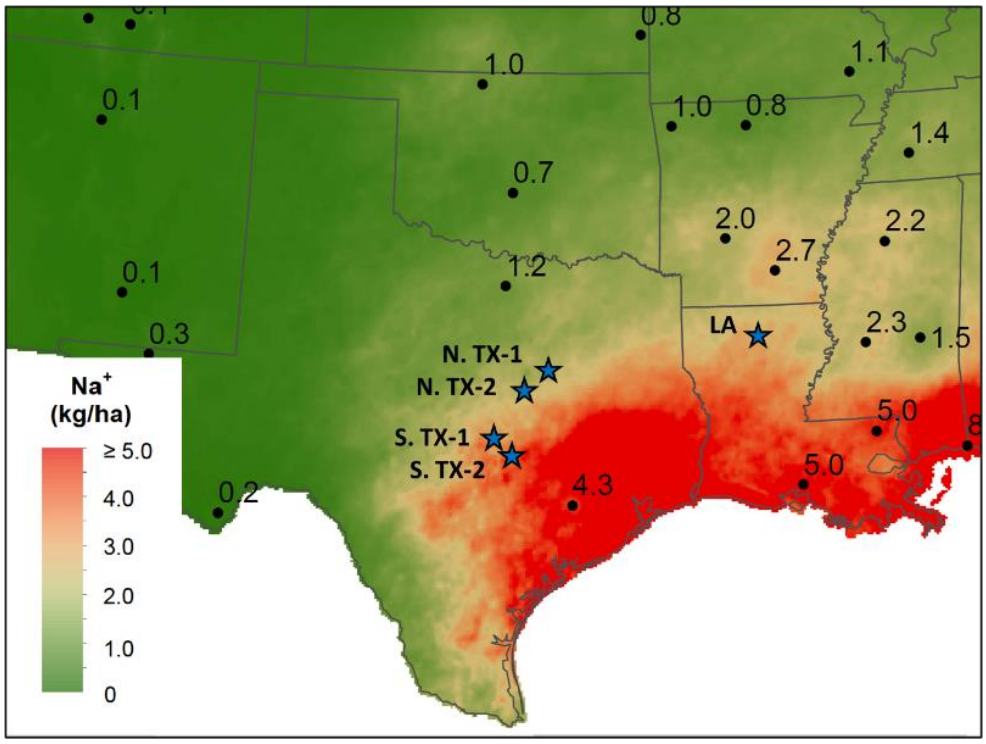

Figure 2-1:Map of wet sodium ion deposition (NADP, 2018) in south-central USA and each of the experimental sites (LA, N. TX-1 and 2, and S. TX-1 and 2).

Blocks within pairings were separated by 30cm (distance between control and NaCl-treatment blocks) and each replicate of paired blocks was separated by 1m. Blocked treatment pairs were used to eliminate variability in decomposition rates caused by potential heterogeneity in microhabitats in litter and soil systems (Decaëns, 2010; Ettema & Wardle, 2002). Blocks of litterbags were placed along the upper banks of a large stream. Due to limited plant tissue biomass produced in the greenhouse growth stage, plant tissues were only placed at three sites (n=30 per tissue type per treatment): two Texas sites (N. TX-1 and S. TX-2) and Wafer Creek Ranch (LA) (Table 2-2). Artificial substrates

(cellulose sponges) were places at all five sites. Specifically, at sites with plant tissue, 10 pairs of blocks each consisted of kale leaves, water oak leaves, water oak stems, cottonwood stems, and cellulose sponges (n= 10 blocks per treatment). Substrates were placed in a random order in a circle separated by ~8cm. An additional 10 paired blocks of just sodium-enriched or control artificial substrates (cellulose sponges) were also placed at these sites. Thus, at each site, 20 sodium-enriched sponges and 20 control sponges were placed in paired blocks, and in 3 of the five sites, 10 of the paired blocks also contained plant material.

Table 2-2: The average sodium concentration (± standard deviation) of plant tissues used in the decomposition experiment. Included is the total dried plant biomass used in the decomposition experiment.

Plant Species	Plant Tissue	Control (sodium ppm)	Control Total Biomass (g)	Salt (sodium ppm)	NaCl Treatment Total Biomass (g)	Plant Biomass (g) in each Litter Bag
Populus deltoides	Stem	322 ± 226	67.0	1208 ± 981	68.2	2.2
Brassica sp.	Leaf	2342 ± 1664	45.2	10662 ± 2676	48.2	1.5
Quercus nigra	Leaf	3944 ± 1646	29.6	9697 ± 3885	23.6	0.9
Quercus nigra	Stem	2849 ± 1736	41.7	7978 ± 4343	27.4	1.2

The artificial substrates (cellulose sponges) and kale leaves were collected after four months because they typically decompose faster. The water oak leaves and woody stems were left in the field for nine months to ensure that these plant tissues had enough time to decompose. The samples were collected, washed in RO water, and placed in a drying oven at 60ºC for 48 hours. They were then weighed to determine percent mass lost. At each visit, a soil core (1.8cm x 15.4cm) was used to collect 6 paired soil samples (n=3 per treatment) from random blocks. Soil was collected from directly under the litter bags

to determine if leaching from litter in blocks changed soil chemistry below NaCl treated blocks vs. control blocks.

Decomposition (proportion mass loss) data were not normal (Kolmogorov-Smirnov, $p=0.006$). I ran a Mann Whitney U tests for each property to test for an effect of block and found none ($p>0.05$). As such, block was omitted from further analyses. To test the null hypothesis that sodium-enrichment does not affect the decomposition rates of leaf and stem tissue, I used Wilcoxon tests. Specifically, for each substrate type at each site, I compared the proportion of mass lost between paired treatment blocks. To determine if decomposition of substrates in blocks impacted soil chemistry below blocks due to sodium-enriched leaves, I used paired t-tests. Specifically, I tested the null hypothesis that sodium-enriched plant tissue would not change soil sodium concentrations relative to controls. Each site was analyzed separately to exclude variations between sites. To test for an effect of time at each site, one-way ANOVAs were used to compare sodium concentrations of the same treatment across time, as soil was sampled from different blocks at each time.

2.1.3 Leaching Rates of Artificial Substrates

I conducted an additional experiment to test how the artificial substrate (cellulose sponge) retained the 0.05% NaCl solution during the decomposition experiment. I first connected a Key Instruments (SSA538 RO) flow meter to a supply of RO water. Artificial substrate was saturated in either RO water or 0.05% ($n= 3$ per treatment) and placed in a funnel underneath the RO water supply. The flow meter was set to 5 liters per minute (LPM), which represents light to moderate rainfall (Schiff et al., 2016). Each sponge was placed in the funnel under the RO water supply, and water was poured over the sponges for 10 minutes. Water samples were collected from under the funnel in 1-minute intervals.

The water samples were measured for conductivity (µS/cm) using a conductivity meter (Orion 122). A repeated-measures ANOVA was used to test the null hypothesis that the conductivity of leachate from sponges did not differ between treatments (0.05% NaCl vs. RO water) or across time and that there was no interaction between treatment and time. Treatment was the within subject factor and time was the between subject factor. I also conducted a Tukey post hoc test to determine differences in conductivity among time periods.

2.2 Growing *Quercus nigra* with Various Levels of NaCl

I also examined how additions of various concentrations of NaCl solutions would affect water oak tissue sodium concentrations and productivity, by conducting a greenhouse experiment in the Louisiana Tech University Greenhouse in Ruston, LA. This experiment was conducted from March 2020 through June of 2020. The focal riparian plant was *Quercus nigra* (water oak), which is commonly found in southeastern United States riparia. In a previous study, water oaks absorbed sodium in higher concentrations compared to other riparian plants (Gruntz, *unpublished data*). Water oak saplings were purchased from the same stock from Arborgen nursery (n=200). Sixty saplings of similar height and development were selected from the stock. Initial sapling heights were 52 ± 6.6cm (measured from the root collar to the tip of the stem). Stem diameter was on average 6.0mm ± 1.0 (measured 2cm above the soil line). To measure initial plant tissue and soil chemistry, five additional water oak saplings (not included in the experiment) and five soil samples were randomly chosen and separated into roots, stems, and leaves to determine initial chemical concentrations. These plant tissues were washed in RO water to remove any dirt

and dried at 60°C for 48 hours. Each sample was sent to the LSU STPAL where plant tissues was analyzed for Na, P, K, Ca, Mg, S, and Total C and Total N.

The water oak saplings were planted in separate round $2.16m^{-3}$ (14cm x 14cm) plastic pots and watered with RO water until they were established, which was determined by the growth of new leaves and buds on all the plants. The water oak saplings were watered with RO water for 8 weeks. The soil used to plant the water oaks was created using $0.17m^3$ ($6\ ft^3$) of peat moss, $0.11m^3$ ($4\ ft^3$) of Perlite, and $0.11m^3$ ($4\ ft^3$) of fine Vermiculite. These components were mixed in an industrial soil mixer for five minutes before being used in pots for oak plant growth.

To determine how a gradient of salinization impacts plant sodium tissue concentrations and water oak productivity, four RO water solutions amended with different NaCl quantities were used: 1) 0% NaCl (control), 2) 0.05% NaCl ($0.5g\ L^{-1}$), 3) 0.1% NaCl ($1g\ L^{-1}$), and 4) 0.4% NaCl ($4g\ L^{-1}$), representing a control, low, medium, and high concentration of NaCl for irrigation respectively (Bazihizina et al., 2012; Brouwer et al., 1985; Salachna et al., 2017). Each sapling (N=60, n=15 per treatment) was randomly assigned to one of three blocks (greenhouse tables). Within each block (n=20 per block), each of the saplings were randomly assigned a treatment (n=5 per treatment per block). Water oak saplings were spaced ~25cm apart in a 3 x 7 grid (one row only had two saplings). Water oak saplings were watered weekly with 500mL of the respective treatment for three months.

Live leaves were collected from five random saplings of each treatment to test how water oak leaf sodium tissue concentrations changed over time and sent to the LSU STPAL for chemical analysis. At the end of the trial, each water oak was separated into stems and

leaves. All the tissues were washed in RO water and dried at 60°C for 48 hours then weighed to determine productivity (final biomass of each tissue type). Stem diameter 2cm above the soil line was measured monthly as a measure of growth. New growth after initial establishment was not uniform across saplings. About half of the water oak saplings grew new tissue from existing stems, while the other half produced new shoots from the soil line. For water oaks that grew new shoots from the soil line, the stem diameter of the tallest shoot was measured. Subsamples from all tissues and pot soils were collected one week after the final watering and sent to the LSU STPAL where plant tissues were analyzed Na, P, K, Ca, Mg, S, and Total N and Total C.

The sodium concentrations (ppm) of stem and leaf tissue did not meet assumptions of normality (Kolmogorov-Smirnov: $p < 0.05$) and were $\log_{10}(x)$ transformed to meet normality assumptions. To test the null hypothesis that 1) additions of various concentrations of NaCl solutions does not affect plant tissue sodium concentration, 2) there is no effect of time on tissue sodium concentrations of plants watered with various concentrations of NaCl solutions, and 3) there is no interaction between time and treatment on sodium tissue concentration of plants watered with various concentrations of NaCl solutions, a generalized linear model was performed where sodium concentration was the dependent variable, time was a random factor, and treatment was a fixed factor. Significant effects of treatment were followed by Tukey HSD post hoc tests and significant effects of time were followed with individual ANOVAs at each time point and Tukey HSD tests for treatment to determine which treatments differed at each time point. Measures of productivity (plant tissue mass and change in stem diameter) did not meet the assumptions of normality (Kolmogorov-Smirnov: $p < 0.05$). To test the null hypothesis that plant

productivity does not differ among treatments, I ran separate Kruskal-Wallis tests for the measures of productivity: dried leaf weight, dried stem weight, and stem diameter.

CHAPTER 3

RESULTS

3.1 Sodium Enrichment of Various Riparian Plants

3.1.1 Kale (*Brassica* sp.)

After 3 months, sodium enrichment impacted kale plant sodium tissue concentrations. The concentration of sodium depended on both tissue and treatment in kale plants (Tissue x Treatment: $F_{1,10}$=8.75, p=0.01). Specifically, the sodium concentrations of leaf tissue (10,662 ± 2,676ppm) were 2-fold higher than in stem tissue (5,138 ± 1,731ppm) of NaCl treatment kale ($p<0.05$; Figure 3-1). Control kale leaves (2342 ± 1664ppm) and stems (2,072 ± 444ppm) did not differ in sodium concentration. NaCl treatment kale leaves (10,661 ± 2,676ppm) had 5-fold higher sodium concentrations than control kale leaves (2,342 ± 1,664ppm) ($p<0.05$). NaCl treatment kale stems (5,138 ± 1,731ppm) had ~2.5 times higher sodium concentrations than controls (2,072 ± 444ppm) ($p<0.05$). Kale plants did not differ in leaf production between controls (4.5 ± 1.4g) and NaCl treatments (5.2 ± 1.5g) (t_{18}=-1.05, p=0.31; Figure 3-2).

3.1.2 Water Oak (*Quercus nigra*)

Water oak saplings responded to sodium-enrichment, but tissues responded similarly within treatments (Figure 3-1). Specifically, water oak saplings did not have an interaction between tissue and treatment (Tissue x Treatment: $F_{1,16}$=0.45, p=0.51). Water

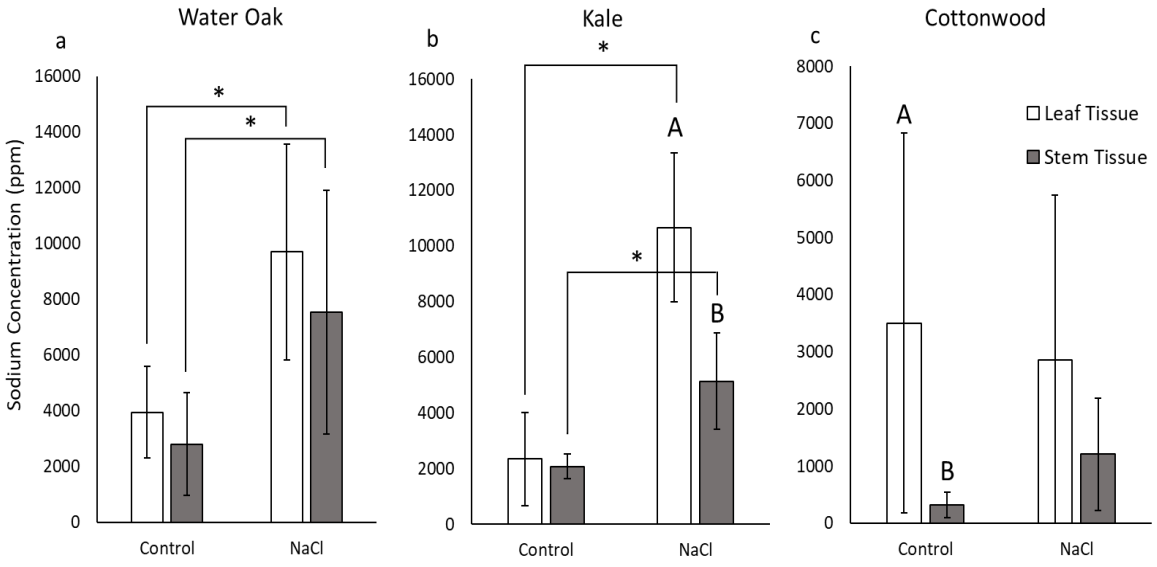

Figure 3-1: Mean sodium concentrations (ppm) of leaf and stem tissues between controls (reverse osmosis H_2O) and NaCl treatment (0.05% NaCl) from a) Water Oak (*Quercus nigra*), b) Kale (*Brassica* sp.), and c) Cottonwood (*Populus deltoides*). Error bars represent the standard deviation. '*' represents significant differences in tissues between treatments, letters represent significant differences between tissues of the same treatment.

oak leaves from saplings watered with NaCl treatments (9,697 ± 3,885ppm) had ~2.5 times higher sodium concentrations compared to controls (3,944 ± 1,646ppm) (t_{16}=4.09, p<0.001). Water oak stems were also ~2.5 times more enriched in sodium in NaCl treatments (7,539 ± 4,364ppm) than controls (2,804 ± 1,835ppm) (p<0.05). The sodium concentration within plants did not differ between water oak leaves and stems for either control grown water oaks or NaCl treated water oaks. Leaf production in water oaks did not differ between controls (3.4 ± 1.2g) and NaCl treatments (2.8 ± 1.5g) (t_{18}=1.02, p=0.32; Figure 3-2).

3.1.3 Cottonwood (*Populus deltiodes*)

Of the fifty cottonwood cuttings originally planted, only nine established in the greenhouse pots (n= 5 treatment, 4 control), and all the cottonwood plants died after two months of being watered with the treatments (both controls and NaCl addition had 100%

mortality). Cottonwood cuttings did not have a tissue x treatment interaction after 2 months ($F_{1,7}$=2.18, p=0.18) (Figure 3-1). However, cottonwood did have an effect of tissue and sodium tissue concentration ($F_{1,7}$=9.50, p=0.02). Specifically, cottonwood leaves (3.38 + 0.44 $\log_{10}$(ppm)) had higher sodium concentrations than stems (2.42 + 0.32 $\log_{10}$(ppm)) tissue for controls ($p<0.05$), but not for NaCl treatments (leaf: 3.22 + 0.55 $\log_{10}$(ppm); stem: 2.88 + 0.54 $\log_{10}$(ppm)). Cottonwood leaves did not differ in sodium concentration between controls (3.38 ± 0.44 $\log_{10}$(ppm)) and NaCl treatments (3.22 ± 0.55 $\log_{10}$(ppm)). Cottonwood stems also did not differ in sodium concentration between controls (2.42 ± 0.32 $\log_{10}$(ppm)) and NaCl treatments (2.88 ± 0.54 $\log_{10}$(ppm)). There was no effect of tissue by treatment on the sodium concentrations of cottonwood cuttings (Tissue x Treatment: $F_{1,7}$=0.59, p=0.47). Leaf production in cottonwood cuttings did not differ between controls (1.8 ± 1.1g) and NaCl treatments (2.6 ± 0.4g) ($t_{3.53}$=-1.45, p=0.23; Figure 3-2).

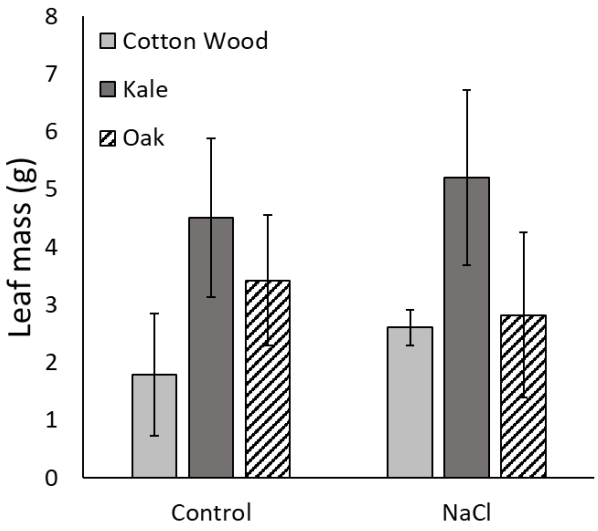

Figure 3-2: Leaf productivity (Leaf mass (g)) of cotton wood, kale, and oak of plants watered with RO water (Control) and NaCl solutions (NaCl). Error bars represent the standard deviation.

3.1.4 Soil

In general, soils in the NaCl addition treatments had higher sodium concentrations than controls that were not given additional NaCl (Figure 3-3). NaCl treated soil (1,590 ± 103ppm) from the kale plants had 5-fold higher sodium concentrations than control soil (316 ± 97ppm) (t_4=-15.61, p<0.001). For water oak saplings, sodium concentrations in the soil did not differ between controls (540 ± 99ppm) and NaCl treatments (913 ± 234ppm) (t_4=-2.55, p=0.06). Soil from the cottonwood plant pots did not differ in sodium concentration between controls (562 ± 100ppm) and NaCl treatments (584 ± 73ppm) (t_4=-0.31, p=0.78).

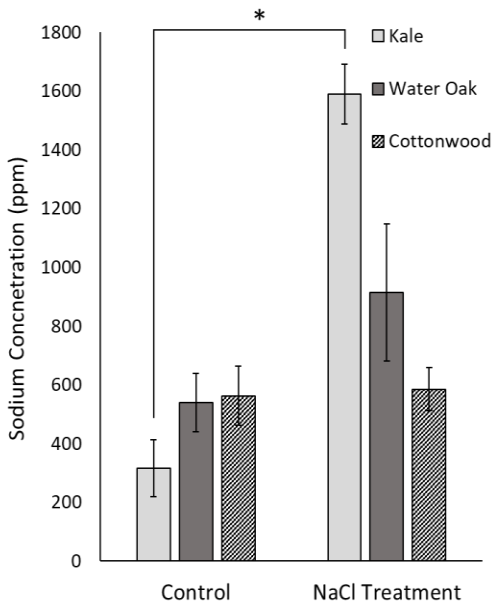

Figure 3-3: Mean sodium concentrations (ppm) of soils for each plant species (Kale, Water Oak, and Cottonwood) between controls (reverse osmosis H2O) and NaCl treatment (0.05% NaCl). Error bars represent the standard deviation. '*' represents significant differences between treatments.

3.2 Decomposition of Sodium-Enriched Plant Tissue

Across all properties I was able to recover 79% of the artificial substrates (sponges), 78% of the water oak leaves, 95% of the cottonwood stems, and 93% of the water oak stems. The main loss of plant tissue and artificial substrates in litterbags was a result of heavy rainfall that led to flooding in one of the sites (N. TX-1). Flooding along the banks of the river led to litterbags buried in ~ 10-30cm of sand and only 9/20 oak leaves, 14/20 oak stems, 16/20 cottonwood stems, and 1/20 artificial substrates being recovered at this

site. Only 2 kale litterbags across all sites were recovered with leaf mass remaining due to rapid decomposition after 3 months. Consequently, kale leaves were not analyzed.

3.2.1 Water Oak Leaves

Overall, water oak leaves lost an average of 78.2 ± 8.7% of mass across sites. After 9 months in the field, no water oak leaves remained in the litter bags at the N. TX-1 site and were thus not analyzed. At the LA site, water oak leaves did not differ in mass lost between control (70.7 ± 4.9%) and NaCl treatment (72.7 ± 6.8%) (Wilcoxon: Z=-0.36, p=0.72) (Figure 3-3). At the S. TX-2 site, water oak leaves did not differ in mass lost between control (72.0 ± 8.7%) and NaCl treatment (75.9 ± 12.7%) (Wilcoxon: Z=-0.89, p=0.37) (Figure 3-4a).

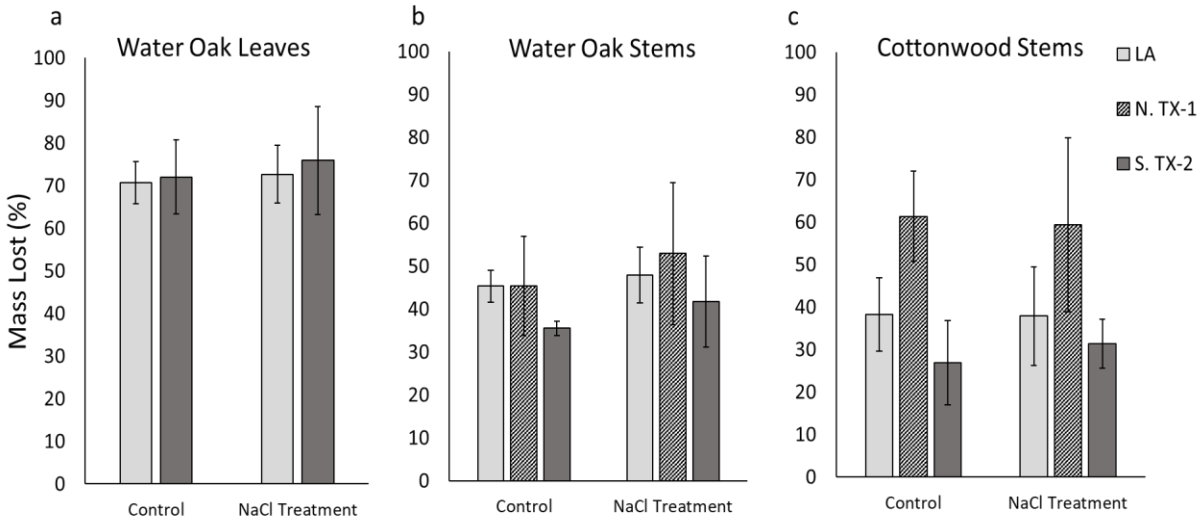

Figure 3-4: The decomposition rates (% Mass Lost) of plant tissues across different sites (LA, N. TX-1, and S. TX-2). a) The decomposition rates of water oak (*Quercus nigra*) leaves at the LA and S. TX-2 sites. b) The decomposition rates of water oak (*Quercus nigra*) stems at the LA, N. TX-1, and S. TX-2 sites. c) The decomposition rates of cottonwood (*Populus deltoides*) stems at the LA, N. TX-1, and S. TX-2 sites. Error bars represent the standard deviation.

3.2.2 Water Oak Stems

Average mass loss for water oak stems was highest at the N. TX-1 site (49.1 ± 14.3%) and lowest at the S. TX-2 site (38.6 ± 8.0%) (Figure 3-4b). At the N. TX-1 site, water oak stems did not differ in mass lost between control (43.4 ± 11.5%) and NaCl treatment (52.9 ± 16.5%) (Wilcoxon: Z=-1.52, p=0.13). At the LA site, water oak stems did not differ in mass lost between control (45.3 ± 3.7%) and NaCl treatment leaves (47.9 ± 6.5%) (Wilcoxon: Z=-1.17, p=0.24). At the S. TX-2 site, water oak stems did not differ in mass lost between control (35.5 ± 1.7%) and NaCl treatment (41.7 ± 10.6%) (Wilcoxon: Z=-1.38, p=0.17).

3.2.3 Cottonwood Stems

At the N. TX-1 site, cottonwood stems did not differ in mass lost between control (61.3 ± 10.6%) and NaCl treatment (59.3 ± 20.4%) (Wilcoxon: Z=-0.14, p=0.89; Figure 3-4c). At the LA site, cottonwood stems did not differ in mass lost between control (38.2 ± 8.6%) and NaCl treatment (37.9 ± 11.6%) (Wilcoxon: Z=-0.46, p=0.65). At the S. TX-2 site, cottonwood stems did not differ in mass lost between control (26.8 ± 9.9%) and NaCl treatment (31.3 ± 5.8%) (Wilcoxon: Z=-1.17, p=0.24).

3.2.4 Artificial Leaf Substrates (sponges)

Across all properties, mass lost from decomposition did not differ between controls and treatments (Figure 3-5). At the S. TX-1 site, the control (4.5 ± 8.4%) and NaCl treated (2.5 ± 7.5%) artificial leaf substrates did not differ in mass lost (Wilcoxon: Z=-1.33, p=0.18). At the S. TX-2 site, the control (59.3 ± 22.1%) and NaCl treated (68.2 ± 27.7%) sponges did not differ in mass lost (Wilcoxon: Z=-1.20, p=0.23). At the LA site, the control (40.7 ± 25.4%) and NaCl treated (35.5 ± 52.4%) sponges did not differ in mass lost

(Wilcoxon: Z=-0.639, p=0.523). At the N. TX-2 site, the control (-23.5 ± 19.0%) and NaCl treated (-16.1 ± 32.5%) sponges did not differ in mass lost (Wilcoxon: Z=-0.36, p=0.72). The sponges at the N. TX-2 site were saturated with clayey soils and gained mass over 3 months. I did not have access to a muffler furnace to accurately determine the percent mass loss of artificial substrates from the N. TX-2 site. Because all the litter bags were buried in sand, all the artificial leaf substrates at the N. TX-1 site had completely decomposed and were unable to be analyzed.

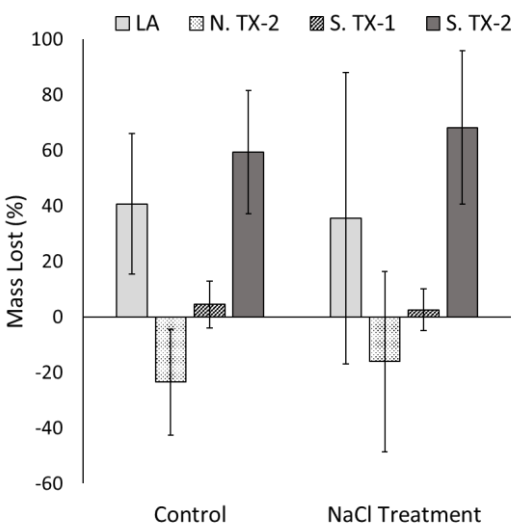

Figure 3-5: The decomposition rates (% mass lost) of artificial substrates (cellulose sponges) at each site (LA, N. TX-2, S. TX-1, S. TX-2). No sponges remained on the N. TX-1 site. Error bars represent the standard deviation.

3.2.5 Leaching Rates of Artificial Substrates

There was an effect of treatment x time on water conductivity collected under the sponges from the laboratory trial to test leaching rates of artificial substrates (Treatment x Time: $F_{9,20}$=5.80, p=0.001). Conductivity readings for controls decreased 5-fold between readings at 1 minute (34.6 ± 18.0µS/cm) and 10 minutes (6.87 ± 0.81µS/cm: p<0.001). NaCl treatment conductivity readings decreased 8-fold between readings at 1 minute (70.0 ± 8.8µS/cm) and 10 minutes (8.7 ± 2.3µS/cm, p<0.001). Conductivity was higher in NaCl treatments than in controls until the 5-minute reading, after which conductivity readings did not differ between treatments (p<0.05) (Figure 3-6).

3.2.6 Soil under decomposition substrates

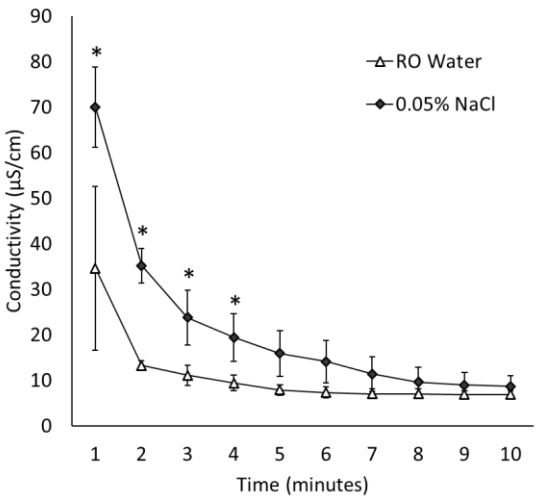

Figure 3-6: Conductivity readings (µS/cm) of leachate collected from artificial substrate (cellulose sponge) over time. Error bars represent the standard deviation. '*' represents differences between treatments (RO water or 0.05% NaCl) at each time period.

Overall, soil sodium concentrations below decomposition substrates fluctuated over time, however, sodium concentrations did not differ between treatments (Figure 3-7). Soil sodium concentrations decreased between initial samples (39.6 ± 4.7ppm) and 4 months (26.2 ± 2.1ppm) under control blocks at the S. TX-1 site ($F_{1,5}$=20.55, p=0.01). Under NaCl treatment blocks, soil sodium concentrations also decreased between initial samples (39.620 ± 4.694ppm) and 4 months (25.5 ± 5.1ppm) at the S. TX-1 site ($F_{1,5}$=12.61, p=0.02). After 4 months, control (26.2 ± 2.1ppm) and NaCl treatment (25.5 ± 5.1ppm) blocks did not differ in soil sodium concentrations (t_2=0.31, p=0.79).

At the N. TX-1 site, sodium content of soil under control blocks remained consistent over time (41.2 ± 3.9ppm) ($F_{2,8}$=3.87, p=0.08). However, the sodium content of soil under NaCl treatment blocks changed over time (52.4 ± 12.7ppm) ($F_{2,8}$=8.20, p=0.02). Specifically, initial soil samples (38.05 ± 3.06ppm) had lower sodium concentrations than soils after 4 months (61.34 ± 3.36ppm; p=0.02) and 9 months (57.78 ± 12.34ppm; p=0.04). After 4 months, soil under NaCl treatment (61.3 ± 3.4ppm) blocks had increased sodium concentrations compared to control (40.8 ± 2.3ppm) blocks (t_2=-14.48, p=0.01). After 9

months, control (44.8 ± 3.5ppm) blocks and NaCl treatment (57.8 ± 12.3ppm) blocks did not differ in soil sodium concentrations (t_2=-1.90, p=0.20).

At the N. TX-2 site, sodium content of soil under control blocks remained consistent over time (59.2 ± 21.5ppm) ($F_{1,5}$=1.16, p=0.32). Sodium content of soil under NaCl treatment blocks also remained consistent over time (54.5 ± 19.5ppm) ($F_{1,5}$=6.54, p=0.06). After 4 months, control (49.9 ± 28.3ppm) and NaCl treatment (40.4 ± 16.3ppm) blocks did not differ in soil sodium concentrations (t_2=1.25, p=0.34).

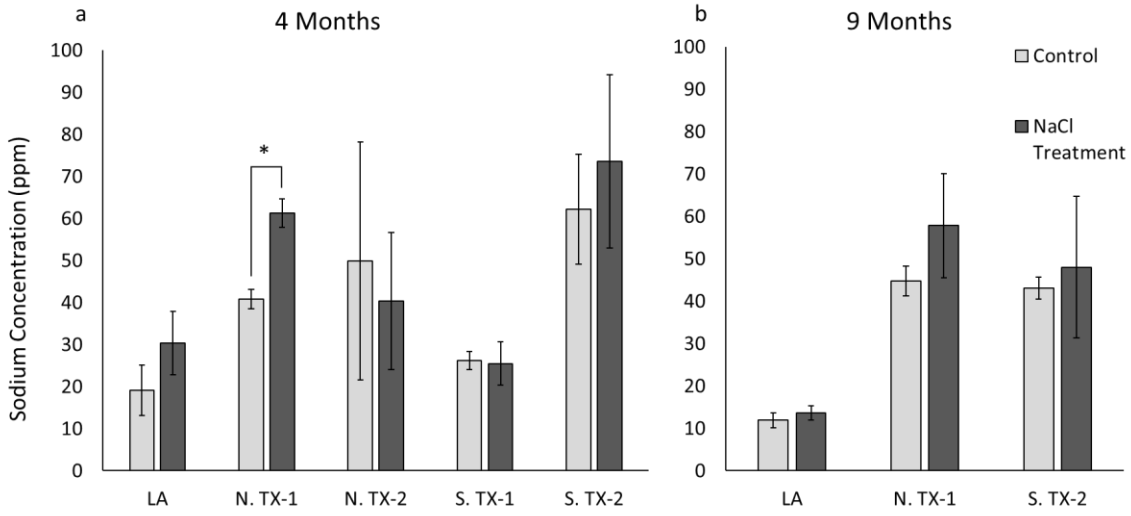

Figure 3-7: Mean soil sodium concentrations (ppm) underneath control and NaCl treatment litter bags at each site (LA, N. TX-1, N. TX-2, S. TX-1, S. TX-2) after a) 4 months and b) 9months. Error bars represent the standard deviation. '*' represents significant differences between treatments.

At the LA site, sodium content of soil under control blocks remained consistent over time (15.6 ± 6.1ppm) ($F_{2,8}$=1.10, p=0.39). However, sodium content of soil under NaCl treatment blocks changed over time (19.9 ± 9.8ppm) ($F_{2,8}$=5.86, p=0.04). Specifically, NaCl treatment soils after 4 months (30.41 ± 7.49ppm) had higher sodium concentrations than soils after 9 months (13.56 ± 1.67ppm; p=0.05). After 4 months, control (19.2 ± 6.0ppm) blocks and NaCl treatment (30.4 ± 7.5ppm) blocks did not differ

in soil sodium concentrations (t_2=-2.03, p=0.18). After 9 months, control (11.9 ± 1.7ppm) blocks and NaCl treatment (13.6 ± 1.7ppm) blocks did not differ in soil sodium concentrations (t_2=-3.45, p=0.08).

At the S. TX-2 site, the soil sodium concentrations under control blocks remained consistent over time (52.09 ± 10.84ppm) ($F_{2,8}$=4.27, p=0.07). Sodium content of soil under NaCl treatment blocks also remained consistent over time (57.5 ± 18.1ppm) ($F_{2,8}$=2.48, p=0.16). After 4 months, control (62.2 ± 13.1ppm) blocks and NaCl treatment (73.6 ± 20.6ppm) blocks did not differ in soil sodium concentrations (t_2=-0.62, p=0.60). After 9 months, control (43.1 ± 2.6ppm) blocks and NaCl treatment (48.0 ± 16.7ppm) blocks did not differ in soil sodium concentrations (t_2=-0.56, p=0.64).

3.3 Sodium Uptake and Storage in Water Oaks (*Quercus nigra)*

3.3.1 Sodium Concentration Across Time and Treatment

Water oak leaf tissue in the high (0.4% NaCl), medium (0.1% NaCl), and low (0.05% NaCl) treatments increased in sodium concentration over time, but sodium concentration in control leaves did not change over time (Figure 3-8a). After 29 days, there was a difference in sodium concentration among treatments ($F_{3,16}$=5.15, p=0.01; Figure 3-5)). Specifically, the sodium concentrations in water oak leaves of the high NaCl treatment (2.14 ± 0.57 $\log_{10}$(ppm)) was 1.4-fold higher than the medium (1.49 ± 0.25 $\log_{10}$(ppm), p=0.04) and 1.6-fold higher than low NaCl treatments (1.36 ± 0.25 $\log_{10}$(ppm), p=0.01). Control water oak leaves (1.57 ± 0.14 $\log_{10}$(ppm)) did not differ from the other treatments after 29 days.

After 50 days, sodium concentrations of leaves differed among treatments ($F_{3,16}$=31.68, p<0.001; Figure 3-8a). Specifically, water oak leaves of the high (3.84 ± 0.37

log_{10}(ppm)) and medium NaCl treatments (2.71 ± 0.76 log_{10}(ppm)) had higher sodium concentrations than all other treatments ($p<0.05$). However, the control (1.30 ± 0.21 log_{10}(ppm)) and low NaCl treatments (1.56 ± 0.33 log_{10}(ppm), $p=0.81$) did not differ in sodium concentration. After 87 days, the sodium concentration of water oak leaves differed among treatments ($F_{3,16}=65.58$, $p<0.001$; Figure 3-8a). Specifically, water oak leaves of the high (4.19 ± 0.37 log_{10}(ppm)) and medium NaCl treatments (3.36 ± 0.48 log_{10}(ppm)) contained higher concentrations of sodium compared to the other treatments ($p<0.05$). However, the control (1.69 ± 0.17 log_{10}(ppm)) and low NaCl treatments (2.03 ± 0.50 log_{10}(ppm), $p=0.36$) did not differ in sodium concentration ($p<0.05$).

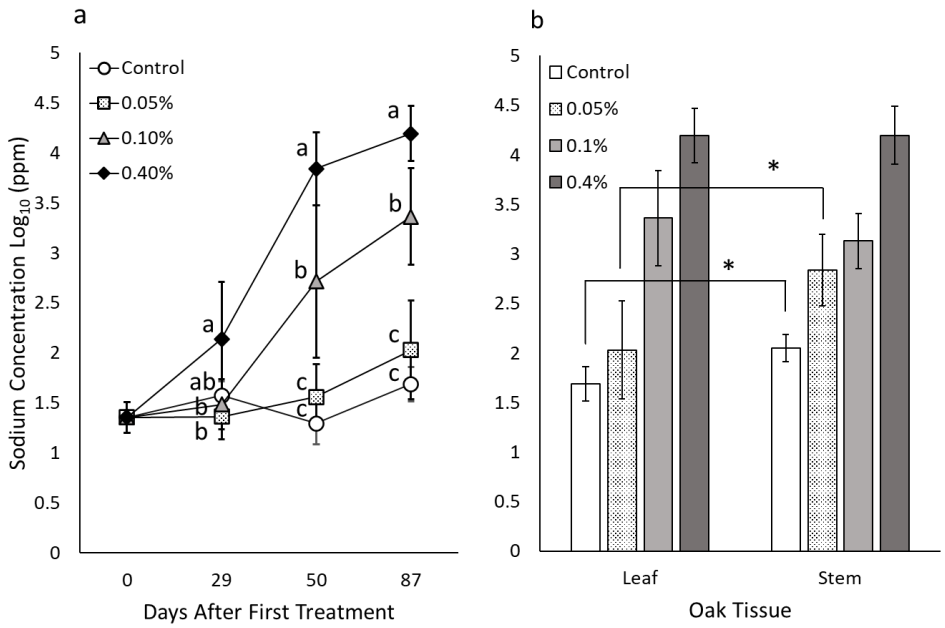

Figure 3-8: Log10 (x) sodium concentrations of water oak (*Quercus nigra*) tissue after weekly watering with treatments (0%, 0.05%, 0.1%, and 0.4% NaCl solution). a) The sodium concentration of leaf tissue for each treatment over time (0, 29, 50, and 87 days). Error bars represent the standard deviation. Letters (a,b,c) show significant difference in sodium concentration among treatments at each time period. b) The sodium concentration of leaf and stem tissue after 87 days. Error bars represent the standard deviation. The '*' shows significant differences between leaf and stem tissue of the same treatment.

After 87 days, control water oak stems (2.05 ± 0.14 $\log_{10}$(ppm)) had a higher sodium concentration than control leaves (1.69 ± 0.17 $\log_{10}$(ppm)) (t_6=-3.31, p=0.02; Figure 3-8b). For the low NaCl treatment (0.05% NaCl), sodium concentrations in leaves (2.03 ± 0.50 $\log_{10}$(ppm)) were lower than in stems (2.84 ± 0.36 $\log_{10}$(ppm)) (t_6=-7.14, p<0.001). Water oak leaves (3.36 ± 0.48 $\log_{10}$(ppm)) and stems (3.13 ± 0.28 $\log_{10}$(ppm)) for the medium NaCl treatment (0.1% NaCl) did not differ in sodium concentrations (t_6=1.26, p=0.25). Water oak leaves (4.19 ± 0.27 $\log_{10}$(ppm)) and stems (4.20 ± 0.30 $\log_{10}$(ppm)) for the high NaCl treatment (0.4% NaCl) did not differ in sodium concentrations (t_6=-0.20, p=0.85).

3.3.2 Plant Productivity

After 35 days from the start of the experiment, eight of the fifteen high NaCl treatment (0.4% NaCl) water oaks had leaves beginning to turn brown, compared to 0 of the controls. By the end of the experiment (87 days after experiment initiation), all the high NaCl treatment water oaks had died. After 64 days from the experiment initiation, three of the fifteen water oaks from the medium NaCl treatment (0.1% NaCl) had leaves beginning to turn brown. After the end of the experiment, eleven of the fifteen medium NaCl treatment water oaks had brown leaves and one of the fifteen had died.

Water oak leaf productivity differed among treatments (χ^2_3 =11.37, p=0.01). Although not significant among control, low, and medium NaCl treatments, leaf production decreased as NaCl concentration increased (p>0.05; Figure 3-9). Specifically, the high NaCl treatment (1.66 ± 0.99g) produced less leaf mass than the low (2.58 ± 1.03g) and control (2.85 ± 0.70g) NaCl treatments. No other treatments differed in leaf mass produced. No treatments differed in stem tissue productivity (χ^2_3 =7.19, p=0.07). Specifically, the

control (4.04 ± 2.37g), low (2.60 ± 1.75g), medium (2.91 ± 2.78g), and high (2.36 ± 2.83g) NaCl treatments did not differ in stem weight. The leaf to stem ratio did not differ across treatments (χ^2_3 =2.88, p=0.41).

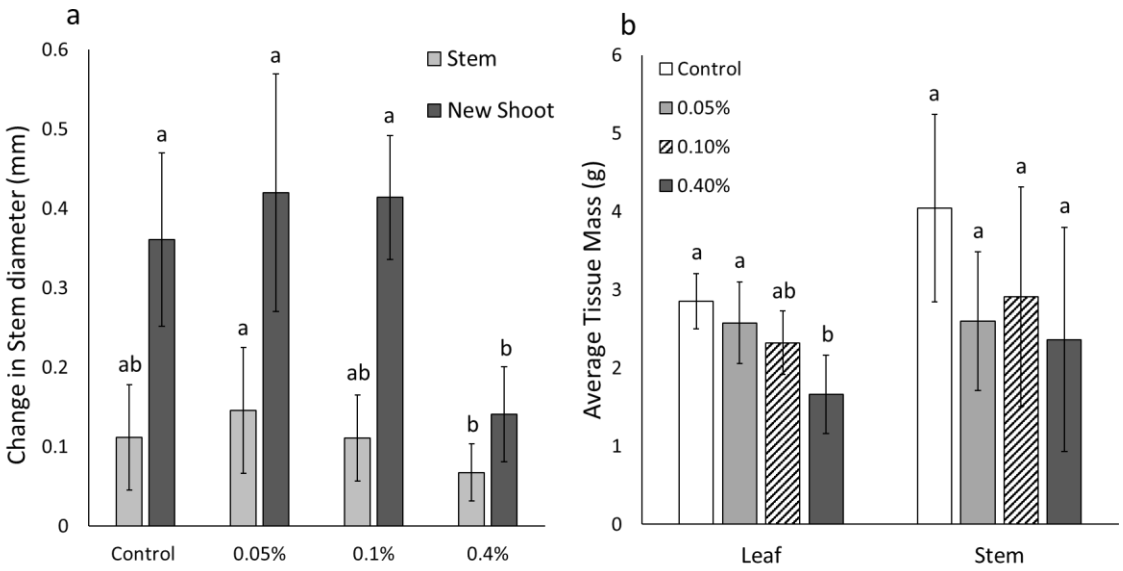

Figure 3-9: Water oak (*Quercus nigra*) productivity across NaCl treatments (0%, 0.05%, 0.1%, and 0.4%) for a) the change in stem and new shoot diameter (mm) and b) the production of leaf and stem tissue (Average Tissue Mass (g). Letters (a,b) represent significance among treatments withing the tissue type. Error bars represent the standard deviation.

The stem growth of water oaks differed among treatments ($F_{3,48}$=3.54, p=0.02). Specifically, the high NaCl treatment (0.25 ± 0.07) had a lower rate of growth than the low NaCl treatment (0.38 ± 0.11). No other treatments differed in stem diameter growth. Of the water oak saplings that grew new shoots, the change in new growth diameter differed across treatment ($F_{3,26}$=12.41, p<0.001). Specifically, the high NaCl treatment (0.38 ± 0.08) grew less than the control (0.64 ± 0.12), low (0.70 ± 0.16), and medium (0.70 ± 0.08) NaCl treatments. The control, low, and medium NaCl treatments did not differ in the change in diameter (p>0.05).

3.3.3 Soil

Soil sodium concentrations differed among treatments ($F_{3,8}$=599, $p<0.001$; Figure 3-10). Specifically, the soil from controls (272 ± 23.2ppm) had lower sodium concentrations than the low (1,674 ± 105.3ppm) NaCl treatments but had higher sodium concentrations than the medium (89.6 ± 19.2ppm) and high (49.1 ± 4.0ppm) NaCl treatments ($p<0.05$). The low (1,674 ± 105.3ppm) NaCl treatments had higher sodium concentrations than all other treatments ($p\leq0.05$).

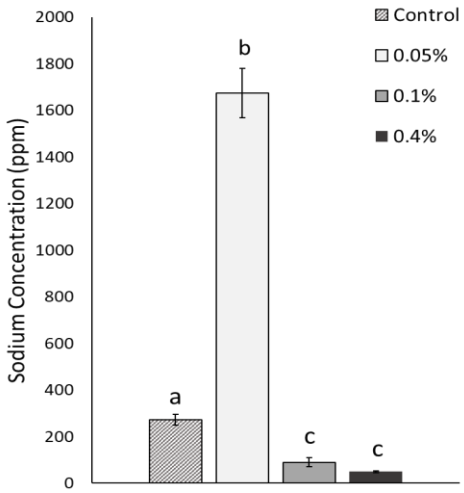

Figure 3-10: Mean sodium concentrations (ppm) of soils for Water Oak saplings watered with either 0%, 0.05%, 0.1%, or 0.4% NaCl solution. Error bars represent the standard deviation. Letters represent significant differences between treatments.

CHAPTER 4

DISCUSSION

Global increases in NaCl salinization has the potential to act as a subsidy or stressor for many ecosystem processes (Montgomery & Matson, 2007; Rengasamy, 2006). Because sodium can quickly become toxic to plants, understanding how salinization impacts plant productivity can give insight into overall ecosystem productivity (Zhu, 2007). Conversely, sodium increases may act as a subsidy for animals such as detritivores and decomposer communities, which can increase detritivore abundances and decomposition rates (Kaspari et al., 2014; Welti et al., 2019). Here, we studied the effects of NaCl salinization on plant productivity and biochemistry and decomposition processes in riparian ecosystems. Our results demonstrate that when riparian plants are watered with low-level NaCl solutions, they store sodium in their tissues, and sodium storage may differ among tissues for some species. We hypothesized that sodium-enriched detritus would increase decomposition rates in inland TX and LA riparia due to sodium shortfalls. However, we found no difference in decomposition rates for leaf, woody, or artificial detritus. Sodium-enriched detritus may have different impacts on decomposition rates than direct NaCl additions. This suggests that the pathway by which sodium enters an environment matters and may impact ecosystem processes differently.

Both woody and herbaceous plants were sensitive to sodium fertilization. When sodium is available in the soil, plants often uptake and store sodium in their tissues (Parida

& Das, 2005; Subbarao et al., 2003). Although plants may use small amounts of sodium to replace potassium in limited roles, sodium can quickly become toxic and reduce growth, interfere with enzymatic functions, and lower potassium uptake (Blumwald et al., 2000; Maathuis, 2014; Zhu, 2007). Here, we found that kale and oak plants increased their sodium concentrations when watered with any NaCl (0.05%-0.4%), but cottonwood did not. However, the cottonwood had a very small sample size that may have contributed to the differing results from other species and poor establishment in the soil so extrapolation of results beyond this study is likely limited. Kale disproportionately stored sodium in leaves when raised on 0.05% NaCl and but did not differ in leaf production. At higher NaCl concentrations, Jamil et al. found that Cabbage (*Brassica* sp.) grown in 0%, 0.29%, 0.58%, and 0.88% NaCl solutions showed reductions in plant growth with increasing NaCl solutions (2007). Conversely, water oaks in my greenhouse experiment did demonstrate a slight subsidy-stress effect of NaCl additions on stem growth but decreases in biomass with increasing NaCl additions. Oaks have shown limited sodium tolerance in previous studies. For example, *Q. robur* has demonstrated reduced growth when watered with 0.23% of NaCl solution and nonsignificant decreases in growth when watered with 0.12% NaCl solution (Sehmer et al., 1995). My results also showed decreases in leaf production when *Q. nigra* is watered with 0.4% NaCl solution and limited but nonsignificant decreases when watered with 0.1% and 0.05% NaCl solutions compared to controls. These results suggest that members of the genus *Quercus* may be particularly sensitive to increases in salinization. Conversely, *Brassica* sp. are considered salt tolerant when compared to other plants and may not represent increased sodium responses in a majority of plants (Subbarao et al., 2003). Similarly, *Populus euphratica* has shown resistance to sodium toxicity in

saline environments (Ottow et al., 2005). Species of the genus *Populus* may be more suited to withstand increases in salinization. This suggests that NaCl salinization of riparia may differentially alter the overall productivity of plant species in these ecosystems.

Differences in productivity and Na-uptake in plant species can alter plant abundances and community structure, ultimately altering riparian ecosystem processes. Because sodium tolerance in plants is species specific, increased salinization may increase productivity for some plants while lowering productivity for others. My results showed that my focal woody species *Q. nigra* demonstrated lowered productivity with increased salinization. My study suggests that, under salinization, some plants such as woody plants may face decreased productivity while others like herbaceous plants may increase productivity, leading to a change in community structure and plant species abundances (Subbarao et al., 2003). Other studies have shown increases in productivity and physiological functioning when species in the genus *Brassica* are grown with low-level additions of sodium (Harmer & Benne, 1945; Sharma & Singh, 1990; Wakeel et al., 2011). Increased plant productivity can benefit riparian and stream ecosystems by improving water quality and influencing runoff (Palmquist et al., 2017; Tabacchi et al., 2000). However, lowered plant productivity via salinization can have lasting negative impacts on riparia such as reduced plant uptake of soil nutrients and increased leaching (Mostafazadeh-Fard et al., 2007), reductions of plant biomass and dead organic matter deposition, and increased soil erosion and particulate matter entering streams (Neave & Rayburg, 2006). Plant uptake of sodium is an often overlooked but important pathway in which sodium enters stream systems via riparia. Ultimately, increased salinization may alter the overall biomass, the species of leaf litter, and the biochemistry of dead organic

matter entering a stream system. These consequences of increased NaCl salinization can reduce aquatic water quality and biodiversity (Dosskey et al., 2010).

The SER hypothesis posits that, in sodium-limited environments, increases in NaCl will speed up decomposition rates (Kaspari et al., 2009), while the SSS hypothesis extends SER to include stress effects of too much NaCl. Direct additions of NaCl solutions between 0.05% and 5% have increased decomposition rates of leaf litter in both tropical and subtropical forests (Ji et al., 2020; Jia et al., 2015; Kaspari et al., 2014) and only one study to my knowledge has demonstrated decreased decomposition likely due to Na-stress in mesic inland terrestrial environments (Gruntz et al. in Review). However, direct NaCl additions only represent one potential pathway that NaCl can enter an ecosystem. This study is the first to my knowledge to use sodium-enriched plant tissue rather than direct additions to test NaCl impacts on decomposition processes (but see Risch et al. (2016) who used sodium-enriched artificial substrates). However, I found no differences in decomposition rates between control and NaCl-enriched detritus at any of the sites. One potential explanation may be that sodium concentrations between controls and treatments were not different enough to discern a sodium treatment effect on decomposition. The difference in sodium concentration between control tissues and treatments for water oak leaves (~5.8g/kg difference), water oak stems (~4.7g/kg difference), and cottonwood stems (~0.9g/kg difference) may not have differed enough on the subsidy-stress curve to alter decomposition rates. However, these differences in sodium concentrations are comparable to concentrations used by other studies (0.1 – 50.0g/kg) that found changes in decomposition rates (Jia et al., 2015; Kaspari et al., 2014; Risch et al., 2016). Another hypothesis for why decomposition rates did not differ between sodium-enriched and

control plant tissue may be due to the unusually high sodium content in the plant tissue for both controls and NaCl treatment, especially the oak leaves and stems. Oak leaves contained 3,944ppm (3.944g/kg) of sodium in controls and 9,697ppm (9.697g/kg) of sodium in treatments. Oak stems had similarly high sodium levels in their tissues (2.804g/kg and 7.539g/kg for controls and NaCl treatments respectively). These sodium concentrations are similar to high NaCl solutions used in other studies, however, these tests were conducted in sodium-limited environments (Ji et al., 2020; Kaspari et al., 2008; Risch et al., 2016). The sites selected may not have been sodium-limited due to increased hurricane activity throughout the year. The high levels of sodium in the plant tissues may have acted as a stressor for detrital communities for both control and NaCl treatments, which would limit decomposition. One reason for the high levels of tissue sodium concentration may be the use of tap water during the establishment period of oak, cottonwood, and kale plants or initial germination and growing conditions of saplings. These results provide evidence for opposite sides of the subsidy-stress curve. The sodium concentrations in both control and NaCl treatment plant tissues may have been too low or did not differ enough to create a subsidy effect, or sodium concentrations were higher than the detrital communities' optimal sodium levels and created a similar stress effect between treatments. Although there were no significant differences in decomposition of sodium-enriched plant tissue than controls, sodium-enriched water oak leaves and stems were consistently more decomposed on average than controls (~3% and 6% respectively), showing a slight subsidy effect. Increased replications may have yielded significant results. A statistical power analysis was performed for sample size estimation. With an $\alpha = 0.05$

and power = 0.80, the projected sample size needed with this effect size is approximately n=34 per treatment per site (G*Power 3.1).

Changes to decomposition rates in the presence of sodium can be attributed to increased or decreased detrital community activity or abundances (Clay et al., 2014; Welti et al., 2019). However, because organisms have different sodium requirements, any given increase in sodium availability may act as a subsidy for one organism, while acting as a stressor for others (Ji et al., 2020; Jia et al., 2015; Rath & Rousk, 2015). Although these increases in detritivores speed up decomposition in rainforests, microbes, which play a large role in decomposition, may be sensitive to increases in sodium availability (Allison et al., 2013; Wichern et al., 2006). In subtropical rainforests, additions of 0.05% and 0.5% NaCl solutions increased invertebrate detritivore abundances but reduced microbial decomposition (Jia et al., 2015). However, in the same study, 0.005% NaCl solutions increased microbial decomposition but had no impact on detritivore activity, demonstrating microbial sensitivity to excess sodium (Jia et al., 2015). When NaCl was added to grassland soils (1.5% and 5%), microbe biomass and respiration decreased with increasing levels of NaCl, leading to a decrease in decomposition (Wichern et al., 2006). These studies suggest that even small increases in salinization may negatively impact microbe community abundance and activity, potentially leading to large scale decreases in decomposition rates. Here, we used sodium-enriched plant tissue, which likely decreased the presence or severity of sodium stress that can occur via direct deposition. However, sodium may have acted as a stressor in both the controls and NaCl treatments for decomposer communities as sodium concentrations in the plant tissues (including controls) matches moderate to high levels of NaCl solutions used in previous studies concerning

microbial activity (Ji et al., 2020; Zhang et al., 2019). Sodium-enriched plant tissue may have decreased microbial abundance; however, my study did not examine this. As microbe communities may be sensitive to increases in salinization, sodium-enriched plant tissues in riparia may lead to decreases in decomposition rates. Reduced decomposition can lead to increased dead organic matter remaining in riparia and decreases in nutrient cycling.

This study uniquely tests how experimental sodium-enrichment of plant material alters decomposition in riparia (but see Bailey et al., 2001; Kennedy & Hobbie, 2004; Pomeroy et al., 2000). When added directly to the soil, NaCl additions often act as a stressor for microbial communities and subsidy for detritivores (Jia et al., 2015; Kaspari et al., 2014; Risch et al., 2016). However, riparian systems are often overlooked but play a critical role in aquatic biodiversity and water quality (Dosskey et al., 2010; Tabacchi et al., 1998). Riparia may be sensitive to increases in NaCl salinization, which can reduce plant productivity and biomass and increase leaching into streams (Cañedo-Argüelles et al., 2013; Naiman & Decamps, 1997). My study specifically examined the effects of plant tissue sodium enrichment on decomposition rates. However, sodium-enrichment would not occur in isolation and would most likely occur alongside direct NaCl deposition in riparia. Direct additions of NaCl and additions of sodium-enriched plant tissue may act as a stressor for decomposer communities, even when additions are low-level. Any changes to riparian biochemistry and productivity can have lasting impacts on nutrient cycles, water quality, and aquatic biodiversity (Cummins et al., 1989; Dosskey et al., 2010; Dwire et al., 2004). To further understand the impacts of global salinization on streams, more studies must be conducted in riparian ecosystems.

Riparian ecosystems play an essential role as a boundary between terrestrial and aquatic ecosystems. Global increases in terrestrial salinization may have lasting impacts on riparia and stream systems. Riparia are a host to a diversity of plants, which provide a large portion of the ecosystem's dead organic matter and nutrient inputs (Burton & Samuelson, 2005; Dosskey et al., 2010; Naiman et al., 1993). According to the SSS hypothesis, sodium will act as a subsidy for any given organism up to a point, after which, sodium will become a stressor (Entrekin et al., 2019). Although some riparian plants may possess limited sodium tolerance, increased salinization will likely lead to large decreases in overall plant biomass (Jamil et al., 2007; Zhu, 2007). This study suggests that some woody species may be particularly sensitive (e.g., *Q. nigra*), but further research is needed to determine which riparian plants are the most sensitive to increased sodium concentrations. NaCl salinization has the potential to alter plant species abundances and overall community structure in riparian zones. Detrital communities may also face sodium stress as salinization continues (Ji et al., 2020; Kennedy & Hobbie, 2004; Risch et al., 2016). Microbes are sensitive to increases in NaCl, which can slow decomposition rates, altering riparian nutrient cycles. Studies should be conducted using both NaCl deposition and sodium-enriched plant tissue to more accurately determine how increases in salinization might impact decomposition processes. These studies can be used to develop best management practices to protect riparian ecosystems.

APPENDIX A

A.1 Plant Biochemistry Tables

Table A-1: The biochemical makeup of leaf and stem tissue from cottonwood, kale, and water oak plants watered with either RO water (control) or 0.05% NaCl solutions. Included is the mean ± standard deviation of calcium, carbon, magnesium, nitrogen, phosphorous, potassium, sodium, and sulfur.

Plant Species	Treatment	Calcium (ppm)	Carbon (%)	Magnesium (ppm)	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)	Sodium (ppm)	Sulfur (ppm)
Cotton Wood									
Leaf	Control	1.96 ± 0.62	39.37 ± 1.84	0.71 ± 0.21	3.62 ± 0.37	0.32 ± 0.03	3.81 ± 0.83	3502 ± 3327	0.74 ± 0.05
	0.05 % NaCl	1.84 ± 0.65	38.10 ± 0.45	0.65 ± 0.29	3.72 ± 0.38	0.29 ± 0.13	3.31 ± 1.56	2858 ± 2891	0.57 ± 0.33
Stem	Control	0.43 ± 0.21	43.80 ± 0.37	0.07 ± 0.01	0.28 ± 0.07	0.02 ± 0.01	0.16 ± 0.08	322 ± 226	0.04 ± 0.01
	0.05 % NaCl	0.53 ± 0.13	43.95 ± 0.44	0.09 ± 0.01	0.60 ± 0.19	0.04 ± 0.01	0.37 ± 0.11	1208 ± 981	0.04 ± 0.00
Kale									
Leaf	Control	0.96 ± 0.18	42.95 ± 0.77	0.45 ± 0.09	2.90 ± 1.08	0.33 ± 0.12	3.70 ± 0.14	2342 ± 1664	1.11 ± 0.21
	0.05 % NaCl	1.33 ± 0.15	41.11 ± 0.58	0.52 ± 0.06	1.80 ± 0.51	0.20 ± 0.08	3.71 ± 0.51	10662 ± 2676	0.69 ± 0.14
Stem	Control	0.44 ± 0.06	39.32 ± 1.25	0.28 ± 0.05	2.33 ± 0.26	0.81 ± 0.14	3.66 ± 0.41	2072 ± 444	0.59 ± 0.16
	0.05 % NaCl	0.40 ± 0.05	38.47 ± 0.68	0.34 ± 0.03	2.43 ± 0.65	0.66 ± 0.07	4.21 ± 1.63	5138 ± 1731	0.51 ± 0.07
Water Oak									
Leaf	Control	0.66 ± 0.14	44.61 ± 1.82	0.25 ± 0.07	2.60 ± 0.45	0.10 ± 0.05	2.88 ± 0.50	3944 ± 1646	0.15 ± 0.01
	0.05 % NaCl	0.56 ± 0.11	44.22 ± 1.88	0.16 ± 0.06	2.52 ± 0.20	0.09 ± 0.01	2.31 ± 0.54	9697 ± 3885	0.15 ± 0.01
Stem	Control	0.99 ± 0.84	44.19 ± 0.65	0.31 ± 0.33	1.38 ± 0.39	0.13 ± 0.15	1.28 ± 1.25	2849 ± 1736	0.19 ± 0.36
	0.05 % NaCl	0.62 ± 0.25	43.63 ± 1.25	0.20 ± 0.15	1.31 ± 0.36	0.11 ± 0.05	1.18 ± 0.55	7978 ± 4343	0.08 ± 0.03

Table A-2: The biochemical makeup of leaf and stem tissue of water oak plants watered with either RO water (control), low (0.05%), medium (0.1%), or high (0.4%) NaCl solutions. Included is the mean ± standard deviation of calcium, carbon, magnesium, nitrogen, phosphorous, potassium, sodium, and sulfur.

Water Oak Tissue	Treatment	Calcium (ppm)	Carbon (%)	Magnesium (ppm)	Nitrogen (%)	Phosphorus (ppm)	Potassium (ppm)	Sodium (ppm)	Sulfur (ppm)
Leaf	Control	0.69 ± 0.14	45.65 ± 0.30	0.31 ± 0.03	1.45 ± 0.15	0.08 ± 0.01	0.55 ± 0.09	52 ± 19	0.10 ± 0.01
	0.05% NaCl	0.67 ± 0.08	44.94 ± 0.57	0.34 ± 0.04	1.57 ± 0.21	0.08 ± 0.01	0.58 ± 0.09	181 ± 178	0.10 ± 0.01
	0.1% NaCl	0.67 ± 0.12	44.56 ± 0.97	0.31 ± 0.06	1.60 ± 0.14	0.10 ± 0.01	0.97 ± 0.24	3494 ± 2904	0.11 ± 0.01
	0.4% NaCl	0.68 ±0.12	41.58 ± 1.37	0.37 ± 0.09	1.68 ± 0.17	0.12 ± 0.03	1.04 ± 0.20	17593 ± 6761	0.11 ± 0.01
Stem	Control	0.67 ± 0.14	44.33 ± 0.46	0.13 ± 0.04	0.40 ± 0.10	0.13 ± 0.02	0.47 ± 0.12	117 ± 32	0.04 ± 0.01
	0.05% NaCl	0.65 ± 0.09	44.23 ± 0.22	0.13 ± 0.03	0.42 ± 0.08	0.09 ± 0.01	0.42 ± 0.09	873 ± 545	0.04 ± 0.01
	0.1% NaCl	0.59 ± 0.10	44.35 ± 0.36	0.15 ± 0.05	0.57 ± 0.20	0.10 ± 0.02	0.34 ± 0.06	1628 ± 1185	0.05 ± 0.02
	0.4% NaCl	0.57 ± 0.18	41.56 ± 1.83	0.15 ± 0.05	0.65 ± 0.20	0.12 ± 0.06	0.39 ± 0.10	18221 ± 7924	0.05 ± 0.02

A.2 Soil Chemistry Tables

Table A-3: The chemical makeup of soil used to grow cottonwood (*Populus deltoides*), kale (*Brassica* sp.), and water oak (*Quercus nigra*) plants watered with either RO water (control) or 0.05% NaCl solution. Included is the mean ± standard deviation of calcium, carbon, magnesium, nitrogen, phosphorous, potassium, sodium, and sulfur.

Plant Species	Treatment	Calcium (ppm)	Magnesium (ppm)	Phosphorus (ppm)	Potassium (ppm)	Sodium (ppm)	Sulfur (ppm)	Carbon (%)	Nitrogen (%)
	Initial	1516 ± 69	684 ± 30	28 ± 5	248 ± 18	419 ± 450	35 ± 3	31 ± 4	0.93 ± 0.05
Cottonwood	Control	4492 ± 455	1666 ± 195	300 ± 17	500 ± 139	562 ± 100	177 ± 110	17 ± 6	0.67 ± 0.10
	0.05% NaCl	3917 ± 426	1450 ± 161	264 ± 31	402 ± 57	584 ± 73	127 ± 31	15 ± 1	0.57 ± 0.03
Kale	Control	7349 ± 127	3292 ± 123	210 ± 46	532 ± 37	316 ± 97	455 ± 65	33 ± 3	0.85 ± 0.04
	0.05% NaCl	7501 ± 625	3282 ± 406	292 ± 117	807 ± 272	1590 ± 103	488 ± 244	30 ± 1	0.87 ± 0.03
Water Oak	Control	4848 ± 750	1881 ± 251	291 ± 50	758 ± 86	540 ± 99	280 ± 88	18 ± 7	0.68 ± 0.11
	0.05% NaCl	4729 ± 585	1938 ± 177	258 ± 23	849 ± 16	913 ± 233	221 ± 81	16 ± 3	0.67 ± 0.14

Table A-4: The chemical makeup of soil underneath leaf litter that was grown with either RO water (control) or NaCl (0.05%) solution. Soil is included from each of the decomposition sites (LA, N. TX-1, N. TX-2, S. TX-1, and S. TX-2) and across time (Initial [0months], 4 months, and 9 months). Included is the mean ± standard deviation of calcium, carbon, magnesium, nitrogen, phosphorous, potassium, sodium, and sulfur.

Site	Time (months)	Calcium (ppm)	Magnesium (ppm)	Phosphorus (ppm)	Potassium (ppm)	Sodium (ppm)	Sulfur (ppm)	Carbon (%)	Nitrogen (%)
LA	Initial	205 ± 100	48 ± 23	11 ± 5.2	29 ± 5.2	16 ± 8.4	8.1 ± 3.5	0.4 ± 0.01	0.027 ± 0.002
Control	4	301 ± 139	33 ± 13	6 ± 1.9	25 ± 7.1	19 ± 6.0	4.3 ± 1.3	0.9 ± 0.37	0.054 ± 0.021
	9	357 ± 201	30 ± 6	4 ± 0.5	23 ± 2.2	12 ± 1.7	3.2 ± 1.2	3.1 ± 4.1	0.127 ± 0.126
NaCl	4	1663 ± 2134	47 ± 9	6 ± 0.7	32 ± 7.1	30 ± 7.5	4.0 ± 0.6	0.51 ± 0.07	0.047 ± 0.007
	9	215 ± 73	31 ± 3	5 ± 1.0	29 ± 12	14 ± 1.7	3.6 ± 0.7	0.23 ± 0.07	0.047 ± 0.007
N. TX-1	Initial	14802 ± 234	167 ± 10	25 ± 0.5	402 ± 19	38 ± 3.1	49 ± 8.8	6.8 ± 0.99	0.150 ± 0.009
Control	4	15655 ± 1022	162 ± 4	16 ± 2.4	337 ± 26	41 ± 2.3	17 ± 3.2	7.2 ± 0.02	0.143 ± 0.023
	9	15501 ± 1681	157 ± 10	14 ± 2.2	328 ± 18	45 ± 3.5	17 ± 1.6	6.9 ± 0.84	0.150 ± 0.023
NaCl	4	19805 ± 3221	179 ± 19	17 ± 2.5	360 ± 59	61 ± 3.4	18 ± 1.8	6.9 ± 1.0	0.144 ± 0.015
	9	17452 ± 2006	166 ± 12	15 ± 2.0	345 ± 25	58 ± 12	20 ± 3.3	5.5 ± 2.0	0.168 ± 0.169
N. TX-2	Initial	14729 ± 963	362 ± 68	68 ± 43	821 ± 81	68 ± 9.8	65 ± 31	12 ± 4.7	0.575 ± 0.241
Control	4	15235 ± 1441	278 ± 23	21 ± 7.4	637 ± 135	50 ± 28	16 ± 6.0	7.1 ± 0.89	0.383 ± 0.097
NaCl	4	15687 ± 733	265 ± 35	18 ± 5.2	637 ± 119	40 ± 16	14 ± 3.8	13 ± 5.5	0.405 ± 0.226
S. TX-1	Initial	17963 ± 3911	498 ± 77	26 ± 14	273 ± 35	40 ± 4.7	46 ± 11	16 ± 2.9	0.402 ± 0.151
Control	4	18540 ± 2895	1008 ± 360	18 ± 3.5	435 ± 33	26 ± 2.1	27 ± 1.9	26 ± 5.8	0.758 ± 0.226
NaCl	4	18378 ± 4936	769 ± 259	18 ± 1.6	444 ± 96	25 ± 5.1	27 ± 3.3	23 ± 7.2	0.944 ± 0.602
S. TX-2	Initial	17916 ± 2126	300 ± 15	35 ± 6.3	413 ± 11	51 ± 3.9	95 ± 20	11 ± 4.2	0.433 ± 0.226
Control	4	19880 ± 1476	326 ± 16	22 ± 2.3	441 ± 47	62 ± 13	26 ± 0.7	9.3 ± 0.96	0.386 ± 0.079
	9	22768 ± 1422	328 ± 12	17 ± 1.1	487 ± 25	43 ± 2.6	27 ± 2.1	8.9 ± 0.87	0.345 ± 0.059
NaCl	4	23204 ± 3232	379 ± 46	25 ± 13	497 ± 34	74 ± 21	31 ± 14	10 ± 0.98	0.351 ± 0.061
	9	21512 ± 2805	318 ± 38	17 ± 3.0	466 ± 44	48 ± 17	27 ± 3.2	8.2 ± 2.2	0.281 ± 0.092

Table A-5: The chemical makeup of soil used to grow water oak (*Quercus nigra*) plants watered with either RO water (control), 0.05%, 0.1%, or 0.4% NaCl solution. Included is the mean ± standard deviation of calcium, carbon, magnesium, nitrogen, phosphorous, potassium, sodium, and sulfur.

Treatment	Calcium (ppm)	Magnesium (ppm)	Phosphorus (ppm)	Potassium (ppm)	Sodium (ppm)	Sulfur (ppm)	Carbon (%)	Nitrogen (%)
Control	2648 ± 279	1183 ± 106	45 ± 2.0	383 ± 31	272 ± 23	100 ± 28	41 ± 2.6	1.05 ± 0.028
0.05%	2839 ± 168	1236 ± 71	67 ± 16	491 ± 42	1674 ± 105	118 ± 35	44 ± 5.2	1.05 ± 0.033
0.1%	2810 ± 163	1332 ± 150	46 ± 12	626 ± 111	90 ± 19	104 ± 52	35 ± 4.1	0.98 ± 0.021
0.4%	3110 ± 257	1595 ± 67	52 ± 4.1	825 ± 132	49 ± 4.0	86 ± 5.9	37 ± 3.9	0.93 ± 0.038

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