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IF YOU BUILD IT, WILL THEY COME? ASSESSING HABITAT QUALITY FOR MARSH BIRDS AT CREATED MARSHES IN SOUTHEASTERN LOUISIANA

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Master of Science

in

The School of Renewable Natural Resources

by
Katherine Aylett Lipford
B.S., Virginia Tech, 2018
May 2024

Dedication

This work is dedicated to the marshes and coastal communities that made me fall in love with coastal Louisiana. The marshes of southeastern Louisiana are an incredibly rich and diverse resource, and I hope that my Master's work contributes in some way to protecting this special place for the future.

ACKNOWLEDGEMENTS

This work would not have been possible without the dedication and expertise of my advisors, Dr. Sammy King and Dr. Andy Nyman. Thank you both for giving me this opportunity and trusting me with a project that expanded my skills and stretched my comfort zone, and for teaching me the importance of being a systems ecologist. Thank you to my committee members Dr. Megan La Peyre and Dr. Phil Stouffer for providing their time and expertise. A special thanks to Dr. Steve Midway and Dr. Drew Fowler for vastly furthering my statistical knowledge and for helping me struggle through Bayesian hierarchical modeling.

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ABSTRACT

Wetland loss occurs at an alarming pace globally, with extremely high rates along the northern Gulf of Mexico. Louisiana loses a football field of wetland every 100 minutes: that is 77,000 m^2 of wetland bird habitat lost daily. In Louisiana, marsh creation projects combat wetland loss, and while wildlife habitat is often used as a justification for restoration, wildlife receives little to no consideration during and after construction. Habitat characteristics such as site-specific hydrology, vegetation composition, and habitat structure affect the abundance of wetland birds and understanding these features is crucial to creating habitat that will benefit birds. My study compares bird species abundance, vegetation, and site-specific hydrology between natural and created marshes across southeastern Louisiana. I conducted point counts and vegetation surveys at six created and six natural marshes in 2021 and at 10 created and 10 natural marshes in 2022 and 2023. All species of birds seen and heard were recorded and call-back surveys were performed to increase detections of secretive marsh birds. At each created site, I used water-level recording devices to quantify differences in water levels and flooding frequency among sites. My results suggest that all sites vary widely in hydrologic regimes and vegetation communities. I completed 766 bird surveys (created = 413, natural = 353) and identified 9,650 individual birds of 110 different bird species including 88 species at natural marshes and 91 species at created marshes. I classified all observed birds into five habitat guilds: 1) Marsh Specialist, 2) Beach and Estuary, 3) Wetlands Generalist, 4) Habitat Mosaic Generalist, and 5) Forest. Additionally, five focal species were selected: Common Gallinule, King/Clapper Rail, Least Bittern, Seaside Sparrow, and Red-winged Blackbird. To determine habitat factors affecting bird abundance across created and natural sites, I built generalized linear mixed models in a Bayesian framework using the brms package in R. For each guild and focal species, I developed a candidate model set based on four a priori hypotheses on the drivers of bird abundance including a hydrology model, a habitat composition model, a habitat structure model, and a combination model. I ranked models using approximate Leave-One-Out (LOO) cross-validation in the loo package. For most guild and focal species, the combination model was ranked highest, indicating that hydrology, composition, and structure all affect bird abundance. The main drivers of marsh bird abundance were water level variability and plant composition. Vegetation community was a driver of abundance for the marsh specialist guild, the wetland generalist guild, and all focal species. Water depth variables positively affected abundance of the wetland generalist guild, the marsh specialist guild, Common Gallinule, Least Bittern, and Red-winged Blackbird and negatively affected the forest guild. The results of my study indicate that whether a marsh is created or natural is not the driver of bird abundance. Rather, depending on the guild and species, the drivers of avian abundance include hydrologic variation, vegetation communities, and/or vegetation structure. Management implications of my study include building marsh creation sites within the tidal range, as well as the inclusion of certain habitat features, such as tidal creeks and ponds, that can promote hydrologic connectivity and emergent vegetation communities. This study is one of the first to connect physical processes, such as hydrology, to vegetation and wildlife responses on created marsh sites in Louisiana and these types of studies must persist to inform and improve future restoration.

1. INTRODUCTION

1.1. Global Coastal Marsh Function and Loss

Coastal marsh provides valuable ecosystem services including storm protection, carbon sequestration, sea level rise adaptation, habitat for organisms, and support of commercial and recreational hunting and fishing (Campbell et al., 2022; Sheng et al., 2022). With the increasing threat of sea level rise, coastal marshes are considered at great risk. While estimates of coastal marsh historic and projected loss vary widely, Kirwan et al. (2016) noted that many studies overestimate coastal marsh vulnerability because they do not consider marsh accretion rates. Marsh systems are adapted to keep up with sea level rise by maintaining their elevation within the tidal range through feedback loops between flooding, sediment deposition, and plant growth in a process known as vertical accretion (Cahoon et al., 2011; Stagg et al., 2016). While coastal marsh systems may be more adaptable to sea level rise than previously thought, other stressors such as erosion, drainage, development, tropical storms, and limited sediment supply threaten these ecosystems (Bromberg & Bertness, 2005; Stagg et al., 2021; Campbell et al., 2022). Because of these threats, coastal managers are implementing marsh restoration and creation, and shoreline fortification to protect from further coastal marsh loss (Boorman et al., 2002; Nordstrom, 2014).

1.2. Coastal Marsh of the Mississippi River Delta

The Mississippi River Delta (MRD) is especially vulnerable to coastal marsh loss, however, many factors in addition to sea level rise are contributing to widespread loss in this area. Historically, the MRD plain was formed by sediment deposition and accumulation due to the heavy load of sand, silt, and clay carried by the river (Li et al., 2020). Prior to human expansion into the MRD in the nineteenth and twentieth century, sediment deposition from the Mississippi River and marsh vertical accretion via vegetative growth kept up with the natural processes of subsidence, erosion, and global sea level rise (Nyman, 2014). However, over the past few centuries, humans have altered the course of the river, blocked sediment flow, and disrupted the natural processes that create new land (Paola et al., 2011; Blum & Roberts, 2012; Twilley et al., 2016). Due to leveeing, the Mississippi River is locked into a position where sediments are deposited offshore at the edge of the continental shelf, and therefore provide minimal aid in building marsh (DeLaune & Pezeshki, 1994; Paola et al., 2011; Li et al., 2020). Collectively, these changes amplify environmental stressors such as rising sea levels, wave erosion, subsidence, and tropical storms, which are increasing in frequency and intensity across the MRD (Peyronnin et al., 2017; Hiatt et al., 2019; Potter & Amer, 2020).

Historically, land loss rates were higher, and over 5000 km^2 of coastal marshes have been lost over the last century, with rates as high as 100 km^2 per year (Day et al., 2000; Nittrouer et al., 2012; Hiatt et al., 2019; Potter & Amer, 2020). Currently, Louisiana loses a football field of land every 100 minutes: that equates to 77,000 m^2 of coastal marsh lost per day, and 28 km^2 per year (Couvillion et al., 2017). To combat such staggering land loss and coastal degradation, Louisiana initiated a Coastal Master Plan (valued at $50 billion) to protect and restore coastal wetlands

(Coastal Protection and Restoration Authority of Louisiana, 2023). The plan defines five main objectives, one of which is providing suitable coastal habitat to support commercial and recreational fisheries and wildlife. One method to achieve the plan's objectives is marsh creation, which is when dredge material is used to convert low marsh or open water back to land. This process requires complex engineering design and implementation, and designs vary based on project objectives and funding source. Two of the most common funding sources are the Beneficial Uses of Dredged Materials Program (BUDMAT) and the Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA).

The BUDMAT Program, initiated in 1987 by the U.S. Army Corps of Engineers (USACE), manages dredged material for nationwide biological, economical, and social use. In 2007, BUDMAT was authorized under the Water Resources Development Act (WRDA), designating $100 million to restore Louisiana's coastal areas (U.S. Army Corps of Engineers, 2010). One of the main objectives of the BUDMAT Program is to use material already being dredged from navigation channels to "restore and create coastal landscape features such as, but not limited to, marshes, ridges, and islands that provide wildlife and fisheries habitat with emphasis on ecological and hydrologic functions" (U.S. Army Corps of Engineers, 2010). Coastal wetlands at the mouth of the Mississippi River especially benefit from this program as the birdfoot delta is not included in the Coastal Master Plan (Coastal Protection and Restoration Authority of Louisiana, 2023). While this program allows for the funding, planning, and construction of restoration sites, there is no monitoring of sites afterwards. Thus wildlife benefits from projects remain largely unknown (U.S. Army Corps of Engineers, 2010).

CWPPRA is a federal law that was executed in 1990 to fund wetland restoration and creation and represents the only guaranteed annual funding source for wetland restoration in Louisiana (*LaCoast.Gov*, n.d.). Implementation of the act is a collaborative effort between the state of Louisiana and five federal agencies (USACE, U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service, Natural Resource Conservation Service, National Oceanic and Atmospheric Administration National Marine Fisheries Service), with the Coastal Protection and Restoration Authority (CPRA) serving as the local partner that manages and implements the act. Each individual project is assigned a federal sponsor, which influences the specific motivation for the project and as of 2023, close to 80 CWPPRA marsh creation projects have been completed (*LaCoast.Gov*, n.d.). The law states that restoration projects must "provide for the long-term conservation of such wetlands and dependent fish and wildlife populations" (Coastal Wetlands Planning, Protection & Restoration Act, 1990). However, during design and construction almost all emphasis is placed on maintaining a target elevation over at least 20 years. Because many projects have limited funds, most of the cost is used for design and construction, with minimal monitoring, often only including elevation, hydrology, and vegetation.

Some marsh creation occurs as mitigation, although less common than CWPPRA or BUDMAT projects in Louisiana. The main goal of wetland mitigation is to compensate for the impacts of development by creating or restoring a degraded area with the result of no net wetland loss (Race & Christie, 1982). However, wetland construction designs vary widely from project to project, which impacts hydrology and resulting vegetation communities. Monitoring of mitigation projects varies and while some sites can be beneficial to wildlife, mitigation is not combating widespread coastal habitat loss, as it only compensates for specific areas.

While Louisiana's Coastal Restoration Program has successfully executed dozens of marsh creation projects, it seldom links biotic responses of vegetation and wildlife to these restoration sites. The lack of monitoring of wildlife responses to marsh creation design limits our ability to improve marsh restoration efforts for wildlife. To implement effective restoration strategies in the future, a greater quantitative understanding of critical habitat needs of wetland-dependent species is needed to guide marsh design and to evaluate whether past restoration efforts have improved or negatively impacted those key habitat features.

1.3. Integrating Wildlife with Restoration Efforts

Current efforts integrate some limited habitat features when constructing marshes. Several recent CWPPRA projects included the creation of ponds for waterfowl and tidal creeks for fish passage (Coastal Protection and Restoration Authority of Louisiana, 2014). Additionally, BUDMAT projects on Delta National Wildlife Refuge included design features that allow for fish passage and shallow water areas where submerged aquatic vegetation thrives, providing important fish habitat (Barret Fortier, USFWS, personal communication). Wildlife interest often stems from commercial and recreational hunting and fishing interests, but recent efforts focused on the development of guidelines for creating habitat for non-game species (Deepwater Horizon Louisiana Trustee Implementation Group, 2023). For example, engineers and biologists worked collaboratively to create a document entitled the "Guidance for Coastal Ecosystem Restoration and Monitoring to Create or Improve Bird-Nesting Habitat" in 2023 with the intent of using it to create habitats that benefit nesting birds (Deepwater Horizon Louisiana Trustee Implementation Group, 2023). Assessing and creating habitat for non-game species can provide important context and insight to the success of restoration projects and the need for future considerations.

Birds serve as indicator species for restoration success and habitat quality because of their sensitivity to environmental changes (Mekonen, 2017). Because habitat loss represents the greatest threat to bird populations, steep declines in bird populations often indicate much larger ecological issues (Rosenberg et al., 2019). Several studies evaluated marsh bird presence in relation to wetland restoration success (Desrochers et al., 2008a; Chabot et al., 2014; Byerly et al., 2020), including in coastal Texas, where results indicated that created sites excluded many wading bird and shorebirds (Darnell & Smith, 2004). These sites differed from natural marshes in elevation gradients and hydrologic regimes, excluding intertidal areas and providing a more densely vegetated marsh than natural marshes in the area (Darnell & Smith, 2004). The presence or absence of different marsh bird species can give insight into the type of vegetation and hydrology present at created sites and therefore, inform restoration success.

Wetland-obligate bird species have been declining coincidently with the rapid loss of their habitat. Rosenberg et al. (2019) found that waterbirds and shorebirds across North America have experienced population declines of 21.5% and 37.4% respectively. Common species, such as Red-winged Blackbirds (*Agelaius phoeniceus*), which have experienced a 40% decline across North America, are becoming vulnerable to habitat loss and degradation (Rosenberg et al., 2019). Additionally, Tricolored Heron (*Egretta tricolor*) and Snowy Egret (*Egretta thula*) have been designated species of high conservation concern by the North American Waterbird

Conservation Plan (Kushlan et al., 2002). While these declines have been documented, their species specific abiotic requirements have been poorly linked and understood, consequently limiting managers' ability to inform restoration design. On the lower Mobile-Tensaw River Delta in Alabama, populations of secretive marsh birds such as King Rail (*Rallus elegans*), Least Bittern (*Ixobrychus exilis*), and Common Gallinule (*Gallinula galeata*) declined from 2004-2015 by 50%, 38%, and 15% respectively (Rush et al., 2019). While unexplored, these relationships could be more dramatic in the Mississippi River Delta due to rapid land loss and alterations of existing marshes across this region.

Louisiana contains 40% of all wetlands in the conterminous U.S., making it a regionally and globally important breeding, wintering, and migratory stopover site for birds (Remsen Jr et al., 2019). The marshes of southeast Louisiana support over 20 of the state's species of greatest conservation concern, including Clapper Rail (*Rallus crepitans*), Seaside Sparrow (*Ammospiza maritima*), Least Bittern (*Ixobrychus exilis*), Mottled Duck (*Anas fulvigula*), Marsh Wren (*Cistothorus palustris*), Brown Pelican (*Pelecanus occidentalis*), and Little Blue Heron (*Egretta caerulea*) (Holcomb et al., 2015). Many of these marsh bird species are habitat specialists, which means they require specific habitat features for survival. For example, Clapper Rails and Seaside Sparrows are marsh specialists, and need marsh grasses such as *Sporobolus alterniflorus* (formerly *Spartina alterniflora*) and *Sporobolus pumilus* (formerly *Spartina patens*) for nest building (Eddleman et al., 1988; Byerly et al., 2020). Since a large portion of wetlands along the Northern Gulf Coast are located in Louisiana, the state provides essential habitat with a gradient from fresh to saline marshes for marsh bird specialists (Chabreck, 1970). It is critical that created marshes and wetlands meet the habitat needs of multiple bird species as proper implementation of these restoration practices may be the only way to prevent more dramatic population declines in the face of rapid land loss.

Site-specific hydrologic conditions such as flooding frequency, inundation depth, ephemeral water, and permanent water can have effects on habitat suitability for marsh bird species such as secretive marsh birds (SMBs), wading birds, shorebirds, and waterfowl (Collazo et al., 2002; Pickens & King, 2014a; Patton et al., 2020). For example, Least Bitterns prefer areas with consistent year-round flooding because they feed on aquatic prey (Budd & Krementz, 2010; Chabot et al., 2014), while gallinules require areas with shallow open water because they feed on submerged aquatic vegetation (Alexander & Hepp, 2014). Areas of sparsely vegetated shallow water are also important for wading birds feeding requirements (Lantz et al., 2011). Migrating shorebirds feed predominately on organisms found in mudflats (Burger et al., 1997), which are maintained by tidal influence, fluctuating water levels, or drawdown and will not be present in areas with stable water levels or areas without flooding (Bouma et al., 2005). Water levels can also greatly affect nest success. Dramatic and prolonged flooding events can cause nest failure as the birds are not able to incubate, or eggs can float away (Rush et al., 2010; Clauser, 2015). However, increased variation in water levels has been found to deter predators, therefore increasing nest success rates in some rail species (Robertson & Olsen, 2015). Conversely, higher water has been associated with increased predation of Seaside Sparrow nests in the Florida Everglades (Baiser et al., 2008). Water depths not only influence all aspects of marsh bird ecology such as foraging, nesting, and cover, but also determine the type of vegetation that will be present on the marsh.

In addition to foraging and nesting, these site-specific hydrologic factors also influence the composition and structure of vegetation that can establish and persist, another aspect that is important for marsh bird habitat (Edwards & Proffitt, 2003; Byerly et al., 2020). These emergent vegetation species can only establish in areas with flooding influence; without water on the landscape, upland species dominate (Van Der Valk, 1981). Many marsh birds are specialists and require emergent vegetation for feeding, cover, and breeding, and often species select for a specific type of vegetation composition. As mentioned previously, Seaside Sparrows and Clapper Rails are marsh grass specialists, so they need *S. alterniflora* and *S. patens* for nest building (Eddleman et al., 1988; Byerly et al., 2020). Additionally, Least Bitterns prefer dense stands of robust emergent vegetation such as *Typha* sp. for clinging while feeding and for building nest platforms (Chabot et al., 2014). *Juncus roemerianus* is necessary wintering cover for wrens and sparrows that overwinter in the marshes of the northern gulf coast (Weitzel et al., 2021). All of these plant communities provide a certain type of structure that is vital for nest building, foraging strategies, and cover from predators.

Habitat structure, such as edge habitat, density of vegetation, and presence of woody vegetation, influence whether birds select for a certain area. Edge habitats are where the marsh platform meets a body of water and often support a high diversity of marsh bird species (O'Connell & Nyman, 2010; Alexander & Hepp, 2014; Patton et al., 2020). Edges support submerged and floating aquatic vegetation, which increases density and diversity of fish and invertebrates, and is important for foraging of many marsh specialist species (Peterson & Turner, 1994; Bolenbaugh et al., 2011; Patton et al., 2020). Vegetation density, which is often measured with the Normalized Difference Vegetation Index, has been found to affect bird abundance (Leveau et al., 2018). Many marsh bird species select areas with high enough NDVI to provide high cover, especially in the winter (Pickens & King, 2014a). The presence of woody vegetation also plays a role in habitat structure, however, for most marsh birds, woody encroachment poses a threat. Not only does woody vegetation increase risk of mammalian and avian predators, but it does not provide the nesting material and cover that is needed for most marsh birds (Winstead & King, 2006; Budd & Krementz, 2010; Pickens & King, 2012). In addition to edge, plant density, and woody vegetation, the design and construction of marsh creation sites can have dramatic effects on habitat structure.

Created marshes in Louisiana are often built at a higher elevation than natural marshes to increase longevity in the face of subsidence and sea level rise (Edwards & Proffitt, 2003; Elsey-Quirk et al., 2009). They are typically built higher than the tidal range, creating a dryer, upland site where emergent vegetation cannot persist (Elsey-Quirk et al., 2009; Byerly et al., 2020). Most marsh creation projects in Louisiana are built confined where containment dikes are placed around the perimeter of the site, sometimes creating a levee or berm that does not promote hydrologic connectivity. Some sites are built semi-confined or unconfined, where sediment is allowed to settle naturally, but this method is less common. Additionally, dredge material is often pumped uniformly across the entire site, excluding ephemeral and permanent ponds and streams (Jacques Boudreaux, CPRA, personal communication). Due to the importance of site-specific hydrologic features and emergent vegetation, it is possible that created marshes do not provide suitable habitat for marsh birds.

I examined whether created marshes in southeastern Louisiana provide suitable habitat for wetland obligate bird species through two main objectives:

1. Compare hydrologic characteristics, plant composition, and habitat structure between natural and created marshes.

2. Determine the effects of hydrology, plant composition, and habitat structure on bird abundance.

I hypothesized that site-specific hydrologic characteristics were the greatest drivers of marsh bird presence at all sites. However, I expected that many created marshes in Louisiana lacked the necessary hydrologic conditions to create suitable marsh bird habitat due to design and construction of these sites. I also hypothesized that created marshes lacking emergent marsh would support upland bird and plant communities better than they would support wetland-obligate bird species and that natural marshes would support the necessary hydrologic and vegetation characteristics for greater abundances of marsh birds.

2. METHODS

2.1. Study Area

I examined ten created marshes and nine natural marshes located within 4 of the 5 hydrologic basins that make up the Deltaic Plain of coastal Louisiana: Terrebonne, Barataria, Pontchartrain, and Mississippi River Delta (Figure 1). Created marsh sites were selected based on age, marsh type (fresh, intermediate, brackish, saline), landowner permission, and accessibility (Table 1). All selected fresh marsh sites (n = 2) occurred within active deltas of the Mississippi River Delta basin, while all intermediate (n = 5), brackish (n = 1), and saline marsh sites (n = 2) occurred within inactive deltas throughout the Terrebonne, Barataria, and Pontchartrain basins (Figure 1).

Delta-1 and Delta-2 are BUDMAT projects, which are part of the Hopper Dredge Disposal Area; the Port Fourchon Mitigation site is part of the Greater Lafourche Port Commission's Floatation Canal project; the remaining sites are CWPPRA projects.

Natural marsh surveys were conducted within a one-kilometer (km) radius of a Coastwide Reference Monitoring System (CRMS) station where salinity and water levels are recorded hourly (*CRMS*, n.d.). All marsh types were classified based on CRMS vegetation classification (Table 1).

Table 1. Marsh type, hydrologic basin, and age for created sites.

Marsh Type	Site ID	Basin	Age
Saline	BA-42	Barataria	2015
	Port Fourchon Mitigation	Terrebonne	2011
Brackish	BA-68	Barataria	2015
Intermediate	BA-36	Barataria	2010
	BA-125	Barataria	2021
	BA-164	Barataria	2017
	PO-104	Pontchartrain	2018
	TE-46	Terrebonne	2011
Fresh	Delta-1	Mississippi Delta	2013
	Delta-2	Mississippi Delta	2015

My study sites were microtidal (average tidal range 0.3 m) with an average tidal range of less than 10 cm (Tweedley et al., 2016; Hiatt et al., 2019; Wu et al., 2019). However, wind and precipitation-driven water fluctuations have a greater effect on water levels than tides in coastal Louisiana (Hiatt et al., 2019). Strong north winds cause extremely low water levels, draining ponds and exposing mudflats (Denes & Caffrey, 1988). Conversely, southerly winds cause flooding and inundation events where water levels can rise a meter within a few hours (Denes & Caffrey, 1988). Louisiana has the highest annual precipitation of any state in the continental U.S., with coastal regions averaging from 140 to 160 cm per year and annual precipitation totals ranging from 90 to 220 cm (Keim et al., 1995; Hiatt et al., 2019).

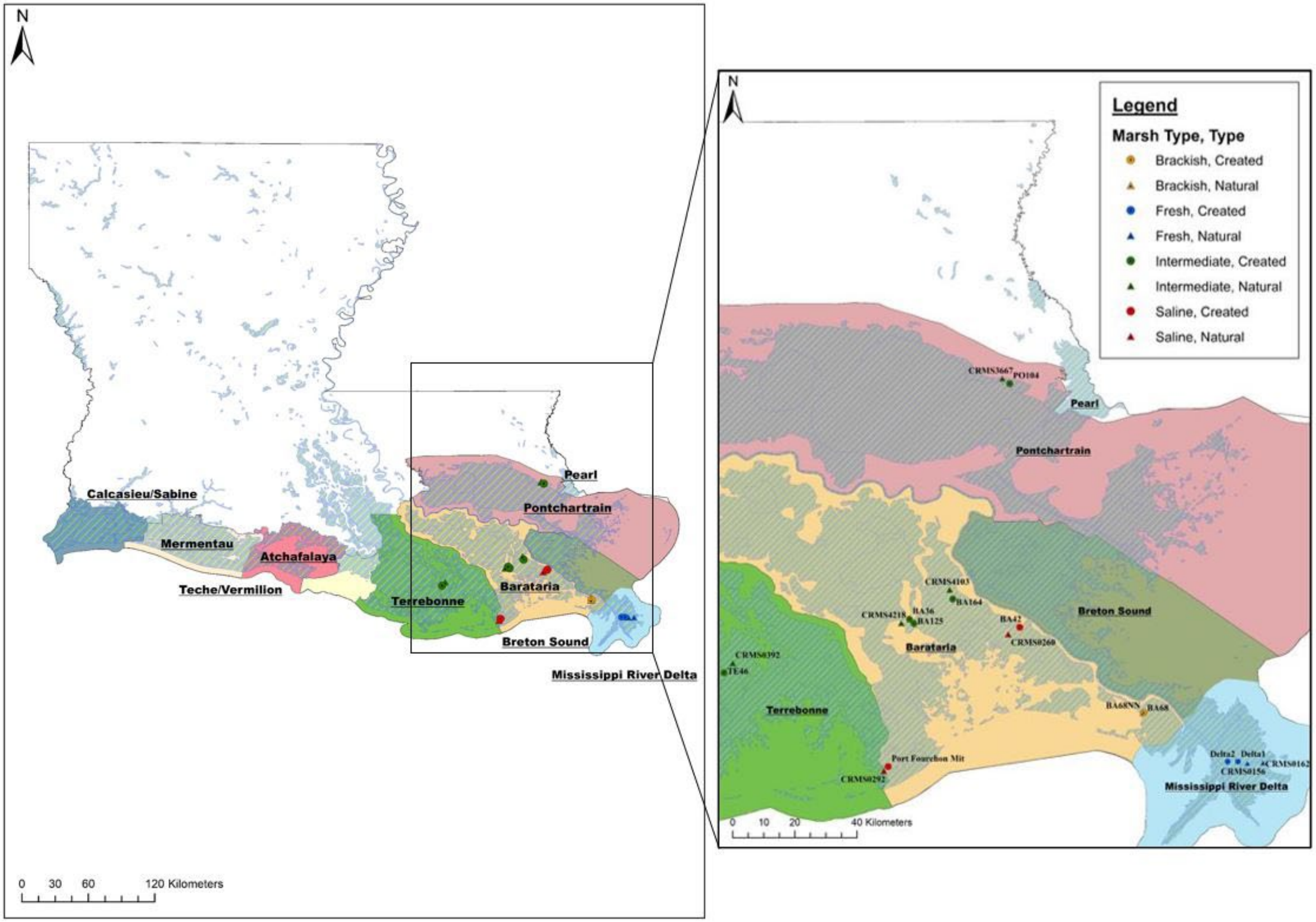


Figure 1. Map of the state of Louisiana, including the 9 hydrologic basins of Louisiana. The zoomed in portion represents my study area and icons indicate the locations of my sites. Shapes and colors represent marsh type and if the site is created or natural.

2.2. Bird Surveys

Field crews and I conducted bird surveys on all created marsh sites and a paired control (nearest natural) marsh. At each site, we surveyed four randomly generated point locations, which were placed at least 250 meters (m) apart to create point independence and minimize double counting of individual birds. We surveyed each point four times during the 2021-2023 breeding seasons (March – June) because at least three surveys are needed to determine presence/absence of some marsh bird species with 90% certainty (Gibbs & Melvin, 1993; Conway, 2011). We conducted surveys from 30 minutes before sunrise until 1030 CDT except during periods of heavy rains or winds >15 kph. We rotated observers and sampling times throughout the season to reduce the potential for observer bias and to ensure that sites were surveyed at least once during early morning hours.

At each survey point, we performed a point count survey in which we recorded visual and auditory detections of all observed birds within a 100-m radius (Conway, 2011). Our surveys began with a five-minute passive listening period (Johnson et al., 2009), which is sufficient for detecting most bird species present during a point count (Dettmers et al., 1999; Bonthoux & Balent, 2012), especially in open grasslands (Savard & Hooper, 1995). However, this does not apply to species with relatively low detection probabilities such as secretive marsh birds (SMBs), which are inconspicuous and often do not call unless a response is elicited (Soehren et al., 2009; Conway, 2011; Orr et al., 2020). To increase detection probability of SMBs, we used the Standardized North American Marsh Bird Monitoring Protocol established by Conway (2011) to preform call-back surveys following the five-minute passive listening period. We used handheld speakers (Foxpro Inferno, Lewistown, PA, USA) to broadcast SMB calls, which included Black Rail (*Laterallus jamaicensis*), Least Bittern (*Ixobrychus exilis*), King Rail (*Rallus elegans*), Clapper Rail (*Rallus crepitans*), Common Gallinule (*Gallinula galeata*), Purple Gallinule (*Porphyrio martinica*), American Coot (*Fulica americana*), and Pied-billed Grebe (*Podilymbus podiceps)*. These calls reflect potential breeding SMB species within this region and can elicit responses from a variety of other SMBs (Conway, 2011). We played each call for 30 seconds, followed by 30 seconds of silence and listening (Conway, 2011), and continuously recorded all bird species detected throughout the entire survey. Any birds that landed or took off from within the 100-m radius were counted for analysis, while birds that flew over without landing were noted but not used in the final analysis. Technicians were trained to identify bird calls.

At each bird survey, we recorded instantaneous environmental variables that could affect bird detection such as wind speed, temperature, sky, noise, and water depth. Wind speed (knots) and temperature (Celsius) were measured using a Kestrel weather device (Kestel Instruments, model 3000). We estimated sky cover on a scale of 0 – 5 where 0 – clear/few clouds, 1 – partly cloudy, 2 – cloudy/overcast, 3 – fog, 4 – drizzle, and 5 – showers. Additionally, we estimated how background noise affected our ability to hear birds within the plot on a scale of 0 – 3 where 0 – not reduced, 1 – barely reduced, 2 – noticeably reduced, and 3 – greatly reduced. We measured water depth (cm) at the survey point location with a meter stick. Technicians were trained in sky cover and noise estimations.

King and Clapper rails are nearly impossible to distinguish by call or morphology and have been known to hybridize, especially in intermediate and brackish marshes (Maley, 2012). King Rails are associated with fresh marsh and Clapper Rails are associated with salt marsh so in fresh marsh we recorded birds in question as King Rail, in salt marsh we recorded them as Clapper Rail, and in intermediate or brackish marsh we recorded them as King/Clapper Rail (Pickens & King, 2014b; Patton et al., 2020). Additionally, White-Faced Ibis (*Plegadis chihi*) and Glossy Ibis (*Plegadis falcinellus*) are difficult to distinguish in the field, so we clumped both observations in a group called "Dark Ibis" (Pickens & King, 2014b; Patton et al., 2020).

2.3. Continuous Hydrologic Measurements

Water loggers (In-Situ RuggedTROLL 100 pressure transducers) were installed at all created marsh sites, as outlined below, to measure water depth every hour throughout the breeding season. Data recorders were set up before March 1 of every year and taken down after the completion of the field season. Hourly water level data were downloaded from CRMS stations in the natural marshes and used to calculate hydrologic characteristics at the natural marshes.

2021-2022 Water Logger Setup

In 2021 and 2022, one water logger was placed at one survey point for each created site and used to assess water levels for all survey points at that site. Loggers were positioned inside a well constructed of a 5-centimeter (cm) diameter PVC pipe cut into 2-m segments. Small holes were drilled into each pipe to allow for water exchange. Screen mesh was attached to the lower 1 m of the pipe with zip ties to keep out sediment and vegetation. Water loggers were attached to a plastic cord and hung near the bottom of the pipe. The cord was attached to a PVC cap which was secured to the top of the pipe and marked with yellow duct tape. A 10-cm diameter soil auger was used to dig a 1-m deep hole where the pipe was placed and secured with sand and capped with clay cat litter (Figure 2). A barometric pressure transducer (In-Situ BaroTROLL 100) was tied to the outside of some of the pipes; one barometric pressure transducer was used for sites within 10 km.

2023 Water Logger Setup

In 2023, I placed two water level recording devices at each created site. I strategically positioned loggers at both the highest and lowest ends of the marsh platform and spaced them evenly between the four survey points to test whether water levels were comparable at the four survey points of a site, especially at created sites, which can have high variability in elevation.
At the natural sites, one water logger was placed at the survey point farthest away (< 1 km) from the CRMS station. To determine if the CRMS water levels could predict water levels at my survey points, I tested the linear relationship between water levels at my water loggers and at the nearest CRMS stations.

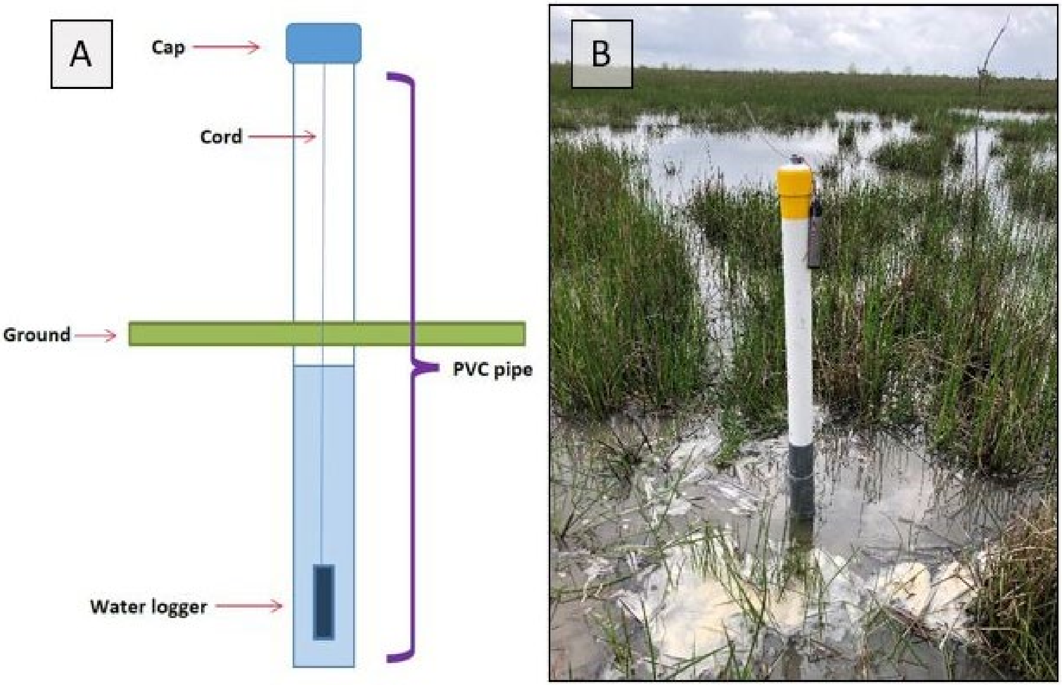


Figure 2. (a) Diagram of water logger well set up. (b) Well installation in the field.

Figure 3. 2023 water logger setup. The logger is inside the mesh-wrapped pipe and the pipe is sitting on the soil surface.

Additionally in 2023, I changed water logger installation methods to increase set up efficiency. Instead of using a 2 m long pipe that had to be inserted into the ground as I did in 2021 and 2022, in 2023, I placed much shorter pipes on the surface of the marsh platform. I placed loggers inside a 30 cm long PVC pipe (5-cm diameter) with drilled holes to allow for water flow. I wrapped screen mesh around the PVC pipe and placed the logger inside the mesh covered pipe so that it sat at the bottom of the pipe. I zip-tied the pipe to a PVC pole and stuck the pole into the ground so that the bottom of the pipe was resting on the soil surface (Figure 3). The water logger was then able to record surface water and the setup was much more efficient than digging a well in the marsh.

2.4. Vegetation Communities

Annually during the second and fourth survey rounds, we stood at the point and drew habitat sketches of major vegetation types and water. In 2022, we collected drone imagery (during the second and fourth survey rounds) of each point to further assist in vegetation classification and to identify the percent woody vegetation (Figure 4).

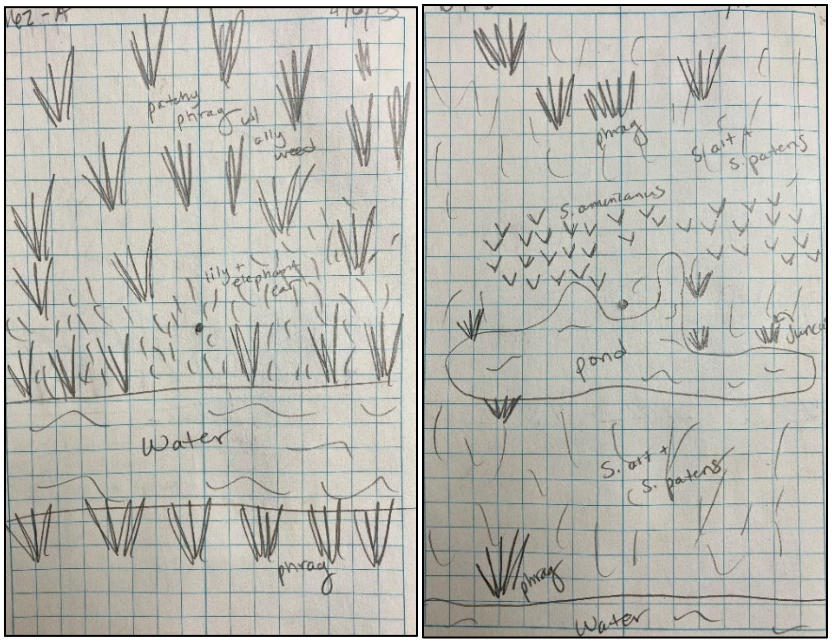


Figure 4. Two habitat sketches. The dot in the center of each image represents the survey point and all vegetation representations are labeled.

I classified vegetation community type within a 100 m radius of each point based on a slight modification of Snedden (2019). For all my points (n = 76), vegetation classifications were: Roseau Cane (n = 16), Wiregrass (n = 14), Brackish mix (n = 13), Three-square (n = 9), Oystergrass (n = 7), Bulrush (n = 6), Mangrove (n = 4), Typha (n = 4), and Bulltongue (n = 3; Table 2). We added two community types (Typha and Mangrove) as four of my points consisted almost entirely of *Typha* sp. and four points consisted almost entirely of *Avicennia germinans*, neither of which fit any of Snedden's (2019) community types. I excluded some vegetation communities the final analysis of certain guilds or focal species because of low detections.

Table 2. Vegetation community types as defined by Snedden et al. (2019) with my modifications. Community types are arranged by increasing salinity. Vegetation community is the name of the classification; dominant species are the seven most abundant taxa for each community type as defined by Snedden et al. (2019). Bolded values represent species that compromised >70% of the community; and points are the survey points that were classified into each community type. Asterisks represent classifications that I added.

Vegetation Community	Dominant Species	Created Points	Natural Points
Bulltongue	***Sagittaria lancifolia, Polygonum punctatum, Alternanthera philoxeroides, Ludwigia grandifolia, Typha sp., Colocasia esculenta, Sacciolepsis striata***		CRMS4103: B, C, D
Three-square	***Schoenoplectus americanus, Spartina patens, Sagittaria lancifolia, Lythrum lineare, Cladium mariscus, Eleocharis macrostachya, Distichlis spicata***	BA-125: C PO-104: A, B, C, D	CRMS4218: A, B, C, D
Roseau Cane	***Phragmites australis***, *Spartina patens, Alternanthera philoxeroides, Spartina alterniflora, Typha domingensis, Zizaniopsis miliacea, Polygonum punctatum*	Delta-1: A, B, C, D Delta-2: A, B, C, D	CRMS0156: A, B, C, D CRMS0162: A, B, C, D
Typha*	***Typha sp., Phragmites australis***, *Iva frutescens, Ipomoea sagittata, Spartina patens, Schoenoplectus americanus, Rumex sp.*	BA-164: A, B, C, D	
Wiregrass	***Spartina patens, Distichlis spicata,*** *Schoenoplectus americanus, Bolboschoenus robustus, Ipomoea sagittata, Lythrum lineare, Spartina alterniflora*	BA-36: A, B, C, D TE-46: B	CRMS0392: A, B, C, D CRMS3667: A, B, C, D CRMS4103: A
Bulrush	***Bolboschoenus robustus, Distichlis spicata, Spartina patens***, *Spartina cynosuroides, Spartina alterniflora, Paspalum distichum, Juncus roemerianus*	BA-125: A, B, D TE-46: A, C, D	
Brackish Mix	***Spartina alterniflora, Spartina patens,*** *Juncus roemerianus, Distichlis spicata, Bolboschoenus robustus, Avicennia germinans, Iva frutescens*	BA-42: A, B, C, D BA-68: A, B, C, D BA-68NN: A, B, C, D	CRMS0260: C
Oystergrass	***Spartina alterniflora,*** *Juncus roemerianus, Spartina patens, Distichlis spicata, Batis maritima, Bolboschoenus robustus, Avicennia germinans*	Port Fourchon Mit: A, B, C, D	CRMS0260: A, B, D
Mangrove*	***Avicennia germinans, Spartina alterniflora***, *Distichlis spicata, Iva frutescens, Solidago sempervirens, Batis maritima, Cakile constricta*		CRMS0292: A, B, C, D

2.5. Remote Sensing

I developed habitat metrics extracted from Harmonized Sentinel-2 MSI (10 meter spatial resolution; European Union/ESA/Copernicus) satellite imagery using Google Earth Engine (GGE; Gorelick et al., 2017) using 100 m radius buffers around survey points for each survey year (2021, 2022, 2023) to assess vegetation cover, wetness, and edge density. Dates were filtered between February 20th – June 30th for each year to account for the differing start and end dates within each survey year. Images with more than 20% cloud coverage were masked and a mean value of each spectral band was calculated for an overall spring mean Sentinel-2 image for each plot point in a survey year. A mean Normalized Difference Vegetation Index (NDVI = [Band 8 – Band 4] / [Band 8 + Band 4]) for each plot point for each survey year was calculated for an index of "greenness" or density of vegetation, with values ranging from -1 (open water) to +1 (dense, green vegetation). Open water was removed from each image to only measure vegetation density within the marsh complex by using a threshold metric from the calculated NDVI to mask open water. The Modified Normalized Difference Water Index (mNDWI = [Band 3 – Band 8] / [Band 3 + Band 8]) was calculated to measure "wetness", or moisture content, within point buffers and any open water present. Values range from -1 (drought, non-aqueous surfaces) to +1 (open, deep water). A value of 0 – 0.2 maybe indicate flooding across the water surface. A modified NDWI was used due to it being able to measure bodies of water more accurately (Xu, 2006). Edge area was measured by quantifying wetland versus water by using NDVI and mNDWI values to create a spectral image analysis with thresholds of -0.2 for wetlands and 0.2 for water. A focal analysis of these thresholds was used to then calculate the edge area between measured wetland and water within the plot points.

2.6. Statistical Analysis

2.6.1. Water logger calibrations and predictions

All water logger data were calibrated with barometric pressure data (In-Situ BaroTroll 100) to determine water depth using Win-Situ 5 and Win-Situ Baro Merge Software (In-Situ, Inc.). At created sites, I predicted water levels for 2021 and 2022 at the point where I installed a water logger in 2023 but did not have water loggers in 2021 and 2022, using data from 2023. I used linear regression in the lme4 package (Bates et al., 2009) in R (R Core Team, 2023) to determine the relationship between the two water loggers. For sites where the R-squared value was > 0.60, I predicted water levels from 2021 and 2022. Each two points closest together were assumed to have similar water levels (Figure 5).

At natural marsh sites, water logger data from 2023 was used to predict water levels for 2021 and 2022 using the CRMS water data. I used linear regression to develop predictive relationships among our water logger data and water levels of the nearest CRMS station. We considered CRMS data accurate in predicting water levels when the R-squared value was > 0.60. For analysis, all four points at a site were assumed to have similar water levels.

2.6.2. Tests for habitat covariates between created and natural sites

I used Welch's two sample t-test to compare differences in NDWI, NDVI, proportion of edge, mean water levels, and water level standard deviation between created and natural sites. Additionally, I used a Pearson's Chi-squared test of independence to compare differences in vegetation communities between created and natural sites.

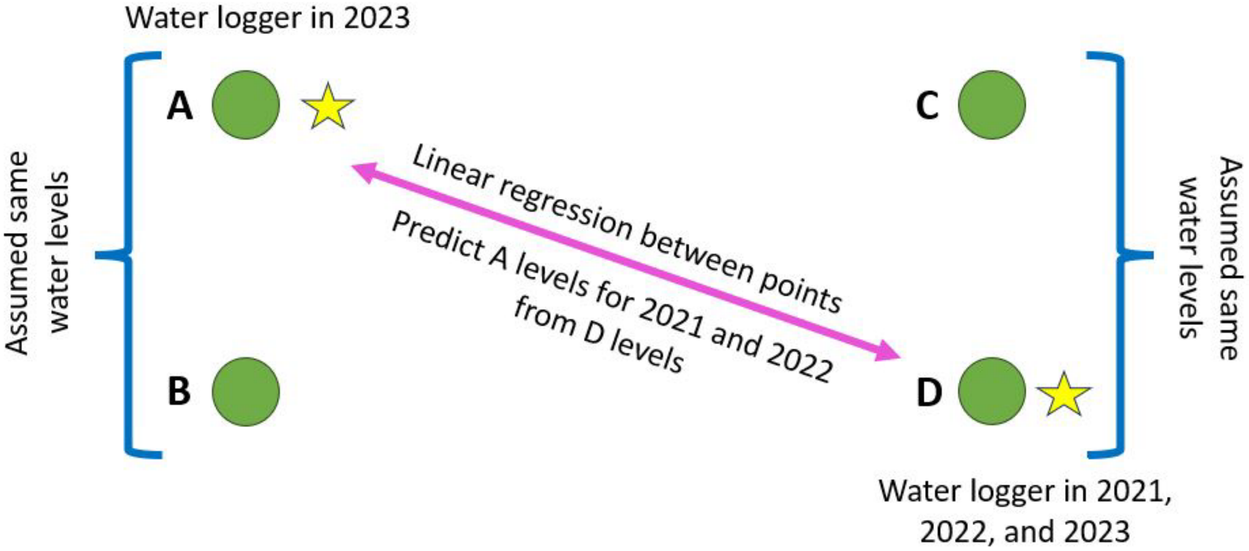


Figure 5. Visual representation of where water loggers were located each year and how I predicted water levels. Green dots represent survey points A—D at each site. Yellow stars represent points with water loggers. For each site, we assumed water levels between the two points closest together were the same (e.g., A and B, C and D). The pink line shows using point D to predict water levels at point A for 2021 and 2022.

2.6.3. Bird classification

I grouped bird species into habitat guilds, which accounted for changing bird communities as wintering, migrating, and breeding birds traveled through my study area. These groupings also allowed me to incorporate species that would not have had enough observations to model independently. I classified all bird species into one of five habitat guilds: 1) Marsh Specialist, 2) Beach and Estuary, 3) Wetlands Generalist, 4) Habitat Mosaic Generalist, and 5) Forest (Table 3). This classification was based on how birds use Louisiana marshes during their annual lifecycle. The classification closely follows habitat specifications by the Partners in Flight Avian Conservation Assessment Database (Partners in Flight, 2021); however, I changed the classification of some species based on local knowledge of how these species utilize habitat in Louisiana (see Appendix A). Additionally, I grouped several habitats together (e.g., freshwater marsh and saltwater marsh was grouped into marsh specialist, and multiple forest types were combined into one guild). In addition to the five habitat guilds, four focal species were selected because of high detections: Common Gallinule, King/Clapper Rail, Least Bittern, Seaside Sparrow, and Red-winged Blackbird. For final analyses, Red-winged Blackbirds were removed from the wetland generalist guild, as they comprised a large portion of detections, thus biasing the results of this guild.

Table 3. Habitat guild classification for species observed during study. The numbers in parentheses are the total number of detections of each individual species.

Habitat Guild	Species Included
Beach and Estuary (BE)	Brown Pelican (6), Caspian Tern (3), Common Tern (9), Gull-billed Tern (8), Laughing Gull (25), Least Sandpiper (15), Least Tern (6), Red Knot (1), Royal Tern (15), Sanderling (48), Sandwich Tern (2), Short-billed Dowitcher (5), Willet (31)
Forest (FO)	American Robin (1), Blue Jay (6), Blue-gray Gnatcatcher (1), Brown Thrasher (2), Carolina Chickadee (1), Carolina Wren (7), Cooper's Hawk (1), Downy Woodpecker (2), Eastern Towhee (16), Gray Catbird (10), Great Crested Flycatcher (2), Northern Flicker (1), Northern Parula (1), Orange-crowned Warbler (1), Pileated Woodpecker (1), Red-bellied Woodpecker (3), Ruby-crowned Kinglet (1), Ruby-throated Hummingbird (1), Tufted Titmouse (2), White-eyed Vireo (4), White-throated Sparrow (1), Yellow-billed Cuckoo (8), Yellow-rumped Warbler (48), Yellow-throated Warbler (1)
Habitat Mosaic Generalist (HMG)	Barn Swallow (20), Brown-headed Cowbird (23), Cattle Egret (1), Cliff Swallow (2), Common Grackle (16), Common Yellowthroat (369), Eastern Kingbird (90), Eastern Phoebe (1), Field Sparrow (2), Fish Crow (2), House Wren (1), Indigo Bunting (3), Killdeer (16), Mourning Dove (36), Northern Cardinal (37), Northern Harrier (6), Northern Mockingbird (8), Northern Rough-winged Swallow (1), Orchard Oriole (195), Painted Bunting (6), Palm Warbler (9), Purple Martin (9), Red-tailed Hawk (1), Savannah Sparrow (9), Turkey Vulture (1)
Marsh Specialist (MS)	American Bittern (3), Black Tern (1), Black-necked Stilt (18), Boat-tailed Grackle (434), Common Gallinule (1274), Dark Ibis (8), Forster's Tern (8), Fulvous Whistling Duck (2), King/Clapper Rail (945), Least Bittern (268), Marsh Wren (655), Mottled Duck (37), Nelson's Sparrow (13), Pied-billed Grebe (40), Purple Gallinule (126), Seaside Sparrow (345), Sora (164)
Wetland Generalist (WG)	American Coot (66), American White Pelican (6), Anhinga (17), Belted Kingfisher (8), Black-bellied Whistling Duck (39), Black-crowned Night Heron (7), Blue-winged Teal (52), Double-crested Cormorant (11), Great Blue Heron (9), Great Egret (32), Greater Yellowlegs (26), Green Heron (12), Lesser Yellowlegs (5), Little Blue Heron (11), Long-billed Dowitcher (5), Neotropic Cormorant (1), Osprey (5), Red-breasted Merganser (2), Red-winged Blackbird (3493), Ring-billed Gull (1), Roseate Spoonbill (7), Sedge Wren (55), Snowy Egret (29), Swamp Sparrow (162), Tree Swallow (27), Tricolored Heron (36), White Ibis (10), Wood Duck (2), Yellow-crowned Night Heron (13)

2.6.4. Water logger covariate selection

To determine which water depth covariates had the greatest effect on abundance, I used maximum likelihood estimations of Poisson generalized linear models (GLMs) in the lme4 package (Bates et al., 2009). For each guild or focal species, I tested the effects of mean, median, maximum, minimum, and standard deviation for water depth at three different time periods: weekly, biweekly, and monthly. I then selected the model with the lowest Akaike information criterion (AIC) to be used for the following models.

2.6.5. Models

To determine habitat factors affecting bird abundance across created and natural sites, I built generalized linear mixed models in a Bayesian framework using the brms package (Bürkner, 2017) in R (R Core Team, 2023). For each guild and focal species, I developed a candidate model set based on four a priori hypotheses on the drivers of bird abundance among my sites. Abundance is defined as the estimated number of birds per point count survey. Before fitting my candidate model set I used Pearson's correlation coefficient (Dormann et al., 2013) to assess collinearity of my covariates (Table 4), ensuring that $|r| < 0.7$. Because marsh type was correlated with vegetation classification, we used maximum likelihood estimates of GLMs to determine which variable was a better predictor of bird abundance. Vegetation classification was a better predictor of bird abundance ($\Delta AIC = -38$) and was used in all subsequent models. Additionally, I chose the appropriate distribution for each guild and focal species by comparing AIC of intercept-only maximum likelihood estimations for Poisson, negative binomial, zero-inflated Poisson, and zero-inflated negative binomial and selecting the distribution with the lowest AIC (Fowler et al., 2023; Table 5).

Random effects were chosen by comparing interclass correlation coefficient (ICC) values, which are used as a diagnostic for how much variation is explained by a specific random effect (Midway, 2022). ICC values range from 0 to 1 with higher values explaining more group-level variation. The threshold for when a random effect should be included in a model based on ICC values is subjective, but in general, ICC values below 0.5 are not considered a great enough source of variance to be included as a random effect (Midway, 2022). Higher ICC values indicate that a parameter explains a high level of variability and therefore would be beneficial to a model as a random effect. For my study, I only included random effects that substantially decreased the model error term (ICC values >0.5). First, I investigated *plot_id*, which is a unique ID for site, survey point, and year to account for variation among sites and year. I decided to include year within *plot_id* because there were events each year that could have affected bird abundance: 2021 was an extremely wet year, 2022 was one of the driest years on record, and hurricane Ida hit my study area between my 2021 and 2022 field seasons. *Plot_id* had high ICC values for some guilds and focal species and therefore I decided to include it in all subsequent models (Table 6). Next, I evaluated more complex random effect structures including adding survey round, observer, and block. Survey round accounts for variation between repeated sampling of a site within each year and block accounts for spatial autocorrelation between pairings of created sites and their nearest natural reference site. Effects of each of these variables were nominal as indicated by the ICC values (Table 6) and therefore to facilitate model parsimony and convergence I elected to only use *plot_id* in all subsequent models.

Table 4. List of all covariates considered in analysis with covariate name, type (response, fixed, random) and a definition of the covariate.

Covariate Name	Covariate Type	Definition
Abundance	Response variable	Estimated number of birds per point count survey
Marsh Type	Fixed effect	4-level categorical; fresh, intermediate, brackish, saline
Vegetation Classification	Fixed effect	9-level categorical; community types based on Snedden classification
Type	Fixed effect	2-level categorical; created, natural
Spring median NDVI	Fixed effect	Normalized Difference Vegetation Index; numeric 0-1 scale
Spring median NDWI	Fixed effect	Normalized Difference Wetness Index; numeric 0-1 scale
Percent woody vegetation	Fixed effect	2-level categorical; true if plot was >25%, false otherwise
Proportion of edge	Fixed effect	Proportion per survey plot; numeric 0-1 scale
Water depth at survey	Fixed effect	Instantaneous water depth; continuous numeric
Monthly water logger metric	Fixed effect	Mean, median, maximum, minimum or standard deviation calculated from water loggers; continuous numeric
Observer	Random effect	Initials of observer who performed count
Survey round	Random effect	4-level categorical; rounds 1-4 for each year
Plot_id	Random effect	Unique ID for site, survey point, and year
Block	Random effect	10-level categorical; represents each pairing of created/natural sites

Table 5. AIC values for different distributions for each guild and focal species. Poisson = Poisson, NegBin = negative binomial, ZIP = zero-inflated Poisson, ZINB = zero-inflated negative binomial. Bolded values represent the lowest AIC for each guild/focal species and correspond with the distribution that was chosen. Abbreviations are as follows: BE = beach and estuary, FO = forest, HMG = habitat mosaic generalist, MS = marsh specialist, WG = wetland generalist, COGA = Common Gallinule, RAIL = King/Clapper Rail, LEBI = Least Bittern, SESP = Seaside Sparrow, RWBL = Red-winged Blackbird.

Model	BE	FO	HMG	MS	WG	COGA	CLRA/ KIRA	LEBI	SESP	RWBL
Poisson	1192	832	2539	4725	2392	3180	2390	1251	1620	5186
NegBin	**660**	**603**	2254	4155	**1907**	2695	2324	1177	1247	**3929**
ZIP	761	635	2305	4376	2038	2696	2317	**1173**	**1197**	4988
ZINB	662	605	**2253**	**4104**	1909	**2656**	**2316**	1174	1199	3931

Table 6. ICC values for *observer, survey round, plot_id,* and *plot_id* nested within *block* for each guild and focal species.

Guild/Species	**Observer**	**Round**	**plot_id**	**block/plot_id**
Beach and Estuary	0.60	0.01	0.91	0.94
Forest	0.32	0.25	0.84	0.83
Habitat Mosaic Generalist	0.07	0.13	0.42	0.51
Wetlands Generalist	0.47	0.00	0.13	0.17
Marsh Specialist	0.19	0.05	0.34	0.35
Common Gallinule	0.05	0.03	0.78	0.85
King/Clapper Rail	0.03	0.02	0.02	0.07
Least Bittern	0.26	0.02	0.02	0.03
Seaside Sparrow	0.13	0.02	0.04	0.08
Red-winged Blackbird	0.50	0.07	0.41	0.40

My first hypothesis was that bird abundance is driven by habitat structure. Fixed effects included in this model were *type* (2-level categorical; created, natural), *proportion of edge* (proportion per survey plot; numeric), *median spring NDVI* (Normalized Difference Vegetation Index; numeric), and *>25% woody vegetation* (2-level categorical: true if plot was >25%, false otherwise). My second hypothesis was that habitat composition drives bird abundance. Fixed effects included in this model were *type* (2-level categorical: created, natural) and *vegetation classification* (9-level categorical). My third hypothesis was that bird abundance is driven mainly by hydrology and fixed effects included in this model were *type* (2-level categorical: created, natural), *water depth at survey* (numeric), *median spring NDWI* (Normalized Difference Vegetation Index; numeric), and the selected water depth variable for each guild or species (numeric). My final hypothesis was that a combination of structure, composition, and hydrology are the main drivers of bird abundance and for this model I chose one parameter from each of the previous models, which would represent structure, composition, and hydrology. Fixed effects included in this model were *type* (2-level categorical: created, natural), *proportion of edge* (proportion per survey plot; numeric), *vegetation classification* (9-level categorical), and the selected water depth variable for each guild or species (numeric). I chose *proportion of edge* and *vegetation classification* based on past studies and my preliminary results which demonstrated the importance of edge habitat and vegetation type on bird abundance (Valente et al., 2011; Patton et al., 2020; Malone et al., 2021). I chose the water logger variable because I believe this parameter is more representative of water depths through time (i.e., hydroperiod) than either the instantaneous *water depth at survey* or *median spring NDWI.* The four hypotheses were compared to an informed null model, which only contained *type* (2-level categorical: created, natural) as a fixed effect. I included *type* in all models to evaluate whether there is a difference in bird abundance between created and natural marshes and to compare the relative effect size of *type* compared to other habitat variables.

For each candidate model testing my hypotheses, I ran four Markov Chain Monte Carlo (MCMC) chains of 3000 iterations and used the default uninformative priors. I examined model convergence using trace plots, the Gelman-Rubin statistic ($\widehat{R}$ value < 1.1; Gelman & Rubin, 1992), and number of effective samples. For each guild and focal species, I ranked models using approximate Leave-One-Out (LOO) cross-validation in the loo package (Vehtari et al., 2017). I used the expected log pointwise predictive density (ELPD) to rank models and selected the model with the lowest ELPD. Models within four ELPD are thought to be competitive (Vehtari et al., 2017) and for a few of my model groups, there were several top competing models (Table 8). In these cases, I built a new model using all the parameters in the top models and examined the posterior distributions of this final model (Table 9). Posterior estimates with 95% CRIs that did not overlap 0 were considered significant. I excluded *type* from the final models for the sake of parsimony, as this variable was not found to affect bird abundance for any guild or focal species. Because all of the beach and estuary guild models were within 4 ELPD, I did not build a final model for this guild, as none of the variables that I measured explained abundance of this guild beyond the Null model. Additionally, after examining the posterior estimates of my final models, I built GLMMs with just *vegetation classification* (*N ~ VegClass + (1|plot_id)*) to understand the absolute value effect of different vegetation communities on bird abundance. I did this only for guilds or focal species that had *vegetation classification* in the top model.

3. RESULTS

We completed 766 surveys (created = 413, natural = 353) including 166 in 2021, 299 in 2022, and 301 in 2023. We detected 12,059 individual birds at our sites, including flyovers. Without flyovers we identified 9,650 individuals of 110 different bird species, including 88 species at natural marshes and 91 species at created marshes.

The marsh specialist guild had the highest number of detections (n = 4341) and contained 17 unique species with the most abundant species including Common Gallinule (n = 1274), King/Clapper Rail (n = 945), Marsh Wren (n = 655), and Boat-tailed Grackle (n = 434; Table 3). The habitat mosaic generalist guild had a total of 864 detections and 25 different species with the most detected species being Common Yellowthroat (n = 369) and Orchard Oriole (n = 195). The wetland generalist guild had a total of 656 detections and 28 different species, and the most abundant species included Swamp Sparrow (n = 162), American Coot (n = 66), Sedge Wren (n = 55), and Blue-winged Teal (n = 52). The beach and estuary guild had 174 detections and 13 different species, and the most detected species in this guild were Sanderling (n = 48), Willet (n = 31), and Laughing Gull (n = 25). The forest guild had the lowest number of detections (n = 122) and 24 different species and the most detected species was Yellow-rumped Warbler (n = 48).

Detections did not vary between created and natural sites for any guild or focal species, indicating that differences in bird communities are related to other factors besides whether a wetland is created or natural (Figure 6). Rather, the vegetation and hydrology metrics were found to be the drivers of bird abundance.

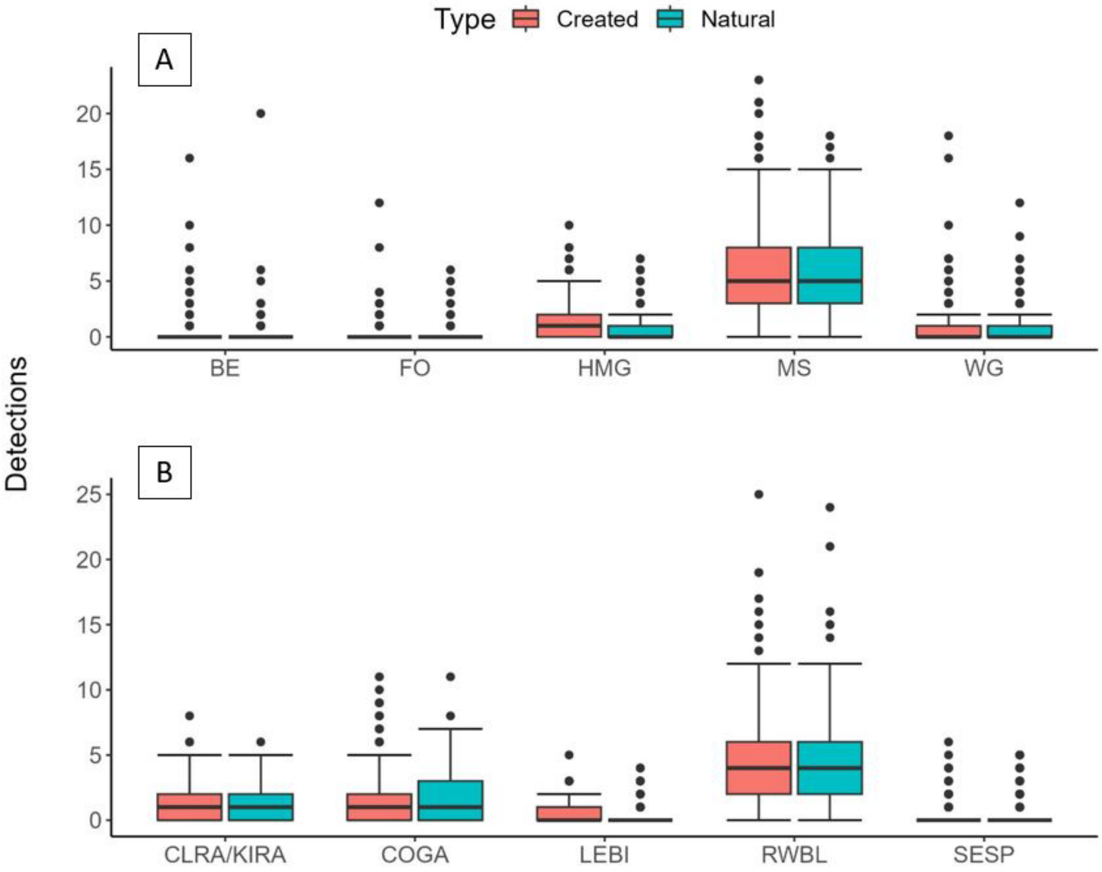


Figure 6. Mean detections at created and natural sites for a) guilds and b) focal species. Boxes represent the lower 25% and upper 75% quantiles, the black line in the middle of the box represents the median per survey, whisker length represents 1.5 the length of the interquartile range, and black dots represent outliers. Abbreviations are as follows: BE = beach and estuary, FO = forest, HMG = habitat mosaic generalist, MS = marsh specialist, WG = wetland generalist, COGA = Common Gallinule, CLRA/KIRA = King/Clapper Rail, LEBI = Least Bittern, SESP = Seaside Sparrow, RWBL = Red-winged Blackbird.

3.1. Habitat Differences Between Created and Natural Marshes

Water levels varied among years and among sites. In general, natural marshes were flooded more often and at deeper levels than created sites, however, some created sites demonstrated high variability in water levels and flooding frequency (Figures 7, 8, and 9). Mean water levels were not statistically different between created and natural ($p > 0.05$) but standard deviation was significantly lower at created sites ($p < 0.001$). In 2021, the mean water depth at created sites was 13.4 cm (SD = 15.7 cm) and the mean at natural sites was 9.8 cm (SD = 7.8 cm). In 2022, the mean water depth at created sites was 5.2 cm (SD = 7.1 cm) and the mean at natural sites was 8.7 cm (SD = 8.3 cm). In 2023, the mean water depth at created sites was 7.6 cm (SD = 9.5 cm) and the mean at natural sites was 7.1 cm (SD = 8.6 cm). The maximum water depth of 73.5 cm was recorded at a created site in the Mississippi River Delta basin (Delta-1D).

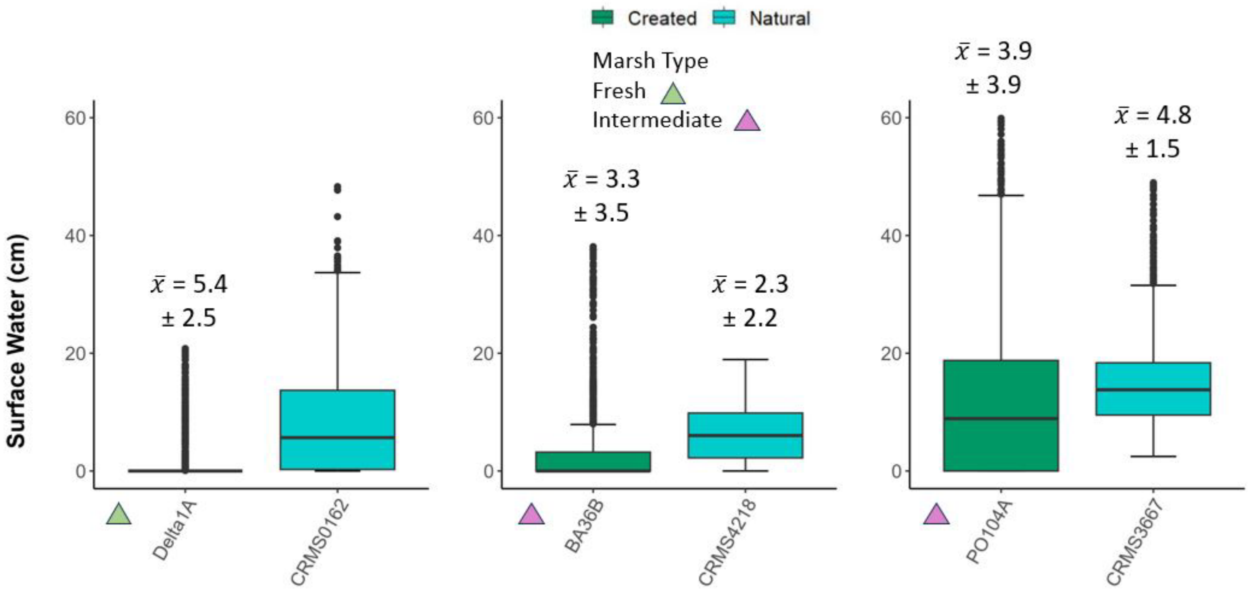


Figure 7. Comparison of mean water depths between created (green) and natural (blue) sites in 2021. Each created site is displayed adjacent to a companion nearest natural or reference site. Boxes represent the lower 25% and upper 75% quantiles, the black line in the middle of the box represents the median, whisker length represents 1.5 the length of the interquartile range, and black dots represent outliers. The numbers above each bar represent the number of average marsh specialist bird detections and standard deviation. Triangles represent the marsh type for each site. Bird data from CRMS0162 was incomplete from 2021.

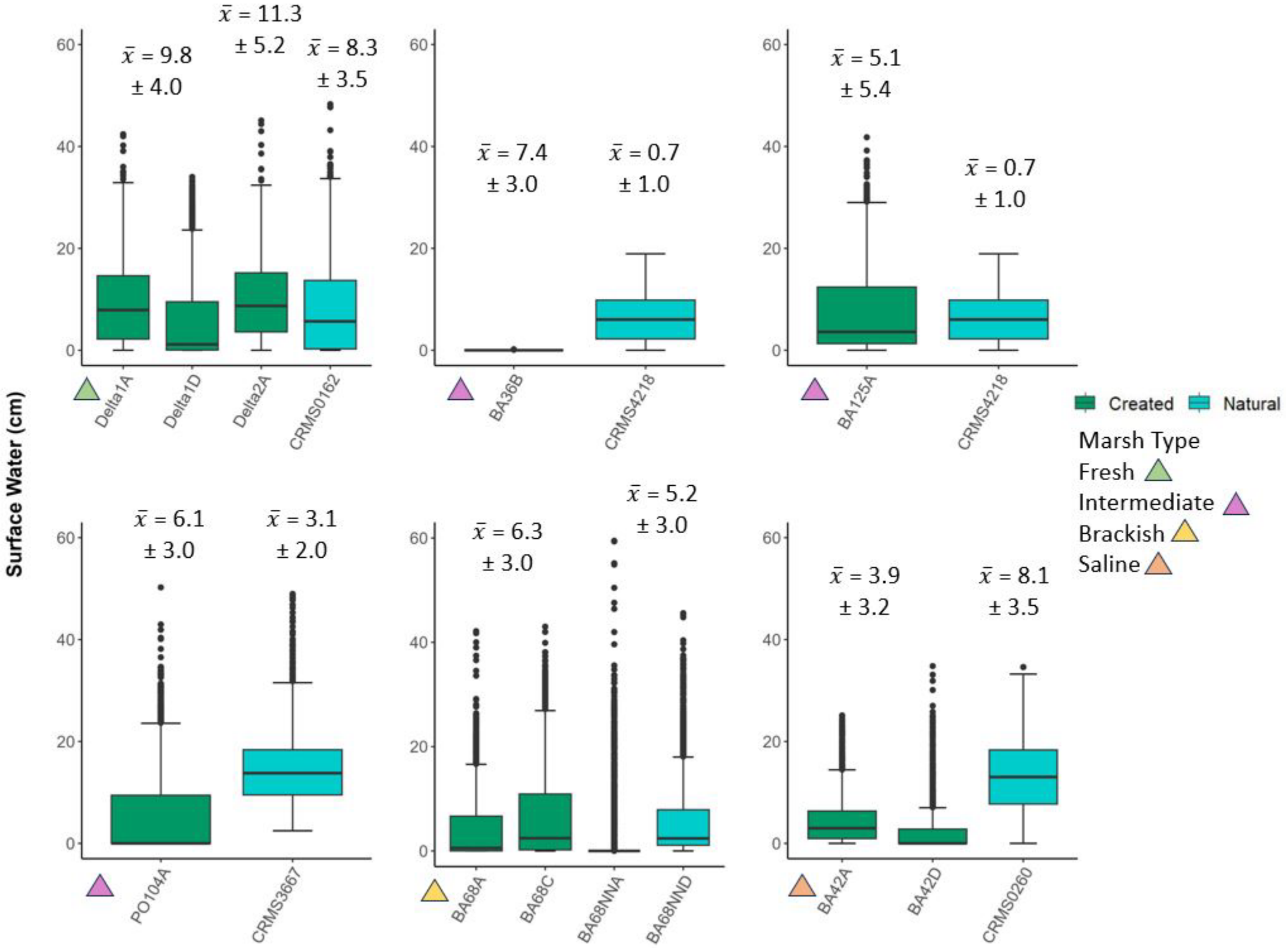


Figure 8. Comparison of mean water depths between created (green) and natural (blue) sites in 2022. Each created site is displayed adjacent to a companion nearest natural or reference site. Boxes represent the lower 25% and upper 75% quantiles, the black line in the middle of the box represents the median, whisker length represents 1.5 the length of the interquartile range, and black dots represent outliers. The numbers above each bar represent the number of average marsh specialist bird detections and standard deviation per site so sites with more than one water logger share a mean and SD. Triangles represent the marsh type for each site.

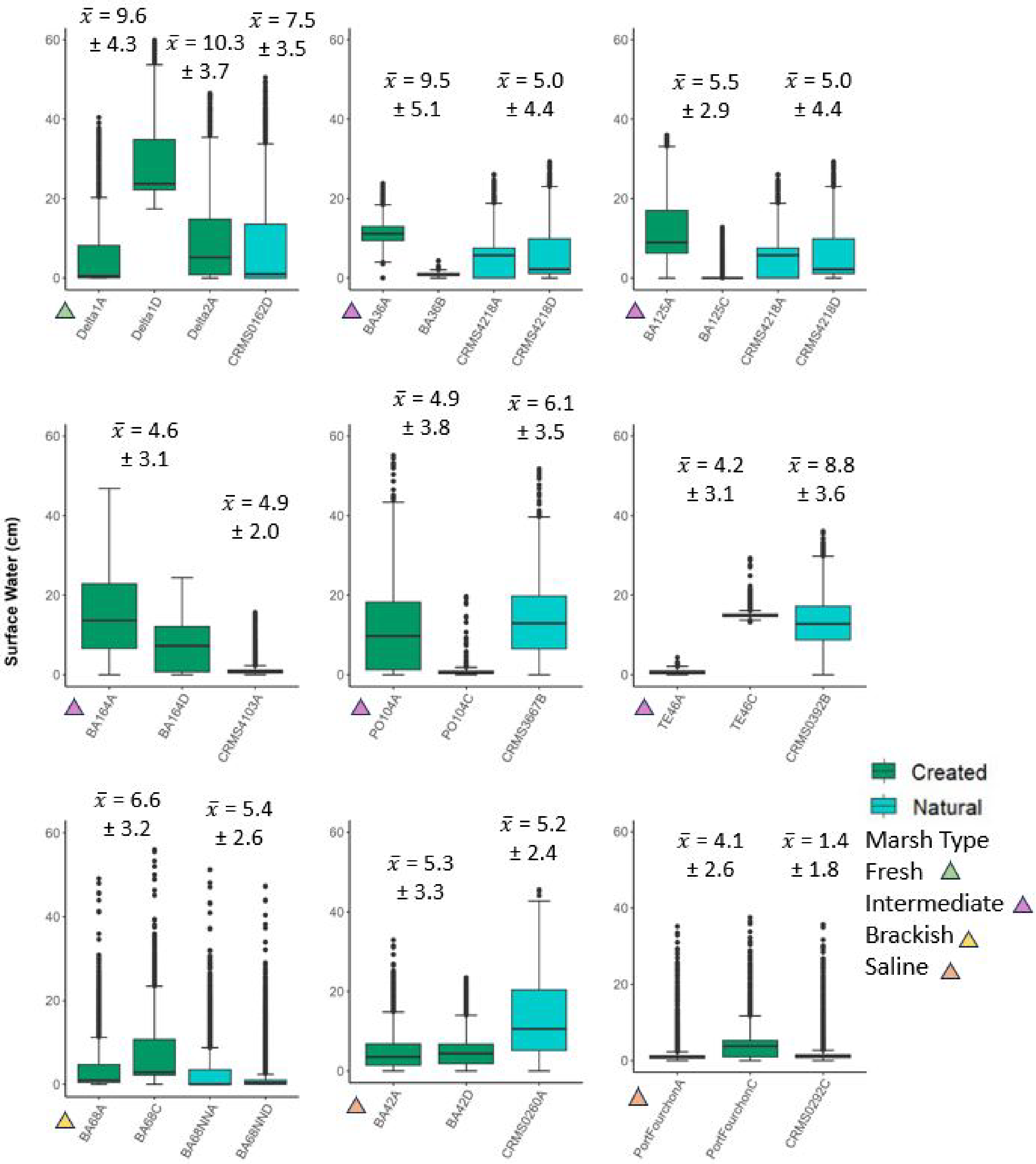


Figure 9. Comparison of water depths between created (green) and natural (blue) sites 2023. Each created site is displayed adjacent to a companion nearest natural or reference site. Boxes represent the lower 25% and upper 75% quantiles, the black line in the middle of the box represents the median, whisker length represents 1.5 the length of the interquartile range, and black dots represent outliers. The numbers above each bar represent the number of average marsh specialist bird detections and standard deviation per site so sites with more than one water logger share a mean and SD. Triangles represent the marsh type for each site.

Vegetation communities were also variable among created and natural sites ($p = 0.015$). Only one site (created) was classified as Typha, only one site (natural) was classified as Mangrove, and only one site (natural) was classified as Bulltongue. Bulrush, Brackish Mix, Three-square, Wiregrass, Oystergrass, and Roseau Cane were found both at created and natural sites (Figure 10).

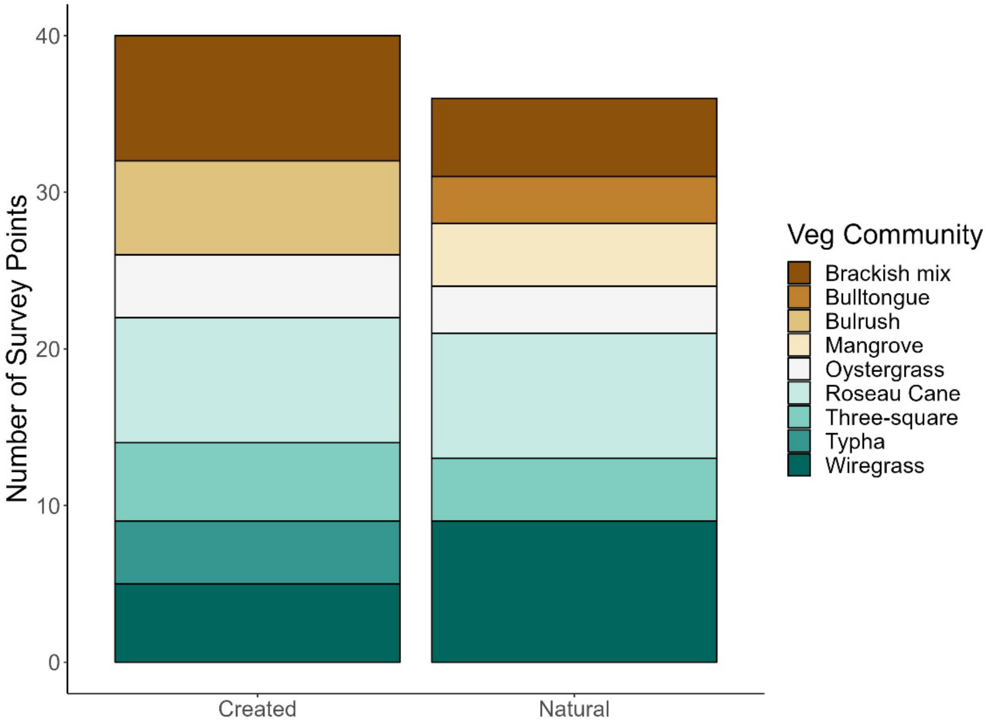


Figure 10. Number of survey points by vegetation classification for all created and natural marshes.

Overall, proportion of edge ranged from 0 to 0.26 with a mean of 0.1 (Figure 11). Proportion of edge at created sites ranged from 0 to 0.22 with a mean of 0.07 and at natural sites ranged from 0 to 0.26 with a mean of 0.14. I found there to be a significantly higher proportion of edge at natural marshes than created ($p < 0.001$; Figure 11).

Median spring NDWI ranged from -0.72 to 0.24 with a mean of -0.31 and was significantly higher at natural marshes than created marshes ($p < 0.001$; Figure 11). Median spring NDWI at created sites ranged from -0.72 to 0.18 with a mean of -0.39 and at natural sites ranged from -0.57 to 0.24 with a mean of -0.22.

Median spring NDVI ranged from 0.09 to 0.80 with a mean of 0.47 and was found to be significantly higher at created sites than natural sites ($p < 0.001$; Figure 11). Median spring NDVI at created sites ranged from 0.22 to 0.80 with a mean of 0.52 and at natural sites ranged from 0.09 to 0.70 with a mean of 0.42.

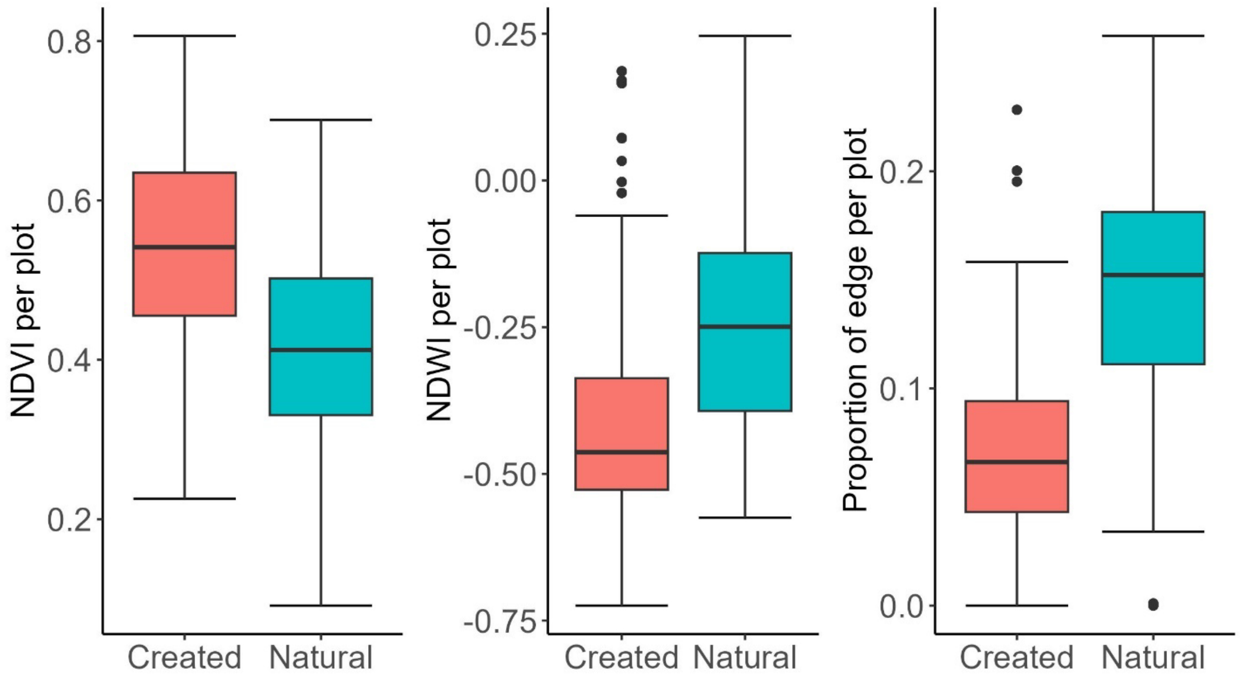


Figure 11. Comparison of median spring NDVI, median spring NDWI, and proportion of edge between created and natural sites across all years. Boxes represent the lower 25% and upper 75% quantiles, the black line in the middle of the box represents the median, whisker length represents 1.5 the length of the interquartile range, and black dots represent outliers.

3.2. Guild Habitat Associations

For all guilds, monthly water depth metrics had the greatest effect on abundance. Monthly standard deviation had the greatest effect on all guilds except for beach and estuary and wetland generalist, both of which were affected most by monthly minimum depth (Table 7). Marsh specialists were positively associated with monthly standard deviation while habitat mosaic generalists and forest species were negatively associated with it. Both beach and estuary and wetland generalist birds were negatively associated with monthly minimum depth.

There were two top competing models for the forest guild: the hydrology and the structure model (Table 8). After these models were combined, monthly water depth standard deviation and woody vegetation had a negative effect on forest guild abundance (Table 10, Figure 13). However, the 95% CRIs were overlapping each other for woody true and false, meaning they were not different from each other (Table 10). Proportion of edge, median spring NDVI, median spring NDWI, and water depth at time of survey had no effect on forest guild abundance (Table 10).

The top model for the habitat mosaic generalist was the structure model (Table 8). Spring median NDVI had a positive effect on the habitat mosaic guild abundance (Figure 14), while woody vegetation had a negative effect (Table 10). However, the 95% CRIs were overlapping with each other for woody true and false, meaning they did not differ from each other (Table 10). Proportion of edge had no effect on the abundance of this guild (Table 10).

There were three competing models for the wetland generalist guild: the hydrology, the combination, and the informed null model (Table 8). Water depth at survey had a negative effect on wetland guild abundance (Figure 14) while proportion of edge and spring median NDWI had no effect on abundance (Table 10). Vegetation classifications Bulrush, Mangrove, Oystergrass, and Three-square had a negative effect on wetland generalist abundance and all other vegetation communities had no effect on abundance (Figure 12, Table 10). All 95% CRIs were overlapping with each other, meaning that vegetation classifications were not different from each other (Figure 12, Table 10).

Table 7. AIC values for GLMs testing water depth variables for guilds. Bolded indicates the lowest AIC score and the corresponding water depth variable that was selected for each guild. Symbols (+/–) represent if each water depth variable was positively (+) or negatively (–) associated with each guild. *N* = abundance.

Model	**BE**	**FO**	**HMG**	**MS**	**WG**
N ~ Weekly Mean	820.0 –	685.2 +	1827.4 –	3351.3 +	1486.4 +
N ~ Weekly Median	820.2 –	683.5 +	1827.4 –	3352.2 +	1486.3 +
N ~ Weekly Maximum	814.0 +	649.6 –	1791.8 –	3305.1 +	1487.6 +
N ~ Weekly Minimum	809.5 –	668.8 +	1805.5 +	3340.7 –	1485.5 –
N ~ Weekly Standard Deviation	794.1 +	595.7 –	1804.1 –	3308.7 +	1481.8 +
N ~ Biweekly Mean	815.8 +	640.9 +	1797.6 –	3307.4 +	1454.6 –
N ~ Biweekly Median	815.0 +	640.8 +	1797.7 –	3309.3 +	1454.5 –
N ~ Biweekly Maximum	815.0 +	619.1 –	1756.5 –	3236.3 +	1453.6 +
N ~ Biweekly Minimum	810.7 –	624.0 +	1784.9 +	3297.4 –	1443.5 –
N ~ Biweekly Standard Deviation	802.0 +	563.0 –	1759.6 –	3203.0 +	1449.5 +
N ~ Monthly Mean	779.8 +	543.4 +	1715.9 –	3072.3 +	1343.9 –
N ~ Monthly Median	779.3 +	542.6 +	1716.0 –	3075.1 +	1344.1 –
N ~ Monthly Maximum	777.1 +	520.7 –	1667.8 –	3001.8 +	1344.2 +
N ~ Monthly Minimum	**774.1** –	526.9 +	1692.7 +	3068.8 –	**1333.6** –
N ~ Monthly Standard Deviation	777.6 +	**464.2** –	**1661.1 –**	**2969.6 +**	1342.1 +

The top model for the marsh specialist guild was the combination model (Table 8). Monthly water depth SD and vegetation classification had a positive effect on marsh specialist abundance, but proportion of edge had no effect on abundance of this guild (Figure 13, Table 10). When I ran the model with just *vegetation classification,* all vegetation types had a positive effect on guild abundance (Figure 12). However, most 95% CRIs were overlapping with each other, meaning that most vegetation communities were not different from each other (Figure 12, Table 10). Wiregrass was higher in guild abundance than Three-square or Bulrush but all other 95% CRIs were overlapping each other (Table 10).

Table 8. Model formulas for guild and focal species abundance and ΔELPD, SE ΔELPD, ELPD, and SEELPD values. Bold indicates the formulas that were within 4 ELPD of the best-fitting model. N = abundance, Type = created/natural, NDVI = median spring NDVI, NDWI = median spring NDWI, VegClass = vegetation classification, Woody = % woody vegetation in plot (>25% = true, <25% = false), WaterDepth = water depth at time of survey, Edge = proportion of edge within each plot, MonthlyMed = monthly median water depth, MonthlyMax = monthly maximum water depth, MonthlyMin = monthly minimum water depth, MonthlySD = monthly standard deviation of water depth, plot_id = random effect to account for variation in site and year.

Model	**ΔELPD**	**SE$_{\Delta ELPD}$**	**ELPD**	**SE$_{ELPD}$**
Beach and Estuary				
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	0.0	0.0	-220.56	27.07
N ~ Type + VegClass + (1|plot_id)	-1.12	5.27	-221.67	27.79
N ~ Type + Edge + VegClass + MonthlyMin + (1|plot_id)	-1.40	5.92	-221.96	27.88
N ~ Type + (1|plot_id)	-2.29	2.75	-222.85	27.22
N ~ Type + WaterDepth + NDWI + MonthlySD + (1|plot_id)	-3.15	3.36	-223.71	27.13
Forest				
N ~ Type + WaterDepth + NDWI + MonthlySD + (1|plot_id)	0.0	0.0	-198.86	22.27
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-3.76	5.79	-202.62	22.64
N ~ Type + Edge + VegClass + MonthlySD + (1|plot_id)	-4.90	6.84	-203.77	23.56
N ~ Type + (1|plot_id)	-5.12	4.63	-203.99	22.80
N ~ Type + VegClass + (1|plot_id)	-6.01	7.39	-204.88	23.61
Habitat Mosaic Generalist				
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	0.0	0.0	-669.16	22.51
N ~ Type + (1|plot_id)	-7.23	4.76	-676.39	23.15
N ~ Type + WaterDepth + NDWI + MonthlySD + (1|plot_id)	-7.73	4.35	-676.90	22.80
N ~ Type + Edge + VegClass + MonthlySD + (1|plot_id)	-9.53	4.79	-678.70	23.64
N ~ Type + VegClass + (1|plot_id)	-10.62	5.01	-679.79	23.87
Beach and Estuary				

Table Cont’d

Model	**ΔELPD**	$\mathbf{SE_{\Delta ELPD}}$	**ELPD**	$\mathbf{SE_{ELPD}}$
Marsh Specialist				
N ~ Type + Edge + VegClass + MonthlySD + (1|plot_id)	0.0	0.0	-1305.84	18.79
N ~ Type + WaterDepth + NDWI + MonthlySD + (1|plot_id)	-5.10	6.02	-1310.94	18.06
N ~ Type + VegClass + (1|plot_id)	-11.85	4.30	-1317.69	18.05
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-25.20	7.51	-1331.03	16.65
N ~ Type + (1|plot_id)	-25.31	7.62	-1331.15	16.55
Wetland Generalist				
N ~ Type + WaterDepth + NDWI + MonthlyMin + (1|plot_id)	0.0	0.0	-549.08	27.17
N ~ Type + Edge + VegClass + MonthlyMin + (1|plot_id)	-2.89	5.25	-551.97	27.26
N ~ Type + (1|plot_id)	-3.77	4.21	-552.85	27.64
N ~ Type + VegClass + (1|plot_id)	-5.14	5.70	-554.22	27.96
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-5.94	4.72	-555.02	27.90
Common Gallinule				
N ~ Type + Edge + VegClass + MonthlySD + (1|plot_id)	0.0	0.0	-642.37	24.35
N ~ Type + VegClass + (1|plot_id)	-1.74	2.26	-644.11	24.65
N ~ Type + WaterDepth + NDWI + MonthlySD + (1|plot_id)	-45.34	10.73	-687.71	23.85
N ~ Type + (1|plot_id)	-45.56	10.59	-687.93	23.98
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-46.34	10.51	-688.71	24.06
King/Clapper Rail				
N ~ Type + Edge + VegClass + MonthlySD + (1|plot_id)	0.0	0.0	-746.33	16.74
N ~ Type + VegClass + (1|plot_id)	-2.70	3.11	-749.03	16.37
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-7.64	5.37	-753.96	16.96
N ~ Type + WaterDepth + NDWI + MonthlySD + (1|plot_id)	-8.64	5.44	-754.97	16.41
N ~ Type + (1|plot_id)	-9.43	5.63	-755.76	16.36

Table Cont'd

Model	**ΔELPD**	**SE$_{ΔELPD}$**	**ELPD**	**SE$_{ELPD}$**
Least Bittern				
N ~ Type + Edge + VegClass + MonthlyMax + (1|plot_id)	0.0	0.0	-397.26	23.12
N ~ Type + WaterDepth + NDWI + MonthlyMax + (1|plot_id)	-4.76	5.33	-402.02	22.36
N ~ Type + VegClass + (1|plot_id)	-10.28	5.13	-407.54	22.98
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-13.32	7.21	-410.58	23.01
N ~ Type + (1|plot_id)	-14.03	6.58	-411.29	22.34
Seaside Sparrow				
N ~ Type + Edge + VegClass + MonthlyMed + (1|plot_id)	0.0	0.0	-338.96	28.60
N ~ Type + VegClass + (1|plot_id)	-1.38	3.04	-340.34	27.98
N ~ Type + (1|plot_id)	-7.31	10.62	-346.27	26.59
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-8.20	9.26	-347.16	27.19
N ~ Type + WaterDepth + NDWI + MonthlyMed + (1|plot_id)	-10.8	10.62	-349.76	27.19
Red-winged Blackbird				
N ~ Type + Edge + VegClass + MonthlySD + (1|plot_id)	0.0	0.0	-1278.07	31.99
N ~ Type + VegClass + (1|plot_id)	-5.44	4.50	-1283.50	34.27
N ~ Type + WaterDepth + NDWI + MonthlySD + (1|plot_id)	-6.06	6.26	-1284.12	32.69
N ~ Type + (1|plot_id)	-21.70	10.98	-1299.77	39.15
N ~ Type + Edge + Woody + NDVI + (1|plot_id)	-23.98	11.37	-1301.95	39.48

Table 9. Final model formula for each guild or focal species. *N* = abundance, *NDVI* = median spring NDVI, *NDWI* = median spring NDWI, *VegClass* = vegetation classification, *WaterDepth* = water depth at time of survey, *Edge* = proportion of edge within each plot, *Woody* = % woody vegetation in plot (>25% = true, <25% = false), *MonthlyMax* = monthly maximum water depth, *MonthlySD* = monthly standard deviation of water depth, *plot_id* = random effect to account for variation in site and year.

Guild or Species	**Final Model Formula**
Forest	$N \sim NDVI + NDWI + MonthlySD + WaterDepth + Edge + Woody + (1\|plot\_id)$
Habitat Mosaic Generalist	$N \sim NDVI + Edge + Woody + (1\|plot\_id)$
Marsh Specialist	$N \sim Edge + VegClass + MonthlySD + (1\|plot\_id)$
Wetland Generalist	$N \sim Edge + VegClass + MonthlyMin + WaterDepth + NDWI + (1\|plot\_id)$
Common Gallinule	$N \sim Edge + VegClass + MonthlySD + (1\|plot\_id)$
King/Clapper Rail	$N \sim Edge + VegClass + MonthlySD + (1\|plot\_id)$
Least Bittern	$N \sim Edge + VegClass + MonthlyMax + (1\|plot\_id)$
Seaside Sparrow	$N \sim Edge + VegClass + MonthlyMed + (1\|plot\_id)$
Red-winged Blackbird	$N \sim Edge + VegClass + MonthlySD + (1\|plot\_id)$

Table 10. Posterior estimate, standard deviation (SD), and 95% CRIs of model variables for each habitat guild. Bold indicates that the 95% CRIs does not overlap 0 and therefore, the variable has a significant effect on guild abundance.

Guild	**Variable**	**Estimate**	**SD**	**Lower 2.5%**	**Upper 97.5%**
Forest	NDVI	2.47	1.63	-0.66	5.80
	Woody: FALSE	-2.15	1.23	-4.70	0.09
	Woody: TRUE	**-2.92**	**1.22**	**-5.43**	**-0.71**
	Proportion of Edge	-4.93	4.12	-13.21	3.10
	Water Depth at Survey	-0.01	0.27	-0.55	0.49
	NDWI	-1.09	1.15	-3.53	1.04
	MonthlySD Water Depth	**-2.16**	**0.52**	**-3.24**	**-1.18**
Habitat Mosaic Generalist	**NDVI**	**4.30**	**0.64**	**3.04**	**5.56**
	Woody: FALSE	**-2.06**	**0.43**	**-2.91**	**-1.22**
	Woody: TRUE	**-2.30**	**0.43**	**-3.16**	**-1.46**
	Proportion of Edge	-0.86	1.47	-3.75	2.00
Wetland Generalist	Proportion of Edge	-0.13	1.89	-3.87	3.55
	Veg Class: Brackish Mix	-0.80	0.42	-1.63	0.03
	Veg Class: Bulltongue	-0.30	0.84	-1.90	1.37
	Veg Class: Bulrush	**-0.97**	**0.44**	**-1.84**	**-0.10**
	Veg Class: Mangrove	**-1.67**	**0.83**	**-3.43**	**-0.12**
	Veg Class: Oystergrass	**-1.30**	**0.44**	**-2.18**	**-0.45**
	Veg Class: Roseau Cane	-0.44	0.35	-1.12	0.25
	Veg Class: Three-Square	**-1.04**	**0.45**	**-1.94**	**-0.18**
	Veg Class: Typha	-0.41	0.52	-1.46	0.62
	Veg Class: Wiregrass	-0.02	0.40	-0.80	0.77
	MonthlyMin Water Depth	-0.20	0.11	-0.41	0.01
	Water Depth at Survey	**-0.42**	**0.16**	**-0.74**	**-0.11**
	NDWI	-0.63	0.55	-1.72	0.43
Marsh Specialist	Proportion of Edge	-1.08	0.62	-2.31	0.14
	Veg Class: Brackish Mix	**1.42**	**0.15**	**1.14**	**1.71**
	Veg Class: Bulltongue	**1.72**	**0.29**	**1.16**	**2.27**
	Veg Class: Bulrush	**1.24**	**0.15**	**0.95**	**1.52**
	Veg Class: Mangrove	0.32	0.31	-0.30	0.91
	Veg Class: Oystergrass	**1.51**	**0.14**	**1.23**	**1.78**
	Veg Class: Roseau Cane	**1.58**	**0.15**	**1.28**	**1.87**
	Veg Class: Three-Square	**1.29**	**0.14**	**1.01**	**1.55**
	Veg Class: Typha	**1.34**	**0.17**	**1.01**	**1.67**
	Veg Class: Wiregrass	**1.78**	**0.10**	**1.57**	**1.98**
	MonthlySD Water Depth	**0.38**	**0.09**	**0.20**	**0.56**

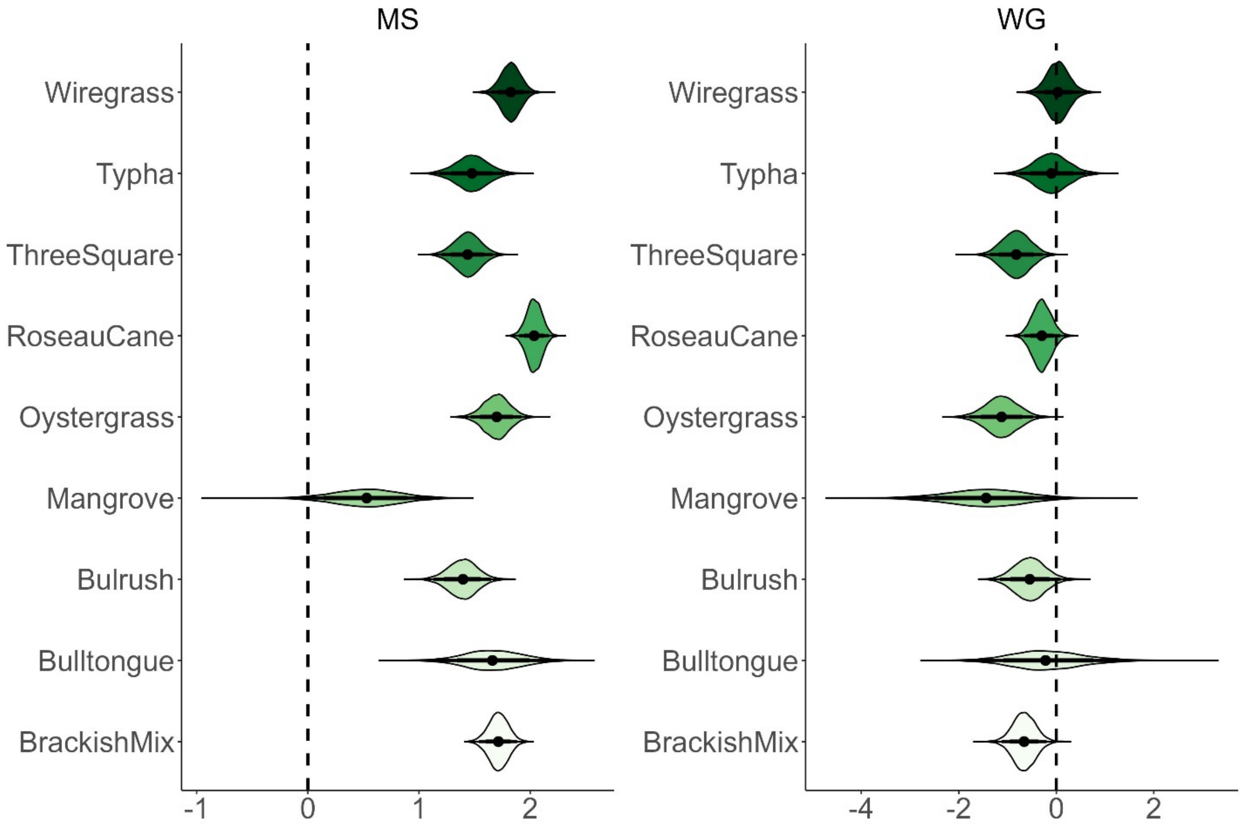


Figure 12. Posterior distributions of each vegetation classification for WG and MS guilds. Plots are of estimates from models run with just *vegetation classification*. The dotted line represents 0 and distributions that overlap 0 are not significant. Vegetation classification distributions that are above 0 positively affect guild abundance, while distributions below 0 negatively affected guild abundance.

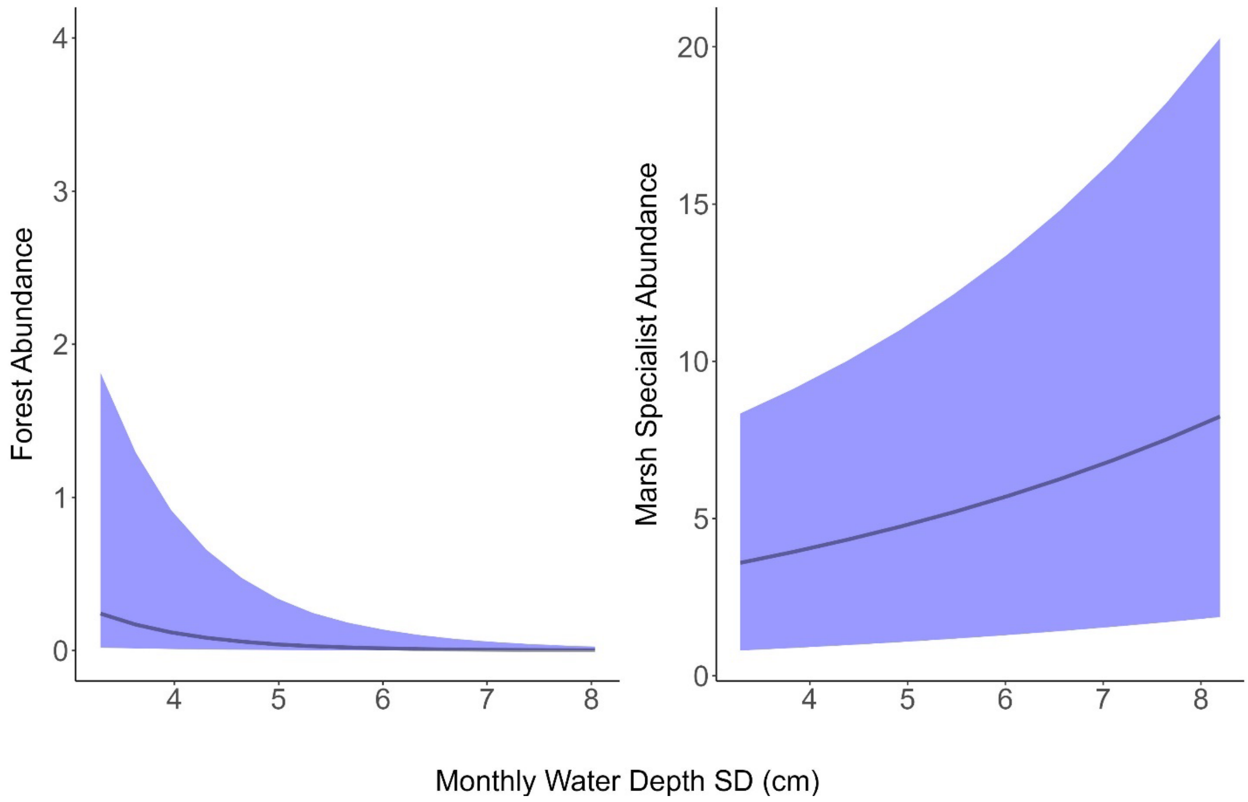


Figure 13. Effect of monthly water depth SD on guild abundance. Regression lines show the mean posterior estimates of each variable from the model and shaded areas depict the 95% CRIs of the posteriors.

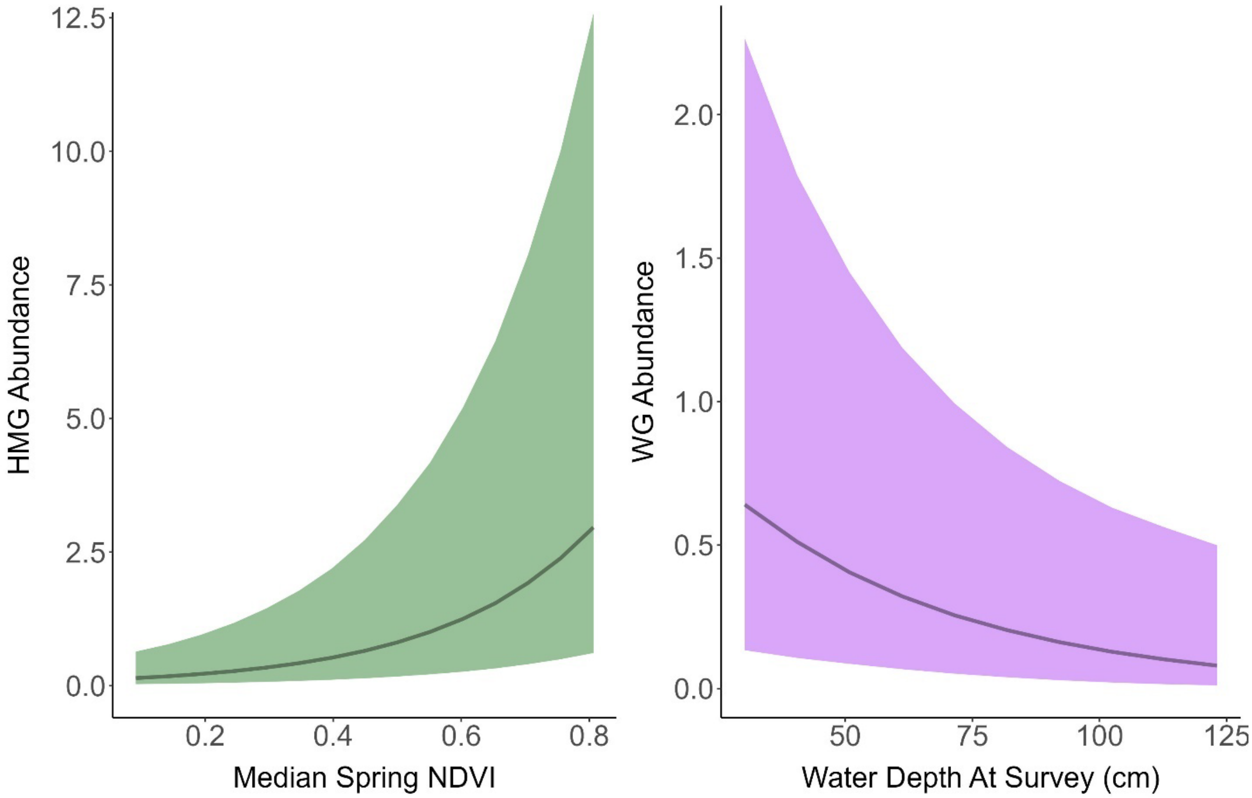


Figure 14. Effect of habitat variables on generalist species abundance. Regression lines show the mean posterior estimates of each variable from the model and shaded areas depict the 95% CRIs of the posteriors.

3.3. Focal Species Habitat Associations

For all guilds, monthly water depth metrics had the greatest effect on abundance (Table 11). Common Gallinules, King/Clapper Rails, and Red-winged Blackbirds were most positively associated with monthly standard deviation while Least Bitterns were positively associated with monthly maximum and Seaside Sparrows were positively associated with monthly median.

There were two top competing models for COGA: the combination model and the composition model (Table 8). Vegetation community and monthly water depth SD had a positive effect on COGA abundance (Figure 16, Table 12). Bulltongue, Roseau Cane, and Wiregrass had a positive effect on abundance while Brackish Mix, Bulrush, and Three-Square had a negative effect on abundance; Typha had no effect (Table 12). This held true when I ran the model with just *vegetation classification* (Figure 15). Wiregrass, Roseau Cane, Bulltongue had highly overlapping 95% CRIs meaning there is no difference between these vegetation communities (Figure 15, Table 12). Brackish Mix and Three-square did not have overlapping 95% CRIs, meaning that Brackish Mix had less of an effect on COGA abundance than Three-square, however, Bulrush had overlapping 95% CRIs with both Brackish Mix and Three-square (Figure 15, Table 12). Median spring NDVI and water depth at survey had no effect on COGA abundance (Table 12).

Table 11. AIC values for GLMs testing water depth variables for focal species. Bolded indicates the lowest AIC score and the corresponding water depth variable that was selected for each species. Symbols (+/–) represent if each water depth variable was positively (+) or negatively (–) associated with each species. *N* = abundance.

Model	**COGA**	**LEBI**	**CLRA/ KIRA**	**SESP**	**RWBL**
N ~ Weekly Mean	2217.5 –	902.2 +	1782.8 +	1192.6 +	4101.1 –
N ~ Weekly Median	2215.9 –	904.1 +	1784.4 +	1192.6 +	4100.7 –
N ~ Weekly Maximum	2229.2 +	898.5 +	1769.9 +	1172.8 +	4100.8 –
N ~ Weekly Minimum	2200.0 –	910.7 +	1786.0 +	1213.8 +	4116.0 –
N ~ Weekly Standard Deviation	2219.0 +	911.1 +	1767.0 +	1207.7 +	4113.4 –
N ~ Biweekly Mean	2194.8 –	886.9 +	1752.2 +	1185.4 +	3455.2 –
N ~ Biweekly Median	2197.0 –	886.2 +	1752.7 –	1191.0 +	3458.2 –
N ~ Biweekly Maximum	2162.9 +	880.7 +	1744.3 +	1182.8 +	3463.2 –
N ~ Biweekly Minimum	2174.0 –	901.3 +	1752.5 –	1203.5 +	3462.7 –
N ~ Biweekly Standard Deviation	2091.0 +	893.1 +	1741.1 +	1206.8 +	3444.8 +
N ~ Monthly Mean	2047.0 –	843.2 +	1637.6 +	1129.5 +	3276.7 –
N ~ Monthly Median	2044.7 –	848.1 +	1638.2 +	**1129.2** +	3277.1 –
N ~ Monthly Maximum	1985.0 +	**835.3** +	1633.3 +	1136.3 +	3275.3 +
N ~ Monthly Minimum	2031.4 –	863.5 +	1637.7 –	1143.4 +	3280.4 +
N ~ Monthly Standard Deviation	**1891.5 +**	850.9 +	**1632.5 +**	1145.1 –	**3258.7 +**

There were two top competing models for CLRA/KIRA: the combination model and the composition model (Table 8). Vegetation classification had the greatest effect on CLRA/KIRA abundance (Figure 15). Brackish Mix and Oystergrass had a positive effect on CLRA/KIRA abundance while Wiregrass had a negative effect (Table 12). All other vegetation classifications had no effect on CLRA/KIRA abundance (Table 12). This held true when I ran the model with just *vegetation classification* (Figure 15). Brackish Mix and Oystergrass had overlapping 95% CRIs, meaning there were no differences between those two vegetation communities (Figure 15, Table 12). Proportion of edge and monthly water depth SD had no effect on CLRA/KIRA abundance (Table 12).

The top model for LEBI was the combination model (Table 8). Monthly maximum water depth had a positive effect on abundance (Figure 16, Table 12). Brackish Mix, Bulrush, Oystergrass, Roseau Cane, Three-square, Typha, and Wiregrass all had a negative effect on LEBI abundance while Bulltongue had no effect (Figure 15, Table 12). However, all 95% CRIs were overlapping, meaning that no vegetation classification had a more negative effect than another (Figure 15, Table 12). Proportion of edge had no effect on LEBI abundance (Table 12).

There were two top competing models for SESP: the combination model and the composition model (Table 8). Vegetation classifications Bulltongue, Mangrove, Roseau Cane, Three-square, and Wiregrass had a negative effect on SESP abundance, while all other vegetation classifications had no effect (Figure 15, Table 12). All 95% CRIs were overlapping with each other, meaning there was no difference between vegetation classifications (Figure 15, Table 12).

Proportion of edge and monthly median water depth also had no effect on abundance of this species (Table 12).

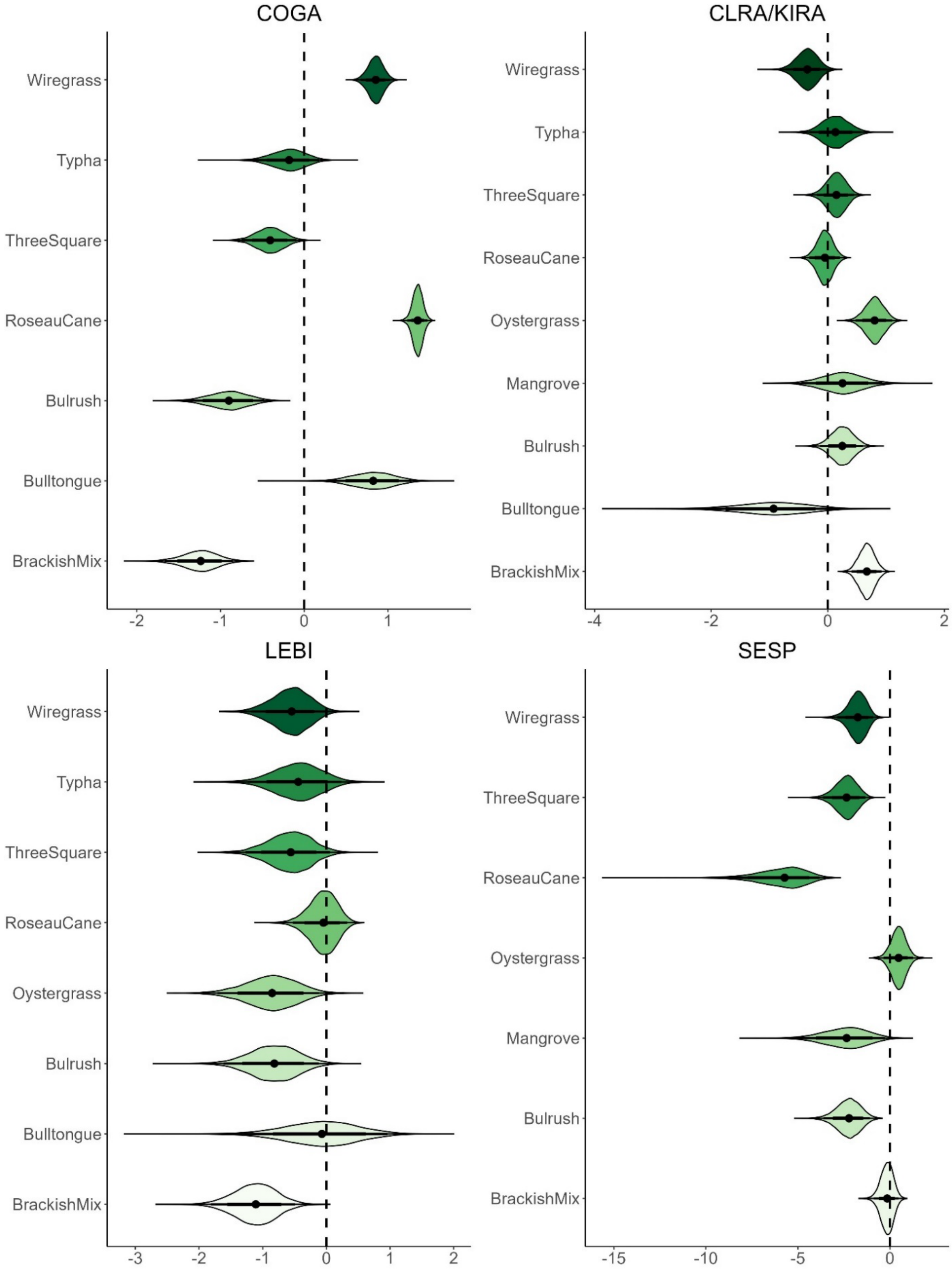
The top model for RWBL was the combination model (Table 8). All vegetation classifications had a positive effect on RWBL abundance, however, many 95% CRIs were overlapping with each other (Figure 15, Table 12). Bulltongue, Typha, and Wiregrass had higher abundances of RWBL than Brackish Mix (Table 12). Bulltongue and Wiregrass had higher abundances than Oystergrass and Typha (Table 12). Water depth monthly SD had a positive effect on abundance while proportion of edge had a negative effect on abundance (Figure 17, Table 12).

Table 12. Posterior estimate, standard deviation and 95% CRIs of model parameters for each focal species. Bold indicates that the 95% CRIs does not overlap 0 and therefore, the parameter has a significant effect on bird abundance.

Focal Species	**Variable**	**Estimate**	**SD**	**Lower 2.5%**	**Upper 97.5%**
Common Gallinule	Proportion of Edge	-0.59	0.83	-2.28	1.02
	Veg Class: Brackish Mix	**-1.48**	**0.26**	**-2.01**	**-0.97**
	Veg Class: Bulltongue	**0.82**	**0.30**	**0.22**	**1.41**
	Veg Class: Bulrush	**-1.01**	**0.26**	**-1.55**	**-0.54**
	Veg Class: Roseau Cane	**1.00**	**0.20**	**0.59**	**1.40**
	Veg Class: Three-Square	**-0.52**	**0.20**	**-0.93**	**-0.13**
	Veg Class: Typha	-0.30	0.23	-0.77	0.14
	Veg Class: Wiregrass	**0.79**	**0.12**	**0.54**	**1.03**
	MonthlySD Water Depth	**0.28**	**0.13**	**0.03**	**0.53**
King/Clapper Rail	Proportion of Edge	-0.32	0.95	-2.20	1.56
	Veg Class: Brackish Mix	**0.45**	**0.22**	**0.02**	**0.87**
	Veg Class: Bulltongue	-0.99	0.65	-2.37	0.19
	Veg Class: Bulrush	0.15	0.21	-0.27	0.56
	Veg Class: Mangrove	0.11	0.36	-0.62	0.81
	Veg Class: Oystergrass	**0.65**	**0.20**	**0.26**	**1.03**
	Veg Class: Roseau Cane	-0.37	0.24	-0.84	0.10
	Veg Class: Three-Square	0.03	0.20	-0.38	0.41
	Veg Class: Typha	0.03	0.25	-0.47	0.52
	Veg Class: Wiregrass	**-0.41**	**0.20**	**-0.81**	**-0.02**
	MonthlySD Water Depth	0.24	0.14	-0.03	0.51
Least Bittern	Proportion of Edge	0.47	1.58	-2.58	3.57
	Veg Class: Brackish Mix	**-2.20**	**0.50**	**-3.23**	**-1.25**
	Veg Class: Bulltongue	-0.60	0.65	-1.94	0.60
	Veg Class: Bulrush	**-1.47**	**0.42**	**-2.33**	**-0.70**
	Veg Class: Oystergrass	**-1.84**	**0.50**	**-2.86**	**-0.90**
	Veg Class: Roseau Cane	**-1.23**	**0.40**	**-2.04**	**-0.48**
	Veg Class: Three-Square	**-1.49**	**0.44**	**-2.39**	**-0.65**

Table Cont'd

Focal Species	**Variable**	**Estimate**	**SD**	**Lower 2.5%**	**Upper 97.5%**
Least Bittern	**Veg Class: Typha**	**-1.42**	**0.49**	**-2.42**	**-0.48**
	Veg Class: Wiregrass	**-1.37**	**0.40**	**-2.21**	**-0.62**
	MonthlyMax Water Depth	**0.84**	**0.21**	**0.43**	**1.27**
Seaside Sparrow	Proportion of Edge	3.16	2.70	-2.09	8.57
	Veg Class: Brackish Mix	-0.67	0.51	-1.73	0.26
	Veg Class: Bulltongue	**-2.56**	**0.67**	**-3.97**	**-1.34**
	Veg Class: Mangrove	**-2.60**	**1.21**	**-5.24**	**-0.41**
	Veg Class: Oystergrass	-0.03	0.47	-0.98	0.87
	Veg Class: Roseau Cane	**-6.28**	**1.37**	**-9.46**	**-4.14**
	Veg Class: Three-Square	**-2.82**	**0.66**	**-4.22**	**-1.63**
	Veg Class: Wiregrass	**-2.29**	**0.59**	**-3.53**	**-1.22**
	MonthlyMed Water Depth	0.25	0.23	-0.19	0.70
Red-winged Blackbird	**Proportion of Edge**	**-2.20**	**0.71**	**-3.59**	**-0.80**
	Veg Class: Brackish Mix	**0.99**	**0.17**	**0.67**	**1.33**
	Veg Class: Bulltongue	**2.15**	**0.31**	**1.54**	**2.76**
	Veg Class: Bulrush	**1.11**	**0.15**	**0.80**	**1.41**
	Veg Class: Mangrove	**1.05**	**0.28**	**0.50**	**1.62**
	Veg Class: Oystergrass	**1.05**	**0.16**	**0.74**	**1.36**
	Veg Class: Roseau Cane	**1.42**	**0.18**	**1.06**	**1.78**
	Veg Class: Three-Square	**1.57**	**0.14**	**1.29**	**1.85**
	Veg Class: Typha	**1.69**	**0.18**	**1.34**	**2.03**
	Veg Class: Wiregrass	**1.77**	**0.12**	**1.53**	**2.00**
	MonthlySD Water Depth	**0.37**	**0.11**	**0.16**	**0.59**



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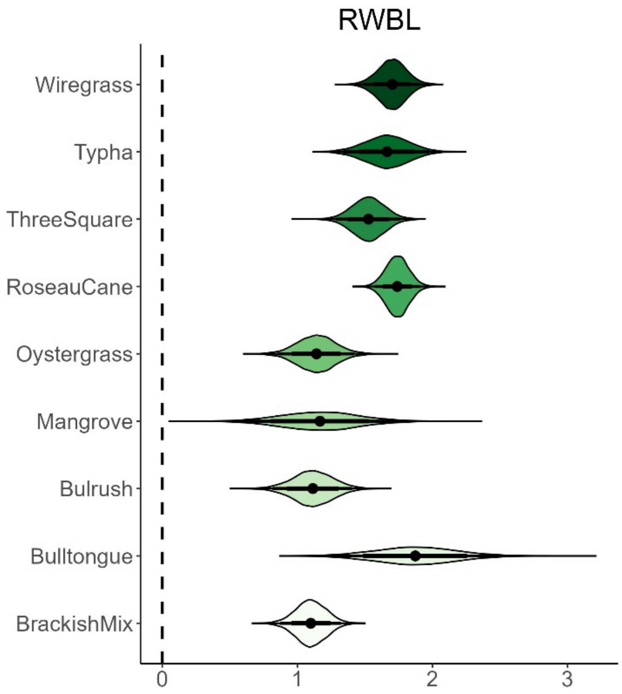

Figure 15. Posterior distributions of the effect of each vegetation classification for focal species. Plots are of estimates from models run with just *vegetation classification*. The dotted line represents 0 and distributions that 95% CRIs overlap 0 are not significant. Vegetation classification distributions that are above 0 positively affect abundance of focal species, while distributions below 0 negatively affect abundance of focal species.

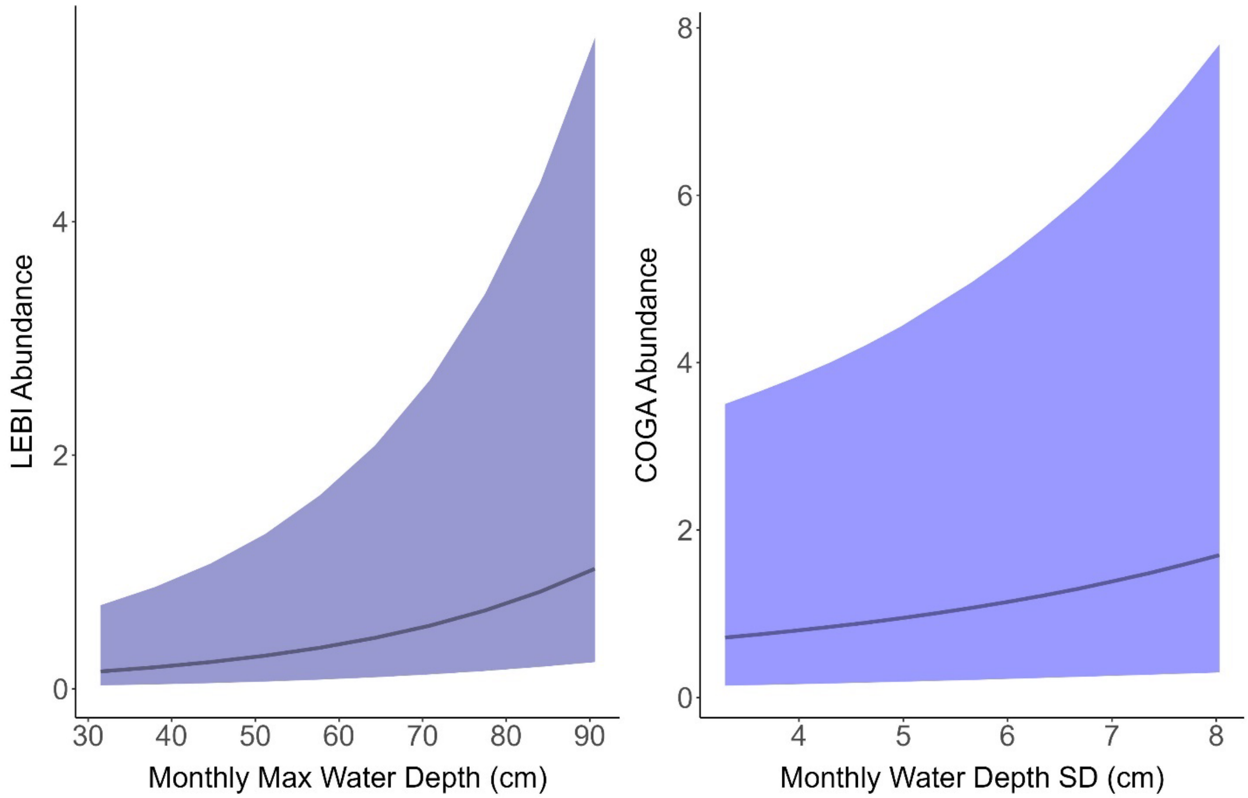

Figure 16. Effect of water depth variables on LEBI and COGA abundance. Regression lines show the mean posterior estimates of each parameter from the model and shaded areas depict the 95% CRIs of the posteriors.

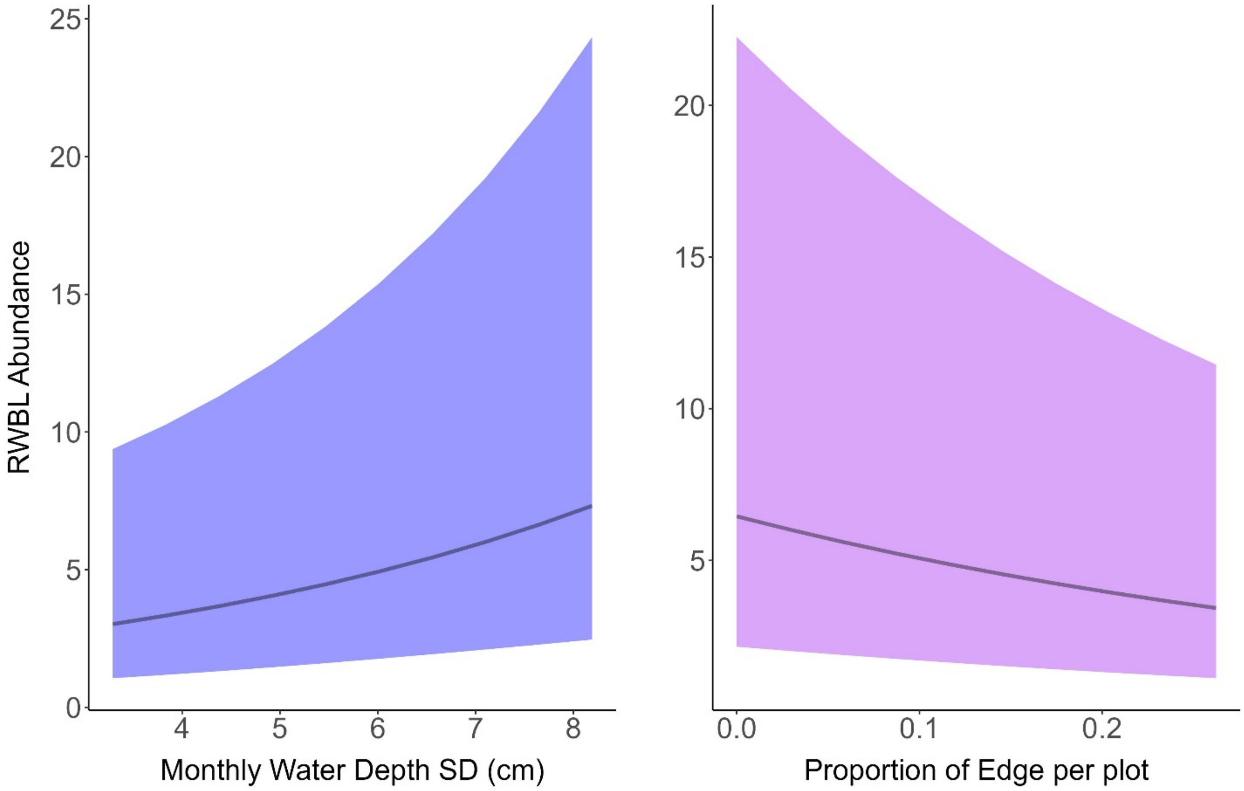

Figure 17. Effects of water depth monthly SD and proportion of edge on RWBL abundance. Regression lines show the mean posterior estimates of each parameter from the model and shaded areas depict the 95% CRIs of the posteriors.

4. DISCUSSION

The results of my study indicate that hydrologic variation, vegetation communities, and/or vegetation structure are the drivers of avian abundance regardless of whether a marsh is created or natural. For example, TE-46 is a created site where two of the survey points were never flooded during my study and this site supported the lowest abundances of marsh birds than any other site in the study. In contrast, natural marsh CRMS0292 had a mean water level of 1-2 cm and supported fewer marsh birds than all created sites. Globally, created marshes support less bird diversity and abundance than natural marshes (Melvin & Webb, 1998; Darnell & Smith, 2004; Desrochers et al., 2008b; Sebastián-González & Green, 2016; Giosa et al., 2018), however, this was not the case for my study. My results indicated that created marshes can support high abundances of wetland-dependent birds, provided that sites are designed to support guild-specific water depths and vegetation communities.

The lack of differences in avian abundance among created versus natural marshes in coastal Louisiana may be due to wide variation in vegetation composition, vegetation structure, and hydrologic characteristics among and within created and natural sites. Few created sites supported a dynamic hydrologic regime. In general, created sites were characterized as having similar mean water levels but lower variability (SD) and NDWI when compared to natural sites. Low NDWI may indicate the absence of open water areas such as shallow water ponds and tidal creeks. These features can be important for suitable bird habitat but are often not considered in the marsh design process. Additionally, created sites had higher NDVI but lower proportions of edge than natural sites, indicating a denser vegetation community and possibly the absence of mudflats and open water areas. Despite these differences, where vegetation occurred, vegetation composition was similar between created and natural sites.

Site specific differences in bird communities were driven by site-specific differences in habitat composition, structure, and hydrology. Created sites that were designed for wildlife habitat, such as the sites on Delta National Wildlife Refuge, hosted the highest abundances of marsh birds. These sites supported dynamic hydrologic regimes promoted by the project design, which included tidal creeks and shallow water areas, and the location along the Mississippi River. Natural marshes also vary in their value to marsh bird species, which could be due to high variation in hydrologic characteristics, vegetation communities and subsidence rates. For marsh creation sites to support more diverse bird communities a focus on habitat features is valuable. Habitat features drive the value of marsh landscapes for marsh birds, therefore, incorporating these features into marsh restoration and creation plans would provide benefits in supporting these bird communities.

Characterizing site-specific hydrologic and vegetation characteristics enabled an in-depth analysis of how these abiotic variables affect marsh bird abundance. Site-specific hydrologic characteristics were important drivers of marsh bird abundance with more variation resulting in higher bird abundances. Water depths play a crucial role in marsh bird abundance (Timmermans et al., 2008; Baschuk et al., 2012), however, few studies investigate bird responses to hydroperiod and instead focus on static water depths. Pickens and King (2014a) found that long-term hydrologic metrics were better predictors of bird abundance than instantaneous water depths. Similarly, my results show that many marsh bird species selected sites that have more dynamic hydrologic regimes as water depth monthly SD was positively associated with abundance of most guild and focal species. Monthly SD is a measure of variability in water depths, as sites with higher monthly SD will have greater fluctuations in water levels and more dramatic flooding and drying events. While varying water depths are important, the mean that these depths fluctuate around also affects marsh bird presence, because deeper water excludes certain species (Norazlimi & Ramli, 2015), and plots that had a mean depth of 4 – 8 cm and a SD ranging from 0 – 50 cm supported the highest abundances of birds. My results also showed that wetland generalist abundance was highest when water levels were around 25 cm but decreased significantly at deeper depths. This guild consisted mostly of waterfowl and wading bird species, and these results further support the importance of shallow water areas for these species (Erwin, 1996; Lantz et al., 2011). Conversely, LEBI abundance increased with increasing monthly maximum water depth, which is not surprising as this species is associated with minimum depths of 20-30 cm (Chabot et al., 2014; Pickens & King, 2014a). LEBI were abundant at plots with maximum water depths of 30 cm and had high abundances in plots with maximum depths of 50 – 75 cm. However, prolonged flooding at deeper levels can be detrimental to nest success of many marsh bird species (Baiser et al., 2008; Rush et al., 2010; Clauser, 2015) and future studies should investigate if nest success differs with varying water level regimes.

Marsh birds may be selecting for sites that are characterized by fluctuating water levels because of the vegetation community that these flooding regimes support. Variability in water levels will favor some types of wetland vegetation communities over others, as plant species are adapted to different frequency and depths of flooding (Gathman et al., 2005). Many emergent species are adapted to withstand flooding, but very few can withstand prolonged flooding at deep levels (Stagg et al., 2021). Some emergent plant species require drawdown in order to regenerate (Van der Valk, 1998), however, where there is prolonged drawdown or no flooding, emergent vegetation will be outcompeted by woody or upland plants (Elsey-Quirk et al., 2009). Many woody species are not adapted to withstand deep and prolonged flooding (Toner & Keddy, 1997), which may be why forest guild abundance decreased with increasing monthly water depth SD. While I did not find that woody vegetation played a significant role in marsh bird habitat selection, studies in other ecological systems found that marsh birds are negatively associated with increasing woody vegetation due to the potential increase in mammalian and aerial predators (Winstead & King, 2006; Budd & Krementz, 2010; Pickens & King, 2012). Restoration sites with dynamic flooding regimes will decrease woody encroachment and promote vegetation communities that are crucial to marsh birds as they rely on them for foraging strategies, nesting material, and cover (Hunter et al., 2016; Hart et al., 2021; Malone et al., 2021).

Roseau Cane, which is the common name for Louisiana’s native *Phragmites* sp., was valuable for COGA, wetland generalist, and marsh specialist abundance. In North America, A European lineage of *Phragmites* often creates a dense monoculture habitat that negatively impacts marsh bird abundance (Benoit & Askins, 1999; Schummer et al., 2012; Robichaud & Rooney, 2017). However, in Louisiana, Roseau Cane generally is either the Delta lineage or the Gulf/Land lineage (Knight et al., 2018), which have occurred in coastal Louisiana since at least 1900 when Phragmites was not included in a list of exotic species (Lloyd & Tracy, 1901). Phragmites communities that I studied were often characterized as having deep and shallow water areas that support submerged and floating aquatic vegetation, an important aspect of marsh bird foraging and nesting behavior (Figures 18 and 19). Roseau Cane stands in Louisiana may function structurally similar to cattail stands where COGA use dead vegetation to form their nests (Post & Seals, 2000). In the Mobile-Tensaw Delta in Alabama, COGA, KIRA, and LEBI also use *Phragmites* extensively (Rush et al., 2019). In short, Roseau Cane habitats that I studied were interspersed with shallow, vegetated and open water areas, and can provide for all foraging, nesting, and cover needs of marsh bird species.

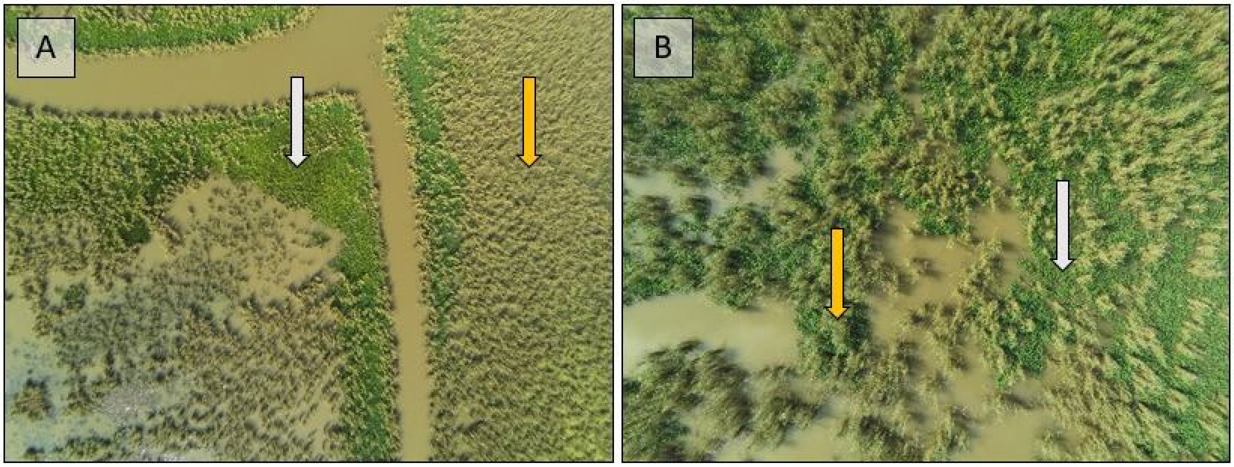

Figure 18. Aerial photos of plots classified as Roseau Cane habitat. Orange arrows indicate lighter gray/green vegetation, which is *Phragmites* sp. and white arrows indicate darker/greener vegetation, which is short herbaceous vegetation and floating aquatic vegetation.

Sites in the MRD supported the highest abundances of marsh birds, emphasizing the importance of this area for bird habitat conservation in Louisiana's coastal marshes. These sites all supported dynamic hydrologic regimes and some of the highest water depth monthly SDs, which could be due to the influence of the Mississippi River. Additionally, Roseau Cane communities occur in high concentrations at the mouth of the Mississippi River, another key component in this area providing suitable habitat for marsh birds. Roseau Cane is considered the backbone of the delta marshes and it comprises tens of thousands of hectares in the Mississippi Delta (*Invasive Pest May Not Be Only Cause of Recent Louisiana Marsh Die-off | U.S. Geological Survey*, n.d.). Roseau Cane protects against coastal erosion since it can survive in deeper water where emergent vegetation cannot establish and because of its strong rhizomes which can secure fine sediments that are deposited by the river (Rooth & Stevenson, 2000; Knight et al., 2018). Since 2016, there has been a Roseau Cane die-back in Louisiana, which is thought to be caused by an invasive scale called *Nipponaclerda biwakoensis* (Knight et al., 2018) and restoration efforts are still being investigated. Roseau Cane restoration will protect the Mississippi River Delta and also provide high-quality habitat to many marsh bird species.

Figure 19. On the ground photos of Roseau Cane habitat in the Mississippi River Delta: a) a Roseau Cane stand surrounded by floating aquatic vegetation (water hyacinth; *Eichhornia crassipes*) and b) a Roseau Cane stand with other emerent vegetation forming an understory including elephant ear (*Colocasia esculenta*) and alligator weed (*Alternanthera philoxeroides*).

In addition to the importance of Roseau Cane communities, the results of my study revealed other interesting conclusions based on vegetation composition. Numerous studies have documented the use of *Typha* sp. by marsh birds including LEBI and COGA (Valente et al., 2011; Malone et al., 2021; Chabot et al., 2014), however, my results showed a negative association for both of these species. *Typha* sp. thrives in areas where there is constant deeper flooding, and in some systems create a dense monoculture where it outcompetes emergent plants (Boyd, 1958; S. Li et al., 2004), which is more characteristic of my study plots classified as Typha (Figures 20 and 21). The Typha plots that I studied had no areas of open water and had a higher mean water depth than other more productive sites (mean = 15.36 cm, SD = 10.25 cm). My results also indicated LEBI and COGA were negatively associated with Bulrush habitats, however, about half of the plots classified as Bulrush also supported high amounts of woody vegetation, which many marsh birds select against. Additionally, two of the Bulrush plots had no flooding at all during my study, explaining the absence of species that require shallow and deeper water habitats and emphasizing the importance of not generalizing about the value of vegetation communities without consideration of hydrologic processes. Surprisingly, LEBI had no positive associations with any vegetation community, but several recent studies have suggested that LEBI may be more habitat generalist than previously thought, however, they still require some emergent vegetation structure to be present (Valente et al., 2011; Rush et al., 2019).

Typha and Bulrush habitats did not support high numbers of marsh birds in our study due to the habitat structure and lack of other important habitat features such as open water areas at these plots.

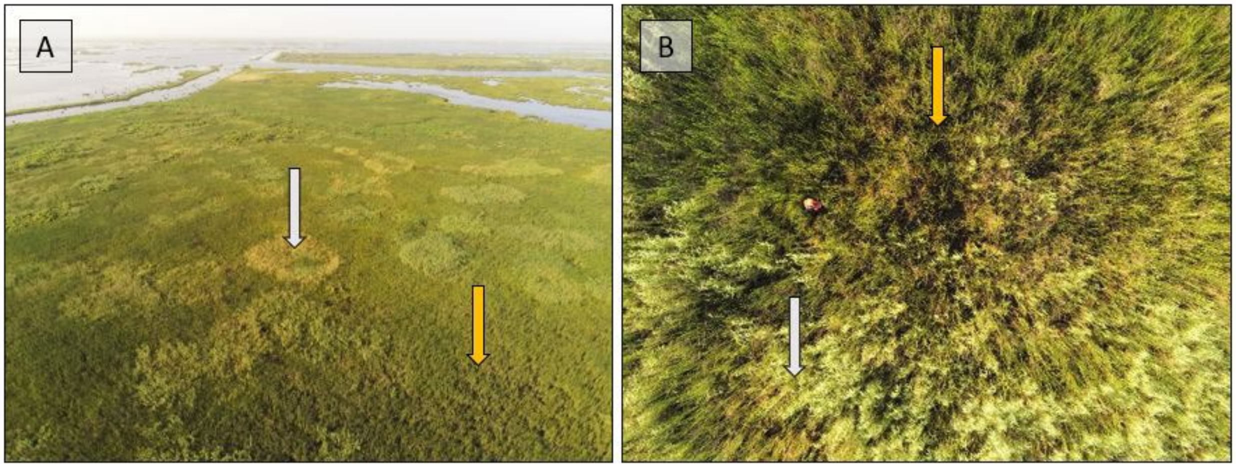

Figure 20. Aerial photos of plots classified as Typha habitat: a) photo of the entire site and b) close up of survey plot classified as Typha. Orange arrows represent darker areas which are *Typha* sp. and white arrows represent lighter patches which are *Phragmites* sp.

Figure 21. On the ground views of plots classified as Typha habitat.

Many marsh bird species are grassland specialists and therefore grass-dominated marsh systems provide essential habitat. Many of the grass-dominated vegetation communities such as Wiregrass, Three-square, Oystergrass and Brackish Mix had high abundances of wetland generalist and marsh specialists, including COGA, KIRA/CLRA and SESP. SESP are grassland specialists most commonly found in *S. alterniflora* dominated marshes (Brawley et al., 1998; Woolfenden, 2019; Byerly et al., 2020). In most coastal systems they are a species of conservation concern, mostly because of the loss of salt marsh systems. My study found that CLRA/KIRA were most abundant in Oystergrass and Brackish Mix communities, both of which are found in higher salinities. However, this may be a bias of lumping the two species, as I detected many more CLRA/KIRA in more saline marshes and CLRA are considered saltmarsh (grassland) specialists (Meanley & Wetherbee, 1962). My study supports Pickens and King (2013) finding of KIRA not selecting for *S. patens* habitats as I found a negative association with KIRA/CLRA abundance and Wiregrass communities dominated by *S. patens*. Wiregrass plots in my study were characterized by thick clumps of *S. patens* often surrounded by flooded and ponded areas, which may not be ideal for KIRA/CLRA nesting and cover, however, plots varied widely (Figure 22). Based on my observations in the field, I think CLRA/KIRA may be selecting sites based more on vegetation structure than the specific type of community. I often observed them in areas that had shorter, dense vegetation that they used for cover, including but not limited to swamp lily (*Crinum americanum*), seaside goldenrod (*Solidago sempervirens*), marshhay cordgrass (*Spartina patens*), smooth cordgrass (*Spartina alterniflora*), three-square (*Schoenoplectus americanus*), and leafy three-square (*Bolboschoenus robustus*). Future studies should investigate how vegetation structure affects CLRA/KIRA abundance. These results show that vegetation community type plays an important role in marsh bird abundance, however, it is more nuanced than just building a marsh with a certain vegetation community. Water levels, amount of open water areas, and edge habitat will also affect if and how a site will be used by marsh birds.

Edge habitats are essential for marsh specialist birds as they can support submerged and floating aquatic vegetation and are important for foraging (O'Connell & Nyman, 2010; Bolenbaugh et al., 2011; Alexander & Hepp, 2014; Patton et al., 2020). While wetland generalist abundance did increase with higher proportions of edge, it was not a significant driver of any of my focal species. This is surprising as edge habitat and marshes with a high degree of interspersion between open water and emergent vegetation have been found to be extremely important for many marsh bird species (Rehm & Baldassarre, 2007; Alexander & Hepp, 2014; Pickens & King, 2014a). It may be that the proportion of edge at the plot level was not representative of the amount of edge of the entire site. My study design precluded multi-scale habitat evaluations because my points were spaced as close at 250 m apart, however, future studies may benefit from assessing edge habitat at multiple spatial scales (King et al., 2010; Pickens & King, 2012, 2014a; Jedlikowski et al., 2016). Additionally, edge averaged 10% of my study plots with only 3 out of the 76 survey points >50% water but other studies that detected effects of edge in coastal Louisiana had differing amounts of edge. O'Connell and Nyman (2010) detected edge effects in plots that averaged 10% edge versus 35% edge, but those plots were dominated by open water rather than emergent vegetation as mine were. Likewise, Patten et al. (2020) detected edge effects on birds in plots that were designed to be 50% edge. Future studies should investigate the land to water ratio within a larger spatial area, as some sites may be surrounded by open water and isolated from larger tracts of contiguous marsh.

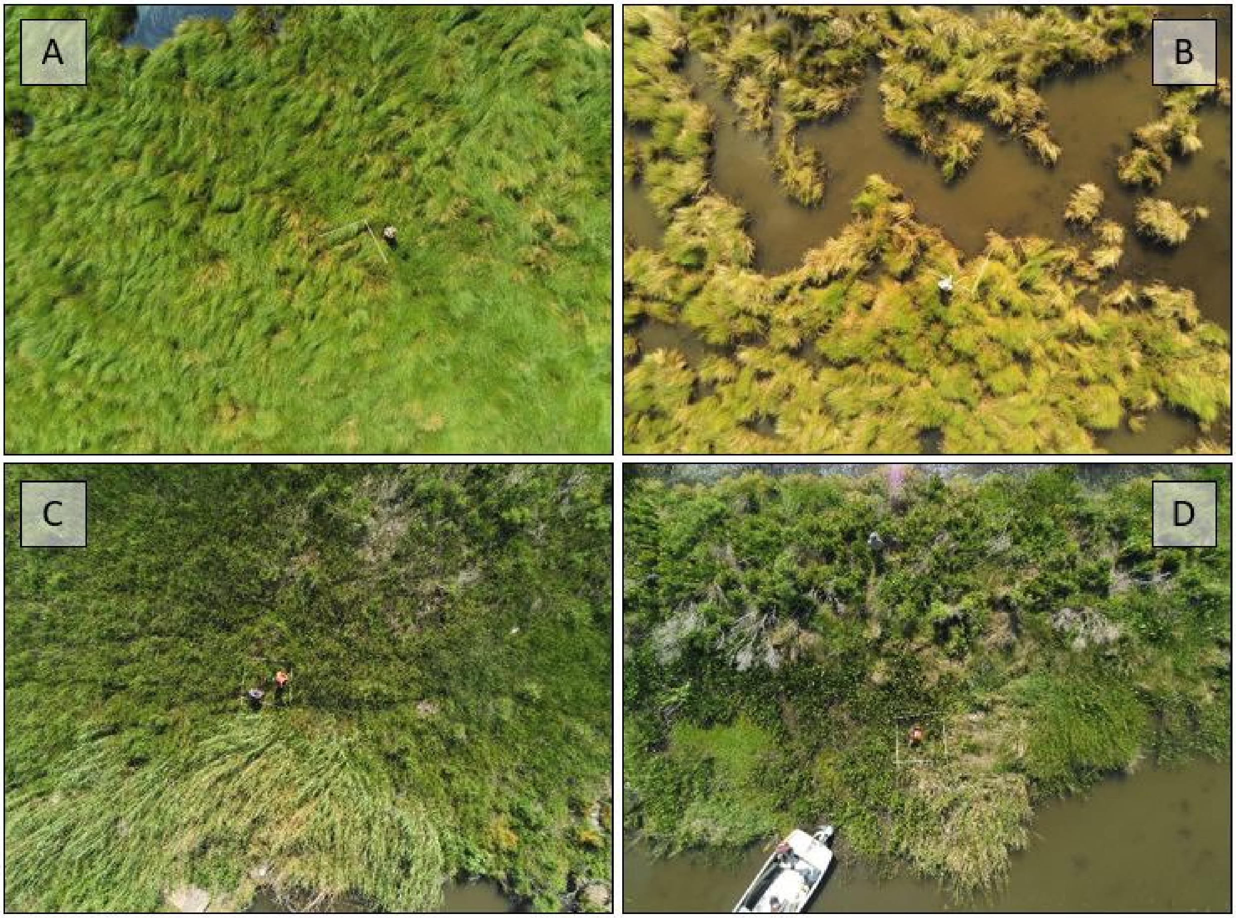

Figure 22. Aerial photos of plots classified as Wiregrass habitat. Person with PVC in the center of the photos represent survey point location: A) and B) are plots at natural sites characterized by clumps of *S. patens* surrounded by ponds or flooded areas and C) and D) are plots at created sites dominated by *S. patens* but also contain many other species including woody plants.

Another reason that edge habitat was not important in my models may be because edge does not have a linear relationship with bird abundance. After graphing my detections with proportion of edge, a trendline revealed that the relationship with edge is not linear (Figure 23). For marsh specialists and CLRA/KIRA, abundance increases when proportion of edge is around 0.1 but starts to decrease around 0.2, indicating that there may be a "sweet spot" for amount of edge within the range of proportion of edge that I observed.

My study found that created marsh sites have significantly lower proportions of edge than natural marshes. In fact, many created sites do not reach the optimal range (0.1 – 0.2 per plot) while many natural marshes fall just in the optimal range. However, some natural marshes are well above 0.2, which is where marsh bird abundance starts to decline. It seems that high amounts of edge compared to contiguous marsh may be representative of degraded natural marsh and therefore support fewer marsh birds. Conversely, some created sites may support fewer species because of extremely low amounts of edge habitat. It is difficult to assess edge proportions on the ground, but aerial photography can assist in the determination of appropriate amounts of edge

(Figures 24 and 25). Managers could increase edge habitat at restoration sites with the inclusion of tidal creeks and ponds as well as the shape of the restoration/creation design.

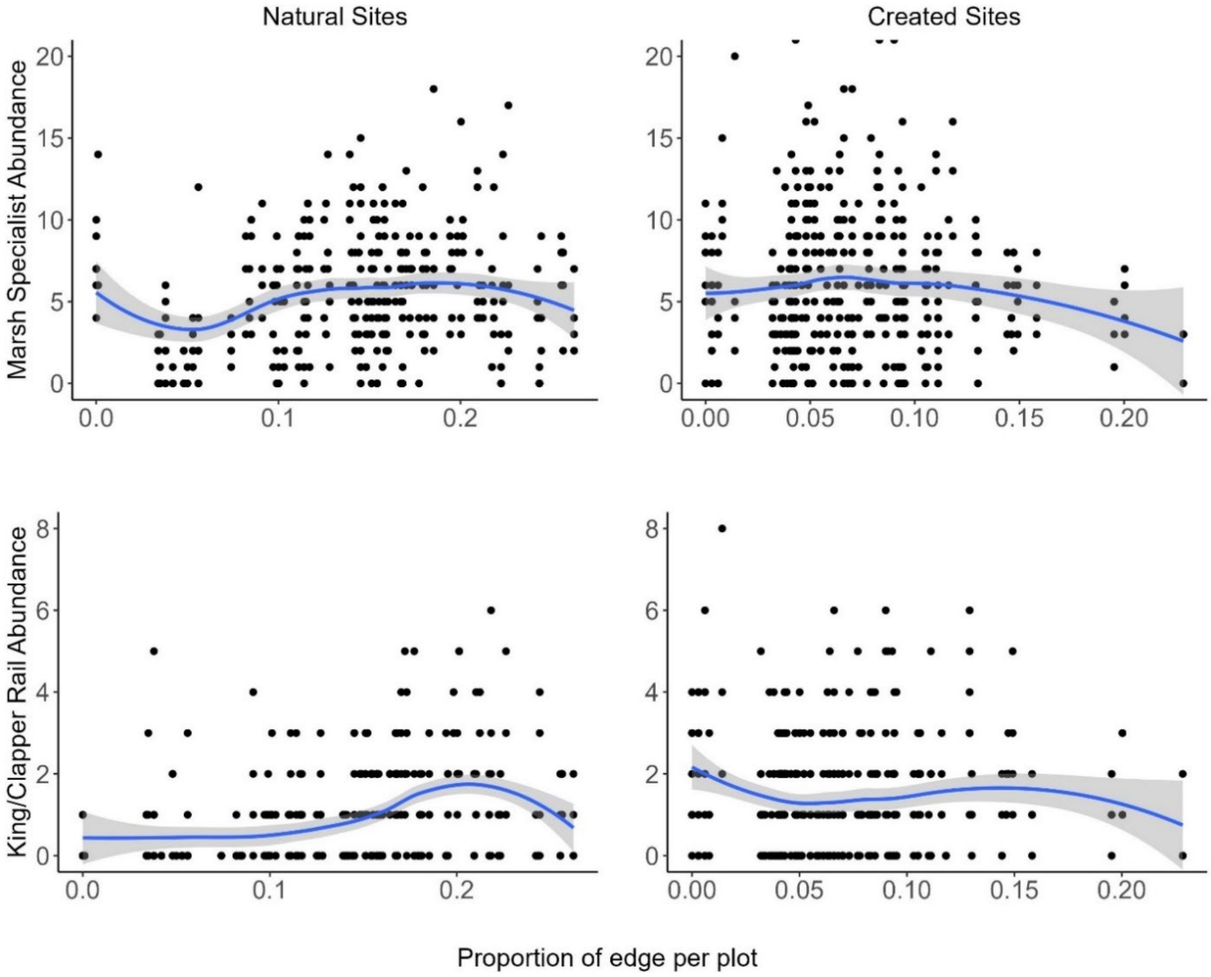

Figure 23. Detections of marsh specialist and King/Clapper Rails per plot with proportion of edge per plot. Each black dot represents a survey. The blue line is a trendline of the data and the shaded areas are 95% confidence intervals.

There is evidence that suggests that created marshes may serve as refugia for marsh species during extreme climactic events such as hurricanes and tropical storms. In August 2021, hurricane Ida made landfall as a category 4 storm in southeast Louisiana. The eye passed closely to one of my study sites and my entire study area was affected by the storm. Although I was unable to quantify the impacts of the hurricane on marsh habitat and bird abundance, I believe that it plays a role. In 2022, I saw a decrease in bird detections overall, but many more birds were detected at created marsh sites in that year than at natural sites. Some of the nearest natural sites lost large amounts of land from the storm, while created marsh sites seemed to remain fully intact (Figure 26). Created marshes may not only provide habitat for birds with increased land loss but may be less susceptible to events such as hurricane Ida. Future studies should investigate if restored and natural marsh sites respond differently to different disturbance events, such as hurricanes and tropical storms.

Figure 24. Created site BA-68 (right) and nearest natural site (left) are examples of a created site with an average proportion of edge (0.11) within the optimal range of 0.1—0.2 and a natural site with a higher average proportion of edge (0.2) than the optimal range.

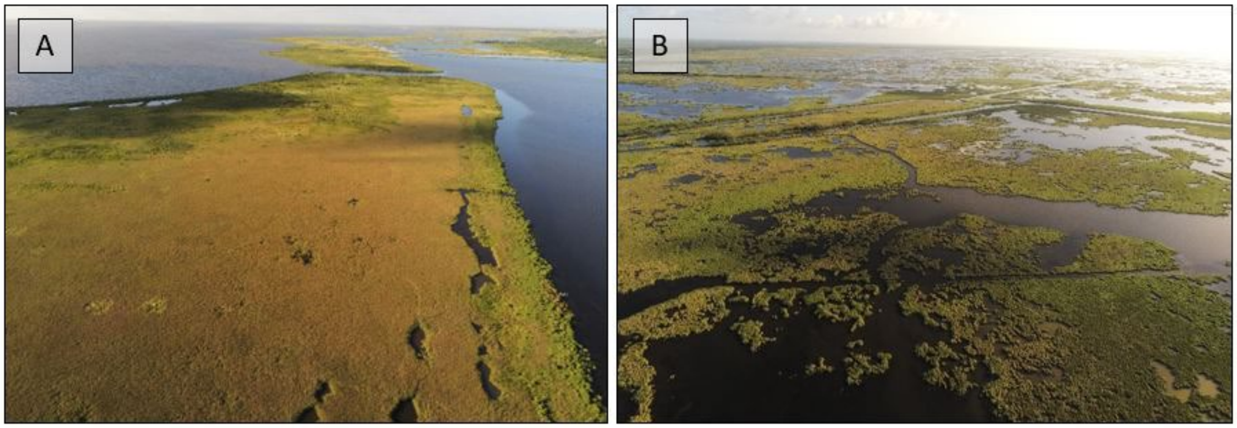

Figure 25. A) example of a created site (TE-46) with a lower proportion of edge (0.05) than the optimal range of 0.1—0.2 and B) the nearest natural site (CRMS0392) with a proportion of edge within the optimal range (0.14).

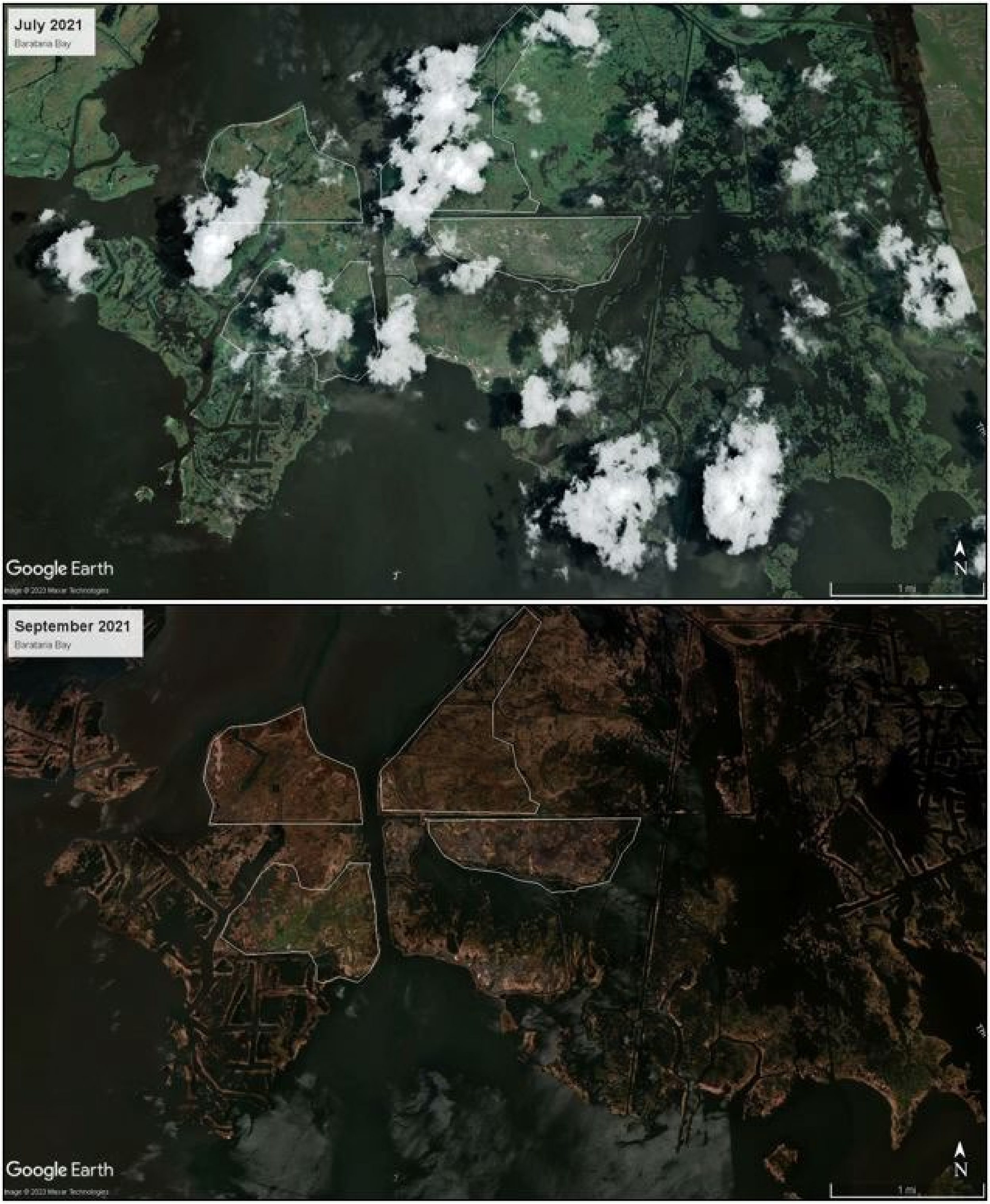

Figure 26. Aerial imagery of created and natural sites in Barataria Bay before and after hurricane Ida in August 2021. White outlines represent created sites and everything else is considered natural marsh.

4.1. Conclusions and Management Implications

I detected birds, including marsh specialist species, at all created sites, indicating that if you build it, they will indeed come. However, some of the sites I surveyed had much higher abundances of marsh birds, demonstrating that there are specific habitat features that are more suitable for marsh birds such as edge habitat, certain vegetation communities, and hydrologic variability. With increased land loss and decline of marsh birds, it is still important that created sites provide suitable habitat for these species.

Ideally, created marshes will be built within the tidal range to allow vertical accretion to keep up with natural subsidence and sea level rise (Craft et al., 1993; Orson et al., 1998). This also allows for frequent shallow flooding, which will promote the hydrologic and vegetation features that are beneficial to bird communities. Marshes above the tidal range will not be able to naturally accrete as periodic flooding allows for sediment deposition and accumulation of organic matter from emergent vegetation, therefore there is a narrow range that is optimal for marsh elevation (Jarvis, 2010). Additionally, vertical accretion may not be able to offset high subsidence rates in some areas (DeLaune et al., 1983). Designing marshes is extremely complex, especially in microtidal systems where 30 centimeters can make a substantial difference (Byerly et al., 2020). Whiskey Island, a barrier island restoration project built within the tidal range, allowing for flooding and establishment of emergent vegetation provided much better habitat for marsh birds than nearby Raccoon Island, which was built higher than the tidal range and supported a more upland vegetation community (Byerly et al., 2020). Because marshes built below the tidal range will quickly convert back to open water, most sites are originally built high, so that they will settle within the tidal range 5-10 years after construction thus avoiding wasting valuable resources on short-term sites, but this is not the case for Raccoon Island (Byerly et al., 2020). Similarly, my study did not see any distinguishable differences between sites due to age and several of my sites that were 10+ years old had high areas that were infrequently flooded, indicating that sites may not subside as fast as previously thought. While created sites may subside over a longer period of time, it seems that the initial settling period has a much greater impact on when a marsh creation site will experience shallow flooding, allowing for emergent vegetation communities to keep up with subsidence and sea level rise by natural vertical accretion.

In addition to building sites within the tidal range, the inclusion of certain habitat features can promote hydrologic connectivity which supports a diversity of marsh bird species. Several studies have found that inclusion of tidal canals and ponds on restored sites help create habitat heterogeneity and hydrologic connectivity (Minello et al., 1994; Boyer & Zedler, 1999; Byerly et al., 2020). Creating tidal creeks and ponds also allows for an increase in edge habitat, which created marshes in Louisiana are lacking. One created site at Big Branch NWR included ponds connected to tidal creeks to promote water exchange and this site hosted a high abundance of marsh birds. Additionally, the sites in Delta NWR were built with a finger design, which is where several strips of land are built with water in between, increasing both edge habitat and shallow water areas. These sites are extremely productive marsh systems, and this design could promote marsh bird habitat in future restoration projects. Moreover, design features that promote hydrologic connectivity and edge habitat will also benefit other important species of fish and wildlife that rely on coastal marsh systems.

It is possible that unconfined sites have better tidal exchange, thus creating more suitable habitat for marsh birds by providing flooded areas and emergent vegetation communities. Most of my study sites were built confined and because of this, I was not able to fully investigate any differences. However, three of the created sites I studied were built unconfined or semi-confined (containment berm only on one side of the site) and these sites had some of the most dynamic hydrologic regimes and highest abundances of marsh birds. Unconfined or semi-confined sites seemed to promote hydrologic connectivity and more dynamic flooding regimes; however, this should be investigated further.

My study emphasizes the importance of monitoring wildlife use of marsh creation sites to inform future restoration decisions. My results also show that a multi-faceted approach is needed for monitoring and design as hydrology, vegetation composition, and vegetation structure all play an important role in creating suitable habitat for marsh birds. Monitoring can be cost, time, and labor intensive, especially when considering fine-scale characteristics such as vegetation and hourly water data, but the costs may be worth it if expensive marsh creation projects can be improved. Collecting long-term water data on created sites informs whether sites are settling within the tidal range and if water levels are promoting emergent vegetation communities. My hourly water depth data over several years represents one of the most temporally and spatially rich dataset for water levels and hydroperiods of created marsh sites in Louisiana. While this method can be data intensive it is an efficient way to collect valuable water data. While I had difficulty with on-the-ground vegetation surveys, especially in natural marshes where I was not able to walk or boat across an entire survey plot, using drones to survey inaccessible areas was very beneficial to my study. However, one third of my sites were located on federal land and therefore the use of drones was not permitted. I was also limited by cost and model of the drone and had several drones malfunction and crash into the water, never to be recovered. Additionally, I did not take drone images with enough overlap to do any in depth vegetation analysis, but when done correctly, this method could be extremely useful to monitoring marsh creation sites. Remote sensing is also a beneficial method for remotely collecting important data, but resolution can be limiting. This study is one of the first to connect physical processes, such as hydrology, to vegetation and wildlife responses on created marsh sites in Louisiana and these types of studies must persist to inform and improve future restoration.

Engineering a marsh is extremely difficult and more work is needed on bridging the gap between abiotic and biotic processes and engineering design and construction. Engineered marshes can support high numbers of all guilds and focal species but my results also indicate that designs can be inadequate. However, sites that were designed to benefit wetland wildlife supported high numbers of birds, indicating that some marsh creation designs are more suitable for marsh bird species. With such extreme amounts of land loss, the main priority becomes the restoration of land without consideration for ecological function including wildlife habitat. In the attempt to build back a disappearing coastal zone, we must consider impacts to wildlife, as wildlife conservation is a crucial piece of restoration that will protect and benefit coastal communities.

APPENDIX A

Table A.1. Bird species that were changed from Partners in Flight database classification based on local knowledge of how they use habitat in Louisiana.

Species	PIF Classification	Updated Classification
Roseate Spoonbill	Coasts: Mangroves	Wetlands Generalist
Red-breasted Merganser	Coasts: Marine Water	Wetlands Generalist
Indigo Bunting	Forests: Temperate Eastern	Habitat Mosaic Generalist
Painted Bunting	Forests: Temperate Eastern	Habitat Mosaic Generalist
Orchard Oriole	Forests: Temperate Eastern	Habitat Mosaic Generalist
Black Tern	Ocean: Pelagic	Marsh Specialist
Red-winged Blackbird	Open Country: Habitat Mosaic	Wetlands Generalist
Wood Duck	Wetlands: Forested	Wetlands Generalist
American Coot	Wetlands: Lakes and Rivers	Wetlands Generalist
Osprey	Wetlands: Lakes and Rivers	Wetlands Generalist
Ring-billed Gull	Wetlands: Lakes and Rivers	Wetlands Generalist
Blue-winged Teal	Wetlands: Seasonally Wet Grasslands	Wetlands Generalist
Sedge Wren	Wetlands: Seasonally Wet Grasslands	Wetlands Generalist

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VITA

Aylett Lipford was born in Richmond, Virginia where she grew up camping, hunting, fishing, birding, and kayaking with her family. This sparked her interest in wildlife conservation and led her to pursue a B.S. in Wildlife Conservation at Virginia Tech. During her undergraduate, Aylett was active in several different labs and pursued an undergraduate research project on flying squirrels. She also had the opportunity to spend a semester helping with a research project studying lemur behavior and population genetics in Madagascar. Her love for coastal systems began as a kid while spending time on the Eastern Shore of Virginia and further developed while working for the Virginia Tech Shorebird Program. After graduating in 2018, she worked field jobs for several years, including surveying for birds and banding owls in Idaho, studying Appalachian Cottontails in North Carolina, and mist netting for bats in Virginia. Aylett spent two more seasons on the Eastern Shore of Virginia working for The Nature Conservancy monitoring beach nesting birds. She enjoyed all the places and species that she had the opportunity to work with, but her main interests remained in coastal ecosystems, which led her to pursue her M.S. in the School of Renewable Natural Resources at Louisiana State University. In May 2024, she plans to receive her M.S. in Wildlife Conservation. After graduation, Aylett plans to continue working in the conservation, management, and restoration of coastal systems.