Fall migrant waterbird community structure and stable isotope ecology in the Mississippi Alluvial Valley and northern Gulf of Mexico: use of Migratory Bird Habitat Initiative sites and other wetlands

By

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A Dissertation
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Doctor of Philosophy
in Forest Resources
in the Department of Wildlife, Fisheries and Aquaculture

Mississippi State, Mississippi

December 2016

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The Mississippi Alluvial Valley (MAV) was dominated by extensive lowland forests, but during the 20th century, most of the MAV was converted to agricultural, aquaculture, and other human uses. These land-use changes created stop-over migration and wintering habitats for waterfowl, shorebirds and other waterbird species. Before landscape modification of the MAV, shorebirds likely migrated past the MAV to wetlands along the northern Gulf of Mexico (NGoM). In 2010, the Deepwater Horizon oil spill impacted coastal marshes of the NGoM. The USDA Natural Resources Conservation Service implemented the Migratory Bird Habitat Initiative (MBHI) to provide waterbirds with wetlands inland of oil-impacted areas. My objectives were to 1) statistically model the waterbird community on wetlands in the MAV and NGoM, 2) estimate relative abundance of shorebird and other waterbirds in idled aquaculture ponds enrolled in MBHI and associated wetlands in the MAV and NGoM, and 3) collect shorebird feathers and blood for stable isotope analysis ($^{13}C/^{12}C$, $^{15}N/^{14}N$) to assess foraging niches and potential migratory connectivity between MAV and NGoM habitats during 2012 – 2013. Respectively, autumns of these years were under a drought, extensively wet from Hurricane Isaac, and average precipitation in the post-hurricane recovery period. A non-metric multidimensional scaling ordination indicated waterbird assemblages differed by year, month, twice-monthly survey period, latitude, region, state, site, and water depth index. Latitude shifted north and water depth was narrowest when abundant wet habitat existed on the landscape in 2012. Bird abundances were greatest in 2011 and never recovered to these levels in 2012 or 2013, which may have reflected effects of drought concentrating birds on remaining wetlands in 2011 and the subsequent the hurricane. Stable isotope analysis of blood indicated spatial segregation of my shorebird species. Neither blood nor feather carbon and nitrogen values revealed definitive linkage of sites between the MAV and NGoM. Shallow water habitat inland may be a limiting resource during migration for waterbirds, especially in drought years when other wetlands may have been limited. Thus, provision of wetlands (mudflat – 15 cm) by MBHI and other conservation strategies across the landscape may allow waterbirds access to needed resources during migration.

DEDICTATION

I dedicate this dissertation to my late grandfather, Richard Peters. He was always willing to explore the outdoors with me. I value and cherish my memories of time spent with him fishing, hunting, birding, biking, hiking, snowmobiling, and countless other outdoor adventures. Additionally, I am thankful for the lessons he taught me while building things in his work shop. Had I not had these experiences with him and other family members in the outdoors over the last 30 years, I would likely not be here today. I also thank my Grandma Carol Peters, parents, sister, and her family for their continual support and interest in my wellbeing during this long process. Without their constant encouragement, I would not have made it this far. During this whole process, I have realized that it takes a family to earn a Ph.D. I could have never done this without the support of family and friends. To the countless people in my life who have helped me get this far, I say thank you.

ACKNOWLEDGEMENTS

. I would like to thank my funding sources, the U.S. Department of Agriculture's Natural Resources Conservation Service for supporting my research project and allowing me the opportunity to conduct research sites previously enrolled in the Migratory Bird Habitat Initiative. I would like to thank my Migratory Bird Habitat Initiative property owners (Austin Jones, Edward Nerren, Billy and Judith Janous, Louie Thompson, and Chat Phillips) for graciously allowing me to use their lands. I would also like to thank the Forest and Wildlife Research Center, the Department of Wildlife, Fisheries and Aquaculture, Department of Plant and Soil Sciences, and the U.S. Geological Survey Mississippi Cooperative Fish and Wildlife Research Unit at Mississippi State University; the U.S. Fish and Wildlife Service, specifically the staff at Mingo National Wildlife Refuge (NWR), Coldwater River NWR, Yazoo NWR, Morgan Brake NWR, and St. Catherine Creek NWR, the Missouri Department of Conservation staff at Duck Creek Conservation Area (CA), Otter Slough CA, and Ten Mile Pond CA, the Grand Bay NWR and National Estuarine Research Reserve, the Louisiana Department of Wildlife and Fisheries' Marine Research Lab, the USDA ARS Poultry Research Unit, Mr. James C. Kennedy, and the James C. Kennedy Endowed Chair in Waterfowl and Wetlands Conservation for lodging, logistical, and in-kind support of my research.

I would like to thank my co-major advisors, Drs. Francisco Vilella and Rick Kaminski for their time, guidance, and support through this whole process during my tenure here at Mississippi State University. I would also like to thank other members of my graduate committee, Drs. Scott Rush and Jac Varco for assisting me with stable isotope work, analysis, and questions arising throughout the whole process. I am eternally grateful to Dr. Varco for taking time from his busy schedule to allow me access to his equipment and teach me how to use the Carlo-Erba elemental analyzer and mass spectrometer at Mississippi State University. Additionally, I would like to thank my project partner Jim Feaga for assisting me throughout his tenure at Mississippi State. I would like to thank all my other lab mates for providing their friendship, assistance, and an outlet to escape thoughts of work. I sincerely thank my technicians, Nate Behl and Jack Toriello, for their assistance in the field counting and capturing shorebirds. I thank all of my student workers for tirelessly sorting aquatic invertebrates from soil cores.

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INTRODUCTION

Introduction

Waterbird (waterfowl, wading birds, and shorebirds) species rely heavily on interior and coastal wetlands in the Atlantic and Mississippi Flyways for migration stopover sites (Davis and Smith 2001, Lehnen 2010). The 2010 Deepwater Horizon oil spill in the Gulf of Mexico prompted management agencies to provide inland and coastal habitats for migratory birds (NRCS 2010). The Migratory Bird Habitat Initiative (MBHI) was implemented through the Natural Resources Conservation Service (NRCS) working with farmers, ranchers, and other landowners to enhance habitat for migratory birds on private lands (NRCS 2010, Kaminski and Davis 2014). Counties within the Mississippi Alluvial Valley (MAV) and northern Gulf of Mexico (NGoM) were prioritized based on habitat potential for migrating bird populations by placing shallow water management practices along well documented migration corridors.

Originally, the MAV consisted primarily of forested wetlands with interspersed temporary and seasonal wetlands adjacent to major rivers and tributaries (Reinecke et al. 1989, Foth et al. 2014). Forested wetlands of the MAV had limited available wetland habitat for migrant shorebirds (Twedt et al. 1998). Conversion of forested wetlands to agriculture (i.e., row crops and aquaculture) has the potential to provide sparsely vegetated shallow water habitat for fall migrants if flooded in the fall. In the southeastern United States, fall represents the driest period annually, on average, with August and September the two months of least precipitation in the central MAV (Belzoni, Mississippi average = 8.89 cm for August, 8.00 cm for September; (Eggleston 2016). Presently, wetlands are often scarce during fall migration (Reinecke et al. 1988, Weller 1988, Sedell et al. 1989). Annual available shallow water habitat across the MAV may have an “oasis” effect, concentrating waterbirds on reliable sites like catfish/baitfish pond complexes, public managed lands, river sandbars, or oxbow lakes (Twedt et al. 1998).

Historically, the NGoM's barrier islands, tidal saltmarshes, and mudflat habitats were the likely stopover grounds for migrating waterbirds, especially shorebirds, in the Mississippi Flyway (Henkel and Taylor 2015). Coastal and nearshore areas provide some of the most heavily used habitats by birds (Burger et al. 2012). Densities and distributions of waterbird foods (i.e., fish and invertebrates) are dependent on habitat quality and nutrient availability (Maccarone and Brzorad 2005); which are often influenced by small-scale variations in the physical environment. Wetlands along the NGoM may be less dynamic, to their MAV counterparts, in their food resources and wet-dry cycles because of precipitation and daily tidal inundations associated with the Gulf of Mexico.

In the last century, interior wetlands and intertidal sand and mud flats have come under considerable pressure from human activities (Galbraith et al. 2002). The loss of habitat to urbanization, natural resource extraction, agriculture, and the invasion of non-native plants have all been identified as mechanisms responsible for habitat loss (Goss-Custard and Moser 1988). Global climate change and subsequent sea level rise have also been identified as major threats to the loss of salt marsh and tidal mudflat habitat. Due to the inundation and intrusion of sea water, foraging habitats available to shorebirds at wetlands in the NGoM may become reduced (Galbraith et al. 2002). Therefore, the objectives for my dissertation were to conduct contemporary surveys of waterbirds to (CHAPTER II; 1) model species assemblages of migratory waterbirds in aquaculture associated habitats and other wetlands in the MAV and NGoM during summer through autumn (August – October); (2) assess possible post-hurricane or oil spill effects on fall migrating waterbirds in the MAV and NGoM; (3) provide managing agencies with justifiable management options for fall migrating waterbird communities; (CHAPTER III; 4) estimate species composition and relative abundance of migrating shorebirds in aquaculture ponds and other associated wetlands in the MAV and NGoM during summer through fall (August – October) migration; (5) my results may provide information to evaluate the implications of MBHI and other management practices; (CHAPTER IV; 6) collect shorebird tissues (i.e., feathers and blood) to use stable isotope analysis ($^{13}C/^{12}C$, $^{15}N/^{14}N$) to assess potential migratory connectivity among MAV and NGoM habitats; (7) use stable isotope analysis to possibly assess use of freshwater and estuarine wetlands by fall migrating shorebirds; (8) use shorebird tissues from capture sites to estimate potential hydrocarbon absorption; and (9) make inferences about differences in isotopic signatures for future studies.

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CHAPTER II

TEMPORAL, GEOGRAPHICAL AND LANDSCAPE INFLUENCES ON FALL MIGRANT WATERBIRD COMMUNITY STRUCTURE AND SPECIES ASSEMBLAGE IN THE LOWER MISSISSIPPI FLYWAY

Introduction

Inland and coastal wetlands are important stopover and wintering sites for resident and migratory waterfowl, shorebirds, and wading birds (hereafter waterbirds). Many species of waterbirds and some Passerines, spend a significant portion of their life cycle in coastal and offshore habitats (Burger et al. 2012). For example, wetlands in the Mississippi Alluvial Valley (MAV) and along the northern Gulf of Mexico (NGoM) are critical habitats for waterbirds using the Mississippi Flyway (Colwell 2010, Baldassarre 2014). Additionally, large-scale wetland conversion and loss in the MAV and NGoM have reduced habitat for fall migrant waterbirds, rendering remaining and emerging habitats through conservation initiatives especially important to sustaining continental populations (Lehnen 2010, Henkel and Taylor 2015).

Originally, the MAV consisted primarily of forested wetlands with interspersed temporary and seasonal wetlands adjacent to major rivers and tributaries (Reinecke et al. 1989, Foth et al. 2014). Forested wetlands of the MAV offered limited shorebird habitats (Twedt et al. 1998). Conversion of forested wetlands to an agricultural (i.e., row crops and aquaculture) dominated landscape has the potential to provide sparsely vegetated shallow water habitat for fall migrants if flooded in the fall. In the southeastern United States, fall represents the driest period annually, on average, with August and September being the two months of least precipitation in the central MAV (Belzoni, Mississippi average = 8.89 cm for August, 8.00 cm for September; Eggleston 2016). Presently, wetlands for fall migrating waterbirds are often scarce during fall migration due to little precipitation unless tropical storms or hurricanes occur, high evapotranspiration, and a disconnect in the river continuum between the floodplain rivers due to extensive hydrological manipulations (Reinecke et al. 1988, Weller 1988, Sedell et al. 1989). The annual available shallow water habitat across the MAV may have an “oasis” effect, concentrating waterbirds on reliable sites like catfish/baitfish pond complexes, public managed lands, river sandbars, or oxbow lakes (Twedt et al. 1998).

The MAV is an area of continental significance for migrating and wintering waterfowl as identified in the North American Waterfowl Management Plan (North American Waterfowl Management Plan 2012). Waterfowl use flooded agricultural fields and moist-soil wetland habitats within this region to acquire energy (Stafford et al. 2006, Hagy and Kaminski 2012). Populations of Canada geese (*Branta canadensis*), Mallard (*Anas platyrhynchos*), Wood Duck (*Aix sponsa*), and Hooded Merganser (*Lophodytes cucullatus*) are the most commonly observed waterfowl species on wetland habitats in late summer to early fall the MAV (Baldassarre 2014). Black-bellied Whistling-duck (*Dendrocygna autumnalis*) has seen a relatively recent expansion of its range. An increases in population (8.2% annually) is the likely mechanism behind their increased observance in the MAV in summer and fall (Baldassarre 2014). Blue-winged Teal (*A. discors*) are the earliest waterfowl species to migrate to the MAV. As their numbers decline, they are replaced by early migrant Northern Shoveler (*A. clypeata*). James and Neal (1986) observed Northern Shovelers in Arkansas as early as late August with most arriving by early November. Blue-winged Teal and Northern Shoveler are Neotropic waterfowl species that use the MAV and NGoM from mid-August to late October to replenish lipid reserves before reaching wintering grounds from Mexico to South America (Baldassarre 2014).

Wading birds in North America exhibit changes in population sizes and diversity along latitudinal or continent-to-ocean gradients. Kushlan (1981) observed species richness of wading birds increase with decreasing latitude in eastern North America. Movements of wading birds species sub-populations are commonly observed in response to fluctuations in resource availability. Kushland and Roberson (1977) observed ibis and herons, nesting in Florida, dispersed northward upon completion of the nesting period. Wood Storks (*Mycteria americana*) exhibit similar northward seasonal migrations in response to resource availability (Bryan Jr et al. 2008). Following nesting, they use wetland habitats across the southeastern United States from late summer to early autumn (Kushlan 1981, Bryan Jr et al. 2008). Coulter et al. (1999) tracked radio-marked juvenile storks banded in southern Florida to wetlands in states along the eastern Gulf of Mexico (i.e., northern Florida to east-central Mississippi). Similarly, Wood Storks originating from Mexico and Central America have been observed in great abundance in the MAV and NGoM (Coulter et al. 1999, Bryan Jr et al. 2008). Birds captured and affixed with satellite transmitters at St. Catherine Creek National Wildlife Refuge (NWR) were observed making annual circular migrations between breeding sites in eastern Mexico and summer foraging grounds in the MAV (Bryan Jr et al. 2008). Similarly to waterfowl, the MAV has been identified as an important migration and wintering area for other waterbird species, namely herons (Mikuska et al. 1998).

A priority for shorebird conservation in the MAV is creating and managing shallowly-flooded shorebird foraging habitat because shallow wetlands are likely limited during late summer and autumn (Hunter et al. 1996, Twedt et al. 1998). Shallow water habitat can be created in a number of ways. The two most common management practices to create shallow water habitat are flood management regime and draw-down management (Twedt et al. 1998). Flood management saturates the soil through pumping from ground, or surface sources, until desired standing water depths are created. Draw-down management retains water within impoundments from winter/spring through summer combined with the periodic removal of boards from water control structures. These actions continually create mudflat habitat during late summer through the manipulation of water levels (Twedt et al. 1998, Lehnen and Krementz 2005). Continually exposing mudflat habitat on the landscape is important for migrant shorebirds because stopover duration for most species is unknown. Shorebirds of differing body size, likely use wetland habitats in the MAV for varying amounts of time. Pectoral Sandpipers ($\overline{x}$ = 73 g; *Calidris melanotos*) have an estimated 10 day stopover duration in the MAV (Lehnen and Krementz 2005); whereas, the Least Sandpiper ($\overline{x}$ = 20 g; *C. minutilla*) is estimated to use the MAV for four to seven days (Lehnen and Krementz 2007). Thus, the lack of information on shorebird migration timing and habitat use in the MAV has hampered the development of shorebird management objectives (Loesch et al. 2000, Lehnen and Krementz 2007).

Historically, the NGoM's barrier islands, tidal saltmarshes, and mudflat habitats were the likely stopover grounds for migrating waterbirds, especially shorebirds, in the Mississippi Flyway (Henkel and Taylor 2015). Coastal and nearshore areas provide some of the most heavily used habitats by birds for nesting, roosting, resting, and foraging on a daily basis (Burger et al. 2012). Densities and distributions of waterbird foods (i.e., fish and invertebrates) depend on habitat quality and nutrient availability (Maccarone and Brzorad 2005); which are often influenced by small-scale variations in the physical environment. Wetlands along the NGoM may be less dynamic, to their MAV counterparts, in their food resources and wet-dry cycles because of precipitation and daily tidal inundations associated with the Gulf of Mexico.

Most waterfowl use the NGoM seasonally. However, a few species have adapted to using the extensive salt marshes of the NGoM year-round. Resident waterfowl species include Mottled Duck (*A. fulvigula*), Fulvous Whistling Duck (*D. bicolor*), and Black-bellied Whistling-duck (McCracken et al. 2001, Baldassarre 2014). Two populations of mottled ducks occur on wetlands surrounding the Gulf of Mexico; peninsular Florida and Alabama westward to Mexico (Durham and Afton 2003). Similarly to the MAV, the NGoM is an important stopover site for Blue-winged Teal and Northern Shovelers. The productive salt marsh ecosystems and adjacent seagrass beds provide dabbling diving ducks abundant forage during migration and overwintering. For example, ~78% of the Redhead (*Aythya americana*) population overwinters on the Laguna Madre of Texas and Mexico (Hammer et al. 1998, Baldassarre 2014).

Coastal breeding and migrant wading bird species use salt marshes, shrubby vegetation, sand spits, or offshore habitats (Burger et al. 2012). Because many wading bird species are colonial nesters, they heavily exploit food resources at a localized scale; typically selecting nesting sites in highly productive systems (i.e., estuaries) and foraging in a variety of adjacent habitats (Maccarone and Brzorad 2005). For example, Least Terns [*Sternula antillarum*], a regionally threatened species, use the productive coastal habitats in the Mississippi Sound, Mississippi to breed and raise their young (Jackson and Jackson 1985). Wood Storks have been observed using gulf coastal wetlands as staging areas between breeding sites and northern migration sites prior to exploiting regional seasonal fluctuations in resource availability (Bryan, Jr et al. 2008). During the breeding and non-breeding season, pelicans and herons use coastal marine habitats favoring shallow bays, inlets, and estuaries (Mikuska et al. 1998, King and Michot 2002). Whereas most waterfowl species and shorebird species use the NGoM primarily for migration and overwintering, wading birds species may represent a large proportion of year-round residents.

The coastlines of the NGoM are important to 28 species of migrating shorebirds (Henkel and Taylor 2015). It is estimated that more than one million shorebirds migrate through the NGoM seasonally and often show great site fidelity to wetlands along a migration route (Colwell 2010). For many species, the NGoM may represent the first suitable stopover habitat between northern breeding grounds and wintering grounds in Central and South America (Withers 2002, Henkel et al. 2012). Shorebirds use intertidal sand and mudflats along salt marshes and barrier islands year-round, during northward and southward migration, and while overwintering. Within these coastal tidal habitats, shorebird species segregate themselves across a narrow band of water depths in these wetland habitats (Davis and Smith 2001).

In the last century, intertidal sand and mud flats have come under considerable pressure from human activities (Galbraith et al. 2002). The loss of habitat to urbanization, natural resource extraction, agriculture, and the invasion of non-native plants have all been identified as mechanisms of habitat loss (Goss-Custard and Moser 1988). Global climate change and subsequent sea level rise has been identified as a major threat to the loss of salt marsh and tidal mudflat habitat. Due to the inundation and intrusion of sea water, foraging habitats available to shorebirds at wetlands in the NGoM may become reduced (Galbraith et al. 2002). Therefore, my objectives were to conduct contemporary surveys of waterbirds to (1) model species assemblages of migratory waterbirds in aquaculture associated habitats and other wetlands in the MAV and NGoM during summer through autumn (August – October), (2) assess possible post-hurricane or oil spill effects on fall migrating waterbirds in the MAV and NGoM, and (3) provide managing agencies with justifiable management options for fall migrating waterbird communities.

Study Areas

I selected study sites in counties identified as priority for the Migratory Bird Habitat Initiative (MBHI) within the MAV and NGoM (Kaminski and Davis 2014). Initially, these only included properties previously enrolled in the MBHI program. I expanded surveys by identifying NWRs and/or state owned Conservation Areas (CA) in the MAV and NGoM. This approach permitted surveying waterbirds throughout the MAV and establishing a latitudinal gradient for tracking their fall migration. Along the NGoM, I selected similar sites from Alabama, Mississippi, and Louisiana, the three states most impacted by the Deep-water Horizon oils spill (Figure 2.1).

North Mississippi Alluvial Valley – Southeast Missouri

Duck Creek Conservation Area

Duck Creek CA is managed by Missouri Department of Conservation (Figure 2.1). Duck Creek CA and adjoining federal lands (i.e., Mingo NWR) are ~10,400 ha moist-soil impoundments, forests, and open water habitat. It is located at the northern end of the MAV near Puxico, Missouri (UTM WGS84: 15 754001 E 4095128 N). Duck Creek CA provides migrating waterbirds with ~260 ha of seasonally flooded moist-soil impoundments.

Otter Slough Conservation Area

Otter Slough CA is managed by the Missouri Department of Conservation and is ~2,000 ha of moist-soil impoundments, forests, and open water habitat (Figure 2.1). It is located at the northern end of the MAV west of Dexter, Missouri (UTM WGS84: 15 758332 E 4068019 N).

Ten Mile Pond Conservation Area

Ten Mile Pond CA is additionally managed by the Missouri Department of Conservation ~1,500 ha of moist-soil impoundments and open water habitat (Figure 2.1). It is also located at the northern end of the MAV southeast of East Prairie, Missouri (UTM WGS84: 16 292978 E 4066373 N).

Mid-Mississippi Alluvial Valley

North Mississippi National Wildlife Refuges Complex – Coldwater River National Wildlife Refuge

Coldwater River NWR, managed by the U.S. Fish and Wildlife Service, ~840 ha of moist-soil impoundments are managed for migrating waterfowl, wading birds, and shorebirds (Figure 2.1). It is located on the eastern edge of the MAV near Crowder, Mississippi (UTM WGS84: 15 764584 E 3776908 N).

Theodore Roosevelt NWR Complex – Yazoo National Wildlife Refuge

Yazoo NWR, managed by the U.S. Fish and Wildlife Service, is ~5,250 ha of bottomland hardwood forests, old fields, and moist-soil habitats (Figure 2.1). It has ~100 ha of former catfish ponds, converted into managed moist-soil wetlands (Fredrickson and Taylor 1982, Twedt et al. 1998, Kross et al. 2007). Yazoo NWR is located southeast of Greenville, Mississippi (UTM WGS84: 15 685597 E 3666651 N).

Migratory Bird Habitat Initiative enrolled sites

All possible MBHI enrolled sites were located within eight states bordering the Gulf of Mexico. From within those states, I selected sites within the Lower Mississippi Alluvial Valley and Western Gulf Coast Joint Venture boundaries. Within these, I refined sites by randomly selecting 10 landowners from a list of properties (*n* = 40) enrolled in

MBHI during fall 2010 and/or 2011 where waterbird habitat (≤ 30 cm water depths) was found in active or idled catfish ponds. After assessing habitat and water conditions in the field, I eliminated some sites because of lack of water, coverage by herbaceous or woody vegetation, or conversion to agricultural crops. I attempted to replace excluded sites with other properties previously enrolled in the MBHI, but I was unsuccessful because additional sites in this region were not available. Therefore, I finally selected five landowners in Sunflower (Bear Creek Fisheries, UTM WGS84: 15 737658 E 3704579 N), Humphreys (Nerren Fisheries, WGS84: UTM 15 717312 E 3676571 N; Janous Properties, UTM WGS84: 15 719934 E 3666233 N), Holmes (Thompson Fisheries, UTM WGS84: 15 744832 E 3660354 N), and Yazoo Counties (Phillips Brother’s Farms UTM WGS84: 15 745416 E 3652558 N), Mississippi (Figure 2.1). I selected MBHI sites in current catfish production and surveyed three pond types: production ponds (≥ 1 m water depth), idled ponds with shallow water and mudflats, or moist-soil impoundments. Sites ranged from 20 – 850 ha ($\bar{x}$ = 80 ha) and contained 29 to 193 ponds ($\bar{x}$ = 101). Shallow water ponds averaged 4 ha, were ≤ 1m deep and enclosed by man-made levees typified by slopes of 2.5:1 (Christopher 1985, Dubovsky and Kaminski 1987, Feaga et al. 2015).

South Mississippi Alluvial Valley

St. Catherine Creek National Wildlife Refuge

St. Catherine Creek NWR (UTM WGS84: 15 648065 E 3468603 N), managed by the U.S. Fish and Wildlife Service, is ~10,500 ha of bottomland hardwood forests, fields, and moist-soil wetlands. The refuge is managed to provide wintering habitat for migrating waterfowl and other waterbirds (Figure 2.1). I surveyed birds on the Sibley Farms moist-soil units and Cloverdale tract of the refuge. The Sibley Farms moist-soil units are an intensively managed moist-soil impoundment complex (Twedt et al. 1998). Each pond was approximately 30 ha and flooded ≤ 0.5 m. The Cloverdale tract has natural ridge and swale topography and is bisected by a levee, which creates ephemeral moist-soil wetlands and mudflat habitats in the swales on either side.

Coastal Wetlands

Dauphin Island, Alabama

Dauphin Island is a 1,606 ha barrier island along the Alabama Gulf Coast. My sites were similar to Johnson and Baldassare (1988) and Henkel and Taylor (2015). Its northern shore lies along the southern boundary of Mobile Bay and the U.S. Army Corps of Engineers Intracoastal Waterway (Figure 2.1). The eastern half of the island is a mix of urban and forested habitats. The western half of the island is a long sandspit extending from the west end beach parking lot. I conducted waterbird surveys within a tidally influenced 4.8 ha lagoon on the north side of the island west of the west end beach parking lot (UTM WGS84: 16 384902 E 3347091 N). At low tide, the lagoon was covered incompletely by an algal mat and wind and water deposited sediments (i.e., sand and silt), while the surrounding habitats consisted of wind deposited vegetated sand dunes.

Grand Bay National Wildlife Refuge & National Estuarine Research Reserve, Mississippi

I conducted bird surveys on tidal mudflats of the Grande Batture Islands, Grand Bay NWR and National Estuarine Research Reserve (NERR). There was a mudflat of ~20 ha at low tide between two Grande Batture Islands (UTM WGS84: 16 364492 E 335797 N). Additional surveys were completed near the South Rigolet Islands, where an eight ha mud flat was exposed during low tide (UTM WGS84 16 366160 E 3358764 N). Grande Batture and Rigolet Island surveys were combined because of close proximity to one another and similar habitat type. I surveyed during low tides to avoid inundated tidal flats inaccessible to waterbirds (Figure 2.1). When weather permitted, I surveyed waterbirds on 81 ha of salt pannes at Point au Chenes (UTM WGS84: 16 360143 E 3356781 N).

Elmer's Island Wildlife Refuge, Louisiana

I conducted waterbird surveys on tidal mudflats and along the beach at Elmer's Island Wildlife Refuge (WR; Figure 2.1). My sites were similar to Henkel and Taylor (2015). Elmer's Island WR is a 93 ha barrier island managed by the Louisiana Department of Wildlife and Fisheries (UTM WGS84 15 787016 E 3232641 N). Substrates used by waterbirds were primarily wind and water deposited sand and silt along the tidal interface of the barrier island. Surrounding habitat types included vegetated dunes. Habitats on the inland side were tidally inundated giant cordgrass (*Spartina alterniflora*) and interspersed with open water.

Methods

Experimental Design

Interior wetland bird surveys

In spring of 2011, the U.S. Department of Agriculture's Natural Resources Conservation Service (NRCS) and I identified landowners with aquaculture ponds enrolled in MBHI during the 2010 summer. From this set of MBHI enrolled sites, I identified sites that remained enrolled in MBHI in 2011 or landowners who planned to provide shallow (≤ 30cm) water for fall migrant waterbirds (NRCS 2010, Kaminski and Davis 2014). I generated site specific maps and individually numbered ponds using ArcMAP version 10.3 (ESRI 2014). Prior to first bird surveys annually, I categorized every pond at each site as full pool, moist-soil, or mudflat. I conducted ground surveys of waterbirds on all ponds with mudflat habitat during fall migration (July –October 2011; August –October 2012 – 2013). Additionally, I used a random number generator to survey waterbirds on 5 – 10% of ponds classified as full pool or moist-soil because pond maintenance and subsequent mudflat habitat occurred within this range (Chat Phillips, Phillips Brother's Farms, personal communication). I chose this range of values to balance surveys among pond types. I divided daylight hours into three time intervals: 0600 to 1000 hours, 1001-1400 hours, and 1501– to 1800 hours (Feaga et al. 2015) and conducted surveys randomly during different intervals during each visit to alleviate possible diurnal biases related to bird use (Davis and Smith 1998, Webb et al. 2010). Surveys followed protocols of the Integrated Waterbird Management and Monitoring Program's Monitoring Manual (2012) for whole area counts. Waterbirds were located and identified with 8.5x42 binoculars and a 20-60x80 spotting scope from the best possible vantage point around wetlands, moving if necessary to survey all waterbirds present. I assumed all birds present within each impoundment were detected given my elevated vantage point from within a vehicle or on levee roads. Because of regular traffic on these roads from daily operations, birds were acclimated to approaching vehicles and did not flush (Feaga et al. 2015).

Point counts on beaches

At Dauphin Island, I surveyed waterbirds while walking the northern edge of the lagoon in a westerly direction using 8.5x42mm binoculars and a 20-60x80mm spotting scope on a tripod. By remaining on the edge of the wetland, I was able to reduce disturbance, avoid flushing birds, and possibly double counting of individuals. As vehicular traffic on the beach at Elmer’s Island WR is commonly practiced by area users, I counted waterbirds with 8.5x42mm binoculars and a window mounted 20-60x80mm spotting scope from a vehicle while driving an easterly transect along the beach. I used a single scan method of counting to minimize double counting of individuals.

Survey of tidal mudflats

Waterbird surveys of islands at Grand Bay NWR and NERR were conducted using 8.5x42mm binoculars and a 20-60x80mm spotting scope from an idling boat where access was not available (Sanders et al. 2004). I conducted surveys of the tidal mudflat between the Grande Batture Islands from the shoreline of an adjacent island. Surveys at salt pannes were conducted from a single location using a single scan of the area to minimize double counting of individuals.

Statistical Analysis

Non-metric multidimensional scaling

Waterbird communities were assessed relative to temporal (year, month, survey time period), geographical (latitude, region, state, site), and environmental (water depth index and land cover types) factors. Species of waterbirds were separated into three functional guilds: 1) waterfowl species in Anatidae; 2) wading birds, species in families Podicipedidae, Pelecanidae, Ardeidae, Threskiornithidae, Ciconiidae, Rallidae, and Laridae; and 3) shorebirds, species in families Charadriidae, Recurvirostridae, and Scolopacidae (APPENDIX B, Table B.1). I used a non-metric multidimentional scaling (NMDS) ordination with package *vegan* in program R version (R Development Core Team 2016) to characterize similarities or dissimilarities in species composition and structure at sites to identify potential waterbird shifts during fall migration (Wilson and Sheaves 2001). My temporal variables included year (2011 – 2013), month (August – October), and six twice-monthly survey time periods within month. My geographical variables included site specific latitude, regions (MAV and NGoM), state (Missouri, MBHI, Mississippi Delta, Southwest Mississippi, Alabama, Mississippi, and Louisiana), and sites (APPENDIX D, Table D.1). I did not measure average water depth at each survey pond. As a surrogate, I indexed depths by calculating the tarsus length to foraging depth ratio (Baker 1979) for every shorebird species observed within a pond. Body metrics for every species present were found in Pyle (2008). I averaged species specific values to generate an average water depth.

I calculated land cover types of sites by generating a 1 km buffer around each site boundary in ArcMAP, using the BUFFER function in *ArcToolbox* (Feaga et al. 2015).

The 2011 National land Cover Database (30 meter spatial resolution) was uploaded into ArcMap (Homer et al. 2015). I used the CLIP function in *ArcToolbox* to extract land cover types between the buffer and site boundary. Percent land cover for each present land cover type (open water, developed land, barren land, other forest, crop, forested wetland, and emergent wetland) was created by calculating the proportion of pixels relative to the total number in the buffer (Feaga et al. 2015).

I encountered 90 species of waterbirds (16 families; Table B.1) during surveys but included in NMDS only 43 species (Table B.2) that comprised ≥ 1% of the total occurrence of waterbirds within a geographic region by year (Desmond et al. 2002). Long-billed Dowitchers (*Limnodromus scolopaceus*) and Short-billed Dowitchers (*Limnodromus griseus*) are difficult to distinguish in the field while in nonbreeding plumage. Therefore, to reduce misclassification of species, I combined both species and categorized them as “Dowitchers” (Twedt et al. 1998). I used Sorenson/Bray-Curtis distance measurements to ordinate waterbird assemblages (Vinson and Dinger 2008, Foth 2011). In the *vegan* package, I square root transformed waterbird counts using the Wisconsin double standardization (Oksanen et al. 2010). I performed four NMDS analyses in two-dimensional ordination space with 1,000 iterations. In *vegan* package, I used ORDIPLOT to plot the outputs. I calculated stress values, which indicated the degree of deviation between the ordination and the original similarity matrix, to indicate degree of fit in the monotonic relationship between matrices (Clarke 1993, Desmond et al. 2002, Foth 2011). In *vegan* package, I used ORDITORP to plot species alpha codes (Pyle and DeSante 2003; 2009) onto the ordination space. In *vegan* package I used ORDILLIPSE to generate ninety-five percent confidence ellipses (year, month, survey time period, region, state, and site) and fit them to the ordination space. To assess possible effects of geographical and environmental vectors on the ordination of the waterbird assemblages, in *vegan* package, I used ORDISURF to fit latitude, water depth, and land cover types using a gradient function to the ordination space. I interpreted individual waterbird species or clusters of species within gradient bands as positively correlated. Lastly, in *vegan* package, I used a PerMANOVA with 1,000 permutations in ADONIS to test for significance of variables within the ordination space. I divided significance test models into two analyses of all related variables: temporal (year, month, and survey time period) and geographical (latitude, region, state, and site).

Results

Waterbird assemblage temporal change during fall migration

The best stress value of the NMDS ordination comparing waterbird communities across years was 0.159, indicating a good fit of the final ordination scores to the original data matrix. The PerMANOVA indicated levels of each temporal factor (year, month, and survey time period,) differed across years ($P < 0.001$). The major axis of the ellipse was diagonal in 2011 and nearly horizontal for 2012 and 2013 and shifted across ordination space indicating different species composition influencing ellipses each year (Figure 2.2; Table B.3). However, overlapping of ellipses indicated a core group of species present within all three years. The greatest shorebird (n = 11) species richness occurred in 2011. The greatest wading bird (n = 9) species richness occurred in 2012; whereas, waterfowl species richness was less overall with Canada Geese (*Branta canadensis*), present within the 2011 and 2012 ellipses only.

Across the August – October fall migration period, monthly 95% confidence ellipses shifted across ordination space as new waterbird species arrived or departed from the MAV and NGoM (Figure 2.3; Table B.4). A zone of overlap across all three months suggested a core group of species present among years within the two regions. For shorebird and wading bird guilds, greatest richness occurred in different months. August had the greatest shorebird species richness (*n* = 7) and September had the greatest wading bird species richness (*n* = 12). Waterfowl species richness was uniform across all months; with species composition shifting from Canada Geese to Ruddy Ducks (*Oxyura jamaicensis*) between September and October. Similar temporal trends were apparent in survey time periods across all three years (Figure 2.4; Table B.5).

Twice-monthly 95% confidence ellipses within August – October differed between first and second survey periods. The 95% confidence ellipses for survey time period were nearly uniform in shape within their respective months but directionally changed for the second survey in all months, indicating the addition or deletion of species from the waterbird assemblage during fall migration. Greatest shorebird species richness (*n* = 9) occurred during the first survey period and included both locally breeding and migratory species. Greatest wading bird (*n* = 14) species richness occurred in late September and waterfowl (period 6, *n* = 2) species richness in late October. This likely represented the arrival of overwintering migratory species.

Ordination analyses in 2011 yielded a best stress value from the NMDS of 0.130. This value indicated good fit of the ordination to the data. The PerMANOVA including month and survey time period indicated levels of each factor differed significantly in 2011. The 95% confidence ellipse for August was displayed on the left side of the ordination space and associated with waterbird communities dominated by four shorebird species (Figure 2.5; Table B.6). The ellipse for September was the largest of the three month sampling period and shifted relative to the August species assemblages; it included the addition of wading bird (*n* = 3) and waterfowl species (*n* = 3). The degree of overlap in the August and September ellipses suggested fall migrant waterbirds had not yet left one or both regions. The larger coverage of the ellipse and greater number of shorebird species within September (i.e., August, *n* = 4; September, *n* = 6) indicated more shorebirds had migrated into the MAV and NGoM. Additionally, the directionality of the ellipse suggested a strong correlation to the observance of three species of waterfowl, namely Wood Duck (*Aix sponsa*), Mallard (*A. Platyrhyncos*) and Blue-winged Teal. Lastly, the narrow breadth and directionality of the ellipse for October suggested an influx of particular species of shorebird and wading bird species into the regions with few species still remaining from September and none from August.

At a more refined scale relative to month, the twice-monthly survey time periods displayed similar trends in waterbird assemblages during autumn migration (Figure 2.6; Table B.7). The 95% confidence ellipse associated with survey period 1 completely encompassed survey periods 2, 3, and a quarter of 4. This indicated that two resident species, Killdeer (*Charadrius vociferus*) and Black-necked Stilt (*Himantopus mexicanus*), and two early migrants, Least Sandpiper and Pectoral Sandpiper, remained in the MAV and NGoM until the third week of September 2011. The axis points of the major ellipse for the first three survey periods were nearly vertical in ordination space indicating an influence on month by species at either end of the ellipses, whereas survey period 4 had a horizontal orientation. Surveys during late September 2011(period 4) illustrated the arrival of early migrant waterfowl by influencing the size and directionality of the ellipse for this period. The 95% confidence ellipses associated with periods 5 and 6 displayed a dramatic shift in composition of species within a relatively short time period. The continued southward migration of waterfowl and influx of shorebird species pulled the ellipses vertically relative to period 4. This resulted in a turnover of the waterbird assemblages in the two regions throughout October 2011.

Ordination space and species groupings in 2012 differed from 2011 and more closely resembled the plot across all years. The best stress value of the NMDS ordination comparing waterbird communities in 2012 was 0.148, a good fit of the final ordination to the original data matrix. The PerMANOVA indicated levels of each factor (month and survey time period) differed significantly in 2012. Across the fall migration period of August – October, monthly ellipses shifted across ordination space as new waterbird species migrated through the regions (Figure 2.7; Table B.8). Similarly to 2011, the 95% confidence ellipse for August 2012 was dominated by early migrant shorebird species. In 2012, waterbird species composition shifted from interior freshwater associated species to more estuarine associated species as fall migration progressed. September 2012 had the greatest species richness (*n* = 13) in waterbird assemblages and was dominated by wading bird species. Species associated with October were not associated with August. The degree of overlap of monthly ellipses suggested a core group of waterbird species use the MAV and NGoM throughout fall migration.

In 2011, 95% confidence ellipses survey periods 2 and 3 were encased in period 1. In 2012, ellipses for survey periods 2 and 3 partly overlapped period 1 (Figure 2.8; Table B.9). This separation of ellipses indicated the early fall migrating waterbird assemblages were structurally different in species composition during each of the three time periods. Survey period 95% confidence ellipses representing periods 4 – 6 overlapped greatly, suggesting late fall migrating waterbird assemblages were fairly uniform. Twice-monthly survey period ellipses in August and September shifted in ordination space; whereas, ellipses for survey periods in October shrank relative previous periods.

The ordination plot for 2013 closely resembled waterbird species assemblages in 2012 and across all years. The best stress value of the NMDS ordination comparing waterbird communities in 2013 was 0.162, a good fit of the final ordination to the original data matrix. The PerMANOVA indicated levels of each factor (month and survey time period) differed significantly in 2013. Ellipses shifted across ordination space from August – October (Figure 2.9; Table B.10). However, overlapping ellipses indicated some species were observed across months, such as Wood Stork (*Mycteria americana*) and Lesser Yellowlegs (*Tringa flavipes*). August waterbird communities were dominated by five shorebird species, and shifted to wading bird dominated communities in September and October. The species of waterfowl migrating through the MAV and NGoM arrived in September and increased through October as indicated by the directionality of the ellipses.

Five species of shorebirds (Black-necked Stilt, Lesser Yellowlegs, Least Sandpiper, Pectoral Sandpiper, and Stilt Sandpiper [*C. himantopus*]) and Wood Storks occurred within ellipses for time periods 1 and 2 in 2013 (Figure 2.10; Table B.11). Survey period 3 included all species encompassed by the first two survey period ellipses and expanded right to include four more wading bird species (White Ibis [*Eudocimus* *albus*], Least Tern, Black Tern [*Chlidonias niger*], and Black Skimmer [*Rynchops niger*]) and one waterfowl species (Wood Duck). All early migrant shorebird species had left sites in the MAV and NGoM between periods 3 and 4. The remaining four wading bird species and one waterfowl species present in period 3 were observed in the ellipse for period 4. Ellipse for period 4 included seven newly migrated waterbird species (Blue-winged Teal, American White Pelican [*Pelecanus erythrorhynchos*], Brown Pelican [*P. occidentalis*], Great Egret [*Ardea alba*], Semipalmated Plover [*C. semipalmatus*], Caspian Tern [*Hydroprogne caspia*], and Royal Tern [*Thalasseus maximus*]) and indicated a new migration of waterbirds into the MAV and NGoM. Survey period five saw the first shift left in ordination space, across all three years. The ellipse for survey period 5 more closely resembled waterbird assemblages associated with period 3 and included two species (Lesser Yellowlegs and Black-necked Stilt) not present in period 4. Additionally, the seven new waterbird species observed in period 4 were not associated with period 5. Survey period 6, shifted right across ordination space and more closely resembled waterbird assemblages in period 4. The directionality of the ellipse for period 6 suggested a relationship with new migrant species, particularly waterfowl.

Geographic variation in waterbird communities

Latitude, region, state, and sites differed across all years. The latitudinal span of my study extended from the northern portions of the MAV in Missouri (~ 37.0° N) to NGoM sites in Louisiana in the south (~ 29.0° N) spanning approximately eight degrees of latitudinal change (centroid, 32.0° N; Figure 2.11; Table B.12). Waterbird assemblages did not differ from 37.0° N (Puxico, Missouri) to 34.0° N (Charleston, Mississippi) or below 31.0° N (Mississippi/Louisiana border) across all years. Greatest change in species richness occurred between 34.0° – 31.0° N latitude. Most waterfowl species were observed at latitudes ≥33.0° N. Only Mallards were observed below 33.0° N. A majority of waterbird species (*n* = 19; > 90%) and all shorebird species (*n* = 16, 100%) were observed between these three degrees of latitude.

Study regions generated 95% confidence ellipses containing different bird assemblages with six co-occurring species (American White Pelican, White-faced Ibis [*Plegadis chihi*], American Avocet [*Recurvirostra americana*], Black Tern, and Black Skimmer) across all years (Figure 2.12; Table B.13). The MAV and NGoM ellipses closely resembled waterbird species assemblages occurring at northern and southern latitudes, respectively.

Within regions, state groupings indicated similar waterbird assemblages for Missouri and MBHI (Figure 2.13; Table B.14). Ellipses associated with the Mississippi Delta and Southwest Mississippi displayed overlap among ellipses associated with Missouri, MBHI, Alabama, Mississippi, and Louisiana in ordination space. The ellipse for Southwest Mississippi showed more relatedness to MAV sites because of greater overlap with Missouri and MBHI; whereas the ellipse for Mississippi Delta showed more relatedness to NGoM sites because of great overlap with all three coastal ellipses.

Further refinement of confidence ellipses from state groupings to site indicated considerable overlap in waterbird assemblages across sites (Figure 2.14; Table B.15; Table D.1). Site ellipses mostly or fully encased within one or more site ellipse were Ten Mile Pond CA and Grand Bay NWR and NERR. Ten Mile Pond CA had similar waterbird assemblages as Otter Slough CA, Bear Creek Fisheries, Nerren Fisheries, Thompson Fisheries, and Phillips Brother's Farms. Grand Bay NWR and NERR displayed similar waterbird communities as Janous Properties and Elmer's Island WR.

Region, state, and sites significantly influenced NMDS ordination in 2011. However, unlike across all year analyses, regional ellipses were segregated in ordination space (Figure 2.15; Table B.16). The MAV waterbird assemblage encompassed a comparatively wide breadth of ordination space and was associated with one waterfowl species (Wood Duck) and four shorebird species (Killdeer, Black-necked Stilt, Least Sandpiper, and Pectoral Sandpiper). The NGoM ellipse was confined to a narrow ellipse around waterbird assemblage associated with five shorebird species (Black-bellied Plover [*C. squatarola*], Semipalmated Plover, Willet [*T. semipalmata*], Sanderling [*C. alba*], and Western Sandpiper [*C. mauri*]) and two wading bird species (Brown Pelican and Black Skimmer).

At the state level in 2011, separation between regions was still evident with no state ellipses associated with the MAV or NGoM overlapping (Figure 2.16; Table B.17). The ellipse for Missouri and MBHI were similar in species assemblages and differed from the ellipse in Southwest Mississippi. Waterbird communities in Southwest Mississippi wetlands were similar to those in the Mississippi Delta. The ellipse for the Mississippi Delta had little overlap with the ellipse for MBHI, and was segregated from Missouri's ellipse. The ellipse for the Mississippi Delta was strongly influenced by the presence of two waterbird species Northern Shoveler and Pied-billed Grebe (*Podilymbus podiceps*) as indicated by the directionality and shape of the ellipse. Coastal ellipses displayed three nearly unique waterbird communities that transitioned from coastal Mississippi to Louisiana with Alabama intermediate.

At the site level in 2011, Duck Creek CA, Otter Slough CA, Bear Creek Fisheries, and St. Catherine Creek NWR have ellipses mostly or fully encased within one or more site ellipses (Figure 2.17; Table B.18; Table D.1). Duck Creek CA had similar waterbird assemblages as Bear Creek Fisheries, Nerren Fisheries, and Phillips Brother's Farms. Otter Slough CA and Bear Creek Fisheries had similar waterbird assemblages as Nerren Fisheries and Phillips Brother's Farms, but differed in ellipsoid orientation in ordination space. St. Catherine Creek NWR had similar waterbird assemblages as Coldwater River NWR and Nerren Fisheries. Yazoo NWR was the only MAV site to share waterbird assemblages with a site along the NGoM (Grand Bay NWR and NERR).

Latitude, region, state, and sites were significant in 2012. Differences in waterbird assemblages due to latitude shifted north a half of degree at northern 34.5° N (Helena, Arkansas) and southern 31.5° N (Natchez, Mississippi) ends relative to across all years (32.0° N; Figure 2.18; Table B.19). Waterbird assemblages did not differ north of 34.5° N or south of 31.5° N. Most (80%) waterfowl species were observed on sites found at latitudes between 34.5° – 31.5° N. Only Wood Ducks were observed at more northerly latitudes (> 34.5° N). The three degree span of latitude from Helena, Arkansas to Natchez, Mississippi encompassed all wading bird species ($n = 16$) and shorebird species ($n = 12$).

In 2012, approximately half of the NGoM's 95% confidence ellipse occurred within the MAV ellipse, and shared eight species of waterbirds (American White Pelican, Brown Pelican, White-faced Ibis, Semipalmated Plover, Dowitchers, Caspian Tern, Royal Tern, and Sandwich Tern [*T. sandvicensis*]; Figure 2.19;Table B.20).

At the state level, Southwest Mississippi and Missouri shared approximately a third of the species in their waterbird assemblages with one another and half with the MBHI (Figure 2.20; Table B.21). Southwest Mississippi was a transitional zone between MAV states and the NGoM, because coastal Mississippi and Louisiana ellipses were nearly completely encased within the 95% confidence ellipse associated with Southwest Mississippi. The narrow width and long directionality of coastal Mississippi and Louisiana also suggested this association was contingent on a few select species in 2012. The ellipse associated with coastal Mississippi was completely encompassed by Alabama. The 95% confidence ellipse associated with Alabama displayed a wide breadth of waterbird assemblages and shared approximately half of the waterbird assemblage with Southwest Mississippi and less with MBHI and Missouri.

At the site level in 2012, waterbird assemblages at Duck Creek CA displayed little overlap with the two other Missouri sites (Duck Creek CA and Ten Mile Pond CA). Ten Mile Pond CA had similar waterbird assemblages as Otter Slough CA, Bear Creek Fisheries, Thompson Fisheries, and Phillips Brother's Farms (Figure 2.21; Table B.22; Table D.1). Bear Creek Fisheries and Thompson Fisheries displayed similar waterbird assemblages as Phillips Brother's Farms. Waterbird assemblages at Grand Bay NWR and NERR were similar to Duck Creek CA, Janous Properties, St. Catherine Creek NWR, and Dauphin Island. Elmer's Island WR had similar waterbird assemblages as Janous Properties, St. Catherine Creek NWR, Dauphin Island, and Grand Bay NWR and NERR.

Latitude, region, state, and sites differed during autumn migration in 2013. Differences in waterbird assemblages relative to latitude shifted south a half a degree (34.0° N) and reflected the distribution of waterbirds across all years (centroid = 31.5° N;

Figure 2.22; Table B.23). Waterbird assemblages did not differ above 34.0° N or below 31.0° N. All waterfowl species (*n* = 6), wading bird species (*n* = 19), and shorebird species (*n* = 12) were found between these latitudes.

In 2013, MAV and NGoM began to separate across ordination space with little overlap relative to regional ellipses in 2012 (Figure 2.23; Table B.24). Only the American White Pelican was included in the area of overlap between both regions. One waterfowl species, five shorebird species, and six wading bird species were enveloped within the MAV ellipse compared to one waterfowl species five shorebird species, and five wading bird species (Brown Pelican, Laughing Gull [*Leucophaeus atricilla*], Caspian Tern, Royal Tern, and Forster's tern [*S. forsteri*]) in the NGoM ellipse.

At the state level in 2013, MBHI, Missouri, and Southwest Mississippi showed no overlap with Alabama or Louisiana (Figure 2.24; Table B.25). Coastal Mississippi waterbird assemblages were split between MBHI and Alabama, and also shared limited portions of its waterbird communities with Southwest Mississippi and Louisiana. Similary to 2012, in 2013, Louisiana displayed a narrow breadth of ordination space and much of the ellipse was encompassed by Alabama. Its shape indicates relatedness to a narrow grouping of waterbird species.

Ten Mile Pond CA, St. Catherine Creek NWR, and Grand Bay NWR and NERR were mostly or fully encapsulated within Phillips Brother's Farms ellipse. Five sites (Otter Slough CA, Ten Mile Pond CA, Bear Creek Fisheries, Thompson Fisheries and St. Catherine Creek NWR) showed no overlap with ellipses associated with Dauphin Island or Elmer's Island WR (Figure 2.25; Table B.26; Table D.1). Grand Bay NWR and NERR had slight overlaps with Otter Sough CA and St. Catherine Creek NWR. Phillips

Brother’s Farms overlapped all sites across both regions. The 95% confidence ellipse associated with Elmer’s Island was nearly encased within Dauphin Island.

Waterbird assemblage relationships to environmental variables

Water depth

The range of water depths associated with waterbird assemblages across years was 5.4 – 7.4 centimeters (Figure 2.26; Table B.27). Waterbird assemblages did not differ above 7.4 cm or below 5.4 cm. Each waterbird guild was found within a different range of water depths, but exhibited great overlap, waterfowl species 5.8 – 7.2 cm, wading bird species greater than 5.6 cm, and shorebird species 5.4 -7.0 cm. Water depth ranges associated with waterbird assemblages in 2011 were 4.5 – 7.5 cm (Figure 2.27; Table B.28). Waterbird assemblages did not differ above 7.5 cm or below 4.5 cm. Each waterbird guild was found within a different range of water depths, but exhibited great overlap, waterfowl species 6.0 – 7.5 cm, wading bird species greater than 5.0 cm, and shorebird species 5.0 – 7.0 cm. The narrowest range of water depths occurred in 2012 (5.4 – 6.8 cm; Figure 2.28; Table B.29). Waterbird assemblages did not differ above 6.8 cm or below 5.4 cm. Each waterbird guild was found within a different range of water depths, but exhibited great overlap, waterfowl were above 6.0 cm, wading bird species were above 5.6 cm and shorebird species all water depths. Water depth ranges for 2013 (5.5 – 8.0 cm; Figure 2.29; Table B.30) were more similar to those observed in 2011 than 2012. Waterbird assemblages did not differ above 8.0 cm or below 5.5 cm. Each waterbird guild was found within a different range of water depths, but exhibited great overlap, waterfowl species 5.5 – 8.0 cm, wading bird species greater than 6.0 cm, and shorebird species less than 8 cm. When expressed in terms of individual foraging guilds (waterfowl, wading birds, and shorebirds), 2012 had the narrowest range of water depths and 2011 had the greatest.

Dominant land cover types

Seven land cover types occurred within a kilometer of sites. Four land cover types (open water, cropland, forested wetlands, and emergent wetlands) were dominant across the MAV and NGoM. The remaining land cover types (developed land, barren land, and other forests) occurred so infrequently (< 5%) they were dropped from analysis.

Across all years, all waterbirds occurred in landscapes with 10 – 50% open water (Figure 2.30; Table B.31). Waterfowl species were found at sites with 10 – 25% open water; ducks used sites with 15 – 20% open water and geese 10% open water. Moreover, wading birds species used sites with 5 – 20% adjacent open water. Shorebird species used sites with 10 – 50% adjacent open water, and all but one species occurred at sites with 10 – 35%. Waterbirds expanded their use of sites in 2011 to include a wider range (0 – > 70%) of open water (Figure 2.31; Table B.35). in 2011, waterfowl species displayed similar open water percentages to those observed across years. Geese used habitats with more (10 – 20%) and ducks used habitats with less (0 – 10%) open water than across all years. Wading bird species selected sites 0 – 70% open water in the surrounding landscape and shorebird species used sites across all water depth ranges greater than 0%. Percent open water in waterbird buffered landscapes was reduced in 2012 relative to 2011 and across all years (Figure 2.32; Table B.39). All waterbirds could be found on sites with 14 – 20% open water and were fairly uniform across all waterbirds, including waterfowl species (15 – 20%), wading bird species (15 – 20%), and shorebird species (14 – 20%). Similar trends in use of sites with reduced ranges (5 – 25%) of open water occurred in 2013 (Figure 2.33; Table B.43). Waterfowl species and wading bird species were associated across all ranges of percent open water in the adjacent landscape. Shorebird species occurred at sites with the narrowest range of percent open water (5 – 20%) in the buffered landscape.

Regarding percent cropland within 1 km of sites, waterbird guilds used sites with 20 – 65% cropland across all years (Figure 2.30; Table B.32). Waterfowl species displayed the narrowest breadth of sites used and only occurred on sites with 50 – 65% cropland in the surrounding buffers across years. Wading bird species also used sites with a narrower cropland range (45 – 65%) compared to shorebird species. Shorebird species were associated with sites which exhibited the widest range (20 – 65%) in percent cropland. However, all but one shorebird species was present on sites with 35 – 55% cropland in the buffered landscape, and if excluded shorebird species ranges would be similar to other waterbird guilds. Waterbirds expanded their use of sites in 2011 to include a wider range (0 – > 60%) of cropland in 1 km buffers (Figure 2.31; Table B.36). Waterfowl species were observed at sites with the narrowest range of cropland in the landscape (above 60%). Wading bird species and shorebird species were observed on sites across all ranges of cropland. Sites used by waterbirds in 2012 were characterized by a narrower range of percent cropland relative to 2011 (Figure 2.32; Table B.40). All waterbird guilds could be found on sites ranging from 51 – 59% cropland. Waterbird guilds did not differ above or below these ranges. They were fairly uniform across all waterbird guilds, waterfowl species (< 51 – 56%), wading bird species (< 51 – 58%), and shorebird species (< 51 – 59%). In 2013, waterbird guilds had expanded their use of sites relative to 2012 but not to the extent of 2011. All waterbird guilds were present at sites with adjacent lands containing less than 70% cropland (Figure 2.33; Table B.44). Waterfowl species were observed on sites with 50 – 65% cropland in the landscape. Wading bird species could be found on sites with < 50 – 70% cropland. Shorebird species were found on sites with a range of 50 – 70% cropland.

The NMDS ordination plot across all years projected the waterbird assemblage as occurring in sites characterized by 6 – > 22% forested wetlands (Figure 2.30; Table B.33). Waterfowl species were observed at sites with 14 – > 22% forested wetlands within buffered areas. Canada geese above 22% and duck species were observed at ranges from 14 – 20% forested wetlands in the adjacent landscape. Wading bird species were associated with 12 – > 22% forested wetlands in the adjacent landscape. Shorebird species exhibited the broadest breadth (6 – >22%) of percent forested wetlands in the adjacent landscape. However, all but one species occurred on sites with 14 – 22% forested wetlands in adjacent 1 km buffers. Similar to other land cover types, 2011 had the widest breadth (0 – 35%) in percent of forested wetland within 1 km buffers (Figure 2.31; Table B.37). Sites associated with waterfowl species were characterized by 15 – 30% forested wetland within buffered areas. With respect to forested wetlands, wading bird species had the widest breadth and reflected the overall yearly percentage of forested wetlands in 1 km buffers around sites. Shorebird species used sites with 0 – 25% adjacent forested wetlands. In 2012, 1 km buffers around sites contained < 16 – > 22% forested wetlands (Figure 2.32; Table B.41). Waterbird guilds were associated with sites characterized by similar percentage of forested wetland, waterfowl species16 – 22%, wading bird species across all percentages, and shorebird species 16 – > 22%. The ordination pattern for 2013 (Figure 2.33; Table B.45) of percent forested wetlands in the adjacent landscape was < 12 – > 24%. Waterfowl species occurred at ranges from < 12 – 20%. Wading bird species ranges were slightly wider < 12 – 22% and shorebird species could be found across all ranges.

Across years, waterbirds in my study were associated with areas characterized by 0 – 20% emergent wetlands within a 1 km buffer of sites (Figure 2.30; Table B.34). Waterfowl species were associated with sites ranging from 0 – 15% emergent wetlands in the adjacent landscape. Geese were associated with 0% emergent wetlands, whereas duck species were found at ranges of 5 – 15%. Wading bird species and shorebird species in were associated with 0 – 20% emergent wetlands. Waterbird assemblages in 2011 used sites with a wider range of emergent wetlands in the landscape (0 – 30%) than across all years (Figure 2.31; Table B.38). Waterfowl species were observed at sites with 0 – 5% emergent wetlands. Wading bird species used sites with 0 – 25% adjacent emergent wetlands. Shorebird species had the widest range (0 – 30%). Waterbird assemblages in 2012 had a contraction in use of sites with adjacent emergent wetlands (Figure 2.32; Table B.42). Waterfowl species and shorebird species used sites ranging from 0 – 12% adjacent emergent wetlands. Wading bird species were associated with all ranges of percent emergent wetlands in 2012. In 2013, all waterbird taxa were associated with 0 – > 16% emergent wetland in the adjacent landscape. (Figure 2.33; Table B.46). Waterfowl were observed using sites across all ranges. Geese were associated with sites 0 – 4% emergent wetlands and duck species ranged from 8 – > 16%. Wading bird species and shorebird species could be found at all ranges greater than 0% emergent wetlands in the adjacent landscape.

Discussion

Waterbird communities temporally and spatially

Waterbirds migrating through the MAV and NGoM during August – October 2011 – 2013 encountered markedly different landscapes each year. In 2011, the southeastern United States was in the midst of a multi-year drought as indicated by the Palmer Drought Severity Indices (Palmer 1965). This invariably concentrated waterbirds on available shallow water habitats in the MAV and NGoM enroute to wintering areas in the Neotropics (Erwin 1996). Birds may be attracted to sites with reliable summer – early fall water such as managed impoundments in aquaculture facilities (i.e., MBHI) and public areas (i.e., Missouri Department of Conservation Areas). Shorebirds, wading birds and early migrant waterfowl species use impoundments during spring and fall migration because these provide roost sites, refuges from hunting and other disturbances, and foraging habitats (Chabreck 1988, Erwin 1996). Wetlands in the southern MAV may be less variable spatially and temporally due to human influenced water level manipulation (Lehnen and Krementz 2005). Sites along the NGoM may also be less variable because of daily tidal inundation, potentially reducing major constraints on migration like predation and limited time for resource acquisition. These sites in turn may provide reliable stopover and refueling habitats during late autumn migration (Warnock et al. 2004).

However, variation in coastal estuarine systems reflects variation in composition of waterbird assemblages. Waterbird guilds partitioned their use of cattle grazed coastal pastures in northern California (Colwell and Dodd 1995). Wading birds used pastures with taller vegetation, shorebirds and gulls frequented short-grass pastures, and waterfowl used flooded pastures (Colwell and Dodd 1995). Coastal sites in my study differed in vegetation composition annually and at varying spatial scales. Coastal ecosystems of the NGoM were characterized by low-medium surf energy shorelines dominated by giant cordgrass (*Spartina patens*) and black needle rush (*Juncus roemerianus*) salt marshes, including narrow barrier islands, peninsular beaches, small bays, and inlets fringed by estuarine marshes or tidal flats (Withers 2002).

Colwell and Dodd (1995) reported densities of Dowitchers and other shorebirds decreased with increased vegetation height. My results similarly revealed Semipalmated Plovers and Dowitchers were associated with low vegetation saltmarsh and adjacent mudflat habitats at Grand Bay NERR. During the 2011 fall migration period, Dauphin Island, a barrier island with beach dunes surrounding a tidally influenced lagoon with a dense ~2 – 3 cm algal and biofilm substrate, was used by Western Sandpiper, Black Skimmer, Black-bellied Plover, and Willet. The greater diversity of species at Dauphin Island may reflect Withers (2002) findings that non-vegetated coastal wetland habitats are favored by wintering and migrating shorebirds.

Dauphin Island may also be a transition zone between low-medium surf energy salt marsh and barrier island habitats and Mississippi River coastal wetlands. Mississippi River coastal wetlands such as Elmer’s Island WR have been identified as regionally important to shorebirds and colonial nesting waterbirds (Withers 2002). These systems include salt marsh, deltaic and mud flats, tidal marshes, barrier islands, and estuarine bays. Elmer’s Island occurs at a more southerly latitude (29° N) relative to my other two coastal sites. Withers (2002) observed an increase in relative abundances of shorebirds from north to south and greatest use of wetlands by shorebirds between 25° – 30° N.

Kushlan (1981) observed similar trends in wading bird species richness. For example, waterbird species assemblage at Elmer's Island WR included Ruddy Turnstones (*Arenaria interpres*) and Sanderlings and may represent one of the last potential stopover sites for these and other fall migrants along NGoM. Mississippi river coastal wetlands may have provided beneficial food resources for refueling prior to migration to wintering sites in Central and South America.

The Atlantic and Gulf Coasts are frequented by tropical depressions and hurricanes. A hurricane is a tropical storm with sustained winds speeds of ≥ 120 km/h (Smith 1999). The Atlantic hurricane season extends from 1 June – 30 November and peaks during mid-August through early October (Smith 1999). The Atlantic hurricane season annually averages six storm events with 1.6 of them making landfall in the United States annually (Herbert and Taylor 1979, Smith 1999). Presently, little literature exists on hurricane disturbance to coastal wetlands and waterbird communities (Fussell, III and Allen-Grimes 1980, Wiley and Wunderle 1993).

Following Hurricane Isaac's (Category 1) landfall on 28 August 2012 at Port Fourchon, Louisiana (Bianchette et al. 2015), barrier island habitats along the NGoM were altered by precipitation, wind, and storm surges. Sand and sediment from the storm surge on the windward side of Dauphin Island was deposited in the leeward lagoon, reducing tidal habitat. Washover deposits and ephemeral channels that breach beaches are commonly caused by hurricanes (Conner et al. 1989). Similarly, the barrier island at Elmer's Island WR was altered by the dredging effect of the storm surge during a washover event as the eye of the hurricane passed over my site. Removal of the protective dune exposed the formerly calm and protected lagoon to direct input of turbulent sea water at high tides from the Gulf of Mexico. Coastal habitats surveyed during autumn 2011 and August 2012, prior to the hurricane, exhibited similar climactic conditions. Post hurricane, waterbird surveys conducted at both barrier islands in September and October 2012 and autumn 2013 differed markedly in abundance from August 2012 and autumn 2011. The 2011 inland drought or changes in habitat structure as a result of the hurricane likely influenced the reduced association of coastal wetlands and unique waterbird assemblages in 2012, such as those observed in 2011. However, hurricanes are a natural and important disturbance across the NGoM (Conner et al. 1989). In the mid twentieth century, barrier islands around Grand Isle, Louisiana experienced two major hurricane events that breached the coastal dune system and modified the shoreline through erosion and accretion (Penland and Boyd 1981). Moreover, Hurricane Katrina, (29 August 2005; Category 3) made landfall near Buras, Louisiana (Fritz et al. 2007), and other tropical depressions have impacted the NGoM in the 21st century. Hurricanes may benefit bird communities by setting back successional plant communities and exposing or altering mudflat habitat. Therefore, keeping these systems in an early successional state and fertilizing them through sediment deposition. The damage is almost always temporary in natural marsh areas and primary production is high for some period following hurricanes (Conner et al. 1989).

Grand Bay NWR and NERR is a salt marsh ecosystem on the mainland of the Mississippi Sound. The structure of salt marshes and associated sediments, coupled with its geographic location may help explain Grand Bay NWR and NERR’s intermediate relationship in ordination space to MAV and other coastal sites. Habitats at Dauphin Island may have recovered more rapidly than Elmer’s Island WR because its dune-plant ecosystem remained largely intact. The tidal action over the course of the year started erosional processes and the recovery process of tidal lagoon formation. An increase in Dauphin Island's ellipse space may be related to altered habitats expanding foraging habitats and niches by increasing heterogeneity on the landscape (Connell 1978, Cardoni et al. 2007).

The 2012 NMDS ordination plot (Figure 2.21) may have suggested an expansion and contraction in the niche space of waterbirds using MAV and NGoM wetlands. Increased shallow water habitat in the MAV following Hurricane Isaac may have provided migrant waterbirds with new foraging habitats as relative abundances increased. For example, Black-tailed Godwits (*Limosa limosa*) on wintering grounds in France expanded their use of wetland types when numbers increased regionally (Robin et al. 2013). Additionally, major precipitation events like hurricanes may provide habitats that are otherwise inaccessible during average precipitation years and reduce the normal soil moisture deficit period of summer (Conner et al. 1989). The minimal separation of waterbird assemblage ellipses in 2012, across all geographic scales (i.e., region, state, and site) may support niche expansion hypothesis in the MAV and a contraction in the NGoM following Hurricane Isaac (Valen 1965). Predominantly at the site level two of three coastal site ellipses were almost entirely encompassed within the St. Catherine Creek NWR ellipse, my southernmost MAV site. In years with major environmental disturbance along the NGoM, southern MAV sites may act as refugia for migrant waterbirds.

Similarities in structure and composition of waterbird assemblages at the site level across geographic regions may be related to increased wetland availability and possible similar water depths associated with an increase in precipitation from the hurricane in 2012. Hurricane Isaac tracked north/northwest through the lower portion of the MAV and likely provided abundant interior shallow water habitat during the driest months of the year as evident by waterbirds association with confined water depth ranges. If the intensity and frequency of tropical cyclones is influenced by increased global sea temperatures (Vecchi 2015), hurricanes in the NGoM may provide an indirect benefit to fall migrating waterbirds by providing shallow water habitat along the coast and at interior sites. Farmer and Wiens (1999) reported years with above average spring precipitation were correlated with increased body fat in female Pectoral Sandpiper. Thus, increased precipitation in the fall may lead to increased abundance and quality of stopover habitats and improved body condition of birds arriving on wintering grounds.

Body condition of migratory shorebirds upon arrival to wintering grounds is linked to survival and access to quality foraging grounds (Myers and McCaffery 1984). Individuals in better body condition (greater mass) were able to establish and defend winter feeding territories; such as, intra- and interspecific territorial behavior observed in Least Sandpipers, Sanderlings, and Black-bellied Plovers on wintering grounds in Peru (Myers and McCaffery 1984). Black-tailed Godwits wintering in good quality habitats also tend to occupy good quality breeding habitats and experience increased breeding success (Alves et al. 2013). Therefore, being in better body condition during southward migration and on the wintering grounds may lead to increased fitness the following breeding season.

One year after Hurricane Isaac, in 2013, confidence ellipse of waterbird assemblages were similar to 2012. However, regional differences became more apparent as two coastal sites continued to recover slowly and return to their pre-hurricane state. It may be possible that ellipses associated with Grand Bay NWR and NERR and Dauphin Island experienced reduced waterbird recovery times because of their greater distance from the eye of the storm relative to Elmer’s Island WR. For example, the waterbird assemblage at Elmer’s Island WR in 2013 ellipse’s still reflected the hurricane impacts to wetland habitats, suggesting a delayed recovery at storm landfall sites because most damage occurs within close proximity of the eye of the storm (Riehl 1979, Scatena and Larsen 1991). For example, forest game species studied across the Gulf of Mexico on the Yucatan Peninsula, Mexico, following Hurricane Dean in 2007 indicated positive trends toward recovery 30 months after the hurricane (Ramírez-Barajas et al. 2012). In my study, assessments of coastal sites were conducted 12 – 14 months after Hurricane Isaac. Therefore, it may have been too soon after the hurricane to encounter different waterbird assemblages in coastal Louisiana. Inland, habitats likely experienced precipitation more reflective of an average year in the MAV as indicated by the 2013 Palmer Drought Severity Indices (Palmer 1965). Droughts and hurricane events emphasize the importance of reliable shallow water habitats on the landscape, such as aquaculture facilities and other managed areas during the typically dry period of late summer-early fall in the MAV.

During the first half of October 2013, I was unable to access public federal sites (i.e., St. Catherine Creek NWR and Grand Bay NERR and NWR) due to a furlough period for federal employees. The ellipse for time period 5 reflected the waterbird assemblage of all other visited sites. The ellipse, coinciding with the furlough, saw a leftward shift across ordination space which differed from the two previous years (Figure

2.10). This indicated waterbird assemblages reflected assemblages more closely associated with early September. The reduction in ellipse size and shift in ordination space illustrated the importance of federal managed wetlands. Had I been able to access sites, I hypothesize time period five would have more closely resembled period six in both shape and composition of waterbird species as in 2011 and 2012.

Latitudinal differences were observed across years and in 2012 – 2013. The greatest species richness for waterbirds was observed on wetlands in the mid to south Mississippi Delta region of Mississippi from Charleston Mississippi (34.0° N) to the Mississippi/Louisiana border (31.0° N). In 2012, species richness shifted north and likely due to the increased wetland habitat on the landscape caused by precipitation associated with Hurricane Isaac. A year following the hurricane, in 2013, latitudinal spread of birds more closely resembled across year (all years, Figure 2.11; 2013, Figure 2.22). Additionally, the highest concentration of aquaculture production facilities are located within these latitudes (Feaga et al. 2015). Due to increasing costs associated with raising catfish and competition with foreign markets, the production pond acreage has declined since highs in the 1980s (Dubovsky and Kaminski 1987, Dubovsky and Kaminski 1992, Feaga et al. 2015). Currently an abundance of idled catfish ponds exist on the landscape. Programs like MBHI could provide waterbirds with abundant shallow water habitat on idled ponds through monetary incentives to landowners.

St. Catherine Creek NWR occurs at the southern end of the most species rich portion of my latitudinal gradient south of Natchez, Mississippi (31.5 ° N). A half of degree shift northward (31.0 – 31.5 ° N) of the southern edge of greatest waterbird diversity in 2012 may indicate that interior sites become important staging sites during inclement weather along the NGoM. The site ellipses of waterbird assemblages at St. Catherine Creek NWR in 2012 – 2013 were intermediate between more northerly sites in the MAV and southerly sites along the NGoM. A history (> 20 years) of shallow water management also exists at this site, where light disking and subsequent flooding provide habitat for migrant shorebirds in moist-soil impoundments (Twedt et al. 1998). Similarly, other migrant waterbird species may rely on refuges to provide annual fall shallow water habitat. Unlike other waterbirds, Wood Storks migrate north in the fall to forage as water levels recede and concentrate aquatic wildlife (Coulter et al. 1999). Wood Storks captured and affixed with satellite transmitters at St. Catherine Creek NWR returned in subsequent years following breeding in eastern Mexico (Bryan Jr et al. 2008). This phytolatry across waterbird guilds to exploit a seasonal resource may indicate the importance of providing reliable annual shallow water wetland habitat as more of the landscape converted for human use.

Waterbird assemblage relationships to environmental variables

Water depth and dominant land cover types

The MAV was historically dominated by forested wetlands and today < 25% of this land cover remains (Fredrickson et al. 2005, Foth et al. 2014). The current land use in the MAV is dominated by agriculture which may provide potentially new foraging habitats for early migrant waterbirds. Twedt *et al*. (1998) made the recommendation of lightly disking harvested soybean fields and subsequent shallow flooding to create mudflat habitat. Similar methods may be applicable to fallow fields, moist-soil impoundments, idled catfish ponds, or areas where crops failed the previous growing season. Across all years, NMDS ordination (Figure 2.26) displayed waterbirds associating with water depths ≤ 8.5 cm. For example, shorebird species in Sri Lanka similarly foraged most efficiently in shallow water (≤ 10 cm) lagoons (Bellio and Kingsford 2013). Besides morphological constraints, the limiting factor allowing shorebirds access to food resources may be the amount of shallow water on the landscape.

Open water habitat within 1 km buffers of my sites was one of four dominant land cover types across both regions. Albanese and Davis (2015) saw a > 200% increase in shorebird density and richness when density of wetlands within their buffers increased. Waterbirds in the MAV used sites with approximately 50% cropland, 20% open water, 20% forested wetlands, and 10% emergent wetlands. Winter assemblages of Mallards and other dabbling ducks used similar landscape compositional affinities (i.e., 50% cropland, 20% emergent wetlands, 20% forested wetlands, and 10% open water) in the Mississippi MAV (Pearse et al. 2012). However, waterbird assemblages in NGoM sites showed greater affinity for open water and emergent wetlands and less of forested wetlands and crops. Withers (2002) saw similar composition of coastal wetland habitats associated with greatest relative abundances of wintering and migrating shorebirds. Also, selection of sites with lower percentages of two dominant land cover types could be related to less land classified as forested wetland or croplands at or near coastal wetland sites. Coastal plain sandy soil types may not be conducive to support row crops. A greater sand and lower clay content than alluvial soils of the MAV may also influence the presence of forested wetlands in the adjacent landscape.

Management Implications

Coastal habitats and waterbird communities were dynamic across my three field seasons. The autumn of 2011, my initial study season, represented a below average precipitation year indicated by the Palmer Drought severity indices. Therefore, shallow water wetland habitat conditions were likely reduced. This was followed by a hurricane disturbance year in 2012 and lastly the beginning of a recovery period along the NGoM during 2013 and average precipitation during autumn in the MAV.

The physical conditions and plant communities of my sites were likely factors structuring these waterbird assemblages (Fretwell 1972, Petit and Petit 1996) but may have also reduced the recovery time of coastal sites impacted by Hurricane Isaac. Residents of Dauphin Island have weathered many storms in the past (Swann 2008). This prompted them to take action against further shoreline loss. Through the installation of concrete structures and subsequent colonization by marine organisms to create "living shorelines," residents were able to buffer against further loss of saltmarsh habitat on Dauphin Island (Swann 2008). These living shorelines had an additional benefit by successfully establishing oyster beds for continued sediment accretion. The exposed portion of the concrete structure acted as a break water and buffered further wetland loss during Hurricane Katrina in 2005 (Swann 2008). The conservation and management of salt marsh ecosystems is important to migrant birds and humans along the NGoM.

Elmer's Island WR experienced the greatest degradation and complete removal of the dune system across wide areas of the barrier island likely due to storm landfall ~15 km to the southwest. To reestablish the dune ecosystem, the Louisiana Department of Wildlife and Parks (LDWFP) closed the refuge to public access for a year and implemented coastal vegetation plantings of black mangroves (*Avicennia germinans*) and cordgrass in washover areas. The installation of sand fencing in front of existing dunes and at washover areas (Nordstrom et al. 2000) by LDWFP provided a foundation for wind and water deposition of sediment to expedite reconstruction of the dune ecosystem critical for maintaining barrier islands. Additionally, conserving and preserving remaining coastal dune and marsh systems are important from a biological and economical perspective. Estuaries have extremely high primary and secondary productivity and support a great abundance and diversity of fish and invertebrates (Beck et al. 2001). Saltmarsh also reduces storm surge by ~7 cm for every one kilometer of intact coastal marsh (Stokstad 2005). Living shorelines and artificial oyster reefs have been successful in the reduction of wave energy erosion in coastal marshes and barrier islands in along the NGoM (Piazza et al. 2005, Swann 2008). However, attenuation and shoreline protection, like other ecosystem services, are likely to vary across time and space (Barbier 2006, Gedan et al. 2011). As sea levels rise and urbanization expands, the preservation of salt marsh ecosystems, through conservation easements, may be of great importance to coastal areas.

Water depth

Seasonal rainfall patterns affect prey availability by causing water levels to fluctuate in shallow water habitats. Relationships between water level changes and wading bird foraging have been demonstrated for many species (Kushlan 1978; 1981). Also, water depth management is often one of the most influential mechanisms influencing occurrence of shorebird and waterbird species presence and distribution in a wetland (Bellio and Kingsford 2013). Shorebird foraging niches, in particular, are further constrained by morphological features such as bill size and structure (i.e., sediment penetration) and tarsus length (i.e., maximum water depth; Baker 1979). Waterbirds migrating in August through the MAV were dominated by shorebirds. These early migrants encountered a landscape of reduced shallow water habitat due to low precipitation and high evapotranspiration in 2011 and 2013; whereas, in 2012, precipitation from Hurricane Isaac likely provided abundant ephemeral wetlands. A simple yet effective management solution for increasing shallow water habitat in the MAV region may be the continuation of programs like MBHI. The MBHI program encouraged landowners to provide inland shallow water (i.e., ≤ 30 cm) habitat to mitigate for potentially oil impacted coastal ecosystems (Feaga et al. 2015).

My study did not specifically assess the MBHI program because aquaculture sites were only enrolled only in 2010, and my study was not initiated until 2011. I selected sites previously enrolled in the MBHI which demonstrated continued use of waterbirds with great abundances in successive years (CHAPTER III). However, the MBHI goal of providing ~30 cm of water during fall migration may have excluded many early migrant species. My ordination analysis associated early migrant (i.e., August) waterbirds with habitats containing approximately five centimeters of water within and across years. Transitioning from the hotter-dryer summer months toward the cooler-wetter winter months, wetland habitats in the MAV and NGoM experienced weather events (i.e., tropical depressions, southward moving fronts) resulting in increased precipitation and availability of wetlands.

In September and October, water depths associated with waterbird communities increased 50%. Across all years, the increase in water depth from five to ≥ seven centimeters was strongly associated with the arrival of migrating Blue-winged Teal. Mid to late September also coincided with teal hunting seasons across much of the Mississippi Flyway. If wetland complexes are managed around these depths, they may encourage increased use by Blue-winged Teal and benefit waterfowl hunters. Waterfowl were present in greatest abundances during autumn migration at water depths of 6.0 – 7.5 cm which was narrower than ranges (4.0 – 16.0 cm) by Hagy and Kaminski (2012) for wintering dabbling ducks in the Mississippi MAV. This difference may be due to the wider foraging niches, increased body size, increased precipitation in winter or a combination of these for waterfowl compared to shorebirds, wading birds, and other waterbirds. Managing shallow wetland habitats (4.0 – 8.0 cm; Figures 2.26, 2.27, 2.28, and 2.29,) early in fall and gradually increasing depths (i.e., ≤ 16.0 cm) for wintering waterfowl would benefit a greater number of waterbird species (Hagy and Kaminski 2012).

Dominant land cover types

Landscape features influence distribution of waterbirds throughout their annual cycle (Weller 1995, Stephens et al. 2005, Pearse et al. 2012, Feaga et al. 2015). Managing public and private lands across the MAV for diverse land cover types would meet the dynamic physiological needs of fall migrant waterbirds. Conservation planning and implementation in the MAV has been primarily focused on wintering waterfowl demand for food energy (assuming this resource may be limited) using daily ration models. The data to support these models for wetland birds other than waterfowl are currently limited and may require frequent updating as land use changes (Loesch et al. 2000). However, once appropriate baseline data (e.g., APPENDIX A) have been collected for a multitude of target species across seasons, these same methods could be applied to the whole waterbird community. Thereby allocating resulting habitat objectives to public and private lands for support of target waterbird population levels during fall migration and wintering periods (Reinecke et al. 1989, Pearse et al. 2012).

Fleming et al. (2015) reported the diversity of contiguous or nearby wetlands may have afforded wintering dabbling ducks with increased diversity of food and other resources at local and landscape scales. Waterbirds migrating to the MAV during the driest parts of the year may be met with a reduction in wetland heterogeneity and instead exhibit hierarchical habitat selection (Johnson 1980, Shepherd and Lank 2004, Folmer et al. 2010). As waterbirds migrate, they likely seek reliable wetland complexes, both natural and artificial (i.e., aquaculture) as they move across the landscape. Migrant waterbirds further select site-specific characteristics within and among wetlands in the adjacent landscape. Public and private areas containing a diversity of wetland habitats at the local and landscape scales will contribute to daily food resource acquisition. This will in turn promote the conservation of waterbird diversity in wetland ecosystems of the MAV and NGoM.

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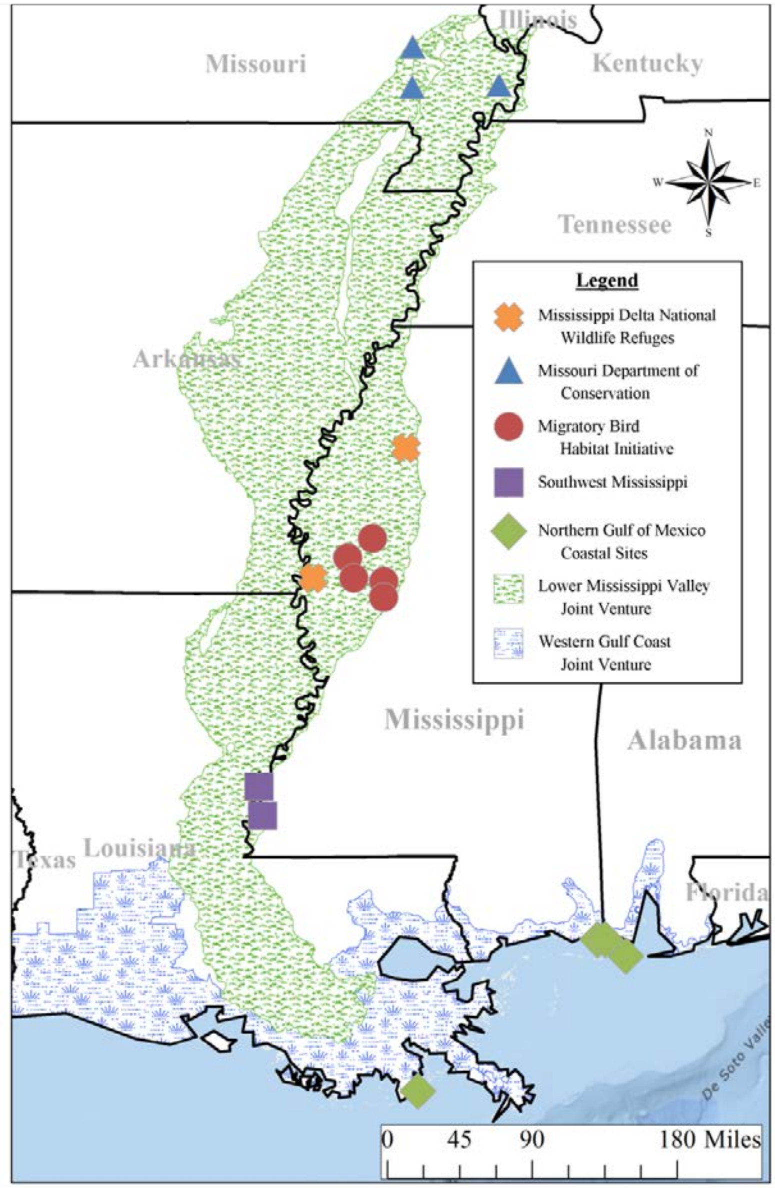

Figure 2.1 Sites used to estimate waterbird species composition and relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Sites (*n* = 16; APPENDIX D. Table D.1) used to estimate waterbird species (waterfowl, wading bird, and shorebird) composition and relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.
Legend: Mississippi Delta National Wildlife Refuges (orange “X”), Missouri Department of Conservation (blue triangle), Migratory Bird Habitat Initiative (red circle), Southwest Mississippi (purple square), Northern Gulf of Mexico Coastal sites (green diamond), Lower Mississippi Valley Joint Venture (green shading), Western Gulf Coast Joint Venture (blue shading).

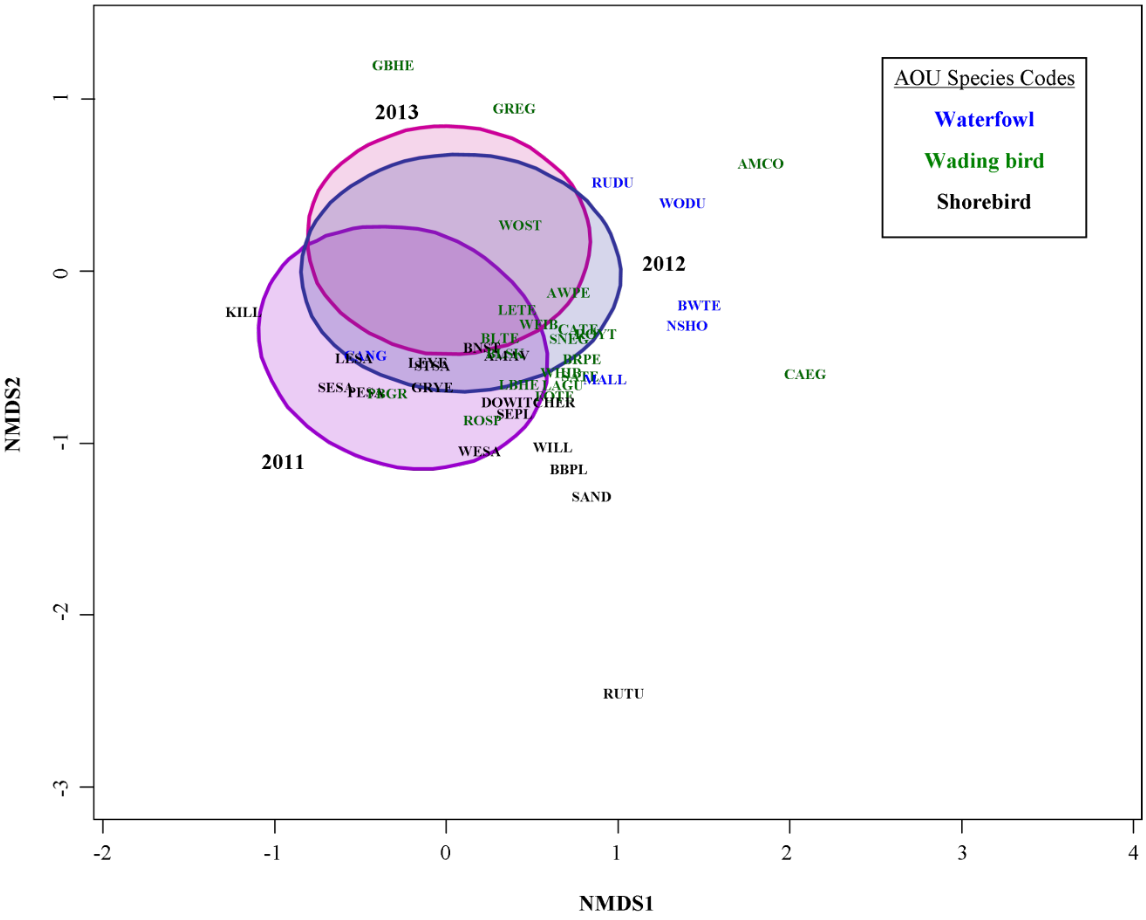

Figure 2.2 Yearly 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages from 2011 – 2013.

Yearly (*n* = 3; 2011 [purple], 2012 [blue], 2013 [pink]; APPENDIX B, Table B.3) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

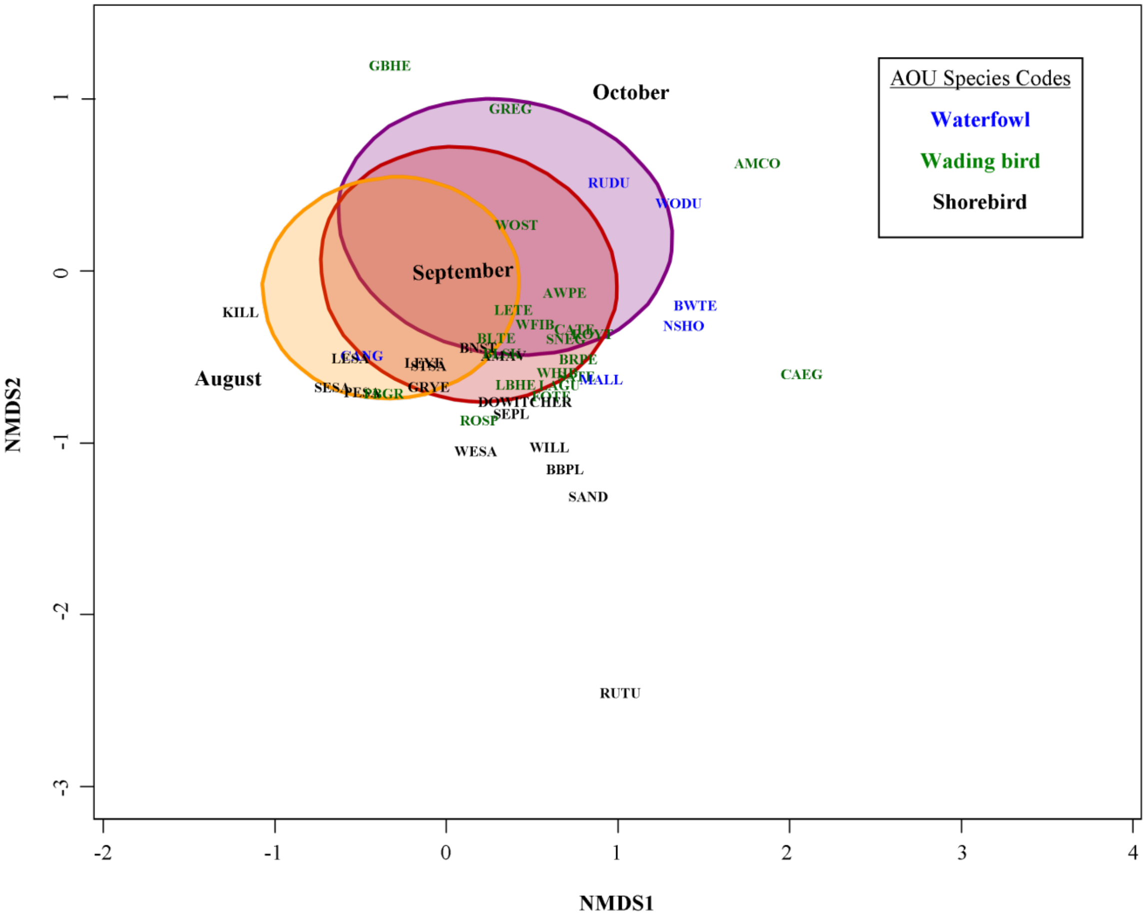

Figure 2.3 Monthly 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages from 2011 – 2013.

Monthly (*n* = 3; August [orange], September [red], October [purple]; APPENDIX B, Table B.4) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages, in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

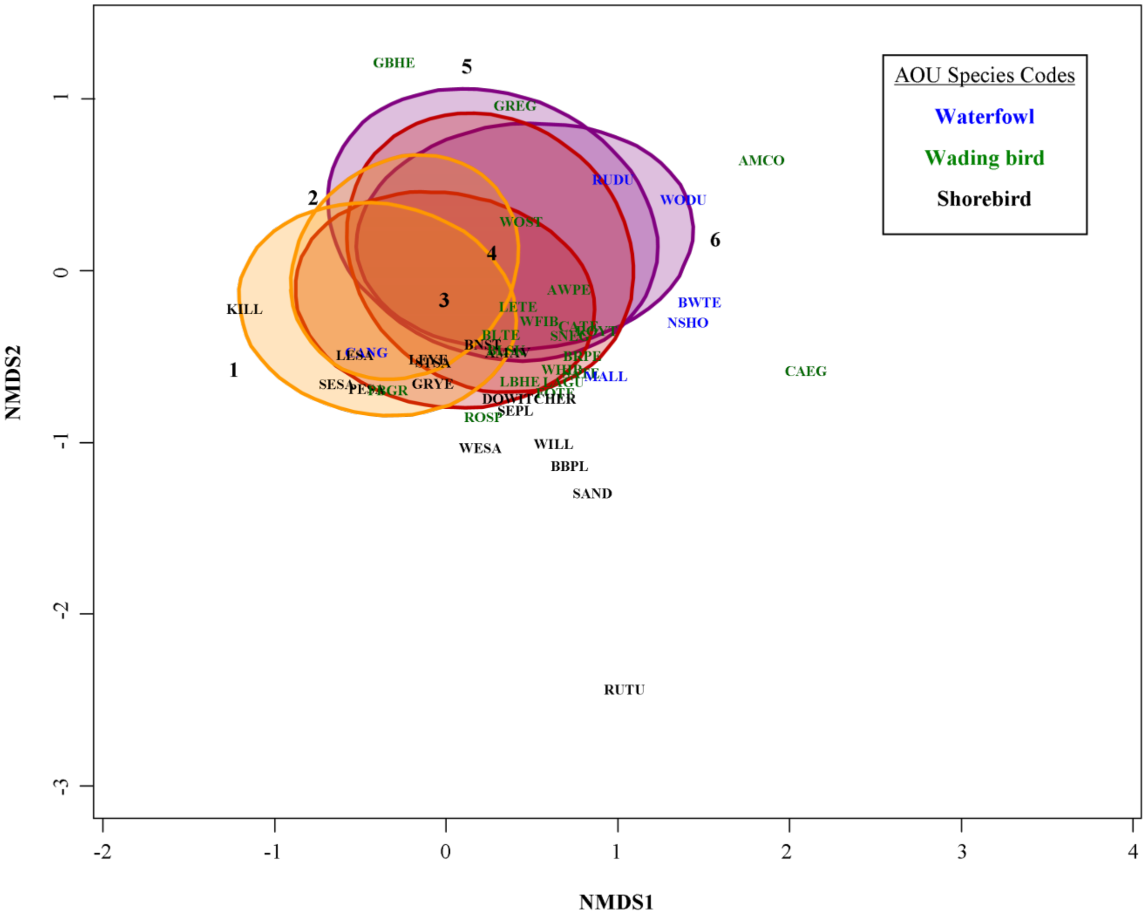

Figure 2.4 Twice-monthly survey period 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages from 2011 – 2013.

Twice-monthly survey time period (*n* = 6; APPENDIX B, Table B.5) 95% confidence ellipses color coded to represent their associated month in Figure 2.3. Ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

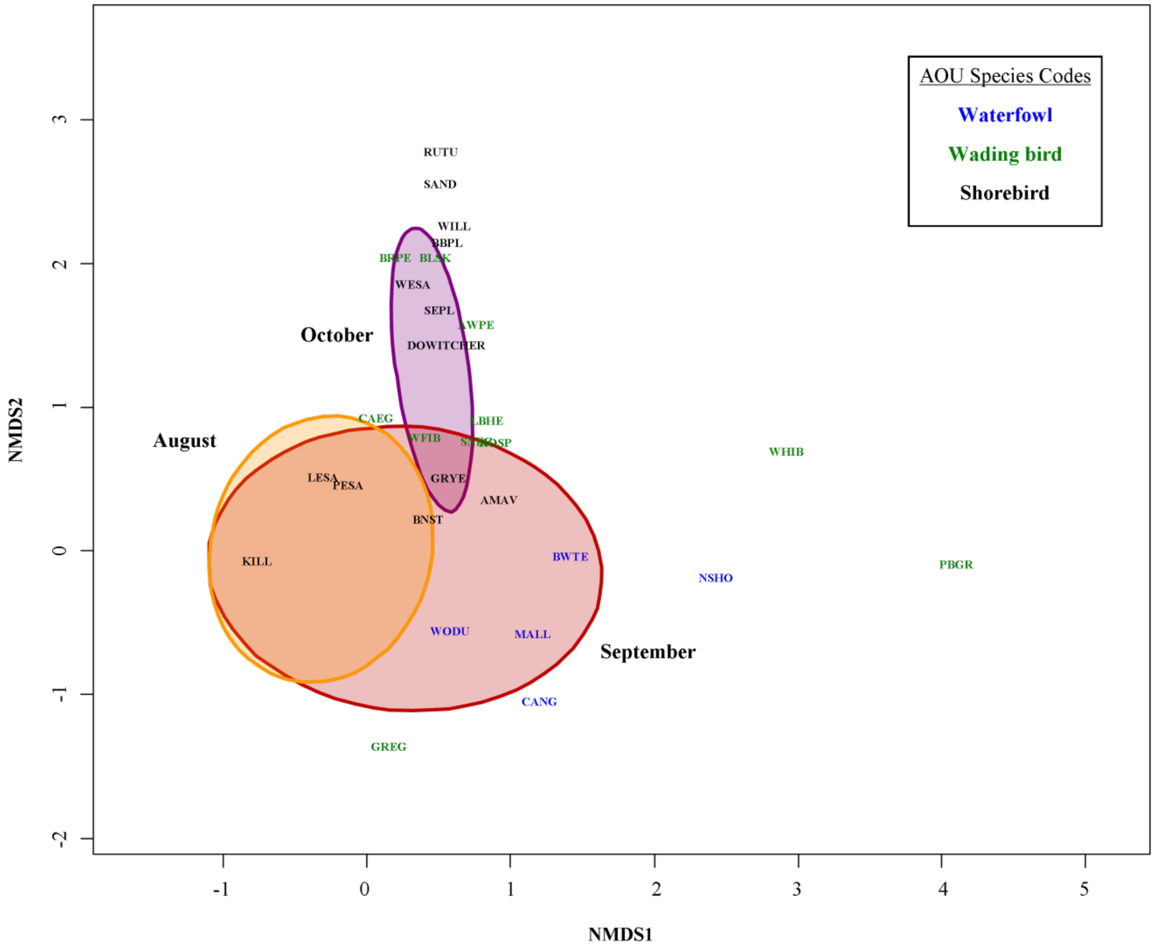

Figure 2.5 Monthly 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2011.

Monthly (*n* = 3; August [orange], September [red], October [purple]; APPENDIX B, Table B.6) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages (Table B.6) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

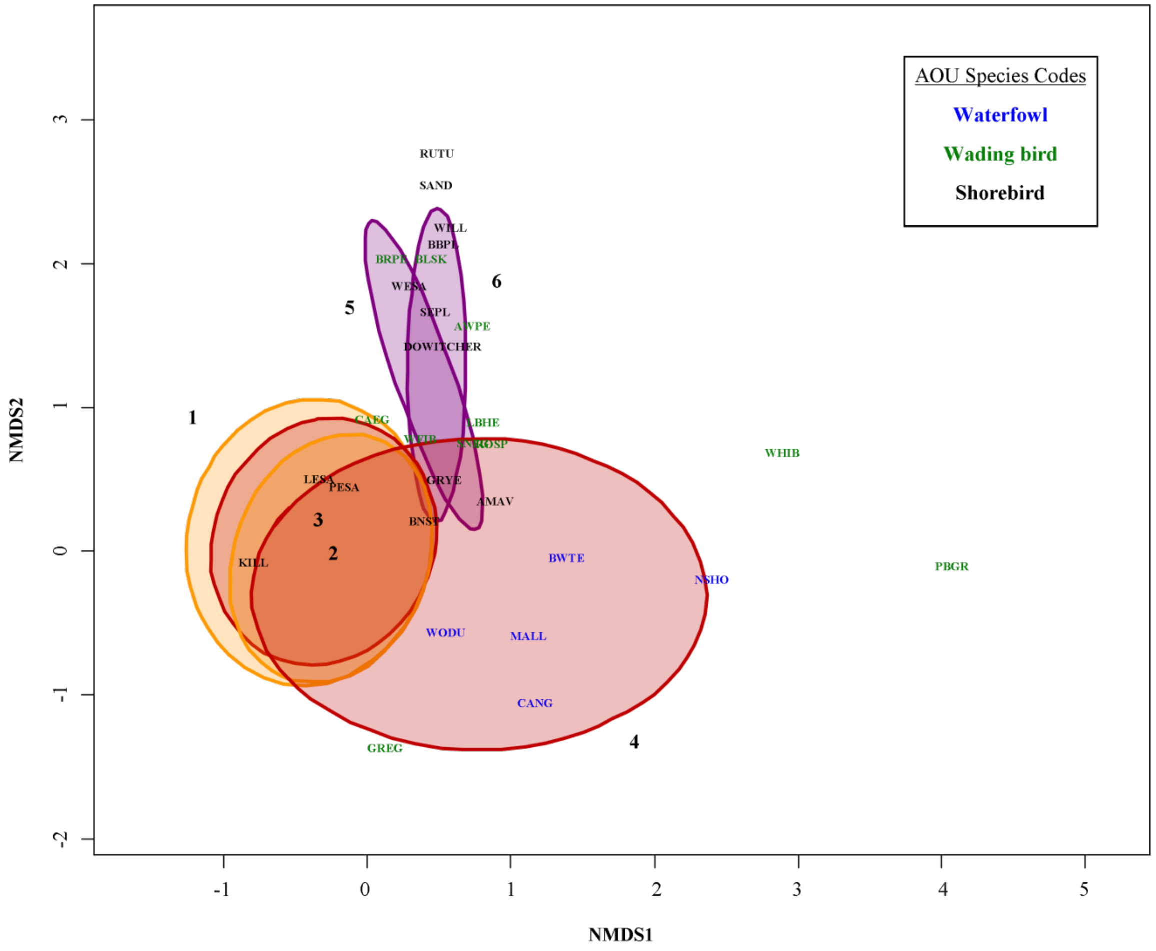

Figure 2.6 Twice-monthly survey period 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2011.

Twice -monthly survey time period (*n* = 6; APPENDIX B, Table B.7) 95% confidence ellipses color coded to represent their associated month in Figure 2.5. Ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading birds**, and **shorebirds**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

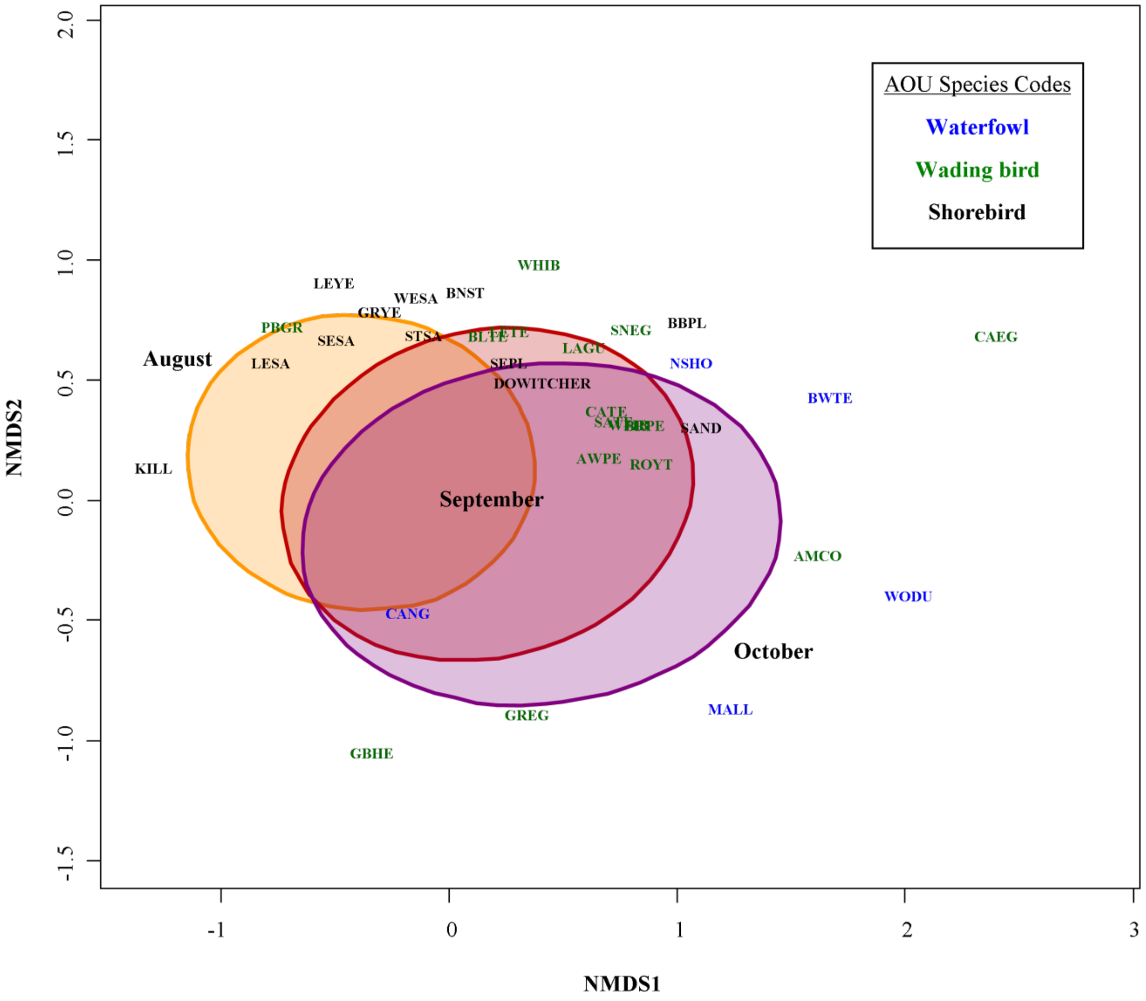

Figure 2.7 Monthly 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2012.

Monthly (*n* = 3; August [orange], September [red], October [purple]; APPENDIX B, Table B.8) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

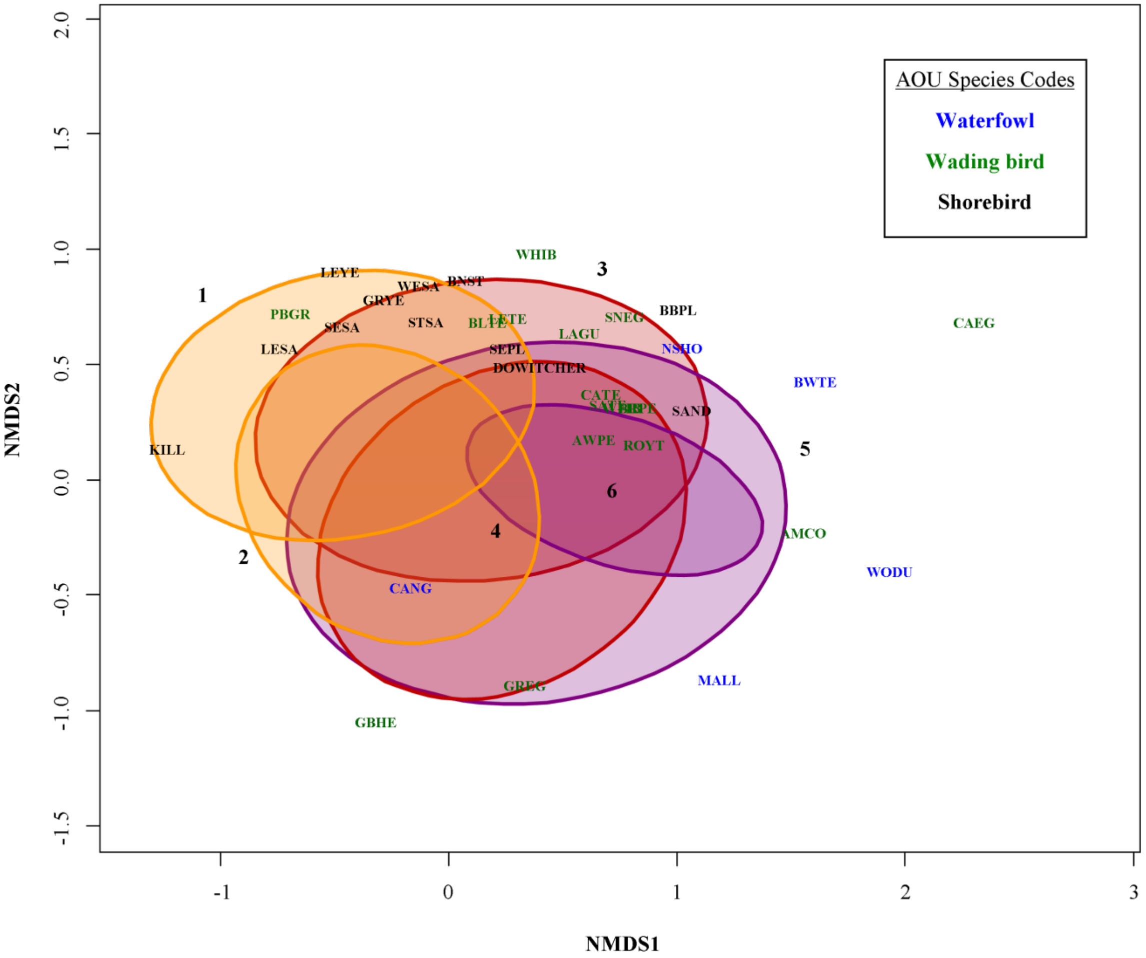

Figure 2.8 Twice -monthly survey period 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2012.

Twice -monthly survey time period (*n* = 6; APPENDIX B, Table B.9) 95% confidence ellipses color coded to represent their associated month in Figure 2.7. Ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

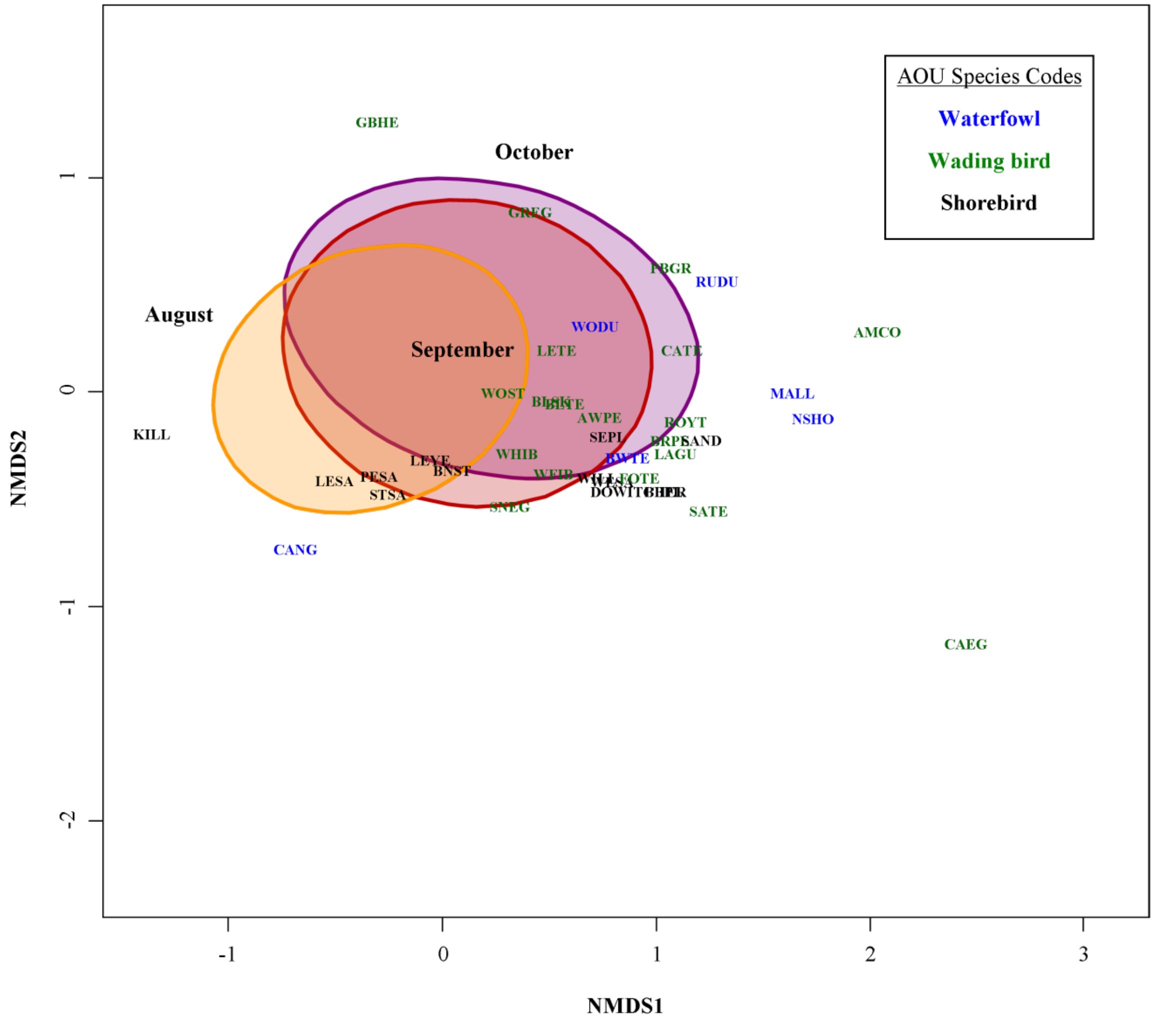

Figure 2.9 Monthly 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2013.

Monthly (*n* = 3; August [orange], September [red], October [purple];APPENDIX B, Table B.10) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

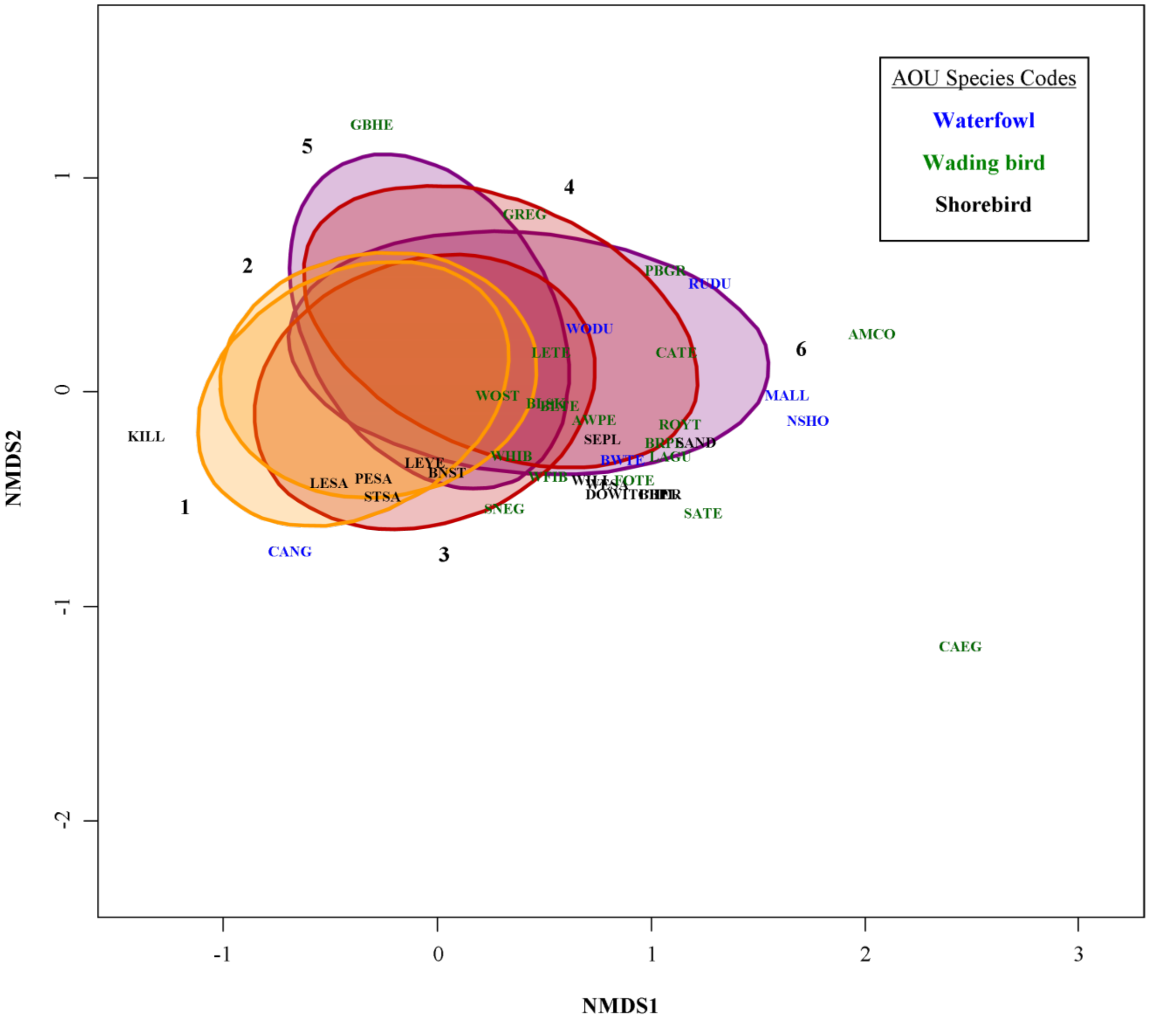

Figure 2.10 Twice -monthly survey period 95% confidence ellipses overlay non-metric multidimensional scaling ordination of waterbird assemblages in 2013.

Twice -monthly survey time period (*n* = 6; APPENDIX B, Table B.11) 95% confidence ellipses color coded to represent their associated month in Figure 2.9. Ellipses overlay non-metric multidimensional scaling ordination of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

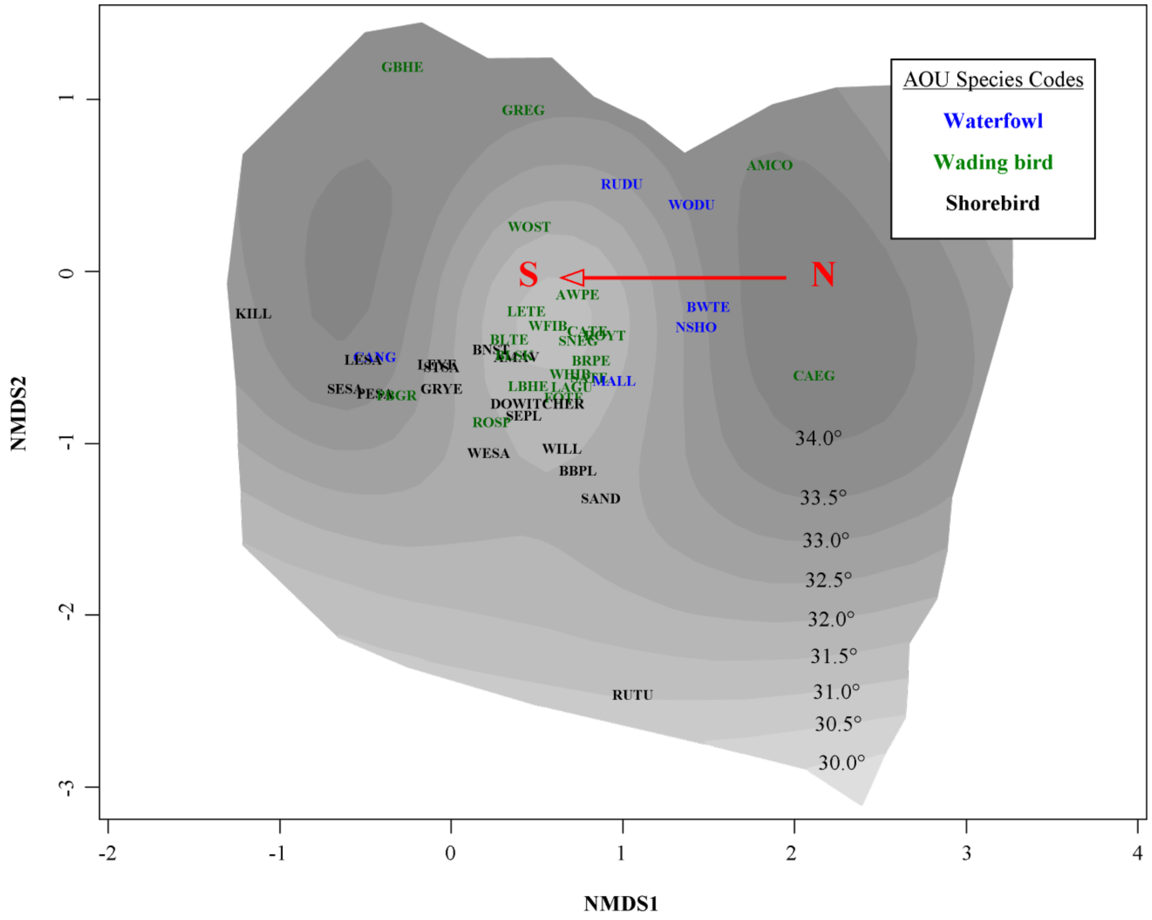

Figure 2.11 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on latitudinal gradient analysis from 2011 – 2013.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**; APPENDIX B, Table B.12) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico overlain on latitudinal gradient analysis (gray) during August – October 2011 – 2013. Moving along the “**Red arrow**” between North (**N**) and South (**S**) visualizes movement in latitude across ordination space. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

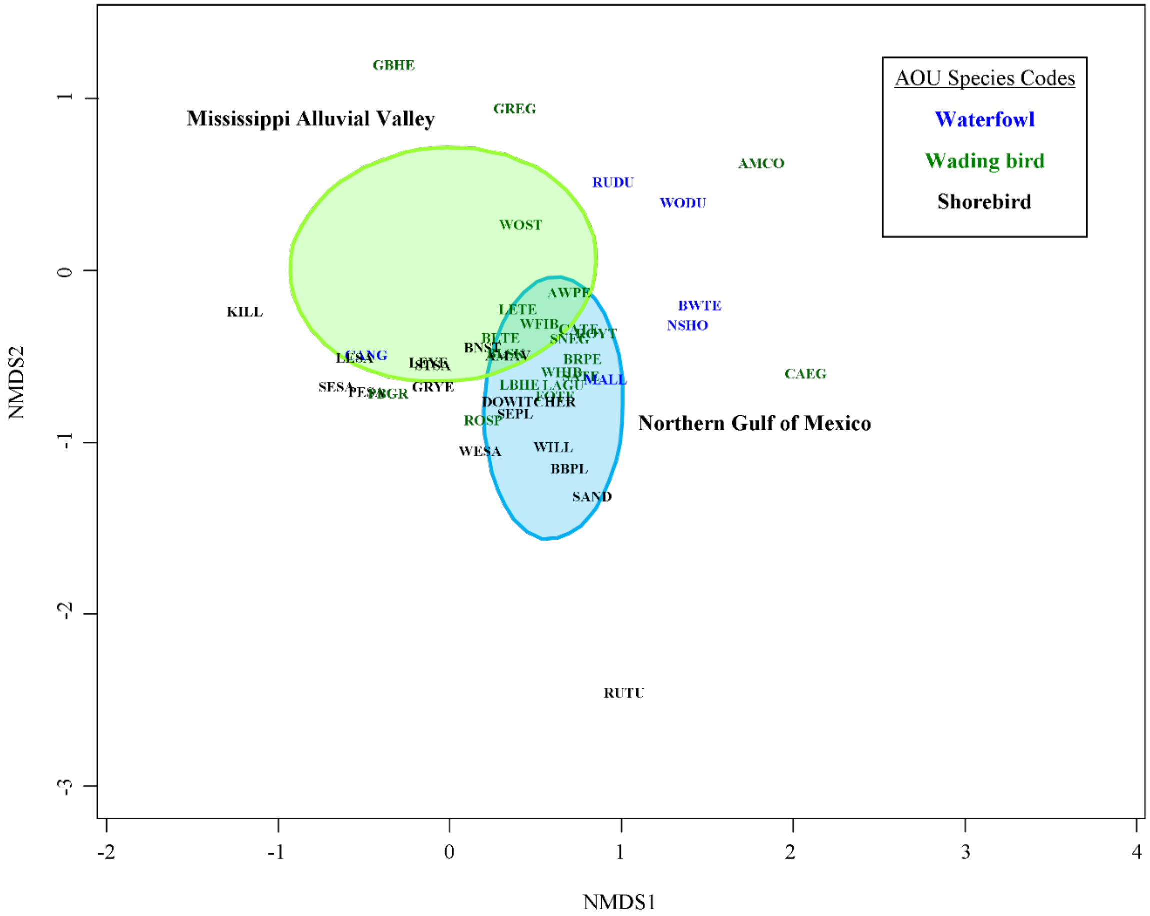

Figure 2.12 Regional 95% confidence ellipses overly non-metric multidimensional scaling ordination of waterbird assemblages from 2011 – 2013.

Regional (*n* = 2; Mississippi Alluvial Valley [light green] and northern Gulf of Mexico [light blue]; APPENDIX B, Table B.13) 95% confidence ellipses overly non-metric multidimensional scaling ordination of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

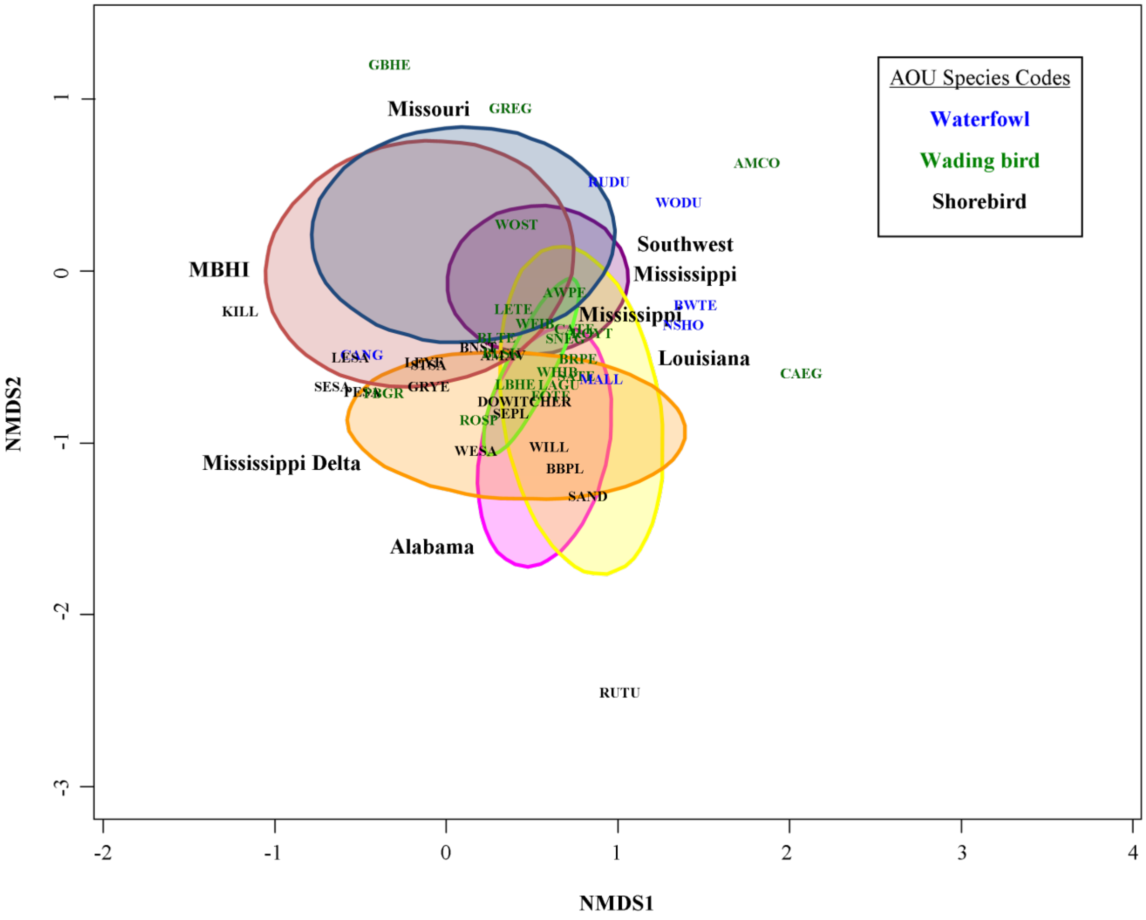

Figure 2.13 State 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages from 2011 – 2013.

State (*n* = 7; Missouri [blue], MBHI [Migratory Bird Habitat Initiative, red], Mississippi Delta [orange], Southwest Mississippi [purple], Alabama [pink], Mississippi [coast; light green], and Louisiana [yellow]; APPENDIX B, Table B.14) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading birds**, and **shorebirds**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

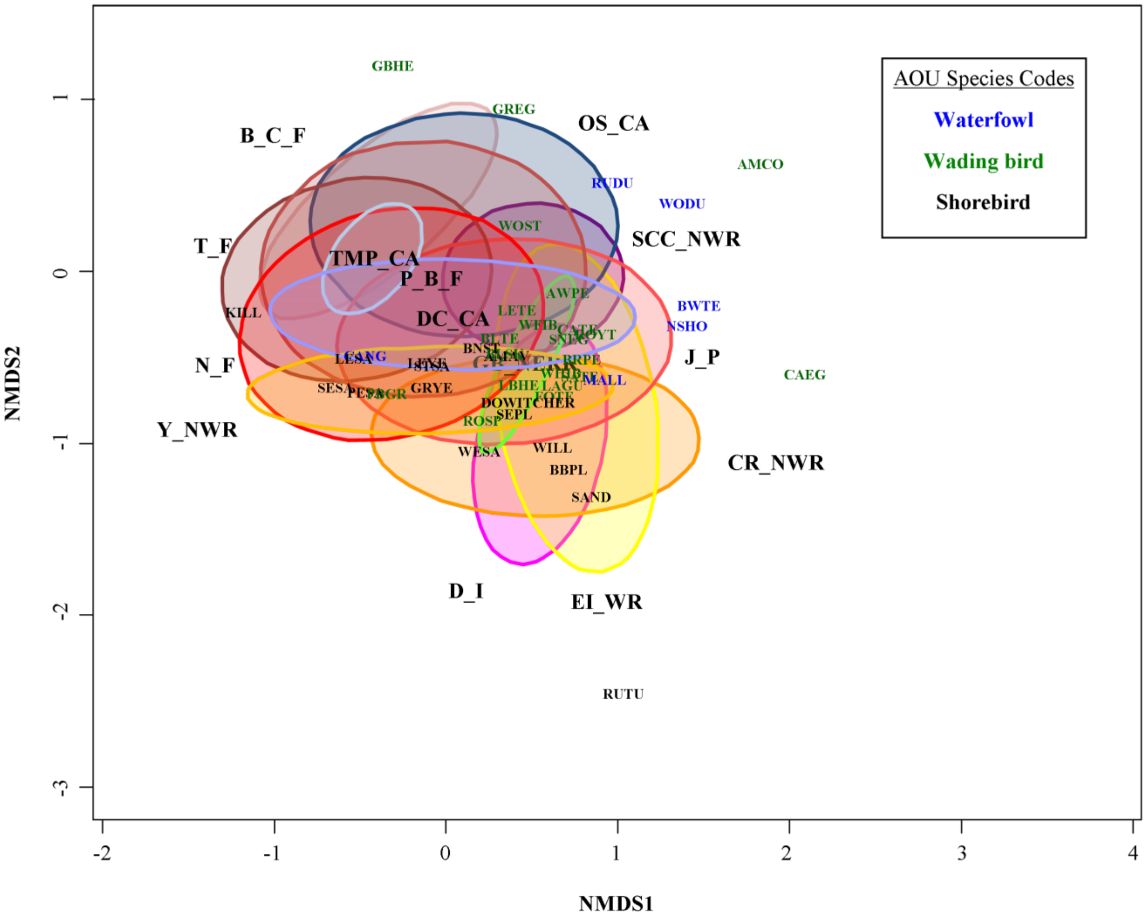

Figure 2.14 Site 95 % confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages from 2011 – 2013.

Site (*n* = 14; APPENDIX D, Table D.1; APPENDIX B, Table B.15) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

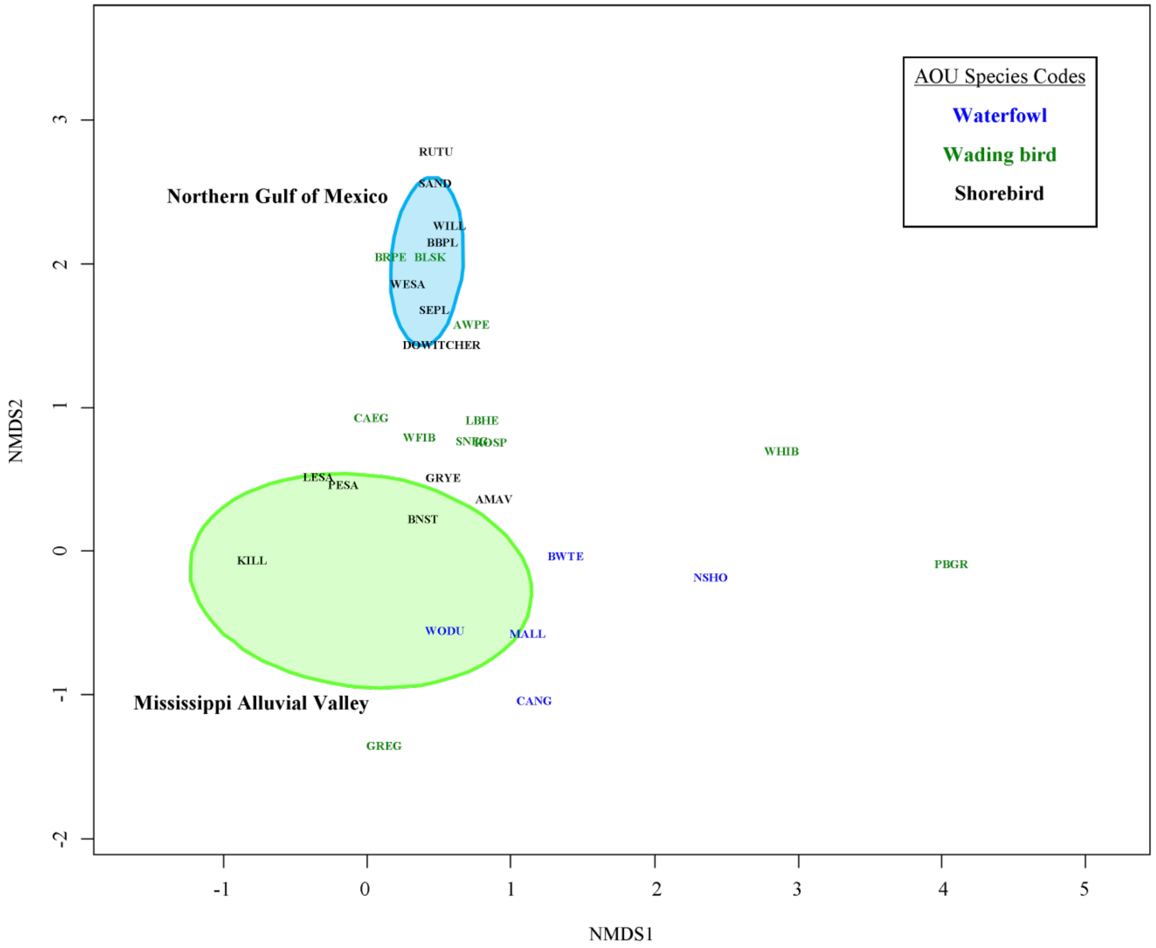

Figure 2.15 Regional 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2011.

Regional (*n* = 2; Mississippi Alluvial Valley [light green] and northern Gulf of Mexico [light blue]; APPENDIX B, Table B.16) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2001. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

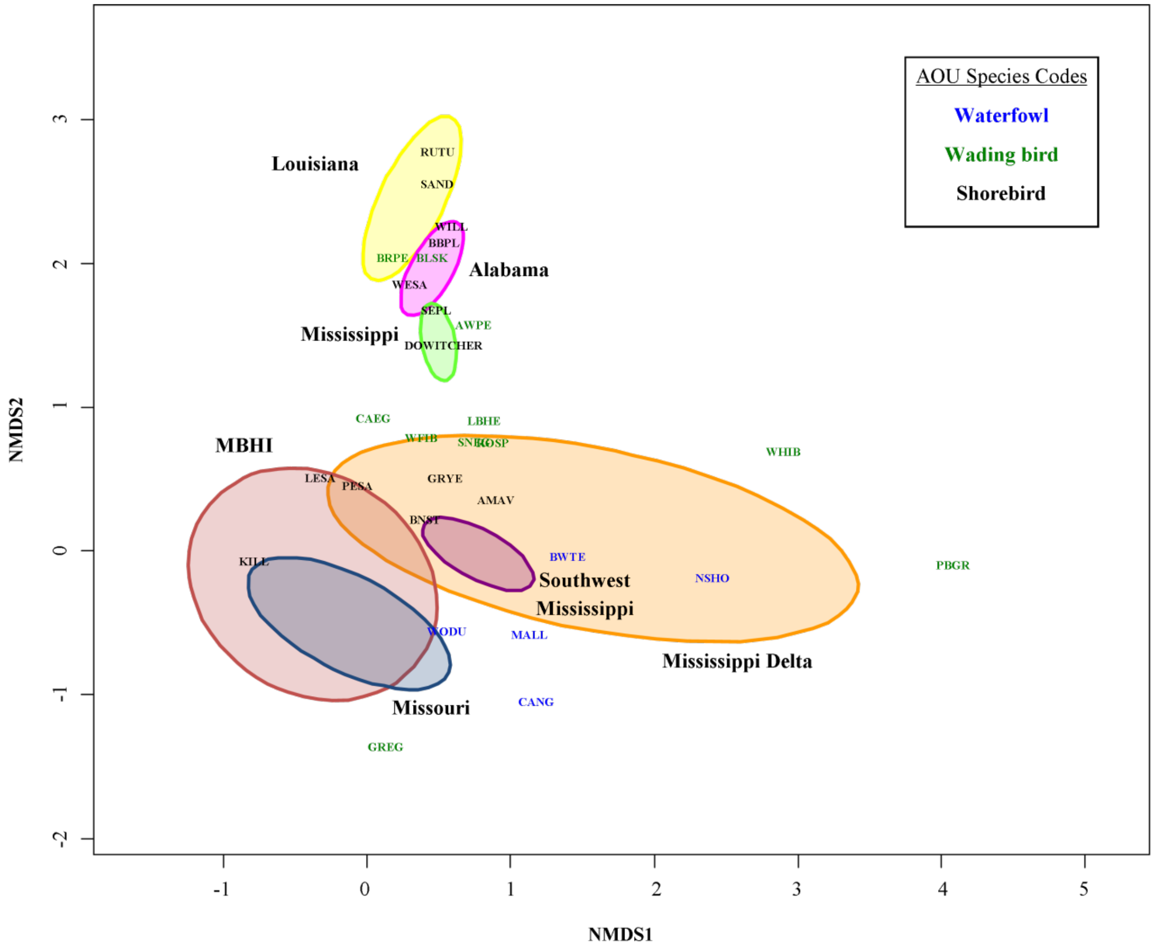

Figure 2.16 State 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2011.

State (*n* = 7; Missouri, MBHI [Migratory Bird Habitat Initiative, red], Mississippi Delta [orange], Southwest Mississippi [purple], Alabama [pink], Mississippi [light green], and Louisiana [yellow]; APPENDIX B, Table B.17) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

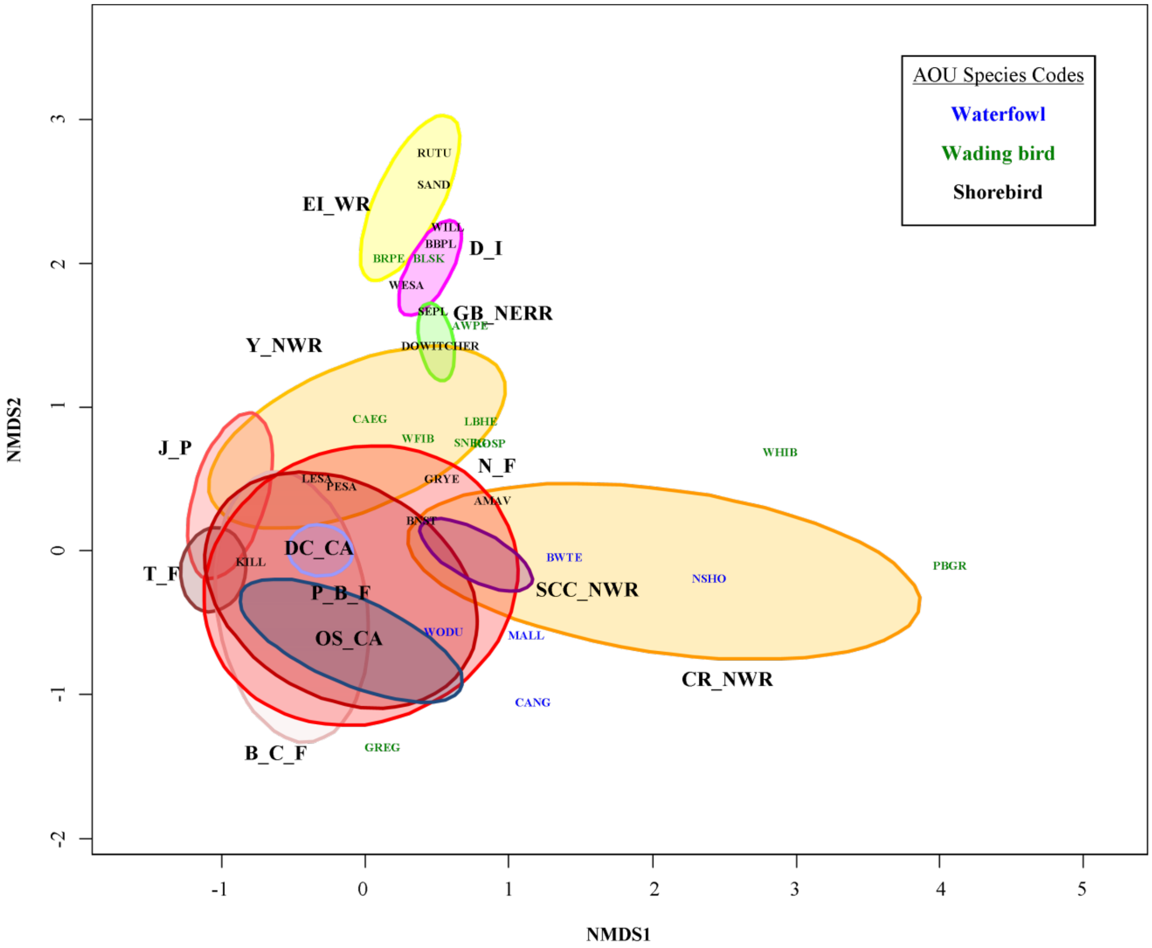

Figure 2.17 Site 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2011.

Site (*n* = 13; APPENDIX D, Table D.1; APPENDIX B, Table B.18) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

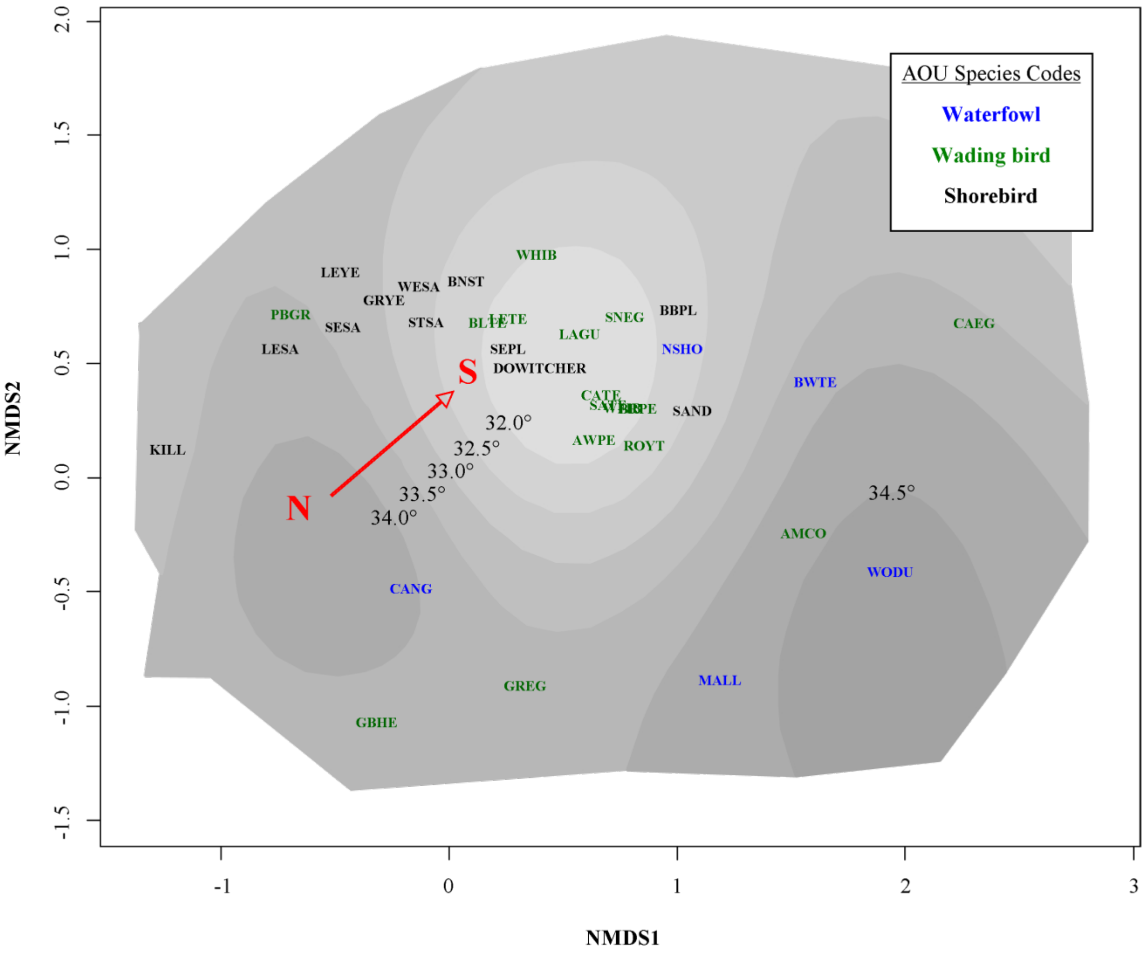

Figure 2.18 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on latitudinal gradient analysis in 2012.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**; APPENDIX B, Table B.19) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico overlain on latitudinal gradient analysis (gray) during August – October 2012. Moving along the "**Red arrow**" between North (**N**) and South (**S**) visualizes movement in latitude across ordination space. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

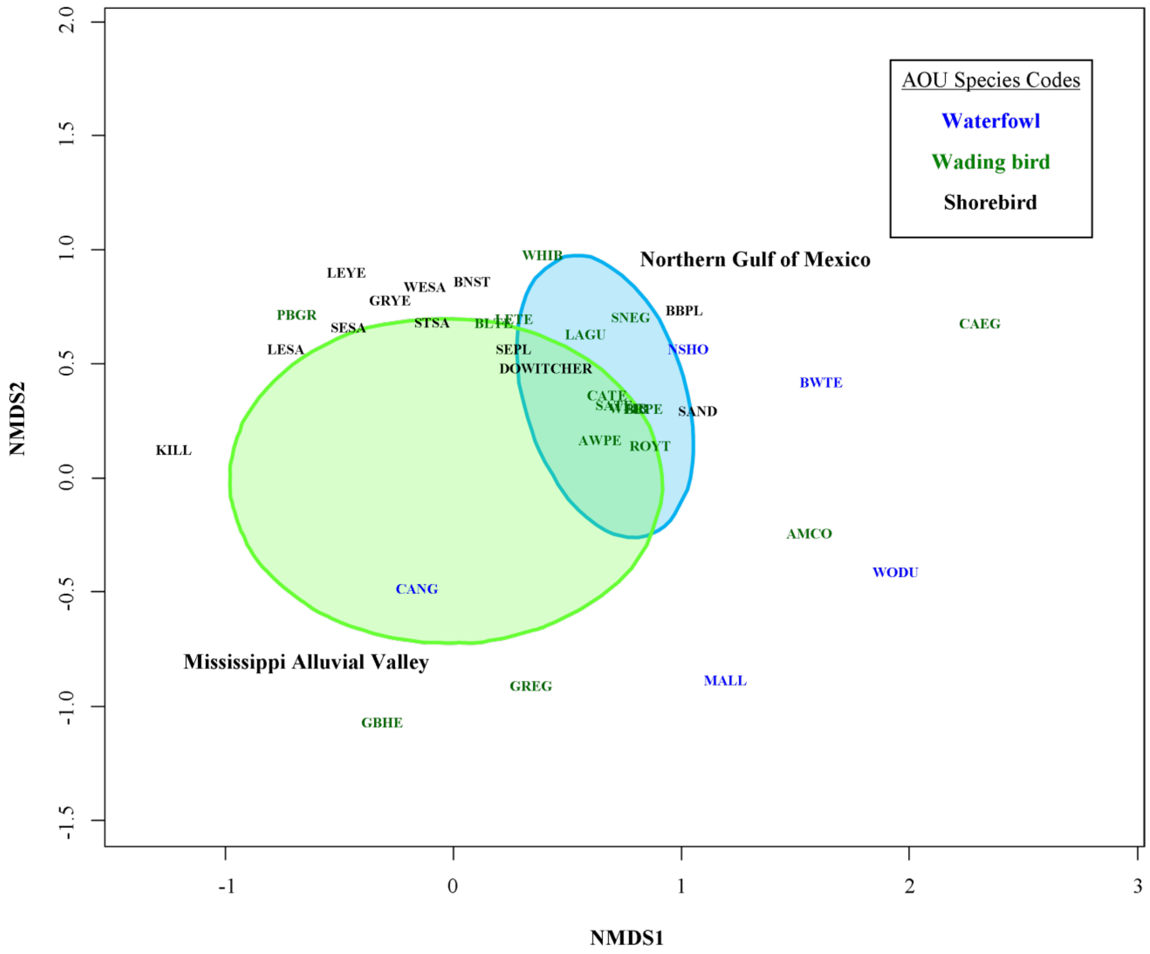

Figure 2.19 Regional 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2012.

Regional (*n* = 2; Mississippi Alluvial Valley [light green] and northern Gulf of Mexico [light blue]; APPENDIX B, Table B.20) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

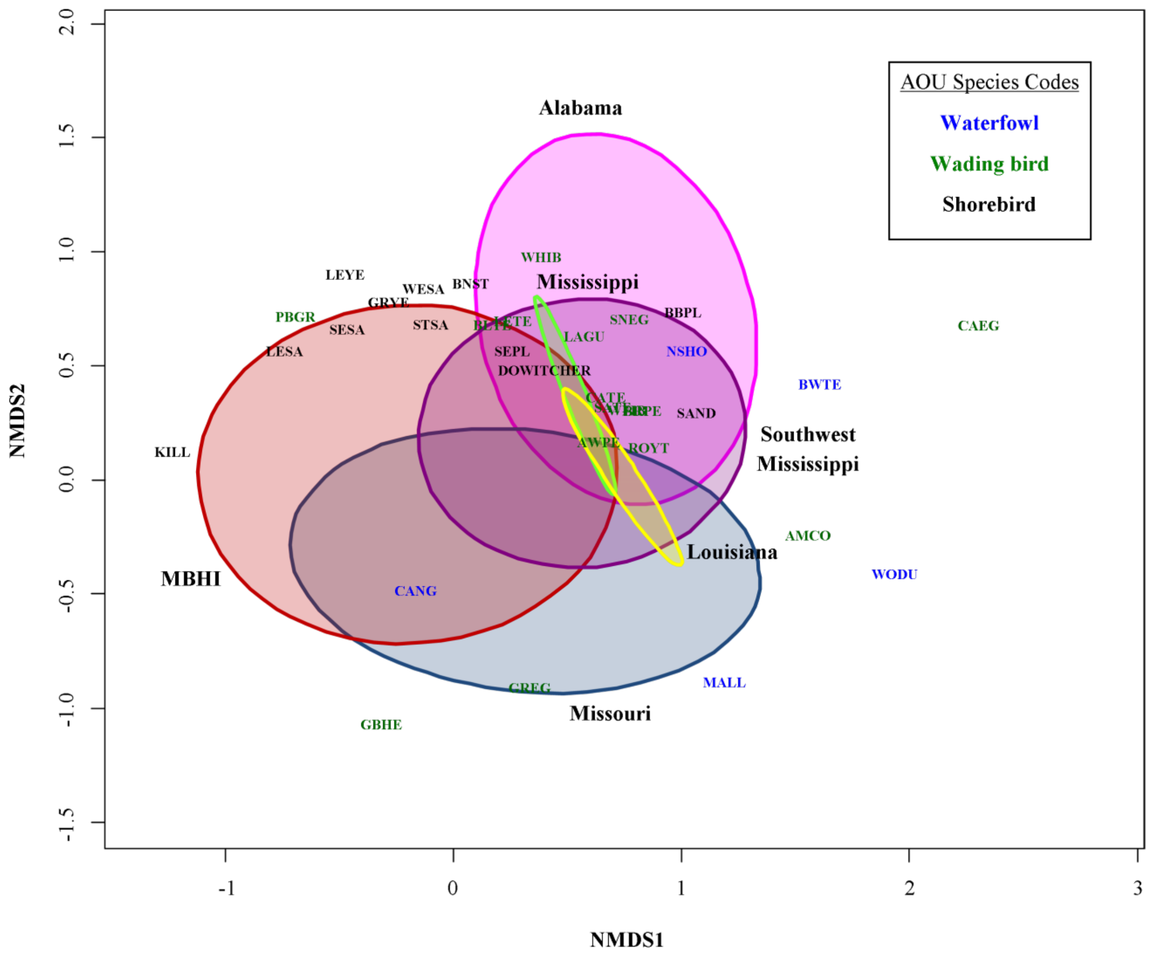

Figure 2.20 State 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2012.

State (*n* = 6; Missouri, MBHI [Migratory Bird Habitat Initiative. red], Southwest Mississippi [purple], Alabama [pink], Mississippi [light green], and Louisiana [yellow]; APPENDIX B, Table B.21) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

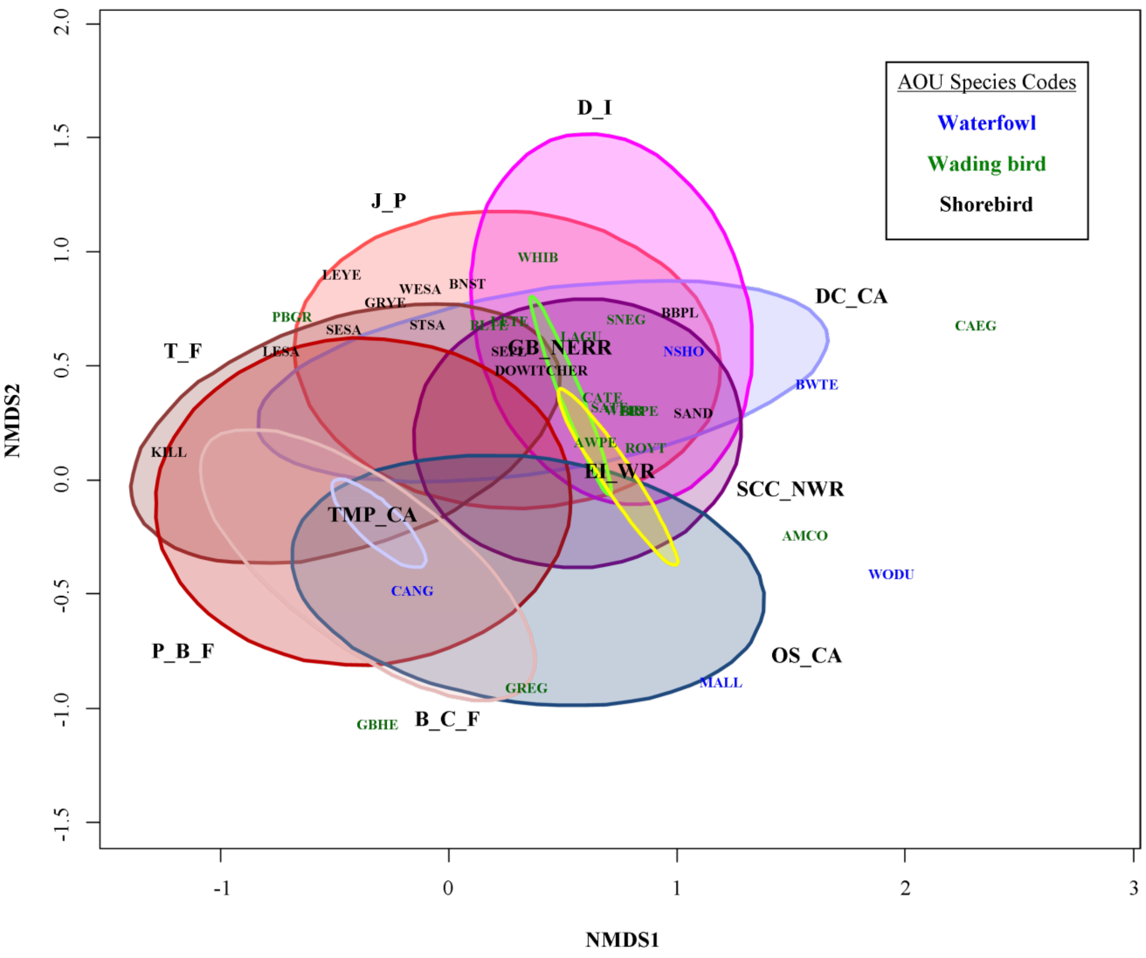

Figure 2.21 Site 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2012.

Site (*n* = 11; APPENDIX D, Table D.1; APPENDIX B, Table B.22) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

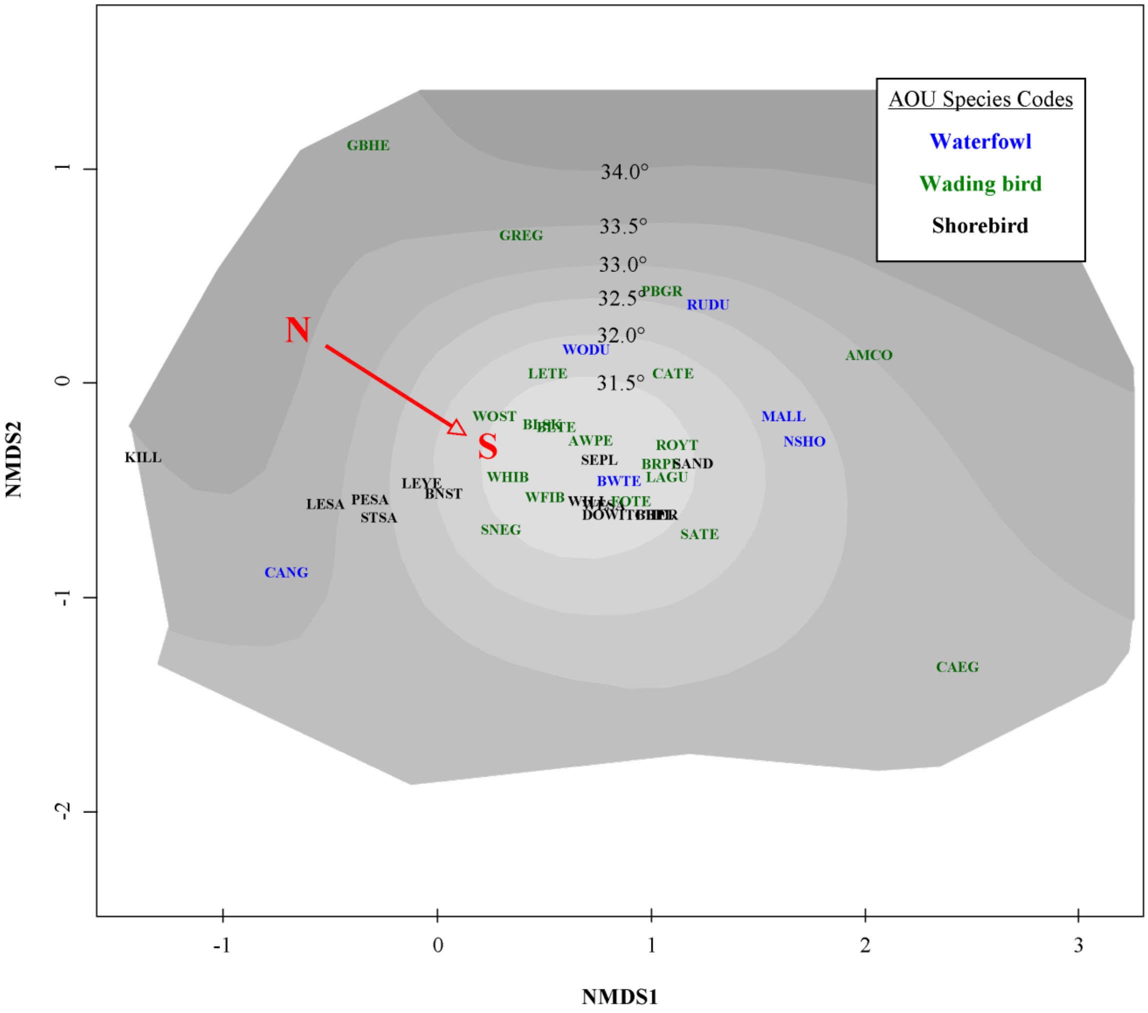

Figure 2.22 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on latitudinal gradient analysis in 2013.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**; APPENDIX B, Table B.23) assemblages overlain on latitudinal gradient analysis (gray)in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Moving along the “**Red arrow**” between North (**N**) and South (**S**) visualizes movement in latitude across ordination space. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

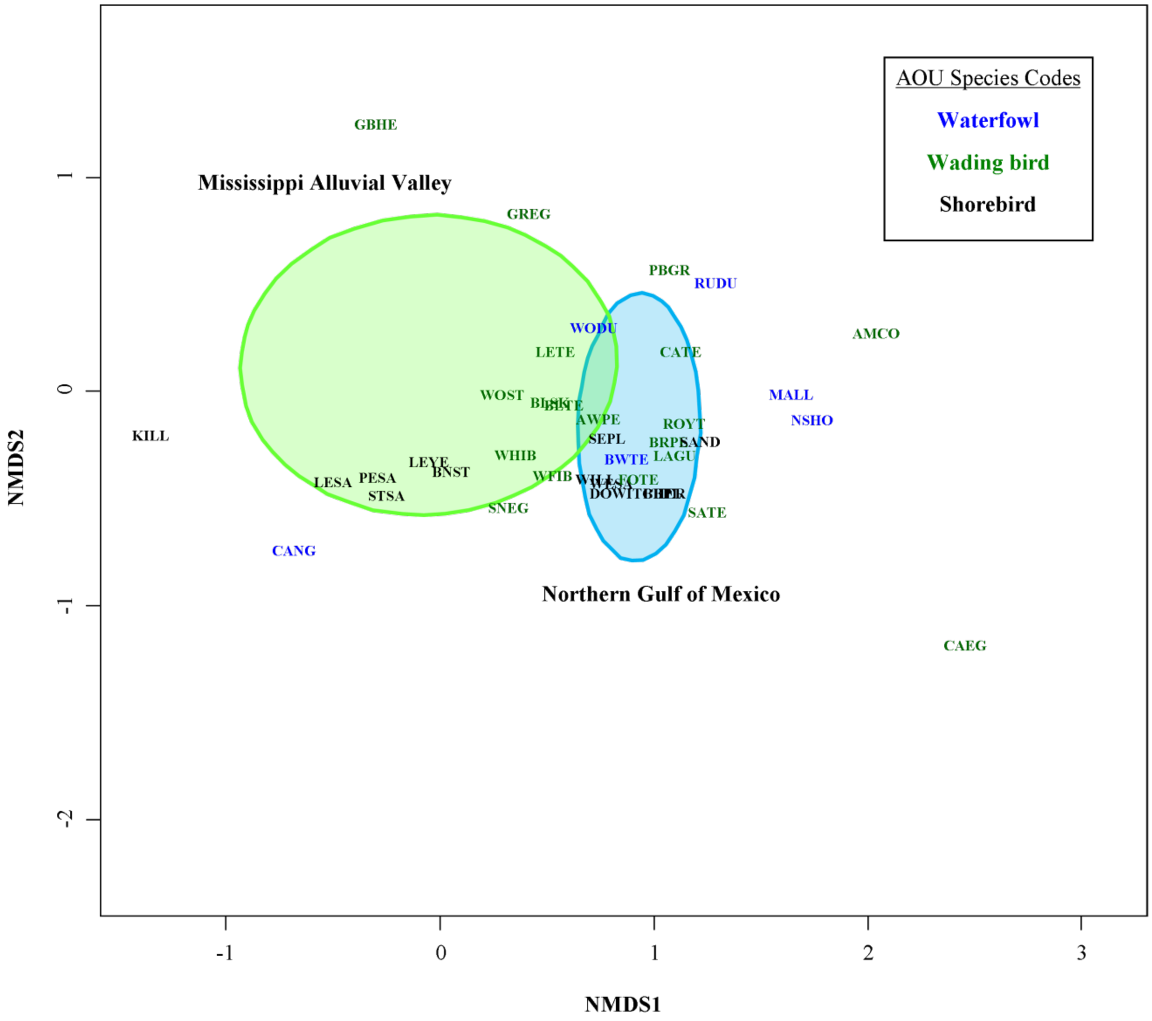

Figure 2.23 Regional 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2013

Regional (*n* = 2; Mississippi Alluvial Valley [light green] and northern Gulf of Mexico [light blue]; APPENDIX B, Table B.24) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages, in 2013, in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

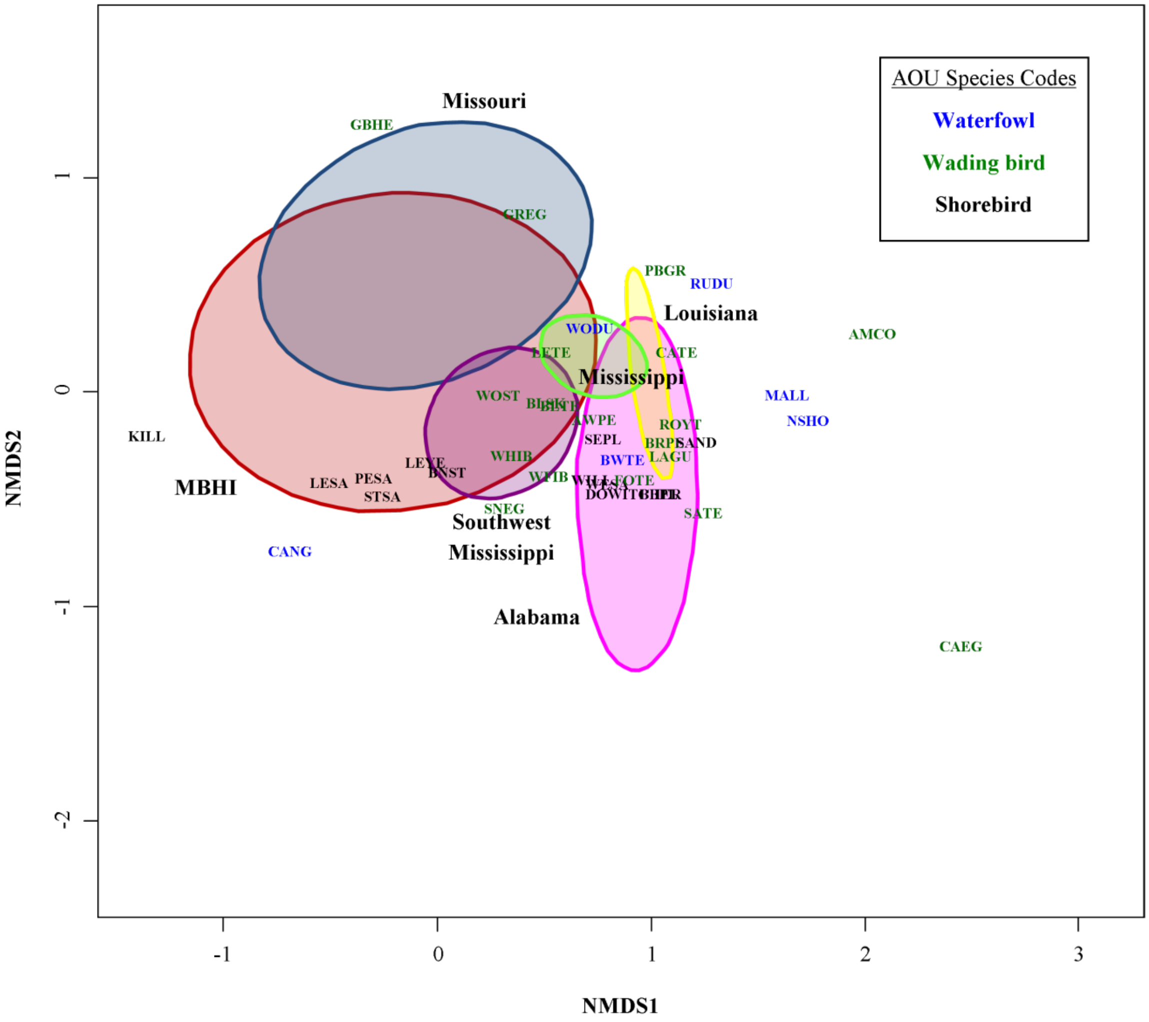

Figure 2.24 State 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2013.

State (*n* = 6; Missouri [blue], MBHI [Migratory Bird Habitat Initiative, red], Southwest Mississippi [purple], Alabama [pink], Mississippi [light green], and Louisiana [yellow]; APPENDIX B, Table B.25) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

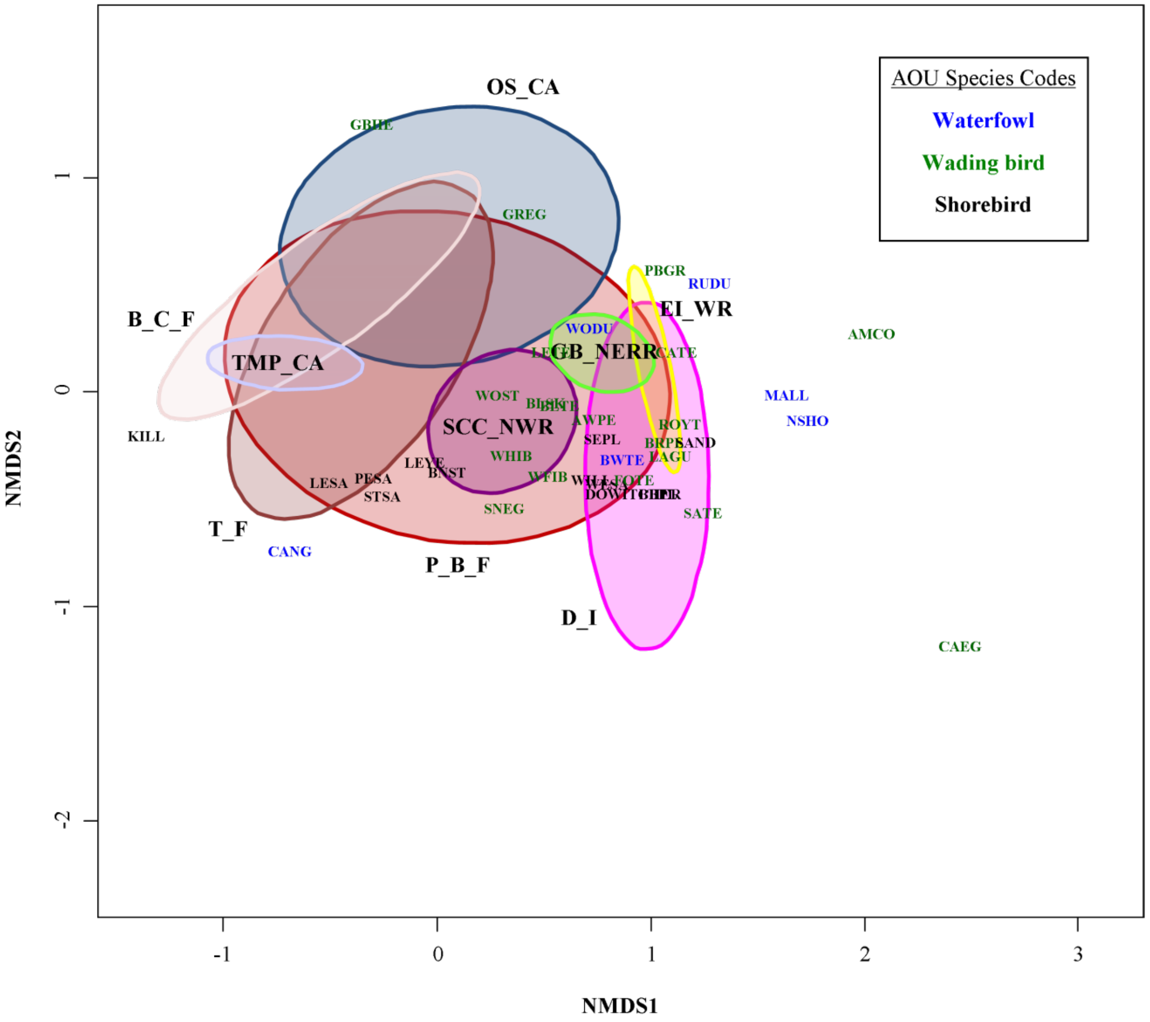

Figure 2.25 Site 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird assemblages in 2013.

Site (*n* = 9; APPENDIX D, Table D.1; APPENDIX B, Table B.26) 95% confidence ellipses overlay non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

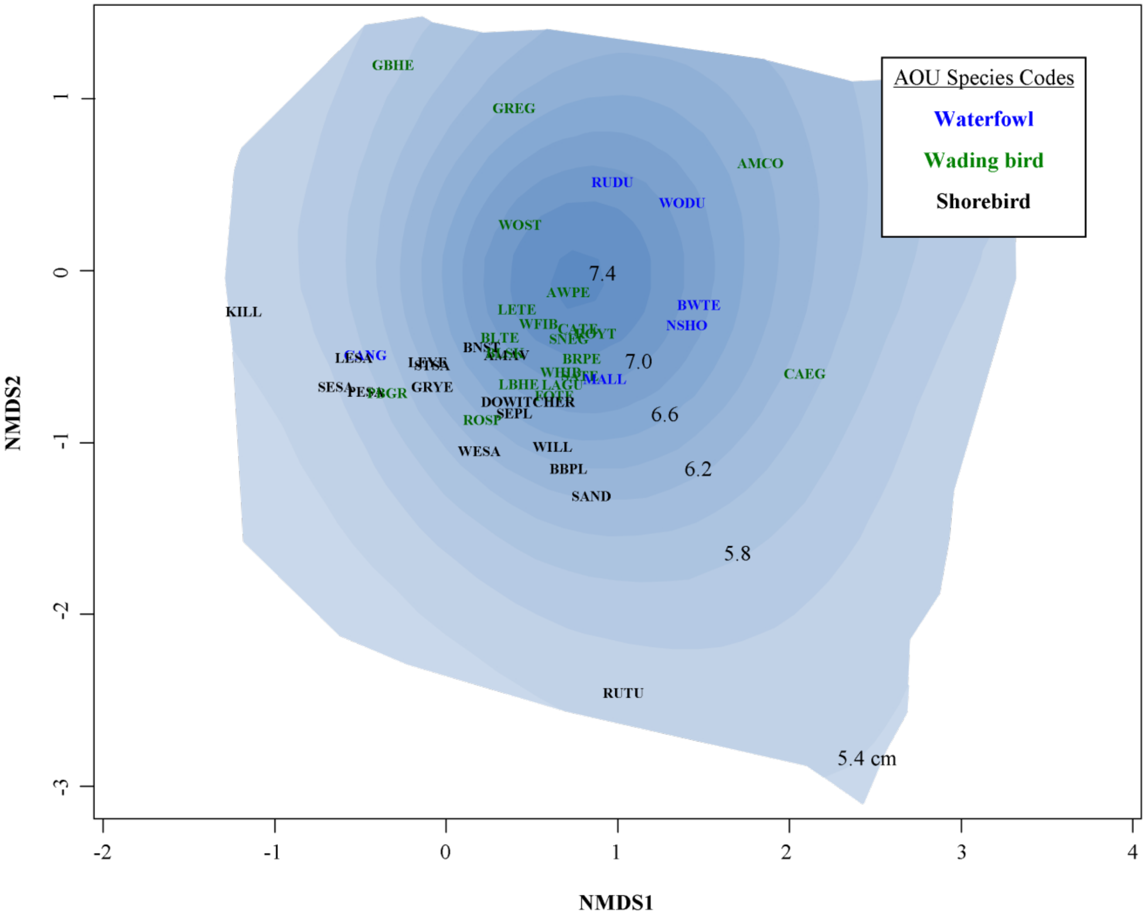

Figure 2.26 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on water depth (cm) gradient analysis from 2011 – 2013.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**; APPENDIX B, Table B.27) assemblages overlain on water depth (cm) gradient analysis (blue) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

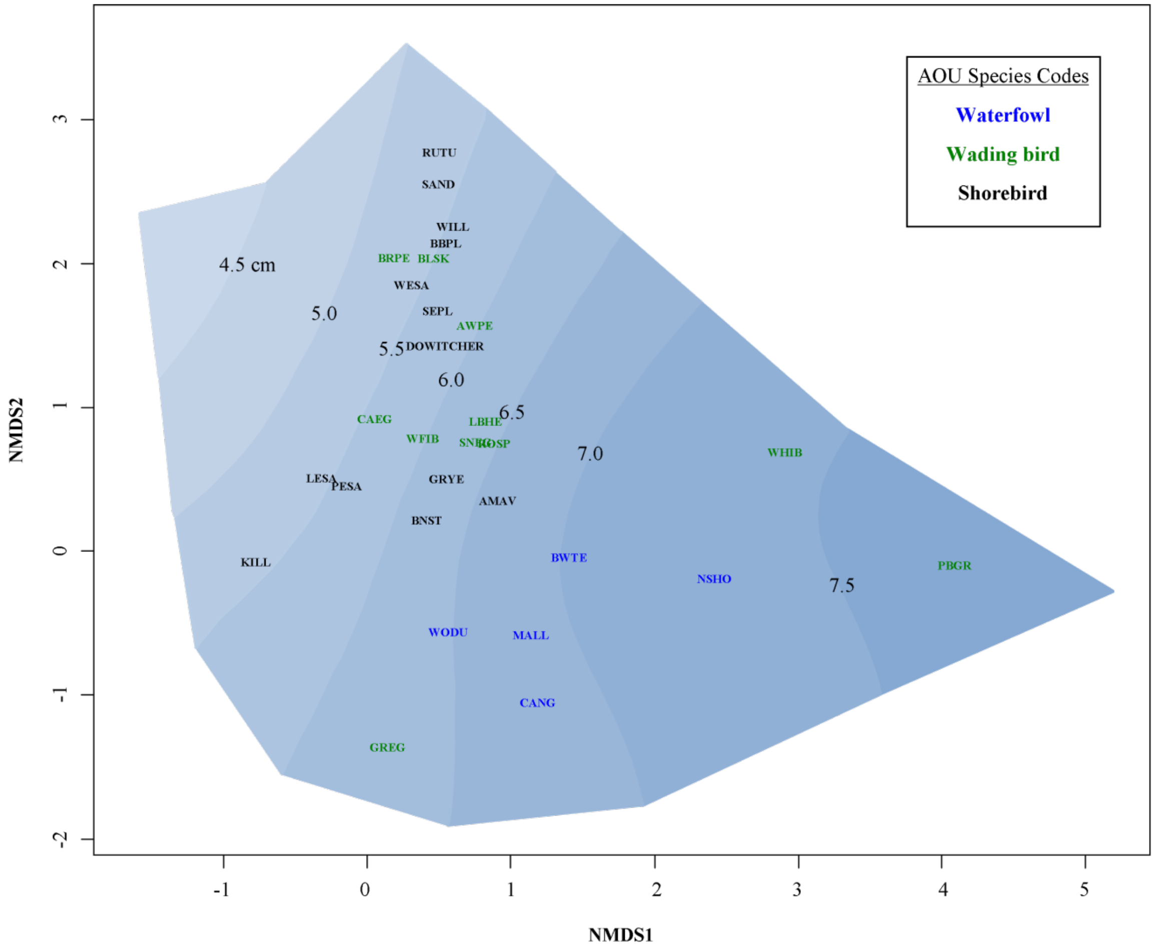

Figure 2.27 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on water depth (cm) gradient analysis in 2011

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**; APPENDIX B, Table B.28) assemblages overlain on water depth (cm) gradient analysis (blue) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

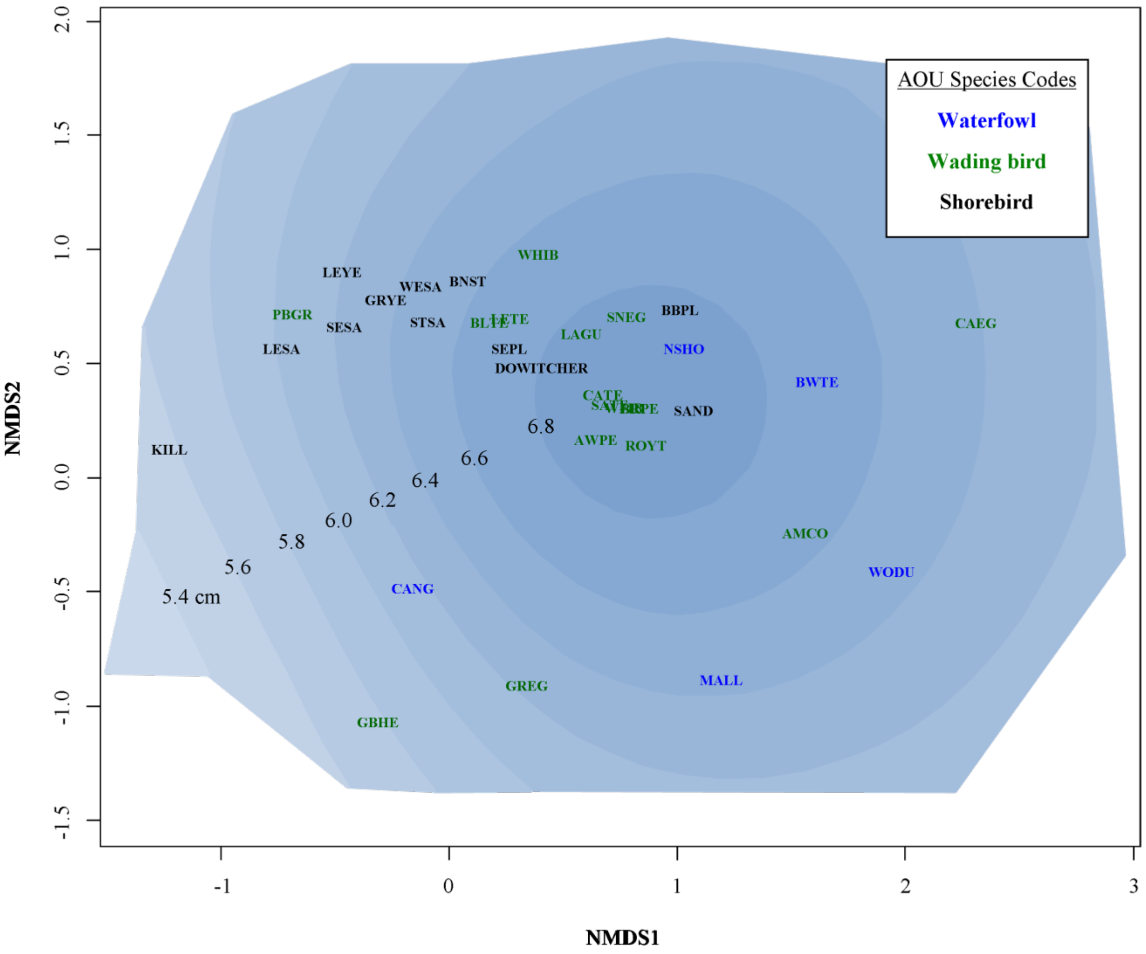

Figure 2.28 Non-metric multidimensional scaling ordination output of waterbird overlain on water depth (cm) gradient analysis assemblages in 2012.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**; APPENDIX B, Table B.29) assemblages overlain on water depth (cm) gradient analysis (blue) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

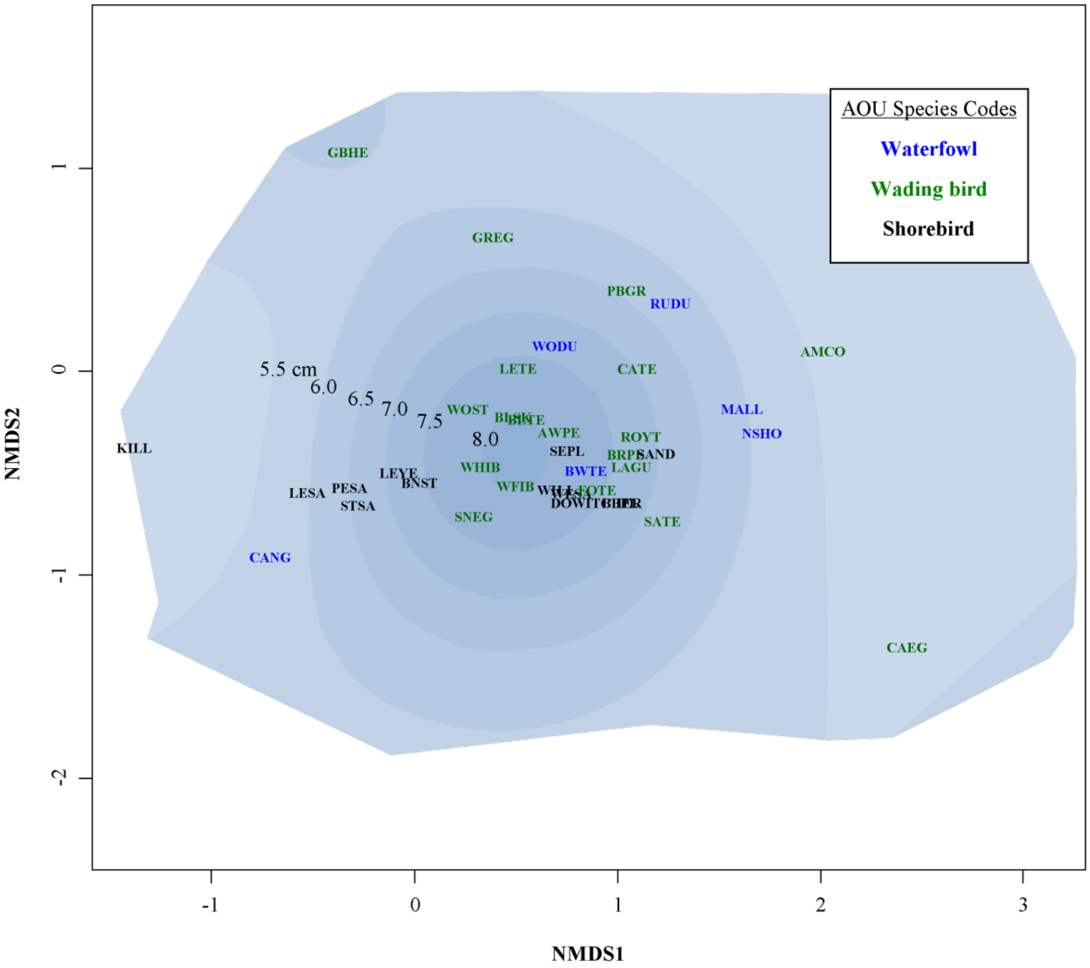

Figure 2.29 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on water depth (cm) gradient analysis in 2013.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**; APPENDIX B, Table B.30) assemblages overlain on water depth (cm) gradient analysis (blue) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. American Ornithological Union (AOU) species alpha codes defined in Table B.2.

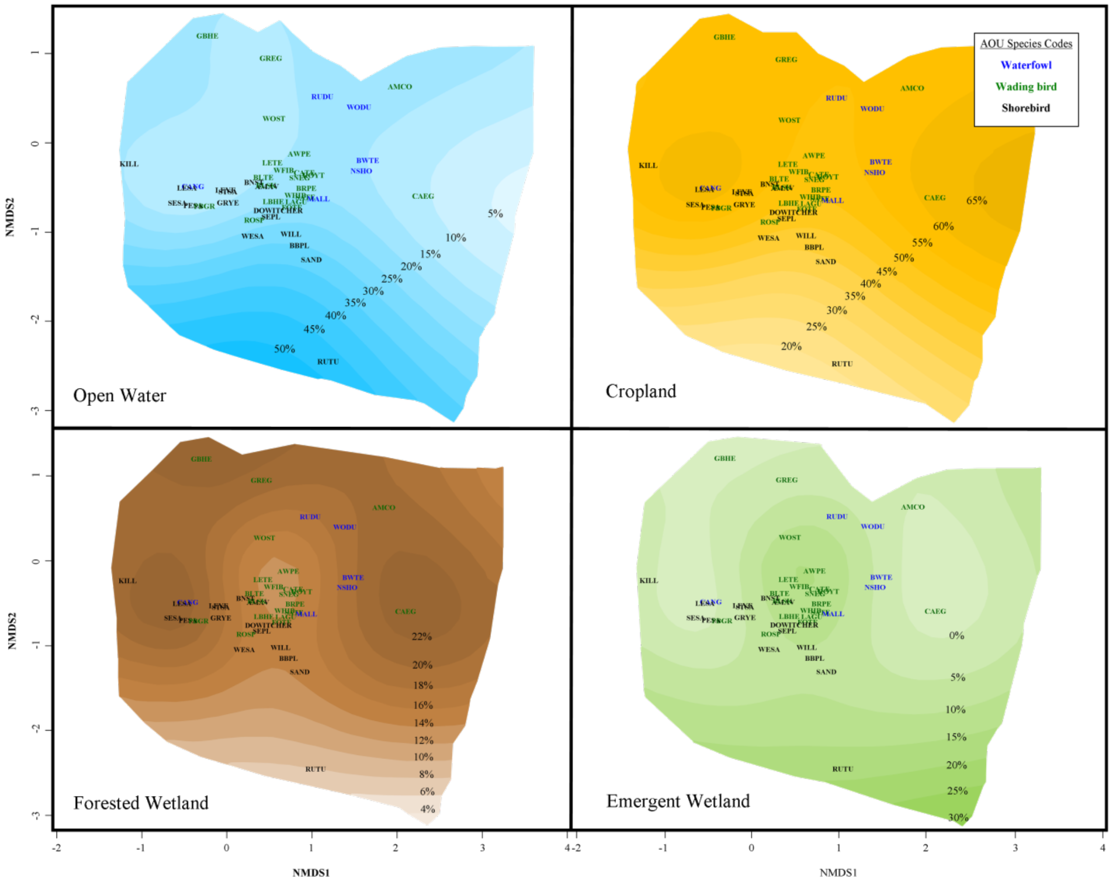

Figure 2.30 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on dominant land cover gradient analysis from 2011 – 2013.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages overlain on dominant land cover type gradient analysis in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Dominant land cover types include: open water (top left, blue; APPENDIX B, Table B.31), cropland (top right, gold; Table B.32), forested wetland (bottom left, brown; Table B.33), and emergent wetland (bottom right, green; Table B.34). American Ornithological Union (AOU) species alpha codes defined in Table B.2.

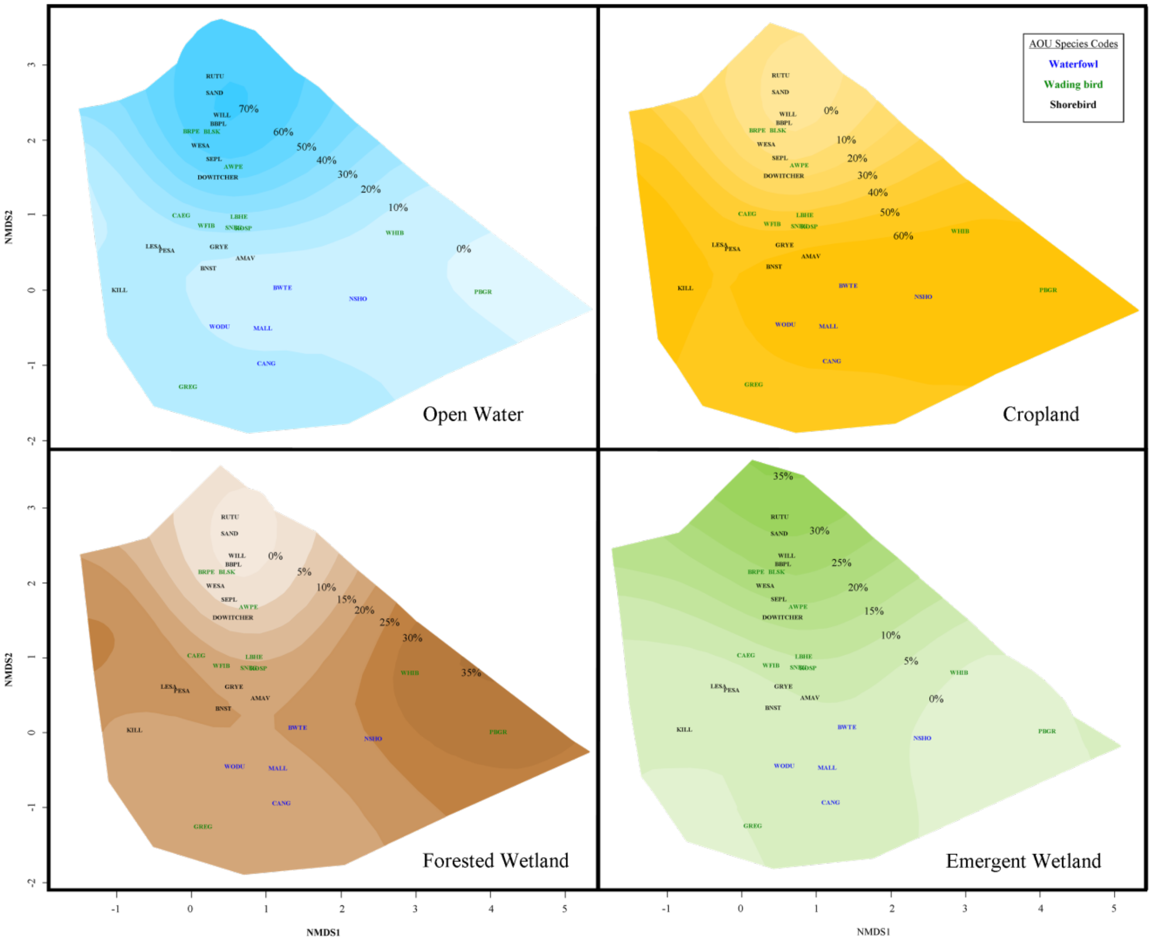

Figure 2.31 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on dominant land cover type gradient analysis in 2011.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages overlain on dominant land cover type gradient analysis in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Dominant land cover types include: open water (top left, blue; APPENDIX B, Table B.35), cropland (top right, gold; Table B.36), forested wetland (bottom left, brown; Table B.37), and emergent wetland (bottom right, green; Table B.38). American Ornithological Union (AOU) species alpha codes defined in Table B.2.

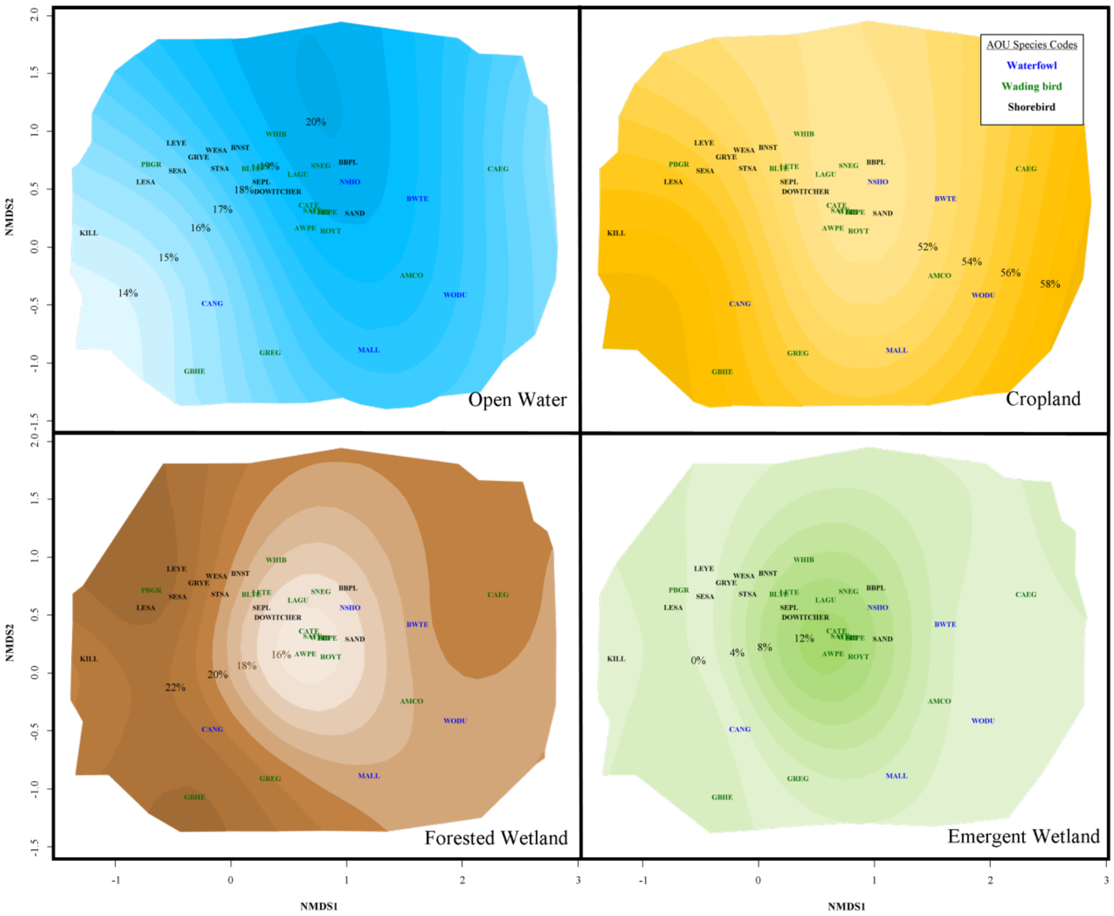

Figure 2.32 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on dominant land cover type gradient analysis in 2012.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages overlain on dominant land cover type gradient analysis in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Dominant land cover types include: open water (top left, blue; APPENDIX B, Table B.39), cropland (top right, gold; Table B.40) forested wetland (bottom left, brown; Table B.41), and emergent wetland (bottom right, green; Table B.42). American Ornithological Union (AOU) species alpha codes defined in Table B.2.

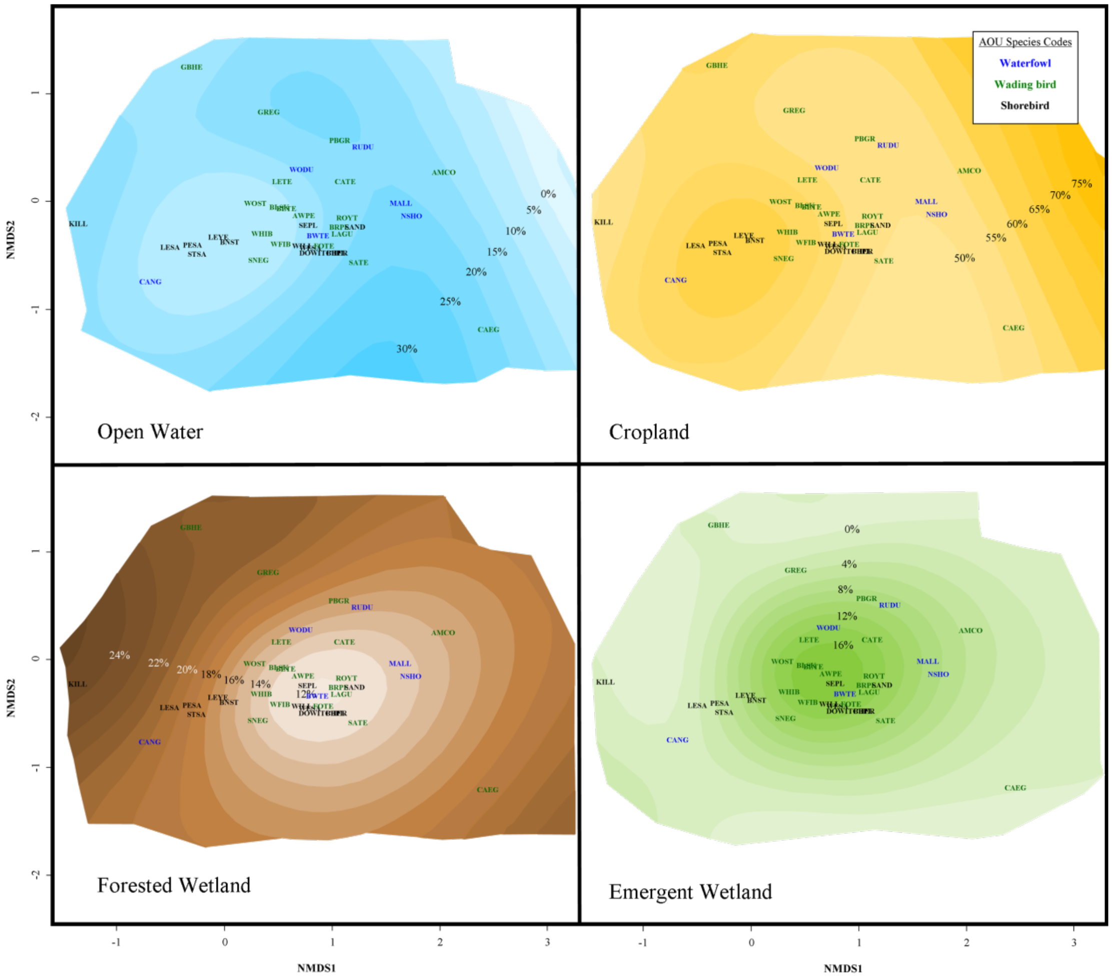

Figure 2.33 Non-metric multidimensional scaling ordination output of waterbird assemblages overlain on dominant land cover type gradient analysis in 2013.

Non-metric multidimensional scaling ordination output of waterbird (**waterfowl**, **wading bird**, and **shorebird**) assemblages overlain on dominant land cover type gradient analysis in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Dominant land cover types include: open water (top left, blue; APPENDIX B, Table B.43), cropland (top right, gold; Table B.44), forested wetland (bottom left, brown; Table B.45), and emergent wetland (bottom right, green; Table B.46). American Ornithological Union (AOU) species alpha codes defined in Table B.2.

CHAPTER III

RELATIVE ABUNDANCE OF SHOREBIRDS IN THE MISSISSIPPI ALLUVIAL VALLEY AND NORTHERN GULF OF MEXICO: USE OF MIGRATORY BIRD HABITAT INITIATIVE SITES AND OTHER WETLANDS FOLLOWING THE DEEPWATER HORIZON OIL SPILL

Introduction

The Order Charadriiformes shorebirds, gulls, and auks represents a diverse group of waterbirds with varied biogeography, physiology, behavioral ecology, and evolutionary biology (Colwell 2010). Among North American Charadriiformes, shorebirds occur primarily in open wetlands ranging from sea level to high elevations. Of 14 families of shorebirds that occur worldwide, seven exist in North America (*Burhinidae*, *Charadriidae*, *Haematopodidae*, *Recurvirostridae*, *Jacanidae*, *Scolopacidae*, *Glareolidae*) but only four (*Charadriidae*, *Haematopodidae*, *Recurvirostridae*, and *Scolopacidae*) are year round residents (O'Brien et al. 2006). Shorebirds are of particular concern for conservation because many species have experienced considerable population declines since the late 1970s (Morrison 1984, Page and Gill 1994, Davis and Smith 1998). Furthermore, the status of many shorebird populations are unknown, and 88% of monitored shorebird species provided strong evidence for population declines (Andres 2009). These declines are attributed mainly to habitat loss and modification during key portions of their migration at stopover habitats and associated food resources (Baker et al. 2004).

Shorebirds exhibit some of the longest migrations among all birds and animals, traveling as much as 25,000 km between wintering and breeding grounds (Helmers 1992, Harrington 2003). An estimated 60% of shorebird species migrate annually, often in flocks of thousands of birds representing a large portion of a species’ global population. Shorebirds traversing the North American continent make several feeding stops at wetlands along their migration route punctuated by short- or intermediate-distance flights (Skagen 2006) and eventually arrive at their wintering grounds. Shorebirds often show great site fidelity to wetland stopover habitats along a migration route, which allows researchers to investigate species population dynamics (Colwell 2010). Stopover sites tend to be small in number, highly productive in food resources, and temporally and spatially variable across the landscape (Atkinson et al. 2005). Most shorebird species rely heavily on stopover habitats to rest and meet energetic requirements of migration (Skagen and Knopf 1993). Birds balance costs and benefits of acquiring energy reserves during migration to arrive at the next location versus staying at a location longer to accrue additional reserves.

The energy-selection hypothesis predicts shorebirds will depart a stopover site once their energy reserves are sufficient to cover the distance, regardless of the quality of, the next site. An alternative, the time-selection hypothesis, predicts shorebirds will minimize the time they spend at stopover sites and bypass poor quality sites in order to reduce the total time spent migrating (Lehnen and Krementz 2007). These two hypotheses may explain how shorebirds buffer against unknown food resources at future stopover sites by adopting three migration strategies: “hop,” “skip,” and “jump” (Piersma 1987, Lehnen and Krementz 2005, Colwell 2010, Henkel and Taylor 2015). Relatively short migratory flights or “hopping” is a strategy used by many inland migratory shorebird species and considered a low-risk migration strategy (Iverson et al. 1998). It also eliminates making long flights to a potential unfamiliar habitat with unknown resource levels. Additionally, “hopping” may reduce time needed for shorebirds to amass fat reserves needed for long migrations. Further, this behavior may be a consequence of the relatively small body size of some shorebirds (Least Sandpiper [*Calidris minima*]; 20 g) and the intrinsic constraints of acquiring and reserving large nutrient reserves for long distance migration (Klaassen 1996). Short “hops” along a migration corridor cushion shorebirds encountering wetland environments that are dynamic in their water regimes and often fluctuating aquatic invertebrates food resources (Davis and Smith 2001).

Larger-bodied species of shorebirds like the Red Knot (*C. canutus*; 135 g) undertake longer flights, often covering thousands of kilometers as they “skip” from site to site (Maillet and Weber 2006). The strategy of “skipping” along a route is a very common for shorebird species using coastal estuarine environments during migration while also crossing large expanses of unsuitable interior continental lands or open water bodies. This migration strategy relies on sites (e.g., Delaware Bay) that consistently produce abundant food resources (i.e., horseshoe crab [*Limulus polyphemus*] eggs) at specific times of the year (Karpanty et al. 2006).

The least common and potentially most risky shorebird migration method is “jumping” large distances in a single move. For example, arctic breeding species like the Bar-tailed Godwit (*Limosa lapponica*; 340 g) make an 11,000 km flight over the Pacific Ocean from Alaska to New Zealand (Colwell 2010). Shorebirds nesting at these near-polar latitudes consume large quantities of invertebrates on productive tidal sites in Alaska, and upon arrival in New Zealand their reserves are exhausted. However, these long-distance migrants exhibit great site fidelity and arrive at wetland sites which provide abundant prey resources. Additionally, many shorebirds winter in the Southern Hemisphere during the Austral summer when food resources are abundant due to blooms in invertebrate biomass (Baker and Baker 1973, Isacch et al. 2005).

In North America in the Mississippi Flyway, shorebird migration and overwintering areas were historically restricted to coastlines of the northern Gulf of Mexico (NGoM; Henkel and Taylor 2015) and sandbars and mudflats in major river channels of the Mississippi Alluvial Valley (MAV; Twedt et al. 1998). The coastlines of the NGoM are important to 28 species of migrating shorebirds (Henkel and Taylor 2015). Historically, in the MAV, flooded wetland area during fall migration resulted from natural hydrologic processes of the Mississippi River and its tributaries (King et al. 2006). Presently, wetlands for fall migrating shorebirds in the MAV often may be scarce due to a lack of precipitation and high evapotranspiration. Moreover, the MAV has experienced a disconnect in the river continuum between the floodplain and its major rivers due to hydrological manipulations (Reinecke et al. 1989, Sedell et al. 1989).

Identification of where wetland areas occur on the landscape and how they are used by shorebirds is critical for effective conservation. Efforts from agencies like the U.S. Department of Agriculture’s Natural Resources Conservation Service (NCRS) and their partners have been directed at conserving and managing breeding, stopover sites, and wintering grounds of shorebirds and other waterbirds (Myers et al. 1987, Hobson 1999). Fleming et al. (2015) observed greater duck species richness on actively managed Wetland Reserve Program lands with late drawdown in Mississippi than those sites with a more passive or early water removal management regime. Also, Harrington (2003) identified areas managed for wildlife had greater mean shorebird numbers than unmanaged locations. Actively managed sites often include manipulation of a food resource and/or water depth (Eldridge 1992). Shallow water (dry uplands – water depths ≤ 15 cm) present on the landscape are important habitat attributes during migration for foraging and loafing. Mean water depths for shorebirds foraging in the Texas Playa Lakes in fall ranged from 1.3 – 10.7 cm depending on species (Davis and Smith 2001).

Despite a history of management for waterfowl in the MAV, information on shorebird abundance, migratory phenology, and resource use is limited and requires regular updating due to the dynamic nature of land use and agricultural practices (Twedt et al. 1998). Nearly a half million shorebirds are estimated to migrate through the MAV annually (Helmers 1992, Skagen et al. 1999). The Lower Mississippi Alluvial Valley Joint Venture (LMVJV) set a tentative population goal of 500,000 shorebirds based on limited data (Loesch et al. 2000, King et al. 2006). Lehnen (2010) estimated approximately 285,000 shorebirds may use public and private lands across the MAV during fall migration.

Shorebirds rely heavily on interior and coastal wetlands in the Atlantic and Mississippi Flyways for migration stopover sites (Davis and Smith 2001, Lehnen 2010). The 2010 Deepwater Horizon oil spill in the Gulf of Mexico prompted management agencies to provide inland and coastal habitats for migratory birds, including shorebirds (NRCS 2010). The Migratory Bird Habitat Initiative (MBHI) was implemented through NRCS by working with farmers, ranchers, and other landowners to enhance habitat for migratory birds on private lands (NRCS 2010, Kaminski and Davis 2014). Counties within the MAV and NGoM were prioritized based on habitat potential for migrating bird populations by placing shallow water management practices along well documented migration corridors. In the Mississippi Delta region, the shallow water management practice for fall migrating shorebirds was implemented on active and idled aquaculture facilities.

Surveys of shallow water habitat mimicking the practices used by the MBHI program may provide updated information on shorebird abundance in the MAV and help improve the LMVJV conservation targets of stopover habitat in private lands. To address these information needs my objectives were to, (1) estimate species composition and relative abundance of migrating shorebirds in aquaculture ponds and other associated wetlands in the MAV and NGoM during summer through fall (August – October) migration; (2) my results may provide information to evaluate the implications of MBHI and other management practices.

Study Areas

For an in-depth description of my study areas refer to Study Areas in CHAPTER II (Figure 2.1).

Methods

Experimental Design

See CHAPTER II for an in-depth description of waterbird survey methods in the MAV and NGoM.

Statistical Analysis

Shorebird relative abundance

I conducted shorebird surveys July to October in 2011, considered the time period encompassing autumn shorebird migration (Lehnen and Krementz 2013). However, in

2012 and 2013 I adjusted my survey efforts to the time period when birds were present in the MAV and along the NGoM because few shorebirds were present in either region in July 2011. Therefore, I only analyzed data from August to October. Bird count data was first standardized across wetland size by calculating the number of birds per hectare. Prior to analysis, data were examined for fit and distribution using Program R version 3.1.2 (RDevelopmentCoreTeam 2016). Outliers were defined as any observation found to be ± 3 SD from the expected sample mean (Strum et al. 2010). Sampling units consisted of individual ponds (n = 807) within a site. Independent variables included year (2011 – 2013), period (1 – 6), region (MAV and NGoM), site specific latitude (n = 16), average water depth, and rainfall. A detailed description of the estimation of water depth can be found in CHAPTER II.

Shorebird relative abundance (hereafter abundance) data were natural log transformed to normalize distribution and correct heterogeneous variances (Quinn and Keough 2002). To account for unequal variances between sites, I used a WEIGHT statement in the *lme4* package to weight models by latitudes. I compared Akaike's information criterion corrected (AIC_C) values between models with equal and unequal variances and determined that models with unequal variances had superior fit to the data (Akaike 1974, Zuur et al. 2009). I compared a mixed model with and without pond ID as a random effect. Model selection including pond ID as a random effect had superior fit to the data and therefore I included it as a random effect in all my models. After all models were run, I compared AIC_C scores (Burnham and Anderson 2002) with the *MuMIn* package in Program R. I considered models with $\Delta AIC_C \leq 2$ as competitive and $\Delta AIC_C = 0$ as the model explaining most variance in shorebird abundance (Burnham and Anderson

2002). Any competing models were model averaged, at $\alpha = 0.05$ level, in the *MuMIn* package to determine if additional variables were significant in influencing shorebird abundances. To test for individual variable significance in my top model, I extracted coefficients in the *nlme* package in Program R. I used an analysis of variance (ANOVA) to test if abundance varied by year, survey time period (hereafter period), latitude, an index of water depth, or average rainfall five days prior to an avian survey if the model deemed the variable significant. I then ran those variables at or below $\alpha = 0.05$, through a Least Significant Difference test in the *agricolae* package in Program R for significance among multiple levels of a treatment effect to determine if levels differed.

Shorebird size and species abundances

I partitioned shorebird species into guilds based on body size using similar methods as reported by Skagen and Knopf (1993). Shorebirds fell into three size guilds by mean body mass; small ($x \leq 50$ g), medium ($50 \text{ g} < x \leq 100$ g), and large ($x > 100$ g). I repeated the methods stated above for analyzing all shorebirds using model selection, comparing AIC_C scores, and identifying significant treatment effects.

I estimated species specific relative abundances, and tested for differences by year, period, latitude, water depth, or average rainfall five days prior to an avian survey, for the four most commonly encountered shorebird. These were Least Sandpiper, Killdeer (*Charadrius vociferus*), Black-necked Stilt (*Himantopus mexicanus*), and Pectoral Sandpiper (*C. melanotos*). I repeated the methods stated above for analyzing all shorebirds using model selection, comparing AIC_C scores, and identifying significant treatment effects.

Results

Shorebird relative abundance

Shorebird abundance data (birds/ha) were right-skewed and exhibited heterogeneous variances. Therefore, I natural log transformed the data and analyzed both transformed and raw data. Both analyses yielded similar results, so I presented results of raw data only (Table 3.1).

The global model containing year, period, region, latitude, water depth, and rainfall explained greatest variation in total shorebird abundance within the MAV and NGoM. The global model (Table 3.2) carried a weight (ω_i) of 0.940. Variables of the global model that were significant in estimating total shorebird abundances were period ($F_{5,801} = 8.821$, $P < 0.001$) and latitude ($F_{15,791} = 8.922$, $P < 0.001$). Mean shorebird abundance differed among periods (Figure 3.1). Periods 1 (early August; $\overline{x} = 15.02$ birds/ha, SE = 3.211, $n = 179$) and 2 (late August; $\overline{x} = 13.97$ birds/ha, SE = 3.124, $n = 150$) had the greatest abundance and were greater than period 4 (late September; $\overline{x} = 2.61$ birds/ha, SE = 0.919, $n = 171$). Periods 3, 5 or 6 were intermediate in total shorebird abundance between the most and least abundant periods. Latitude was negatively correlated with shorebird abundance. For every 1° of latitude south from Duck Creek CA (Missouri) to Elmer’s Island WR (Louisiana), shorebird abundance increased by 2.3 birds/ha. Greatest total shorebird abundances were observed at Phillips Brother’s Farms (Table 3.1) and mean abundance was greater than 12 sites (Figure 3.2). Year, region, water depth, and rainfall were not significant variables influencing total shorebird abundance.

Shorebird relative abundance by size

Shorebird species (APPENDIX C) were segregated into three body size guilds (0) with the first group represented by small shorebirds (x ≤ 50 g; Table C.1). The global model containing year, period, region, latitude, water depth, and rainfall explained greatest variation in small shorebird abundance within the MAV and NGoM. The global model (Table 3.3) carried a ω_i of 0.620. Variables of the global model that were significant in estimating total shorebird abundances were period ($F_{5,801} = 4.897$, $P < 0.001$) and latitude ($F_{15,791} = 4.624$, $P < 0.001$). Mean small shorebird abundance differed amongst time periods (Figure 3.4). Period 2 (late August; $\overline{x}$ = 5.71 birds/ha, SE = 1.391, $n = 150$) had the greatest abundance of small shorebirds and was greater than periods 4 (late September; $\overline{x}$ = 0.29 birds/ha, SE = 0.090, $n = 171$). Periods 1, 3, 5, or 6 were intermediate between the most or least abundant time periods. Latitude was negatively correlated with shorebird abundance. For every 1° of latitude south, abundance increased by 0.89 small shorebirds/ha. Greatest small shorebird abundances were observed at Phillips Brother's Farms and mean abundance was greater than 10 sites (Figure 3.5).Year, region, water depth, and rainfall were not significant variables influencing small shorebird abundance.

The global model containing year, period, region, latitude, water depth, and rainfall explained greatest variation in medium (50 < x ≤ 100 g; Table C.2) shorebird abundance within the MAV and NGoM. The global model (Table 3.4) carried a ω_i of 0.959. Variables of the global model that were influential in estimating medium shorebird abundances were year ($F_{2,805} = 3.717$, $P = 0.03$), period ($F_{5,801} = 7.891$, $P < 0.001$), latitude ($F_{15,791} = 11.200$, $P < 0.001$), and water depth ($F_{203,805} = 4.813$, $P < 0.001$). There was greater medium shorebird abundance in 2011 ($\overline{x}$ = 4.22 birds/ha, SE = 0.972, n = 139) than 2013 ($\overline{x}$ = 1.63 birds/ha, SE = 0.373, n =255) with 2012 being intermediate between 2011 and 2013 (Figure 3.6). Period 2 (late August; $\overline{x}$ = 5.48 birds/ha, SE = 1.394, n = 151) had the greatest abundances and differed from periods 4 (late September; $\overline{x}$ = 0.39 birds/ha, SE = 0.112, n = 171), 5 (early October; $\overline{x}$ = 0.45 birds/ha, SE = 0.115, n = 103), and 6 (late October; $\overline{x}$ = 0.61 birds/ha, SE = 0.188, n = 47; Figure 3.7). Periods 1 and 3 were intermediate between the most or least abundant time periods. Latitude was negatively correlated with medium shorebird abundance. For every 1° of latitude south, abundance increased by 0.84 medium shorebirds/ha. Greatest medium shorebird abundances were observed at Phillips Brother's Farms (Figure 3.8) and mean abundance was greater than estimated means at nine sites. There was a negative relationship with medium shorebird abundance and water depth. For every 1 cm increase in water depth, there were 0.35 fewer medium shorebirds/ha. Medium shorebirds were observed most often on shallow water habitats with average water depths ~ 6.5 cm. Region and rainfall were not significant variables influencing medium shorebird abundance.

The model containing period and water depth explained greatest variation in large (x > 100 g; Table C.3) shorebird abundance within the MAV and NGoM. It was the top model with no competing models (Table 3.5) and carried a ω_i of 0.760. Of the two variables, only water depth ($F_{203,805}$ = 44.434, P < 0.001) was influential in estimating large shorebird abundances. There was a positive relationship with large shorebird abundance and water depth. For every 1 cm increase in water depth, the model predicted

0.54 more large shorebirds/ha. Large shorebirds were observed most often in shallow water habitats with average water depths ~10.6 cm.

Species specific relative abundances

I estimated species specific relative abundances for the four most common (*n* = 31,891 [67.06%]) shorebird species encountered namely; Least Sandpiper (*n* = 18,748 [39.42%]), Killdeer (*n* = 5,040 [10.60%]), Black-necked Stilt (*n* = 4,848 [10.19%]), and Pectoral Sandpiper (*n* = 3,255 [6.84%]). The remaining 32.94% (*n* = 15,668) of shorebirds encountered (*n* = 29 species) occurred in proportions < 5% of total counts.

The model containing year, period, and region explained greatest variation in Least Sandpiper abundance within the MAV (*n* = 18,222, 97.2%) and NGoM (*n* = 526, 2.8%). It was the top model with two competing models (Table 3.6). However, model averaging revealed variables within the three competing models were not influential in explaining variation of Least Sandpiper abundance.

The global model containing year, period, region, latitude, water depth, and rainfall explained greatest variation in Killdeer abundance within the MAV (*n* = 5,037, > 99.9%) and NGoM (*n* = 3, < 0.01%). The global model (Table 3.7) carried a ω_i of 0.971. Variables of the global model influential in estimating Killdeer abundances were year ($F_{2,805}$ = 9.672, $P < 0.001$), period ($F_{5,801}$ = 6.707, $P < 0.001$), region ($F_{1,805}$ = 3.745, P = 0.02), latitude ($F_{15,791}$ = 7.150, $P < 0.001$), water depth ($F_{203,805}$ = 15.433, $P < 0.001$), and rainfall ($F_{35,771}$ = 1.439, P = 0.05). There was greater Killdeer abundance in 2011 ($\bar{x}$ = 2.10 birds/ha, SE = 0.415, *n* =139) than 2012 ($\bar{x}$ = 0.83 birds/ha, SE = 0.157, *n* = 413) or 2013 ($\bar{x}$ = 0.63 birds/ha, SE = 0.182, *n* =255; Figure 3.9). Periods 2 (late August; $\bar{x}$ = 1.53 birds/ha, SE = 0.358, *n* = 150) and 3 (early September; $\bar{x}$ = 1.92 birds/ha, SE =

0.453, *n* =157) had the greatest abundances of Killdeer (Figure 3.10). Period 4 (late September; $\bar{x}$ = 0.10 birds/ha, SE = 0.020, *n* =171) had the least Killdeer abundance; with periods 1, 5, and 6 being intermediate between the most and least abundant periods. The MAV ($\bar{x}$ = 1.05 birds/ha, SE = 0.131, *n* =756) had greater Killdeer abundance than the NGoM ($\bar{x}$ < 0.01 birds/ha, SE = 0.004, *n* =51; Figure 3.11). Latitude was negatively correlated with Killdeer abundance. For every 1° of latitude south, abundance increased by 0.29 Killdeer/ha. Greatest Killdeer abundances were observed at Nerren Fisheries ($\bar{x}$ = 2.79 birds/ha, SE = 1.01, *n* =8) and Phillips Brother's Farms ($\bar{x}$ = 2.07 birds/ha, SE = 0.379 birds/ha, *n* = 192; Figure 3.12). There was a negative relationship with water depth and Killdeer abundance. For every 1 cm increase in water depth, there were 0.23 fewer Killdeer/ha. Most Killdeer were observed on shallow water habitats with average water depths ~ 5 cm. Rainfall was negatively related to Killdeer abundance. For every 1 cm of measured rainfall there were 0.45 fewer Killdeer/ha.

The model containing period and water depth explained greatest variation in Black-neck Stilt abundance within the MAV (*n* = 4,815, 99.3%) and NGoM (*n* = 33, 0.7%). It was the top model with no competing models (Table 3.8) and carried a ω_i = 0.802. Of the two variables, only water depth ($F_{203,805}$ = 24.8655, *P* < 0.001) was influential in estimating Black-necked Stilt abundances. There was a positive relationship with water depth and Black-necked Stilt abundance. For every 1 cm increase in water depth, the model predicted 0.32 more Black-necked Stilts/ha. Black-necked Stilts were observed most often on shallow water habitats with average water depths ~8 cm.

The model containing year explained greatest variation in Pectoral Sandpiper abundance within the MAV (*n* = 3,249, 99.8%) and NGoM (*n* = 6, 0.2%). It was the top model with no competing models (Table 3.9) and carried a ω_i = 0.571. There was greater Pectoral Sandpiper abundance in 2011 ($\bar{x}$ = 1.39 birds/ha, SE = 0.790, *n* =139) than 2012 ($\bar{x}$ = 0.34 birds/ha, SE = 0.085, *n* = 413) or 2013 ($\bar{x}$ = 0.11 birds/ha, SE = 0.035, *n* =255; Figure 3.13).

Discussion

Temporal shorebird abundance

Shorebirds exhibit pulsed migrations where adult birds migrate first followed by juveniles, and females migrate before males (Page 1974, Lehnen and Krementz 2005). Grönroos et al. (2012) found shorebirds migrate in discrete pulses, likely differing seasonally, by sub-populations, and age-class. For example, Red Knot males take care of young, with most females leaving the breeding grounds as soon as the eggs hatch (Whitfield and Brade 1991, Piersma et al. 1999). Pulsed migration may explain differences in survey period revealed by temporal variation in total shorebird abundances. Similar to Twedt et al. (1998), I observed greatest total shorebird abundance in August (i.e. periods 1 and 2), which decreased dramatically by late September. Wirwa (2009) observed similar trends in abundance, richness, and diversity on Kentucky Reservoir, Kentucky, USA at similar latitudes as my northern sites. Following the lowest observed abundances in late September, shorebird abundances increased through the month of October, but never reached previous levels. This increase could be caused by the arrival of hatch year and over wintering birds of all age classes in the MAV and along the NGoM. Many shorebird species over winter along the NGoM (Johnson and Baldassarre 1988, Henkel and Taylor 2015).

Small shorebirds abundances peaked similarly (late August) to total shorebird abundances. Least Sandpipers made up the majority (> 74%) of small shorebirds in the two regions. Page (1974) observed adult female and male Least Sandpipers in greatest proportion of the population at Bolinas Lagoon, California through mid-August. Adult Least Sandpipers started arriving in California in early July and second year immature birds arrived later than older birds (Page 1974). Bolinas Lagoon (UTM WGS84 10 528059 E 4197069 N) is located at latitudes ~ 0.5° north of my most northern MAV sites. The variability in Least Sandpiper abundances likely masked any temporal detectable differences within species, because, like other small Calidridine sandpipers, they use habitats opportunistically and disperse across the landscape (Brown et al. 2000). Least Sandpipers abundances made up a majority of small shorebird species abundances and their peak abundances were observed at similar temporal scales as Page (1974). However, unlike along the coast of California, where peak abundances lasted from late August – mid-October (Page 1974), small shorebird peak abundance in the MAV and NGoM had decreased dramatically by late September.

Medium shorebird abundance differed yearly, with 2011 having greater medium shorebird abundances than 2013, but with overall decreasing trends in abundances each successive survey year. For two medium sized shorebird species, year explained variation in Killdeer abundance during my study and was the only covariate to estimate variation in Pectoral Sandpiper abundances in the MAV and along the NGoM. Both species' greatest abundance occurred in 2011 with an overall decreasing trend in the following two years. A drought year occurred in 2011with limited wetland habitat on the landscape, which possibly concentrated shorebird abundances on few available wetland habitats. In 2012, Hurricane Isaac made its second landfall in Port Fourchon, Louisiana on 28 August (Bianchette et al. 2015). The storm tracked north/northwest through the lower portion of the MAV. Hurricane Isaac was unique due to its large size, slow speed, and heavy rainfall depositing 20 – 38 cm of rain during its passage over the lower MAV. Its landfall also coincided with late August and peak bird abundance. Whether the decreasing trend in bird abundance among years is a response influenced by drought concentrating birds in 2011, dispersion by Hurricane Isaac in 2012, or the associated increase in shallow water habitat due to hurricane cannot be concluded. Both species resistance to population rebounds in 2013 to pre-hurricane levels may be a consequence of decreased habitat quality due to lagging effects of droughts or hurricanes.

At finer temporal scale across years, greatest (late August) medium shorebird abundances and least (late September) medium shorebird abundances resembled trends observed in total shorebird abundances and small shorebird abundances. However, medium shorebird abundances never rebounded to levels comparable to earlier migration periods. Killdeer peak abundances peaked slightly longer than all medium sized shorebirds from late August – early September (period 3). This likely coincides with the end of nesting season for resident birds and the arrival of migratory birds (Conway et al. 2005, Davis et al. 2008). Across sites, peak Killdeer abundance was 10 times greater during peak migration than their lowest observed abundances during late September. The abrupt departure of shorebirds expressed in total abundance, guilds, and species during southerly migration suggest shorebirds may use the MAV and NGoM for shorter periods than stopover areas along the west coast (Page 1974). However, their abbreviated stay in the MAV and along the NGoM is not uncommon among migrant shorebirds using habitats along the Atlantic coast. Red Knots spend ~3 weeks refueling in the Delaware Bay prior to nonstop flights to the breeding grounds in the tundra (Karpanty et al. 2006). The relative importance of inland (MAV) and coastal (NGoM) habitats as stopover areas for shorebirds and their functional role in providing needed resources for similar nonstop flights across the Gulf of Mexico to wintering areas is not fully understood and needs further research.

Regional shorebird abundance

Killdeer and Pectoral Sandpipers are both medium sized shorebirds and showed similar patterns in yearly differences. They may also share preference patterns between freshwater and marine habitats. Even though I did not encounter differences in Pectoral Sandpiper abundance by region, Yohannes et al. (2009) observed them favoring inland over marine environments. Killdeer abundance was the only response variable to exhibit regional differences. Many more Killdeer were observed in the MAV than along NGoM. Within my study regions, Killdeer included both seasonal breeders and migratory populations (Conway et al. 2005). Killdeer breeding near the hypersaline Mono Lake, California were observed nesting within close proximity of freshwater seeps and springs that flowed into the lake (Rubega and Robinson 1997). Even though Killdeer have been classified as an abundant habitat generalist species that breeds across North America (Withers 2002), they may in fact use freshwater and marine habitats differently.

Water depth and shorebird abundance

The Central and Mississippi Flyways s make up the interior migration routes for migratory birds in the United States. Wetlands in the Central Flyway are dynamic and highly unpredictable in space and time and shorebird use of habitats is opportunistic and dispersed across the landscape (Brown et al. 2000). In the southeastern United States, fall is on average the driest period of the year with August and September being the two months of least precipitation in the central MAV (Eggleston 2016). Therefore, limited shallow water habitats found on the landscape during these months may have an “oasis” effect, concentrating shorebirds on reliable sites like catfish pond complexes, public managed lands, river sandbars, or oxbow lakes (Twedt et al. 1998).

Shorebirds also vary greatly in body size, which partitions their foraging behaviors across narrow water depth bands within a wetland and theoretically reducing competition (Davis and Smith 2001). Shorebird foraging depth is primarily partitioned by body morphology metrics and typically ranges from adjacent dry uplands to water depths of 15 cm (Baker 1979, Colwell 2010). In my study, medium shorebird abundances and large shorebird abundances were observed on shallow water habitats differing in average water depths (~6.5 and ~10.6 cm, respectively). Gammonley and Laubhan (2002) found Killdeer foraged across a range of depths from the water’s edge to 10 cm in Colorado. The median water depth used by foraging Killdeer estimated by Gammonley and Laubhan (2002) is similar to my estimate of use of average shallow water habitat in the MAV and NGoM (i.e., 5 cm). Additionally, medium and large shorebird guilds differed in respect to the average depth of used areas when in shallow water habitats. Medium shorebirds decreased in abundance while large shorebirds increased. By foraging at deeper sites, larger shorebirds could theoretically reduce competition by exploiting resources otherwise unavailable to smaller birds (Davis and Smith 2001, Gammonley and Laubhan 2002). In my study, this resource partitioning pattern held true at the species level. Killdeer had a negative relationship with increasing water depth and likely related to median (3.6 cm) tarsal length (Pyle 2008). Black-neck Stilts had a positive relationship to increasing water depth and likely related to its longer median (10.75 cm) tarsal length (Pyle 2008). Unlike the larger shorebird guilds in my study, small shorebirds showed no relationship with water depth because their foraging behaviors are concentrated along wetland edges and adjacent sparsely vegetated terrestrial habitats (Colwell and Oring 1988). Further, shoreline edges shift frequently due to growth of vegetation, evaporation, and precipitation.

Seasonal wetlands in the MAV and tidal wetlands along the NGoM provide breeding and migrating shorebirds with a mosaic of foraging opportunities annually. On sites with reliable annual water, shallow depths are important for providing migratory shorebirds with access to food resources. In the Mississippi Delta region of the MAV where catfish ponds are most abundant, a 1 cm increase in water depth would result in greater water surface area, because catfish ponds are constructed with a uniform laser-leveled bottom (Feaga et al. 2015). The uniform construction of these ponds allows producers easy access and extraction of their fish stocks for market. Aquaculture ponds are regularly managed (Chat Phillips, Phillips Brother’s Farms, personal communication) and typically, 5 –10% of ponds at a facility are subjected to activities such as removing water for levee repair or seasonal idling from production. This consequently generates mudflats and shallow water that provides migrant shorebirds and other waterbirds with foraging and stopover habitats. Managed interior wetlands, such as those created by MBHI, could become consistent important sites for the limited number of shorebirds that breed in the southeast. Conway et al. (2005) studied shorebird breeding biology of

American Avocet (*Recurvirostra americana*), Black-necked Stilt, Killdeer, and Snowy Plover (*C. alexandrinus*) in the playa lakes region of Texas and emphasized the importance of maintaining wetland hydrology throughout the breeding season and into fall migration. In California, on functioning evaporation and converted evaporation basins, Black-necked Stilts nesting density were 1 – 2 orders of magnitude greater on converted and managed basins (Davis et al. 2008).

Inter-annual variability of shallow water habitats on the landscape may reduce feeding habitat and thereby increase competition for the remaining resources (Le V Dit Durell 2000). Similar mechanisms could be driving prey abundance and thereby bird abundance on habitats recovering from a major disturbance such as droughts, hurricanes, floods or oil spills. Intra-annual variability in peak shorebird abundance may also reflect seasonal pulses of food resources (i.e., aquatic invertebrates). Shorebirds and other migratory birds time their migration relative to key resources such as food (Schneider and Harrington 1981).

Hurricane disturbance

Few studies have assessed the impacts of hurricanes on shorebirds (Johnson and Baldassarre 1988), but Wiley and Wunderle (1993) reported southern migrants are frequently displaced northward along the east coast of North American as tropical storms track north. Hurricanes can also displace migrant shorebirds west of their traditional southern migration routes. In 1974 Hurricane Fifi had major effects on southbound bird migration including, localized concentrations of migrants, deflected individuals from normal routes, temporary extension of winter ranges, and delayed passage of some species (Fisk 1979, Wiley and Wunderle 1993). Johnson and Baldassarre (1988) observed increased mortality and/or emigration in Snowy Plovers after the passage of two hurricanes along the Alabama coast during the fall of 1985. Hurricanes are low pressure tropical storms with cyclic winds spinning counterclockwise and known for carrying birds off course from established flightpaths (Fussell, III and Allen-Grimes 1980).

Hurricane Isaac made landfall during the peak migration period associated with a wide range of shorebird response variables and therefore, likely influenced shorebird migration pathways with a consequent influence on bird abundances in the study region. During the course of my study, I encountered droughts, hurricanes, and flooding events. Thus, it is difficult to empirically identify which natural disturbance was most influential on affecting bird abundances in the MAV and along the NGoM. Additionally, the direct impact of Hurricane Isaac, combined with increased acreage of standing water across the landscape, may have dispersed shorebirds away from survey areas to sites otherwise seasonally unavailable during years of average rainfall.

Latitudinal variation in shorebird abundance

Historically, shorebirds migrating along the interior portions of the United States likely bypassed heavily forested regions such as the MAV, and moved from their northern breeding grounds and stopover sites to coastal marshes of the NGoM (Henkel and Taylor 2015). Shorebirds exhibit strong site fidelity to breeding, migration and wintering sites (Skagen and Knopf 1994, Maxted et al. 2016). Therefore, the relationship of decreasing latitude and increasing abundance across guilds and species likely represented their propensity to select specific stopover habitats along historical migration and overwintering routes.

Both small and medium sized shorebirds were most abundant at one MBHI site, Phillips Brother's Farms. Killdeer are an abundant habitat generalist species that breeds across North America with time and latitude playing a major role in determining areas of concentration in any portion of their range (Withers 2002). Their abundances increased as latitude decreased and had greatest abundances at two MBHI sites, Nerren Fisheries and Phillips Brother's Farms. The MBHI may have been important for providing shallow water habitat for resident and migrant Killdeer and other shorebirds that breed regionally during the driest months of the year. However, following major precipitation events (i.e., hurricanes), I observed a decrease in Killdeer abundance at my sites. Increased precipitation and therefore increased water depth, on sites with current suitable habitat (e.g., drained catfish ponds) likely influenced the negative relationship with water depth above 5 cm. Shorebirds are confined to foraging zones in wetlands due to their morphological constraints where larger bodied birds have greater access to a wider range of foraging locations (Gammonley and Laubhan 2002). Catfish ponds likely provide suitable shorebird habitat because of their inherent design (i.e. flat uniform bottom). Thus allowing migrant shorebirds to partition themselves across water depths as ponds increase or decrease in volume and area due to precipitation or evaporation.

Management Implications

The area of surface water under catfish production has seen a 60% decline in Mississippi since its peak in the 1980s (Feaga et al. 2015). The decline in catfish production is due to increasing costs associated with production and competition from foreign fish markets (Falconer 2014). If producers drained idled ponds partially or completely at staged intervals starting in the spring and continued throughout fall migration, they would provide breeding habitat for breeding resident shorebirds (e.g., Killdeer, Black-necked Stilts) and stopover habitat for fall migrating shorebirds (Smith et al. 1991, Twedt et al. 1998). This may be important because interior shallow water habitat may be limiting to migrant shorebirds as they fly through the MAV during the driest months of the year. Least Sandpiper, Pectoral Sandpiper, and Killdeer may need these interior fresh shallow water habitats to forage on food resources. Least Sandpipers are one of the most abundant shorebird species in the Mississippi Flyway (Lehnen 2010, Lehnen and Krementz 2013) and were the most abundant shorebird species I encountered in the MAV. Baker et al. (2004) observed reduced adult survival in wintering populations of Red Knots to be correlated with nutrient stores accumulated in Delaware Bay before migration to breeding grounds in the Canadian Arctic. Seasonal reductions in survival may be observed in Least Sandpipers without interior shallow water habitat on the landscape, as a result of inadequate energy reserves to successfully migrate to their wintering or breeding grounds. The LMVJV attempts to address the challenges associated with accommodating a wide breadth of habitat requirements for many shorebird species annually through partnering with agencies that provide incentive support to private landowners.

The MBHI program and other sites enrolled in similar programs had added benefits beyond providing inland freshwater habitat to migrants to mitigate for oil impacted coastal habitats following the 2010 Deepwater Horizon oil spill. Specifically, the MBHI program provided inland shallow water habitat during a severe drought, as indicated by the Palmar Drought Severity Indices (Palmer 1965), in the southeastern United States in 2010 – 2011 to a multitude of species (APPENDIX B, Table B.1).

Additionally, shallowly flooded sites provided spring/summer wetland habitat for resident breeding shorebirds and fall flooded habitat for migrants. Thus, shallow water habitats in the MAV and along the NGoM should be conserved and actively managed to provide food resources for migrant waterbirds during critical times of their migration (Twedt et al. 1998, Kaminski and Davis 2014, Feaga et al. 2015, Fleming et al. 2015).

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Table 3.1 Site specific shorebird relative abundance (mean [$\overline{x}$] birds/ha, ± standard errors [SE], and [n] surveys) in regions, states, and sites during August – October 2011 – 2013.

Region	**State**	**Site**	***n***	$\overline{x}$	**SE**
Mississippi Alluvial Valley			756	7.16	0.783
	Missouri		120	0.83	0.306
		Duck Creek Conservation Area (CA)	12	3.01	2.639
		Ten Mile Pond CA	8	1.72	0.571
		Otter Slough CA	100	0.50	0.181
	Mississippi		636	8.36	0.921
		Migratory Bird Habitat Initiative	501	10.03	1.14
		Phillips Brothers Farms	192	17.79	2.613
		Nerren Fisheries	8	13.84	7.789
		Janous Properties	98	8.49	1.961
		Thompson Fisheries	45	4.96	1.774
		Bear Creek Fisheries	158	2.79	0.612
		National Wildlife Refuges (NWR)	135	2.15	0.698
		Yazoo NWR	4	2.44	1.113
		Coldwater River NWR	13	0.53	0.338
		St. Catherine Creek NWR	118	2.33	0.796
		Cloverdale tract	13	8.55	6.857
		Sibley Farms moist-soil units	105	1.56	0.279

Site specific shorebird relative abundance (mean [$\overline{x}$] birds/ha, ± standard errors [SE], and shallow water habitats surveyed [n]) in regions, states and sites (Figure 3.2) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table 2.1 (continued)

Region	**State**	**Site**	***n***	$\bar{x}$	**SE**
Northern Gulf of Mexico			51	6.07	1.007
	Alabama	Dauphin Island	17	11.88	2.229
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve	16	5.27	0.972
		Grande Batture Islands	14	5.54	1.060
		Salt Pannes	2	3.37	2.615
	Louisiana	Elmer's Island Wildlife Refuge	18	1.31	0.228

Site specific shorebird relative abundance (mean [$\bar{x}$] birds/ha, ± standard errors [SE], and shallow water habitats surveyed [*n*]) in regions, states, and sites (Figure 3.2) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table 3.2 Candidate models examined to explain variation in total shorebird relative abundance ranked by Akaike's Information Criterion corrected for small sample size (AIC_C) and included number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AIC_C**	**ΔAIC_C**	**ω_i**
Year + Period + Region + Latitude + Rainfall + Water Depth	14	7110.9	0.00	0.940
Year + Period + Latitude	11	7117.5	6.52	0.036
Year + Period + Rainfall	11	7119.6	8.70	0.012
Year + Period + Region	11	7120.2	9.33	0.009
Year + Period	10	7123.2	12.28	0.002
Year + Period + Water Depth	11	7125.4	14.47	0.001
Period	8	7125.7	14.73	0.001
Period + Water Depth	9	7127.9	16.93	0.000
Latitude + Rainfall	5	7156.6	45.66	0.000
Rainfall	4	7160.3	49.36	0.000
Year	5	7172.6	61.71	0.000
Region	4	7173.1	62.21	0.000
Latitude	4	7173.4	62.42	0.000
Year + Water Depth	6	7174.5	63.55	0.000
Latitude + Water Depth	5	7174.7	63.73	0.000
null	3	7176.1	65.17	0.000
Water Depth	4	7177.9	66.92	0.000

Candidate models examined to explain variation in total shorebird relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected for small sample size (AIC_C) and included number of estimable parameters (K) and model weight (ω_i).

Table 3.3 Candidate models examined to explain variation in small ($x \leq 50$ g) shorebird relative abundance ranked by Akaike's Information Criterion corrected (AIC$_C$) and includes number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AIC$_C$**	**ΔAIC$_C$**	**ω_i**
Year + Period + Region + Latitude + Rainfall + Water Depth	14	6398.2	0.00	0.620
Year + Period + Region	11	6401.5	3.27	0.121
Year + Period + Rainfall	11	6401.5	3.30	0.119
Year + Period + Latitude	11	6402.8	4.59	0.062
Year + Period	10	6403.6	5.42	0.041
Period	8	6405.3	7.07	0.018
Year + Period + Water Depth	11	6406.0	7.73	0.013
Period + Water Depth	9	6407.7	9.43	0.006
Latitude + Rainfall	5	6422.0	23.77	0.000
Rainfall	4	6422.4	24.21	0.000
Year	5	6429.9	31.67	0.000
Region	4	6430.1	31.87	0.000
Year + Water Depth	6	6430.5	32.31	0.000
null	3	6432.3	34.09	0.000
Latitude	4	6432.5	34.23	0.000
Latitude + Water Depth	5	6432.5	34.25	0.000
Water Depth	4	6433.0	34.81	0.000

Candidate models examined to explain variation in small ($x \leq 50$ g; APPENDIX C, Table C.1) shorebird relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected (AIC$_C$) and includes number of estimable parameters (K) and model weight (ω_i).

Table 3.4 Candidate models examined to explain variation in medium ($51 \leq x \leq 100$ g) shorebird relative abundance ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AIC_C**	**ΔAIC_C**	**ω_i**
Year + Period + Region Latitude + Rainfall + Water Depth	14	5821.5	0.00	0.959
Year + Period + Latitude	11	5828.7	7.18	0.026
Year + Period + Rainfall	11	5831.4	9.93	0.007
Year + Period + Region	11	5832.4	10.90	0.004
Year + Period	10	5833.2	11.77	0.003
Year + Period + Water Depth	11	5834.9	13.41	0.001
Period	8	5837.9	16.47	0.000
Period + Water Depth	9	5839.1	17.63	0.000
Latitude + Rainfall	5	5862.0	40.57	0.000
Rainfall	4	5862.7	41.27	0.000
Year + Water Depth	6	5869.4	47.90	0.000
Year	5	5870.2	48.70	0.000
Latitude + Water Depth	5	5872.9	51.42	0.000
Water Depth	4	5874.1	52.63	0.000
Region	4	5875.0	53.48	0.000
null	3	5875.9	54.44	0.000
Latitude	4	5876.1	54.62	0.000

Candidate models examined to explain variation in medium ($51 \leq x \leq 100$ g; APPENDIX C, Table C.2) shorebird relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Table 3.5 Candidate models examined to explain variation in large (x ≥ 101 g) shorebird relative abundance ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AICc**	**ΔAICc**	**ω_i**
Period + Water Depth	9	4755.3	0.00	0.760
Year + Period + Water Depth	11	4759.0	3.75	0.116
Year + Period + Region + Latitude + Rainfall + Water Depth	14	4760.2	4.93	0.065
Water Depth	4	4761.0	5.78	0.042
Latitude + Water Depth	5	4763.9	8.61	0.010
Year + Water Depth	6	4764.7	9.44	0.007
Region	4	4790.8	35.56	0.000
null	3	4792.5	37.27	0.000
Latitude	4	4792.7	37.46	0.000
Period	8	4793.0	37.72	0.000
Rainfall	4	4794.3	39.07	0.000
Latitude + Rainfall	5	4794.5	39.29	0.000
Year + Period + Region	11	4794.9	39.67	0.000
Year + Period + Latitude	11	4795.5	40.22	0.000
Year	5	4796.3	41.07	0.000
Year + Period	10	4796.7	41.47	0.000
Year + Period + Rainfall	11	4797.8	42.54	0.000

Candidate models examined to explain variation in large (x ≥ 101 g; APPENDIX C, Table C.3) shorebird relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Table 3.6 Candidate models examined to explain variation in Least Sandpiper (*Calidris minutilla*) relative abundance ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AICc**	**ΔAICc**	**ω_i**
Year + Period + Region	11	6102.1	0.00	0.336
Year + Period + Rainfall	11	6102.8	0.72	0.234
Year + Period + Region + Latitude + Rainfall + Water Depth	14	6103.0	0.86	0.219
Year + Period	10	6104.2	2.09	0.118
Year + Period + Latitude	11	6105.5	3.39	0.062
Year + Period + Water Depth	11	6107.4	5.28	0.024
Period	8	6110.1	7.97	0.006
Period + Water Depth	9	6113.3	11.23	0.001
Year	5	6118.1	16.04	0.000
Rainfall	4	6118.9	16.81	0.000
Latitude + Rainfall	5	6119.9	17.82	0.000
Year + Water Depth	6	6120.5	18.36	0.000
Region	4	6122.2	20.13	0.000
null	3	6124.4	22.31	0.000
Latitude	4	6125.8	23.68	0.000
Water Depth	4	6126.9	24.81	0.000
Latitude + Water Depth	5	6127.9	25.80	0.000

Candidate models examined to explain variation in Least Sandpiper (*Calidris minutilla*) relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Table 3.7 Candidate models examined to explain variation in Killdeer (*Charadrius vociferous*) relative abundance ranked by Akaike's Information Criterion corrected (AIC$_C$) and includes number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AICc**	**ΔAICc**	$\boldsymbol{\omega_i}$
Year + Period + Region + Latitude + Rainfall + Water Depth	14	4262.7	0.00	0.971
Year + Period + Water Depth	11	4271.1	8.34	0.015
Year + Period + Region	11	4272.3	9.60	0.008
Year + Period	10	4274.3	11.59	0.003
Year + Period + Rainfall	11	4275.0	12.29	0.002
Year + Period + Latitude	11	4277.1	14.34	0.001
Period + Water Depth	9	4278.6	15.88	0.000
Period	8	4283.4	20.66	0.000
Year + Water Depth	6	4290.5	27.73	0.000
Year	5	4296.4	33.64	0.000
Water Depth	4	4301.2	38.49	0.000
Rainfall	4	4302.5	39.75	0.000
Latitude + Water Depth	5	4304.9	42.19	0.000
Latitude + Rainfall	5	4306.8	44.04	0.000
Region	4	4307.8	45.07	0.000
null	3	4309.3	46.52	0.000
Latitude	4	4313.9	51.17	0.000

Candidate models examined to explain variation in Killdeer (*Charadrius vociferous*) relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected (AIC$_C$) and includes number of estimable parameters (K) and model weight (ω_i).

Table 3.8 Candidate models examined to explain variation in Black-necked Stilt (*Himantopus mexicanus*) relative abundance ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AICc**	**ΔAICc**	**ω_i**
Period + Water Depth	9	4355.3	0.00	0.802
Year + Period + Water Depth	11	4359.6	4.22	0.097
Water Depth	4	4360.0	4.68	0.077
Year + Water Depth	6	4364.4	9.03	0.009
Latitude + Water Depth	5	4364.4	9.10	0.008
Year + Period + Region + Latitude + Rainfall + Water Depth	14	4365.2	9.90	0.006
Region	4	4373.6	18.29	0.000
null	3	4373.7	18.39	0.000
Period	8	4374.1	18.80	0.000
Rainfall	4	4374.8	19.49	0.000
Latitude	4	4377.2	21.82	0.000
Year	5	4377.7	22.40	0.000
Year + Period	10	4377.9	22.56	0.000
Year + Period + Region	11	4378.0	22.62	0.000
Latitude + Rainfall	5	4378.1	22.77	0.000

Candidate models examined to explain variation in Black-necked Stilt (*Himantopus mexicanus*) relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Table 3.9 Candidate models examined to explain variation in Pectoral Sandpiper (*Calidris melanotos*) relative abundance ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

Model	**K**	**AICc**	**ΔAICc**	**ω_i**
Year	5	4559.4	0.00	0.571
Rainfall	4	4563.4	3.98	0.078
Year + Period	10	4563.6	4.10	0.073
Year + Period + Region	11	4563.9	4.42	0.063
null	3	4564.2	4.79	0.052
Year + Period + Rainfall	11	4564.8	5.35	0.039
Region	4	4564.8	5.36	0.039
Year + Water Depth	6	4564.9	5.40	0.038
Period	8	4566.9	7.48	0.014
Year + Period + Latitude	11	4567.5	8.06	0.010
Latitude + Rainfall	5	4568.2	8.75	0.007
Year + Period + Water Depth	11	4569.1	9.64	0.005
Latitude	4	4569.1	9.69	0.005
Water Depth	4	4569.3	9.86	0.004
Year + Period + Region + Latitude + Rainfall + Water Depth	14	4572.1	12.63	0.001

Candidate models examined to explain variation in Pectoral Sandpiper (*Calidris melanotos*) relative abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Models were ranked by Akaike's Information Criterion corrected (AIC_C) and includes number of estimable parameters (K) and model weight (ω_i).

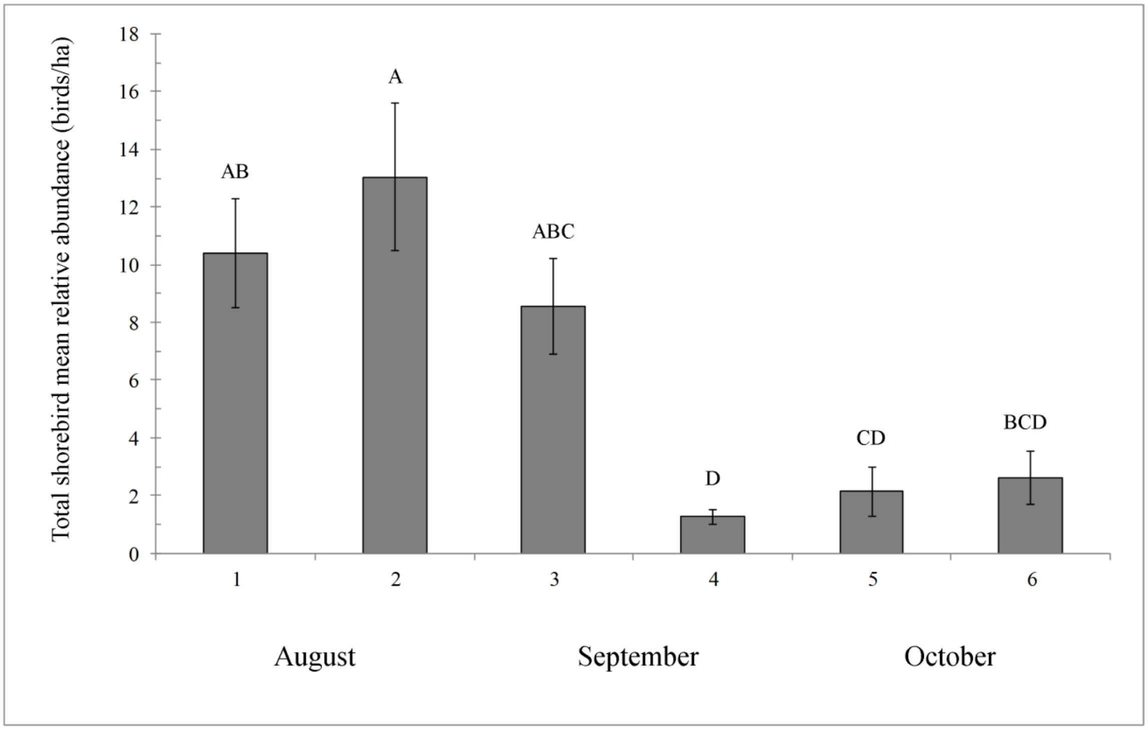

Figure 3.1 Mean total shorebird relative abundance (birds/ha), ± standard errors, and surveys (n = 807) by survey period from 2011 – 2013.

Mean total shorebird relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (n = 807) by survey time period (n = 6) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

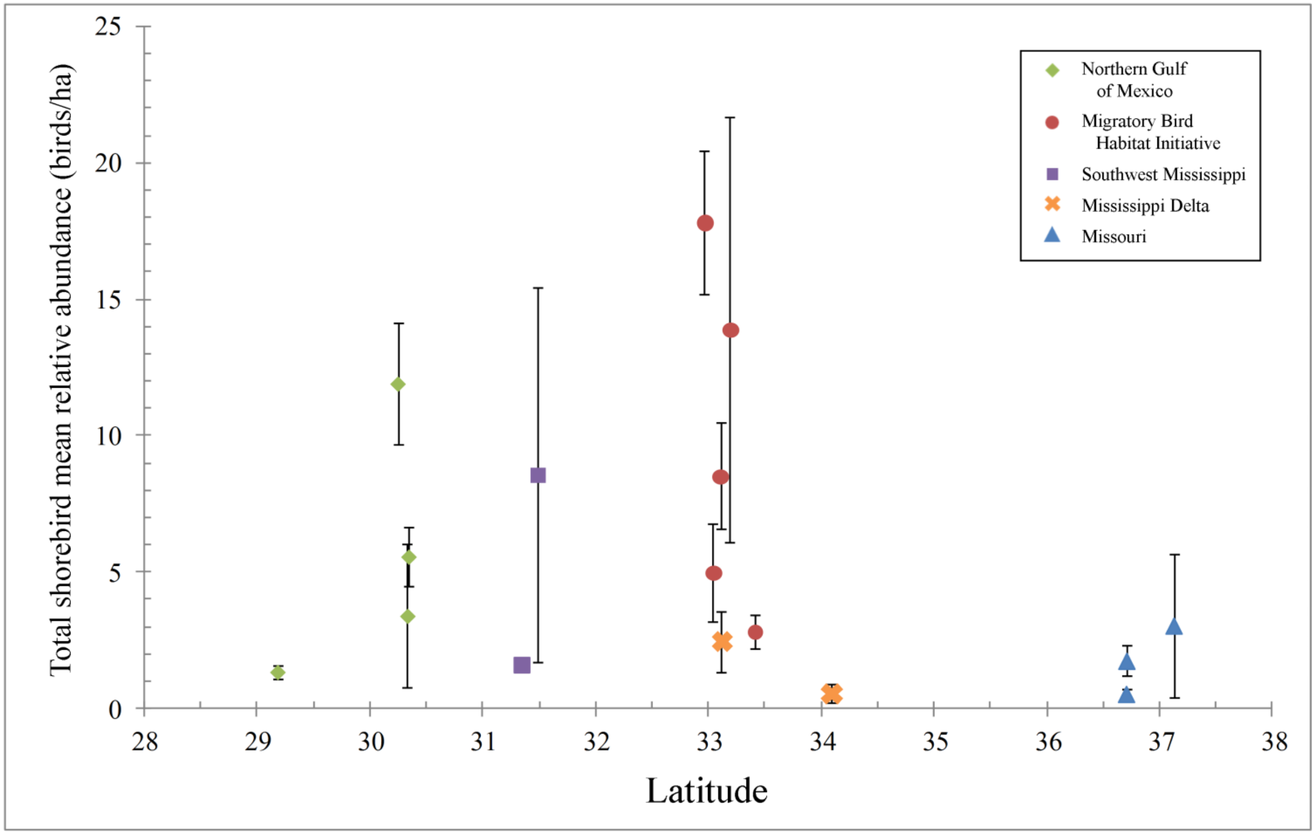

Figure 3.2 Total shorebird mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by site, latitude, and years.

Total shorebird mean relative abundance (APPENDIX B, Table B.1, Charadriidae – Scolpacidae; birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by site (APPENDIX D, Table D.1), latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Colors represent similar management regimes: Northern Gulf of Mexico [green diamond), Migratory Bird Habitat Initiative (red circle), Southwest Mississippi (purple square), Mississippi Delta (orange “X”), and Missouri (blue triangle).

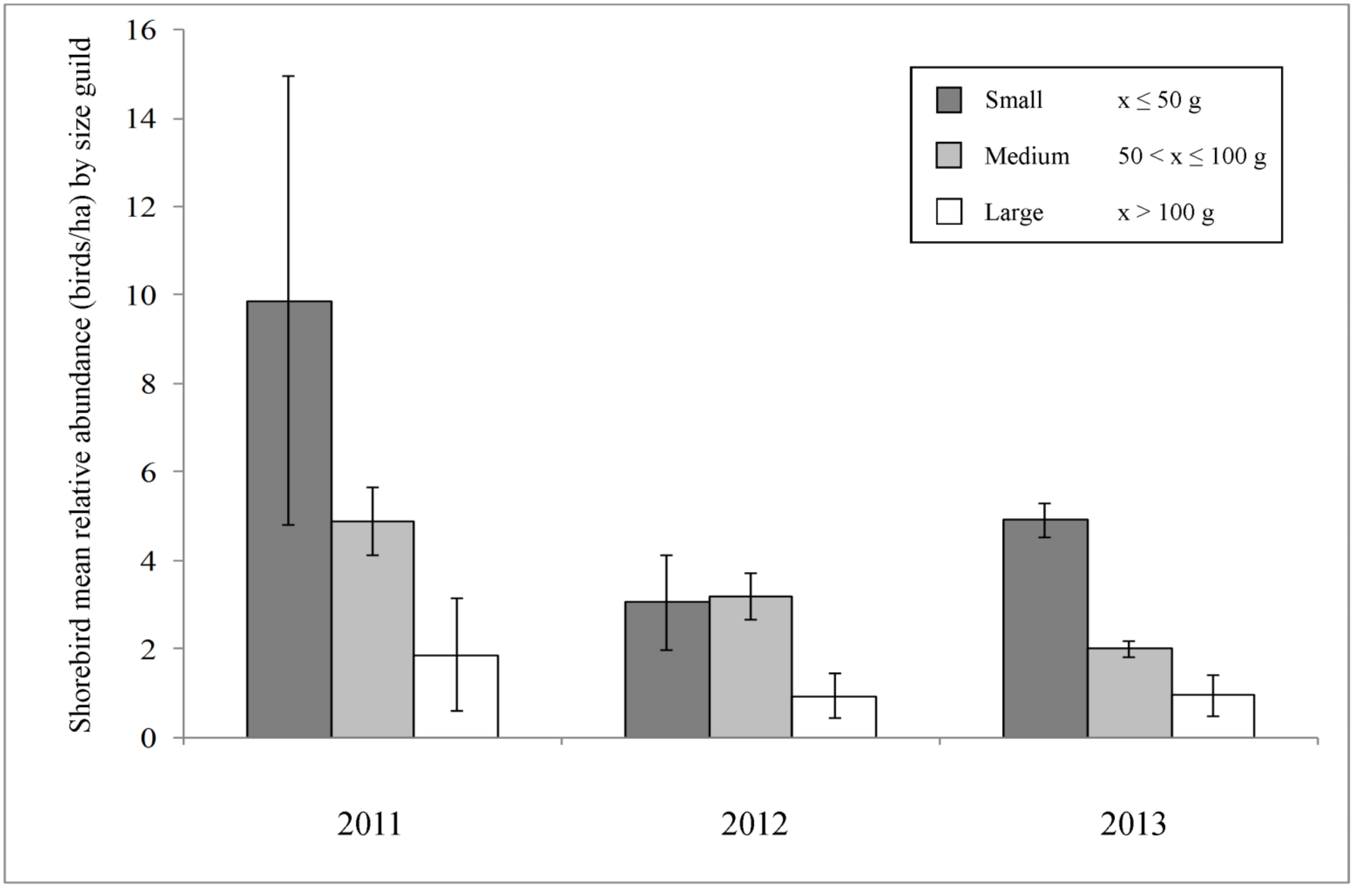

Figure 3.3 Total shorebird mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by guilds from 2011 – 2013

Total shorebird mean relative abundance (birds/ha; APPENDIX C, Tables C.1, C.2, and C.3), ± standard errors, and shallow water habitats surveyed (*n* = 807) by guilds (small, medium, large) determined using weight (g) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

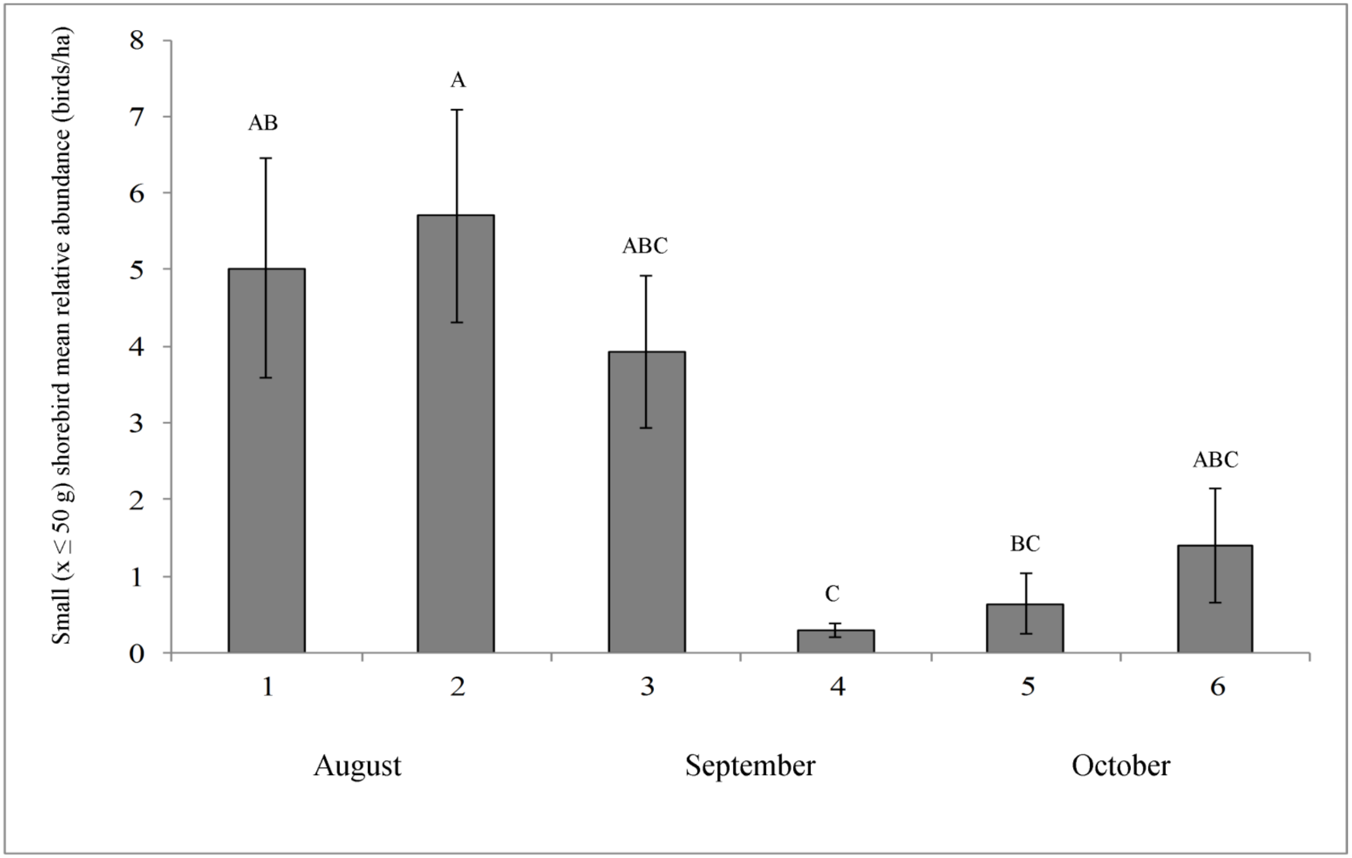

Figure 3.4 Small (x ≤ 50 g) shorebird mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by survey period from 2011 – 2013.

Mean small (x ≤ 50 g; APPENDIX C, Table C.2) shorebird relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by survey time period (*n* = 6) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

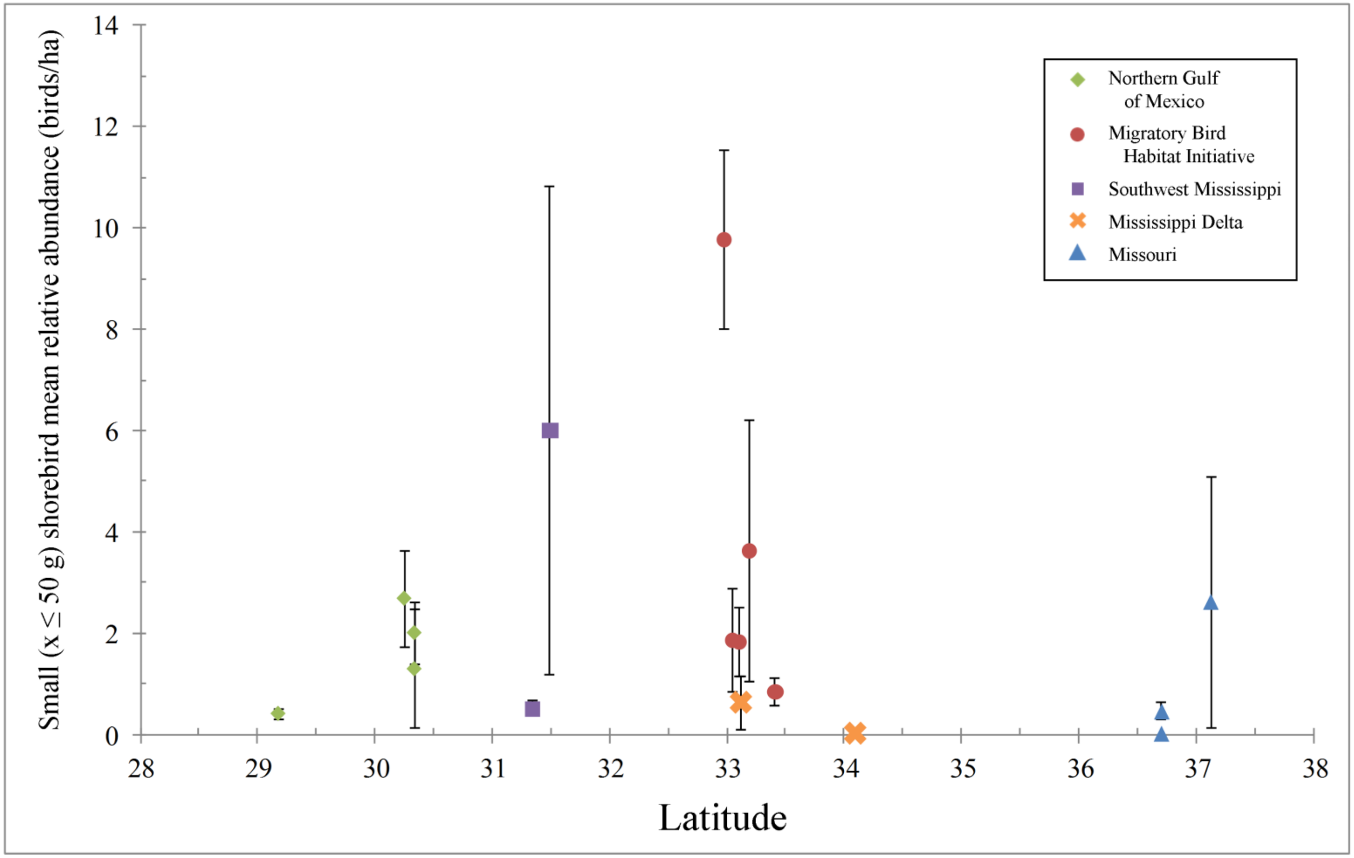

Figure 3.5 Small (x ≤ 50 g) shorebird mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by site across latitude and years.

Small (x ≤ 50 g, APPENDIX C, Table C.2) shorebird mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by site (*n* = 16; APPENDIX D, Table D.1) across latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Colors and shapes represent similar management regimes: Northern Gulf of Mexico [green diamond), Migratory Bird Habitat Initiative (red circle), Southwest Mississippi (purple square), Mississippi Delta (orange “X”), and Missouri (blue triangle).

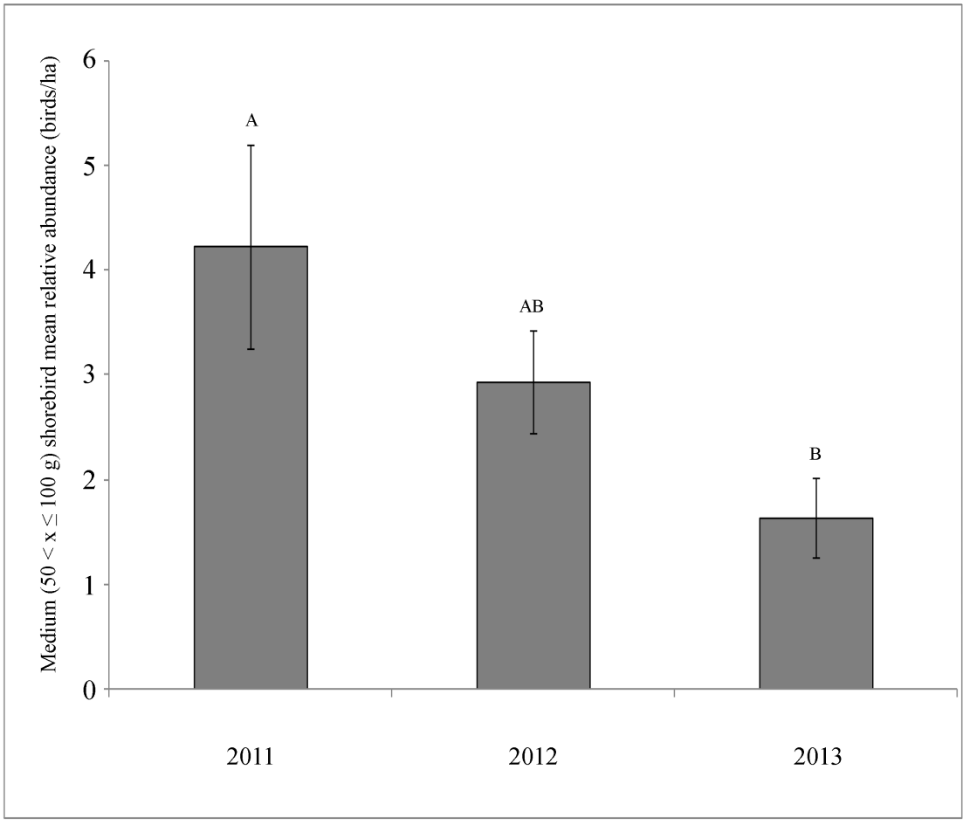

Figure 3.6 Medium (50 < x ≤ 100 g) shorebird mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by year.

Mean medium (50 < x ≤ 100 g; APPENDIX C, Table C.3) shorebird relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by year (*n* = 3) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

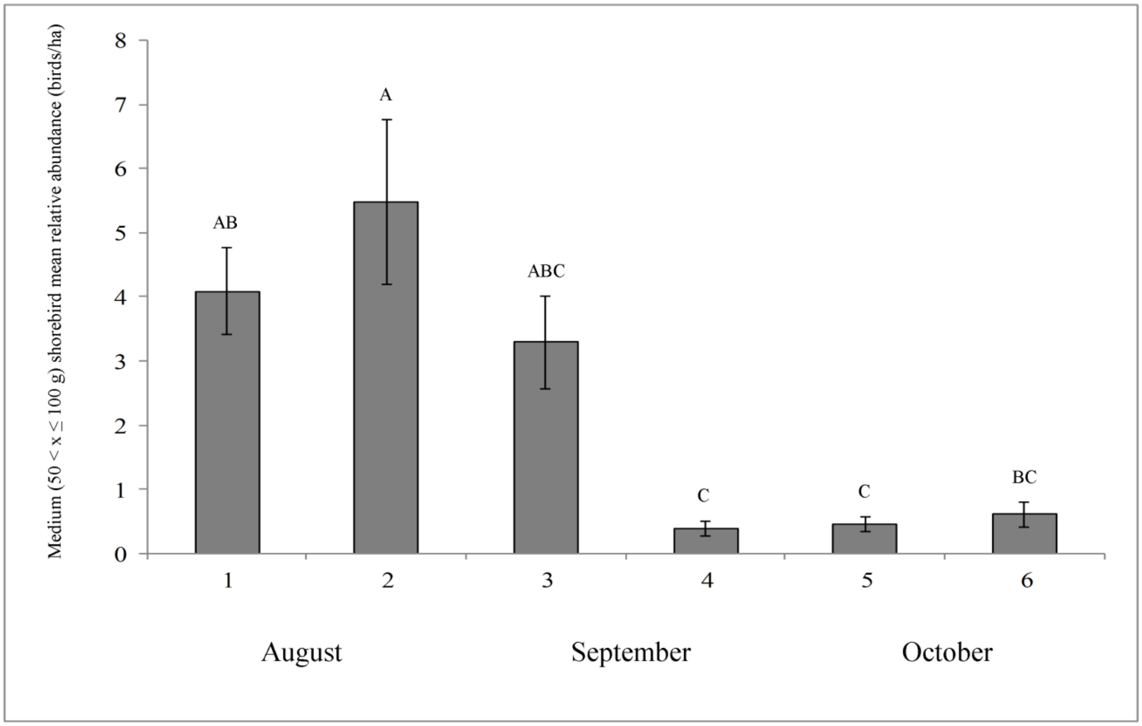

Figure 3.7 Medium (50 < x ≤ 100 g) shorebird mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by survey period across all years.

Medium (50 < x ≤ 100 g; APPENDIX C, Table C.3) shorebird mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by survey time period (*n* = 6) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

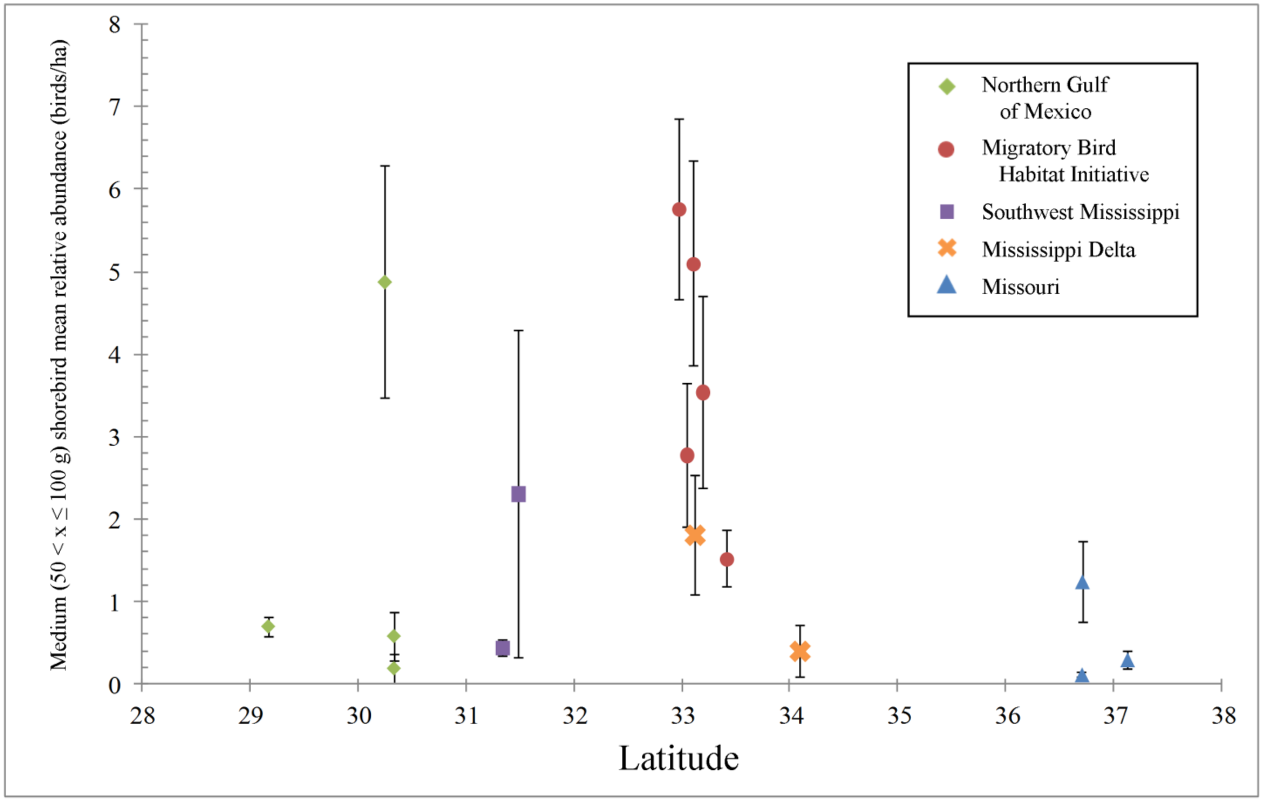

Figure 3.8 Medium (50 < x ≤ 100 g) shorebird mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by site across latitude and years.

Medium (50 < x ≤ 100 g; APPENDIX C, Table C.3) shorebird mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by site (*n* = 16; APPENDIX D, Table D.1) across latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Colors and shapes represent similar management regimes: Northern Gulf of Mexico [green diamond), Migratory Bird Habitat Initiative (red circle), Southwest Mississippi (purple square), Mississippi Delta (orange “X”), and Missouri (blue triangle).

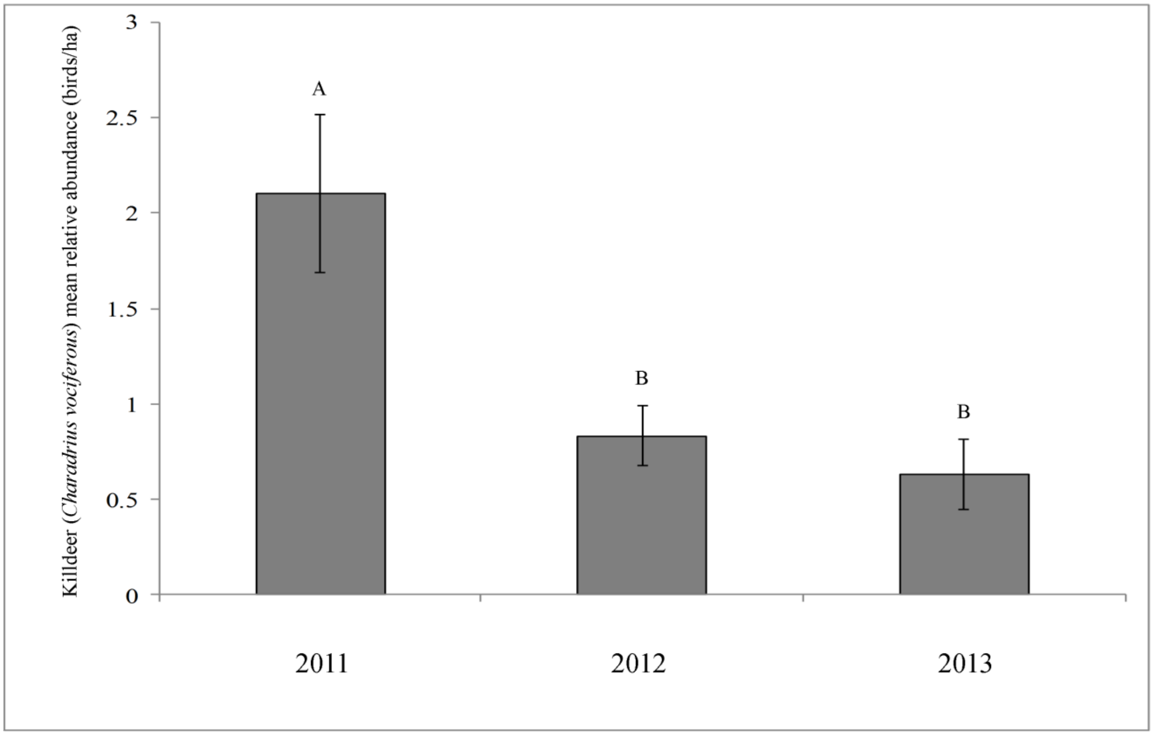

Figure 3.9 Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by year.

Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by year (*n* = 3) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

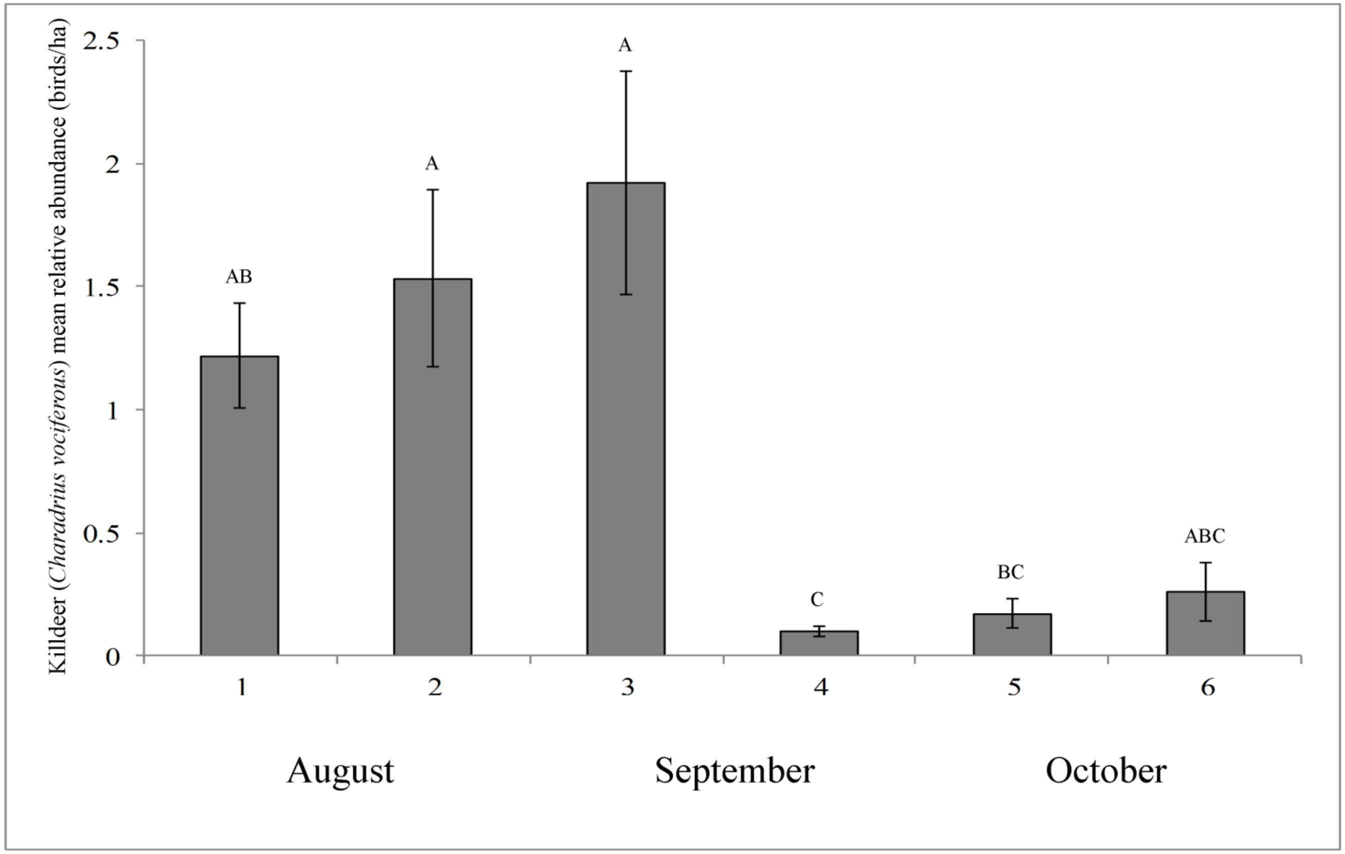

Figure 3.10 Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and surveys (n = 807) by survey period from 2011 – 2013.

Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (n = 807) by survey time period (n = 6) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

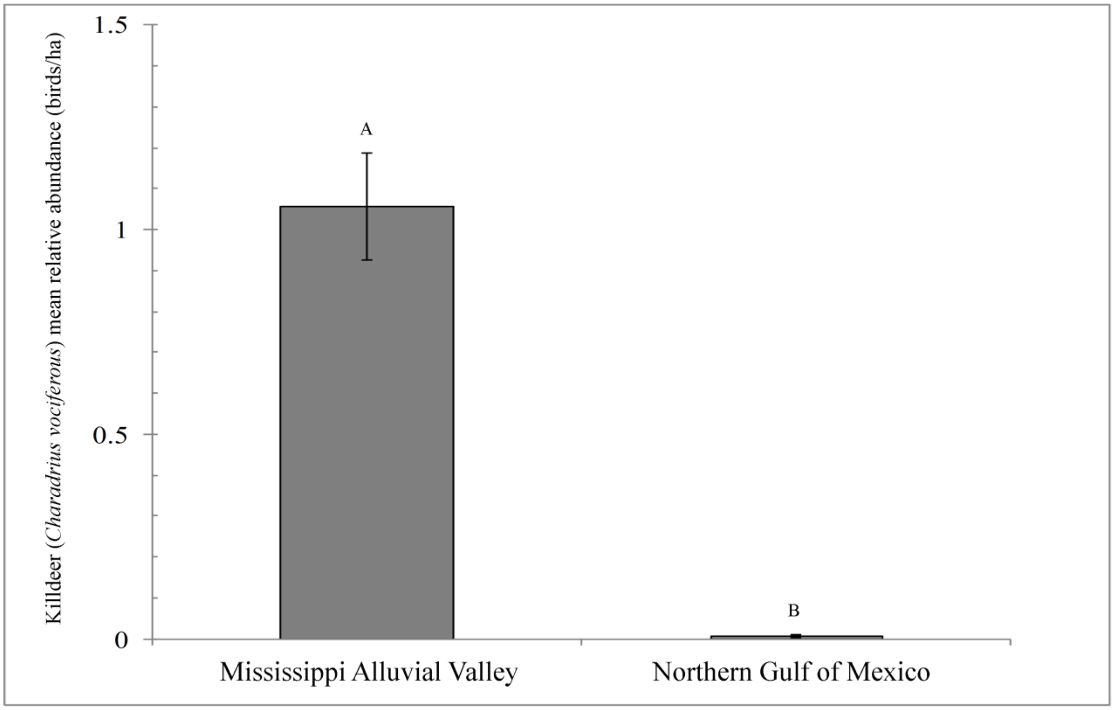

Figure 3.11 Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by region from 2011 – 2013.

Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by region (*n* = 2) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

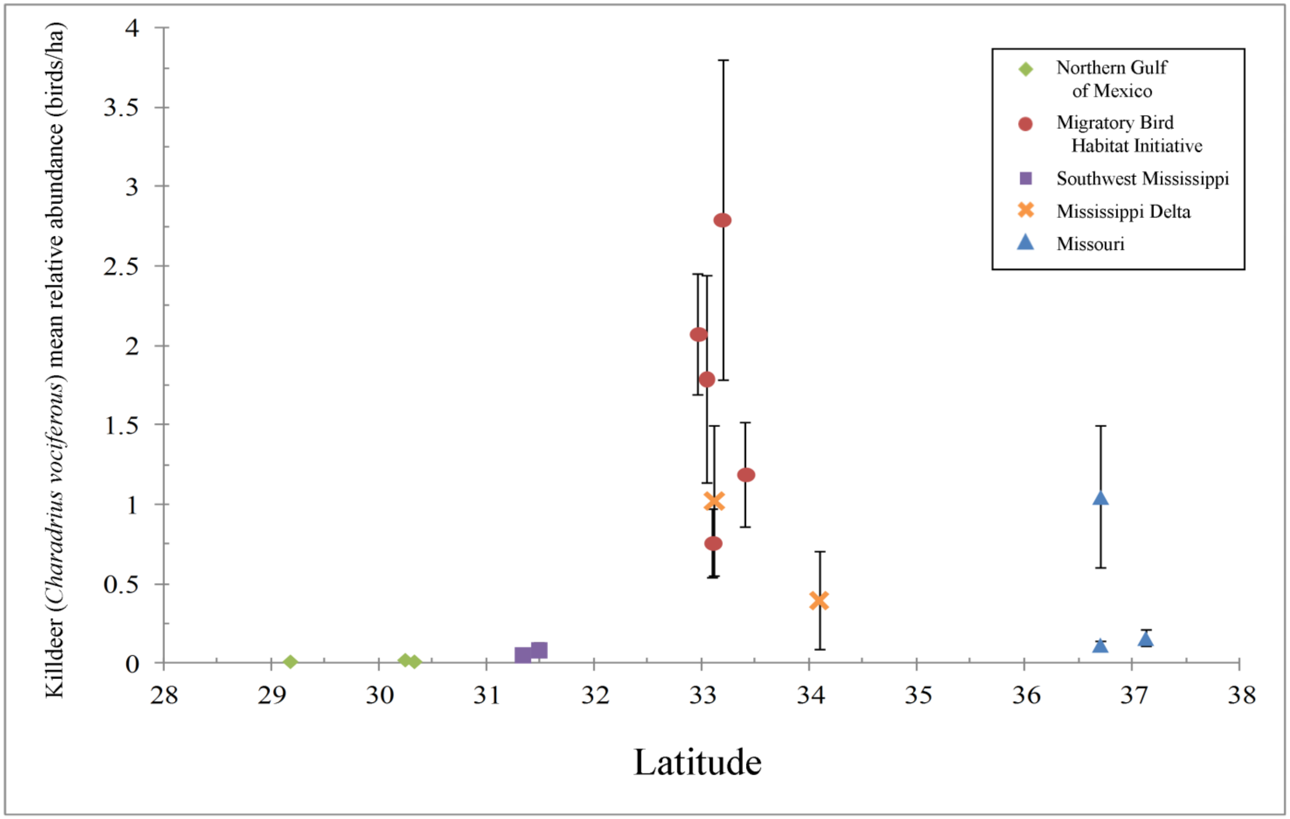

Figure 3.12 Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by site across latitude and years.

Killdeer (*Charadrius vociferous*) mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by site (n = 16; APPENDIX D, Table D.1) across latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Colors and shapes represent similar management regimes: Northern Gulf of Mexico [green diamond), Migratory Bird Habitat Initiative (red circle), Southwest Mississippi (purple square), Mississippi Delta (orange “X”), and Missouri (blue triangle).

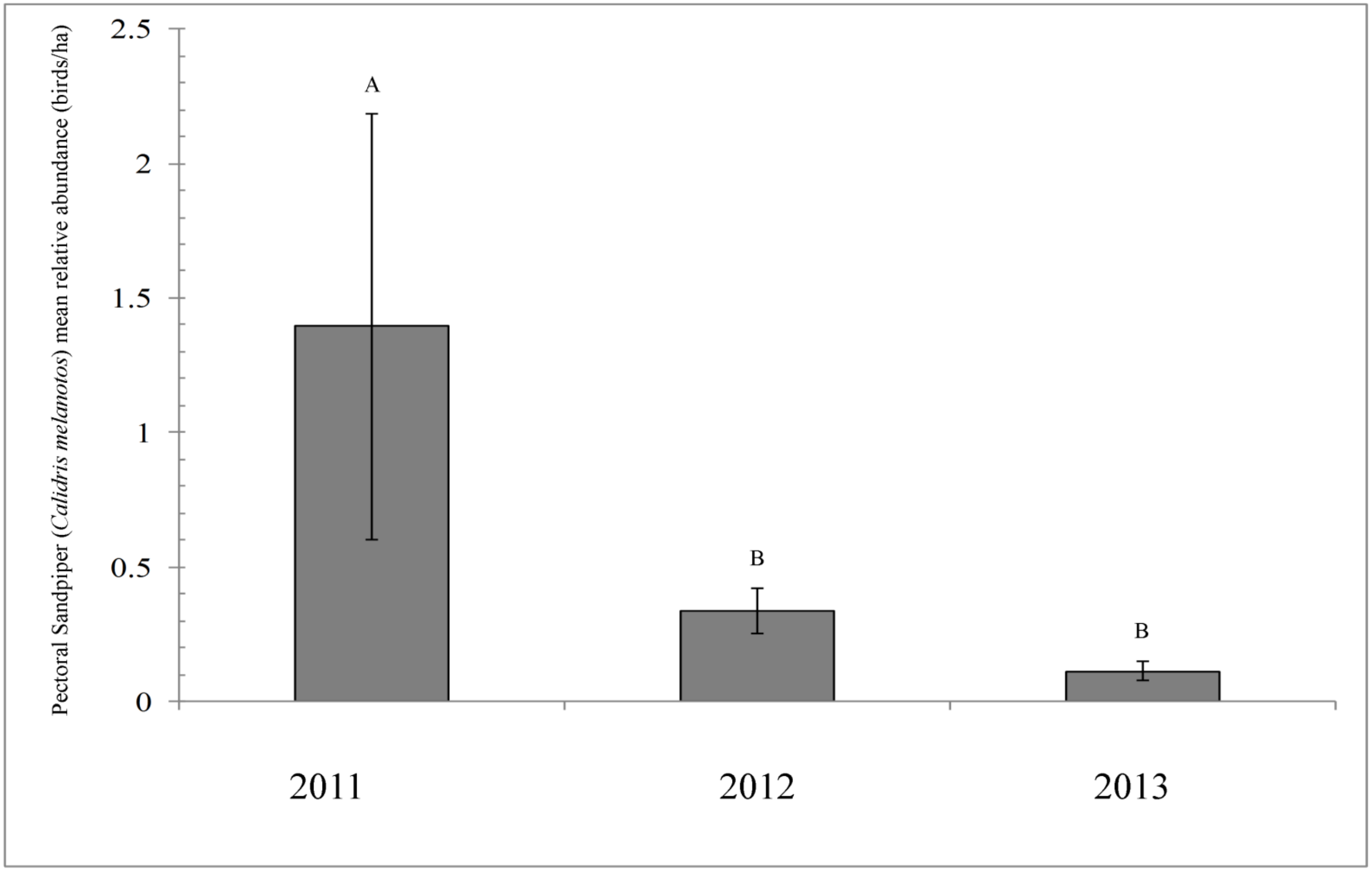

Figure 3.13 Pectoral Sandpiper (*Calidris melanotos*) mean relative abundance (birds/ha), ± standard errors, and surveys (*n* = 807) by year.

Pectoral Sandpiper (*Calidris melanotos*) mean relative abundance (birds/ha), ± standard errors, and shallow water habitats surveyed (*n* = 807) by year (n = 3) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Letters above bars indicate statistical differences.

CHAPTER IV

STABLE ISOTOPIC ASSESSMENT OF FALL MIGRATION HABITAT USE PATTERNS OF THREE CALIDRIDINE SANDPIPERS IN THE MISSISSIPPI ALLUVIAL VALLEY AND NORTHERN GULF OF MEXICO

Introduction

A large component of shorebird conservation involves identifying and protecting crucial wetland habitats along migration routes. Shorebird use of inland regions in the southeastern United States is primarily confined to fall and spring migration, with few species breeding and overwintering. Wetland habitats used by shorebirds in the Mississippi Alluvial Valley (MAV) are primarily found on public lands, near major waterways, and on aquaculture facilities (Twedt et al. 1998, Lehnen and Krementz 2013). To increase wetland habitat and invertebrate food resources for fall migrant shorebirds, the Lower Mississippi Valley Joint Venture and their partners encourage private landowners through incentive based programs (i.e., Migratory Bird Habitat Initiative [MBHI], Wetlands Reserve Program) to provide shallow water habitats ($\leq$ 30 cm) on their properties. However, quantitative information on shorebird us of the MAV is limited

(Lehnen and Krementz 2005, Lehnen 2010, Lehnen and Krementz 2013), constraining the decision making ability of the Joint Venture.

Stable isotopes have been used to study migratory pathways of Neotropical shorebirds (Farmer et al. 2003). This approach may be similarly suited to identify sites of conservation concern for migrating shorebirds, in the southeastern United States. Further, the techniques associated with the collection and analysis of stable isotopes (Hobson and Wassenaar 2008) may be used to link food webs. Kuwae et al. (2012) restructured trophic links in an intertidal ecosystem using stable isotopes by demonstrating a direct link between biofilm and foraging shorebirds. Traditionally, intertidal food webs have been classified using distinct energy channels; such as, three-species food webs: producer (biofilm), consumer (invertebrates), and predator (shorebirds), but may be better explained through omnivory models (McCann and Hastings 1997, Kuwae et al. 2012). Therefore, the use of stable isotope analysis techniques on migrating shorebirds in the MAV and coastlines of the northern Gulf of Mexico (NGoM) may help explain complex trophic interactions or linkages among wetland sites.

Stable isotopes are atoms with nuclei containing the same number of protons but varying numbers of neutrons, which changes their atomic mass. Isotopic elements of importance in biological processes include Hydrogen (H), Carbon (C), Nitrogen (N), Oxygen (O), and Sulphur (S). The lightest stable isotopes are more common, as much as 20 times more abundant than their heavier counterparts (Fry 2007). Stable isotopes are useful because small differences in mass cause subtle differences in their behavior during chemical reactions and diffusion which alter the ratio of heavy to light isotopes. This process, known as isotopic fractionation (Inger and Bearhop 2008, van Gils and Salem

2015) occurs during photosynthesis (i.e., C^3 or C^4 plants), chemosynthesis (e.g., deep sea hydrothermal vents, shallow-water coastal sediments), diet shift due to habitat switching (i.e., fresh to marine), or accumulation via environmental contaminants (i.e., oil and/or pollution). Additionally, stable isotope differences can also be used to trace locations of origin for breeding, migration, and wintering areas of migratory animals (Hobson 1999, Chamberlain et al. 2000, Bearhop et al. 2002).

Wetlands in the MAV and NGoM differ; sites in the MAV are freshwater, while NGoM sites represent a gradient of freshwater, brackish, and saline habitats. Further, invertebrate foods consumed by shorebirds on marine sediments are often defined by different isotopic composition than foods derived from terrestrial and freshwater sources (Chisholm et al. 1982, Gannes et al. 1997). The distinction between fresh and marine environments is important for stable isotope analysis because these habitat types differ isotopically in the ratios of $^{13}C/^{12}C$ and $^{15}N/^{14}N$, allowing researchers to discriminate between animals using different habitats by examining C and N (Hobson 1987, Bearhop et al. 1999, Bearhop et al. 2002). Stable isotopes are a useful tool to demonstrate habitat linkages in situations where two isotopically distinct dietary sources are available to consumers (Hobson and Clark 1992). As shorebird species migrate from breeding grounds to stopover sites in the MAV and NGoM to wintering grounds in South America they encounter both fresh and marine environments.

Least Sandpipers (*Calidris minutilla*) initiate body molt upon leaving the breeding grounds (Page 1974) and have completed a full feather molt by November, whereas many other shorebird species initiate molt late in migration or on the wintering grounds (McNeil and Cadieux 1972, Naranjo et al. 1994, Fernández et al. 2007). Feathers are composed of keratin which is metabolically inert following formation, and thus they preserve their isotopic record indefinitely (Inger and Bearhop 2008). Feathers can be particularly useful when molt chronology and location (i.e., breeding, migration, and wintering grounds) are distinct (Hobson 2005). Adult Western Sandpipers (*C. mauri*) undergo wing molt after they arrive on the nonbreeding grounds and, juvenile birds molt their wing feathers after their second summer. Also, juvenile Western Sandpipers undergo an incomplete body molt into alternate breeding plumage and it is believed many spend their first boreal summer in Panamá (O'Hara et al. 2002).

Additionally, tissues turn over at different rates and integrate isotopic information over different temporal and spatial scales. Consequently, the isotopic make-up of new tissues generally reflects the diet/habitat of animals at the time of synthesis (Cherel et al. 2000, Bearhop et al. 2002, Inger and Bearhop 2008). Isotopic turnover is greater for blood, on the order of a few days to weeks because it is continuously biologically active (van Gils and Salem 2015). The collection of feathers and blood has become common practice for stable isotope analysis in birds. These tissues are minimally invasive to birds (i.e., feathers regrow, low volume of blood collected) and easily collected from birds already in hand after capture (Bearhop et al. 2002). By diligently selecting tissues prior to capture, an animal’s diet or habitat over a range of different temporal and spatial scales may become apparent (Inger and Bearhop 2008). Sampling blood and feathers concurrently at different latitudes may allow researchers a minimally invasive technique to assess migration pathways between breeding and wintering sites, as well as linking stopover sites.

The process of fractionation of N isotopes occurs between trophic relationships in food webs, because the isotopic composition of tissue reflects animal's diet during formation (Hobson et al. 1994, Bearhop et al. 2001). Animals typically show fractionations ranging from +2 parts per thousand (per mil, ‰) to 5 ‰ between N in diet versus tissues (DeNiro and Epstein 1981, Bond and Hobson 2012). Because shorebirds consume invertebrate prey, the N isotope in their tissues tends to be heavier (i.e., more positive ^{15}N values) than that of invertebrate prey lower in the food chain (Minagawa and Wada 1984, Gannes et al. 1997). This relationship in N among primary producers, decomposers, primary consumers, secondary consumers, and up through the food chain enables inferences about trophic relationships and habitat use (Inger and Bearhop 2008). For example, stable isotopes have been used to link Red Knots (*C. canutus*) foraging on horseshoe crab (*Limulus polyphemus*) eggs at stop over areas along the Delaware Bay to their wintering sites in South America and the Caribbean (Atkinson et al. 2005).

Therefore my objectives were to (1) collect shorebird tissues (i.e., feathers and blood) to use stable isotope analysis (^{13}C/^{12}C, ^{15}N/^{14}N) to assess potential migratory connectivity among MAV and NGoM habitats, (2) use stable isotope analysis to possibly assess use of freshwater and estuarine wetlands by fall migrating shorebirds, (3) use shorebird tissues from capture sites to estimate potential hydrocarbon absorption, and (4) make inferences about differences in isotopic signatures for future studies.

Study sites

I initiated sample collection in 2012 because I was not on the Federal banding permit in 2011. I used a subset of my sites as capture locations for shorebirds and collection of feather and blood tissues. Sites in the north MAV managed by the Missouri

Department of Conservation, included Duck Creek Conservation Area (CA), Otter Slough CA, and Ten Mile Pond CA. Birds were collected on Duck Creek CA and Otter Slough CA only during 2012 because area managers did not mow or disk moist-soil impoundments prior to flooding in 2013. They flooded vegetated moist soil units immediately preceding teal hunting season (~15 September annually). Therefore, I had restricted access to sites following flooding to reduce disturbance of hunters in 2013. Flooding precluded access to Ten Mile Pond CA in 2012, thus birds were only collected in 2013. Area managers retained spring flood waters from the Mississippi River and used the draw-down method (Twedt et al. 1998) to create mudflat habitat in their moist-soil impoundments during fall. I attempted to capture birds until flooding prior to teal season. Two locations (Sibley Farms moist-soil units and Cloverdale tract) at St. Catherine Creek National Wildlife Refuge (NWR) were used as capture locations in 2012 and 2013, representing southerly MAV sites. I selected two coastal sites for shorebird capture: 1) Dauphin Island, Alabama, 2012 – 2013; and 2) Elmer's Island Wildlife Refuge (WR) in 2013. Elmer's Island WR was not sampled in 2012 because Hurricane Isaac made landfall 15 km to the southwest and I had limited access to the site. Detailed descriptions of sites are presented in CHAPTER II.

Methods

Mist netting

I surveyed sites one day before shorebird capture events to identify wetlands with greatest bird abundance and maximize capture and marking potentials. One hour before sunrise on capture dates, I erected mist nets (12 m x 2.6 m, mesh size = 36 mm), in close proximity of where I saw greatest bird concentrations the previous day but left them closed. Having mist nets erected before sunrise on capture dates, increased likelihood of capturing of “net-wary” individuals or shorebird species, namely Greater and Lesser Yellowlegs (*Tringa melanoleuca* and *T. flavipes*, respectively), Solitary Sandpiper (*T. solitaria*), and Willet (*T. semipalmatus*) based on previous reports (Lehnen and Krementz 2005). I erected mist nets in a “T” formation with one center pole and three nets (Lehnen and Krementz 2005, Doherty 2009). I erected two mist nets parallel with the wind direction to minimize net movement. I placed the third net perpendicular to the others and thus created two capture quadrants. I placed a motion wing dove decoy in one of the quadrants to attract birds to the capture sites. I deployed mist nets 30 minutes prior to first light until 1000 hours (Guglielmo et al. 2002). I deployed nets during falls 2012 – 2013 for eight hours at Duck Creek CA, 16 hours at Otter Slough CA, eight hours at Ten Mile Pond CA, 40 hours at St. Catherine Creek NWR, 40 hours a Dauphin Island, and 24 hours at Elmer’s Island WR. Shorebirds flew into the nets or were flushed into the nets by one or more people walking toward the birds (Lehnen and Krementz 2005, Henkel and Taylor 2015).

I continually monitored nets for captured birds and extracted them quickly. I placed birds in individual fabric drawstring bags to keep them from overheating. I suspended the bags from a dowel in a 37.85 liter cooler with a 5 cm layer of ice across the bottom until I was able to process them in accordance with my Institutional Animal Care and Use Committee (IACUC, #11-106) protocol. I targeted Pectoral Sandpiper (*C. melanotos*), Least Sandpiper, Semipalmated Sandpiper (*C. pusilla*), and Western Sandpiper. Pectoral and Least Sandpipers are the most abundant migratory shorebirds in the MAV (Lehnen 2010). Semipalmated and Western Sandpipers were observed in low abundances inland but are common stopover migrants at wetlands along the NGoM. Species were also selected based on varying characteristics including migration corridor (i.e., Mississippi Flyway), relatively small size, and foraging strategy.

After extracting birds from bags, I immediately attached a numbered aluminum USGS Bird Banding Lab band on the right tarsus. I recorded the following body metrics: tarsus length, culmen length, and wing cord length to the nearest 0.1 mm with digital calipers or 150 mm wing rule. Culmen length is reliable for sexing > 90% of individuals for Western Sandpipers (Fernández and Lank 2006, Fernández et al. 2007, Pyle 2008). Body metrics are largely unreliable for sexing Semipalmated and Least Sandpipers except at the extremes (≤ 17.4 mm males, ≥ 18.6 mm females) of culmen length (Pyle 2008). Coloration of the proximal coverts is the most reliable way to age Calidridine sandpipers. In Hatch Year (HY) and some Second Year (SY) birds, proximal coverts are fringed with a rufous to buff color, whereas coverts of After Second Year (ASY) birds are fringed with white (Pyle 2008). If possible, the combination of culmen length and covert molt were used to classify birds as HY female/male or After Hatch Year (AHY) female/male. I included sex and age classes as covariates in stable isotope analysis when certain about my determinations.

Stable isotope tissue collection

For stable isotope analysis ($^{13}C/^{12}C$, $^{15}N/^{14}N$), I collected feathers and blood from shorebirds (Ainley et al. 2003). Concentrations of C or N are assimilated at locations where feathers were formed during molt (Guglielmo et al. 2002). I collected the ninth primary to reduce variation in isotopic signature, because shorebirds initiate flight feather molt closer to the body and move outward (Page 1974). By selecting an outer primary, the variation in stages of molt among birds was likely reduced. Least Sandpipers initiated rectrix molt from the innermost to the outermost feathers (Page 1974). I collected the third tail rectrix from the right side of an individual’s tail to potentially capture a migration isotopic signature, because tail rectrices are molted during migration (Page 1974). I stored each feather individually in a labeled envelope for further processing at Mississippi State University. I recorded captured shorebirds already affixed with a tarsal band as recaptures, and then I collected body metrics, tissues, and released the bird.

Concurrently with feathers, I collected blood to measure stable isotopes for migratory tracking (Sheldon et al. 2008). Isotopic niche represented by blood corresponds to the most recent foraging activity given the isotopic half-life of bird blood is ~13 days (Vander Zanden et al. 2015). Brachial, femoral, and jugular veins are commonly sampled to collect blood samples from birds. I punctured the brachial vein with a sterile 26-gauge needle and filled a 70 μL capillary tube with blood (Marra et al. 1998, Sheldon et al. 2008). I sealed capillary tubes with clay at both ends, placed on ice in the field, and froze at the field station prior to transporting to Mississippi State University until processing.

Following banding, I collected 10, 5 cm soil cores with a 20 mm diameter probe to provide soil material to generate a site specific value for stable isotope analysis (Buscaglia and Varco 2003). I selected a depth of 5 cm because it represented over twice the median culmen length for my target species (Pyle 2008) and thus exceeded the maximum foraging depths of my species. To represent prey items, I saved oven dried aquatic invertebrates removed from soil core samples collected concomitantly to estimate shorebird food resources (APPENDIX A).

Stable isotope sample preparation

I placed feathers in individually labeled 5 mL Nalgene bottles to clean them of surface oils using a 2:1 (v/v) chloroform/methanol soak for 24 hours (Evans et al. 2012, Guillemain et al. 2014). I then rinsed feathers twice with deionized water (Atkinson et al. 2005) and dried at 60° C for 24 hours in a forced-air oven (Cherel et al. 2000). After drying, I put on nitrile gloves and extracted feathers from bottles. I then clipped feathers into fine pieces (< 1 mm sections) using a scalpel (Atkinson et al. 2005). Following preparation of each sample, I cleaned all equipment and surfaces with ethanol and Kim wipes (USGS 2011). I weighed feather samples in duplicate to ~800 ± 10 μg, placed in tin capsules, and loaded tins into an automatic sampler. I used a 2.5 cm ceramic capillary tube cutter to open both sealed ends of each capillary tube containing blood. I first attempted to force blood from capillary tubes with compressed air but the force was too great. I then blew air into one end of the tube and blood was blown from tubes onto a glass plate. I absorbed blood with Chromosorb W (i.e., acid washed diatomaceous earth) to prepare/stabilize liquids, weighed the blood and Chromosorb W mixture into tins, and loaded tins into an automatic sampler.

I report all stable isotope values in (‰) using the delta (δ) notation (Atkinson et al. 2005, Bond and Hobson 2012). The δ notation is the sample isotope ratio relative to a standard and reported to their relative international standards (i.e., Vienna Peedee belemnite [VPDB] for δ^{13}C, atmospheric N_2 [Air] for δ^{15}N). I used a Carlo Erba N/C 1500 dry combustion analyzer (Carlo Erba, Milan, Italy) coupled to an Isoprime (Beverly, MA) continuous-flow isotope ratio mass spectrometer to measure δ^{13}C and δ^{15}N. Daily, prior to the first run of samples, I tested the instrument to ensure it was working properly by evaluating the stability and linearity with a standard deviation of fit of less than 1E-6. Reference gas precision of the instrument for $\delta^{13}C$ and $\delta^{15}N$ are < 0.1 ‰, and linearity of ^{13}C and ^{15}N are < 0.3 ‰. The $\delta^{13}C$ and $\delta^{15}N$ are in relation to N_2 and CO_2 reference gasses. Prior to each run, I ran atropine as a quality control check for stating isotopic consistency (Table 4.1). Following all runs, I ran L-Glutamic acid as an isotopic check sample (Wassenaar and Hobson 2003). Stable isotope terminology are reported following recommendations of Bond and Hobson (2012).

I prepared soil and invertebrate samples collected at banding sites similarly. First, I rinsed soil and invertebrates with deionized water and placed in an oven for 24 hours (Foth et al. 2012, Foth et al. 2014). I further refined soil samples by crushing particles until they passed through a 2 mm sieve and mixed thoroughly (Buscaglia and Varco 2003). I ground soil and invertebrates with a pestle and mortar to pass a 250 μm (60-mesh) sieve and then oven-dried (105° C) for 24 hours. Following preparation of each sample, I cleaned all equipment and surfaces with ethanol and Kim wipes (USGS 2011). I followed weighing (soil 30-40 mg; invertebrates 0.8 mg) and analyzing protocols stated previously.

Statistical methods

Three species were used for stable isotope analysis. Pectoral sandpipers were not abundant in 2012 or 2013 (CHAPTER III) and when present were observed foraging in mixed species flocks with Least Sandpiper, Western Sandpiper, and Semipalmated Sandpipers but avoided nets at capture locations. I compared relative differences of isotope ratios of blood from my species, if appropriate sample sizes exist, with invertebrates and soil collected at capture sites using package *SIAR* in Program R version

3.1.2 (RDevelopmentCoreTeam 2016). Further, to examine species-level isotopic niche differences, I used a multivariate ellipse-based approach (Stable Isotope Bayesian Ellipses) using package *SIBER* in Program R. This approach quantifies the size of each species' isotopic niche by tissue type and among-species differences in core isotopic niches (Jackson et al. 2011). To estimate niche sizes, I calculated the standard ellipse area corrected for small sample size (SEA_C) for each species by tissue type.

Additionally, I assessed intra-population differences in core isotopic niches based on age and feather type for Least Sandpiper, by estimating niche size ellipses for AHY and HY individuals. I then quantified core isotopic niche for each species and/or age class by tissue type and generated 95% confidence ellipses for each estimated SEA_C to determine whether core isotopic niche overlapped.

Results

Shorebird banding data

In 2012 and 2013, across all banding years, I captured and banded 236 shorebirds, and most were Least Sandpipers (83.1%). In 2012, I captured 95 shorebirds; again, most (86.3%) were Least Sandpipers. I encountered 82 Least Sandpipers and most were male (70.7%), but ~20% of birds could not be reliably sexed by culmen length. I was able to definitively classify ~10% of Least Sandpipers as female. The age ratio of Least Sandpipers was skewed toward AHY birds (63.4%) based on plumage. Of the 52 AHY Least Sandpipers I encountered 69.2% were male, 13.5% female, and 17.3% unknown gender. I encountered nine Semipalmated Sandpipers, and they comprised 9.5% of captured shorebirds in 2012. I was able to classify 88.9% of Semipalmated Sandpipers as male. The age ratio of Semipalmated Sandpipers was skewed towards AHY birds (77.8

%). One HY Semipalmated Sandpiper was classified as a male and the other had an unknown gender. Western Sandpipers were captured least (4.2%) in 2012. Of the four Western Sandpipers I captured, all were classified as male and 75% were adults.

In 2013, I captured 141 shorebirds; again, most (80.9%) were Least Sandpiper. I encountered 85 Least Sandpipers and most were male (74.6%), but ~18% of birds could not be reliably sexed by culmen length. I was able to definitively classify seven percent of Least Sandpipers as female. The age ratio of Least Sandpipers was skewed towards AHY birds (71.1%) in 2013. Of the 81 AHY Least Sandpipers I encountered 70.4% were male, 9.9% female, and 19.7% unknown gender. I encountered 24 Western Sandpipers and they comprised 21.1% of captured shorebirds in 2013. Similarly to Least Sandpipers, 79.2% of Western Sandpipers were male. All five females and 89.5% of males were AHY birds. I captured Semipalmated Sandpipers the least (2.6%) in 2013. All three Semipalmated Sandpipers I encountered were adults and 66.7% could be classified as male.

I recaptured one previously banded Western Sandpiper at Dauphin Island, Alabama in 2012 and one Western Sandpiper at Elmer’s Island WR, Louisiana in 2013. Both birds were banded by J. Henkel, Tulane University. Two of my Western Sandpipers captured at Elmer’s Island WR were recaptured/resighted. The first was banded in October 2013 and recaptured on Vancouver Island, British Columbia in July 2014. The second was banded in September of 2013 and resighted, on Elmer’s Island WR in October 2015.

Stable Isotope Analysis

I estimated possible migratory connectivity of Least Sandpipers, Semipalmated Sandpipers, and Western Sandpipers using only 152 blood samples relative to invertebrate reference values collected concomitantly at capture sites. I encountered a mismatch between blood $\delta\ ^{13}$C and $\delta\ ^{15}$N values and my site reference invertebrate food resource $\delta\ ^{13}$C and $\delta\ ^{15}$N values across species (Figure 4.1). I used blood $\delta\ ^{13}$C and $\delta\ ^{15}$N values from 124 Least Sandpipers; of these, only six captured at St. Catherine Creek NWR (Cloverdale tract, n = 2; Sibley Farms moist-soil units, n = 4) displayed relatedness to invertebrate food resource $\delta\ ^{13}$C and $\delta\ ^{15}$N values to other sites in the MAV or NGoM. I encountered five Least Sandpipers that reflected $\delta\ ^{13}$C and $\delta\ ^{15}$N values of their capture locations. The sixth individual reflected invertebrate $\delta\ ^{13}$C and $\delta\ ^{15}$N values for Missouri. I captured one Least Sandpiper at Elmer's Island WR, which reflected invertebrate values associated with MBHI sites. None of my captured birds reflected invertebrate $\delta\ ^{13}$C and $\delta\ ^{15}$N values associated with the NGoM.

I used blood $\delta\ ^{13}$C and $\delta\ ^{15}$N values from 22 Western Sandpipers captured at Elmer's Island WR; of these, half displayed relatedness to invertebrate food resource $\delta\ ^{13}$C and $\delta\ ^{15}$N values to other sites in the MAV or NGoM. I encountered two birds with $\delta\ ^{13}$C and $\delta\ ^{15}$N values similar to invertebrate $\delta\ ^{13}$C and $\delta\ ^{15}$N values for Missouri. Nine birds had $\delta\ ^{13}$C and $\delta\ ^{15}$N values similar to invertebrate $\delta\ ^{13}$C and $\delta\ ^{15}$N values associated with MBHI properties. I did not encounter any invertebrate $\delta\ ^{13}$C and $\delta\ ^{15}$N values associated with the NGoM.

I used blood $\delta\ ^{13}$C and $\delta\ ^{15}$N values from six Semipalmated Sandpipers, none of which reflected invertebrate values associated with sites in the MAV or NGoM. I may have encountered a mismatch between Semipalmated Sandpiper blood δ^{13}C and δ^{15}N values and invertebrate δ^{13}C and δ^{15}N values collected at capture locations because of low (*n* = 6) sample size. Due to low sample size (*n* = 28) across shorebird species, I was unable to definitively link blood and invertebrate δ^{13}C and δ^{15}N values collected at capture locations in the MAV and NGoM.

I was able to estimate core isotopic niche for each species. Each SEA_C contained approximately 40% of the bivariate isotope data (δ^{13}C, δ^{15}N), representing the core isotopic niche for each species and/or age class by tissue type. My results revealed considerable overlap in core isotopic niches among species, although extent of overlap varied by tissue type (Figure 4.1). The area of overlap I observed among core isotopic niches among all species was greatest for rectrices with area of overlap between pairwise combinations of each species ranging from 13.3 – 69.8% (Figure 4.1). The area overlap estimated from primary feathers also was substantial, comprising 42.4% and 31.4% for Least Sandpiper and Western Sandpiper core isotopic niche area, respectively; whereas, area of overlap between Semipalmated Sandpipers and Western Sandpipers was small (2.4% and < 1% respectively). Also, Least Sandpipers and Semipalmated Sandpipers had no overlap in core niche space estimated from primary feathers (Figure 4.2).

I recorded substantial partitioning of core isotopic niches associated with values from blood samples (Figure 4.2). For example, Least Sandpipers and Semipalmated Sandpipers did not share core isotopic niche space with Western Sandpipers. The core isotopic niche of Semipalmated Sandpipers was found entirely within the core niche space of Least Sandpipers (Figure 4.2). I recorded smaller blood values for each species compared to isotopic niches estimated from rectrix or primary feathers, which may persist for ≤ 18 months (Figure 4.3). I was only able to test for age class differences in Least Sandpiper, although I found no evidence of age structure in the isotopic data for these sandpipers (Figure 4.4). Lastly, I encountered one Least Sandpiper exhibiting a potential hydrocarbon signature. The signature was present in a rectrix from a HY bird encountered at Dauphin Island, Alabama on 25 August 2012 (Figure 4.5).

Discussion

Animal tissues are synthesized and replaced at different rates. Consequently the isotopic make-up of new tissues generally reflects the diet/habitat of animals at the time of synthesis (Cherel et al. 2000, Bearhop et al. 2002, Inger and Bearhop 2008). Foraging shorebirds partition themselves across habitats by exploiting varying water depths and associated invertebrates and biofilms in the sediment to reduce competition (Isola et al. 2000, Kuwae et al. 2012). Spatial partitioning is largely determined by differences in body metrics (i.e., culmen length, tarsus length) and vertical prey distribution (Elner and Seaman 2003). Western Sandpipers, Semipalmated Sandpipers, and Least Sandpipers forage in similar habitats close to the tidal/wetland edge, but Western sandpipers forage slightly deeper than Least Sandpipers (Colwell and Landrum 1993, Weber and Haig 1996). Therefore, sampling blood will yield information on diet or habitat over the days prior to sample collection (Pearson et al. 2003).

Shorebird blood relative difference of isotope ratios had too few δ^{13}C and δ^{15}N values associated with food resources at my sampled sites to definitively link MAV and NGoM sites. Most individuals (81.6%) fell outside of the mixing space relative to collected invertebrates at capture sites. Therefore, I was not able to definitively confirm migratory connectivity amongst MAV and NGoM sites, because their blood likely represents foraging at other locations along their migratory route or they were foraging on food items I did not sample (i.e., greater taxonomic discrimination of food sources needed). Half-lives for $\delta\ ^{13}$C and $\delta\ ^{15}$N values for the Red Knot (*C. canutus*), were 6.03 and 15.07 days for blood plasma and blood cells, respectively (Klaassen et al. 2010, van Gils and Salem 2015). Ogden et al. (2004) estimated $\delta\ ^{13}$C and $\delta\ ^{15}$N values from wild Dunlin (*C. alpina*) represented the diet over the last 20 day period. Whereas, Lehnen and Krementz (2005) estimated residence times for Pectoral Sandpiper in the MAV to be 10 days. A similar study by Lehnen and Krementz (2007) estimated Least Sandpipers to have stopover durations from 4 – 7 days. If Western Sandpipers and Semipalmated Sandpipers also averaged 4 – 10 day residence times in the MAV, whole blood may have not had the opportunity to stabilize with the capture site and could still reflect northern stopover sites for all three targeted species. Therefore, my Least Sandpiper data may validate Ogden et al. (2004) estimated blood value of ~20 days because most shorebird blood relative difference of isotope ratios fell outside of mixing space associated with invertebrate values collected at capture sites. Also, my data may suggest similar residence times for Least Sandpipers estimated by Lehnen and Krementz (2005; 2007) because equilibrium was not met between blood and food resources I sampled. Half of my Western Sandpipers were associated with MAV invertebrate $\delta\ ^{13}$C and $\delta\ ^{15}$N values. This may indicate this species uses coastal wetlands of the NGoM longer prior to migrating across the Gulf of Mexico or the NGoM represents the northern wintering range for this species (Fernández and Lank 2006). A more in depth study of Western Sandpipers tissues and invertebrate resource $\delta\ ^{13}$C and $\delta\ ^{15}$N values at southerly MAV sites (i.e., St.

Catherine Creek NWR, Atchafalaya Basin) and along the NGoM may provide evidence of greater migratory connectivity between the two regions.

I was able to provide evidence for foraging niche separation at the species level with isotopic niche ellipses, with longer-billed Western Sandpipers foraging on isotopically different invertebrates, compared to shorter-billed Least Sandpiper or Semipalmated Sandpiper. Within a marine estuarine system, Burns and Ydenberg (2002) observed most Western Sandpipers and Least Sandpipers foraging in two different tidal systems, where Western Sandpipers were observed more often on unvegetated mudflats and Least Sandpipers in vegetated salt marshes. This habitat partitioning by two Calidridine sandpiper species may be reflected in my data as evident in the locational difference of blood SEA_C in iso-space (Figure 4.1).

Unlike Least Sandpipers (*n* = 183) and Western Sandpipers (*n* = 48), sample size for Semipalmated Sandpipers (*n* = 9) was small and may account for the size and shape of all SEA_Cs. Lower abundances and subsequent fewer captures of Semipalmated Sandpipers could be linked to differences in migration strategies of these three species. During southbound migration, Semipalmated Sandpipers make a 4,000 km non-stop flight of 60 – 70 hours to wintering grounds in southern South America (Hicklin and Smith 1984, Wilson, Jr 1990). The other two species, Western Sandpiper and Least Sandpiper make a series of shorter migrational flights to reach their more northerly overwintering latitudes from Mexico to northern South America (Burns and Ydenberg 2002, Elner and Seaman 2003). I did not examine species specific migration phenology related to stable isotope ecology at my study areas, but future research needs to identify if species with diverse migrational strategies (i.e., one long flight versus many short stops) differentially use coastal ecosystems of the NGoM during migration.

Feathers represent a longer isotopic time frame spanning their growth period, often several weeks to months (Bearhop et al. 2003, Pearson et al. 2003). Also unlike the high isotopic turnover in blood, keratinized tissues are metabolically inert and thus preserve their isotopic record indefinitely (Inger and Bearhop 2008). I sampled feathers from two distinct body regions on each bird to identify possible migratory connectivity during migration. Shorebirds molt strategies have been well documented (Page 1974, Atkinson et al. 2005, Fernández et al. 2007, Colwell 2010), and feather groups are generally replaced at different locations during their annual cycle. However, conflicting molt patterns of flight feathers have been reported in the literature. Page (1974) in California reported most Least Sandpipers initiated molt after leaving the breeding grounds and completed a full body molt, including remiges, by the end of October. McNeil and Cadieux (1972) examined molting Least Sandpipers in Venezuela and observed similar body molt patterns but flight feathers were regrown exclusively on the wintering grounds during January – February. Western Sandpipers observed in Panama exhibit similar molt strategies as Least Sandpipers in California (Naranjo et al. 1994). Confounding effects related to molt could be masking any detectable differences in linking breeding, migration, and wintering areas of my birds.

Differences in feather molt location may relate to short summer seasons, time constraints, migration route, or some combination of these (O'Hara et al. 2002). For example, interior migrating Least Sandpipers may encounter wetlands with more temporally and spatially variable food resources than coastal migrants, making it advantageous for interior migrating individuals to delay molt until arriving at wintering areas during the austral summer of South America. It was not within the scope of my project to identify overwintering areas of shorebird species of interest. However, future research is needed to identify whether interior migrating shorebird populations overwinter in different habitats than coastal migrants (e.g., Atlantic versus Pacific coasts of South America).

The relative difference of isotope ratios of individual species did not differ among tissue types. Although blood stable isotopes have relatively quick turnover (half-life = ~13 days) compared with feather tissues (i.e., months), I was unable to distinguish between blood SEA_C and SEA_Cs associated with primary and retricies. This may be related to residence times for shorebirds in the MAV (Lehnen and Krementz 2005; 2007). The observed longer turnover time in stable isotopes (Ogden et al. 2004) versus residence times for similar Calidridine sandpipers coupled with my three study species exhibiting molt during migration, may explain the overlap of SEA_Cs across tissue types. If I had been able to euthanize birds, I could have sampled internal tissues, which have quicker turnover times. Hobson and Clark (1992) estimated tissue turnover rates of Japanese Quail (*Coturnix japonica*) and estimated turnover rates in the liver were quicker than blood. Published information on experimentally tested, species-specific stable isotope half-lives for the three species in my analysis is currently unavailable.

Conversely, at the level of an individual bird, the $\delta^{13}C$ and $\delta^{15}N$ values do not necessarily indicate different diets (DeNiro and Epstein 1981, Gannes et al. 1997). This phenomenon may explain the lack of separation between age classes in Least Sandpipers. Hatch Year birds grow their first set of feathers on the breeding grounds incorporating local relative differences of isotope ratios. However, a portion of this age class population undergoes a partial molt of body contour feathers, coverts, tertials, and rectrices in autumn (Page 1974). I was only able to classify birds as AHY and HY because there was not a definitive method to separate SY birds based on plumage (Pyle 2008). Second Year birds undergo a complete body molt and visually resemble AHY birds, but do not molt their first set of flight feathers, grown on the breeding grounds (O'Hara et al. 2002). My inability to distinguish between SY and AHY birds by feather plumage may have contributed to the overlap in $\mathrm{SEA_C}$s because SY primary feather relative difference of isotope ratios resembled HY birds.

Due to low sample size by sex class, I was also unable to definitively identify individual gender unless culmen lengths measures were within extreme values (Page 1974, Pyle 2008). Niche partitioning is well documented across species (Burger et al. 1977, Davis and Smith 2001), but at the population level, it may occur intraspecifically where longer-billed females may forage deeper in the sediment horizon compared to shorter-billed males (Elner and Seaman 2003). Conserving wetland habitats with a variety of water depths may be important for providing stopover habitat for different species, genders, and age classes. Van Gils et al. (2016) observed Red Knots with shorter (30 mm) versus longer (40 mm) bills had lower apparent survival due to reduced access to an abundant bivalve food source. The development of better techniques for assigning age and sex (i.e., DNA typing), coupled with food resource estimates and soil isoscapes, may further refine stable isotope analysis techniques in the future. Furthermore, this may be useful to identify wetlands or regions of greatest conservation concern and drive future wetland conservation and water management for migratory shorebirds.

The tail rectrix of a single HY Least Sandpiper with a possible hydrocarbon signature was likely grown on the arctic nesting grounds (Pyle 2008) and represented petroleum contamination somewhere in the breeding grounds. However, juvenile Least Sandpipers may initiate rectrix molt during their first autumnal migration (Page 1974). Therefore, the feather could have been grown during migration across the North American continent or while staging on the coast of the NGoM. While I did not explicitly test for compound specific hydrocarbons related to the 2010 Deepwater Horizon oil spill, stable isotope analysis of blood and feathers isotope signatures could have been used to test resident and migratory waterbirds immediately following the spill. Stable isotope analysis could be applied to any future oil spills (e.g., May 2016 Shell Oil pipeline spill of > 333,116 liters into the Gulf of Mexico) of where wetland dependent birds are affected.

Future stable isotope studies on shorebird and other migrant waterbirds in the MAV and NGoM should first estimate species specific tissue turnover rates using birds held in captivity. This could be accomplished through feeding trials of isotopically distinct food resources fed ad libitum and collecting blood at regular intervals. Van Gils and Salem (2015) measured blood plasma discrimination factors for δ^{13}C and δ^{15}N in Red Knots fed bivalves who acquire energy from two distinct food webs (i.e., chemosynthesis, photosynthesis). Also, the observance of wild birds and identification of consumed invertebrate prey similar to Wirwa (2009) or Kuwae *et al*. (2012) are needed at a regional or continental scale. A follow up study could collect soil cores to estimate relative difference in isotope ratios of consumed invertebrate foods at a hemispheric scale. For example, by systematically tracking and observing Least Sandpipers and immediately sampling (i.e., soil, water quality, plants, animal prey) their foraging environments, a comprehensive picture may emerge allowing researchers to better understand the needs of other migratory shorebird species. Within wetlands, invertebrate taxa (i.e., family, order) and soil collected from cores along with clipped moist-soil plant matter could provide trophic links between shorebird blood or feces (Kuwae et al. 2012). This would generate baseline data at site specific levels for relative difference of isotope ratios across food webs. Further, isoscapes for soil, moist-soil plants, and invertebrate food resources would be in place for future shorebird research and may identify additional baseline isotopic data required to model wetland food webs.

If captive studies are not feasible, I recommend selecting tissues (i.e., blood cells and plasma, feather types) of target species previously tested on other sympatric species until further refinement of relative difference in isotope ratios. Paired with appropriate tissue selection, estimating residence times for more shorebird species in both regions may further refine appropriate target tissues. One of the Lower Mississippi Valley Joint Venture's top research priorities for shorebirds in the MAV is estimating fall migration turnover rates (Lehnen and Krementz 2005).

Additionally, few species breed or overwinter in southeastern wetlands; breeding shorebirds include Snowy Plover (*Charadrius nivosus*), Wilson's Plover (*C. wilsonia*), Piping Plover (*C. melodus*), Killdeer (*C. vociferous*), and Black-necked Stilt (*Himantopus mexicanus*). Stable isotope analysis may be useful to examine possible diet switching during different stages of their annual cycle (i.e., pre-nesting phase, egg laying, incubation, and chick rearing) or the movement of inland breeders to coastal wintering sites. Many large bodied shorebirds overwinter along the NGoM, namely Black-bellied

Plover (*Pluvialis squatarola*), Willet, Marbled Godwit (*Limosa fedoa*). Few small bodied shorebirds overwinter along the NGoM (Western Sandpipers; (Fernández and Lank 2006). Applying stable isotope analysis techniques to wintering birds may allow researchers to link northern breeding grounds with distinct wintering grounds along coastlines of the Gulf of Mexico.

If logistics allow, collecting tissues (i.e., blood, feather, nail, feces) from shorebirds at known breeding, stopover, and wintering locations may allow researchers to examine species specific migration phenology using stable isotope ecological approaches. Lastly, do species with diverse migrational strategies (i.e., one long flight versus many short stops) differentially use shallow water habitat in interior and coastal ecosystems during migration? I encountered a complete mismatch of blood values from Semipalmated Sandpipers (longer-distance migrants) and my $\delta\ ^{13}C$ and $\delta\ ^{15}N$ values associated with invertebrate food resources. My shorter-distance migrant species (Least Sandpiper, Western Sandpipers) exhibited limited connectivity among MAV and NGoM invertebrate food resources. As previously stated, it is my opinion that future research is needed to identify whether interior or short-distant migrant shorebird species differ in overwintering habitats compared to their coastal or long-distance migrant counterparts. By using stable isotope analysis, these questions may help identify why many species are exhibiting population declines (Andres 2009).

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Table 4.1 Mean ($\overline{x}$, ± standard deviation [STD], and sample size [*n*, number of run days]) of δ ^{13}C and δ ^{15}N in Atropine.

Sample	***n***	**δ ^{13}C**		**δ ^{15}N**	
		$\overline{x}$	**STD**	$\overline{x}$	**STD**
Atropine: sample	13	-13.46	2.779	1.41	2.659
Atropine: elemental	13	-13.99	1.165	1.22	2.309

Mean ($\overline{x}$, ± standard deviation [STD], and number of sample run days [*n*]) of δ ^{13}C and δ ^{15}N for Atropine (sample and elemental) to assess within lab quality control checks for stating isotopic consistency.

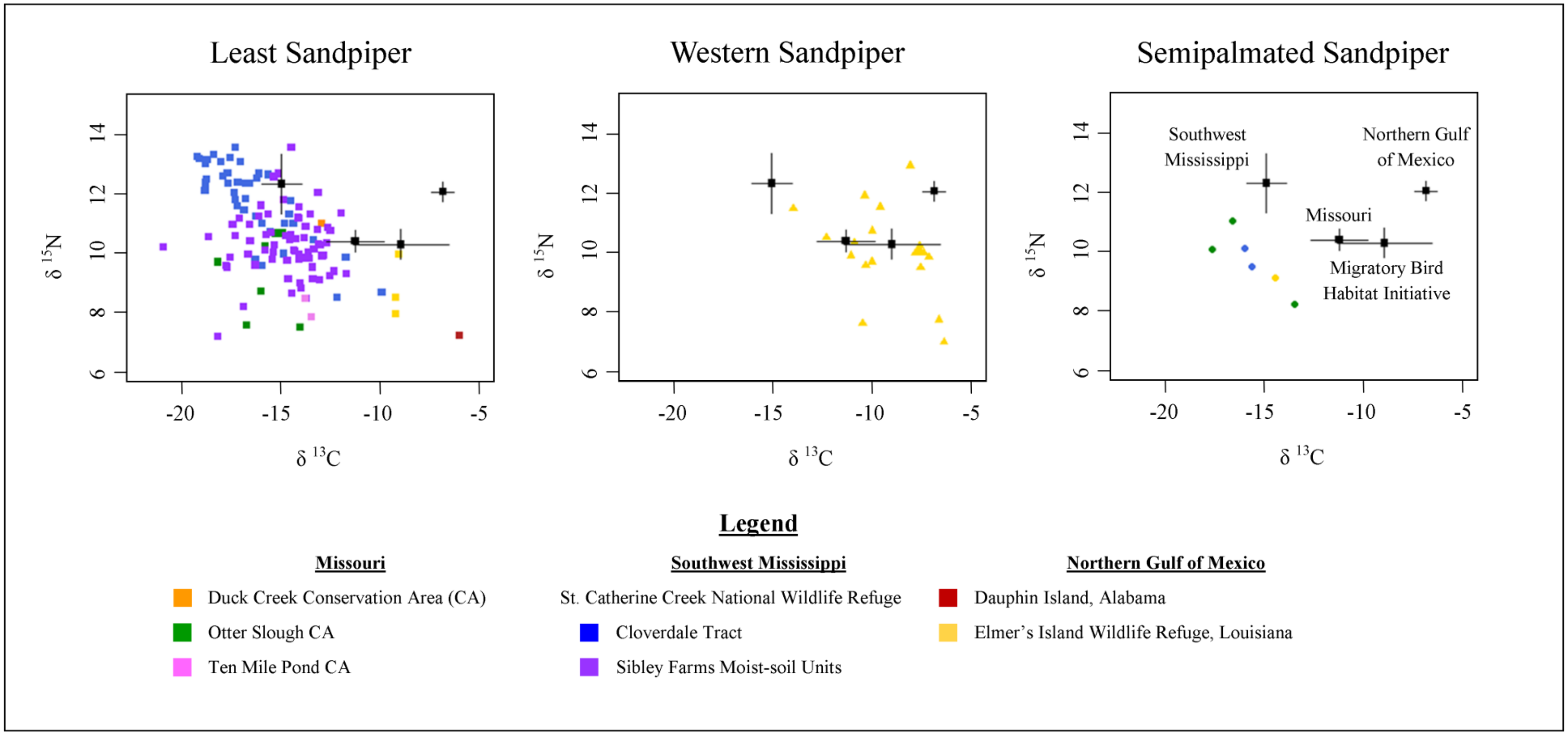

Figure 4.1 Assessing migratory connectivity of $\delta\ {}^{13}$C and $\delta\ {}^{15}$N values for blood (colored shapes) and invertebrate food resources (black squares with ± standard deviations) for three Calidridine sandpiper species.

Assessing possible migratory connectivity of $\delta\ {}^{13}$C and $\delta\ {}^{15}$N values for blood (colored shapes) and invertebrate food resources (black squares with ± standard deviations) for three Calidridine sandpiper species (Least Sandpiper [*Calidris minutilla*]; Western Sandpiper [*C. mauri*]; Semipalmated Sandpiper [*C. pusilla*]) captured in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012 – 2013. Colors of shapes indicate capture locations: Duck Creek Conservation Area (CA; orange), Otter Slough CA (green), Ten Mile Pond CA (pink), St. Catherine Creek NWR-Cloverdale tract (blue), St. Catherine Creek NWR-Sibley Farms moist-soil units (purple), Dauphin Island (red), and Elmer's Island Wildlife Refuge (gold).

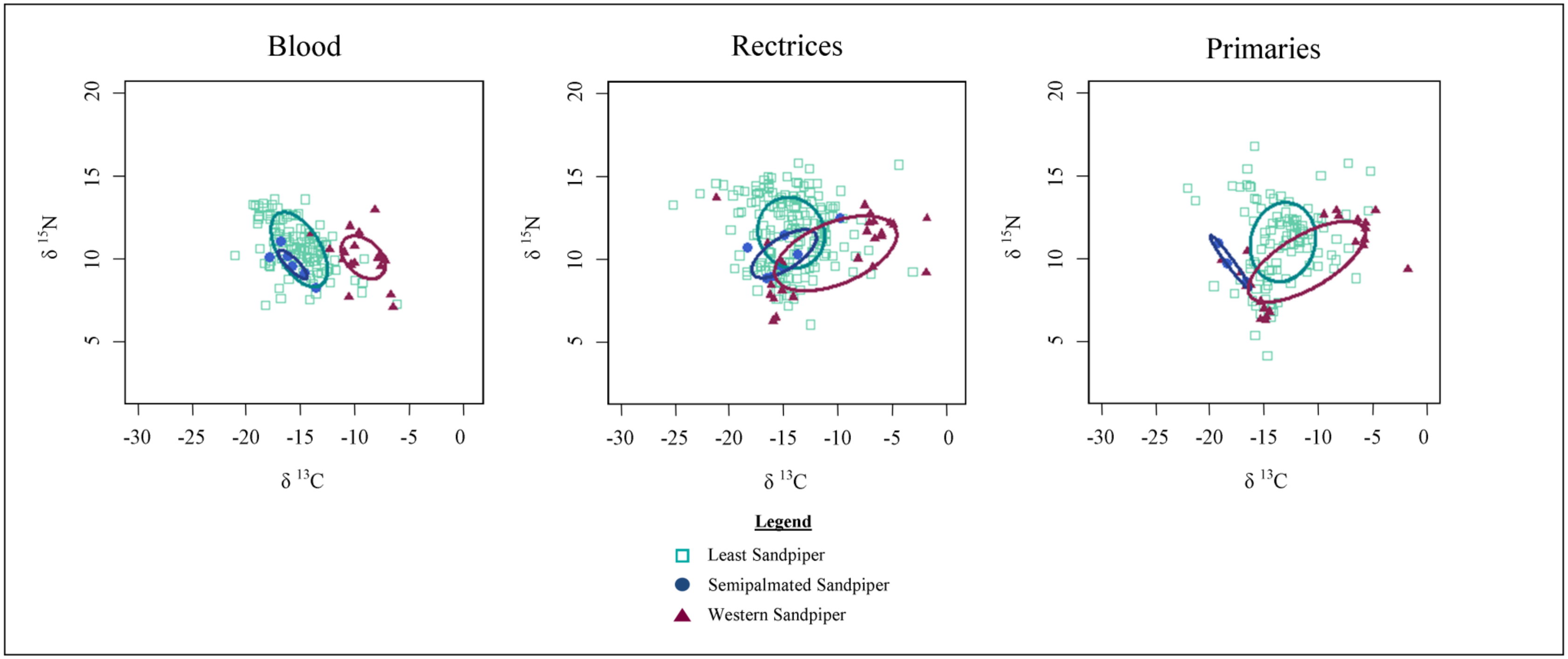

Figure 4.2 Core isotopic niches ($^{13}C/^{12}C$, $^{15}N/^{14}N$) by tissue type (blood, rectrix and primary feather) for three Calidridine sandpiper species.

Core isotopic niches ($^{13}C/^{12}C$, $^{15}N/^{14}N$) by tissue type (blood, rectrix and primary feather) for three Calidridine sandpiper species (Least Sandpiper [*Calidris minutilla*], green hollow square; Semipalmated Sandpiper [*C. pusilla*], filled blue circle; Western Sandpiper [*C. mauri*], maroon triangle) captured in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012 – 2013.

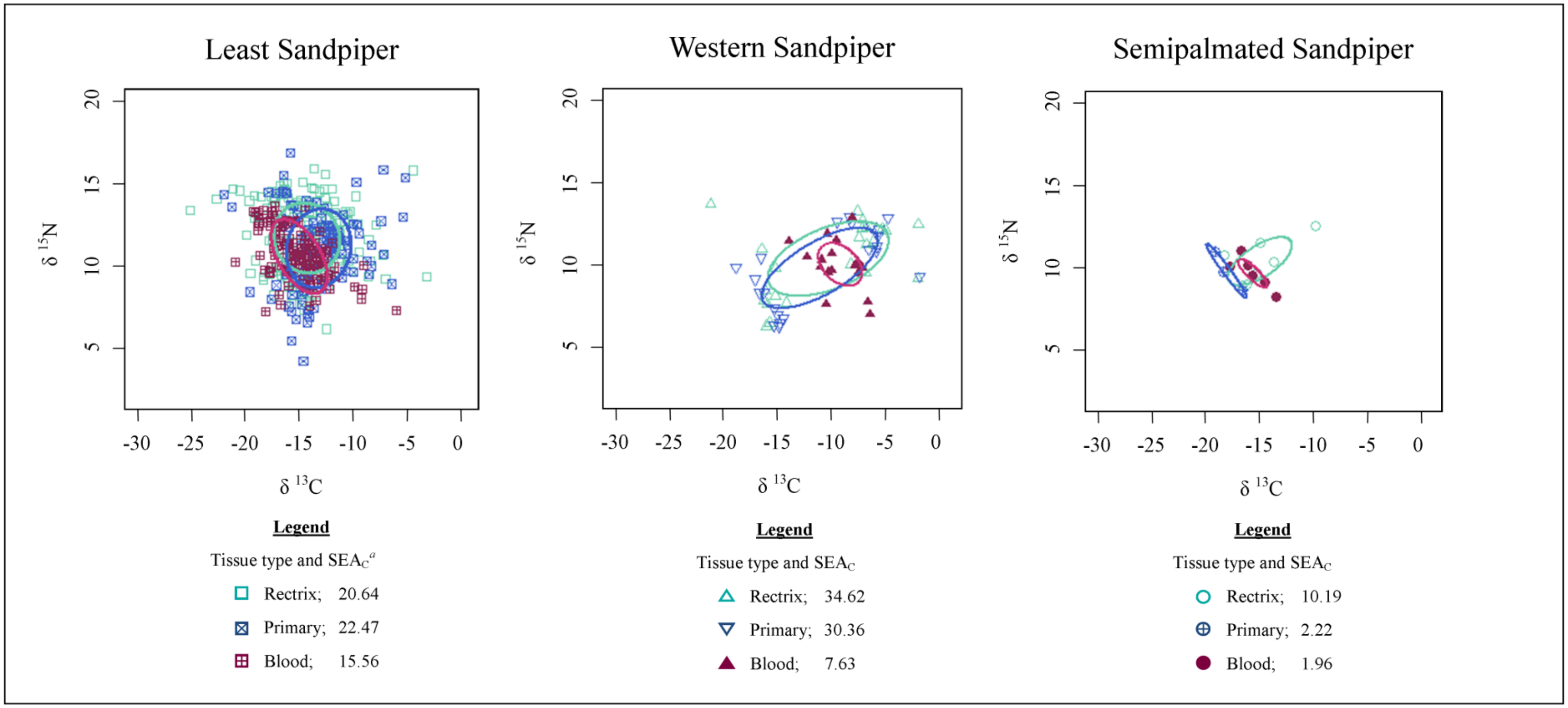

Figure 4.3 Tissue (blood, feather [primary and rectrix]) isotopic niche space ($^{13}C/^{12}C$, $^{15}N/^{14}N$) for three Calidridine sandpipers.

[a]Standard Ellipse Area corrected for small sample size
Tissue (blood, feather [primary and rectrix]) isotopic niche space ($^{13}C/^{12}C$, $^{15}N/^{14}N$) for three Calidridine sandpipers (Least Sandpiper [*Calidris minutilla*], square; Western Sandpiper [*C. mauri*]; Semipalmated Sandpiper [*C. pusilla*], circle) captured in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012 – 2013.

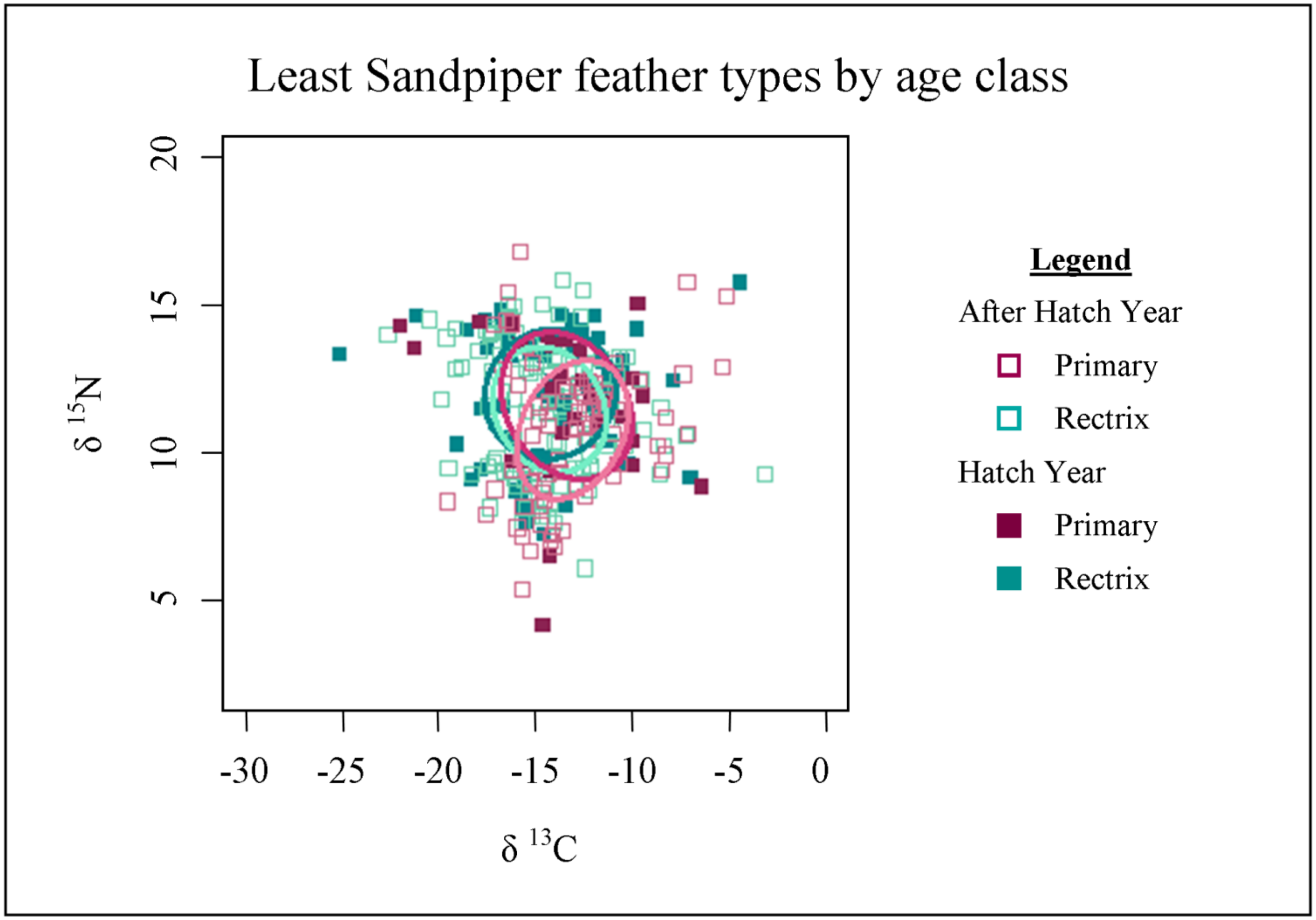

Figure 4.4 Isotope (^{13}C/^{12}C, ^{15}N/^{14}N) niche space for Least Sandpipers (*Calidris minutilla*) by age class and feather type.

Isotope (^{13}C/^{12}C, ^{15}N/^{14}N) niche space for Least Sandpipers (*Calidris minutilla*) captured in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012 – 2013; by age class (After Hatch Year [hallow square], Hatch Year [filled square]) and feather type (primary [maroon] and rectrix [teal]).

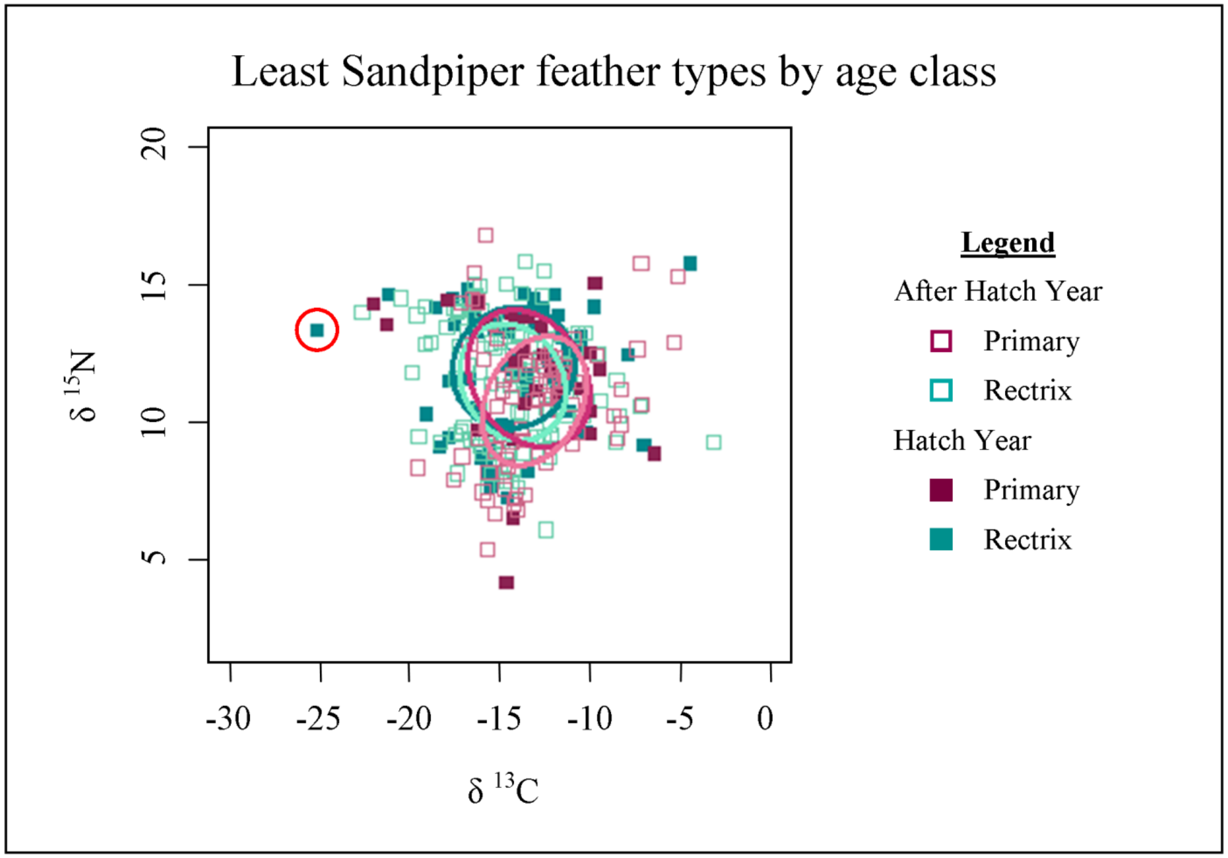

Figure 4.5 Isotope ($^{13}C/^{12}C$, $^{15}N/^{14}N$) niche space for Least Sandpipers (*Calidris minutilla*) and hydrocarbon signature emphasized by the outlier (**O**).

Isotope ($^{13}C/^{12}C$, $^{15}N/^{14}N$) niche space for Least Sandpipers (*Calidris minutilla*) captured in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012 – 2013; by age class (After Hatch Year [hallow square], Hatch Year [filled square]) and feather type (primary [maroon] and rectrix [teal]). Hydrocarbon signature emphasized by the outlier (**O**).

APPENDIX A

WATERBIRD FOODS: INVERTEBRATE BIOMASS IN THE MISSISSIPPI ALLUVIAL VALLY AND NORTHERN GULF OF MEXICO

Introduction

Inland and coastal wetlands are important stopover and wintering sites for resident and migrant waterfowl, wading birds, and shorebird species (hereafter waterbirds; Lehnen 2010, Henkel and Taylor 2015). Large-scale wetland conversion and loss within the Mississippi Alluvial Valley (MAV) and along the coastline of the northern Gulf of Mexico (NGoM) have resulted in reduced habitat for these birds. Despite a history of management for waterfowl in the MAV, information on shorebird abundance, migratory phenology, and resource use in the MAV is limited and requires regular updating due to the dynamic nature of land use from landscape-scale and agricultural practices (Twedt et al. 1998). Nearly half a million shorebirds are estimated to migrate through the MAV annually (Helmers 1992, Skagen et al. 1999). Based on limited data, the Lower Mississippi Alluvial Valley Joint Venture (LMVJV) set a tentative goal of providing habitat and food resources for half a million shorebirds (Loesch et al. 2000, King et al. 2006). Therefore, biologists and conservationists desire to identify shallowly flooded water complexes (e.g., aquaculture ponds, moist-soil impoundments, croplands) that provide potential invertebrate food resources for shorebirds. The LMVJV estimates that ~2,000 ha of shallow water habitat across seven states are required to support the energetic needs of half a million migrant shorebirds (Loesch et al. 2000). Additionally, the U.S. Department of Agriculture’s Natural Resources Conservation Service (NRCS) was interested in generating an estimate of potential shorebird invertebrate foods during fall migration on lands enrolled in the Migratory Bird Habitat Initiative (MBHI; Kaminski and Davis 2014).

Most shorebird species meet their daily nutrient requirements by consuming soft-bodied aquatic invertebrates. Sites with greater densities of invertebrates typically support higher shorebird densities (Goss-Custard 1980, Galbraith et al. 2002). In interior wetlands, Loesch et al. (2000) estimated chironomid larvae were primary food resource for migrant shorebirds and estimated invertebrate abundance at ~20 kg (dry mass)/ha. At coastal sites, some species also consume hard-bodied invertebrates (i.e., bivalves and crustaceans; (Colwell 2010). Shorebirds foraging on benthic invertebrates can increase body mass significantly (> 100%), which is critical for survival during migration (Mihuc et al. 1997, Mitchell and Grubaugh 2005). Shorebirds forage on mudflats to ~16 cm water depth depending on body morphology (e.g., culmen-, tarsus-, and neck-lengths) and feeding behaviors (Helmers 1992, Callazo et al. 2002). Additionally, shorebirds have evolved extraordinary feeding adaptions (e.g., needle-like, spatulate, recurved, and decurved culmens). This ecomorphology allows shorebird species to partition among foraging niches and water depths, theoretically to reduce competition for food resources (Davis and Smith 2001). Therefore, herein I provide contemporary biomass estimates of aquatic invertebrates in the MAV and NGoM for use in conservation planning by the LMVJV and other partners.

Study Sites

See CHAPTER II for an in-depth description of my study areas.

Methods

Invertebrate sample collection

Shorebirds feed on aquatic macro- and microinvertebrates within the water column and benthic substrates (Colwell 2010). To estimate potential invertebrate foods available for shorebirds and possibly other waterbirds in these sediments, I used a modified 1,000 mL graduated cylinder (6.5 cm diameter; Swanson 1978) attached to a PVC pipe. During my first field season, I collected 10 cores monthly on five MBHI properties during August – October, 2011. In my second field season, I reevaluated my sampling protocols and decided to change my invertebrate sampling framework to coincide with twice-monthly shorebird surveys (n = 6/year/site) and included all sites in the MAV and NGoM during August – October 2012 – 2013. I collected cores immediately following each bird survey at a site. I collected soil cores in a randomly selected and surveyed pond along a gradient from mudflat – 16 cm (Helmers 1992). I took soil cores to a depth of 5 cm to reduce soil core processing time associated with clayey soils (Stafford et al. 2011, Tapp 2013). Additionally, most invertebrates tend to occur within the top 10 cm of soils (Frisch 2002, Tronstad et al. 2005). I selected a depth of 5 cm because it represented over twice the median culmen length for my target species: Least Sandpiper (*Calidris minutilla*; 19 mm), Semipalmated Sandpiper [*C. pusilla*; 19 mm], and Western Sandpiper [*C. mauri*; 25 mm]; (Pyle 2008). I preserved soil cores and associated invertebrates in a 10% formalin solution stained with rose bengal (Edwards et al. 2009). Rose bengal aided in sorting and identifying invertebrates. I placed samples in Ziploc bags and stored them on ice until transport to Mississippi State University for laboratory processing.

Invertebrate sample processing

At Mississippi State University, I froze soil cores at -10° C (Murkin et al. 1994, Stenroth and Nyström 2003, Foth et al. 2014). I used tap water for processing all samples, because other flotation media did not increase recovery of invertebrates from samples (Foth et al. 2012, Foth et al. 2014). I removed invertebrates by hand and identified them to Family (Pennak 1989, Merritt and Cummins 2008). I placed processed samples in a forced-air oven at 60° C for 24 hours until they were dried to a constant mass and weighed to the nearest 0.0001 g (Foth et al. 2014).

Statistical analysis

Site specific and similarly managed sites were grouped to generate mean invertebrate biomass (kg[dry mass]/ha) and standard errors in Microsoft Excel. My results may provide an updated estimate of invertebrate biomass during fall migration at the scale of the MAV. To my knowledge there is not an invertebrate biomass estimate for wetlands and beaches along the NGoM; thus, my results may provide a baseline for future research. My current invertebrate biomass estimate can be incorporated into Loesch et al. (2000) estimated theoretical shorebird-existence days for an average (45 g) sized shorebird.

Results

In 2011, invertebrates were collected only from MBHI lands, Mississippi (n = 120 cores; $\bar{x}$ = 22.35 kg/ha, SE = 5.565). Thirty samples were unintentionally discarded during a freezer cleaning in spring 2012 prior to processing. Invertebrate biomass increased from July through August 2011 and decreased in September 2011. Regional and site specific invertebrate biomass can be found on Table A.1. Greatest invertebrate biomass was estimated at Phillips Brother’s Farms ($\overline{x}$ = 51.65 kg/ha, SE = 20.671, *n* = 30)

Soil cores for estimating invertebrate biomass were collected at all sites in the MAV and NGoM in 2012 (Tables A.2, A.3, and A.4). In Missouri, mean invertebrate biomass across months was 52.63 kg/ha, SE = 10.356, *n* = 140. In 2012, monthly estimates from August – October were greatest in August ($\overline{x}$ = 76.31 kg/ha, SE = 19.216, *n* = 60), with an overall decreasing trend through autumn (September [$\overline{x}$ = 44.72 kg/ha, SE = 14.026, *n* = 60] and October [$\overline{x}$ = 5.29 kg/ha, SE = 1.608, *n* = 20]). At MBHI properties mean invertebrate biomass across all months was 49.42 kg/ha, SE = 12.70, *n* = 140. Similarly to 2012, monthly estimates from August – October were greatest in August ($\overline{x}$ = 72.16 kg/ha, SE = 28.479, *n* = 40), with an overall decreasing trend through autumn (September [$\overline{x}$ = 49.04 kg/ha, SE = 15.929, *n* = 80] and October [$\overline{x}$ = 5.41 kg/ha, SE = 2.047, *n* = 20]). In the southern portion of the MAV, at St. Catherine Creek National Wildlife Refuge (NWR), Mississippi, across all months, mean invertebrate biomass was 21.63 kg/ha, SE = 4.784, *n* = 100. In 2012, biomass increased from August ($\overline{x}$ = 14.70 kg/ah, SE = 5.016, *n* = 60) to September ($\overline{x}$ = 23.69 kg/ha, SE = 9.615, *n* = 60) but estimates were similar in September and October ($\overline{x}$ = 23.04 kg/ha, SE = 6.773, *n* = 60). At all NGoM sites, mean invertebrate biomass increased from August to September. Greatest invertebrate biomass continued to increase through October at Grand Bay NWR and National Estuarine Research Reserve [NERR], Mississippi. In 2012, across all months, Grand Bay NWR and NERR had the greatest overall biomass estimate ($\overline{x}$ = 40.08 kg/ha, SE = 12.971, *n* = 70). The site with greatest estimated biomass for August was Dauphin Island, Alabama ($\overline{x}$ = 11.08 kg/ha, SE = 3.369, *n* = 20). Grand Bay NWR and NERR had the greatest biomass estimates for September ($\overline{x}$ = 36.95 kg/ha, SE = 15.348, *n* = 20) and October ($\overline{x}$ = 75.75 kg/ha, SE = 34.635, *n* = 20).

In 2013 (Tables A.5, A.6, and A.7), in Missouri, mean invertebrate biomass was only estimated in August ($\overline{x}$ = 94.80 kg/ha, SE = 25.303, *n* = 40). In 2013, across months, on MBHI lands, invertebrate biomass was estimated at 377.91 kg/ha, SE = 142.027, *n* = 180. Invertebrate biomass estimates increased from August ($\overline{x}$ = 29.19 kg/ha, SE = 5.872, *n* = 60) to September ($\overline{x}$ = 1,057.42 kg/ha, SE = 414.347, *n* = 60), but decreased in October ($\overline{x}$ = 47.12 kg/ha, SE = 11.679, *n* = 60). In the southern portion of the MAV, at St. Catherine Creek NWR, mean invertebrate biomass across months, in 2013, was 30.02 kg/ha, SE = 6.708, *n* = 100. Biomass estimates increased from August ($\overline{x}$ = 24.01 kg/ha, SE = 7.342, *n* = 40) to September ($\overline{x}$ = 42.05 kg/ha, SE = 13.658, *n* = 20). No samples were collected in October due to the government furlough (i.e., no access to federal sites) and flooding. At sites along the NGoM, mean invertebrate biomass was dynamic in peak biomass. Some sites decreased from August to September (Dauphin Island and Grand Bay NWR and NERR) but increased again in October; whereas, Elmer’s Island Wildlife Refuge, Louisiana, increased from August to September and decreased in October. In 2013, across sites, monthly estimates of greatest invertebrate biomass were estimated at Dauphin Island in August [$\overline{x}$ = 34.88 kg/ha, SE = 6.098, *n* = 20] and September [$\overline{x}$ = 21.81 kg/ha, SE = 4.399, *n* = 20]). Greatest biomass for October was estimated at Grand Bay NWR and NERR ($\overline{x}$ = 64.52 kg/ha, SE = 45.195, n = 20). Greatest invertebrate biomass along the NGoM across all months was estimated at Grand Bay NWR and NERR ($\overline{x}$ = 39.17 kg/ha, SE = 20.825, n = 60).

Across all years (Table A.8), I estimated regional biomass increased from Missouri ($\overline{x}$ = 61.33 kg/ha, SE = 9.805, n = 180) to MBHI properties ($\overline{x}$ = 135.53 kg/ha, SE = 43.140, n = 440) and decreased at St. Catherine Creek ($\overline{x}$ = 24.49 kg/ha, SE = 39.908, n = 160). Across all years, at NGoM sites, Grand Bay NWR and NERR had the greatest mean invertebrate biomass ($\overline{x}$ = 36.40 kg/ha, SE = 10.821, n = 120). Additionally, in APPENDIX B, I have taxa specific estimates by total count and weight (g; kg/ha) at each site. Taxa specific estimates are across months (August – October), but are separated by year (2011 – 2013). In the last column, I calculated an estimated kg/ha across all invertebrate taxa I encountered.

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Table A.1 Site specific invertebrate biomass (kg/ha; mean [$\bar{x}$] kg/ha and standard errors [SE]) estimated from soil cores Migratory Bird Habitat Initiative properties during 2011.

MBHI Site	***n***	**August**		**September**		**October**		**Overall**	
		$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**
Bear Creek Fisheries	30	2.29	2.038	26.38	9.502	0.93	0.670	9.87	3.812
Nerren Properties	20	2.08	1.415	40.31	7.197	[a]		21.20	5.655
Janous Properties	20	1.72	1.105	27.89	6.674			14.80	4.455
Thompson Fisheries	20	4.49	2.746	7.21	2.068			5.85	1.702
Phillips Brother's Farms	30	1.21	0.921	111.05	57.079	42.69	13.709	51.65	20.671
All Sites	120	2.36	0.778	42.57	12.366	21.81	8.220	22.35	5.565

[a] Blanks denote samples unintentionally discarded during a freezer cleaning in spring 2012 (October).

Site specific invertebrate biomass (kg/ha; mean [$\bar{x}$] kg/ha and standard errors [SE]) estimated from soil cores (n = 120) collected at Migratory Bird Habitat Initiative properties during July – September 2011.

Table A.2 August invertebrate dry biomass (kg/ha; mean [$\bar{x}$], standard error [SE], and sample size [n]) from soil cores in the Mississippi Alluvial Valley and northern Gulf of Mexico during 2012.

Region	State	Site	n	August					
				Period 1		Period 2		Overall	
				$\bar{x}$	SE	$\bar{x}$	SE	$\bar{x}$	SE
Mississippi Alluvial Valley	Missouri		60	47.36	17.265	97.76	32.814	76.31	19.216
		Duck Creek Conservation Area (CA)	20	4.85	3.460	92.02	65.681	48.44	33.534
		Otter Slough CA	20	44.32	20.130	111.71	65.977	78.02	34.448
		Ten Mile Pond CA	20	115.42	51.908	89.55	41.336	102.48	32.429
	Mississippi		60	72.16	28.479	14.70	5.016	53.01	19.302
		Migratory Bird Habitat Initiative	40	72.16	28.479	[a]		72.16	28.479
		Bear Creek Fisheries	10	88.22	44.773			88.22	44.773
		Janous Properties	10	49.93	11.704			49.93	11.704
		Thompson Fisheries	10	138.21	104.589			138.21	104.589
		Phillips Brother's Farms	10	12.27	3.307			12.27	3.307
		St. Catherine Creek National Wildlife Refuge (NWR)	20	[b]		14.70	5.016	14.70	5.016
		Cloverdale tract	10			27.86	8.206	27.86	8.206
		Sibley Farms moist-soil units	10			1.54	0.615	1.54	0.615
Northern Gulf of Mexico	Alabama	Dauphin Island	20	14.29	4.938	7.87	4.610	11.08	3.369
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve	30	5.07	1.271	5.85	5.849	5.33	2.062
		Grande Batture Islands	20	9.20	1.580	5.85	5.849	7.52	2.974
		Salt Pannes	10	0.93	0.731	[c]		0.93	0.731
	Louisiana	Elmer's Island Wildlife Refuge	20	4.16	1.419	6.84	3.010	5.50	1.649

[a] Blanks denote samples that were not collected on Migratory Bird Habitat Initiative sites due to technician error (Period 2)

[b] Inundation of St. Catherine Creek National Wildlife Refuge by flood waters of the Mississippi River (Period 1)

[c] Dry Salt Pannes at Grand Bay NWR & National Estuarine Research Reserve (Period 2).

Table A.3 September invertebrate dry biomass (kg/ha; mean [$\overline{x}$], standard error [SE], and sample size [*n*]) from soil cores in the Mississippi Alluvial Valley and northern Gulf of Mexico during 2012.

Region	**State**	**Site**	***n***	**September**					
				Period 3		**Period 4**		**Overall**	
				$\overline{x}$	**SE**	$\overline{x}$	**SE**	$\overline{x}$	**SE**
Mississippi Alluvial Valley	Missouri		60	36.58	13.953	52.86	24.520	44.72	14.026
		Duck Creek Conservation Area (CA)	20	0.93	0.493	5.94	1.893	3.44	1.112
		Otter Slough CA	20	4.46	2.149	0.48	0.281	2.47	1.149
		Ten Mile Pond CA	20	104.35	33.332	152.17	64.520	128.26	35.765
	Mississippi		120	44.83	10.980	36.35	19.427	40.59	11.118
		Migratory Bird Habitat Initiative	80	57.08	15.964	41.01	27.745	49.04	15.929
		Bear Creek Fisheries	20	0.78	0.530	2.53	1.260	1.66	0.695
		Janous Properties	20	50.11	21.524	160.37	105.972	105.24	54.124
		Thompson Fisheries	20	174.73	41.575	0.87	0.723	87.80	28.411
		Phillips Brother's Farms	20	2.68	1.189	0.27	0.271	1.48	0.655
		St. Catherine Creek National Wildlife Refuge (NWR)	40	20.35	5.439	27.03	18.676	23.69	9.615
		Cloverdale tract	20	28.73	9.948	50.32	36.764	39.53	18.700
		Sibley Farms moist-soil units	20	11.97	3.211	3.74	0.756	7.85	1.863
Northern Gulf of Mexico	Alabama	Dauphin Island	20	6.60	1.244	51.80	12.547	29.20	8.033
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve	20	31.00	8.788	42.91	30.157	36.95	15.348
		Grande Batture Islands	20	31.00	8.788	42.91	30.157	36.95	15.348
		Salt Pannes		[a]					
	Louisiana	Elmer's Island Wildlife Refuge	20	7.06	2.139	24.00	6.978	15.53	4.049

[a] Blanks denote samples that were not collected because dry Salt Pannes at Grand Bay National Wildlife Refuge & National Estuarine Research Reserve (Periods 3 – 4).

Table A.4 October and overall invertebrate dry biomass (kg/ha; mean [$\bar{x}$], standard error [SE], and sample size [n]) from soil cores in the Mississippi Alluvial Valley and northern Gulf of Mexico during 2012.

Region	**State**	**Site**	**n**	**October**						***n***	**Regional and Site Totals**	
				Period 5		**Period 6**		**Overall**				
				$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**		$\bar{x}$	**SE**
Mississippi Alluvial Valley	Missouri		20	5.29	1.608	[a]		5.29	1.608	140	52.63	10.356
		Duck Creek Conservation Area (CA)	10	6.90	2.890			6.90	2.890	50	22.13	13.578
		Otter Slough CA	10	3.68	1.411			3.68	1.411	50	32.93	14.560
		Ten Mile Pond CA								40	115.37	23.917
	Mississippi		60	12.53	4.815	26.44	10.074	17.17	4.673	240	37.84	7.471
		Migratory Bird Habitat Initiative	20	5.41	2.047			5.41	2.047	140	49.42	12.270
		Bear Creek Fisheries	10	6.72	3.802			6.72	3.802	40	24.57	12.302
		Janous Properties								30	86.81	36.293
		Thompson Fisheries								30	104.60	38.777
		Phillips Brother's Farms	10	4.10	1.691			4.10	1.691	40	4.83	1.184
		St. Catherine Creek National Wildlife Refuge (NWR)	40	19.64	9.255	26.44	10.074	23.04	6.773	100	21.63	4.784
		Cloverdale tract	20	33.11	17.830	12.09	2.421	22.60	9.083	50	30.42	8.409
		Sibley Farms moist-soil units	20	6.17	1.843	40.79	19.413	23.48	10.287	50	12.84	4.315
Northern Gulf of Mexico	Alabama	Dauphin Island	20	10.88	2.039	0.00	0.000	5.44	1.595	60	15.24	3.187
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve	20	54.97	23.986	96.54	66.284	75.75	34.635	70	34.48	11.226
		Grande Batture Islands	20	54.97	23.986	96.54	66.284	75.75	34.635	60	40.08	12.971
		Salt Pannes		[b]						10	0.93	0.731
	Louisiana	Elmer's Island Wildlife Refuge	20	1.15	0.776	20.35	7.719	10.75	4.371	60	10.59	2.094

[a] Blanks denote samples that were not collected on Migratory Bird Habitat Initiative (Periods 5 – 6) and Missouri Department of Conservation Areas (Period 6) because access was prohibited prior to waterfowl hunting season

[b] Dry Salt Pannes at Grand Bay NWR & National Estuarine Research Reserve (Periods 5 – 6).

Table A.5 August invertebrate dry biomass (kg/ha; mean [$\bar{x}$], standard error [SE], and sample size [*n*]) from soil cores in the Mississippi Alluvial Valley and northern Gulf of Mexico during 2013.

Region	**State**	**Site**	***n***	**August**					
				Period 1		**Period 2**		**Overall**	
				$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**
Mississippi Alluvial Valley	Missouri		40	149.56	46.655	40.04	11.664	94.80	25.303
		Otter Slough Conservation Area (CA)	20	209.94	78.385	76.49	16.696	143.22	41.899
		Ten Mile Pond CA	20	89.19	47.288	3.59	0.612	46.39	25.022
	Mississippi		100	25.80	6.381	28.43	6.604	27.12	4.570
		Migratory Bird Habitat Initiative	60	34.54	9.280	23.84	7.225	29.19	5.872
		Bear Creek Fisheries	20	81.56	20.373	6.24	1.039	43.90	13.160
		Thompson Fisheries	20	1.09	0.862	61.84	16.130	31.46	10.506
		Phillips Brother's Farms	20	20.99	5.125	3.44	1.489	12.21	3.286
		St. Catherine Creek National Wildlife Refuge (NWR)	40	12.69	7.091	35.32	12.551	24.01	7.342
		Cloverdale tract	20	12.45	10.506	22.37	6.067	17.41	6.013
		Sibley Farms moist-soil units	20	12.93	10.095	48.27	24.311	30.60	13.437
Northern Gulf of Mexico	Alabama	Dauphin Island	20	30.51	10.823	39.26	5.968	34.88	6.098
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve							
		Grande Batture Islands	20	52.31	52.212	0.99	0.962	26.65	26.087
	Louisiana	Elmer's Island Wildlife Refuge	20	1.27	0.984	3.89	1.205	2.58	0.814

Table A.6 September invertebrate dry biomass (kg/ha; mean [$\bar{x}$], standard error [SE], and sample size [n]) from soil cores in the Mississippi Alluvial Valley and northern Gulf of Mexico during 2012.

Region	**State**	**Site**	***n***	**September**					
				Period 3		**Period 4**		**Overall**	
				$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**
Mississippi Alluvial Valley	Mississippi		80	79.15	46.823	2,010.95	793.619	803.57	314.043
		Migratory Bird Habitat Initiative	60	103.88	77.716	2,010.95	793.619	1,057.42	414.347
		Bear Creek Fisheries	20	6.03	2.318	5.94	0.884	5.98	1.207
		Thompson Fisheries	20	242.48	233.487	50.47	21.209	146.47	116.204
		Phillips Brother's Farms	20	63.14	21.902	5,976.44	1,861.975	3,019.79	1,131.957
		St. Catherine Creek National Wildlife Refuge (NWR)	20	42.05	13.658	[a]		42.05	13.658
		Cloverdale tract	10	46.49	15.102			46.49	15.102
		Sibley Farms moist-soil units	10	37.60	23.561			37.60	23.561
Northern Gulf of Mexico	Alabama	Dauphin Island	20	29.01	7.993	14.62	2.511	21.81	4.399
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve							
		Grande Batture Islands	20	13.48	7.576	13.48	7.576	[b]	
	Louisiana	Elmer's Island Wildlife Refuge	20	5.52	2.160	8.41	7.947	6.96	4.022

[a] Blanks denote samples that were not collected because of inundation of St. Catherine Creek National Wildlife Refuge by flood waters of the Mississippi River (Period 4)

[b] Mechanical problems with my marine research vessel at Grand Bay NWR & National Estuarine Research Reserve (Period 4).

Table A.7 October and overall invertebrate dry biomass (kg/ha; mean [$\bar{x}$], standard error [SE], and sample size [n]) from soil cores in the Mississippi Alluvial Valley and northern Gulf of Mexico during 2012.

Region	**State**	**Site**	***n***	**October**						***n***	**Regional and Site Totals**	
				Period 5		**Period 6**		**Overall**				
				$\bar{x}$	**SE**	$\bar{x}$	**SE**	$\bar{x}$	**SE**		$\bar{x}$	**SE**
Mississippi Alluvial Valley	Missouri			[a]						40	94.80	25.303
		Otter Slough Conservation Area (CA)								20	143.22	41.899
		Ten Mile Pond CA								20	46.39	25.022
	Mississippi		60	42.79	10.739	51.44	20.937	47.12	11.679	240	290.94	106.904
		Migratory Bird Habitat Initiative	60	42.79	10.739	51.44	20.937	47.12	11.679	180	377.91	142.027
		Bear Creek Fisheries	20	18.54	7.016	72.97	62.858	45.75	31.407	60	31.88	11.416
		Thompson Fisheries	20	68.32	26.194	37.48	7.293	52.90	13.697	60	76.95	39.035
		Phillips Brother's Farms	20	41.52	15.539	43.87	12.393	42.69	9.677	60	1,024.90	413.863
		St. Catherine Creek National Wildlife Refuge (NWR)		[b]						60	30.02	6.708
		Cloverdale tract								30	27.11	6.772
		Sibley Farms moist-soil units								30	32.94	11.690
Northern Gulf of Mexico	Alabama	Dauphin Island	20	20.77	5.936	12.66	1.936	16.72	3.178	60	24.47	2.854
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve										
		Grande Batture Islands	20	20.20	9.841	108.85	89.950	64.52	45.195	60	39.17	20.825
	Louisiana	Elmer's Island Wildlife Refuge	20	20.71	5.042	29.61	4.186	25.16	3.349	60	11.57	2.152

[a] Blanks denote samples that were not collected because area was closed following teal hunting season in preparation for waterfowl hunting season at Missouri Department of Conservation Areas

[b] Government furlough (Period 5) and subsequent inundation of St. Catherine Creek National Wildlife Refuge by flood waters of the Mississippi River (Period 6).

Table A.8 Estimated invertebrate dry biomass (kg/ha; mean [$\overline{x}$], standard error [SE], and sample size [*n*]) at state and site levels during August – October 2011 – 2013.

Region	**State**	**Site**	***n***	**Overall**	
				$\overline{x}$	**SE**
Mississippi Alluvial Valley	Missouri		180	61.33	9.805
		Duck Creek Conservation Area (CA)	50	21.99	13.582
		Otter Slough CA	70	63.97	16.787
		Ten Mile Pond CA	60	91.05	18.052
	Mississippi		600	135.53	43.140
		Migratory Bird Habitat Initiative	440	176.19	58.842
		Bear Creek Fisheries	130	24.13	6.532
		Nerren Fisheries	20	21.2	5.655
		Janous Properties	50	57.02	22.294
		Thompson Fisheries	110	71.37	23.861
		Phillips Brother's Farms	130	485.69	195.224
		St. Catherine Creek National Wildlife Refuge (NWR)	160	24.49	3.908
		Cloverdale tract	80	28.66	5.813
		Sibley Farms moist-soil units	80	20.33	5.219
Northern Gulf of Mexico	Alabama	Dauphin Island	120	19.64	2.163
	Mississippi	Grand Bay NWR & National Estuarine Research Reserve	120	36.40	10.821
		Grand Batture Islands	110	39.62	11.761
		Salt Pannes	10	0.93	0.731
	Louisiana	Elmer's Island Wildlife Refuge	120	10.79	1.490

State and site scale estimated invertebrate dry biomass (kg/ha; mean [$\overline{x}$], standard error [SE], and sample size [*n*]) from soil cores in the Mississippi Alluvial Valley and northern Gulf of Mexico during August - October 2011 – 2013.

Table A.9 Invertebrate count and weight by taxa during August – October 2011 – 2013.

Year	State	Site	Sphaeriidae		Culicidae	
			Count	Weight	Count	Weight
2011	Migratory Bird Habitat Initiative					
		Bear Creek Fisheries	[a]			
		Janous Properties				
		Nerren Fisheries				
		Thompson Fisheries				
		Phillips Brother’s Farms				
2012	Missouri					
		Duck Creek Conservation Area (CA)			36	0.0055
		Otter Slough CA	14	0.0094	56	0.0106
		Ten Mile Pond CA	11	0.0308	85	0.0145
	Migratory Bird Habitat Initiative					
		Bear Creek Fisheries			26	0.0018
		Janous Properties			15	0.0045
		Thompson Fisheries			39	0.0111
		Phillips Brother's Farms			8	0.0067
	Southwest Mississippi					
		St. Catherine Creek National Wildlife Refuge (NWR)				
		Cloverdale tract	29	0.0202	62	0.0161
		Sibley Farms moist-soil units	68	0.0351	1	0
	Alabama	Dauphin Island				
	Mississippi	Grand Bay NWR and National Estuarine Research Reserve (NERR)				
		Grand Batture Islands	2	0.0369	100	0.0098
		Salt pannes				
	Louisiana	Elmer's Island Wildlife Refuge				
2013	Missouri					
		Otter Slough CA	42	0.0187	2	0.0000
		Ten Mile Pond CA	26	0.1093	5	0.0002
	Migratory Bird Habitat Initiative					
		Bear Creek Fisheries			5	0.0001
		Thompson Fisheries	2	0.0264	74	0.0070
		Phillips Brother's Farm	15	0.0023	483	0.0336
	Southwest Mississippi					
		St. Catherine Creek NWR				
		Cloverdale tract	6	0.0010	15	0.0038
		Sibley Farms moist-soil units	4	0.0244	191	0.0078
	Alabama	Dauphin Island			52	0.0085
	Mississippi	Grand Bay NWR and NERR				
		Grand Batture Islands			13	0.0040
	Louisiana	Elmer's Island Wildlife Refuge			12	0.0040

[a] Blanks denote taxa not present or recovered from sample cores.

Aquatic invertebrate total count and weight (g) by taxa for all invertebrate taxa recovered from soil cores collected at sites in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table A.9 (continued)

Year	Site[a]	Lumbricidae		Stratiomyidae[b]		Chironomidae[b]		Lumbrineridae	
		Count	Weight	Count	Weight	Count	Weight	Count	Weight
2011	**MBHI**								
	B_C_F	439	0.0862	2	0.0013	10	0.0083	[c]	
	J_P	23	0.0076	1	0.0003	124	0.0181		
	N_F	635	0.1165			179	0.0161		
	T_F	200	0.0180			29	0.0118		
	P_B_F	515	0.2598			391	0.0466		
2012	**Missouri**								
	DC_CA	1,003	0.0763	1	0.0003	67	0.0472		
	OS_CA	873	0.1315	2	0.0000	175	0.0363		
	TMP_CA	484	1.4093	1	0.0043	109	0.0153		
	MBHI								
	B_C_F	353	0.0463			60	0.0181		
	J_P	821	0.0991	3	0.0019	26	0.0090		
	T_F	8,156	0.3918	5	0.0076	627	0.3655		
	P_B_F	587	0.0245	5	0.0054	18	0.0002		
	Southwest Mississippi								
	SCC_NWR								
	SCC_C	1,299	0.1319	6	0.0242	44	0.0316		
	SCC_S	960	0.0668	19	0.0034	60	0.0094		
	D_I			2	0.0000	1	0.0000	4,815	0.2288
	GB_NWR								
	GB_GB					1	0.0003	2,516	0.2619
	GB_SP	3	0.0024				0.0000	19	0.0007
	EI_WR	4	0.0001			3	0.0007	843	0.1777
2013	**Missouri**								
	OS_CA	3,412	0.2069	4	0.0020	48	0.0065		
	TMP_CA	1,133	0.1447			66	0.0084		
	MBHI								
	B_C_F	4,782	0.6118			15	0.0021		
	T_F	3,954	0.3006	1	0.0004	817	0.1118		
	P_B_F	34,881	2.9544	1	0.0005	233	0.0391		
	Southwest Mississippi								
	SCC_NWR								
	SCC_C	3,496	0.1894			9	0.0023		
	SCC_S	1,459	0.0682			84	0.0162		
	D_I							43,553	0.4643
	GB_NWR								
	GB_GB							990	0.1102
	EI_WR							1,801	0.1838

[a] Site definitions found in APPENDIX D, Table D.1.

[b] larval form.

[c] Blanks denote taxa not present or recovered from sample cores.

Table A.9 (continued)

Year	Site[a]	Isopoda		Psychoda[b]		Cladocera		Decapoda	
		Count	Weight	Count	Weight	Count	Weight	Count	Weight
2011	**MBHI**								
	B_C_F	[c]							
	J_P								
	N_F								
	T_F	1	0.0029						
	P_B_F	3	0.0031						
2012	**Missouri**								
	DC_CA	2	0.0000	2	0.0059	77	0.2176		
	OS_CA	1	0.0015	12	0.0017	2	0.0013		
	TMP_CA			3	0.0019	5	0.0000		
	MBHI								
	B_C_F					6	0.0012		
	J_P	11	0.0048			1	0.0000		
	T_F	1	0.0024			1	0.0033		
	P_B_F	7	0.0150			85	0.0013		
	Southwest Mississippi								
	SCC_NWR								
	SCC_C	5	0.0113	2	0.0000	12	0.0000		
	SCC_S	37	0.0105	1	0.0007	20	0.0019		
	D_I					13	0.0000	8	0.0013
	GB_NWR								
	GB_GB	3	0.0000			1	0.0000	4	0.4167
	GB_SP								
	EI_WR			2	0.0031	27	0.0007		
2013	**Missouri**								
	OS_CA	2	0.0028	7	0.0063				
	TMP_CA	1	0.0001						
	MBHI								
	B_C_F			14	0.0102	14	0.0012		
	T_F	7	0.0037	2	0.0013	10	0.0007		
	P_B_F	7	0.0027	188	0.0320	4	0.0003		
	Southwest Mississippi								
	SCC_NWR								
	SCC_C			590	0.0422				
	SCC_S	9	0.0002	55	0.0138				
	D_I	2	0.0000	97	0.0105			1	0.0000
	GB_NWR								
	GB_GB	8	0.0010	29	0.0018			52	0.2089
	EI_WR			35	0.0070			2	0.0284

[a] Site definitions found in APPENDIX D, Table D.1.

[b] larval form

[c] Blanks denote taxa not present or recovered from sample cores.

Table A.9 (continued)

Site[a]	**Hirudinea**		**Hydrachnidiae**		**Corixidae**		**Diptera**[b]	
	Count	**Weight**	**Count**	**Weight**	**Count**	**Weight**	**Count**	**Weight**
MBHI								
B_C_F	[c]							
J_P							3	0.0004
N_F								
T_F								
P_B_F							3	0.0107
Missouri								
DC_CA	1	0.0004			2	0.0007	1	0.0003
OS_CA	1	0.0182						
TMP_CA	12	0.0501						
MBHI								
B_C_F	25	0.1720			1	0.0001		
J_P	24	0.5437						
T_F	2	0.0000						
P_B_F					1	0.0000	1	0.0083
Southwest Mississippi								
SCC_NWR								
SCC_C	48	0.0408					1	0.0000
SCC_S	2	0.0132					1	0.0266
D_I			1	0.0000			42	0.0196
GB_NWR								
GB_GB	4	0.0008						
GB_SP								
EI_WR							27	0.0151
Missouri								
OS_CA	12	0.0666			1	0.0000		
TMP_CA	21	0.0229						
MBHI								
B_C_F								
T_F	75	0.2608			3	0.0000		
P_B_F	60	0.0298					1	0.0002
Southwest Mississippi								
SCC_NWR								
SCC_C	1	0.0071						
SCC_S	1	0.0006	2	0.0000			5	0.0004
D_I							35	0.0035
GB_NWR								
GB_GB	1	0.0002						
EI_WR							22	0.0045

[a] Site definitions found in APPENDIX D, Table D.1.

[b] larval form

[c] Blanks denote taxa not present or recovered from sample cores.

Table A.9 (continued)

Year	Site[a]	Anostraca		Amphipoda		Odonata[b]		Ostracoda	
		Count	**Weight**	**Count**	**Weight**	**Count**	**Weight**	**Count**	**Weight**
2011	**MBHI**								
	B_C_F	[c]				7	0.0000		
	J_P			2	0.0004	13	0.0020		
	N_F					1	0.0013		
	T_F								
	P_B_F					25	0.0165		
2012	**Missouri**								
	DC_CA								
	OS_CA	1	0.0026						
	TMP_CA			1	0.0000				
	MBHI								
	B_C_F			1	0.0000	1	0.0690	3	0.0000
	J_P	8	0.0010	1	0.0000				
	T_F			1	0.0000				
	P_B_F	8	0.0003	2	0.0000				
	Southwest Mississippi								
	SCC_NWR								
	SCC_C							3	0.0001
	SCC_S	1	0.0000	1	0.0000				
	D_I			62	0.0296			36	0.0155
	GB_NWR								
	GB_GB	3	0.0004	47	0.0073				
	GB_SP								
	EI_WR								
2013	**Missouri**								
	OS_CA					2	0.0626	3	0.0031
	TMP_CA								
	MBHI								
	B_C_F			3	0.0000				
	T_F			4	0.0006	1	0.0016		
	P_B_F					2	0.1291		
	Southwest Mississippi								
	SCC_NWR								
	SCC_C								
	SCC_S					11	0.0443		
	D_I								
	GB_NWR								
	GB_GB			4	0.0013				
	EI_WR					5	0.0000		

[a] Site definitions found in APPENDIX D, Table D.1.

[b] larval form

[c] Blanks denote taxa not present or recovered from sample cores.

Table A.9 (continued)

Year	Site[a]	Physidae		Planorbidae		Tricladida		Syrphidae[b]	
		Count	Weight	Count	Weight	Count	Weight	Count	Weight
2011	**MBHI**								
	B_C_F	[c]							
	J_P								
	N_F								
	T_F			1	0.0000	11	0.0061		
	P_B_F					456	0.0445		
2012	**Missouri**								
	DC_CA	1	0.0104	1	0.0000				
	OS_CA	11	0.0279	34	0.2973				
	TMP_CA								
	MBHI								
	B_C_F					18	0.0091		
	J_P	162	0.1445					1	0.0391
	T_F	50	0.2556			1	0.0017	1	0.0001
	P_B_F								
	Southwest Mississippi								
	SCC_NWR								
	SCC_C	11	0.0934	1	0.1242				
	SCC_S			1	0.0448				
	D_I								
	GB_NWR								
	GB_GB	11	0.0634						
	GB_SP								
	EI_WR	1	0.0014					1	0.0028
2013	**Missouri**								
	OS_CA	9	0.0203	127	0.5511				
	TMP_CA								
	MBHI								
	B_C_F								
	T_F	5	0.0345	1	0.7765				
	P_B_F	49	0.2555	112	16.8934				
	Southwest Mississippi								
	SCC_NWR								
	SCC_C			2	0.0017				
	SCC_S	6	0.0256	14	0.1026	62	0.0215	4	0.0014
	D_I							1	0.0002
	GB_NWR								
	GB_GB	2	0.0010					1	
	EI_WR							1	0.0002

[a] Site definitions found in APPENDIX D, Table D.1.
[b] larval form
[c] Blanks denote taxa not present or recovered from sample cores.

Table A.9 (continued)

Year	Site[a]	Dytisidae[b]		Pharidae		Total		
		Count	Weight	Count	Weight	Count	weight (g)	kg (dry mass)/ha
2011	**MBHI**							
	B_C_F	6	0.0014			464	0.0972	293.07
	J_P	43	0.0549			209	0.0837	252.36
	N_F	6	0.0067			821	0.1406	423.92
	T_F					242	0.0388	116.99
	P_B_F	147	0.1251			1,540	0.5063	1,526.55
2012	**Missouri**							
	DC_CA					1,194	0.3646	1,099.31
	OS_CA					1,182	0.5383	1,623.04
	TMP_CA					711	1.5262	4,601.67
	MBHI							
	B_C_F					494	0.3176	957.60
	J_P	1	0.0142			1,074	0.8618	2,598.42
	T_F					8,884	1.0391	3,133.00
	P_B_F					722	0.0617	186.03
	Southwest Mississippi							
	SCC_NWR							
	SCC_C					1,523	0.4938	1,488.86
	SCC_S					1,172	0.2124	640.35
	D_I					4,980	0.2948	888.86
	GB_NWR							
	GB_GB					2,692	0.7975	2,404.55
	GB_SP					22	0.0031	9.35
	EI_WR					908	0.2016	607.85
2013	**Missouri**							
	OS_CA					3,671	0.9469	2,855.01
	TMP_CA					1,252	0.2856	861.12
	MBHI							
	B_C_F					4,833	0.6254	1,885.65
	T_F					4,956	1.5259	4,600.76
	P_B_F	1	0.0000			36,037	20.3729	61,426.60
	Southwest Mississippi							
	SCC_NWR							
	SCC_C	96	0.0191			4,215	0.2666	803.83
	SCC_S					1,907	0.3270	985.94
	D_I					43,741	0.4870	1,468.36
	GB_NWR							
	GB_GB	494	0.0215	3	0.2982	1,597	0.6481	1,954.09
	EI_WR					1,878	0.2279	687.14

[a] Site definitions found in APPENDIX D, Table D.1.
[b] larval form
[c] Blanks denote taxa not present or recovered from sample cores

APPENDIX B

WATERBIRD SPECIES LISTS AND RELATIVE ABUNDANCES FROM WETLANDS OF THE MISSISSIPPI ALLUVIAL VALLEY AND ALONG THE NORTHERN GULF OF MEXICO

Table B.1 Waterbird taxonomy and total abundance, by species, observed using wetlands in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Family	**Genus**	**Species**	**Common Name**	**Total Abundance**			**Species Totals**
				2011	**2012**	**2013**	
Anatidae	*Anser*	*albifrons*	Greater White-fronted Goose	2	1	1	4
	Branta	*canadensis*	Canada Goose	1,091	1,751	799	3,641
	Dendrocygna	*autumnalis*	Black-bellied Whistling Duck	12	26	28	66
	Aix	*sponsa*	Wood Duck	131	1,112	342	1,585
	Anas	*platyrhynchos*	Mallard	238	277	175	690
		fulvigula	Mottled Duck	0	33	22	55
		strepera	Gadwall	4	14	16	34
		acuta	Northern Pintail	9	76	2	87
		discors	Blue-winged Teal	1,161	5,236	1,536	7,933
		clypeata	Northern Shoveler	300	260	463	1,023
		carolinensis	American Green-winged Teal	2	26	75	103
	Aythya	*americana*	Redhead	2	3	[a]	5
		collaris	Ring-necked Duck		1		1
	Oxyura	*jamaicensis*	Ruddy Duck	10	23	258	291

[a] Blanks denote a specie(s) not observed during that year.

Waterbird (waterfowl, wading bird, and shorebird) taxonomy and yearly total abundance, by species, observed using wetlands in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table B.1 (continued)

Family	**Genus**	**Species**	**Common Name**	**Total Abundance**			**Species Totals**
				2011	**2012**	**2013**	
Podicipedidae	*Podilymbus*	*podiceps*	Pied-billed Grebe	24	1,511	93	1,628
Pelecanidae	*Pelecanus*	*erythrorhynchos*	American White Pelican	45	864	510	1,419
		occidentalis	Brown Pelican	87	1,331	528	1,946
Fregatidae	*Fregata*	*magnificens*	Magnificent Frigatebird	[a]	3	5	8
Anhingidae	*Anhinga*	*anhinga*	Anhinga	8	8	11	27
Phalacrocoracidae	*Phalacrocorax*	*auritus*	Double-crested Cormorant	13	219	417	649
		brasilianus	Neotropic Cormorant	3	27	1	31
Ardeidae	*Ixobrychus*	*exilis*	Least Bittern		1		1
	Ardea	*herodias*	Great Blue Heron	178	363	710	1,251
		alba	Great Egret	1,726	3,968	3,003	8,697
	Egretta	*thula*	Snowy Egret	454	1,028	742	2,224
		caerulea	Little Blue Heron	47	317	138	502
		tricolor	Tricolored Heron	1	67	27	95
		rufescens	Reddish Egret	5	24	13	42
	Bubulcus	*ibis*	Cattle Egret	97	832	786	1,715
	Butorides	*virescens*	Green Heron	3	5	4	12
	Nycticorax	*nycticorax*	Black-crowned Night-heron		12	1	13
	Nyctanassa	*violacea*	Yellow-crowned Night-heron		19	4	23
Threskionrithidae	*Eudocimus*	*albus*	White Ibis	273	2,073	1,259	3,605
	Plegadis	*chihi*	White-faced Ibis	80	73	440	593
		falcinellus	Glossy Ibis		2		2
	Platalea	*ajaja*	Roseate Spoonbill	123	193	197	513

[a] Blanks denote a specie(s) not observed during that year.

Table B.1 (continued)

Family	**Genus**	**Species**	**Common Name**	**Total Abundance**			**Species Totals**
				2011	**2012**	**2013**	
Ciconidae	*Mycteria*	*americana*	Wood Stork	1,033	10	544	1,587
Rallidae	*Gallinula*	*galeata*	Common Gallinule	[a]	7		7
	Fulica	*americana*	American Coot	9	1,017	1,205	2,231
	Rallus	*crepitans*	Clapper Rail	0	17	18	35
		limicola	Virginia Rail	1			1
	Porzana	*carolina*	Sora			1	1
Charadriidae	*Pluvialis*	*squatarola*	Black-bellied Plover	125	296	138	559
		dominica	American Golden Plover	8	4	1	13
	Charadrius	*nivosus*	Snowy Plover	1	28	12	41
		wilsonia	Wilson's Plover	14	60	25	99
		melodus	Piping Plover	9	61	59	129
		semipalmatus	Semipalmated Plover	154	417	270	841
		vociferus	Killdeer	1,918	2,155	967	5,040
Haematopodidae	*Haematopus*	*palliatus*	American Oystercatcher	45	50	56	151
Recurvirostridae	*Himantopus*	*mexicanus*	Black-necked Stilt	1,315	1,422	2,111	4,848
	Recurvirostra	*americana*	American Avocet	293	778	73	1,144

[a] Blanks denote a specie(s) not observed during that year.

Waterbird (waterfowl, wading bird, and shorebird) taxonomy and total abundance, by species, observed using wetlands in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table B.1 (continued)

Family	**Genus**	**Species**	**Common Name**	**Total Abundance**			**Species Totals**
				2011	**2012**	**2013**	
Scolopacidae	*Actitis*	*macularius*	Spotted Sandpiper	25	22	76	123
	Tringa	*solitaria*	Solitary Sandpiper	1	53	3	57
		melanoleuca	Greater Yellowlegs	334	250	77	661
		semipalmata	Willet	175	364	144	683
		flavipes	Lesser Yellowlegs	203	1,089	753	2,045
	Numenius	*phaeopus*	Whimbrel	[a]	10	1	11
		macularius	Long-billed Curlew		1		1
	Limosa	*fedoa*	Marbled Godwit	11	16	2	29
	Arenaria	*interpres*	Ruddy Turnstone	86	146	102	334
	Calidris	*canutus*	Red Knot	21	71	13	105
		alba	Sanderling	688	889	518	2,095
		pusilla	Semipalmated Sandpiper	1,431	450	158	2,039
		mauri	Western Sandpiper	260	570	658	1,488
		minutilla	Least Sandpiper	7,337	4,688	6,723	18,748
		fuscicollis	White-rumped Sandpiper	1			1
		bairdii	Baird's Sandpiper		6		6
		melanotos	Pectoral Sandpiper	1,428	1,471	356	3,255
		alpina	Dunlin	41	78	2	121
		himantopus	Stilt Sandpiper	57	915	461	1,433
	Tryngites	*subruficollis*	Buff-breasted Sandpiper	5	22		27
	Limnodromus	*Spp.*	Dowitcher spp.	333	615	479	1,427
	Gallinago	*delicata*	Wilson’s Snipe			1	1
	Phalaropus	*tricolor*	Wilson's Phalarope	1	1	2	4

[a] Blanks denote a specie(s) not observed during that year.

Table B.1 (continued)

Family	**Genus**	**Species**	**Common Name**	**Total Abundance**			**Species Totals**
				2011	**2012**	**2013**	
Laridae	*Chroicocephalus*	*philadelphia*	Bonaparte's Gull	[a]	0	20	20
	Leucophaeus	*atricilla*	Laughing Gull		4,726	1,623	6,349
	Larus	*delawarensis*	Ring-billed Gull		2	5	7
		argentatus	Herring Gull		32	13	45
		fuscus	Lesser Black-backed Gull		6		6
	Chlidonias	*niger*	Black Tern	11	335	427	773
	Sternula	*antillarum*	Least Tern		500	564	1,064
	Gelochelidon	*nilotica*	Gull-billed Tern		9	3	12
	Sterna	*hirundo*	Common Tern		57		57
		forsteri	Forster's Tern		200	427	627
	Hydroprogne	*caspia*	Caspian Tern		246	249	495
	Thalasseus	*maximus*	Royal Tern		1,265	1,468	2,733
		sandvicensis	Sandwich Tern		242	136	378
	Rynchops	*niger*	Black Skimmer	41	96	360	497
Alcedinidae	*Megaceryle*	*alcyon*	Belted Kingfisher		6	4	10

[a] Blanks denote a specie(s) not observed during that year.

Waterbird (waterfowl, wading bird, and shorebird) taxonomy and total abundance, by species, observed using wetlands in the Mississippi Alluvial Valley and Northern Gulf of Mexico during August – October 2011 – 2013

Table B.2 Waterbird taxonomy and American Ornithological Union (AOU) species alpha codes used in NMDS ordination outputs during August – October 2011 – 2013.

Family	Genus	Species	Common name	AOU Species Alpha Codes
Anatidae	*Branta*	*canadensis*	Canada Goose	**CANG**
	Aix	*sponsa*	Wood Duck	**WODU**
	Anas	*platyrhynchos*	Mallard	**MALL**
		discors	Blue-winged Teal	**BWTE**
		clypeata	Northern Shoveler	**NSHO**
	Oxyura	*jamaicensis*	Ruddy Duck	**RUDU**
Podicipedidae	*Podilymbus*	*podiceps*	Pied-billed Grebe	**PBGR**
Pelecanidae	*Pelecanus*	*erythrorhynchos*	American White Pelican	**AWPE**
		occidentalis	Brown Pelican	**BRPE**
Ardeidae	*Ardea*	*herodias*	Great Blue Heron	**GBHE**
		alba	Great Egret	**GREG**
	Egretta	*thula*	Snowy Egret	**SNEG**
		caerulea	Little Blue Heron	**LBHE**
	Bubulcus	*ibis*	Cattle Egret	**CAEG**
Threskiornithidae	*Eudocimus*	*albus*	White Ibis	**WHIB**
	Plegadis	*chihi*	White-faced Ibis	**WFIB**
	Platalea	*ajaja*	Roseate Spoonbill	**ROSP**
Ciconidae	*Mycteria*	*americana*	Wood Stork	**WOST**
Rallidae	*Fulica*	*americana*	American Coot	**AMCO**

Waterbird (**waterfowl**, **wading bird**, and **shorebird**) taxonomy (Family, Genus, Species, and Common Name) and American Ornithological Union (AOU) species alpha codes used in NMDS ordination outputs. Species were observed using wetlands in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table B.2 (continued)

Family	**Genus**	**Species**	**Common name**	**AOU Species Alpha Codes**
Charadriidae	*Pluvialis*	*squatarola*	Black-bellied Plover	**BBPL**
	Charadrius	*semipalmatus*	Semipalmated Plover	**SEPL**
		vociferus	Killdeer	**KILL**
Recurvirostridae	*Himantopus*	*himantopus*	Black-necked Stilt	**BNST**
	Recurvirostra	*americana*	American Avocet	**AMAV**
Scolopacidae	*Tringa*	*melanoleuca*	Greater Yellowlegs	**GRYE**
		semipalmatus	Willet	**WILL**
		flavipes	Lesser Yellowlegs	**LEYE**
	Arenaria	*interpres*	Rudy Turnstone	**RUTU**
	Calidris	*alba*	Sanderling	**SAND**
		pusilla	Semipalmated Sandpiper	**SESA**
		mauri	Western Sandpipe	**WESA**
		minutilla	Least Sandpiper	**LESA**
		melanotos	Pectoral Sandpiper	**PESA**
		himantopus	Stilt Sandpiper	**STSA**
	Lymnodromus	*spp.*	Dowitcher spp.	**DOWITCHER**
Laridae	*Leucophaeus*	*atricilla*	Laughing Gull	**LAGU**
	Chlidonias	*niger*	Black Tern	**BLTE**
	Sternula	*antillarum*	Least Tern	**LETE**
	Sterna	*forsteri*	Forster's tern	**FOTE**
	Hydroprogne	*caspia*	Caspian Tern	**CATE**
	Thalasseus	*maximus*	Royal Tern	**ROYT**
		sandvicensis	Sandwich Tern	**SATE**
	Rynchops	*niger*	Black Skimmer	**BLSK**

Waterbird (**waterfowl**, **wading bird**, and **shorebird**) taxonomy (Family, Genus, Species, and Common Name) and American Ornithological Union (AOU) species alpha codes used in NMDS ordination outputs. Species were observed using wetlands in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table B.3 Waterbird assemblages by year in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Year	**American Ornithological Union (AOU) Species Alpha Codes**[a]										
2011 – Waterfowl (WF)	CANG										
Wading bird (WB)	PBGR	LBHE	ROSP	BLTE	LETE	BLSK					
Shorebird (SB)	SEPL	BNST	AMAV	GRYE	LEYE	SESA	WESA	LESA	PESA	STSA	DOWITCHER
2012 – WF	CANG										
WB	AWPE	SNEG	WFIB	WOST	BLTE	LETE	CATE	ROYT	BLSK		
SB	BNST	AMAV	GRYE	LEYE	LESA	STSA					
2013 – WB	AWPE	WFIB	WOST	BLTE	LETE						
SB	BNST										

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.2) by year ($n = 3$) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.4 Waterbird assemblages by month in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Month	**American Ornithological Union (AOU) Species Alpha Codes**[a]											
August – Waterfowl (WF)	CANG											
Wading bird (WB)	PBGR	BLTE	LETE									
Shorebird (SB)	BNST	GRYE	LEYE	SESA	LESA	PESA	STSA					
September – WF	CANG											
WB	AWPE	BRPE	SNEG	LBHE	WHIB	WFIB	WOST	BLTE	LETE	CATE	ROYT	BLSK
SB	BNST	AMAV	GRYE	LEYE	STSA							
October – WF	RUDU											
WB	AWPE	GREG	SNEG	WFIB	WOST	LETE	BLTE	CATE	ROYT	BLSK		
SB	BNST	AMAV										

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.3) by month ($n = 3$) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.5 Waterbird assemblages by period in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Survey Time Period	**American Ornithological Union (AOU) Species Alpha Codes**[a]									
1 – Waterfowl (WF)	CANG									
Wading bird (WB)	PBGR	BLTE	BLSK							
Shorebird (SB)	KILL	BNST	AMAV	GRYE	LEYE	SESA	LESA	PESA	STSA	
2 – WF	CANG									
SB	LEYE	LESA	STSA							
3 – WF	CANG									
WB	AWPE	BRPE	SNEG	LBHE	WHIB	WFIB	WOST	BLTE	LETE	CATE
		ROYT	BLSK							
SB	BNST	AMAV	GRYE	LEYE	LESA	STSA				
4 – WB	AWPE	BRPE	SNEG	LBHE	WHIB	WFIB	WOST	LAGU	BLTE	LETE
		CATE	ROYT	SATE	BLSK					
SB	BNST	AMAV	LEYE	STSA						
5 – WF	RUDU									
WB	AWPE	GREG	SNEG	WFIB	WOST	BLTE	LETE	CATE	ROYT	BLSK
SB	BNST	AMAV								
6 – WF	WODU	RUDU								
WB	AWPE	SNEG	WFIB	WOST	BLTE	LETE	CATE	ROYT		
SB	BNST									

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.4) by survey time period ($n = 6$), across years, in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.6 Waterbird assemblages by month in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Month	**American Ornithological Union (AOU) Species Alpha Codes**[a]					
August – Shorebird (SB)	KILL	BNST	LESA	PESA		
September – Waterfowl (WF)	WODU	MALL	BWTE			
Wading bird (WB)	SNEG	WFIB	ROSP			
SB	KILL	BNST	AMAV	GRYE	LESA	PESA
October – WB	BRPE	WFIB	BLSK			
SB	SEPL	GRYE	WESA	DOWITCHER		

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.5) by month (*n* = 3), in 2011, in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.7 Waterbird assemblages by period in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Survey Time Period	American Ornithological Union (AOU) Species Alpha Codes[a]					
1 – Wading bird (WB)	CAEG					
Shorebird (SB)	KILL	BNST	LESA	PESA		
2 - SB	KILL	BNST	LESA	PESA		
3 - SB	KILL	BNST	LESA	PESA		
4 – Waterfowl (WF)	CANG	WODU	MALL	BWTE		
WB	SNEG	ROSP				
SB	BNST	AMAV	GRYE	LESA	PESA	
5 – WB	BRPE	SNEG	WFIB			
SB	GRYE	WESA	DOWITCHER			
6 – WB	WFIB	BLSK				
SB	BBPL	SEPL	GRYE	WILL	WESA	DOWITCHER

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.6) by period ($n = 2$) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.8 Waterbird assemblages by month in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Month	American Ornithological Union (AOU) Species Alpha Codes[a]								
August – Wading bird (WB)	PBGR								
Shorebird (SB)	SESA	LESA	STSA						
September – Waterfowl (WF)	CANG								
WB	AWPE	BRPE	WHIB	LAUG	BLTE	LETE	CATE	ROYT	SATE
SB	SEPL	STSA	DOWITCHER						
October – WF	CANG								
WB	AWPE	BRPE	WHIB						
SB	SEPL	SAND	DOWITCHER						

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.7) by month ($n = 2$) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.9 Waterbird assemblages by period in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Survey Time Period	**American Ornithological Union (AOU) Species Alpha Codes**[a]									
1 – Wading bird (WB)	PBGR	BLTE	LETE							
Shorebird (SB)	SEPL	KILL	GRYE	LEYE	SESA	WESA	LESA	STSA		
2 – Waterfowl (WF)	CANG									
3 – WF	NSHO									
WB	AWPE	BRPE	SNEG	WHIB	LAGU	BLTE	LETE	CATE	ROYT	SATE
SB	SEPL	BNST	GRYE	SAND	SESA	WESA	STSA	DOWITCHER		
4 – WF	CANG									
WB	AWPE	BRPE	WHIB	CATE	ROYT	SATE				
SB	DOWTICHER									
5 – WF	CANG									
WB	AWPE	BRPE	GREG	WHIB	CATE	ROYT	SATE			
SB	SEPL	SAND	DOWITCHER							
6 - WB	AWPE	ROYT								

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.8) by period (*n* = 6) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.10 Waterbird assemblages by month in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Month	**American Ornithological Union Species Alpha Codes**[a]								
August – Wading bird (WB)	WOST								
Shorebird (SB)	BNST	LEYE	LESA	PESA	STSA				
September – Waterfowl (WF)	WODU								
WB	AWPE	GREG	WHIB	WFIB	WOST	BLTE	LETE	BLSK	
SB	SEPL	BNST	LEYE	PESA					
October – WF	WODU	BWTE							
WB	AWPE	GREG	WHIB	WFIB	WOST	BLTE	LETE	CATE	BLSK
SB	SEPL	LEYE							

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.9) by month ($n = 3$) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.11 Waterbird assemblages for period in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Survey Time Period	**American Ornithological Union Species Alpha Codes**[a]											
1 – Wading bird (WB)	WOST											
Shorebird (SB)	BNST	LEYE	LESA	PESA	STSA							
2 – WB	WOST											
SB	BNST	LEYE	LESA	PESA	STSA							
3 – Waterfowl (WF)	WODU											
WB	WHIB	WOST	BLTE	LETE	BLSK							
SB	BNST	LEYE	LESA	PESA	STSA							
4 – WF	WODU	BWTE										
WB	AWPE	BRPE	GREG	WHIB	WOST	BLTE	LETE	CATE	ROYT	BLSK		
SB	SEPL											
5 – WB	WHIB	WOST	BLTE	LETE	BLSK							
SB	BNST	LEYE										
6 – WF	WODU	BWTE	RUDU									
WB	PBGR	AWPE	BRPE	WHIB	WFIB	WOST	LAGU	BLTE	LETE	CATE	ROYT	BLSK
SB	SEPL	SAND										

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.10) for survey time period in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.12 Waterbird assemblages by latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Latitude	**American Ornithological Union Species Alpha Codes**[a]								
> 34.0° N –Wading bird (WB)	CAEG	AMCO							
34.0° – 33.5° N – Waterfowl (WF)	CANG	WODU	BWTE						
WB	GBHE	GREG							
Shorebird (SB)	SESA	LESA	PESA						
33.5° – 33.0° N – WF	NSHO								
WB	PBGR								
SB	KILL								
33.0° – 32.5° N – WF	RUDU								
SB	GRYE	LEYE	STSA						
32.5° – 32.0° N – WB	ROSP	WOST							
SB	BBPL	SAND	WESA						
32.0° – 31.5° N – WF	MALL								
WB	BRPE	LBHE	WHIB	LAGU	BLTE	FOTE	ROYT	SATE	BLSK
SB	SEPL	BNST	AMAV	WILL	DOWITCHER				
31.5° – 31.0° N – WB	AWPE	SNEG	WFIB	CATE					
SB	RUTU								
< 31.5° N –	[b]								

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with latitudes below 31.5° N.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.11) by latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.13 Waterbird assemblages by region in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Region	American Ornithological Union Species Alpha Codes[a]									
Mississippi Alluvial Valley – Waterfowl (WF)	CANG									
Wading bird (WB)	WOST									
Shorebird (SB)	BNST	LEYE	LESA	STSA						
Northern Gulf of Mexico – WF	MALL									
WB	BRPE	SNEG	LBHE	WHIB	ROSP	LAGU	FOTE	CATE	ROYT	SATE
SB	BBPL	SEPL	WILL	SAND	DOWITCHER					
Both regions – WB	AWPE	WFIB	LETE	BLSK						
SB	AMAV									

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.12) by region (*n* = 2; APPENDIX D; Table D.1) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.14 Waterbird assemblages by state in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

State[a]	**American Ornithological Union Species Alpha Codes**[b]								
Missouri –Wading bird (WB)	AWPE	WFIB	WOST	BLTE	LETE				
MBHI – Waterfowl (WF)	CANG								
WB	AWPE	WFIB	WOST	BLTE	LETE	BLSK			
Shorebird (SB)	BNST	AMAB	LEYE	LESA	STSA				
Mississippi Delta – WF	MALL								
WB	PBGR	BRPE	LBHE	WHIB	ROSP	LAGU	FOTE	SATE	BLSK
SB	BBPL	SEPL	AMAV	GRYE	WILL	LEYE	SAND	WESA	PESA
		STSA	DOWITCHER						
Southwest Mississippi – WB	AWPE	SNEG	WFIB	WOST	BLTE	LETE	CATE	ROYT	
Mississippi (coast) – WB	AWPE	SNEG	LBHE	WFIB					
SB	SEPL	DOWITCHER							
Alabama – WF	MALL								
WB	BRPE	SNEG	LBHE	WHIB	LAGU	FOTE	CATE	SATE	
SB	BBPL	SEPL	WILL	SAND	WESA	DOWITCHER			
Louisiana – WF	MALL								
WB	AWPE	BRPE	SNEG	LBHE	WHIB	WFIB	LAGU	LETE	FOTE
		CATE	ROYT	SATE	BLSK				
SB	BBPL	SEPL	AMAV	WILL	SAND	DOWTICHER			

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.

[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.13) by state (*n* = 7) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.15 Waterbird assemblages by site in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October, 2011 – 2013.

Site[a]	American Ornithological Union Species Alpha Codes[b]									
DC_CA – Waterfowl (WF)	CANG									
Wading bird (WB)	AWPE	SNEG	WFIB	BLTE	LETE	CATE	ROYT	BLSK		
Shorebird (SB)	BNST	AMAV	LEYE	LESA	LEYE					
OS_CA – WB	AWPE	WOST	LETE							
TMP_CA	[c]									
CR_NWR – WF	MALL									
WB	BRPE	LBHE	WHIB	ROSP	LAGU	FOTE	SATE	BLSK		
SB	BBPL	SEPL	AMAV	GRYE	WILL	SAND	WESA	DOWITCHER		
Y_NWR – WF	CANG	MALL								
WB	PBGR	BRPE	LBHE	WHIB	ROSP	LAGU	FOTE	SATE	BLSK	
SB	SEPL	BNST	AMAV	GRYE	LEYE	SESA	LESA	PESA	STSA	DOWITCHER
SCC_NWR – WB	AWPE	SNEG	WFIB	WOST	BLTE	LETE	CATE			

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.
[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.
[c] Ellipse was not associated with any species.
Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.14) by site (*n* = 14) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.15 (continued)

Site[a]	**American Ornithological Union Species Alpha Codes**[b]								
B_C_F	[c]								
N_F – Waterfowl (WF)	CANG								
Wading bird (WB)	PBGR	WFIB	BLTE	LETE	BLSK				
Shorebird (SB)	BNST	AMAV	GRYE	LEYE	SESA	LESA	PESA	STSA	
J_P – WF	CANG	MALL							
WB	PBGR	AWPE	BRPE	SNEG	LBHE	WHIB	WFIB	ROSP	LAGU
		BLTE	LETE	FOTE	CATE	ROYT	SATE	BLSK	
SB	SEPL	BNST	AMAV	GRYE	LEYE	LESA	PESA	STSA	DOWITCHER
T_F – WF	CANG								
SB	KILL	LESA							
P_B_F – WF	CANG								
WB	PBGR	AWPE	WFIB	WOST	BLTE	LETE	BLSK		
SB	BNST	AMAV	GRYE	LEYE	LESA	STSA			

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.
[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.
[c] Ellipse was not associated with any species.
Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.14) by site (n = 14) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October, 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.15 (continued)

Site[a]	American Ornithological Union Species Alpha Codes[b]								
D_I – WF	MALL								
WB	BRPE	SNEG	LBHE	WHIB	ROSP	LAGU	FOTE	CATE	SATE
SB	BBPL	SEPL	AMAV	WILL	SAND	WESA	DOWITCHER		
GB_NERR – WB	AWPE	LBHE	WFIB	ROSP	BLSK				
SB	AMAV	SEPL	DOWITCHER						
EI_WR – WF	MALL								
WB	AWPE	BRPE	SNEG	LBHE	WHIB	WFIB	LAGU	BLTE	LETE
		FOTE	CATE	ROYT	SATE	BLSK			
SB	BBPL	SEPL	AMAV	WILL	SAND	DOWTICHER			

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.

[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.14) by site (*n* = 14) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.16 Waterbird assemblages by region in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Region	**American Ornithological Union Species Alpha Codes**[a]				
Mississippi Alluvial Valley – Waterfowl (WF)	WODU				
Shorebird (SB)	KILL	BNST	LESA	PESA	
Northern Gulf of Mexico – Wading bird (WB)	BRPE	BLSK			
SB	BBPL	SEPL	WILL	SAND	WESA
Both regions	[b]				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No overlap in regional 95% confidence ellipses in ordination space.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.15) by region (*n* = 2; APPENDIX D; Table D.1) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.17 Waterbird assemblages by state in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

State[a]	**American Ornithological Union Species Alpha Codes**[b]			
Missouri	[c]			
Mississippi Delta – Waterfowl (WF)	BWTE	NSHO		
Wading bird (WB)	SNEG	WFIB	ROSP	
Shorebird (SB)	BNST	AMAV	GRYE	PESA
MBHI – SB	KILL	LESA	PESA	
Southwest Mississippi – SB	BNST			
Alabama – WB	BLSK			
SB	BBPL	WILL	WESA	
Mississippi (coast) – SB	SEPL	DOWITCHER		
Louisiana – WB	BRPE			
SB	RUTU	SAND		

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.

[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[c] Ellipse was not associated with any species.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.16) by state (n = 7) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.18 Waterbird assemblages by site in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Site[a]	American Ornithological Union Species Alpha Codes[b]					
DC_CA	[c]					
OS_CA – WB	[c]					
CR_NWR – WF	BWTE	NSHO				
SB	BNST	AMAV				
Y_NWR – WB	SNEG	LBHE	CAEG	WFIB		
SB	LESA	PESA	DOWITCHER			
B_C_F – SB	KILL					
N_F – WF	WODU					
SB	KILL	BNST	AMAV	GRYE	LESA	PESA
J_P	[c]					
T_F	[c]					
P_B_F – WF	WODU					
SB	KILL	BNST	LESA	PESA		
SCC_NWR – SB	BNST					
D_I – WB	BLSK					
SB	BBPL	WILL	WESA			
GB_NERR – SB	SEPL	DOWITCHER				
EI_WR – WB	BRPE					
SB	RUTU	SAND				

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.

[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[c] Ellipse was not associated with any species.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.17) by site (*n* = 14) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.19 Waterbird assemblages by latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Latitude	American Ornithological Union Species Alpha Codes[a]									
> 34.5° N – Waterfowl (WF)	WODU									
34.5° – 34.0° N – WF	MALL	CANG								
Wading bird (WB)	AMCO									
34.0° – 33.5° N – WF	BWTE									
WB	PBGR	GBHE	GREG	CAEG						
Shorebird (SB)	LESA									
33.5° – 33.0° N – SB	KILL	LEYE	SESA							
33.0° – 32.5° N – SB	GRYE	SAND	WESA	STSA						
32.5° – 32.0° N – WF	NSHO									
WB	ROYT									
SB	BBPL	BNST								
< 32.0° N – WB	AWPE	BRPE	SNEG	WHIB	WFIB	LAGU	BLTE	LETE	CATE	SATE
SB	SEPL	DOWITCHER								

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.18) by latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.20 Waterbird assemblages by region in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Region	**American Ornithological Union Species Alpha Codes**[a]					
Mississippi Alluvial Valley – Waterfowl (WF)	CANG					
Wading bird (WB)	BLTE					
Shorebird (SB)	STSA					
Northern Gulf of Mexico – WB	SNEG	LAGU				
Both regions – WB	AWPE	BRPE	WFIB	CATE	ROYT	SATE
SB	SEPL	DOWITCHER				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.19) by region (*n* = 2; APPENDIX D; Table D.1) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.21 Waterbird assemblages by state in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

State[a]	American Ornithological Union Species Alpha Codes[b]										
Missouri – Waterfowl (WF)	CANG										
Wading bird (WB)	AWPE	GREG									
MBHI – WF	KILL	LESA	PESA								
WB	AWPE	BLTE									
Shorebird (SB)	SEPL	GRYE	SESA	LESA	STSA	DOWITCHER					
Southwest Mississippi – WF	NSHO										
WB	AWPE	BRPE	SNEG	WFIB	LAGU	BLTE	LETE	CATE	ROYT	SATE	
SB	SEPL	SAND	DOWITCHER								
Alabama – WF	NSHO										
WB	AWPE	BRPE	SNEG	WHIB	WFIB	LAGU	BLTE	LETE	CATE	ROYT	SATE
SB	BBPL	SEPL	BNST	SAND	DOWITCHER						
Mississippi (coast) – WB	AWPE										
Louisiana – WB	AWPE										

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.

[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.20) by state (*n* = 7) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.22 Waterbird assemblages by site in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Site[a]	**American Ornithological Union Species Alpha Codes**[b]								
DC_CA – Waterfowl (WF)	NSHO								
Water bird (WB)	AWPE	BRPE	SNEG	WFIB	LAGU	BLTE	LETE	CATE	ROYT
		SATE							
Shorebird (SB)	SEPL	SAND	STSA	DOWITCHER					
OS_CA – WF	CANG								
WB	GREG								
TMP_CA	[c]								
B_C_F – WF	CANG								
WB	GREG								
J_P – WF	NSHO								
WB	AWPE	BRPE	SNEG	WHIB	WFIB	LAGU	BLTE	LETE	CATE
		ROYT	SATE						
SB	BBPL	SEPL	BNST	GRYE	LEYE	SAND	SESA	WESA	STSA
		DOWITCHER							
T_F – WB	LETE	BLTE							
SB	SEPL	KILL	SESA	LESA	STSA	DOWITCHRE			
P_B_F – SB	KILL	LESA							

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.
[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.
[c] Ellipse was not associated with any species.
Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.21) by site ($n = 14$) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.22 (continued)

Site[a]	American Ornithological Union Species Alpha Codes[b]										
SCC_NWR – WF	NSHO										
WB	AWPE	BRPE	SNEG	WFIB	LAGU	BLTE	LETE	CATE	ROYT	SATE	
SB	SEPL	SAND	DOWITCHER								
D_I – WF	NSHO										
WB	AWPE	BRPE	SNEG	WHIB	WFIB	LAGU	BLTE	LETE	CATE	ROYT	SATE
SB	BBPL	SEPL	BNST	SAND	DOWITCHER						
GB_NERR – WB	AWPE										
EI_WR – WB	AWPE										

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.

[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.21) by site (*n* = 14) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.23 Waterbird assemblages by latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Latitude	American Ornithological Union Species Alpha Codes [a]								
> 34.0° N	[b]								
34.0° – 33.5° N –Wading birds (WB)	GBHE								
33.5° – 33.0° N – Waterfowl (WF)	CANG								
WB	GREG	AMCO							
Shorebird (SB)	KILL	LESA							
33.0° – 32.5° N – WF	RUDU								
WB	PBGR	CAEG							
SB	PESA	STSA							
32.5° – 32.0° N – WF	MALL	NSHO							
SB	LEYE								
32.0° – 31.5° N – WF	WODU								
WB	SNEG	WOST	LETE	CATE	SATE				
< 31.5° N – WF	BWTE								
WB	AWPE	BRPE	WHIB	WFIB	LAGU	BLTE	FOTE	ROYT	BLSK
SB	BBPL	SEPL	WILL	SAND	WESA	DOWITCHER			

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with latitudes above 34.0° N.

Waterbird assemblages (Figure 2.22) by latitude in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.24 Waterbird assemblages by region in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Region	**American Ornithological Union Species Alpha Codes**[a]					
Mississippi Alluvial Valley – Waterfowl (WF)	WODU					
Wading bird (WB)	WHIB	WOST	BLTE	LETE	BLSK	
Shorebird (SB)	BNST	LEYE	LESA	PESA	STSA	
Northern Gulf of Mexico – WF	BWTE					
WB	BRPE	LAGU	FOTE	CATE	ROYT	
SB	BBPL	SEPL	WILL	SAND	WESA	DOWITCHER
Both regions – WB	AWPE					

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.23) by region (n = 2; APPENDIX D; Table D.1) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.25 Waterbird assemblages by state in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

State[a]	**American Ornithological Union Species Alpha Codes**[b]					
Missouri – Wading bird (WB)	GREG					
MBHI – Waterfowl (WF)	WODU					
WB	WHIB	WOST	BLTE	LETE	BLSK	
Shorebird (SB)	BNST	LEYE	LESA	PESA	STSA	
Southwest Mississippi – WB	WHIB	WFIB	WOST	BLTE	BLSK	
SB	BNST					
Alabama – WF	BWTE					
WB	AWPE	BRPE	LAGU	FOTE	CATE	ROYT
SB	BBPL	SEPL	WILL	SAND	WESA	DOWITCHER
Mississippi (coast) – WF	WODU					
WB	LETE					
Louisiana – WB	BRPE	LAGU				

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.

[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.24) by state ($n = 7$) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.26 Waterbird assemblages by site in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Site[a]	**American Ornithological Union Species Alpha Codes**[b]									
OS_CA – Water bird (WB)	GBHE	GREG								
TMP_CA	[c]									
B_C_F	[c]									
T_F – Shorebird (SB)	LESA	PESA								
P_B_F – Waterfowl (WF)	WODU	BWTE								
WB	AWPE	BRPE	SNEG	WHIB	WFIB	WOST	BLTE	LETE	FOTE	BLSK
SB	SEPL	BNST	WILL	LEYE	WESA	LESA	PESA	STSA	DOWITCHER	
SCC_NWR – WB	WHIB	WOST	BLTE	BLSK						
SB	BNST									
D_I – WF	BWTE									
WB	AWPE	BRPE	LAGU	FOTE	CATE	ROYT	SATE			
GB_NERR – WF	WODU									
WB	LETE									
EI_WR – WB	BRPE	LAGU	ROYT							

[a] Full state names and their associated regions and sites can be found in APPENDIX D, Table D.1.
[b] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.
[c] Ellipse was not associated with any species.

Waterbird assemblages (waterfowl, wading bird, and shorebird; Figure 2.25) by site (*n* = 14) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within temporal 95% confidence ellipses overlaid on non-metric multidimensional scaling ordination output.

Table B.27 Waterbird assemblages by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Water Depth	**American Ornithological Union Species Alpha Codes**[a]				
< 5.4 cm	[b]				
5.4 – 5.6 cm – Shorebird (SB)	KILL	RUTU			
5.6 – 5.8 cm – Waterfowl (WF)	CANG				
Wading bird (WB)	GBHE				
SB	SESA	LESA	PESA		
5.8 – 6.0 cm – WB	PBGR				
6.0 – 6.2 cm – WB	CAEG				
SB	GRYE	WESA			
6.2 – 6.4 cm – WB	ROSP				
SB	BBPL	LEYE	SAND	STSA	
6.4 – 6.6 cm – WB	GREG	AMCO			
SB	SEPL	WILL			
6.6 – 6.8 cm – SB	DOWITCHER				
6.8 – 7.0 cm – WF	WODU	BWTE	NSHO		
WB	LBHE	LAGU	BLTE	FOTE	BLSK
SB	BNST	AMAV			
7.0 – 7.2 cm – WF	MALL	RUDU			
WB	BRPE	WHIB	WOST	SATE	
7.2 – 7.4 cm – WB	SNEG	WFIB	LETE	CATE	ROYT
> 7.4 cm – WB	AWPE				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with water depths in this range.

Waterbird assemblages (Figure 2.26) by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.28 Waterbird assemblages by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Water Depth	**American Ornithological Union Species Alpha Codes**[a]				
< 4.5 cm	[b]				
4.5 – 5.0 cm	[b]				
5.0 – 5.5 cm –Wading bird (WB)	BRPE	BLSK			
Shorebird (SB)	KILL	RUTU	SAND	WESA	LESA
5.5 – 6.0 cm – WB	AWPE	CAEG	WFIB		
SB	BBPL	SEPL	WILL	PESA	DOWITCHER
6.0 – 6.5 cm – Waterfowl (WF)	WODU				
WB	GREG	SNEG	ROSP	LBHE	
SB	BNST	GRYE			
6.5 – 7.0 cm – WF	CANG	MALL			
SB	AMAV				
7.0 – 7.5 cm – WF	BWTE	NSHO			
WB	WHIB				
> 7.5 cm – WB	PBGR				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with water depths in this range.

Waterbird assemblages (Figure 2.27) by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.29 Waterbird assemblages by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Water Depth	**American Ornithological Union Species Alpha Codes**[a]							
< 5.4 cm	CAEG	AMCO						
5.4 – 5.6 cm – Shorebird (SB)	KILL							
5.6 – 5.8 cm – Wading bird (WB)	GBHE							
5.8 – 6.0 cm	[b]							
6.0 – 6.2 cm – Waterfowl (WF)	CANG							
WB	PBGR							
SB	LESA							
6.2 – 6.4 cm – WB	GREG							
SB	GRYE	LEYE	SESA					
6.4 – 6.6 cm – WF	WODU	MALL						
WB	CAEG							
SB	BNST	WESA	STSA					
6.6 – 6.8 cm – WF	BWTE							
WB	WHIB	AMCO	BLTE	LETE				
SB	SEPL	DOWITCHER						
> 6.8 cm – WF	NSHO							
WB	AWPE	BRPE	SNEG	WFIB	LAGU	CATE	ROYT	SATE
SB	BBPL	SAND						

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with water depths in this range.

Waterbird assemblages (Figure 2.28) by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.30 Waterbird assemblages by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Water Depth	**American Ornithological Union Species Alpha Codes** [a]					
< 5.5 cm – Wading bird (WB)	CAEG	AMCO				
5.5 – 6.0 cm – Waterfowl (WF)	NSHO					
Shorebird (SB)	LESA					
6.0 – 6.5 cm – WF	MALL	RUDU				
WB	PBGR	GBHE	GREG			
SB	PESA					
6.5 – 7.0 cm – WB	CATE	SATE				
SB	STSA					
7.0 – 7.5 cm – WF	WODU					
WB	BRPE	LAGU	ROYT			
SB	BBPL	BNST	LEYE	SAND	DOWITCHER	
7.5 – 8.0 cm – WF	BWTE					
WB	AWPE	SNEG	WOST	LETE	FOTE	BLSK
SB	SEPL	WILL	WESA			
> 8 cm – WB	WHIB	WFIB	BLTE			

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (Figure 2.29) by water depth (cm) in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.31 Waterbird assemblages by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]									
Open Water – < 5%	[b]									
5 – 10%	[b]									
10 – 15% – Waterfowl (WF)	CANG	BWTE								
Wading bird (WB)	PBGR	GREG	CAEG	WOST	BLTE	LETE				
Shorebird (SB)	KILL	BNST	LEYE	SESA	LESA	PESA	STSA			
15 – 20% –WF	WODU	NSHO	RUDU							
WB	AWPE	BRPE	GBHE	SNEG	WHIB	WFIB	AMCO	CATE	ROYT	BLSK
SB	AMAV	GRYE								
20 – 25% – WF	MALL									
WB	LBHE	ROSP	LAGU	SATE						
SB	SEPL	DOWITCHER								
25 – 30% – SB	WILL	WESA								
30 – 35% – SB	BBPL	SAND								
35 – 40%	[b]									
40 – 45%	[b]									
45 – 50%	RUTU									
> 50%	[b]									

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.30) by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.32 Waterbird assemblages by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]										
Cropland – < 20%	[b]										
20 – 25% – Shorebird (SB)	RUTU										
25 – 30%	[b]										
30 – 35%	[b]										
35 – 40% – SB	SAND										
40 – 45% – SB	BBPL	WILL	WESA								
45 – 50% – Wading bird (WB)	LBHE	LAGU	FOTE	ROSP							
SB	SEPL	DOWITCHER									
50 – 55% – Waterfowl (WF)	MALL	RUDU									
WB	AWPE	BRPE	SNEG	WHIB	WFIB	BLTE	LETE	CATE	ROYT	SATE	BLSK
SB	BNST	AMAV									
55 – 60% – WF	WODU	BWTE	NSHO								
WB	PBGR	GBHE	GREG	WOST	AMCO						
SB	KILL	GRYE	LEYE	SESA	PESA	STSA					
60 – 65% – WF	CANG										
WB	CAEG										
SB	LESA										
> 65%	[b]										

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.30) by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.33 Waterbird assemblages by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]									
Forested Wetland – < 4%	[b]									
4 – 6%	[b]									
6 – 8% – Shorebird (SB)	RUTU									
8 – 10%	[b]									
10 – 12%	[b]									
12 – 14% – Wading bird (WB)	AWPE	SNEG	WHIB	WFIB	LETE	CATE				
14 – 16% – Waterfowl (WF)	MALL									
WB	BRPE	LBHE	ROSP	WOST	LAGU	BLTE	FOTE	ROYT	SATE	BLSK
SB	BBPL	SEPL	BNST	AMAV	WILL	SAND	WESA	DOWITCHER		
16 – 18% – WF	RUDU									
18 – 20% – WF	WODU	BWTE	NSHO							
SB	GRYE	LEYE	STSA							
20 – 22% – WB	PBGR	GREG	AMCO							
SB	KILL	PESA								
> 22% – WF	CANG									
WB	GBHE	CAEG								
SB	SESA	LESA								

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.30) by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.34 Waterbird assemblages by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Dominant Land Cover Type	American Ornithological Union Species Alpha Codes[a]									
Emergent Wetland – 0% – Waterfowl (WF)	CANG									
Wading bird (WB)	GBHE	CAEG	AMCO							
Shorebird (SB)	SESA	LESA	PESA							
0 – 5% – WF	WODU	BWTE	NSHO							
WB	PBGR	GREG								
SB	GRYE	LEYE	STSA							
5 – 10% – WF	RUDU									
WB	ROSP									
SB	BBPL	WILL	SAND							
10 – 15% – WF	MALL									
WB	AWPE	BRPE	SNEG	LBHE	WHIB	WOST	LAGU	BLTE	LETE	FOTE
		CATE	ROYT	BLSK	SATE					
SB	SEPL	BNST	AMAV	DOWITCHER						
15 – 20% – WB	WFIB									
SB	RUTU									
20 – 25%	[b]									
25 – 30%	[b]									
> 30%	[b]									

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.30) by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.35 Waterbird assemblages by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Dominant Land Cover Type	American Ornithological Union Species Alpha Codes [a]				
Open Water – 0% – Wading bird (WB)	PBGR				
0 – 10% – Waterfowl (WF)	WODU	MALL	BWTE	NSHO	
WB	WHIB				
Shorebird (SB)	BNST	AMAV			
10 – 20% – WF	CANG				
WB	GREG				
SB	KILL	GRYE	LESA	PESA	
20 – 30% – WB	SNEG	LBHE	CAEG	WFIB	ROSP
30 – 40%	[b]				
40 – 50% – SB	DOWITCHER				
50 – 60% – WB	AWPE				
SB	SEPL				
60 – 70% – WB	BRPE	BLSK			
SB	BBPL	RUTU	SAND	WESA	
> 70% – SB	WILL				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.31) by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.36 Waterbird assemblages by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]				
Cropland – 0% – Shorebird (SB)	BBPL	WILL	RUTU	SAND	
0 – 10% – Wading bird (WB)	BRPE	BLSK			
SB	SEPL	WESA			
10 – 20% – WB	AWP				
SB	DOWITCHER				
20 – 30%	[b]				
30 – 40%	[b]				
40 – 50% – WB	SNEG	LBHE	CAEG	WFIB	ROSP
50 – 60% – WB	GREG				
SB	GRYE	LESA	PESA		
> 60% – Waterfowl (WF)	CANG	WODU	MALL	BWTE	NSHO
WB	PBGR				
SB	KILL				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.31) by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.37 Waterbird assemblages by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Dominant Land Cover Type	American Ornithological Union Species Alpha Codes[a]				
Forested Wetland – 0% – Wading bird (WB)	BLSK				
Shorebird (SB)	BBPL	WILL	RUTU	SAND	
0 – 5% – WB	BRPE	AWPE			
SB	SEPL	WESA			
5 – 10% – SB	DOWITCHER				
10 – 15% – WB	LBHE				
15 – 20% – Waterfowl (WF)	CANG	WODU	MALL		
WB	GREG	SNEG	CAEG	WFIB	ROSP
SB	KILL	AMAV	GRYE		
20 – 25% – WF	BWTE				
SB	BNST	LESA	PESA		
25 – 30% – WF	NSHO				
30 – 35% – WB	PBGR	WHIB			
> 35%	[b]				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.31) by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.38 Waterbird assemblages by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]			
Emergent Wetland – 0% – Waterfowl (WF)	NSHO			
Wading bird (WB)	PBGR	WHIB		
0 – 5% – WF	CANG	WODU	MALL	BWTE
WB	GREG			
Shorebird (SB)	KILL	BNST	LESA	PESA
5 – 10% – WB	SNEG	CAEG	WFIB	ROSP
SB	GRYE	AMAV		
10 – 15% – WB	LBHE			
15 – 20% – WB	AWPE			
SB	DOWITCHER			
20 – 25% – WB	BRPE	BLSK		
SB	SEPL	WESA		
25 – 30% – SB	BBPL	WILL		
30 – 35%	[b]			
> 35%	[b]			

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.31) by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.39 Waterbird assemblages by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Dominant Land Cover Type	American Ornithological Union Species Alpha Codes [a]								
Open Water – < 14.0%	[b]								
14 – 15% – Shorebird (SB)	KILL								
15 – 16% – Waterfowl (WF)	CANG								
Wading bird (WB)	GBHE								
SB	LESA								
16 – 17% – WB	PBGR	GREG							
SB	SESA								
17 – 18% –WF	WODU								
WB	CAEG								
SB	GRYE	LEYE	STSA						
18 – 19% –WF	MALL	BWTE							
WB	AMCO	BLTE	LETE						
SB	SEPL	BNST	WESA						
19 – 20% –WF	NSHO								
WB	AWPE	BRPE	SNEG	WHIB	WFIB	LAGU	CATE	ROYT	SATE
SB	BBPL	SAND							
> 20%	[b]								

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.32) by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.40 Waterbird assemblages by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Dominant Land Cover Type	American Ornithological Union Species Alpha Codes[a]							
Cropland – < 51% – Waterfowl (WF)	NSHO							
Wading bird (WB)	AWPE	BRPE	SNEG	WFIB	LAGU	CATE	ROYT	SATE
Shorebird (SB)	BBPL	SAND						
51 – 52% – WB	WHIB	LETE						
SB	SEPL	DOWITCHER						
52 – 54% – WF	MALL	BWTE						
WB	AMCO	BLTE						
SB	BNST	WESA	STSA					
54 – 56% – WF	WODU							
WB	PBGR	GREG	CAEG					
SB	GRYE	LEYE	SESA					
56 – 58% – WF	CANG							
WB	GBHE							
SB	LESA							
58 – 59% – SB	KILL							
> 59%	[b]							

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.32) by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.41 Waterbird assemblages by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]					
Forested Wetland – < 16% – Wading bird (WB)	AWPE	BRPE	WFIB	CATE	ROYT	SATE
16 – 18% – Waterfowl (WF)	NSHO					
WB	SNEG	WHIB	LAGU	LETE		
Shorebird (SB)	BBPL	SEPL	SAND	DOWITCHER		
18 – 20% – WF	WODU	BWTE	MALL			
WB	AMCO	BLTE				
SB	BNST					
20 – 22% – WF	CANG					
WB	GREG	CAEG				
SB	KILL	GRYE	WESA	STSA		
> 22% – WB	PBGR	GBHE				
SB	LEYE	SESA	LESA			

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (Figure 2.32) by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.42 Waterbird assemblages by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]						
Emergent Wetland – 0% – Waterfowl (WF)	CANG	WODU					
Wading bird (WB)	CAEG						
Shorebird (SB)	LEYE	SESA					
0 – 4% – WF	MALL	BWTE					
WB	PBGR	GBHE	GREG	AMCO			
SB	KILL	GRYE	LESA				
4 – 8% – SB	BNST	WESA	STSA				
8 – 12% – WF	NSHO						
WB	BRPE	SNEG	WHIB	LAGU	BLTE	LETE	ROYT
SB	BBPL	SEPL	SAND	DOWITCHER			
> 12% – WB	AWPE	SFIB	CATE	SATE			

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

Waterbird assemblages (Figure 2.32) by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2012. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.43 Waterbird assemblages by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]						
Open Water – 0%	[b]						
0 – 5%							
5 – 10% – Waterfowl (WF)	CANG						
Wading bird (WB)	SNEG	WHIB	WFIB	WOST	BLTE	BLSK	
Shorebird (SB)	BNST	LEYE	LESA	PESA	STSA		
10 – 15% – WF	BWTE						
WB	AWPE	GBHE	LETE				
SB	SEPL	WILL	WESA				
15 – 20% –WF	WODU	RUDU					
WB	BRPE	GREG	AMCO	LAGU	FOTE	CATE	ROYT
SB	BBPL	KILL	SAND	DOWITCHER			
20 – 25% –WF	MALL	NSHO					
WB	PBGR	CAEG	SATE				
25 – 30% –WF	[b]						
> 30%	[b]						

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.33) by open water land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.44 Waterbird assemblages by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes**[a]				
Cropland – < 50% – Wading bird (WB)	SATE				
50 – 55% – Waterfowl (WF)	WODU	MALL	NSHO	RUDU	
WB	PBGR	BRPE	GREG	CAEG	
Shorebird (SB)	BBPL	KILL	SAND	DOWITCHER	
55 – 60% – WF	BWTE				
WB	AWPE	GBHE	AMCO	BLTE	LETE
SB	SEPL	WILL	WESA		
60 – 65% – WF	CANG				
WB	WHIB	WFIB	WOST	BLSK	
65 – 70% – WB	SNEG				
SB	BNST	LEYE	LESA	PESA	STSA
70 – 75%	[b]				
75 – 80%	[b]				
> 80%	[b]				

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.33) by cropland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.45 Waterbird assemblages by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]								
Forested Wetland – < 12% – Waterfowl (WF)	BWTE								
Wading bird (WB)	BRPE	LAGU	FOTE						
Shorebird (SB)	SEPL								
12 – 14% – WF	MALL	NSHO							
WB	AWPE	SNEG	WHIB	WFIB	BLTE	CATE	ROYT	SATE	BLSK
SB	BBPL	WILL	SAND	WESA	DOWITCHER				
14 – 16% – WF	WODU	RUDU							
WB	PBGR	WOST	AMCO	LETE					
SB	BNST								
16 – 18% – SB	LEYE	STSA							
18 – 20% – WF	CANG								
WB	CAEG								
SB	LESA	PESA							
20 – 22% – WB	GBHE	GREG							
22 – 24%	[b]								
> 24 – SB	KILL								

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.33) by forested wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

Table B.46 Waterbird assemblages by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013.

Dominant Land Cover Type	**American Ornithological Union Species Alpha Codes** [a]								
Emergent Wetland – 0%	[b]								
0 – 4% – Waterfowl (WF)	CANG								
Wading bird (WB)	GBHE	GREG	CAEG						
Shorebird (SB)	KILL	LESA							
4 – 8% – WB	AMCO								
SB	PESA	STSA							
8 – 12% – WF	MALL	NSHO	RUDU						
WB	PBGR	SATE							
SB	BNST	LEYE							
12 – 16% – WF	WODU								
WB	BRPE	WHIB	WFIB	WOST	LAGU	LETE	FOTE	CATE	ROYT
SB	BBPL	WILL	SAND	WESA	DOWITCHER				
> 16% – WF	BWTE								
WB	AWPE	BLTE	BLSK						
SB	SEPL								

[a] American Ornithological Union (AOU) species alpha codes defined in APPENDIX B, Table B.2.

[b] No waterbird species associated with percent cover type in this range.

Waterbird assemblages (Figure 2.33) by emergent wetland land cover type in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2013. Species alpha codes represent those species within non-metric multidimensional scaling ordination space.

APPENDIX C

SHOREBIRD SIZE GUILDS

Table C.1 Small sized (x ≤ 50 g) shorebird species and total abundance during August – October 2011 – 2013.

Family	**Genus**	**Species**	**Common Name**	**Total Abundance**			**Species Totals**
				2011	**2012**	**2013**	
Charadriidae	*Charadrius*	*nivosus*	Snowy Plover	1	28	12	41
		semipalmatus	Semipalmated Plover	154	417	270	841
Scolopacidae	*Tringa*	*solitaria*	Solitary Sandpiper	1	53	3	57
	Actitis	*macularius*	Spotted Sandpiper	25	22	76	123
	Calidris	*pusilla*	Semipalmated Sandpiper	1,431	450	158	2,039
		mauri	Western Sandpiper	260	570	658	1,488
		minutilla	Least Sandpiper	7,337	4,688	6,723	18,748
		bairdii	Baird's Sandpiper	[a]	6		6
		fuscicollis	White-rumped Sandpiper	1			1
Grand Total				9,210	6,234	7,900	23,344

[a] Blanks denote a specie(s) not observed during that year.

Small sized (x ≤ 50 g) shorebird species and total abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table C.2 Medium sized (50 < x ≤ 100 g) shorebird species and total abundance during August – October 2011 – 2013.

Family	Genus	Species	Common Name	Total Abundance 2011	2012	2013	Species Totals
Charadriidae	*Charadrius*	*wilsonia*	Wilson's Plover	14	60	25	99
		melodus	Piping Plover	9	61	59	129
		vociferus	Killdeer	1,918	2,155	967	5,040
Scolopacidae	*Tringa*	*flavipes*	Lesser Yellowlegs	203	1,089	753	2,045
	Calidris	*alba*	Sanderling	688	889	518	2,095
		melanotos	Pectoral Sandpiper	1,428	1,471	356	3,255
		alpina	Dunlin	41	78	2	121
		himantopus	Stilt Sandpiper	57	915	461	1,433
	Tryngites	*subruficollis*	Buff-breasted Sandpiper	5	22		27
	Phalaropus	*tricolor*	Wilson's Phalarope	1	1	2	4
Grand Total				4,364	6,741	3,143	14,248

Medium sized (50 < x ≤ 100 g) shorebird species and total abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

Table C.3 Large sized (x >100 g) shorebird species and total abundance during August – October 2011 – 2013.

Family	**Genus**	**Species**	**Common Name**	**Total Abundance**			**Species Totals**
				2011	**2012**	**2013**	
Charadriidae	*Pluvialis*	*squatarola*	Black-bellied Plover	125	296	138	559
		dominica	American Golden Plover	8	4	1	13
Haematopodidae	*Haematopus*	*palliatus*	American Oystercatcher	45	50	56	151
Recurvirostridae	*Himantopus*	*mexicanus*	Black-necked Stilt	1,315	1,422	2,111	4,848
	Recurvirostra	*americana*	American Avocet	293	778	73	1,144
Scolopacidae	*Tringa*	*melanoleuca*	Greater Yellowlegs	334	250	77	661
		semipalmata	Willet	175	364	144	683
	Numenius	*phaeopus*	Whimbrel	[a]	10	1	11
		macularius	Long-billed Curlew		1		1
	Limosa	*fedoa*	Marbled Godwit	11	16	2	29
	Arenaria	*interpres*	Ruddy Turnstone	86	146	102	334
	Calidris	*canutus*	Red Knot	21	71	13	105
	Limnodromus	*Spp.*	Dowitcher spp.	333	615	479	1,427
	Gallinago	*delicata*	Wilson’s Snipe			1	1
Grand Total				2,746	4,023	3,198	9,967

[a] Blanks denote a specie(s) not observed during that year.

Large sized (x > 100 g) shorebird species and total abundance in the Mississippi Alluvial Valley and northern Gulf of Mexico during August – October 2011 – 2013.

APPENDIX D

STUDY SITES

Table D.1 Survey sites by region, state with their associated abbreviated names used within text, tables and figures throughout the document.

Region	Color	State	Color	Site	Abbreviation	Color
Mississippi Alluvial Valley	Light green	Missouri	Blue	Duck Creek Conservation Area (CA)	DC_CA	Periwinkle
				Otter Slough CA	OS_CA	Blue
				Ten Mile Pond CA	TMP_CA	Light blue
		Mississippi Delta	Orange	North Mississippi National Wildlife Refuge (NWR) Complex, Coldwater River NWR	CR_NWR	Orange
				Theodore Roosevelt NWR Complex Yazoo NWR	Y_NWR	Tangerine
		Migratory Bird Habitat Initiative[a]	Red	Bear Creek Fisheries	B_C_F	Light pink
				Nerren Fisheries	N_F	Red
				Janous Properties	J_P	Red-orange
				Thompson Fisheries	T_F	Maroon
				Phillips Brother's Farm	P_B_F	Dark red
		Southwest Mississippi	Purple	St. Catherine Creek NWR	SCC_NWR	Purple
				Cloverdale tract	SCC_C	[b]
				Sibley Farms moist-soil units	SCC_S	[b]
Northern Gulf of Mexico	Light blue	Alabama	Pink	Dauphin Island	D_I	Pink
		Mississippi	Light green	Grand Bay NWR and National Estuarine Research Reserve	GB_NERR	Light green
				Grande Batture Islands	GB_GB	[b]
				Salt Pannes	GB_SP	[b]
		Louisiana	Yellow	Elmer's Island Wildlife Refuge	EI_WR	Yellow

[a] Migratory Bird Habitat Initiative (MBHI).

[b] Sites only referenced in text or tables.

Regions, states, and site; associated abbreviated names; and colors used within text, tables and figures throughout the document, unless otherwise stated in figure.

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