WOOD STORK USE OF AND CONTAMINANT LEVELS IN URBAN MAN-MADE WATER BODIES IN NORTHEAST FLORIDA

by

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(Under the Direction of Sara H. Schweitzer)

ABSTRACT

The federally listed Wood Stork (Mycteria americana) is dependent on shallow, ephemeral wetlands for foraging. Most of these natural wetlands have been lost in Florida due to increased urban development, but numbers of man-made bodies of water have increased. I used program PRESENCE to predict stork occurrence in man-made water bodies. Storks were more likely to be detected relatively far from the nesting colony, suggesting that late in the breeding season, storks use water bodies relatively far from their nesting colony to find available and abundant prey. Additionally, storks were more likely to be detected when other wading birds were present, reflecting their social and opportunistic foraging behavior. During the summers of 2007 and 2008 I collected samples of prey items and sediment from 30 sample sites, and dead or moribund chicks from the Jacksonville Zoo stork colony for analysis of 18 inorganic elements, 46 polycyclic aromatic hydrocarbons (PAH), and a suite of eight organophosphate and 29 organochlorine pesticides. I did not detect organophosphates in samples of sediment, prey, or chicks. When detected, concentrations of metals, PAHs, polychlorinated biphenyls (PCBs), and organochlorine pesticides in sediment, prey, and chicks were below previously reported effects thresholds for birds. Each water body type harbored a fairly unique contaminant profile. I concluded that overall risk to storks from foraging in man-made water bodies in the Jacksonville, FL area was likely low but requires further investigation, particularly for selenium and PAHs.

INDEX WORDS: endangered species, Mycteria americana, environmental contaminants
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DEDICATION

For my loving mother. Thank you for always letting me be me and for encouraging me to follow my dreams. Thank you for being a wonderful example of what a person should be. One of my greatest blessings is our friendship. I love you.
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INTRODUCTION AND LITERATURE REVIEW

STUDY OVERVIEW

Section 3.8 of the recovery plan issued by the United States Fish and Wildlife Service (USFWS) for the endangered Wood Stork (*Mycteria americana*) states that contaminants must be assessed in the stork’s foraging areas (USFWS 1996). Contaminants need to be addressed because many contaminants of concern, such as mercury, selenium, and dichloro-diphenyl-trichloroethane (DDT), are compounds that reduce reproductive success (Fry 1995). Wood Storks that use urban or agricultural areas for foraging may be at increased risk because these contaminants tend to accumulate in certain urban and agricultural sites such as man-made wetlands and ditches. Contaminants tend to be distributed unevenly and different colonies of birds are exposed to different levels of contamination (Blus *et al.* 1985; Fasola *et al.* 1998; Gariboldi *et al.* 2001). Contaminant studies of a few Wood Stork colonies in Georgia and Florida have been conducted, and only one site currently harbors contaminants at detrimental levels (Fleming *et al.* 1984; Gariboldi *et al.* 1998; Bowerman *et al.* 2007). Storks first started nesting freely in the Jacksonville Zoo and Gardens (Zoo) in 1999 and have nested successfully each year since, fledging on average, greater than two chicks per pair (Rodgers *et al.* 2008). There have been no comprehensive contaminant studies of the Zoo colony. To address all goals of the USFWS Wood Stork recovery plan, we must have baseline knowledge of the contaminants that storks are exposed to during the breeding season, especially those nesting in urban areas.
My study had two primary objectives that are addressed in the following chapters. My first objective was to quantify use of urban man-made water bodies by Wood Storks. This objective was achieved by occupancy modeling. One hundred random water bodies were visited multiple times at different times of day and at varying distances from the colony location. The water bodies were in areas of varying degrees of urbanization and were also surveyed for presence of other wading birds. First, I expected that storks would have a greater likelihood of using water bodies in the early morning and early evening. Second, I expected that storks would use water bodies close to their nesting colony. I also expected that storks would feed in water bodies that were in areas with a lower degree of urbanization. Finally, I expected detection probability of storks would be greater in water bodies with other wading birds present.

My second objective was to identify contaminants within urban water bodies used as foraging sites by storks and to identify specific water body types that would carry more risk to storks based on contaminant load. To accomplish this objective, six Wood Storks from the Jacksonville Zoo Colony were fitted with satellite transmitters in 2007 and 2008 headed by Donna Bear-Hull, head bird curator of the Jacksonville Zoo and Gardens. I identified stork foraging locations from transmitter data, and collected samples from the locations during June and July 2007 and 2008. I recorded water quality parameters, and collected samples of sediment and prey (fish and invertebrates) from each foraging location. My samples of water, sediment, and prey were analyzed for presence and concentration of heavy metals, organic contaminants, polycyclic aromatic hydrocarbons (PAHs), and inorganic contaminants by USFWS contracted labs. I sorted the man-made, urban water bodies into four types (golf course, residential, industrial, and rural), and compared variables among water body type. I expected that contaminants would be detected in all wetlands. I also suspected that contaminant levels would
differ among types of water bodies, but because of limited existing data, I did not know which water body type would have higher contaminant levels. My final chapter includes conclusions, management implications, and suggestions for future research.

WETLANDS

From the beginning of human habitation on Earth, wetlands have influenced human life. Early civilizations arose on fertile grounds of floodplains, cities arose along the coasts and along rivers, and we depend on clean freshwater every day (Keddy 2000). There are many types of wetlands, such as swamps, bogs, wet meadows, fens, and marshes (Keddy 2000). Wetlands are found in every climactic zone and every county of the United States (USEPA 2004). Some of the many functions that wetlands perform are: cleaning water, recharging groundwater, producing energy and fuel, preventing soil erosion and floods, recycling organic matter, providing wildlife habitat and opportunities for tourism and recreation, and being aesthetically pleasing (deGroot 1994).

Wetland decline in the United States has been documented by the USFWS since the late 1950s. The first report on the loss of wetlands in the United States gives an account of substantial declines in migratory waterfowl habitat (Shaw and Fredline 1956). From the 1950s to the 1970s, the rate of wetland loss was 185,400 ha/yr (Frayer et al. 1983). Between the mid-1970s and the mid-1980s, the rate of wetland loss slowed to 117,000 ha/yr (Dahl and Johnson 1991). From 1986 to 1997, the rate of wetland loss decreased to 23,700 ha/yr (Dahl 2000). According to the most recent wetland status study, from 1998 to 2004 there was a net gain of 12,900 ha/yr (Dahl 2005). This increase is largely due to regulatory programs such as Section 404 of the Clean Water Act and other federal and state incentive programs such as mitigation
banking and conservation programs, as well as restoration and conservation actions of non-governmental organizations such as Ducks Unlimited (Dahl 2005; Zedler 2006).

Wetlands account for 5.5% of the land cover of the United States. In 2004, there were 43.6 million ha of wetlands in the United States, 95% of which were freshwater (Dahl 2005). From 1998 to 2004, freshwater ponds increased 12.6%; without this increase there would have been no net gain in wetlands during this time (Dahl 2005). During this same time, urban and rural development accounted for 61% of the loss of wetlands (Dahl 2005). Wetlands found in urban areas are usually constructed, or man-made, water bodies that serve a city’s functions such as mitigation payments, aesthetic purposes (i.e., neighborhood ponds), and catchments for stormwater runoff. Man-made water bodies range from golf course ponds, retention ponds for industrial use, detention ponds, neighborhood ponds, roadside ditches, and include wetlands that superficially look natural. Water bodies in urban areas may be degraded but still provide important functions and often provide opportunities for recreational and educational experiences in areas where little natural habitat is available (West 1995; Simenstead and Thom 1996; Zedler 1996; Grayson et al. 1999). Most of these man-made water bodies are open-water habitats that do not provide in-kind replacement for filled marshes and swamps; thus, many critical, ecological functions are lost.

There have been many correlational studies on avian communities within man-made water bodies (Adams et al. 1985a; Duffield 1986; Coulter 1987; Ogden 1991; Frederick and McGehee 1994; Brusati et al. 2001; Snell-Rood and Cristol 2003; Cristol and Rodewald 2005; White and Main 2005). One study reported seasonal variation in abundance and diversity of waterbirds between man-made and natural water bodies (Duffield 1986). Another study reported that avian communities in man-made water bodies were significantly lower in species richness
and diversity and differed in community composition compared to reference wetlands (Snell-Rood and Cristol 2003). Additionally, there may be differences in diversity and abundance among man-made water bodies. For instance, detention basins have lower abundance than retention ponds and larger lakes (Adams et al. 1985b). Golf course ponds have higher avian diversity and abundance when the adjacent land is forested rather than residential (Cristol and Rodewald 2005).

Species abundance and diversity of avian communities are important to understand, but more importantly, there is a need to identify reasons birds use man-made water bodies. Golf course ponds provide ample foraging grounds for waders but do not provide nesting sites (White and Main 2005). Wading birds, specifically Wood Storks, foraged extensively for two months during the breeding season in artificial water bodies that were specifically created for storks (Coulter 1987). Storks also nested in large numbers at created and altered water bodies in Florida (Ogden 1991). Experimental studies are needed to assess the use of created and natural water bodies by avian communities, specifically, wading birds communities. The contaminant loads present in man-made water bodies should also be assessed.

CONTAMINANTS

Four major groups of environmental contaminants affect avian species: petroleum and its by-products (e.g., PAH), organochlorine compounds, organophosphate compounds, and heavy metals. All groups are toxic, persistent in the environment, and have both synergistic and bioaccumulative effects (Newman and Unger 2003). A species’ reproductive success rate is the population parameter commonly affected by contaminants (Newman and Unger 2003).

Polycyclic aromatic hydrocarbons are generated from the incomplete combustion of organic matter, caused naturally or by human activities (Newman and Unger 2003). Polycyclic
aromatic hydrocarbons are highly variable in molecular weight and size; thus, their physical properties are highly variable as are their effects on organisms. Heavier PAHs are hydrophobic and can accumulate in sediments and organisms. Some PAHs, such as benzo(a)pyrene, are known carcinogens (Newman and Unger 2003).

Organochlorine compounds, such as the synthetic pesticides aldrin, dieldrin, toxaphene, and DDT, have high molecular weights, are hydrophobic, and can act as xenoestrogens (Fry 1995). They degrade slowly in the environment because of their high degree of chlorine substitution that can not be quickly metabolized by microbes (Newman and Unger 2003). They may also bioaccumulate and bioconcentrate in sediments and organisms. During the 1970s, most organochlorine pesticides were banned from use in United States (Newman and Unger 2003). Organochlorine compounds affect bird reproductive success rates by harming egg shell formation. Thin eggshells resulted from female’s consumption of fish and other prey in which DDT had accumulated (Mendenhall et al. 1983; Henny et al. 1984; Powell 1984; Rattner et al. 1984; Bunck et al. 1985; Henny and Herron 1989; Fry 1995). Clutch sizes and nesting success rates of Black-crowned Night-herons (Nycticorax nicticorax) with >8 ppm DDE concentrations in liver tissues were lower than those of herons not exposed to DDE (Henny et al. 1984). Barn Owls (Tyto alba) experimentally exposed to levels of DDE, had significantly more eggshell thinning, egg breakage, embryo mortality, and reduced reproductive effort per pair than those not exposed (Mendenhall et al. 1983). The same study also exposed owls to dieldrin and found eggshell thinning but the reproductive success rate did not decline; however, adult mortality was reported (Mendenhall et al. 1983). Eggshell thickness is negatively correlated with DDT, DDE, and DDD levels in White-faced Ibis (Plegadis chihi), Bald Eagles (Haliaeetus leucocephalus), Screech Owls (Otus spp.), Mallards (Anas platyrhynchos), and American Kestrels (Falco
Organophosphate compounds such as chlorpyrifos, parathion, and diazinon, are insecticides that inhibit acetylcholinesterase activity and alter nerve function. These compounds affect invertebrates most severely but may also affect humans and other vertebrates (Newman and Unger 2003). In addition to their direct effect on birds, the use of organophosphate compounds to kill invertebrates affects insectivorous birds indirectly by decreasing food availability.

Organophosphate insecticides impair avian reproductive function, possibly by altering the secretion of leutinizing hormones and progesterone (Rattner et al. 1984). When Red-winged Blackbirds (*Agelaius phoeniceus*) were exposed to organophosphates, they exhibited an increased frequency of nest abandonment, and they experienced decreased clutch size, hatching success, and fledgling success (Powell 1984).

Organophosphate compounds seem to affect appetite also. Northern Bobwhites (*Colinus virginianus*) exposed to organophosphates in lab studies reduced their consumption of food; thus, their body weights were lower than those of control birds, and fertility rates and production of eggs were lower (Rattner et al. 1984). European Starlings (*Sturnus vulgaris*) exposed to organophosphates fed less, their nestlings lost weight, and exhibited decreased parental care relative to controls (Grue et al. 1982). Because hundreds of millions of hectares of land are treated each year with organophosphates around the world for pest control, impacts to birds and other wildlife may be significant (Rattner et al. 1984).
The last group of major contaminants includes heavy metals and metalloids. These contaminants occur naturally in the environment but become a problem when human activities cause them to concentrate above natural background levels. The most commonly studied metals and metalloids harmful to birds are arsenic (As), lead (Pb), mercury (Hg), selenium (Se), and cadmium (Cd). Metals have many adverse effects on wildlife from reproductive impairment (Leland et al. 1978; Heinz 1979; Wolfe et al. 1998, Santolo et al. 1999), renal failure (King et al. 1983), loss of appetite and weight loss (Spalding et al. 2000), to death from acute toxicity (Leland et al. 1978; Spalding et al. 1994, Wolfe et al. 1998). Several studies have found colonies of birds that do not seem to be affected by exposure to heavy metals (Blus et al. 1985; King and Cromartie 1986; DeBowy 1989; Henny and Herron 1989; Burger 1996; Burger et al. 2004; Ratti et al. 2006).

Mercury, one of the most studied heavy metals in wildlife and human health, is naturally occurring in the earth’s crust and found locally in high concentrations (Dallinger et al. 1987; Burger 1996). Sources of Hg include paints, electronics, chlorine-alkali production, gold mining, and as fungicides at pulp mills (Newman and Unger 2003). Mercury becomes methlyated in anaerobic conditions causing an increase in solubility, volatility, and bioavailability (Atlas and Bartha 1997; Williams et al. 2000; Newman and Unger 2003). Mercury is very copious in the environment and in one study in Florida, there were detectable levels of Hg in each sample taken, including those in rural areas (Fleming et al. 1984).

Species that forage in fresh water, including Wood Storks, are at a greater risk of Hg toxicity than species that forage solely in saltwater (Gariboldi et al. 1998) because freshwater prey items have higher concentrations of Hg than saltwater prey items, likely due to point source pollution from nearby urbanized areas (Gariboldi et al. 1998). In the Florida Everglades,
Clecker et al. (1998) found that fish had the highest concentrations of methylmercury of all prey items examined. Data from feeding trials conducted in controlled lab settings suggest that effects of mercury on birds’ body condition, such as reduced field of vision, numbness in extremities, and loss of coordination, likely would lead to higher juvenile mortality in the wild (Spalding et al. 2000). Piscivorous birds exposed to Hg exhibit embryonic mortality and deformities, abnormal chick behavior, altered parental care, decreased reproductive success, decreased survival of adults and juveniles, and decreased general health (Heinz 1979; Barr 1986; Nocera and Taylor 1998). The effects of Hg are well documented though the concentrations in the environment are lesser known because they tend to vary from location to location. Mercury and selenium (Se) concentrations are positively correlated, and Se may decrease the toxicity of Hg in some species (Pelletier 1985; Henny and Herron 1989; Sepulveda et al. 1998).

Selenium, a metalloid, is an essential element as well as a dietary component and occurs naturally in soil, but concentrations of it increase where glass, electronics, pigments, and metal alloys are produced; it is a byproduct of mining; and it is in metal alloys (Newman and Unger 2003). Microbes alkylate Se, making it more available for uptake by organisms, increasing its likelihood of causing toxic effects (Atlas and Bartha 1997; Williams et al. 2000; Newman and Unger 2003). Selenium does not breakdown in the environment, and once in the environment it is hard to remove (Bienen 2003); thus, its concentration may increase annually. DeBowy (1989) reported a three-fold increase in concentration of Se from algae and vegetation to invertebrates, then to fish. In birds, Se levels do not seem to differ between sexes, but levels increase with age, and are higher in the summer than any other season (King and Cromartie 1986; Sepulveda et al. 1998). In California, levels of Se did not differ between adjacent water bodies constructed for mitigation and natural wetlands (Gordus 1999). However, Se toxicity is localized in many
instances, with birds from some areas showing little to no effects from Se ingestion (Fox et al. 2005; Ratti et al. 2006). In addition, Fox et al. (2005) found that most studies focus on breeding individuals, so more research is necessary on non-breeding individuals because they may be impaired from high Se levels.

There have been many studies on the impacts of As, Cd, and Pb on birds. Arsenic is found in metal alloys, pesticides, herbicides, plant desiccants, and wood preservatives, and it is associated with mining and coal fly ash (Newman and Unger 2003). Methylated forms of As are more volatile, toxic, and known carcinogens (Atlas and Bartha 1997; Williams et al. 2000; Newman and Unger 2003). Cadmium is found in plastic stabilizers, electroplating, galvanizing, pigments, batteries, alloy production, and often in sewage sludge (Alloway and Jackson 1991; Williams et al. 2000; Newman and Unger 2003). Lead is ubiquitous in the environment because of its use in gasoline for many years (Newman and Unger 2003). It is also found in batteries, solders, pigments, piping, ammunition, paints, caulking, and ceramics (Williams et al. 2000; Newman and Unger 2003). In studies of lead ingestion and toxicosis in wild birds there was no difference in Pb levels in male and female birds (King and Cromartie 1986; Scheuhammer 1989). Lead shot in soils, where hunting is frequent, is of great concern because it causes acute toxicosis when ingested (Schulz et al. 2006). However, use of lead shot during waterfowl hunting was banned in 1991, so further accumulation will not occur due to waterfowl hunting (Federal Regulation 50, C.F.R. 20). Heavy metals have many effects on wildlife, avian species in particular, ranging from reproductive impairment to death (Blus et al. 1985; Spalding et al. 1994).

Little is known about contaminants and storks. Because of storks’ endangered status, no laboratory dosing tests are possible; however, nestling contaminant levels may indicate the
exposure level of adult storks. Gariboldi et al. (1998) focused on the contaminant levels, particularly Hg, in stork prey, and found freshwater prey had higher concentrations of contaminants than prey in saltwater. In a later study, Gariboldi et al. (2001) took blood, down, and contour feathers from 300 nestlings in coastal and inland South Carolina and Georgia during 1996 to 1999. They found that the coastal colonies had lower Hg concentrations present in both blood, down, and feathers, but these results varied annually and regionally (Gariboldi et al. 2001). Reproductive success of the colonies studied varied directly with average Hg concentration found in tissues (Gariboldi et al. 2001). Another study of contaminants in coastal and inland colonies in Georgia that tested for organochlorine pesticides, Hg, and PCBs, only found detectable levels of p,p’DDE in the plasma of nestlings (Bowerman et al. 2007). They suggest that the levels of p,p’DDE and the other contaminants for which they tested are not detrimental to the colonies they studied (Bowerman et al. 2007). In 1982, a study on eight colonies throughout central and northern Florida found DDE and Hg present in all eggs, and the authors suggest that although the DDE levels were higher in those nests that did not have 100% hatching success, that PCBs, organochlorine pesticides, and Hg were not depressing Wood Stork populations (Fleming et al. 1984). Other Wood Storks have been tested for contaminants when they were found dead, mostly as roadkill, and have had contaminants present, but not in alarming levels.

DESCRIPTION OF THE WOOD STORK

The Wood Stork is a large wading bird with long legs, and head-to-tail length of 85 to 115 cm (Hancock 1992). Adults weigh up to 8.5 kg and are generally silent except for hissing and bill clattering during mating displays and nest building (Hancock 1992; USFWS 1996). Storks fly with their neck and legs extended and have a wingspan of 150 to 165 cm (Hancock
Wood Storks’ plumage is all white, except the tail, primaries, and secondaries under the wing are black. The adult Wood Stork has a scaly bald head and has several colloquial names: wood ibis, flinthead, ironhead, and gannet (Hancock 1992; USFWS 1996; Sibley 2000).

**LIFE HISTORY OF THE WOOD STORK**

The Wood Stork is the only stork species (Ciconiidae) that breeds in the United States (Hancock 1992). Wood Storks breed from coastal North Carolina to Florida, south through Mexico, Central America, Cuba, and Hispaniola to northern Argentina (Hancock 1992; Brooks and Dean 2008). In the United States, breeding populations occur primarily in Florida but are expanding their breeding range northward each year (Brooks and Dean 2008). Overall, Wood Stork numbers are increasing as the species expands farther north, although some researchers have suggested that the Everglades, formerly a significant breeding site, may be a population sink because of its varying manipulated hydrologic regime (Kushlan 1986; Frederick et al. 2008). However, the Everglades still remain a valuable wintering ground for storks and are thought to sustain up to half of the wintering U.S. population (USFWS 1996).

Wood Storks use both estuarine and freshwater habitats for nesting, roosting, and foraging (USFWS 1996). Storks typically choose nesting sites in patches of medium to tall trees, except in the Everglades where they will nest in small trees (USFWS 1996; Murphy and Coker 2008; Winn et al. 2008). Nesting sites are typically over water. Trees are usually cypress (*Taxodium distichum*), black gum (*Nyssa sylvatica*), and southern willow (*Salix carolina*), but may also include red mangrove (*Rhizophora mangle*) and button bush (*Cephalanthus occidentalis*; USFWS 1996). Storks select nesting sites that remain inundated during the entire nesting season to protect nestlings from mammalian predators (USFWS 1996). Roosting sites
are similar to nesting sites and include trees over dry ground, mangrove, pine or hardwood islands in marshes, cypress heads and swamps, willow thickets, dry marshes, and on the ground (USFWS 1996). Foraging sites are diverse and include many different shallow wetlands such as tidal creeks and pools, managed impoundments, agricultural ditches, stock ponds, freshwater marshes, depressions in cypress heads, and swamp sloughs (Coulter et al. 1987; Hodgson 1987; USFWS 1996; Depkin et al. 2005). Foraging sites are characterized by calm water, 5-40 cm deep, a high prey density, and clear of dense vegetation (Ogden et al. 1976; Coulter 1987; USFWS 1996).

Several studies have focused on storks’ foraging location in relation to freshwater, saltwater, and brackish water sites (Kahl 1964; Coulter 1987; Coulter and Bryan 1993; Gaines et al. 1998; Romenak 2000; Depkin et al. 2005). Both freshwater and saltwater sites are significant to storks in coastal zones (Coulter and Bryan 1993; Gaines et al. 1998; Depkin et al. 2005). Tidal salt or brackish water sites are important foraging areas for storks in coastal zones. During low tide, there are high prey densities which lead to higher foraging efficiencies (Gaines 1998; Depkin et al. 2005). Wood Storks in a coastal colony on St. Simons Island, Georgia, preferentially fed in freshwater sites (Romenak 2000). Freshwater sites often have lower prey densities, but have a larger window of opportunity for foraging, and storks may fly farther to forage in them (Gaines et al. 1998; Coulter and Bryan 1993).

Storks have a unique feeding strategy called tactilocation where the bill is swept back and forth and snaps shut when a prey item is felt (Kahl 1964). Wood Storks have the fastest tactilocation reflex in the animal kingdom (Kahl 1964). Occasionally storks will stir up the water with their feet to startle hiding prey (Kahl 1964; Kushlan 1978, 1979). Tactilocation requires no visual observation of prey and enables storks to forage in unclear waters, such as
brackish or blackwater swamps, and during low light. During the breeding season, storks forage in areas of drying water, presumably because of increasing prey density. They forage in coastal marshes, then move to creeks, streams, and pools, then to inland wetlands (Ogden et al. 1976). Prey items of storks are mainly fish, but also include crayfish (Cambaridae) and other invertebrates, snails (Gastropoda), frogs and tadpoles (Anura), and salamanders (Salmandridae; Ogden et al. 1976). Storks have been documented eating mammals, other birds, and reptiles (USFWS 1996). Prey fish range in size from 2 to 25 cm in length (Kahl 1964; Ogden et al. 1976; Coulter 1987).

Storks use two different types of flight, flapping and soaring (Kahl 1964). Storks use flapping flight in the early morning, late afternoon, at night, and on cloudy days. Storks may flap on average, 175 times a minute (Kahl 1964). During warmer periods, thermal air currents support the weight of storks so no flapping is necessary (Kahl 1964). Thermals enable storks to fly farther distances by reducing the amount of energy needed (Bryan and Coulter 1995).

Storks are seasonally monogamous and form pair bonds yearly after highly ritualized courtship displays (USFWS 1996). There is little information on the breeding age of storks, although three- and four-year-olds have bred (Hancock 1992; USFWS 1996). It is thought that breeding probably occurs annually once storks reach sexual maturity (Hancock 1992; USFWS 1996). Nests are built at varying heights (1 to 30 m) and are made from sticks, vines, leaves, and Spanish moss (Tillandsia usneoides); Wood Storks will also nest in artificial structures (USFWS 1996). Nesting commences at various times of the year (November to March) depending on latitude (Rodgers 1990; Ogden 1994; USFWS 1996).

Female Wood Storks lay from two to five eggs, but average clutch size is three eggs. Unless a nest fails early in the season, storks will not re-nest (USFWS 1996). Incubation lasts
approximately 30 days, and chicks typically fledge after nine weeks, but parents care for the juveniles for a few weeks post-fledging (USFWS 1996). Nest failure occurs for many reasons including predation by raccoons (*Procyon lotor*), stress induced by cold weather, storms, intraspecific aggression, and starvation because of fish kills during heavy summer rains (Ogden 1994; Coulter and Bryan 1995; USFWS 1996). Although there are few data on survival of birds post-fledging, a study by Hylton *et al.* (2006) found that the percentage of chicks that survived to six months was 63%, to one year was 41%, and to two years was 75%. Hylton (2004) estimates 17% of Wood Storks that survive to the fledgling stage will survive to breeding age.

**STUDY AREA**

Our study was conducted within a 25-km radius of the Jacksonville Zoo and Gardens (Zoo) in the city of Jacksonville, Florida (30°E 24.4′N/ 81°E 26.8′N). Metro Jacksonville has a population of 1.3 million people, is the twelfth largest city in the contiguous United States by population, and is the largest inland area with over 217,500 ha (http://www.coj.net accessed 10-1-2009). Jacksonville borders the Atlantic Ocean, is approximately 40 km south of the Georgia border, and is bisected by the St. Johns River. Because of its unique geography there are many available freshwater and brackish water bodies, both man-made and natural, available as Wood Stork foraging sites. The drydown period in Jacksonville is from March to July, and water bodies begin to refill in July (Henry *et al.* 1994). Annual precipitation is 132 cm and average annual temperature is 20.6° C, with March signaling the end of freezing (Henry *et al.* 1994). Within the African Savanna Habitat exhibit at the Zoo, a colony of Wood Storks selected two live oak trees (*Quercus virginiana*) and other smaller trees as nesting sites. They have nested at this site successfully since 1999. The water bodies that were part of this study were man-made,
constructed water bodies such as neighborhood, golf course, and other types of retention ponds within 25 km of the Zoo.

LITERATURE CITED


United States Fish and Wildlife Service. 1996. Revised recovery plan for the U.S. breeding population of the Wood Stork, Atlanta, Georgia.


CHAPTER 2

FACTORS INFLUENCING USE OF MAN-MADE WATER BODIES BY WOOD STORKS IN NORTHEAST FLORIDA

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ABSTRACT: The federally listed Wood Stork (*Mycteria americana*) is dependent on shallow, ephemeral wetlands for foraging, and most of these natural wetlands have been lost in Florida due to increased urban development. The frequency of use of urban, man-made water bodies by Wood Storks is unknown. Our objectives were to assess use of urban water bodies by storks near a known colony (Jacksonville Zoo colony) and evaluate the relations between stork use and landscape and local water body characteristics. We also investigated the effect of two sampling covariates on the probability of detecting storks: time-of-day and presence of other wading birds. We surveyed 100 random water bodies with multiple visits in July 2008 for stork use. We used program PRESENCE to fit a set of candidate models to predict stork use of man-made wetlands. Wood storks were detected at 7 sites, with as many as 30 storks observed at a single man-made body of water. The best approximating model determined by AIC, included distance to zoo colony and presence of other wading birds. Storks from the zoo colony were more likely to be detected far from their nesting colony, indicating that late in the breeding season, storks travel relatively long distances to find prey. Storks were more likely to be detected when other wading birds were present, which is consistent with their social behavior and opportunistic use of foraging sites with dense, accessible prey. Future studies should identify factors that will enhance urban, man-made water bodies so they provide additional, quality feeding sites for Wood Storks.

Key Words: Ciconiiformes, endangered species, foraging, *Mycteria americana*, occupancy modeling, presence, urban wetlands, wading birds, Wood Stork
The Wood Stork (*Mycteria americana*) was listed as endangered in 1984 by the U.S. Fish and Wildlife Service because of significant population decline, presumably resulting from loss of foraging habitat, human disturbance, exposure to pesticides and other contaminants, and water level manipulations, among other factors (USFWS 1996). Among these factors, loss of foraging habitat is believed to be the primary factor affecting population growth and reproductive rates (USFWS 1996). The rate of habitat loss in the Wood Stork’s range is high due to urbanization and human population growth. For example, it is estimated that Florida will have a human population of 28.7 million by 2030, an overall rate of increase of 79.5% from 2000 to 2030 (2005 United States Census). Thus, the potential threats to Wood Storks are likely to increase in the future.

The Wood Stork is the only stork endemic to North America and it has a wide distribution. There are active colonies in Florida, Georgia, South Carolina, and North Carolina. Surveys from 2001 to 2006 found 5,560 to 11,279 breeding pairs of Wood Storks in the United States (Brooks and Dean 2008). Wood Storks are colonial nesters, choosing nest trees that are protected from most predators by water throughout the nesting season.

Storks typically feed in shallow wetlands where prey concentrations are high (Ogden *et al.* 1976; Coulter and Bryan 1993). Foraging sites include tidal creeks, shallow tidal pools, seasonally flooded roadside or agricultural ditches, stock ponds, freshwater marshes, swamp sloughs, depressions in cypress heads, managed impoundments, man-made sites such as retention ponds and neighborhood ponds, and almost any other shallow wetland depression (USFWS 1996; Depkin *et al.* 2005). When storks soar, they use only one-tenth the energy of flying, so they can travel long distances in search of food without expending much energy.
(Bryan *et al.* 1995). Storks use thermals to reduce energy expenditures and are regularly observed soaring as far as 40 km from nesting colonies to foraging grounds. However, soaring long distances from a nesting colony may decrease the frequency by which chicks are fed, so foraging areas close to a nesting colony are important (Kahl 1964; Bryan *et al.* 1995) and may influence the survival of nestlings and provide newly fledged birds with opportunities to learn effective feeding skills (Kahl 1964, USFWS 1996). Depkin *et al.* (2005) found that Wood Storks foraging in tidal areas spent most of their time feeding, whereas storks in palustrine habitats foraged, rested, preened, and exhibited other behaviors. Feeding in tidal areas may be most efficient during low tide because storks can take advantage of high prey densities in tidal pools; however, times of high prey densities are relatively brief and available only twice daily (Gaines *et al.* 1998; Depkin *et al.* 2005). freshwater foraging sites (e.g., swamps, ponds, ditches) often have lower prey densities, but if water levels slowly recede during dry periods, densities of prey increase and such situations are stable until they are filled again by precipitation or prey are depleted; thus, they offer a larger window of opportunity for foraging and storks may soar farther from nesting colonies to forage in them (Coulter and Bryan 1993; Gaines *et al.* 1998).

Many fresh water artificial bodies of water have been created in urban developments throughout the Wood Stork’s range. These water bodies are usually man-made wetlands that serve as mitigation payments, aesthetic viewscapes (i.e., neighborhood ponds), and catchments for stormwater runoff. Man-made water bodies range from golf course ponds, stormwater retention ponds for industrial use, detention ponds, neighborhood ponds, and roadside ditches. Superficially, these water bodies often look natural. Wood Storks use foraging locations according to prey availability; thus, as the availability of man-made water bodies with abundant prey increases, use of them for foraging by Wood Storks may increase (Romanek *et al.* 2000).
However, there may be a risk associated with Wood Storks’ use of man-made bodies of water for foraging because storks may be exposed to increased levels of contaminants often found in stormwater retention and urban runoff catchments (Scholes et al. 1998; Carleton et al. 2000; Bavor et al. 2001; Raimund et al. 2003).

The interface between Wood Stork populations and increasing urban development is typified by Jacksonville, Florida. In 2009, Jacksonville had a population of 1.3 million people, and a large metropolitan area with an increasing number of man-made water bodies (http://quickfacts.census.gov/qfd/states/12/12031.html, accessed August 22, 2009). The Jacksonville Zoo and Gardens (Zoo) hosts a free-ranging colony of Wood Storks that has been nesting successfully since 1999 (USFWS 2007). These storks tend to feed in tidal areas during the non-breeding season and in freshwater sites, often man-made water bodies in urban settings, during the nesting season (B. Brooks, USFWS, unpublished data). Thus, the Jacksonville metropolitan area provides a unique opportunity to evaluate the frequency of use of man-made water bodies by Wood Storks and to predict if use was influenced by factors associated with the water bodies such as, degree of urbanization around them, distance from water bodies to the zoo colony, distance from water bodies to closest colony, distance from water bodies to closest tidal area, size of the man-made water body, presence of other wading birds, tidal stage, and time of day. We also wanted to account for incomplete detection of Wood Storks during surveys in order to use occupancy models, so we incorporated a sampling regime to model variability in detection probability. We hypothesized that storks’ use of man-made wetlands would be higher in areas relatively close to the nesting colony and higher in areas surrounded by less urbanization. We also hypothesized that detection probability would be higher for water bodies with other wading birds present, during the early morning and evening, and during high tide.
STUDY AREA

Research was conducted within a 25-km radius of the Jacksonville Zoological Gardens in Jacksonville, Florida. Metropolitan Jacksonville is the twelfth largest city by population in the contiguous United States and the largest in land area (>217,500 ha, http://quickfacts.census.gov/qfd/states/12/12031.html, accessed August 22, 2009). It is bordered by the Atlantic Ocean and is bisected by the St. Johns River. Because of its geographical location, there are many freshwater and brackish water bodies, man-made and natural, available as stork foraging sites.

The colony of Wood Storks at the Zoo nests in two live oak trees (Quercus virginiana) within the African Savanna Habitat exhibit. The colony size has ranged from 84 to 147 nesting pairs. During our study, there were two other stork colonies in the general area. The Dee Dot colony was 28 km southeast of the Zoo colony, and the Pumpkin Hill colony was 20 km northeast of the Zoo colony. The Pumpkin Hill and Dee Dot colonies were 28 km apart, and both were on private timberland. The Dee Dot colony ranged from 62 to 251 nesting pairs in the past ten years in a remnant, impounded, cypress swamp (Brooks and Dean 2008, Rodgers et al. 2008). The Pumpkin Hill colony ranged from 0 to 98 nesting pairs in recent years in two isolated cypress-dominated domes. This colony failed to initiate nesting during several years, presumably because of drought conditions (Brooks and Dean 2008; Rodgers et al. 2008).

The water bodies we surveyed were man-made and permanent, and included neighborhood, golf course, and other types of retention ponds within 25 km of the Zoo. These bodies of water ranged from 0.02 to 3.9 ha, and typically were surrounded by mown grasses.

The Southeast Geography Analysis Project (SEGAP) data for Land Cover Mapping has four classes of urban landuse (open developed, low developed, medium developed, and high
developed). Each category was defined by the amount of impervious surface. Open developed had >20% impervious surface, low developed was between 20-49%, medium developed was between 50-79%, and high developed was between 80-100% (Center 2008).

METHODS

Surveys

We used Google™ Earth (Mountain View, CA, 2007) to select bodies of water for study sites. First, we randomly selected ten man-made water bodies from all those available ≤25 km of the Jacksonville Zoo Colony because we believed this colony was the primary source of potential wood storks in our study. Eight to ten additional water bodies surrounding each of the ten initial bodies of water were selected to form ten sampling routes, and a total of 100 water bodies. Each water body was surveyed one to three times during the sampling period (11 July 2008 to 31 July 2008). Each survey of a body of water consisted of visually scanning for storks and other wading birds for 2 min. We conducted surveys from roads because the small (0.02 – 3.9 ha) bodies of water could be seen in entirety and they were close (2-10 m) to roads. Also, surveys from roads were efficient, safe, less likely to flush birds, and avoided trespassing on private property.

We used the Southeast Geography Analysis Project (SEGAP) data for Land Cover Mapping and ArcMap™ 9.3 (Center 2008) to determine the degree of urbanization around each body of water we surveyed. The SEGAP data set had four classes of urban land use (open developed, low developed, medium developed, and high developed). We grouped the open and low developed classes of urban land use together to form our low urban category (binary coded as 0 for models), and the medium and high developed classes of urban land cover together to form our high urban category (binary coded as 1 for models). These categories were assigned to
the dominant land cover type, defined by the SEGAP data set, immediately surrounding (50-m
buffer) each water body.

We used ArcMap™ 9.3 to measure distance (to the nearest meter) to the zoo colony, to
the nearest colony (Zoo, Pumpkin Hill, or Dee Dot), and to a tidal area from each of the 100
bodies of water. We delineated water bodies from aerial photographs using ArcMap™ 9.3 to
obtain the area (ha) of each, following wetland delineation guidelines (Tiner 1996; Philipson
1997).

During each 2-min survey of a water body, we recorded Wood Stork presence (coded as
1) or absence (0), presence of other wading birds (1 or 0), time of day, and tidal stage. Time of
day was divided into AM (0700-1059 hrs), MID (1100-1459 hrs), and PM (1500-1859 hrs).
Tidal stage was recorded as high (coded as 0) and low (1).

Statistical Analysis

We used a single-season occupancy model to estimate occupancy of man-made water
bodies by Wood Storks (MacKenzie et al. 1996). In our study, occupancy was more
appropriately termed “use” because Wood Storks may forage in many water bodies over the
course of a day. Candidate variables that may have affected the probability of use of a water
body by Wood Storks included: class of urban land use (high or low urbanization), distance to
the zoo colony, distance to the closest colony, distance to a tidal area, size of water body.
Candidate variables that may have affected the detection probability included: presence of other
wading birds, time of day, and tidal stage. We included a global model (included all candidate
variables) for both distance-to-zoo-colony, and distance-to-closest-colony, to determine from
which colony the storks originated. Each candidate model that included distance-to-zoo-colony
was duplicated with distance-to-closest-colony in its place for the same purpose.
Using Program PRESENCE (Hines 2006 PRESENCE version 2.2), we evaluated the relative support for a set of 30 candidate models that represented hypothesized effects of landscape and local factors on Wood Stork use of man-made water bodies. Before, analysis, we used a Pearson correlation to identify variables that were highly correlated to avoid multicolinearity, if variables were highly correlated, they were not used in the same model. We used Akaike’s Information Criterion (AIC) to evaluate the relative support of each candidate model (Akaike 1973) such that models with low AIC values were considered the best supported. We also calculated Akaike weights ($w$) following Burnham and Anderson (2002). The weights range from 0-1, where 1 indicated the best approximating model.

To incorporate model selection uncertainty, we calculated model-averaged parameter estimates ($\hat{p}$; Burnham and Anderson 2002) using all 30 a priori models because each model was biologically plausible. Relative importance of individual predictor variables was calculated as the sum of Akaike weights for all models in which the variable appeared (Burnham and Anderson 2002). To evaluate the precision of the model averaged parameter estimates, we calculated 90% confidence limits. We also calculated scaled odds ratios (Hosmer and Lemeshow 2000) for each predictor variable to facilitate interpretation. The odds ratio scalars corresponded to what we believed were ecologically relevant unit changes in the predictors.

RESULTS

During July 2008, we surveyed 66 water bodies one time, eleven water bodies twice, and 23 water bodies three times for a total of 157 2-min surveys. We distributed our surveys among the three times of day: 54 AM, 44 MID, and 61 PM (Table 2.1). There were 79 water bodies in the low urbanization category and 21 in the high urbanization category. We conducted 46 surveys during high tide and 111 surveys during low tide. The average size of water bodies was
0.53 ha (range, 0.02 to 3.94 ha). The average distance from the zoo colony and a surveyed water body was 11.9 km (range, 2.6 – 24.3 km); the nearest known Wood Stork colony was 9.8 km (range, 2.6 – 20.2 km); and the closest tidal area was 4.2 km (0.2 – 13.7 km; Table 2.2).

Wood Storks were detected eleven times at seven different water bodies (Table 2.1). Other species of wading birds were detected 30 times at 25 different water bodies, and included the Little Blue Heron (*Egretta caerulea*), Green Heron, (*Butorides virescens*), Tricolored Heron (*E. tricolor*), Anhinga (*Anhinga anhinga*), Double-crested Cormorant (*Phalacrocorax auritus*), Great Egret (*Ardea alba*), Snowy Egret (*E. thula*), and Cattle Egret (*Bubulcus ibis*).

The naïve probability of use estimate from program PRESENCE was 0.07, the mean use estimate was 0.36, and the mean detection probability was 0.60. The best approximating model included water body use modeled as a function of the distance from the zoo colony, and detection as a function of presence of other wading birds (Table 2.3). It was slightly (1.53 times) more likely than the next best model, which included constant probability of use and detection as functions of presence of other wading birds. Ten candidate models accounted for 0.84 of the weight of evidence (Table 2.3). The ten best approximating models all included the presence of other wading birds as an important variable related to Wood Stork detection (Table 2.3). The model weights indicate there is evidence that distance from water body to the Zoo colony, degree of urbanization, and presence of other wading birds were plausible factors influencing the probability of a Wood Stork being present (Table 2.4). However, there was little evidence that distance from water body to nearest colony, distance from water body to tidal zone, size of water body, tidal stage, or time of day were feasible factors affecting presence of wood storks at a body of water (Table 2.4).
Model selection indicated relatively strong evidence that use of man-made bodies of water by wood storks was related to distance from colony and urbanization. The parameter estimates suggested that Wood Stork use was positively related to a high degree of urbanization and distance from the zoo colony. We estimate that Wood Storks were, on average, 2.2 times more likely to use a water body in areas of high urbanization and 1.04 times more likely to use water bodies with each 250-m increase in distance from the Zoo (Table 2.5). The parameter estimates, however, were relatively imprecise. We also found that the probability of detecting Wood Storks at a water body, given that they use the water body, was positively related to the presence of other wading birds. We estimate that Wood Storks were, on average, 23.2 times more likely to be detected using a water body when other wading birds were present (Table 2.5).

**DISCUSSION**

Zoo colony Wood Storks used water bodies in both low and high urbanization categories for foraging, with 79% of surveys of low urbanization sites detecting Wood Storks, and 21% of surveys detecting Wood Storks in water bodies in the high urbanization category. Thus, the Zoo colony Wood Storks appear to use bodies of water in areas of some degree of urbanization for foraging. If storks used water bodies in areas with much urbanization associated with them most frequently, they may be exposing themselves and their chicks to urban contaminants such as oils, pesticides, and pharmaceuticals. Our results found that although storks foraged in water bodies with much urbanization around them, they also soared great distances from their nesting colony, late in the nesting season, to forage. Perhaps their exposure to risk was infrequent enough to preclude contaminants from causing them physiological harm.

The single-season occupancy model used to estimate probability of presence of Wood Storks, determined that the best model included distance between a body of water and the Zoo.
colony, and the greater the distance, the greater the probability that Wood Storks would use it for foraging. We expected a negative relationship between distance between colony and water body, but our results suggest the opposite relationship. This may be explained because late in the breeding season, when chicks are nearly fledged or fledged, adult Wood storks could soar greater distances from the colony to forage. Chicks in these older age categories likely do not need to be fed as frequently as newly hatched chicks (Bryan et al. 1995). In their study in Georgia, Bryan et al. (1995) found adults soared great distances from the colony, late in the nesting season, which is consistent with our findings.

It is also possible that later in the nesting season, storks and other wading birds have already depleted available prey in water bodies relatively close to nesting colonies. If the amount of prey available does not outweigh the costs of foraging at a particular location, storks may travel farther distances in search of food (Gawlick 2002). This giving up density of prey is a probable explanation because storks are tactile feeders and require high densities of prey to forage effectively. It is likely that the results we obtained were affected by a combination of these mechanisms. Future studies should include some measurement of prey abundance.

There is some evidence suggesting that storks are using water bodies in highly urban areas. We expected to find more storks in areas that were in less urbanized parts of the city. Storks from the Jacksonville Zoo may perhaps be more habituated to humans because of their colony location inside the Zoo. Storks may also be attracted to ponds in urban areas because of fish stocking, which is a common practice in neighborhoods and golf courses.

Our models that examined factors that may affect our detection of storks, suggested there was a greater probability of detecting Wood Storks if other wading birds were also present. Storks are drawn to foraging grounds by the presence of other wading birds, which is consistent
with our findings. Our data supported the hypothesis that the chances of detecting storks, given that they use the water body, is be greater when there were other wading birds present. Storks from a colony often use the same roosting and feeding sites as others from the same colony (Bryan et al. 2002). Storks that were followed from roosting sites to foraging sites by Bryan et al. (2002), used the same water bodies for foraging, and these water bodies were occupied by other species of wading birds 79% of the time. Other wading birds act as communication media, letting storks know where prey is abundant, which is likely the mechanism at work in our study (Kushlan 1981; Bancroft et al. 2002; Bryan et al. 2002). Stork use of man-made urban water bodies can potentially be managed by restricting or promoting access to water bodies by other wading birds, depending on the desired result.

Areas of high urbanization typically have many man-made water bodies for mitigation and aesthetic purposes and often are stocked with fish. Man-made urban water bodies may be important foraging grounds for storks during periods when prey from other water bodies may not be available. Storks follow other storks to foraging and roosting sites (Kushlan 1981; Bryan and Coulter 1987; Gawlick 2002). In some cases, we saw as many as 30 storks foraging in the same water body, suggesting that our predictions of use could be low. In 2008 there were 85 nests successfully made, which gives us approximately 170 adult storks in the colony. If there are 30 storks from the colony at a single water body, use of other surrounding water bodies may be lower during the sampling time. Additionally, future studies should take into account the nocturnal behavior of storks, such as the one done by Bryan et al. (2001) because storks feed by tactilocation and actively forage at night.

Estimated use of urban, man-made water bodies in this study was high (36%) during July of 2008, which suggests that storks could be exposed to potential contaminants. Use of these
water bodies may be lower during the early breeding season when storks stay on the nest for longer periods of time and are feeding fledglings more frequently. Our data should be supplemented with continued study to clarify factors that will enhance urban, man-made water bodies so their use is beneficial to Wood Storks.

ACKNOWLEDGMENTS

This research was made possible by funds from the United States Fish and Wildlife Service and the D.B. Warnell School of Forestry and Natural Resources, University of Georgia. Billy Brooks from USFWS and Donna Bear-Hull from the Jacksonville Zoo provided data from previous research on this colony. Volunteers from the USFWS, Ecological Services, Jacksonville Field Office provided assistance on various aspects of this project. W. E. Ricks and G. I. Martin provided valuable assistance with GIS analyses.

LITERATURE CITED


Biodiversity and Spatial Information Center. 2008. Southeast gap regional land cover (Fl subsection). USGS North Carolina Cooperative Fish and Wildlife Research Unit, North Carolina State University, Raleigh.


U. S. Fish and Wildlife Service. 1996. Revised recovery plan for the U.S. breeding population of the Wood Stork, Atlanta, Georgia.


Table 2.1. Detection of Wood Storks (*Mycteria americana*) during surveys of man-made water bodies (N=100) within 25 km of the Jacksonville Zoo and Gardens, Jacksonville, Florida, July 2008. Factors are effects we predicted would influence the presence and detection of Wood Storks.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Factor</th>
<th>Frequency</th>
<th>Wood Stork detection&lt;sup&gt;1&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time of day</td>
<td>AM</td>
<td>54</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>MID</td>
<td>44</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>PM</td>
<td>61</td>
<td>3</td>
</tr>
<tr>
<td>Number of visits</td>
<td>One</td>
<td>66</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Two</td>
<td>11</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Three</td>
<td>23</td>
<td>2</td>
</tr>
<tr>
<td>Degree of urbanization</td>
<td>High urban</td>
<td>21</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Low urban</td>
<td>79</td>
<td>7</td>
</tr>
<tr>
<td>Tidal stage</td>
<td>High tide</td>
<td>46</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Low tide</td>
<td>111</td>
<td>5</td>
</tr>
<tr>
<td>Presence of other wading</td>
<td>Present</td>
<td>28</td>
<td>6</td>
</tr>
<tr>
<td>birds</td>
<td>Not present</td>
<td>131</td>
<td>5</td>
</tr>
</tbody>
</table>

<sup>1</sup>Number of times at least one Wood Stork was detected.
Table 2.2. Distances and sizes of water bodies surveyed (N=100) for Wood Stork presence in Jacksonville, Florida, July 2008.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Average</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance to Zoo</td>
<td>11.9 km</td>
<td>2.6 – 24.3 km</td>
</tr>
<tr>
<td>Distance to nearest colony</td>
<td>9.8 km</td>
<td>2.6 – 20.2 km</td>
</tr>
<tr>
<td>Distance to tidal area</td>
<td>4.2 km</td>
<td>0.2 – 13.7 km</td>
</tr>
<tr>
<td>Size of water body</td>
<td>0.53 ha</td>
<td>0.02 – 3.9 ha</td>
</tr>
</tbody>
</table>
Table 2.3. Candidate set of models including AIC, difference in AIC ($\Delta$AIC), model weight ($w$), and number of parameters ($K$) to predict use and detection ($p$) of Wood Storks (*Mycteria americana*), at 100 randomly selected bodies of water within 25 km of the Jacksonville Zoo and Gardens, Jacksonville, Florida, in July 2008.

<table>
<thead>
<tr>
<th>Model</th>
<th>$K$</th>
<th>AIC</th>
<th>$\Delta$AIC</th>
<th>$w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Psi$ (distance to zoo), $p$(presence of wading birds)</td>
<td>4</td>
<td>63.39</td>
<td>0</td>
<td>0.216</td>
</tr>
<tr>
<td>$\Psi$ (distance to zoo, high urban), $p$(presence of wading birds)</td>
<td>5</td>
<td>64.91</td>
<td>1.52</td>
<td>0.101</td>
</tr>
<tr>
<td>$\Psi$ (distance to tidal area), $p$(tidal stage, presence of wading birds)</td>
<td>5</td>
<td>65.48</td>
<td>2.09</td>
<td>0.076</td>
</tr>
<tr>
<td>$\Psi$ (urban), $p$(presence of wading birds)</td>
<td>4</td>
<td>65.93</td>
<td>2.54</td>
<td>0.061</td>
</tr>
<tr>
<td>$\Psi$ (distance to zoo), $p$(presence of wading birds)</td>
<td>4</td>
<td>66.19</td>
<td>2.80</td>
<td>0.053</td>
</tr>
<tr>
<td>$\Psi$ (distance to tidal area), $p$(presence of wading birds)</td>
<td>4</td>
<td>66.24</td>
<td>2.85</td>
<td>0.052</td>
</tr>
<tr>
<td>$\Psi$ (size of water body), $p$(presence of wading birds)</td>
<td>4</td>
<td>66.24</td>
<td>2.85</td>
<td>0.052</td>
</tr>
<tr>
<td>$\Psi$ (high urban), $p$(am, presence of wading birds)</td>
<td>5</td>
<td>66.30</td>
<td>2.91</td>
<td>0.050</td>
</tr>
<tr>
<td>Global (distance to zoo colony)</td>
<td>9</td>
<td>66.99</td>
<td>3.60</td>
<td>0.036</td>
</tr>
<tr>
<td>$\Psi$ (distance to closest colony, high urban), $p$(presence of wading birds)</td>
<td>5</td>
<td>67.92</td>
<td>4.53</td>
<td>0.022</td>
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<tr>
<td>$\Psi$ (distance to zoo colony ), $p$(.)</td>
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<td>68.12</td>
<td>4.73</td>
<td>0.020</td>
</tr>
<tr>
<td>$\Psi$ (.), $p$(.)</td>
<td>2</td>
<td>68.16</td>
<td>4.77</td>
<td>0.020</td>
</tr>
<tr>
<td>$\Psi$ (.), $p$(am)</td>
<td>3</td>
<td>69.67</td>
<td>6.28</td>
<td>0.009</td>
</tr>
<tr>
<td>$\Psi$ (distance to zoo colony), $p$(am)</td>
<td>4</td>
<td>69.74</td>
<td>6.35</td>
<td>0.009</td>
</tr>
<tr>
<td>$\Psi$ (distance to zoo colony), $p$(tidal stage)</td>
<td>4</td>
<td>69.79</td>
<td>6.40</td>
<td>0.009</td>
</tr>
<tr>
<td>$\Psi$ (.), $p$(tidal stage)</td>
<td>3</td>
<td>69.83</td>
<td>6.44</td>
<td>0.009</td>
</tr>
<tr>
<td>$\Psi$ (high urban), $p$(.)</td>
<td>3</td>
<td>69.84</td>
<td>6.45</td>
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</tr>
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<td>$\Psi$ (water body size), $p$(.)</td>
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<td>70.02</td>
<td>6.63</td>
<td>0.008</td>
</tr>
<tr>
<td>$\Psi$ (distance to tidal area), $p$(.)</td>
<td>3</td>
<td>70.15</td>
<td>6.76</td>
<td>0.007</td>
</tr>
<tr>
<td>$\Psi$ (distance to closest colony), $p$(.)</td>
<td>3</td>
<td>70.16</td>
<td>6.77</td>
<td>0.007</td>
</tr>
<tr>
<td>$\Psi$ (high urban), $p$(am)</td>
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<td>71.18</td>
<td>7.79</td>
<td>0.004</td>
</tr>
<tr>
<td>$\Psi$ (high urban), $p$(tidal stage)</td>
<td>4</td>
<td>71.49</td>
<td>8.10</td>
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</tr>
<tr>
<td>$\Psi$ (water body size), $p$(am)</td>
<td>4</td>
<td>71.55</td>
<td>8.16</td>
<td>0.004</td>
</tr>
<tr>
<td>Global (distance to closest colony)</td>
<td>9</td>
<td>71.65</td>
<td>8.26</td>
<td>0.004</td>
</tr>
<tr>
<td>$\Psi$ (distance to tidal area), $p$(am)</td>
<td>4</td>
<td>71.66</td>
<td>8.27</td>
<td>0.004</td>
</tr>
<tr>
<td>$\Psi$ (distance to closest colony) $p$(am)</td>
<td>4</td>
<td>71.67</td>
<td>8.28</td>
<td>0.003</td>
</tr>
<tr>
<td>$\Psi$ (water body size), $p$(tidal stage)</td>
<td>4</td>
<td>71.71</td>
<td>8.32</td>
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</tr>
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<td>$\Psi$ (distance to tidal area), $p$(tidal stage)</td>
<td>4</td>
<td>71.82</td>
<td>8.43</td>
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</tr>
<tr>
<td>$\Psi$ (distance to closest colony), $p$(tidal stage)</td>
<td>4</td>
<td>71.83</td>
<td>8.44</td>
<td>0.003</td>
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</tbody>
</table>
Table 2.4 Akaike importance weights of predictor variables and the number of models in which each variable occurs (N) for modeling Wood Stork (*Mycteria americana*) use of urban water bodies in northeast Florida in July 2008.

<table>
<thead>
<tr>
<th>Importance weight</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of use, $\Psi$</td>
<td></td>
</tr>
<tr>
<td>Distance to Zoo</td>
<td>0.391</td>
</tr>
<tr>
<td>High Urban</td>
<td>0.291</td>
</tr>
<tr>
<td>Distance to Tidal Area</td>
<td>0.181</td>
</tr>
<tr>
<td>Size of Water Body</td>
<td>0.106</td>
</tr>
<tr>
<td>Distance to Closest Colony</td>
<td>0.093</td>
</tr>
<tr>
<td>Constant</td>
<td>0.179</td>
</tr>
<tr>
<td>Probability of detection, $p$</td>
<td></td>
</tr>
<tr>
<td>Presence of Wading Birds</td>
<td>0.865</td>
</tr>
<tr>
<td>Tidal Stage</td>
<td>0.146</td>
</tr>
<tr>
<td>AM</td>
<td>0.123</td>
</tr>
<tr>
<td>Constant</td>
<td>0.327</td>
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Table 2.5. Model-averaged parameter estimates, unconditional standard errors (SE), upper and lower 90% confidence limits, and odds ratios (OR) for use (Ψ) and detection (p) of Wood Storks (*Mycteria americana*) at man-made water bodies within 25 km of the Jacksonville Zoo and Gardens, Jacksonville, Florida, in July 2008.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
<th>SE</th>
<th>Lower</th>
<th>Upper</th>
<th>Unit</th>
<th>Scaled OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probability of use (Ψ)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-2.4455</td>
<td>2.4257</td>
<td>1.5325</td>
<td>-6.4236</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to Zoo Colony</td>
<td>0.0002</td>
<td>0.0002</td>
<td>0.0004</td>
<td>-0.0008</td>
<td>250</td>
<td>1.0437</td>
</tr>
<tr>
<td>Distance to Tidal Area</td>
<td>-0.0005</td>
<td>0.0002</td>
<td>0.0003</td>
<td>-0.0004</td>
<td>500</td>
<td>0.9765</td>
</tr>
<tr>
<td>Distance to Closest Colony</td>
<td>0.0002</td>
<td>0.0001</td>
<td>0.0002</td>
<td>-0.0002</td>
<td>250</td>
<td>1.0057</td>
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<tr>
<td>High Urban</td>
<td>0.7866</td>
<td>1.2637</td>
<td>2.8591</td>
<td>-1.2858</td>
<td>1</td>
<td>2.1961</td>
</tr>
<tr>
<td>Size of Water Body</td>
<td>-0.1117</td>
<td>0.9279</td>
<td>1.4101</td>
<td>-1.6334</td>
<td>0.5</td>
<td>0.9457</td>
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<tr>
<td>Probability of detection (p)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-1.1529</td>
<td>1.4054</td>
<td>1.1520</td>
<td>-3.4578</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Presence of Wading Birds</td>
<td>3.1434</td>
<td>3.1554</td>
<td>8.3182</td>
<td>-2.0314</td>
<td>1</td>
<td>23.182</td>
</tr>
<tr>
<td>Low Tide</td>
<td>-1.6249</td>
<td>1.5876</td>
<td>0.9789</td>
<td>-4.2286</td>
<td>1</td>
<td>0.193</td>
</tr>
<tr>
<td>AM</td>
<td>-14.3780</td>
<td>15.6964</td>
<td>11.3640</td>
<td>-40.1201</td>
<td>1</td>
<td>0.001</td>
</tr>
</tbody>
</table>
CHAPTER 3

MAN-MADE WATER BODIES AS WOOD STORK FORAGING HABITAT: CONTAMINANT CONCERNS

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ABSTRACT: The Wood Stork (*Mycteria americana*) was listed as federally endangered in 1984, due primarily to loss of foraging and nesting habitats. Natural wetlands have been filled and modified as the human population has grown and man-made water bodies have replaced many of the natural wetland areas. Wood Storks feed in these open-water sites during the breeding season, and in urban areas, we are concerned about storks’ exposure to contaminants and impacts they may have on Wood Storks’ reproductive success rates. To determine storks’ use of urban water bodies for foraging, during 2007 and 2008, we monitored six Wood Storks marked with satellite transmitters, from a colony within the Jacksonville Zoo and Garden, Jacksonville, Florida. We hypothesized that urban man-made water bodies would harbor concentrations of contaminants that may be sufficient to adversely affect Wood Stork health. Locations and activities of marked Wood Storks revealed sites used for foraging. Sites were categorized into four types of man-made water bodies according to their surrounding land use: residential, golf course, agricultural, and general retention. We collected samples of prey items and sediment from each site, and dead or moribund chicks from the colony for analysis of 18 inorganic elements, 46 polycyclic aromatic hydrocarbons (PAH), and a suite of eight organophosphate and 29 organochlorine compounds. When detected, concentrations of metals, PAHs, polychlorinated biphenyls (PCBs), and organochlorine pesticides in sediment, prey, and chicks were below previously reported effects thresholds for birds. Each water body type harbored a fairly unique contaminant profile. Golf course ponds had higher concentrations of arsenic, selenium, and mercury in fish (p < 0.05), and higher selenium levels in sediment (p < 0.05). We recommend management of golf course ponds such that the slope is too steep for stork foraging to minimize their exposure to contaminants in these types of ponds.

*Key words.*—DDT/DDE, heavy metals, *Mycteria americana*, organic contaminants, PAH, PCB, polycyclic aromatic hydrocarbons, polychlorinated biphenyls, urban water bodies, wading birds.
The United States Fish and Wildlife Service (USFWS) listed the Wood Stork (*Mycteria americana*) as federally endangered in 1984 based on significant declines in population numbers due to loss of foraging and nesting habitat (USFWS 1996). Wood Storks breed from coastal North Carolina to Florida, south through Mexico, Central America, Cuba, and Hispaniola to northern Argentina (Hancock 1992; Brooks and Dean 2008). Wood Storks use both estuarine and freshwater habitats for nesting, roosting, and foraging (USFWS 1996). Foraging sites are diverse and include shallow wetlands such as tidal creeks and pools, managed impoundments, agricultural ditches, stock ponds, freshwater marshes, depressions in cypress heads, swamp sloughs, and man-made water bodies (Coulter et al. 1987; Hodgson 1987; USFWS 1996; Depkin et al. 2005). Foraging sites are characterized by calm water, 5-40 cm deep, a high prey density, and clear of dense vegetation (Ogden et al. 1976; Coulter 1987; USFWS 1996).

Wood Storks exhibit opportunistic foraging patterns. Over the course of a day they forage in coastal marshes, then move to creeks, streams, and pools, then to inland bodies of water (Ogden et al. 1976). Prey items of storks are mainly fish, but also include crayfish (Cambaridae) and other invertebrates, snails (Gastropoda), frogs and tadpoles (Anura), and salamanders (Salmandridae; Ogden et al. 1976). Storks have also been documented eating small mammals, small birds and chicks, and reptiles (USFWS 1996). Prey fish range in size from 2 to 25 cm in length (Kahl 1964; Ogden et al. 1976; Coulter 1987).

One of the primary objectives of the USFWS’s Wood Stork Recovery Plan is to assess concentrations of contaminants in foraging areas (Section 3.8, USFWS 1996). In storks, contaminants may adversely affect reproductive rates, cause severe birth defects, or cause chronic illness and death (Heinz 1979; Henny and Herron 1989; Fry 1995). With time, residential, industrial, and other development projects have damaged or destroyed wetlands.
while areas of man-made water bodies have increased (Dahl 2005). Man-made water bodies may harbor contaminants because most are designed to catch runoff (Crites et al. 1997; Scholes et al. 1998; Kao et al. 2001; Moore et al. 2002). Wood Storks nesting freely at the Jacksonville Zoo and Gardens, Jacksonville, Florida, forage in man-made water bodies such as golf course ponds, drainage ditches, retention ponds, and detention basins (W. Brooks, UFSWS, unpubl. data). Results of satellite telemetry studies on the Jacksonville Zoo storks indicate that adults forage primarily in estuarine sites before nesting, in freshwater sites during nesting and fledging of young, then in estuarine sites after the breeding season. Analyses of stable isotopes in these storks’ feathers suggest they are feeding mostly freshwater prey to their young (D. Bear-Hull, Jacksonville Zoo, unpubl. data). Many of the freshwater foraging sites are man-made water bodies (D. Bear-Hull, Jacksonville Zoo, unpubl. data).

Contaminants tend to be distributed unevenly in the environment and birds with differing feeding habits are exposed to different levels of contamination (Blus et al. 1985; Fasola et al. 1998; Gariboldi et al. 2001). Man-made water bodies and other open-water sites serve as areas for water detention and retention, habitat for wildlife, especially wading birds, and as a means of controlling pollution in urban areas (Crites et al. 1997; Scholes et al. 1998; Kao et al. 2001; Moore et al. 2002). It is unknown whether different types of man-made water bodies have different levels of contaminants or how this may influence management strategies for wading birds such as the Wood Stork.

The four major groups of environmental contaminants that affect avian species include petroleum and its by-products (e.g., polycyclic aromatic hydrocarbons, PAH), organochlorine compounds, organophosphate (OP) compounds, and heavy metals (Williams et al. 2000; Newman and Unger 2003). PAHs occur from the incomplete combustion of fossil fuels; they
originates naturally from sources such as volcanic eruptions, and from anthropogenic sources such as coal burning and urban runoff (Neff *et al.* 1979; Baek *et al.* 1991). They are known carcinogens in humans, and they accumulate in sediments and fish (Neff *et al.* 1979; Baek *et al.* 1991). Organochlorine compounds such as polychlorinated biphenyls (PCBs) and dichloro-dimethyl-trichloroethane (DDT), are commercial pesticides and lubricants. Most organochlorine and OP compounds have been banned since the 1970s, but are persistent in the environment (Wiemeyer 1993). These compounds cause eggshell thinning and reduced clutch size in piscivorous birds (Mendenhall *et al.* 1983; Henny *et al.* 1984; Henny and Herron 1989; Fry 1995). Clutch size, hatching success, and fledgling survival rates may all be reduced in birds exposed to OP compounds (Powell 1986). Many metals of concern (e.g., arsenic, cadmium, lead, mercury, selenium) occur naturally in the environment, but are increased by human activities (Leland *et al.* 1978). If birds accumulate large concentrations of metals, it may result in death, embryonic mortality, decreased reproductive success, and abnormal chick behavior (Heinz 1979; Barr 1986; Nocera and Taylor 1998). Exposure to high levels of selenium may prevent birds from breeding (Fox 2006).

To determine the relative risk of adverse effects from contaminant exposure to Wood Storks foraging in man-made ponds, we identified urban water bodies used by satellite-marked Wood Storks for foraging, and assessed presence and concentrations of contaminants within them. Assessments of these sites and their characteristics will allow identification of those foraging habitat types that pose a risk to storks due to contaminants. We hypothesized that contaminants would be present in urban water bodies, and that concentrations would differ among them based on land use surrounding the water body (i.e., golf courses may use more insecticides and general retention may have more PAH from road runoff).
STUDY AREA

Our study was conducted within a 40-km radius of the Jacksonville Zoological Gardens in Jacksonville, Duval County, Florida (30°E 24.4’N/ 81°E 26.8’N). Metro Jacksonville borders the Atlantic Ocean, is approximately 40 km south of the Georgia border, and is bisected by the St. Johns River. The dry season in Jacksonville is from March to July. Water bodies begin to refill in July when summer rains begin (Henry et al. 1994). Annual precipitation is 132 cm and average annual temperature is 20.6° C with March signaling the end of freezing temperatures (Henry et al. 1994). In Florida, after a rain, the first 2.5 cm of runoff contains 90% of the contaminants, most of which ends up in man-made water bodies (Livingston 1993). Because of Jacksonville’s unique geography, there are many freshwater and brackish wetlands, man-made and natural, available as forage sites for storks. Foraging sites surveyed for this study were man-made water bodies on both private and public property in various parts of Jacksonville, and varied in sizes and type (neighborhood, golf course, agricultural, and retention ponds). Neighborhood water bodies were surrounded by residential development and general retention ponds were surrounded by industrial or highway use. Golf course water bodies were those located on golf courses and agricultural water bodies were those surrounded by farming.

We studied a colony of Wood Storks that has nested within the African Savanna Habitat exhibit at the Jacksonville Zoo since 1999 (D. Bear-Hull, Jacksonville Zoo, pers. comm). Numbers of nests have fluctuated from 47 to 117 (average = 85 nests per year) since 1999 (D. Bear-Hull, Jacksonville Zoo, unpubl. data). In 2007, there were 47 nests and apparent nest success was low (68.09%). In 2008, there were 86 nests and apparent nest success was high (87.21%), which is average for this colony. Nest failure occurs for many reasons including predation by raccoons (*Procyon lotor*), stress induced by cold weather, storms, intraspecific
aggression, and starvation because of fish kills during heavy summer rains (Ogden 1994; Coulter and Bryan 1995; USFWS 1996).

METHODS

Site Selection

During summers 2007 and 2008, Jacksonville Zoo staff and contracted biologists attached six solar-powered, Argos Global Positioning System Platform Terminal Transmitter (GPS PTT) tags (satellite tags; Microwave Telemetry, Inc., Columbia, MD) to Wood Storks (N = 2 in 2007 and N = 4 in 2008). Every 2 hours, the satellite tags provided the date, time, latitude, longitude, speed, course, and altitude. We downloaded data once weekly and parsed them with Argos/GPS PTT-100 Parsing Software (Microwave Telemetry, Inc. Columbia, MD) during the nesting season (March–July) to pinpoint storks’ foraging locations. We only used data if the altitude was <5 m (indicating the bird was on the ground) and if the speed was <2 km/h (a bird moving slowly enough to forage). We did not use data if the transmitter recorded a weak battery signal because the latitude and longitude would be inaccurate. We entered parsed locations (latitude and longitude) into Google Earth™ (Mountain View, CA, 2007) to identify foraging locations within man-made water bodies in urban Jacksonville, Florida. In 2007, because only two transmitters were deployed and we received few foraging site locations from tagged storks, we also collected samples from sites identified as stork foraging habitat by USFWS biologists (W. Brooks, USFWS pers. comm).

Water Quality

We measured water quality parameters during one visit to each site in June and July 2007 and 2008. Temperature, dissolved oxygen, conductivity, and pH were measured by standard methods using an YSI multi-probe (YSI Environmental, Yellow Springs, OH). We
photographed each site and recorded date and time of day of each visit, latitude and longitude, and presence of storks or other wading birds (Family Ciconiiformes).

Prey

During June and July 2007 and 2008, we collected representative prey samples at each site using minnow traps, cast nets, hook and line, and dip netting. We used >1 method to maximize the number of species of prey captured. We continued sampling until we had ≥80 g of prey or ≥5 individuals of the same species if they were larger fish such as bluegill (*Lepomis macrochirus*). If possible, multiple species were collected at each site. We put prey into plastic freezer bags and on ice in the field for transport, then we stored them at -80°C until analysis. In 2007, we shipped all frozen prey samples to a commercial lab (Alpha Woods Hole Labs, Woods Hole, MA) to be analyzed for 18 inorganic elements by Inductively Coupled Plasma-Mass Spectrometry according to EPA methods. The samples then went to another commercial lab (Geochemical & Environmental Research Group, Texas A&M, College Station, TX) to be analyzed for 46 PAHs, and a suite of 29 organochlorine pesticides (Appendix A) using capillary gas chromatography (CGC) with a flame ionization detector for aliphatic hydrocarbons, CGC with electron capture detector for pesticides and PCBs, and a mass spectrometer detector in the SIM mode for aromatic hydrocarbons (Wade *et al.* 1988).

In 2008, we kept prey samples frozen, transported them to the University of Georgia, and identified them to species. We obtained the mass (g) and length (tip to caudal peduncle, mm) of each prey item except in instances where it was impossible (e.g., tadpoles liquefied after freezing). Then we ground prey items from each man-made site with a high speed tissue homogenizer (Omni, Marietta, GA) and divided them into two aliquots. We sent one aliquot to Alpha Woods Hole Labs (Woods Hole, MA) to be analyzed for the 18 inorganic elements, and
then sent the samples to GPL Laboratories, LLC (Frederick, MD) to analyze them for 46 PAHs, and a suite of eight organophosphates (Appendix A). Methods used were the same as those used in 2007. On the second aliquot, we used a commercially-available enzyme-linked immunosorbent assay (ELISA; Abraxis, LLC. Warminster, PA) to extract (with pesticide grade methanol) and analyze for cyclodienes, organophosphates, DDT/DDE, and dieldrin according to manufactured protocols.

Sediments

We collected 15 sediment samples in 2007 and 15 in 2008 using certified pre-washed 250-ml amber glass jars and a unique plastic spoon at each site. We collected the top three cm of sediment, the most biologically available to storks, at three different points within each site, filling the jars to capacity. Sediments were stored at 4°C until analysis. In 2007, sediment samples were shipped to Alpha Woods Hole Labs (Woods Hole, MA) to be analyzed for 18 inorganic elements by Inductively Coupled Plasma-Mass Spectrometry according to EPA methods. The samples then went to Geochemical and Environmental Research Group labs (Texas A&M, College Station, TX) to be analyzed for 46 PAHs, and a suite of 29 organochlorine pesticides (Appendix A) using capillary gas chromatography (CGC) with a flame ionization detector for aliphatic hydrocarbons, CGC with electron capture detector for pesticides and PCBs, and a mass spectrometer detector in the SIM mode for aromatic hydrocarbons (Wade et al. 1988). We sent one aliquot from 2008 to Alpha Woods Hole Labs (Woods Hole, MA) to be analyzed for 18 inorganic elements, then it was shipped to GPL Laboratories, LLC (Frederick, MD) to be analyzed for 46 PAHs and a suite of eight organophosphates (Appendix A). We kept a second aliquot to analyze for cyclodienes, organophosphates, DDT/DDE, and dieldrin using ELISAs as previously described for prey items.
Chicks

In 2008, Jacksonville Zoo staff and volunteers collected dead and moribund chicks and froze them in a -80°C freezer. The Southeastern Cooperative Wildlife Disease Study (SCWDS, Athens, GA) performed necropsies on the chicks and collected tissues from them (fat, feathers, brain, liver, and kidney) for contaminant analysis. We pooled tissues from ≤3 animals for a sample, for a total of ten composite samples, because there was not enough tissue for analysis of individual storks and all individuals came from the same colony.

Statistical Analysis

We used an analysis of variance (ANOVA; PROC GLM; SAS Institute, Inc. 2002-2003) to detect differences in contaminant concentrations (individual metals, PAH, organochlorine pesticides, and PCBs) from sediment or prey samples among types of man-made water bodies. For these analyses, we kept PCBs separate from the organochlorine pesticides (i.e., DDT, aldrin, chlordane, etc.). If a difference was detected, we used Tukey’s Honestly Significant Difference test to identify differences (PROC GLM; SAS Institute, Inc. 2002-2003). We set the \textit{a priori} level of significance to $\alpha = 0.05$ for all tests. For samples from sediment, prey, and chicks, we calculated the mean, standard error, minimum and maximum concentration for contaminant class (individual metals, PAH, organochlorine pesticides, and PCBs).

RESULTS

We observed storks at seven of the 30 man-made water bodies, and other wading birds at 16 of the 30 man-made water bodies; storks and other wading birds were both present at seven water bodies. There was an uneven distribution of use of water bodies among types, with greater use of general retention and residential water bodies than golf course and agricultural water bodies (Table 3.1). Water quality varied considerably among sites. The pH ranged from 4.79 to
10.57, with a median of 7.30. The temperature at each site ranged from 23.2°C to 36.2°C with a median of 29.38°C. Conductivity ranged from 27.73 mS to 2230 mS. We were unable to analyze dissolved oxygen because of a collection error.

Prey

We collected prey items from 15 man-made water bodies in 2007 and 2008 (N = 30 water bodies). In 2007, we collected crawfish (Cambaridae), snails (Gastropoda), tadpoles (Anura), crabs (Decapoda), shrimp (Decapoda), and five species of fish: Mosquitofish (Gambusia spp.), Killifish (Fundulus spp.), Redbreast Sunfish (Lepomis auritus), Mullet (Mugil mugil), and Bluegill from man-made water bodies. In 2008, we collected aquatic insects, tadpoles, crayfish, and five species of fish: Mosquitofish, Redbreast Sunfish, Bluegill, Largemouth Bass (Micropterus salmoides), and Gizzard Shad (Dorosoma cepedianum) from man-made water bodies. Fish mass and length varied among species; however, individual species length and mass among water bodies (Tables 3.2 and 3.3) were similar in size to normal stork prey items (Ogden 1976; Depkin 2005). We caught multiple species at each water body, and proportions of fish weights were similar among the bodies of water studied (Table 3.4).

Metals

Concentrations of arsenic, cadmium, mercury, lead, and selenium in sediment ranged from no detection to 3.5 ppm (Table 3.5), and in prey, these concentrations ranged from no detection to 0.3 ppm (Table 3.5). In chicks (Table 3.6), cadmium was not detected, and the highest concentration of lead was 0.05 ppm. Mercury and selenium were found in all chick specimens at detectable levels (Table 3.6). The highest concentration found in chicks of selenium and mercury was 7.82 ppm and 0.58 ppm, respectively (Table 3.6).
Arsenic was found in all samples. Bodies of water on golf courses had higher (p = 0.02) arsenic levels in sediment than any other type of water body, and residential water bodies had higher (p = 0.02) arsenic levels in prey than general retention ponds. There was no cadmium found in chicks. Cadmium levels in sediment (p = 0.93) and in prey (p = 0.28) did not differ among types of water bodies. Lead was found in moderate levels (≤3.5 ppm) in sediment, and did not differ among types of water bodies (p = 0.72). Lead levels detected in prey from different types of water bodies did not differ (p = 0.45). Mercury concentrations in sediment from different types of water bodies did not differ (p = 0.83), but concentrations in prey from golf course ponds were higher than in prey from residential water bodies (p = 0.02). Zinc concentrations did not differ among types of water bodies for sediment (p = 0.40) or prey (p = 0.69).

PAH

Of the 41 PAH compounds we examined in sediment, prey, and chicks, we detected only one PAH compound, methylnaphthalene, in chick samples and its concentration was <0.03 ppm. Mean levels of PAH compounds from both sediment and prey samples did not differ among types of water bodies (Table 3.7). In sediment, detections of PAH compounds ranged from zero to 18. The number of PAH compounds detected in prey ranged from zero to 16. Overall, PAH profiles were similar among samples. Concentrations of total PAH were <0.01 ppm in both sediment and prey (Table 3.7). The mean PAH concentration in sediment differed among types of water bodies (p < 0.001) except between residential and golf course water bodies (p = 0.58). Sediment from agricultural water bodies had the highest total PAH concentrations, followed by general retention ponds, and residential and golf course ponds. There were no differences in PAH concentrations in prey among types of man-made water bodies (p = 0.55). Detection rates
of PAH compounds were low (0 to 43% of PAHs) and mean detections per site were low (Table 3.8).

Organochlorine Compounds

All samples had detectable levels of some of the 31 organochlorine compounds for which we tested. The only PCB detected in samples of both sediment and prey was PCB-1268. Concentrations of PCB-1268 in prey samples ranged from 0.043 to 0.17 ppm, and in sediment samples it ranged from 0.00 to 0.022 ppm. Concentrations of PCBs did not differ among types of man-made water bodies for either sediment (p = 0.82) or prey (p = 0.74). The congener PCB-1268 was found in detectable levels in all prey and sediment samples, with the exception of one sediment sample which was from a residential water body.

Organochlorine pesticides were detected in all samples of sediment and prey. The number of organochlorine pesticides detected per type of man-made water body, within sediment or prey, differed among types of man-made water bodies (Table 3.8). In sediment, detections ranged from zero to 18 organochlorine compounds. Toxaphene was not detected in sediment or prey samples. In prey, detections of organochlorine compounds ranged from zero to 21. Levels of total organochlorine pesticides in sediment and prey were all < 4 ppb (Table 3.7). Organochlorine loads in sediment (p = 0.82) and in prey (p = 0.73) were not different among types of man-made water bodies.

Organophosphates and ELISA

There were no detections of organophosphates in sediments, prey, and chicks measured by the commercial ELISA kits, and therefore, results could not be verified and were not analyzed.
DISCUSSION

Concentrations of contaminants varied by water body type. Organochlorine pesticides were greatest in residential ponds and golf course ponds, whereas PAHs were greatest in agricultural and retention ponds. Individual metals were variable among pond types. Overall, contaminant levels in man-made water bodies were low.

All prey we collected were potential stork prey items and were within the size range of normal prey items (Kahl 1967; Ogden 1976; Coulter 1987; Coulter and Bryan 1993; Gariboldi 1998). Water quality parameters ranged considerably and fluctuated according to time of day, season, last rain, etc. Bodies of water on golf courses, which tended to have the highest concentrations of contaminants, had slightly lower pH than the other three types of water bodies. General retention ponds and neighborhood water bodies were slightly basic and tended to have lower contaminant concentrations than golf course ponds but similar concentrations as each other. Agricultural water bodies had circumneutral pH and generally had the lowest contaminant concentrations of all four water body types.

Metals

Dietary exposure to cadmium, lead, and zinc at urban, man-made water bodies was low in this study. Healthy birds have liver cadmium levels of 0.1 ppm and kidney cadmium levels of 0.3 ppm (Walsh 1990). There were no detections of cadmium in any samples of chicks, although the samples were collected from dead and moribund chicks and cadmium concentrations are usually greater in older birds (Furness and Hutton 1979; Walsh 1990). No contaminant data were collected from adult storks, so we do not know if they had cadmium levels greater than those in chicks. Levels of zinc in our samples of chicks and prey were consistent with levels found in healthy birds (Zdzarski et al. 1994). Commonly, zinc toxicosis is associated with
ingestion of objects containing zinc such as copper coated coins or fence clips, and no such items were found in the stomachs or crops of chicks during necropsy (Zdzarski et al. 1994).

Lead poisoning has been documented in >30 species of birds (Franson 1995). Studies of dietary exposure to lead in an urban environment suggest that lead exposure in birds is via industrial effluents and metal smelters (Ohi et al. 1974; Ohi et al. 1981; Grue et al. 1986). Concentrations of lead in prey and sediment in our study were lower than those that would cause an adverse effect to birds (Blue et al. 1985; Shulz 2006). Lead was not present in all samples, but when it was detected, it was present in low levels. These data suggest that lead poisoning is not a significant contaminant factor affecting Wood Stork recovery in northeast Florida.

Because mercury is resistant to degradation, it stays in the environment for long periods of time (Heinz 1995). Unlike other metals, it is methylated by bacteria and in the organic form, it can biomagnify from plankton to fish to birds (Heinz 1995), and in our study, mean levels of mercury in chicks were higher than in sediments and prey. In our samples of chicks, the highest concentration detected (0.58 ppm) was below the level known to cause toxic effects in birds, but only by one order of magnitude which could indicate a chronic problem (Fimerite 1971; Heinz 1995).

Several studies have focused on mercury levels in Wood Storks and in their prey (Fleming et al. 1984; Gariboldi 1991; Gariboldi et al. 1998; Brant et al. 2001; Frederick et al. 2002). Frederick (2002) reported that coastal colonies had lower levels of mercury dietary exposure than inland colonies, which may be explained by Gariboldi (1998), who reported a higher level of mercury in freshwater prey than saltwater. The Jacksonville Zoo colony is a coastal colony, so exposure to mercury may be limited by the amount of time feeding in freshwater. Annual and regional variation of contaminants should be considered as well; Wood
Stork colonies in Georgia present significant variation of contaminant concentrations between inland and coastal sites and among years (Gariboldi 2001). Our samples of chicks only represent one year, and although year was not taken into consideration, sediment and prey levels should not change annually like levels in storks, as sediments in this situation are generally not mobile.

Selenium, an essential nutrient, is toxic at high levels and becomes a concern due to its bioaccumulative nature in the food web (Lemly 1995; Hamilton 2004). Lemly (1995) reports that selenium levels of 3 to 4 ppm in skeletal muscle and 10 to 15 ppm in ovaries in Bluegill caused reproductive failure and mortality. Similar to other contaminants, acute Se poisoning is less likely than reproductive failure (Lemly 1995). In the present study, selenium levels found in prey differed among types of water bodies; those on golf courses had higher levels than those in residential areas and general retention ponds, although levels were low in all cases. Levels of selenium in sediment were low and did not differ among types of water bodies. The highest amount of selenium we detected in a chick sample was 7.82 ppm, and levels of 10 ppm in liver samples are considered harmful to birds (Heinz 1995). Selenium levels in chicks were relatively high compared to other contaminants, and the adverse effects on this colony are currently unknown. Females have the ability to excrete excess selenium through their eggs (Lemly 1995) which may account for the high levels of selenium found in young chicks in this study. Therefore, high levels of selenium in dead or moribund chicks may indicate high adult levels of dietary exposure to selenium. Selenium concentrations from water bodies sampled in our study do not indicate high selenium concentrations in sediment, or prey, so bioaccumulation is likely the reason behind higher levels in chicks. Further investigation is strongly recommended to determine if Se is potentially affecting nesting success at the Jacksonville Zoo colony.
Organophosphates and ELISA

The working range of the ELISA was such that we should have detected these compounds in the concentrations that were measured by CGC analysis. The extraction technique (which was validated for soil samples) may not have been effective for our matrices. In the future, evaluation of OP-spiked samples would allow additional insight into quality assurance and quality control issues with the ELISA kits.

PAH

Sediment PAH levels differed relative to surrounding land use but the concentrations were generally low, and it is unlikely there would be a detrimental effect on Wood Storks that forage in any of the four types of urban man-made water bodies from this study. However, biochemical and physical changes can be observed when there are concentrations of 0.1 to 1 ppm in tissue (Hellou 1995). The threshold for these effects are PAH concentrations in water between 8,620-1,120 ppm for mussels and 2,900-540 ppm for clams (Hellou 1995). Mallards exposed via diet to 2000 mg/kg of a PAH combination over a 7-month period experienced liver enlargement but no other deleterious effects were detected (Patton and Dieter 1980). PAH levels in our samples were substantially below 2000 mg/kg for individual PAHs. Levels of PAH in sediment do not correlate with PAH levels in vertebrates from other studies, likely because of the restricted data available (Hellou 1995). Levels of PAH in sediment do not correlate with PAH levels in vertebrates from other studies, likely because of the restricted data available (Hellou 1995). There are few studies on PAH and birds other than those associated with the Exxon Valdez oil spill and direct oil contamination, so it is currently unknown if PAHs pose a risk to Wood Storks from the Jacksonville Zoo colony and further investigation is warranted.
Organochlorine Compounds

Generally, the highest levels of PCB contamination occur in wildlife at or near sites where PCBs were manufactured, used, or discarded (Kubiak, 1995). Jacksonville, Florida is 90 km from a Superfund site where PCB congener 1268 was manufactured (Maruya et al. 1997). Congener 1268 was the only PCB we detected in sediments and prey, and mean levels were low (≤0.6 ppm), which may be a result of degradation, biomagnification, and contaminant dispersal. Low levels of PCBs may have no deleterious effects. Screech owls (*Otus asio*) exposed through their diet to 3 ppm PCBs for eight weeks before egg laying showed no difference in general health and reproduction than controls, and dosed adult carcasses had 12.8 ppm PCB (McLane and Hughes 1980). There was no adverse effect on reproductive success or survival of Mallards given 25 ppm of PCB in their feed for 2 months during the breeding season (Custer and Heinz 1980). Because levels of PCBs detected in our study were substantially lower than the lowest reported effect levels in birds, PCBs in urban Jacksonville are likely not adversely affecting Wood Storks.

We detected more organochlorine pesticides prey items than in sediment, which is expected because organochlorine compounds are lipophilic (Blus, 1995). Sublethal effects, like eggshell thinning, occur at dietary exposures of 12 to 219 ppm of DDT in Black Ducks (*Anas rubripes*), American Kestrels (*Falco sparverius*), and Barn Owls (*Strix occidentalis*) in experimental studies (Wiemeyer and Porter 1970; Longcore *et al.* 1971; Mendenhall 1983). Peregrine Falcons (*F. peregrino*) exposed via diet to DDT in prey at 1 ppm had a decrease in production (Enderson *et al.* 1982). None of the levels of pesticides in this study were at or above these lowest reported effect concentrations. Given that most pesticides were only detected at a few man-made water bodies, mean concentrations are low, and maximum concentrations are all...
below the levels known to negatively affect birds, it is reasonable to assume that the storks from 
the Jacksonville Zoo colony are not at risk of deleterious effects from organochlorine pesticides. 

In summary, storks from the Jacksonville Zoo colony have limited dietary exposure to 
contaminants from foraging in urban man-made water bodies. Man-made water bodies, 
especially golf courses, are used by many bird species as well as storks (Adams et al. 1995; 
Snell-Rood and Cristol 2003; Cristol and Rodewald 2005). We measured low concentrations of 
many legacy and current use chemicals as well as metals in all types of water bodies. However, 
water bodies on golf courses are of the most concern to storks based on the contaminant loads 
found in this study. We recommend managing golf course impoundments to prevent stork 
foraging by increasing the slope. This can be done during building or renovating. Selenium, in 
particular, was found at high concentrations in chick carcasses and warrants further study. We 
suggest that man-made water bodies be further studied for PAHs and additional contaminants, in 
stork foraging areas in Northeast Florida. We suggest that man-made water bodies be 
investigated for additional suites of contaminants, and further study with Se and PAHs, in most 
locations storks are feeding in Northeast Florida. Additionally, a cause-effect relationship 
between Wood Stork health and contaminant exposure should be established before any 
recommendations on management are made. Specifically, blood and feathers from adult birds 
should be taken during contaminant sampling of the water bodies to achieve this goal. 
Experimental studies are not practical for an endangered species, such as the Wood Stork, and 
effects from dietary exposure vary among species; therefore, studies with closely related species 
acting as surrogates are needed. Species that are closely related to storks (i.e., herons, egrets, 
pelicans, vultures) have demonstrated adverse effects to legacy contaminants (e.g., DDT, PCB) 
and heavy metals; however, deleterious effects occurred when contaminant levels were much
higher than those measured in water bodies used by the JZG colony. We recommend future studies to determine the effects on contaminants on adult storks because little is known about the long term effects of man-made water body use on Wood Storks.

ACKNOWLEDGMENTS

This study was made possible by funds from the USFWS, Ecological Services Jacksonville Field Office and the D. B. Warnell School of Forestry and Natural Resources at the University of Georgia. Dr. Kevin Keel and externs at Southeastern Cooperative Wildlife Disease Study at the University of Georgia conducted necropsies of Wood Stork chicks. Volunteers with the USFWS helped collect data and find foraging sites. Rena Borkhataria and Donna Bear-Hull assisted with satellite data from the Jacksonville Zoo birds.

LITERATURE CITED


Walsh, P. M. 1990. The use of seabirds as monitors of heavy metals in the marine environment. CRC Press. Boca Raton, Florida


Table 3.1. Numbers and types of man-made water bodies in Jacksonville, Florida used by Wood Storks (*Mycteria americana*) for foraging in 2007 and 2008. Contaminant presence and concentrations within each water body were determined.

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>Golf Course</th>
<th>Agricultural</th>
<th>Retention</th>
</tr>
</thead>
<tbody>
<tr>
<td>2007</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>2008</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>10</td>
<td>6</td>
<td>3</td>
<td>11</td>
</tr>
</tbody>
</table>
Table 3.2. Prey length (mm), reported as mean ± SE, captured in July 2008 from man-made water bodies used as Wood Stork (*Mycteria americana*) foraging sites in Jacksonville, Florida. The number in parentheses is N, sample size.

<table>
<thead>
<tr>
<th>Water Body</th>
<th>Mosquitofish (<em>Gambusia</em> spp.)</th>
<th>Largemouth Bass (<em>Micropterus salmoides</em>)</th>
<th>Bluegill Sunfish (<em>Lepomis macrochirus</em>)</th>
<th>Gizzard Shad (<em>Dorosoma cepedianum</em>)</th>
<th>Redbreast Sunfish (<em>Lepomis auritus</em>)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27.9 ± 0.7 (69)</td>
<td>45.6 (1)</td>
<td>68.9 ± 4.0 (9)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>2</td>
<td>27.2 ± 1.2 (15)</td>
<td>-</td>
<td>90.3 ± 1.6 (3)</td>
<td>146.7 ± 9.5 (3)</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>30.1 ± 1.1 (25)</td>
<td>-</td>
<td>84.6 ± 0.5 (3)</td>
<td>-</td>
<td>168.9 (1)</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>111.2 ± 7.0 (5)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>115.4 ± 5.5 (5)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>29.2 ± 1.7 (12)</td>
<td>-</td>
<td>121.7 ± 7.5 (4)</td>
<td>132.1 (1)</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>39.4 ± 5.2 (3)</td>
<td>-</td>
<td>116.9 ± 7.0 (5)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>35.9 ± 2.4 (13)</td>
<td>50.6 (1)</td>
<td>171.9 (1)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>32.4 ± 0.8 (28)</td>
<td>109.4 ± 74.8 (2)</td>
<td>74.6 ± 5.75 (5)</td>
<td>73.4 (1)</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>35.9 ± 0.6 (163)</td>
<td>61.7 (1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>11</td>
<td>29.6 ± 0.7 (85)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>12</td>
<td>27.6 ± 1.0 (82)</td>
<td>37.2 ± 8.62 (2)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>13</td>
<td>26.9 ± 0.8 (82)</td>
<td>26.6 (1)</td>
<td>73.4 ± 5.18 (4)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>48.9 (1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>15(a)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

\(a\) insects, tadpoles, and crayfish – lengths not recorded

\(\text{“-“}\) indicates none collected
Table 3.3. Prey mass (g), presented as mean ± SE, collected from 15 man-made water bodies used by Wood Storks (*Mycteria americana*) for foraging in Jacksonville, Florida during July 2008. Sample size (N) is presented in parentheses.

<table>
<thead>
<tr>
<th>Water Body</th>
<th>Mosquitofish (<em>Gambusia</em> spp.)</th>
<th>Largemouth Bass (<em>Micropterus salmoides</em>)</th>
<th>Bluegill Sunfish (<em>Lepomis macrochirus</em>)</th>
<th>Gizzard Shad (<em>Dorosoma cepedianum</em>)</th>
<th>Redbreast Sunfish (<em>Lepomis auritus</em>)</th>
<th>Other*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.21 ± 0.03 (69)</td>
<td>0.5 (1)</td>
<td>5.03 ± 1.05 (9)</td>
<td>-</td>
<td>-</td>
<td>0.1b</td>
</tr>
<tr>
<td>2</td>
<td>0.27 ± 0.04 (15)</td>
<td>-</td>
<td>17.0 ± 2.69 (3)</td>
<td>43.7 ± 11.0 (3)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3</td>
<td>0.35 ± 0.04 (25)</td>
<td>-</td>
<td>9.33 ± 0.56 (3)</td>
<td>-</td>
<td>80.7 (1)</td>
<td>0.2b, 1.8c</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>26.4 ± 4.61 (3)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>23.6 ± 4.44 (5)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>0.33 ± 0.05 (12)</td>
<td>-</td>
<td>30.7 ± 7.13 (5)</td>
<td>26.2 (1)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>7</td>
<td>0.80 ± 0.40 (3)</td>
<td>-</td>
<td>33.7 ± 6.59 (4)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>8</td>
<td>0.63 ± 0.11 (13)</td>
<td>1.4 (1)</td>
<td>81.6 (1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>9</td>
<td>0.31 ± 0.02 (28)</td>
<td>143.4 ± 142.7 (2)</td>
<td>6.32 ± 1.49 (5)</td>
<td>2.5 (1)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>10</td>
<td>0.65 ± 0.03 (163)</td>
<td>3.3 (1)</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
<td>11</td>
<td>0.41 ± 0.03 (85)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.8b, 1.7c</td>
</tr>
<tr>
<td>12</td>
<td>0.23 ± 0.03 (82)</td>
<td>4.13 ± 3.81 (2)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.1b</td>
</tr>
<tr>
<td>13</td>
<td>0.25 ± 0.03 (82)</td>
<td>0.2 (1)</td>
<td>6.73 ± 1.93 (4)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>20 (1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.5b, 21c, 0.1d</td>
</tr>
<tr>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.3c</td>
</tr>
</tbody>
</table>

*a* After thawing, weighed as a whole group, not individuals.

*b* aquatic insects, *c* amphibians, *d* snails, *e* crayfish

In the case of data without reported standard error there was only one of that species.
Table 3.4. Proportions of total prey mass collected from 15 man-made water bodies used by Wood Storks (*Mycteria americana*) for foraging in July 2008 in Jacksonville, Florida. Proportions indicate availability of types of prey based on our sampling using multiple collection methods.

<table>
<thead>
<tr>
<th>Water Body</th>
<th>Mosquitofish (<em>Gambusia</em> spp.)</th>
<th>Largemouth Bass (<em>Micropterus salmoides</em>)</th>
<th>Bluegill Sunfish (<em>Lepomis macrochirus</em>)</th>
<th>Gizzard Shad (<em>Dorosoma cepedianum</em>)</th>
<th>Redbreast Sunfish (<em>Lepomis auritus</em>)</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.02</td>
<td>-</td>
<td>0.27</td>
<td>0.7</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.14</td>
<td>0.43</td>
<td>0.43</td>
<td>-</td>
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<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>-</td>
<td>0.1</td>
<td>-</td>
<td>0.87</td>
<td>0.02a</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>0.03</td>
<td>-</td>
<td>0.8</td>
<td>0.17</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>0.01</td>
<td>-</td>
<td>0.99</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>0.09</td>
<td>0.02</td>
<td>0.89</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>0.03</td>
<td>0.87</td>
<td>0.1</td>
<td>0.01</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>0.91</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.06a</td>
</tr>
<tr>
<td>11</td>
<td>0.84</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.16b</td>
</tr>
<tr>
<td>12</td>
<td>0.09</td>
<td>0.91</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>0.43</td>
<td>0</td>
<td>0.57</td>
<td>-</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>-</td>
<td>0.48</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.51b</td>
</tr>
<tr>
<td>15</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1c</td>
</tr>
</tbody>
</table>

*a* crayfish  
*b* insects, tadpoles  
*c* insects, tadpoles, crayfish
Table 3.5. Concentrations (ppm wet wt.; mean ± SE) of metals in sediment and prey samples from four types of man-made water bodies (N = number of water bodies from which samples taken) used by Wood Storks (*Mycteria americana*) for foraging in June and July 2007 and 2008. Within rows, mean ± SE followed by the same or no letter were not different (p > 0.05) as determined by an analysis of variance. BDL indicates that the sample mean is below the detection limit.

<table>
<thead>
<tr>
<th>Contaminant type</th>
<th>Medium</th>
<th>Residential (N=10)</th>
<th>Golf Course (N=6)</th>
<th>Agricultural (N=3)</th>
<th>Retention (N=11)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Arsenic</strong></td>
<td>Sediment</td>
<td>0.225 ± 0.067&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.048 ± 0.503&lt;sup&gt;B&lt;/sup&gt;</td>
<td>0.163 ± 0.042&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.218 ± 0.047&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>0.156 ± 0.069&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.282 ± 0.106&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.005 ± 0.025&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.071 ± 0.021&lt;sup&gt;B&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Cadmium</strong></td>
<td>Sediment</td>
<td>0.023 ± 0.015</td>
<td>0.032 ± 0.020</td>
<td>0.017 ± 0.009</td>
<td>0.028 ± 0.008</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>0.001 ± 0.001</td>
<td>0.026 ± 0.024</td>
<td>BDL</td>
<td>0.003 ± 0.003</td>
</tr>
<tr>
<td><strong>Mercury</strong></td>
<td>Sediment</td>
<td>0.001 ± 0.001</td>
<td>BDL</td>
<td>BDL</td>
<td>0.001 ± 0.001</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>0.003 ± 0.003&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.039 – 0.295&lt;sup&gt;B&lt;/sup&gt;</td>
<td>0.032 ± 0.016&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.005 ± 0.003&lt;sup&gt;AB&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Lead</strong></td>
<td>Sediment</td>
<td>3.493 ± 2.047&lt;sup&gt;A&lt;/sup&gt;</td>
<td>1.901 ± 0.642</td>
<td>2.725 ± 1.205</td>
<td>0.023 ± 0.014</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>0.026 ± 0.099</td>
<td>0.0187 ± 0.067</td>
<td>0.061 ± 0.035</td>
<td>0.136 ± 0.052</td>
</tr>
<tr>
<td><strong>Selenium</strong></td>
<td>Sediment</td>
<td>0.045 ± 0.024</td>
<td>0.132 ± 0.064</td>
<td>0.087 ± 0.058</td>
<td>0.068 ± 0.031</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>0.036 ± 0.056&lt;sup&gt;A&lt;/sup&gt;</td>
<td>0.717 ± 0.219&lt;sup&gt;B&lt;/sup&gt;</td>
<td>0.345 ± 0.057&lt;sup&gt;AB&lt;/sup&gt;</td>
<td>0.379 ± 0.060&lt;sup&gt;A&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>33.233 ± 5.399</td>
<td>39.083 ± 8.146</td>
<td>43.500 ± 6.526</td>
<td>48.400 ± 5.399</td>
</tr>
</tbody>
</table>
Table 3.6. Concentrations (ppm; wet weight) of metals in Wood Stork (*Mycteria americana*) chicks (N = 10) found dead in the Jacksonville Zoo Colony, Jacksonville, Florida in July 2008.

<table>
<thead>
<tr>
<th>Metal</th>
<th>Mean ± SE</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>3.39 ± 0.84</td>
<td>0.92 – 8.99</td>
</tr>
<tr>
<td>As</td>
<td>0.12 ± 0.02</td>
<td>0.00 – 0.20</td>
</tr>
<tr>
<td>Cd</td>
<td>0.00 ± 0.00</td>
<td>0.00 – 0.00</td>
</tr>
<tr>
<td>Hg</td>
<td>0.24 ± 0.07</td>
<td>0.03 – 0.58</td>
</tr>
<tr>
<td>Pb</td>
<td>0.02 ± 0.01</td>
<td>0.00 – 0.05</td>
</tr>
<tr>
<td>Se</td>
<td>1.86 ± 0.67</td>
<td>0.56 – 7.82</td>
</tr>
<tr>
<td>Zn</td>
<td>25.55 ± 3.90</td>
<td>8.55 – 50.1</td>
</tr>
</tbody>
</table>
Table 3.7. Contaminant concentrations in sediments and prey from four types of man-made water bodies used as foraging sites by Wood Storks (*Mycteria americana*) in Jacksonville, Florida during June and July 2007 and 2008. Within rows, concentrations of contaminants followed by the same or no letter did not differ among types of water bodies (p > 0.05) as determined by analysis of variance. N indicates sample size.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Medium</th>
<th>Unit</th>
<th>Residential Mean ± SE</th>
<th>Golf Course Mean ± SE</th>
<th>Agricultural Mean ± SE</th>
<th>Retention Mean ± SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCBs</td>
<td>Sediment</td>
<td>ppm</td>
<td>0.005 ± 0.004 (N=3)</td>
<td>0.003 ± 0.002 (N=3)</td>
<td>0.005 ± 0.004 (N=2)</td>
<td>0.003 ± 0.001 (N=7)</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>ppm</td>
<td>0.042 ± 0.036 (N=3)</td>
<td>0.014 ± 0.009 (N=3)</td>
<td>0.057 ± 0.039 (N=2)</td>
<td>0.053 ± 0.002 (N=7)</td>
</tr>
<tr>
<td>OCs</td>
<td>Sediment</td>
<td>ppm</td>
<td>0.969 ± 0.049 (N=3)</td>
<td>0.810 ± 0.550 (N=3)</td>
<td>0.076 ± 0.031 (N=2)</td>
<td>0.077 ± 0.023 (N=7)</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>ppm</td>
<td>3.60 ± 0.86 (N=3)</td>
<td>3.82 ± 2.34 (N=3)</td>
<td>1.98 ± 0.657 (N=2)</td>
<td>2.74 ± 0.34 (N=7)</td>
</tr>
<tr>
<td>PAHs</td>
<td>Sediment</td>
<td>ppb</td>
<td>0.003 ± 0.003 A(N=10)</td>
<td>0.002 ± 0.002 B(N=6)</td>
<td>4.393 ± 1.118 AB(N=3)</td>
<td>2.159 ± 0.482 AB(N=11)</td>
</tr>
<tr>
<td></td>
<td>Prey</td>
<td>ppb</td>
<td>3.20 ± 0.179 (N=10)</td>
<td>0.006 ± 0.002 (N=6)</td>
<td>0.137 ± 0.006 (N=3)</td>
<td>2.571 ± 1.993 (N=11)</td>
</tr>
</tbody>
</table>
Table 3.8. Number of contaminants detected in samples of sediment and prey from each of four types of man-made water bodies used by Wood Storks (*Mycteria americana*) for foraging in Jacksonville, Florida during June and July 2007 and 2008. The number in parentheses next to the contaminant indicates how many compounds were tested for and the number in parentheses under the type of water body indicates the number of the water bodies from which sediment and prey were sampled.

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Residential (N = 10)</th>
<th>Golf Course (N = 6)</th>
<th>Agricultural (N = 3)</th>
<th>Retention (N = 11)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
<td>Mean ± SE</td>
</tr>
<tr>
<td><strong>Metals (19)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>17 ± 1</td>
<td>17 ± 1</td>
<td>18 ± 2</td>
<td>17 ± 1</td>
</tr>
<tr>
<td>Prey</td>
<td>15 ± 1</td>
<td>15 ± 1</td>
<td>14 ± 2</td>
<td>14 ± 1</td>
</tr>
<tr>
<td><strong>PAHs (41)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>6 ± 6</td>
<td>4 ± 2</td>
</tr>
<tr>
<td>Prey</td>
<td>2 ± 1</td>
<td>2 ± 1</td>
<td>1 ± 1</td>
<td>4 ± 2</td>
</tr>
<tr>
<td><strong>Organochlorine Pesticides (26)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>3 ± 2</td>
<td>3 ± 1</td>
<td>5 ± 4</td>
<td>4 ± 1</td>
</tr>
<tr>
<td>Prey</td>
<td>20 ± 1</td>
<td>16 ± 1</td>
<td>14 ± 5</td>
<td>17 ± 1</td>
</tr>
<tr>
<td><strong>PCBs (5)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
</tr>
<tr>
<td>Prey</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
<td>1 ± 1</td>
</tr>
</tbody>
</table>
Figure 3.1. Man-made water bodies (white spheres) surveyed for foraging Wood Storks (Mycteria americana) from the Jacksonville Zoo and Gardens (yellow star) in Jacksonville, Florida as part of a contaminant study conducted in June and July 2007 and 2008
CHAPTER 4

CONCLUSIONS

This study produced interesting and valuable results. I documented Wood Stork use of urban man-made water bodies and some potential factors influencing this use. I also identified contaminant loads in four types of man-made water bodies in the metropolitan Jacksonville, Florida area. Use of man-made water bodies was high (36%) and contaminant levels within water bodies were low (means >5 ppm) for multiple classes of contaminants (OPs, PCBs, OCs, PAHs, and metals). Storks appear to be using water bodies in more urban areas, perhaps because their population is habituated to humans due to their colony location within the Zoo. They are also detected more often in areas where other wading birds were present, which is consistent with their social and opportunistic foraging behavior. Additionally, storks may be using man-made water bodies relatively far away from the colony in the later part of the nesting season because they are able to be away from nests for longer periods of time.

MANAGEMENT IMPLICATIONS

In 2007, Wood Storks were proposed to be reclassified as Threatened in the 5 year review (USFWS 2007). Overall, the stork population is increasing in population size and range (Brooks and Dean 2008). As the human population and development increase, more and more man-made water bodies will be built and precautions must be taken in order to minimize stork exposure to contaminants. My data suggests that the overall contaminant load in urban man-made water bodies in Jacksonville, FL is low.
Wood Stork use of urban man-made water bodies is also low. However, there are significant differences in contaminant loads, with Golf Courses having higher concentrations for most contaminant classes. As new golf courses are being built and old ones are being refurbished, I recommend steep slopes being implemented on water hazards, so storks are less likely to use these water bodies for foraging. Since storks are tactile feeders, they require shallow areas for foraging, which steep slopes would prohibit. Many golf courses I encountered also stocked ponds, which would encourage stork foraging. I would recommend that golf courses, and other areas of concern, not stock their man-made water bodies to discourage stork foraging. However, areas that harbor high contaminant loads may still be beneficial for stork nesting or roosting areas and should not implement other means of discouraging storks. In addition to storks, other wading birds may be at risk of contaminant exposure as well and most management techniques employed for storks will be beneficial to them as well.

RECOMMENDATIONS FOR FUTURE RESEARCH

I recommend additional research on Wood Stork use of urban man-made water bodies. There are most likely other factors that would help explain storks’ use during the breeding season. I would suggest multiple people visiting water bodies at the same time (i.e. multiple routes driven at the same time) and more parameters being investigated. Roadside sampling is efficient and relatively inexpensive and this technique could be used to help further determine the use of urban man-made water bodies by storks in a time where there will be more and more bodies of water constructed due to mitigation and city needs. I recommend performing an additional occupancy/use model that takes into account more factors, such as prey densities and nocturnal feeding.
Contaminant data collection is an ongoing process, but levels in Jacksonville, FL were quite low for legacy pesticides (DDT, PCBs). However, I recommend future research for those contaminants that may be ‘up and coming’ (PAH, nano-materials) in Jacksonville, FL and other locations where colonies exist. Additionally, further research that directly links Wood Stork health to contaminant levels and foraging in urban man-made water bodies is necessary. I recommend capturing adult Wood Storks from the Jacksonville Zoo during several points during the year (once a season) to determine maternal transfer of contaminants to eggs and basal levels of contaminants present in Wood Storks foraging in urban man-made water bodies. Furthermore, research on differences in male and female concentrations of contaminants would be an interesting facet to study.

LITERATURE CITED


U. S. Fish and Wildlife Service. 2007. Wood stork (Mycteria Americana) 5 year review: Summary and evaluation. Atlanta, Georgia
APPENDIX A

A TOTAL LIST OF CONTAMINANTS SAMPLED FROM SEDIMENT AND PREY
FROM MAN-MADE WATER BODIES IN JACKSONVILLE, FL AND CHICKS
FROM THE JACKSONVILLE ZOO COLONY IN JUNE AND JULY OF 2007 AND
2008.
Inorganics (2007 and 2008)
Al
AS
B
Ba
Be
Cd
Cr
Cu
Fe
Hg
Ma
Mo
Ni
Pb
Se
Sr
V
Zn

1,6,7-trimethyl-naphthalene
1-methylnaphthalene
1-methylphenanthrene
2,6-dimethylnaphthalene
2-methylnaphthalene
acenaphthene
acenaphthene
anthracene
benzo(a)anthracene
benzo(a)pyrene
benzo(b)fluoranthene
benzo(e)pyrene
benzo(g,h,i)perylene
benzo(k)fluoranthene
biphenyl
C1-chrysenes
C1-dibenzothiophenes
C1-fluoranthenes & pyrenes
C1-fluorenes
C1-naphthalenes
C1-phenanthrenes
C2-chrysenes
C2-dibenzothiophenes
C2-fluorenes
C2-naphthalenes
C2-phenanthrenes
C3-chrysenes
C3-dibenzothiophenes
C3-fluorenes
C3-naphthalenes
C3-phenanthrenes
C4-chrysenes
C4-dibenzothiophenes
C4-fluorenes
C4-naphthalenes
C4-phenanthrenes
chrysene
dibenz(a,h)anthracene
dibenzothiophene
fluoranthe
fluorene
indeno(1,2,3-cd)pyrene
naphthalene
perylene
phenanthrene
pyrene

Organics (2007)
aldrin
alpha BHC
alpha chlordane
beta BHC
cis-nonachlor
delta BHC
dieldrin
endosulfan II
endrin
gamma chlordane
HCB
heptachlor
heptachlor epoxide
mirex
o,p’-DDD
o,p’-DDE
o,p’-DDT
oxychlordane
p,p’-DDD
p,p’-DDE
p,p’-DDT
PCB-1242
PCB-1248
PCB-1254
PCB-1268
PCB-TOTAL
pentachloro-anisole
toxaphene
trans-nonachlor

**Organophosphates (2008)**
parathion
phorate
prothiofos
runnel
stirphos
sulfothep
sulprofos
trichloronate