Florida Field Naturalist 35(1):9-21, 2007.

THE AVIFAUNA OF CONSTRUCTED TREATMENT WETLANDS IN SOUTH FLORIDA USED FOR EVERGLADES RESTORATION

MICHAEL J. CHIMNEY[1] AND DALE E. GAWLIK[2]
[1]*South Florida Water Management District, MSC-4470, 3301 Gun Club Road, West Palm Beach, Florida 33406*
E-mail: mchimney@sfwmd.gov

[2]*Department of Biological Sciences, Florida Atlantic University, 777 Glades Road, Boca Raton, Florida 33431*
E-mail: dgawlik@fau.edu

Constructed treatment wetlands invariably create wildlife habitat (Kadlec and Knight 1996, U.S. Environmental Protection Agency 1999, Knight et al. 2001). Habitat improvement can be dramatic, especially when these systems are built on degraded areas such as farm fields (Hickman 1994). The South Florida Water Management District (SFWMD) and the U.S. Army Corps of Engineers have built a complex of large treatment wetlands, known as Stormwater Treatment Areas (STAs), on reclaimed farmland in south Florida as part of a multi-billion dollar effort by State and Federal governments to protect and restore the Everglades (Chimney and Goforth 2001, Sklar et al. 2005, SFWMD 2006). Current plans call for the STAs to encompass more than 17,000 ha. These wetlands were designed to treat and reduce high phosphorus concentrations in stormwater runoff from the Everglades Agricultural Area (EAA) before this water enters the northern portion of the remaining Everglades, the Water Conservation Areas (WCAs) (Fig. 1). The STAs have attracted a high abundance and diversity of wildlife species, including many birds. This paper presents a checklist of the avifauna found in two of the STAs and compares STA bird community composition and species richness with regional and other treatment wetlands.

METHODS

Birds in two STAs were surveyed: STA-1West (STA-1W) in Palm Beach County (2,699 ha, 26°39' N, 80°25' W) and STA-5 in Hendry County (1,663 ha, 26°26' N, 80°54' W). Both STAs are located within the EAA and are part of a regional landscape dominated by wetlands (Fig. 1). The STAs were built on relict Everglades marshland that had been drained and farmed for decades. Portions of STA-1W were flooded in 1989 and first opened for public birding in 2005; STA-5 was flooded in 1999 and opened for public birding in 2004. Each STA has a perimeter earthen levee that impounds water and various control structures (pump stations, interior levees, culverts, etc.) to manage flow through the system. The STAs are kept inundated except when inflow is restricted during ex-

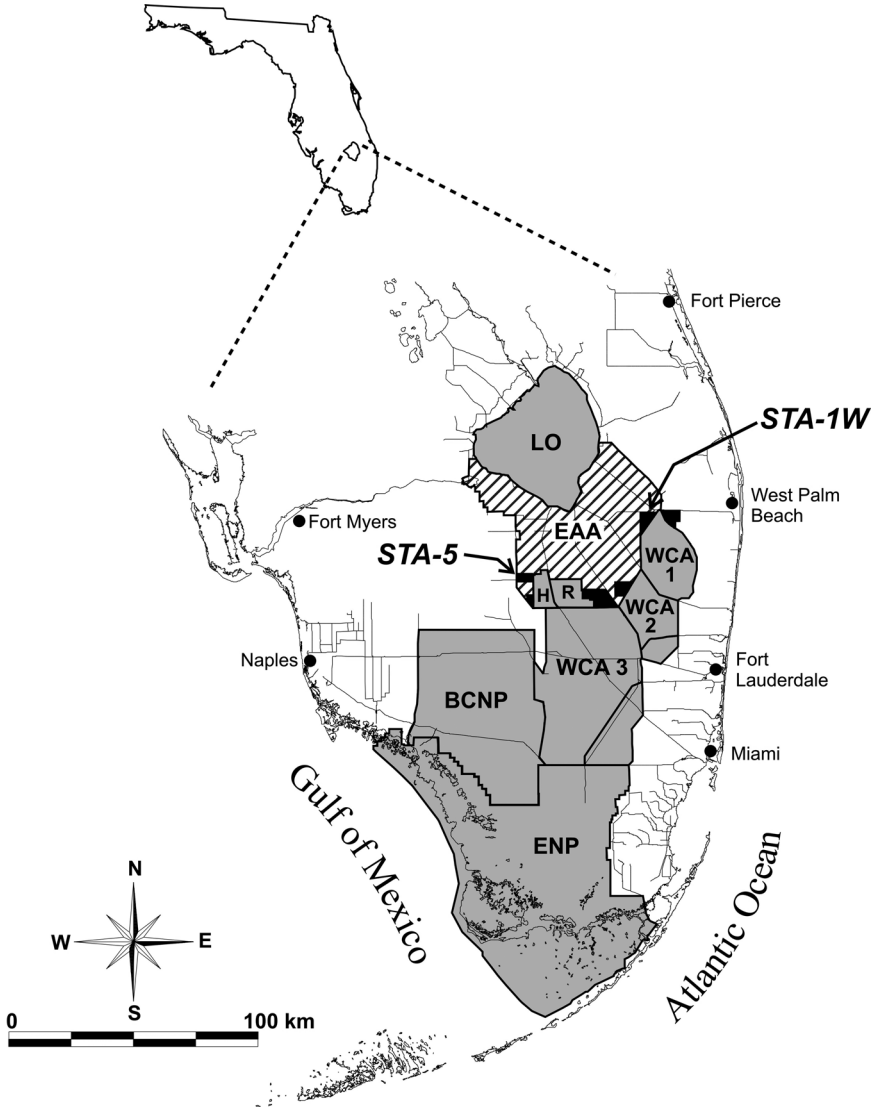

Figure 1. Location of Stormwater Treatment Areas 1-West and 5 (STA-1W and STA-5) in relation to the Everglades Agricultural Area, the other STAs (black areas), Lake Okeechobee, and major wetland management units (gray areas) in south Florida. More than 40% of the landscape in this region is classified as freshwater habitat. BCNP = Big Cypress National Preserve; EAA = Everglades Agricultural Area; ENP = Everglades National Park; H = Holey Land Wildlife Management Area; LO = Lake Okeechobee; R = Rotenberger Wildlife Management Area; WCA = Water Conservation Areas 1, 2, and 3. Water Conservation Area 1 also is designated as the Arthur R. Marshall Loxahatchee National Wildlife Refuge.

treme droughts or when treatment cells are taken off-line for maintenance. The target depth in these systems is ~0.5 m, but can exceed 1 m after large rain events when the STAs are treating runoff. Water depth in these systems can fluctuate rapidly in response to management activities. Flooded areas in the STAs developed into a mosaic of habitat types that included open-water areas intermixed with stands of *Typha* spp., other emergent marsh species (e.g., arrowhead [*Sagittaria* spp.], spikerush [*Eleocharis* spp.] and pickerelweed [*Pontederia cordata*]), submersed vegetation (e.g., coontail [*Ceratophyllum demersum*], southern naiad [*Najas guadalupensis*] and hydrilla [*Hydrilla verticillata*]) and floating species (e.g., water hyacinth [*Eichhornia crassipes*], water lettuce [*Pistia stratiotes*] and duckweed [*Lemna* spp.]). The STA levees, access roads and adjacent lands were upland areas that include grassed, old-field, and woodland habitats.

A master bird list was compiled for each STA by combining species identifications made by one of us (DEG) on 84 occasions in STA-1W from May 1995 to November 1997 (primarily winter and spring), by amateur ornithologists from local Audubon Society chapters in both STAs during fall, winter and spring (12 trips to STA-1W from September 2005 to March 2006; 15 trips to STA-5 from February 2004 to March 2006) and other incidental sightings. The accuracy of identifications made by citizen volunteers can be comparable to data collected by professional biologists (Hoyer et al. 2001). We did not estimate individual species densities from our survey data, but did ascertain the more abundant bird groups. Birds seen on at least 50% of all trips to each STA from 2004 to 2006 were designated as "frequent" species. The nomenclature, classification and sequence of each species followed American Ornithologists' Union (2006); habitat preferences are from American Ornithologists' Union (1998). The protective status of birds was based on Florida Fish and Wildlife Conservation Commission (2004). Breeding status and seasonality of birds in south Florida was based on distribution maps and descriptions provided in Robertson and Kushlan (1974), Robertson and Woolfenden (1992), Ridgely et al. (2003) and U.S. Fish & Wildlife Service (2006). Wetland bird species richness in the STAs, the Arthur R. Marshall Loxahatchee National Wildlife Refuge (LNWR; see Fig. 1) and a subset of treatment wetlands (Knight et al. 1993, USEPA 1999) was fit to wetland surface area as a power function: $S = cA^z$, where S is species richness, A is surface area, c is a constant and z is the slope of the regression (Gotelli 2001).

RESULTS

A total of 139 bird species representing 39 families was observed in the STAs; 100 species in 31 families occurred in STA-1W, whereas STA-5 had 118 species in 38 families (Table 1). Combined, the two STAs had 20 of the 21 families identified by Kadlec and Knight (1996) as common in North American treatment wetlands. Wading birds (Ciconiiformes, 15 species), shorebirds (Charadriiformes, 31 species), gallinules and coots (Gruiformes, 7 species) and ducks (Anseriformes, 16 species) were often numerically abundant in the STAs as were perching birds (Passeriformes, 39 species) on occasion. Twenty-eight of the 35 frequently observed species belonged to these aforementioned groups. Sixteen species are State and/or Federally listed as Endangered, Threatened or a Species of Special Concern. Seventy-two species are classified as residents and are known to breed in south Florida. Six frequent species (Osprey [*Pandion haliaetus*], Roseate Spoonbill [*Platalea ajaja*], Snowy Egret [*Egretta thula*], Tricolored Heron [*Egretta*

Table 1. Checklist of birds observed in Stormwater Treatment Areas 1-West and 5 (STA-1W and STA-5) including seasonality, breeding and protective status and habitat preference. + = species present, * = frequently observed species listed on at least 50% of all surveys in that STA. Status key: E = endangered (Federal), e = endangered (State), s = species of special concern (State), T = threatened (Federal), t = threatened (State), R = breeding resident, R_e = exotic resident, S = uncommon straggler (non-breeding), M = transient migrant (non-breeding), V = seasonal visitor (non-breeding). Habitat preference key: A = aquatic, U = upland.

Order / Family / Species Name	Common Name	STA-1W	STA-5	Status	Habitat
Anseriformes					
Anatidae	Ducks, Geese, & Swans				
Dendrocygna autumnalis	Black-bellied Whistling-duck	+	*	V	A
Dendrocygna bicolor	Fulvous Whistling-duck	+	*	R	A
Anser albifrons	Greater White-fronted Goose	+		V	A
Aix sponsa	Wood Duck		+	R	A
Anas americana	American Wigeon		+	V	A
Anas platyrhyncho	Mallard		+	V	A
Anas fulvigula	Mottled Duck	+	*	R	A
Anas discors	Blue-winged Teal	*	*	V	A
Anas cyanoptera	Cinnamon Teal		+	V	A
Anas clypeata	Northern Shoveler	+	+	V	A
Anas acuta	Northern Pintail	+	+	V	A
Anas crecca	Green-winged Teal		+	V	A
Aythya collaris	Ring-necked Duck	+	*	V	A
Aythya affinis	Lesser Scaup		+	V	A
Lophodytes cucullatus	Hooded Merganser	+		V	A
Oxyura jamaicensis	Ruddy Duck		+	V	A
Podicipediformes					
Podicipedidae	Grebes				
Podilymbus podiceps	Pied-billed Grebe	+	+	R	A
Pelecaniformes					
Pelecanidae	Pelicans				
Pelecanus erythrorhynchos	American White Pelican	+	+	V	A
Pelecanus occidentalis	Brown Pelican	+	+	R,s	A
Phalacrocoracidae	Cormorants				
Phalacrocorax auritus	Double-crested Cormorant	*	*	R	A
Anhingidae	Darters				
Anhinga anhinga	Anhinga	*	*	R	A
Ciconiiformes					
Ardeidae	Herons, Bitterns, & Allies				
Botaurus lentiginosus	American Bittern	+	+	V	A
Ixobrychus exilis	Least Bittern	+	+	R	A
Ardea herodias	Great Blue Heron	*	*	R	A
Ardea alba	Great Egret	*	*	R	A

Table 1. (Continued) Checklist of birds observed in Stormwater Treatment Areas 1-West and 5 (STA-1W and STA-5) including seasonality, breeding and protective status and habitat preference. + = species present, * = frequently observed species listed on at least 50% of all surveys in that STA. Status key: E = endangered (Federal), e = endangered (State), s = species of special concern (State), T = threatened (Federal), t = threatened (State), R = breeding resident, R_e = exotic resident, S = uncommon straggler (non-breeding), M = transient migrant (non-breeding), V = seasonal visitor (non-breeding). Habitat preference key: A = aquatic, U = upland.

Order / Family / Species Name	Common Name	STA-1W	STA-5	Status	Habitat
Egretta thula	Snowy Egret	*	+	R,s	A
Egretta caerulea	Little Blue Heron	*	+	R,s	A
Egretta tricolor	Tricolored Heron	*	*	R,s	A
Bubulcus ibis	Cattle Egret	*	*	R	A/U
Butorides virescens	Green Heron	+	*	R	A
Nycticorax nycticorax	Black-crowned Night-heron	+	+	R	A
Nyctanassa violacea	Yellow-crowned Night-heron		+	R	A
Threskiornithidae	Ibises & Spoonbills				
Eudocimus albus	White Ibis	*	+	R,s	A
Plegadis falcinellus	Glossy Ibis	*	*	R	A
Platalea ajaja	Roseate Spoonbill	*	+	R,s	A
Ciconiidae	Storks				
Mycteria americana	Wood Stork	*	+	R,E,e	A
Cathartidae	New World Vultures				
Coragyps atratus	Black Vulture	+	*	R	U
Cathartes aura	Turkey Vulture	+	*	R	U
Phoenicopteriformes					
Phoenicopteridae	Flamingos				
Phoenicopterus ruber	Greater Flamingo		+	S	A
Falconiformes					
Accipitridae	Hawks, Kites, Eagles, & Allies				
Pandion haliaetus	Osprey	*	+	R,s	A
Elanoides forficatus	Swallow-tailed Kite		+	R	U
Rostrhamus sociabilis	Snail Kite	+		R,E,e	A
Haliaeetus leucocephalus	Bald Eagle	*	+	R,T,t	A
Circus cyaneus	Northern Harrier	+	+	V	A/U
Accipiter striatus	Sharp-shinned Hawk		+	V	U
Accipiter cooperii	Cooper's Hawk	+	+	V	U
Buteo lineatus	Red-shouldered Hawk	+	+	R	A/U
Buteo jamaicensis	Red-tailed Hawk		*	R	U
Falconidae	Caracaras & Falcons				
Caracara cheriway	Crested Caracara		+	R,T,t	U
Falco sparverius	American Kestrel	+	+	R,T	U
Falco columbarius	Merlin		+	V	A/U
Falco peregrinus	Peregrine Falcon	+	+	R,e	A/U

Table 1. (Continued) Checklist of birds observed in Stormwater Treatment Areas 1-West and 5 (STA-1W and STA-5) including seasonality, breeding and protective status and habitat preference. + = species present, * = frequently observed species listed on at least 50% of all surveys in that STA. Status key: E = endangered (Federal), e = endangered (State), s = species of special concern (State), T = threatened (Federal), t = threatened (State), R = breeding resident, R_e = exotic resident, S = uncommon straggler (non-breeding), M = transient migrant (non-breeding), V = seasonal visitor (non-breeding). Habitat preference key: A = aquatic, U = upland.

Order / Family / Species Name	Common Name	STA-1W	STA-5	Status	Habitat
Gruiformes					
Rallidae	Rails, Gallinules, & Coots				
Rallus elegans	King Rail	+		R	A
Porzana carolina	Sora	+	+	V	A
Porphyrio martinica	Purple Gallinule	+	+	R	A
Porphyrio porphyrio	Purple Swamphen	+	+	R_e	A
Gallinula chloropus	Common Moorhen	*	*	R	A
Fulica americana	American Coot	*	*	R	A
Aramidae	Limpkin				
Aramus guarauna	Limpkin	+	+	R,s	A
Charadriiformes					
Charadriidae	Plovers				
Pluvialis squatarola	Black-bellied Plover	+	+	V	A
Pluvialis dominica	American Golden-Plover		+	M	A/U
Charadrius semipalmatus	Semipalmated Plover	+		V	A
Charadrius vociferus	Killdeer	*	*	R	A/U
Recurvirostridae	Stilts & Avocets				
Himantopus mexicanus	Black-necked Stilt	*	*	R	A
Recurvirostra americana	American Avocet	+	+	V	A
Scolopacidae	Sandpipers & Allies				
Tringa solitaria	Solitary Sandpiper	+		M	A
Tringa melanoleuca	Greater Yellowlegs	+	*	V	A
Tringa flavipes	Lesser Yellowlegs	*	+	V	A
Tringa semipalmata	Willet	+	+	R	A
Arenaria interpres	Ruddy Turnstone	+		V	A
Calidris alba	Sanderling	+		V	A
Calidris mauri	Western Sandpiper	+		V	A
Calidris minutilla	Least Sandpiper	*	*	V	A
Calidris melanotos	Pectoral Sandpiper	+	+	M	A
Calidris alpina	Dunlin	+	+	V	A
Calidris himantopus	Stilt Sandpiper	+	+	V	A
Philomachus pugnax	Ruff		+	V	A
Limnodromus griseus	Short-billed Dowitcher	+	+	V	A
Limnodromus scolopaceus	Long-billed Dowitcher	+	+	V	A
Gallinago delicata	Wilson's Snipe	+	+	V	A
Laridae	Skuas, Gulls, Terns, & Skimmers				
Larus atricilla	Laughing Gull	+		R	A

Table 1. (Continued) Checklist of birds observed in Stormwater Treatment Areas 1-West and 5 (STA-1W and STA-5) including seasonality, breeding and protective status and habitat preference. + = species present, * = frequently observed species listed on at least 50% of all surveys in that STA. Status key: E = endangered (Federal), e = endangered (State), s = species of special concern (State), T = threatened (Federal), t = threatened (State), R = breeding resident, R_e = exotic resident, S = uncommon straggler (non-breeding), M = transient migrant (non-breeding), V = seasonal visitor (non-breeding). Habitat preference key: A = aquatic, U = upland.

Order / Family / Species Name	Common Name	STA-1W	STA-5	Status	Habitat
Larus delawarensis	Ring-billed Gull	+	+	V	A
Larus argentatus	Herring Gull		+	V	A
Larus fuscus	Lesser Black-backed Gull		+	V	A
Sternula antillarum	Least Tern	+		R,t	A
Gelochelidon nilotica	Gull-billed Tern	+		R	A
Hydrorprogne caspia	Caspian Tern	*	+	V	A
Sterna forsteri	Forster's Tern	+		V	A
Thalasseus maximus	Royal Tern	+		R	A
Rynchops niger	Black Skimmer	+	+	R,s	A
Columbiformes					
Columbidae	Pigeons & Doves				
Columba livia	Rock Pigeon	+	+	R_e	U
Streptopelia decaocto	Eurasian Collared-Dove		+	R_e	U
Zenaida asiatica	White-winged Dove	+		R	U
Zenaida macroura	Mourning Dove	+	+	R	U
Columbina passerina	Common Ground-Dove	+	+	R	U
Cuculiformes					
Cuculidae	Cuckoos, Roadrunners, & Anis				
Crotophaga ani	Smooth-billed Ani	+		R	A/U
Strigiformes					
Strigidae	Typical Owls				
Strix varia	Barred Owl		+	R	A/U
Caprimulgiformes					
Caprimulgidae	Goatsuckers				
Chordeiles minor	Common Nighthawk		+	R	U
Coraciiformes					
Alcedinidae	Kingfishers				
Ceryle alcyon	Belted Kingfisher	+	+	R	A
Piciformes					
Picidae	Woodpeckers & Allies				
Melanerpes carolinus	Red-bellied Woodpecker	+	+	R	U
Passeriformes					
Tyrannidae	Tyrant flycatchers				
Sayornis phoebe	Eastern Phoebe		+	V	U
Myiarchus crinitus	Great Crested Flycatcher		+	R	U

Table 1. (Continued) Checklist of birds observed in Stormwater Treatment Areas 1-West and 5 (STA-1W and STA-5) including seasonality, breeding and protective status and habitat preference. + = species present, * = frequently observed species listed on at least 50% of all surveys in that STA. Status key: E = endangered (Federal), e = endangered (State), s = species of special concern (State), T = threatened (Federal), t = threatened (State), R = breeding resident, R_e = exotic resident, S = uncommon straggler (non-breeding), M = transient migrant (non-breeding), V = seasonal visitor (non-breeding). Habitat preference key: A = aquatic, U = upland.

Order / Family / Species Name	Common Name	STA-1W	STA-5	Status	Habitat
Laniidae	Shrikes				
Lanius ludovicianus	Loggerhead Shrike	+	+	R	U
Vireonidae	Vireos				
Vireo griseus	White-eyed Vireo		+	R	U
Corvidae	Crows & Jays				
Cyanocitta cristata	Blue Jay	+	+	R	U
Corvus brachyrhynchos	American Crow		+	R	U
Corvus ossifragus	Fish Crow	+	+	R	A
Hirundinidae	Swallows				
Progne subis	Purple Martin	+	+	R	U
Tachycineta bicolor	Tree Swallow	+	*	V	U
Stelgidopteryx serripennis	Northern Rough-winged Swallow	+	+	V	U
Petrochelidon pyrrhonota	Cliff Swallow		+	M	A
Hirundo rustica	Barn Swallow		+	M	A/U
Troglodytidae	Wrens				
Troglodytes aedon	House Wren		+	V	U
Sylviidae	Old World Warblers				
Polioptila caerulea	Blue-gray Gnatcatcher	+	+	R	U
Turdidae	Thrushes				
Sialia sialis	Eastern Bluebird		+	R	U
Turdus migratorius	American Robin		+	V	U
Mimidae	Mockingbirds & Thrashers				
Dumetella carolinensis	Gray Catbird		+	V	U
Mimus polyglottos	Northern Mockingbird	+	+	R	U
Sturnidae	Starlings				
Sturnus vulgaris	European Starling	+	+	R_e	U
Parulidae	Wood-Warblers				
Parula americana	Northern Parula		+	R	A/U
Dendroica petechia	Yellow Warbler		+	R	U
Dendroica coronata	Yellow-rumped Warbler	+	+	V	U
Dendroica discolor	Prairie Warbler	+		R	U
Dendroica palmarum	Palm Warbler	*	+	V	U
Minotilta varia	Black-and-white Warbler		+	V	U
Seiurus noveboracensis	Northern Waterthrush	+		M	A
Geothlypis trichas	Common Yellowthroat	+	+	R	A
Emberizidae	Emberizids				
Pipilo erythrophthalmus	Eastern Towhee	+		R	U

Table 1. (Continued) Checklist of birds observed in Stormwater Treatment Areas 1-West and 5 (STA-1W and STA-5) including seasonality, breeding and protective status and habitat preference. + = species present, * = frequently observed species listed on at least 50% of all surveys in that STA. Status key: E = endangered (Federal), e = endangered (State), s = species of special concern (State), T = threatened (Federal), t = threatened (State), R = breeding resident, R_e = exotic resident, S = uncommon straggler (non-breeding), M = transient migrant (non-breeding), V = seasonal visitor (non-breeding). Habitat preference key: A = aquatic, U = upland.

Order / Family / Species Name	Common Name	STA-1W	STA-5	Status	Habitat
Spizella pusilla	Field Sparrow		+	V	U
Passerculus sandwichensis	Savannah Sparrow	+	+	V	A
Melospiza georgiana	Swamp Sparrow	+		V	A/U
Cardinalidae	Cardinal, Saltators, & Allies				
Cardinalis cardinalis	Northern Cardinal	+		R	U
Passerina ciris	Painted Bunting		+	V	U
Icteridae	Blackbirds				
Agelaius phoeniceus	Red-winged Blackbird	*	*	R	A
Sturnella magna	Eastern Meadowlark	+	+	R	U
Quiscalus quiscula	Common Grackle		+	R	A/U
Quiscalus major	Boat-tailed Grackle	*	*	R	A/U
Molothrus ater	Brown-headed Cowbird		+	V	U
Passeridae	Old World Sparrows				
Passer domesticus	House Sparrow		+	R_e	U

tricolor], White Ibis [*Eudocimus albus*], and Wood Stork [*Mycteria americana*]) are both State/Federally listed and breed in the region. The STAs were used by many migratory species, often in great numbers, during the spring and fall (e.g., American White Pelican [*Pelecanus erythrorhynchos*], Black-bellied Whistling-Duck [*Dendrocygna autumnalis*], Blue-winged Teal [*Anas discors*], Lesser Yellowlegs [*Tringa flavipes*] and Black-necked Stilt [*Himantopus mexicanus*]). Sixty-nine percent of STA bird species preferred aquatic habitats or shared an affinity for both aquatic and upland areas. However, all pigeons and doves, and many of the raptors and perching birds are considered upland species.

DISCUSSION

Bird diversity and abundance in wetlands is influenced by a number of variables such as wetland surface area (Reaves and Croteau-Hartman 1994), water depth (Breininger and Smith 1990, Twedt et al. 1998, Bancroft et al. 2002), composition of the vegetation community (Johnson and Montalbano 1984, Bancroft et al. 2002), prey availability

(Gawlik 2002) and trophic status (Hoyer and Canfield 1994, Crozier and Gawlik 2002). High quality upland habitat immediately adjacent to wetlands also attracts a number of species that may be only facultative wetland inhabitants (Kent 1994, Knight et al. 2001). The STAs shared 91% of their avifauna with the LNWR (USFWS 2006), but only 78% with the EAA (Pearlstine et al. 2005). The EAA notably had fewer co-occurring species of perching birds and ducks, which may be related to its limited shrub habitat and type of wetlands (largely restricted to rice fields, flooded fallow fields and drainage canals). Differences in surface area accounted for slightly more than one-half of the variance in bird species richness among wetlands ($r^2 = 0.59$, $p < 0.01$) (Fig. 2). The unexplained variance can be attributed to the other species-habitat relationships noted above (Rafe et al. 1985) or factors such as differences in sampling methods among investigators.

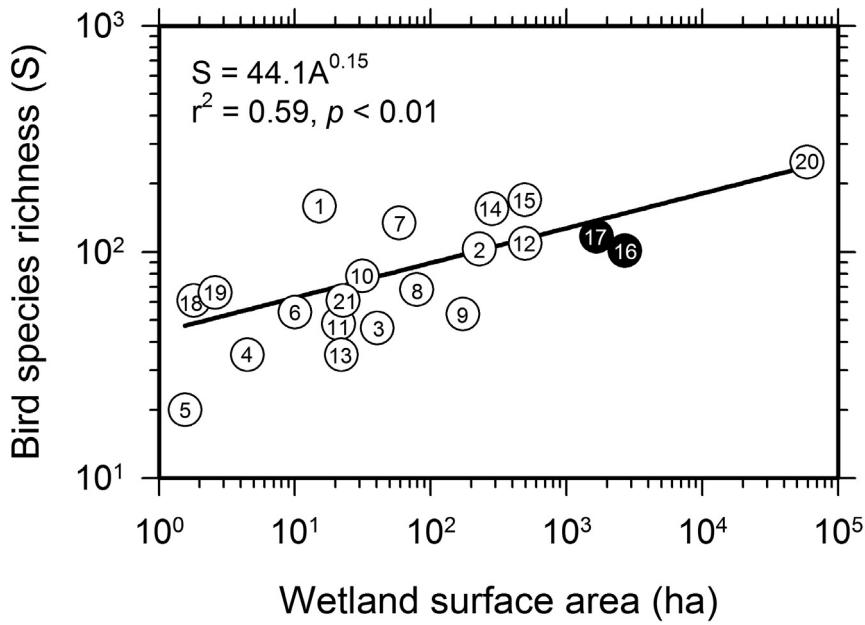

Figure 2. Species-area curve for wetland bird communities. Symbol key: 1 = Arcata (CA), 2 = Bear Bay (SC), 3 = Biwabik (MN), 4 = Collins (MS), 5 = Cypress Domes (FL), 6 = Des Plaines (IL), 7 = Hayward (CA), 8 = Houghton Lake (MI), 9 = Incline Village (NV), 10 = Lake Buena Vista (FL), 11 = Lake Coral (FL), 12 = Lakeland (FL), 13 = Ocean Springs (MS), 14 = Orlando Easterly (FL), 15 = Show Low (AZ), 16 = STA-1W (FL), 17 = STA-5 (FL), 18 = Tres Rios Cobble (AZ), 19 = Tres Rios Hayfield (AZ), 20 = LNWR (FL), 21 = West Jackson County (MS). Data sources: 1-9, 12, 15, 18, 19, & 21 (USEPA 1999); 10 (Kent and Langston 2000); 11 (Knight et al. 1985); 13 (Kadlec and Knight 1996); 14 (M. Sees pers. comm.); 16 & 17 (this paper); 20 (USFWS 2006). All systems except LNWR are treatment wetlands.

The bird assemblage in the STAs was not static. The periodic influx of large numbers of birds of a single species or group of species into the STAs generally occurred under one of two circumstances. The first was associated with large numbers of migrating birds moving into the area that found the STAs suitable habitat. Seasonal migrants accounted for the high concentrations of Tree Swallows, Blue-winged Teal and other waterfowl. The STAs at normal operating depth (~0.5 to 1.0 m) afforded birds with moderate to deep-water marsh habitat. The sharp increases in bird abundance during the fall and spring was somewhat predictable, but varied in magnitude from year to year, probably because of external factors such as annual recruitment and habitat suitability of the surrounding landscape.

The second circumstance that produced dramatic increases in bird abundance occurred when water depth in the STAs decreased during recessions. In this case, the habitat changed quickly and local birds attracted to shallow water (e.g., wading- and shorebirds) moved in to exploit it. An example of this situation occurred in March 1996 when water levels in portions of STA-1W rapidly fell from depths that approached 1 m to 0.2 m or less. A group of over 1000 herons, egrets, ibis and Wood Storks, many of which had been feeding in the surrounding area, quickly moved in and began feeding in the drying marsh. Although we did not continue observations, we suspect that as soon as water levels increased to normal, most of the wading birds would have returned to their previous feeding areas. A similar managed drawdown in winter 2005 of a substantial portion of STA-1W that contained little emergent vegetation attracted a great number of shorebirds. The influx of birds into the STAs in response to falling water levels has occurred on other occasions; these events were driven by management activities and therefore were unpredictable from the bird's perspective or occurred during prolonged regional droughts. The proximate factor for the increase in bird density was likely a sharp increase in food availability (Gawlik 2002) because prey was suddenly more vulnerable to being captured. This situation differed from seasonal migrations in that the increase in bird abundance was from a redistribution of local birds rather than a regional influx of migrants and it was caused by a short-term change in the habitat (i.e., water depth) rather than from long-term processes that structure vegetation, such as trophic status.

The two situations that cause high bird abundance in the STAs are not mutually exclusive and it is possible that a decrease in water depth that coincides with seasonal bird migration could result in very high bird density and diversity. Such a convergence of events contributed to the high diversity of shorebirds in STA-1W. Although the STAs are operated as treatment systems to reduce nutrients in stormwater runoff, bird use of these areas is extensive and dependent on variable wetland conditions, much like in natural wetlands.

ACKNOWLEDGMENTS

We thank the many Audubon Society members for their interest in documenting the avifauna of the STAs and Margaret England (Hendry-Glades Audubon Society), Vincent Lucas (Tropical Audubon Society), Bijaya Kattel (SFWMD), and Ann McElhatton (Florida Atlantic University) for sharing this information with us. The paper was improved based on helpful comments from Mark Cook, Bijaya Kattel, Jana Newman, Scott Robinson, Seán Sculley, Gary Williams and two anonymous reviewers.

LITERATURE CITED

AMERICAN ORNITHOLOGISTS' UNION. 1998. Check-list of North American birds, 7th ed. American Ornithologists' Union, Washington, D.C.

AMERICAN ORNITHOLOGISTS' UNION. 2006. Check-list of North American Birds—online birdlist 47 [www.aou.org/checklist/index.php3]. Viewed 28 March 2007.

BANCROFT, G. T., D. E. GAWLIK, AND K. RUTCHEY. 2002. Distribution of wading birds relative to vegetation and water depths in the northern Everglades of Florida, USA. Waterbirds 25:265-277.

BREININGER, D. R., AND R. B. SMITH. 1990. Waterbird use of coastal impoundments and management implications in east-central Florida. Wetlands 10:223-241.

CHIMNEY, M. J., AND G. GOFORTH. 2001. Environmental impacts to the Everglades ecosystem: a historical perspective and restoration strategies. Water Science and Technology 44:93-100.

CROZIER G. E., AND D. E. GAWLIK. 2002. Avian response to nutrient enrichment in an oligotrophic wetland, the Florida Everglades. Condor 104:631-642.

FLORIDA FISH AND WILDLIFE CONSERVATION COMMISSION. 2004. Florida's endangered species, threatened species, and species of special concern [www.myfwc.com/imperiledspecies/pdf/Endangered-Threatened-Special-Concern-2004.pdf]. Viewed 22 March 2007.

GAWLIK, D. E. 2002. The effects of prey availability on the numerical response of wading birds. Ecological Monographs 72:329-346.

GOTELLI, N. J. 2001. A Primer of Ecology, 3rd ed. Sinauer Associates, Inc., Sunderland, MA.

HICKMAN, S. 1994. Improvement of habitat quality for nesting and migrating birds at the Des Plaines River wetlands demonstration project. Ecological Engineering 3:485-494.

HOYER, M. V., AND D. E. CANFIELD, JR. 1994. Bird abundance and species richness on Florida lakes: influence of trophic status, lake morphology, and aquatic macrophytes. Hydrobiologia 297/298:107-119.

HOYER, M. V., J. WINN, AND D. E. CANFIELD, JR. 2001. Citizen monitoring of aquatic bird populations using a Florida lake. Lake and Reservoir Management 17:82-89.

JOHNSON, F. A., AND F. MONTALBANO III. 1984. Selection of plant communities by wintering waterfowl on Lake Okeechobee, Florida. Journal of Wildlife Management 48:174-178.

KADLEC, R. H., AND R. L. KNIGHT. 1996. Treatment Wetlands. CRC Press, Inc., Boca Raton, FL.

KENT, D. M. (ed.) 1994. Applied Wetlands Science and Technology. Lewis Publishers, Boca Raton, FL.

KENT, D. M., AND M. A. LANGSTON. 2000. Wildlife use of a created wetland in central Florida. Florida Scientist 63:17-19.

KNIGHT, R. L., R. A. CLARKE JR., AND R. K. BASTIAN. 2001. Surface flow (SF) treatment wetlands as habitat for wildlife and humans. Water Science and Technology 44:27-37.

KNIGHT, R. L., R. W. RUBLE, R. H. KADLEC, AND S. REED. 1993. Wetlands for wastewater treatment: performance database. Chapter 4. Pages 35-58 *in* Constructed Wetlands for Water Quality Improvement (G. A. Moshiri, ed.). Lewis Publishers, Boca Raton, FL.

KNIGHT, R. L., B. H. WINCHESTER, AND J. C. HIGMAN. 1985. Ecology, hydrology, and advanced wastewater treatment potential of an artificial wetland in north-central Florida. Wetlands 5:167-180.

PEARLSTINE, E. V., M. L. CASLER, AND F. J. MAZZOTTI. 2005. A checklist of birds of the Everglades Agricultural Area. Florida Scientist 68:84-96.

RAFE, R. W., M. B. USHER, AND R. G. JEFFERSON. 1985. Birds on reserves: the influence of area and habitat on species richness. Journal of Applied Ecology 22:327-335.

REAVES, R. P., AND M. R. CROTEAU-HARTMAN. 1994. Biological aspects of restored and created wetlands. Proceedings of the Indiana Academy of Sciences 103:179-194.

RIDGELY, R. S., T. F. ALLNUTT, T. BROOKS, D. K. MCNICOL, D. W. MEHLMAN, B. E. YOUNG, AND J. R. ZOOK. 2003. Digital Distribution Maps of the Birds of the Western Hemisphere, version 1.0 [www.natureserve.org/explorer]. Viewed 9 March 2007. NatureServe, Arlington, VA.

ROBERTSON, W. B., JR., AND J. A. KUSHLAN. 1974. The southern Florida avifauna. Pages 414-452 *in* Memoir 2: Environments of South Florida: Present and Past. Miami Geological Society, Miami, FL.

ROBERTSON, W. B. JR., AND G. E. WOOLFENDEN. 1992. Florida Bird Species: An Annotated List. Special Publication 6, Florida Ornithological Society, Gainesville, FL.

SKLAR, F. H., M. J. CHIMNEY, S. NEWMAN, P. MCCORMICK, D. GAWLIK, S. MIAO, C. MCVOY, W. SAID, J. NEWMAN, C. CORONADO, G. COZIER, M. KORVELA, AND K. RUTCHEY. 2005. The ecological-societal underpinnings of Everglades restoration. Frontiers in Ecology and the Environment 3:161-169.

SOUTH FLORIDA WATER MANAGEMENT DISTRICT (SFWMD). 2006. Comprehensive Everglades Restoration Plan (CERP) [www.evergladesplan.org/index.cfm]. Viewed 9 March 2007.

TWEDT, D. J., C. O. NELMS, V. E. RETTIG, AND S. R. AYCOCK. 1998. Shorebird use of managed wetlands in the Mississippi alluvial valley. American Midland Naturalist 140:140-152.

U.S. ENVIRONMENTAL PROTECTION AGENCY (USEPA). 1999. Treatment Wetland Habitat and Wildlife Use Assessment, Executive Summary. EPA 832-S-99-001.

U.S. FISH & WILDLIFE SERVICE (USFWS). 2006. Arthur R. Marshall Loxahatchee National Wildlife Refuge bird list.