Ecological characteristics and soil processes in terrestrial forest habitats on coastal ridges and a survey of avifauna usage of four coastal ridges of different origin in the Caminada-Moreau Headland, Louisiana

A Thesis

Submitted to the Graduate Faculty
of Nicholls State University
in Partial Fulfillment
of the Requirements for the Degree
Master of Science in Marine and Environmental Biology

by
Carissa Thiel
B.S., Florida Institute of Technology, 2015

Fall 2023

Certificate

This is to certify that the thesis entitled "Ecological characteristics and soil processes in terrestrial forest habitats on coastal ridges and a survey of avifauna usage of four coastal ridges of different origin in the Caminada-Moreau Headland, Louisiana" submitted for the award of Master of Science to Nicholls State University is a record of authentic, original research conducted by Ms. Carissa Thiel under our supervision and guidance and that no part of this thesis has been submitted for the award of any other degree, diploma, fellowship, or other similar titles.

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Abstract

Coastal ridges are linear upland features in the coastal landscape that provide an abundance of ecosystem services. However, quantitative assessments of the ecological characteristics and processes of these habitats are limited. Little is known regarding either trajectories of terrestrial vegetation succession for restored coastal ridges, or the role of abiotic factors in structuring vegetation community composition in these habitats. The resolution of these knowledge gaps will enable ridge restoration projects to proceed in a more informed fashion, increasing the likelihood of success for future restoration projects along Louisiana's coast. Terrestrial vegetation community composition and growth responses were studied using four nested ridge plots at ten sites within the Barataria-Terrebonne National Estuary System of varied hydrogeomorphic setting, landform age, and site history from June 2022 to September 2023. All live trees within replicates with a diameter at breast height (DBH) greater than 5 cm were identified and tagged with numbered aluminum tags. Soil core samples, 5-cm in diameter, were taken to a depth of 15 cm and analyzed for relevant soil metrics, including carbon content. High resolution elevation surveys were performed using Real-Time Kinematic (RTK) methods across the width of each replicate and at the base of individually tagged trees. Avian surveys that collected species sightings, calls, and observed behaviors, were conducted monthly from January 2023 to October 2023 by walking the length of the four maritime ridge sites. Trail cameras were also installed at these sites to record general biota presence and activity. Notable patterns were detected in various ecological characteristics and processes across the terrestrial habitats of coastal ridge types, settings, and ages. Importantly, reference (natural) ridges, restored and managed ridges, and spoil banks did not differ in either woody or understory vegetation community composition. Further, *Quercus virginiana* and *Ilex vomitoria* were noted as occurring across a wide range of ridge hydrogeomorphic settings and elevations within ridge settings, highlighting their importance in these habitats and desirability as a target species for restoration. Overall community composition of both woody forest species and understory composition demonstrated gradients with site age and soil salinity concentration. For example, younger, more coastal sites had a higher presence of shrub species *Iva frutescens* and *Baccharis halimifolia*. Older, natural forests had larger individuals but less sapling abundance. Terrestrial carbon stock in woody forest species also exhibited a discernible pattern with age. Key soil properties (e.g., bulk density, moisture content, etc.) fell within expected ranges for healthy coastal habitat in Louisiana, and displayed expected trends in extractable salinity consistent with distance from maritime influence. Surveys of avifauna occurrence suggests that the restored BTNEP ridge at Port Fourchon is successfully providing neo-tropical migratory song-bird habitat.

Acknowledgments

This study was supported by the U.S. Department of the Treasury through the Louisiana Coastal Protection and Restoration Authority's Center of Excellence Research Grants Program under the Resources and Ecosystems Sustainability, Tourist Opportunities, and Revived Economies of the Gulf Coast States Act of 2012 (RESTORE Act) (Award No. 1 RCEGR260007-01-00). The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the Department of the Treasury.
In addition, the Barataria-Terrebonne National Estuary Program, The Nature Conservancy, Grand Isle State Parks, Louisiana Department of Wildlife, Apache Inc, The National Wildlife Refuge System, and the Coastal Protection and Restoration Authority provided permitting and site access. Research took place on the historic lands of the Chitimacha, Choctaw, and Biloxi peoples, and the United Houma Nation.

I would like to thank my advisor Dr. Jonathan Willis for their insight, support, comic relief, and exceptional sign-offs. My committee members Dr. Gio McClenachan and Dr. Gary LaFleur for fueling my desire to protect coastal Louisiana and continuously search for the Forest Spirit. I have been immensely helped by other graduate students within the program, but Erik Nati-Johnson, Elizabeth Myers, and Connor Lee deserve extra recognition for field help, boat training, and personal friendship. Lastly, my given and chosen family all deserve special recognition for their continued support and pushes to constantly grow and improve as a human. You are too abundant to list, and I am immensely grateful.

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Introduction

Louisiana's coastal ridges are important landforms that stabilize adjacent ecosystems, provide crucial terrestrial habitat for faunal support, and reduce damage from high-energy meteorological events (Temmerman et al. 2013). However, substantial data gaps exist regarding characteristics of coastal ridges and the prevailing ecological processes around them, which impede the development of informed restoration strategies for these habitats. The loss of coastal lands in Louisiana is well documented, with coastal wetlands in the region having an estimated loss rate of 75 km^2 per year over the period from 1932 to 2016 in an analysis by Couvillion et al. (2017). This high rate of coastal wetland land loss has resulted in a large-scale, collective effort by local, state, and federal agencies to create and restore these vital lands (Groves et al. 2021, Peyronnin et al. 2013). Historical coastal restoration efforts in Louisiana have primarily focused on coastal marsh, forested wetland, and barrier island habitats (Boesch et al. 1994). More recently, inclusion of ridges in the broader coastal landscape rehabilitation plan has been recognized as beneficial, demonstrated by multiple ridge construction projects being incorporated into the Louisiana Coastal Master Plan (CMP) established by the Coastal Protection and Restoration Authority (CPRA). Specifically, three coastal ridge restoration projects, Bayou Dupont (BA-48), Grand Liard (BA-68), and Bayou DeCade (TE-0138), have been implemented since 2014 as a component of the CMP (Baustian et al. 2020, Lopez 2009, Groves et al. 2021). However, very little empirical data is available to define coastal ridge characteristics or inform how they are likely to evolve over time (Richardi 2017, Richard 2018). This is particularly true regarding the terrestrial vegetation habitats of ridges, which are typically narrow strips of coastal forest occurring above mean high tide (Lopez 2009). The unique position of these habitats in the coastal landscape likely results in differing exposure to the environmental factors and differing tolerances by ridge vegetation. This research aims to reduce data gaps by providing an ecological characterization of the terrestrial portion of several coastal ridges, as well as anthropogenic analogues such as spoil banks, with differing site histories and in different hydrogeomorphic settings.

Coastal Ridge Formation

In general, coastal ridges are thought of as relatively narrow strips of land with supratidal elevations for the establishment of terrestrial vegetation (Lopez 2009); however, there are multiple geomorphic mechanisms by which they may form (Figure 1). Elevated banks along bayous are formed by association with distributary channels in deltaic systems because of sediment deposition during high flow events, and are where cities and towns were historically established in Louisiana (Lopez 2006). In areas more directly influenced by wave action, beach ridges can establish in a shore-parallel fashion through wave-mediated deposition of longshore sediments (Otvos 1979). In Louisiana, these beach ridges are often referred to as “cheniers" because of the prevalence of oak species that occur in this setting (Otvos 1979). Currently, due to decades of human exploration and creation of canals for oil transport and navigation, the most extensive narrow, linear, supratidal habitats in coastal Louisiana are spoil banks (Turner and McClenachan 2018). Spoil banks are created from the piling of sediment excavated for canal creation and can exert several negative effects on adjacent marshes through modification of hydrologic parameters (Turner and McClenachan 2018). However, little is known regarding how spoil banks may provide services as terrestrial habitat, especially given the comparative scarcity of supratidal land in coastal Louisiana (Turner and McClenachan 2018). Including spoil banks in this study will assist in understanding anthropogenic influences not focused on restoration.

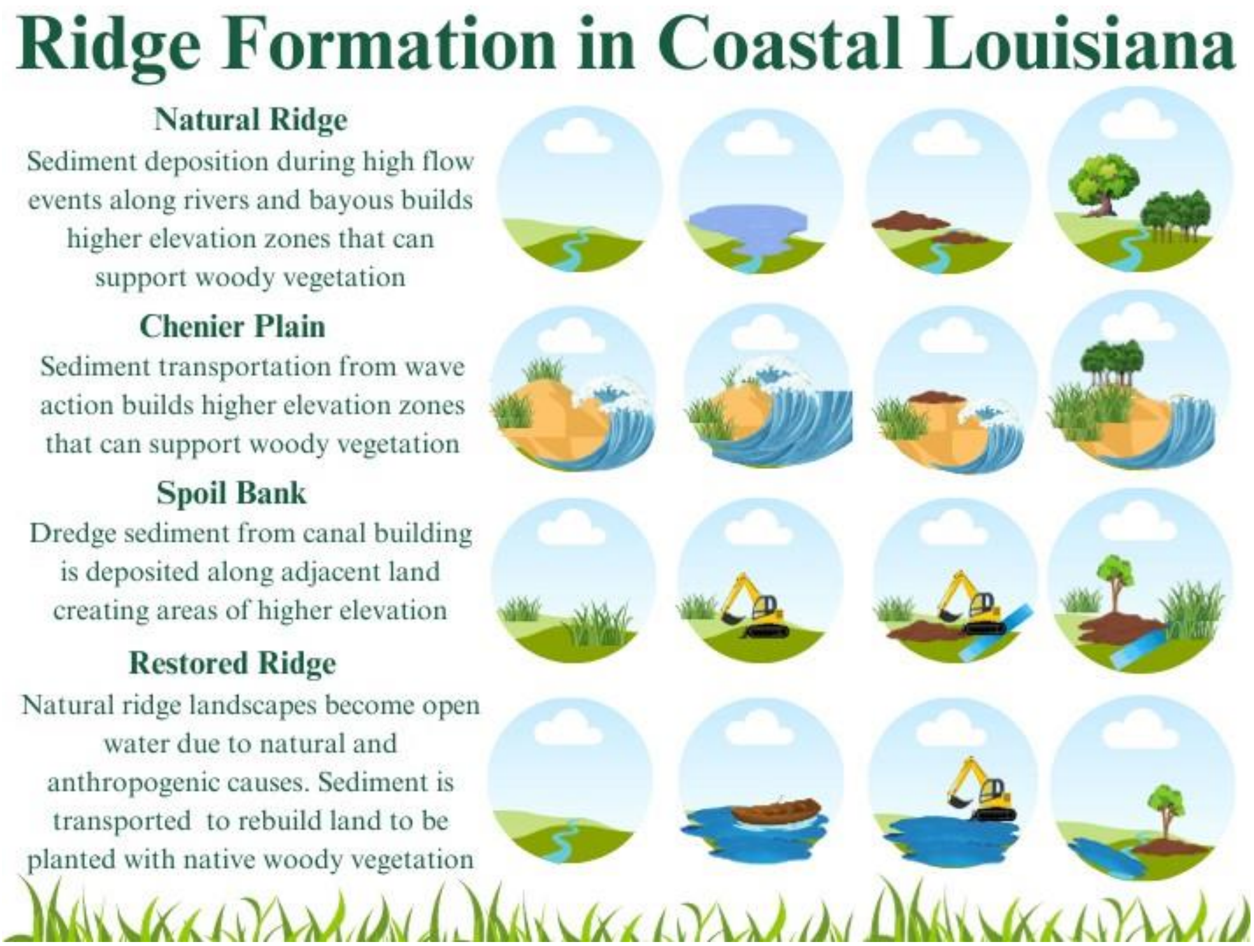

Figure 1. An example of different ridge formations found in coastal Louisiana as categorized for this research project.

Louisiana Coastal Land Loss and Restoration

Louisiana's extraordinary coastal wetland land loss rates are driven by a combination of natural and anthropogenic factors (Penland et al. 1990; Linscombe and Hartley 2010), with a number of these same stressors also potentially influencing coastal ridge persistence. Disconnection of adjacent wetlands from annual Mississippi River sediment deposition reduces accretion, which in combination with the natural processes of subsidence and sediment dewatering, reduces surface elevation, thereby increasing flooding stress on wetland vegetation (Morton et al. 2002). Coastal development, particularly canal dredging and generation of associated spoil banks, results in direct impacts (removal of marsh area) as well as indirect impacts (impoundment and increased flooding stress) to wetlands (Scaif et al. 1983). Coastal ridges are similarly impacted by subsidence and related processes, with the loss of elevation directly impacting their longevity. As ridge elevation decreases, the depth to the water table simultaneously decreases and wetland species can colonize the former ridge terrestrial habitat (Anderson et al. 2022; Penfound and Hathaway 1938). Coastal ridge habitats are comparatively poorly studied regarding their fundamental ecological processes and resultant ecosystem services, or the alteration of these services by environmental and anthropogenic stressors.

This drastic land loss has led to an increase in restoration efforts by government and individual agencies throughout coastal Louisiana. The CPRA funds projects like marsh restoration, river diversions, sediment nourishment, and ridge creation (Groves et al 2021). Ridge restoration efforts are relatively new, but focus on areas with historic marsh and ridge landscapes that have become open water. New sediment is dredged, transported, and deposited to rebuild ridges with a target elevation of 5 ft (Richardi 2017). Natural subsidence of the fresh sediment occurs, and strategic plantings occur to aid in re-establishing target woody vegetation. Many of these projects gather insight from the Barataria-Terrebonne National Estuary Program (BTNEP), which initiated the first of its kind ridge restoration effort in Port Fourchon with portions of construction being completed in 2005 (Benoit 2016; Richardi 2017). Given the recent initiation of ridge restoration projects, ideal elevations, soil characteristics, and most beneficial plantings are not fully understood.

Structuring Factors

Vegetated ecosystems in coastal Louisiana are primarily structured by various aspects of hydrology, including frequency, duration, depth, and salinity of floodwaters (Keim et al. 2019). For instance, terrestrial forests occurring within the coastal zone can experience salinization of the freshwater storage they depend on due to chronic saltwater intrusion and extended periods of drought (Lopez, 2009). Similarly, acute salinization events can result from other climate-driven phenomena (e.g., tropical cyclones), as well as salinity exposure due to man-made hydrological changes and disturbance events (Lopez, 2009). Changes in salinity gradients may be a key factor in the distribution of terrestrial forested species along coastal ridges, and in recovery of tree species post stress events. For example, *Quercus virginiana* (southern live oak) has been found to have comparatively higher resistance to salinity and inundation stressors than other coastal forest species, as seen in Bayou Sauvage post Hurricane Katrina inundation, but saltwater intrusion can push this limit and cause large die-offs (Keim et al. 2019). Healthy coastal forests often demonstrate resilience to large-scale disturbance events such as hurricanes, helping to shield adjacent ecosystems in the process (Dietz et al. 2018). However, resiliency can change under changing hydrological conditions. Given the highly dynamic nature of Louisiana's coastal setting, characterizing forested ridge communities, and identifying species that contribute substantially to ridge ecosystem resilience and stability under likely environmental pressures will enhance the design of sustainable coastal ridge restoration projects.

Hydrology of coastal ridge systems is directly influenced by elevation, which is currently a key element in consideration of Louisiana's coastal restoration projects. However, there is a lack of knowledge regarding the optimal elevation and morphology for Louisiana ridge restoration project designs. Due to high rates of subsidence throughout coastal Louisiana, particularly in the Barataria Basin (2-7-mm yr^{-1}, Byrnes et al. 2019), elevation plays a changing role in hydrologic regime. Previous studies in secondary forests have found that the combination of elevation and slope, through modulation of hydrology, greatly impact forest diversity and tree survival by determining inundation characteristics and influencing soil properties (Rodrigues et al. 2021). Because differences of only a few centimeters result in substantial alteration of vegetation community composition, elevation is considered to exert an outsized effect on plant assemblage (Anderson et al. 2022). For instance, Denslow and Battaglia (2002) examined forested communities in Jean Lafitte National Park, Louisiana and found that across a 1.4-meter elevation gradient that species richness of trees did not change, but overall community composition was altered. *Sabal minor* (dwarf palmetto) exhibited a decreased abundance at lower elevations, *Acer rubrum* (red maple) abundance increased despite previous documentation of lower flood tolerance in that species, and invasive *Triadica sebifera* (Chinese tallow) sapling presence increased (Denslow and Battaglia 2002). Identifying favorable elevations for long-term planting success, optimal community composition, and physical ridge persistence will be invaluable for enhancing ridge restoration design. Further, because of the substantial cost of mobilizing sediments for restoration activities, restored ridge projects that are built to excessive elevations will not only detrimentally impact planting success by increasing drought-related stressors, but also lower overall cost-effectiveness due to unnecessary construction costs. Restoring ridges to inefficient elevations will impact planting success by increasing flood-related stressors and decreasing the expected time for the ridge to maintain ideal ecosystem functions. Understanding the ideal elevation for sediment transport and natural subsidence may increase success of woody vegetation establishment.

Soil Properties

Due to the complex interactions of belowground vegetation processes and soil characteristics (e.g., salinity, density, etc.), the chemical and physical properties of ridge substrates are anticipated to be highly influential not only on long-term vegetation growth, but also ridge persistence and carbon sequestration. Changes in soil physio-chemical properties can have wide-ranging ecological effects, such as modulating nutrient availability, vegetation productivity, forest persistence, and regime shifts (Tully et al. 2019). Further, many soil properties, such as bulk density, conductivity, salinity, and soil organic matter, can vary vertically within systems, regionally throughout the coast, and locally after sediment deposition during hurricanes (Wang et al. 2017). Nitrogen, typically the limiting nutrient for plant productivity via its role in photosynthetic processes, exhibits varying forms and concentrations throughout and within systems and is dynamic in response to Louisiana's changing coastal landscape (Rivera-Monroy et al. 2010). Tidal freshwater marshes often demonstrate higher organic nitrogen content than their saline counterparts, although proximity to eutrophication and bioturbation sources may change these (Yuan et al. 2020; Loomis and Craft 2010). In addition, soil organic matter is highly associated with carbon sequestration (Baveye et al. 2020), but the regulation of soil organic matter production in different ridge ages and plant communities is poorly understood. Several studies have revealed differences in carbon sequestration processes and rates in restored versus natural coastal wetland ecosystems. For example, Suir et al. (2019) found higher rates of carbon accumulation in naturally occurring wetlands than restoration sites, though the sediment diversion sites had significantly higher accumulation rates than all other sites. Further qualifying coastal ridge soil properties can lead to increased added benefits of restored land as carbon sinks.

Better understanding of soil physio-chemical properties and processes in coastal ridges, particularly how they change over time, will further inform likely success of ridge restoration and plantings. Plant species presence can be indicators into likely soil properties (Penfound and Hathaway 1938); however, development of specific relationships between soil characteristics and tree species occurrence, health, and growth rates within coastal ridge settings will be useful to understand probable outcomes of ridge restoration projects more fully. For example, the presence *Q. virginiana* is often associated with mildly alkaline soils that have higher pH levels, as well as greater availability of nutrients (Schmalzer and Foster 2020). Localized soil redox potential, salinity levels, and interstitial sulfide concentrations are known to be highly influential to *Avicennia germinans* (black mangrove) seedling survival and growth responses (McKee 1993). Establishing a similar understanding of forested vegetation relationships with soil properties would aid in understanding and predicting the success of restoration plannings.

<u>Coastal Ridge Plant Species</u>

Identifying surrounding abiotic factors influencing gradients in both tree species abundance and the associated understory community at coastal ridges will enable estimation of likely ridge resilience associated with biodiversity. Specifically, developing an understanding of successional trajectories, the likely driving factors, and reasonable restoration targets will allow for greater insight regarding restoration timelines to success. A common species used during restoration plantings is *Q. virginiana*, a climax species in coastal forests in areas of decreased flood risk (Penfound and Howard 1940). However, Penfound and Howard (1940) documented while *Q. virginiana* appears as the predominant species in an old growth forest, *Quercus nigra* (water oak) had a larger influence based on basal area. Mimicking the successional process of vegetation is generally recognized as increasing soil stability, thereby limiting erosion, and enhancing overall seedling success, indicating that delaying plantings of climax species may be beneficial to restoration efforts (Ghestem et al. 2014). *Zanthoxylum clava-herculis*, known as “tooth-ache tree,” has an expanse of medicinal and culinary uses and survives better in shaded understories provided by other key ridge tree species such as *Q. virginiana*, *Liquidambar stryaciflua* (sweetgum), or *Celtis laevigata* (sugarberry; Thakore et al. 2022). *Ilex vomitoria* (yaupon holly) is the one of two native plants containing caffeine in North America, and has historical use as an ingredient of “Black Drink” in many Indigenous cultures (Folch 2021; Green 2016). Including culturally important species in restoration processes can enhance biodiversity and provide a multi-disciplinary approach solving to Louisiana’s unique coastal issues.

Less is known about the connections between woody vegetation and the importance of understory vegetation for enhancing diversity and other ecosystem functions on coastal ridges. Understanding community composition at multiple levels as it relates to flood risk and elevation can aid in enhancing modeling projections (Brock et al. 2013). Understory vine species that can grow high into trees such as *Campsis radicans* (trumpet vine), *Smilax sp.,* and *Toxicodendron radicans* (poison ivy), have higher survival rates than those fully grounded during post flood events (Noble and Murphy 1975), but can also impact survival of woody species (Rayamajhi and Dray 2022). Including understory composition can also provide insight to sapling success, as some species have decreased likelihood for long-term survival at different times of succession and under different flooding conditions/risk (Noble and Murphy 1975; Penfound and Howard 1940). Maintaining a relatively diverse coastal forest community composition is typically associated with enhanced productivity, function, and resilience of these areas (Ford et al. 2016). Understanding the feedbacks of soil quality, the evolution of its characteristics, and its influence on the successional processes that drive terrestrial diversity will be important in designating realistic ridge restoration vegetation community composition targets and designing coastal ridge restoration projects that accomplish these objectives.

Avian Presence as an Indicator of Ridge Health

Louisiana provides unique and important habitat for year-round and for migrating avian species (Remsen et al. 2019). Coastal land loss increases the distance migratory species need to travel after long energy-depleting seasonal flights that may include traversing the Gulf of Mexico from the Yucatan (Lafleur et al 2016). Specific loss of critical coastal ridges may decrease important food sources for the many migrating bird species that utilize Louisiana's coast as a significant stopover habitat (Patton et al. 2020). While many efforts have been made to restore coastal nesting habitats, the need to restore migration stop-over points for neotropical migrants is relatively new in restoration planning (Groves et al. 2021, Benoit 2016). Identifying the relationship between neotropical migrants and the community structure that best provides food and habitat can improve land restoration at a collective ecosystem level.

Importance

As Louisiana's coastline continues to be lost, many organizations, agencies, and communities are working to rebuild natural ridges as a component of overall coastal restoration. The CPRA of Louisiana has implemented multiple ridge restoration projects through Louisiana's Coastal Master Plan. Identifying the key abiotic influences throughout coastal Louisiana's ridge communities can increase the success rate of land recovery strategies. Understanding the shifts in plant composition due to different abiotic factors is important for predicting the net change of an area, and can aid in establishing a timeline for restored ridges to reach natural productivity rates. Identifying the most productive and resilient forest composition as related to abiotic factors can improve sapling selection for improved long-term success of restoration efforts. The purpose of this research is to identify current forested vegetation community composition throughout coastal Louisiana's ridge systems, establish how that composition varied by ridge origin, and assess what key abiotic factors influences forested vegetation communities. In addition, this research aimed to determine if BTNEP's restored ridge at Port Fourchon reached planning goals of acting as successful migratory bird habitat.

Methods

Site Selection and Data Collection

Study sites were selected to represent a range of ridge ages, histories, and hydrogeomorphic settings within the Barataria-Terrebonne National Estuary, Louisiana (Table 1). Ten sites were established over the fall of 2022 and winter of 2023 (Figure 2). Climax forest ridge communities at Mandalay National Wildlife Refuge (MR) and The Nature Conservancy (TNC) at Grand Isle were chosen as reference sites due to having established forested vegetation and the most minimal anthropogenic influence of the ten sites. Multiple sites that had been actively restored or managed were selected. Grand Isle State Park (GISP) has been modified by beach renourishment, and Point Farm (PF) was previously agricultural land within a state Wildlife Management Area that was replanted with various hardwood species to enhance wildlife habitat. The construction of BTNEP's restored ridge at Port Fourchon was completed in 2005, with over six years of experimental plantings of *Morus rubra* (red mulberry), *C. laevigata*, *Q. virginiana*, *Callicarpa americana* (American beautyberry), *I. vomitoria*, *Morella cerifera* (wax myrtle), *A. germinans*, *Quercus germinata* (sand live oak), *Gleditsia triacanthos* (honeylocust), *Diospyros virginiana* (persimmon), *Cornus drummondii* (roughleaf dogwood), and *Z. clava-herculis* (Benoit 2016). Two restored CPRA ridges Bayou Dupont (BDUP) and Grand Liard (GLIA) were completed in 2015 and 2016 respectively. Both CPRA ridges had similar plantings to BTNEP, including: *M. rubra*, *C. laevigata*, *Q. virginiana*, *C. americana*, *I. vomitoria*, *M. cerifera*, and *D. virginiana*. Three spoil banks created from the dredging of canals were included for comparison to ridges of anthropogenic origin. A spoil bank in Mandalay National Wildlife Refuge (MSB) was created in 1942, on Elmer's Island (ELM) in 1953, and Isle de Jean Charles (IDJC) in 1962. IDJC was historically a natural ridge, but had sediment

Table 1. Ten study sites in the Barataria-Terrebonne National Estuary System that represent ridges of various formation types and ages. Codes are used for the sites throughout the following results. Asterisk indicates a historic ridge that had dredged sediment from an adjacent canal creation deposited on top of it, giving it the classification of spoil bank for the purpose of this research project.

CODE	NAME	AGE (years)	Habitat Notes
	Reference Site		
MR	Mandalay National Wildlife Refuge Ridge	1250	Fresh
TNC	The Nature Conservancy at Grand Isle	676	Mesohaline
	Restored/Managed Site		
GISP	Grand Isle State Park	55	Saline
PF	Point Farm	29	Mesohaline
BTNEP	Barataria-Terrebonne National Estuary Program at Port Fourchon	18	Saline
BDUP	Bayou Dupont (CPRA)	8	Mesohaline
GRLI	Grand Liard (CPRA)	7	Mesohaline
	Spoil Bank Site		
MSB	Mandalay National Wildlife Refuge Spoil Bank	81	Fresh
ELM	Elmer’s Island	70	Saline
IDJC	Isle de Jean Charles*	61	Mesohaline

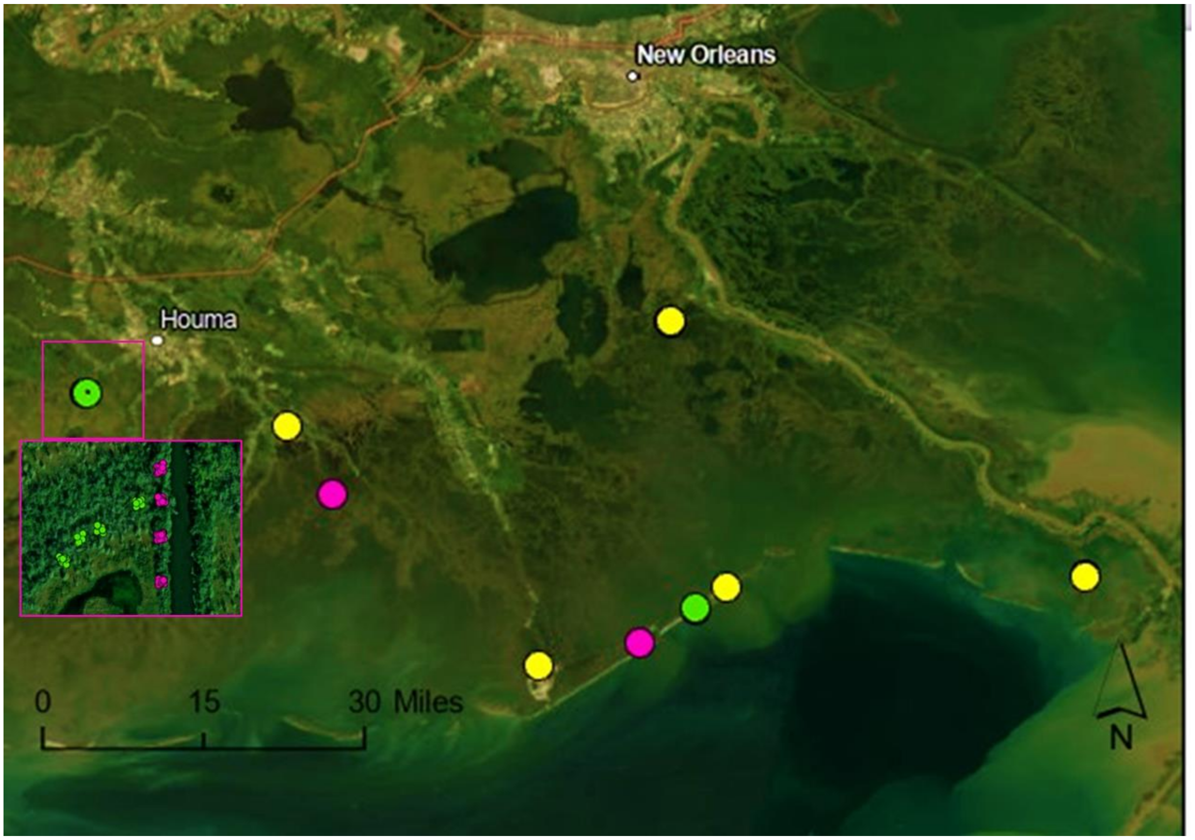

Figure 2. A map of the ten sites chosen within the Barataria-Terrebonne National Estuary System to characterize coastal ridge systems. Green represents reference ridges, yellow represents restored, replanted, or managed ridges, and pink represents spoil banks. The inset displays the two sites at Mandalay National Wildlife Refuge.

deposited on top of the natural ridge during canal creation. Due to this anthropogenic alteration and different sediment source, it was not considered a reference ridge for this research.

At each site, four 8 m^2 plots approximately 20 m apart were established on the crown of the ridge as nested ridge replicates. At BDUP and GLIA, areas outside of CPRA's previously established plots were prioritized as replicates. All live trees within the plots with a diameter at breast height (DBH) greater than 5 cm were identified and tagged with numbered aluminum tags. DBH was measured and recorded below and above the tag and averaged to provide one estimate per individual. Note that an exception was made at ELM, where *A. germinans, I. vomitoria,* and *Baccharis halimifolia* (salt-marsh elder) with a DBH of 2 cm or larger were tagged and measured due to a lack of larger individual trees. DBH was used to calculate basal area and estimate carbon stock and sequestration based on equations from the literature (Torres and Lovett 2013). Allometric equations for carbon stock and sequestration were available for *Q. virginiana, Q. nigra, Quercus phellos* (willow oak), *G. triacanthas, I. vomitoria, C. laevigata, A. rubrum, L. styracifula,* and *Carya illinoensis* (pecan; McPherson et al. 2016).

Immediately after plot establishment, soil core samples, 5 cm in diameter, were taken to a depth of 15 cm using a sharpened thin-wall aluminum corer. In the lab, wet weight was recorded and soil samples were oven dried to a constant weight at 65°C. After determining soil sample dry weight, soil samples were homogenized by mortar and pestle. A 20 g subsample from each plot was subjected to a 1:1 de-ionized water extraction for determination of extractable soil pH, salinity, and conductivity. Additionally, a 3 g soil subsample from each plot was submitted to an external laboratory for the determination of soil carbon and nitrogen content. Throughout fall of 2022 and spring of 2023, high-resolution (1-5 cm) soil surface elevation determinations were performed every one meter to develop a cross-ridge profile, as well as at the base of each tagged tree as part of another component of the overall study (Nati-Johnson 2023). The high-resolution elevation surveys were performed using Real-Time Kinematic (RTK) methods with a Trimble R10 Global Navigation Satellite System (Trimble Navigation Limited, Sunnyvale, CA, USA) in combination with a Continuously Operating Reference Station (CORS) network developed by C4Gnet at the LSU Center for Geoinformatics (Hu et al. 2003, Montane and Torres 2006).

In May-June of 2023 and August of 2023 two 1 m^2 subplots were randomly selected within the four nested ridge replicates at each site, and understory vegetation cover visually estimated by species. Overstory canopy coverage was calculated using a densiometer following standard methods in the center of each nested ridge replicate (Hietz et al. 2015). In August of 2023, presence counts were performed for trees with DBH lower than 5 cm within each replicate at the ten sites to include in overall abundance comparisons. In addition, DBH of tagged trees was remeasured in late summer of year two and used to calculate annual growth. Leaf level normalized difference vegetation index (NDVI) was measured on two randomly selected leaves from two randomly selected trees within each plot at each site with a PlantPen PSI meter (Model NDVI 310; PRI 210/ N-Pen N 110) in late summer of 2023 to provide insight into physiological stress. *Q. virginiana* and *I. vomitoria* were prioritized for selection when available due to their presence at multiple sites.

Avian Surveys

Avian surveys were conducted monthly from January 2023 to October 2023 by walking the length of previously established forested ridge plots at BTNEP, ELM, TNC, and GISP for 30 minutes. During avian surveys, species sightings, calls, and observed behaviors (feeding, flying, walking, etc.), along with weather and understory coverage were recorded. In addition, Vikeri trail cameras were installed approximately 30 cm above ground level at the four forested ridge sites to record overall fauna presence and activity. Cameras were moved to haphazardly located plots along the ridge monthly to gather images from both the terrestrial forested ridge and the adjacent marsh areas. Images were uploaded to a computer and sorted into false positives and positives. If multiple positives of the same individual occurred within similar time stamps that visit was considered a “unique visit.” Avian unique visits from field cameras were used to supplement species presence data.

Statistical Analysis

Univariate vegetation (total tree abundance, total basal area, total understory cover, annual growth, estimated carbon stock and sequestration) and soil (moisture, bulk density, total carbon content, total nitrogen content) metrics were tested for significance differences using one-way ANOVAs with Tukey post-hoc tests applied where appropriate. For annual growth IDJC was removed from analysis due to human error collecting measurements in year one. To assess patterns in both forested vegetation and understory community composition, as well as among avian species, non-metric multidimensional scaling analysis (NMDS) was implemented using the Vegan package in R version (Clarke 1993; Oksanen et al. 2022). Vegetation NMDS was performed using the Bray distance measure and with permutations set to two. Avifauna presence and abundance data were descriptively summarized, and visualized in regards to site and time using NMDS performed with Gower’s distance measure with permutations set to three due to the sparseness of the avifauna data set.

Detected gradients in vegetation community composition were related to species abundance/cover as well as environmental variables using Pearson rank correlation tests, as well as being visualized with vector overlays. Differences between sites in regards to community composition were tested via perMANOVA (Oksanen et al. 2022). Elevation readings were categorized by tree species and site, then visualized in Microsoft Excel. Alpha was set at 0.05 for all significance tests. For all parametric analyses, data residuals were screened for adherence to test assumptions.

Results

Plant Communities

Basal area differed significantly by site ($F=3.12$, $p<0.05$), with MR having significantly greater basal area than GISP, PF, BTNEP, or ELM (all Tukey HSD $p<0.05$; Figure 3). Sites exhibited significant differences in tree abundance ($F=4.23$, $p<0.05$) with *Q. virginiana* and *I. vomitoria* the most ubiquitous tree species, present at 7 of the ten sites each (Figure 4). *Q. virginiana* was the most abundant tree at BTNEP, and *I. vomitoria* was the most abundant tree at TNC, BDUP, and IDJC. *A. germinans* was present on the ridge crown at only two sites (GISP, ELM), both geographically close to the Gulf of Mexico. *S. minor* was only present at the freshwater sites (MR, MSB). Tree species richness differed significantly ($F=5.06$, $p<0.05$) with MR and PF having the most species and TNC and ELM having the least (Tukey HSD $p<0.05$; Figure 5). Notably, forested canopy coverage was largely similar between sites, except for GLIA and ELM, which were significantly lower than all sites (Tukey HSD $p<0.05$; Figure 6;). No significant difference in forested canopy coverage was detected between the spring and fall sampling periods. Significant differences were detected in the NDVI of *Q. virginiana* ($F=7.18$; $p<0.05$) with TNC (0.78±0.01), BDUP (0.80±0.02) and IDJC (0.78±0.01) having values significantly higher than BTNEP (0.72±0.01). At sites where *I. vomitoria* occurred, significant differences were detected in NDVI ($F=2.83$; $p<0.05$) with TNC (0.79±0.01) and IDJC (0.77±0.01) demonstrating higher values than GLIA (0.63±0.02). All NDVI values fell within expected ranges.

BDUP demonstrated statistically higher growth than all other sites ($F=5.34$; $p<0.05$; Figure 7) from fall 2022 to fall 2023, but measurements fell within normal growth rates for the *Q. virginiana* present at that site. MR (-0.03±0.19cm) demonstrated decreases in average DBH

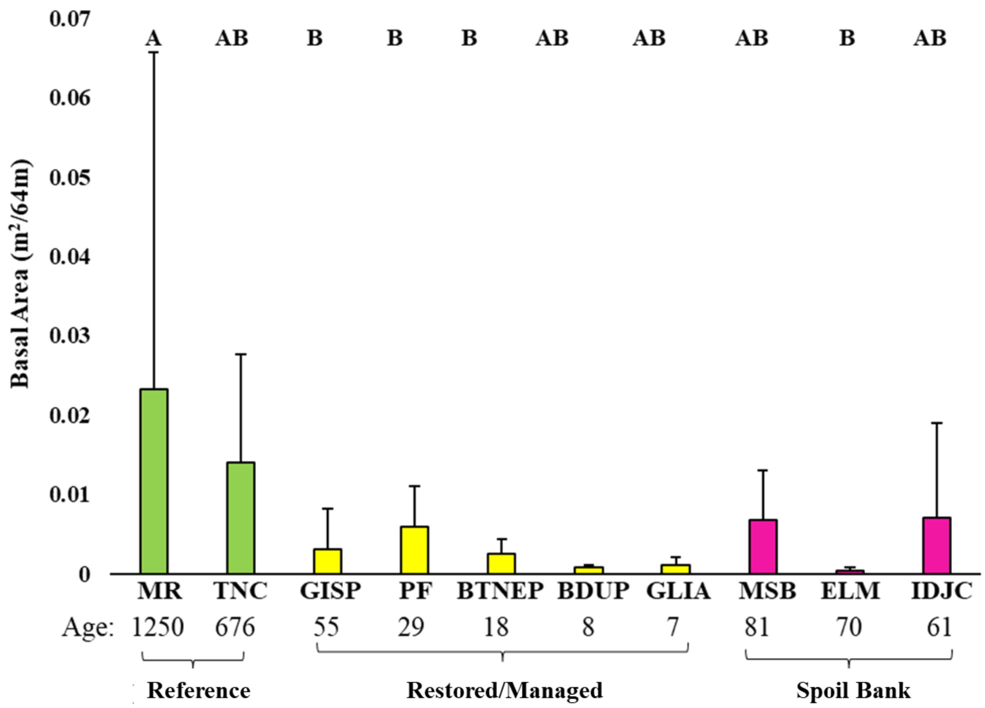

Figure 3. The effect of ridge history on basal area (mean m^2/64 m ±SE) from four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System in fall of 2023. Sites that share a letter are statistically similar.

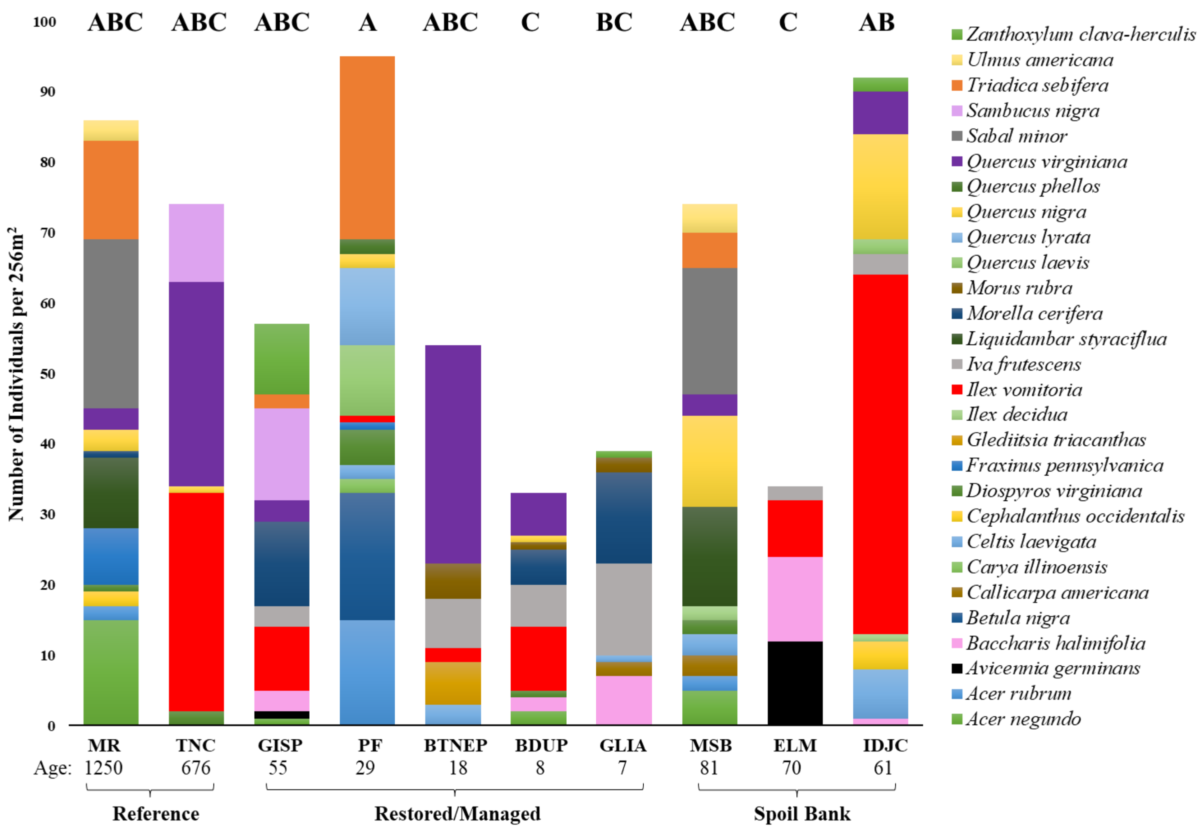

Figure 4. The effect of ridge type on woody tree species abundance from four nested ridge replicates covering 264 m^2 at ten sites within the Barataria-Terrebonne National Estuary System in fall of 2023.

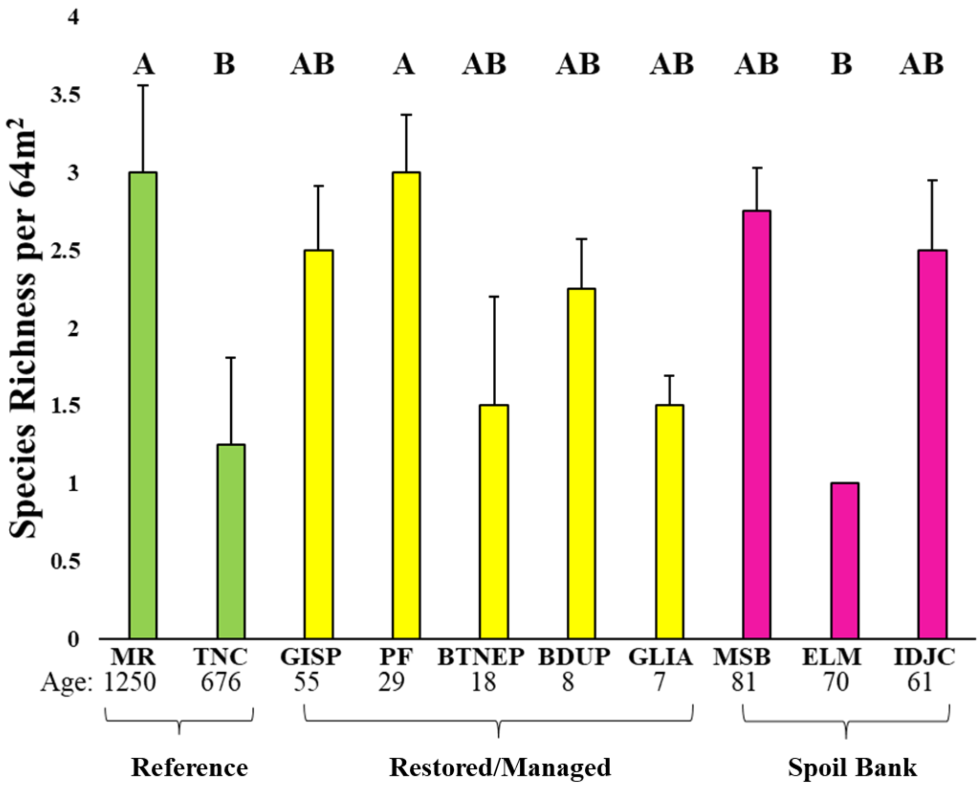

Figure 5. The effect of ridge type on tree species richness (mean ±SE) of individual trees with a DBH>5 cm in four 64 m^2 nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System in fall of 2023. The four species documented at ELM occurred in four different replicates.

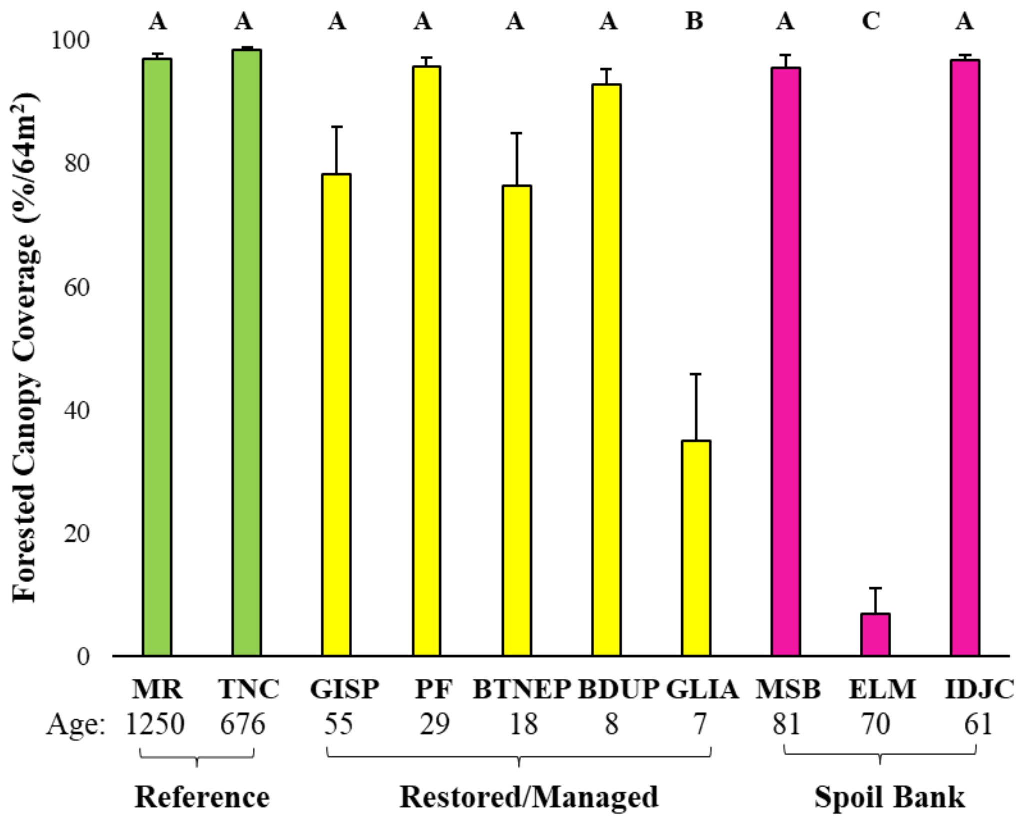

Figure 6. The effect of ridge type on forested canopy coverage (%; mean ±SE) determined using a densiometer in four 64 m^2 nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System in fall of 2023. Sites that share a letter are statistically similar.

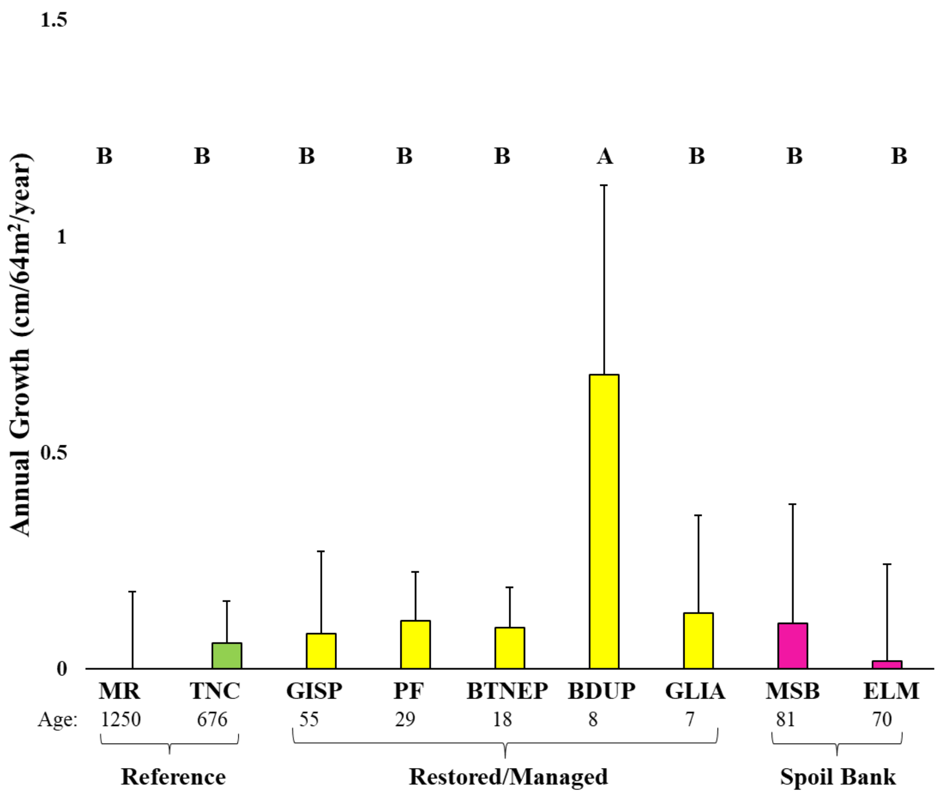

Figure 7. The effect of ridge type on tree annual growth (cm ±SE) from fall 2022 to fall 2023 of individual trees with a DBH>5 cm in four 64 m^2 nested ridge replicates at nine sites within the Barataria-Terrebonne National Estuary System. Growth occurred in all individuals at BDUP and all measurements fell in expected rates for the species present.

measurements from fall 2022 to fall 2023, most likely due to the flaky consistency of the bark on old-growth trees. TNC old-growth chenier forest had statistically higher values of estimated carbon stock ($F=8.88$, $p<0.05$; Figure 8), and estimated carbon sequestered ($F=7.91$; $p<0.05$; Figure 9) from fall 2022 to fall 2023.

A two-dimensional solution to overall ridge woody vegetation abundance was obtained (stress=0.14; Figure 10), in which dimension one was positively correlated with *B. halimifolia* (r= 0.73) and *Iva frutescens* (marsh elder; r=0.67), but negatively correlated with *T. sebifera (*r= -0.78), *D. virginiana* (r= -0.72), and *S. minor* (r= -0.63). Dimension two was positively associated with *M. rubra* (r= 0.54), and negatively associated with *Sambucus nigra* (elderberry; r= -0.55). Dimension one was pulled by shrub species, mostly documented at ELM, GISP, BDUP, and GLIA. Including saplings in the analysis emphasized differences between sites with freshwater sites pulling dimension one negatively as *S. minor* is only present at MR and MSB.

A two-dimensional solution to abundance of tagged trees with a DBH>5 was obtained (stress=0.11; Figure 11), in which dimension one was positively correlated with *M. rubra* (0.48) and *G. triacanthas* (r= 0.48), but negatively correlated with *T. sebifera* (r= -0.65), *Fraxinus pennsylvanica* (green ash; r= -0.59), and *A. rubrum (*r= -0.53). Dimension two was positively associated with *M. cerifera* (r=0.56) and *Z. clava-herculis* (r=0.53), but negatively associated with *L. styraciflua* (r= -0.48) and *Acer negundo* (boxelder; r= -0.41). Species largely present at BTNEP pulled dimension one, in addition to aligning with pH and bulk density measurements. The vector overlays demonstrate a possible relationship between restored ridge BDUP's tagged species and the high carbon and nitrogen content of the soil.

A three-dimensional solution to understory species distribution was obtained with Gowers distance measure (stress=0.155; Figure 12) in which dimension one was positively correlated

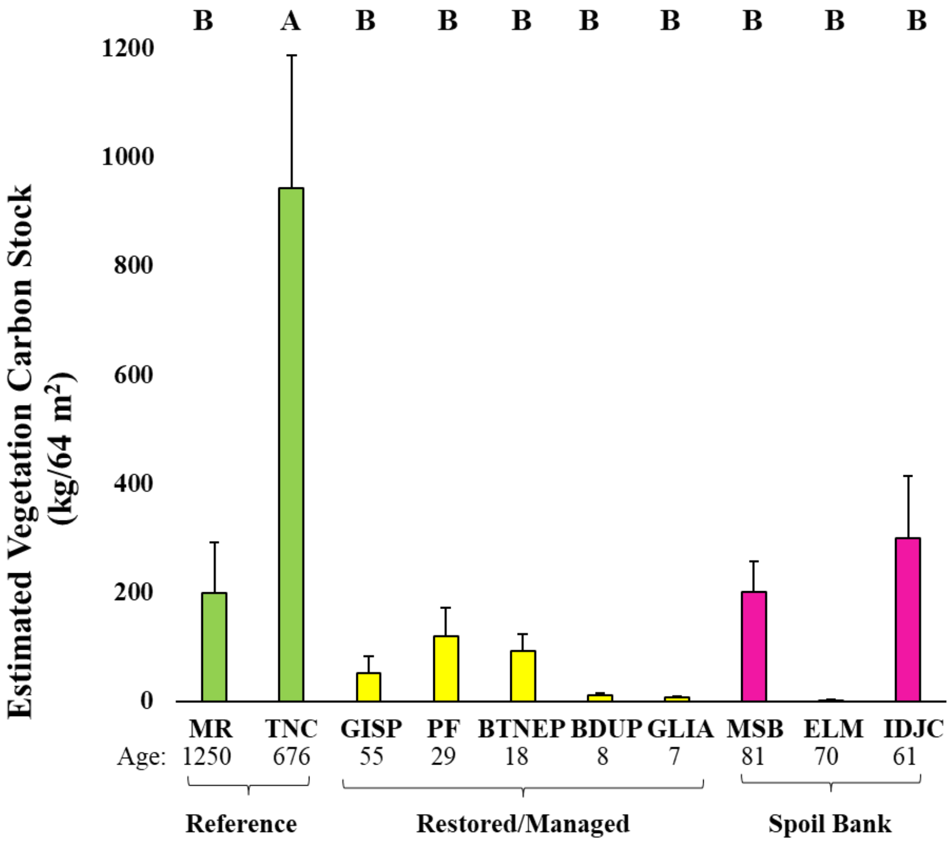

Figure 8. The effect of ridge type on estimated carbon stock exchange (mean ±SE) per 64 m^2 in four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2022 to fall of 2023.

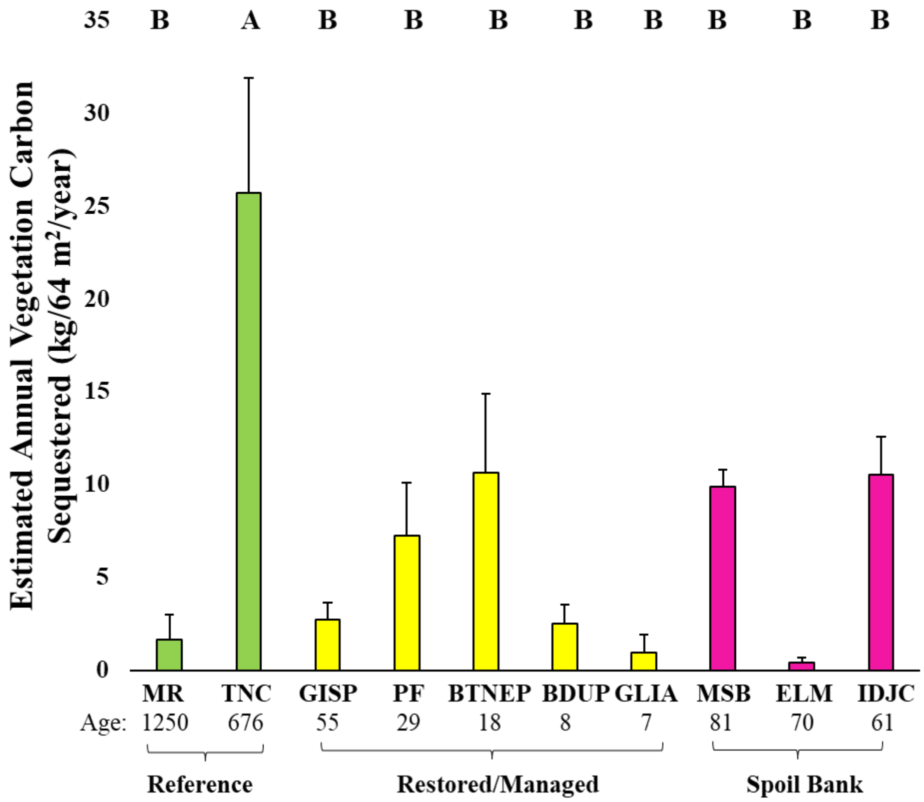

Figure 9. The effect of ridge type on estimated carbon sequestration (mean ±SE) per 64 m^2 in four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2022 to fall of 2023.

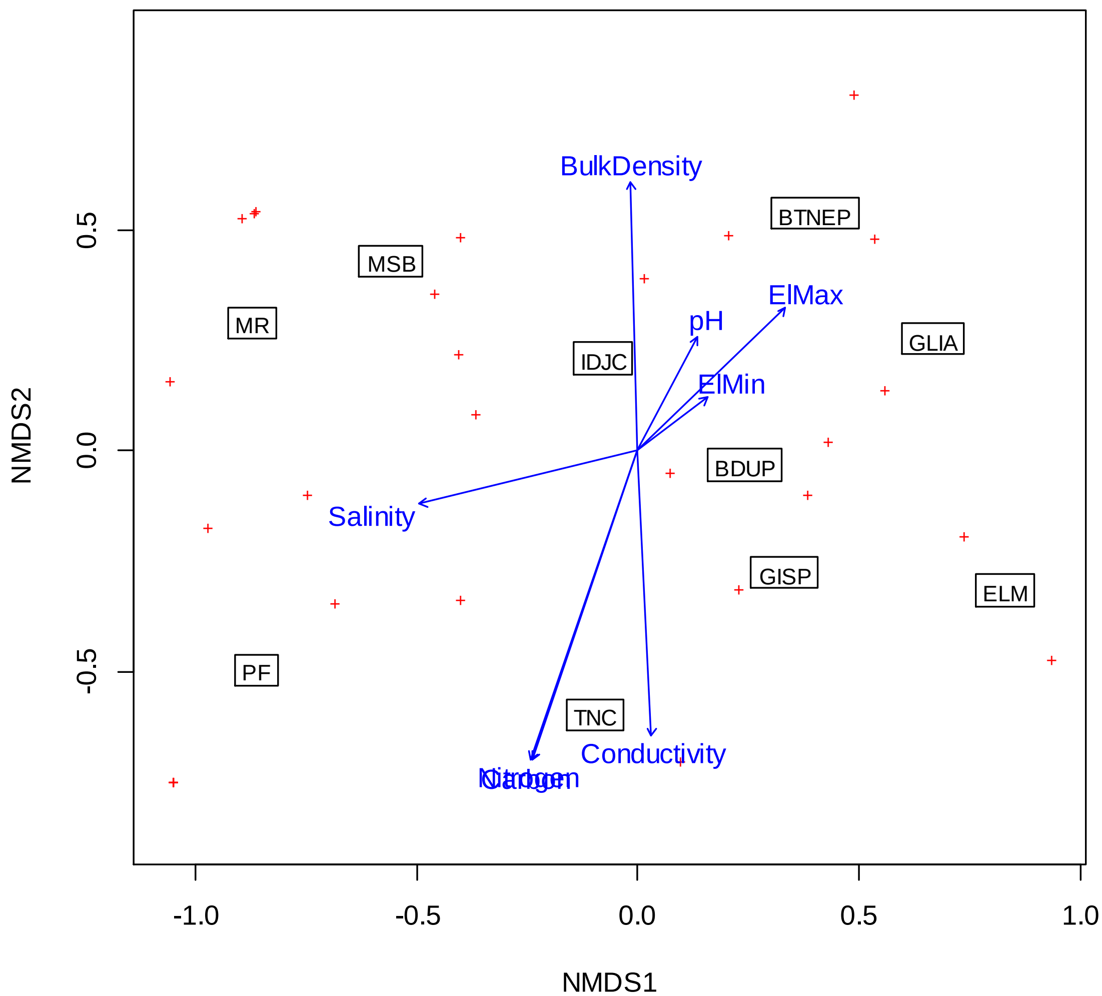

Figure 10. The relationship of woody vegetation and soil properties from four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2023. Percent carbon and percent nitrogen are overlapped. Dots represent woody vegetation observed.

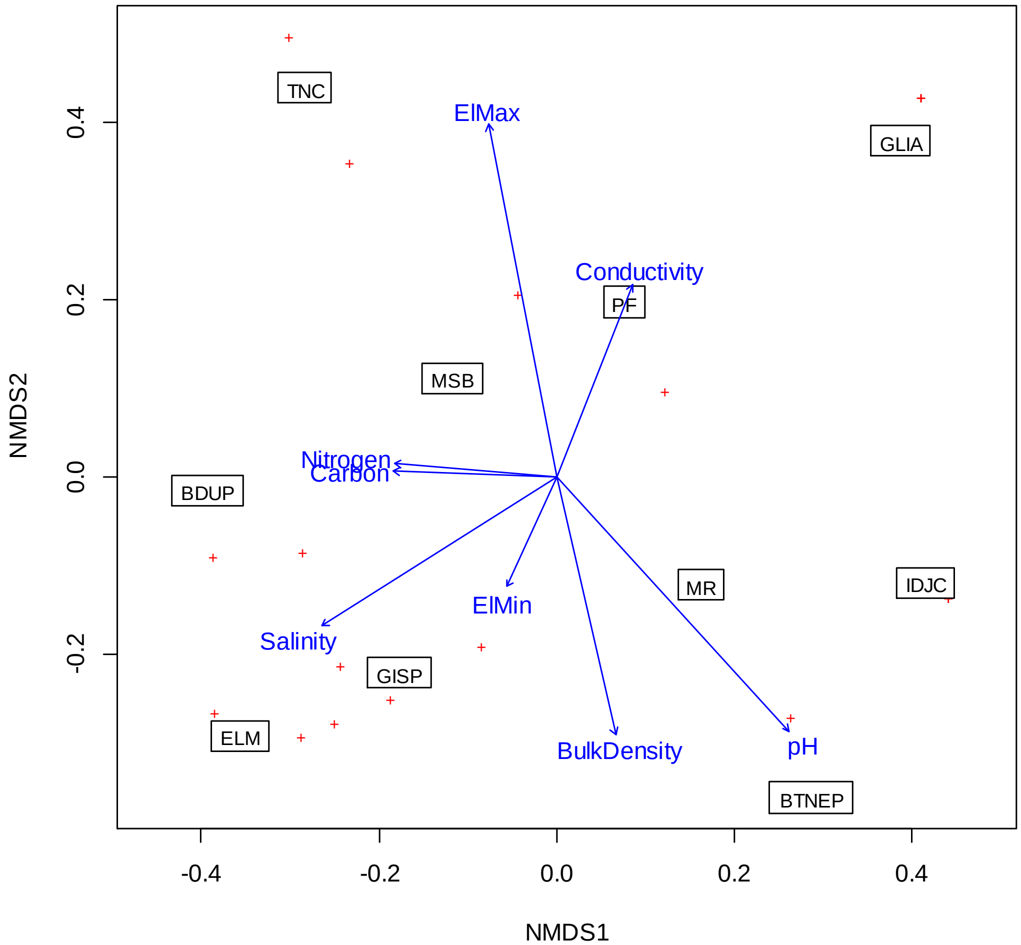

Figure 11. The relationship of tagged trees with a DBH>5 cm from four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2023. Dots represent tagged tree species observed.

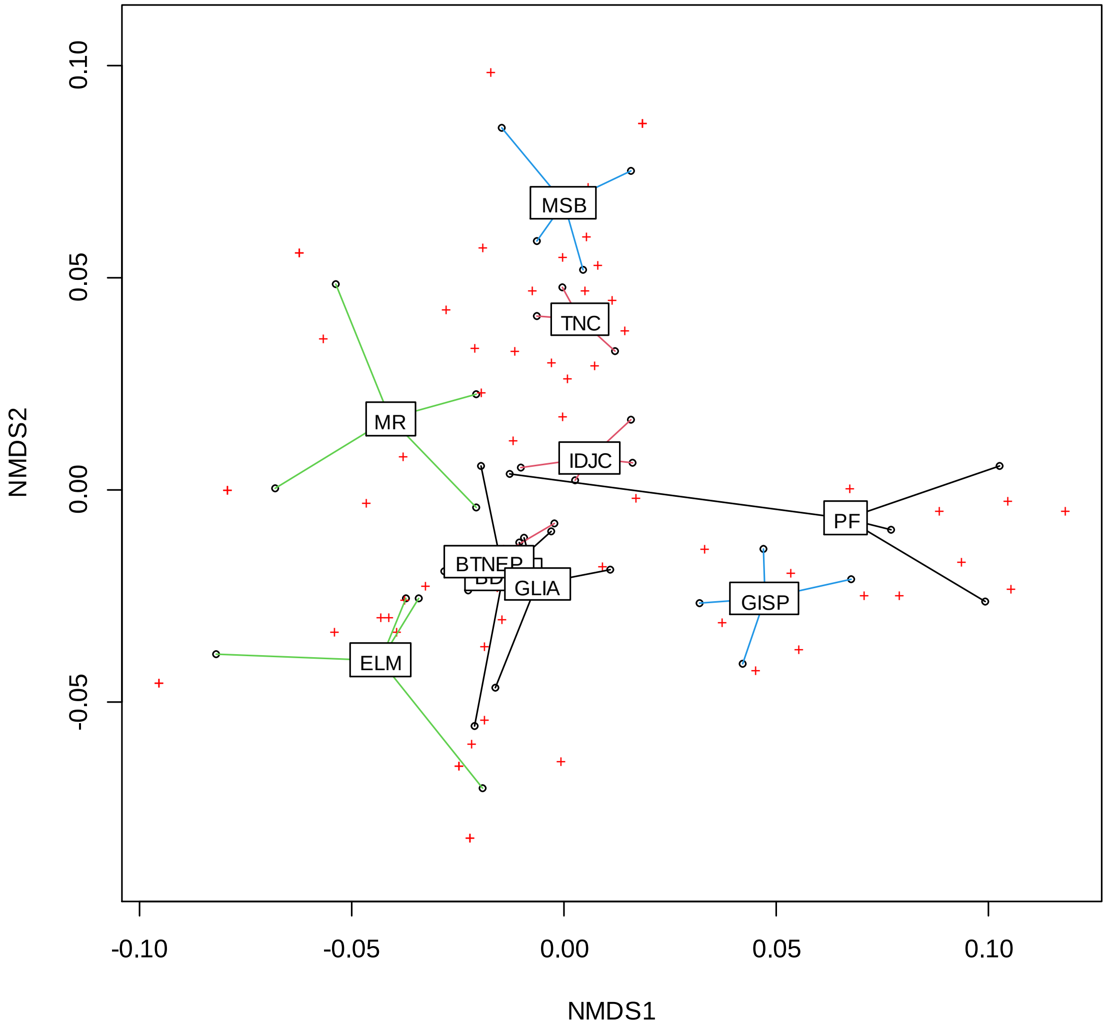

Figure 12. The relationship of understory species richness from two 1X1 m subplots per 64 m^2 in four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2023. BDUP is labeled under BTNEP and GLIA, demonstrating similarities in understory composition. Dots represent understory species observed.

with *Rubus sp.* (blackberry; r=0.703), *Ambrosia sp.* (ragweed; r=0.64), *Ampelospis arborea* (peppervine; r=0.695), and *Quercus lyrata* (overcup oak; r=0.529), but negatively correlated with *Juncus sp*. (r= -0.353). Dimension two was positively associated with *C. radicans* (r=0.579), *Oplismenus hirtellus* (basketgrass; r=0.485), and *Smilax sp.* (r=0.478), but negatively associated with *M. rubra* (r= -0.339). Dimension three was positively associated with *Alternanthera philoxeroides* (alligatorweed; r=0.535), and *Hydrocotyle bonariensis* (pennywort; r=0.495), but negatively associated with *Discorea bulbifera* (air potato; r=-0.426). The ten sites were not significantly different in terms of understory species richness (F=1.81; p>0.05; Figure 13). The youngest restored ridges (BTNEP, GLIA, BDUP), demonstrated the most similarity in understory composition.

<u>Abiotic Influences</u>

Significant differences were detected between soil samples taken from the four subplots established at the ten sites of bulk density, carbon content, nitrogen content, extractable pH, and extractable conductivity (Table 2). BDUP demonstrated the highest values of total carbon (F=14.11; p<0.05) and total nitrogen (F=15.54; p<0.05) and the lowest bulk density (F=6.05; p<0.05). BTNEP, ELM, and GISP demonstrated the highest pH values (F=20.98; p<0.05) and high bulk density. No significant differences were detected in extractable salinity across sites. BDUP and GLIA had high soil conductivity (F=10.26; p<0.05), The elevation of tagged trees was significantly different across the 22 species represented on the 10 coastal ridges (p<0.05; Figure 14). In addition, the elevation of tagged trees was significantly different between the ten sites (p<0.05) with CPRA’s restored ridges GLIA and BDUP demonstrating similarities. Transect elevations across the ten sites demonstrated similarities in slope when an adjacent

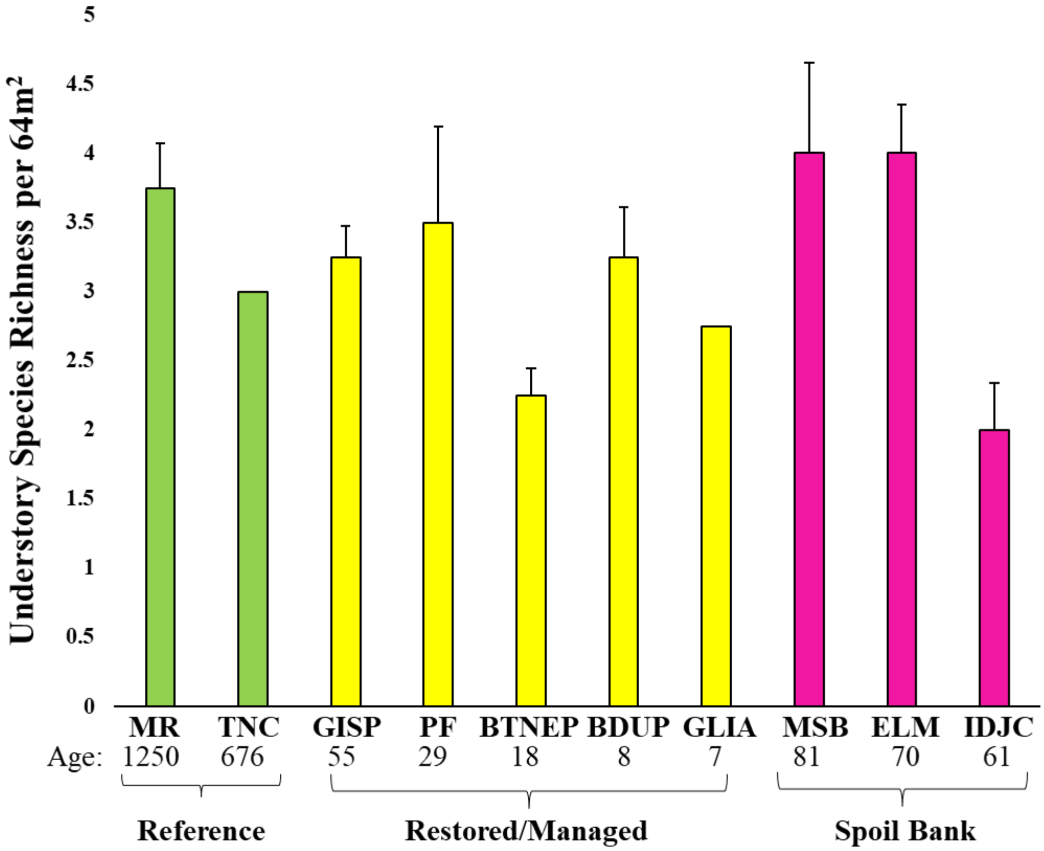

Figure 13. The effect of ridge type on understory species richness (mean ±SE) from two 1X1 m subplots per 64 m^2 in four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2023. Sites were not significantly different.

Table 2. The effect of ridge type on soil bulk, density, total carbon, total nitrogen, extractable pH, extractable conductivity, and extractable salinity (mean ±SE) from four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System in fall of 2022. Means of each measurement that share a letter are not significantly different.

Site	Type Age	Bulk Density ($g\ cm^{-3}$)	Total Carbon (%)	Total Nitrogen (%)	Extractable pH	Extractable Conductivity (dS cm)	Extractable Salinity (psu)
MR	Reference 1250	0.627 ± 0.0882 BC	3.543±0.998 B	0.333 ± 0.062 B	7.24± 0.406 ABC	383.1 ± 188.677 BC	0.1 ± 0.058
TNC	Reference 676	0.812 ± 0.07 ABC	0.955±0.232 BC	0.134 ± 0.023 C	5.943 ± 0.125 CD	12.2 ± 5.625 C	0 ±0
GISP	Restored/Created 55	0.914± 0.05 AB	0.778±0.173 C	0.112 ± 0.024 C	7.528 ± 0.2 AB	5.675 ± 1.678 C	0 ±0
PF	Restored/Created 29	0.852± 0.89 ABC	1.192±0.026 BC	0.157 ± 0.002 C	5.55 ± 0.098 D	167.125 ± 14.35 C	0.1 ± 0
BTNEP	Restored/Created 18	1.075± 0.08 A	1.26±0.247 BC	0.131 ±0.023 C	8.228 ± 0.216 A	204.2 ± 54.408 C	0.075 ± 0.025
BDUP	Restored/Created 8	0.549 ± 0.009 C	7.312±1.182 A	0.552 ± 0.137 A	3.413 ± 0.078 E	1062 ± 201.184 AB	0.425 ± 0.025
GLIA	Restored/Created 7	0.762± 0.04 ABC	1.563 ±0.307 BC	0.148 ±0.026 C	7.11 ± 0.36 ABC	1151.75 ± 325.507 AB	0.575 ± 0.18
MSB	Spoil bank 81	0.689± 0.012 BC	2.172±0.431 BC	0.218 ±0.031 BC	5.768± 0.624 CD	172.025± 63.5 C	0.1 ± 0.041
ELM	Spoil bank 70	1.033± 0.125 A	0.481±0.123 C	0.085 ±0.028 C	6.183± 0.246 BCD	18.315± 7.639 C	0.95 ± 0.917
IDJC	Spoil bank 61	0.815± 0.038 ABC	1.216 ±0.347 BC	0.149 ±0.028 C	6.183± 0.246 BCD	86.55 ± 21.724 C	0.025 – 0.025

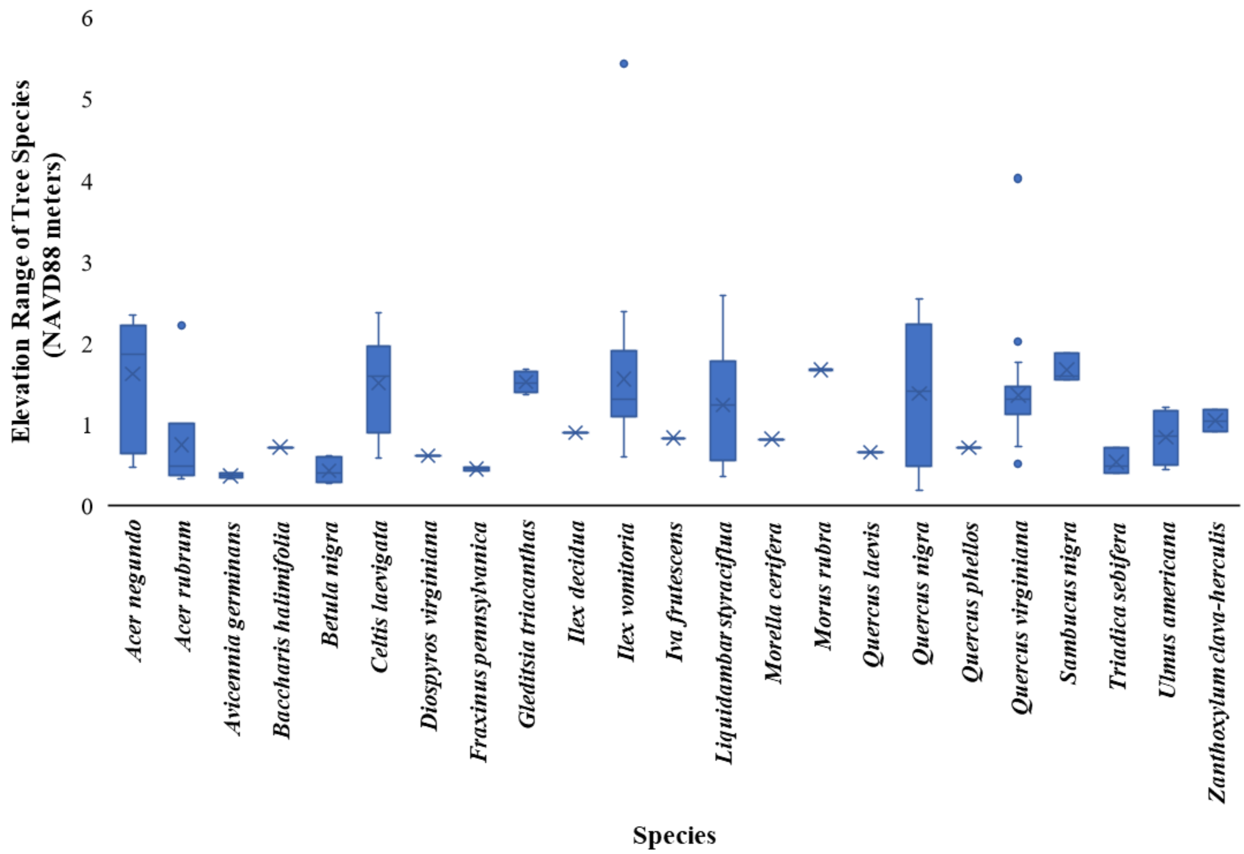

Figure 14. Elevation ranges of tree species (mNAVD88) with a DBH>5 cm from four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2022 to spring of 2023.

marsh was present, and the two barrier island sites (TNC and GISP) had the highest average elevations and outliers (Figure 15).

Avian Presence

A three-dimensional solution to overall avian presence across the four sites was obtained (stress=0.137; Figure 16), in which dimension one was positively correlated with *Mimus polyglottos* (northern mockingbird; r=0.56) and *Polioptila caerulea* (blue-gray gnatcatcher; r=0.403), but negatively correlated with *Rallus crepitans* (clapper rail; r=0.463) and *Ardea alba* (great egret; r=0.413). Dimension two was positively correlated with *A. alba* (r=0.526), *R. crepitans* (r=0.52), and *Ardea herodias* (great blue heron; r=0.486), but negatively correlated with *Dumetella carolinensis* (gray catbird; r= -0.426), *Setophaga coronata* (yellow-rumped warbler; r= -0.497), and *Setophaga dominica* (yellow-throated warbler; r=-0.429). Dimension three was positively associated with *Progne subis* (purple martin; r=0.418), *Molothrus ater* (brown-headed cowbird; r=0.443), and *Tyrannus tyrannus* (eastern kingbird; r=0.405), but negatively correlated with *S. coronata* (r= -0.611), and *Melospiza georgiana* (swamp sparrow; r= -0.662). TNC has no adjacent marsh system and therefore lacked the wading bird species that made ELM, BTNEP, and GISP more similar.

Of the 70 avian species observed from January to October 2023, 34 were considered year-round residents (Table 3). Shannon-Weiner Diversity and Simpson’s diversity indices were similar across the four sites (Table 4). The relationship between tree and bird species richness was insignificant ($p>0.05$), however the relationship between number of individually tagged trees (DBH>5cm) and bird species richness had a significant intercept, but only accounted for 9% of the model ($R^2=0.09$).

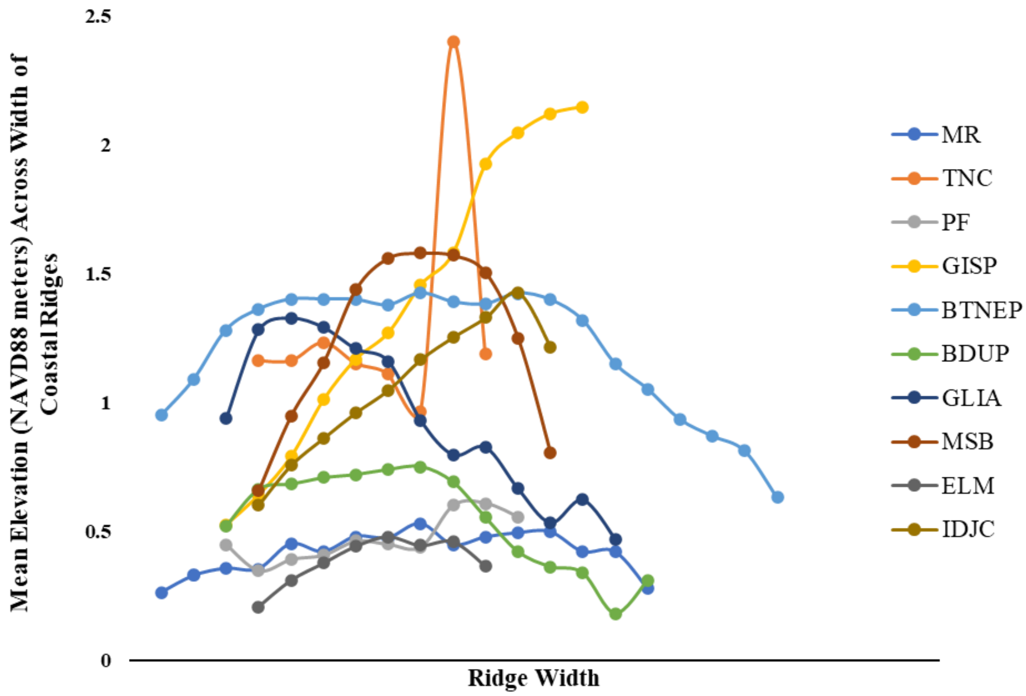

Figure 15. Elevation averages of points taken 1 m apart across the width of four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System from fall of 2022 to spring of 2023.

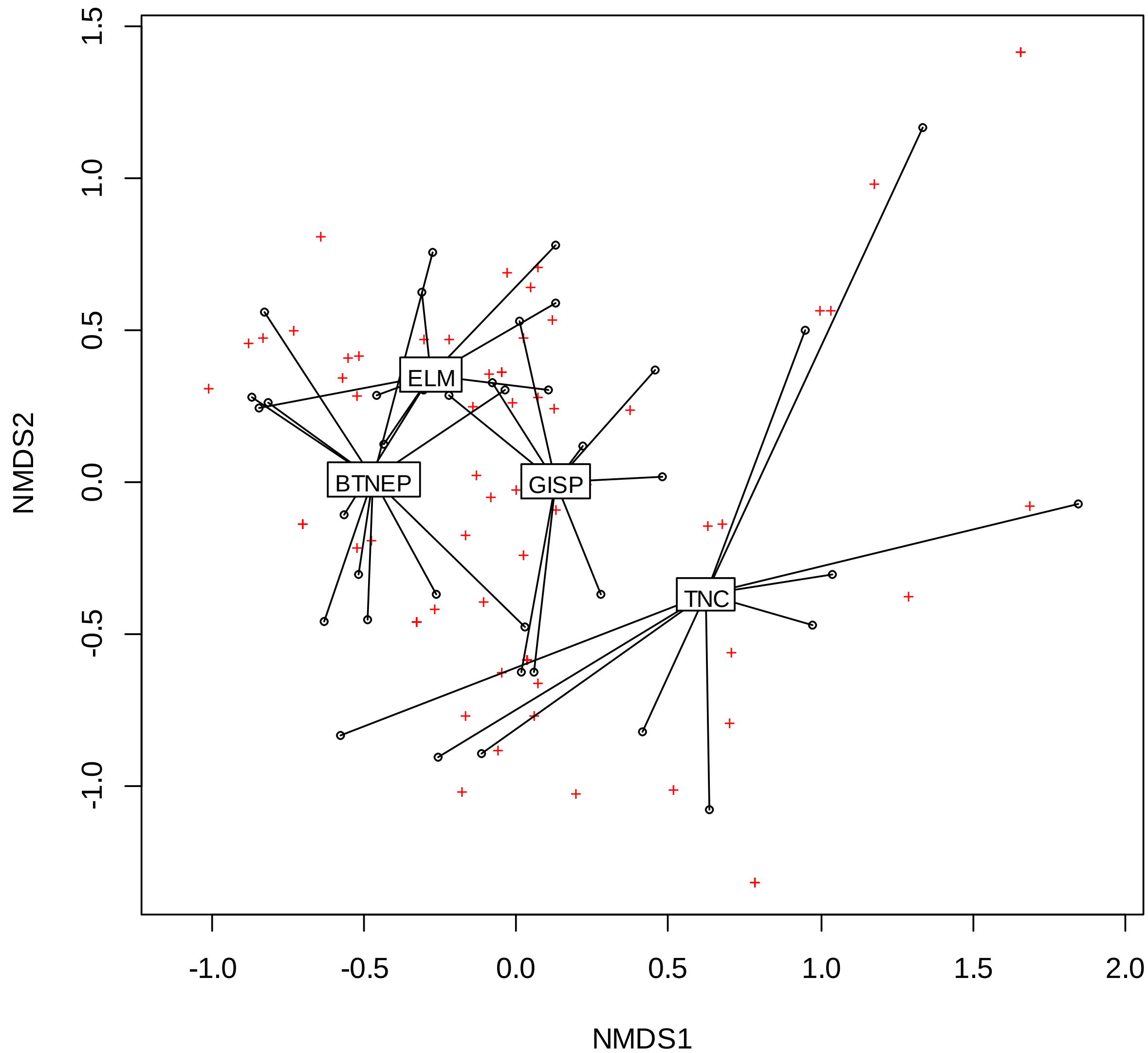

Figure 16. The relationship of avian species across four sites within the Barataria-Terrebonne National Estuary System from January to October 2023.

Table 3. Avian species observed during walking transects or on field cameras from January to October 2023 at four sites in the Barataria-Terrebonne National Estuary System. Season information indicates time of year presence is expected as designated by The Cornell Lab. X indicates observed at that site.

Common Name	**Scientific Name**	**Season**	**ELM**	**BTNEP**	**TNC**	**GISP**
Barn Swallow	*Hirundo rustica*	Breeding	X	X		X
Chimney Swift	*Chaetura pelagica*	Breeding			X	X
Common Nighthawk	*Chordeiles minor*	Breeding	X			
Eastern Kingbird	*Tyrannus tyrannus*	Breeding	X	X		X
Great Crested Flycatcher	*Myiarchus crinitus*	Breeding			X	
Indigo Bunting	*Passerina cyanea*	Breeding		X	X	
Least Tern	*Sternula antillarum*	Breeding		X		
Purple Martin	*Progne subis*	Breeding	X		X	X
Ruby-throated Hummingbird	*Archilochus colubris*	Breeding		X	X	
Summer Tanager	*Piranga rubrua*	Breeding		X		X
Yellow-billed Cuckoo	*Coccyzus americanus*	Breeding		X		X
Yellow-throated Warbler	*Setophaga dominica*	Breeding			X	X
Hooded Warbler	*Setophaga citrina*	Migratory			X	X
Baltimore Oriole	*Icterus galbula*	Migratory		X	X	X
Bay-breasted Warbler	*Setophaga castanea*	Migratory			X	
Prairie Warbler	*Setophaga discolor*	Migratory				X
Reddish Egret	*Egretta rufescens*	Migratory	X			
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	Migratory		X		
Semipalmated Sandpiper	*Calidris pusilla*	Migratory	X			
American White Pelican	*Peacanus erythrorhynchos*	Nonbreeding		X		
Belted Kingfisher	*Megaceryle alcyon*	Nonbreeding	X			X
Cedar Waxwing	*Bombycilla cedrorum*	Nonbreeding		X		X
Double-crested Cormorant	*Nannopterum auritum*	Nonbreeding	X			X
Eastern Phoebe	*Sayornis phoebe*	Nonbreeding				X
Gray Catbird	*Dumetella carolinensis*	Nonbreeding		X	X	X
Magnificent Frigatebird	*Fregata magnificens*	Nonbreeding	X		X	X
Merlin	*Falco columbarius*	Nonbreeding		X		
Northern Harrier	*Circus hudsonius*	Nonbreeding		X		
Orchard Oriole	*Icterus spurius*	Nonbreeding	X	X		X
Palm Warbler	*Setophaga palmarum*	Nonbreeding	X			
Ring-billed Gull	*Larus delawarensis*	Nonbreeding				X
Swamp Sparrow	*Melospiza georgiana*	Nonbreeding	X	X		X
Willet	*Tringa semipalmata*	Nonbreeding	X	X		X
Yellow-rumped Warbler	*Setophaga coronata*	Nonbreeding	X	X	X	X
Anhinga	*Anhinga anhinga*	Year-round	X			X
Black Skimmer	*Rynchops niger*	Year-round				X
Black-crowned Night-Heron	*Nycticorax nycticorax*	Year-round	X	X		
Blue Jay	*Cyanocitta cristata*	Year-round			X	

Table 3. Continued

Common Name	**Scientific Name**	**Season**	**ELM**	**BTNEP**	**TNC**	**GISP**
Blue-gray Gnatcatcher	*Polioptila caerulea*	Year-round		X	X	X
Boat-tailed Grackle	*Quiscalus major*	Year-round		X		
Brown Pelican	*Pelecanus occidentalis*	Year-round	X			X
Brown-headed Cowbird	*Molothrus ater*	Year-round	X	X	X	X
Carolina Wren	*Thryothorus ludovicianus*	Year-round		X		
Caspian Tern	*Hydroprogne caspia*	Year-round		X		X
Cattle Egret	*Bubulcus ibis*	Year-round		X		
Clapper Rail	*Rallus crepitans*	Year-round	X	X		X
Common Grackle	*Quiscalus quiscula*	Year-round	X		X	X
Common Yellowthroat	*Geothylpis trichas*	Year-round		X	X	X
Eastern Bluebird	*Sialia sialis*	Year-round		X		
Eastern Meadowlark	*Sturnella magna*	Year-round		X		
Forster's Tern	*Sterna forsteri*	Year-round	X			X
Great Blue Heron	*Ardea herodias*	Year-round	X	X	X	
Great Egret	*Ardea alba*	Year-round	X	X		X
Green Heron	*Butorides virescens*	Year-round	X			
Killdeer	*Charadrius vociferus*	Year-round	X			X
Laughing Gull	*Leucophaeus atricilla*	Year-round	X	X	X	X
Little Blue Heron	*Egretta caerulea*	Year-round	X			
Northern Cardinal	*Cardinalis cardinalis*	Year-round			X	X
Northern Mockingbird	*Mimus polyglottos*	Year-round		X	X	X
Osprey	*Pandion haliaetus*	Year-round	X		X	X
Pileated Woodpecker	*Dryocopus pileatus*	Year-round			X	
Red-shouldered Hawk	*Buteo lineatus*	Year-round			X	
Red-winged Blackbird	*Agelaius phoeniceus*	Year-round	X	X	X	X
Roseate Spoonbill	*Platalea ajaja*	Year-round	X	X		
Royal Tern	*Thalasseus maximus*	Year-round	X		X	X
Sandwich Tern	*Thalasseus sandvicensis*	Year-round	X		X	X
Snowy Egret	*Egretta thula*	Year-round	X			X
Tricolored Heron	*Egretta tricolor*	Year-round	X	X		X
White Ibis	*Eudocimus albus*	Year-round		X		X
White-eyed Vireo	*Viero griseus*	Year-round		X	X	X

Table 4. The relationship of avian species diversity across four sites within the Barataria-Terrebonne National Estuary System from monthly observations from January to October 2023.Seasonal and migratory distinctions were determined using The Cornell Lab species guide.

Site	**Type** **Age**	**Species Richness**		**Shannon-Weiner Diversity Index**	**Simpson's Diversity Index**
		Seasonal	**Migratory**		
BTNEP	Restored/Managed 18	18	2	3.3	0.95
ELM	Spoil Bank 70	14	2	3.1	0.94
TNC	Reference 676	12	3	3.3	0.96
GISP	Restored/Managed 55	21	3	3.2	0.93

Discussion

Notable patterns were detected in various ecological characteristics and processes across the terrestrial habitats of coastal ridge types, settings, and ages. Community composition of woody forest species and understory composition demonstrated gradients with age and salinity. Specifically, older, natural forests had larger individuals but less sapling abundance, and restored ridges BDUP and GLIA, as well as disturbed spoil bank IDJC, demonstrated lower understory species richness. Interestingly, terrestrial carbon stock in woody forest species also exhibited a discernible pattern with age, where TNC had significantly higher values despite overall woody vegetation richness. Key soil properties (e.g., bulk density, moisture content, etc.) fell within expected ranges for healthy coastal habitat in Louisiana, and displayed intuitive trends in extractable salinity consistent with distance from maritime influence. Surveys of avifauna occurrence suggests that the restored BTNEP ridge at Port Fourchon is successfully providing neo-tropical migratory song-bird habitat.

Vegetation Community Composition

Woody vegetation community composition reflected the hydrological and age differences between sites. When including understory species in analysis, freshwater sites MR and MSB were more similar due to the presence of *S. minor*. At lower elevations MR supported *A. philoxeroides,* a further indication of its relation to freshwater and adjacent cypress swamp (Monte 1978; Howard 2012). PF and TNC, the two sites without adjacent marsh ecosystems, also demonstrated similarities in composition. Differences through overall abundance may relate to age and whether the ridge recently experienced a disturbance that would increase sapling success of species with historically higher flood tolerance such as *A. negundo* or *C. laevigata* (Noble and Murphy 1975). The recently restored ridge at BDUP demonstrated similar species composition to previous studies by CPRA (Richardi et al. 2022) with a high natural recruitment of *B. halimifolia*, and *I. frutescens.* The presence of these shrubs aligned ELM, GLIA, BDUP, and GISP in the overall abundance NMDS. Extending the time range of this study in addition to measuring growth of more shrublike species at all sites could aid in identifying how recruitment of saplings varies with shrub presence and disturbance events such as drought years, flood events, or post hurricane canopy opening (Denslow and Battaglia 2002). When only analyzing tagged trees, PF and TNC demonstrated less similarities to each other, due to the dominance of two species *Q. virginiana* and *I. vomitoria* at TNC and the higher species richness at PF. ELM and GISP were still more similar to each other than other sites, despite only *I. vomitoria* being present at both. While *I. vomitoria* was not dominant at GISP in overall abundance, it was the most abundant tagged species.

Basal area can provide further insights to the relative dominance of woody species beyond simple abundance by accounting for the cross-sectional area occupied by individuals (Croker and Boyer 1976). Throughout the ten sites, basal area was driven more by the presence of a handful of large, old growth species than overall community composition. For example, *Q. virginiana* at TNC only had four saplings present across the study site, despite having the highest abundance and basal area across the ten sites. Differences occurred between the two climax forests, as the tree species most tagged at MR was *L. styraciflua* and at TNC was *Q. virginiana*, most likely due to the freshwater nature of MR and TNC forming as a chenier plain. Previous studies found *Q. virginiana* as the dominant species at most old-growth sites, but other species, such as *Q. nigra* or *C. laevigata*, could exhibit substantial influence in regards to basal area due to large trunk size (Penfound and Howard 1940; Wall and Darwin 1999). However, of tagged individual trees, *Q. nigra* was mostly present at MSB, and *C. laevigata* at IDJC, possibly indicating a different stage of succession on the younger spoil banks compared to climax forests. Assessing both basal area in conjunction with overall abundance may provide insight to succession stages.

Overall canopy coverage was similar at all sites, except for ELM spoil bank. The limited shade cover, salinity, and narrowness of the ELM provides optimal conditions for the establishment and expansion of *A. germinans*, and provided sun exposure for the unique understory species observed only along that ridge in fall of 2023. Salt and sun tolerant herbs like *Blutaparon vermiculare* (silverhead) and *Sesuvium portulacastrum* (sea purslane) have been observed to do well post hurricane disturbance in other mangrove dominated systems (Fickert 2020). Despite having a wide range and documented ability to grow in soils with low fertility, *Centrosema virginianum* (butterfly pea) was only documented at ELM during this study (Schultze-kraft et al. 1990). The recently restored ridge at BDUP demonstrated similar species composition to previous studies by CPRA (Richardi et al 2022). The generally ubiquitous *Solidago sempervirens* (seaside goldenrod) occurred at seven of the ten sites, consistent with the species broad range and ability to survive in various habitat types (Lonard et al. 2015). In addition, *I. vomitoria* was present throughout the understory at seven of the ten sites. *I. vomitoria* has been demonstrated to have a wide range of soil conditions, surviving in high pH and salt content, with varied leaf sizes based on habitat and sun exposure (Martin and Mott 1997; Stalter and Kincaid 1994). While not specifically measured for this research, leaves of *I. vomitoria* did qualitatively appear smaller at ELM and GLIA. This may be due to proximity to salinity via salt spray and high tide events, lack of canopy coverage, or overall poor soil conditions (Martin and Mott 1997). Monitoring the growth of specific species at restored sites in addition to soil biogeochemistry could increase our understanding of sapling success and overall health of restored areas.

In addition, changes in canopy coverage and species richness after Hurricane Ida, which made landfall in Louisiana on August 29th 2021 as a category 4 storm, may have influenced the measurements and species composition observed during this study (Figure 17; Zhu et al. 2022). Wind damage, flood sediment deposition, and delayed vegetation responses from flooding inundation can influence sapling recruitment (Keim et al. 2019). Establishing long-term monitoring can improve understanding of how hurricanes may play a role in sapling success and understory coverage. Sapling success is modulated by a multiplicity of biotic and environmental factors, and understanding how hurricanes alter coastal ridges can increase long-term success of restored ridges (Rayamajhi and Dray 2022). TNC had a lower species richness of woody species compared to other Chenier forests in Cameron and Vermillion Parishes (Neyland and Meyer 1997), which may result from isolation, and differences in site age and extent of human influence, or changes in composition due to hurricanes. TNC's understory is currently dominated by the invasive vine *D. bulbifera,* and PF's by invasive tree *T. sebifera*. Many invasive species thrive after hurricanes disrupt systems, with possible transient inundation or the opening of the tree canopy increasing sunlight availability among potential mechanisms (Keim et al. 2019).

<u>Vegetation Growth and Physiological Status</u>

Although understanding patterns in vegetation community composition is an integral component of understanding habitat health and integrity, assessing growth rates and physiological status of individuals also provides key insights into the likely longevity of these systems. BDUP and GLIA demonstrated high average growth in DBH, however the five measured branches occur on three trees for both sites, and at GLIA all individuals occur in only

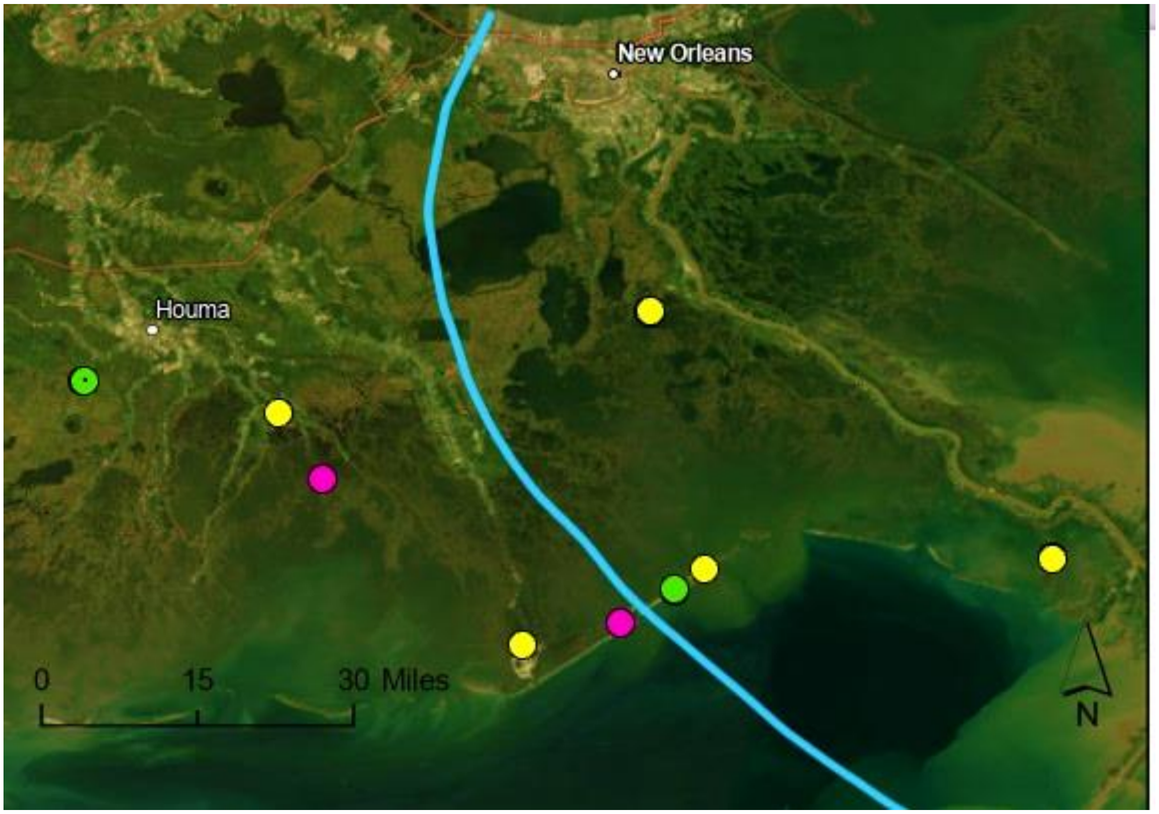

Figure 17. A map of the ten sites chosen within the Barataria-Terrebonne National Estuary System to characterize coastal ridge systems, with Hurricane Ida's August 2021 track in light blue.

one replicate. While growth is a positive indication for restored ridge success, the low sample size and lack of mature trees may not reflect what is happening along the full length of the ridge. For the available individuals the high growth rates align with tree age, space availability for growth, and overall favorable conditions most likely found from ridge remnants before restoration (Mcpherson et al. 2016). Remaining sites demonstrated similarities among annual DBH changes, possibly reflecting slowed growth as individual trees age. Hand-held NDVI measurements can serve as an indicator of physiological stress in vegetation by providing a nondestructive estimate of chlorophyll content; however, comparisons generally need to be performed within species (Nagler et al. 2003). Although no woody species occurred at all sites, *Q. virginiana* and *I. vomitoria* were sufficiently extensive in occurrence to enable comparisons among sites. *Q. virginiana* values were higher at TNC, BDUP, and IDJC, demonstrating no difference between ridge types. At sites where *I. vomitoria* occurred, TNC and IDJC had higher values than GLIA. Individuals tested at GLIA were all smaller shrubs, with increased sun exposed. However, all sites had values within "healthy" ranges (Nagler et al. 2003). Interestingly, *M. rubra* at the BTNEP restored ridge demonstrated leaf stages inconsistent with season first noticed in May 2023. This may be an indication of changing environmental cues or an increase in environmental stressors. *M. rubra* can grow taller or wider faster under different shade and soil conditions, and this change of leaf pattern may be a leading indicator of integrated physiological stress and eventual species decline (Dibala et al. 2021). Specifically including phenological monitoring on restored ridges would provide an additional dimension to vegetation health through time.

Standing Carbon Stock

Both estimated carbon standing stock in woody vegetation and surficial soils varied among sites, though not in a consistent fashion. Notably, estimated carbon standing stock in woody vegetation was greatest at reference sites, followed by spoil banks, then restored sites, reflecting basal area at these locations. Locally-based allometric equations did not exist for all species present across the ten sites, but the linear relationship of basal area and estimated carbon is still represented, although trees may have similar DBH but less canopy coverage or extensive branching (as seen in *Q.* virginiana) to further increase biomass and carbon stock opportunities (Torres and Lovett 2012). Importantly, old growth trees are thought to contribute minimally to carbon sequestration processes, but continue facilitating carbon storage (Mcpherson et al. 2016), which was demonstrated by *Q. virginiana* across the older reference sites of MR and TNC. Further research should include longer monitoring over various climatic patterns, as little is known how increased heat alters rates of photosynthesis, therefore decreasing rates of CO_2 uptake and storage into tissues, in natural settings (Meineke et al. 2016). Surficial soil carbon does not reflect woody basal area, but tended to be higher in restored than reference sites. This could be a result of the source material (i.e., adjacent bayou bottoms) for the ridge construction having comparatively high carbon content. The higher mineral content of recently restored sites may enhance the accumulation of recalcitrant carbon as there is a greater availability of polar binding locations for carbon molecules to bind to (Marin-Spiotta and Ostertag 2016), which could have resulted in greater carbon accumulation and short-term carbon stock. Since carbon content was assayed in the top 15 cm, this could also represent short-term additions to the surficial soil layer, that are likely to metabolize.

Elevation

Although elevation demonstrated significant differences between both the ten ridge sites and documented tree species, insights into both ridge longevity and the role of elevation in modulating woody species presence can be distinguished. The CPRA restored ridges had target constructed elevations of 1.4 meters and target 20-year elevations of approximately 1 meter (Hymel et al. 2022, Richardi et al. 2022). Within the selected plots of BDUP mean elevation was 0.62 meters and GLIA was 0.96 meters, demonstrating that at least these portions of the ridge may be subsiding faster than was anticipated. Particularly notable was the wide range of elevations at which *A. negundo, C. laevigata, Q. nigra,* and *Q. virginiana* were found, suggesting that these species should be receptive to a comparatively wide range of restoration designs in regards to ridge height. These species were found across multiple sites and some, like *A. negundo,* have been demonstrated to have higher flood tolerance (Overton 1990). However, this should be adjusted to local flood likelihood in the restored area, as prolonged flooding and salinity of floodwaters can influence future sapling success (Wall and Darwin 1999). In contrast, *Z. clava-herculis,* a culturally important native species that is known to have a low occurrence across terrestrial habitats in coastal Louisiana, exhibited a relatively small elevation range of occurrence for the two individuals recorded at GISP and GLIA. Across all ten sites the elevation of individual tagged trees was consistent with findings by Denslow and Battaglia (2002) at Jean Lafitte, where *A. rubrum* had lower overall elevation and demonstrated a possibly higher flood tolerance than previously expected. Further studies would benefit from longer data collection to better understand the rate of subsidence after restoration efforts, in addition to taking elevation measurements at large shrubs present at multiple sites, such as *B. halimifolia* or *I. frutescens.*

Soil Properties

Soil characterization in this study aligns with previous research documenting differences in the substrate properties of restored and natural ridges (Suir et al. 2019). Of the ten sites selected for this study, the CPRA restored ridges BDUP and GLIA were youngest, and demonstrated higher conductivity values than other sites, consistent with their comparatively recent construction and the brackish nature of their sediment (Richardi et al. 2017; Richard 2018). Further, the higher carbon and nitrogen content, as well as the lower pH, of the BDUP restored ridge also aligns with the sediment borrow sites (Alliance Anchorage and Wills Point Anchorage; Richardi et al. 2017). Increased understanding of the dynamics of soil composition as it relates to hydrology and vegetation can improve assessments of the multiple benefits of coastal restoration (Wang et al. 2017). Although soil properties varied among sites, distinct relationships with woody vegetation abundance were not discerned, contrasting with previous research suggesting that *Q. virginiana* is an effective indicator of soils with high nutrient value and basicity (Schmalzer and Foster 2020). Importantly, all restored ridge and spoil bank sites exhibited soil characteristics that fell within ranges considered typical of terrestrial maritime forests in the Gulf south (Suir et al. 2019). Using this research as a comparison for future work under changing climatic conditions should also provide a baseline to improve our understanding of how drought can influence soil structure, stability, and suitability, and therefore planting success, of restored ridges (Zhange et al. 2019).

Avian Presence

Louisiana's coastal terrestrial habitat provides shelter and food for multiple avian species, both year-round and through migration periods. Monitoring the changing coastal landscape throughout the year can provide insight into the health of various systems. While forested tree species composition was similar at TNC, GISP, and BTNEP, sites with adjacent marsh (GISP, BTNEP, ELM) provided more habitat for wading birds. The BTNEP restored ridge is adjacent to a large mudflat and mangrove forest, and wading birds were mostly seen flying over instead of perching in the ridge proper. The BTNEP restored ridge demonstrated extensive use by various migratory species as stopover habitat during spring migration of 2023. However, limitations of sampling timing may have influenced the lower documentation of fall migrants than expected from historical observations, as nighttime migration is more common and weather patterns largely influence fall movements across the Gulf of Mexico (Able 1972). Further studies should include phenology of trees present at stopover habitats and climate patterns to best understand how changing systems can influence the success of coastal ridges as migratory avian habitat in Louisiana. *M. rubra*, often a popular avian food source for local and migrant species at multiple areas in its range, was observed at phenological stages inconsistent with season first noticed in May 2023, and the tree species importance as an avian food source in Louisiana should be further studied (Jackson II and Kanaan 2018). In addition, *S. sempervirens* can provide nesting habitat for coastal species documented at GISP but seen near BTNEP and ELM, such as *Rynchops niger* (black skimmer; Safina and Burger 1983). Louisiana's CMP has begun to include projects focusing on nesting bird habitat, and understanding the role of key plant species on established ridges may improve future restoration planning (Sable et al. 2019).

Conclusion

The diversity of the ten sites included in this study highlights the wide range of ridge habitat communities and characteristics that occur in coastal Louisiana. Notably, age was more influential than site origin, suggesting that restoration plans and efforts will likely be more effective when incorporating and understanding of natural succession. Similarly, hydrogeomorphic setting, particularly in regards to maritime setting, appears to be more influential to plant community composition than site origin. Although soil characteristics fell within expected ranges at all sites, samples did not reflect soil characteristics at time of establishment for climax forests, which may explain why some ubiquitous species such as *Q. virginiana* and *I. vomitoria* do not always have high sapling success in restoration plantings. Focusing on native species with high natural recruitment in disturbed sites (i.e., r-selected species) may facilitate desirable native species outcompeting invasive species that can become problematic at restoration sites. For maritime sites, ensuring that the possible influence of salt spray on woody vegetation is addressed could provide insight to the abiotic factors most influencing ridge community composition. Importantly, given that hydrogeomorphic setting and site age tended to structure terrestrial plant communities to a greater extent than site origin, the benefits of these landforms are likely driven more by site specific characteristics than their general category. Regarding support of avifauna, BTNEP’s restored ridge acted as successful migratory bird stopover habitat during spring migration of 2023, suggesting that it could provide a template for future ridge restoration designs that focus on this ecosystem service.

Recommendations

Overall, this research suggests that while coastal ridge restoration efforts in Louisiana have generally been successful in providing this crucial habitat, source material and time allowed for natural selection may play an important role in initial vegetation establishment. The in-depth multidisciplinary restoration plan provided by BTNEP for the Port Fourchon restored ridge is an excellent resource for future coastal ridge planning efforts. Despite being one of the first, the BTNEP ridge has demonstrated ongoing planting success and successfully provided habitat for avian migrators during the spring 2023 season. Because of the comparatively high importance of soil properties in determining vegetation establishment, budgeting for soil remediation, increased monitoring in the first years after establishment, and for possible replanting is important. Coastal ridge restoration should prioritize mimicking the environmental conditions (e.g., elevation, slope, orientation, etc.) of the geographically closest natural systems, as possible, as minor changes in hydrological patterns can greatly impact vegetation diversity. Studies should be continued that utilize more advanced methods of avian population counts across full migration season. Advancements in audio technology could aid in identifying key patterns in avian migration, and identify the possibly increasing threat of noise pollution in coastal landscapes. Connecting avian presence to woody vegetation phenology can also increase understanding of the ecosystem under changing climatic conditions.

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Appendix A
Woody vegetation composition across 10 sites in the Barataria-Terrebonne National Estuary System

Table A.1. Tree abundance (mean ±SE) per 64 m^2 of four nested ridge replicates at ten sites within the Barataria-Terrebonne National Estuary System in fall of 2023. X indicates tree species not documented within replicates.

Scientific Name	MR	TNC	GISP	PF	BTNEP	BDUP	GLIA	MSB	ELM	IDJC
Acer negundo	3.75 ±1	X	0.25 ±0.5	X	X	0.5 ± 0.7	X	1.25 ±0.9	X	X
Acer rubrum	0.5 ±0.4	X	X	3.75 ±0.7	X	X	X	0.25 ±1	X	X
Avicennia germinans	X	X	0.25 ±0.5	X	X	X	X	X	3	X
Baccharis halimifolia	X	X	0.75 ±0.6	X	X	0.5 ± 0.7	1.75 ±0.9	X	3± 0.3	0.25 ±0.5
Betula nigra	X	X	X	4.5 ±0.7	X	X	X	X	X	X
Carya illinoensis	X	X	X	0.5 ±0.7	X	X	X	X	X	X
Celtis laevigata	X	X	X	0.5 ±0.4	0.75 ±0.6	X	0.25 ±0.5	0.75 ±0.9	X	1.15 ±0.5
Diospyros virginiana	0.25 ±1	0.5 ±0.7	X	1.25 ±0.7	X	0.25 ±0.5	X	0.5 ±0.6	X	X
Fraxinus pennsylvanica	2 ±0.4	X	X	0.25 ±0.5	X	X	X	X	X	X
Gledittsia triacanthas	X	X	X	X	1.5 ±0.5	X	X	X	X	X
Ilex decidua	X	X	X	X	X	X	X	0.5 ±0.7	X	X
Ilex vomitoria	X	7.75 ±0.8	2.25 ±0.7	0.25 ±0.5	0.5 ±0.7	2.25 ±0.6	X	X	2 ±0.9	12.75 ±0.5
Iva frutescens	X	X	0.75 ±0.6	X	1.75 ±0.4	1.5 ±1	3.25 ±0.6	X	0.5 ±0	0.75 ±0.9
Liquidambar styraciflua	2.5 ±0.4	X	X	X	X	X	X	3.5 ±0.8	0.41 ±0	X
Morella cerifera	0.25 ±0.5	X	3 ±0.4	X	X	1.25 ±0.6	3.25 ±0.7	X	X	X
Morus rubra	X	X	X	X	1.25 ±0.6	0.25 ±0.5	0.5 ±0.7	X	X	X
Quercus laevis	X	X	X	2.5 ±0.8	X	X	X	X	X	0.5 ±0.7
Quercus lyrata	X	X	X	2.75 ±0.6	X	X	X	X	X	X
Quercus nigra	0.75 ±0.6	0.25 ±0.5	X	0.5 ±0.7	X	0.25 ±0.5	X	4.5 ±0.6	X	3.75 ±0.4

Table A.1. Continued

Scientific Name	MR	TNC	GISP	PF	BTNEP	BDUP	GLIA	MSB	ELM	IDJC
Quercus phellos	X	X	X	0.5 ±0.4	X	X	X	X	X	X
Quercus virginiana	0.75 ±0.5	6.75 ±0.4	0.75 ±0.5	X	7.75 ±0.9	1.5 ±0.5	X	0.75 ±0.6	X	1.5 ±0.8
Sambucus nigra	X	2.75 ±0.8	3.25 ±0.7	X	X	X	X	X	X	X
Triadica sebifera	X	X	0.5 ±0.7	6.5 ±1.8	X	X	X	1.25 ±1.1	X	X
Ulmus americana	0.75 ±0.9	X	X	X	X	X	X	1 ±0.6	X	X
Zanthoxylum clava-herculis	X	X	2.5 ±0.8	X	X	X	0.25 ±0.5	X	X	0.5 ±0.4

Table A.2. Understory species and tree saplings documented two randomly selected 1x1 m plots in four nested ridge replicates covering 264 m^2 at ten sites within the Barataria-Terrebonne National Estuary System in fall of 2023. X indicates presence at that site.

Species	MR	TNC	GISP	PF	BTNEP	BDUP	GLIA	MSB	ELM	IDJC
Acer negundo						X		X		
Acer rubrum	X			X						
Adiantum capillus-veneris								X		
Alternanthera philoxeroides	X									
Ambrosia sp			X	X						
Ampelopsis arborea			X	X				X		X
Asclepias incarnata								X		
Avicennia germinans									X	
Baccharis halimifolia						X	X			X
Blutaparon vermiculare									X	
Borrichia frutescens					X				X	
Campsis radicans		X		X				X		
Callicarpa americana							X	X		
Carex sp	X							X		X
Centrosema virginianum									X	
Cissus trifoliata			X							
Commelina virginica	X									
Cyperussp				X						
Dichanthelium sp								X		
Dioscorea bulbifera		X								
Diospyros virginiana		X								
Distichilis spicata							X		X	
Erechtites hieraciifolius		X								
Eupatorium capillifolium						X				
Euphorbia cordifolia							X			
Eustachys sp				X					X	
Gaillardia pulchella			X							
Hydrocotyle bonariensis	X									
Ilex vomitoria		X				X			X	X
Ipomoea sp			X				X		X	
Iva frutescens			X		X	X			X	X
Juncus sp									X	
Lantana camara		X	X				X			X
Lepidium virginicum									X	

Table A.2. continued

Species	MR	TNC	GISP	PF	BTNEP	BDUP	GLIA	MSB	ELM	IDJC
Liquidambar styraciflua	X							X		
Lonicera japonica		X								
Lygodium japonicum	X									
Monarda punctata			X							
Morella cerifera			X			X	X			
Morus Rubra						X	X			
Oplismenus hirtellus	X	X						X		
Panicum sp					X					
Paspalum vaginatum					X					
Persicaria virginiana								X		
Phragmites sp									X	
Phytolacca americana						X				
Quercus laevis				X						
Quercus lyrata				X						
Quercus nigra				X		X		X		X
Quercus virginiana		X	X		X					
Rubrus sp			X	X						
Sabal minor	X							X		
Sambucus nigra		X								
Sanicula canadensis								X		
Saururus cernuus	X									
Schoenoplectus americanus						X				
Sesuvium portulacastrum									X	
Sida rhombifolia					X			X		
Smilax sp		X						X		
Solidago sempervirens	X			X	X	X	X		X	X
Spartina sp					X				X	
Thelypteris kunthii	X									
Toxicodendron radicans		X	X	X						
Triadica sebifera	X			X				X		
Typha latifolia						X				
Vigna luteola					X					
Vitis rotundifolia				X				X		
Zanthoxylum clava-herculis			X							

Biographical Sketch

Carissa was born and raised in northwest Indiana. She attended the Florida Institute of Technology for an undergraduate degree in marine biology. From there Carissa fell into environmental education, learning and teaching in California, Georgia, Delaware, and finally plunking in Louisiana. On a journey to figure out what to be when she grows up, Carissa returned to school at Nicholls State University to learn more about to protect the new landscape she calls home.

Curriculum Vitae.

Carissa Thiel
(219) 775-3388
carissathiel@gmail.com

EDUCATION

Nicholls State University, Thibodaux, Louisiana January 2022-December 2023
Master's Student in **Marine and Environmental Biology**, expected graduation December 2023
Research assistant aiding in determining the abiotic factors most influential on plant communities of coastal ridges with the goal of understanding drivers of forest diversity and determining best plans for successful restoration efforts. Leading an ornithological component within a multi-structured restored ridge study by initiating avian species presence/absence surveys on coastal ridges.

Florida Institute of Technology, Melbourne, FL Graduated May 2015
Bachelor of Science in **Marine Biology**
Gained interdisciplinary skills regarding research and conservation while honing in leadership and time management skills as a student athlete.

WORK EXPERIENCE

Retail Associate August 2022-Current
Vintage Green Review, New Orleans, LA Supervisor: Sarah Anderson

- Assist sales and restocking of a zero-waste store while encouraging community members to decrease their use of plastic and make more environmentally friendly choices

Assistant Manager/Sales Associate July 2020-March 2022
Bayou Bicycles, New Orleans, LA Supervisor: Jesse Hutmaker

- Train and supervise sales associates while assisting customers with bicycle and accessory purchases, scheduling repairs
- Co-manage social media accounts, emails, and open/close of business

Outreach Coordinator, Wetland Express March 2019-May2020
Audubon Zoo, AZA Accredited, New Orleans, LA Supervisor: Emily George

- Developed lesson plans and engagement strategies to educate youth preK-12 following LA science standards and for alternative education spaces
- Formal and informal interpretation of live ambassador animals and biofacts at festivals, sponsor events, and libraries
- Supervised youth and adult volunteers while handling animals and engaging participants onsite, in classrooms, and at festivals
- On glove raptor training including Red-tailed Hawk and Turkey Vulture species

Guest Engagement Educator October 2017–March 2019
Audubon Zoo, AZA Accredited, New Orleans, LA Supervisor: Hayley Shannon

- Created programming to educate guests on animals, conservation efforts, and sustainable practices
- Aided in the creation of inclusive spaces and programs to fulfill the needs of all New Orleans learners
- Supervised youth and adult volunteers while interpreting in formal and informal settings on zoo grounds

Naturalist May 2017-October2017
Cape Henlopen State Park, Delaware Supervisor: Richard Julian

- Created and implemented indoor and outdoor lesson plans for nature center programing open to the public that helped transform the history and conservation goals of the park into relatable stories

Coastal Eco Tour Guide May 2017-October 2017
Cape Water Tours, Delaware Supervisor: David Green

- Spread a conservation message focusing on salt marshes and migrating birds while on microphone
- Utilized various trapping methods to collect live animals for on boat demonstrations
- Deckhand duties as assigned

Environmental Educator August 2016-May2017
Burton 4-H Center on Tybee Island, Georgia Supervisor: David Weber

- Led outdoor classes for students of all ages covering local ecosystems, animals, and coastal changes according to Georgia STEAM standards
- Participated in animal care, including Loggerhead Sea Turtle food preparation, behavior enrichment, and observation
- Participated in plankton monitoring with NOAA

Naturalist August 2015 – May 2016
Arrowhead Ranch Outdoor Science School, California Supervisor: Charlie Young

- Led hikes in the San Bernardino Mountains and taught students (grades 5-8) following California State science curriculum
- Served overnight cabin leader duties, providing team building activities and maintaining a safe, comfortable space for students to stay away from home

Volunteer Experience

NPS Volunteer, Jean Lafitte National Historical Park & Preserve, LA January 2023-Current

- Assist the Resource Management Team with phenology monitoring, hydrological data collection, and data stewardship for long-term monitoring projects in the Barataria Preserve

Community Chemical Analyst Research Team, Rise St. James, LA July 2022-March 2023

- Assist with data collection to provide information to support op-ed articles and social media posts that inform community members of key pollutants in Jefferson Parish, Louisiana

Shark Tagging, Saving the Blue, Andros, Bahamas November 2022

- Assisted with drum line shark collecting tagging including pit tags and work ups of local shark species to Andros Bahamas
- Participated in continuing education focused on various shark species and local environments to increase community engagement

Animal Care, Audubon Nature Institute, New Orleans, LA January 2021-May 2022

- Help with diet preparation and enclosure cleaning of rescued sea turtles at Audubon Nature Institute's Species Survival Center

Research Project Surveyor, New Orleans, LA March 2018-May 2020

- Record sightings of local reptile species in various field locations, assist in blood draws of snake species

Skills

Computer Skills: GIS (Basic), R Studio (Basic)
Louisiana Boat Safety Certified