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COMMUNITY PATTERNS IN TREATMENT WETLANDS, NATURAL WETLANDS, AND CROPLANDS IN FLORIDA

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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. *Received 21 September 2012. Accepted 2 February 2013.*

Key words: agriculture, American Coot, Everglades, habitat creation, waterfowl, wetland loss, wintering habitat.

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 (Fig. 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 (Fig. 1; United States 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 (United States 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

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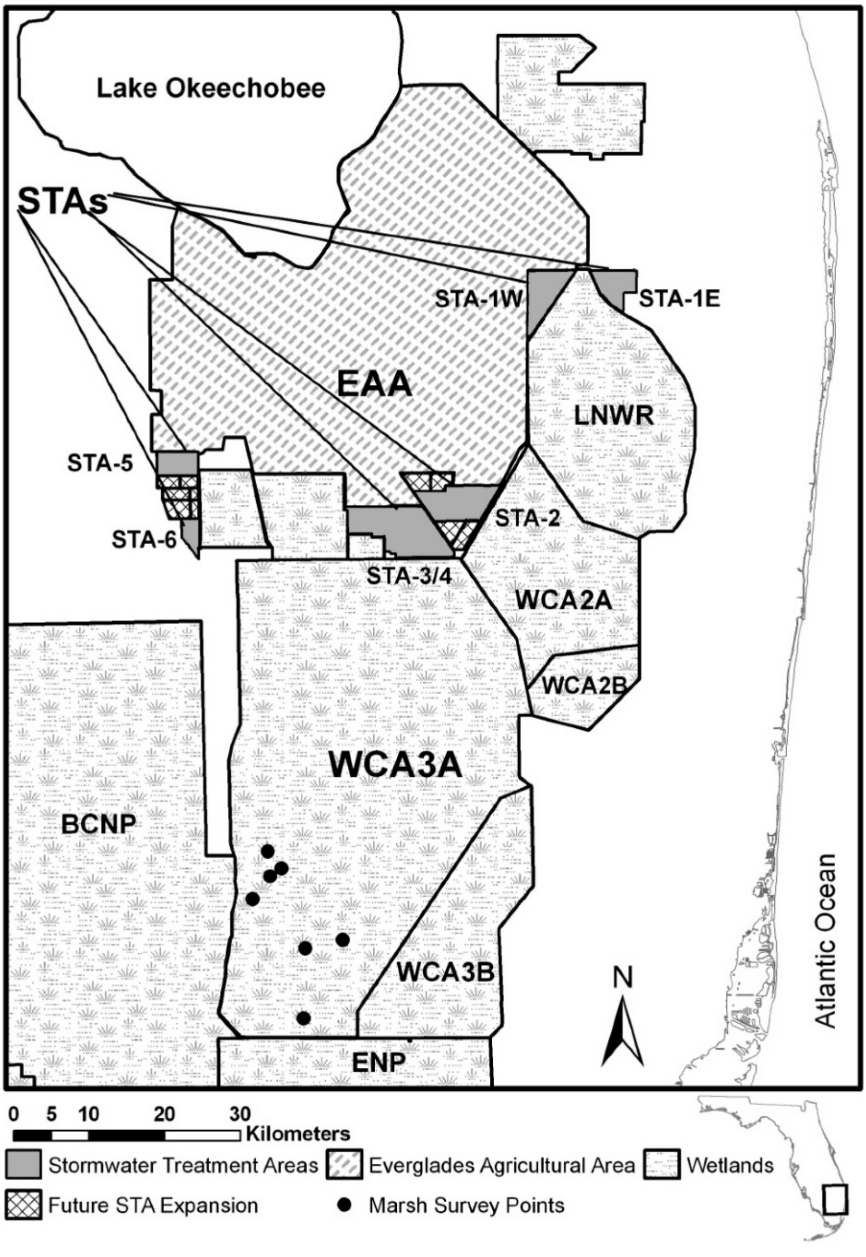

FIG. 1. Locations of WCAs, STAs and EAA within the Everglades system. Most of the nearly one million hectares of historic Everglades marshland have been drained to create the Everglades Agricultural Area (EAA) or have been compartmentalized for flood protection and water supply. What remains consists 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.

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; Fig. 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 (Fig. 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; Fig. 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 (Fig. 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, 400 m $\times$ 100 m 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° 22′ 2″ N, 80° 36′ 53″ W (Fig. 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 hrs. 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.

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 and Mowbray 2002).

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) 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 (SAS Institute 2008). A full list of species detected during this study and their guild associations is available in Appendix 1.

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).

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 (Fig. 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

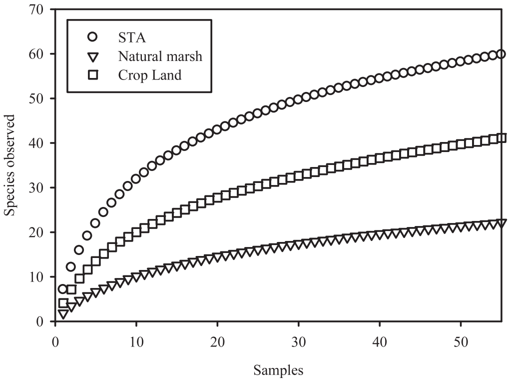

FIG. 2. Rarefaction curves showing accumulation of species with sampling effort. Correcting for differences in sampling effort, the STA surveys ($n = 722$) accumulated species much more rapidly than surveys in the crop ($n = 816$) and natural marsh ($n = 54$) land types. This suggests that the STAs support a richer community of bird species than the crop and natural marsh land types.

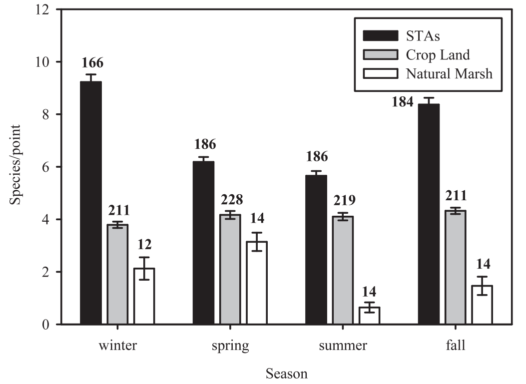

FIG. 3. Species richness in STAs, cropland, and natural marsh in winter, spring, summer, and fall (mean ± 1SE). Species richness was always highest in the STAs and lowest in the natural marsh. However, the magnitude of these differences was very dependent upon season. Numbers above bars indicate respective sample sizes.

$P < 0.05$). 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; Fig. 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; Fig. 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).

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 and Mowbray 2002).

Species Composition.—Pooled across seasons, the most common species in the STAs were the American Coot and Common Gallinule *(Gallinula galeata)*. Red-winged Blackbird *(Agelaius phoeniceus)*, Tree Swallow, and Killdeer (*Charadrius vociferus*), were the most common species, in croplands. Red-winged Blackbird, Tree Swallow, and Boat-tailed Grackle (*Quiscalus major*), were the most common species in the natural marsh.

Guild compositions were significantly different among all three land types (all $P < 0.001$; Fig. 5). Waterfowl, with 70% of the total abundance, was the dominant guild in the STAs. This contrasts

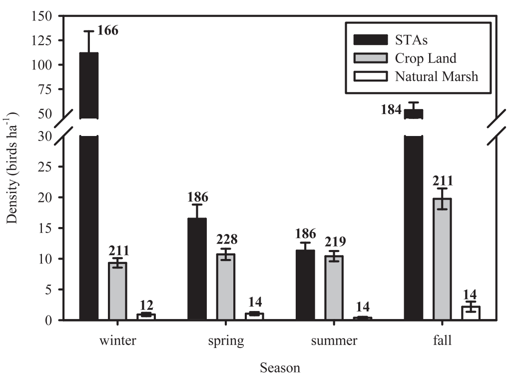

FIG. 4. Avian density in STAs, cropland, and natural marsh in winter, spring, summer, and fall (mean ± 1SE). Avian density was highest in the STAs in all seasons except for summer. The natural marsh always had the lowest density. Numbers above bars indicate respective sample sizes.

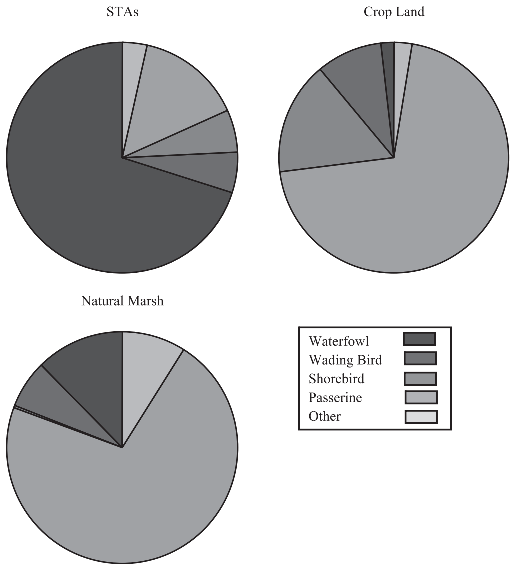

FIG. 5. Avian community composition in STAs, cropland, and natural marsh. Waterfowl were the dominant guild in the STAs, whereas the crop and natural marsh land types were dominated by passerines.

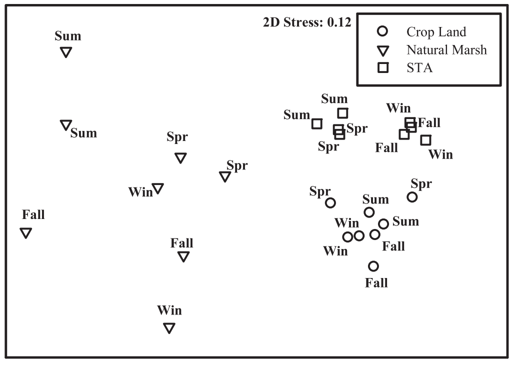

FIG. 6. Non-metric multidimensional scale (NMDS) ordinations were used to show that the avian communities in each land type are clearly different from each other. The STA survey sets showed the highest similarity (lowest spread) when compared to the other two land types. Furthermore, the STA survey sets were separated into two distinct clusters (fall/winter and spring/summer) showing the influence season had on the bird community in the STAs.

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 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 (Fig. 6) also showed clear grouping of winter/fall and spring/summer seasons in the STAs. The other two land types did not show such patterns.

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

TABLE 1. Bird densities found in treatment wetlands and reference wetlands in studies across the United States. (McAllister 1992, 1993a, b). 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[a]	NV	19.1	2.6
STAs	FL	43.0	1.1

[a] Passerines were not counted in this study.

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.

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 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 (United States 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.

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APPENDIX. 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
Glossy Ibis	*Plegadis falcinellus*	Crop, STA, NM
Great Blue Heron	*Ardea herodias*	Crop, STA, NM
Great Egret	*Ardea alba*	Crop, STA, NM
Green Heron	*Butorides virescens*	Crop, STA, NM
Limpkin	*Aramus guarauna*	STA
Little Blue Heron	*Egretta caerulea*	Crop, STA, NM
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		
American 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

APPENDIX. Continued.

Guild/species	*Scientific name*	Land type present
Pied-billed Grebe	*Podilymbus podiceps*	Crop, STA, NM
Purple Gallinule	*Porphyrio martinicus*	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 Rough-winged Swallow	*Stelgidopteryx serripennis*	Crop, STA
Northern Waterthrush	*Parkesia noveboracensis*	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

APPENDIX. Continued.

Guild/species	*Scientific name*	Land type present
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
Barn Owl	*Tyto alba*	Crop
Black Vulture	*Coragyps atratus*	Crop, STA, NM
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		
American White Pelican	*Pelecanus erythrorhynchos*	STA
Anhinga	*Anhinga anhinga*	Crop, STA, NM
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