Winter waterbird use and food resources of aquaculture lands in Mississippi

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The conversion of wetland systems to aquaculture provides alternate aquatic habitats for a variety of waterbirds. In response to the 2010 British Petroleum oil spill, the National Resource Conservation Service (NRCS) enacted the Migratory Bird Habitat Initiative (MBHI) through which NRCS partnered with landowners to provide additional wetlands and associated foraging habitat for migrating waterbirds. During winters 2011–2013, I estimated abundances of waterbirds, seeds, and invertebrates in six production and idled aquaculture facilities in the Mississippi Alluvial Valley. Wintering waterbirds exhibited similar densities on production (i.e., ~22 birds/ha) and idled (i.e., ~20 birds/ha) MBHI sites. My results suggest production and idled MBHI aquaculture impoundments produced suitable conditions for waterbirds in terms of food and habitat. I recommend future programs strive to enroll properties that promote an increased diversity of habitats in terms of vegetation structure, available forage, and varying water depth, with the aim of maximizing waterbird diversity.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

WINTER WATERBIRD USE OF AQUACULTURE LANDS IN MISSISSIPPI

The conversion of hardwood bottomlands and other wetlands to aquaculture ponds in the Mississippi Alluvial Valley (MAV), has provided alternate habitat, especially in Mississippi, for numerous waterbirds, including northern shoveler (*Anas clypeata*), lesser scaup (*Aythya affinis*), ruddy duck (*Oxyura jamaicensis*), Canada goose (*Branta canadensis maxima*), American coot (*Fulica americana*), great blue heron (*Ardea herodias*), American white pelicans (*Pelecanus erythrorhynchos*), double-crested cormorant (*Phalacrocorax auritus*), and other waterbirds (Christopher 1985, Dubovsky 1987, Dubovsky and Kaminski 1992, Fleury and Sherry 1995, Huner and Musumeche 1999, Sebastián-González et al. 2010, Strickley 1992, Zhijun et al. 2004). Aquaculture ponds also provide predictable habitats in terms of water permanency and food resources (Fleury and Sherry 1995, Zhijun et al. 2010). Finally, aquaculture ponds may partially mitigate adverse influences of loss and degradation of natural wetlands (Zhijun et al. 2010, Elliott and McKnight 2000, Hunter et al. 2006, Twedt et al. 1998).

The MAV is an >800 km long floodplain ranging from 32-128 km wide and comprising approximately 10 million ha in 7 states (Reinecke et al. 1989). It is a major wintering area for waterbirds in North America (Bellrose 1976, Hunter et al. 2006, Reinecke et al. 1989). Government agencies and non-governmental organizations, including the Natural Resource Conservation Service (NRCS), Ducks Unlimited, Inc., the

North American Waterfowl Management Plan (NAWMP), Lower Mississippi Valley Joint Venture, and other partners have documented the ecological importance of the MAV in the annual cycle of migratory birds (Canadian Wildlife Service and U.S. Fish and Wildlife Service 1986, Ducks Unlimited, Inc. 2005, Faulkner et al. 2011, King et al. 2006, Loesch et al. 2000). Further, the MAV harbors 86% of all the commercial catfish (*Ictalurus punctatus*) production in Mississippi (Wellborn et al. 1986, USDA 2010). Between 1977 and 1986, catfish producing lands increased from 7,000 ha to >40,000 ha (Wellborn 1983, Wellborn et al. 1986). Agricultural producers, biologists, and waterfowl hunters are acquainted with use of aquaculture ponds by wintering waterbirds. Furthermore, aquaculture ponds may provide important alternate waterbird habitat during dry winters (Reinecke et al. 1989). Christopher (1985) estimated 50,000 - 80,000 waterfowl used catfish ponds weekly during winter 1985-1986 in the MAV. Dubovsky (1987) and Dubovsky and Kaminski (1992) conducted subsequent surveys and estimated 150,000 birds used catfish ponds, with an average of 100,000 individuals using the ponds weekly. Although these studies provided reliable estimates of waterbird use of aquaculture ponds, no studies have been conducted to update this information since the 1980s. During 1998 – 2005, Mississippi catfish production area decreased 24% from 34,264 ha to 25,910 ha and has continued to decline because of rising operating costs (e.g., fuel, fish forage), competition from foreign markets, and economic adversity (Wellborn et al. 1986, USDA 2010). In addition, previous studies only addressed waterfowl and not other waterbird guilds.

In response to the 2010 British Petroleum oil spill (Peterson et al. 2012), NRCS enacted the Migratory Bird Habitat Initiative (MBHI) and partnered with private landowners and managers in 8 states (Alabama, Arkansas, Florida, Georgia, Louisiana, Mississippi, Missouri, and Texas) through the Wetlands Reserve Program (WRP), Environmental Quality Incentives Program (EQIP), and Wildlife Habitat Incentive Program (WHIP) to provide wetlands for migrating waterfowl, shorebirds, and other waterbirds inland and away from coastal wetlands where the impact of the Deep Water Horizon oil spill occurred. Lands eligible for MBHI included lowland farmlands and aquaculture ponds, which provided mudflats and shallow water (≤30 cm) important to a diversity of waterbirds. In total, NRCS distributed approximately $40 million and enrolled >190,000 ha among eight states (NRCS 2012).

In addition to easements, NRCS sponsored research to evaluate MBHI relative to waterbird abundance and diversity and potential food availability (NRCS 2012). Waterbird use of various types of aquaculture have been studied worldwide including, shrimp (*Penaeus* spp.) in northwest Ecuador (Cheek 2009), rainbow trout (*Oncorhynchus mykiss)* in southern Patagonia (Lancelotti el al. 2009, Lancelotti et al. 2010), blue mussel (*Mytilus edulis*) in southwest Ireland (Roycroft et al. 2004, Roycroft et al. 2007) and England (Caldow et al. 2003), and fish aquaculture in Europe (Lekuona 2002, Steffens 2010). However, few studies have examined waterbird use of aquaculture ponds in the United States, especially in the MAV (cf. Christopher et al. 1985, Dubovsky and Kaminski 1992, Weller 1988). Most of the existing body of knowledge on bird use of aquaculture sites is related to fish depredation by double-crested cormorants (Stickley et al. 1992; Glahn and Brugger 1995; Dorr et al. 2008), American white pelicans (*Pelecanus erythrorhynchos*; King and Werner 2001), herons (Glahn et al. 2002, Taylor et al. 2010), ducks (Wooten and Werner 2004, Kirk 2007), egrets (Werner et al. 2001), black-crowned night herons (Taylor et al 2010) and ospreys (Bechard and Márquez-Reyes 2003). The remaining body of knowledge on bird use of aquaculture sites relates to disease transfer (Overstreet and Curran 2004, Doffitt et al. 2009), lethal control of depredating species (Blackwell et al. 2000, Belant et al. 2000), and deterrents of wading birds (Reinhold and 1997, Nemtzov and Olsvig-Whittaker 2003).

To complement previous studies, my objectives were to assess waterbird community composition, abundance, and species richness in production aquaculture ponds and retired sites now managed as alternate wetlands (hereafter idled sites). I examined composition of avian communities in production sites relative to surrounding land use types. I also compared my data on waterfowl use of production aquaculture ponds with previous studies by Christopher (1985, 1988), Dubovsky (1987), and Dubovsky and Kaminski (1992) to identify any trends and changes in use over time. I hypothesized: (1) waterbird abundance and diversity would differ among production and idled sites, (2) waterbird densities in production sites are influenced by surrounding land use types, and (3) waterbird use of aquaculture sites in the MAV has changed since the time of previous studies.

Study Area

My study area encompassed the northwest region of Mississippi and was comprised of flat alluvial soils bordered by the Mississippi River on the west and the Yazoo River on the east. I surveyed waterbirds at 10 aquaculture locations in this region, including sites in Humphreys, Holmes, Leflore, Sunflower, Washington, and Yazoo counties, Mississippi (Fig 1.1). I initiated fieldwork in November 2011 and had 6 production and 4 idled aquaculture sites (e.g., moist soil units or cropland). Each site ranged from 20-850 ha ($\bar{x}$ = 80 ha) and contained 13 to 101 ponds. Each pond within a site averaged 8 ha. Most aquaculture ponds were ≤ 1 m deep and bordered by man-made levees with slopes of 2.5:1(Christopher 1985, Dubovsky 1987).

Methods

Waterbird Abundance

I conducted ground surveys of waterbirds on all ponds within each site from November to March 2011-2013. I visited each site 3 times monthly to conduct diurnal scan surveys that I randomly selected within one of the following periods: 0600-1000 (early morning), 1000-1400 (mid-day), 1400-1800 (late afternoon), and during alternate times within periods among sites in subsequent visits, so I would not survey each pond at the same time during each survey (Christopher 1985, Hagy 2010, Heitmeyer 2006). I enumerated all detected birds by species, within the levees of the impoundment to the center of each impoundment. I assumed nearly all birds present within each impoundment were detected given my elevated vantage point from a vehicle on the levees. Since these levee roads were used often by workers, birds normally did not flush when the vehicle approached. I did not survey during inclement weather conditions characterized by heavy rain, wind >30 kpm, or low visibility (i.e., fog).

Statistical Analyses

I standardized waterbird data by averaging relative abundances among surveys within the same 7-day calendar period of each sampling year because timing of bird surveys varied among months and years due to unforeseen flooding and weather constraints (Hagy and Kaminski 2012). I used ArcMap10 to estimate total area flooded within each pond which enabled me to calculate densities of waterbirds (waterbirds/wet ha; hereafter waterbirds/ha), as well as waterbird species richness (mean species richness/ha) as dependent variables for analyses. Additionally, I used ArcMap10, paired with ground-level observations to classify and calculate area of land use types (e.g., soybean, milo, cotton, fallow, rice, aquaculture, bottomland hardwoods, and other water bodies) within a 1.6 km buffer surrounding each of my production sites for later comparisons to waterbird use (Dubovsky 1987).

I used non-metric multidimensional scaling (NMDS) to ordinate waterbird densities per site of species with ≥2% occurrence relative to site type (production vs. idled). To reduce variation and zero values, I combined data from several waterbird species (e.g., sandpipers, *Calidris spp*.; dowitchers, *Limnodromus spp*.; ibises, *Plegadis spp*.; and scaup, *Aythya spp*.), which were either difficult to discern or rarely detected (Table 1.2). Use of NMDS has been used successfully to characterize plant and animal community composition in various types of environments, including wetlands (Dungey et al. 2000, Foster & Tilman 2000, Bailey & Whitham 2002, Li et al. 2011). This analysis considers abundance and species richness, arranging samples in ordination space based on a dissimilarity matrix created using the Bray–Curtis distance measure (Faith et al. 1987). I applied a Monte Carlo randomization test with 999 runs (Choi et al. 2009) and used a permutation multivariate analysis of variance (PNMANOVA) to test for differences in waterbird community composition between idled and production sites (Anderson 2001). This technique is an alternative to sums-of-squares based analysis of variance (ANOVA) that compares groups with distance measures, without requiring any assumptions about distributions. I then used the SIMPER procedure to describe percentage contribution of each species to overall dissimilarity and discerned dominant species in idled and production ponds (Clarke 1993).

I also used canonical correspondence analysis (CCA) to ordinate densities of three waterbird guilds (i.e., diver, surface, and wader/shoreline [hereafter wader] feeders/ha/site; Paszkowski and Tonn 2006; Table 1.1) relative to area of the following land use types within a 1.6 km radius of each site: (1) aquaculture, (2) other water bodies, (3) cotton fields, (4) woody wetland/bottomland hardwoods, (5) fallow/idled land, (6) milo fields, (7) rice fields, and (8) soybean fields (Dubovsky (1987). In a similar manner to principal component analysis, it displays data in two-dimensional form. I ordinated each winter separately because land uses differed between winters 2011-2012 and 2012-2013. These included: (1) production ponds being idled and vice versa, (2) changes in total site area surveyed, and (3) changes in surrounding land uses. I used the statistical software PAST^{TM} for all ordinations and associated tests (Hammer et al. 2001).

I used repeated measures ANOVA to compare waterbird densities standardized by site between production and idled sites using PROCMIXED (SAS Institute 2008). I designated pond types (e.g. production and idled) as fixed effects, year and site as random effects, and week as repeated measure. I natural log transformed all waterbird density and species richness data to achieve normality and homogenous variances (Kamamura 1999, Conquest 2000). To avoid loss of biologically relevant information, I designated $\alpha = 0.10$ due to the small number of survey sites (6 production and 4 idled sites) and survey periods (Tacha et al. 1982). When differences were significant, I performed all pair-wise comparisons of least-squared means using two-tailed t-test (Wiseman 2009). I then back-transformed dependent variables and reported means and

90% confidence limits. Lastly, I used a Wilcoxon signed rank test to compare Christopher (1985) and Dubovsky (1987) ranked waterfowl densities with my waterfowl density data. Christopher (1985) and Dubovsky (1987) expressed waterfowl density data on two production sites; however, I could only locate a site to match one of their sites with similar characteristics (i.e. size, proximity to former location, type of production, etc.).

Results

Waterbird Habitat Associations

For production and idled catfish ponds, I observed 20 species of waterfowl and 18 species of other waterbirds (i.e., wading birds, shorebirds, and grebes; Table 1.2). In production sites, the most frequently observed waterbirds during 156 surveys were great blue heron (99%), ruddy duck (98%), scaup (96%; *Aythya affinis* and *marila* combined), and northern shoveler (95%). The northern shoveler (n = 378,765) was the most abundant species, comprising 44% of total waterbird abundance. Other waterfowl species and all other waterbirds comprised 46% and 10% of total waterbird abundance, respectively (Table 1.2). For idled ponds, the most frequently observed waterbirds were mallard (83%, n = 95 surveys; *A. platyrhynchos*), northern shoveler (77%), American coot (74), and gadwall (68%; *A. strepera*). The most abundant species in idled ponds was mallard (n = 43,968), which comprised 28% of all waterbird abundance. Other waterfowl species comprised 58%, whereas other waterbirds comprised 14% of total waterbird abundance (Table 1.2).

Ordination results revealed substantial separation of waterbird communities by pond type with Axes 1 and 2 explaining 49% and 15% of the variation in waterbird densities, respectively (Fig. 1.2). Axes 1 and 2 of the NMDS plot represented idled and production ponds, respectively. Dabbling ducks tended to cluster with species typically using emergent and forested wetlands and occurred toward the bottom of figure (i.e., mallard, northern pintail [*Anas acuta*] and American green-winged teal [*A. crecca*]); whereas, species that typically use open water areas aggregated toward the top (i.e., double crested cormorant, sandpipers [*Calidris spp*.]; Fig. 1.2). The PNMANOVA test revealed a significant difference among waterbird communities between production and idled sites ($F_{2,6} = 11.67$, $P = 0.005$). The SIMPER procedure indicated mallard (23%), ruddy duck (16%), northern shoveler (14%), gadwall (11%), and American green-winged teal (10%) were associated dissimilarly between production and idled ponds (Table 1.3).

Land use within the 1.6-km buffer around sites and waterbird guild density were associated as indicated by the pattern of the first CCA axis, with 94% and 90% of the variation in waterbird guild density explained for winters 2011-2012 and 2012-2013, respectively (Fig. 1.3 and 1.4). In both winters, the first axis separated land use into aquatic related land use types (i.e. aquaculture, rice, open water, flooded fallow fields, and flooded bottomland hardwoods) on the right and upland related land use types (i.e. soybeans, cotton, and milo fields) on the left (Figs. 1.3 and 1.4). The only deviation from this pattern was cotton fields in winter 2011-2012, which indicates these fields had inconsistent influence on waterbird densities and may not be a strong indicator of potential waterbird use (Fig. 1.3). During both winters, wader and diver feeders were more associated with aquatic land types present in the surrounding landscape (Figs. 1.3 and 1.4). However, during this same time-period, surface feeders were more associated with cropland and other upland land uses in the surrounding landscape (Figs. 1.3 and

1.4). In fact, I found the greatest densities (~16 birds/ha) of surface feeders on sites adjoined by milo and soybean fields (Fig 1.3 and 1.4).

Waterbird Richness

The interaction of survey week and pond type (i.e. production vs. idled ponds) explained variation in mean waterbird species richness for winters 2011-2012 and 2012-2013, combined ($F_{12, 204} = 2.75$, $P = 0.002$; Fig. 1.5). During early November, species richness in idled sites ($\bar{x} = 0.88$ species richness/wet ha; 90% CI = 0.48-1.10) was over twice that of production sites ($\bar{x} = 0.40$ species richness/wet ha; 90% CI = 0.23-0.57; $t_{204} = -2.72$, $P = 0.007$; Fig. 1.5). Mean species richness in production sites progressively increased from early November ($\bar{x} = 0.40$ species richness/wet ha, 90% CI = 0.23-0.57) through late December ($\bar{x} = 0.68$ species richness/wet ha, 90% CI = 0.48-0.88; $t_{204} = -3.02$, $P = 0.003$; Fig. 1.5). However, mean species richness in idled sites declined during November, with late November ($\bar{x} = 0.34$ species richness/wet ha; 90% CI = 0.16-0.52) averaging 2.5 times less than early November ($\bar{x} = 0.88$ species richness/wet ha; 90% CI = 0.48-1.10; t204 = 3.58, $P < 0.001$; Fig. 1.5). During late November to mid-December, species richness in idled sites increased from 0.34 (90% CI = 0.16-0.52) to 0.65 (90% CI = 0.38-0.92; t204 = -2.59, P = 0.01) then increased again from 0.49 (90% CI = 0.28-0.70) to 0.82 (90% CI = 0.51-1.13; $t_{204} = -2.50$, $P = 0.013$) during mid-January to early February (Fig. 1.5). The last major change in mean species richness in idled sites occurred during early February ($\bar{x} = 0.82$ species richness/wet ha; 90% CI = 0.51-1.13) to late February ($\bar{x} = 0.56$ species richness/wet ha; 90% CI = 0.34-0.78; $t_{204} = 1.97$, $P = 0.05$; Fig. 1.5). During early March, mean species richness in idled sites ($\bar{x} = 0.89$ species richness/wet ha; 90% CI = 0.60-1.18) was significantly greater than production sites ($\bar{x}$ = 0.54 species richness/wet ha; 90% CI = 0.37-0.71; t_{204} = -2.1, P = 0.037; Fig. 1.5).

Mean waterbird species richness also varied in relation to interactive effects of survey week by winter of survey ($F_{12, 204}$ = 1.81, P = 0.048; Fig. 1.6). Throughout most surveys, mean species richness in winter 2011-2012 was less than winter 2012-2013 (Fig. 1.6). During early November (t_{204} = -2.78, P = 0.006), mid-November (t_{204} = -4.33, P = <0.001), late November (t_{204} = -3.78, P < 0.001), early December (t_{204} = -2.82, P = 0.005), late December (t_{204} =-1.81, P = 0.072), and early March (t_{204} = -2.92, P = 0.004), mean species richness in winter 2011-2012 was significantly less than winter 2012-2013 (Fig. 1.6).

Waterbird Density

I detected an interactive effect of survey week and pond type on mean waterbird densities for winters 2011-2012 and 2012-2013, combined ($F_{12, 204}$ = 2.19, P = 0.013; Fig. 1.7). Mean waterbird density during early November was 5 times greater in idled sites ($\bar{x}$ = 32.49 waterbirds/wet ha; 90% CI = 20.84-50.86) than production sites ($\bar{x}$ = 6.45 waterbirds/wet ha; 90% CI = 3.53-6.71; t_{204} = -2.79, P = 0.006; Fig. 1.7). Mean waterbird density in idled sites declined abruptly from early November ($\bar{x}$ = 6.18 waterbirds/wet ha; 90% CI = 4.08-9.44) to mid-November ($\bar{x}$ = 32.49 waterbirds/wet ha; 90% CI = 20.84-50.86; t_{204} = 3.81, P < 0.001; Fig. 1.7). After mid-November, mean waterbird densities in idled sites increased gradually from 6.18 (90% CI = 4.08-9.44) to 18.87 (CI = 10.82-23.75) in late December (Fig. 1.7). Meanwhile in production sites, mean waterbird densities steadily increased from early November ($\bar{x}$ = 6.45 waterbirds/wet ha; 90% CI =

3.53-6.71) to mid-December ($\bar{x}$ = 21.35 waterbirds/wet ha; 90% CI = 10.59-20.12; Fig. 1.7). During the remainder of both winters, mean waterbird densities in production and idled sites remained stable (Fig. 1.7).

Mean waterbird densities also varied in relation to the interaction of winter of survey and pond type ($F_{1, 204}$ = 6.36, P = 0.012; Fig 1.8). Mean waterbird density was similar for all comparisons between pond types and survey years except between idled sites in winter 2011-2012 ($\bar{x}$= 10.11 waterbirds/wet ha; 90% CI = 5.42-14.8) and winter 2012-2013 ($\bar{x}$ = 21.08 waterbirds/wet ha; 90% CI = 10.69-31.46; t_{204} = -4.93, P = <.0001, Fig. 1.8).

Winter of survey and survey week also interacted to explain variation in mean waterbird densities ($F_{12, 204}$ = 2.2, P = 0.013; Fig 1.9). Similar to richness, mean waterbird densities in winter 2011-2012 was less than winter 2012-2013 (Fig 1.9). Mean waterbird densities in winter 2011-2012 were significantly less than 2012-2013 for most surveys (early November t_{204} = -3.24, P = 0.001; mid-November t_{204} = -5.16, P = <.0001; late November t_{204} = -2.25, P = 0.026; and early December t_{204} = -1.77, P = 0.078; Fig. 1.9).

Historical and Contemporary Waterfowl Use

Overall, duck and American coot densities on Christopher's and Dubovsky's production ponds in winters 1984-1986 were less than production ponds on my production site winters 2011-2013 (Fig. 1.10). Wilcoxon signed rank test indicated waterfowl densities in winters 2011-2012 exceeded those of winters 1984-1985 (S_{12} = -38.5, P = 0.005) and 1985-1986 (S_{12} = -44.5, P < 0.001; Fig 1.10). Likewise, waterfowl densities in winter 2012-2013 were also greater than winters 1984-1985 (S_{12} = -44.5, P < 0.001) and 1985-1986 (S_{12} = -44.5, P < 0.001; Fig 1.10).

Discussion

Waterbird Habitat Associations

I observed different waterbird community compositions between production and idled sites throughout the study. The dominant species in production sites were those typically using open-water habitats averaging ~1 m, the depth of most active catfish ponds (e.g., lesser scaup, double crested cormorant, and ruddy duck), as well as generalist species (e.g., northern shoveler, American coot, great blue heron, and great egret), consistent with previous studies in the MAV (Christopher 1985, 1988; Dubovsky 1987, 1992). Additional studies of waterbirds in other lacustrine systems (e.g., shallow lakes, reservoirs, and gravel-pit wetlands) with comparable water depths reported similar wintering species composition to production aquaculture ponds (Severo et al. 2002, Santoul and Mastrorillo 2004, Epners et al. 2010). Idled sites were dominated by species associated with shallow (≤ 40 cm), emergent wetlands, such as mallard, northern pintail, gadwall, and American green-winged teal use of moist-soil wetlands in the MAV (Hagy and Kaminski 2012). Additionally, I consistently observed northern shoveler, American coot, lesser snow goose (*Chen caerulescens*), and greater white-fronted goose (*Anser albifrons*) use both pond types.

Waterbirds densities were greater in winters 2011-2012 (~30 waterbirds/ha) and 2012-2013 (~39 waterbirds/ha) on sites with increased land cover in aquaculture ponds, other permanent water bodies, and bottomland hardwoods in the surrounding landscape. Buler et al. (2013) similarly reported more waterbirds on MBHI sites in Arkansas with increased open water and forested wetlands in close proximity of managed sites. During both winters, wader and diver densities also were more associated with aquatic related land uses of the surrounding landscape (e.g., aquaculture ponds, other open water wetlands, flooded fallow fields, rice fields, and bottomland hardwoods). However, during the same time period, surface feeders associated more with uplands such as milo and soybean fields in the surrounding landscape. This finding differs from Wiseman (2009) who reported greater densities (2-3 times) of surface feeders other than mallards on moist soil and flooded fallow field wetlands than milo, soybean, and rice fields. However, the aforementioned study only reported results from 2 sites in Arkansas. Pearse et al. (2012) performed aerial surveys for ducks in the Mississippi portion of the MAV and reported greatest abundance of mallards and other dabbling ducks associated with wetland complexes composed predominately of flooded cropland, which was expected given that much of the MAV landscape is in agriculture. Thus, catfish ponds selected for future MBHI and other management should be associated with complexes of surrounding croplands, forested, moist-soil, and other wetlands to promote use of MBHI and other wetlands.

Waterbird Richness and Density

The interactive effects of both survey week and pond type and survey week and year influenced waterbird species richness and density. During most of November in both survey years, I detected a decrease in waterbird species richness and density among idled sites. At that time, I observed the greatest abundance of American green-winged teal, blue-winged teal, and various shorebirds, which are known early and mid-fall migrants in North America (Sykes and Hunter 1978, Twedt et al.1998, Elliott and McKnight 2000). Conversely, I observed increases in waterbird richness and density on production sites coinciding with large influxes of wintering species (e.g., northern shoveler, ruddy duck, American coot, double-crested cormorant, and lesser scaup). These species exhibited similar trends to results reported by Christopher (1985, 1988) and Dubovsky (1987, 1992), except for double crested cormorant which was not studied by these authors and was rare in occurrence during the 1980s. Once migrant species became established by mid-late December, waterbird communities remained relatively unchanged on production sites throughout the remainder of winter.

After the passing of early fall migrants, waterbird density and richness incrementally increased on idled sites. As mallard, gadwall, and northern pintail arrived, they increased numerically until early and mid-January. At this time, minimum daily temperatures in both years plummeted to near or below freezing, causing several idled ponds to freeze partially or completely. Additionally, in winter 2012-2013, flash floods inundated several idled study areas making them too deep for most species to use. Waterbirds searched for open areas (i.e., fringes of floodwaters) or dispersed presumably in search of available wetlands and resources. All idled ponds had thawed and water levels returned to normal levels by early February in both years. This allowed some waterbird species to return but in fewer numbers perhaps because mallards, northern pintails, and gadwall began migrating northward to follow the winter thaws. Spring migrants such as little blue heron (*Egretta caerulea*), blue-winged teal, and yellowlegs (*Tringa spp*) were observed during early March.

Differences in available surface water among idled sites likely contributed to differences in waterbird metrics during the first half of both winters. Previous studies have reported positive relationships between waterbird abundance and wetland area (Heitmeyer and Vohs 1984, Fleming 2010, Pearse et al. 2012, Buler et al. 2013). During winter 2011-2012, total amount of available surface water (~102 ha) was more than 50% less the amount winter 2012-2013 (~180 ha). During winter 2011-2012, most idled sites did not accumulate surface water until mid-December, although landowners and managers actively pumped since early-October or earlier.

In conclusion, both winter waterbird species richness and density differed between idled and production sites, as well as, among times of year. These wintering differences could be attributed to a number of factors including weather (Schummer et al. 2010, Almaraz et al. 2012), differences in food resources (Greer et al. 2009, Foster et al. 2010), hunting vulnerability (Dehorter and Tamisier 1998), availability of water (Heitmeyer 2006, Buler et al. 2013), water depth (Colwell and Taft 2000, Bolduc and Afton 2008), and etc. Nonetheless, due to the limited nature of this study, I was unable to neither collect this data nor test for these effects.

Historical and Contemporary Waterfowl Use

Overall, waterfowl density (ducks and coots/ha) during winters of 1984-1986 was lower than during my study period (winters 2011-2013). Differences in duck use of aquaculture ponds between the 1980s and current surveys may be related to a number of factors. For example, Mississippi catfish production area decreased 24% (34,264 ha to 25,910 ha) from 1998-2005 and at present, continues to decline (Wellborn et al. 1986, USDA 2010). This reduction in aquaculture associated wetlands may in turn concentrate birds on remaining habitat. Additionally, Christopher (1985, 1988) and Dubovsky (1987, 1992) indicated production aquaculture impoundments attracted few waterbird species ($n = 9$). However, in the span of these two studies, it is possible that additional waterbird species could have habituated to active aquaculture ponds and associated idled ponds with native emergent, submersed, and woody vegetation, which led to the nearly four-fold increase in waterbird species richness (*n* = 35) using these production aquaculture impoundments (Glahn et al. 2000, this study). Furthermore, current winter waterbird species richness in aquaculture ponds is similar numerically of wintering species richness in bottomland hardwood systems (*n* = 40), which historically dominated the MAV (Heitmeyer et al. 2005). This further suggests Christopher (1985, 1988) and Dubovsky (1987, 1992) may have experienced a temporary shift in species richness due to disturbances in the landscape (i.e. landscape changes from bottomland hardwoods to aquaculture ponds; Mestre 2013). Lastly and perhaps most profoundly, North American duck populations were much greater during my study than those of the mid-1980s (USFWS 2012). In spite of decreased area, remaining production and idled ponds provide wetlands habitats for migrating and wintering ducks and other waterbirds.

Management and Research Implications

In the aftermath of the Deep Water Horizon oil spill, the MBHI provided waterbird habitat by incentivizing flooding of agricultural and fallow fields in the MAV. Migrating and wintering waterfowl and other waterbirds exhibited similar densities on production (i.e., ~22 birds/ha) and idled (i.e., ~20 birds/ha) MBHI aquaculture impoundments. My results suggest production and idled aquaculture impoundments harbor different waterbird communities. When flooded, waders and diving and dabbling ducks dominated production impoundments, whereas idled impoundments were used by dabbling ducks, shorebirds, waders, and other waterbirds. While conditions provided by aquaculture and other agricultural resources are not a substitute for restoration and management of natural wetlands, my results suggest these environments may provide alternate migration and overwintering habitat for a diverse waterbird community.

I found the greatest waterbird densities on production sites which contained the greatest continuum of aquaculture ponds, other water bodies, and bottomland hardwoods in the surrounding landscape. Similar to Buler et al. (2013) and Pearse et al. (2012), my results suggest future programs should incorporate the surrounding landscape in the decision process to enroll properties in conservation easements. These landscapes should encompass a diversity of habitat types in terms of vegetation structure (e.g., open, emergent, and forested wetlands), available forage (e.g., moist soil and agricultural seeds), and varying water depth to maximize potential for attracting a diversity of waterbirds. Further research should be conducted to determine diet preferences of waterbirds, as well as proximate and ultimate factors (e.g., vegetation structure, available forage) that might help explain waterbird use of active and idle aquaculture impoundments in the MAV. Finally, as additional active aquaculture impoundments are converted to idled land, further monitoring of waterbird use of active and idled impoundments seems justified. This insight would be helpful in understanding how waterbirds will respond to changes in diversity of wetland types (i.e. habitat-specific survival) within the landscape. Understanding these circumstances is challenging but may become essential for future conservation efforts in critical wintering areas of waterbirds such as the MAV.

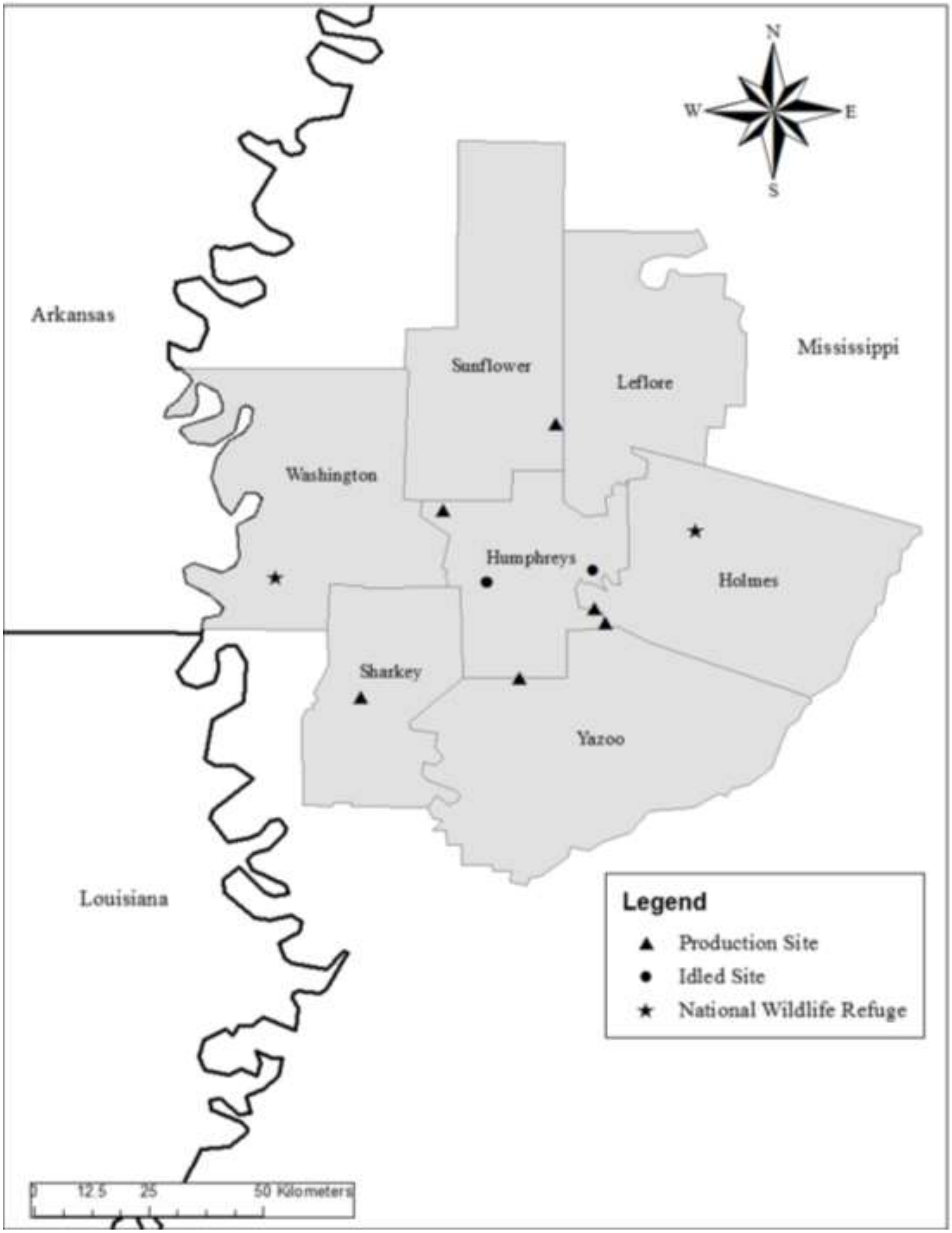

Figure 1.1 Study sites in the Mississippi Alluvial Valley surveyed during winters 2011-2012 and 2012-2013.

Table 1.1 Guilds of waterbirds using Migratory Bird Habitat Initiative production catfish ponds in Mississippi, November – March 2011-2013.

Guild	Common name	Scientific name
Surface Feeder	American coot	*Fulica americana*
	American green-winged teal	*A. crecca*
	American wigeon	*A. americana*
	Black-bellied Whistling-duck	*Dendrocygna autumnalis*
	Blue-winged teal	*A. discors*
	Canada goose	*Branta canadensis*
	Gadwall	*A.strepera*
	Lesser snow goose	*Chen caerulescens*
	Mallard	*A. platyrhynchos*
	Northern pintail	*Anas acuta*
	Northern shoveler	*A. clypeata*
	White-fronted goose	*Anser albifrons*
Diver Feeder	Bufflehead	*Bucephala albeola*
	Canvasback	*Aythya valisineria*
	Common Merganser	*Mergus merganser*
	Double-crested Cormorant	*Phalacrocorax auritus*
	Hooded Merganser	*Lophodytes cucullatus*
	Horned Grebe	*Podiceps auritus*
	Scaup	*Aythya spp.*
	Pied-billed grebe	*Podilymbus podiceps*
	Redhead	*Aythya americana*
	Ring-necked Duck	*Aythya collaris*
	Ruddy Duck	*Oxyura jamaicensis*
Wader/Shoreline Feeder	American White Pelican	*Pelecanus erythrorhynchos*
	Black-necked stilt	*Himantopus mexicanus*
	Dowitchers	*Limnodromus spp.*
	Great blue heron	*Ardea herodias*
	Great egret	*Ardea alba*
	Ibises	*Plegadis spp.*
	Killdeer	*Charadrius vociferus*
	Least Tern	*Sternula antillarum*
	Ring-billed gull	*Larus delawarensis*
	Sandpipers	*Calidris spp.*
	Wilson's Snipe	*Gallinago delicata*
	Yellowlegs	*Tringa spp.*

Table 1.2 Total detections (*n*) of waterbirds using Migratory Bird Habitat Initiative MBHI production and idled catfish ponds.

Common name	*n*	
	Production	Idled
Waterfowl		
White-fronted goose	8,886	6,362
Canada goose	4,466	79
Lesser snow goose	41,788	5,808
Wood duck		769
Northern pintail	[a]	7,509
American wigeon	32	818
Northern shoveler	378,765	18,257
American green-winged teal	1,258	17,721
Blue-winged teal	176	906
Mallard	728	43,968
Gadwall	10,302	25,908
Scaup	26,538	775
Redhead	69	10
Ring-necked Duck	147	3,742
Canvasback	349	85
Bufflehead	724	458
Black-bellied Whistling-duck	18	19
Hooded Merganser	11,052	279
Common Merganser	3	
Ruddy Duck	285,014	2,015
Other waterbirds		
Great egret	6,584	179
Great blue heron	12,832	41
Sandpipers	389	2
Killdeer	6	60
Little Blue Heron		112
American coot	50,013	21,383
Wilson's Snipe	7	125
Black-necked stilt	40	
Ring-billed gull	59	
Dowitchers	42	176

Table 1.2 (continued)

Common name	*n*	
	Production	Idled
Black-crowned Night-heron		7
Double-crested Cormorant	12,918	5
Ibises	118	366
Horned Grebe	3	
Pied-billed grebe	51	118
Least Tern	60	
Greater Yellowlegs	21	213

[a]Indicates species with only one occurrence

Blanks denote species not detected

Table 1.3 Average dissimilarity, percent contribution to dissimilarity (%), and cumulative percent dissimilarity (%) of waterbird species.

Common name	Average Dissimilarity	% Contribution	Cumulative %
Mallard	18.78	23.24	23.24
Ruddy Duck	13	16	39.29
Northern shoveler	11	13.6	52.89
Gadwall	9	11	63.65
American green-winged teal	7.976	9.87	73.52
American coot	5.439	7	80.25
Northern pintail	3.829	4.739	84.99
Lesser snow goose	3	3	88.14
White-fronted goose	3	3	91.29
Lesser Scaup	1.374	1.7	92.99
Ring-necked Duck	1.067	1	94.31
Double-crested Cormorant	1	1	95.18
American wigeon	1	0.7926	95.97
Great blue heron	0.6382	0.7898	96.76
Hooded Merganser	0.5657	1	97.46
Great egret	0.5491	0.6796	98.14
Wood duck	0.4729	0.5853	98.72
Canada goose	0.2337	0.2892	99.01
Blue-winged teal	0	0.2288	99.24
Bufflehead	0.1546	0.1913	99.43
Ibises	0	0	99.61
Wilson's Snipe	0.09112	0.1128	99.72
Yellowlegs	0.06982	0.0864	99.81
Sandpipers	0	0.06546	99.88
Canvasback	0	0.04892	99.92
Pied-billed grebe	0.03404	0.04213	99.97
Dowitchers	0.01946	0.02409	99.99
Redhead	0.007938	0.009824	100

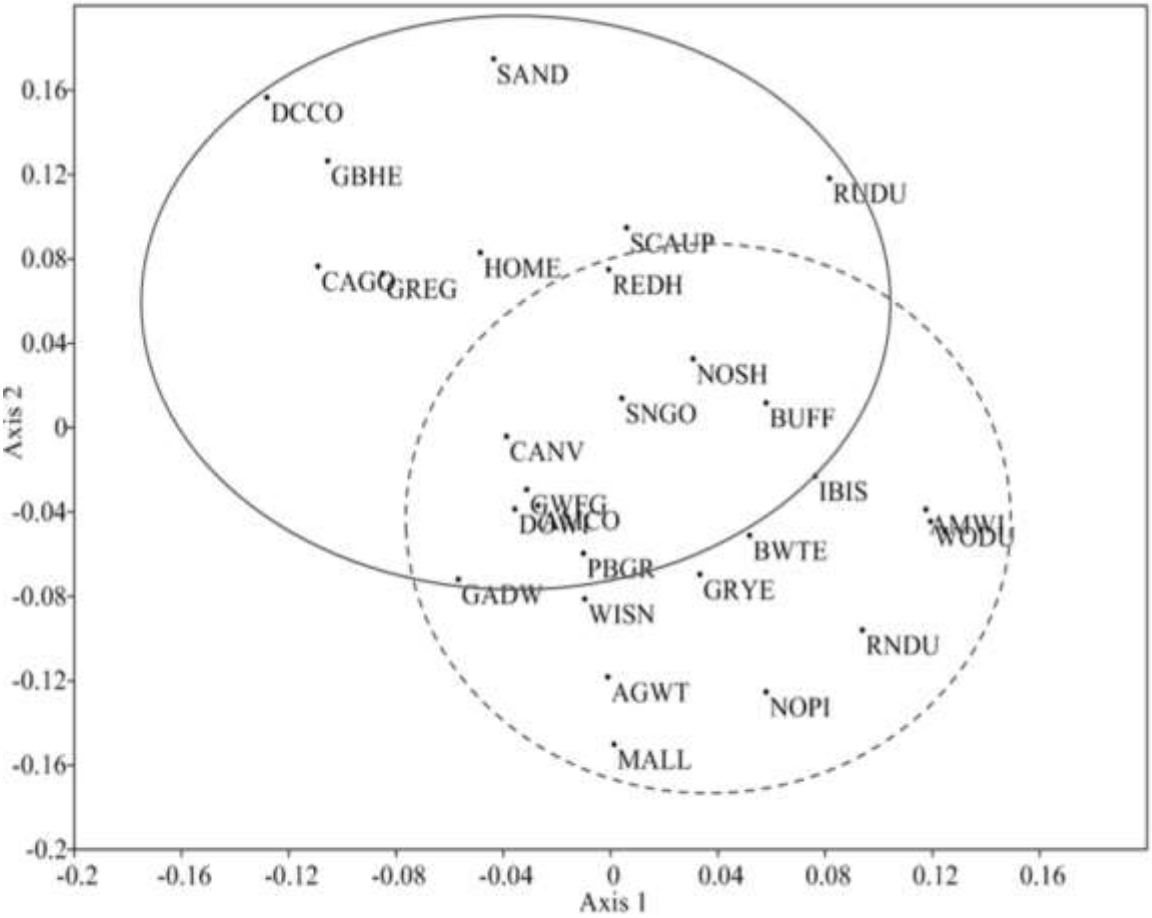

Figure 1.2 Non-metric multi-dimensional scaling of mean waterbird abundance (waterbirds/ha) from 6 production (solid elipse) and 4 idled (dashed elipse) Migratory Bird Habitat Initiative catfish ponds.

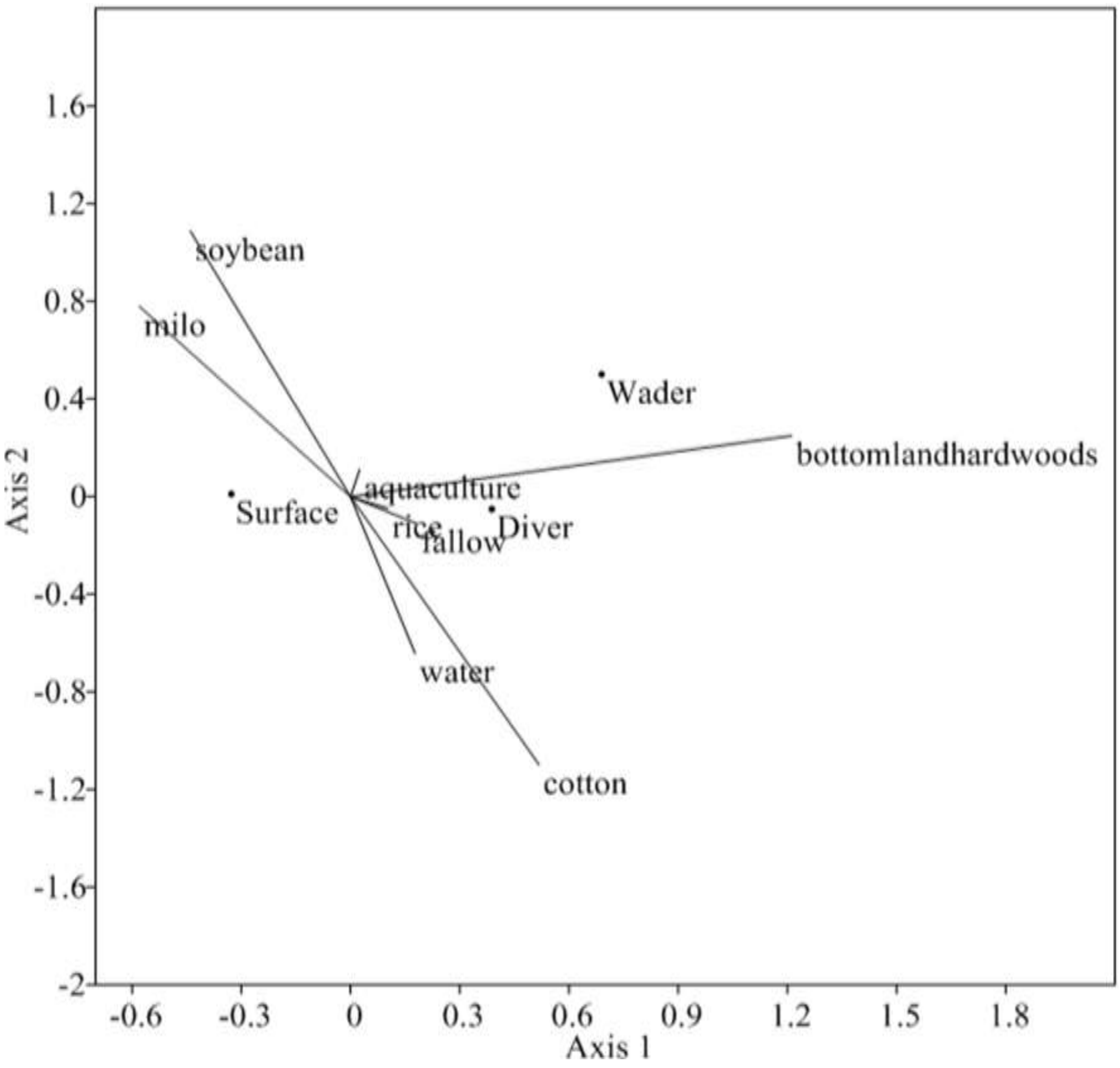

Figure 1.3 Canonical correspondence analysis of mean guild density of waterbirds (i.e., wader, diver, and surface feeders/ha) using 6 catfish production ponds in Mississippi, winter 2011-2012.

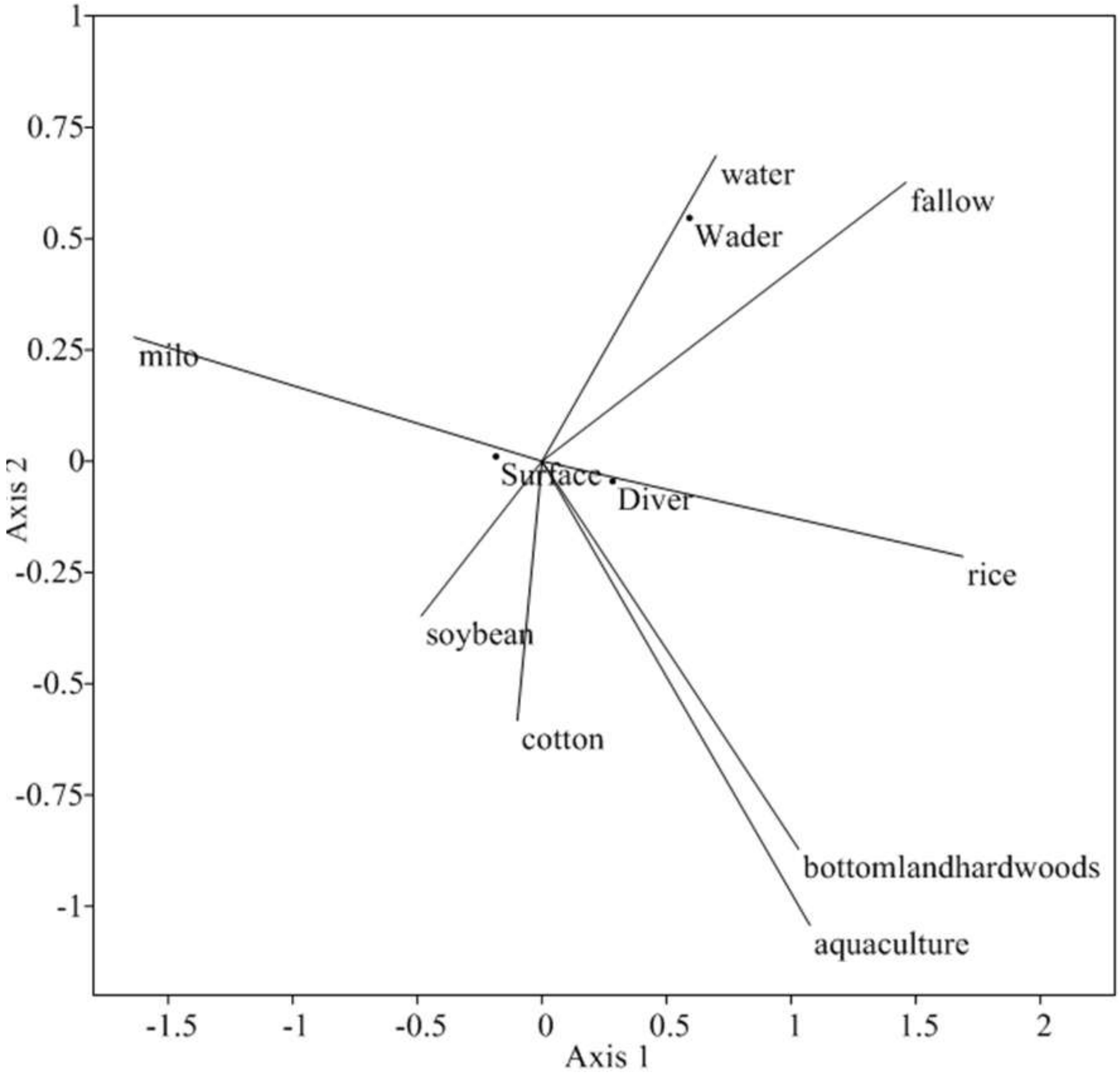

Figure 1.4 Canonical correspondence analysis of mean guild density of waterbirds (i.e., wader, diver, and surface feeders/ha) using 6 catfish production ponds in Mississippi, winter 2012-2013.

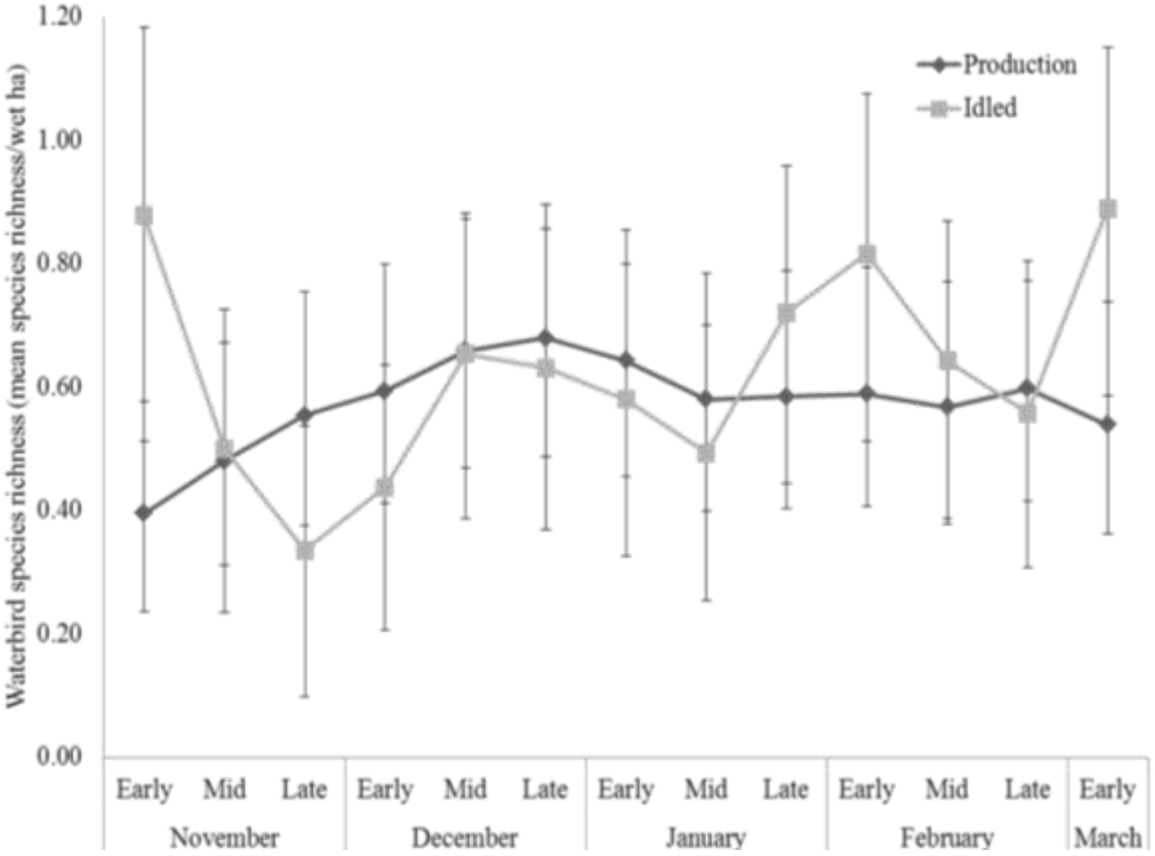

Figure 1.5 Natural log back-transformed mean species richness (waterbirds/ha) with 90% confidence limits for production and idled catfish ponds in Mississippi for winters 2011-2012 and 2012-2013 combined.

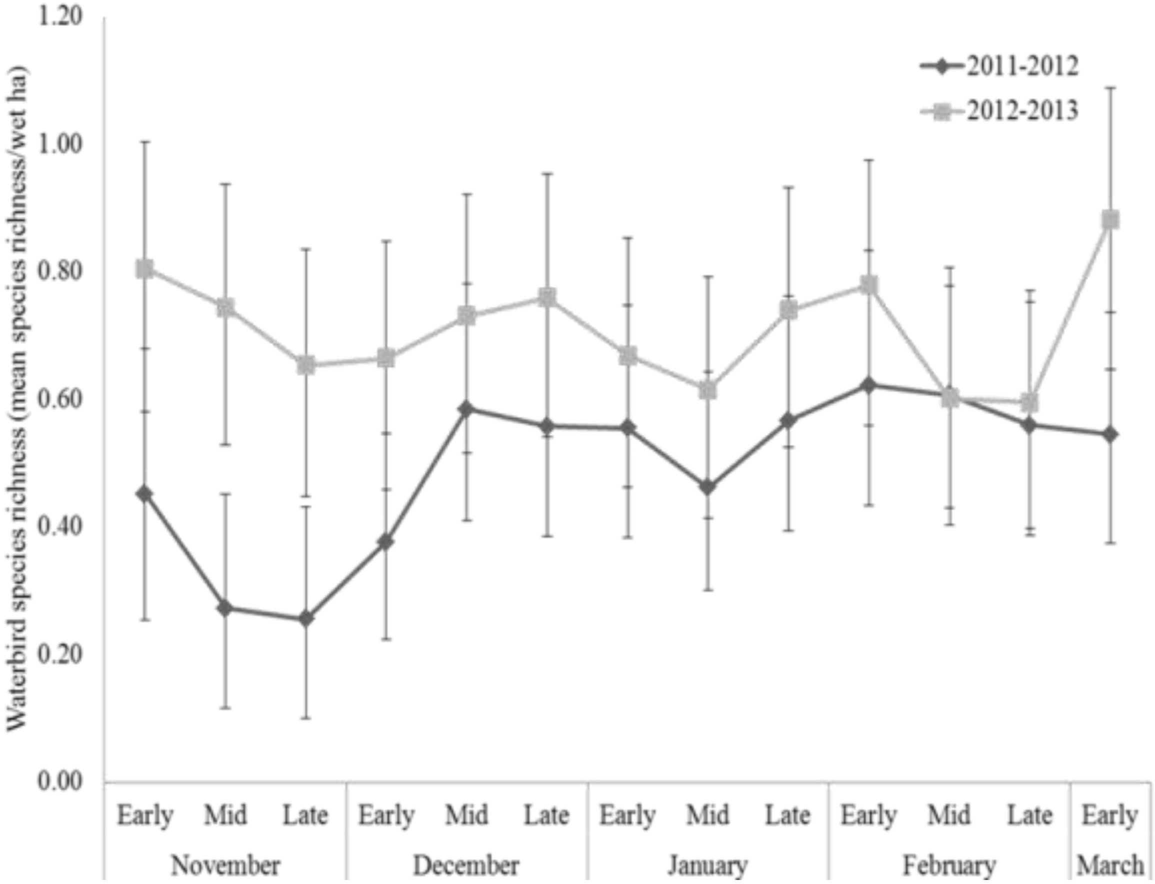

Figure 1.6 Natural log back-transformed mean species richness values (waterbirds/ha) with 90% confidence limits for production and idled catfish ponds combined in Mississippi during winters 2011-2012 and 2012-2013.

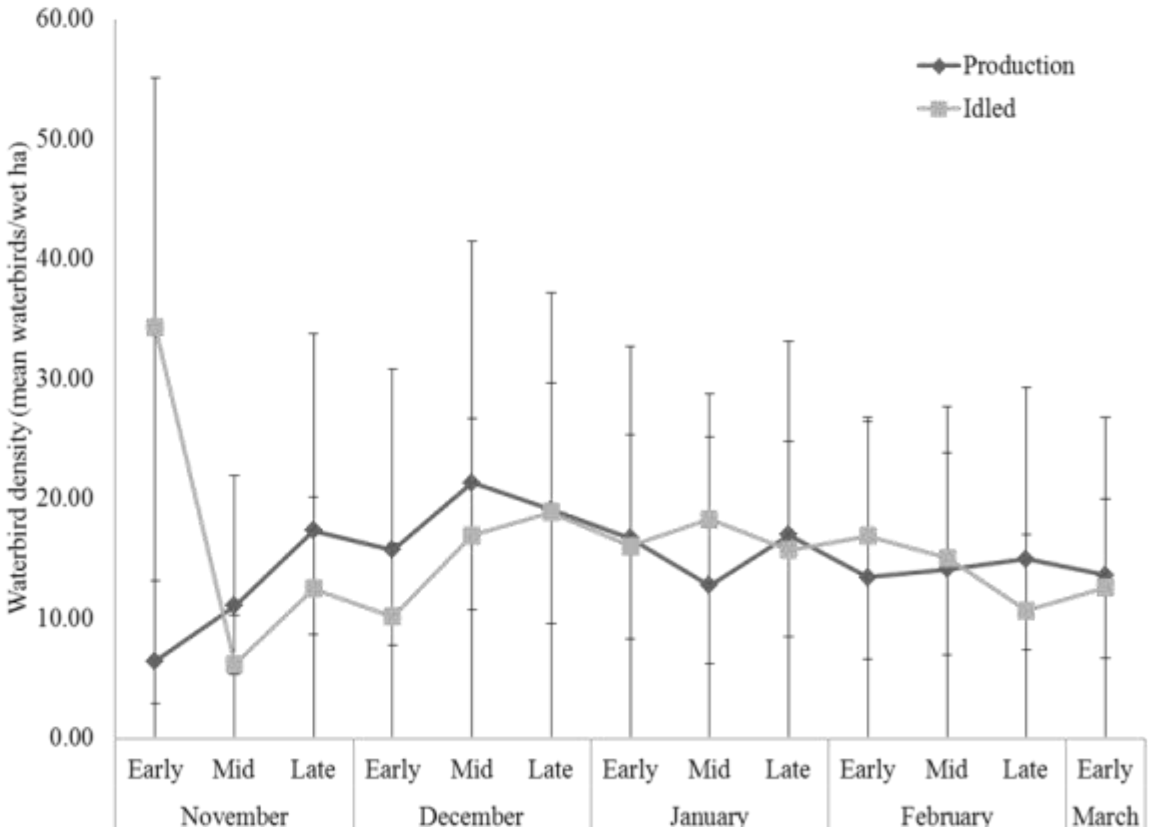

Figure 1.7 Natural log back-transformed mean waterbird densities (waterbirds/ha) with 90% confidence limits for production and idled catfish ponds in Mississippi for winters 2011-2012 and 2012-2013 combined.

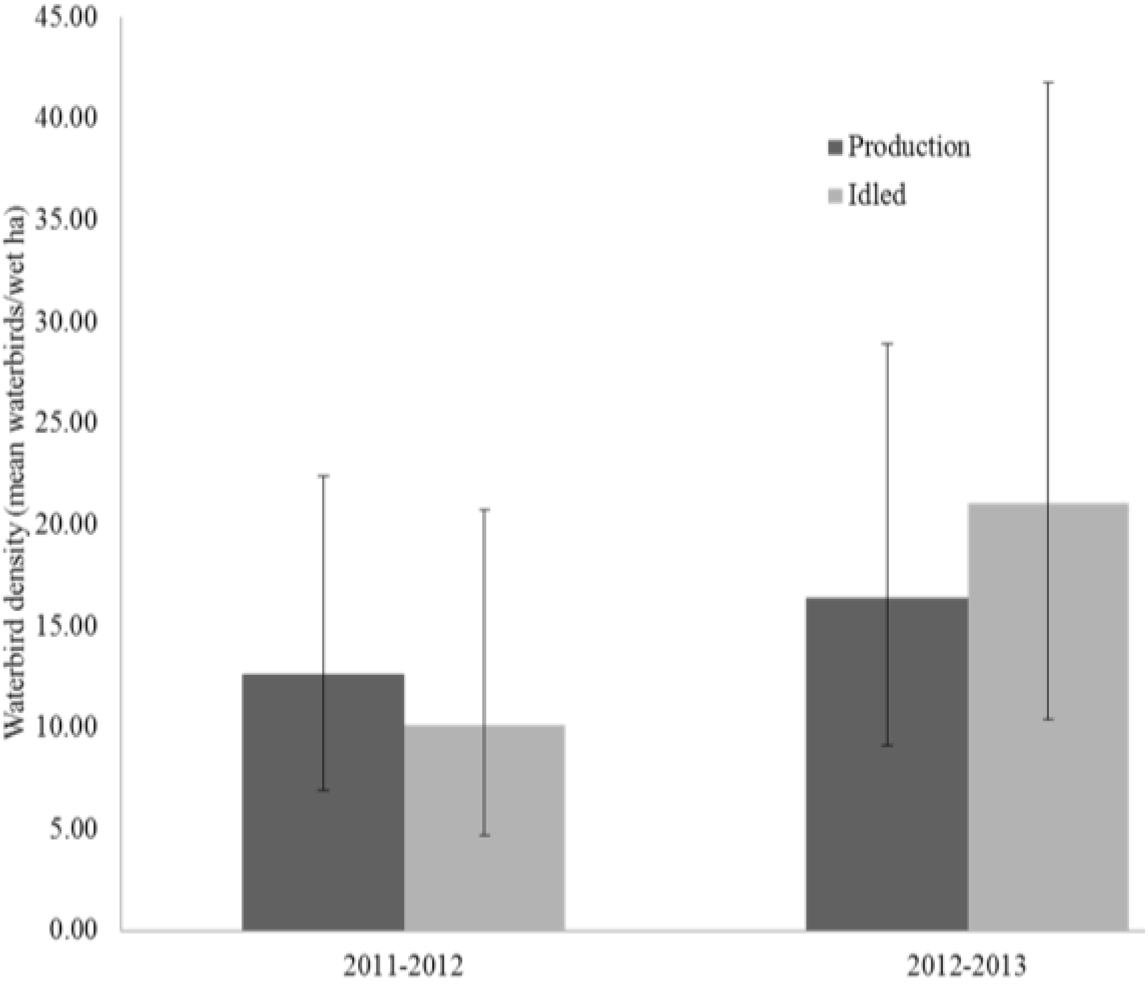

Figure 1.8 Natural log back-transformed mean waterfowl and other waterbird densities combined (birds/ha) with 90% confidence limits for production and idled catfish ponds in Mississippi during winters 2011-2012 and 2012-2013.

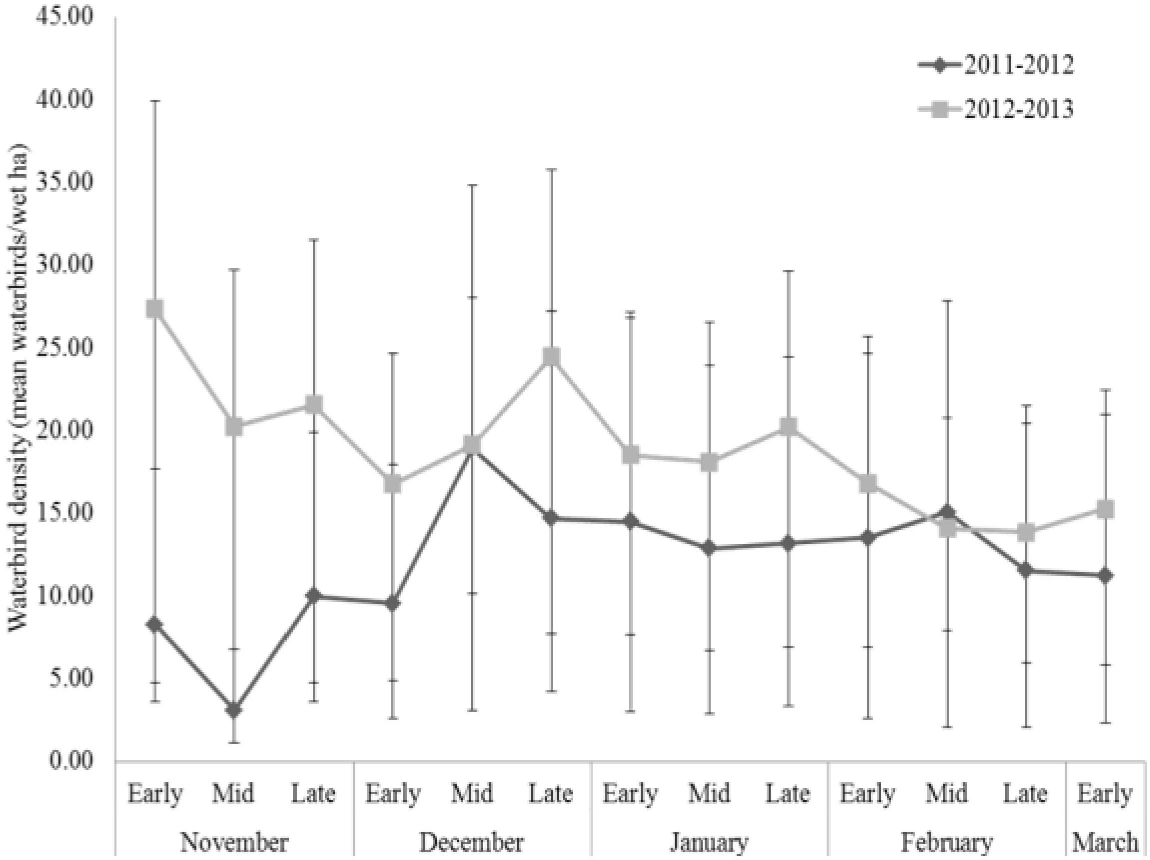

Figure 1.9 Natural log back-transformed mean waterbird densities (waterbirds/ha) with 90% confidence limits for production and idled catfish ponds combined in Mississippi during winters 2011-2012 and 2012-2013.

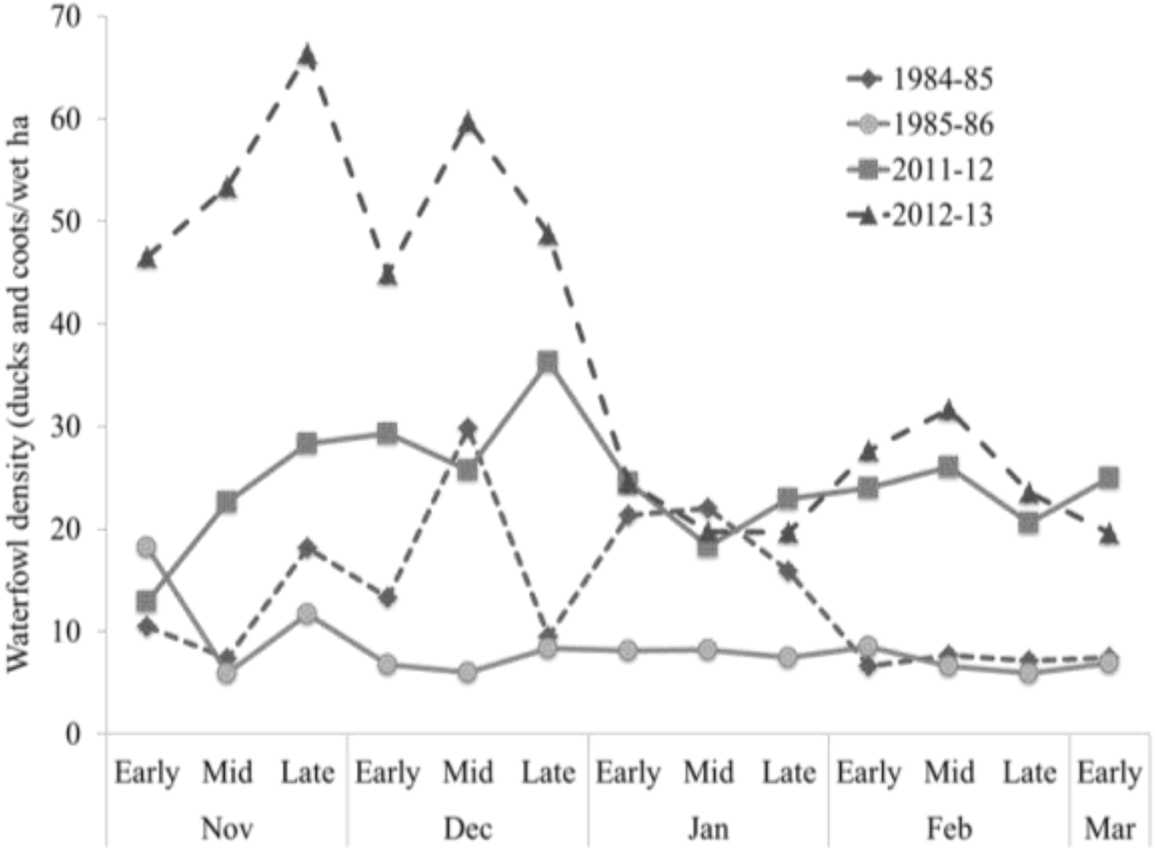

Figure 1.10 Waterfowl and American coot densities (birds/ha) on production catfish ponds in Mississippi during winters 1984-1985 and 1985-1986 and 2011-2012 and 2012-2013.

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CHAPTER II

POTENTIAL FOODS FOR WINTERING WATERBIRDS IN PRODUCTION AND IDLED AQUACULTURE LANDS IN MISSISSIPPI

The conversion of hardwood bottomlands and other wetlands to aquaculture ponds in the Mississippi Alluvial Valley (MAV), has provided alternate habitat, especially in Mississippi, for numerous waterbirds, including northern shoveler (*Anas clypeata*), lesser scaup (*Aythya affinis*), ruddy duck (*Oxyura jamaicensis*), Canada goose (*Branta canadensis maxima*), American coot (*Fulica americana*), great blue heron (*Ardea herodias*), American white pelicans (*Pelecanus erythrorhynchos*), double-crested cormorant (*Phalacrocorax auritus*), and other waterbirds (Christopher 1985, Dubovsky 1987, Dubovsky and Kaminski 1992, Fleury and Sherry 1995, Huner and Musumeche 1999, Sebastián-González et al. 2010, Strickley 1992, Zhijun et al. 2004). Many species of waterbirds use both active and non-active aquaculture ponds for loafing and feeding (Elliott and McKnight 2000, Fleury and Sherry 1995, Hunter et al. 2006, Morrison and Vogel. 2009, Sripanomyom et al. 2011, Twedt et al. 1998). Aquaculture ponds may provide high densities of preferred forage items for diverse waterbirds such as fish, seeds, and macroinvertebrates (Dubovsky 1987, Fleury and Sherry 1995, Zhijun et al. 2010). Finally, aquaculture ponds may partially mitigate adverse influences of loss and degradation of natural wetlands (Zhijun et al. 2010, Elliott and McKnight 2000, Hunter et al. 2006, Twedt et al. 1998).

Since the mid-1980s, Mississippi aquaculture production acreage has experienced a 24% decrease in area and continues to decline (Wellborn et al. 1986, USDA 2010). Former aquaculture sites have been managed as different types of wetlands and croplands. Flooded wetlands and croplands provide macroinvertebrates and moist soil seeds for migrating waterbirds which have partially mitigated loss of historical foraging habitat (Dubovsky 1987, Reinecke et al. 1989, Smith et al. 1989, Stafford et al. 2006, Green et al. 2013). Accordingly, my objectives were to (1) evaluate invertebrate abundances and diversity on production aquaculture ponds (2) compare moist soil seed abundance and diversity on idled aquaculture ponds [hereafter idled ponds] managed by National Wildlife Refuges (NWR) in the MAV portion of Mississippi or enrolled in the Migratory Bird Habitat Initiative (MBHI). I hypothesized that (1) macroinvertebrate metrics will vary between and (2) moist soil seed metrics will vary among NWR and MBHI wetlands.

Study Area

My study area encompassed the northwest region of Mississippi and was comprised of flat alluvial soils bordered by the Mississippi River on the west and the Yazoo River on the east. I surveyed waterbirds at 10 aquaculture locations in this region, including sites in Humphreys, Holmes, Leflore, Sunflower, Washington, and Yazoo counties, Mississippi (Fig 1.1). I sampled for macroinvertebrates and moist soil seeds from 6 production sites and 4 idled sites (including 2 U.S. Fish and Wildlife Service National Wildlife Refuges) in winters 2011-1012/2012-2013, respectively. Each site ranges from 20-850 ha ($\bar{x}$ = 80 ha) and contained 13 to 101 ponds. Each pond within a site averaged 8 ha.

Methods

Macroinvertebrate Abundance

I collected nektonic and benthic macroinvertebrates from each production site once monthly from November-February 2011-2013, following general protocol of Dubovsky (1987). I sampled macroinvertebrates from one randomly selected impoundment within each site using both a sweep net and soil core sampler. For each method, I obtained 10 samples each from both the shoreline edge and open-water strata of ponds. I defined the shoreline sampling as 1-m wide area extending outward from the base of the levees of a pond and the open-water stratum as anywhere in the pond exclusive of the shoreline zone. During each sampling session, I randomly selected the north, south, east, or west shoreline of ponds to sample. I conducted open water sampling along 1 of 2 randomly selected diagonal transects extending between opposite corners of the impoundment.

At each sample location, I obtained a sweep-net and soil core sample and measured water depth. I identified my shoreline locations by walking a random number of paces beginning from one corner of the impoundment. I obtained the open water samples from a boat by rowing a random number of strokes between 10 and 20.

Sweep Net Method.

I sampled nektonic macroinvertebrates using a 500 µm rectangular sweep net (46 x 20 cm; Wehrle et al. 1995). I obtained shoreline samples using a straight handled net which I pushed through the water column and along to substrate for 1.1m to sample a 0.5 m^2 area (Gray et al. 1999). For the open water samples, I used a 90° angled attachment, which I lowered to the pond bottom and then pulled upward through the water column. Once collected, I placed each sample in a plastic bag and labeled them appropriately.

Soil Core Method

I sampled benthic and subterranean macroinvertebrates using a 1.7 m long, 6.6 cm diameter core sampler (Swanson 1978). At each sampling location, I pushed the corer into the substrate to an approximate depth of 10 cm (Stafford et al. 2006). Once collected, I placed each sample in a plastic bag and labeled them appropriately.

Sample Processing

I preserved macroinvertebrate samples while afield with a 10% formalin solution mixed with rose bengal dye. Rose bengal dye is an agent used to color macroinvertebrates for ease of sorting. Once preserved, I stored all macroinvertebrate samples in ice during transportation and eventually maintain them at -15°C until processed.

In the laboratory, I rinsed samples through nested sieves to divide them into coarse (>1 mm) and fine (<1 mm,>0.5 mm) fractions. Using dissecting microscopes and tweezers, I separated macroinvertebrates from debris and sorted them to the Family taxonomic level when possible (Thorp and Covich 1991, McCafferty 1998, Voshell 2002). After sorting, I dried each taxon to constant mass at 80°C for 24 hrs, weighed them to the nearest 0.1 mg, calculated their respective biomasses (kg [dry]/wet ha), and calculated mean biomass per shoreline strata, open water strata, and both strata combined for each site (Salonen and Sarvala. 1985).

Moist-Soil Seed Abundance

I collected moist soil seed samples from three randomly selected impoundments within each idled site twice a winter (i.e. November and March) from 2011-2013. I collected 10 core samples from each impoundment using similar sized corer and methods as macroinvertebrate sampling. I collected core samples along a randomly placed transect within each impoundment. I selected a random distance (0–25 m) to the first sample location and then located each subsequent location at fixed intervals spanning the remainder of the impoundment (Greer et al. 2007, Hagy and Kaminski 2012).

I thawed core samples in warm water, added a solution of 3% hydrogen peroxide (H2O2), sodium bicarbonate, and water for 1hour (Bohm 1979), followed by washing cores through a series of nested sieves (Kross et al. 2008, Hagy 2010). I recovered and air dried seeds and other material from each sample separately for 24–48 hrs. Using dissecting microscopes and tweezers, I separated seed and tubers from debris. After sorting, I dried seeds and tubers at 80°C for 24 hrs to dry mass, sorted them to the Genus taxonomic level, and weighed seeds to the nearest 0.1 mg. I adjusted all seed masses using seed size-class correction factors to account for bias associated with core sample processing (Hagy et al. 2011). After correcting masses, I calculated their respective mean biomasses (kg [dry]/wet ha) for all seeds, seeds commonly consumed by waterfowl, and all seed genera richness (n/wet ha) for each site (Hagy and Kaminski 2012).

Statistical Analyses

In three separate analyses, I tested for differences in open water, shoreline, and total macroinvertebrate biomasses (kg [dry]/ha) among production aquaculture sites using repeated measures ANOVA (PROCMIXED; SAS Institute 2008). I designated year, site, and month as repeated measures. Also, I used a paired t-test to test for differences between shoreline and open water strata macroinvertebrate biomass (kg [dry]/wet ha). Additionally, in separate analyses, I used a mixed model ANOVA to compare effects of NWR and MBHI management regimes on all moist soil seeds biomass, waterfowl food biomass, and all moist soil seed genera richness (PROCMIXED; SAS Institute 2008). I designated management area (e.g. NWR and MBHI) as fixed effects, year and site as random effects, and month as repeated measure and fixed effect. I natural log transformed all macroinvertebrate and moist soil seed densities and species richness data to achieve normality and homogenous variances (Kamamura 1999, Conquest 2000). To avoid loss of biologically relevant information, I selected $\alpha = 0.10$ a priori due to the small number of survey sites (6 production and 4 idled) and survey periods (Tacha et al. 1982). When I detected significant differences, I performed a pair-wise comparison of least-squared means (Wiseman 2009). I then back-transformed dependent variables and reported their means with 90% confidence limits.

Results

Macroinvertebrates

I sampled macroinvertebrates in 6 production aquaculture sites and recorded 17 benthic and nektonic taxa in winters 2011-2013 (Table 2.1). I recorded 15 and 17 taxa in the open water and shoreline strata, respectively (Table 2.2). Among nektonic macroinvertebrates in open-water and shoreline strata, respectively, copepods (Eucopepoda; (58%, 40%), aquatic worms (Oligochaeta; 21%, 21%), water fleas (Cladocera; 16%, 13%), backswimmers (Notonectidae; 14%, 47%), amphipods (Talitridae; 13%, 28%), and chironomids (Chironomidae; 7%, 17%) accounted for most occurrences in both strata(n = 480 each; Table 2.2). Among benthic macroinvertebrate samples, aquatic worms (Oligochaeta; 53%, 61%), chironomids (Chironomidae; 42%, 71%), and snails (Physidae; 14%, 14%) accounted for most of the occurrences of invertebrates collected in the open water (n = 480) and shoreline strata (n = 480), respectively (Table 2.2).

Overall, mean macroinvertebrate biomass for shoreline and open-water strata of production aquaculture ponds combined was 53.16 kg (dry)/ha (SE = 6.596). I neither observed any differences in invertebrate biomass among production sites in shoreline ($F_{5, 7} = 2.18$, $P = 0.138$) and open water sites ($F_{5, 7} = 1.64$, $P = 0.176$), nor for total biomass ($F_{5, 7} = 2.31$, $P = 0.125$). Additionally, I did not detect any difference in mean macroinvertebrate biomass between shoreline ($\bar{x}$ = 69.14 kg/ha; 90% CI = 50.15 to 88.13) and open-water strata among production pond sites ($\bar{x}$ = 39.98 kg / ha; 90% CI = 32.47-48.69; $t_{92} = 1.66$, $P = 0.172$), although the shoreline stratum harbored, on average, nearly 1.5 times more invertebrate biomass than did open water sites.

Moist-Soil Seeds

I sampled moist soil seeds and tubers on 2 MBHI and 2 NWR idled aquaculture sites and recorded a total of 43 genera in winters 2011-2013 (Table 2.3). I recorded 30 and 42 genera of moist soil plants in MBHI and NWR sites, respectively, for both winters combined (Table 2.3). In MBHI sites, the ten most frequently occurring taxa were smartweed (*Polygonum spp.*; 70%), bristlegrass (*Setaria spp.*; 27%), barnyardgrass (*Echinochloa spp.*; 19%), milo (*Sorghum bicolor*; 17%), coffeeweed (*Sesbania herbaccea*; 17%), pigweed (*Amaranthus spp.*; 17%), daisy (*Eclipta spp.*; 17%), sumpweed (*Iva annua*; 15%), prickly sida (*Sida spinosa*; 14%), and morning glory

(*Iopomea spp*.; 14%; Table 2.3). The most frequently occurring taxa in NWR sites were smartweed (85%), barnyardgrass (35%), coffeeweed (29%) dallisgrass (*Paspalum spp*.; 28%), daisy (26%), bristlegrass (19%), milo (18%), flatsedge (*Cyperus spp*.; 17%), buttercup (*Ranunculus spp*.; 14%), and beaksedge (*Rynchospora corniculata*; 13%; Table 2.3).

Within MBHI and NWR sites, combined seed densities ($F_{1,9} = 6.77$, $P = 0.029$) and waterfowl foods densities ($F_{1,9} = 12.66$, $P = 0.006$) differed between survey periods. Combined seed densities ($t_9 = 2.60$, $P = 0.029$) and waterfowl food densities ($t_9 = 3.56$, $P = 0.006$) were approximately 3 times greater for November than March surveys (Table 2.4). In addition, genera richness also differed between survey period ($F_{1,9} = 5.76$, $P = 0.04$), but was approximately 1.3 times less in November than March ($t_9 = -2.40$, $P = 0.04$; Table 2.4). The only difference between MBHI and NWR sites was in mean waterfowl food densities ($F_{1,9} = 3.85$, $P = 0.081$). Mean waterfowl food densities were approximately 1.4 times less in MBHI sites than NWR sites ($t_9 = 1.96$, $P = 0.081$; Table 2.4). Combined seed densities ($F_{1,9} = 12.16$, $P = 0.176$) and genera richness ($F_{1,9} = 2.07$, $P = 0.184$) did not differ between MBHI and NWR sites, nor were there interactive effects of management area and survey period ($F_{1,9} = 1.04$, $P = 0.85$, $F_{1,9} = 1.03$, $P = 0.336$; respectively). Lastly mean waterfowl foods did not differ due to the interactive effects of management area and survey period (($F_{1,9} = 0.5$, $P = 0.495$).

Discussion

Macroinvertebrates

Macroinvertebrate diversity and densities in production catfish ponds in winters 2011-2013 were comparable to other wetland systems despite having relatively large biomass, >50 kg/ha (Wehrle et al. 1995, Michaletz et al. 2005). Hagy (2010) assessed invertebrate biomasses in retired catfish impoundments and found < 2 kg (dry)/ha, over 25 times less than my study. However, Hagy (2010) investigated ponds that were shallowly flooded for only a small portion of the year. My sites were active catfish producing ponds that were deeply flooded for most of the year allowing larger biomasses to accumulate. Furthermore, Hagy (2010) only sampled invertebrates using a sweep net, whereas, I used both sweep nets and core samples to estimate invertebrate biomasses. Hagy (2010) could have potentially missed invertebrates within the substrate that I collected causing the differences in invertebrate biomasses.

Shoreline and open water strata produced similar densities of macroinvertebrates despite the former being ~1.5 time greater than the latter. This biologically greater density in the shoreline strata relative to open water strata could be due to several factors, including differences in nutrient loads (Harris 1999, Carvalho et al. 2006), dissolved oxygen (Lancaster et al. 2009), temperatures (Dossena et al. 2012), water depth (Nhiwatiwa et al. 2009) ,and presence of avian and fish predators eating invertebrates. Also, I found no differences in shoreline, open water, and total mean macroinvertebrate biomass between production ponds. Perhaps this lack of difference could be attributed similarities in catfish pond construction within Mississippi.

Moist-Soil Seeds

Overall, I observed considerable differences in seed metrics between November and March survey periods. For seed biomass, both management regimes exhibited marked decreases as winter progressed. This difference is likely due to seed decomposition and mammalian and avian granivory (Stafford et al. 2006, Hagy and

Kaminski 2012). Contrary to biomass, genera richness of seeds increased as winter progressed. During November, several species of plants (e.g., ground cherry, *Physalis spp.*; cutgrass, *Leersia spp.*; heliotropes, *Heliotropium spp.*; rockcress, *Arabis spp.*; and balloon vine, *Cardiosperma halicacabum*) were still standing and had not initiated senescence which may have potentially affected estimates observed during this time; however, by March, all plants completed senescence and those species missed in the earlier sampling were then detected.

MBHI and NWR sites exhibited differences in mean waterfowl food biomasses. Overall, I found mean waterfowl food biomass were less in MBHI than NWR sites. However, NWR site mean waterfowl food biomasses were similar to other studies (Kross et al. 2008, Hagy and Kaminski 2012). When I compared biomasses of only waterfowl foods present in the top 10 most frequently observed plants, I found those species comprised 52% ($\bar{x}$ = 407 kg/wet ha) and 59% ($\bar{x}$ = 221 kg/wet ha) of the total seed biomass in NWR and MBHI sites, respectively. In most cases, MBHI sites were not actively planted or disturbed prior to the program implementation. This suggests most plants present occurred naturally in the seed bank and germinated during the early stages of the program. Meanwhile, NWR sites were usually planted and managed for water levels prior to my sampling. Actively managing these sites generally produced a dominance of grasses, rushes, and sedges (i.e., waterfowl foods) and, when forbs (e.g., Bidens, *Bidens* spp.), vines (e.g., balloon vine), and woody plants (e.g., willow, *Salix* spp.) colonize a site, soil disturbance or a change in water regime is usually implemented to re-achieve more desirable species for foraging waterfowl (Fredrickson and Taylor 1982, Kross et al. 2008). Thus, even though MBHI had smaller densities of waterfowl foods, effective water level management could translate to greater biomasses, comparable to NWR sites without the need for planting.

Management and Research Implications

My results suggest both production and idled aquaculture ponds produce suitable conditions for wintering waterfowl and other waterbirds in terms of food (e.g., macroinvertebrates and moist soil seeds) and habitat (e.g., loafing, foraging, etc.). In production ponds, management of water levels (i.e. water level drawdowns) for levee maintenance and fish harvesting should occur during migration and wintering periods to make them more beneficial to foraging waterbirds. Because most ponds are filled to an approximate depth of 1m, waterbirds other than diving ducks (e.g. dabbling ducks, shorebirds, and wading birds) may not be able to access all macroinvertebrates since depths exceed their foraging space (i.e., > 40cm; Fredrickson 2005). Timing the temporary drawing down of production ponds to ideal foraging depths (i.e., 10–40 cm vs. ≥ 1 m) may benefit macroinvertebrate populations and foraging waterbirds. Depending on ability of managers to move water among production ponds, providing a cluster of drawn down ponds would maximize available food resources and mimic natural wetland system making them more attractive to wintering waterbirds.

In idled ponds, proper development and management practices are warranted to mitigate decreased abundance of natural wetlands, waste rice, and other agricultural seeds (Stafford et al. 2006, Kaminski et al. 2005). Furthermore, I recommend that landowners engage in active management where they time flooding and drawdown rates, vegetation management such as disking or bushogging, and other activities to maintain desirable early succession habitat, such as annual grasses and sedges (Fredrickson and Taylor 1982, Gray et al. 1999).

Table 2.1 Taxonomy of aquatic macroinvertebrates among 6 aquaculture production ponds during winters 2011-2012 and 2012-2013.

- Phylum Annelida
  - Class Clitellata
    - Subclass Euhirudinea
    - Subclass Oligochaeta
- Phylum Mollusca
  - Class Gastropoda
    - Order Pulmonata
      - FamilyPhysidae
      - Family Planorbidae
  - Class Pelecypoda
    - Family Sphaeriidae
- Phylum Arthopoda
  - Class Crustacea
    - Order Eucopepdoa
    - Order Amphipoda
      - Family Talitridae
  - Class Arachnida
    - Order Trombidiformes
      - Family Hydrachnidae
  - Class Branchiopoda
    - Subclass Phyllopoda
      - Order Cladocera
  - Class Insecta
    - Order Ephemeroptera
      - Family Baetidae
    - Order Odonata
      - Family Coenegrionidae
    - Order Hemiptera
      - Family Notonectidae
      - Family Veliidae
    - Order Coleoptera
      - Family Dytiscidae
    - Order Diptera
      - Family Chironomidae
    - Order Tricoptera
      - Family Polycentropodidae
  - Class Malacostraca
    - Order Isopoda

Table 2.2 Percent occurrence of aquatic macroinvertebrates in 6 aquaculture production ponds during winters 2011-2012 and 2012-2013.

Common name	Taxon	Stratum and realized niche			
		Open Water		Shoreline	
		Nekton	Benthos	Nekton	Benthos
Copepods	*Eucopepdoa*	58	tr	40	tr
Worms	*Oligochaeta*	21	53	21	61
Water Fleas	*Cladocera*	16	tr	13	1
Back Swimmers	*Notonectidae*	14	tr	47	2
Scuds	*Talitridae*	13	4	28	12
Midges	*Chironomidae*	7	42	17	71
Water Mites	*Hydrachnidae*	3	[a]	4	tr
Snail	*Physidae*	3	14	12	14
Caddisflies	*Polycentropodidae*	1	tr	2	2
Mayflies	*Baetidae*	tr		4	tr
Dragonflies	*Coenegrionidae*	tr		1	
Predaceous Diving Beetle	*Dytiscidae*	tr	tr	tr	
Leeches	*Euhirudinea*	tr	5		12
Isopods	*Isopoda*			tr	
Snail	*Planorbidae*	tr	4	4	4
Fingernail Clams	*Sphaeriidae*		tr	tr	tr
Riffle Bugs	*Veliidae*			tr	
Mean biomass (kg[dry] /wet ha ± SE)		1.2 ±0.6	72.6 ±9.0	0.7 ±0.2	134.7 ±9.1

(n = 480/sample zone)

[a] Blanks denote absence of taxon.

[b] "tr" indicates that there were trace amounts (<0.01 of mass present).

Table 2.3 Percent of occurrence of plant genera or species of seeds in idled aquaculture ponds enrolled in the Migratory Bird Habitat Initiative and National Wildlife Refuges.

Common name	Scientific name	MBHI	NWR
Smartweed	*Polygonum* spp.	70	85
Bristlegrass	*Setaria* spp.	27	19
Barnyardgrass	*Echinochloa* spp.	19	35
Milo		17	18
Coffeeweed	*Sesbania herbaccea*	17	29
Pigweed	*Amaranthus* spp.	17	11
Daisy	*Eclipta* spp.	17	26
Sumpweed	*Iva annua*	15	5
Prickly sida	*Sida spinosa*	14	8
Morning Glory	*Iopomea* spp.	14	8
Dallisgrass	*Paspalum* spp.	13	28
Panicgrass	*Panicum* spp.	10	6
Buttercup	*Ranunculus* spp.	7	14
Balloon vine	*Cardiospermum halicacabum*	6	1
Spikerush	*Eleocharis*spp.	5	4
Crabgrass	*Digitaria* spp.	5	4
Signalgrass	*Urochloa* spp.	5	6
Mallow	*Malva* spp.	5	1
Flatsedge	*Cyperus* spp.	3	17
Heliotropes	*Heliotropium* spp.	3	2
Sorrel	*Rumex* spp.	2	4
Sprangletop	*Leptochola* spp.	1	3
Water primrose	*Ludwigia* spp.	1	6
Groundcherry	*Physalis* spp.	1	3
Sedge	*Carex* spp.	1	9
Canarygrass	*Phalaris* spp.	1	1
Cutgrass	*Leersia* spp.	tr	1
Rockcress	*Arabis* spp.	tr	tr
Bush Clover	*Lespedeza* spp.	tr	1
Cocklebur	*Xanthium strumarium*	tr	[a]
Buttonweed	*Diodia* spp.		1
Rice			tr
Beaksedge	*Rynchospora corniculata*		13
Duck Potato	*Sagittaria latifolia*		6
Carolina coralbead	*Coccolus carolinus*		6

Table 2.3 (continued)

Common name	*Scientific name*	MBHI	NWR
Bermuda Grass	*Cynodon dactylon*		tr
Bundleflower	*Desmanthus* spp.		8
Alfalfa			3
American Lotus	*Nelumbo lutea*		tr
American Pokeweed	*Phytolacca americana*		tr
Plantain	*Plantago* spp.		1
Verbena	*Verbena brasiliensis*		3
Vetch	*Vicia* spp.		1

(*n* = 240)

[a] Blanks denote absence of taxon.

[b] "tr" indicates that there were trace amounts (<0.01 kg [dry] /ha) of mass present.

Table 2.4 Natural log back-transformed mean (and lower and upper 90% confidence limits (LCL, UCL) for moist-soil seed mass (kg [dry]/flooded [i.e., wet ha]) of idled Migratory Bird Habitat Initiative (MBHI) and National Wildlife Refuges (NWR) in Mississippi.

	Month	MBHI (*n* = 2)			NWR (*n* = 2)		
		Mean	LCL	UCL	Mean	LCL	UCL
All seeds	November	300.05	135.49	452.60	639.81	245.32	834.32
	March	180.74	12.12	339.48	235.61	171.79	289.453
Waterfowl foods[a]	November	227.97	43.29	415.43	554.57	214.21	774.94
	March	87.22	18.53	158.93	106.83	70.23	130.41
Genera richness (*n*/wet ha)	November	14.75	8.83	20.69	17.25	13.91	20.61
	March	16.50	11.86	21.14	22.75	19.49	25.41

[a] Seeds waterfowl commonly consumed in the Mississippi Alluvial Valley (Hagy and Kaminski 2012).

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