Wood Stork Use of Roadway Corridor Features in South Florida

Final Report

March 2017

Principal Investigator: Dale E. Gawlik
Investigator: Jessica A. Klassen
PhD Student: Betsy A. Evans
Collaborators: Wendy Cyriacks (CECOS) and Andy Gottlieb (CECOS)

Department of Biological Sciences
Florida Atlantic University
777 Glades Road
Boca Raton, FL 33431
dgawlik@fau.edu
Office (561) 297-3333, Fax (561) 297-2749

Contract #BDV27-977-02
Submitted to The Florida Department of Transportation
Project Manager: Fernando Ascanio
Email: Fernando.Ascanio@dot.state.fl.us
Office: (954) 777-4325

Disclaimer

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

Metric conversion table

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T

*Adapted from the Federal Highway Administration at http://www.fhwa.dot.gov/aaa/metricp.htm

Technical report documentation

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Wood Stork Use of Roadway Corridor Features in South Florida		5. Report Date March 2017 6. Performing Organization Code
7. Author(s) Dale E. Gawlik, Jessica A. Klassen, Betsy A. Evans, Wendy Cyriacks, & Andy Gottlieb		8. Performing Organization Report No.
9. Performing Organization Name and Address Florida Atlantic University 777 Glades Road Boca Raton, FL 33431		10. Work Unit No. (TRAIS) 11. Contract or Grant No. BDV27-977-02
12. Sponsoring Agency Name and Address Florida Department of Transportation 605 Suwannee Street, MS 30 Tallahassee, FL 32399		13. Type of Report and Period Covered Draft Final February 2014 – May 2016 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

We conducted a three-year study to determine (1) features of corridors and neighboring natural areas that are preferred and avoided by wood storks based on monthly aerial surveys and bimonthly roadway surveys of storks in corridors and adjacent natural areas; (2) biomass and community structure of aquatic fauna (stork prey) produced in corridor features and natural marsh based on samples taken monthly using throw-traps and minnow traps; and (3) the portion of the fish community in corridors that is considered stork prey based on a comparison between food samples regurgitated by nestling storks and samples of the available aquatic fauna in roadways and natural marshes. We found that storks were more likely to use canals and permanently inundated ponds than they were to use swales, ephemeral ponds, and natural marshes within 500 m of the roadway. Furthermore, we found that stork prey production in permanently inundated ponds and canals increased with decreasing slope and increasing urban cover type. In contrast, prey production in ephemeral features increased with steeper slopes. The diet study showed that storks ate fish that were more similar to prey communities found within permanently inundated ponds and canals than to prey in the natural marsh. If FDOT wants to discourage stork use of roadways, then canals and permanently inundated ponds should have steep slopes to discourage stork foraging and reduce prey production. Swales and ephemeral ponds should have shallow slopes to reduce prey production and should be designed to drain water quickly to discourage stork use.

17. Key Word	18. Distribution Statement
Wood Stork, roadway corridor features, stormwater pond, canal, swale	No restrictions.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	110	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Executive summary

Use of roadway water features (swales, canals, and stormwater ponds) by Wood Storks (hereafter referred to as "storks") and the degree to which these features produce stork prey was previously unknown but relevant to the Florida Department of Transportation (FDOT) because the agency is required to mitigate for wetland habitat impacts created by roadway building and stormwater treatment facilities, as required under Section 404 of the Clean Water Act. Roadway developments may impact natural wetlands or impact-related drainage features in existing roadways. Because wetlands and drainage features can both provide habitat for storks, separate mitigation for each is often required under Section 7 of the Endangered Species Act. Within this broad regulatory framework, there are at least three ways FDOT can use information on the use of roadway features by storks and on their corresponding value for stork prey production: (1) knowledge of roadway features to which storks are attracted or which they avoid could be used to refine mitigation; (2) the degree to which corridors and adjacent wetlands produce food for storks could be used to refine mitigation calculations; and (3) knowing what portion of the fish community is actually consumed by storks would allow for a refinement of the Suitable Wood Stork Biomass calculation used by the U.S. Fish and Wildlife Service (USFWS).

Here we describe a study of Wood Stork use of roadway features in South Florida conducted from February 2014 to May 2016. The study had three main components, each with a separate objective and methodology. (1) The objective of the first component (storks and roadway corridor features) was to determine the features of corridors and neighboring natural areas that are preferred or avoided by storks. This was conducted through monthly aerial surveys, bimonthly roadway surveys of storks in corridors and adjacent natural areas, and the characterization of the morphology and plant community structure of water features. (2) The objective of the second component (stork prey production in roadway corridor features) was to determine the biomass and community structure of aquatic fauna produced in three corridor features (swales, stormwater ponds, canals) and adjacent natural marsh. Sites were sampled monthly to account for the ephemeral patterns of standing water in many features. (3) The third objective (stork prey) was to determine what portion of the overall fish community in corridors should be considered as stork prey. This portion was conducted by collecting food samples regurgitated by nestling storks and comparing these prey samples to samples of the available fish and crayfish community in roadways and natural marshes.

For the first component (storks and roadway corridor features), we created resource selection functions to determine probability of stork use of roadway corridor features. We found that storks used roadway corridor features in South Florida primarily from January to June, corresponding with stork breeding season. Additionally, we did not observe a difference in age classes of storks using roadway features, suggesting that there isn't a particular cohort of storks (i.e., juveniles or adults) that forage strictly in

Stork use of roadway corridors

- Storks were least likely to use swales; however, when they did use swales, it was most likely to be in the dry season.
- Storks were more likely to use ephemeral stormwater ponds in the dry season than the wet season.
- Canals and permanently inundated stormwater ponds were the most likely to be used by storks.
- Natural marshes along roadways had a low overall probability of use by storks.

constructed wetlands. Stork use of roadway feature sites varied between ephemeral (swales and ephemeral ponds that are dry part of the year) and permanently inundated sites (canals and ponds that are inundated all year) with storks having a higher probability of use of permanently inundated stormwater ponds and canals over ephemeral swales and stormwater ponds. For ephemeral features, there was a higher probability of use during the breeding season, likely because energy demands are high while raising young, and dynamic water levels in the natural system periodically reduce quality (accessibility of prey) of natural foraging habitat. Overall, permanently inundated feature sites had a high probability of use regardless of site characteristic parameters measured. Permanently inundated roadway features are continuously wet whereas natural marshes fluctuate between wet and dry conditions. Furthermore, canals have open edges for foraging where fish seek refuge from deep water predators and have potentially high secondary productivity from nutrient subsidies. Natural marshes can produce exceedingly high densities of available prey for storks under certain hydrologic regimes, which is thought to control the size of stork nesting populations. But given that marsh water levels fluctuate between wet and dry periods, the anthropogenic water features may at times provide wading birds with more predictable, albeit possibly lower quality habitat.

For the second component (stork prey production in roadway corridor features), we used an information-theoretic approach to investigate competing predictive models for stork prey production in roadway features. We found that stork prey production in permanently inundated features was influenced by slope, water depth, and landscape cover type. Canals and permanently inundated ponds with more shallow slopes resulted in a higher production of stork prey whereas swales and ephemeral ponds with steeper slopes had higher prey production. Landscape cover type was important in that roadside features (stormwater ponds and canals) in the urban cover type had a higher overall production of fish when compared to features in natural landscapes (i.e., forested and herbaceous marsh features along I-75/Alligator Alley). A larger part of the fish production of urban roadway features when compared to the natural landscape roadway features comprised exotic cichlids.

Factors that increased stork prey production in roadway features

- Canals and permanently inundated stormwater ponds
    - Shallow slopes
    - Shallow water depth
    - Urban landscape cover type
- Ephemeral stormwater ponds and swales
    - Steep slopes
    - Low rainfall

There were also features that did not produce any stork prey and therefore should not be viewed as stork habitat. These features consisted of “dry” swales that did not hold water during the study period. These areas included four “dry swales” in the urban and forested marsh landscape types. Furthermore, swales in urban areas met original stormwater design criteria and were more likely to drain water than were swales in the forested/herbaceous marshes along I-75/Alligator Alley, which were more likely to hold water and produce stork prey. Additionally, there were forested marsh swales that were wet for multiple months due to direct connections to canals. If there is an interest in discouraging stork use of swales, one simple design feature is to have them drain water quickly to prevent fish production.

Stork prey

- Stork diet samples are significantly different from natural marsh prey communities.
- Stork diet samples are more similar to prey communities found in large stormwater ponds and canals.
- There was a high occurrence of large-bodied and exotic prey within stork diet samples and permanently inundated corridor features.

For the third component (stork prey), we found that storks are consuming prey that are larger than what is generally available in the natural Everglades landscape. Additionally, we found that storks are consuming exotic prey species, which have become more prevalent in South Florida since the 1950s. The vast system of canals throughout the Everglades has facilitated the spread of exotic fish from the urban landscape into the more natural landscape. Long hydroperiod areas, like canals and stormwater ponds have a higher abundance of larger prey species (i.e. sunfish and exotic cichlids) than do shorter hydroperiod areas. One place that storks may be finding these prey species is in large stormwater ponds and canals, as these species are rare in the natural landscape during the dry season, particularly the larger size classes consumed by storks. But, without tracking storks to feeding areas, we do not know for certain where they are getting the exotic species.

Information from stork diet analyses and prey production models can be used to improve the USFWS Suitable Wood Stork Biomass calculation and refine mitigation in the following ways: (1) update fish biomass estimates for natural marsh and include roadway feature hydroperiod classes; (2) consider the importance of slope for stork prey production in permanently inundated and ephemeral roadway features; (3) consider importance of landscape cover for prey production in permanently inundated roadway features (urban vs. forested/herbaceous marsh); and (4) update historic stork prey range from species lengths of 1.5 to 9.0 cm to current stork prey range of 2.0 to 11.1 cm.

The U.S. Army Corps of Engineers (USACE) requires wetland mitigation for all wetland and stormwater features that are considered suitable foraging habitat, which includes roadway features like roadside ditches or small ponds. The current calculation uses fish biomass (g/m^2) estimates that are solely based on natural marsh systems; however, impacted areas may include roadway features which have different hydrologic conditions than the natural marsh system. Updated fish biomass estimates for ephemeral and permanently inundated roadway features could change average biomass of the current hydroperiod classes used in the calculation.

Slope influenced stork prey production in roadway features and varied between ephemeral and permanently inundated roadway features. Shallower slopes produced high prey biomass in permanently inundated features and steep slopes produced high prey biomass in ephemeral features. For permanently inundated features we found that average prey biomass decreased by 26.7% between shallow (0.0-0.20) and moderate slopes (0.21-0.50) and decreased by 44.2%

between shallow and steep slopes (>0.50). For ephemeral feature slopes, we did not have a high variation in sites sampled, so we classified slope into only two categories: shallow (0.0-0.15) and steep (>0.16). Average prey biomass decreased by 37% in the shallow slope features relative to the steep features.

Landscape cover types also influenced stork prey production. Permanently inundated roadway feature sites in the urban landscape produced significantly more stork prey biomass when compared to similar features in the herbaceous and forested marsh areas along I-75/Alligator Alley. Average prey biomass decreased by 22.3% between urban and forested marsh landscape cover types and decreased by 53.8% between urban and herbaceous marsh landscape cover types.

The USFWS currently uses the Suitable Wood Stork Biomass Equation to assess impacted areas for loss of stork prey biomass. The calculation uses biomass estimates from natural wetland habitats only; however, if biomass production was differentiated between roadway features and natural wetlands, it would provide a more precise measure of impacts. This distinction will improve the calculation used to quantify compensatory wetland mitigation of roadway features and natural wetlands that are considered Suitable Foraging Habitat (SFH) by the U.S. Army Corps of Engineers (USACE). We found that some wet roadway features (i.e., permanently inundated ponds and canals) on average produce more stork prey biomass than natural wetlands. However, the spatial extent of the Everglades is much greater than scattered roadway wetlands found throughout South Florida so natural wetlands likely produce more stork prey biomass overall than do roadways. Furthermore, roadway features can produce risks for storks, such as mortality from collisions with vehicles

Given the improved understanding of stork utilization of roadway water features and the improved estimates of prey production, we can make recommendations for roadway feature design that discourages or promotes stork use. As noted in the biomass production data, not all roadway features produce prey at the same rates. If stork use is desired, permanently inundated features should incorporate a shallow slope component (littoral zone or shelf) to improve biomass production. Littoral features not only provide appropriate habitat for prey production but also facilitate foraging.

Although permanently inundated features produce stork prey, the proximity of these features to roadways carries the risk of increased stork mortality. Further study of feature proximity to roadway and the presence or absence of roadway fencing or vegetation effects on mortality could inform future roadway designs. If desired, there is potential to improve access and forage in parts of permanently inundated sites, which could decrease roadway collisions. For example, stork use could be decreased near road edges by expanding littoral zone at the far edge of a water body and reducing it at the near edge. Similarly, wooded habitat on the near edge may minimize utilization attempts and hence collision mortality.

Ephemeral sites generally produce less biomass due to the short-term nature of inundation and thus are not good stork foraging areas. However, swales that do not drain as intended may attract storks during wet periods, partially because natural areas are too deep for foraging while swales are artificially drained and facilitate forage access.

Roadway design applications to discourage stork use

- Canals and permanently wet stormwater ponds should have a steep slope component as this discourages foraging and results in lower prey production.
- Swales and ephemeral stormwater ponds should have shallow slopes as they result in lower stork prey production.
- Swales should be designed to drain water quickly to discourage stork prey production. All dry swales sampled during this project had no stork prey.

In addition to specific feature improvements (maximum depths, managed timing, littoral zone expansion, and actual placement of features), we recognized that not all water features were inundated based on their FAC (Florida Administration Code) definitions. That is, some swales and ephemeral ponds contained standing water for extended periods. This can create confusion because not all "swales" are dry features. For instance, some swales slope in one direction to a canal feature. In some cases, these edges are short to intermediate hydroperiod wetlands rather than "directional water features." Ongoing efforts to clarify water feature definitions (terminology and related characterization) and to consistently evaluate features will improve our understanding of how roadway design features can be used to affect use by wood storks and the production of their prey.

Based on the findings of this study, we have some recommendations for future phases. (1) Stork prey production will likely vary geographically. We found that storks in South Florida used canals and large stormwater ponds more frequently than ephemeral roadway features due partially to the presence of large-bodied and exotic prey. Roadway features in north Florida likely do not have a high percentage of exotic fish species, thus stork use of roadway features could be very different than in South Florida. (2) Stork prey availability in agricultural areas is unknown. We sampled aquatic fauna in roadway corridor features across three landscape cover types (urban, forested marsh, and herbaceous marsh); however, we surveyed storks in four landscape cover types, with the additional landscape cover type of agriculture. We found that storks use irrigation ditches of crop fields, thus aquatic fauna sampling of these areas might identify another source of exotic prey species. (3) We found that storks are consuming prey that is larger than what is generally available in the natural Everglades landscape. When comparing bolus samples to prey communities in roadway features and natural marsh landscape, roadways and bolus samples were the most similar. While stork diet is similar to what is found within roadways, there is still some uncertainty as to where those storks foraged. The addition of satellite transmitters on individual birds would allow us to know the degree to which storks forage in roadway habitat versus habitats far from roads.

Table of contents

List of tables

List of figures

1.0 Introduction and literature review

Currently, there is little information on the use of roadway water features (swales, canals, and stormwater ponds) by Wood Storks (hereafter referred to as "storks") and the degree to which these features produce stork prey. This information is relevant to the Florida Department of Transportation (FDOT) because the agency is required to mitigate for wetland habitat impacts created by roadway building and stormwater treatment facilities, as required under Section 404 of the Clean Water Act. Roadway developments may impact natural wetlands or impact-related drainage features in existing roadways. Because wetlands and drainage features can both provide habitat for storks, separate mitigation for each is often required under Section 7 of the Endangered Species Act. Within this broad regulatory framework, there are at least three ways FDOT can use information on the use of roadway features by storks and on their corresponding value for stork prey production (the term "prey production" here refers to the abundance of prey species in an area due to reproduction and immigration).

First, knowledge of the roadway features to which storks are attracted to or which they avoid could be used to refine mitigation. Drainage features could be designed to discourage use by foraging storks, thereby decreasing the risk of mortality from automobile collisions. Avoidance would be a preferred option where roads pass close to large nesting colonies and juvenile birds are likely to prospect on their own while still clumsy and learning to fly.

Second, the degree to which corridors and adjacent wetlands produce food for storks could be used to refine mitigation calculations. Current estimates of forage fish biomass are based largely on hydroperiod and the density of exotic vegetation, with no regard for connectivity and the relationship of natural marshes with corridor features like stormwater ponds (URS Corporation, 2012). A refinement of the fish biomass estimate in corridors with particular features and surrounding landscapes could produce a very different estimate of the habitat impact or enhancement of corridor projects. An accurate estimate of forage fish and crayfish produced in corridors and surrounding wetlands is critical when mitigation requires that "…habitat compensation replaces the foraging value matching the hydroperiod of the wetlands affected and provides foraging value similar to, or higher than, that of impacted wetlands" as specified in guidelines of section 404 of the Clean Water Act.

Third, knowing what portion of the fish community is actually consumed by storks would allow for a refinement of the Suitable Wood Stork Biomass calculation used by the U.S. Fish and Wildlife Service (USFWS). The current calculation for determining the biomass of forage produced in wetlands (natural or corridor features) does not distinguish stork preferences for prey species or sizes (URS Corporation, 2012). This oversight matters little if storks consume all fish present, but the effect increases as the proportion of the overall prey community consumed by storks decreases. Ogden et al. (1976) found that storks were selecting for larger fish later in the nesting season, but less than 20% of marsh fishes are typically greater than 2 cm in size, which is the minimum size preferred by many wading bird species. If 2 cm is a size threshold for storks, then it is likely that most of the focus on mitigation should really be on a relatively few species or size classes.

The project had three components, each corresponding to a justification above and having a separate objective and methodology. (1) The objective of the first component (storks and roadway corridor features) was to determine the features of corridors and neighboring natural areas that are preferred and avoided by storks. This was conducted through monthly aerial surveys, bimonthly roadway surveys of storks in corridors and adjacent natural areas, and the characterization of the morphology and plant community structure of water features. (2) The objective of the second component (stork prey production in roadway corridor features) was to determine the biomass and community structure of aquatic fauna produced in three corridor features (swales, stormwater ponds, canals) and adjacent natural marsh. Sites were sampled monthly to account for the ephemeral patterns of standing water in many features. (3) The third objective (stork prey) was to determine what portion of the overall fish community in corridors should be considered as stork prey. This portion was conducted by collecting food samples regurgitated by nestling storks and comparing these prey samples to samples of the available fish and crayfish community in roadways and natural marshes.

2.0 Methods

2.1 Field methods

2.1.1 Storks and roadway corridor features

We conducted aerial surveys each month from February 2014 to May 2016 along the aerial survey route (Fig. 2-1). The aerial survey route was selected based on the location of major roadways of interest to FDOT (i.e., I-75, Florida Turnpike), location of landscape cover types (i.e., natural marsh and urban), and restricted flight zones. The direction of flight was determined randomly on the first flight and was alternated from north to south on each subsequent flight to reduce directional bias. We conducted aerial surveys at an altitude of 150 to 300 m and at a speed of 100 knots. When surveying, one observer faced the road and observed the roadway corridor including 500 m of adjacent habitat, while the other observer viewed 500 m of the surrounding habitat from the opposite side of the plane. Each time we detected a stork along the survey route, we circled its location. For each flock, we assigned a unique ID, recorded its location with a GPS unit, and took photos. We noted the flock size and species composition and determined whether the birds were roosting, foraging, nesting, or resting. We classified the feature type of the flock location as swale, canal, irrigation ditch, stormwater pond (ephemeral or permanently inundated), natural marsh, or upland habitat (see Appendix E for specific definitions). We recorded the landscape cover type of each stork location as agricultural, urban, forested marsh, or herbaceous marsh. We classified the vegetation structure of the location as mowed or natural (i.e., unmowed). We noted the slope gradient at each location and classified it as shallow, moderate, or steep. It is important to note that slope measurements were taken from aerial surveys, and thus are course measurements, and not directly related to the littoral width of the feature.

After each flight, we entered stork flock location and information into Microsoft Excel and ArcMap for data storage. Since some spatial error can occur when collecting flock locations from the air, we compared downloaded flock points on aerial imagery to photographs of flocks taken in-flight. If a flock location point on aerial imagery did not match those of the in-flight photographs, we moved the flock point to match the in-flight photographs, ensuring correct flock location in landscape and roadway featuresWe were unable to conduct aerial surveys from August to November 2015 because our charter aircraft company abruptly and unexpectedly went out of business. Few aviation charters have the requisite experience with specialized low-level wildlife surveys, so it took several months to find a suitable alternate company. However, we did find a new company and resumed flights in December 2015, consequently aerial surveys were extended through May 2016 to compensate for the missed surveys in 2015.

We added road surveys in September 2014 to increase the sample size of storks observed because we were concerned that observations from only aerial surveys would not allow for robust habitat models. We selected the road survey route to include more of the urban landscape cover type and to cover more of the major roadways along the east coast urban corridor (Fig. 2-2), which was constrained to some extent by airspace restrictions. Additionally, the road survey extended north of the Southern Blvd transect, thereby incorporating areas closer to north Palm Beach County stork colonies. We conducted road surveys bi-monthly from September 2014 to May 2016 along the road survey route. We determined the direction of the road survey randomly on the first survey and alternated the route from north to south on each subsequent survey to reduce directional bias. Consequently, we surveyed each side of the road right of way each month. We conducted road surveys at a speed of 60 mph, with the passenger surveying the right-side of the roadway corridor during each survey. Each time we detected a stork, we pulled over, took photos, and assigned a unique ID and recorded its location with a GPS unit. We noted the flock size, age, and species composition and determined whether the birds were roosting, foraging, or resting. We classified the feature type of the flock location as swale, canal, irrigation ditch, pond, natural marsh, or upland habitat. We classified the vegetation structure of the location as mowed or tall. We noted the slope gradient at each location and classified it as shallow, moderate, or steep.

After surveys, rainfall and hydrology data were collected as precipitation influences the availability of potential prey within roadway features and natural wetlands. Hydrologic data was obtained from the South Florida Water Management District which provides rainfall data based on Next Generation Radar (NEXRAD) from the U. S. National Weather Service. Data is received every 15 minutes continuously on a 2 km x 2 km grid resolution. Vegetation data was collected from the Florida Vegetation and Land Cover 2004 (FFWCC, 2004). The vegetation map uses Landsat Thematic Mapper satellite imagery and is categorized into 43 vegetation and land cover types at a 30 m x 30 m resolution. We used the following categories for fine-scale vegetation: high intensity urban (>5 dwelling units per acre), low intensity urban (< 5 dwelling units per acre), forested marsh, agriculture, and herbaceous marsh. We used the Geospatial Modeling Environment extension in ArcGIS 10.3 (ESRI Inc., Redlands, CA, USA) to measure distances between flock locations and nearest colony, wetland, and roadway.

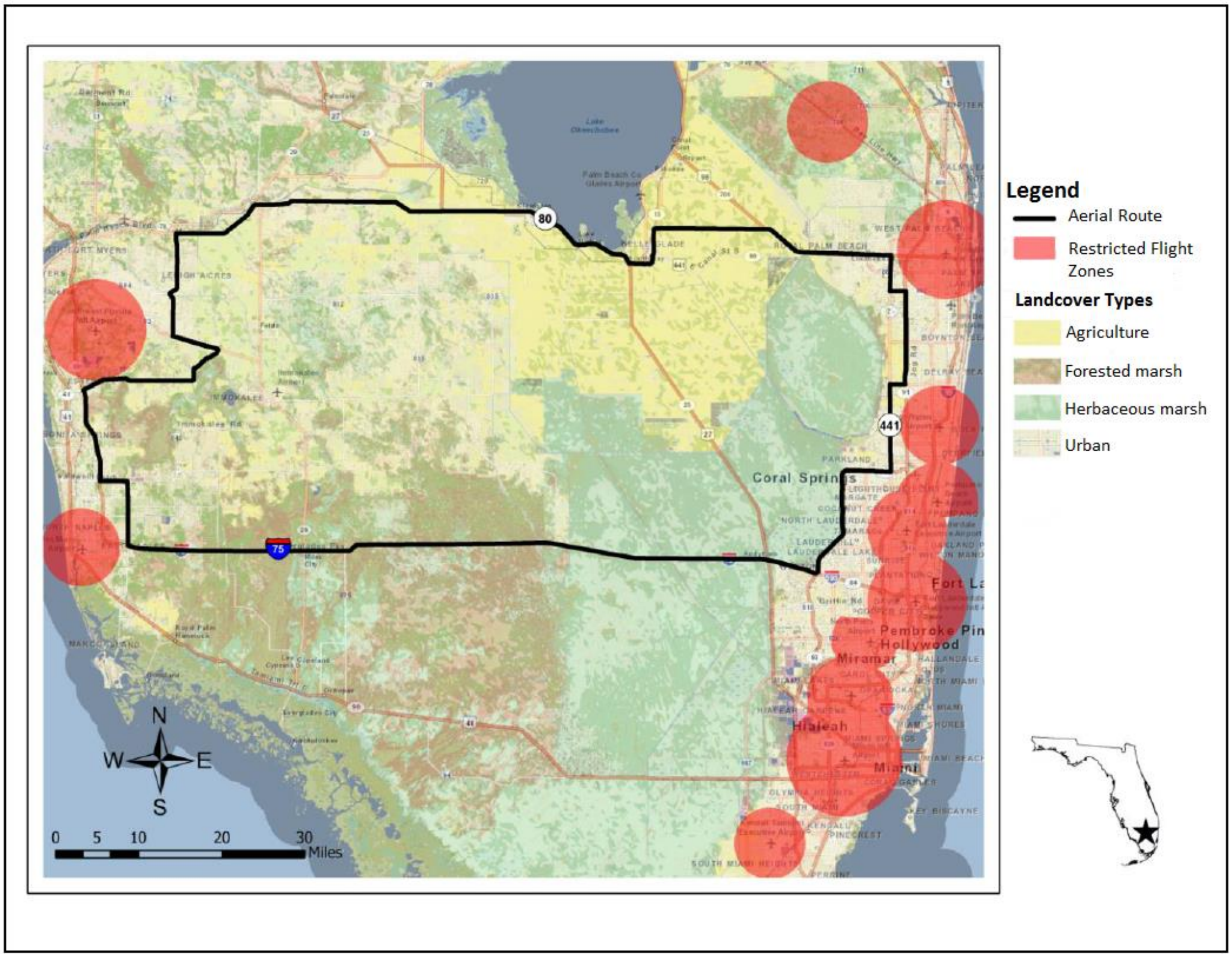

Figure 2-1. Aerial survey route showing restricted fly zones and landscape cover types of South Florida.

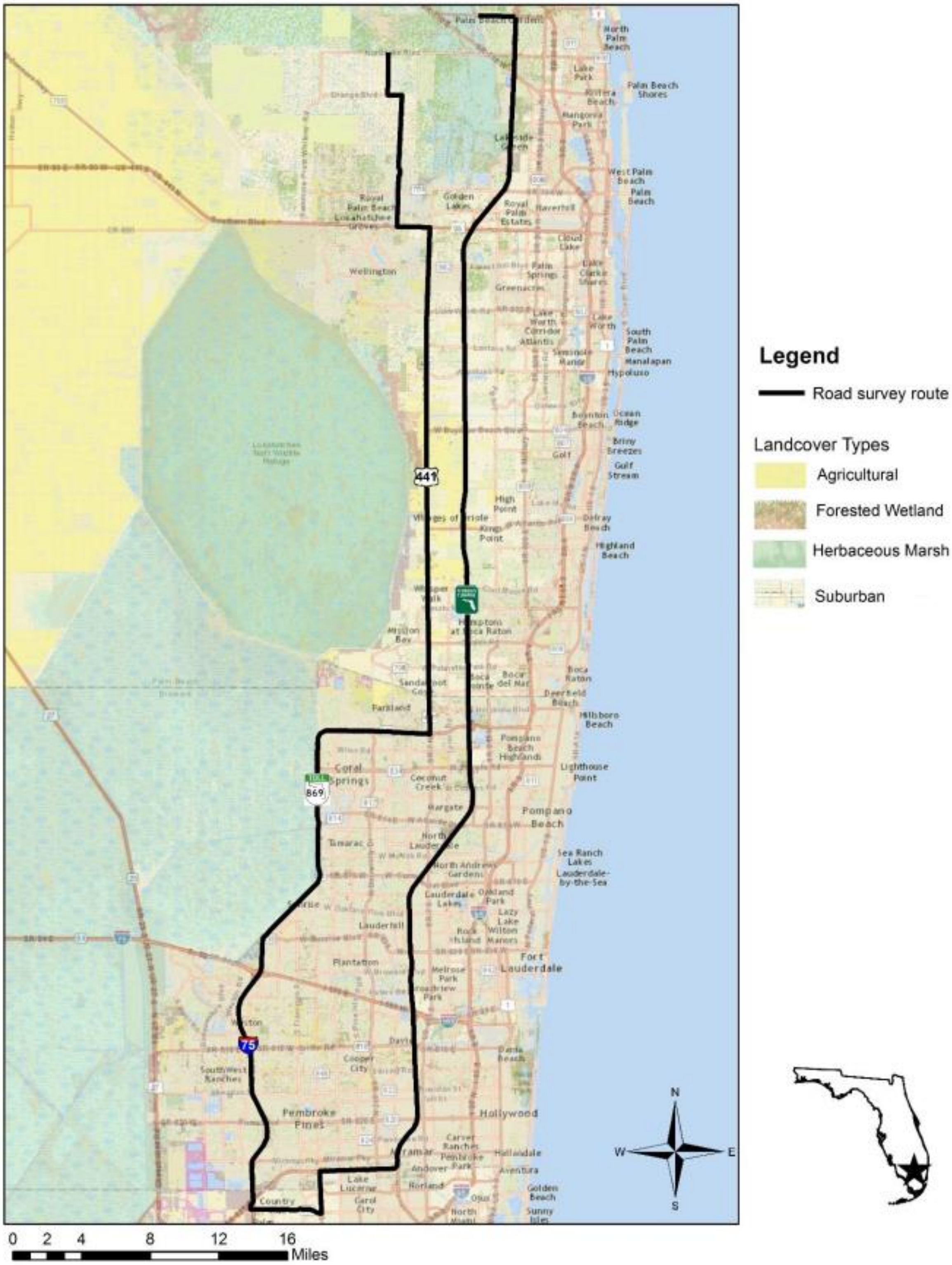

Figure 2-2. Road survey route with landscape cover types of South Florida.

2.1.2 Stork prey production in roadway corridor features

From June 2014 to May 2016, we sampled four roadway corridor features—swales, canals, permanently inundated stormwater ponds, ephemeral stormwater ponds within three landscape cover types (herbaceous marsh, forested marsh, urban) (Fig. 2-3). Irrigation ditches and upland habitats were removed from analyses as we did not sample aquatic fauna in these features or in the agricultural landscape cover type. The fourth landscape cover type, natural marsh, was sampled from March to June 2014, May 2015, and April to June 2016 to correspond with the stork breeding season (Fig. 2-5). Normally we would have collected samples in the natural marsh from February-May each year, but these samples are collected as part of a separate study that had a delayed start date and relied on the start of the dry season. However, we have archived 10 years of samples from the natural marsh from which to draw inferences. The natural marsh landscape cover type serves as a comparison between natural and man-made wetlands and therefore does not have any corridor features.

Permanently inundated site sampling methods – We sampled canals and permanently inundated ponds at three replicate sites within three landscape cover types (herbaceous marsh, forested marsh, urban) resulting in 18 total sites. Within each replicate site, we sampled three sub-sites. To select random sub-site locations within each canal and pond site, one observer stood at the site location and estimated the minimum and maximum bearing and distance that encompassed the site with a compass and rangefinder. We then selected a random bearing and distance that was within the pre-determined ranges with a random number table. The location of the second sub-site was determined by selecting a random distance (≥10 m) from the first sub-site, and the location of the third sub-site was determined by selecting a random distance (≥10 m) from the second sub-site.

After the sub-sites were selected, we sampled aquatic fauna using a modified Gee's G-40 minnow trap. The maximum size of fish that can be caught in a minnow trap is determined by the size of the funnel opening. Since the Gee's G-40 minnow trap opening has a diameter of only 2.54 cm, the traps are biased to the capture of small-bodied fish. As such, we modified the opening of the minnow traps to a 10 cm oval, allowing for the capture of larger bodied fish. At each sub-site, we placed an array of minnow traps set at various distances and depths (Fig. 2-4). For each sub-site we placed a minnow trap at opposite edges of the shoreline to capture fish where storks would most likely forage. In the interior of the pond or canal, we placed three series of equally spaced traps. The number of minnow traps in a series depended on the depth of the canal or pond. For instance, deep canals or ponds (depths > 1.5 meters) consisted of three traps: one just below the water surface, one in the middle, and one resting on the substrate. For intermediate canal or pond depths (1.0 to 1.5 meters), each trap series included two traps: one just below the water surface, and one resting on the substrate. For shallow canal or pond depths (< 1.0 meter), each trap series included only one trap resting on the substrate. At each surface trap, we used a 1-m^2 quadrat to measure emergent and submerged vegetation (Daubenmire, 1959). We estimated percent cover of submerged and emergent vegetation and noted the dominant species at each surface trap.

To allow time for aquatic fauna to enter the traps, we left the minnow traps in place overnight and retrieved them the following day. We transferred captured aquatic fauna <15 cm in total length, directly from the minnow traps to jars containing a solution of water and MS 222, a rapid euthanizing agent. Aquatic fauna >15 cm were identified, measured, weighed, and released. We stored samples on ice for the remainder of the sampling day.

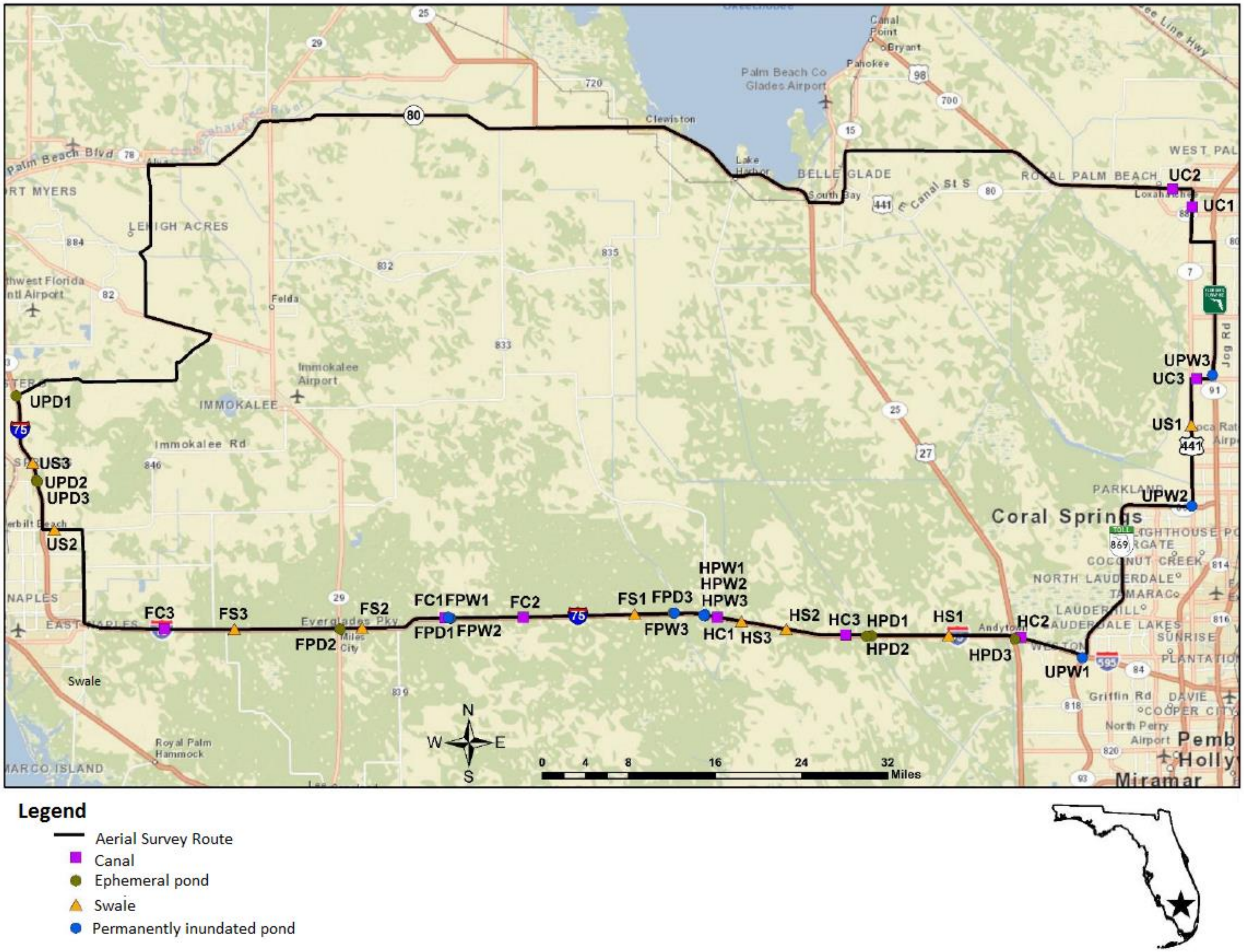

Figure 2-3. Locations of fish sampling sites along roadway corridors in South Florida.

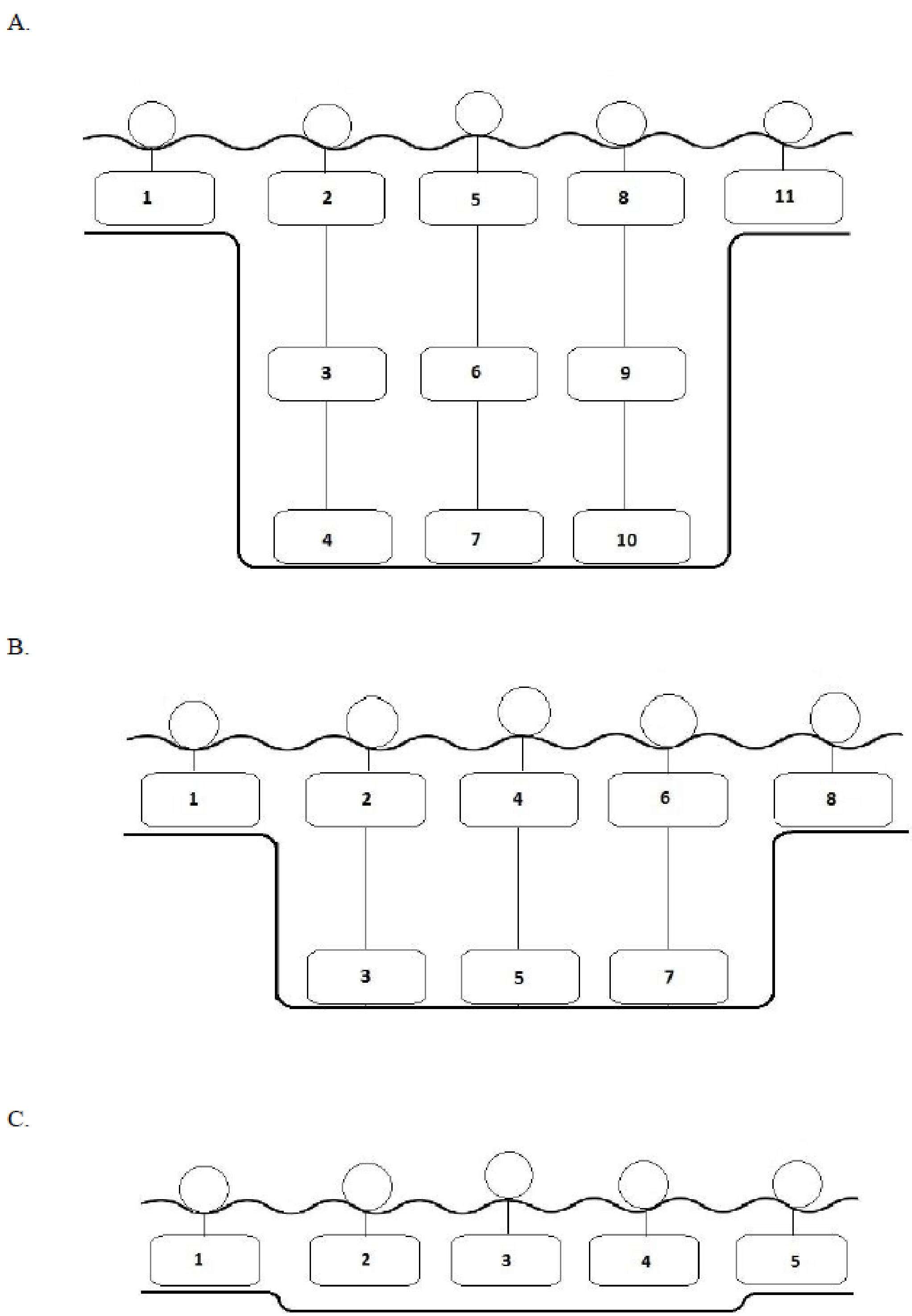

Figure 2-4. Cross-section of minnow trap arrays used to sample fish at canal and permanently inundated pond sites in South Florida. Circles depict floats that are connected via line to the minnow traps, which are depicted as rectangles. A. Sub-site with a depth greater than 1.5 m B. Sub-site with a depth between 1.0 and 1.5 m. C. Sub-site with a depth <1.0 m.

Ephemeral site sampling methods – We sampled swale and ephemeral pond sites with a 1-m^2 throw-trap. A throw-trap is a 1-m^2 box with mesh sides and an open top and bottom that allows sampling of aquatic fauna (Jordan et al., 1998). We sampled swales and ponds at three replicate sites within three landscape cover types (herbaceous marsh, forested marsh, urban) resulting in 18 total sites sampled. Within each site, we sampled three sub-sites for a total of 54 sub-sites sampled.

To select a random throw-trap location within a site, one observer stood at the site location and estimated the minimum and maximum bearing and distance that encompassed the site with a compass and rangefinder. The observer then selected a random bearing and distance that was within the pre-determined ranges from a random number table. Once at the throw-trap location, the observer tossed the throw-trap to the north (standardized direction). If the north direction was outside the range of suitable habitat, then the trap was deployed east to west, respectively. The location of the second throw-trap was determined by selecting a random direction and random distance (≥10 m) from the first throw-trap, and the location of the third throw-trap was determined by selecting a random direction and random distance (≥10 m) from the second throw-trap.

After the throw-trap was tossed, emergent and submerged vegetation structure was measured within throw-traps and characterized using the point-quarter method (Cottham and Curtis, 1956) calculating the distance from the center point of the throw-trap to the closest piece of submerged live or dead vegetation, in each of the four quadrants. This distance was inversely proportional to the density of vegetation. After vegetation measurements, we removed any vegetation from the trap then removed aquatic fauna from the throw-trap by passing a 100 cm x 40 cm bar seine through the water column within the trap until there were five consecutive sweeps with no fish or invertebrates. We transferred captured fauna <15 cm in total length directly from the bar seine to jars containing a solution of water and MS 222, a rapid euthanizing agent. Aquatic fauna >15 cm were identified, measured, weighed, and released. We stored samples on ice for the remainder of the sampling day.

Natural marsh sampling methods – The study uses a multi-stage sampling design (Cochran, 1977) consisting of landscape units (LSU), primary sampling units (PSU), sites, and throw-trap locations (Fig. 2-5). Landscape units were previously delineated based on hydroperiod and vegetative characteristics by Restoration Coordination and Verification (RECOVER) personnel. Each LSU contains at least seven 500 m x 500 m PSUs randomly placed using ArcGIS 10.3 (ESRI Inc., Redlands, CA, USA). Each PSU contains two random points that vary for every sampling year. The sampling site is the closest suitable wading bird foraging habitat to the random points. Suitable foraging habitat is defined as an area with sparse to moderate vegetation <30 cm in water depth (Lantz et al., 2011). Once at the site, we determined the maximum bearing and distance encompassed by the suitable habitat. We determined the throw-trap location by using a random number table to select a random bearing and distance within the maximum range. A second throw-trap location was determined in the same manner, by using a random number table to select a random bearing and distance that was at least 10 m away from the first throw-trap location.

After the throw-trap was tossed, emergent and submerged vegetation structure was measured within throw-traps and characterized using the point-quarter method (Cottham and Curtis, 1956) calculating the distance from the center point of the throw-trap to the closest piece of submerged live or dead vegetation, in each of the four quadrants. This distance was inversely proportional to the density of vegetation. After vegetation measurements, we removed vegetation from the trap to facilitate collection of aquatic fauna. We removed aquatic fauna from the throw-trap by passing a 100 cm x 40 cm bar seine through the water column within the trap until there were five consecutive sweeps with no fish or invertebrates. We transferred captured fauna <15 cm in total length directly from the bar seine to jars containing a solution of water and MS 222, a rapid euthanizing agent. Aquatic fauna >15 cm were identified, measured, weighed, and released. Samples were immediately stored on ice and remained so until they were transported to the lab.

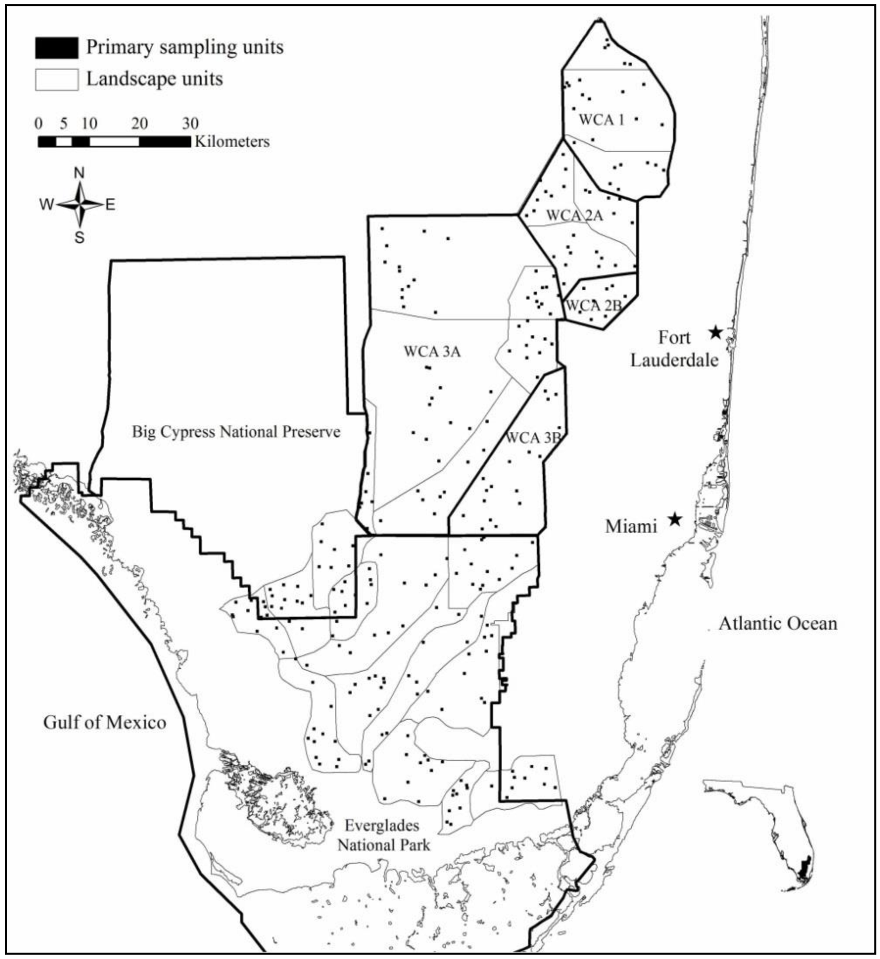

Figure 2-5. Map of the Florida Everglades with landscape unit delineations and locations of primary sampling units.

Site morphology and plant community structure methods – Vegetation cover and community structure were sampled using triplicate 1-m^2 plots in all roadway features (swales, canals, permanently inundated ponds, ephemeral ponds) across three landscape cover types (urban, herbaceous marsh, and forested marsh). We sampled canals and permanently inundated pond vegetation at two locations 1) toe of slope (TOS) and 2) littoral zone; ephemeral sites were sampled at the bottom of each feature. We estimated percent cover (using cover classes) and plant community structure for each plot, and identified plants with 5% cover or greater to species level when possible (modified from Daubenmire, 1959).

We used ArcGIS 10.3 (ESRI Inc., Redlands, CA, USA) to measure area, edge-to-area, and perimeter length. We measured the littoral zone of canal and permanently inundated ponds from the base of each slope. For all feature types, we measured slope with a minimum of four slope measurements. When slope variance was high, we took additional measurements to ensure accurate characterization. We estimated feature depth using the rise component of slope measurements. For elevation measurements, we used a Real Time Kinematic (RTK) GPS unit tied to FDOT benchmarks, which allowed for a 2 cm vertical accuracy.

Hydrologic data was obtained from the South Florida Water Management District which provides rainfall data based on Next Generation Radar (NEXRAD) from the U. S. National Weather Service. Data is received every 15 minutes continuously on a 2 km x 2 km grid resolution.

2.1.3 Stork prey

We collected nestling boluses (stomach regurgitations) within Paurotis Pond and Tamiami West nesting colonies in Everglades National Park during the 2014-2016 breeding seasons. We selected these study colonies based on their range of hydrological conditions and history of repeated use by nesting storks. Paurotis Pond is located near the southern tip of Florida in a coastal wetland, whereas Tamiami West is located further north in the interior of the Florida Everglades. In addition to Everglades colonies, we collected samples at three urban colonies during the 2015-2016 breeding seasons. The Griffin colony is located at Griffin Road and I-75. The Sawgrass colony is located at Sunrise Boulevard and the Sawgrass Expressway. The BallenIsles colony is located in the BallenIsles community near North Lake Road and Military Trail. We selected the three urban colonies based on their location to our aerial and road survey routes and proximity to the urban landscape (Fig. 2-6).

Figure 2-6. Location of Wood Stork nesting colonies in South Florida.

We visited each colony via kayak or on foot 1-2 times a week during the stork breeding season (approximately February through May). All work within colonies took place in the morning or early evening to reduce heat stress upon birds and nests potentially exposed to sun. Before entering a colony, we observed the colony through binoculars to locate active nests and an appropriate entrance point with minimal disturbance on nesting birds. Once in a colony, we moved locations frequently within our sampling area so that no nest was disturbed for more than 30 minutes. Nestlings often regurgitate in the presence of a human, making bolus contents readily available. In the event a targeted nestling did not voluntarily regurgitate, we gently massaged its trachea to encourage regurgitation. Once a nestling regurgitated, we left a dead bait fish in the nest to compensate for loss of bolus contents. For each bolus collected, we recorded the age of the nestling in weeks and its hatching order. We also sprayed water on nestling's legs to keep them cool on hotter days. Lastly, we exited the colony at a different location than we entered to prevent flushing nests more than once. For the duration of the sampling trip, we placed all bolus contents in a labeled Ziplock© bag stored on ice in a cooler.

2.1.4 Lab methods

Stork prey production samples were transferred to a solution of Prefer, a color fixative, for three days. After three days, we transferred samples to a 70% ethanol solution for storage. Aquatic fauna were identified, weighed to the nearest 0.01 g, and measured (standard length and total length). Invertebrates with irregular body shapes (e.g., shrimp) were measured from the tip of the mandibles to the tip of the tail.

Bolus samples were poured through a 0.6 micrometer mesh net, rinsed with water, and sorted prey remains under a magnifying lens. Each animal was identified using a variety of keys, field guides, and online databases. We weighed, and measured each prey item found within each bolus, noting whether each piece represented a part or whole prey species. We entered species code, length, weight, sampling location, and date collected for each prey item into a Microsoft Excel spreadsheet for data storage. We stored sorted bolus contents in a freezer for preservation.

2.2 Statistical methods

2.2.1 Storks and roadway corridor features

We used a discrete choice model as storks forage in a temporally and spatially dynamic landscape, which allows available resource units to change over time, more accurately representing resource selection (Manly et al., 2002).

Aerial and roadway survey data were used to determine use-availability of roadway features by storks. We defined used sites as areas where storks were observed within 500 m of each side of the roadway for aerial surveys and within 100 m of the surveyed side of the road for roadway surveys. We defined available sites as areas where storks were not observed during surveys, but could potentially be used (Manly et al., 2002). A unique set of random unused points were generated within an 80 km radius of each known foraging location on each survey day in ArcView 10.3 (ESRI Inc., Redlands, CA, USA). An 80 km buffer was used as storks are rarely reported flying greater distances to forage (Browder, 1984; Herring and Gawlik, 2011). Within each 80 km buffer, we randomly selected one unused site using Program R (R Development Core Team, 2016). Each used and available site were attributed with the parameters of interest using Program R (R Development Core Team, 2016).

We determined resource selection of storks by creating competing predictive models explaining how features of roadway corridors influence stork use and compared them in an information theory framework (Burnham and Anderson, 2004). We developed six a priori candidate models for stork use (Table 2-1). We used Akaike's Information Criterion for small sample sizes (AICc) to determine which of our a priori models were most parsimonious. Additionally, we calculated ΔAIC_c values and model probabilities (wi) to determine the distance between the best model and other models in the candidate set. To determine the importance of individual explanatory variables, we calculated the summed Akaike weights (Σwi) for each model containing the variable. We calculated averaged parameter estimates for each model to determine the effect of an explanatory variable on stork presence. To examine model variability, we also calculated 95% confidence intervals for the parameter estimates. Lastly, we calculated a likelihood version of the correlation coefficient for each model to evaluate model fit.

We used Proc Glimmix (SAS Institute, 2013) to build multinomial logit models with fixed and random effects (Chen and Kuo 2001). Before running our models, we confirmed that multicollinearity did not exist between variables (Appendix B, Table B1). We used stork presence (1) or stork absence (0) as our explanatory variable. We also included survey type (road or aerial) and month as random variables to account for temporal and spatial variation in our sampling design. Lastly, we ran a null model including month, feature type, survey type, and season to evaluate the performance of other models in the candidate set. We used the most parsimonious model to determine resource selection functions of stork use along roadway corridors. Resource selection functions yield values proportional to the probability of use of a resource unit (Manly et al., 2002) and range from 0-1, with 0 having the lowest probability of use and 1 having the highest probability of use.

Table 2-1. A priori model hypotheses of roadway feature parameters influencing stork use in South Florida. Landscape = landscape cover type, DistRoad = distance to nearest roadway, DistColony = distance to nearest colony, DistWetland = distance to nearest natural wetland, BreedingSeason = breeding or nonbreeding season, VegM = vegetation maintenance (mowed or natural), VegF = vegetation cover at a 30x30 m scale, Rainfall = total rainfall in past seven days, Slope = slope of feature site, SurveyType = road or aerial survey, and Season = hydrologic season (wet or dry).

Hypothesis	Model
Global[1, 2]	Y = Landscape + DistRoad + DistColony + DistWetland + BreedingSeason +VegM + VegF + Rainfall + Slope
Landscape[1, 2]	Y = Landscape + DistRoad + DistColony + DistWetland + DistColony*BreedingSeason + BreedingSeason
Local[1, 2]	Y = VegF + Rainfall + Slope + VegM
Feature[1, 2]	Y = Slope + VegM
Hydrologic[1, 2]	Y = Rainfall
Null	Y = Month + FeatureType + Season + SurveyType

Y = stork presence (1) or stork absence (0)
[1] Survey type and month added as random variables to all models
[2]FeatureType and Season added to all models

2.2.2 Stork prey production in roadway corridor features

Site morphology and plant community structure – We compared all site morphological variables across land use (urban or natural marsh), landscape cover type (forested marsh, herbaceous marsh, or urban), and feature type (swales, ephemeral ponds, permanently inundated ponds, canals). We used a one-way ANOVA to compare slope, feature depth, and edge-to-area ratios. We used t-tests to compare slope and water depth by land use (JMP v12). Two-way and nested ANOVAs were used to evaluate interactions between feature type and landscape cover type (JMP v12).

We compared plant cover by land use, landscape cover type, and feature type using one-way ANOVA (JMP v12). We used two-way ANOVA to compare feature type cover by landscape cover type (JMP v12). We used non-metric multidimensional scaling (nMDS) derived from Bray-Curtis similarities and principal components analysis (PCA) to compare plant community structure across all feature types and landscape cover classes. We used nMDS to further compare plant community structure between features within landscape cover classes (McCune and

Mefford, 1999). nMDS is nonmetric and hence axes do not have specific values. Sites with more similar communities appear more closely in ordinate space (McCune and Medford, 1999). We eliminated vegetation that accounted for less than 5% of cover and excluded sites with no vegetation from all analyses.

Fish production models – We used an information-theoretic approach to investigate competing predictive models for stork prey biomass in roadway features (Burnham and Anderson 2004; Appendix B, Table B2). We developed a priori candidate models for both permanently inundated sites (Table 2-2) and ephemeral sites (Table 2-3). We used Akaike's Information Criterion for small sample sizes (AICc) to determine which of our a priori models were most parsimonious. We also calculated ΔAIC_c values and model probabilities (wi) to determine the distance between the best model and other models in the candidate set. To determine the importance of individual explanatory variables, we calculated the summed Akaike weights (Σwi) for each model containing the variable. We calculated averaged parameter estimates for each model to determine the effect of an explanatory variable on stork prey biomass. To examine model variability, we also calculated 95% confidence intervals for the parameter estimates. Lastly, we calculated a likelihood version of the correlation coefficient for each model to evaluate model fit.

We used Proc Mixed (SAS Institute, 2013) to build generalized linear mixed models for the biomass of two categories of stork prey: 1) prey comprised of only stork prey species, and 2) prey comprised of stork prey species and size classes. We determined stork prey species and size classes from Objective 3. Stork prey species include the top 95% of species observed in bolus contents. Stork prey sizes include the middle 95% (top and bottom 2.5% removed) observed in bolus contents, thus we included prey sizes from 2 – 11 cm in analyses. Before running our models, we confirmed that multicollinearity did not exist between explanatory variables. We used average prey biomass (biomass/trap) within each site as our explanatory variable. We log-transformed all prey biomass measurements to ensure normality requirements. We also included sampling year and month as random variables to account for temporal variation in our sampling design. Lastly, we ran a null model including sampling year, month, feature type, landscape cover type, and season for each prey category to evaluate the performance of other models in the candidate set. Elevation was initially included in models, however, we found that it was not correlated with slope, there was little variation, and confidence intervals significantly overlapped zero with its inclusion, thus we removed it from all models.

Table 2-2. A priori model hypotheses of hydrologic and site variables influencing stork prey concentrations within permanently inundated sites in South Florida. WaterDepth = average water depth of site, Rainfall = total rainfall in past seven days, SubVeg = % cover of submerged vegetation, EmergeVeg = % cover of emergent vegetation, Slope = average slope of feature site, LittoralWidth = average littoral width, Area = total area of feature site, Landscape = landscape cover type, and Season = hydrologic season (wet or dry).

Hypothesis	Model
Global[1, 2]	Y = WaterDepth + Rainfall + SubVeg + EmergeVeg + Slope + LittoralWidth + Area
Production[1, 2]	Y = WaterDepth + Rainfall + Area
Habitat[1, 2]	Y = WaterDepth + SubVeg + EmergeVeg + Area
Feature[1, 2]	Y = SubVeg + EmergeVeg + Slope + LittoralWidth + Area
Hydrologic[1, 2]	Y = WaterDepth + Rainfall
Null	Y = Year + Month + FeatureType + Landscape + Season

Y = Prey concentration (biomass/trap)
[1]Year and Month added as random variables to all models
,[2]FeatureType, Landscape, and Season added to all models

Table 2-3. A priori model hypotheses of hydrologic and site variables influencing stork prey concentrations within ephemeral sites in South Florida. Hydroperiod = average number of months site was inundated with water, WaterDepth = average water depth of site, Rainfall = total rainfall in past seven days, SubVeg = % cover of submerged vegetation, EmergeVeg = % cover of emergent vegetation, Slope = average slope of feature site, Connectivity = total connections with more permanently inundated features, Area = total area of feature site, Landscape = landscape cover type, and Season = hydrologic season (wet or dry).

Hypothesis	Model
Global[1, 2]	Y = Hydroperiod + WaterDepth + Rainfall + SubVeg + EmergeVeg + Slope + Connectivity + Area
Hydrologic[1, 2]	Y = Hydroperiod + Waterdepth + Rainfall
Feature[1, 2]	Y = SubVeg + EmergeVeg + Connectivity + Area + Slope
Migration[1, 2]	Y = Hydroperiod + WaterDepth + Rainfall + Connectivity + Area + Rainfall*Connectivity
Null	Y = Year + Month + FeatureType + Landscape + Season

Y = Prey concentration (biomass/trap)
[1]Year and Month added as random variables to all models
,[2]FeatureType, Landscape, and Season added to all models

2.2.3 Stork prey

To determine prey composition and size structure of aquatic fauna consumed by storks, we used nonparametric multivariate techniques (Clarke and Warwick, 2001). We combined bolus samples collected from the same colony on the same date to reduce stress from having a large number of replicates (i.e. individual boluses). Each sample point was representative of prey communities consumed by storks spatially (colony location) and temporally (sample date). We calculated total biomass of each prey species found within each sample point and eliminated prey species that accounted for less than 1% of total biomass to prevent over representation of rare species. We used a square root transformation to down weight the effect of dominant prey. We used one-way analysis of similarity (ANOSIM) analyses to determine if prey composition varied among nestling age classes, nesting colonies, and sampling years. If no statistical difference occurred, we combined all prey composition data to increase sample size and improve our ability to detect statistical differences.

In order to determine prey composition and size structure of aquatic fauna consumed by storks and how prey consumption relates to prey availability in roadways and the natural marsh system, we used the same multivariate techniques described above (Clarke and Warwick, 2001). To maximize our characterization of prey types available within the natural marsh and roadway feature samples, we included throw-trap and minnow trap samples that occurred within 130 km of each colony, the maximum foraging distance for storks (Coulter et al., 1999). Additionally, we only included throw-trap and minnow trap samples that were collected within the same data range as bolus samples for each year. Throw-trap and minnow trap data were combined from the same site on the same day to reduce stress from a large number of replicates. Roadway feature site data did not vary by year; thus, these samples were combined by feature site (ANOSIM, $P > 0.05$).

We used non-metric multi-dimensional scaling (nMDS) derived from Bray-Curtis similarities to examine the overlap of stork prey and prey availability in roadway features and the natural marsh system. Stress values associated with nMDS plots indicate the degree of distortion relative to the actual multidimensional similarity between points. Stress values < 0.3 indicate a satisfactory level of representation of the data. We used an ANOSIM analysis to determine if there was a statistical difference among bolus samples, natural marsh samples, and roadway feature samples. If there was a statistical difference, we performed a similarities of percentage (SIMPER) analysis to determine which prey species were driving the differences between samples.

We used two separate trapping methodologies to sample prey in roadway feature sites. Minnow traps were used in permanently inundated roadway features sites whereas throw-traps were used in ephemeral roadway features and the natural marsh. Two different methods were used as neither method could sample aquatic fauna effectively in both feature types. These sampling methods are not directly comparable; however, the two sampling methods effectively captured aquatic fauna in their respective feature and wetland type. For fish production models (Objective 2), the two sampling methods were not directly compared and were used in two separate models. For comparisons between stork diet and prey availability in permanently inundated and ephemeral roadway corridor features (Objective 3), we use multivariate techniques derived from Bray-Curtis similarities. Multivariate techniques allow us to compare species composition across multiple samples including varying sampling methods.

3.0 Results and conclusions

3.1 Storks and roadway corridor features

We recorded 107 observations with a total of 1,199 storks during monthly aerial survey from February 2014 to May 2016 (Fig. 3-2). Additionally, we recorded 191 observations with a total of 387 storks during bimonthly roadway surveys from September 2014 to May 2016 (Fig. 3-3). We observed storks in all landscape cover types and feature types (Appendix A; Table A1, A2). We observed the most storks on average from January to June with stork observations decreasing from July to October (Table 3-1; Fig. 3-1). Stork observations began to increase in November and December as storks returned to South Florida for the breeding season (Table 3-1; Fig. 3-1).

Table 3-1. Mean number of storks ± SE observed in roadway corridor features each month, 2014-2016, South Florida.

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.
Avg. # of storks ± SE	34.33 ± 0.98	30.71 ± 3.33	32.29 ± 3.99	29.14 ± 9.55	34.43 ± 13.46	36.00 ± 11.28
Month	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Avg. # of storks ± SE	17.75 ± 9.71	2.33 ± 0.40	9.00 ± 1.89	6.80 ± 0.15	18.8 ± 0.34	19.2 ± 0.44

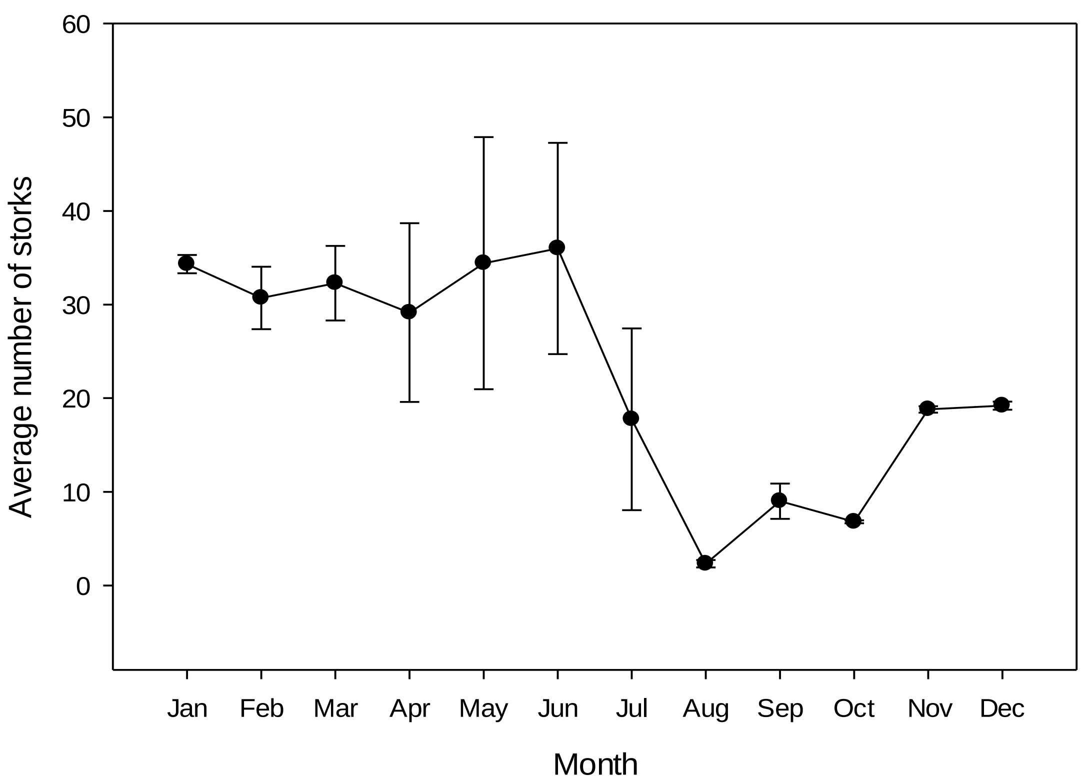

Figure 3-1. Average number of storks ± SE observed in roadway corridor features each month, 2014-2016, South Florida.

We found differences in the landscape cover type and corridors used by storks, depending on whether storks were foraging in large groups or solitarily (Appendix A; Table A1, A2). We observed stork flocks (more than 1 bird) more in the herbaceous marsh and agriculture landscape cover types with 88% of observed stork locations containing more than 1 bird in herbaceous marsh and 68% in the agriculture landscape cover type. We observed more single birds in the urban landscape cover type with 88% of our observed stork locations containing only 1 bird each. Overall there was a low occurrence of storks in the forested marsh landscape cover type, accounting for less than 3% of all birds observed. We observed more stork flocks (more than 1 bird) in the irrigation ditch, natural marsh, and flooded upland feature types, whereas 84% of our observed stork locations contained only single birds in the canal feature type. We observed stork flocks (more than 1 bird) and solitary storks equally in swales, ephemeral ponds, and permanently inundated ponds. Overall, the majority of storks were observed in permanently inundated ponds and the urban landscape cover type (Table 3-2). The fewest storks were observed within the upland and ephemeral pond feature types and the forested marsh landscape cover type (Table 3-2).

Table 3-2. Total number of storks observed in roadway corridor features and landscape cover types, 2014-2016, South Florida.

	Survey Type		
Feature type	Roadway	Aerial	***Total***
Canal	254	40	***294***
Ephemeral pond	7	6	***13***
Irrigation ditch	0	263	***263***
Natural marsh**	0	225	***225***
Permanently inundated pond	33	527	***560***
Swale	93	119	***212***
Upland	0	19	***19***
Landscape cover type			
Agriculture	NA*	375	***375***
Forested marsh	NA*	30	***30***
Herbaceous marsh	NA*	236	***236***
Urban	387	558	***945***

*Roadway surveys only included urban landscape cover type
**Width of natural marsh observation area is reduced in roadway surveys relative to aerial surveys

For roadway surveys, we were usually able to distinguish between adult and juvenile storks. Fifty-one percent of observed storks were adults whereas 34% were juveniles, assuming that there was no difference in flushing distance between age groups. We were unable to classify 15% of storks as adult or juveniles due to storks flushing sooner than expected. Both adult and juvenile storks used the canal feature type most frequently and the ephemeral and permanently inundated ponds least frequently (Table 3-3).

Table 3-3. Age classes of storks observed in corridor features during roadway surveys, 2014-2016, South Florida. Percent of age class using each feature type.

Feature type	Adult	Juvenile	Unknown
Canal	131*(66%)*	93*(70%)*	30 *(56%)*
Permanently inundated pond	11 *(6%)*	13 *(10%)*	9 *(16%)*
Ephemeral pond	3 *(2%)*	2 *(1%)*	2 *(4%)*
Swale	55 *(26%)*	25 *(19%)*	13 *(24%)*
Total	***200***	***133***	***54***

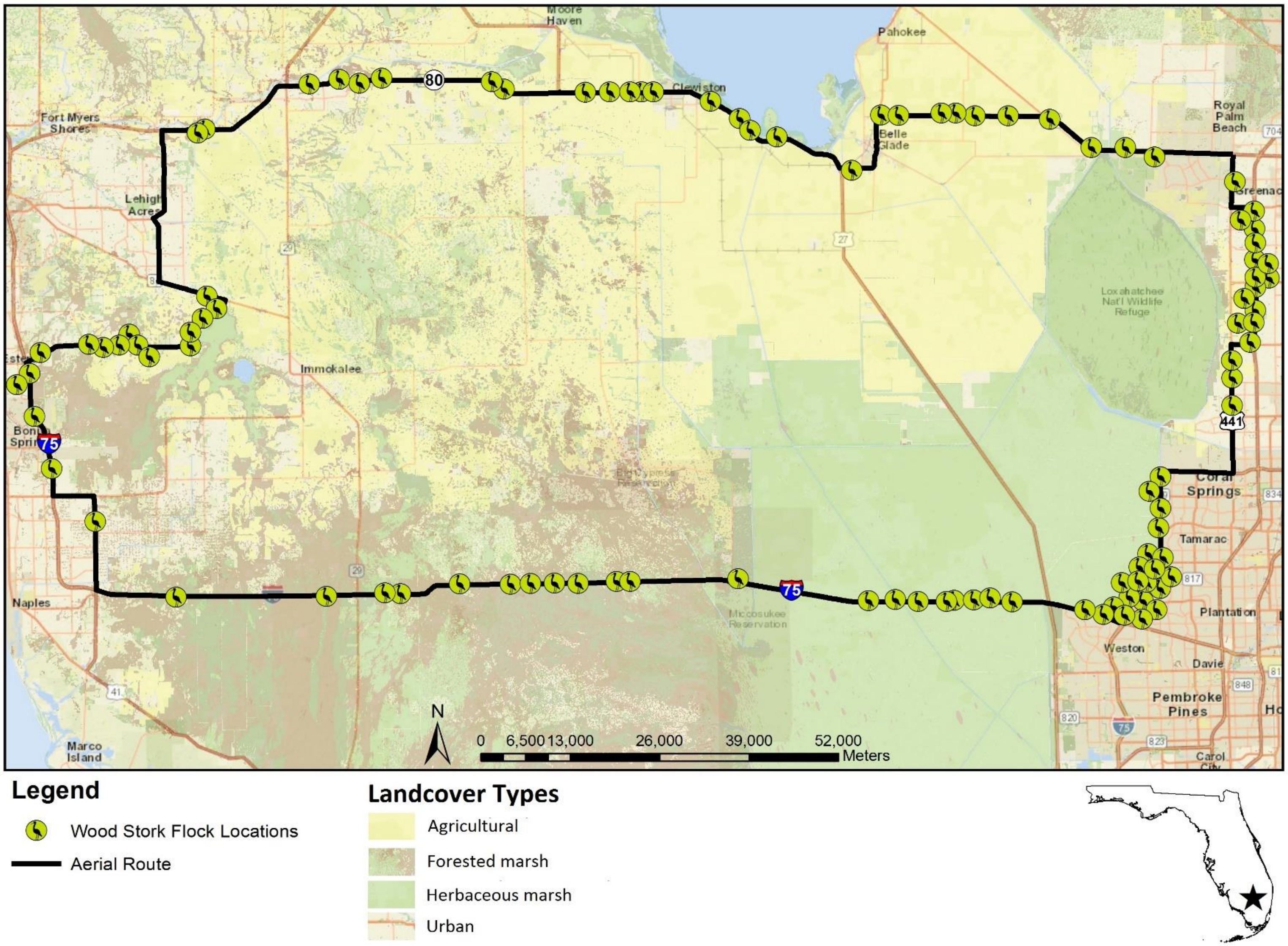

Figure 3-2. Locations of storks observed from monthly aerial surveys, February 2014 to May 2016, South Florida

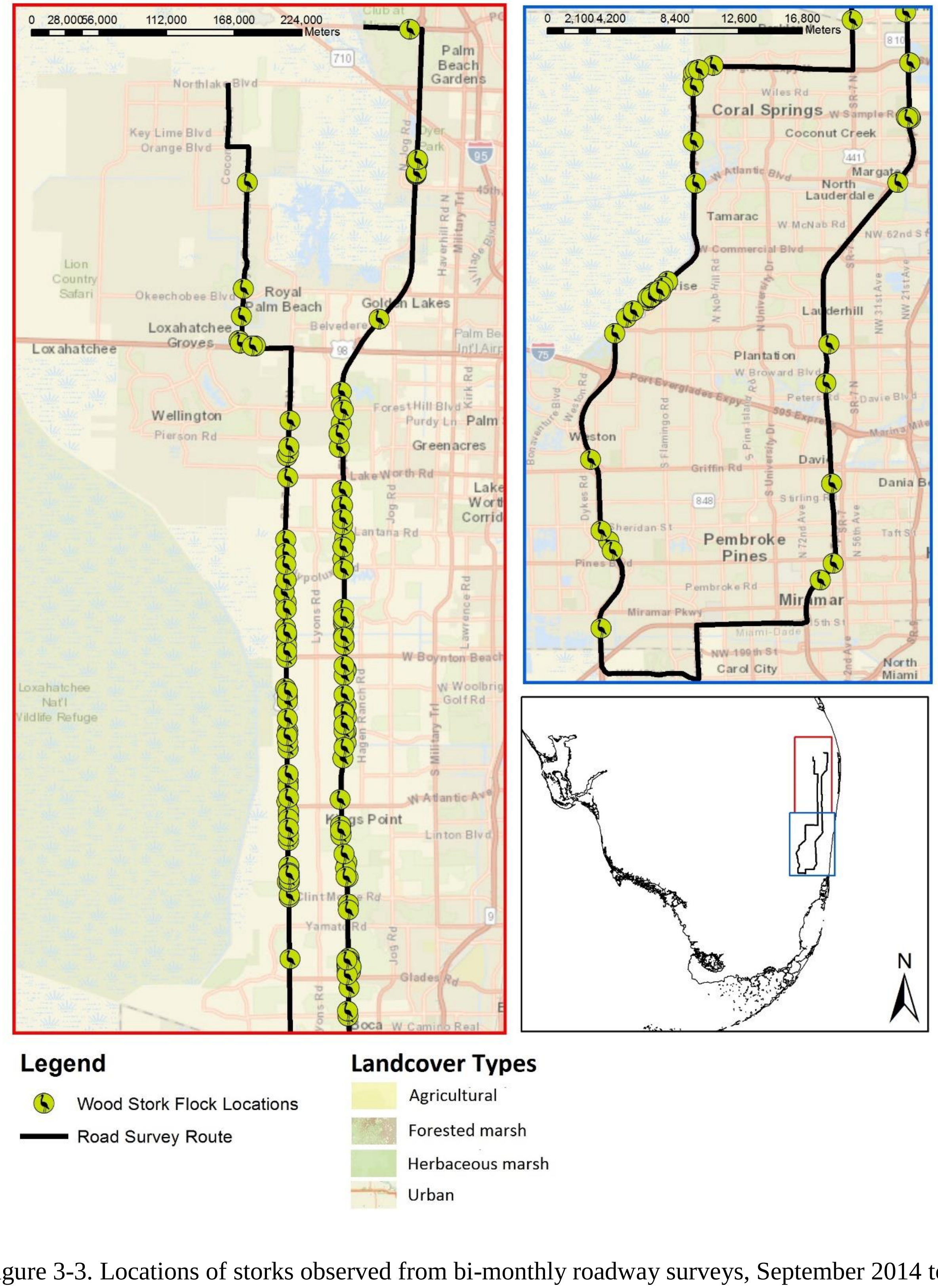

Figure 3-3. Locations of storks observed from bi-monthly roadway surveys, September 2014 to May 2016, South Florida.

3.1.1 Resource selection functions

During the survey period (2014 to 2016), 298 stork observations were recorded. We used 596 observations for model development, 298 used points, and 298 random points. The top model was the global model (w_i = 0.99, R^2 = 0.19; Table 3-4) which explained the most variation in stork use along roadway corridors.

Most of the parameter estimates' confidence intervals overlapped zero (Table 3-5), suggesting some model uncertainty whether a particular estimate has a positive or negative effect on stork use of roadway corridors. Overall, canals had the greatest probability of use by storks while parameter estimates for all other feature types overlapped zero, indicating uncertain relationships with stork use. Storks were more likely to use roadway corridor features during the breeding season than the nonbreeding season. Parameter estimates for distance to nearest roadway, colony, and wetland were all negative, suggesting that features nearest roadways, colonies, and wetlands were more likely to be used. The coefficient for moderate and shallow slopes was negative, suggesting that features with shallower slopes were not likely to be used by storks. For fine scale vegetation, areas of low intensity and high intensity urbanization were less likely to be used as compared with more natural areas. Parameter estimates for all classes of landscape cover types and vegetation maintenance overlapped zero, indicating little influence on stork use.

Table 3-4. Ranking of models used to assess use of roadway corridors by storks in South Florida, 2014-2016. Models are described with -2 log likelihood (-2Loglike), number of parameters (k), AIC_c values, differences in AIC_c values between the best model and each candidate model (ΔAIC_c), AIC_c weights (w_i), and the likelihood coefficient of determination (R^2).

Model	-2Loglike	k	AIC_c	ΔAIC_c	w_i	R^2
Global	592.8	32	658.56	0	0.99	0.19
Local	631.58	20	668.85	10.28	0.01	0.13
Landscape	667.1	16	697.98	39.42	0.00	0.08
Feature	658.65	20	698.06	39.50	0.00	0.09
Null	712.42	13	731.84	73.38	0.00	0.00
Hydrologic	699.66	18	734.79	76.23	0.00	0.02

Table 3-5. Model averaged parameter estimates (β) and 95% confidence limits (LCL, UCL) for models ($\Delta AIC_c < 7$) predicting stork use along roadway corridors in South Florida, 2014-2016.

Parameter	β	LCL	UCL
FeatureType			
Swale	-0.076	-2.529	2.377
Ephemeral Pond	1.001	-2.379	4.381
Natural Marsh	-0.827	-3.569	1.915
Permanently inundated Pond	2.020	-0.212	4.251
Canal	2.98	0.998	4.959
BreedingSeason			
Nonbreeding	-0.642	-1.258	-0.026
Breeding	0		
Season			
Dry	-0.559	-1.399	0.281
Wet	0		
DistanceRoadway	-0.002	-0.005	0.001
DistanceColony	-0.001	-0.001	-0.0001
DistanceWetland	-0.001	-0.001	-0.0001
Landscape			
Urban	0.524	-1.098	2.185
Agriculture	0.264	-1.484	2.013
Herbaceous	1.113	-0.804	3.032
Forested	0		
Slope			
Shallow	-0.102	-0.887	0.683
Moderate	-1.861	-2.569	-1.152
Steep	0		
VegM			
Mowed	0.017	-0.636	0.670
Natural	0		
VegF			
LowIntensityUrban	-1.233	-2.199	-0.267
HighIntensityUrban	-1.156	-2.169	-0.142
Agriculture	-0.771	-1.778	0.235
Herbaceous	0.0279	-0.780	1.339
Forested	0		
Rainfall	-0.029	-0.183	0.012

Swales – Regardless of levels of rainfall, storks were not likely to use swales, however, probability of swale use did increase during the dry season months (Fig. 3-4a). Swales had a low probability of use regardless of distance to colony, however storks were more likely to use swales at low to moderate distances from the colony (Fig. 3-5a). Similarly, swales had a low probability of use regardless of distance to roadway, however they were more likely to forage near roadways during the dry season than wet season (Fig. 3-6a). Likewise, swales had a low probability of use regardless of distance to nearest wetland, however storks were more likely to forage near wetlands during the dry season than wet season (Fig. 3-7a.). Swales had a low probability of use regardless of slope, however storks were more likely to use swales with low and high slopes during the dry season (Fig. 3-8a). Swales had a low probability of use across most landcover types during the wet season, excluding herbaceous marsh swales (Fig. 3-9a). Storks were more likely to use swales in all landcover types during the dry season (Fig. 3-9a). Vegetation maintenance did not affect stork use of swales (Fig. 3-10a; based solely on mowed or unmowed characterization, rather than changes in plant community structure, plant cover, and feature profile). Local scale vegetation influenced stork use of swales, whereas storks preferred to use areas that were more natural, like forested and herbaceous marshes during the dry season (Fig. 3-11a). Overall, there was a low probability of use of swales, however swales were used more often during the dry season.

Stork use of roadway corridors

- Storks were least likely to use swales, however, when they did use swales it was most likely to be in the dry season
- Storks were more likely to use ephemeral stormwater ponds in the dry season than the wet season
- Canals and permanently inundated stormwater ponds were the most likely to be used by storks
- Natural marshes along roadways had a low overall probability of use by storks

Ephemeral ponds – Storks were more likely to use ephemeral ponds during low and moderate levels of rainfall during the wet season (Fig. 3-4b). Ephemeral ponds were likely to be used regardless of distance to colony in both the breeding and nonbreeding seasons (Fig. 3-5b). Similarly, storks were likely to use ephemeral ponds regardless of distance to roadways during the dry season, however as distance from roadways increased during the wet season, they were less likely to use ephemeral ponds (Fig. 3-6b). Similarly, storks were likely to use ephemeral ponds regardless of distance to wetland during the dry season; however, as distance increased during the wet season storks were less likely to use ephemeral ponds (Fig. 3-7b). Storks were most likely to use ephemeral ponds with low and high slopes (Fig. 3-8b). Regardless of the landcover type, storks were likely to use ephemeral ponds in both dry and wet seasons (Fig. 3-9b). Similarly, storks were likely to use ephemeral ponds regardless of vegetation maintenance (Fig. 3-10b). Local scale vegetation did not influence stork use of ephemeral ponds during the dry season, however during the wet season storks were most likely to use more natural areas, like forested and herbaceous marshes (Fig. 3-11b). Overall, there was a high probability of stork use of ephemeral ponds during the dry season.

Permanently inundated ponds and canals – Overall, storks had a high probability of use of permanently inundated ponds and canals regardless of which parameter was examined (Figs. 3-4c-11c, 3-4d-11d).

Natural marsh – All natural marshes observed during surveys were within 500 m of the roadway. The overall probability of use of these natural marshes was low. The probability of use was not affected by distance to nearest active colony, distance to roadway, distance to nearest wetland, slope, or vegetation maintenance (mowed or unmowed; Figs. 3-5-10e). However, there was a tendency for storks to use natural marshes during times of moderate to high rainfall and when located within the herbaceous marsh landscape cover type (Figs. 3-4e, 3-11e).

While the data shows that storks had a low probability of use of natural marshes within 500 m of the roadways sampled, we know that storks depend on natural marsh habitat and the prey it contains. Wading birds, including storks, time their breeding season to coincide with high prey availability in natural marshes during the dry season in South Florida (Kahl, 1964; Kushlan et al., 1975). One possible reason for the low use of natural marsh within 500 m of a road is that birds prefer marsh habitat that is further from roads and that when they are close to roads they are actually feeding in the road feature habitat that may have a longer hydroperiod.

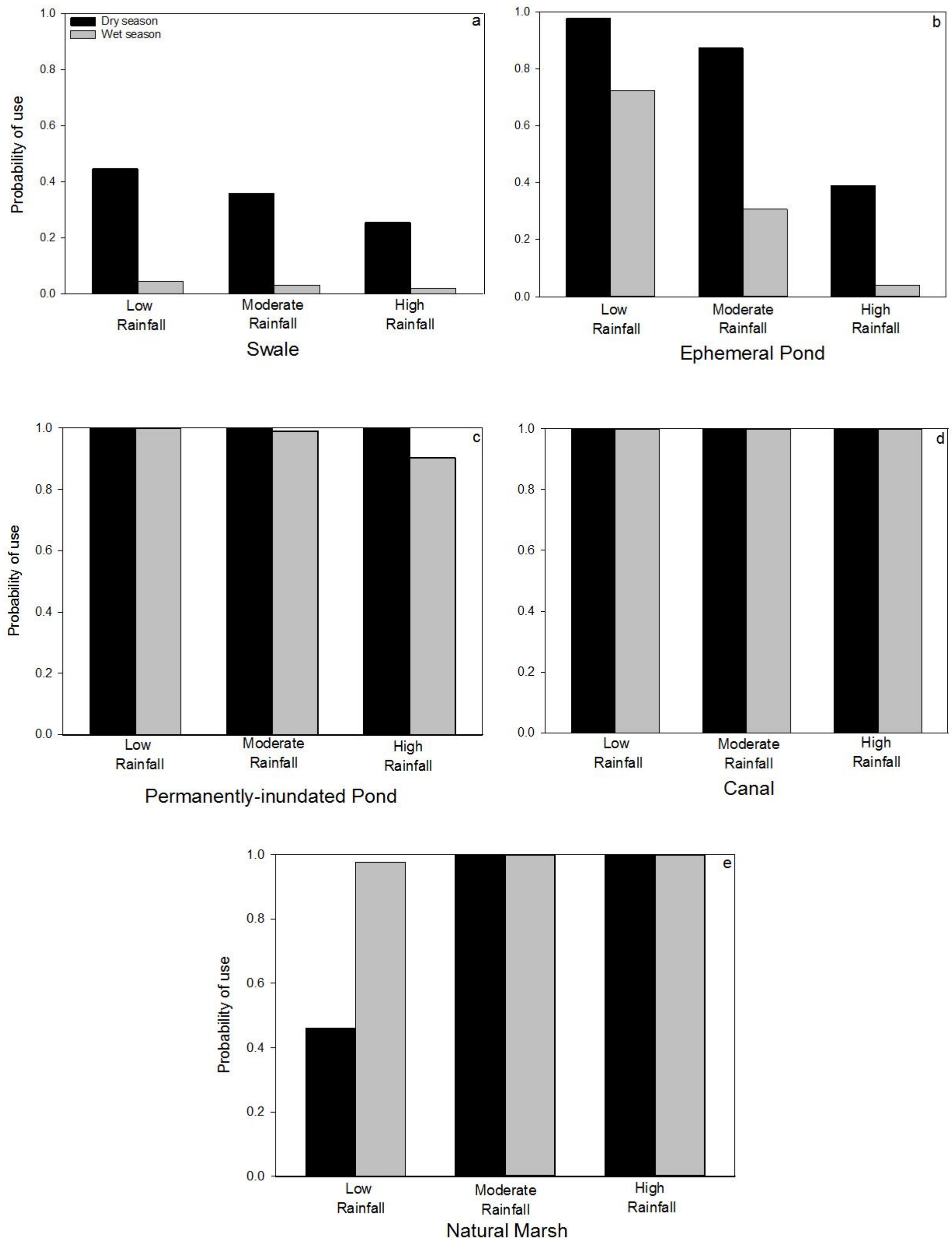

Figure 3-4. Changes in probability of use of roadway features by storks with low (<5 cm), moderate (6-10 cm), and high levels (>10 cm) of rainfall during wet (May-October) and dry (November-April) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

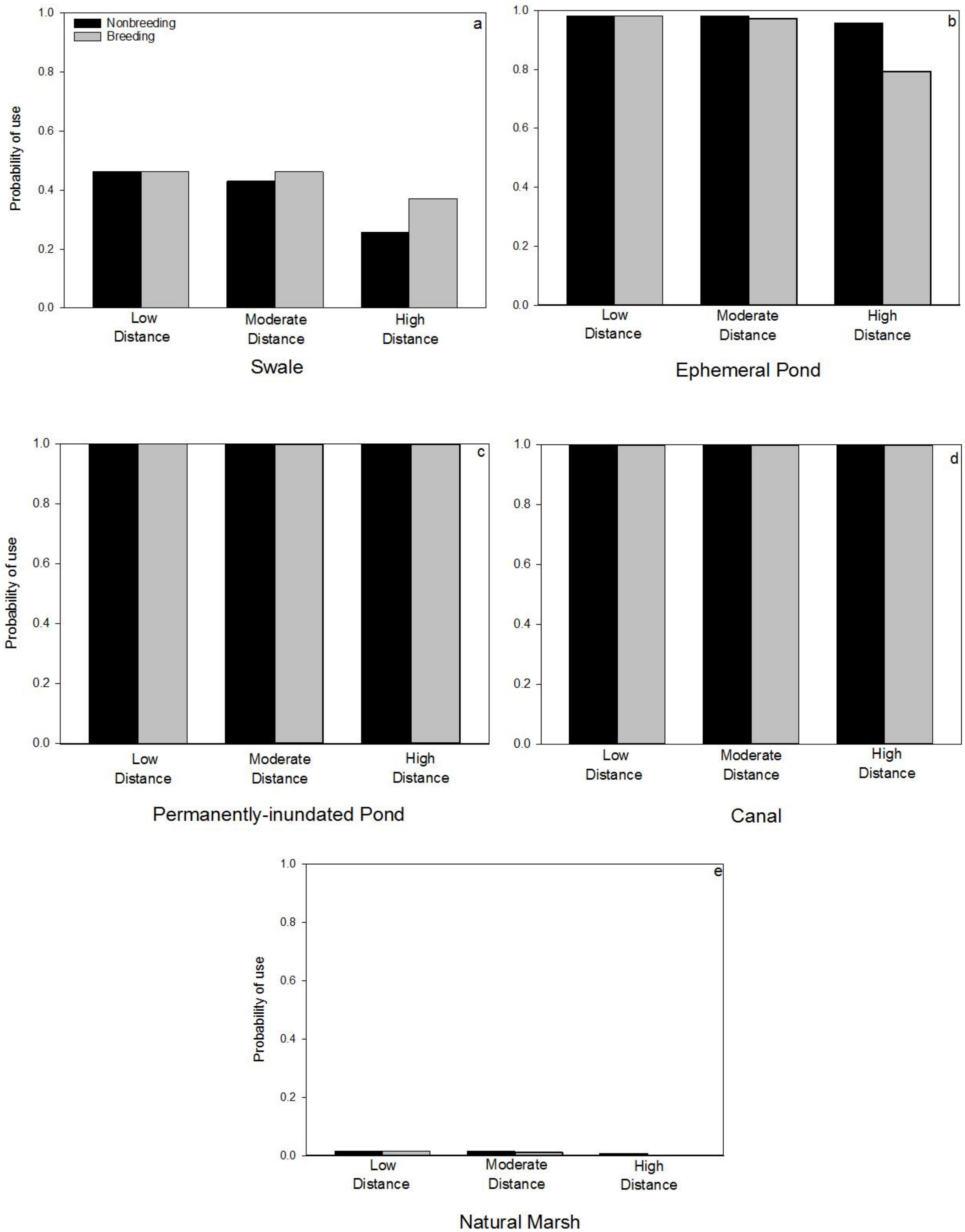

Figure 3-5. Changes in probability of use of roadway features by storks with low (<10 km), moderate (10.1 – 20 km), and high distances (>20 km) from active colonies during breeding (February-June) and nonbreeding (July-January) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

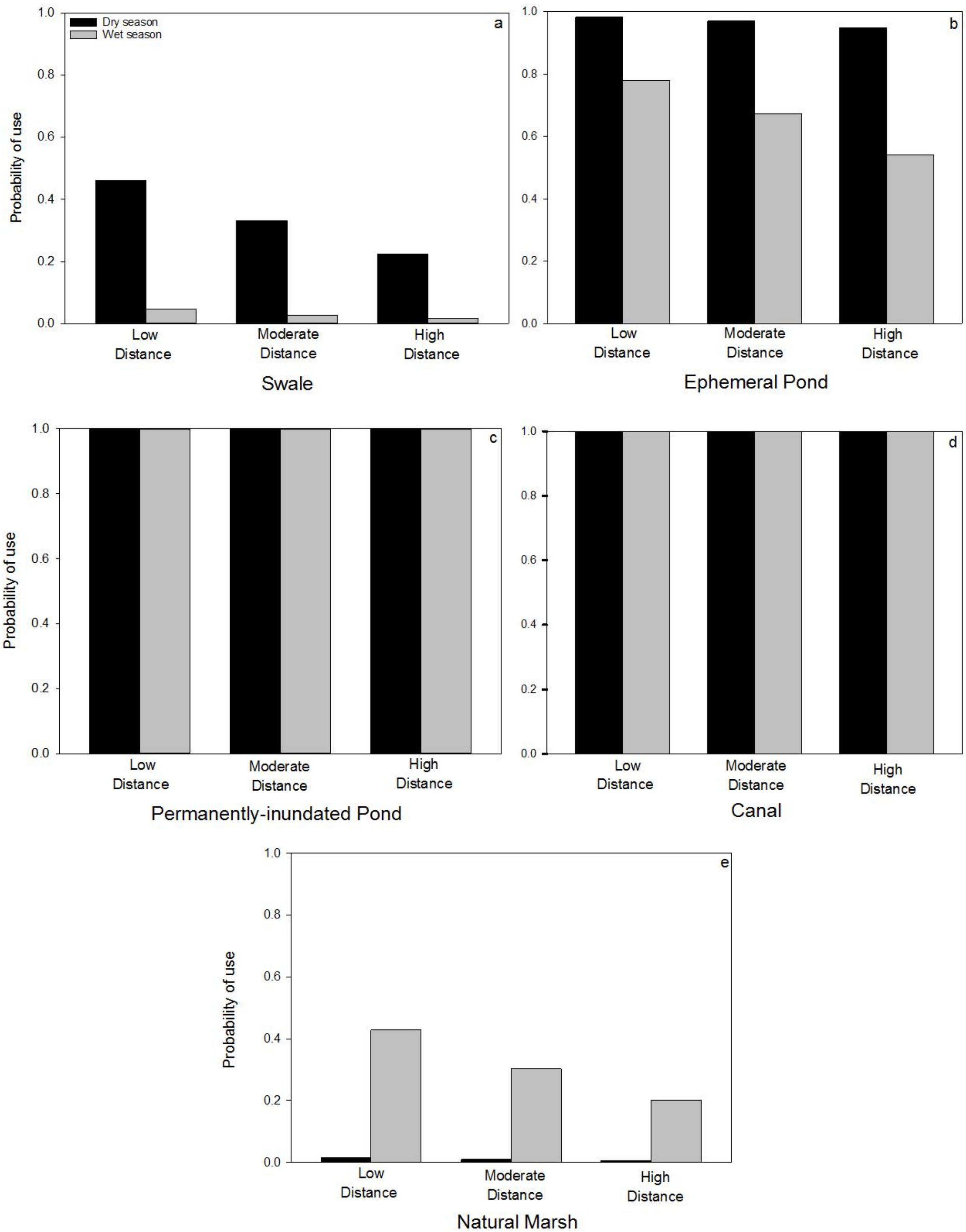

Figure 3-6. Changes in probability of use of roadway features by storks with low (<150 m), moderate (151-300 m), and high distances (>300 m) from roadways during wet (May-October) and dry (November-April) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

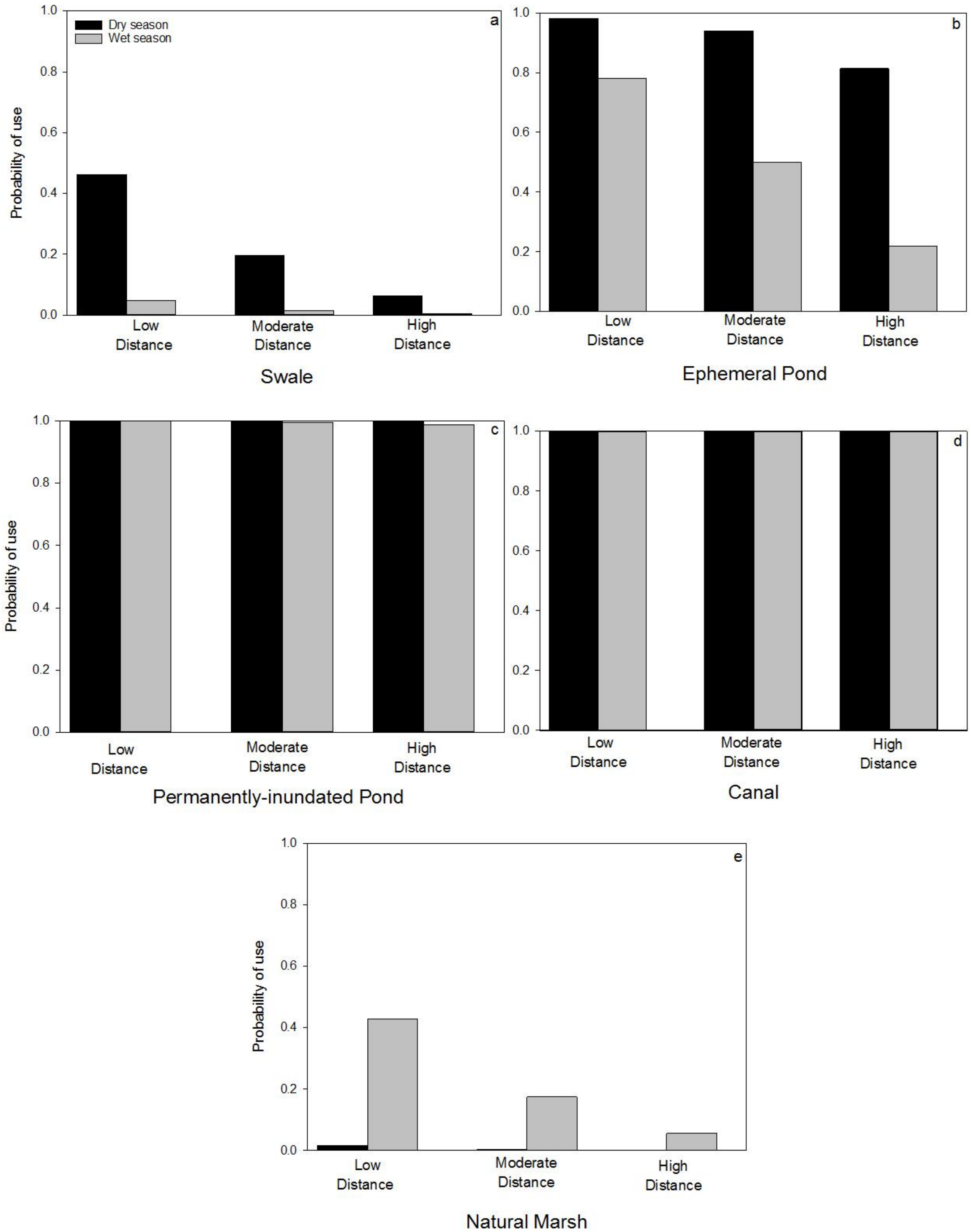

Figure 3-7. Changes in probability of use of roadway features by storks with low (<7,000 m), moderate (7,001-14,000) and high distances (>14,000 m) from wetlands during wet (May-October) and dry (November-April) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

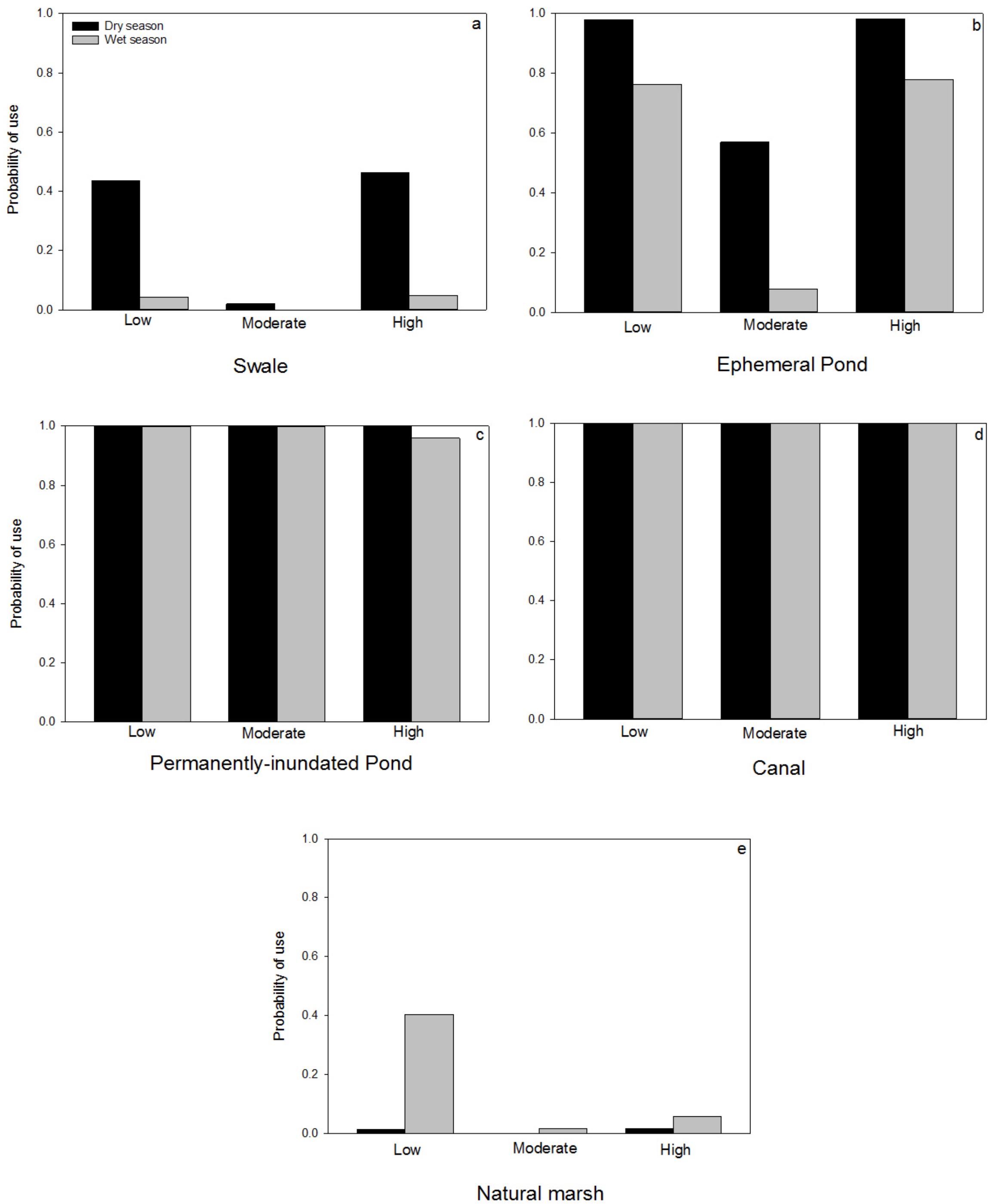

Figure 3-8. Changes in probability of use of roadway features by storks with low, moderate, and high slopes during wet (May-October) and dry (November-April) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

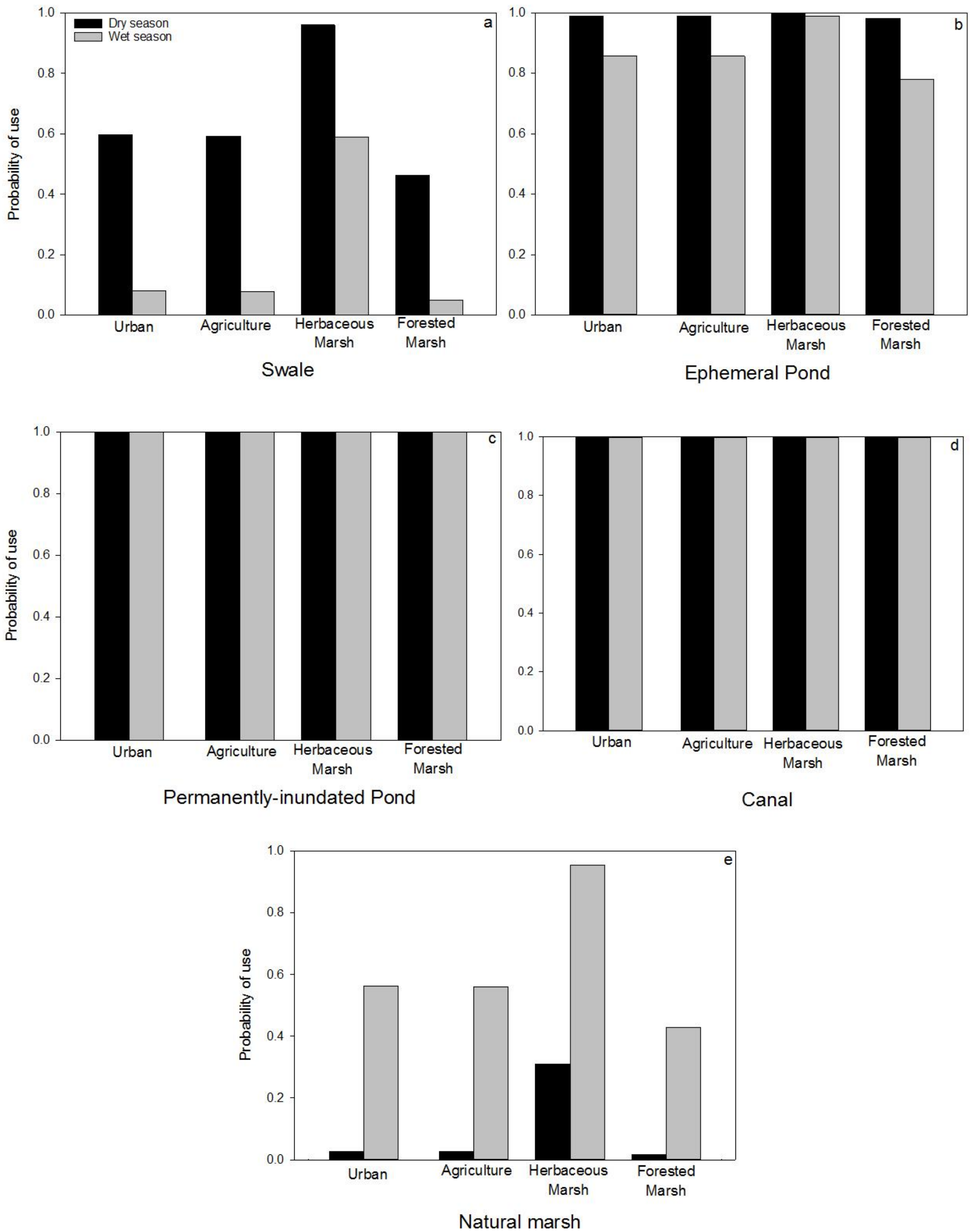

Figure 3-9. Changes in probability of use of roadway features by storks with landscape cover types during wet (May-October) and dry (November-April) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

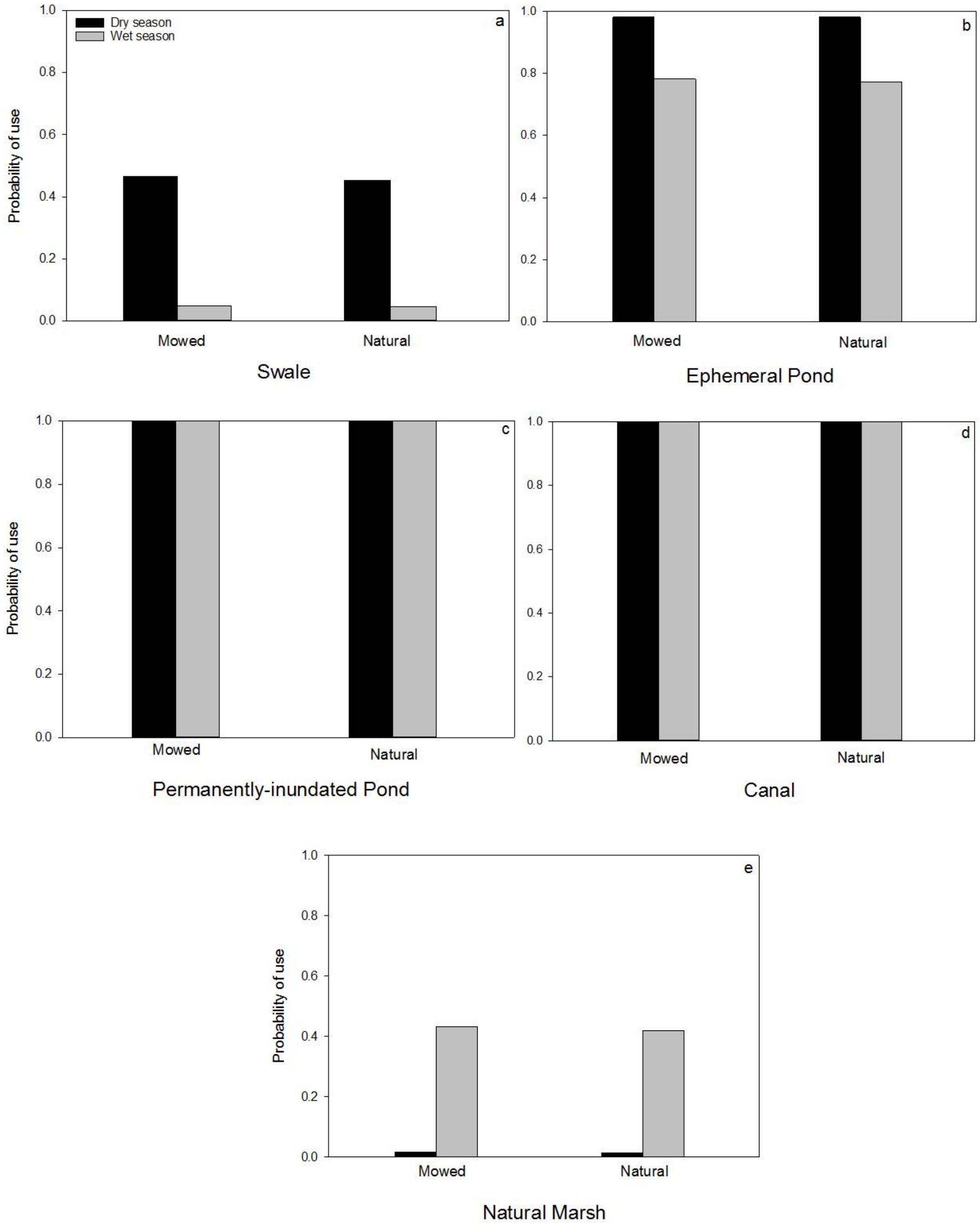

Figure 3-10. Changes in probability of use of roadway features by storks with vegetation maintenance (mowed or natural/tall) during wet (May-October) and dry (November-April) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

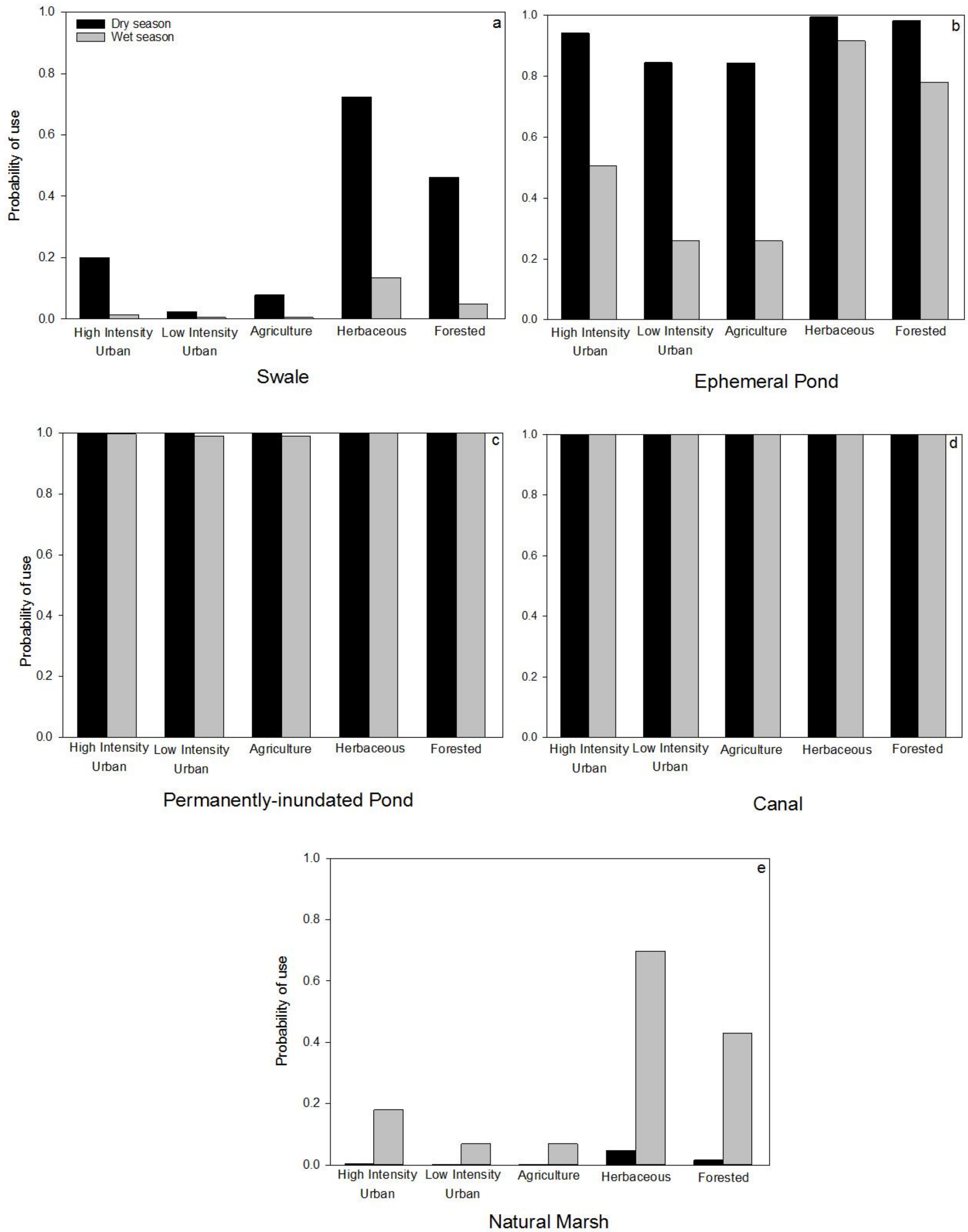

Figure 3-11. Changes in probability of use of roadway features by storks with vegetation cover at a 30x30 m resolution local scale during wet (May-October) and dry (November-April) seasons in South Florida, 2014-2016. All other variables in the model are assumed to be constant.

3.1.2 Conclusions

Storks used roadway corridor features primarily from January through June, with an initial increase in November and December as storks returned for the breeding season. Many storks disperse north after the breeding season, and return to Florida in early winter; thus, it's not surprising that more storks used roadways during the breeding season months. Overall, we observed more solitary storks than large foraging flocks in permanently inundated roadway features within the urban landscape. In the natural system, storks are attracted to flocks of other white wading birds (Kushlan, 1977; Green and Leberg, 2005) to signal that suitable prey resources are available at a site (Green and Leberg, 2005; Herring et al., 2015). Storks in the Everglades rely on the presence of other birds as a cue for foraging habitat to a much greater degree than do storks in other systems, likely because the Everglades fluctuates greatly in habitat quality (Herring et al., 2015). In contrast, storks in urban landscapes adjacent to the Everglades relied little on other white birds, suggesting that resources are more predictable in urban areas. Additionally, we did not observe a difference in age classes of storks using roadway features, suggesting that there isn't a particular cohort of storks (i.e., juveniles or adults) that forage strictly in constructed wetlands. It is not known whether the adults were breeding and thus having to find adequate food when energy demands are highest.

Stork use of roadway feature sites varied between ephemeral and permanently inundated sites with storks using permanently inundated sites more frequently than ephemeral sites. There was an overall trend at ephemeral sites for stork use to decrease with increasing rainfall during the dry season. This pattern was unexpected, but in light of other evidence suggesting that the permanent water features provide stork habitat, the decreasing use of ephemeral sites with increasing rain could simply be because, even with rain, ephemeral sites never reach the quality of permanent water features. Indeed, stork use of natural marshes and permanently inundated features increased with increasing rainfall, suggesting that storks preferred these areas even when ephemeral features were available.

Regardless of distance to nearest colony, roadway, or wetland, swales were not likely to be used by storks. Ephemeral ponds, however, had a high probability of use, which increased as the distance from colonies, wetlands, and roadways decreased. Similarly, Herring and Gawlik (2011) found that sites closer to colonies were more likely to be used than more distant sites. Previous studies suggest that birds in anthropogenic environments are often more closely associated with landscape-level features than with local-scale habitat measures (Melles et al., 2003; Luther et al., 2008; Mora et al., 2011), and another study in the Everglades found that storks preferred to forage closer to colonies rather than far from them (Herring and Gawlik, 2011). Thus, we were not surprised that proximity to colonies and wetlands increased use of ephemeral roadway features. However, given that storks are well-documented as being sensitive to human disturbance (Rodgers and Smith, 1995; Rodgers and Schwikert, 2002), we expected that stork use would increase the further from the roadway whereas the opposite was true. We do note that we never surveyed areas greater than 500 m from the roadway so all storks observed during our surveys were located relatively near the roadway. Nevertheless, this is another pattern that is consistent with the notion that roadways may provide higher quality foraging habitat than previously understood.

Physical attributes such as slope also affected stork use of ephemeral sites. Ephemeral pond use was highest when feature slopes were shallow and high, with use being lowest at moderately sloped features. This trend is likely influenced by the lack of moderately-sloped features within our survey routes. However, ephemeral features with higher slopes potentially lead to higher prey concentrations (see Section 3.2), which may attract foraging storks. Additionally, the high variation in morphology and hydrology of our ephemeral ponds likely leads to noted results. Features in urban areas tended to have high slopes while features in wetland cover were more gently sloped. The later tended to contain standing water and/or saturated soils a good part of the year.

Vegetative attributes influenced stork use of ephemeral sites. For overall landscape cover type, storks were most likely to use swales in herbaceous marshes during the dry season. All other landscape cover types had a lower probability of use. Swales located in the herbaceous marsh cover type were nearest the natural marsh system, suggesting some landscape-level of use. While stork use seems to indicate swales as poor-quality habitat, their location near the natural system may make them more attractive to storks already foraging in the natural marsh. Overall the maintenance of vegetation of roadway features did not seem to influence stork use, however fine-scale vegetation (30 x 30 m scale) did influence use of ephemeral features. Similar to landscape level vegetation, swales were most likely to be used in herbaceous marsh areas. Ephemeral ponds had a low probability of use in urbanized and agricultural areas during the wet season, however probability of use of these areas increased during the dry season when breeding storks experience increased energetic demands of raising nestlings during (Kahl, 1964). Many of the ephemeral features in herbaceous and forested marsh cover had high native species composition. At these sites, slopes were low and drainage limited, likely due to the flat nature of the South Florida landscape.

Clearly defining feature types is critical to identifying and evaluating differences in habitat quality. Some of the roadside features are contiguous with neighboring canals and natural marsh. At given periods in the year, the marsh, canal and “swale” or broad roadway edge complex is often inundated with surface water for extended periods. These roadway edges are readily available for foraging by storks, likely increasing the probability of roadway collision

Overall there was a general trend for ephemeral roadway features to be used during the dry season, likely because energy demands are high while raising young, and dynamic water levels in the natural system periodically reduce the quality of natural foraging habitat. An unpredictable increase in water during the dry season allows prey to disperse out of concentrated pools in the natural marsh (Frederick and Collopy, 1989; Botson et al., 2016) at which time some species of wading birds temporarily switch to anthropogenic habitats (Dorn et al., 2011). Hydrologic reversals reduce prey availability for storks, which require a narrow range of water depths to forage optimally (Gawlik, 2002). Whereas stork use of ephemeral features increased during the dry season, stork use of permanently inundated sites, such as large storm water ponds or canals, was high regardless of season, local, and landscape level characteristics.

Overall, permanently inundated feature sites had a high probability of use regardless of parameters measured. Permanently inundated roadway features are consistently wet whereas natural marshes fluctuate between wet and dry conditions. Furthermore, canals have open edges for foraging where fish seek refuge from deep water predators and potentially high secondary productivity from nutrient subsidies (Stolen et al., 2007; Fidorra et al., 2016). Furthermore, anthropogenic water features provide a dispersal pathway for exotic fish species (Shafland et al., 2008; Kline et al., 2014). Canals in particular are dominated by large-bodied and exotic fish species due to deeper water and warmer temperatures, providing refuge during drought and cold stress conditions (Shafland and Pestrak, 1982; Loftus and Kushlan, 1987; Trexler et al., 2000).

While permanently inundated features have longer hydroperiods than natural marshes, natural marshes can produce exceedingly high densities of available prey for storks under certain hydrologic regimes, which is thought to control the size of stork nesting populations (Bancroft, 1989; Ogden, 1994). But given that marsh water levels fluctuate between wet and dry periods, the anthropogenic water features may at times provide wading birds with more predictable, albeit possibly lower quality habitat.

3.2 Stork prey production in roadway corridor features

3.2.1 Prey summary

We sampled aquatic fauna in swales, canals, ephemeral ponds, and permanently inundated ponds from June 2014 to May 2016. We collected 42,024 aquatic fauna identified to 44 taxonomic groups (Table 3-6). We collected 14,178 aquatic fauna from the natural marsh landscape (Table 3-6) The length of fauna captured ranged from 0.1–73.8 cm with an average of 2.22 cm ± 0.01 SE in all roadway corridor features (Table 3-7). Aquatic fauna weight ranged from 0.001–690 g with an average of 0.67 g ± 0.04 SE. Average stork prey biomass and water depth varied across both ephemeral and permanently inundated features (Fig. 3-12, 3-19). There were four swales that never were wet and had no stork prey biomass (Fig. 3-13).

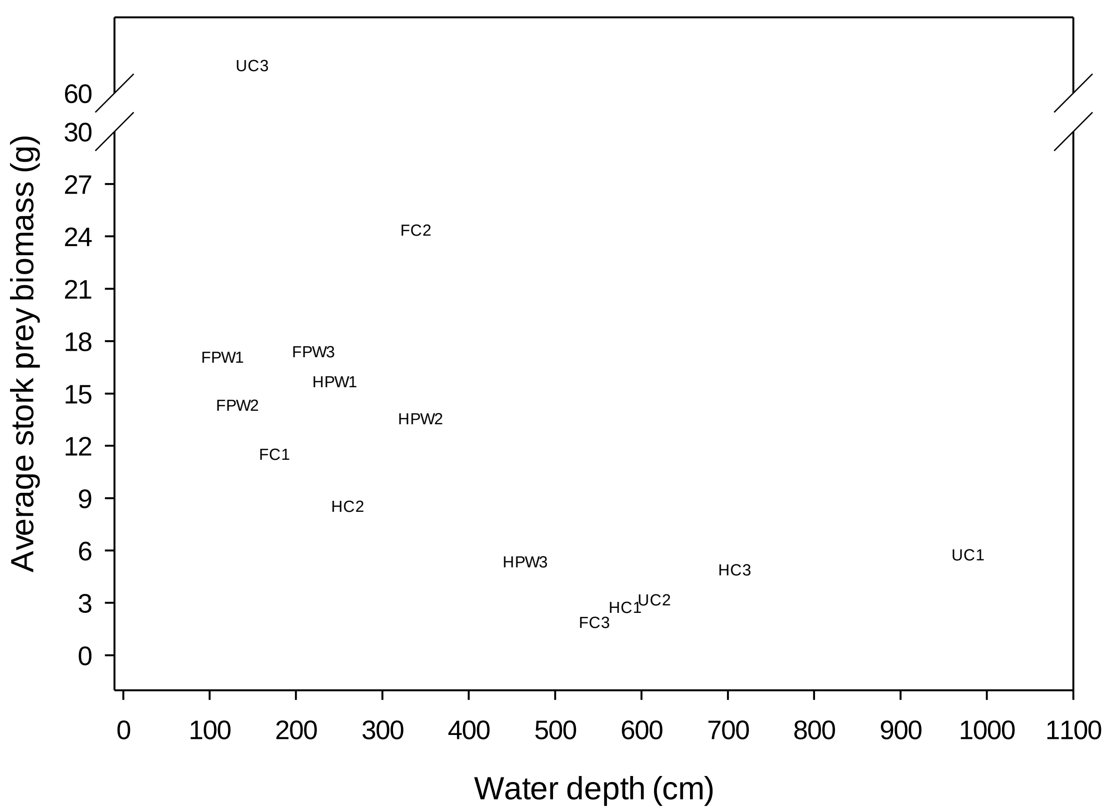

Figure 3-12. Average stork prey biomass and water depth of permanently inundated feature sites, 2014-2016, South Florida. Abbreviations: UC, urban canal; UPW, urban permanently-inundated pond; HC, herbaceous canal; HPW, herbaceous permanently inundated pond; FC, forested canal; FPW, forested permanently inundated pond;

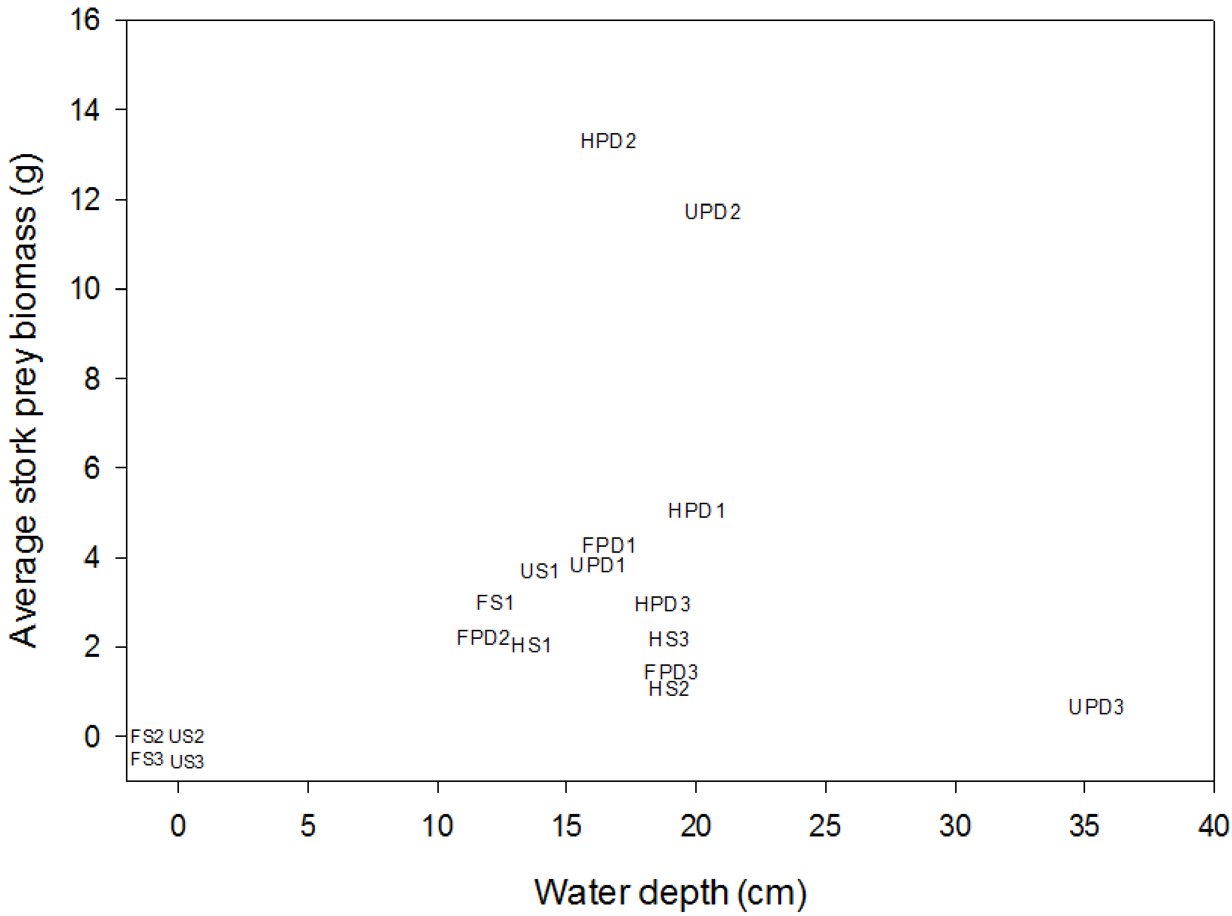

Figure 3-13. Average stork prey biomass and water depth of ephemeral feature sites, 2014-2016, South Florida. Abbreviations: UPD, urban ephemeral pond; US, urban swale; HPD, herbaceous ephemeral pond; HS, herbaceous swale; FPD, forested ephemeral pond; FS, forested swale.

Prey summary by landscape cover type – For landcover types, the most common species in the forested landscape were least killifish (*Heterandria formosa*), grass shrimp (*Palaemonetes paludosus*), tadpoles (*Anura* species), and mosquitofish (*Gambusia holbrooki*), accounting for 86% of all fauna captured. Crayfish (*Procambarus* species), least killifish, warmouth (*Lepomis gulosus*), and grass shrimp contributed 50% to the total biomass in the forested marsh landscape. For the herbaceous marsh landscape, grass shrimp, tadpoles, and bluefin killifish (*Lucania goodei*) were the most common species, accounting for 77% of all fauna captured. Largemouth bass (*Micropterus salmoides*), mosquitofish, bowfin (*Amia calva*), and tadpoles contributed 50% to the total biomass in the herbaceous marsh landscape. For the urban landscape, the most common species were mosquitofish, African jewelfish (*Hemichromis bimaculatus*), tadpoles, and Mayan cichlids (*Cichlasoma urophthalmus*), accounting for 68% of all fauna captured. Similarly, Mayan cichlids, African jewelfish, and crayfish contributed 73% to the total biomass in the urban landscape. The most common species in the natural marsh landscape were grass shrimp, mosquitofish, least killifish, and bluefin killifish, accounting for 81% of all fauna captured. Grass shrimp, crayfish, mosquitofish, and bluefin killifish contributed 55% to the total biomass.

Prey summary by feature type – For feature types, the most common species in canals were grass shrimp, mosquitofish, bluefin killifish, and African jewelfish, accounting for 76% of all fauna captured. African jewelfish, warmouth, grass shrimp, largemouth bass, and Mayan cichlids contributed 68% to the total biomass in canal feature types. For permanently inundated stormwater ponds, least killifish, grass shrimp, mosquitofish, and tadpoles were the most common species, accounting for 84% of all fauna captured. Mayan cichlids, crayfish, African jewelfish, least killifish, and largemouth bass contributed 66% to the total biomass in the permanently inundated stormwater pond feature type. For ephemeral ponds, mosquitofish and tadpoles were the most numerous species, accounting for 75% of all fauna captured and accounted for 73% of the total biomass. For the swales, tadpoles were the most common species captured, accounting for 47% of all fauna captured. Similarly, tadpoles and crayfish contributed 64% to the total biomass in the swale feature type.

Prey summary by feature type nested within landscape cover type – Species composition also varied by feature type depending on the larger landscape cover class. The most common species found in forested canals were grass shrimp and mosquitofish, accounting for 50% of all fauna captured. Warmouth, African jewelfish, and largemouth bass contributed 54% to the total biomass in forested canals. In forested permanently inundated ponds, the most common species were least killifish, tadpoles, and grass shrimp, accounting for 90% of all fauna captured. Least killifish, crayfish, grass shrimp, tadpoles, and Mayan cichlids contributed 61% to the total biomass in permanently inundated forested ponds. The most common species found in forested ephemeral ponds were tadpoles and mosquitofish, accounting for 63% of all fauna captured. Crayfish and tadpoles contributed 63% to the total biomass in forested ephemeral ponds. The most common species found in forested swales were least killifish and mosquitofish, accounting for 71% of all fauna captured. Crayfish contributed 50% to the total biomass in forested swales.

In herbaceous canals, the most common species were mosquitofish and tadpoles, accounting for 77% of all fauna captured and contributed 54% to the total biomass. The most common species found in herbaceous permanently inundated ponds were mosquitofish and bluefin killifish, accounting for 69% of all fauna captured. Amphiuma (*Amphiuma* spp.) and largemouth bass contributed 53% to the total biomass in herbaceous permanently inundated ponds. Mosquitofish and tadpoles were the most common species found in herbaceous ephemeral ponds, accounting for 81% of all fauna captured and contributed 66% to the total biomass. The most common species found in herbaceous swales were tadpoles and mosquitofish, accounting for 54% of all fauna captured. Tadpoles contributed 73% to the total biomass in herbaceous swales.

In urban canals, the most common species were African jewelfish, grass shrimp, mosquitofish, and Mayan cichlids, accounting for 77% of all fauna captured. African jewelfish, Mayan cichlids, largemouth bass, and jaguar cichlids (*Parachromis managuensis*) contributed 73% to the total biomass in urban canals. The most common species found in urban permanently inundated ponds were mosquitofish and African jewelfish, accounting for 61% of all fauna captured. African jewelfish, Mayan cichlids, and crayfish contributed 78% to the total biomass in urban permanently inundated ponds. Tadpoles and mosquitofish were the most common species found in urban ephemeral ponds, accounting for 70% of all fauna captured. The most common species found in urban swales were tadpoles, accounting for 90% of all fauna captured and contributed 91% to the total biomass.

Table 3-6. Number of individuals of each species identified from minnow trap and throw-traps nested within landscape cover types and corridor features from June 2014 to May 2016, South Florida.

Common name (species name)	**UC**	**UPW**	**UPD**	**US**	**HC**	**HPW**	**HPD**	**HS**	**FPD**	**FC**	**FPW**	**FS**	**NM**
African jewelfish (*Hemichromis letourneauxi*)	620	437	47	0	53	2	47	0	1	256	56	6	17
Amphiuma (*Amphiuma* species)	0	0	0	0	1	4	3	0	0	2	2	0	0
Apple snail (*Pomacea* species)	142	2	0	1	7	0	22	33	0	2	12	0	1
Beetle *(Coleoptera* species)	0	0	14	2	1	1	76	41	66	1	51	2	26
Black acara (*Cichlisoma bimaculatum*)	17	2	0	0	0	2	6	0	0	2	0	0	1
Bluefin killifish (*Lucania goodei*)	72	2	1	0	919	694	52	0	1	250	89	0	1,386
Bluegill (*Lepomis macrochirus*)	9	70	0	0	10	15	0	0	0	0	3	0	2
Bluespotted sunfish (*Enneacanthus gloriosus*)	1	1	0	0	32	32	0	0	0	56	5	0	37
Blue tilapia (*Oreochromis aureus*)	2	0	0	0	0	0	0	0	0	2	1	0	4
Bowfin (*Amia calva*)	0	1	0	0	1	0	0	0	0	0	0	0	0
Brook silverside (*Labidesthes sicculus*)	2	0	0	0	2	1	0	0	0	1	0	0	0
Brown hoplo *(Hoplosternum littorale*)	0	0	6	0	0	0	0	0	0	2	7	0	2
Brown bullhead (*Ameiurus nebulosus*)	0	0	0	0	0	0	0	1	0	1	7	0	1
Chain pickerel (*Esox niger*)	0	0	0	0	0	0	0	0	0	1	0	0	0
Clown knifefish (*Chitala ornata*)	2	0	0	0	0	0	0	0	0	0	0	0	0
Crayfish (*Procambarus* species)	24	47	4	0	36	12	137	24	343	32	252	19	535
Damselfly (*Zygoptera* species)	4	2	12	7	0	1	17	10	26	0	12	1	19
Dollar sunfish (*Lepomis marginatus*)	0	0	0	0	3	122	0	0	0	113	5	0	18
Everglades pygmy sunfish (*Elassoma evergladei*)	0	0	0	0	2	0	0	17	0	1	2	1	428
Dragonfly (*Odonata* species)	3	1	109	102	39	0	83	38	223	16	86	3	263
Flagfish (*Jordanellae floridae*)	0	0	0	0	41	59	3	0	7	111	23	13	341
Florida gar (*Lepisosteus platyrhincus*)	0	0	0	0	0	1	0	0	0	1	3	0	0
Giant water bug (*Belostomatidae* species)	4	4	85	4	0	3	74	49	67	0	0	2	12
Golden topminnow (*Fundulus chrysotus*)	9	1	0	0	34	60	2	0	7	40	18	2	223
Grass shrimp (*Palaemonetes paludosus*)	347	45	0	0	2,747	84	10	0	12	1,970	3,954	12	6,410
Jaguar cichlid (*Parachromis managuensis*)	10	1	3	0	0	2	2	0	0	1	0	0	0
Largemouth bass (*Micropterus salmoides*)	6	92	0	0	15	55	1	0	0	39	7	0	2
Least killifish (*Heterandria Formosa*)	8	0	0	0	95	131	156	6	35	48	8,688	123	1,840
Marsh killifish (*Fundulus confluentus*)	0	0	1	0	0	1	7	1	3	7	0	0	52
Mayan cichlid (*Cichlasoma urophthalmus*)	319	149	0	0	41	53	4	0	0	23	50	3	4

Table 3-6, continued

Common name (species name)	**UC**	**UPW**	**UPD**	**US**	**HC**	**HPW**	**HPD**	**HS**	**FPD**	**FC**	**FPW**	**FS**	**NM**
Mayfly (*Ephemeroptera* species)	0	1	1	0	0	0	20	2	6	0	0	0	0
Mosquitofish (*Gambusia holbrooki*)	325	500	364	0	797	1,458	2,372	68	702	629	637	267	1,896
Oscar (*Astronotus ocellatus*)	4	4	0	0	1	0	0	0	0	1	2	0	0
Predaceous diving beetle (*Dystiscidae* species)	0	0	0	0	1	1	4	8	22	1	7	0	37
Redear sunfish (*Lepomis microlophus*)	10	30	3	0	37	24	0	0	0	71	5	0	2
Sailfin molly (*Poecilia latipinna*)	52	3	0	0	304	61	78	2	0	13	10	10	421
Spotted sunfish (*Lepomis punctatus*)	5	5	0	0	12	8	0	0	0	16	26	0	45
Spotted tilapia (*Pelmatolapia mariae*)	34	95	1	0	42	1	1	0	0	54	34	0	1
Swamp darter (*Etheostoma fusiforme*)	27	1	0	0	397	146	0	0	0	68	31	0	0
Tadpole madtom (*Notorus gyrinus*)	5	0	0	0	2	0	0	0	0	0	0	0	6
Threadfin shad (*Dorosoma cepedianum*)	1	34	0	0	0	0	0	0	0	0	0	0	0
Unknown fish (*Osteichthyes* species)	6	4	25	0	21	15	6	0	7	33	18	2	73
Walking catfish (*Clarias batrachus*)	0	0	15	0	0	0	6	3	0	0	3	0	0
Warmouth (*Lepomis gulosus*)	9	10	0	0	28	47	1	0	1	34	48	0	3
	2,079	**1,544**	**1,230**	**492**	**5,722**	**3,097**	**4,847**	**555**	**2,379**	**3,921**	**15,691**	**467**	**14,178**

Abbreviations: UC, urban canal; UPW, urban permanently- inundated pond; UPD, urban ephemeral pond; US, urban swale; HC, herbaceous canal; HPW, herbaceous permanently inundated pond; HPD, herbaceous ephemeral pond; HS, herbaceous swale; FC, forested canal; FPW, forested permanently inundated pond; FPD, forested ephemeral pond; FS, forested swale; NM, natural marsh.

Table 3-7. Length mean ± SE and range and biomass mean ± SE and range of fish sampled in landscape cover types and corridor features from June 2014 to May 2016 in South Florida. N is the number of sites sampled within each feature type.

	N	Length mean (cm)	Length range (cm)	Biomass mean (g)	Biomass range (g)
Urban canal	3	3.10 ± 0.03	0.4 – 24.0	2.04 ± 0.14	0.01 – 200.0
Urban permanently inundated pond	3	3.42 ± 0.05	1.0 – 26.5	3.65 ± 0.42	0.01 –190.0
Urban ephemeral pond	3	1.71 ± 0.02	0.1 – 6.1	0.2 ± 0.01	0.01 – 12.4
Urban swale	2	1.74 ± 0.05	0.4 – 4.3	0.2 ± 0.01	0.01 – 2.3
Herbaceous canal	3	2.35 ± 0.02	0.3 – 69.5	0.44 ± 0.13	0.01 – 690.0
Herbaceous permanently inundated pond	3	2.71 ± 0.04	0.8 – 73.8	1.36 ± 0.32	0.01 – 560.0
Herbaceous ephemeral pond	3	1.82 ± 0.01	0.4 – 8.1	0.23 ± 0.01	0.01 – 17.6
Herbaceous swale	3	1.67 ± 0.03	0.4 – 7.6	0.23 ± 0.02	0.01 – 6.9
Forested canal	3	2.61 ± 0.02	0.2 – 37.0	0.91 ± 0.17	0.01 – 500.0
Forested permanently inundated pond	3	2.12 ± 0.01	0.1 – 72.0	0.39 ± 0.04	0.01 – 250.0
Forested ephemeral pond	3	1.26 ± 0.01	0.1 – 8.2	0.15 ± 0.01	0.01 – 20.1
Forested swale	1	1.39 ± 0.04	0.4 – 4.5	0.16 ± 0.03	0.01 – 5.2
Natural marsh	116	1.55 ± 0.06	0.01-51.0	0.16 ± 0.01	0.01 – 7.0

3.2.2 Site morphology and plant community structure

Slope and feature depth – The difference in slopes between land use type (wetland vs. urban) was only marginally significant ($F_{1,36}$=6.20, P < 0.018). The difference in slopes between feature types were marginally significant when grouped across landscape type ($F_{2,27}$=3.72, P < 0.03; Appendix C, Fig. C1); however, slopes did differ by feature type ($F_{3,34}$=13.17, P < 0.001) with canals having the steepest slopes (Fig. 3-14). There was a significant difference in slopes between permanently inundated features (ponds and canals) and ephemeral feature types (ponds and swales) ($F_{1,36}$=7.80 P < 0.002). Permanently inundated ponds and canals had steeper slopes than ephemeral ponds and swales. For landscape cover types, there was a significant difference between slopes ($F_{11,26}$ = 10.65, P < 0.001) and feature type nested within landscape cover type ($F_{1,36}$= 5.04, P = 0.0008).

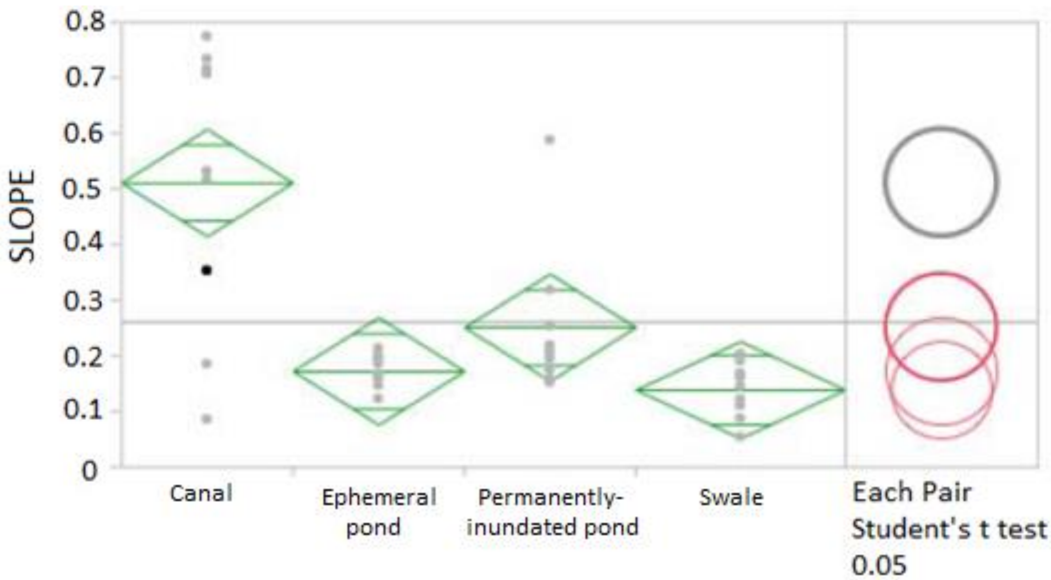

Figure 3-14. Comparison of slopes by feature type, 2014-2016, South Florida.

The difference in mean feature depth by land use type was marginally significant ($F_{2,27}$ = 3.72, P < 0.03), however there was no significant difference in mean feature depth by landscape cover type or feature type.

Edge-to-area ratio – There was no significant different in edge-to-area ratio across landscape cover types. There was a significant difference by land use (urban or natural marsh) in the permanently inundated pond feature type. Permanently inundated ponds in the natural marsh landscape cover type had greater edge-to-area ratios than Permanently inundated ponds in urban areas (Fig. 3-15).

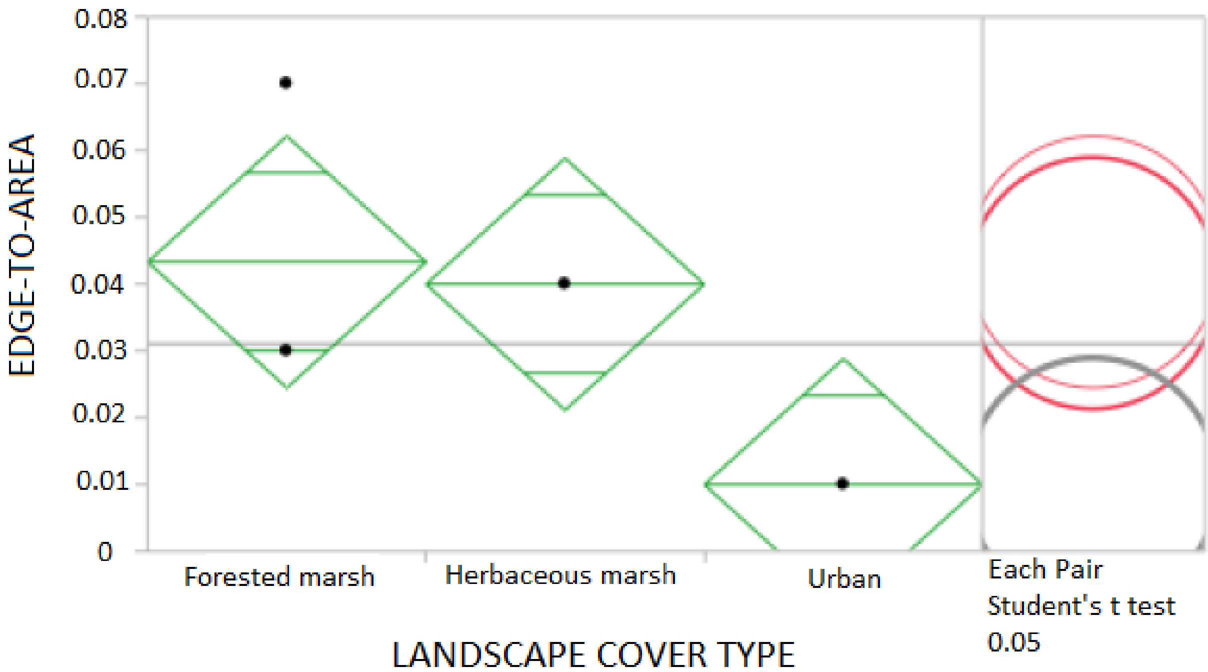

Figure 3-15. Comparison of edge-to-area ratios of permanently inundated pond feature type across landscape cover types, 2014-2016, South Florida.

Plant percent cover – The urban land use type had a greater percent cover than natural marsh (herbaceous and forested) land use type (t=-2.37, df=117). There was a marginally significant difference in plant cover by landscape cover type ($F_{2,156} = 3.45$, $P < 0.03$; Appendix C, Fig. C2). There was a significant difference in plant cover across feature types ($F_{5,153} = 10.20$, $P < 0.0001$). Swales, ephemeral ponds, and canal banks had the greatest percent cover (Fig. 3-16). There was a significant difference in plant cover across feature types nested within landscape cover types ($F_{17,441} = 5.00$, $P < 0.001$). For permanently inundated feature types, banks and littoral zones differed with banks having a greater percentage of plant cover than littoral zones (t = 2.918, df = 91, P = 0.004). Although not represented by the limited number of sample sites, canopy cover appears greater in natural marsh landcover type with forested wetland features containing greater tree canopy cover (particularly on the far bank of canals and in wet ponds). Shrub cover, predominantly *Ludwigia peruviana*, was greater in the natural marsh landcover than in urban features.

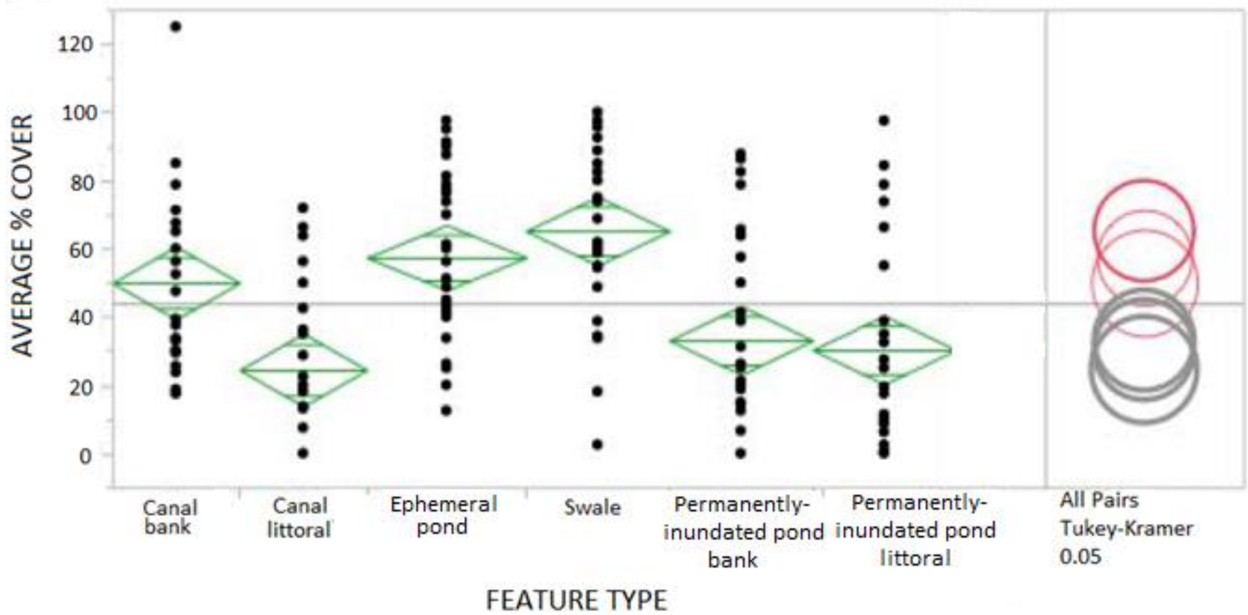

Figure 3-16. Comparison of average percent cover across all feature types, 2014-2016, South Florida.

Plant community structure – Using 144 sites and cover of 71 species, nMDS results indicated little difference in plant community structure across all samples driven primarily by one axis. However, PCA results indicated that the first three axes explained approximately 34% of the cumulative variance in plant community structure (Fig. 3-17). Bray Curtis ordination indicated similar results: the first three axes (Fig. 3-18).

Differences in plant community structure were observed between feature types and within the urban landscape cover type, with ephemeral features dominated by sod and weedy species (*Bidens* spp., *Richardia* spp., and *Spermacoce*; Appendix C, Figs. C3, C4). Permanently inundated features contained wet prairie vegetation (*Eleocharis elongata*, *Rhynchospora traycii*) and marsh species (*Utricularia* spp., *Nymphaea* spp.). Permanently inundated features did not have a high percent cover, unless floating species (*Utricularia* spp., *Pistia* spp., and *Eichhornia crassipes*) were included.

Plant community structure varied between forested and herbaceous marsh landscape cover types (Appendix C, Fig. C5). Plant community structure also differed between feature types in the forested marsh landscape cover type (Appendix C, Fig. C6). Plant community structure of feature types in the herbaceous marsh landscape cover type did not significantly differ. The high variability between feature type structure and relatively low sample numbers likely made it more difficult to observe significant differences in community structure between landscape cover types.

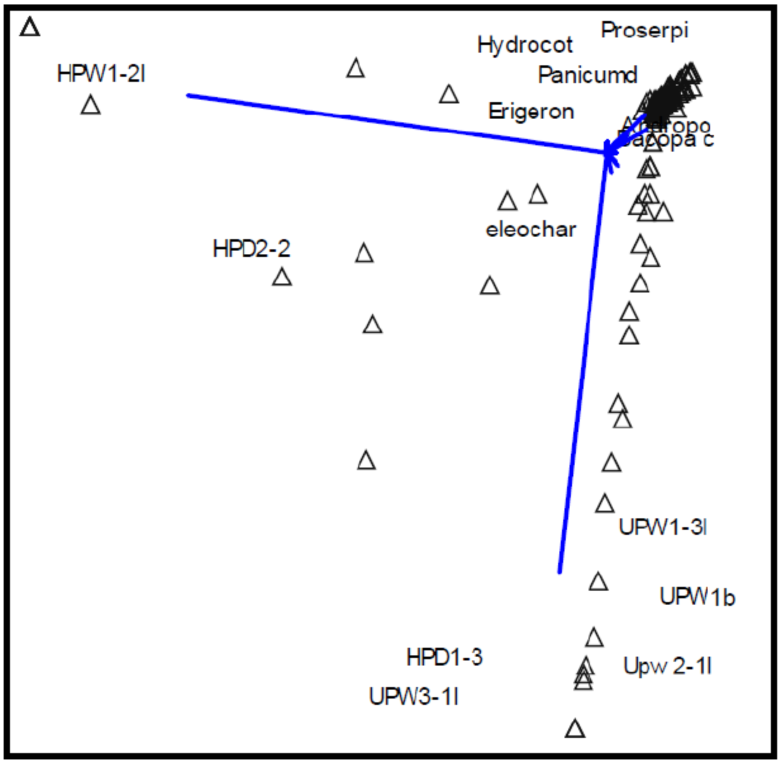

Figure 3-17. Plant community differences between sampling sites using PCA, 2014-2016, South Florida.

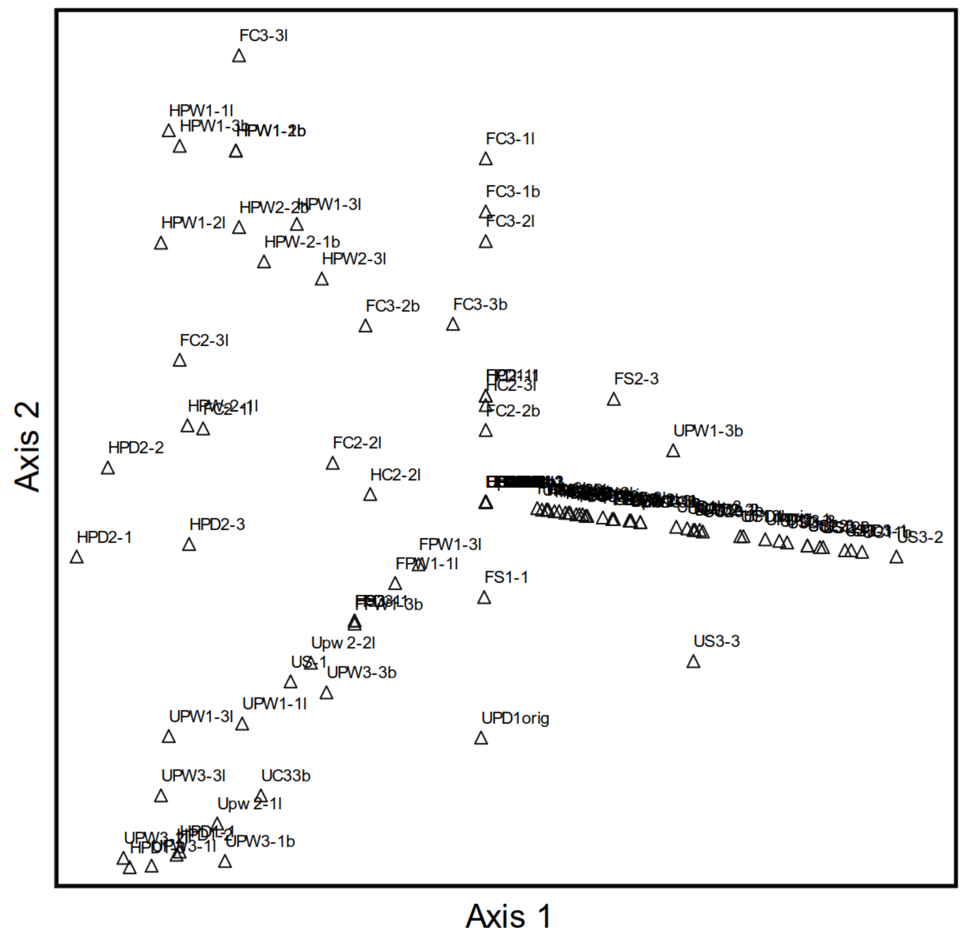

Figure 3-18. Bray Curtis ordination of all sites indicates axes 1&2 explain only a limited amount of variance 17% of the community structure data.

3.2.3 Permanent feature prey production models

The global model was the top model (w_i = 0.97, R^2 = 0.20; Table 3-8) explaining Stork prey species – the variation in stork prey species within permanently inundated roadway sites. The coefficient for slope had the strongest influence on prey biomass, with more shallow slopes providing higher concentrations of prey. Similarly, the coefficient for water depth was negative, suggesting that areas with shallow water depths had higher prey biomass. However, the influence of water depth was minimal, with a coefficient close to zero. Landscape cover type and season also influenced prey biomass. Roadway sites within an urban landscape contained more prey biomass than all other landscape cover types; roadway sites within an herbaceous landscape contained the least prey biomass. Additionally, roadway sites had higher stork prey biomass in the dry season compared to the wet season. Parameter estimates for other variables overlapped zero, indicating uncertain relationships with prey biomass (Table 3-9). Furthermore, the spatial extent of the Everglades is much greater than scattered roadway wetlands found throughout South Florida so natural wetlands likely produce more stork prey biomass overall than do roadways. Furthermore, roadway features can produce risks for storks, such as mortality from collisions with vehicles

Stork prey species and size classes – The global model was the top model (w_i = 0.55, R^2 = 0.16; Table 3-8) for explaining the variation in stork prey species and size classes within permanently inundated roadway sites. The second-best model was the hydrologic hypothesis (w_i = 0.22, R^2 = 0.13) containing the variables water depth and rainfall. The third best model was the habitat hypothesis (w_i = 0.14, R^2 = 0.14) containing the variables water depth, submerged and emergent vegetation, and feature area. The fourth best model was the production hypothesis (w_i = 0.09, R^2 = 0.13) containing the variables water depth, rainfall, and feature area. Together, these models accounted for 100% of the Akaike weight. Similar to the models for only stork prey, the coefficient for water depth was negative, suggesting that features with shallower water have higher prey biomass. Additionally, models with both stork prey species and size classes were influenced by landscape cover type. Prey biomass within roadway features was positively influenced by urban landscape cover, but negatively influenced by herbaceous landscape cover. Differing from prey models of only stork species, we did not find an influence of slope or season on models predicting both stork prey species and size classes. Parameter estimates for other variables overlapped zero, indicating uncertain relationships with prey biomass (Table 3-9).

Table 3-8. Results of generalized mixed models for stork prey within permanently inundated features in South Florida, 2014-2016. Only models with ΔAIC_c < 7 and null models are shown. Model are described with -2 log likelihood (-2Loglike), number of parameters (k), AIC_c values, differences in AIC_c values between the best model and each candidate model (ΔAIC_c), AIC_c weights (w_i), and the likelihood coefficient of determination (R^2).

Model	-2Loglike	k	AIC_c	ΔAIC_c	w_i	R^2
Prey species all lengths						
Global	1452.53	13	1479.42	0.00	0.97	0.20
	:	:	:	:	:	:
Null	1542.60	6	1554.80	75.38	0.00	0.000
Prey species and prey lengths						
Global	1379.69	14	1408.74	0.00	0.55	0.16
WaterDepth + Rainfall	1392.12	9	1410.56	1.82	0.22	0.13
WaterDepth + SubVeg + EmergeVeg + Area	1388.77	11	1411.42	2.69	0.14	0.14
WaterDepth + Rainfall + Area	1391.86	10	1464.94	3.66	0.09	0.13
	:	:	:	:	:	:
Null	1450.68	7	1465.95	56.21	0.00	0.000

Table 3-9. Model averaged parameter estimates (β), 95% confidence limits (LCL, UCL), and variable importance values (Σw_i) for models ($\Delta AIC_c < 7$) predicting stork prey concentrations in permanently inundated sites in South Florida, 2014-2016.

Parameter	β	LCL	UCL	Σw_i
Prey species all lengths				
Intercept	0.301	-0.405	1.007	1.00
Rainfall	-0.001	-0.033	0.031	1.00
Area	0.003	-0.007	0.013	1.00
SubVeg	0.006	-0.0001	0.012	1.00
EmergeVeg	-0.007	-0.014	0.0006	1.00
Slope	-1.878	-2.99	-0.763	1.00
WaterDepth	-0.003	-0.003	-0.002	1.00
LittoralWidth	0.313	-0.012	0.637	1.00
FeatureType				
Canal	0.461	-0.004	0.925	1.00
Permanently inundated Pond	0			1.00
Landscape				
Urban	0.682	0.280	1.084	1.00
Herbaceous	-0.807	-1.215	-0.400	1.00
Forested	0			1.00
Season				
Dry	0.296	0.020	0.572	1.00
Wet	0			1.00
Prey species and prey lengths				
Intercept	-0.254	-0.806	0.299	1.00
Rainfall	0.005	-0.022	0.032	0.86
Area	0.001	-0.006	0.009	0.78
SubVeg	0.004	-0.001	0.009	0.69
EmergeVeg	-0.004	-0.010	0.001	0.69
Slope	0.004	-0.001	0.009	0.55
LittoralWidth	0.155	-0.063	0.373	0.55
WaterDepth	-0.002	-0.002	-0.002	1.00
FeatureType				
Canal	0.171	-0.420	0.762	1.00
Permanently inundated	0			1.00
Landscape				
Urban	0.506	0.044	0.968	1.00
Herbaceous	-0.554	-1.077	-0.030	1.00
Forested	0			1.00
Season				
Dry	0.298	-0.011	0.607	1.00
Wet	0			1.00

3.2.4 Ephemeral feature prey production models

Stork prey species – The global model was the top model (w_i = 0.62, R^2 = 0.29; Table 3-10) for explaining the variation in stork prey species within ephemeral roadway sites. The second-best model was the feature hypothesis (w_i = 0.37, R^2 = 0.23) containing the variables submerged and emergent vegetation, connectivity to a permanently inundated feature, feature area, and slope. Together, these models accounted for 99% of the Akaike weight. Prey biomass within roadway features was positively influenced by slope, suggesting that steeper ephemeral features contain higher prey biomass. Rainfall negatively influenced prey biomass, but to a minimal extent since the parameter estimate was very close to zero. Additionally, season influenced stork prey biomass in ephemeral sites, with increased prey biomass in the wet season compared to the dry season. Parameter estimates for other variables overlapped zero, indicating uncertain relationships with prey biomass (Table 3-11).

Stork prey species and size classes – The feature hypothesis was the top model (w_i = 0.72, R^2 = 0.15) for explaining the variation in stork prey species and size classes within ephemeral roadway sites. The feature hypothesis contained the variables submerged and emergent vegetation, connectivity to a permanently inundated feature, feature area, and slope. The global model was the second-best model (w_i = 0.16, R^2 = 0.17; Table 3-10). Together, these models accounted for 89% of the Akaike weight. Similar to the models for only stork prey species, prey biomass including prey size classes within roadway features was positively influenced by slope, suggesting that steeper ephemeral features contained higher prey biomass. All other parameter estimates overlapped zero, indicating uncertain relationships with stork prey biomass (Table 3-11).

Table 3-10. Results of generalized mixed models for stork prey within ephemeral features in South Florida, 2014-2016. Only models with $\Delta AIC_c < 7$ and null models are shown. Model are described with -2 log likelihood (-2Loglike), number of parameters (k), AIC_c values, differences in AIC_c values between the best model and each candidate model (ΔAIC_c), AIC_c weights (w_i), and the likelihood coefficient of determination (R^2).

Model	-2Loglike	k	AIC_c	ΔAIC_c	w_i	R^2
Prey species all lengths						
Global	422.96	16	460.24	0.00	0.62	0.29
SubVeg + EmergeVeg + Connectivity + Area + Slope	431.80	13	461.23	0.99	0.37	0.23
	:	:	:	:	:	:
Null	462.93	8	480.23	20.00	0.00	0.000
Prey species and prey lengths						
SubVeg + EmergeVeg + Connectivity + Area + Slope	356.33	13	386.46	0.00	0.72	0.15
Global	353.90	15	389.48	3.01	0.16	0.17
Null	375.21	7	390.40	3.94	0.10	0.00

Table 3-11. Model averaged parameter estimates (β), 95% confidence limits (LCL, UCL), and variable importance values (Σw_i) for models ($\Delta AIC_c < 7$) predicting stork prey concentrations in ephemeral sites in South Florida, 2014-2016.

Parameter	β	LCL	UCL	Σw_i
Prey species all lengths				
Intercept	-5.23	8.89	-1.57	1.00
Area	0.087	-0.585	0.759	1.00
SubVeg	0.035	-0.001	0.072	1.00
EmergeVeg	-0.031	-0.057	-0.005	1.00
Slope	35.28	19.44	49.12	1.00
WaterDepth	0.020	-0.012	0.050	0.62
Rainfall	-0.066	-0.127	-0.005	0.62
Connect				
No	-0.546	-1.907	0.815	1.00
Yes	0			1.00
Hydroperiod	0.004	-0.049	0.057	0.62
FeatureType				
Swale	0.670	-0.445	1.785	1.00
Ephemeral pond	0			1.00
Landscape				
Urban	-0.745	-2.779	1.290	1.00
Herbaceous	-0.017	-1.144	1.110	1.00
Forested	0			1.00
Season				
Dry	-0.979	-1.647	-0.310	1.00
Wet	0			1.00
Prey species and prey lengths				
Intercept	-4.340	-7.678	-1.112	1.00
Area	-0.179	-0.770	0.412	1.00
SubVeg	0.031	-0.002	0.064	1.00
EmergeVeg	-0.020	-0.043	0.003	1.00
Slope	22.56	8.088	37.022	1.00
WaterDepth	0.003	-0.006	0.011	0.16
Rainfall	-0.008	-0.026	0.009	0.16
Connect				
No	-0.235	-1.468	0.999	1.00
Yes	0			1.00
Hydroperiod	0.003	-0.013	0.019	0.16
FeatureType				
Swale	0.416	-0.488	1.32	1.00
Ephemeral pond	0			1.00
Landscape				
Urban	-0.273	-2.098	1.552	1.00
Herbaceous	0.173	-0.828	1.174	1.00
Forested	0			1.00
Season				

Table 3-11, continued

Parameter	β	LCL	UCL	Σw_i
Dry	-0.399	-1.023	0.225	1.00
Wet	0			1.00

3.2.5 Conclusions

For roadway features, permanently inundated stormwater ponds and canals had the highest average stork prey biomass whereas ephemeral features had the lowest average stork prey biomass. There were also features that did not produce any stork prey and therefore should not be viewed as stork habitat. These features consisted of "dry" swales that did not hold water during the study period. These areas included four "dry swales" in the urban and forested marsh landscape types. Furthermore, swales in urban areas met original stormwater design criteria and were more likely to drain water than were swales in the forested/herbaceous marshes along I-75/Alligator Alley, which were more likely to hold water and produce stork prey. Additionally, there were forested marsh swales that were wet for multiple months due to direct connections to canals. If there is an interest in discouraging stork use of swales, one simple design feature is to have them drain water quickly to prevent stork prey production.

Fish sampling site physical features and vegetation structure – There was little variation in slope between feature types and feature types nested within landscape cover types. Canals were often more steep and deeper than other feature types, which is expected as ponds and swales have specific design criteria allowing for little difference in morphology. Similarly, there was a little variation in edge-to-area ratios; however, permanently inundated ponds in natural marshes (forested and herbaceous marsh) had greater edge-to-area ratio than those in the urban landscape cover type. Due to South Florida's low topography and minimal landscape slopes, the intended design criteria did not always match actual conditions. Many of the swales in the forested and herbaceous marsh landscape connected to neighboring canals, allowing aquatic fauna to move between features during times of high water levels.

Plant communities varied across landscape cover types, with urban environments dominated by planted sod, and forested and herbaceous marshes dominated by more native vegetation. Canals often contained direct hydrologic connection to adjacent natural marshes; thus, canals within the forested and herbaceous marsh landscape contained abundant native species. Ephemeral features (ephemeral ponds and swales) had greater vegetation cover than permanently inundated features (canals and permanently inundated ponds). Additionally, there was little difference observed in plant community structure across all feature types and landscape cover types. Permanently inundated features and ephemeral features did vary in their community structure. Differences in community structure were not observed in the herbaceous marsh landscape cover type; this may be due to a lower elevational profile resulting in ephemeral features which were wet a substantial part of the year.

Spraying, mowing, and other vegetation management strategies should continue to consider natural system variability to improve efficiency. For instance, mowing in already wet swales (holding standing water) can lead to soil disturbance, equipment degradation, and other unnecessary impacts whereas the prolonged water saturation during certain times of the year acts as a natural vegetation management tool.

Exotic plant species exist throughout the roadway corridor, yet cover (not including sod and other herbaceous ground-cover) was limited in our individual samples. A few species are dominant in all landscape cover types. The shrubs *Schinus terebinthifolius* and *Ludwigia peruviana*, and the grass *Panicum repens* are abundant. Little exotic tree cover was noted at sample sites, though small patches of *Melaleuca* were evident along the full project corridor. Exotic vegetation that precludes access by storks and hence foraging is included in the current stork foraging habitat mitigation calculations. Additionally, some shrub species may actually preclude access as much as larger species such as *Melaleuca* or *Casuarina* depending on plant cover and density.

Permanently inundated feature prey production models – Stork prey production in permanently inundated sites, such as large storm water ponds and canals, was influenced by slope, water depth, and landscape cover type. Features with more shallow slopes resulted in a higher production of stork prey. Prey production was likely higher due to the increased littoral zone with more shallow slopes. Fish use the littoral zone to feed, spawn, and seek refuge in vegetation from predators (Crowder and Cooper, 1982; Crowder et al., 1997; Rozas and Odum 1988), thus it's expected that sites with larger littoral zones would have an increased amount of fish present.

Fish production varied in permanently inundated roadway corridors depending on the landscape cover type. Urban stormwater ponds and canals had a higher overall production of fish when compared to the natural landscapes (i.e., forested and herbaceous marsh sites along I-75). High fish production in the urban landscape may be explained by the increased number of exotic cichlids in the urban landscape. The average prey weight for exotic cichlids in permanently inundated sites was 3.58 ± 0.29 g with an average length of 3.66 ± 0.04 cm whereas native fish had an average prey weight of 0.41 ± 0.04 g and length of 2.12 ± 0.01 cm. The spread of exotic fish in South Florida has been facilitated through the canal system. Dispersal of fishes have been demonstrated effectively for cichlid species, like African jewelfish and Mayan cichlids (O'Connor and Rothermel, 2013; Kline et al., 2014). African jewelfish one of the most common cichlid species was released in the 1960s through the aquarium trade. There are more exotic fish in the urban landscape probably due to the close proximity of the canals and stormwater ponds to the highly-populated east coast of South Florida. These patterns are consistent with the notion that aquarium fish releases are the origin of most introduced exotic fish (FFWCC, 2015).

Factors that increased stork prey production in roadway features

- Canals and permanently inundated stormwater ponds
    - Shallow slopes
    - Shallow water depth
    - Urban landscape cover type
- Ephemeral stormwater ponds and swales
    - Steep slopes
    - Low rainfall

Ephemeral feature prey production models – Stork prey production at ephemeral sites, such as ephemeral ponds and swales, was influenced by slope and rainfall. Features with more steep slopes resulted in a higher production of stork prey. Steep slopes likely increase water drainage opportunities into these features as well as have increased water retention. Thus, allowing or longer periods of inundation and increased fish production. Many of the swales in the forested marsh landscape connected to neighboring canals, allowing aquatic fauna to move between features during times of high water levels. Fish were able to use swales to colonize and act as refuges from larger predatory fish. Furthermore, there were urban swales that were rarely inundated due to the placement of grates to drain the water in these areas. These swales were observed to hold water for less than one hour and stork prey was never produced in these swales.

Rainfall had a minimal effect on prey biomass, however it was negative, suggesting that prey production was greater during low rainfall when shorter hydroperiod wetlands may be dry. High amounts of rainfall throughout the season will result in ephemeral sites being inundated longer, allowing for higher production of prey. Prey production does not necessarily respond to high amounts of rainfall immediately, thus this response may be delayed which resulted in the negative effect on prey biomass.

Not surprisingly, ephemeral sites had higher prey biomass during the wet season than the dry season. The majority of ephemeral sites were dry throughout the majority of the dry season resulting in no prey production during those times.

3.3 Stork prey

3.3.1 Stork diet summary

We collected 547 boluses from nestling storks during the 2014-2016 nesting seasons (Table 3-12). Bolus contents included 4,050 prey items identified to 41 taxonomic groups (Table 3-13). The most common prey species found in the Everglades colonies were African jewelfish, spotted sunfish (*Lepomis punctatus*), and dollar sunfish (*Lepomis marginatus*), accounting for 63% of all prey items within boluses. Similarly, the most common species found in urban colonies were mosquitofish, warmouth, spotted sunfish, and dollar sunfish, accounting for 52% of all prey items within boluses. For Everglades colonies, spotted sunfish, African jewelfish, brown bullhead (*Ameiurus nebulosus*), warmouth, and dollar sunfish contributed to the majority of prey biomass, comprising 78% of the total biomass. For urban colonies, warmouth, spotted sunfish, grass carp, and largemouth bass, contributed to the majority of the prey biomass, comprising 66% of the total biomass. Exotic species accounted for 32% of prey species and 18% of prey biomass in Everglades colonies, whereas exotic species only accounted for 5% of prey species and 10% of prey biomass in urban colonies. Prey length ranged from 0.5 cm – 35.7 cm with an average of 5.01 cm ± 0.18 SE in Everglades colonies, whereas prey length ranged from 0.4 cm – 70 cm with an average of 3.77 cm ± 0.07 SE in urban colonies (Fig. 3-19). Prey weight ranged from 0.01 g – 107 g with an average of 5.02 g ± 0.05 SE in Everglades colonies, whereas prey weight ranged from 0.01 g – 230 g with an average of 6.07 g ± 0.28 SE in urban colonies.

Table 3-12. Sample dates and number of stork boluses collected from colonies during the 2014-2016 nesting seasons, South Florida.

Paurotis Pond		Tamiami West		BallenIsles		Griffin		Sawgrass	
Sample date	No. of boluses	Sample date	No. of boluses	Sample date	No. of boluses	Sample date	No. of boluses	Sampl e date	No. of boluses
04/01/2014	3	03/24/2014	3	4/14/2015	7	4/16/2015	6	5/3/2015	5
04/04/2014	2	03/31/2014	3	4/21/2015	7	4/24/2015	7	5/9/2015	6
04/24/2014	8	04/03/2014	4	4/27/2015	6	4/30/2015	5	5/16/2015	5
04/29/2014	16	04/07/2014	3	5/4/2015	6	5/6/2015	10	5/18/2015	3
05/02/2014	2	04/10/2014	2	5/12/2015	11	5/13/2015	15	6/3/2016	5
05/06/2014	18	04/21/2014	3	5/20/2015	13	5/19/2015	12	6/11/2016	4
05/13/2014	4	04/24/2014	5	5/27/2015	17	5/28/2015	9	6/13/2016	1
05/20/2014	1	04/28/2014	5	6/2/2015	2	6/4/2015	4	6/18/2016	1
4/13/2015	1	05/01/2014	6	3/31/2016	10	4/5/2016	8	6/25/2016	2
4/20/2015	5	05/05/2014	8	4/7/2016	8	4/11/2016	7		
4/28/2015	8	05/08/2014	4	4/21/2016	10	4/19/2016	8		
5/1/2015	2	05/12/2014	6	4/28/2016	6	4/25/2016	8		
5/8/2015	3	05/16/2014	4	5/5/2016	18	5/3/2016	4		
5/11/2015	4	3/25/2015	4	5/12/2016	8	5/12/2016	7		
5/15/2015	3	3/28/2015	2	5/19/2016	4	5/17/2016	10		
5/18/2015	2	3/31/2015	5	6/2/2016	2	5/26/2016	1		
5/21/2015	5	4/4/2015	2	6/8/2016	3	5/31/2016	2		
4/15/2016	1	4/11/2015	8						
4/18/2016	9	4/18/2015	8						
4/26/2016	12	4/22/2015	6						
5/4/2016	13	4/30/2015	2						
5/9/2016	11	5/6/2015	4						
5/11/2016	2	5/13/2015	1						
5/16/2016	12	5/19/2015	1						
5/23/2016	1	5/28/2015	2						
5/25/2016	5								
Totals	**153**		**101**		**138**		**123**		**32**

Table 3-13. Species identified within Everglades and urban stork boluses during the 2014-2016 nesting seasons, South Florida. Number listed is total number of individuals identified within each taxonomic group.

Common name	**Species name**	**Everglades**	**Urban**
African jewelfish	*Hemichromis letourneauxi*	571	10
Black acara	*Cichlisoma bimaculatum*	16	21
Black seabass*	*Centropristis striata*	1	0
Bluefin killifish	*Lucania goodei*	7	37
Blue tilapia	*Oreochromis aureus*	0	12
Bluegill	*Lepomis macrochirus*	6	55
Brown bullhead	*Ameiurus nebulosus*	53	27
Brown hoplo*	*Hoplosternum littorale*	0	1
Brook silverside*	*Labidesthes sicculus*	0	1
Bluespotted sunfish	*Enneacanthus gloriosus*	14	66
Chain pickerel*	*Essox niger*	1	1
Common snook*	*Centropomus undecimalis*	6	0
Crayfish	*Procambarus* species	12	105
Dollar sunfish	*Lepomis marginatus*	174	150
Flagfish	*Jordanellae floridae*	57	85
Golden topminnow	*Fundulus chrysotus*	50	61
Grass carp	*Ctenopharyngodon idella*	12	20
Grass shrimp	*Palaemonetes paludosus*	5	17
Largemouth bass	*Micropterus salmoides*	4	34
Least killifish*	*Heterandria formosa*	0	5
Lined topminnow*	*Fundulus lineolatus*	0	2
Longnose gar*	*Lepisosteus osseus*	0	1
Marsh killifish	*Fundulus confluentus*	112	47
Mayan cichlid	*Cichlasoma urophthalmus*	29	32
Mosquitofish	*Gambusia holbrooki*	50	446
Pig frog	*Rana grylio*	1	24
Pike killifish*	*Belonesox belizanus*	8	0
Rainwater killifish	*Lucania parva*	3	0
Redear sunfish	*Lepomis microlophus*	1	35
Redfin pickerel*	*Esox americanus*	1	2
Sailfin molly	*Poecilia latipinna*	77	125
Amphiuma	*Amphiuma* species	3	4
Spotted sunfish	*Lepomis punctatus*	478	154
Spotted tilapia	*Pelmatolapia mariae*	5	5
Swamp darter	*Etheostoma fusiforme*	0	11
Tadpole species	*Anura* species	1	45
Tadpole madtom	*Nocturus gyrinus*	21	0
Threadfin shad*	*Dorosoma petenense*	0	2
Unknown sunfish	*Lepomis* species	56	70
Walking catfish	*Clarias batrachus*	1	0

Table 3-13, continued

Common name	Species name	Everglades	Urban
Warmouth	*Lepomis gulosus*	86	354
Yellow bullhead	*Ameiurus natalis*	9	1
Trash (human food)		0	45
	Totals	**1934**	**2116**

*****indicates species that were excluded from stork prey analyses as they accounted for less than 1% of the total biomass.

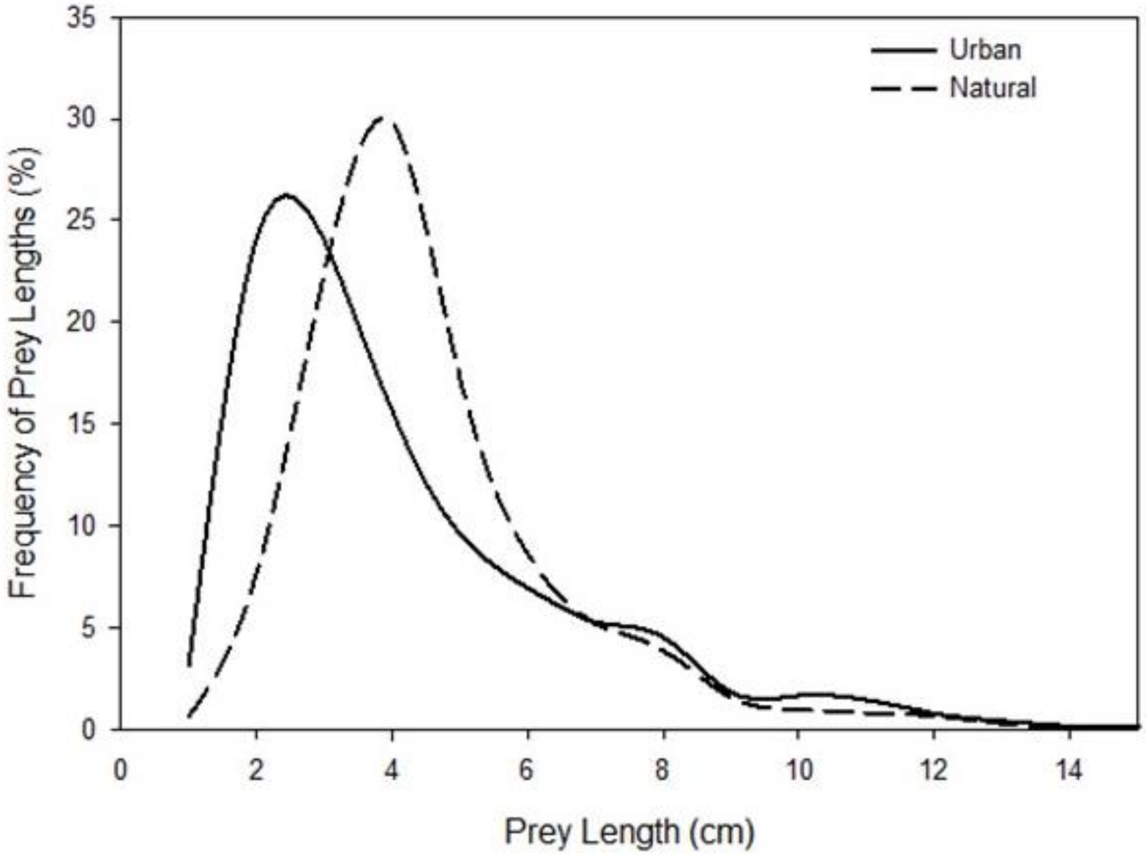

Figure 3-19. Distribution of prey lengths within stork boluses during the 2014-2016 breeding season, South Florida.

We used 143 throw-traps to characterize the aquatic fauna available to foraging storks in the natural marsh landscape. Mean fish length was 1.53 cm ± 0.01 SE. Grass shrimp, crayfish, and bluefin killifish comprised the majority of the prey biomass, whereas grass shrimp, least killifish, mosquitofish, and bluefin killifish were the most common species, representing 51% of biomass and 80% of individuals, respectively. The prey composition within stork boluses from natural marsh colonies was significantly different than the prey community available in the natural marsh landscape (Fig. 3-20; $R = 0.79$, $P < 0.01$).

Stork prey

- Stork diet samples are significantly different from natural marsh prey communities
- Stork diet samples are more similar to prey communities found in large stormwater ponds and canals than to prey in natural marshes
- There was a high occurrence of large-bodied and exotic prey within stork diet samples and permanently inundated corridor features

We used minnow traps and throw-traps to characterize the aquatic fauna available to foraging storks in 32 roadway corridor features (swales, canals, and ephemeral and permanently inundated stormwater ponds). Mean fish length was 2.22 cm ± 0.01 SE. Least killifish, grass shrimp, and mosquitofish were the most common species, representing 84% of individuals. Mayan cichlids, African jewelfish, crayfish, largemouth bass, and warmouth contributed 55% to the total biomass. When comparing bolus samples to prey communities in roadway features and natural marsh landscape, the samples were statistically different (Fig. 3-21; $R = 0.50$, $P < 0.01$) with roadways and bolus samples being the most similar ($R = 0.40$; $P < 0.01$). The prey composition within stork boluses from urban colonies were similar to the prey community available in the urban landscape (Fig. 3-22, $R=0.39$, $P<0.01$). Additionally, urban colony boluses were most similar to the prey communities found in roadway features (Fig. 3-23, $R=0.59$, $P < 0.01$). Most of the dissimilarity between natural marsh landscape samples and bolus samples was caused by the dominance of large-bodied (Fig. 3-24) and exotic prey (Fig. 3-25).

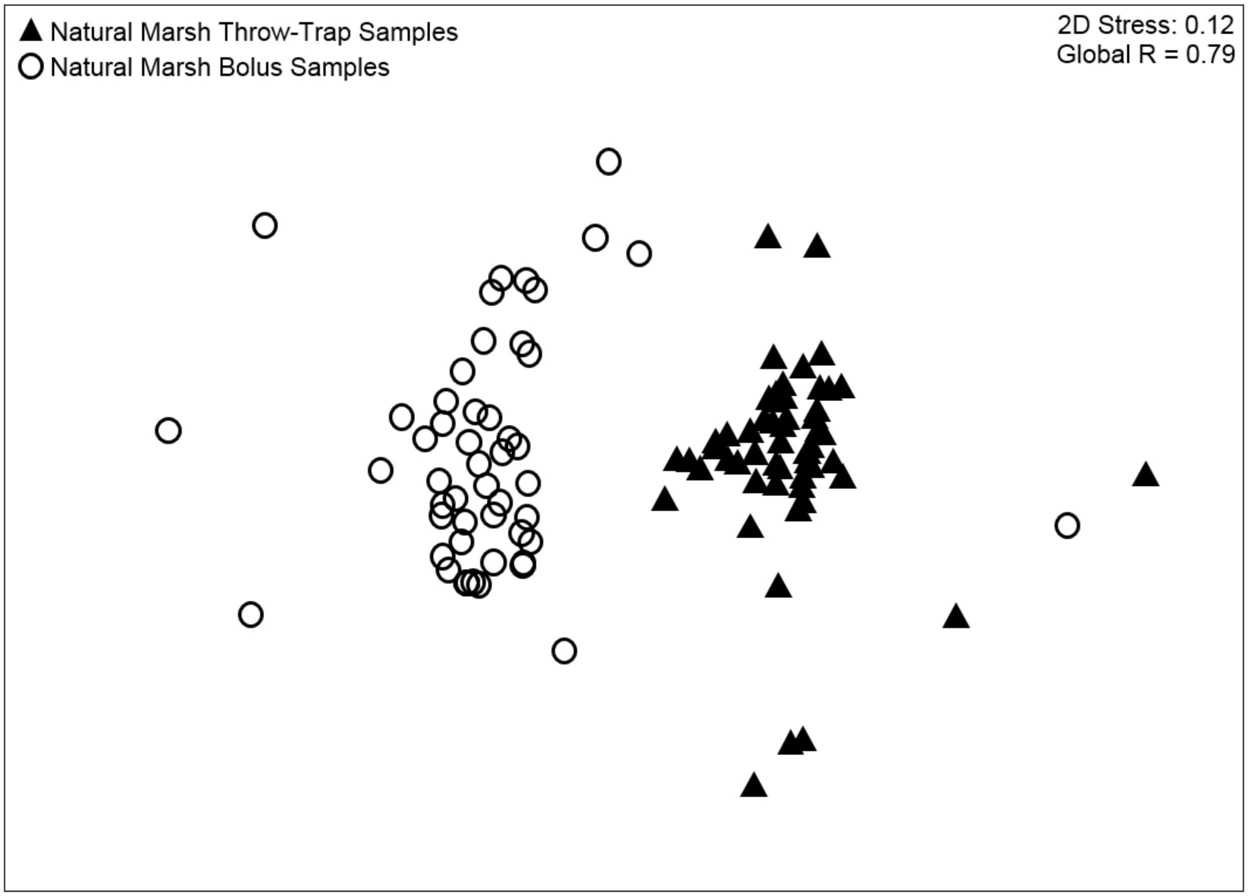

Figure 3-20. Prey composition of stork boluses collected from natural marsh colonies and throw-trap samples from the natural marsh landscape, 2014-2016. Each point is representative of the prey composition within boluses collected in the same colony on the same date, or a throw-trap sample collected at the same site on the same day. The proximity of points indicates the level of Bray-Curtis similarity in 2D space. Stress values indicate the degree of distortion relative to the actual multidimensional similarity between points. A stress value less than 0.20 indicates a useful 2 dimensional representation of the data.

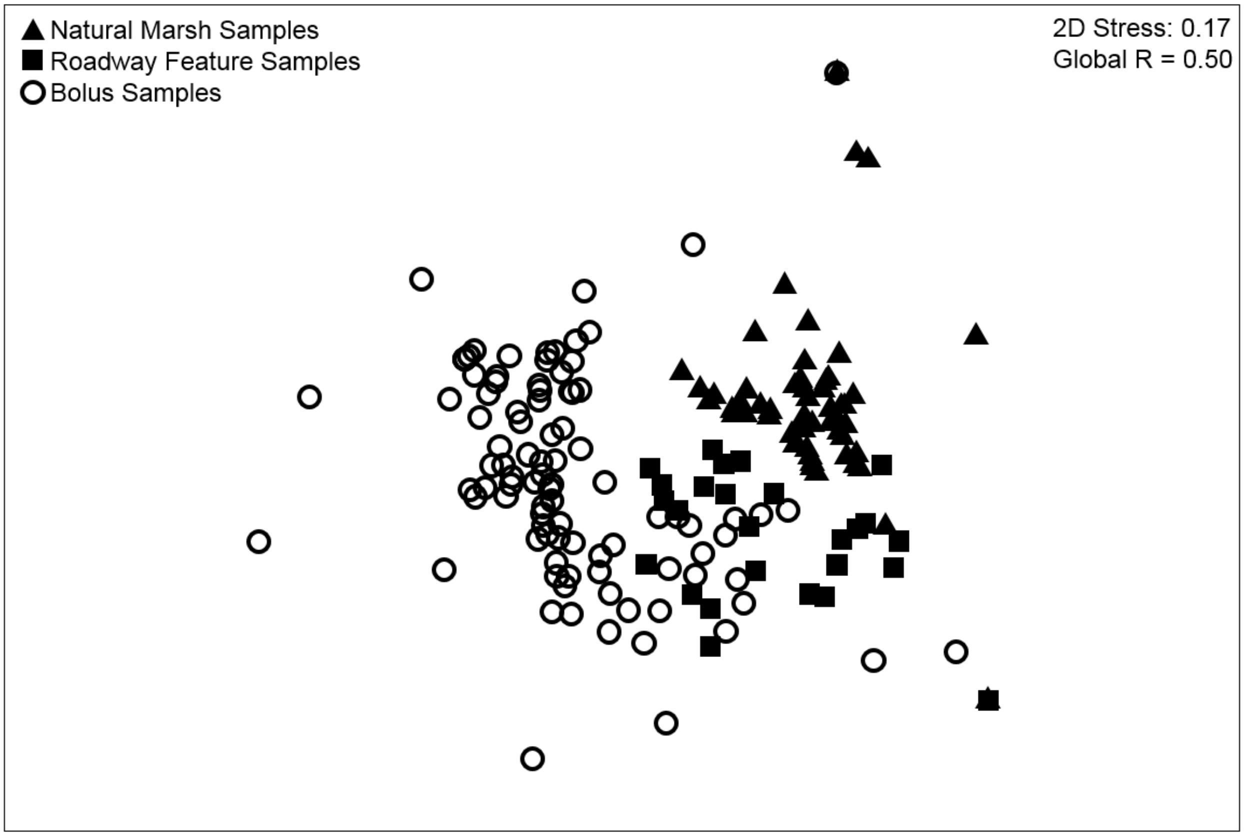

Figure 3-21. Prey composition of stork boluses collected from natural marsh and urban colonies, throw-trap and minnow trap samples from roadway corridor features, and throw-trap samples from the natural marsh landscape, South Florida, 2014-2016. Each bolus sample point is representative of the prey composition within boluses collected in the same colony on the same date. Each roadway feature sample point is representative of the prey composition found within each roadway feature site over all years. Each natural marsh throw-trap sample point is representative of the prey composition collected at the same site on the same day. The proximity of points indicates the level of Bray-Curtis similarity in 2D space. Stress values indicate the degree of distortion relative to the actual multidimensional similarity between points. A stress value less than 0.20 indicates a useful 2 dimensional representation of the data.

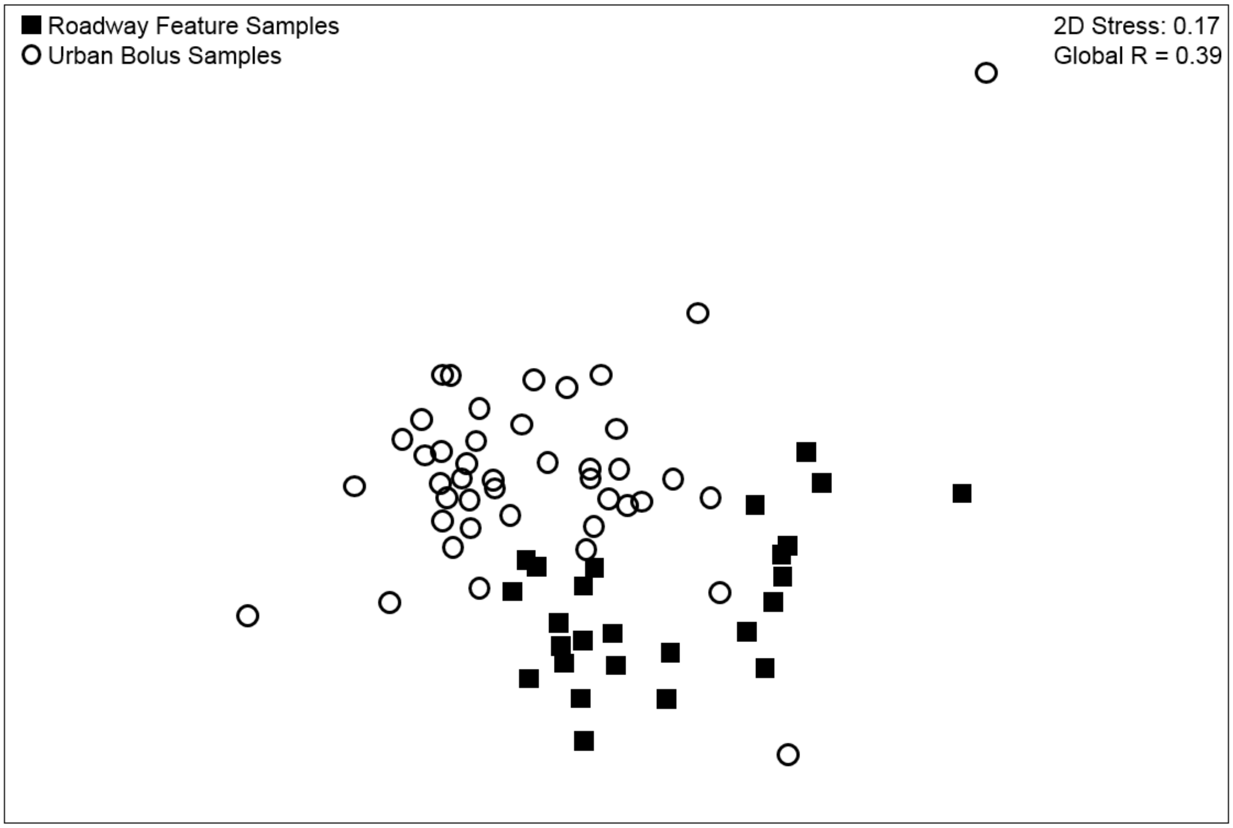

Figure 3-22. nMDS ordination of prey biomass depicting prey composition of stork boluses collected from urban colonies and throw-trap and minnow trap samples from roadway corridor features, South Florida, 2014-2016. Each bolus sample point is representative of the prey composition within boluses collected in the same colony on the same date. Each roadway feature sample point is representative of the prey composition found within each roadway feature site over all years. The proximity of points indicates the level of Bray-Curtis similarity in 2D space. Stress values indicate the degree of distortion relative to the actual multidimensional similarity between points. A stress value less than 0.20 indicates a useful 2 dimensional representation of the data.

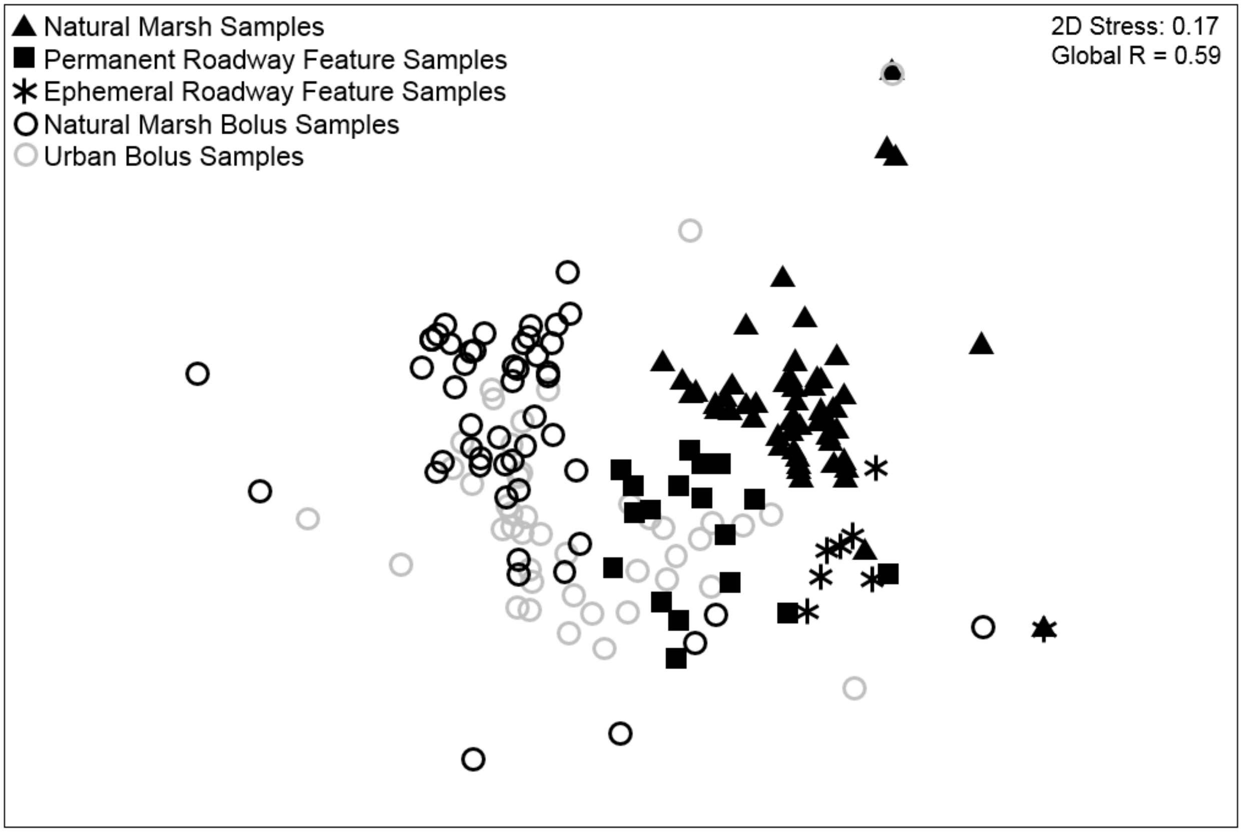

Figure 3-23. nMDS ordination of prey biomass depicting prey composition of stork boluses collected from natural marsh and urban colonies, throw-trap and minnow trap samples from roadway corridor features, and throw-trap samples from the natural marsh, South Florida, 2014-2016. Each bolus sample point is representative of the prey composition within boluses collected in the same colony on the same date. Each roadway feature sample point is representative of the prey composition found within each roadway feature site over all years. Each natural marsh throw-trap sample point is representative of the prey composition collected at the same site on the same day. The proximity of points indicates the level of Bray-Curtis similarity in 2D space. Stress values indicate the degree of distortion relative to the actual multidimensional similarity between points. A stress value less than 0.20 indicates a useful 2 dimensional representation of the data.

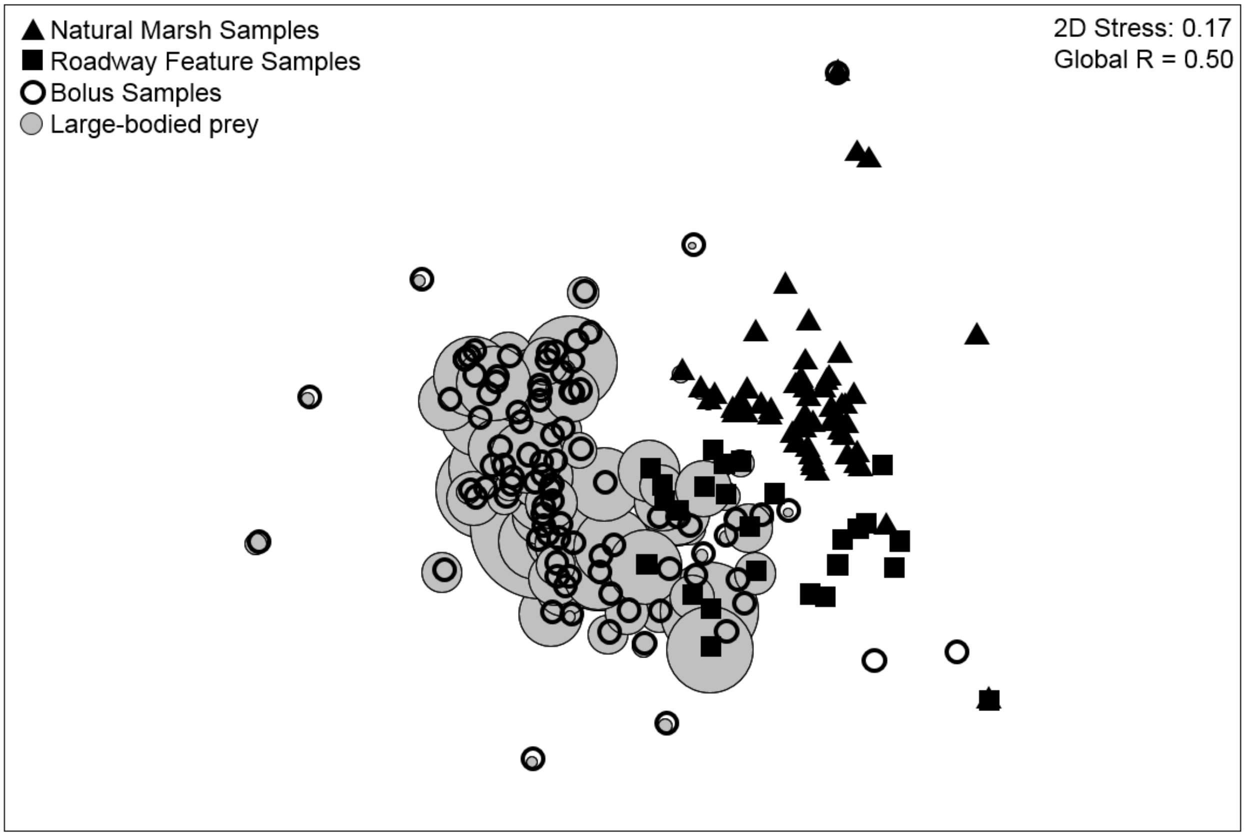

Figure 3-24. Prey composition of stork boluses collected from natural marsh and urban colonies, throw-trap and minnow trap samples from roadway corridor features, and throw-trap samples from the natural marsh landscape, South Florida, 2014-2016. Each bolus sample point is representative of the prey composition within boluses collected in the same colony on the same date. Each roadway feature sample point is representative of the prey composition found within each roadway feature site over all years. Each natural marsh throw-trap sample point is representative of the prey composition collected at the same site on the same day. The proximity of points indicates the level of Bray-Curtis similarity in 2D space. Stress values indicate the degree of distortion relative to the actual multidimensional similarity between points. Biomasses of large-bodied prey are superimposed on the samples to indicate the relative biomass of large-bodied prey in boluses, roadway features, and natural marsh landscape. Larger circles indicate samples of relatively more biomass of large-bodied prey. A stress value less than 0.20 indicates a useful 2 dimensional representation of the data.

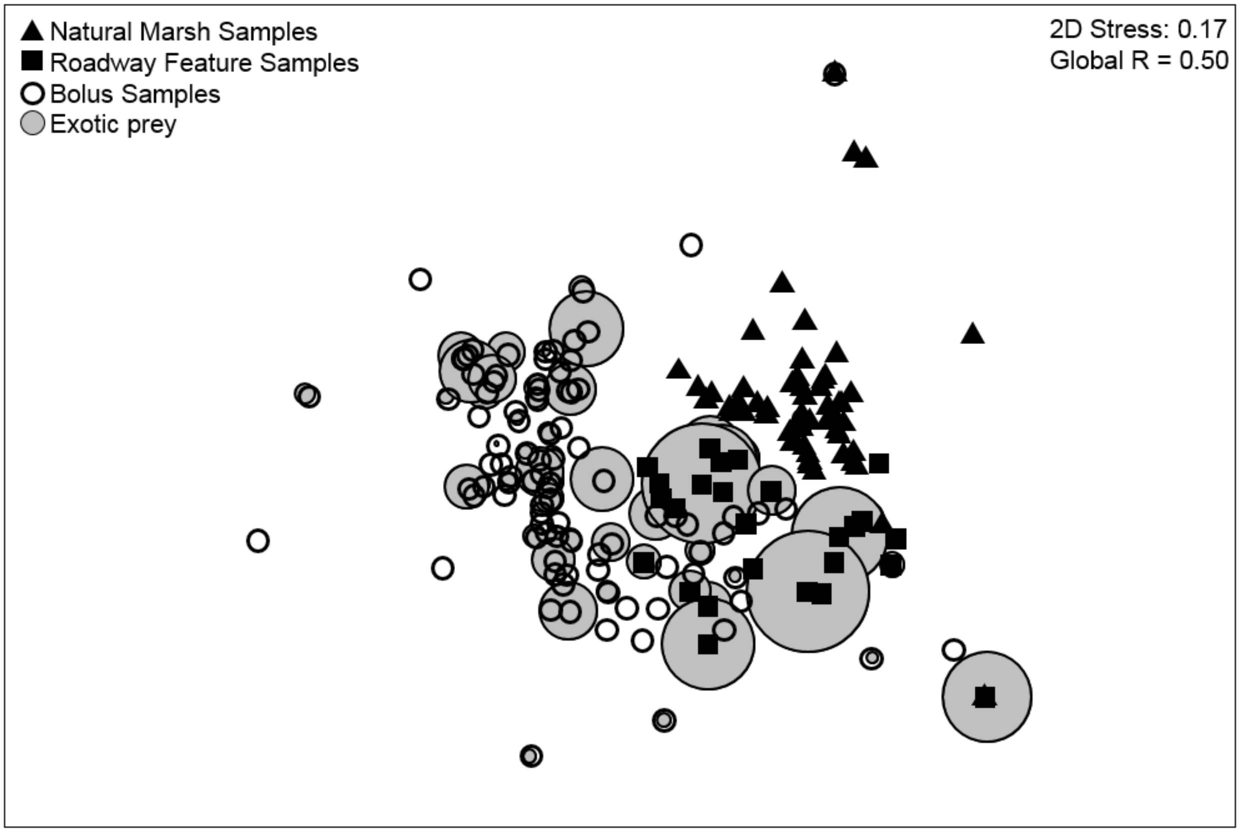

Figure 3-25. nMDS ordination of prey biomass depicting prey composition of stork boluses collected from natural marsh and urban colonies, throw-trap and minnow trap samples from roadway corridor features, and throw-trap samples from the natural marsh, South Florida, 2014-2016. Each bolus sample point is representative of the prey composition within boluses collected in the same colony on the same date. Each roadway feature sample point is representative of the prey composition found within each roadway feature site over all years. Each natural marsh throw-trap sample point is representative of the prey composition collected at the same site on the same day. The proximity of points indicates the level of Bray-Curtis similarity in 2D space. Stress values indicate the degree of distortion relative to the actual multidimensional similarity between points. Biomasses of exotic prey are superimposed on the samples to indicate the relative biomass of exotic prey in boluses, roadways, and natural marshes. Larger circles indicate samples of relatively more biomass of exotic prey. A stress value less than 0.20 indicates a useful 2 dimensional representation of the data.

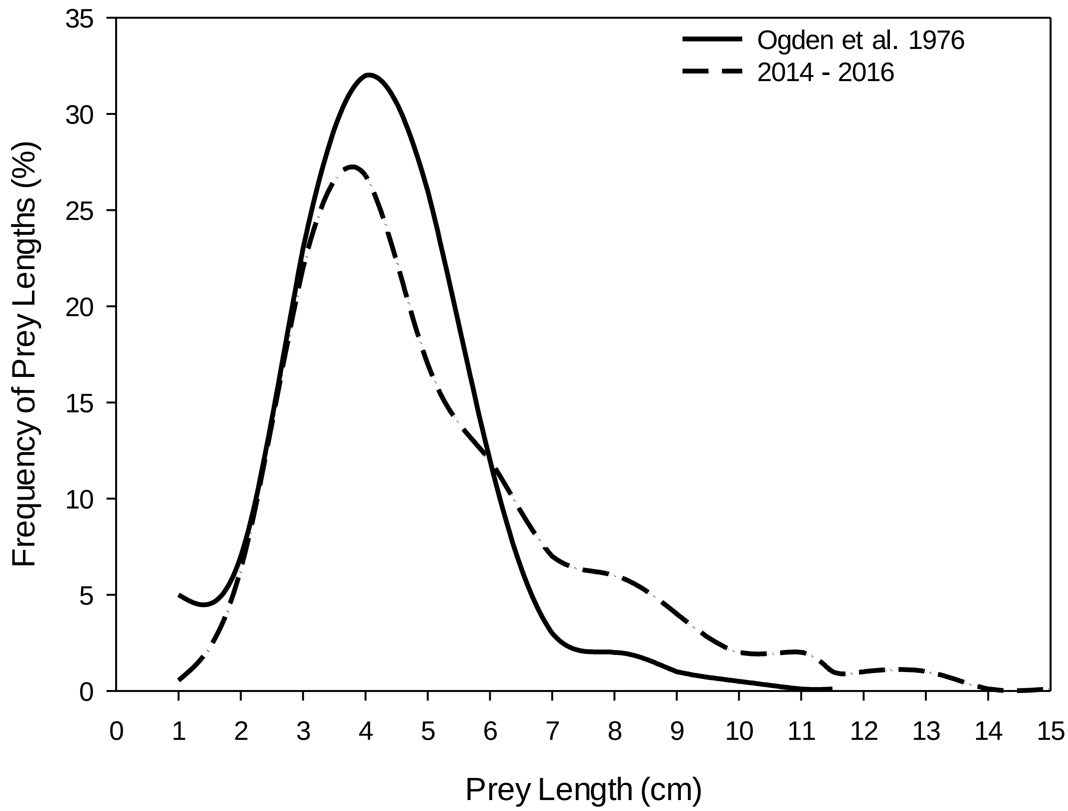

Figure 3-26. Frequency of prey lengths found within boluses from South Florida. Historical data were estimated from figures produced in Ogden et al., 1976.

3.3.2 Conclusions

The USFWS uses the following Suitable Wood Stork Biomass Equation to calculate the potential stork foraging biomass in an impacted area:

(*Meters*^{2} ** actual biomass consumed) * Foraging Suitability % / 1,000 = biomass/kg*

Each impacted area is measured in meters squared, then multiplied by the amount of actual biomass consumed. Actual biomass consumed is determined by hydroperiod classifications (Table D1), then is multiplied by the foraging suitability index (Table D2; % exotic vegetation). This estimate is the total biomass in kilograms lost or gained within an impacted area.

Information from stork diet analyses and prey production models can be used to improve the USFWS Suitable Wood Stork Biomass calculation and refine mitigation in the following ways: (1) update fish biomass estimates for natural marsh and include roadway feature hydroperiod classes, (2) consider the importance of slope for stork prey production in permanently inundated and ephemeral roadway features, (3) consider importance of landscape cover for prey production in permanently inundated roadway features (urban vs.

forested/herbaceous marsh), and (4) update historic stork prey range from species lengths of 1.5 to 9.0 cm to current stork prey range of 2.0 to 11.1 cm.

The U.S. Army Corps of Engineers (USACE) requires wetland mitigation for all wetland and stormwater features, that are considered suitable foraging habitat, which includes roadway features, like roadside ditches or small ponds. The current calculation uses fish biomass (g/m^2) estimates that are solely based on natural marsh systems; however, impacted areas may include roadway features, which have different hydrologic conditions than the natural marsh system. Updated fish biomass estimates for ephemeral and permanently inundated roadway features could change average biomass of the current hydroperiod classes used in the calculation.

Slope influenced stork prey production in roadway features and varied between ephemeral and permanently inundated roadway features. Shallower slopes produced high prey biomass in permanently inundated features and steep slopes produced high prey biomass in ephemeral features. For permanently inundated features we found that average prey biomass decreased by 26.7% between shallow (0.0-0.20) and moderate slopes (0.21-0.50), and decreased by 44.2% between shallow and steep slopes (>0.50). For ephemeral feature slopes, we did not have a high variation in sites sampled, so we classified slope into only two categories: shallow (0.0-0.15) and steep (>0.16). Average prey biomass decreased by 37% in the shallow slope features relative to the steep features.

Landscape cover types also influenced stork prey production. Permanently inundated roadway feature sites in the urban landscape produced significantly more stork prey biomass when compared to similar features in the herbaceous and forested marsh areas along I-75/Alligator Alley. Average prey biomass decreased by 22.3% between urban and forested marsh landscape cover types, and decreased by 53.8% between urban and herbaceous marsh landscape cover types.

The calculation does not distinguish current stork preferences for prey species or sizes. The USFWS currently uses the historic length range of stork prey species of 1.5 to 9.0 cm (Ogden et al., 1976) to assess stork forage; however, current diet indicates that storks have shifted their diet to include even larger prey (2.0 to 11.0 cm; Fig. 3-26). We found that storks are consuming prey that is larger than what is generally available in the natural Everglades landscape. Furthermore, we found that storks are consuming exotic prey species which have become more prevalent since the 1950s (Shafland et al., 2008; Kline et al., 2014). The vast system of canals throughout the Everglades has facilitated the spread of exotic fish from the urban landscape into the more natural landscape (Kline et al., 2014). Long hydroperiod areas, like canals and stormwater ponds, have a higher abundance of larger prey species (i.e., sunfish and exotic cichlids) than shorter hydroperiod areas. Based on data collected from roadway corridors, it seems likely that storks are finding these prey species in large stormwater ponds and canals, as these species are rare in the natural landscape, particularly the larger size classes consumed by storks (Loftus and Kushlan, 1987).

The USFWS currently uses the Suitable Wood Stork Biomass Equation to assess impacted areas for loss of stork prey biomass. The calculation uses biomass estimates from natural wetland habitats only; however, if biomass production was differentiated between roadway features and natural wetlands, it would provide a more precise measure of impacts. This distinction will improve the calculation used to quantify compensatory wetland mitigation of roadway features and natural wetlands that are considered Suitable Foraging Habitat (SFH) by the U.S. Army Corps of Engineers (USACE). We found that some wet roadway features (i.e., permanently inundated ponds and canals) on average produce more stork prey biomass than natural wetlands. However, the spatial extent of the Everglades is much greater than scattered roadway wetlands found throughout South Florida so natural wetlands likely produce more stork prey biomass overall than do roadways. Furthermore, roadway features can produce risks for storks, such as mortality from collisions with vehicles

4.0 Synthesis discussion

4.1 Implications of roadway feature design

> **Roadway design applications to discourage stork use**
>
> - Canals and permanently-wet stormwater ponds should have a steep slope component as this discourages foraging and results in lower prey production
> - Swales and ephemeral stormwater ponds should have shallow slopes as it results in lower stork prey production
> - Swales should be designed to drain water quickly to discourage stork prey production. All dry swales sampled during this project had no stork prey.

Permanently inundated features, such as canals and stormwater ponds, were more likely to be used by storks whereas ephemeral features, such as ephemeral ponds and swales were least likely to be used by storks. If encouraging the use of ephemeral features by storks, the features should have steep slopes with the ability to hold water. If ephemeral features do not become inundated they will produce little stork prey. Additionally, swales and ephemeral ponds that are connected to natural marsh areas or permanently inundated roadway features will likely have a higher biomass of stork prey due to recolonization from longer hydroperiod areas. However, if FDOT would like to discourage use of storks, then swales and ephemeral ponds with shallow slopes that are not capable of holding water for prolonged periods of time will result in little prey production. If stork use of permanently inundated features is encouraged, features with shallow slopes encourage stork prey production and provide an area for storks to forage. Furthermore, canals and stormwater ponds created in urban landscapes tend to produce higher stork prey biomass than those created herbaceous and forested marsh areas, such as areas along I-75/Alligator Alley.

Given the improved understanding of stork utilization of roadway water features and the improved estimates of prey production which now include constructed roadway features, we can make recommendations for roadway feature design that discourages and/or promotes stork use. As noted in the biomass production data, not all roadway features produce prey at the same rates. If stork use is desired, permanently inundated features should incorporate a shallow slope component (littoral zone or shelf) to improve biomass production. Littoral features not only provide appropriate habitat for prey production but also facilitate foraging.

Although permanently inundated features produce stork prey, the proximity of these features to roadways carries the risk of increased stork mortality. Further study of feature proximity to roadway and the presence and absence of roadway fencing or vegetation effects on mortality could further aid in roadway feature design. If desired, there is potential to improve access and forage in parts of permanently inundated sites which may decrease roadway collisions (expand far edge littoral zone and reduced near edge littoral). Similarly, wooded habitat on near edge may minimize utilization attempts and hence collision mortality.

Ephemeral sites generally produce less biomass due to the short-term nature of inundation and thus are not good stork foraging areas. However, swales that do not drain as intended may actually attract storks during wet periods, partially because natural areas are too deep for foraging while swales are artificially drained and facilitate forage access.

In addition to specific feature improvements (maximum depths, managed timing, littoral zone expansion, and actual placement of features), we recognized that not all water features were inundated based on their FAC (Florida Administration Code) definitions. That is, some swales and ephemeral ponds actually contained standing water for extended periods. This can create confusion because not all “swales” are dry features. For instance, some swales slope unidirectionally to a canal feature. In some cases, these edges are short to intermediate hydroperiod wetlands rather than “directional water features.” Ongoing efforts to clarify water feature definitions (terminology and related characterization) and to consistently evaluate features will improve our understanding of how roadway design features can be used to affect use by Wood Storks at and the production of their prey.

4.2 Wood Stork habitat mitigation

Currently, FDOT is responsible for notifying the U.S. Army Corps of Engineers and USFWS if there is a potential impact of foraging habitat within a Core Foraging Area (CFA) of an active Wood Stork colony (Appendix D, Fig. D1). The U.S. Environmental Protection Agency and U.S. Army Corps of Engineers implement Section 404, under the Clean Water Act, which regulates the dredge and fill activities that adversely affect wetlands. FDOT is required to provide compensation for impacts to wetlands in accordance with the Clean Water Act, Section 404. Based on current practices, habitat compensation can be provided within a CFA through the creation of wetland mitigation areas, or purchase of wetland mitigation credits. Wetlands include any area that is “inundated and saturated by surface or groundwater at a frequency and duration sufficient to support…a prevalence of vegetation typically adapted for life in saturated soil conditions”. FDOT is required to compensate for foraging habitat loss if the impacted area is within 0.76 km of an active colony site. Current practices allow suitable foraging habitat (wetlands) to be replaced with equal or higher suitable foraging wetlands, thus roadway features can only offset impacts of stork foraging habitat loss in other roadway features (i.e. swales or ponds cannot replace natural wetlands).

The USFWS uses the Suitable Wood Stork Biomass Equation to assess impacted areas for loss of stork prey biomass when wetland impacts exceed 5 acres. The current calculation uses biomass estimates from natural wetland habitats only; however, if biomass production was differentiated between roadway features and natural wetlands it would provide a more precise measure of impacts. This is necessary to adequately quantify the potential for compensatory wetland mitigation of roadway features and natural wetlands that are considered SFH by the U.S. Army Corps of Engineers. We found that roadway features on average produce more stork biomass/m^2 than natural wetlands, however these areas can produce risks for storks. Foraging sites along roadways, such as the Florida Turnpike could result in an increased risk of storks colliding with vehicles

While permanently inundated features have longer hydroperiods than natural marshes, natural marshes can produce exceedingly high densities of available prey for storks under certain hydrologic regimes, which is thought to control the size of stork nesting populations (Bancroft, 1989; Ogden, 1994). But given that marsh water levels fluctuate between wet and dry periods, the anthropogenic water features may at times provide wading birds with more predictable, albeit possibly lower quality habitat.

5.0 Lessons learned and recommendations for future phases

Stork prey production will likely vary geographically. We found that storks in South Florida used canals and large stormwater ponds more frequently than ephemeral roadway features due partially to the presence of large-bodied and exotic prey. Roadway features in north Florida likely do not have a high percentage of exotic fish species, thus stork use of roadway features may vary in comparison to South Florida. Additionally, stork prey varies geographically, for example, storks in Georgia are known to eat frogs and crayfish in higher quantities than found in South Florida (Depkin et al., 1992).

We sampled aquatic fauna in roadway corridor features across three landscape cover types (urban, forested marsh, and herbaceous marsh); however, we surveyed storks in four landscape cover types, with the additional landscape cover type of agriculture. We found that storks use the irrigation ditches of crop fields, thus aquatic fauna sampling of these areas would be beneficial.

We found that storks are consuming prey that is larger than what is generally available in the natural Everglades landscape. When comparing bolus samples to prey communities in roadway features and natural marsh landscape, roadways and bolus samples were the most similar. While stork diet is similar to what is found within roadways, there is still some uncertainty of the exact locations those storks foraged. The addition of satellite transmitters on individual birds would allow us to know the degree to which storks forage in roadway habitat relative to other habitats.

Literature cited

Bancroft, G. T. 1989. "Status and conservation of wading birds in the Everglades". American Birds 43: 1258-1265.

Botson, B. A., D. E. Gawlik, and J. C. Trexler. 2016. "Mechanisms that generate resource pulses in a fluctuating wetland". PLOS One 11: e0158864. doi: 10.1371/journal.pone.0158864

Browder, J. A. 1984. "Wood Stork feeding areas in southwest Florida". Florida Field Naturalist 12: 81-96.

Burnham, K. P., and D. R. Anderson. 2004. "Multimodel inference understanding AIC and BIC in model selection". Sociological Methods and Research 33: 261-304.

Chen, Z., and L. Kuo. 2001. "A note on the estimation of the multinomial logit model with random effects". The American Statistician 55:89-95.

Clarke, K. R., and R. M. Warwick. 2001. *Change in marine communities: an approach to statistical analysis and interpretation, 2nd edition*. Plymouth, UK: PRIMER-E.

Cochran, W. G. 1977. *Sampling techniques*. New York: John Wiley and Sons Inc.

Cottham, G., and J. T. Curtis. 1956. "The use of distance measure in phytosociological sampling". Ecology 37:451-460.

Coulter, M. C., J. A. Rodgers, J. C. Ogden, and F. C. Depkin. 1999 "Wood Stork (*Mycteria americana*)". In: A. Poole (Ed.), *The Birds of North America Online*. Ithaca: Cornell Lab of Ornithology. Retrieved from the Birds of North America Online: http://bna.birds.cornell.edu.ezproxy.fau.edu/bna/species/409.

Crowder, L. B., and W. E. Cooper. 1982. "Habitat structural complexity and the interaction between bluegills and their prey". Ecology 63:1802-1813.

Crowder, L. B., D. D. Squires, and J. A. Rice. 1997. "Nonadditive effects of terrestrial and aquatic predators on juvenile estuarine fish". Ecology 78:1796-1804.

Daubenmire, R. F. 1959. "Canopy coverage method of vegetation analysis". Northwest Science 33: 43-64.

Depkin, F. C., M. C. Coulter, and A. L. Bryan, Jr. 1992. "Food of nestling Wood Storks in East-Central Georgia". Colonial Waterbirds 15: 219-225.

Dorn, N. J., M. I. Cook, G. Herring, R. A. Boyle, J. Nelson, and D. E. Gawlik. 2011. "Aquatic prey switching and urban foraging by the White Ibis *Eudocimus albus* are determined by wetland hydrologic conditions". Ibis 153: 323-335.

ESRI. 2014. ArcGIS Desktop: Release 10.3. *Environmental Systems Research Institute*, Redlands, CA: ArcGIS.

Fidorra, J. C., P. C. Frederick, D. C. Evers, and K. D. Meyer. 2016. "Selection of human-influenced and natural wetlands by Great Egrets at multiple scales in the southeastern USA". Condor 118: 46-56.

Florida Department of Transportation (FDOT). 1999. "Florida Land Use, Cover and Forms Classification System". *FDOT Surveys and Mapping Office Geographic Mapping Section Handbook 3rd edition*.

Florida Fish and Wildlife Conservation Commission (FFWCC). 2004. Digital raster data: fl_veg03. http://myfwc.com/research/gis/data-maps/terrestrial/fl-vegetation-land-cover. Fish and Wildlife Commission, FL.

Florida Fish and Wildlife Conservation Commission. 2015. Nonnative freshwater fish. Retrieve from http://myfwc.com/wildlifehabitats/nonnatives/freshwater-fish/.

Frederick, P. C., and M. W. Collopy. 1989. "Nesting success of five ciconiiform species in relation to water conditions in the Florida Everglades". Auk 106: 625-634.

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

Goodall, D. W. 1952. "Some considerations in the use of point quadrats for the analysis of vegetation". Australian Journal of Biological Sciences 5:1-41.

Green, M. C., and P. L. Leberg. 2005. "Flock information and the role of plumage colouration in Ardeidae". Canadian Journal of Zoology 83:683-693.

Herring, H. K., and D. E. Gawlik. 2011. "Resource selection functions for Wood Stork foraging habitat in the southern Everglades". Waterbirds 34: 133-142.

Herring, G., H. K. Herring, and D. E. Gawlik. 2015. "Social cues and environmental conditions influence foraging flight distances of breeding Wood Storks (*Mycteria americana*)". Waterbirds 38: 30-39.

Jordan, F. K., K. J. Babbit, and C. C. McIvor. 1998. "Seasonal variation in habitat use by marsh fishes". Ecology of Freshwater Fish 7:159-166.

JMP. 1989-2007. Version 12. Cary, NC: SAS Institute, Inc.

Kahl Jr., M. P. 1964. "Food ecology of the wood stork (*Mycteria americana*) in Florida". Ecological Monograph 34: 97-117.

Kline, J. L., W. F. Loftus, K. Kotun, J. C. Trexler, J. S. Rehage, J. J. Lorenz, and M. Robinson. 2014. "Recent fish introductions into Everglades National Park: an unforeseen consequence of water management?" Wetlands 34:175-187.

Kushlan, J. A., J. C. Ogden, and A. L. Higer. 1975. *Relation of water level and fish availability to Wood Stork reproduction in the southern Everglades, Florida.* U. S. Geologic Survey Open File Report 75-434, Tallahassee, Florida.

Kushlan, J. A. 1977. "The significance of plumage colour in the formation of feeding aggregations of Ciconiiformes". Ibis 119: 361-364.

Lantz, S. M., Gawlik. D. E., and M. I. Cook. 2011. "The effects of water depth and emergent vegetation on foraging success and habitat selection of wading birds in the Everglades". Waterbirds 34: 439-447.

Loftus, W. F., and J. A. Kushlan. 1987. "Freshwater fishes of southern Florida". Bulletin of the Florida State Museum, Biological Sciences. 31: 147-344.

Luther, D., J. Hilty, J. Weiss, C. Cornwall, M. Wipf, and G. Ballard. 2008. "Assessing the impact of local habitat variables and landscape context on riparian birds in agricultural, urbanized, and native landscapes". Biodiversity and Conservation 17: 1923-1935.

Manly, B. F. J., L. McDonald, D. L. Thomas, T. L. McDonald, and W. P. Erickson. 2002. *Resource selection by animals: statistical design and analysis for field studies, second edition*. Boston, Massachusetts: Kluwer Press.

McCune, and Mefford. 1999. *PC-ORD. Multivariate analysis of ecological data*. Version 4.0. Gleneden Beach, Oregon: MjM Software.

Melles, S., S. Glenn, and K. Martin. 2003. "Urban bird diversity and landscape complexity: species-environment associations along a multiscale habitat gradient". Conservation Ecology 7: 5 [online] URL: http://www.consecol.org/vol7/iss1/art5/.

Mora, J. W., J. N. Mager III, and D. J. Spieles. 2011. "Habitat and landscape suitability as indicators of bird abundance in created and restored wetlands". Ecology 2011: 1-10.

Ogden, J. C., J. A. Kushlan, and J. T. Tilmant. 1976. "Prey selectivity by the wood stork". Condor 78: 324-33.

Ogden, J. C. 1994. "A comparison between wading bird nesting colony dynamics (1931-1946 and 1974-1989) as an indication of ecosystem conditions in the southern Everglades", p.

533-570 *in Everglades: the ecosystem and its restoration* (S. M. Davis and J. C. Ogden, Eds.). Delray Beach, Florida: St Lucie Press.

O'Connor, J. H., and B. B. Rothermel. 2013. "Distribution and population characteristics of African jewelfish and brown hoplo in modified wetlands in South Florida". American Midland Naturalist 170: 52-65.

Pierce, R. L., and D. E. Gawlik. 2010. "Wading bird foraging habitat selection in the Florida Everglades". Waterbirds 33: 494-503.

R Development Core Team. 2016. *R: A language and environment for statistical computing.* R version 3.2.4. Vienna, Austria: R Foundation for Statistical Computing.

Rodgers, J. A., Jr., and H. T. Smith. 1995. "Set-back distances to protect nesting bird colonies from human disturbances in Florida". Conservation Biology 9: 89-99.

Rodgers, J.A., Jr., and S. T. Schwikert. 2002. "Buffer-zone distances to protect foraging and loafing waterbirds from disturbance by personal watercraft and outboard-powered boats". Conservation Biology 16: 216-224.

Rozas, L. P., and W. E. Odum. 1988. "Occupation of submerged aquatic vegetation by fishes: testing the roles of food and refuge". Oecologia 77: 101-106

SAS Institute Inc. 2013. The SAS system for Windows Version 9.4. SAS Cary, NC: SAS Institute.

Shafland, P. L., and J. M. Pestrak. 1982. "Lower lethal temperatures for fourteen non-native fishes in Florida". Environmental Biology of Fishes 7: 149-156.

Shafland, P. L., K. B. Gestring, and M. S. Stanford. 2008. "Florida's exotic freshwater fishes—2007". Florida Scientist 71: 220-245.

Stolen, E. D., J. A. Collazo, and H. F. Percival. 2007. "Scale-dependent habitat selection of nesting Great Egrets and Snowy Egrets". Waterbirds 30: 384-393.

Trexler, J. C., W. F. Loftus, F. Jordan, J. J. Lorenz, J. H. Chick, and R. M. Kobza. 2000. "Empirical assessment of fish introduction in a subtropical wetland: an evaluation of contrasting views". Biological Invasions 2: 265-277.

Trexler, J. C., W. F. Loftus, F. Jordan, J. H. Chick, K. L. Kandl, T. C. McElroy, and O. L. Bass. 2002. "Ecological scale and its implications of freshwater fishes in the Florida Everglades". Pages 153-181. *In* J. W. Porter and K. G. Porter (eds.). *The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook*. Boca Raton, FL: CRC Press.

URS Corporation. 2012. "Wood Stork status, impact assessments and mitigation". Report to the Florida Department of Transportation.

Yu, S. L., M. Barnes, and V. W. Gerde. 1993. *Testing of best management practices for controlling highway runoff*. Charlottesville, VA: Virginia Transportation Research Council.

Appendix A: Wood stork flock locations – aerial and roadway surveys

Table A1. Location features, landscape cover type, and flock size of storks observed from monthly aerial surveys, February 2014 to May 2016, South Florida.

Date	Flock ID number	Flock size	Location feature	Landscape cover type
02/10/2014	140201	1	Canal	Forested marsh
02/10/2014	140202	5	Upland	Agriculture
02/10/2014	140203	1	Ephemeral pond	Agriculture
03/27/2014	140301	1	Swale	Agriculture
03/27/2014	140302	1	Natural marsh	Forested marsh
03/27/2014	140303	4	Natural marsh	Herbaceous marsh
03/27/2014	140304	2	Natural marsh	Herbaceous marsh
03/27/2014	140305	3	Natural marsh	Herbaceous marsh
04/24/2014	140401	2	Canal	Herbaceous marsh
04/24/2014	140402	1	Natural marsh	Herbaceous marsh
05/16/2014	140501	4	Permanently inundated Pond	Forested marsh
05/16/2014	140502	4	Natural marsh	Herbaceous marsh
05/16/2014	140503	88	Permanently inundated Pond	Urban
05/16/2014	140504	1	Swale	Urban
05/16/2014	140505	36	Natural marsh	Herbaceous marsh
06/26/2014	140601	57	Swale	Agriculture
07/28/2014	140701	17	Permanently inundated Pond	Urban
07/28/2014	140702	1	Swale	Urban
08/25/2014	140801	3	Upland	Forested Marsh
08/25/2014	140802	1	Permanently inundated Pond	Urban
09/26/2014	140901	4	Irrigation ditch	Agriculture
09/26/2014	140902	22	Swale	Agriculture
10/20/2014	141001	1	Canal	Urban
10/20/2014	141002	1	Canal	Urban
10/20/2014	141003	2	Upland	Agriculture
10/20/2014	141004	1	Upland	Agriculture
10/20/2014	141005	3	Irrigation ditch	Agriculture
10/20/2014	141006	1	Canal	Urban
11/24/2014	141101	1	Irrigation ditch	Agriculture
11/24/2014	141102	4	Swale	Agriculture
11/24/2014	141103	1	Ephemeral pond	Agriculture
11/24/2014	141104	7	Permanently inundated Pond	Urban
11/24/2014	141105	12	Permanently inundated Pond	Urban
11/24/2014	141106	1	Canal	Forested Marsh
11/24/2014	141107	13	Swale	Urban
11/24/2014	141108	1	Upland	Agriculture
12/15/2014	141201	9	Irrigation ditch	Agriculture
12/15/2014	141202	17	Irrigation ditch	Agriculture
12/15/2014	141203	1	Irrigation ditch	Agriculture
12/15/2014	141204	3	Irrigation ditch	Agriculture

Table A1, continued.

Date	Flock ID number	Flock size	Location feature	Landscape cover type
12/15/2014	141205	4	Permanently inundated Pond	Agriculture
12/15/2014	141206	1	Canal	Agriculture
12/15/2014	141207	2	Canal	Forested Marsh
12/15/2014	141208	1	Canal	Forested Marsh
12/15/2014	141209	1	Canal	Urban
12/15/2014	141210	1	Canal	Urban
01/27/2015	150101	1	Canal	Urban
01/27/2015	150102	1	Canal	Urban
01/27/2015	150103	1	Swale	Urban
01/27/2015	150104	2	Canal	Herbaceous Marsh
01/27/2015	150105	2	Canal	Forested Marsh
01/27/2015	150106	1	Canal	Forested Marsh
01/27/2015	150107	1	Canal	Urban
01/27/2015	150108	3	Swale	Urban
01/27/2015	150109	1	Swale	Agriculture
02/24/2015	150201	1	Canal	Herbaceous Marsh
02/24/2015	150202	5	Upland	Herbaceous Marsh
02/24/2015	150203	1	Canal	Forested Marsh
03/23/2015	150301	115	Permanently inundated Pond	Urban
03/23/2015	150302	1	Swale	Urban
04/27/2015	150401	55	Natural Marsh	Herbaceous Marsh
04/27/2015	150402	28	Natural Marsh	Herbaceous Marsh
05/18/2015	150501	4	Natural Marsh	Herbaceous Marsh
05/18/2015	150502	102	Permanently inundated Pond	Urban
06/22/2015	150601	4	Natural Marsh	Herbaceous Marsh
06/22/2015	150602	41	Natural Marsh	Herbaceous Marsh
06/22/2015	150603	42	Natural Marsh	Herbaceous Marsh
07/30/2015	150701	51	Permanently inundated Pond	Urban
12/14/2015	151201	1	Permanently inundated Pond	Urban
12/14/2015	151202	2	Permanently inundated Pond	Herbaceous marsh
12/14/2015	151203	13	Irrigation ditch	Forested marsh
12/14/2015	151204	1	Canal	Urban
12/14/2015	151205	1	Canal	Urban
12/14/2015	151206	1	Canal	Agriculture
1/20/2016	160101	1	Permanently inundated Pond	Urban
1/20/2016	160102	6	Irrigation ditch	Agriculture
1/20/2016	160103	2	Irrigation ditch	Agriculture
1/20/2016	160104	6	Irrigation ditch	Agriculture
1/20/2016	160105	2	Canal	Agriculture
1/20/2016	160106	4	Canal	Agriculture
1/20/2016	160107	2	Swale	Agriculture
1/20/2016	160108	10	Irrigation ditch	Agriculture
1/20/2016	160109	1	Irrigation ditch	Agriculture

Table A1, continued.

Date	Flock ID number	Flock size	Location feature	Landscape cover type
1/20/2016	160110	2	Irrigation ditch	Agriculture
1/20/2016	160111	4	Irrigation ditch	Agriculture
1/20/2016	160112	7	Permanently inundated Pond	Urban
2/4/2016	160201	2	Canal	Urban
2/4/2016	160202	1	Swale	Agriculture
2/4/2016	160203	7	Permanently inundated Pond	Agriculture
2/4/2016	160204	2	Upland	Agriculture
2/4/2016	160205	138	Irrigation ditch	Agriculture
2/4/2016	160206	1	Irrigation ditch	Agriculture
2/17/2016	160201b	2	Canal	Agriculture
2/17/2016	160202b	2	Irrigation ditch	Agriculture
2/17/2016	160203b	2	Swale	Agriculture
2/17/2016	160204b	2	Swale	Agriculture
2/17/2016	160205b	6	Swale	Urban
2/17/2016	160206b	1	Swale	Urban
3/29/2016	160301	39	Irrigation ditch	Agriculture
3/29/2016	160302	1	Canal	Urban
3/29/2016	160303	1	Canal	Urban
3/29/2016	160304	1	Canal	Urban
3/29/2016	160305	1	Canal	Urban
4/20/2016	160401	108	Permanently inundated Pond	Urban
4/20/2016	160402	1	Ephemeral pond	Urban
4/20/2016	160403	3	Ephemeral pond	Urban
5/24/2016	160501	1	Irrigation ditch	Urban
Totals	**107**	**1199**		

Table A2. Location features, landscape cover type, and flock size of storks observed from bimonthly road surveys, September 2014 to May 2016, South Florida.

Date	Flock ID number	Flock size	Location feature
09/24/2014	RA140901	1	Canal
09/24/2014	RA140902	1	Ephemeral pond
09/24/2014	RA140903	1	Canal
09/24/2014	RA140904	2	Canal
09/24/2014	RA140905	1	Ephemeral pond
10/22/2014	RA141001	1	Ephemeral pond
10/22/2014	RA141002	1	Canal
10/22/2014	RA141003	1	Canal
10/22/2014	RA141004	1	Canal
10/31/2014	RB141001	2	Canal
10/31/2014	RB141002	1	Permanently inundated Pond
10/31/2014	RB141003	1	Permanently inundated Pond
10/31/2014	RB141004	2	Swale
10/31/2014	RB141005	2	Canal
10/31/2014	RB141006	2	Permanently inundated Pond
11/23/2014	RA141101	1	Canal
11/23/2014	RA141102	3	Swale
11/23/2014	RA141103	1	Canal
11/23/2014	RA141104	1	Canal
11/23/2014	RA141105	1	Canal
11/23/2014	RA141106	1	Canal
11/23/2014	RA141107	1	Canal
11/23/2014	RA141108	1	Canal
11/23/2014	RA141109	1	Canal
11/23/2014	RA141110	1	Canal
11/23/2014	RA141111	3	Canal
11/23/2014	RA141112	1	Canal
11/23/2014	RA141113	1	Canal
11/26/2014	RB141101	1	Canal
11/26/2014	RB141102	1	Canal
11/26/2014	RB141103	1	Canal
11/26/2014	RB141104	1	Canal
11/26/2014	RB141105	4	Swale
11/26/2014	RB141106	1	Swale
12/05/2014	RA141201	1	Canal
12/05/2014	RA141202	1	Canal
12/05/2014	RA141203	1	Ephemeral pond
12/05/2014	RA141204	1	Canal
12/05/2014	RA141205	1	Canal
12/05/2014	RA141206	2	Canal
12/05/2014	RA141207	1	Canal
12/05/2014	RA141209	1	Canal
12/05/2014	RA141210	1	Canal

Table A2, continued.

Date	Flock ID number	Flock size	Location feature
12/05/2014	RA141211	1	Canal
12/05/2014	RA141212	1	Canal
12/05/2014	RA141213	1	Permanently inundated Pond
12/05/2014	RA141214	1	Permanently inundated Pond
12/05/2014	RA141215	1	Canal
12/05/2014	RA141216	1	Canal
12/05/2014	RA141217	2	Canal
12/05/2014	RA141218	1	Canal
12/05/2014	RA141219	1	Canal
12/05/2014	RA141220	1	Canal
12/05/2014	RA141221	1	Canal
12/05/2014	RA141222	1	Canal
12/12/2014	RB141201	1	Canal
12/12/2014	RB141202	1	Canal
12/12/2014	RB141203	1	Ephemeral pond
12/12/2014	RB141204	1	Ephemeral pond
01/17/2015	RA150101	6	Swale
01/17/2015	RA150102	2	Permanently inundated Pond
01/17/2015	RA150103	1	Swale
01/17/2015	RA150104	1	Canal
01/17/2015	RA150105	1	Canal
01/17/2015	RA150106	1	Canal
01/17/2015	RA150107	1	Canal
01/17/2015	RA150108	1	Canal
01/17/2015	RA150109	2	Canal
01/17/2015	RA150110	1	Canal
01/17/2015	RA150111	1	Canal
01/17/2015	RA150112	2	Permanently inundated Pond
01/17/2015	RA150113	1	Canal
01/17/2015	RA150114	2	Canal
01/17/2015	RA150115	1	Permanently inundated Pond
01/31/2015	RB150101	1	Canal
01/31/2015	RB150102	53	Canal
01/31/2015	RB150103	12	Swale
02/14/2015	RA150201	1	Ephemeral pond
02/14/2015	RA150202	2	Canal
02/14/2015	RA150203	1	Canal
02/14/2015	RA150204	1	Canal
02/14/2015	RA150205	1	Canal
02/28/2015	RB150201	8	Canal
03/15/2015	RA150301	1	Permanently inundated Pond
03/27/2015	RB150301	1	Canal
03/27/2015	RB150303	1	Canal
04/10/2015	RA150401	1	Canal

Table A2, continued.

Date	Flock ID number	Flock size	Location feature
05/09/2015	RA150501	1	Canal
07/11/2015	RA150701	1	Canal
07/28/2015	RB150701	1	Permanently inundated Pond
08/08/2015	RA150801	1	Permanently inundated Pond
08/08/2015	RA150802	1	Canal
08/27/2015	RB150801	1	Canal
09/12/2015	RA150901	1	Canal
09/12/2015	RA150902	1	Canal
09/28/2015	RB150901	1	Canal
09/28/2015	RB150902	1	Canal
10/17/2015	RA151001	1	Swale
10/17/2015	RA151002	1	Canal
10/17/2015	RA151003	1	Canal
10/17/2015	RA151004	1	Canal
10/22/2015	RB151001	1	Canal
10/22/2015	RB151002	1	Canal
10/22/2015	RB151003	3	Irrigation ditch
10/22/2015	RB151004	1	Canal
11/14/2015	RA151101	1	Canal
11/14/2015	RA151102	1	Canal
11/14/2015	RA151103	2	Swale
11/14/2015	RA151104	1	Canal
11/14/2015	RA151105	1	Canal
11/14/2015	RA151106	1	Canal
11/14/2015	RA151107	1	Canal
11/14/2015	RA151108	1	Canal
11/14/2015	RA151109	1	Canal
11/14/2015	RA151110	1	Canal
11/14/2015	RA151111	1	Canal
11/14/2015	RA151112	1	Canal
11/14/2015	RA151113	1	Canal
11/14/2015	RA151114	1	Canal
11/14/2015	RA151115	1	Canal
11/14/2015	RA151116	1	Canal
11/14/2015	RA151117	1	Canal
11/14/2015	RA151118	1	Permanently inundated Pond
11/30/2015	RB151101	1	Canal
11/30/2015	RB151102	1	Canal
11/30/2015	RB151103	2	Irrigation ditch
11/30/2015	RB151104	1	Swale
11/30/2015	RB151105	1	Permanently inundated Pond
11/30/2015	RB151106	3	Permanently inundated Pond
12/12/2015	RA151202	1	Canal
12/12/2015	RA151203	1	Canal

Table A2, continued.

Date	Flock ID number	Flock size	Location feature
12/12/2015	RA151204	1	Canal
12/12/2015	RA151205	1	Canal
12/12/2015	RA151206	1	Canal
12/12/2015	RA151207	1	Canal
12/12/2015	RA151208	1	Canal
12/12/2015	RA151209	1	Canal
12/12/2015	RA151210	1	Canal
12/12/2015	RA151211	2	Canal
12/12/2015	RA151212	1	Canal
12/21/2015	RB151201	1	Canal
12/21/2015	RB151202	1	Canal
12/21/2015	RB151203	1	Swale
12/21/2015	RB151204	3	Swale
12/21/2015	RB151205	1	Swale
12/21/2015	RB151206	2	Permanently inundated Pond
1/16/2016	RA160101	2	Permanently inundated Pond
1/16/2016	RA160102	1	Swale
1/16/2016	RA160103	1	Canal
1/16/2016	RA160104	1	Canal
1/16/2016	RA160105	1	Canal
1/16/2016	RA160106	1	Canal
1/16/2016	RA160107	1	Canal
1/16/2016	RA160108	1	Canal
1/16/2016	RA160109	1	Canal
1/16/2016	RA160110	1	Canal
1/16/2016	RA160111	1	Canal
1/16/2016	RA160112	1	Canal
1/25/2016	RB160101	2	Canal
1/25/2016	RB160102	12	Canal
1/25/2016	RB160103	4	Canal
1/25/2016	RB160104	2	Swale
1/25/2016	RB160105	21	Canal
1/25/2016	RB160106	1	Swale
1/25/2016	RB160107	1	Swale
2/8/2016	RA160201	1	Canal
2/8/2016	RA160202	1	Swale
2/8/2016	RA160203	2	Permanently inundated Pond
2/8/2016	RA160204	1	Swale
2/8/2016	RA160205	1	Swale
2/8/2016	RA160206	1	Canal
2/8/2016	RA160207	1	Canal
2/8/2016	RA160208	1	Canal
2/8/2016	RA160210	1	Canal
2/8/2016	RA160211	1	Canal

Table A2, continued.

Date	Flock ID number	Flock size	Location feature
2/22/2016	RB160201	1	Canal
2/22/2016	RB160202	1	Swale
2/22/2016	RB160203	1	Canal
2/22/2016	RB160204	2	Permanently inundated Pond
2/22/2016	RB160205	3	Permanently inundated Pond
2/22/2016	RB160206	1	Canal
3/7/2016	RA160301	26	Swale
3/7/2016	RA160302	1	Permanently inundated Pond
3/7/2016	RA160303	3	Swale
3/7/2016	RA160304	3	Swale
3/7/2016	RA160305	3	Swale
3/7/2016	RA160306	1	Canal
3/7/2016	RA160307	1	Canal
3/7/2016	RA160308	1	Canal
3/18/2016	RB160301	1	Canal
3/18/2016	RB160302	3	Canal
3/18/2016	RB160303	1	Swale
3/18/2016	RB160304	1	Permanently inundated Pond
3/18/2016	RB160305	1	Swale
3/18/2016	RB160306	4	Swale
4/9/2016	RA160401	1	Permanently inundated Pond
4/9/2016	RA160402	2	Canal
4/9/2016	RA160403	1	Canal
4/9/2016	RA160404	1	Canal
Totals	**191**	**387**	

Appendix B: Model variables for stork use and stork prey production of roadway corridor features

Table B1. Model parameters for factors influencing stork use along roadway corridor features

Model variable	Justification
Hydrology	
Rainfall	Rainfall is included as precipitation influences the availability of potential prey within roadway features and natural wetlands (Gawlik 2002).
Vegetation	
Maintenance (VegM)	Previous studies suggest that emergent and submerged vegetation may influence foraging site use by wading birds (Lantz et al. 2011, Pierce and Gawlik 2010). Vegetation is categorized as either short (mowed) or tall for water features.
Landscape cover type Local scale vegetation (VegF) Distance to nearest wetland (DISTW)	Previous studies suggest that birds in anthropogenic environments are often closely associated with landscape-level features and local-scale habitat measures (Melles et al. 2003, Luther et al. 2008, Mora et al. 2011).
Physical	
Feature slope	The slope of each feature may affect the availability of a littoral edge for foraging. The amount of littoral edge will affect the ability of a stork to forage at the feature.
Distance to nearest roadway (DistRoad)	Storks are well-documented as being sensitive to human disturbance, thus distance to nearest roadway will be included in models (Rodgers and Smith 1995).
Distance to nearest colony (DistColony)	Storks are rarely reported flying greater distances than 80 km to forage during the breeding season, thus distance to colony should influence stork presence along roadway corridors (Browder 1984, Herring and Gawlik 2011).
Other	
Season	Stork presence will be influenced by hydrologic season (wet or dry)
Breeding season	Stork presence will be influenced by breeding season (breeding or nonbreeding).
Time (Month)	Month will be included as a random variable.
Survey type	Survey type (aerial and road) will be included as a random variable.
Feature type	Feature type will be included in models to determine how probability of use by storks varies among feature types.

Table B2. Model parameters for factors influencing stork prey production in roadway corridor features.

Model variable	Justification
Hydrology	
Water depth Hydroperiod	Community structure and size of prey is related to hydroperiod length and water depth (Trexler et al. 2002).
Rainfall	Rainfall is included as precipitation influences prey availability, specifically in features (swales and ephemeral ponds) that are dry part of the year.
Vegetation	
Submerged vegetation (SubVeg) Emergent vegetation (EmergeVeg)	Vegetative structure and cover affect the abundance and diversity of aquatic prey present in wetland systems (Lantz et al. 2011, Herring and Gawlik 2011) and it's likely that vegetation structure will influence prey in anthropogenic water features
Physical	
Littoral width	The littoral zone of canals and permanently inundated ponds will likely influence prey available to storks. The littoral zone allows sunlight to penetrate to the sediment and allows aquatic plants to grow, providing small fish with refuge from larger predatory fish.
Connectivity	Connectivity to surrounding wetlands will affect the degree to which anthropogenic water features produce aquatic fauna. Anthropogenic water features may act as refuges during drought conditions or a source of recolonization for fish species.
Slope	The steepness of the slope of a feature type may influence the amount of time a feature type holds water, thus influencing prey production in the feature.
Area	The area of a feature type, particularly ephemeral features, will likely influence stork prey production.
Other	
Season	Hydrologic season (wet or dry) is included in all models as some sites will not be available during both the wet and dry season.
Time (year and month)	Month and year will be included as random variables.
Landscape cover type	Feature types were sampled across three landscape cover types (herbaceous marsh, forested marsh, and urban) to determine if feature types nested within landscape cover types produce different amounts of stork prey.
Feature type	Feature type will be included in models to determine which features produce a high amount of stork prey.

Appendix C: Supplemental figures for morphological and vegetative attributes for feature sites

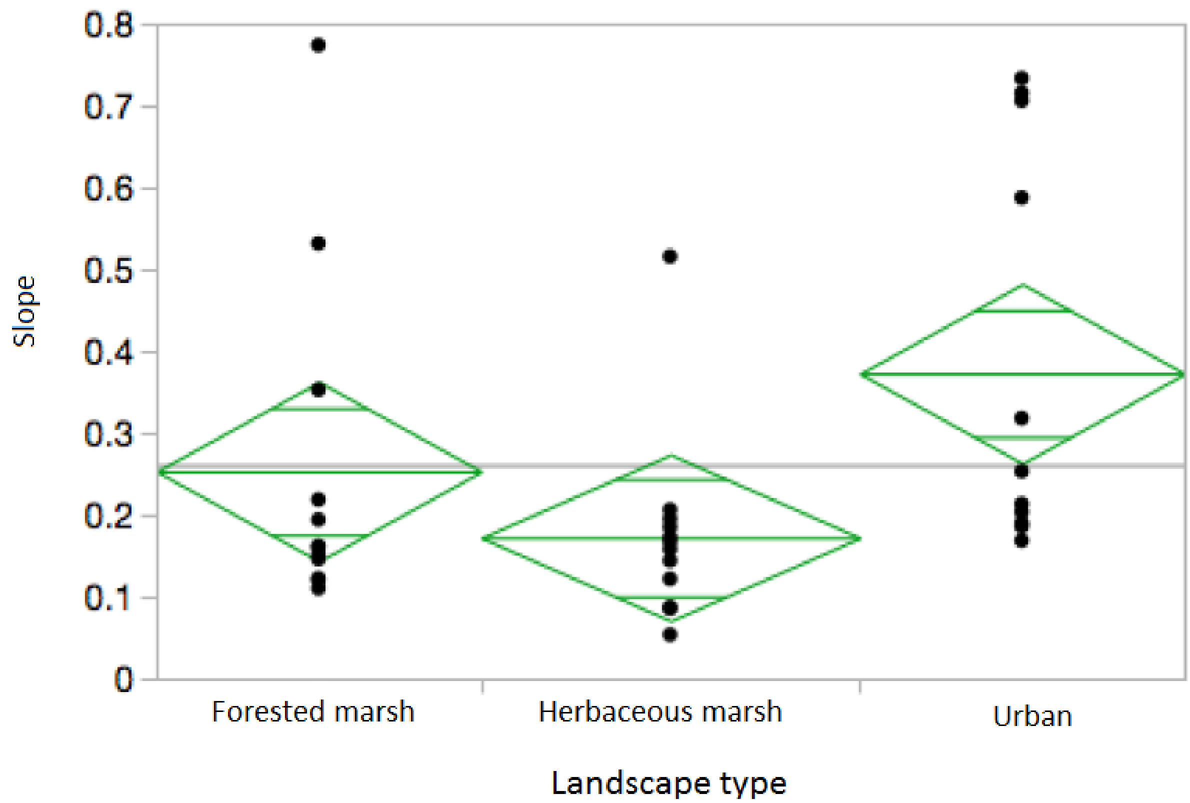

Figure C1. Differences in slope with feature types grouped across landscape cover types, 2014-2016, South Florida.

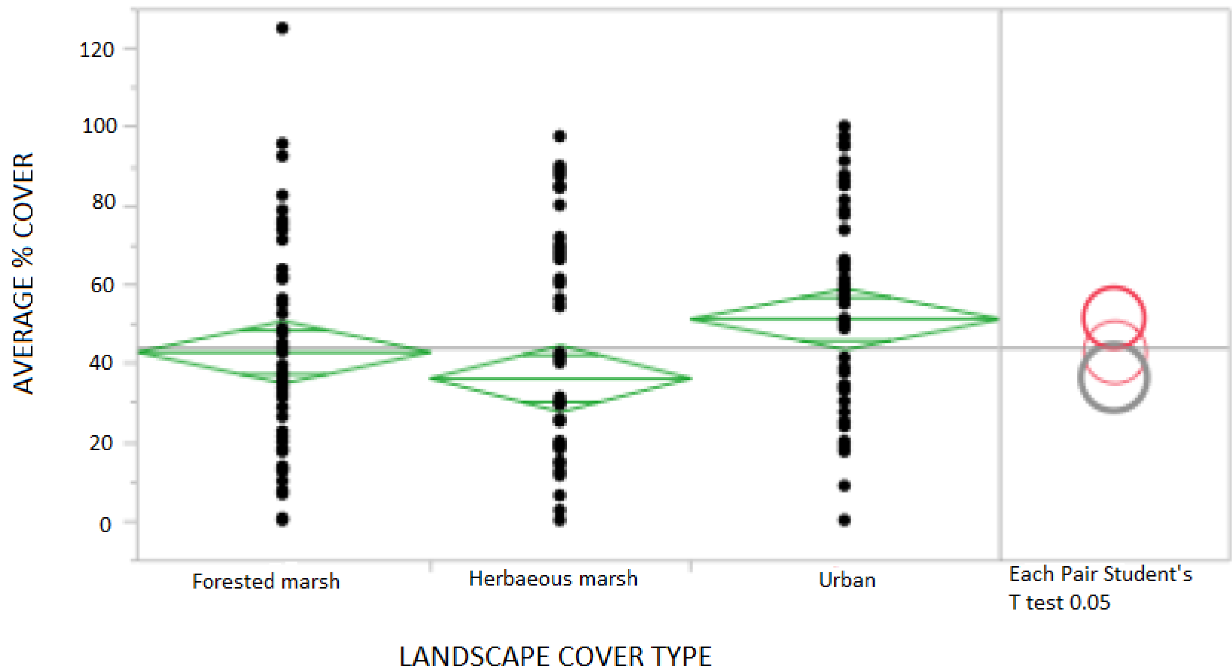

Figure C2. Difference in % vegetation cover across landscape cover types, 2014-2016, South Florida.

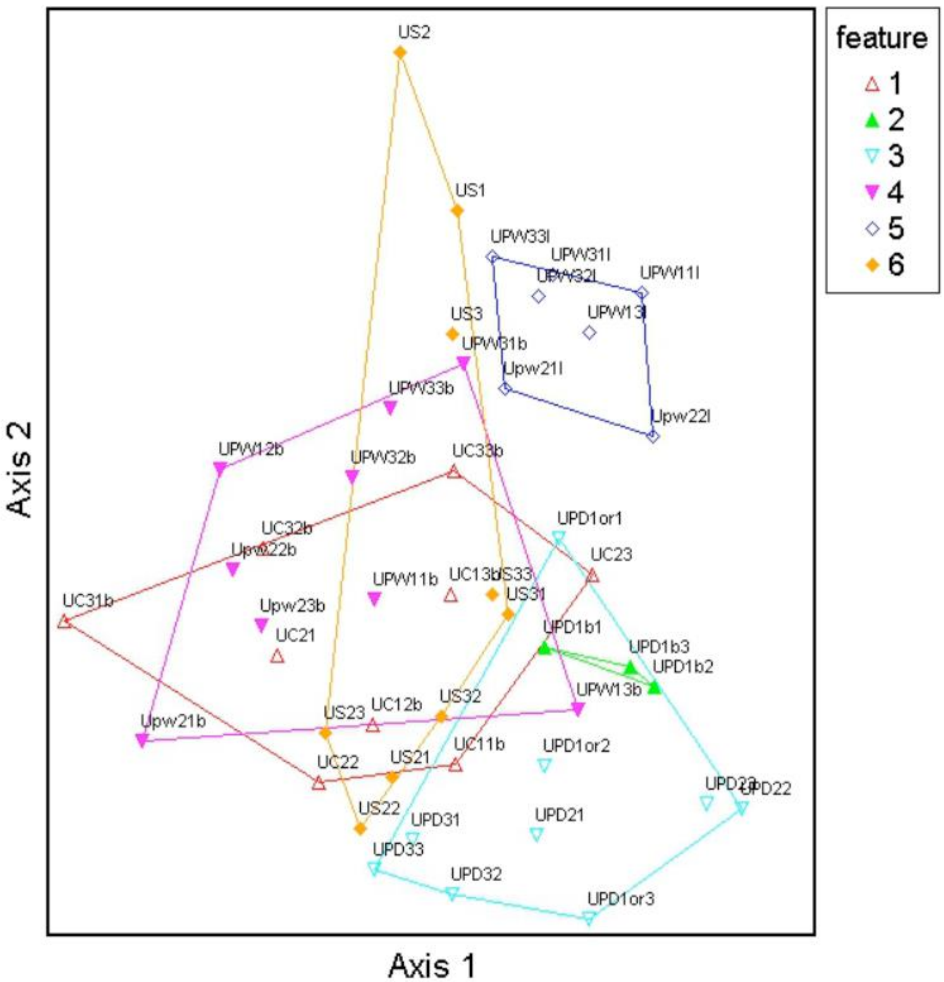

Figure C3. nMDS of vegetation structure at urban water features. Convex hulls indicate groupings by feature type. 1 = canal bank, 2 and 3 = Ephemeral pond, 4 = Permanently inundated Pond, 5 = Permanently inundated Pond littoral, and 6 = swale).

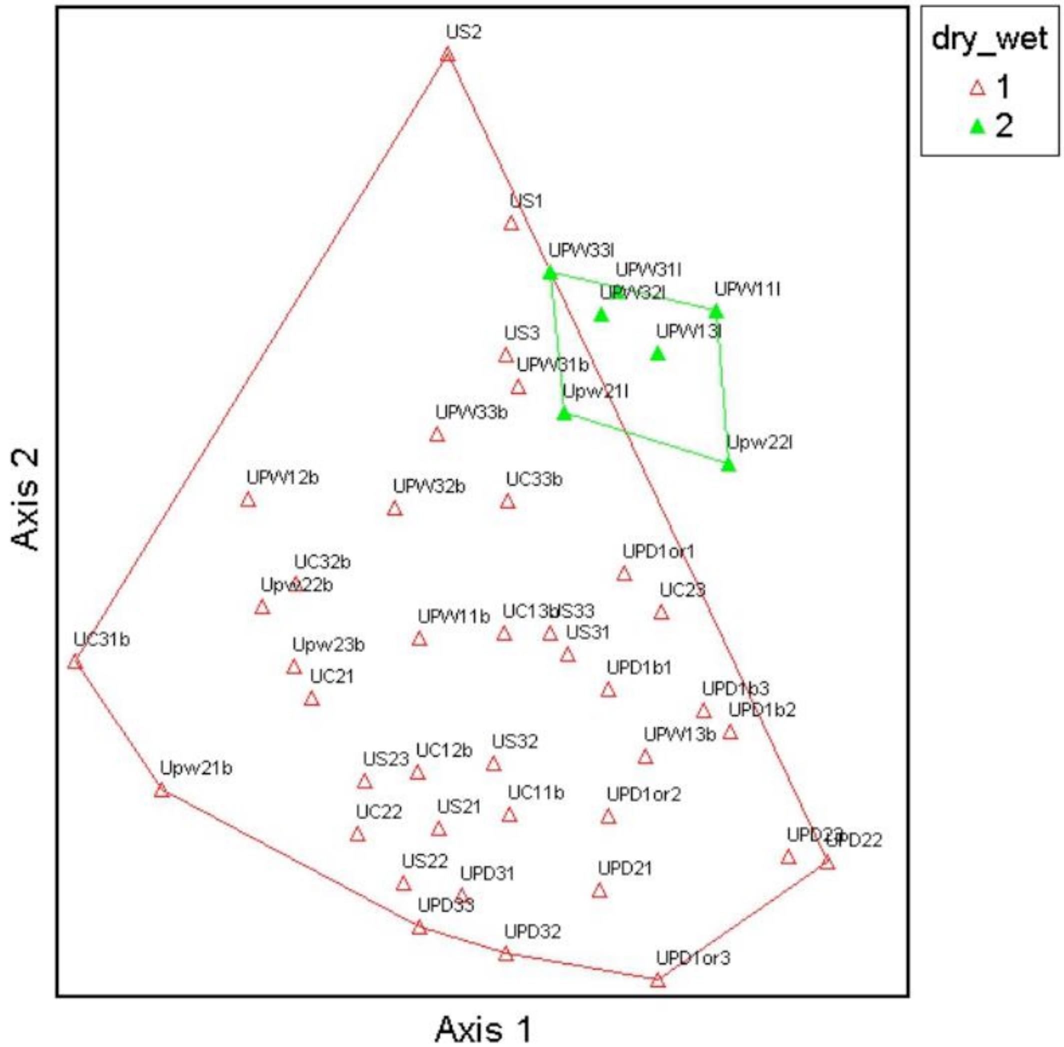

Figure C4. nMDS of urban water features showing separation in community structure between ephemeral (red triangle) and wet (green triangle) features. Canal littoral is not included due to low to no cover at most sites.

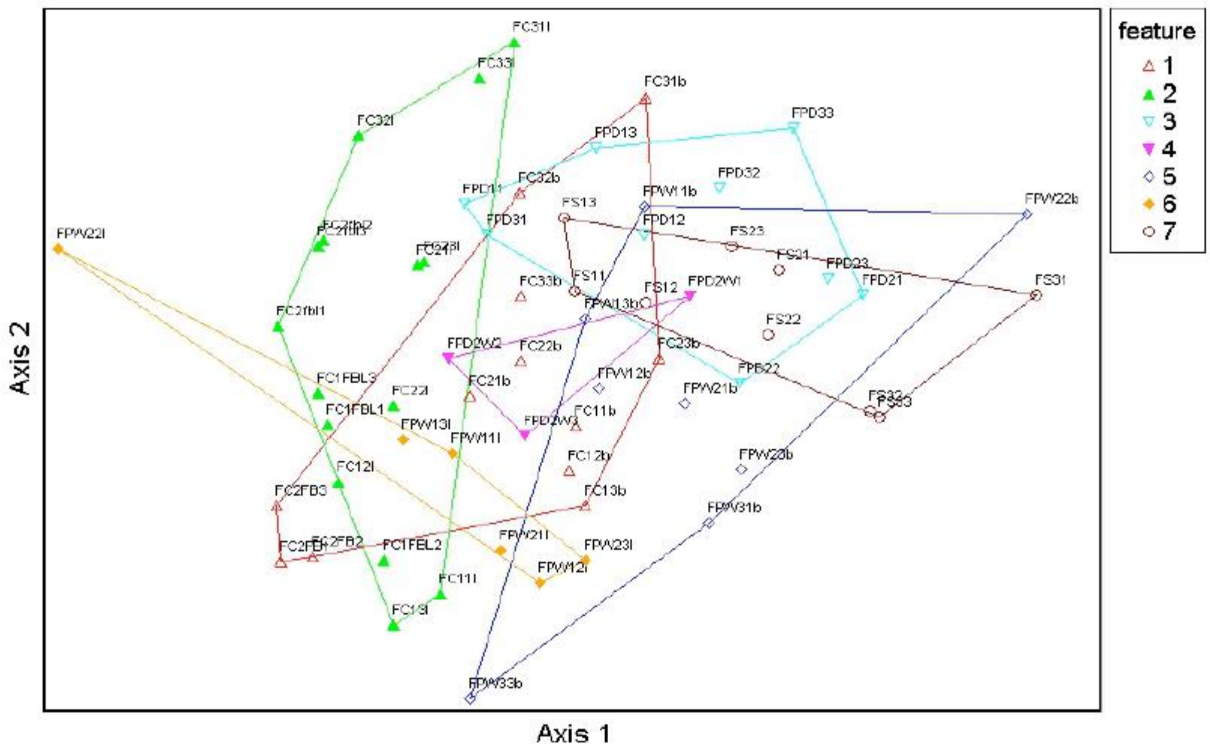

Figure C5. nMDS of vegetation structure at forested marsh feature types. Convex hulls indicate groupings by feature type (1 = canal bank, 2 = canal littoral, 3 = Ephemeral ponds, 4 = Ephemeral pond embedded wet features, 5 = Permanently inundated Pond bank, 6 = Permanently inundated Pond littoral, 7 = swales).

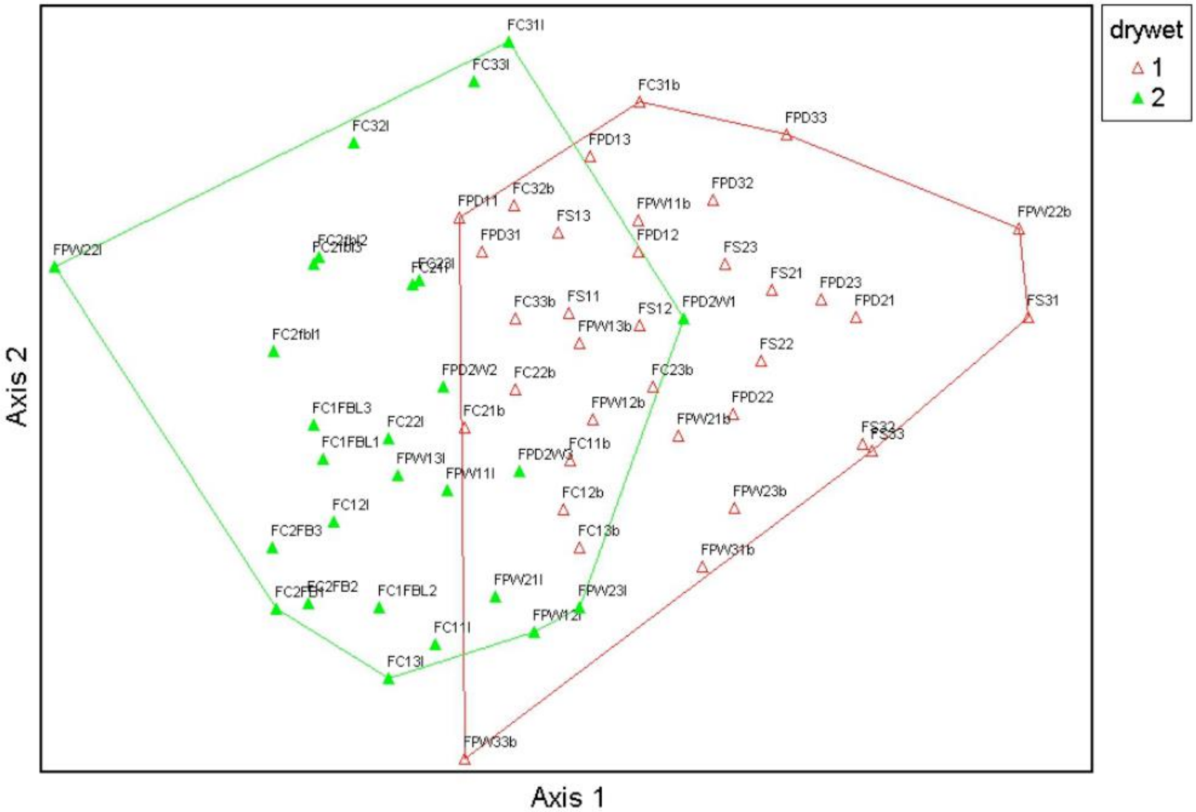

Figure C6. nMDS of forested marsh feature types showing separation in community structure of ephemeral (red triangle) and wet (green triangle) features.

Table C1. Measured vegetative and physical characteristics of fish sampling sites, 2014-2016, South Florida.

Site	Slope (Avg. ± SE)	Depth (Avg. ± SE)	Area (hectares)	Perimeter Length (m)	Edge-to-area	Littoral width (m)	Elevation (Avg. ± SE)	Hydroperiod (Avg. months wet/year ± SE)	% cover (Avg. ± SE)
FC1	0.27 ± 0.07	75.26 ± 21.39	12.71	11,660.43	0.03	1.52	3.87 ± 0.22	12 ± 0.00	47.71 ± 8.44
FC2	0.72 ± 0.21	89.54 ± 23.60	1.22	1,107.95	0.03	1.33	3.52 ± 0.01	12 ± 0.00	85.42 ± 36.71
FC3	0.53 ± 060	168.48 ± 13.03	22.19	23,099.27	0.03	0.85	1.34 ± 0.15	12 ± 0.00	42.08 ± 27.71
FPD1	0.14 ± 0.02	103.71 ± 4.93	0.62	1,562.10	0.03	------	3.76 ± 0.04	8 ± 1.41	36.25 ± 12.81
FPD2	0.16 ± 0.09	121.08 ± 40.59	4.16	888.18	0.01	------	3.56 ± 0.02	5 ±0.71	43.75 ± 1.25
FPD3	0.12 ± 0.03	116.84 ± 20.62	0.60	454.45	0.02	------	4.27 ± 0.08	8 ± 0.71	60.83 ± 15.39
FPW1	0.15 ± 0.03	67.95 ± 46.89	1.31	1,312.77	0.03	1.78	2.49 ± 0.24	12 ± 0.00	55.42 ± 28.60
FPW2	0.22 ± 0.11	89.54 ± 18.59	0.02	59.13	0.07	0.78	3.12 ± 0.35	12 ± 0.00	22.50 ± 8.59
FPW3	0.19 ± 0.09	77.29 ± 29.36	0.24	218.24	0.03	1.19	3.05 ± 0.02	12 ± 0.00	16.79 ± 13.57
FS1	0.16 ± 0.01	136.65 ± 3.60	0.07	168.86	0.08	------	3.45 ± 0.04	4 ± 1.41	78.96 ± 16.53
FS2	0.11 ± 0.02	104.65 ± 4.17	0.08	189.58	0.08	------	3.26 ± 0.64	0 ± 0.00	72.71 ± 21.91
FS3	0.12 ± 0.04	87.38 ± 12.52	0.06	136.56	0.07	------	3.55 ± 0.22	0 ± 0.00	67.92 ± 13.09
HC1	0.18 ± 0.05	87.20 ± 16.92	9.01	7,358.79	0.02	1.45	2.93 ± 0.15	12 ± 0.00	42.29 ± 20.77
HC2	0.52 ± 0.06	118.36 ± 27.28	44.40	22,678.64	0.02	1.83	-1.58 ± 0.24	12 ± 0.00	33.34 ± 19.20
HC3	0.09 ± 0.04	92.28 ± 98.42	28.19	23,860.05	0.03	0.91	2.65 ± 0.04	12 ± 0.00	37.92 ± 19.92
HPD1	0.16 ± 0.03	86.36 ± 22.94	0.08	122.53	0.04	------	2.65 ± 0.06	9 ± 0.71	79.17 ± 15.05
HPD2	0.20 ± 06	158.50 ± 153.29	0.13	167.03	0.04	------	2.74 ± 0.16	7 ± 0.71	45.42 ± 23.38
HPD3	0.17 ± 0.08	107.70 ± 36.53	1.33	613.26	0.01	------	1.69 ± 0.05	10 ± 1.41	24.17 ± 18.81
HPW1	0.16 ± 0.02	85.34 ± 18.19	0.23	271.58	0.04	1.78	2.88 ± 0.02	12 ± 0.00	20.21 ± 19.17
HPW2	0.17 ± 0.03	72.72 ± 20.65	0.18	228.90	0.04	2.42	2.68 ± 0.05	12 ± 0.00	0.00 ± 0.00
HPW3	0.21 ± 0.08	85.34 ± 6.12	0.19	232.88	0.04	1.75	2.98 ± 0.04	12 ± 0.00	8.33 ± 14.03
HS1	0.12 ± 0.02	101.60 ± 14.22	0.07	252.98	0.12	------	2.76 ± 0.04	3 ± 1.41	69.58 ± 13.23
HS2	0.09 ± 0.01	91.44 ± 2.54	0.03	73.76	0.08	------	2.80 ± 0.03	5 ± 1.41	25.00 ± 26.61
HS3	0.05 ± 0.01	71.96 ± 8.15	0.06	115.21	0.06	------	3.18 ± 0.03	3 ± 1.41	78.33 ± 14.91
UC1	0.72 ± 0.16	99.90 ± 48.23	12.41	15,239.39	0.04	1.38	4.18 ± 0.06	12 ± 0.00	57.50 ± 25.36
UC2	0.71 ± 0.10	356.87 ± 29.49	60.41	35,835.03	0.02	0.51	2.54 ± 0.02	12 ± 0.00	47.25 ± 28.75
UC3	0.73 ± 0.06	154.10 ± 21.11	0.47	1,562.10	0.10	0.00	3.90 ± 0.20	12 ± 0.00	44.25 ± 21.35
UPD1	0.21 ± 0.09	132.08 ± 38.15	0.35	449.28	0.03	------	4.37 ± 0.02	3 ± 1.41	53.75 ± 6.61
UPD2	0.20 ± 0.03	151.13 ± 16.36	0.56	408.43	0.02	------	3.54 ± 0.03	3 ± 1.41	58.33 ± 18.21
UPD3	0.19 ± 0.05	145.52 ± 29.13	0.60	491.64	0.02	------	2.92 ± 0.03	2 ± 0.71	87.50 ± 12.31
UPW1	0.25 ± 0.04	136.88 ± 77.82	1.12	436.47	0.01	1.62	0.61 ± 0.05	12 ± 0.00	22.08 ± 20.17
UPW2	0.59 ± 0.09	188.60 ± 20.57	1.05	383.43	0.01	0.87	2.51 ± 0.05	12 ± 0.00	17.08 ± 19.85
UPW3	0.32 ± 0.06	108.20 ± 53.04	1.13	547.42	0.01	1.37	3.82 ± 0.02	12 ± 0.00	67.50 ± 13.73

Table C1, continued

Site	Slope (Avg. ± SE)	Depth (Avg. ± SE)	Area (hectares)	Perimeter Length (m)	Edge-to-area	Littoral width (m)	Elevation (Avg. ± SE)	Hydroperiod (Avg. months wet/year ± SE)	% cover (Avg. ± SE)
US1	0.17 ± 0.05	57.33 ± 10.57	0.21	396.85	0.06	------	4.62 ± 0.01	4 ± 0.71	37.08 ± 2.89
US2	0.20 ± 0.03	56.62 ± 7.72	0.13	192.04	0.11	------	3.92 ± 0.03	0 ± 0.00	97.71 ± 2.19
US3	0.19 ± 0.05	59.69 ± 7.06	0.15	183.18	0.09	------	4.09 ± 0.02	0 ± 0.00	85.00 ± 8.75

Appendix D: Suitable wood stork biomass calculation variables and core foraging area map

Table D1. Actual biomass consumed by storks for the southern region. Actual biomass consumed is determined by hydroperiod classifications provided by USFWS.

Class	Days inundated	Fish biomass (g/m^2)
Class 1	0-60	0.31
Class 2	60-120	0.62
Class 3	120-180	1.32
Class 4	180-240	2.34
Class 5	240-300	2.93
Class 6	300-330	3.36
Class 7	330-365	3.63

Table D2. Foraging Suitability Index (FSI) for stork for the southern region. FSI is determined by % exotic vegetation and provided by the USFWS.

% exotics	Fish biomass (g/m^2)
0 – 25%	1.0
25 – 50%	0.64
50 – 75%	0.37
75 – 90%	0.03
> 90%	0.03

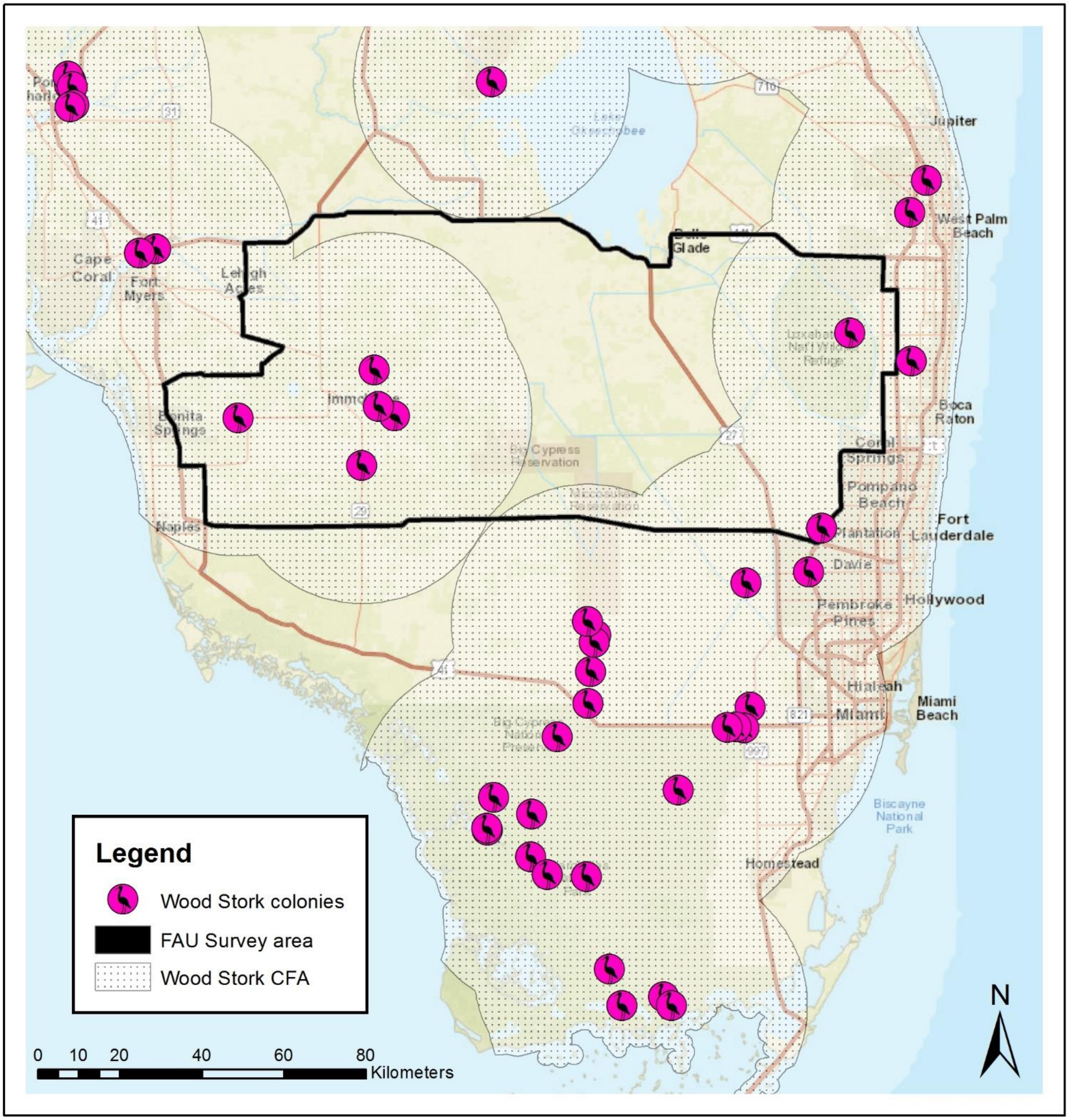

Figure D1. South Florida Wood Stork colonies Core Foraging Areas (CFA) located near FAU survey routes, 2014-2016.

Appendix E: Feature type definitions

Table E1. Feature site definitions.

Features	Definition
Canal	Canals are defined as a trench with a bottom usually covered by water, with the upper edges normally above water (Florida Statute, Section 403.802(2)). Urban canals followed this design criteria, however some canals in herbaceous (HC3) and forested marsh (FC1 and FC2) areas along I-75/Alligator Alley often only had one edge above water with the other connecting directly to the natural marsh system.
Ephemeral pond	Ephemeral ponds are described as waterbodies which exist for only a portion of the year. Water levels rely upon precipitation or runoff (FDOT 1999).
Irrigation ditch	Irrigation ditches are ditches located in agricultural fields designed to drain water for irrigation. These features were located primarily south of Lake Okeechobee in sugarcane fields.
Permanently inundated pond	Ponds that hold water year-round and are generally used for drainage and water storage. May also provide water quality benefits depending on feature morphology (Yu et al. 1993).
Swale	Swales consist of man-made trenches with a top width-to-depth ratio of the cross section equal to or greater than 6:1 or side slopes equal to or greater than 3 feet horizontal to one foot vertical (Florida Statute, Section 402.803(14)). They contain contiguous area of standing or flowing water only following a rainfall event. Swales in this study often held water for extended periods of time during wet season (US1, FS1, HS1-3). Swales in urban areas followed design criteria, whereas swales in the forested marsh landscape cover type along I-75/Alligator Alley connected directly to nearby canals influencing prey communities.
Upland	Uplands consist of flooded areas after rain events such as agricultural fields where storks were observed during aerial surveys.
Slope classifications	Slopes were classified as shallow, moderate, and steep during aerial surveys. Shallow slopes were features with a slope greater than 6:1, often including the natural marsh or swale feature types. Steep slopes were features with a slope less than 2:1, often including permanently inundated ponds and canals. Moderate slopes were features with a slope between 2:1 and 6:1.