THE AVIAN COMMUNITY CHARACTERISTICS OF CONSTRUCTED TREATMENT WETLANDS OF SOUTH FLORIDA

by

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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Dale Gawlik, Department of Biological Sciences, and has been approved by the members of his supervisory committee. It was submitted to the faculty of the Charles E. Schmidt College of Science and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

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This study compared the avian communities of treatment wetlands in South Florida called Stormwater Treatment Wetlands (STAs) to those in natural marshes and crop lands, and examined factors that influenced the size and structure of the avian communities within the STAs. The STAs contained a more abundant, rich and distinct avian community compared to reference land types. The STAs were dominated by wintering waterfowl, and therefore community patterns fluctuated more seasonally other land types. Within the STAs, density and richness in the fall and winter were much greater in the submerged aquatic vegetation than in the mixed emergent vegetation when waterfowl were present. The STAs maintain two vegetation treatments which enhanced their biodiversity value by supporting distinct avian communities with different migratory strategies This suggests the increase in treatment wetlands could partially offset the loss of natural wetlands, but avian communities in treatment wetlands are not surrogates for natural wetlands.

THE AVIAN COMMUNITY CHARACTERISTICS OF CONSTRUCTED TREATMENT WETLANDS OF SOUTH FLORIDA

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CHAPTER 1: GENERAL INTRODUCTION

Wetlands are the most valuable ecosystems on Earth in terms of value per unit area. Despite covering only 1.5% of the Earth's surface, they provide as much as 40% of the world's ecosystem services (Zedler 2000; Zedler 2003). Valuable services that they provide include disturbance regulation, waste treatment, recreational opportunities, and habitat provisioning (Costanza et al. 1997; Mitsch and Gosselink 2007). In addition to economic value, wetlands are also centers of high biodiversity due to their high levels of productivity and strong natural selection pressures (Gibbs 1993). Because of their morphological and behavioral diversity and plasticity, birds are uniquely adapted to exploit the wide variety of resources and environmental variability displayed in wetland systems (Weller 1999).

Despite their enormous economic and ecological value, wetlands have been extensively destroyed by human development. It is estimated that nearly half the world's wetlands have been destroyed primarily due to expansion of agricultural crops (Finlayson and Spiers 1999). Wetlands are attractive for agriculture use because their soils typically contain high amounts of organic matter, have high nutrient availability, and have level and easily cultivated land (Reddy and Gale 1994). The United States has experienced particularly high levels of wetland loss with states such as California and Ohio losing as much as 90% of their wetlands since the 1780s. Florida, having the highest total wetland area in the lower 48 states, has lost more wetland area than any other state (Dahl 1990).

Of those wetlands that remain, most are extensively degraded. Benke (1990) estimates that 98% of stream extents in the lower 48 states are not worthy of federal designation as wild and scenic rivers. Eutrophication is the most widespread cause of water quality problems in the US and many other countries. Additionally, conversion of wetlands to agriculture has exacerbated the issue of eutrophication. Excess nutrient runoff has been linked to toxic algal blooms, oxygen depletion, fish kills, loss of biodiversity and loss of aquatic plant beds in wetlands (Carpenter et al. 1998).

Although eutrophication of natural wetlands is typically considered undesirable, people have capitalized on the ability of wetlands to trap nutrients and other pollutants by constructing artificial wetlands to treat runoff. The use of constructed treatment wetlands (CTWs) has been steadily increasing since the 1950s (Kadlec and Knight 1996). To date, there are over 600 CTWs being used to treat industrial byproduct, mining wastewater, domestic wastewater, urban stormwater runoff, and agricultural runoff (U.S. Environmental Protection Agency 1999a; Kadlec and Wallace 2009). Modern agricultural practices necessitated the use of CTWs to remove excess nutrients, chemicals, and other contaminants from agricultural runoff.

CTWs are also an attractive option compared to traditional water treatment facilities because they may provide other benefits in addition to water quality improvements (U.S. Environmental Protection Agency 1999b). High among those benefits are recreational uses such as waterfowl and alligator hunting, exercise areas, and birdwatching. CTWs may also provide vegetative material for livestock feed and educational opportunities for school children (Kadlec and Wallace 2009).

Habitat provisioning is arguably the most valuable secondary service provided by CTWs considering the historic loss of natural wetlands. Over 1,400 species of invertebrates, fish, amphibians, reptiles, birds and mammals have been reported to utilize treatment wetlands in North America (Knight et al. 2001). Additionally, high wildlife usage has been reported in treatment wetlands in Great Britain (Worrall et al. 1997), Australia (Greenway and Simpson 1996), and Africa (Nyakang'o and van Bruggen 1999).

Avifauna in particular may be benefiting from the creation of CTWs. A total of 361 bird species have been documented as using CTWs in the US (U.S. Environmental Protection Agency 1999b). Avian densities in treatment wetlands are frequently 5-40 times higher in treatment wetlands than reference wetlands (McAllister 1992; McAllister 1993a; McAllister 1993b). Frederick and McGehee (1994) found high wading bird use of wastewater treatment wetlands in central Florida when compared to natural marshes of Florida and Nicaragua. Nevertheless, despite multiple studies about the utility of treatment wetlands as wildlife habitat, there is little documentation as to when and how wildlife benefit from these wetlands (Knight et al. 2001).

South Florida is the ideal location to investigate questions about wildlife and CTWs because the area supports both large populations of wildlife and a high concentration of CTWs. Treatment wetlands are common in South Florida because the natural wetlands are highly oligotrophic and they receive runoff from a robust agricultural area (McCormick et al. 2002). This eutrophic runoff has drastically impacted the Everglades. Historically the Everglades was a wide, shallow, herbaceous marsh characterized by slow moving oligotrophic waters (Gunderson and Loftus 1993). The primary source of phosphorous input was atmospheric deposition. This began to change with drainage projects starting around 1906 and intensified with further projects starting in 1950 (Snyder and Davidson 1994). These projects drained land for agriculture, channelized water flow through the system, and compartmentalized most of the remaining system. The area of land directly south of Lake Okeechobee was drained for agriculture and is now called the Everglades Agricultural Area (EAA). Sugarcane is the primary crop of the EAA while other crops include sod, corn and other vegetables (Pearlstine et al. 2004). The remaining "natural" Everglades marsh has been preserved in a series of water conservation areas (WCAs) and in Everglades National Park.

Until recently, most of the runoff from the EAA drained directly into the WCAs. The elevated levels of nutrients in this water caused shifts in algal species composition, displacement of natural sawgrass (*Cladium jamaicensis*) vegetation communities with cattail (*Typha dominogensis*) dominated communities and shifts in macroinvertebrate species composition (Rader and Richardson 1992, 1994; Craft and Richardson 1997; Doren et al. 1997; Vaithiyanathan and Richardson 1999; Crozier and Gawlik 2002; McCormick et al. 2004; Newman et al. 2004). Additionally Crozier and Gawlik (2002) found more Boat-tailed Grackles and Common Moorhens and less Common Yellowthroats in the eutrophied areas of Water Conservation Area 2A when compared to nearby unenriched areas. Abundances of wading birds including Great Egrets (*Ardea alba*) and Wood Storks (*Mycteria americana*) were greater in enriched areas however these relationships also depended upon hydrologic patterns.

In response to these detrimental effects, the South Florida Water Management District (SFWMD) in 1989 started construction on a system of treatment wetlands to cleanse runoff from the EAA. The wetlands, a type of CTW referred to as Stormwater Treatment Areas (STAs), were mostly built on reclaimed agricultural fields of the EAA. The STAs remove phosphorous (P) from surface waters by a combination of sediment accretion and uptake by vegetation (Abtew et al. 2007). Currently the STAs consist of over 18,000 ha of treatment wetlands. Recent expansion projects have brought their total area to over 23,000 ha and the State of Florida recently purchased nearly 11,000 ha of EAA land with the intent to convert at least a portion of the land to STAs.

Like other CTWs, the primary purpose of the STAs is to improve water quality flowing into the remnant Everglades. However, they also offer a number of secondary benefits such as water storage, recreational hunting, fishing, wildlife observation and wildlife habitat. The STAs may be providing especially good habitat for avifauna. Chimney and Gawlik (2007) documented 139 avian species using STAs 1W and 5 and the Hendry-Glades Audubon Society has documented 186 avian species in and around STA-5 alone (Lucas and England 2010).

Studies are needed to understand how the trend of expanding treatment wetlands can affect bird communities on local, regional and continental scales. Are these artificial wetlands proper surrogates for natural wetlands? Our knowledge of avian communities in treatment wetlands and how they might differ from those in natural wetlands is lacking. Understanding these relationships is essential to predicting how the increasing proportion of wetlands serving as treatment marshes may change current wetland bird communities. On a smaller scale, understanding of how and why birds are using treatment wetlands will be critical to designers and managers who wish to encourage or discourage wildlife use of these areas. The influence of components such as habitat structure, hydrology, and geographic position should be investigated to better understand how to manage and design treatment wetlands with bird use in mind. Understanding how season influences these bird communities is also critical because many waterbirds are highly migratory or shift their habitat usage throughout the year. Thus, the goals of my study is to compare the avian communities of the STAs with reference land types that preceded them, and to assess what features and conditions influence avian abundance, richness and community composition within the STAs and reference land types that preceded them.

Chapter 2 looks at how the avian communities may have changed with conversion from natural wetland to agriculture and then to treatment wetland. It was not possible to compare the avian community before and after construction of STAs. Therefore, I compared avian density, richness and community composition of the STAs to nearby agricultural and natural land types that preceded them. Chapter 3 uses a model selection approach to examine the question of what factors are influencing avian density, richness and community composition of the STAs. Both studies were conducted over four seasons to capture the highly seasonal nature of the South Florida avifauna. Chapter 4 summarizes and synthesizes the information from both the preceding chapters.

CHAPTER 2: COMMUNITY PATTERNS IN TREATMENT WETLANDS, NATURAL WETLANDS, AND CROPLANDS IN FLORIDA

ABSTRACT

In Florida, roughly 18,000 ha of treatment wetlands called Stormwater Treatment Areas (STAs) have been constructed on agricultural land to reduce phosphorous loads to the Everglades. Little is known about how avian communities in these STAs compare to those present on other similar land types. In 2008–2009, point counts were conducted seasonally in the STAs, nearby croplands, and natural Everglades marsh to compare avian communities among these habitats. Overall, avian densities were nearly three times greater in STAs than in the croplands and 38 times greater than in the natural marsh. Local species richness in the STAs was 78% greater than in croplands and nearly four times greater than in the natural marsh. Although natural marshes may have more structural complexity than the croplands and STAs, their oligotrophic status probably limits their ability to support a large bird community. Avian densities varied seasonally among habitat types; avian density was greatest in the winter in STAs as a result of high densities of migratory waterfowl. The STAs may be providing wintering habitat to a significant portion of the North American waterfowl population, including as much as 8% of the breeding population of American Coots (*Fulica americana*). If the trend of increasing numbers of treatment wetlands continues, it has the potential to alter the

distribution of wetland birds, a group that has previously suffered population declines because of habitat loss.

INTRODUCTION

Half the world's wetlands have been destroyed since 1900, primarily from conversion to agriculture (Finlayson and Spiers 1999). This widespread loss of wetlands led to a reduction in vital wetland services such as flood protection, nutrient retention, groundwater replenishment and biodiversity enhancement (Costanza et al. 1997; Zedler 2003).

Whereas the extent of natural wetlands has greatly decreased, the creation of constructed wetlands for wastewater treatment has been increasing since the 1950s (Kadlec and Knight 1996). There are now thousands of treatment wetlands in operation worldwide with hundreds in North America (Kadlec and Wallace 2009). Constructed treatment wetlands capitalize on a wetland's natural ability to capture and store pollutants. Their relatively low maintenance, cost-effectiveness, and versatility have made constructed wetlands an attractive alternative to centralized water treatment facilities (Kadlec and Wallace 2009).

Starting in the late 1990s, a set of treatment wetlands, called Stormwater Treatment Areas (STAs), were constructed in retired cropland in the Everglades Agricultural Area (EAA) of Florida (Figure 2.1) to remove high levels of phosphorous from agricultural runoff (Newman and Pietro 2001). The STAs now contain over 18,000 ha of treatment marsh forming six individual STAs, with an additional 4,500 ha of marsh to be completed in the next several years (Figure 2.1; U.S. Army Corps of Engineers 2010). Additionally, the state of Florida recently purchased 10,845 ha of EAA cropland and plans to expand the use of treatment wetlands in the area (U.S. Army Corps of Engineers 2010). Conversion of this agricultural land to treatment wetland would be a significant addition of wetland area to Florida, and indeed the nation, considering that vegetated freshwater wetland area in the US decreased by 75,000 ha between 2004–2009 (Dahl 2011).

Treatment wetlands appear to support large and diverse biological communities. Over 1,400 species of invertebrates, fish, amphibians, reptiles, birds, and mammals have been reported in treatment wetlands of North America (Knight et al. 2001). High wildlife occurrence has also been reported in treatment wetlands in Great Britain (Worrall et al. 1997), Australia (Greenway and Simpson 1996), and Africa (Nyakang'o and van Bruggen 1999). In South Florida, a single study of bird presence in STAs (Chimney and Gawlik 2007) suggest that STAs support a rich avian community as compared to other nearby wetland types. More quantitative comparisons of how avian communities of the STAs compare to other wetland habitat types are lacking. Also, little attention has been given to seasonal patterns of wildlife occurrence in treatment wetlands. Avian communities in treatment wetlands of South Florida should vary seasonally, because most species that occur regularly in the region do so primarily in winter or during migration (Robertson and Kushlan 1974).

The aim of this study was to investigate the effects of STAs on avian communities. It was not possible to compare the avian community before and after construction of STAs. Therefore, we compared differences in bird density, species richness, and avian community composition between STAs and reference land types that preceded them (i.e., croplands and natural Everglades marshes; Figure 2.1). We also evaluated seasonal changes in avian communities among these land types.

METHODS

Study Area

This study was conducted in 2008–2009 across six STAs, natural marsh land and cropland in South Florida. The six STAs are distributed across the interface between the extant Everglades and the EAA (Figure 2.1). STA-1E, along with STA-1W straddles the northern boundary of the Arthur R. Marshall Loxahatchee Wildlife Refuge. STA-2 and STA-3/4 are the most centrally located of the STAs and are directly adjacent to WCA2A and WCA3A, respectively. STA-3/4 is centered at 26° 22' 2" N, 80° 36' 53" W (geographic center of all STAs lies within the EAA). STA-5 and STA-6 are the most westerly located STAs. The STAs primarily utilize two vegetation treatments to remove phosphorous from agricultural runoff (Gu and Dreschel 2008). One vegetation treatment, termed MIX, was dominated by *Typha* and contained sporadic open water patches. The other vegetation treatment consisted of large areas of open water with submerged aquatic vegetation (e.g., *Najas guadalupensis, Chara* spp., *Ceratophyllum demersum,* and *Hydrilla verticillata*). Within each STA, surveys were distributed nearly evenly between the two vegetation treatments (388 surveys in MIX and 398 surveys in SAV).

Surveys in the natural marsh land type were conducted in a 203,500 ha region of extant Everglades known as southern Water Conservation Area 3A (WCA3A; Figure 2.1) that predominantly consists of sawgrass (*Cladium jamaicense*) ridges and herbaceous sloughs (Davis et al. 1994; Gunderson 1994; Ogden 2005). This area was chosen because it contains relatively natural hydrologic patterns and low nutrient levels, so it best represents the historical condition of the STAs footprint prior to agricultural development. Additionally, these sites have long hydroperiods, similar to STAs, which allowed us to access our survey sites via airboat during times of the lowest water levels.

Surveys in the crop land type were conducted in the EAA (centered on 26° 38' 18" N 80° 38' 32" W), a vast agricultural matrix that encompasses nearly all land between Lake Okeechobee and the extant Everglades (Figure 2.1). The main crop produced in the EAA is sugarcane; however, corn, rice, sod, and other vegetables are also produced there (Snyder and Davidson 1994). Potential habitat for birds includes various stages of sugarcane and sod cultivation including dense, mature sugarcane stands, fallow and recently harvested fields, canals and ditches between fields, and flooded fields (Pearlstine et al. 2005).

Survey Design

This study consisted of point count surveys conducted in three land types during four seasons over 2 years. The three land types in this study had different accessibility requirements which prevented us from utilizing one type of survey in all areas. The natural marsh of WCA3A was most practically accessible by airboat. The cropland of the EAA consists of a grid of sugarcane and other crop fields (16 ha each). This area was only accessible by automobile; therefore, surveys in this land type were conducted from road levees bordering crop fields. The STAs consisted of large (some >900 ha) treatment cells separated by levees. Because of their large size and extensive levee system, surveys in the STAs consisted of both point counts from levees and from airboats. Dual survey techniques also allowed for direct comparisons between STAs and the other two land types.

To capture seasonal and annual variation in bird use, we conducted surveys during winter (Feb), spring (May), summer (Aug), and fall (Nov) of 2008–2009 for a total of eight survey periods. During each survey period, survey areas (individual STAs, the natural marsh, and cropland sites) were visited in the same sequence to maximize efficiency. However, the starting survey area was randomized each survey period to reduce sampling bias. Similarly, survey sites within each area were visited sequentially, with the starting point randomized each survey period.

Twelve levee point counts were generated in each of the six STAs (six per vegetation treatment) along levees using ArcGIS 9.3 (ESRI 2008). STA-6 was dominated by shrubby vegetation rather than a target vegetation treatment. Therefore, 12 completely random levee point count locations were selected in STA-6 rather than locations stratified by vegetation treatment. Airboat point counts were not performed in STA-6, because it is dominated by shrubby vegetation, and it often did not have sufficient standing water to safely operate an airboat.

Point counts in the STAs conducted from airboats were added during the spring 2008 survey period to allow for direct comparisons between the interior marsh and levee point counts. Airboat point counts were initially intended to accompany strip transect surveys. The locations of two, 400m x 100m strip transects were generated randomly per vegetation treatment within each STA using ArcGIS 9.3 (ESRI 2008). Transects were dropped from the study, because they did not effectively survey birds in the open water

SAV habitat. Point count data from the ends of each transect were continued and pooled (hereafter ‘point count set’), because these points were not independent of each other and some transects could not accommodate point counts at both ends. Two airboat point count sets were conducted in each vegetation treatment of each STA (except STA-6) for each survey period.

In the natural marsh, seven point count locations were surveyed. Five airboat point count locations were used from a previous study by Gawlik and Rocque (1998) and two random point count sets associated with strip transects were created using the same methods as those in the STAs. Only points located in sawgrass ridge and slough habitat were selected for surveys because this was the dominant vegetative community where the STAs are now located (Gunderson 1994; Ogden 2005). Survey points encompassed an area of roughly 12,000 ha of southern WCA3A centered at 25° 54' 32" N, 80° 45' 47" W (Figure 2.1). All survey sites were well within known distribution ranges for all species detected during this study.

Point counts in the cropland were conducted from roads at field edges that were adjacent to canals, analogous to levee point counts in the STAs. Random survey locations were generated in sugarcane, sod, and fallow fields in roughly equal proportions to their availability. Unlike the other two land types, field types in the EAA were not static and often changed between survey periods. When fields changed to a type other than sugarcane, sod, or fallow, the fields were dropped from the study and replaced with new sugar, sod or fallow fields. Between 103–116 (total 869, median = 108) points were surveyed in the crop land type each survey period.

Field Methods

All surveys consisted of double-observer, fixed interval, semicircular point counts (Reynolds et al. 1980; Ralph et al. 1995; Nichols et al. 2000; Rosenstock et al. 2002). At a maximum radius of 200 m, each semicircular point count covered a survey area of ~7 ha. Surveys began within a half hour of sunrise and lasted up to 4 hours. Upon arrival at the survey location, observers recorded time and weather conditions and waited at least 3 mins before beginning surveys. In a previous study using airboat point counts, Gawlik and Rocque (1998) found that 2 mins was sufficient time for birds to recover from the disturbance caused by their arrival. Each survey period lasted 6 mins followed by 3 mins of call-back surveys for secretive marsh birds modified from Conway (2008). During the 6-min survey period, the two observers identified as many birds as possible by sight and sound within the 200-m semicircle in front of them. Birds were identified to species. We also recorded the group size, method of identification (seen or heard), distance class (<10 m, 10–25 m, 26–50 m, 51–100 m, 101–150 m, 151–200 m), and habitat characteristics where birds were observed (Nichols et al. 2000). Birds that were flying over the survey area were recorded only if they were utilizing the surveyed habitat; i.e. aerial foraging by species such as Northern Harriers (*Circus cyaneus*) and Tree Swallows (*Tachycineta bicolor*). Call-back tapes included calls from American Bittern *(Botaurus lentiginosus)*, Least Bittern *(Ixobrychus exilis)*, King Rail *(Rallus elegans)*, Marsh Wren *(Cistothorus palustris)*, and Sora *(Porzana carolina)*. Calls were played in the same sequence for every survey. Any of these species that responded to the callback recordings were added to the point count datasheets and noted as being detected by callback surveys (Conway 2008).

Statistical Analyses

DISTANCE 6.0 release 2 (Thomas et al. 2010) was used to estimate the bird density in each land type, while accounting for differences in detectability among land types and seasons. All species were pooled to calculate overall bird densities. Guild, season, vegetation treatment, and survey area (levee or interior marsh) were used as covariates to model the detection probability curve (Buckland et al. 2004). Non-overlapping standard errors were used as evidence of significant differences in densities among land types and seasons. For the analysis of land types, data were pooled across STAs and pooled across crop types.

Local species richness was calculated as the total number of species detected per point. All data were rank transformed to remove the influence of the distribution of the data (Conover and Iman 1981). General linear models (Proc GLM; SAS Institute 2008(Proc GLM in SAS 2008) were used to test for differences in species richness between land types, seasons, and years. Initial general linear models contained all pertinent variables and interactions. Nonsignificant ($P > 0.05$) terms were removed using backwards model selection. Least squared means and Tukey Tests were used to compare among levels within variables. All richness and density values are reported in the results as means ± SE. To correct for potential bias associated with unequal sampling effort, we used rarefaction curves to examine species richness relationships among land types.

In order to assess patterns in species compositions, species were grouped into guilds defined by their resource requirements, habitat use, and/or detectability for some analyses. Guilds were defined as follows: Wading Birds (egrets, ibis, storks, etc.), Waterfowl (ducks, coots, gallinules, etc.), Passerines (and near passerines; blackbirds, warblers, sparrows, etc.), Shorebirds (sandpipers, plovers, yellowlegs, dowitchers, etc.), Secretive Marsh Birds (rails, bitterns, etc.), Raptors (hawks, kites, falcons, eagles, etc.) and Diving Piscivores (cormorants, anhingas, terns, pelicans). Chi-square goodness-of-fit was used to test for differences in community structure among habitat types (Cochran 1952) using the SAS statistical software (Cochran 1952; SAS 2008). A full list of species detected during this study and their guild associations is available in Table 2.2.

Plymouth Routines in Multivariate Ecological Research, Version 6 (Primer v6) was used to compare community structure in each land type and season (Clarke and Gorley 2006). Individual species abundances from each survey were square root transformed to reduce the influence of numerically dominant species (Clarke and Warwick 2001). Non-metric multidimensional scale (NMDS) ordinations based on Bray-Curtis similarities were used to visually illustrate relationships among different groupings. Species abundances from a single land type and survey period were averaged into survey "sets" for better graphical representation. A non-parametric analog of analysis of variance (Analysis of Similarity-ANOSIM) with a two-way crossed design was used to test for significant differences in species abundances between seasons and land types. ANOSIM uses a Monte Carlo randomization procedure to test if dissimilarities among *a priori* groupings are significantly different from random samples. A pair-wise R statistic < 0.05 was used as evidence of significant differences (Clarke and Gorley 2006).

Post Hoc Analyses

After conducting and examining all a priori analyses of the avian community patterns in treatment wetlands and their nearby reference land types, it was clear that one species guild was overwhelmingly driving avian use patterns among land types. In order to examine the influence of other guilds on avian community patterns, I removed that species group from the dataset and reanalyzed the data.

One species, the American Coot (*Fulica americana*), showed exceedingly high densities in the STAs, which prompted us to conduct a post hoc analysis of how their numbers in the STAs compare to the North American population. We estimated coot densities for both MIX and SAV treatments and these estimates were multiplied by the corresponding area of each vegetation treatment. These numbers were then compared to the estimated American Coot breeding population in North America (Brisbin Jr. and Mowbray 2002)

RESULTS

We conducted a total of 54 airboat point counts in the natural marsh, 582 levee and 140 airboat point counts in the STAs, and 869 levee point counts in the crop land type. We detected 257 individual birds from 24 species in the natural marsh, 53,607 individuals from 102 species in the STAs and 38,999 individual birds from 85 species in the cropland (Appendix 1). There was no difference in bird density, richness, species composition, or community structure between years (all $P > 0.05$). Therefore, data from both years were pooled.

Density and Species Richness

Averaged across all seasons, local species richness and density were greatest in the STAs and lowest in the natural marsh (all $P < 0.01$). Local species richness in the STAs averaged 7.3 ± 0.1 species per survey compared to 4.1 ± 0.1 species per survey in the crop land type and 1.8 ± 0.2 species per survey in the natural marsh. Mean density in the STAs was 43.0 ± 1.7 birds/ha compared to 15.9 ± 0.5 birds/ha in crops and 1.1 ± 0.2 birds/ha in the natural marsh. The rarefaction curves (Figure 2.2) showed a similar difference in species richness among land types, with specific estimates corrected for sampling effort.

Bird density and species richness per point varied among land types depending on season (all $P < 0.05$). However, the natural marsh always had the lowest values of any land type for both metrics. Local species richness in the STAs peaked in fall and winter (8.4 ± 0.3 and 9.2 ± 0.3 species/point, respectively) and was always higher than in the crop land type. Richness in the croplands did not vary greatly by season (3.8–4.3 species/point; Figure 2.3). Bird density in the STAs peaked during winter and was higher than in the croplands during winter, spring, and fall (111.7 ± 22.5 vs. 9.3 ± 0.8 birds/ha, 16.5 ± 2.3 vs. 10.7 ± 0.9 birds/ha, and 53.5 ± 0.5 vs. 19.8 ± 1.7 birds/ha, respectively; Figure 2.4). Bird density during summer was not different between the croplands (10.4 ± 0.8 birds/ha) and STAs (11.3 ± 1.3 birds/ha).

Species Composition

Pooled across seasons, the most common species in the STAs were the American Coot and Common Gallinule *(Gallinula galeata)*, respectively. The Red-winged

Blackbird *(Agelaius phoeniceus)*, Tree Swallow, and Killdeer (*Charadrius vociferus*), were the most common species, respectively, in croplands. The Red-winged Blackbird, Tree Swallow, and Boat-tailed Grackle *(Quiscalus major*), respectively, were the most common species in the natural marsh.

Guild compositions were significantly different among all three land types (all $P < 0.001$; Figure 2.5). Waterfowl, with 70% of the total abundance, was the dominant guild in the STAs. This contrasts with both the crop and natural marsh land types, which were dominated by passerines (71% and 74% respectively). In addition to waterfowl, the STAs had higher abundances of diving piscivores and secretive marsh birds compared to the other land types. In addition to passerines, there were higher than expected numbers of shorebirds, raptors, and wading birds in the crop land type. The natural marsh had higher than expected numbers of secretive marsh birds. The NMDS ordination showed that the community compositions were clearly segregated by land types, with the lowest spread (highest similarity) shown by the survey sets of the STAs and the greatest spread (lowest similarity) shown by the sets of the natural marsh. The stress value of 0.12 shown by the 2-D NMDS in Figure 2.6, means that this representation is useful in discerning groupings (Clarke and Warwick 2001).

Our interpretations of the patterns shown by the NMDS analyses were supported by the ANOSIM results. All three pairwise comparisons between land types were significantly different ($R = 0.75$), all $P < 0.001$), thus showing that bird communities in all three land types were significantly different from one another.

Guild compositions varied by season in all land types (all $P \leq 0.02$). Waterfowl comprised 74 and 77% of all birds in the STAs during fall and winter respectively. However, during spring and summer this guild comprised only 43 and 59% of all birds, respectively. As a result, the contribution of passerines grew from 10 and 15% during fall and winter, respectively, to 37 and 22% during spring and summer, respectively. Passerines, the dominant guild in the crop land type, did not fluctuate as much by season as did waterfowl, the dominant guild in the STAs. Passerine abundance in the croplands was lowest in fall with 65% of total abundance, and peaked in the winter with 80% of total abundance. Passerine dominance in the natural marsh was lowest during winter at 55% of total abundance and peaked in fall at 85% of total abundance. The 2D NMDS diagram (Figure 2.3) also showed clear grouping of winter/fall and spring/summer seasons in the STAs. The other two land types did not show such patterns.

Post-hoc Analyses

It was clear from all a priori analyses that the dominant avian use patterns among land types were driven by waterfowl. To examine the influence of guilds other than waterfowl, I removed all waterfowl data from the dataset and reran analyses. Density and richness were still greatest in the STAs and lowest in the natural marsh after waterfowl were removed from the dataset (Figure 2.7). Density was estimated at 16.8 ± 2.1 birds/ha in the STAs (61% reduction), 10.7± 0.3 birds/ha in the crop lands (32% reduction) and 1.6 ± 0.4 birds/ha in the natural marsh (not significantly different). Local richness averaged 5.4 ± 0.1 species/survey in the STAs (26% reduction), 4.0 ± 0.1 species/survey in the crop lands (not significantly different) and 1.6 ± 0.2 species/survey in the natural marsh (not significantly different). Seasonal patterns were not very different after waterfowl were removed except the magnitude of the differences between the STAs and crop lands was reduced in most cases. After removal of waterfowl from the dataset, seasonal density patterns could not be calculated for the natural marsh because confidence intervals overlapped zero. One difference in seasonal patterns without waterfowl was that density in the crop lands was greater in summer than in the STAs (Figure 2.8). Density was still greater in the STAs during all other seasons. Similarly, without waterfowl, richness in summer is not different between the STAs and crop lands (Figure 2.9) where it was greatest in the STAs during all seasons with waterfowl.

Patterns in species compositions among land types were less clear after waterfowl were removed from the dataset; especially between the STAs and crop lands (Figure 2.10). The composition of the natural marsh is clearly different from the other two land types. The STAs are still showing two seasonal groupings but there is not clear separation between the crops and STAs, like was shown when waterfowl were driving community patterns among these land types.

Densities of American Coots in the STAs during winter averaged 22.2 coots/ha in SAV habitat and 0.70 coots/ha in MIX habitat. STAs contain roughly 8,200 ha of SAV habitat and 10,000 ha of MIX habitat with another 2,175 ha of SAV and 2,650 ha of MIX habitat to be created in STA expansion projects. Applying the observed coot densities to the area of each vegetation treatment suggests that STAs currently support roughly 190,000 American Coots during winter, with the potential to support up to 240,000 coots after the expansion of STAs is complete. The latter estimate constitutes 8% of the 3 million breeding individuals estimated in the North American population (Brisbin Jr. and Mowbray 2002).

Averaged over all seasons, the STAs had more species overall, higher densities, and higher local species richness than did the crop or natural marsh land types. While these metrics were lowest in the natural marsh during all seasons, density was highest in the STAs during all seasons except summer. Local species richness was highest in the STAs during all seasons. Waterfowl were the numerically dominant guild in the STAs, particularly in winter and fall. The crop and natural marsh land types were dominated by resident passerines whose abundances were more stable through the seasons. Each land type's community composition was distinct from one another and the STAs had distinct compositions between pairs of seasons (winter and fall vs. spring and summer).

DISCUSSION

The STAs provided habitat for a much larger and more diverse bird community than their reference land types. Density in the STAs was nearly three times that of the crop land type and 38 times greater than in the natural marsh. Local species richness in the STAs was 78% greater than in the crops and nearly four times greater than in the natural marsh. Moreover, the addition of the STAs supported a distinct bird community within the landscape of the Everglades that does not match either that of the croplands or the natural marsh, as evidenced by the differences in species composition and the distinct separation of land types in the NMDS analysis.

Land Use Changes

In most systems, conversion of natural land types to agriculture reduces bird use because croplands and pastures have less structure than the natural land types they replace (Gaston et al. 2003). However, the opposite has happened in the EAA. With conversion of marsh in the Everglades to cropland, bird density likely increased, although not species representative of the natural marsh community. Although natural marsh may have slightly more structural complexity than croplands, their oligotrophic status probably limits their ability to support a large bird community.

The greater density and richness in the STAs compared to the other land types may reflect their combination of high primary production and habitat heterogeneity (Wiens 1989; Weller 1999). The primary production of the STAs and EAA is orders of magnitude greater than the natural marsh of the Everglades (Newman et al. 2004; Chimney and Goforth 2006) and is likely why the density of avian herbivores was so high in STAs. High primary production can increase waterbird abundance by supporting more macrophyte and macroinvertebrate food resources (Lodge 1996; Weller 1999) as well as increasing the abundance of birds that forage at higher trophic levels like raptors, wading birds, and diving piscivores. Habitat heterogeneity increases the diversity of food resources in an area and allows multiple species to forage without competing for similar resources (Wiens 1989). In contrast to the STAs, the EAA had high primary production because of intensive agricultural practices, but low structural complexity because of field leveling and planted monocultures.

Creation of the STAs has both concentrated and reallocated primary production from the EAA into more usable forms for birds, while at the same time increased habitat heterogeneity. The 18,000 ha of marsh that make up the STAs collect phosphorous-rich runoff from about 280,000 ha of EAA land. The productivity from this nutrient rich water is allocated to a diverse mix of emergent (e.g., cattail, *Typha* spp.; bulrush, *Scirpus* spp.; bent alligator-flag, *Thalia geniculata),* submergent (e.g., waterthyme, *Hydrilla verticillata*; muskgrass, *Chara* spp.; and common waternymph, *Najas guadalupensis*), and floating (e.g., American white waterlily, *Nymphaea odorata*; common water hyacinth, *Eichhornia crassipes*; water lettuce, *Pistia stratiotes*) plants. Many other herbaceous and woody plants inhabit the high ground of the levees. The diversity of macrophytes as feeding, perching, foraging, and nesting substrates in the STAs likely exceeds that in the monocultures of the EAA.

Another feature of the STAs that makes them attractive to waterbirds, especially waterfowl, is that when surrounding areas are dry, STAs usually remain inundated. Bird use (especially by waterfowl and shorebirds) is highest in STAs during South Florida’s dry season when water is increasingly less available in the Everglades and other surrounding wetlands. The STAs are managed to maintain standing water throughout the dry season to sustain the preferred vegetation communities and prevent the release of phosphorus from sediment when rewetted. At a time when few areas of the Everglades system and surrounding wetlands may have shallow standing water, the STAs continue to be available habitat for various waterbirds. Long hydroperiods also favor production of large fish which are prey for species such as Double-crested Cormorants (*Phalacrocorax auritus*) and Osprey (*Pandion haliaetus*).

Avian Community Effects

Seasonality had a great effect on the community composition and density among land types with bird density being greatest in winter, both in the natural marsh and in the STAs. Florida lies along the major Atlantic Flyway which brings large numbers of birds in close proximity to the Everglades system during winter migration. The pool of birds available to settle in any land type in southern Florida is greatest in winter and during migration (Robertson and Kushlan 1974), and indeed this was the pattern of bird density in the natural marsh and STAs. However in the EAA, bird density was greatest in fall. This pattern may result from resident species recruitment and stopover of migrants like shorebirds. Migrating waterfowl were the primary driver of the seasonal differences in bird use within the STAs. Despite their near absence for half of the survey periods, two of the three most abundant species in the STAs, the American Coot and Blue-winged Teal (*Anas discors*), were wintering waterfowl. This seasonal influx of waterfowl also affected bird use within vegetation treatments of the STAs. Density and richness were much greater in the SAV vegetation treatment, wintering waterfowl were much more dominant in the SAV habitat treatment, and the SAV treatment was affected more by seasonal fluctuations in density and richness than was the MIX habitat.

Although waterfowl were clearly driving most of the avian use patterns among these land types, the STAs still had higher bird densities and richness without waterfowl than the other two land types. At the same time, the community compositions of the STAs and crops were more similar, but still distinct without waterfowl. This suggests that the productivity and heterogeneity of the STAs are still attracting a richer and more abundant bird community than the other two land types in addition to exceedingly high waterfowl populations.

The use of treatment wetlands by such a large percentage of the population of American Coots opens the possibility that increased construction of these wetlands could influence the distribution of some wintering waterbirds, over winter survival, and could partially offset the effects of historic wetland losses (Nichols et al. 1983; Sutherland 1998; Jefferies et al. 2004). It is known that birds, particularly the Anatidae, alter migration routes, wintering grounds and breeding grounds in response to changes in habitat (Nichols et al. 1983; Sutherland 1998; Jefferies et al. 2004).

High productivity, consistent shallow water habitat and vegetation structure make treatment wetlands attractive to birds in Florida and elsewhere in the US. Studies of bird use in treatment wetlands from Mississippi, Arizona, and Nevada also show high densities compared to their reference wetlands (Table 2.1; McAllister 1992; McAllister 1993a; McAllister 1993b). These wetlands are not as large as the STAs (4.5–498 ha compared to 348–6,879 ha in the STAs), suggesting that treatment wetlands have the potential to influence bird communities regardless of size, climate, and region.

Expanded use of treatment wetlands is expected to continue in the U.S. and throughout the world. In South Florida, planning and implementation are underway for >9,000 ha of constructed treatment wetland projects to treat runoff entering Lake Okeechobee, the Saint Lucie estuary, and the Caloosahatchee River (U.S. Army Corps of Engineers 2010). The results presented here suggest that expanded use of these treatment wetlands will provide an increase in the amount of habitat for a large group of native wetland birds. Although treatment wetlands do not support the same avian community as neighboring natural marshes, they do provide significant conservation value for a group of birds that has for decades experienced a steady loss of habitat.

CHAPTER 2 TABLES

TABLE 2.1. Bird densities found in treatment wetlands and reference wetlands in studies across the United States. (McAllister 1992, 1993a, 1993b). Densities are reported as birds/ha.

Site Name	State	Treatment Wetland Density	Reference Site Density
Collins	MS	8.5	0.35
Ocean Springs	MS	14.5	0.35
Show Low	AZ	13.8	2.6
Incline Village[1]	NV	19.1	2.6
STAs	FL	43.0	1.1

[1] Passerines were not counted in this study.

TABLE 2.2 Species detected in the crop, STA, and natural marsh (NM) land types grouped by their associated guilds. Species in gray were not identified to species level.

Guild/Species	***Scientific Name***	**Land Type Present**
Wading		
Black-crowned Night-Heron	*Nycticorax nycticorax*	Crop, STA
Cattle Egret	*Bubulcus ibis*	Crop, STA
Great Blue Heron	*Ardea herodias*	Crop, STA, NM
Glossy Ibis	*Plegadis falcinellus*	Crop, STA, NM
Great Egret	*Ardea alba*	Crop, STA, NM
Green Heron	*Butorides virescens*	Crop, STA, NM
Little Blue Heron	*Egretta caerulea*	Crop, STA, NM
Limpkin	*Aramus guarauna*	STA
Roseate Spoonbill	*Platalea ajaja*	Crop, STA
Snowy Egret	*Egretta thula*	Crop, STA
Tricolored Heron	*Egretta tricolor*	Crop, STA, NM
White Ibis	*Eudocimus albus*	Crop, STA, NM
Wood Stork	*Mycteria americana*	Crop, STA
Yellow-crowned Night-Heron	*Nyctanassa violacea*	Crop, STA
Waterfowl		
America Coot	*Fulica americana*	Crop, STA
American Wigeon	*Anas americana*	STA
Black-bellied Whistling-Duck	*Dendrocygna autumnalis*	Crop, STA
Blue-winged Teal	*Anas discors*	Crop, STA
Common Gallinule	*Gallinula galeata*	Crop, STA, NM
Fulvous Whistling-Duck	*Dendrocygna bicolor*	Crop, STA
Greater Scaup	*Aythya marila*	Crop
Green-winged Teal	*Anas crecca*	STA
Hooded Merganser	*Lophodytes cucullatus*	Crop, STA
Mallard	*Anas platyrhynchos*	STA
Mottled Duck	*Anas fulvigula*	Crop, STA
Northern Pintail	*Anas acuta*	STA
Northern Shoveler	*Anas clypeata*	Crop, STA
Pied-billed Grebe	*Podilymbus podiceps*	Crop, STA, NM
Purple Gallinule	*Porphyrio martinica*	Crop, STA
Purple Swamphen	*Porphyrio porphyrio*	STA
Ring-necked Duck	*Aythya collaris*	STA
Ruddy Duck	*Oxyura jamaicensis*	STA
Wood Duck	*Aix sponsa*	STA
Duck		Crop, STA

Passerines		
American Redstart	*Setophaga ruticilla*	STA
Barn Swallow	*Hirundo rustica*	Crop, STA, NM
Blue-gray Gnatcatcher	*Polioptila caerulea*	Crop, STA, NM
Boat-tailed Grackle	*Quiscalus major*	Crop, STA, NM
Bobolink	*Dolichonyx oryzivorus*	Crop
Common Grackle	*Quiscalus quiscula*	Crop
Common Ground-Dove	*Columbina passerina*	Crop, STA
Common Nighthawk	*Chordeiles minor*	Crop, STA
Common Yellowthroat	*Geothlypis trichas*	Crop, STA, NM
Eastern Kingbird	*Tyrannus tyrannus*	STA
Eastern Meadowlark	*Sturnella magna*	Crop, STA
Eastern Phoebe	*Sayornis phoebe*	Crop, STA
Eastern Towhee	*Pipilo erythrophthalmus*	Crop
Fish Crow	*Corvus ossifragus*	STA
Gray Catbird	*Dumetella carolinensis*	Crop, STA
Loggerhead Shrike	*Lanius ludovicianus*	STA
Mourning Dove	*Zenaida macroura*	Crop, STA
Northern Cardinal	*Cardinalis cardinalis*	Crop, STA
Northern Mockingbird	*Mimus polyglottos*	Crop, STA
Northern Waterthrush	*Parkesia noveboracensis*	STA
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	Crop, STA
Palm Warbler	*Setophaga palmarum*	Crop, STA, NM
Purple Martin	*Progne subis*	Crop, STA
Red-winged Blackbird	*Agelaius phoeniceus*	Crop, STA, NM
Savannah Sparrow	*Passerculus sandwichensis*	Crop, STA
Swamp Sparrow	*Melospiza georgiana*	STA
Tree Swallow	*Tachycineta bicolor*	Crop, STA, NM
White-eyed Vireo	*Vireo griseus*	STA
Yellow Warbler	*Setophaga petechia*	Crop, STA
Yellow-rumped Warbler	*Setophaga coronata*	Crop, STA, NM
Blackbird		STA
Flycatcher		Crop
Sparrow		Crop, STA
Swallow		Crop, STA
Warbler		Crop, STA
Shorebirds		
American Avocet	*Recurvirostra americana*	Crop, STA
Black-bellied Plover	*Pluvialis squatarola*	Crop, STA
Black-necked Stilt	*Himantopus mexicanus*	Crop, STA
Greater Yellowlegs	*Tringa melanoleuca*	Crop, STA
Killdeer	*Charadrius vociferus*	Crop, STA, NM
Least Sandpiper	*Calidris minutilla*	STA
Lesser Yellowlegs	*Tringa flavipes*	Crop, STA
Long-billed Dowitcher	*Limnodromus scolopaceus*	STA

Pectoral Sandpiper	*Calidris melanotos*	STA
Ruddy Turnstone	*Arenaria interpres*	Crop
Short-billed Dowitcher	*Limnodromus griseus*	STA
Solitary Sandpiper	*Tringa solitaria*	STA
Spotted Sandpiper	*Actitis macularius*	STA
Wilson's Phalarope	*Phalaropus tricolor*	Crop
Wilson's Snipe	*Gallinago delicata*	STA
Dowitcher	*Limnodromus* spp.	Crop, STA
Peep Sandpiper	*Calidris* spp.	Crop, STA
Sandpiper		Crop, STA
Shorebird		Crop
Yellowlegs	*Tringa* spp.	Crop, STA
Secretive Marsh Birds		
American Bittern	*Botaurus lentiginosus*	Crop, STA
King Rail	*Rallus elegans*	Crop, STA, NM
Least Bittern	*Ixobrychus exilis*	Crop, STA, NM
Marsh Wren	*Cistothorus palustris*	Crop, STA, NM
Sora	*Porzana carolina*	Crop, STA
Raptors		
American Kestrel	*Falco sparverius*	Crop, STA
Bald Eagle	*Haliaeetus leucocephalus*	Crop
Black Vulture	*Coragyps atratus*	Crop, STA, NM
Barn Owl	*Tyto alba*	Crop
Cooper's Hawk	*Accipiter cooperii*	STA
Crested Caracara	*Caracara cheriway*	Crop
Merlin	*Falco columbarius*	Crop, STA
Northern Harrier	*Circus cyaneus*	Crop, STA
Osprey	*Pandion haliaetus*	Crop, STA
Peregrine Falcon	*Falco peregrinus*	Crop, STA
Red-shouldered Hawk	*Buteo lineatus*	Crop, STA, NM
Red-tailed Hawk	*Buteo jamaicensis*	Crop
Sharp-shinned Hawk	*Accipiter striatus*	STA
Snail Kite	*Rostrhamus sociabilis*	STA
Swainson's Hawk	*Buteo swainsoni*	Crop
Turkey Vulture	*Cathartes aura*	Crop, STA, NM
Piscivorous Diving Birds		
Anhinga	*Anhinga anhinga*	Crop, STA, NM
American White Pelican	*Pelecanus erythrorhynchos*	STA
Belted Kingfisher	*Megaceryle alcyon*	Crop, STA, NM
Black Skimmer	*Rynchops niger*	STA
Black Tern	*Chlidonias niger*	STA
Caspian Tern	*Hydroprogne caspia*	STA
Double-crested Cormorant	*Phalacrocorax auritus*	Crop, STA
Forster's Tern	*Sterna forsteri*	STA

Gull-billed Tern	*Gelochelidon nilotica*	Crop, STA
Laughing Gull	*Leucophaeus atricilla*	Crop, STA
Least Tern	*Sternula antillarum*	Crop, STA
Ring-billed Gull	*Larus delawarensis*	Crop, STA
Gull	*Larus* spp.	Crop, STA
Tern		STA

CHAPTER 2 FIGURES

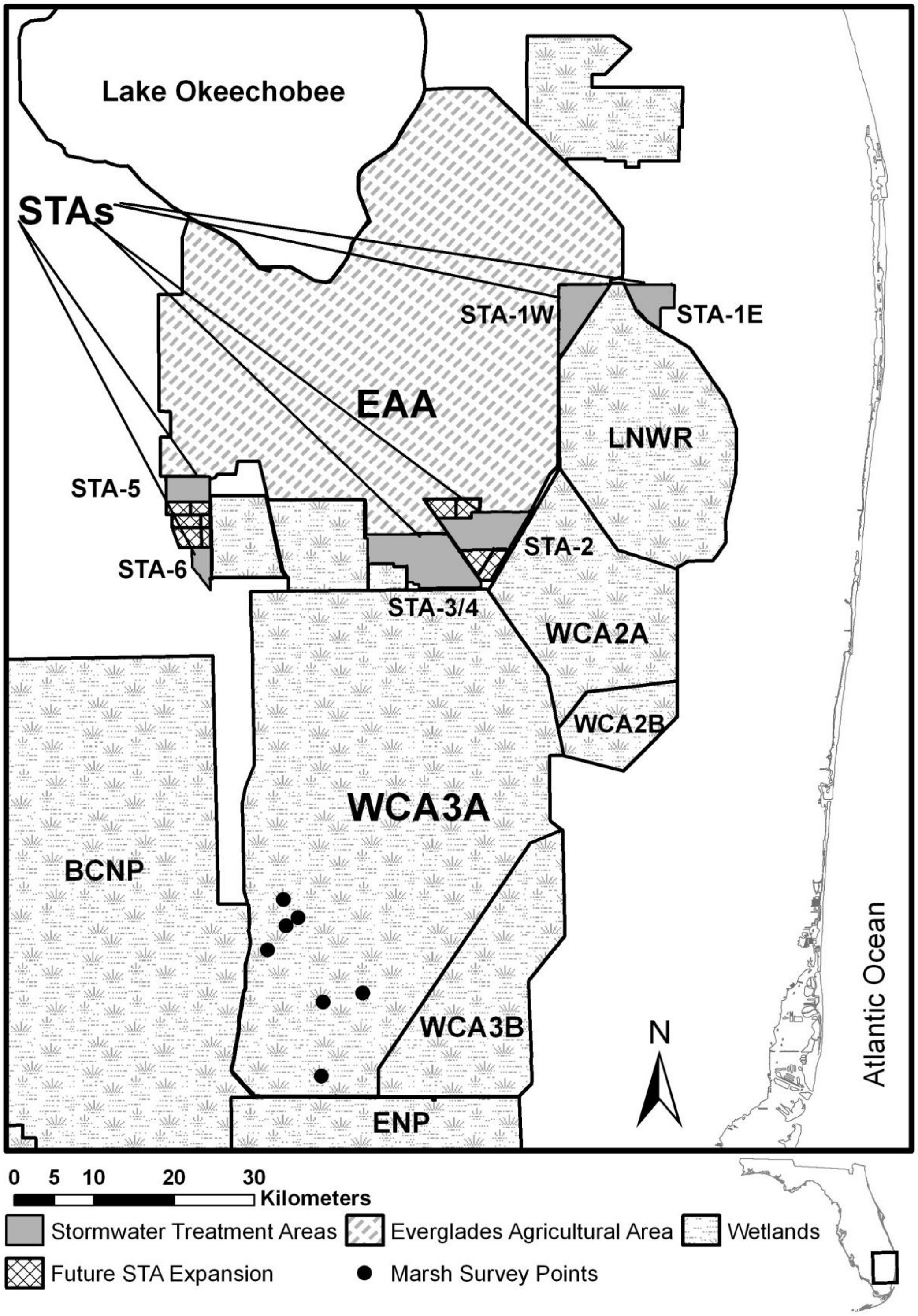

FIGURE 2.1. Locations of WCAs, STAs and EAA within the Everglades system. Most of the nearly one million hectares of historic Everglades marshland have been drained to create the Everglades Agricultural Area (EAA) or have been compartmentalized for flood protection and water supply. What remains consists of the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR), the water conservation areas (WCA2A, WCA2B, WCA3A and WCA3B), Everglades National Park (ENP), and Big Cypress National Preserve (BCNP). The Stormwater Treatment Areas (STAs) are designed to buffer the remaining natural wetlands from agricultural nutrient runoff.

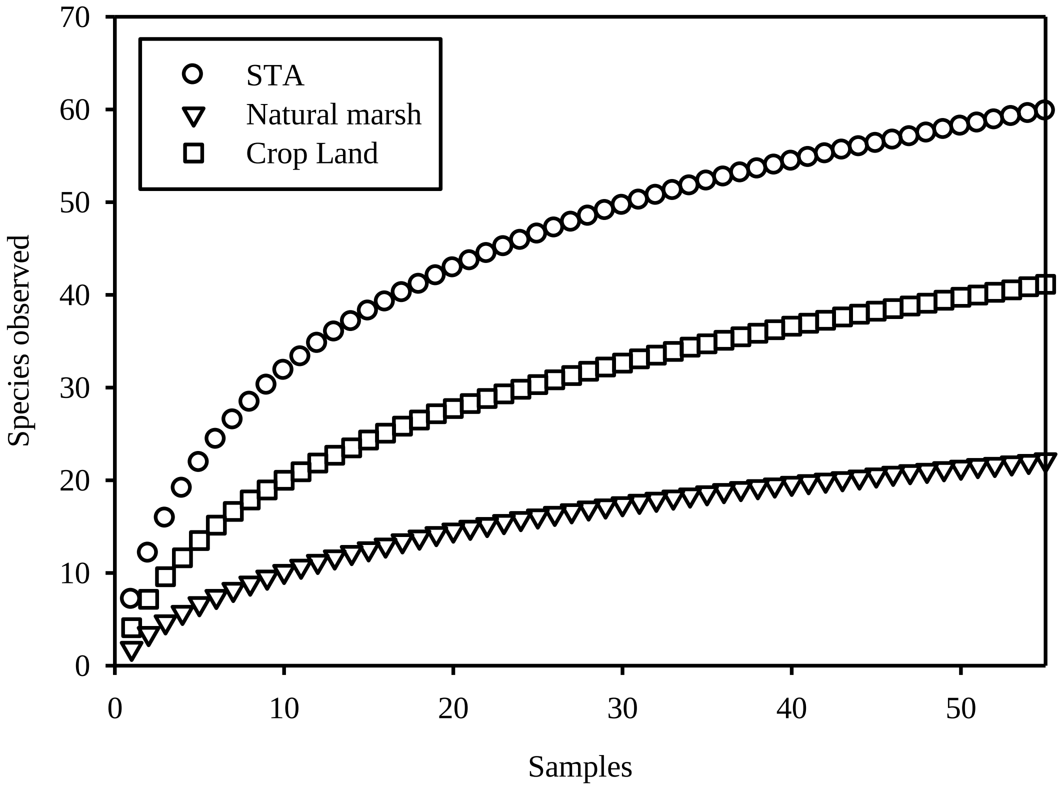

FIGURE. 2.2. Rarefaction curves showing accumulation of species with sampling effort. Correcting for differences in sampling effort, the STA surveys (n=722) accumulated species much more rapidly than surveys in the crop (n=816) and natural marsh (n=54) land types. This suggests that the STAs support a richer community of bird species than the crop and natural marsh land types.

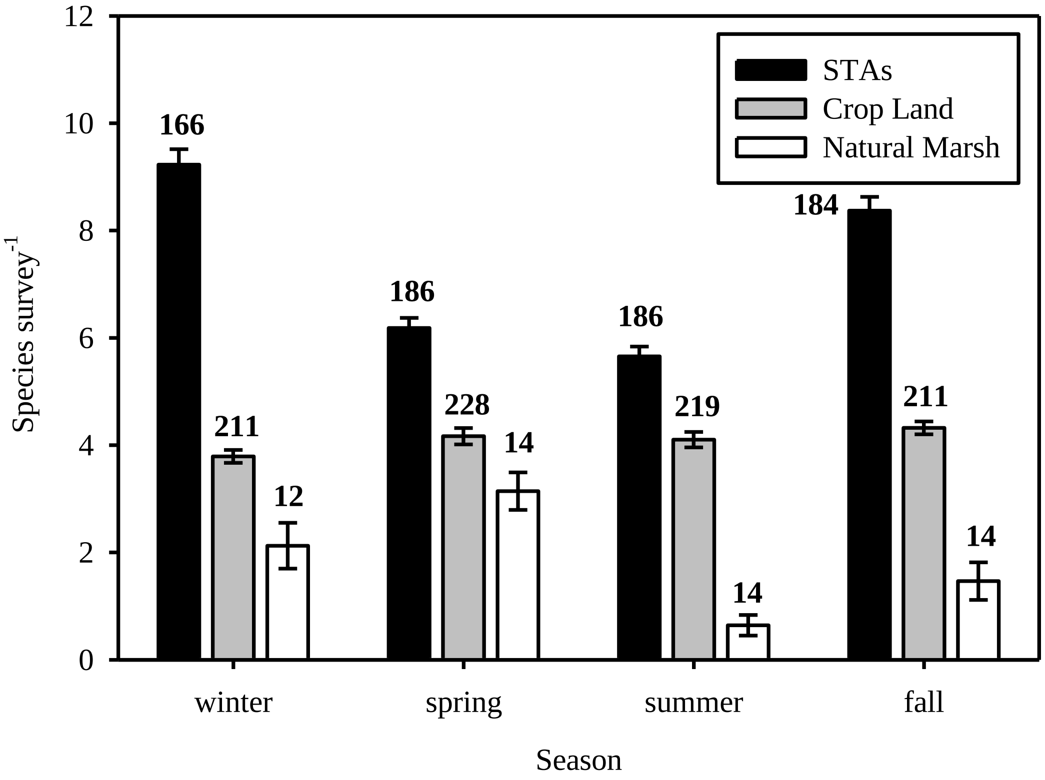

FIGURE 2.3. Species richness in STAs, cropland, and natural marsh in winter, spring, summer, and fall (mean ± 1SE). Species richness was always highest in the STAs and lowest in the natural marsh. However, the magnitude of these differences was very dependent upon season. Numbers above bars indicate respective sample sizes.

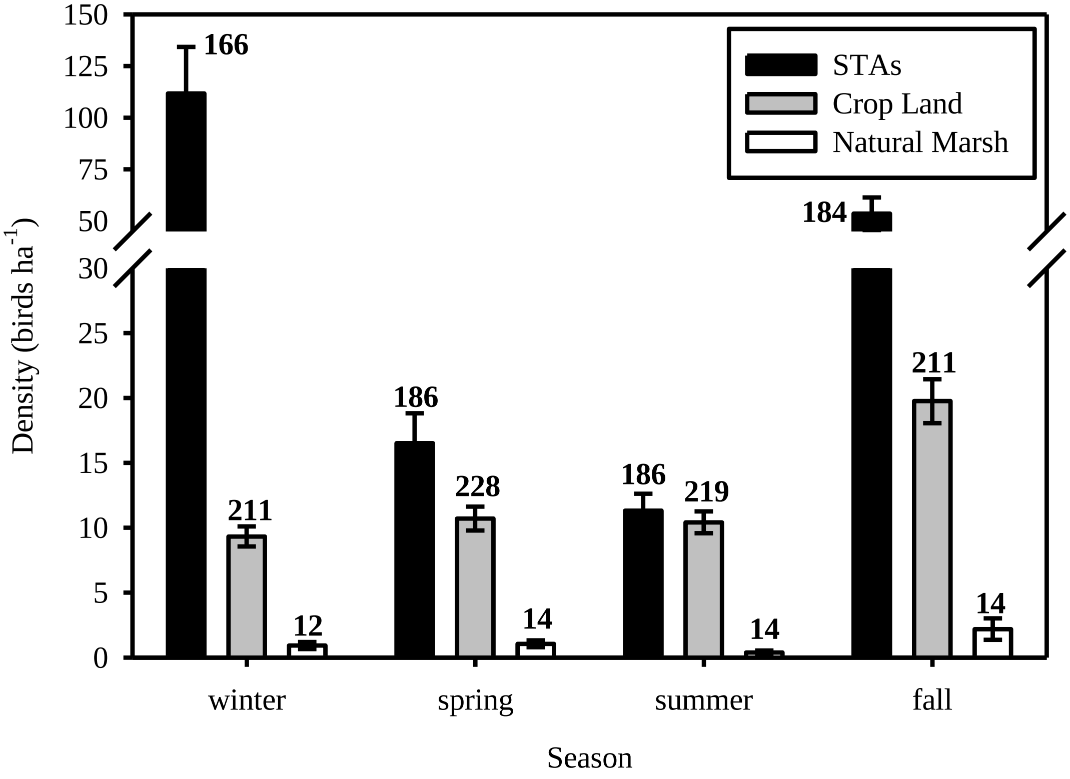

FIGURE 2.4. Avian density in STAs, cropland, and natural marsh in winter, spring, summer, and fall (mean ± 1SE). Avian density was highest in the STAs in all seasons except for summer. The natural marsh always had the lowest density. Numbers above bars indicate respective sample sizes.

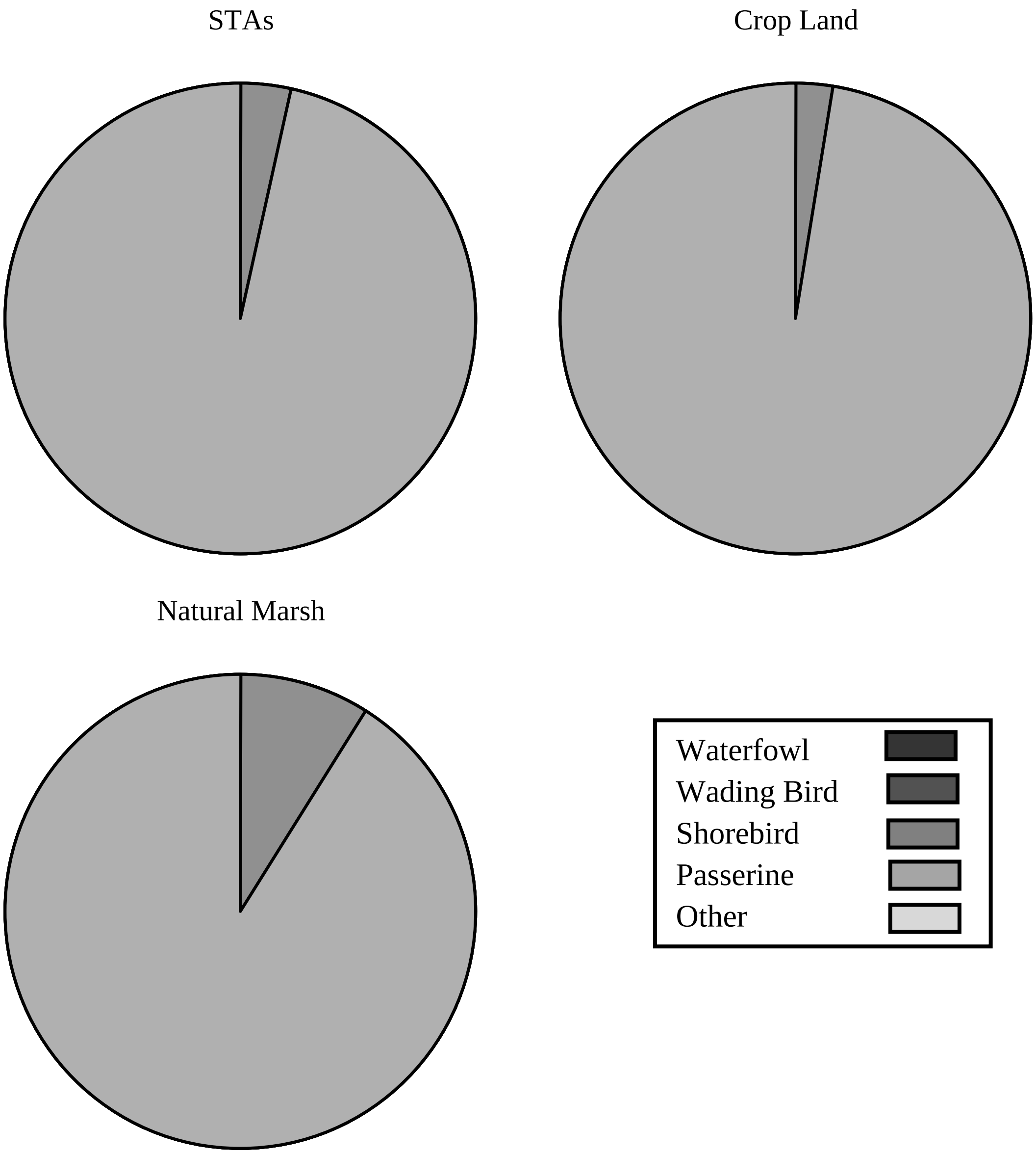

FIGURE 2.5. Avian community composition in STAs, cropland, and natural marsh. Waterfowl were the dominant guild in the STAs, whereas the crop and natural marsh land types were dominated by passerines.

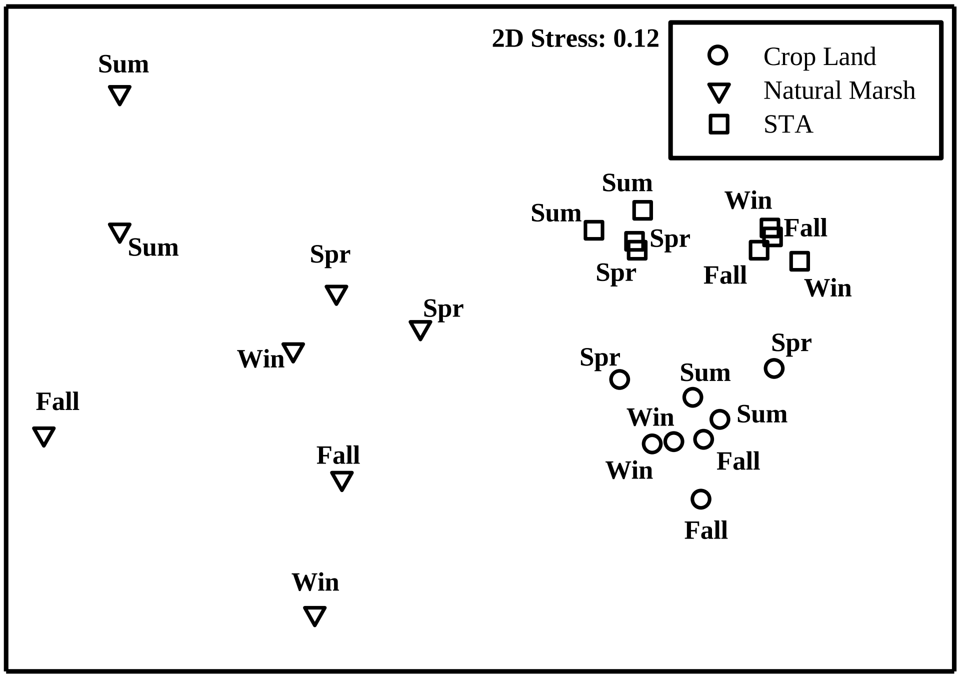

FIGURE 2.6. Non-metric multidimensional scale (NMDS) ordinations were used to show that the avian communities in each land type are clearly different from each other. The STA survey sets showed the highest similarity (lowest spread) when compared to the other two land types. Furthermore, the STA survey sets were separated into two distinct clusters (fall/winter and spring/summer) showing the influence season had on the bird community in the STAs.

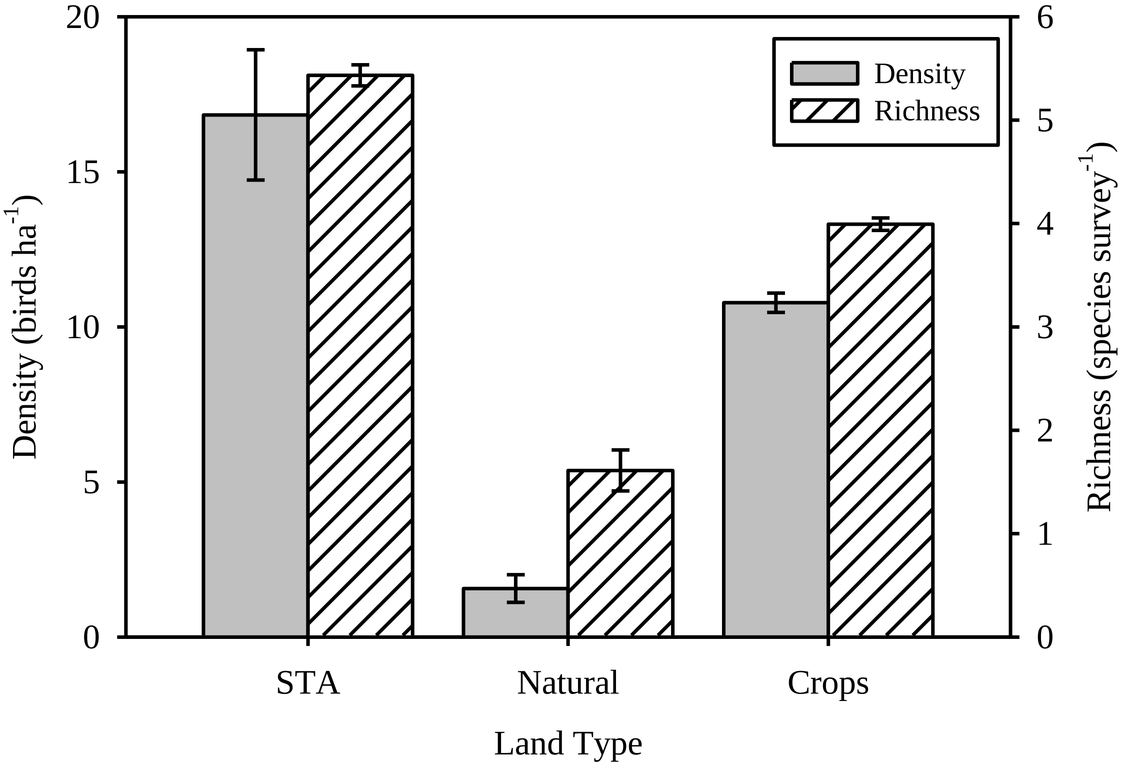

FIGURE 2.7. Avian density and richness in the STAs, natural marsh and crop lands after waterfowl were removed from the dataset. The STAs still had more birds and species than the other two land types but the magnitude of the differences was much smaller.

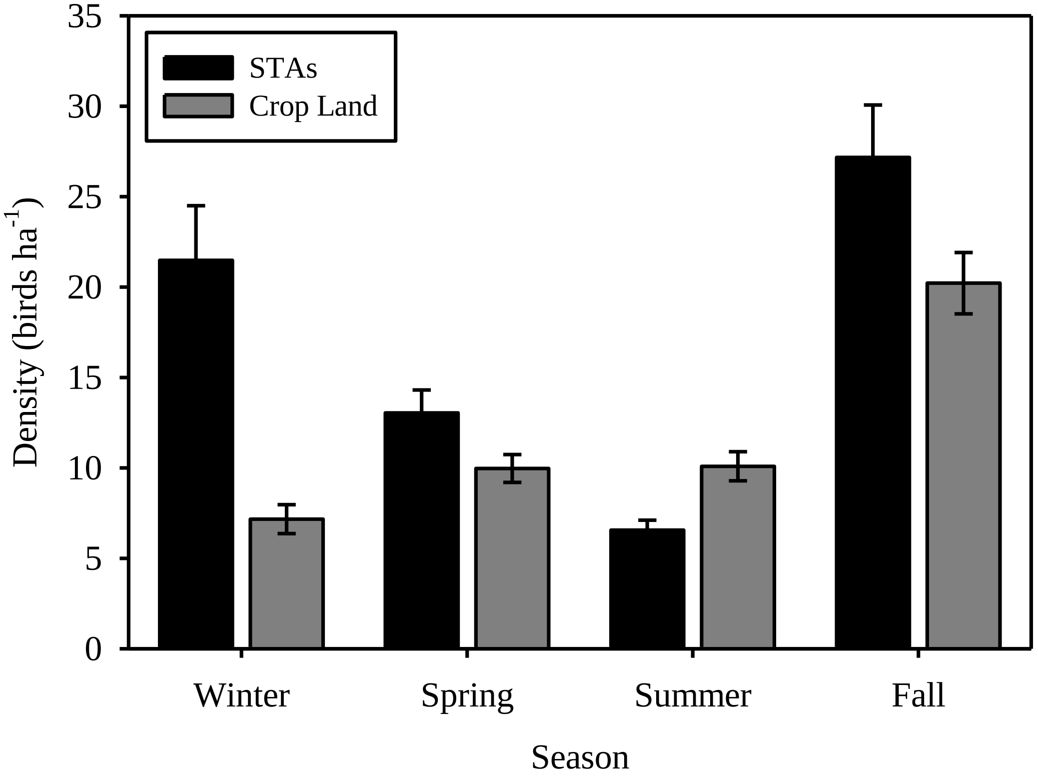

FIGURE 2.8. Avian density in the STAs and crop lands after waterfowl were removed from the dataset was greatest in the STAs in all seasons except summer when it was greatest in the crop land. Avian densities for the natural marsh land type were not calculated.

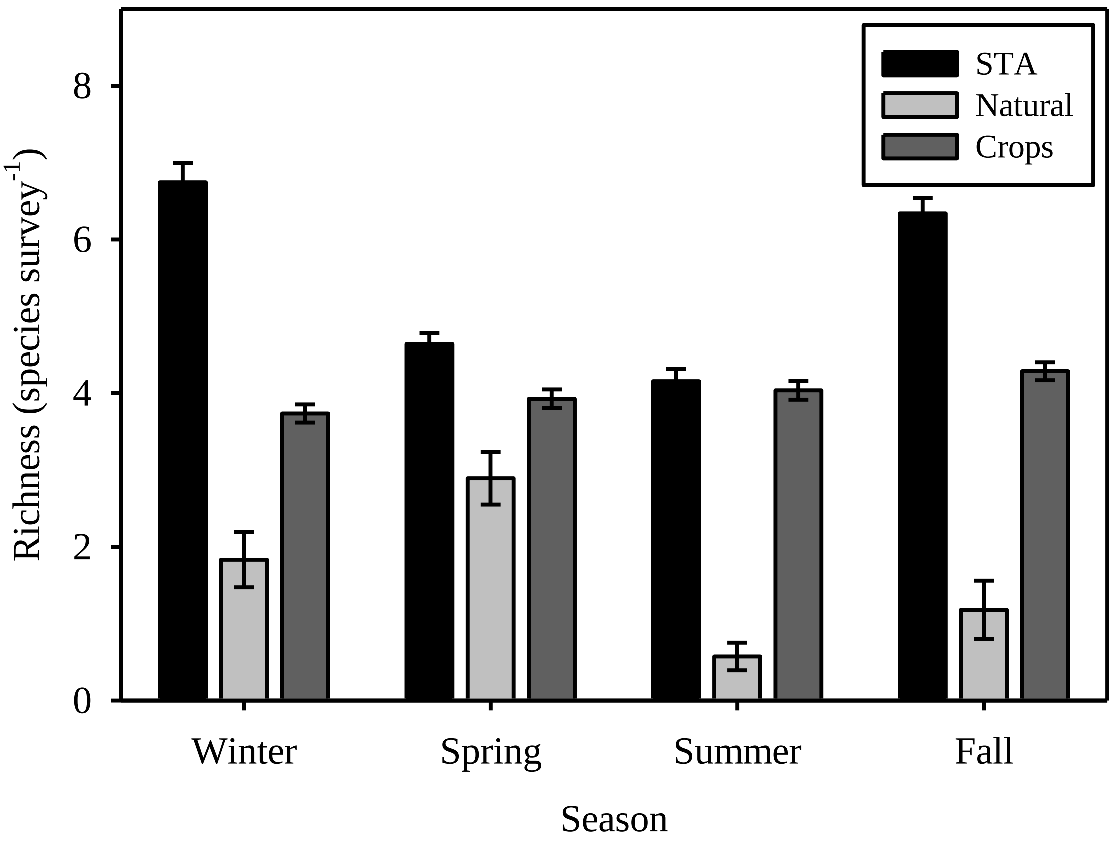

FIGURE 2.9. Species richness in the STAs, natural marsh and crop lands after waterfowl were removed from the dataset showed similar patterns to species richness with waterfowl. Richness was greatest in the STAs during fall and winter and lowest in the natural marsh.

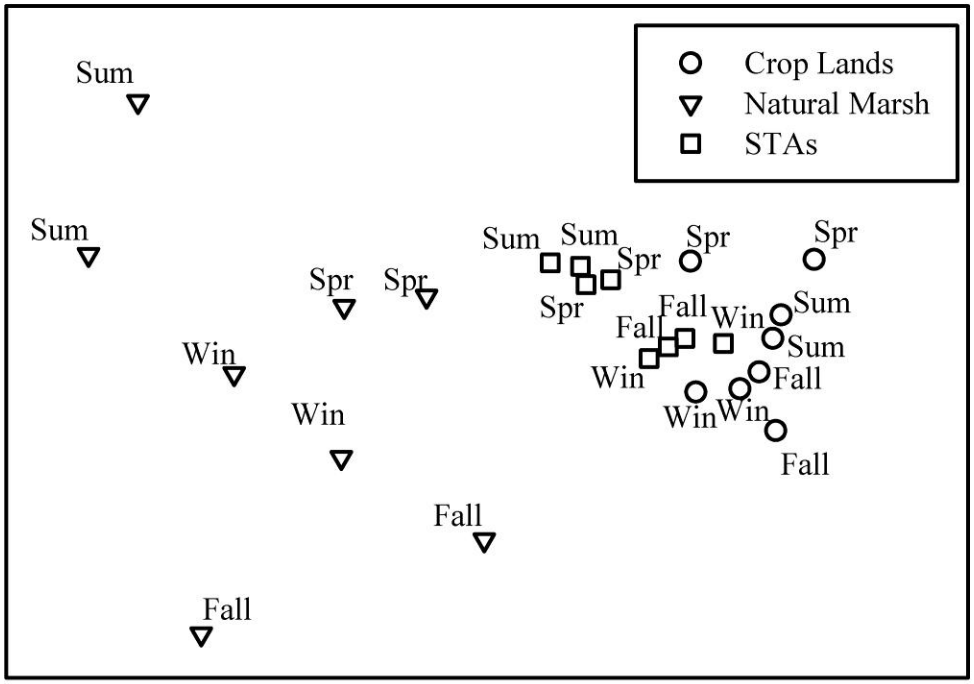

FIGURE 2.10. The NMDS conducted with waterfowl removed from the dataset shows that the STA survey sets still cluster by seasonal groups but survey sets from the crop lands are more similar without waterfowl.

CHAPTER 3: FACTORS THAT INFLUENCE AVIAN USE OF TREATMENT WETLANDS IN SOUTH FLORIDA

ABSTRACT

The use of constructed treatment wetlands to reduce nutrient pollution has been increasing steadily since the 1950's. Wildlife habitat provisioning and its associated recreational opportunities are often listed as ancillary benefits to treatment wetlands. However, there is little quantitative information available on the characteristics of treatment wetlands that are associated with high bird use and diversity. Avian surveys were conducted in five treatment wetlands during four seasons over two years to identify treatment wetland characteristics associated with high bird diversity and density. Season, vegetation treatment and their interaction influenced avian abundance, richness and community composition the most. Avian density in the fall and winter were much greater in the submerged aquatic vegetation (SAV) treatment than in the mixed emergent (MIX) vegetation when wintering waterfowl were present but not different during spring and summer. Species richness was greatest in SAV vegetation in all seasons, but particularly during winter. Utilizing two vegetation treatments enhanced the biodiversity value of the treatment wetlands because each vegetation type supported a distinct avian community with different migratory strategies. Hydrological variables had little influence on waterfowl abundance and richness, probably because the high nutrient levels in treatment wetlands drove productivity more than did water level fluctuations, which

are more typical of oligotrophic wetlands. This study suggests that management aimed at maintaining a diversity of vegetation structure and types will have a positive effect on avian density and diversity.

INTRODUCTION

The use of constructed wetlands for water quality improvement has been steadily increasing since the 1950's (Kadlec and Knight 1996). The increased popularity of constructed wetlands can be attributed to their relatively low maintenance, long-term cost effective, versatile, convenient and environmentally conscious when contrasted with traditional water treatment options. In addition to benefits in terms of water quality improvement, treatment wetlands can provide attractive habitat to a wide range of wildlife. More than 800 species of mammals, reptiles, amphibians and birds have been documented using treatment wetlands in North America (Knight et al. 2001). Attracting wildlife can be both beneficial and detrimental to the support, design, and operations of treatment wetlands. Wildlife attraction enhances biodiversity and provides recreational opportunities such as hunting, fishing, nature observation, photography, exercise and education (Kadlec and Wallace 2009). However, high wildlife abundance has raised concerns about reduced water treatment efficiency due to introduction of external nutrients, increased exposure to harmful contaminants or pathogens (Andersen et al. 2003) and reduced management flexibility due to the presence of protected species.

Waterbirds are especially common in treatment wetlands (Frederick and McGehee 1994; Murray and Hamilton 2010; Beck et al. 2013). In Florida, treatment wetlands host a larger and more diverse bird community than the nearby Everglades marshes or crop lands (Beck et al. 2013). Less is known about the features and conditions that influence bird use of treatment wetlands. Habitat structure is a major influence of bird use (Wiens 1992) and can determine food resources, nesting substrate and cover. The shallow water, vegetative complexity, and high productivity of treatment wetlands may provide high food availability for many species of waterbirds. The relative amount of food that is available to different species probably varies greatly due to differences in bird morphology and behavior and could be a large determinant of the particular bird community present at any one time. Additionally, ground substrate and topography can influence bird abundance (Whittingham and Markland 2002; Seoane et al. 2004). Stable water conditions in treatment wetlands consistently provide habitat when the surrounding areas are unstable or without water, making treatment wetlands a relatively predictable site for resources.

These observations and generalizations do not provide managers with enough quantitative information to develop management regimes that attract or deter birds as desired (Murray and Hamilton 2010). This study aims to investigate the features and conditions of treatment wetlands in South Florida that determine avian abundance, richness, and community composition.

METHODS

Study Area

I chose the Stormwater Treatment Wetlands (STAs) of south Florida as a model system to investigate the factors that influence bird use of treatment wetlands. The South Florida Water Management District constructed six STAS to remove phosphorous from agricultural runoff before it reaches the historically oligotrophic Everglades. The STAs assimilate and filter phosphorous using a combination of emergent and submergent vegetation treatments. The phosphorous laden runoff that feeds the STAs is primarily a product of sugarcane production in the Everglades Agricultural Area (EAA) and each STA receives water from a separate agricultural sub-basin.

The STAs present a unique opportunity to study factors which influence bird use of treatment wetlands because they are a series of treatment wetlands each with independent hydrology, topography and geology. Additionally, the use of two distinct vegetation treatment regimens provides a contrast in contaminant removal methods.

Five STAs are located between the EAA and the Water Conservation Areas (WCAs) of the Everglades. Individually they are named (listed roughly from East to West): STA-1E, STA-1W, STA-2, STA-3/4, and STA-5 (Figure 3.1). STAs 1E and 1W straddle the northern tip of A.R.M. Loxahatchee National Wildlife Refuge. STA-2 is located on the northwestern boundary of WCA 2A. STA-3/4, along with Holey Land and Rotenberger Wildlife Management Areas, make up the northern boundary of WCA3A. STA-5 is located on the western boundary of Rotenberger Wildlife Management Area (Figure 3.1). STA-6 data was not analyzed for this study because it is dominated by shrubby vegetation rather than the marsh habitat types found in the other five STAs.

Survey Timing

This study was designed to capture the pronounced seasonal variation in bird abundance in Florida (Robertson and Kushlan 1974). Therefore, I surveyed birds during each of four seasons; winter (February), spring (May) summer (August), and fall

(November) of 2008 and 2009, for a total of eight survey periods. Individual STAs and survey points within STAs were visited in the same sequence during each survey period to maximize efficiency. However, the starting STA and survey points were randomized each survey period to reduce sampling bias. Surveys began shortly after sunrise and were completed as quickly as possible to maximize bird detectability (Robbins 1981).

Survey Design

I divided survey effort within each STA roughly evenly between two vegetation types that reflect treatment methods for phosphorus (P) removal. One vegetation type utilizes the emergent macrophyte *Typha sp.* to treat waters with the highest levels of P. This vegetation treatment is dominated by *Typha* but also includes sporadic open water patches. I collectively termed this vegetation type as MIX. The other vegetation type (SAV) is dominated by submerged aquatic vegetation (e.g. *Najas guadalupensis, Chara sp., Ceratophyllum demersum,* and *Hydrilla verticillata*) and open water patches. This vegetation type is used to reduce moderate to low P levels (Gu and Dreschel 2008). Although dominated by submergent vegetation, this vegetation treatment sometimes contained emergent vegetation strips and/or exposed spoil from remnant agricultural ditches. Vegetation classes were identified by a combination of site visits and vegetation maps. All areas of SAV and MIX vegetation treatments were delineated on GIS maps of each STA. All levees bordering proper vegetation were outlined for placement of levee point counts. If a levee was bordered by the defined vegetation on both sides, a duplicate line to represent that levee was generated to discern which side of the levee would be surveyed. Six random point count locations were generated along levees bordering each defined vegetation treatment in each STA using ArcGIS 9.3 (ESRI 2008). Strip transect surveys conducted via airboat were originally planned to survey the interior marsh of the STAs. Two 400m transect locations per vegetation treatment of each STA were generated randomly using ArcGIS 9.3 (ESRI 2008). Point counts were added to the end of each transect during the spring of 2008 survey period to give comparable data to levee point counts. Point count data from the same transect were pooled because some transects could not accommodate point counts at both ends and points from the same transect were not independent of each other. Data from airboat transects was not used in this study because airboat transects proved to be ineffective method for surveying birds in the open water SAV.

Hydrology data was collected from DBHYDRO, an online environmental database managed by the South Florida Water Management District (SFWMD). Mean water stage level data for all surveyed STA cells were collected for the duration of the study. Mean cell ground elevation data was collected from SFWMD documentation. To estimate water depth for each survey, the mean cell ground elevation was subtracted from the daily mean water stage of that cell on the day that cell was surveyed. The water level recession rate for the one-week period preceding each survey was calculated by subtracting the water depth 7 days prior to a survey from the depth on the day of the survey and dividing by 7.

Field Methods

Levee and airboat surveys consisted of double-observer, fixed interval, semicircular point counts (Reynolds et al. 1980; Ralph et al. 1995; Nichols et al. 2000; Rosenstock et al. 2002) and surveyed roughly 62.8 hectares (200m radius). Time and weather conditions were recorded upon arrival at the survey location while observers waited at least three minutes to allow nearby birds to acclimate to their presence. A previous study consisting of avian point counts conducted in the Everglades showed that two minutes was an adequate time to allow birds to acclimate to the initial disturbance of the airboat and observers (Gawlik and Rocque 1998). Each survey period lasted 6 mins and was followed by 3 mins of call-back surveys. During surveys, the primary and secondary observers attempted to identify all birds within the 200-meter semicircle by sight and sound. The primary observer announced the birds identified by species, number in group, method of identification (seen or heard), distance class (>10 m, 10-25 m, 26-50 m, 51-100 m, 101-150 m, 151-200 m), and habitat characteristics. The secondary observer recorded the birds identified by the primary observer as well as any birds they detected but were missed by the primary observer (Nichols et al. 2000). Birds that were flying over the survey area were not recorded if it was deemed that they were not utilizing the surveyed area (i.e. aerial foraging by species such as Northern Harriers (*Circus cyaneus*)). Survey participants took turns being primary and secondary observers to avoid observer bias. After the point count survey, observers played three minutes of secretive marsh bird calls into the survey area. Each playback call included calls from American Bittern *(Botaurus lentiginosus),* Least Bittern *(Ixobrychus exilis),* King Rail *(Rallus elegans),* Marsh Wren *(Cistothorus palustris),* and Sora *(Porzana carolina).* Any of these species that responded to the callback recordings were recorded and noted as being detected by callback surveys (Conway 2011).

Statistical Analyses

I accounted for differences in detectability between various factors (i.e. species, vegetation, observers, etc.) to allow for reliable estimation of bird densities using program DISTANCE 6.0 release 2 (Thomas et al. 2010). Program DISTANCE uses count data with associated distances to account for birds that were present during individual surveys but not detected. It does so by incorporating the change in an observer's ability to detect an object as a function of its distance. Non-overlapping 95% confidence intervals were used as evidence of significant differences in densities. Airboat and levee point count data were pooled for density analyses to maximize accuracy. Covariates such as guild, season, vegetation, and survey method were used to model the detection probability curve (Buckland et al. 2004).

An information theoretic approach was used to determine which parameters significantly influenced relative abundance and local species richness in the STAs (Burnham and Anderson 2002). Relative abundance and local species richness (hereafter; abundance and richness, respectively) were measured as the total number of individual birds and bird species, respectively, detected per point count survey. I used PROC GLIMMIX in SAS (SAS 2008) with a Laplace approximation and a negative-binomial distribution to determine the maximum-likelihood variance estimator for all competing models. Competing models were developed based on a biological understanding of factors that influence bird use in wetlands (Burnham and Anderson 2002). Models with interaction terms contained all corresponding main effects. I used Akaike's information criterion adjusted for small sample sizes (AICc) in all models. I calculated delta AICc (ΔAIC) and AIC weights (w_i) from AICc values. Models with the lowest AICc value were considered to be the best explanatory models, although additional competing models with ΔAIC < 2 were considered equally supported, (hereafter "top" models) given the data. Models with ΔAICc < 4 have enough support to be considered plausible

(Burnham and Anderson 2002). Survey year was included as a random variable in all models to account for inherent differences between years. Survey method was included in all models as a fixed effect to account for differences in bird response from the two survey methods.

Justification for Parameter Selection

The influence of vegetation density and composition on waterbird patterns (Weller 1999) is well known to wetland managers who use a wide variety of methods to manipulate vegetation patterns in controlled marshes. Waterbirds rely on both emergent and submerged vegetation for food, cover, nest protection/substrate, territorial/breeding displays and foraging substrate. I investigated the influence of vegetation on bird abundance and richness in the STAs by including a parameter signifying whether surveys were conducted in MIX or SAV vegetation. A parameter for vegetation (MIX/SAV) was used to investigate the effects of vegetation structure on bird abundance and richness in the STAs.

The unique ability of many bird species to take advantage of seasonal resource fluctuations and avoid hazardous climate conditions has led to great fluctuation of their occurrence in time and space. About 60% of avian species that regularly occur in south Florida, do so during winter or migration (Robertson and Kushlan 1974). Even without migrating, species resource requirements may influence their habitat use seasonally. For instance, many dabbling ducks prefer more vegetated habitats during breeding and move to more open habitats in the same wetland during summer and fall (Murkin et al. 1997). A parameter for season was used to investigate temporal variation in avian use of the STAs.

Preliminary analyses of bird abundance showed that models containing an interaction of vegetation type and season performed substantially better than those that did not have the term. Thus, I included the term in all abundance models here.

Hydrology is the main driver of wetland variability and wetland resources because it influences seasonal vegetation characteristics and faunal abundance (Weller 1999). Wetland managers manipulate depths in order to maximize wintering, migrating and breeding waterbird use and success (Anderson and Smith 1999; Taft et al. 2002). Wading birds, shorebirds and waterfowl are limited to certain water depths by morphology (Weller 1999). I used a quadratic depth (depth + depth^2) parameter instead of a linear depth parameter because many aquatic birds like wading birds and shorebirds feed most optimally at a certain water depth and less efficiently as the water gets deeper or shallower than that optimum (Bancroft et al. 2002; Bolduc and Afton 2008).

In addition to water depth, the direction of water level change can also influence food and nesting resources for waterbirds. Species that nest at or near the water surface can be flooded out by rising water or lose protection from predators in a drying marsh. In the Everglades, wading birds require declining water levels in order to concentrate prey for successful nesting (Kushlan 1976) and rising water levels can cause large nest abandonment due to reduced prey availability (Kushlan 1978, 1986). One week recession rate was calculated by subtracting water depth in an STA cell on the date that cell was surveyed from the water depth one week prior and dividing by seven.

While receding water can concentrate food resources, the morphological limitations of many birds will keep those resources from becoming available until water levels reach shallow enough depths for them to effectively forage (Kushlan 1976). Therefore, avian response to water level changes should be greatest when water depth is within an optimal range. Thus, I included an interaction term between quadratic depth and recession rate to inspect for this relationship.

The rate of water level recession was not included in the model selection results for species richness because it was shown to be a “pretending variable” (Anderson 2008). In other words, recession rate was not influencing a models ability to predict species richness. Thus, models that contained the recession parameter had nearly the same model fit and were 2 ΔAICc points (the penalty for adding each parameter) greater than nearly identical models without the recession parameter. Therefore I removed all models for species richness that contained the recession parameter from the model set for richness.

STAs differ by physical features as well as geographic location, although all STAs are within 20 km of another STA. Each STA is responsible for treating water from separate sub-basins of the EAA which causes variations in water quality and supply among STAs. Additionally, the substrate of the STAs varies. The STAs that drain the central portion of the EAA are constructed on a thick layer of traditional Everglades organic peat. However, the STAs on the periphery of the system (STA-1E, 5) may have very thin peat and a sandy bottom.

Both automobiles and airboats were used for transportation to survey sites depending on whether sites were situated along levees or in the interior marsh. However, the response of birds to disturbances caused by different survey vehicles may depend upon vegetative density. Birds that typically associate with dense vegetative cover are more likely to remain in place when disturbed while species associated with more open environments tend to quickly move away from the disturbance (Blumstein et al. 2005). For this reason, an interaction term between survey method and vegetation was included in some models.

Species Composition

For some analyses, avian species were grouped into guilds defined by their habitat use, resource requirements and/or detectability. The guilds used were; Wading birds, Waterfowl, Shorebirds, Passerines, Raptors, Secretive Marsh Birds, and Diving Piscivores (Table 2.2). These analyses helped determine differences in the types of birds that are utilizing the various strata. Differences in guild distribution among strata were determined using Chi-square goodness-of-fit (Cochran 1952).

The Plymouth Routine in Multivariate Ecological Research, Version 6 (Primer v6) was used to conduct multivariate analyses on the species abundances among strata (seasons, STAs, treatments; Clarke and Gorley 2006). The influence of numerically dominant species was reduced by square root transforming species abundance data (Clarke and Warwick 2001). The square root transformation was selected because it is a mild transformation that balances the contributions of abundant species with less abundant but common species (Clarke et al. 2006). I felt that more drastic transformations such as presence/absence would put too much emphasis on uncommon species. Species abundances were averaged by STA, vegetation and survey period (hereafter: survey set) to inspect for natural groupings among seasons and vegetation types. Non-metric multidimensional scale (NMDS) ordination was used to illustrate relationships among survey sets. A non-parametric analog of analysis of variance

(Analysis of Similarity-ANOSIM) with a two-way crossed design was used to test for significant differences in species abundances among seasons and vegetation types. ANOSIM uses a Monte Carlo randomization procedure to test if differences among *a priori* groupings are significantly different than random samples. A pair-wise R statistics less than 0.05 determined significant differences (Clarke and Gorley 2006). I used the similarity percentages procedure (SIMPER) to compare similarities and dissimilarities of species abundances among strata. Only species with at least 10% contribution to similarities/dissimilarities are reported. The full, non-averaged, square root transformed species abundance dataset was used for both the ANOSIM and SIMPER tests.

Post-hoc Analyses

After conducting and examining all a priori analyses of the factors that influence avian use of the STAs, it was clear that one species guild was overwhelmingly driving avian use patterns. In order to examine the influence of other guilds on avian community patterns, I removed that species group from the dataset and reanalyzed the data.

RESULTS

In total, 46,131 individual birds from 103 species were detected during 486 levee point counts and 140 airboat point counts. On average, we detected 73.7±5.1 individual birds and 7.7±0.03 species per point count. Overall density in the STAs is estimated at 34.4± 1.6 birds/ha. The most abundant species detected in the STAs were the American Coot (*Fulica americana*) and the Common Gallinule (*Gallinula galeata*). There were no differences in bird abundance, richness or species composition between years (all tests, $p > 0.05$) so the data from both years were pooled.

Abundance and Density

There was little model selection certainty with the abundance models however all models had an R^2 of ≈0.65 suggesting these models are explaining a great deal of the variation in the data (Table 3.1). Nine models were considered top models with another four plausible models. All models that contained the season and vegetation interaction parameter were considered plausible except for the global model. Six of the nine top models also contained the vegetation and method interaction parameter, including the top model, which only had these two interaction terms and their constituent parameters.

Season had a large effect on abundance in the STAs, particularly when interacting with vegetation. Avian density ($p < 0.05$) was greatest in winter and fall and lowest in spring and summer (Figure 3.2). Density was estimated at 78.2 ± 17.7 birds/ha and 101.2 ± 17.2 birds/ha during winter and fall, respectively. In contrast, density estimates were 31.6 ± 5.1 birds/ha and 14.8± 2.0 birds/ha in spring and summer, respectively.

Averaged across all seasons, density was much greater in the SAV vegetation than in the MIX vegetation ($p < 0.05$; Figure 3.3). Mean density in SAV vegetation was 37.8 ± 3.5 birds/ha while mean density in MIX vegetation was 22.3 ± 1.7 birds/ha.

The interaction term between season and vegetation showed how differences in vegetation are dependent upon season. Season influenced bird density (Figure 3.4) much more in SAV vegetation than in MIX vegetation. Bird density was much greater in SAV vegetation than MIX vegetation during fall and winter but was not different during spring and summer. Additionally, densities in SAV vegetation were much greater in fall and winter than they were in spring and summer, whereas densities in MIX vegetation were not different among seasons.

In addition to the season and vegetation interaction, the method and vegetation interaction also appeared in most of the top models (6 of 9 with ΔAIC < 2) for abundance (Table 3.1). This suggests that the influence of survey location and/or method differed consistently between vegetation. Bird density was higher in SAV vegetation than MIX vegetation during levee point counts and lower in SAV during airboat point counts (Figure 3.5).

STA appeared to influence species richness more than abundance. STA appeared in two top models and one additional plausible model for abundance (Table 3.1). The addition of the STA term to the top abundance model added 1.3 AIC points and dropped this model to the seventh best abundance model. STA-5 showed both high richness (8.2 ± 0.3 species/point) and high density (70.8 ±17.2 birds/ha; Figure 3.6). However, density was also high in STA-1E (61.5 ± 13.6 birds/ha) and lowest in STA-3/4 (26.3 ± 5.7 birds/ha).

Water depth appeared in four top models (two with an interaction) and three additional plausible models (one with an interaction) for abundance (Table 3.1). Addition of the depth parameter added 1.27 ΔAIC points to the best abundance model. This suggests that depth had little influence on bird abundance in the STAs. Recession rate appeared in four top models (one with an interaction) and one additional plausible model (with an interaction) for abundance (Table 3.1) including two of the three models with ΔAIC < 1. The second best model was identical to the top model except for the addition of the recession parameter and only had a ΔAIC of 0.26. Since the penalty for the addition of a parameter is 2 ΔAIC points this suggests that recession does influence abundance in the STAs.

The depth and recession interaction appeared in the third best model and another additional model for abundance (Table 3.1). The third best abundance model is roughly 0.6 ΔAIC points less than the best model which is exactly the same model without the depth and recession terms and their interaction. Also, the fifth best model is the same as the third best model except for the interaction of the two terms and is 0.58 ΔAIC points more than the third best model. This suggests that the depth and recession interaction term does help explain abundance of birds in the STAs.

The depth and STA interaction appeared in one top model for abundance (Table 3.1). The only difference between the global model for richness and the third best model is the addition of the Depth and STA interaction, yet the global model had a ΔAIC more than 5 points lower and was 14.5 times more likely to be the correct model. This suggests that this interaction was especially important in predicting avian species richness in the STAs.

Richness

The global model was the highest ranked model for species richness suggesting that all variables and interactions in the model set are important in describing species richness in the STAs (Table 3.2). However the global model for richness explains little of the variation in the data (R^2=0.36) and far less than the models for abundance. The next best model had a ΔAIC > 4, meaning the global model was the only plausible model.

Season also had a large effect on species richness in the STAs, particularly when interacting with vegetation. Species richness was greatest in winter and fall and lowest in spring and summer (Figure 3.2). Species richness averaged 9.9 ± 0.3 species/survey and 8.7 ± 0.3 species/survey in winter and fall, respectively. In contrast, species richness averaged 6.6 ± 0.2 species/survey and 5.96 ± 0.2 species per survey in spring and summer, respectively.

Averaged across all seasons, species richness was much greater in the SAV vegetation than in the MIX vegetation (all tests $p < 0.05$; Figure 3.3). Overall, 82 species were detected in MIX vegetation and 90 species were detected in SAV vegetation. Eleven species were only detected in MIX vegetation and 19 species were detected only in SAV vegetation. Local species richness in SAV vegetation averaged 8.6 ± 0.2 species per survey while MIX vegetation averaged 6.8 ± 0.2 birds per survey.

All richness models within 7 ΔAIC points of the top model contained the interactions of habitat x season and habitat x method. Like abundance, season influenced richness much more in SAV vegetation than in MIX vegetation (Figure 3.7). There were always more species detected in SAV vegetation and the greater difference between vegetation treatments was only apparent in fall.

In addition to the season and vegetation interaction, the method and vegetation interaction also appeared in most of the top models for richness (all 5 models with ΔAIC < 7; Table 3.2). Species richness was much greater in SAV vegetation than MIX vegetation based on levee point counts whereas this was not the case during airboat point counts (Figure 3.8). These patterns were also similar to those for avian abundance.

STA appeared in the top model (global model) for species richness (Table 3.2). Removal of the STA term from the second best richness model increased the AIC value by roughly 2.2 points and dropped it to the fifth best model. STA-5 showed both high richness (8.2 ± 0.3 species/point) and high density (70.8 ±17.2 birds/ha; Figure 3.6). Richness was also relatively high in STA-3/4 (8.1 ± 0.4 species/point) and lowest in STA-1W (7.2 ± 0.3 species/point).

The depth and STA interaction appeared in the best model for richness (Table 3.2). The only difference between the global model for richness and the third best model is the addition of the Depth and STA interaction, yet the global model had a ΔAIC more than 5 points lower and was 14.5 times more likely to be the correct model. This suggests that this interaction was especially important in predicting avian species richness in the STAs.

Guild Composition

Guild composition was significantly different among seasons ($p < 0.01$; Figure 3.9). Waterfowl made up 75% and 79% of the bird abundance in the STAs during fall and winter, respectively. During spring and summer, the proportion of waterfowl in the STAs dropped to 45% and 61% respectively. Consequently, passerines went from making up 9% and 13% of bird abundance in fall and winter, respectively, to making up 35% and 20% of the abundance in spring and summer, respectively. Shorebirds showed a different seasonal pattern of abundance with higher abundances during the migration seasons of fall and spring (9% and 6% respectively) than during winter and summer (both 2%).

Guild distributions also varied between vegetation ($p < 0.01$; Figure 3.10). Waterfowl consisted of 40% of the birds in the MIX vegetation and 80% of the birds in the SAV vegetation. Passerines showed the opposite pattern, making up 41% of the birds in MIX vegetation and only 8% of the birds in SAV vegetation.

Community Composition

The NMDS representation (Figure 3.11) shows a distinct pattern of community similarity for two seasonal groups. Fall and winter survey sets were clustered together, as were the spring and summer survey sets. This pattern indicated that the avian communities were more similar to that of another season within each of the two season groups than they were to a season outside a respective season group. The stress value of 0.14 shown by the 2-D NMDS in Figure 3.11 means that this representation is useful in discerning groupings (Clarke and Warwick 2001). The seasonal pattern observed in the NMDS visualization was supported by the ANOSIM test. There were significant differences in the avian communities from different seasons ($p < 0.01$).

American Coots (14.4% and 21.3%, respectively) and Common Gallinules (13.8% and 12.7%, respectively) contributed the most to similarities among survey sets in fall and winter. Common Gallinules (22.7% and 27.8%, respectively) contributed the most to similarities among survey sets in spring and summer, followed by Red-winged Blackbirds (17.5%) and Boat-tailed Grackles (16.6%) in spring and Boat-tailed Grackles (12.1%) in summer.

American Coots were the only species to contribute more than 10% to dissimilarities between seasons. They accounted for 18.5% of both the 60% and 61.8%

dissimilarity between winter and spring and between winter and summer, respectively. They also accounted for 13.8% of the 59.4% dissimilarity between fall and spring, 14.7% of the 58.0% dissimilarity between fall and summer and 10.4% of the 45% dissimilarity between fall and winter. No species contributed > 10% to the 44.8% dissimilarities between spring and summer.

The NMDS scaling (Figure 3.11) shows that there is clear separation in the bird communities between vegetation types. The separation between the vegetation types is not as stark as between the two seasonal pairings (fall/winter and spring/summer) but there is little overlap of survey sets from different vegetation types.

Common Gallinules (18.9% contribution), Red-winged Blackbirds (16.5% contribution), and Boat-tailed Grackles (12.1% contribution) contributed the most to the 58.4% similarity of survey sets in MIX vegetation. Common Gallinules (20.0% contribution) and American Coots (15.7% contribution) contributed the most to the 61.2% similarity between survey sets in SAV vegetation. American Coots contributed 12.4% of the 53.7% dissimilarity between MIX and SAV survey sets.

The NMDS scaling showed slightly more separation between MIX and SAV samples from fall and winter than during spring and summer (Figure 3.11). This differential influence of season on bird richness, abundance and community composition by vegetation was likely due to migratory species, primarily waterfowl, utilizing SAV vegetation in greater proportions than MIX vegetation (Figure 3.10).

Post-hoc Non-waterfowl Analysis

It was clear from all a priori analyses that the dominant avian use patterns within the STAs were driven by waterfowl. To examine the influence that factors affecting bird use in the STAs had on guilds other than waterfowl, I removed all waterfowl data from the dataset and reran analyses.

Without waterfowl, the model selection results for abundance contained only five top models and one additional plausible model (Table 3.3). Removing waterfowl from the dataset increased the influence of hydrologic variables on bird abundance while still showing the importance of season and vegetation. All five of the top models still contained the season and vegetation interaction, but also contain the depth and recession parameters with two of those models also containing their interaction. Furthermore, there was much more support for models that contained both hydrologic parameters than those that contained only one of those parameters. For instance, removal of either the recession or depth parameter from the top model increased the AIC values by 4.6 and 4.9 respectively.

After waterfowl were removed from the dataset, density still varied among seasons (Figure 3.12) but not between vegetation (Figure 3.13). Non-waterfowl birds were most dense during winter and least dense during summer. Spring and fall were not different. Density also did not vary between vegetation in any one season (Figure 3.14).

The recession parameter was no longer acting as a “pretending variable” (Anderson 2008) for richness after removal of waterfowl from the dataset, therefore models containing recession were included in the new model set. The model selection results for richness contained two top models and three additional plausible models for after removal of waterfowl from the dataset (Table 3.4). In addition to the season and habitat interaction, all plausible models contained the parameters for depth, recession and STA. The top model is identical to the second best model (the global model) except it does not contain the depth and recession interaction; however the other four plausible models did contain the depth and recession interaction. The top three models also contained the depth and STA interaction.

The pattern of seasonal richness did not change after waterfowl were removed from the dataset (Figure 3.12). Richness was still highest in fall and winter. Unlike density, richness was different between vegetation after the removal of waterfowl; with SAV having significantly more species per survey than MIX vegetation (Figure 3.13). Richness was also higher in SAV vegetation during all seasons except winter (Figure 3.15).

Patterns in community compositions after waterfowl were removed from the dataset were similar to patterns with waterfowl in the dataset with a few slight alterations (Figure 3.16). There was still a clear separation between the two seasonal groups (winter/fall and spring/summer); however spring and summer survey sets are somewhat more distinctly separated from each other. The ANOSIM test showed that the community compositions were all significantly different among seasons without waterfowl (all $p < 0.01$). Tree Swallows (*Tachycineta bicolor*), Palm Warblers (*Setophaga palmarum*), Red-winged Blackbirds and Greater/Lesser Yellowlegs (*Tringa melanoleuca* and *Tringa flavipes*, respectively) contributed the most to differences among seasonal groups.

In addition to the more apparent separation between spring and summer survey sets, the separation between vegetation became less clear with some SAV survey sets encroaching well into areas dominated by MIX survey sets in both seasonal groups. However, the ANOSIM test showed that the community compositions were still different between vegetation types ($p < 0.01$). Red-winged Blackbirds, Greater/Lesser Yellowlegs and Boat-tailed Grackles contributed the most to dissimilarities between vegetation types.

DISCUSSION

Although many bird species were found in both vegetation types, the significant differences in bird communities between vegetation types suggest that the diversity of vegetation may be an important factor for maintaining overall avian diversity and density in STAs. The effect of vegetation type was even stronger than hydrologic variables, which are known to have a strong effect on density of wading birds in more oligotrophic wetlands (Kushlan 1976). The strong association with wintering waterfowl in the SAV vegetation provides justification for maintaining this vegetation type if recreational bird watching and hunting opportunities are part of the management objectives for STAs.

Utilizing multiple vegetation treatment methods may also benefit species that were detected in both vegetation types. Many organisms require more than one habitat type for acquisition of all of their essential resources (Nummi and Poysa 1993; Law and Dickman 1998; Weller 1999). Resident species like Common Gallinules (Bannor and Kiviat 2002) may utilize the open water of SAV during non-breeding seasons but shift to MIX vegetation during spring and summer because they provide better nesting substrate and cover. Snail Kites (*Rostrhamus sociabilis*) nest in dense emergent vegetation but forage in more open water areas (Sykes Jr. et al. 1995).

Multiple vegetation treatments were especially effective at enhancing bird diversity because they supported species groups with different life history characteristics. Migratory waterfowl were most predominant in the SAV vegetation while the MIX vegetation had high proportions of resident species. Density and richness were much greater in SAV than MIX habitat during fall and winter when migratory and wintering species were present in South Florida. Waterfowl were primarily responsible for these fluctuations because they greatly preferred the SAV vegetation to the MIX vegetation. Resident passerines were more prevalent in MIX vegetation causing populations in that vegetation to be more stable throughout the year.

I expected hydrologic variables to have a strong impact on avian use of the STAs because nearby oligotrophic wetlands develop large aggregations of foraging birds only when cyclic water levels produce and then concentrate food resources (Kushlan 1986). Although hydrological variables were present in many top models for both richness and abundance, it is clear that depth and recession are not influencing bird use of the STAs nearly as much as season and vegetation treatment. The STAs are a eutrophic, productive system that may not require cycles of high and low water to produce adequate food resources for a large bird community. The STAs are also typically maintained at depths that are too deep for most depth sensitive species like wading birds and shorebirds. Large wading birds were often seen foraging from the water’s edge and smaller wading birds and some shorebirds forage from floating or densely matted vegetation, areas which collectively represent a small part of the STAs and thus preclude the formation of dense aggregations of wading birds. In contrast, the vast SAV vegetation cells supported large numbers of waterfowl, which also happened to be less sensitive to specific water depths than are wading birds.

Hydrologic parameters were important in determining avian abundance and richness after waterfowl were removed from the dataset. This supports the notion that waterfowl are less sensitive to hydrologic influences. It also shows how the exceedingly high waterfowl abundance in the STAs were driving bird use patterns and masking factors that influence non-waterfowl use of the STAs. This also suggests that manipulation of hydrologic factors may be a useful tool to aid wetland managers in attracting non-waterfowl birds to treatment wetlands.

The recent popularity of treatment wetlands can be partially attributed to their utility and attractiveness as wildlife habitat. This study found that a large part of that attractiveness to avian wildlife is due to maintaining multiple vegetation treatments. Although I compared only two vegetation types in this study it is possible that more diverse vegetation communities could produce even more diverse avian communities. If designers and managers wish to encourage waterbird use in their wetlands, using multiple vegetation types to treat their targeted pollutant may be an effective way to do so.

CHAPTER 3 TABLES

Table 3.1: Relative abundance results for model selection analysis. All models with interactions contained corresponding main effect parameters. Survey method was included in all models as a main effect.

Model Parameters	K	Model Fit	AIC_C	Δ_i	Model Weight	R^2
Season*Vegetation Method*Vegetation	11	5869.33	5891.76	0	0.138	0.65
Season*Vegetation Method*Vegetation Recession	12	5867.51	5892.03	0.27	0.121	0.65
Season*Vegetation Method*Vegetation Depth*Recession	14	5863.54	5892.23	0.47	0.109	0.65
Season*Vegetation	10	5872.44	5892.80	1.04	0.082	0.65
Season*Vegetation Method*Vegetation Depth Recession	13	5866.22	5892.82	1.06	0.081	0.65
Season*Vegetation Method*Vegetation Depth	12	5868.52	5893.04	1.27	0.073	0.65
Season*Vegetation Method*Vegetation STA	15	5862.26	5893.06	1.29	0.072	0.65
Season*Vegetation STA*Depth	19	5862.26	5893.06	1.29	0.072	0.65
Season*Vegetation Recession	11	5870.72	5893.15	1.39	0.069	0.65
Season*Vegetation Depth*Recession	13	5867.19	5893.79	2.03	0.050	0.65
Season*Vegetation STA	14	5865.13	5893.83	2.07	0.049	0.65
Season*Vegetation Depth	11	5871.81	5894.24	2.48	0.040	0.65
Season*Vegetation STA Depth	15	5863.88	5894.68	2.91	0.032	0.65
Global	22	5851.24	5896.94	5.17	0.010	0.66
Null	3	6517.65	6525.71	633.95	<0.001	0

Table 3.2: Local species richness results for model selection analysis. All models with interactions contained corresponding main effect parameters. Survey method was included in all models as a main effect.

Model Parameters	K	Model Fit	AIC_C	Δ_i	Model Weight	R^2
Global	20	2839.74	2881.14	0	0.768	0.36
Season*Vegetation Vegetation*Method STA	15	2854.62	2885.42	4.27	0.091	0.34
Season*Vegetation Vegetation*Method Depth STA	16	2853.6	2886.5	5.36	0.053	0.34
Season*Vegetation Vegetation*Method Depth	12	2862.28	2886.8	5.65	0.045	0.33
Season*Vegetation Vegetation*Method	11	2865.24	2887.67	6.53	0.029	0.33
Season*Vegetation STA*Depth	19	2850.89	2890.15	9.01	0.008	0.35
Vegetation*Method Season Depth	9	2874.11	2892.41	11.26	0.003	0.32
Season*Vegetation STA	14	2865.43	2894.12	12.98	0.001	0.33
Season*Vegetation STA Depth	15	2864.14	2894.94	13.79	0.001	0.33
Season*Vegetation Depth	11	2872.98	2895.42	14.27	0.001	0.32
Season Vegetation STA Depth	12	2874.85	2899.36	18.22	<0.001	0.32
Season Vegetation Depth	8	2883.69	2899.93	18.79	<0.001	0.31
Null	3	3111.12	3117.16	236.01	<0.001	0

Table 3.3: Relative abundance results for model selection analysis after removal of all waterfowl data. All models with interactions contained corresponding main effect parameters. Survey method was included in all models as a main effect.

Model Parameters	K	Model Fit	AIC_C	Δ_i	Model Weight	R^2
Season*Vegetation Depth Recession	12	4757.84	4784.44	0	0.252	0.27
Season*Vegetation Depth Recession STA	16	4749.73	4784.75	0.31	0.216	0.28
Season*Vegetation Depth*Recession	13	4756.88	4785.57	1.13	0.143	0.27
Season*Vegetation Depth*Recession STA	17	4748.99	4786.13	1.69	0.108	0.28
Season*Vegetation Method*Vegetation Depth Recession	13	4757.65	4786.35	1.91	0.097	0.27
Season*Vegetation Method*Vegetation Depth*Recession	14	4756.67	4787.47	3.03	0.055	0.27
Season*Vegetation Recession	11	4766.64	4789.08	4.64	0.025	0.26
Season*Vegetation STA	14	4760.4	4789.1	4.66	0.025	0.27
Season*Vegetation Depth	11	4764.86	4789.38	4.94	0.021	0.26
Season*Vegetation	10	4769.58	4789.94	5.5	0.016	0.26
Global	22	4742.83	4790.69	6.25	0.011	0.29
Season*Vegetation Method*Vegetation Recession	12	4766.54	4791.05	6.61	0.009	0.26
Season*Vegetation Method*Vegetation STA	15	4760.34	4791.13	6.69	0.009	0.27
Season*Vegetation Method*Vegetation Depth	12	4764.72	4791.32	6.88	0.008	0.26
Season*Vegetation STA*Depth	19	4751.19	4792.59	8.15	0.004	0.28
Null	3	4952.51	4958.54	174.1	< 0.001	0

Table 3.4: Local species richness results for model selection analysis after removal of all waterfowl data. All models with interactions contained corresponding main effect parameters. Survey method was included in all models as a main effect.

Model Parameters	K	Model Fit	AICc	Δ_i	Model Weight	R^2
Season*Vegetation Vegetation*Method Depth*STA Recession	17	2693.39	2730.53	0	0.334	0.24
Global	22	2683.05	2730.9	0.37	0.278	0.25
Season*Vegetation Depth*Recession STA*Depth	21	2687.48	2733.18	2.65	0.089	0.25
Season*Vegetation Vegetation*Method Depth*Recession STA	18	2693.95	2733.22	2.68	0.087	0.24
Season*Vegetation Depth*Recession STA	17	2696.09	2733.23	2.69	0.087	0.24
Season*Vegetation Vegetation*Method STA	15	2704.3	2735.09	4.56	0.034	0.23
Season*Vegetation STA*Depth	19	2693.89	2735.3	4.77	0.031	0.24
Season*Vegetation Depth Recession STA	16	2700.71	2735.73	5.2	0.025	0.23
Season*Vegetation STA Depth	15	2704.39	2737.29	6.76	0.011	0.23
Season*Vegetation STA	14	2708.82	2737.52	6.99	0.01	0.22
Season*Vegetation Depth*Recession	13	2708.84	2737.53	7	0.01	0.22
Season*Vegetation Vegetation*Method Depth	12	2715.28	2739.79	9.26	0.003	0.21
Season*Vegetation Vegetation*Method	11	2720.22	2742.66	12.12	0.001	0.21
Season Vegetation STA Depth	12	2718.89	2745.49	14.95	< 0.001	0.21
Null	3	2861.56	2867.6	137.07	< 0.001	0

CHAPTER 3 FIGURES

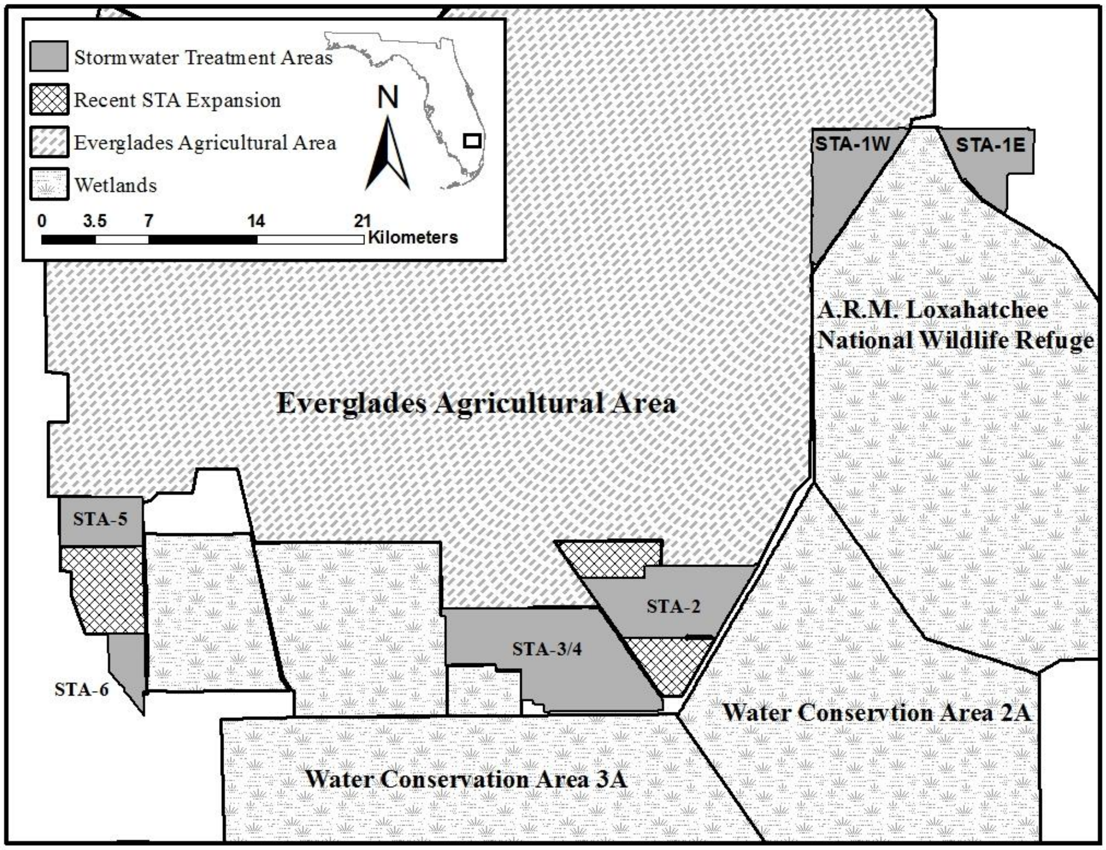

FIGURE 3.1. The Stormwater Treatment Areas (STAs) consist of six independent treatment wetlands primarily surrounded by agriculture and other wetlands.

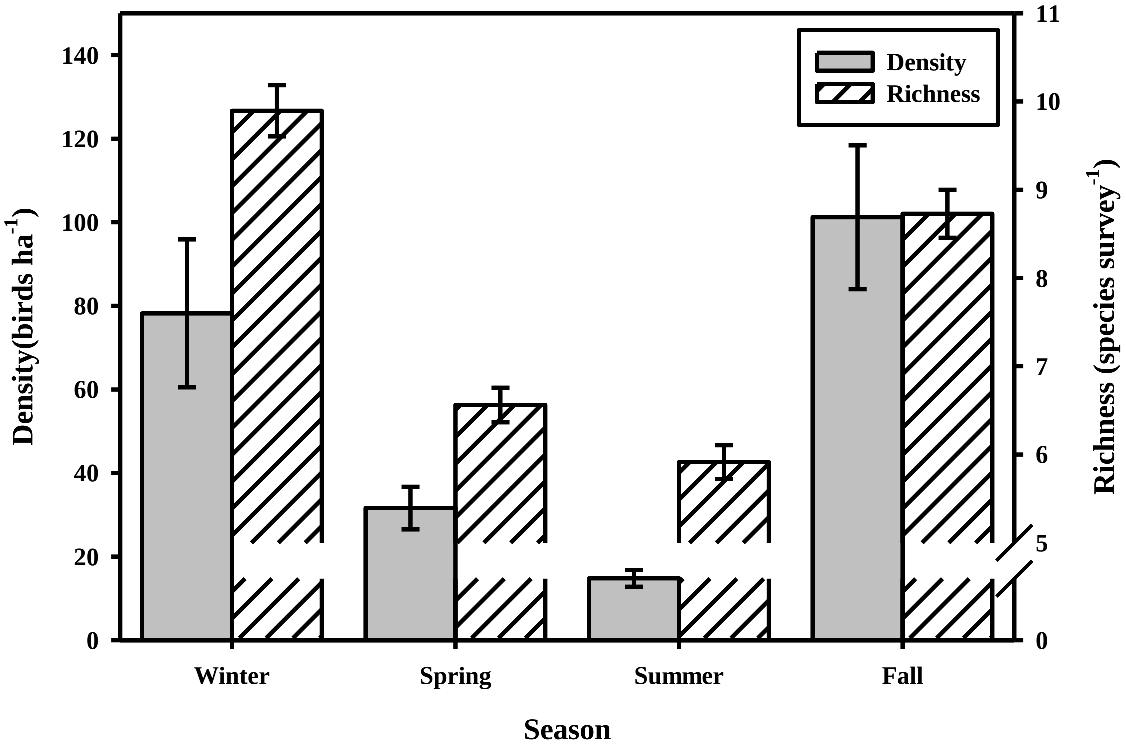

FIGURE 3.2. Avian density and richness were greatest in the STAs during fall and winter and lowest in the summer

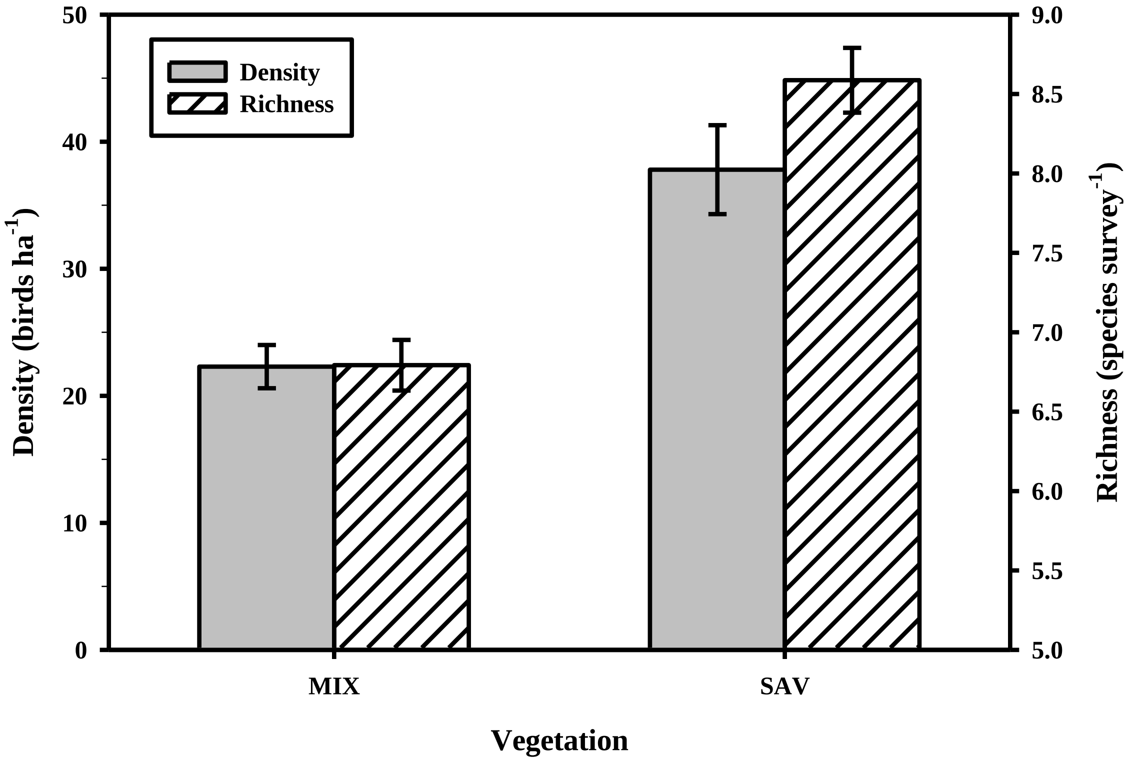

FIGURE 3.3. Avian density and richness were significantly greater in the SAV vegetation than in the MIX vegetation of the STAs.

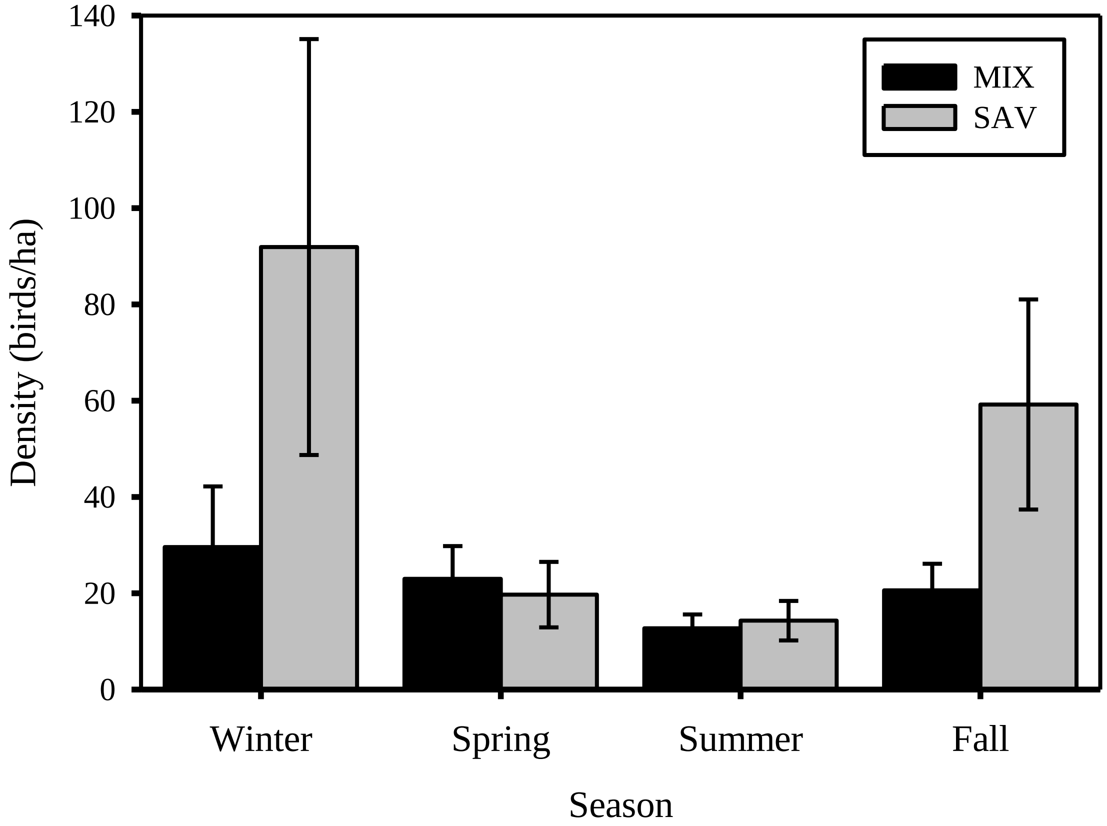

FIGURE 3.4. Avian density was much greater in SAV vegetation than MIX vegetation during winter and fall but not different in spring and summer.

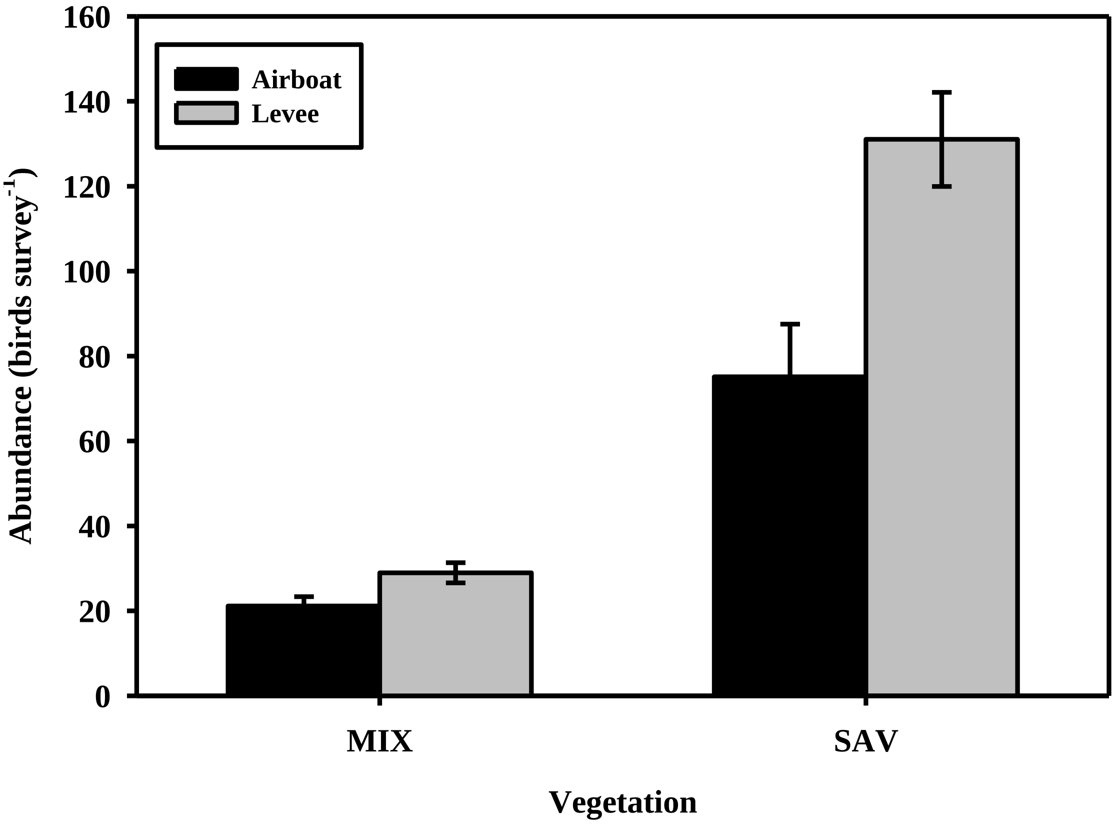

FIGURE 3.5: Relative abundance was similar in MIX vegetation during both survey methods but very different in SAV vegetation.

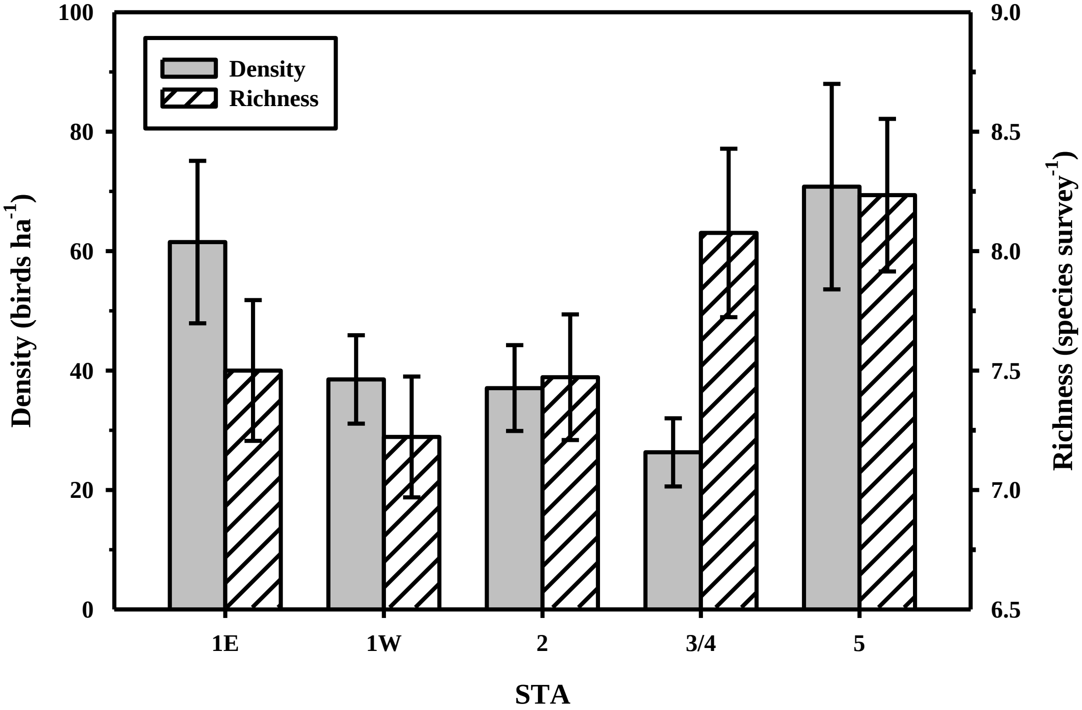

FIGURE 3.6: Both local species richness and bird density were high in STA-5 while richness was also high in STA-3/4 and density was also high in STA-1E.

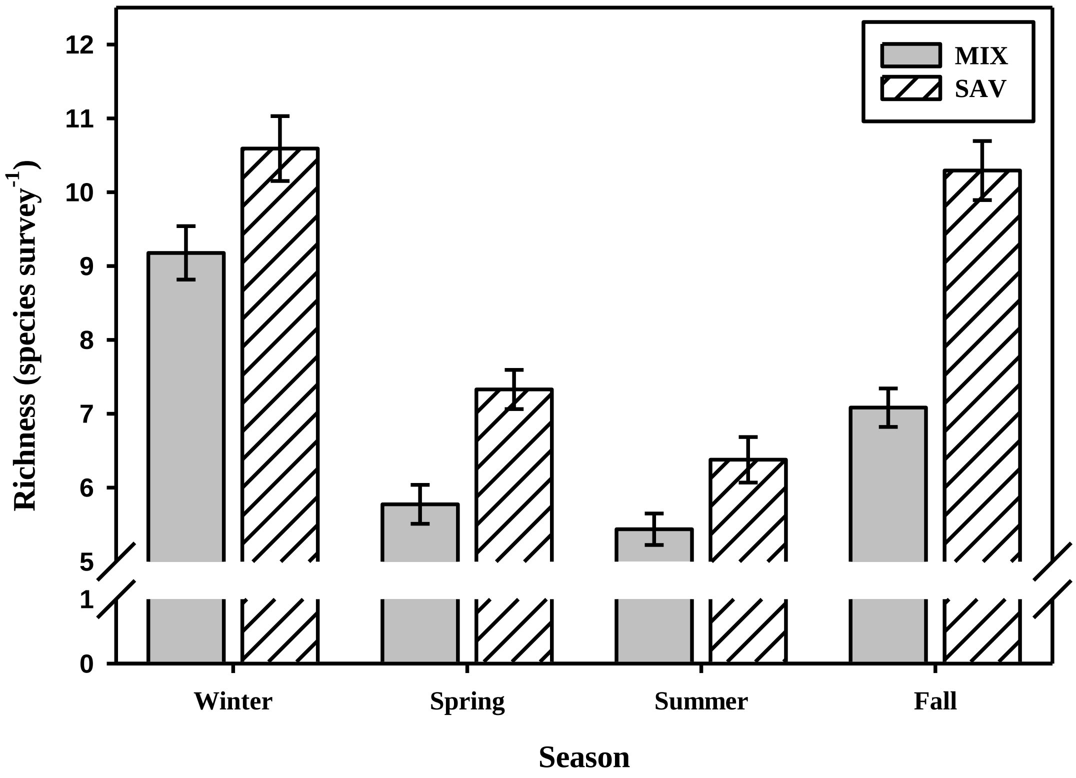

FIGURE 3.7: Local species richness was higher in SAV vegetation than MIX vegetation during all seasons but the differences were more pronounced during fall.

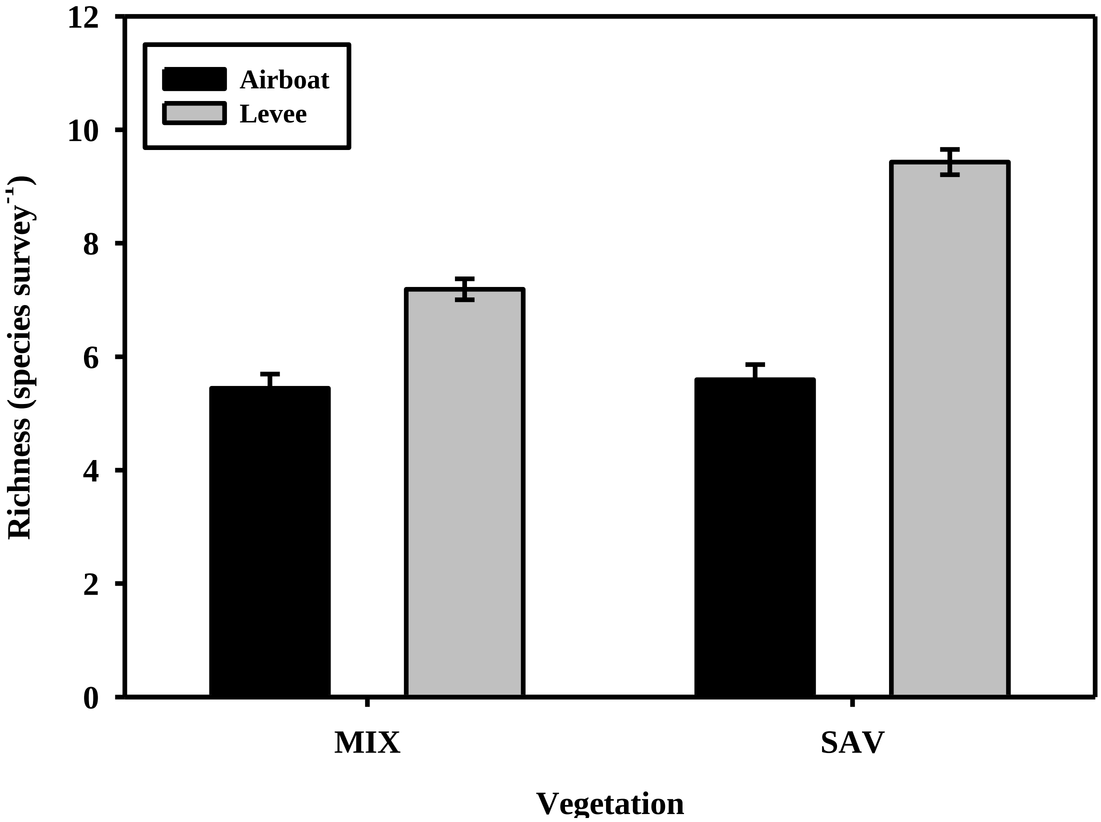

FIGURE 3.8: Species richness varied by vegetation treatment during levee point counts but not during airboat point counts.

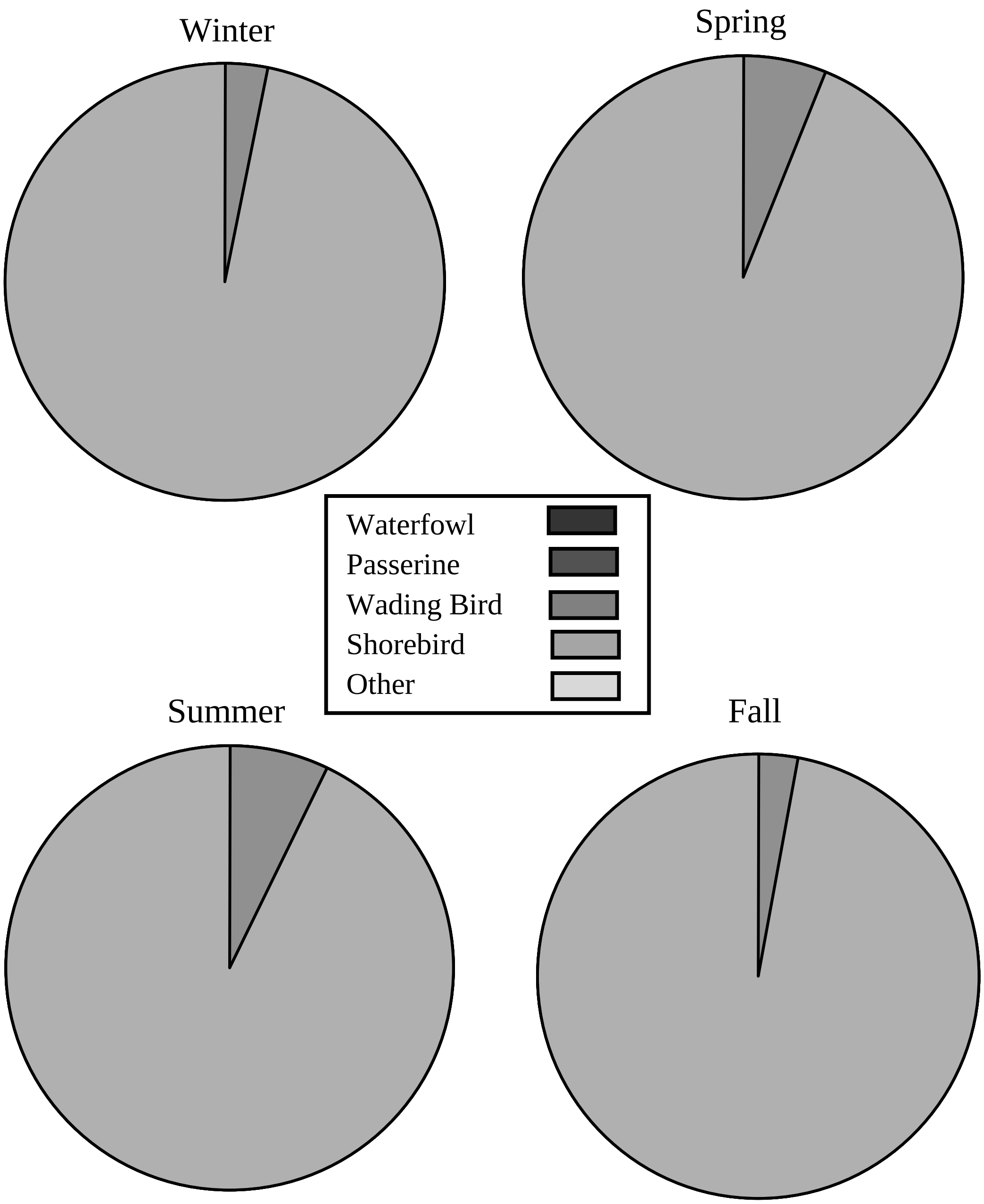

FIGURE 3.9. Waterfowl were most prominent in the STAs during the winter and fall seasons while passerines made up larger proportions of the avian communities in spring and summer.

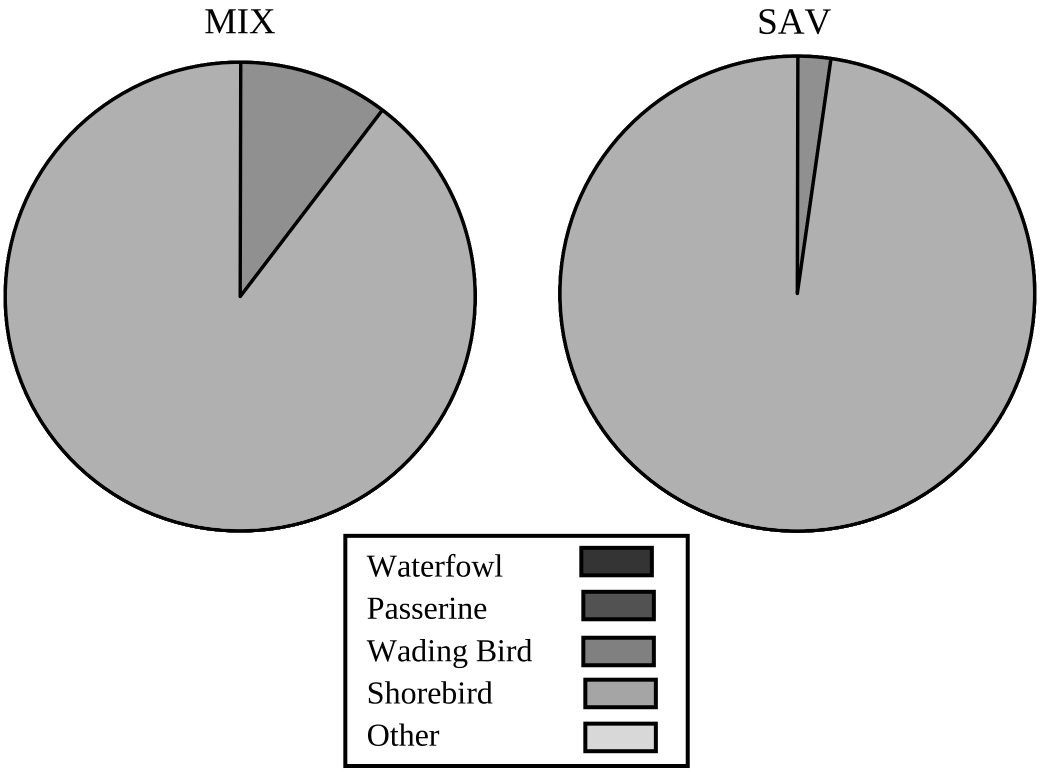

FIGURE 3.10. Waterfowl were much more predominant in the SAV vegetation while passerines made up a much larger proportion of the avian community in MIX vegetation.

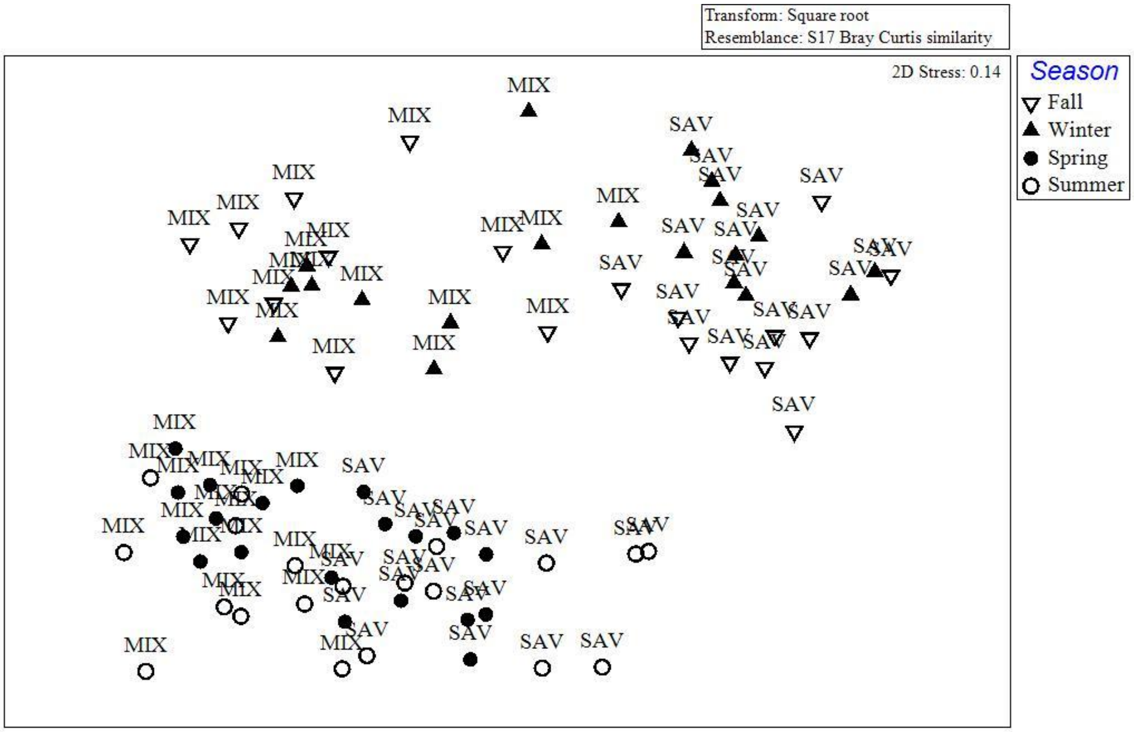

FIGURE 3.11. Non-metric multidimensional scale (NMDS) ordinations show survey sets from the STAs clustered roughly into four groups based on two seasonal associations (winter/fall and spring/summer; top and bottom respectively) and two vegetation types (MIX and SAV; left and right respectively). Each point represents the mean species abundances from one vegetation treatment in one STA during one survey period**.**

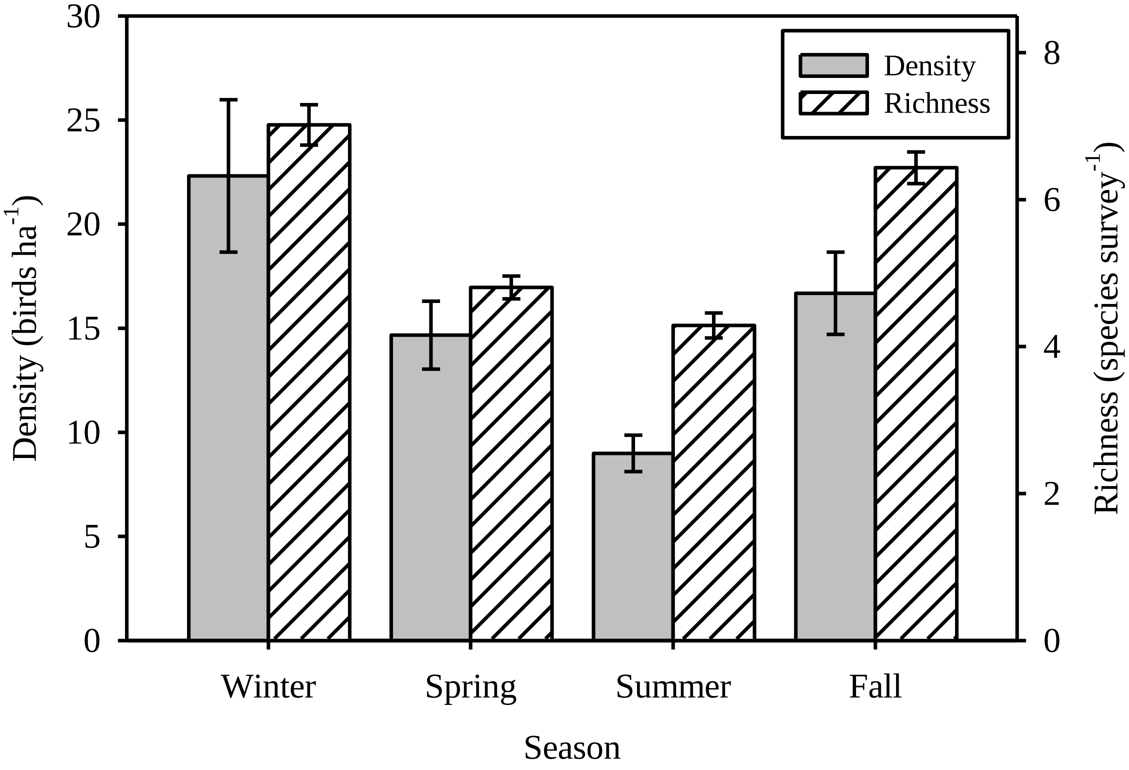

FIGURE 3.12. Seasonal patterns of avian density and local species richness were still present after waterfowl were removed from the dataset. However, density showed a slightly different pattern without waterfowl.

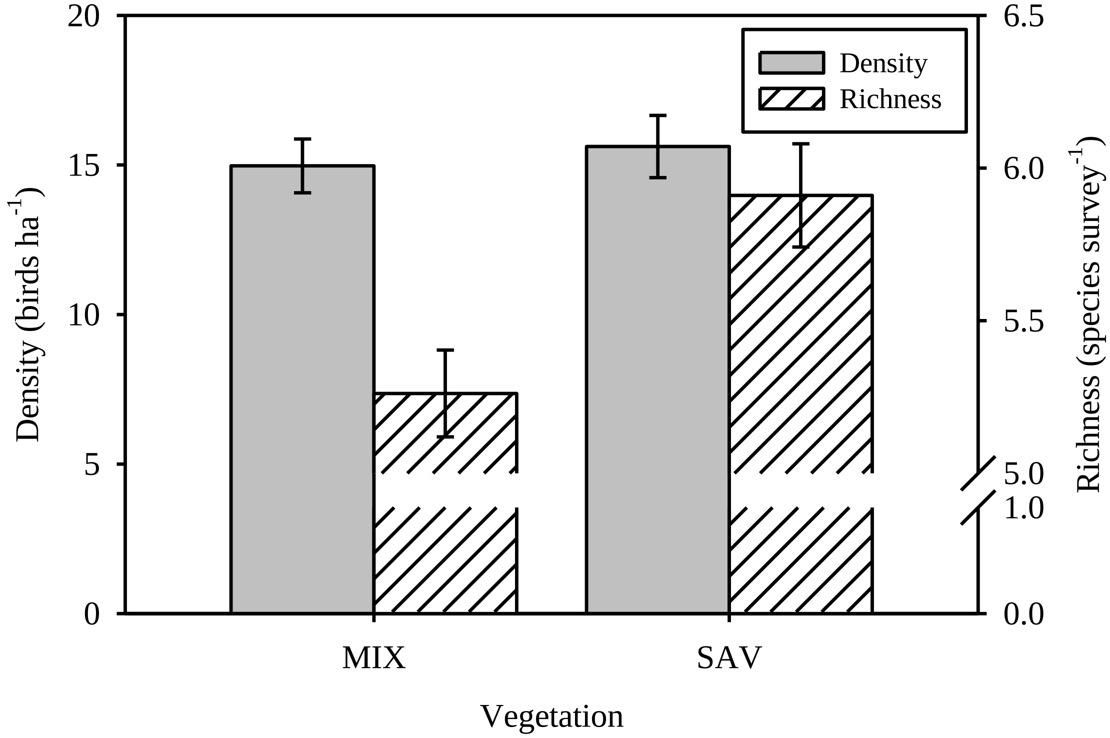

FIGURE 3.13. Avian density was not different between vegetation types after waterfowl were removed from the dataset. Local species richness, however were still different between vegetation types without waterfowl.

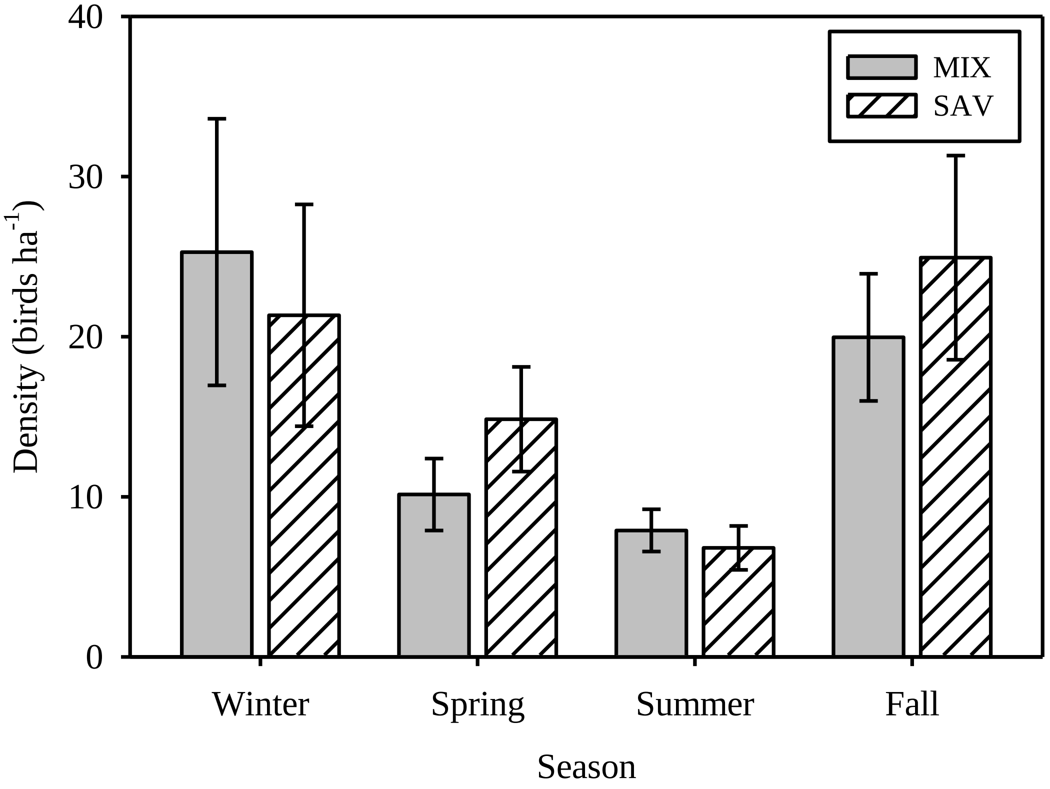

FIGURE 3.14. Seasonal differences in avian density between vegetation types were no longer present after waterfowl were removed from the dataset.

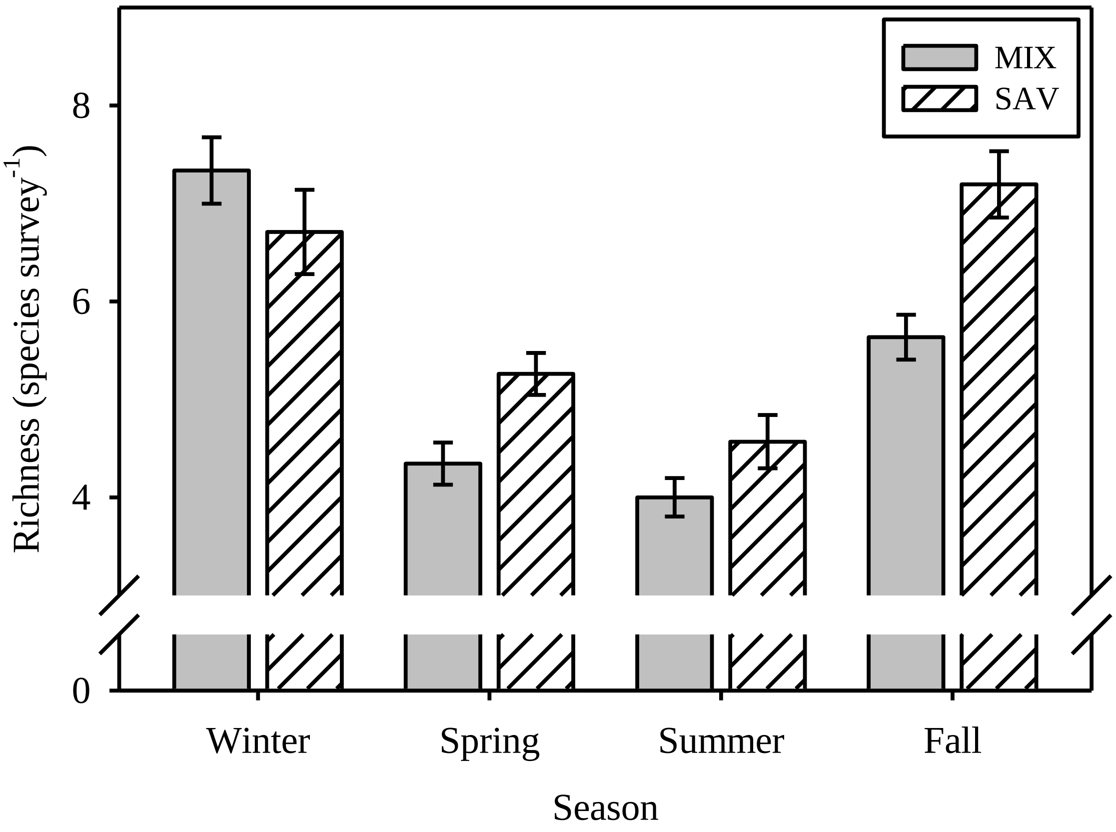

FIGURE 3.15. Differences in species richness between vegetation types were still present after waterfowl were removed from the dataset in all seasons except winter.

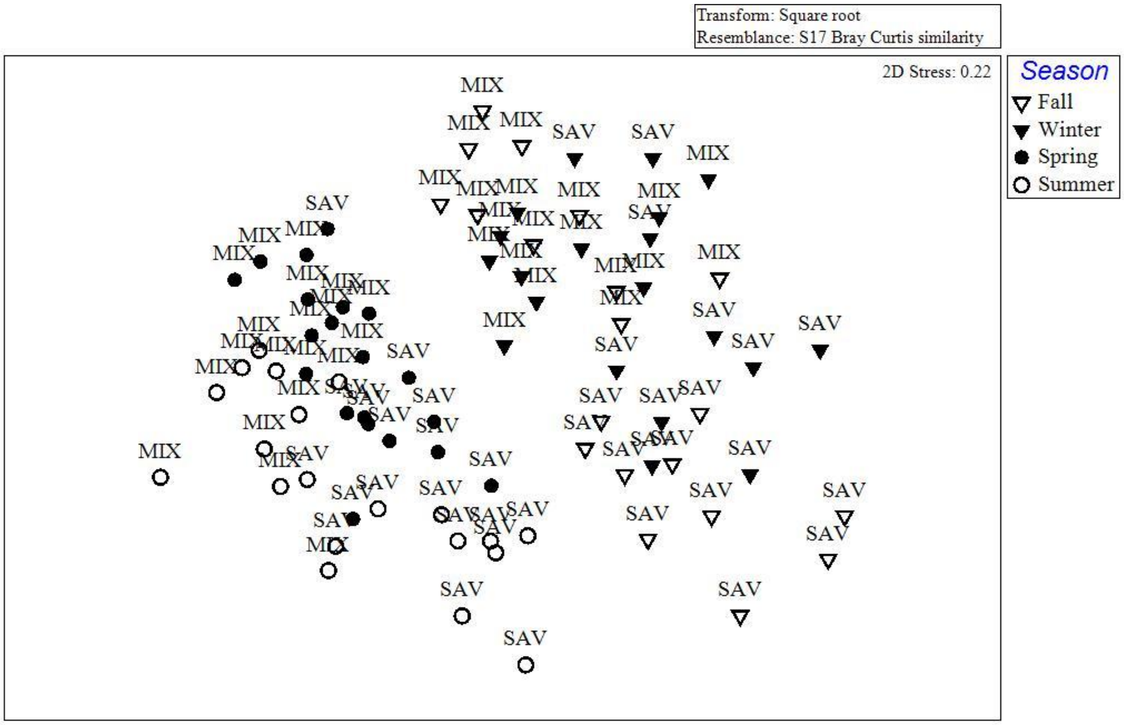

FIGURE 3.16. The NMDS conducted with waterfowl removed from the dataset shows that community composition patterns in the STAs were similar to those with waterfowl. Survey sets still segregated into two seasonal groups (winter/fall and spring/summer). However, the definition between vegetation types is less clear. Each point represents the mean species abundances from one vegetation treatment in one STA during one survey period**.**

CHAPTER 4: SYNTHESIS

Avian use of the STAs was much greater in the STAs than in the natural marsh and crop lands. The STAs were also decidedly more seasonal than the other two land types because they supported a large waterfowl community. Waterfowl were the primary driver of seasonal patterns within the STAs as well. Multiple vegetation treatments enhanced the biodiversity of the STAs by providing more habitat diversity. Avian communities were significantly different between vegetation treatments and among seasons mostly because waterfowl preferred SAV vegetation, whereas resident passerines preferred MIX vegetation. Season and vegetation treatment were much more influential on bird use in the STAs than were hydrologic variables that are so important for wading birds in oligotrophic wetlands.

The STAs support a much more diverse, abundant and distinct avian community when compared to reference land types. Avian densities in the STAs were three times greater than in the crop lands and 38 times greater than in the natural marsh. Local species richness in the STAs was 78% greater than in the crops and nearly four times greater than in the natural marsh. The avian community of the STAs was distinctly different than the crop lands and natural marsh.

The high productivity of the STAs, coupled with higher structural complexity, gave the treatment wetlands a much more abundant and diverse avian community compared to the crop lands and natural marsh. The STAs have orders of magnitude more productivity than the oligotrophic Everglades marsh (Newman et al. 2004; Chimney and Goforth 2006). Likewise, the STAs exhibit more structural complexity than the level fields and monocultures of the EAA. The combination of these two factors are known to increase bird use by supporting more abundant and diverse food resources (Wiens 1992).

The STAs are probably also attractive to large numbers of wading birds because they have consistent and stable water conditions, even when surrounding areas are dry. South Florida receives the majority of its rainfall in the summer and fall and is considerably drier during winter and spring. This seasonal rainfall pattern causes many natural wetlands to go dry at a time when wintering waterbirds like waterfowl and shorebirds are most abundant. However, the STAs provide habitat during this time because they are managed to maintain standing water throughout the dry season to sustain preferred vegetation communities and prevent the release of phosphorous from sediment when rewetted. These long hydroperiods also help support more birds by allowing for nearly constant macrophyte, invertebrate and fish production.

The high productivity that supports a more dense and rich bird community in the STAs than the natural marshes of the Everglades also reduces the impact that hydrology has on that bird community. The oligotrophic Everglades are known for large aggregations of wading birds that form when annual fluctuations in water levels produce and then concentrate small fish and invertebrate prey populations (Kushlan 1986). The eutrophic STAs, on the other hand, are productive enough to generate enough food resources to support high densities of waterfowl without the need to concentrate those resources. However, hydrologic dynamics are still important in influencing non-waterfowl bird communities.

Seasonality played a major role in shaping bird communities both among land types and within the STAs. The high proportion of waterfowl in the STAs made their populations fluctuate more across seasons than the other two land types which were dominated by more resident passerines. Avian density and local species richness in the STAs were much greater during fall and winter than during spring and summer. Species richness in the natural marsh increased in winter and spring when water levels were lowest but the natural marsh had the lowest richness and density of all three land types during all seasons. Species richness in the EAA did not change seasonally but density showed an increase during fall, possibly due to local recruitment and seasonal migrants.

The waterfowl that drove the overall seasonal pattern of the STAs also drove seasonal patterns between vegetation treatments within the STAs. Waterfowl were much more abundant in SAV vegetation than in MIX vegetation. Avian density in the fall and winter were much greater in the SAV vegetation when wintering waterfowl were present but not different during spring and summer. However, when waterfowl were removed from the dataset, avian density was not different between vegetation types. Meanwhile species richness, which was greatest in SAV vegetation in all seasons, was especially greater in SAV during winter with waterfowl in the dataset, but was not different without waterfowl in the dataset. Community composition also differed between vegetation treatments and among seasons as a result of disproportionate use by wintering waterfowl.

American Coot (*Fulica americana*) density in the STAs demonstrated how treatment wetlands could affect continental bird populations. Applying the estimate of coot density in this study on continental population estimates suggests that STAs may support up to 8% of the 3 million breeding individuals estimated in the North American population (Brisbin Jr. and Mowbray 2002). The use of treatment wetlands by such a large percentage of the population of American Coots opens the possibility that increased construction of these wetlands could influence the distribution of some wintering waterbirds, over winter survival, and could partially offset the effects of historic wetland losses (Nichols et al. 1983; Sutherland 1998; Jefferies et al. 2004). It is known that birds, particularly the Anatidae, alter migration routes, wintering grounds and breeding grounds in response to changes in habitat distributions (Nichols et al. 1983; Sutherland 1998; Jefferies et al. 2004) so there is no reason to believe that large scale changes in the distribution of wetlands, albeit treatment wetlands, would not produce a change in bird distributions .

The expansion of treatment wetlands has the potential to aid in the recovery of some wetland bird populations that have long suffered from habitat loss. This study showed that the STAs are supporting an abundant, rich and distinct bird community when compared to reference land types. The construction of the STAs has created a great deal of habitat for many birds that were not being supported by prior land uses of the STAs. However, this bird community was different from that of the natural wetlands, so the STAs cannot be considered surrogates for natural wetlands.

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