ABIOTIC FACTORS AFFECTING WADING BIRD UTILIZATION OF ISOLATED FRESHWATER AQUATIC HABITAT

A Ph.D. DISSERTATION PROPOSAL

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BACKGROUND

Predators dominate the faunal community in many wetlands. Wading birds (Order Ciconiiformes), often at the top of the food web, are one of the standards for recognizing "wetlands of international importance" (RAMSAR 1990). In world heritage sites such as the Brazilian Pantanal and the Florida Everglades, large colonies of nesting ciconiiforms are an important component of ecotourism (Bouton and Frederick 2003, Stolen 2003). Wood storks (Mycteria americana) are considered ecological indicators of South Florida wetlands; their migration and breeding cycles are directly linked to hydroperiod of southern marshes (Netherton 1998). Unfortunately hunting, development, altered hydrology, and climate change have severely reduced global wading bird populations (Robertson and Kushlan 1974, Kushlan and White 1977, Frederick and Collopy 1989, Frohring *et al.* 1988, David 1994, Wilson *et al*. 2004, Wetlands International 2009). Despite conservation measures implemented over the last four decades, wading birds must continue to cope with the effects of human intrusion and climate change on their breeding and foraging habitat.

In order to thrive, wading bird species require seasonally fluctuating water to attract and concentrate prey, and safe breeding and roosting sites close to suitable foraging habitat. Relationships between the presence and abundance of wading birds nesting or foraging in freshwater wetlands and hydrology, prey availability and/or vegetation have been examined throughout the world – coastal lagoons in Ghana (Ntiamoa-Baidu *et al*. 1988); Lake Kerkini in Greece (Dimalexis and Pyrovetsi 1997); the Camargue in southern France (Cézilly *et al*. 1995); wet grasslands in England (Ausden and Hirons 2002; Wilson *et al*. 2004); an urban lagoon in Rio de Janeiro (Moreno *et al*. 2004); the Venezuelan *llanos* (Kushlan *et al*. 1985); the San Joaquin Valley and Kesterson Reservoir in California (Colwell and Taft 2000; Elphick and Oring 1998, Hoffman 2001; Elphick and Oring 2002); New Jersey salt marshes (Master *et al*. 2005); northeastern United States estuaries (Parsons *et al.* 2001); coastal marshes in Louisiana (DuBowy 1996) – and exhaustively in the Florida Everglades (Kushlan 1976a, 1976b, 1986 and 1989; Powell 1987; Surdick Jr. 1998; Frederick and Ogden 2001; Gawlik 2002; Bancroft *et al*. 2002; Townsend *et al*. 2006; Gawlik and Crozier 2007; Lantz *et al.* 2010; Dorn *et al*. 2011; *etc*.).

Investigations in the Everglades have evaluated hypotheses regarding the quantitative effects of water level on wading bird population parameters. Wetlands are dominated by water level fluctuation, a key factor in maintaining avian populations because it drives vegetation composition and density as well as prey availability (Kushlan 1989). When water levels decline and shallow wetlands dry out, prey migrate into progressively deeper patches and become concentrated (Kushlan 1976a,b). Hydrology may explain behavioral and ecological adaptations of wading birds and the fact that species with different adaptations may be supported in a single system due to spatial and/or temporal variations in water level fluctuation patterns (Kushlan 1989).

Disparate feeding strategies (*e.g.*, searching for new high-quality patches or staying and exploiting food patches of declining quality) of different species are affected by water depth, prey density and availability (Gawlik 2002). Furthermore, wading bird reproduction and migration have been linked to food availability and water level declines, driven by pulsed productivity in the aquatic food web after infrequent, yet severe, droughts (Frederick and Ogden 2001). A conceptual model of prey availability (Gawlik 2002) suggests that physical characteristics related to the Everglades environment, including landscape configuration, spatial extent, microtopography and hydroperiod, directly influence the quality of patches and therefore the reproductive output of a breeding population through small-scale concentrations of prey density.

Bancroft *et al*. (2002) and Lantz *et al*. (2010) suggest three important environmental aspects that Everglades studies have generally overlooked: scale, microtopography and hydroperiod. West-central Florida has a humid, subtropical climate with a 'wet season' extending from roughly May through October (Obeysekera *et al*. 1999); however, the areal extent and landscape distribution of freshwater marshes consists of small, isolated patches at (relatively) higher elevations. Also, wetland fauna are influenced by top-down and bottom-up controls on their community, whether from above by predators or below by food sources. In isolated freshwater wetlands that are subject to periodic drying, the mechanisms and results of these controls will vary spatially (*i.e.*, size and microtopographic variability) and temporally (*i.e*., hydroperiod).

Purpose

The purpose of this study is to (1) determine whether small, isolated freshwater marshes provide comparable functional value to wading birds as large cells in the Everglades, (2) determine whether urban aquatic sites provide the same attraction to wading birds as rural sites, and (3) fill knowledge gaps regarding landscape and wetland structural components underlying their functional value in this context.

Wading birds respond to specific cues, such as water depth and prey availability, when selecting foraging habitat (Master *et al*. 2005). An assumption of this study is that such cues are controlled by landscape variables and physical wetland characteristics that indirectly influence wading bird utilization. For example, a few faunal surveys have been conducted in wetlands in west-central Florida in the vicinity of northern Hillsborough County wellfields. Frequently in close proximity to urban centers, these wetlands are under the influence of regional groundwater withdrawals, and are therefore particularly susceptible to long-term changes in hydroperiod (although a handful are augmented to minimize this impact). Over time, regional drawdowns could affect the availability of prey for wading bird species. Guzy *et al*. (2006) found significantly higher tadpole densities in wetlands that were not affected by groundwater pumping. In another study, diversity and abundance of anurans were lower in urban wetlands, and different hydroperiods resulted in different anuran assemblages (Haggerty 2010).

Objectives

Gawlik (2002) showed that wading bird abundance in large aquatic habitats (>100 hectares) is strongly correlated to water level, density of submerged aquatic vegetation, and prey availability, but these relationships have not been studied in isolated tropical and subtropical systems. Also, a need to examine factors related to water level, such as hydroperiod and microtopography have been identified in previous studies (Bancroft *et al*. 2002; Lantz *et al*. 2010).

Site fidelity (Melvin *et al*. 1999) and wading bird populations (Butler 1994; Hafner 1997; Gawlik 2002; Lantz *et al*. 2010) are constrained by oscillations of prey availability which can stem from wetland size, landscape position, microtopographic variability and seasonal precipitation cycles (Colwell and Taft 2000). Therefore, variables related to three categories will be examined to determine their importance in site selection: (1) hydroperiod, (2) structural complexity, and (3) landscape components. Landscape components will consist of: surrounding land use and intensity; age since creation or urban incorporation; distance to urban centers, similar habitat, and nearest lotic ecosystem; and hydrologic connectivity. Structural components will consist of delineated wetland size, shoreline development and convolution, bathymetry, and microsite rugosity. Historic and current water level data will be compiled to determine an average annual and decadal hydroperiod. Constrained variables will include, depending on the analyses desired, dominant vegetation, upland buffer size and condition, time of day, weather, and wetland geometry.

Rationale

Wading birds possess several characteristics that make them ideal bioindicators for wetlands. They are typically conspicuous, easily identified, high trophic-level predators that are closely associated with aquatic habitats. Also, they utilize multiple sites within and among years based on their life stage and breeding cycles. Understanding their movements and how this relates to wetland characteristics such as connectivity and structural complexity will be helpful in designing conservation strategies for a suite of organisms associated with the habitats occupied by wading birds (Haig *et al.* 2008).

Research Hypotheses

This dissertation will test the following hypotheses regarding the presence and abundance of wading birds in isolated freshwater wetlands:

1. **Hydroperiod:** Hydroperiod can covary with wetland size (Snodgrass *et al*. 2001; Baber *et al*. 2004), and is interrelated with seasonal drydowns and wetland productivity (Gawlik 2000). Hydroperiod is important to site suitability in terms of the availability of aquatic foraging habitat (Kushlan 1976a,b) and prey (Babbitt *et al.* 2003) both before and during the breeding

season. Increased hydroperiod has been linked with increased fish densities and increased fish biomass (Loftus and Eklund 1994; Trexler *et al*. 2002; Chick *et al.* 2004). Aquatic macrophyte production increases as water levels increase in shallow wetlands (Robel 1962), leading to increased refugia and food resources for prey during the wet season. However, as water levels decline, prey become concentrated as they migrate into progressively deeper and smaller patches, increasing the abundance of wading birds foraging at these locations (Kushlan 1976a,b). As such, hypotheses pertaining to this portion of the dissertation include:

- Hydroperiod alone has no significant effect on wading bird utilization (*i.e*., species presence and relative abundance) since these birds assess foraging sites in their migration corridors on a daily basis; rather, utilization is expected to vary temporally with hydroperiod, with birds exploiting sites with short hydroperiods early in the dry season, as drawdown concentrates prey, and increasingly exploiting sites with longer hydroperiods as the dry season progresses.

2. **Aboveground Net Primary Productivity**: Terrestrial plants senesce and produce aboveground detrital material annually. Therefore, measurements of peak aboveground biomass can be used as a measure of Aboveground Net Primary Production (ANPP). Living plants within 0.25-m^2 quadrats placed at 5-m intervals along 50-m transects that radiate from the wetland edge inward will be harvested during late September or early October by clipping at ground level, oven-drying at 65°C for 2 to 3 days, and weighing to estimate biomass in units of grams per square meter per year (*sensu* Rocha and Goulden 2008). Annual net production between sites will be compared by extrapolating the ANPP to the delineated area of each wetland.

3. **Scale:** The ability of wading birds to respond to patchiness of wetlands in the landscape depends on how they scale their environment. The ability of an observer to detect environmental heterogeneity, on the other hand, depends on the scale of measurements taken. Therefore, it is important that the scale of data collection is within the same domain as wading bird response (Weins 1989). Wading birds evaluate foraging habitat at a landscape scale on a daily basis (Pierce and Gawlik 2010), but it is not clear to what degree wetland size or structural complexity is a factor. Larger habitats generally support more species than smaller habitats (MacArthur and Wilson 1967; Batzer *et al*. 2006). This may be because larger sites provide more suitable foraging habitat across a wider range of water levels than sites that are smaller. Hydroperiod and prey assemblages can be positively correlated with wetland size (Snodgrass *et al.* 2001; Baber *et al*. 2004) and, in a study by Brennan (2011), wetland size consistently predicted wading bird abundance. Also, the presence and abundance of certain species of wading birds in large, contiguous expanses of remote freshwater marshes in the Everglades are dependent on water level fluctuations (Gawlik 2002; Gawlik and Crozier 2007), which drive specific wetland conditions such as water depth, vegetation composition and prey availability.

Hypotheses pertaining to this portion of the dissertation include:

- Wetland size and hydroperiod will be positively correlated at sites for which water level is not actively managed.
- Wading bird diversity should vary proportionally with wetland size, in accordance with the theory of island biogeography.
- Wading bird utilization (*i.e.*, species presence and relative abundance) should increase with increased available aquatic habitat (*e.g.*, delineated wetland size, bathymetric variation, and number and size of microsites within each wetland).
- Wading bird utilization (*i.e.*, species presence and relative abundance) will increase with increased shoreline convolution due to increased surface area of the littoral zone.
- Wading bird species found within smaller sites will be a subset of those found in larger sites.

4. **Vertical and Horizontal Complexity:** Although poorly studied, wading bird distributions may likely be influenced by intrawetland morphometric variability as well as foraging conditions (Bancroft *et al*. 2002). Habitat heterogeneity is generally believed to increase the diversity of aquatic sediment biota, and microtopographic variability is important for creating prey refugia (Kushlan 1976). In addition, seasonal dry-downs produce shallow, small-scale patches that are clumped in space and 'migrate' across the landscape over time (Gawlik 2002). The number and size of pools, and therefore flyover search time, may be a function of microtopographic variation as well as water level, since portions of a habitat are instantly recognizable as suitable for foraging when flooded. Furthermore, large aquatic sites with variable microtopography should provide more suitable foraging habitat across a wider range of water levels than sites that are smaller or less topographically variable.

Rugosity was selected as an ecological indicator of the amount of habitat available for colonization by benthic prey, and foraging and refugia for mobile prey. Increased substrate complexity provides habitat for benthic invertebrates, which comprise a portion of diet for many wading bird species. Surface topography of soft-bottomed aquatic substrates can be fractal at spatial scales relevant to habitat structure important for benthic organisms (Commito and Rusignuolo 2000). Aquatic mammals and fish can enhance habitat heterogeneity for benthic invertebrates through grazing and spawning activities (Palmer *et al.* 2000). However, large animals (especially hoofed mammals) can crush vegetation and increase turbidity, indirectly altering composition of wading bird species by reducing prey diversity (Waters 1995). Additionally, Cahoon and Reed (1995) found that marsh surface topography, as well as elevation, strongly influenced hydroperiod.

Hypotheses pertaining to this portion of the dissertation include:

- Wading bird utilization (*i.e.,* species presence and relative abundance) will increase at sites with increased microsite rugosity as the dry season progresses, since decreased water levels lead to increased prey availability despite greater structural complexity of the substrate (Flecker and Allan 1984, Diehl 1988).

- Wading bird utilization (*i.e.,* species presence and relative abundance) will increase during the dry season at sites with increased bathymetric heterogeneity because, as water levels decrease over the dry season, sites with more uniform bottom topography will have fewer pools available to exploit.

- Rugosity is expected to be a function of hydroperiod, greatest at some moderate level of inundation, and lowest for perpetually dry or inundated sites.

5. **Landscape Components**: As previously discussed, flyover search time may be a function of microtopographic variation, hydroperiod and marsh size since portions of a habitat are instantly recognizable as suitable for foraging when flooded. Search time (and in turn, energy expenditure) is reduced as distance to nearest aquatic neighbor is reduced.

In terms of landscape configuration, the theory of island biogeography (MacArthur and Wilson 1967) may be used to examine species richness of birds in isolated terrestrial ecosystems incorporated within human-altered landscapes. Dispersal is greater between connected patches (Haas 2002); distance between similar sites determines their degree of isolation. However, in the context of this dissertation, this distance may be species-specific.

With respect to landscape composition, surrounding land use is an important variable in the distribution of avifauna (Weins 2008). Land use influences abundance and species composition by altering habitat quality and landscape composition (Chapman and Reich 2007). For example, ardeids, but not ibises or storks, are known to forage in deeper wastewater impoundments (Frederick and McGehee 1994), but most birds tend to avoid urban areas (Clergeau *et al.* 1998; Palomino and Carrascal 2006, 2007). Road density and distance to roads exert a strong influence on abundance and species composition (Palomino and Carrascal 2007; Minor and Urban 2010). Marzluff and Ewing (2001) identified the need to study whether undeveloped areas that connect native habitat across urban areas function as dispersal corridors by birds.

Intermediate levels of disturbance should result in the greatest diversity because disturbance disrupts superior competitive species and allows less competitive species to coexist (Connell 1978); intermediate levels of development along an urban-rural gradient function in much the same way (McDonnell *et al.* 1993, Hansen *et al.* 2005). Urban-rural gradients are characterized by increasing vegetation and decreasing manmade structures, from city center to surrounding periurban and rural areas. As an understanding of urbanization and its ecological effects have grown, so has the value of understanding landscape variables along the urban-rural gradient (McDonnell and Hahs 2008).

Hypotheses pertaining to this portion of the dissertation include:

- Wading bird abundance should increase with increasing distance from urban centers.
- Species composition will vary between urban and rural sites.
- Wading bird presence/abundance should increase with decreasing distance from nearby aquatic habitat.
- Wading bird diversity should be inversely proportional to distance to nearest neighbor, in accordance with the theory of island biogeography.
- Wading bird species diversity should be highest at sites that experience disturbance at intermediate temporal or spatial scales.

METHODS

Site Selection (Reference Sites)

The study area is comprised of sandy surficial deposits overlying karst limestone deposits, a lack of topographic relief, and a discontinuous confining unit which results in numerous depressions and points of hydrologic connectivity between the water table and the underlying Floridan aquifer (SWFWMD 2011). This combination of features results in a high water table that intersects the land surface at low elevations, creating wetlands, lakes, and rivers. Groundwater pumping harms the overlying wetlands, lakes, and rivers by lowering the water table (Dedekorkut 2005). The surficial aquifer is particularly responsive to pumping in the Cross Bar Ranch and Cypress Creek wellfield areas (Fretwell 1988), from which Tampa Bay Water obtains most of its water (Tampa Bay Water 2011).

Due to the availability of data from the Southwest Florida Water Management District (SWFWMD), 23 potential sampling sites (

Table 1) were selected from a subset of currently monitored wetlands in four of the larger properties in the northern part of a consolidated wellfield system (Figure 1) -- Cypress Creek, Morris Bridge, Starkey and Cross Bar Ranch. These wellfields of northern Hillsborough and Pasco counties provide drinking water to 2.4 million people (Tampa Bay Water 2011) in the suburban and urban communities to the south. Site selection criteria included wetland type (non-forested), wetland size (<20 hectares to maximize detectability), dominant vegetation, and site accessibility. It should be noted that perching and confinement is more prevalent at the Morris Bridge wellfield than the Starkey, Cypress Creek, and Cross Bar Ranch wellfields (M. Rains, pers. comm. 2012). This difference is expected to be revealed by different hydroperiods, if at all.

Table 1. Proposed rural sampling sites in northern Hillsborough and Pasco Counties.

Wellfield Association[a]	ULTRA-Ex Wetland ID	Longitude[b]	Latitude[b]	Acres	Type[c]
CBR	4*	505737.16	1466179.92	4.5	IM
	5*	505304.86	1468989.84	8.7	IM
	6*	510060.12	1472592.31	4.5	IM
	8	499840.53	1469238.25	35.4	IM
	13	511913.77	1469875.72	17.4	IM
	17	494760.10	1462303.38	20.3	IM
	34*	507070.07	1471763.75	5.0	IM
CYC	189*	534892.68	1443060.32	6.8	IM
	190	534284.60	1443708.93	6.4	IM
	198	529865.91	1438053.82	4.4	IM
	205	533777.87	1441661.74	3.3	IM
	206	531446.91	1441459.05	5.9	IM
	234	534446.75	1442533.32	1.2	IM
MBR	258	548497.90	1377907.13	4.9	IM
	259	552009.42	1378290.75	2.6	IM
	266	555447.17	1374321.84	2.6	IM
	267	553558.62	1378335.01	3.3	IM
	296	558132.45	1374853.00	1.2	IM
STK	411	448295.14	1424649.71	0.94	IM
	414	448864.57	1421951.07	4.2	IL
	417	450597.64	1422223.41	1.4	IM
	420	452256.44	1422223.41	2.8	IM
	431	461615.01	1422396.72	0.97	IP

* indicates augmented site

[a] CBR = Cross Bar Ranch; CYC = Cypress Creek; MBR = Morris Bridge; STK = Starkey

[b] NAD83 UTM 17N

[c] IM = isolated marsh; IP = isolated prairie; IL = isolated lake

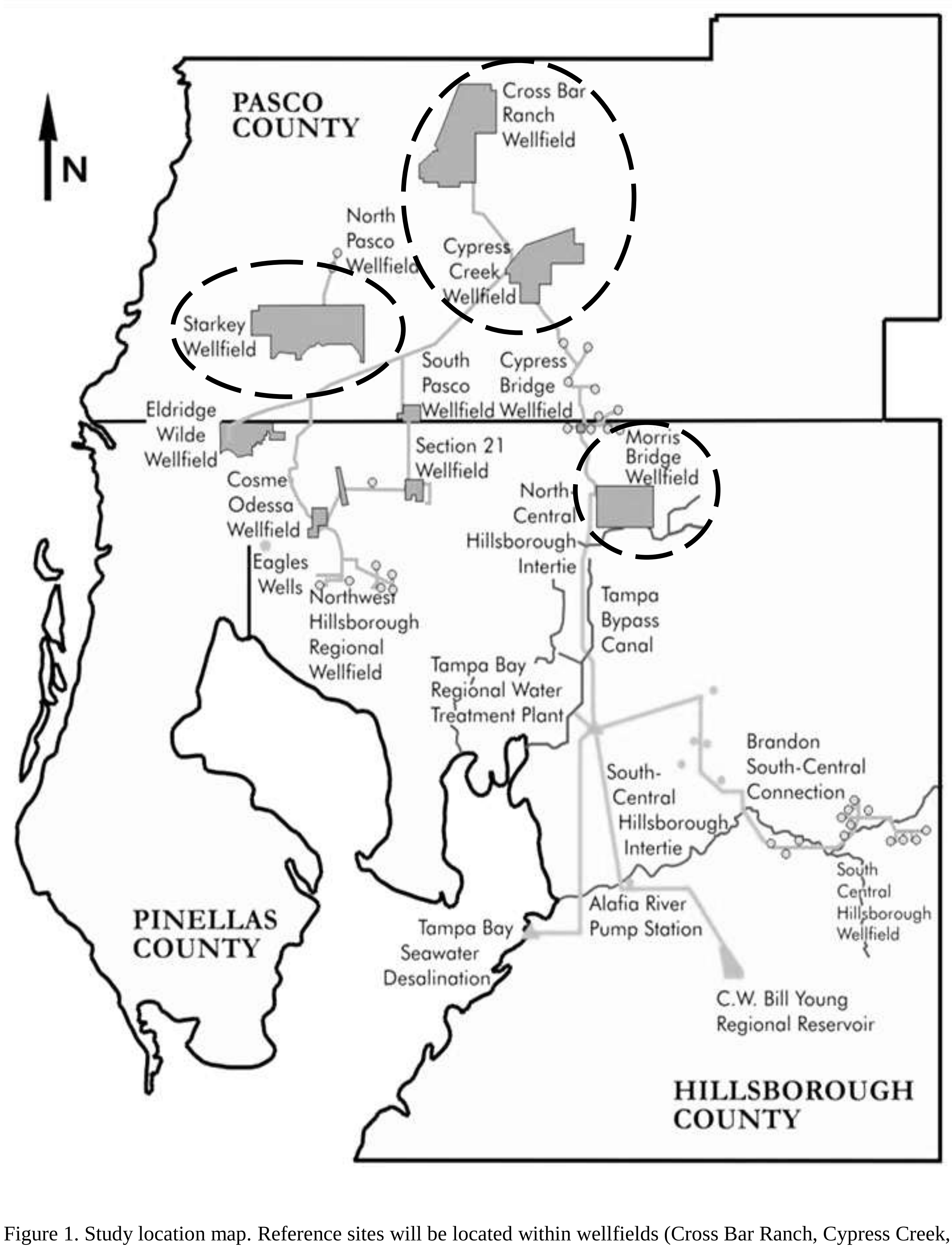

Figure 1. Study location map. Reference sites will be located within wellfields (Cross Bar Ranch, Cypress Creek, Morris Bridge, and Starkey) indicated by dashed circles. Image source: SWFWMD and Tampa Bay Water 2011.

Sampling Schedule (Reference Sites)

Encounters with ten wading bird species (Order Ciconiiformes) are anticipated – diurnal species such as great egrets (*Ardea alba*), snowy egrets (*Egretta thula*), great blue herons (*Ardea herodias*), little blue herons (*Egretta caerulea*), tricolored herons (*Egretta tricolor*), white ibis (*Eudocimus albus*), wood storks (*Mycteria americana*), and roseate spoonbills (*Platalea ajaja*), as well as nocturnal black-crowned (*Nycticorax nycticorax*) and yellow-crowned (*Nyctanassa violacea*) night herons and crepuscular green herons (*Butorides virescens*). In peninsular Florida, six of these species are state and/or federally listed as "endangered" or "species of special concern". The wood stork is federally listed as endangered, state-listed by Texas as Endangered, and state-listed by Georgia and South Carolina as a Species of Special Concern (SSC). Little blue herons (*Egretta caerulea*), snowy egrets (*Egretta thula*), tricolored herons (*Egretta tricolor*), roseate spoonbills (*Platalea ajaja*), and white ibises (*Eudocimus albus*) are all state-listed as Species of Special Concern in Florida. Little blue herons (*Egretta caerulea*) and tricolored herons (*Egretta tricolor*) are also both state-listed as SSC in Georgia.

Since most encounters will be diurnal species that tend to forage throughout the day (Bent 1963), sampling will be scheduled during daylight hours, preferably within three hours after sunrise to coincide with the period of greatest activity (Bibby *et al.* 2000). Each survey will be conducted for at least 15 minutes following a 5-minute acclimation period. Whenever possible, surveys will be conducted by a team of observers to minimize sampling bias. Sampling frequency will be based on breeding and precipitation cycles. In Florida, most wading bird species nest between January and June (Hancock and Kushlan 1984, Bent 1963), and the wet season runs from June through October (SWFWMD 2000). Therefore, sampling frequency will be highest (weekly or biweekly) from October through June when number of sightings should be greatest due to the nesting season and receding water levels, and lowest (monthly or bimonthly) from June through October when prey becomes less concentrated, the number of available foraging sites increases, and birds become more dispersed to minimize competition. Finally, to maximize using these birds as biological indicators, data must extend beyond a single breeding season both to improve accuracy and consistency in survey methods and to quantify and mitigate disruptive effects of observation on individual behavior (Custer and Osborn 1977). Therefore, data will be collected for two years, which should be sufficient to determine the distribution and abundance of species, population trends and the impact of management activities (Haig *et al*. 1998).

Bird Observations (Reference Sites)

A feasibility study using infrared, motion-triggered wildlife cameras (Figure 2) is planned to assess their usefulness in collecting additional capture data and determine the best time of day for observations. Manual observations can be time-consuming and expensive since repeat visits are required to assess the presence and abundance of wading birds at the sampling sites.

Proposed sampling sites are between 15 and 70 miles round-trip from the starting point of the University of South Florida in Tampa. The proposed sampling frequency would entail driving approximately 200 miles per week, which roughly translates to $2,600/yr at current fuel prices. In addition, collecting data for 15 minutes from 23 stations translates to nearly 6 hours of observation time and over 4 hours travel time to and between sites per week. Also, the approach of an observer may disturb foraging or resting birds that may then leave the site prior to the start of observation, resulting in the loss of valuable information (Towerton *et al.* 2008).

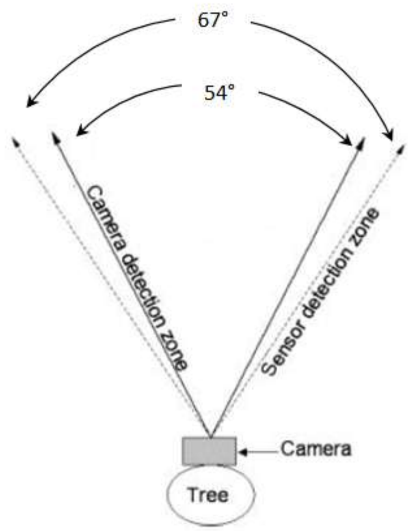

Figure 2. Proposed camera setup attached to tree or post, showing detection zones of the infrared sensor and camera field of view. Image modified from Towerton *et al*. 2006.

Infrared, motion-triggered digital cameras offer an alternative for long-term observations to be collected with minimal cost ($100-500 per unit) and effort (data retrieval takes minutes per site and batteries can last for weeks). Date and time of bird visits are recorded within the image file, providing a record of both common and cryptic fauna that are otherwise not easily surveyed (Towerton *et al*. 2006). Furthermore, maximum image resolution and post-processing techniques enhance the ability to identify individuals (Claridge *et al.* 2004), providing a means to estimate abundance (O'Brien and Kinnaird 2008) as well as site fidelity.

Camera trapping samples a finite area over a period of time limited only by battery life and camera integrity. Remote camera trapping is also limited by the visual detection range of the camera (a few meters). Point count surveys are typically time-limited but are able to capture data from a larger sampling radius (125 to 250 m). As previously mentioned, however, point counts are more labor-intensive and disruptive to wildlife than camera trapping. Additionally, in point count surveys, it can be difficult to identify the number of unique individuals observed (O'Brien and Kinnaird 2008). Camera trap studies, by comparison, can be regarded as point count sampling of terrestrial species. In both cases, however, recognition of individuals can be difficult, and data can be sparse, containing many low or zero counts. Bias in abundance estimates typically occurs for species with low detection probabilities and when too few sites are sampled (O'Brien and Kinnaird 2008). Therefore, 100 points must be sampled at least 10 times to yield practical estimates of point abundance for species with low detection probabilities, but for species with greater detection probabilities, five replicates may suffice (Royle and Nichols 2003). Fortunately, temporal replication in camera trap surveys requires relatively little effort.

In the absence of, or in addition to, remote camera trapping, point count data (specifically, species identification and abundance) will be collected at regular intervals from predetermined sampling stations (*sensu* Ralph *et al.* 1993 and Manley *et al.* 2006) within sampling sites of 10 acres or less to maximize viewing opportunities. Since the goal is to estimate population trends for a specific management unit (in this case, isolated freshwater marshes), point counts shall be located within each sampling unit (Ralph *et al*. 1993). More than 99 percent of individuals can be detected within 125m of the observer; in open environments such as marshes, this minimum distance can be increased due to the increased ability to visually detect birds (Ralph *et al*. 1993). Therefore, where applicable, point count radii may be doubled.

Statistical Analysis (Reference Sites)

Bird and hydrology data will be statistically analyzed in a manner which will aid in comparison of the current isolated wetland data with those of the Everglades. Additional analyses may include frequency distributions, analysis of variance methods, principle component analysis, Spearman's correlations, linear regression, and multivariate regression analysis.

Site Selection (Urban-Rural Gradient)

A pilot study is planned to test the hypothesis that developed areas along the I-4 corridor, an interstate which runs east to west connecting Tampa to Daytona, function as a geographical barrier to migration for wading birds. Marshes within four north-south transects will be selected along the corridor between the I-75 junction and US-27 (two each through rural and urban areas) to characterize the distribution of wading birds on either side of the corridor. Most of the I-4 corridor is highly developed, with the exception of the eastern portion of the area of interest (Figure 3) that lies east of SR-33, west of US-27, south of CR-474 (in Lake County) and north of SR-60. This portion is comprised of parcels of the Green Swamp Land Authority (GSLA) and the Hilochee Wildlife Management Area (WMA).

The mosaic of swamps, pastures and flatwoods that comprise the Green Swamp are vital to central Florida's water supply due to connectivity to the Floridan Aquifer and four major river systems (SWFWMD website, 2012). Hilochee WMA is popular for bass fishing and supports breeding populations of several species of egrets and herons year-round

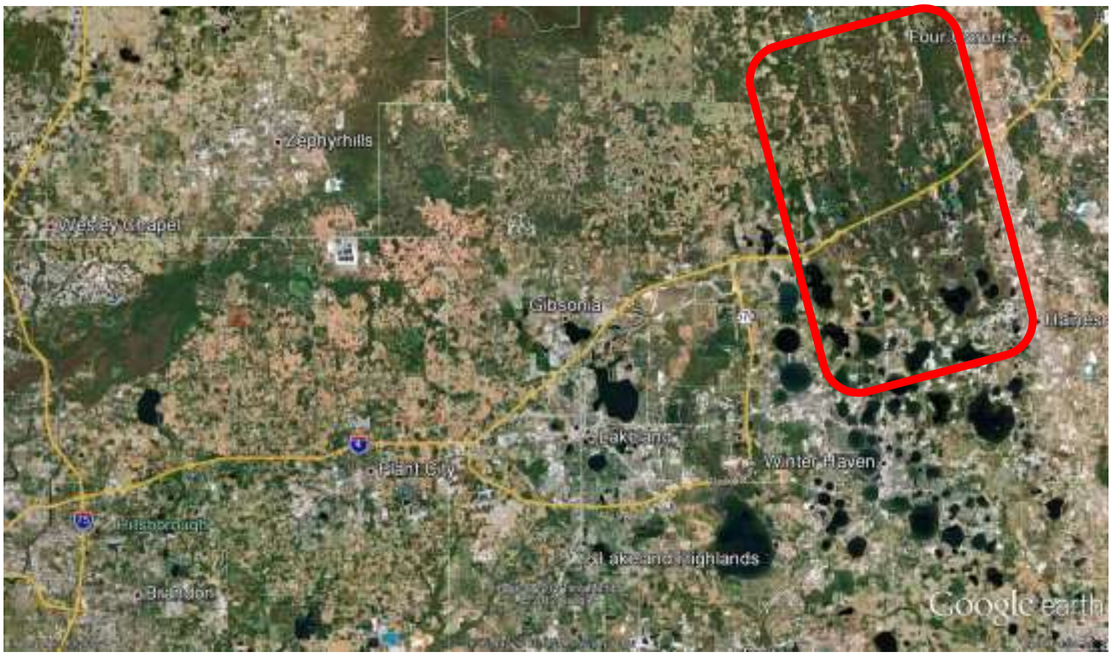

Figure 3. Satellite image of the I-4 corridor, an east-west interstate highway that connects Tampa to the northeast Florida coast; portion shown extends across Hillsborough and Polk Counties to Osceola County. Red outline indicates undeveloped land comprising portions of Green Swamp and the Osprey Unit of Hilochee Wildlife Management Area. Image Source: Google Earth 2012.

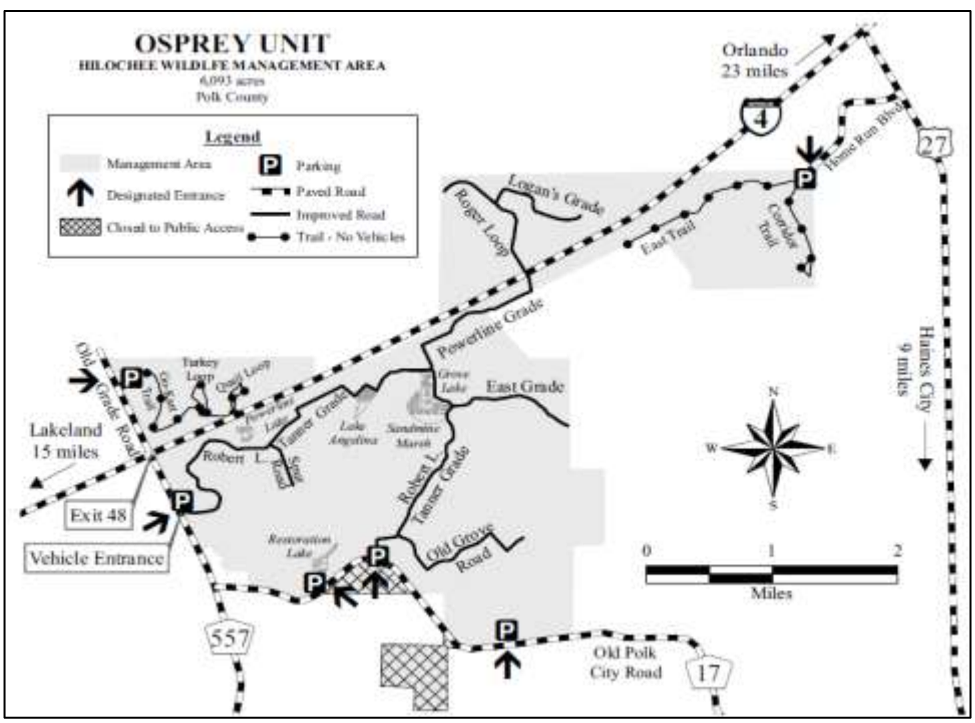

Figure 4. Osprey Unit of Hilochee WMA showing four potential sampling locations: Powerline Lake, Lake Angelina, Sandmine Marsh, and Restoration Lake. Image Source: myfwc.com.

(http://myfwc.com/media/304976/Hilochee_birdlist.pdf). The southern Osprey Unit (Figure 4) lies directly adjacent to I-4. The northern portion of the WMA (Figure 6) crosses into Lake County. In addition to sampling transects along the I-4 corridor, marshes along transects extending from Tampa's city center radially outward to surrounding suburban and rural areas (Figure 7) will be sampled to characterize wading bird distribution along an urban-rural gradient. A minimum of four marshes along each of four transects will be sampled for the pilot study, followed by 48 sites (Figure 5) for both the Tampa urbanization study (two to the north and two to the east) and I-4 corridor study (two each through less and more developed areas along the corridor).

Sampling Schedule (Urban-Rural Gradient)

For both the Tampa urbanization and I-4 corridor studies, a study period of one year (January through December) is proposed to encompass one full breeding season, as well as the wet and dry season. Since most encounters are diurnal species that tend to forage throughout the day (Bent 1963), sampling will be scheduled during daylight hours, preferably within three hours after sunrise to coincide with the period of greatest activity (Bibby *et al.* 2000). Each survey will be conducted for at least 15 minutes following a 5-minute acclimation period. Whenever possible, surveys will be conducted by a team of observers to minimize sampling bias.

Methods Pertaining to Specific Hypotheses

Hydroperiod: It is hypothesized that hydroperiod alone will have no significant effect on wading bird utilization (*i.e*., species presence and relative abundance) since these birds assess foraging sites in their migration corridors on a daily basis; rather, utilization is expected to vary temporally with hydroperiod, with birds exploiting sites with short hydroperiods early in the dry season, as drawdown concentrates prey, and increasingly exploiting sites with longer hydroperiods as the dry season progresses. To address this hypothesis, historical hydrologic data will be compiled for the selected sites; current water level data will be collected using on-site instrumentation (*i.e*., staff gauges and piezometers) or meter sticks during each point count event. Hydroperiod will be determined by calculating the number of days per year that water levels were above ground surface elevation at the deepest point in each site. These results will then be compared to point count data and statistically analyzed using analysis of variance methods, frequency distributions, and multiple regression techniques to determine if wading bird distribution can be predicted by hydroperiod.

Structural Complexity: It is hypothesized that wetland size and hydroperiod will be positively correlated at sites for which water level is not actively managed, and that wading bird utilization (*i.e.*, species presence and relative abundance) will increase with (1) increased available aquatic habitat (*e.g.*, delineated wetland size, bathymetric variation, and number and size of microsites within each wetland), and (2) increased shoreline convolution due to increased surface area of the littoral zone. Wading bird species found within smaller sites are expected to be a subset of those found in larger sites.

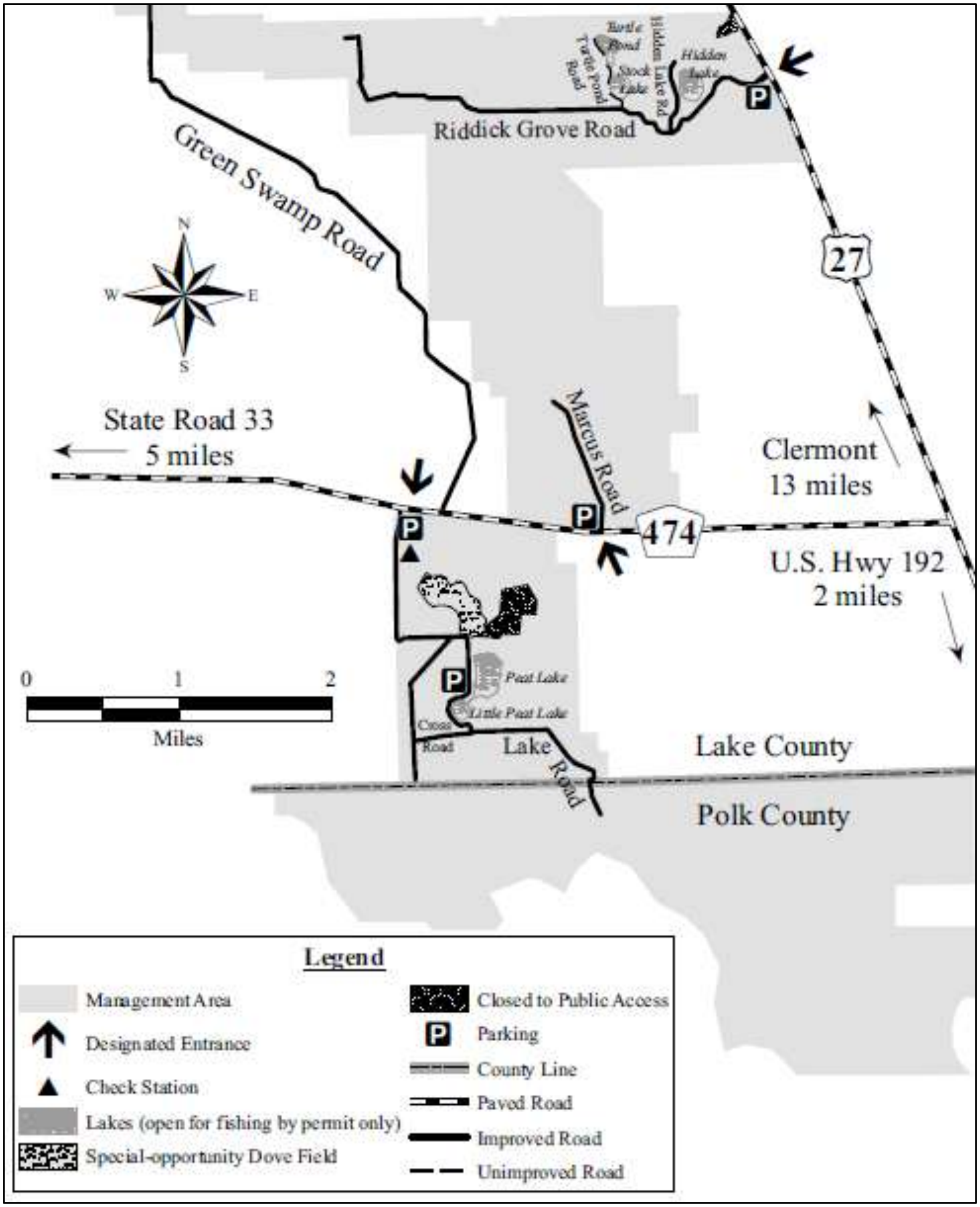

Figure 6. Map of northern portion of Hilochee WMA showing five potential sampling sites: Peat Lake, Little Peak Lake, Turtle Pond, Stock Lake, and Hidden Lake. Image Source: myfwc.com.

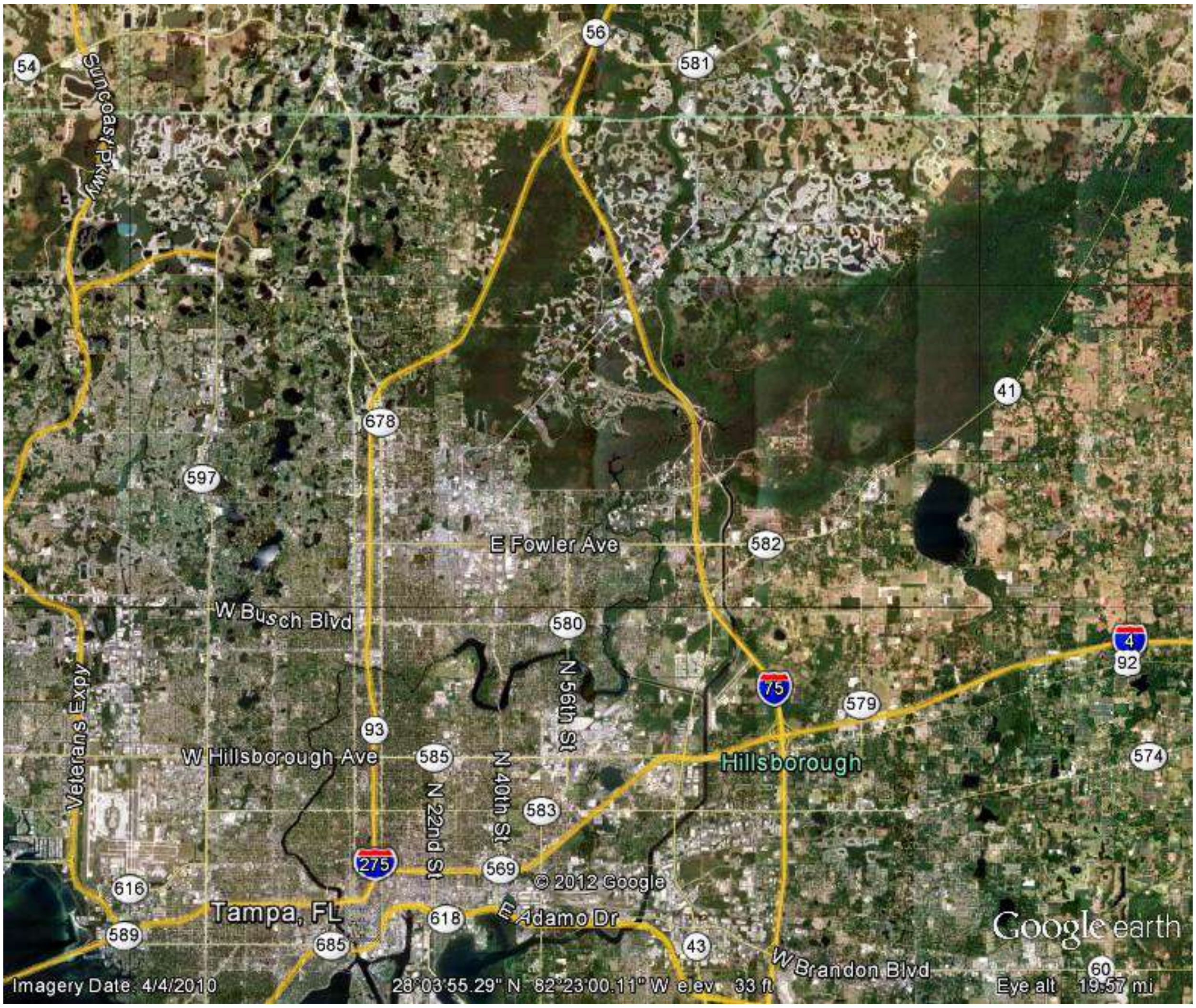

Figure 7. Satellite image of Tampa, Florida and surrounding suburban and rural areas to the north and east. Image Source: Google Earth 2012.

Wading bird distribution in the Everglades is dependent on water depth and vegetation composition and density. Bancroft *et al.* (2002) collected bird data via aerial flight surveys, water levels via modeling, and vegetation data through remote sensing in 1-km^2 (100 ha) grid cells within Water Conservation Areas 1 and 2A, while Lantz *et al.* (2010) used an experimental approach that included two treatments of water depth and three treatments of vegetation density in 100-m^2 (0.01 ha) outdoor enclosures constructed in Water Conservation Area 1. Due to the scale and geographic layout of the proposed study, however, all data will be collected using ground survey techniques in sites 20-ha or smaller.

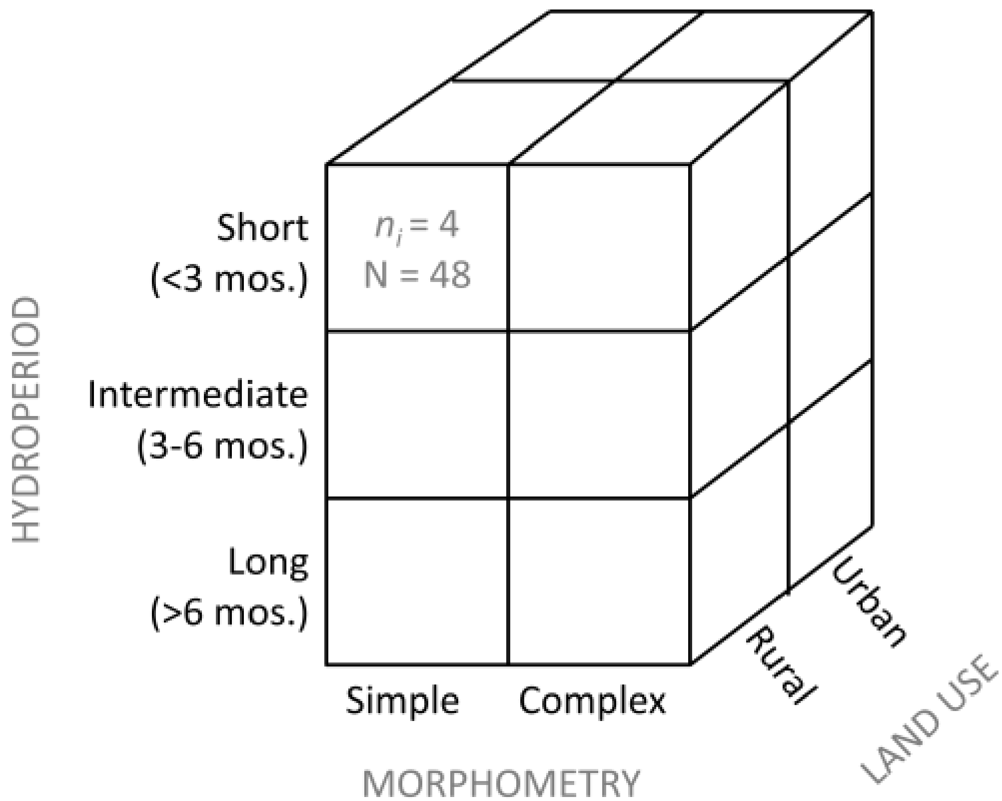

Figure 8. Cartoon illustrating representative sampling design. Target replicate n = 4 for each treatment.

Individuals observed will be identified to species and counted to estimate abundance at sampling stations (*sensu* Ralph *et al*. 1993 and Manley *et al*. 2006) within sampling sites of 20-ha or less (to maximize detectability). Data will be statistically analyzed in a manner comparable to Bancroft *et al.* (2002) and Lantz *et al.* (2010) to aid in comparison of data with that of the Everglades, including frequency distributions, analysis of variance methods, indices of diversity and similarity, and multiple regression techniques.

Additionally, it is expected that wading bird utilization (*i.e.*, species presence and relative abundance) will increase (1) at sites with increased microsite rugosity as the dry season progresses, since decreased water levels lead to increased prey availability despite greater structural complexity of the substrate (Flecker and Allan 1984; Diehl 1988), and (2) during the dry season at sites with increased bathymetric heterogeneity because, as water levels decrease over the dry season, sites with more uniform bottom topography will have fewer pools available to exploit.

To address these questions, the bottom topography of each wetland will be determined, along with estimates of rugosity at microsites within each wetland. First, using GPS and GIS, the shoreline of each site will be mapped throughout the dry season and related to water level.

Alternatively, it may be possible to use optical remote sensing data (LiDAR) to create digital elevation models (DEM) of each site. These DEMs can be converted to elevation contours and calibrated by comparing to contours generated by physically mapping the shoreline across the dry-down period. From these data, a plan-view contour elevation map and hypsographic (area-altitude) curves can be generated for each site. Hypsographic curves use dimensionless parameters to relate the horizontal cross-sectional area of a basin to elevation relative to a particular datum, allowing them to be described and compared regardless of true scale (Strahler 1952). This technique can also be used to estimate the volume of the basin by calculating the area of the basin that falls below a given datum and integrating the area under the curve. In addition, the relative distribution of benthic-surface area at different depths can be estimated using hypsographic curves (Oertel 2001).

Microtopographic relief is expected to be very subtle (on the order of mm) in these sites. However, substrate surface complexity is strongly correlated to biodiversity in aquatic environments (Friedman *et al.* 2010). For this reason, microsite rugosity will be measured within randomly selected 1-m intervals along 10-m transects using a fine chain (*sensu* Risk 1972) designed to lie along the bottom substrate. Where applicable, microtopography will be determined by classifying points along the 10-m transects as tussock, hollow, or intermediate (Figure 8) and recording the length of each type encountered (*sensu* Chimner and Hart 1996). Elevation of the wetland surface will be measured at 1-m intervals or each significant topographic break (*i.e.*, the top of a tussock or the bottom of a hollow), whichever comes first, using a tape measure or meter stick and a laser level. Tussock height, number of tussocks per unit length, and the sum of spatial distances along a transect between consecutive tussock top and hollow elevations will provide additional measures of microtopographic relief (in cm per m transect).

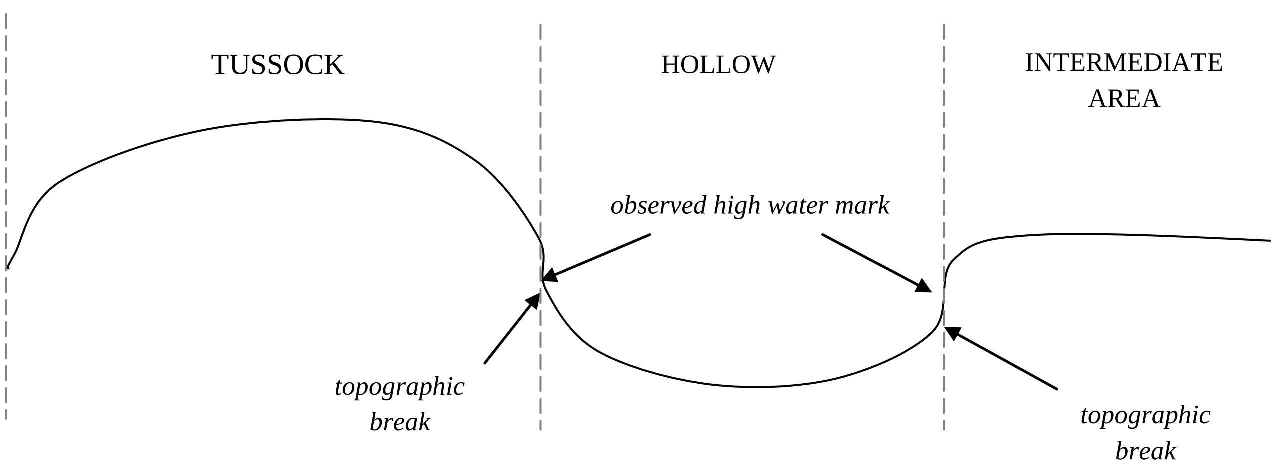

Figure 8. Microtopographic relief classification diagram. Linear distance between topographic breaks measured using high water marks, where applicable. Image source: Chimner and Hart 1996.

These data will be compared to point count data and statistically analyzed using analysis of variance techniques to determine the degree of variability within and between sites; other techniques such as multiple regression and frequency distributions will be used to determine if the degree of microtopographic variability can be used to predict wading bird abundance, and *vice versa*.

Landscape Components: This portion of the dissertation will deal with landscape structure (spatial extent and distribution of resources) and connectivity (functional relationships among patches in response to structure). These aspects are frequently devalued by wetland managers and conservation planners (With *et al.* 1997). Wading bird abundance is expected to increase with increasing distance from urban centers and decreasing distance from nearby aquatic habitat. Species composition is expected to vary between urban and rural sites, and species diversity should be highest at sites that experience disturbance at intermediate temporal or spatial scales. To test the hypothesis that developed areas along the I-4 function as a geographical barrier to dispersal for wading birds, marshes within at least 4 north-south transects will be selected along the corridor between the I-75 junction and US-27 (two each through rural and urban areas) to characterize the distribution of wading birds on either side of the corridor. Using GIS, land use surrounding each sampling site, rural or urban, will be determined and analyzed against bird data. Distances between aquatic habitats and urban centers will be calculated and compared to bird data as well. Data will be statistically analyzed using regression models and other techniques to determine if landscape variables can predict wading bird abundance or species presence.

EXPECTED OUTPUTS

This dissertation can be organized into four distinct chapters, each dealing with a particular aspect of this study:

1. Effect of Scale on Wading Bird Utilization of Isolated Freshwater Marshes
2. Does Hydroperiod Affect Wading Bird Utilization of Isolated Freshwater Marshes?
3. Effect of Structural Complexity on Wading Bird Utilization of Isolated Freshwater Marshes
4. Effect of Landscape Composition and Configuration on Wading Bird Utilization of Isolated Freshwater Marshes

Since many variables comprise this study, several publications may result from the proposed project. Prospective forums for publication include semiannual *Ardea* (Impact Factor = 0.473), *The Journal of Wildlife Management* (1.555) which is published eight times per year, or quarterly journals such as *Ibis* (2.295), *The Auk* (1.807), *The Condor* (1.290), *Wetlands* (1.238), *Journal of Field Ornithology* (0.849), *Waterbirds* (0.575), or the *Journal of Freshwater Ecology* (0.438). The following publications are potential outcomes of this study:

1. "Spatial and Temporal Variability of Wading Bird Utilization of Isolated Freshwater Marshes"
2. "Wading Bird Distribution Along a Hydrologic Gradient"
3. "Effect of Habitat Complexity on Wading Bird Utilization"
4. "Landscape Variables Affecting Wading Bird Utilization of Isolated Freshwater Marshes"
5. "Does Wading Bird Diversity Along a Hydrologic or Urbanization Gradient Support the Intermediate Disturbance Hypothesis?"
6. "Using the Theory of Island Biogeography to Explain Wading Bird Diversity in Isolated Freshwater Marshes"

TIMELINE

Summer & Fall 2011 - Site selection & historical data compilation

Summer 2012 through Spring 2015 - Field surveys (3 years)

One-Time Only

1. Site bathymetry (toward the end of dry season)
2. Pilot study along I-4 corridor

Weekly

3. Bird presence/abundance (P/A) at rural sites (2 yrs, Nov – May)

Monthly

4. P/A surveys at rural sites (2yrs, May – Nov)
5. P/A surveys at urban/periurban sites in Tampa and along I-4 corridor (1 yr, Jan – Dec)

Fall 2014 to Spring 2015 - Data analysis

2015 – Work on Manuscripts

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