Wood Stork Foraging Probability Index

(STORKI v. 1.0)

Ecological and Design Documentation

(photograph by William Perry, Everglades National Park)

Alicia Lo Galbo*, Leonard Pearlstine, Janice Lynch, Robert Fennema, Matthew Supernaw

South Florida Natural Resources Center, National Park Service, Everglades National Park, 950 North Krome Avenue, Homestead, FL 33030, USA

**Corresponding author. Telephone: 305-224-4243*

E-mail addresses: Alicia_Logalbo@nps.gov, Leonard_Pearlstine@nps.gov, Janice_Lynch@nps.gov, Robert_Fennema@nps.gov

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Introduction

The southeastern U.S. wood stork (*Mycteria americana*) population plummeted following the wide scale drainage, compartmentalization, and urbanization of the Everglades that altered the natural hydroperiods and hydropatterns of the Florida Everglades (Ogden 1994). Wood stork nesting has declined by more than 70% since the 1930s and productivity has generally shifted from the southern mainland estuary (from Cape Sable peninsula across to the lower Taylor Slough basin) and the headwaters that feed into Whitewater Bay and the lower Gulf Coast in the Everglades to interior freshwater marshes (Cook and Cobza 2010; Ogden 1994). Another change caused by altered hydrological conditions was the delayed initiation of the wood stork natural breeding cycle (Ogden 1994). The decline of the wood stork in the southeastern U.S. was so substantial that the U.S. Fish and Wildlife Service declared the southeastern U.S. wood stork population endangered in 1984. Loss of wetland foraging habitat is a primary causal factor linked to the decline of the southeastern U.S. wood stork population in the Everglades ecosystem (Herring and Gawlik 2011; Ogden 1994).

Wood storks exhibit some of the most selective foraging strategies of the Ciconiiformes due to their tactile foraging strategy and selectivity for fast-moving piscivorous prey (Gawlik et al. 2010; Kushlan 1980). This foraging strategy requires prey densities to be concentrated within a restricted water depth range (Kushlan 1980). This type of foraging strategy makes wood storks sensitive to fluxing hydroperiods and hydropatterns (Bancroft et al. 2002; Coulter and Bryan 1993; Gawlik et al. 2004; Herring and Gawlik 2011; Russell et al. 2002). Adequate foraging conditions prove especially critical to wood storks during the nesting season because of the high energetic demands of developing chicks (Clark 1980).

To reverse past environmental degradation and restore habitat for wildlife such as the wood stork, the largest environmental restoration project in the world began in the Everglades ecosystem. The Modified Water Deliveries Project (MWD) and the Comprehensive Everglades Restoration Project (CERP) are two of the most significant Everglades restoration programs. Wood storks, due to their significant decline and sensitivity to environmental parameters, are recognized as a key indicator species of the Everglades. Development of ecological modeling tools that can simulate the effects of restoration on wood stork habitats is of keen interest to natural resource managers, restoration planners, and conservation planners.

The main goal of this project is to develop a wood stork foraging probability model that could be used to assess the effects of Everglades' restoration scenarios, such as the MWD and CERP, on habitat foraging suitability for the wood stork.

Key objectives of this project include the following:

- develop a spatially-explicit wood stork foraging model whose spatial domain will include the freshwater marshes within the Florida Everglades Water Conservation Areas and Everglades National Park;
- develop the model in collaboration with other scientists and facilitate code sharing to encourage the long-term development and use of the model;
- develop a model that can be used to readily evaluate Everglades restoration scenarios from hydrologic input provided by models such as the Regional System Model (RSM) and the South Florida Water Management Model (SFWMM);
- generate spatio-temporal output that meets international NetCDF file formatting standards; and
- develop a flexible modeling framework so that existing model parameters can be readily modified and new model parameters can be incorporated.

This document describes the rationale and methodology used to develop the Everglades Wood Stork Foraging Probability Index (STORKI v. 1.0) and is intended to serve as a general reference document for model users. Please refer to the User's Guide for detailed instructions on how to install and run the STORKI v. 1.0 model.

Review of Existing Wood Stork Foraging Models

We reviewed existing wood stork foraging predictive and statistical modeling tools to identify opportunities for predictive tool development and to identify research findings for incorporation into a predictive modeling tool.

Herring and Gawlik (2011)

Herring and Gawlik (2011), of Florida Atlantic University, funded by the U.S. Department of the Interior, developed a proportional hazards regression model from a flight following study conducted in 2006 that simulates wood stork foraging response as a function of distance from the nesting colony, water depth, and vegetation type (Equation 1).

Equation 1: $h(x) = \exp\{-0.146(\text{distance})-0.0004(\text{depth}+\text{depth}^2)+2.148626(\text{freshwater marsh})+2.611(\text{shrub swamp})+2.999(\text{saltmarsh})+2.953(\text{mangrove swamp})+(\text{exotic})\}$ (Herring and Gawlik 2011).

The geographic domain of this model is Water Conservation Area 3 and Everglades National Park. Water depths used in the model were estimated from the Everglades Depth Estimation Network (EDEN). During the flight following study, wood storks foraged in an average water depth of 8 cm (+-21 standard deviation (SD), range -45 to 50 cm) (Herring and Gawlik 2007). Water depths between -25 cm and 25 cm in EDEN grid cells had the highest probability of use (Herring and Gawlik 2011). Modeled wood stork foraging used a broader response in relation to water depths (Herring and Gawlik 2007, Herring and Gawlik 2011) as illustrated in Figure 1.

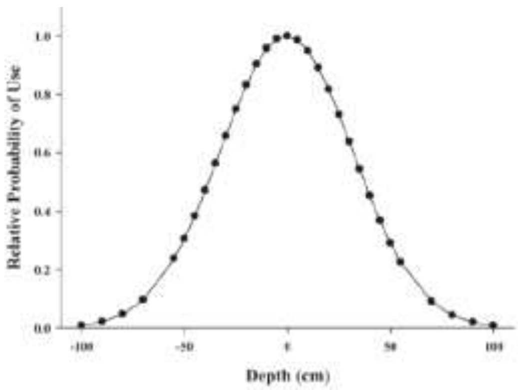

Figure 1. Wood stork foraging probabilities estimated from the Everglades Depth Estimation Network. (Figure provided courtesy of Herring and Gawlik 2011).

Vegetation types used by wood storks were estimated from the 2003 Florida Fish and Wildlife Conservation Commission Vegetation and Land Cover Map (Florida Fish and Wildlife Commission 2003). Wood storks foraged in the following vegetation community types with the following relative percent of use: freshwater marsh and wet prairie (45.2%), saltwater marsh (23.3%), mangrove swamp (19.2%), shrub swamp (9.6%), sawgrass marsh (1.4%), and exotic vegetation (1.4%) (Herring and Gawlik 2007). The model incorporates the preferential wood stork foraging behavior in the mangrove swamp-saltwater marsh ecotone (Herring and Gawlik 2011; Equation 1). The model simulates foraging probability of use in relation to nesting colony locations (Figure 2). Wood storks foraged a mean distance of 10.3 km (+-13.4 SD, range 0.5 km-74.5 km) from nesting colony locations in the flight following study (Herring and Gawlik 2011; Herring and Gawlik 2007; Figure 2).

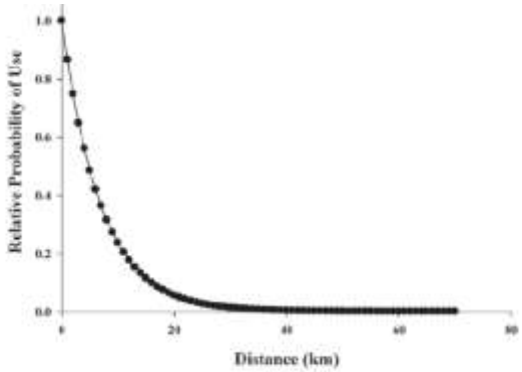

Figure 2. Wood stork foraging probabilities as a distance from nesting colony. (Figure provided courtesy of Herring and Gawlik 2011.)

Gawlik et al. (2004)

The Wading Bird Habitat Suitability Index (HSI) developed by Gawlik et al. (2004), of the Florida Atlantic University and the South Florida Water Management District (SFWMD), calculates wading bird suitability as a weekly time step as the minimum of either water recession or water depth (Gawlik et al. 2004; Figures 3-4; Equation 2).

Equation 2: $SI_{WB} = \min(SI_{depth}, SI_{recession})$

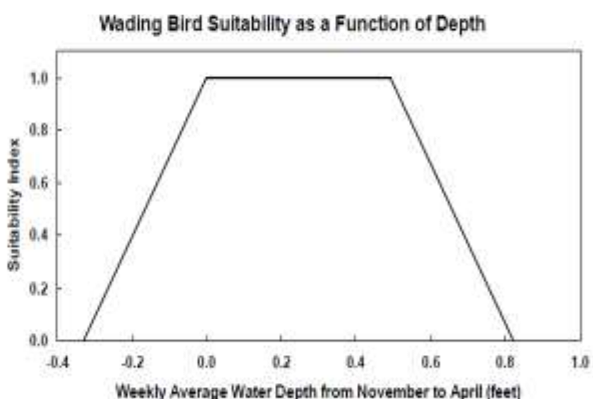

Figure 3. Estimated wading bird foraging suitability (scale of 0-1.0) as a function of water depth. (Figure provided courtesy of Gawlik et al. 2004.)

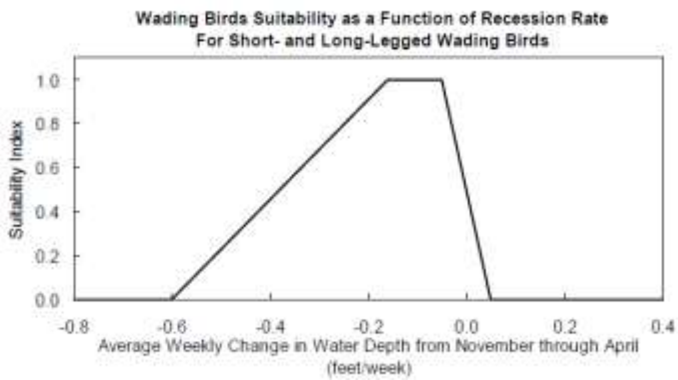

Figure 4. Estimated wading bird foraging suitability as a function of water level recession rate (scale of 0-1.0). (Figure provided courtesy of Gawlik et al. 2004).

The input for this model is the SFWMM that provides grid output in a 2 mile X 2 mile grid cell resolution. The mean suitability score for the top 23% of model grid cells is calculated each week within specified Everglades interior and coastal regions respectively. The summary variable that best described wood stork foraging, per the validation exercise, was the landscape index from January to the end of March.

Bancroft et al. (2002)

The National Audubon Society in association with the South Florida Water Management District (Bancroft et al. 2002) modeled great blue heron (*Ardea herodias*), great egret (*Ardea alba*), wood stork, and white ibis (*Eudocimus albus*) abundance as a response to water levels and vegetation community composition within Water Conservation Area 1 and Water Conservation Area 2A. These multivariate regression models utilized a water depth index simulated from the SFWMM and eight vegetation types estimated from remote sensing analyses (Figure 5). This model indicated that water depth had the greatest influence on wading bird foraging and that area of open water slough had the next most significant effect on wading bird abundance. Slough was defined as habitats dominated by white water lily (*Nymphaea odorata*), floating hearts (*Nymphaea aquatica*), and spatterdock (*Nuphar advena*).

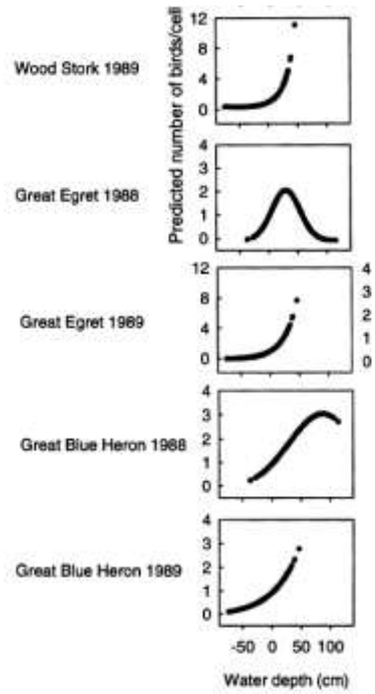

Figure 5. Wading bird foraging water depth preferences simulated with the South Florida Water Management Model. (Figure provided courtesy of Bancroft et al. 2002.)

Comiskey et al. (1998)

The Across Trophic Level System Simulation (ATLSS) Foraging Conditions Index was developed by the University of Tennessee (Comiskey et al. 1998) with funding provided by the U.S. Department of the Interior. This model simulates the foraging response of long-legged wading birds and short-legged wading birds (species were not specified in the model description). This model simulates spatial foraging patterns assuming a preferential 5-35 cm foraging depth for long-legged wading birds and a 0-20 cm preferential foraging depth for short-legged waders (Comiskey et al. 1998). The index simulates water reversal conditions and also hydroperiod conditions as they relate to prey density. The input for this model is hydrological data from the SFWMM that is converted to a finer 500 meter X 500 meter using the ATLSS high-resolution methodology (Comiskey et al. 1998).

Wood Stork Foraging Probability Index (STORKI v. 1.0) Model

STORKI was developed to provide rapid simulations of wood stork foraging conditions in response to modeled CERP scenarios. The modular programming utilizes NetCDF file-formatting standards and is designed to ease updating of wood stork forage selection relationships and parameters in the model as new research findings become available.

Domain of the Wood Stork Foraging Probability Index (STORKI v. 1.0)

The STORKI v. 1.0 model domain is described by the domain of the input hydrologic file (see User's Guide). Typically, the hydrologic inputs are from the SFWMM, RSM or EDEN and would include Water Conservation Area 1, Water Conservation Area 2, Water Conservation Area 3, and wetlands of Everglades National Park (Figure 6).

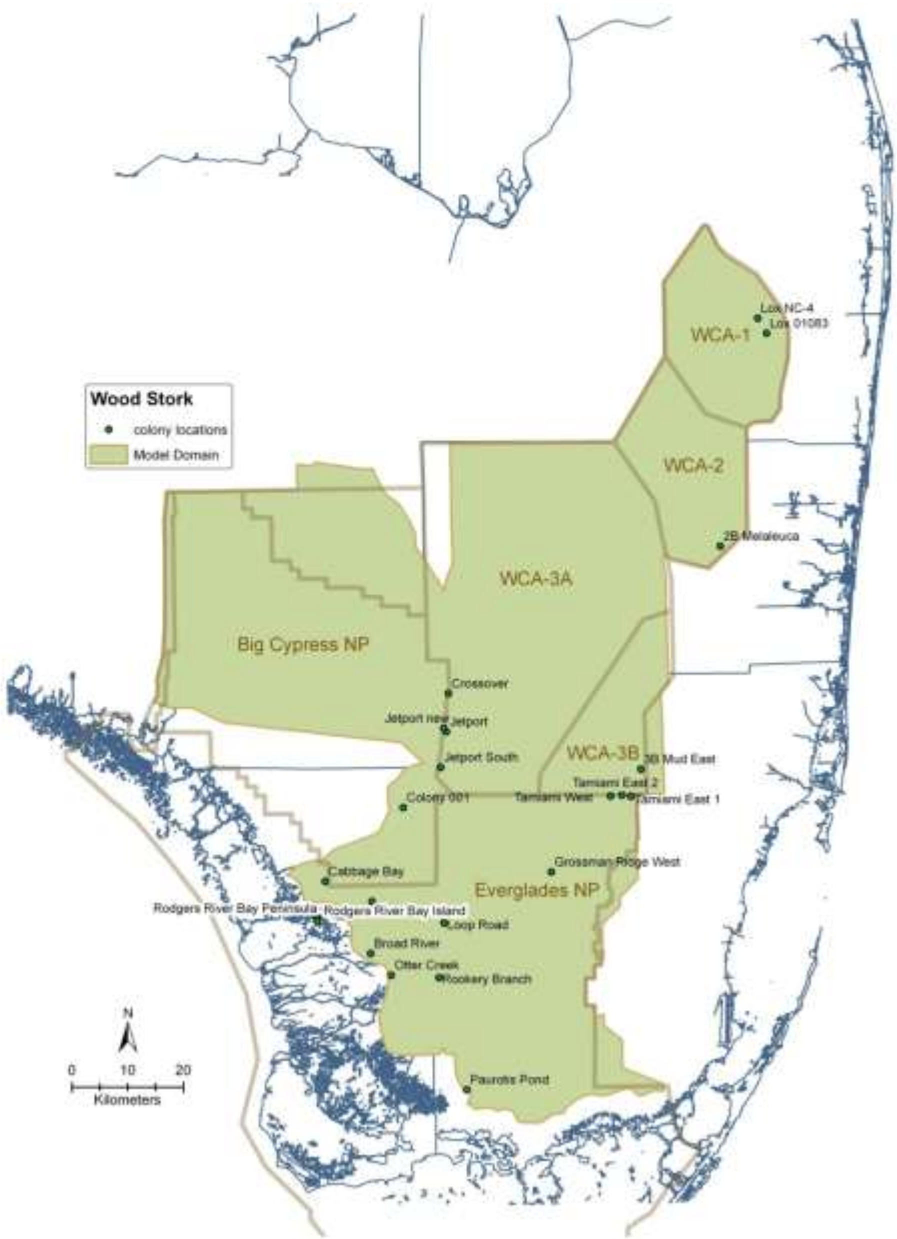

Figure 6. The typical domain of STORKI is shaded and includes Water Conservation Area 1 (WCA 1), Water Conservation Area 2 (WCA 2), Water Conservation Area 3 (WCA 3A and WCA 3B), and Everglades National Park (ENP). Also shown are colony locations used in the current model.

Wood Stork Foraging Probability Index (STORKI v. 1.0) Rules and Justification

Model Outputs.

Output	File type	Description
Proportional depth change	NetCDF	Proportional change in water depth from 7 days prior to the present.
Cell forage probability	NetCDF	Probability index at each grid cell that wood stork will forage at that cell.
Cell suitability index	NetCDF	Index at each grid cell of cell forage probability modified by proportional depth change over the previous week.
Neighborhood forage probability*	NetCDF	Average forage probability in user defined radius around each grid cell (Default = 23.5 km).
Neighborhood suitability index*	NetCDF	Average suitability index in user defined radius around each grid cell (Default = 23.5 km).
Neighborhood top forage probability*	NetCDF	Average of top user defined % of forage probability values in user defined radius around each grid cell (Defaults = 23% & 23.5 km).
Neighborhood top suitability index*	NetCDF	Average of top user defined % of suitability index values in user defined radius around each grid cell (Defaults = 23% & 23.5 km).
Foraging probability indices at colonies	Text (tab-delimited)	Each of the above output variables at specific colony locations.

* Neighborhood raster GIS output is only created if the user choses the option of treating each grid cell in the input domain as a potential colony. If the user only wants output at specific colony locations, then this output is not produced. The raster output for proportional depth change, cell forage probability, cell suitability, and the text file of indices (including neighborhood indices) at colonies is produced regardless of the user's choice.

Temporal Rules. We chose a priori to restrict the STORKI v. 1.0 model to the active (estimated historical) wood stork breeding season because of the importance of foraging energetics during the wood stork breeding season (Herring and Gawlik 2011). The majority of the Everglades National Park Systematic Reconnaissance wood stork data is collected during the breeding season, which limits the model validation exercises to the breeding season. This provides further justification for limiting our model to the breeding season. Wood stork nesting initiation has been delayed from November- December in the early 1900s to later in the dry season in February-March (Frederick et al. 2009; Ogden, 1994). The onset date of the rainy season can flux each year; however, based on past rainfall records, assuming a 15 July onset of the rainy season will provide a reasonable cutoff date for the wood stork nesting season. *Therefore, the wood stork foraging probability is only calculated during the active wood stork breeding season from a calendar date of 1 December to 15 July. The output is provided as a weekly time-step during the breeding season (1 December – 15 July).*

Hydrologic Input and Resolution. Hydrologic input for the STORKI v. 1.0 model can be provided from EDEN, the RSM, or the SFWMM. The Delaunay Triangulation method is used to convert the SFWMM input (provided at a 2 mile X 2 mile resolution) or RSM (varying resolution) to a finer 500 meter X 500 meter resolution. The purpose of using finer resolution modeling is to simulate model output in a scale more similar to how organisms respond to environmental conditions.

Hydrologic Rules. During initial model development, we attempted to simulate reversal probabilities defined in Herring and Gawlik (2007), however, the sensitivity of the SFWMM precluded our ability to actually reach the appropriate reversal probability conditions. These conditions exist in the field but we were not able to simulate these conditions with the SFWMM (ECB3, CERP0 runs). However, we recognized the importance of simulating the effects of reversal conditions to foraging suitability. *For the foraging suitability model, any cell increasing in depth more than 20% over a seven-day period was assigned a zero foraging probability. Any cell not meeting these conditions was assigned a value of one. The 20% reversal conditions therefore, provides a general mechanism to simulate reversals but is not based on a scientifically-derived reversal rate such as those described in Herring and Gawlik (2007).*

Wood stork foraging in relation to water depth was tested with the Herring and Gawlik (2007) wood stork foraging preferences defined in their flight-following study, from a Coulter and Bryan (1983) field study, and from a derived intermediate probability distribution. The field study conducted in east-central Georgia and west-central South Carolina revealed that wood stork foraging depths ranged from 4 to 63 cm (N=181) with an average water depth of 23.1 km +-11.2 SD; wood storks most frequently foraged at sites in the 10 – 25 cm depth range (Figure 7; Coulter and Bryan 1993). Herring and Gawlik (2011) estimated that wood stork foraging was most prevalent in simulated EDEN water depths (400 meter X 400 meter cell resolution) from -25 cm to 25 cm. Bancroft et al. (2002) estimated that wood storks foraged in water depths from 1-50 cm in simulated SFWMM output (2 mile X 2 mile resolution) and that foraging increased in relation to water depth. Adult wood stork leg length is approximately 50 cm long, which explains the upper physical limitations of wood stork foraging (Coulter and Bryan 1993). Prey availability may be affected by water depths less than 10 cm during the breeding season due to increased temperatures and decreasing dissolved oxygen (Coulter and Bryan 1993).

Based on our calibration trials (described below), we defined the foraging water depth probabilities in the wood stork foraging suitability model (STORKI v. 1.0) based on the wood stork foraging preferences defined in Herring and Gawlik (2007).

The Everglades Wood Stork Foraging Probability Index is calculated by multiplying the probability of suitable water depths by the probability of recession (Equation 3). This equation is calculated on a weekly time step throughout the wood stork breeding season.

Equation 3. Everglades Wood Stork Foraging Probability Index at Each Grid Cell = [(P(recession) * P(water depth)]

Spatial Rules. Wood storks exhibit some philopatry for colony breeding sites and have occupied colony sites for over 25 years (Frederick and Ogden 1997). Average distance between nesting and foraging sites in the Birdsville Colony of Georgia was 11.94 km +-10.54 SD; 85% of foraging sites were within 20 km on the nesting colony (Coulter and Bryan 1993; Figure 7).

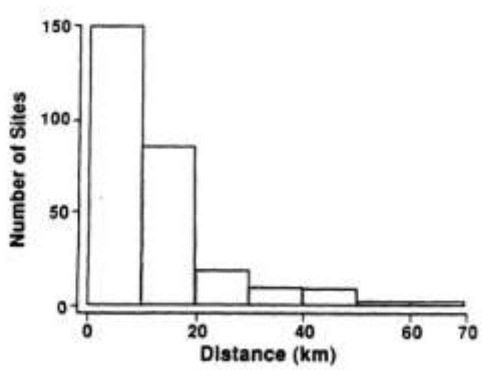

Figure 7. Wood stork foraging sites and relative distance from nesting colony. (Figure provided courtesy of Coulter and Bryan 2003.)

Wood storks foraged a mean distance of 10.3 km (+-13.4 SD, range 0.5 km-74.5 km) from Everglades National Park nesting colony locations (Herring and Gawlik 2011; Herring and Gawlik 2007; Figure 2).

For the Wood Stork Foraging Probability Index, we can limit the area evaluated to only model cells within 23.4 km of a wood stork colony (Figure 8). 23.4 km is the average foraging distance + 1 SD used by nesting wood storks in Everglades National Park (Herring and Gawlik 2007). Cells that are partially located within the foraging radius area are included in the model output.

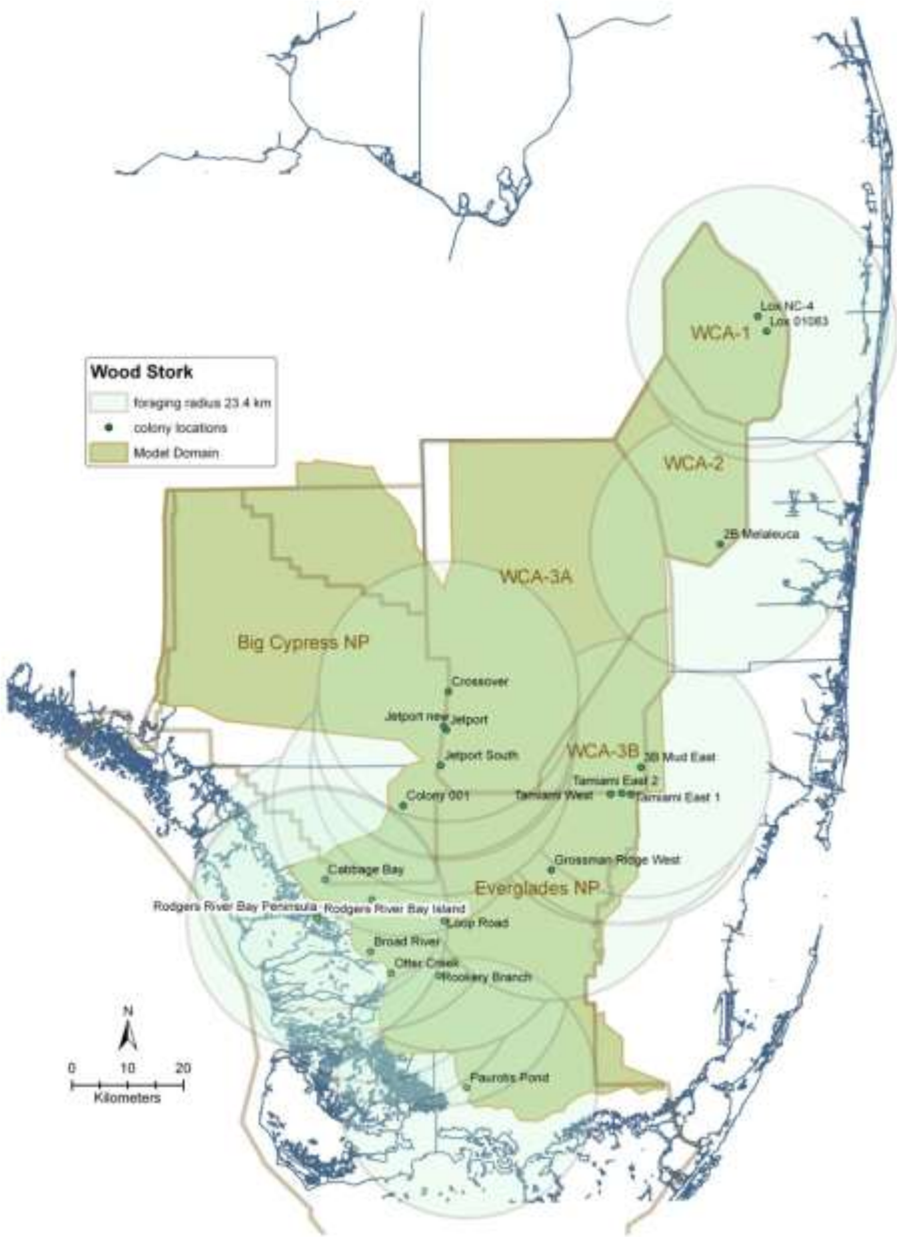

Figure 8. Illustration of 23.4 km foraging areas around each of the colonies in the modeling domain.

There are two options available for output. The first option reports average foraging suitability with 23.4 km of known wood stork colonies. Wood stork colonies are evaluated that have had any active nesting from 2000-2011 within the hydrologic model domain grid within Water Conservation Area 1, Water Conservation Area 2, Water Conservation Area 3, and Everglades National Park (Data sources: Cook and Kobza 2010-2008; Cook and Herring 2007;

Cook and Call 2006; Cook and Call 2005; Crozier and Cook 2004; Crozier and Gawlik 2003; Gawlik 2002-2000).

The second option treats each grid cell in the domain as a potential wood stork colony and report the average foraging suitability within 23.4 km of every cell. This option results in substantially slower processing, but is recommended if the user would like to evaluate effects to potential foraging habitats outside the average range of existing colonies, possibility because of changing conditions in the environment.

Coulter and Bryan (1993) reported that there were suitable foraging wetlands available to wood storks that were not used. Satellite imagery analysis of an area 35 km east-west and 45 km north-south of the Birdsville colony in Georgia revealed that approximately 32% of this area provided viable foraging habitat with shallow water, marsh, cypress, and bottomland hardwood habitat (Coulter et al. 1987). This study indicates that the core foraging area around a wood stork colony may not require suitable foraging conditions throughout its entire spatial habitat. Dale Gawlik (personnel communication, unpublished data) estimates that wood storks require approximately 23% of habitat within their colony foraging range for feeding in the Florida Everglades. *The STORKI v. 1.0 model calculates the top 23% grid cell index scores within the average foraging radius of breeding colonial sites.*

Calibration and Sensitivity Exercises

For these exercises, foraging suitability model output was compared with estimated wood stork abundance data collected from Everglades National Park Systematic Reconnaissance Flight (SRF) surveys. For a description of the wading bird SRF survey method, please refer to Bancroft et al. (2002). We developed an application that sums wood stork abundance from Everglades National Park SRF data by colony foraging radius and by month. We compared the SRF data sorted by colony locations to monthly model output generated within 23.4 km of a known wood stork colony.

Wood stork foraging in relation to water depth was tested with three distributions (Figure 9):

1. the Herring and Gawlik (2007) wood stork foraging probabilities estimated from EDEN,
2. the Coulter and Bryan (1983) field study, and
3. an intermediate relationship.

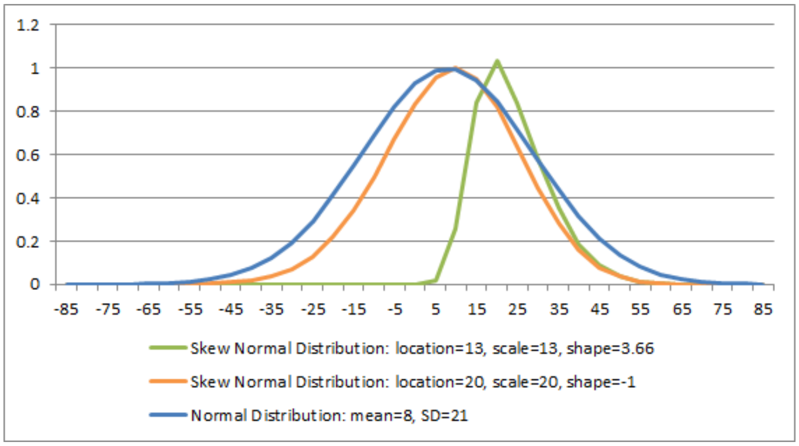

Figure 9. Three tested relationships of wood stork foraging probability and water depth. The Coulter and Bryan (1983) is shown as the green line, the Herring and Gawlik (2007) is shown in blue, and the orange line is an intermediate trial that extends the Coulter and Bryan range of low water depths in which there is foraging, but maintains the same limits on high water.

Coulter and Bryan's (1993) observations were fitted to a skew normal distribution with location = 13, scale = 14 and shape = 3.66. Dividing the result by 0.66 rescaled the foraging response to range from 0-1.0, with 1.0 representing most suitable foraging water depths (Figure 10). The Herring and Gawlik (2007) relationship increases the range of potential foraging in both wetter and drier conditions, but mostly toward drier conditions. The Herring and Gawlik (2011) relationship is a scaled (0 to 1.0) normal distribution with a mean = 8 and standard deviation = 21. An intermediate relationship was also tested that held the upper range to the Coulter and Bryan range, but allowed much drier conditions for foraging, though not as dry as for Herring and Gawlik (2007). The limit on the upper range reflects likely limits to foraging from wood stork leg height. The intermediate relationship is a skew normal distribution with location=20, scale=20, shape=1 that was also scaled (divided by 0.4) to range between 0 and 1.0.

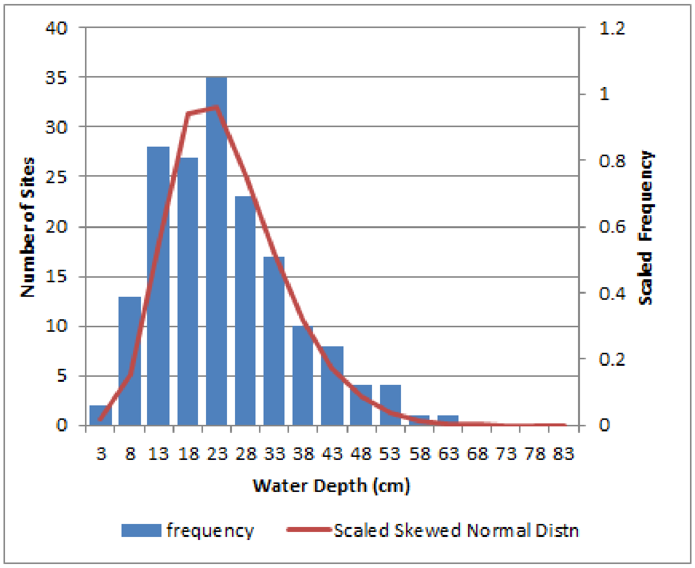

Figure 10. Bars are wood stork foraging sites in relation to water depth (Coulter and Bryan 2003). Line is skewed normal distribution fitted to the observations.

For each of the three alternative relationships, Pearson's correlation coefficients were calculated for modeled neighborhood top forage probability and the neighborhood top suitability index. Pearson's correlations are known to be sensitive to temporal and spatial scales of analysis (Cressie 1998). The correlations were conducted for 2 ranges of time, 2000 – 2010 and 2003 – 2006, and for 2 foraging radii, 23.4 km and 12 km.

Tables 1 -3 show the results of the Pearson's correlations for the 3 alternatives during the breeding seasons of 2000 – 2010. The neighborhood top suitability index correlation to observations is also shown for the breeding seasons of 2003 – 2006. The range of dates used in the correlations has a clear impact on the absolute results, however, in most cases, the Herring and Gawlik (2007) relationship was a substantial improvement over the other alternatives. Table 4 shows the Pearson's correlation results for the Herring and Gawlik (2007) relationship when the foraging radius was changed from 23.4 km to 12 km. The table illustrates that the selected foraging radius also impacts correlation results. In this case, the 23.4 km radius returns improved correlations as compared to the 12 km foraging radius.

Table 1. Pearson's correlations for wood stork foraging observations versus model results using the Coulter and Bryan (1983) relationship between foraging and water depth and a foraging radius of 23.4 km. Two date ranges are shown for the correlations, 2000 – 2010 and 2003 – 2006.

colony	2000-2010 Top Forage Corr	2000-2010 Top Suitability Corr	2003-2006 Top Suitability Corr
Colony 001	-0.03	-0.01	-0.05

Broad River	0.31	0.33	0.18
Grossman Ridge West	-0.10	-0.09	-0.23
Loop Road	0.08	0.09	-0.16
Otter Creek	0.31	0.32	0.16
Paurotis Pond	-0.20	-0.22	-0.39
Rodgers River Bay Island	0.42	0.44	0.24
Rodgers River Bay Peninsula	0.41	0.43	0.23
Rookery Branch	0.07	0.06	-0.05
Tamiami East 1	0.23	0.24	0.37
Tamiami East 2	0.22	0.23	0.33
Tamiami West	0.19	0.20	0.3

Table 2. Pearson's correlations for wood stork foraging observations versus model results using the Herring and Gawlik (2007) relationship between foraging and water depth and a foraging radius of 23.4 km. Two date ranges are shown for the correlations, 2000 – 2010 and 2003 – 2006.

colony	**2000-2010 Top Forage Corr**	**2000-2010 Top Suitability Corr**	**2003-2006 Top Suitability Corr**
Colony 001	0.28	0.28	-0.23
Broad River	0.24	0.19	-0.04
Grossman Ridge West	0.53	0.55	0.45
Loop Road	0.42	0.42	0.2
Otter Creek	0.02	0.03	-0.04
Paurotis Pond	0.39	0.47	-0.3
Rodgers River Bay Island	0.08	0.04	-0.14
Rodgers River Bay Peninsula	0.27	0.23	-0.13
Rookery Branch	0.42	0.41	0.21
Tamiami East 1	0.22	0.22	0.5
Tamiami East 2	0.35	0.43	0.49
Tamiami West	0.41	0.42	0.52

Table 3. Pearson's correlations for wood stork foraging observations versus model results using an intermediate relationship between foraging and water depth and a foraging radius of 23.4 km. Two date ranges are shown for the correlations, 2000 – 2010 and 2003 – 2006.

colony	2000-2010 Top Forage Corr	2000-2010 Top Suitability Corr	2003-2006 Top Suitability Corr
Colony 001	0.14	0.14	-0.12
Broad River	0.29	0.32	-0.03
Grossman Ridge West	0.26	0.26	0.42
Loop Road	0.34	0.35	0.19
Otter Creek	0.30	0.34	-0.02
Paurotis Pond	0.02	-0.07	-0.3
Rodgers River Bay Island	0.20	0.23	-0.11
Rodgers River Bay Peninsula	0.20	0.23	0.11
Rookery Branch	0.28	0.24	-0.001
Tamiami East 1	0.45	0.48	0.49
Tamiami East 2	0.44	0.47	0.49
Tamiami West	0.43	0.46	0.52

Table 4. Pearson's correlations for wood stork foraging observations versus model results using the Herring and Gawlik (2007) relationship between foraging and water depth and a foraging radius of 12 km.

colony	2000-2010 Top Forage Corr	2000-2010 Top Suitability Corr
Colony 001	-0.14	-0.15
Broad River	0.25	0.26
Grossman Ridge West	0.20	0.22
Loop Road	0.32	0.31
Otter Creek	0.33	0.34
Paurotis Pond	-0.09	-0.13
Rodgers River Bay Island	-0.08	-0.07
Rodgers River Bay Peninsula	-0.07	-0.07
Rookery Branch	0.33	0.34
Tamiami East 1	0.28	0.29
Tamiami East 2	0.31	0.32

Tamiami West	0.32	0.33

Model Output and Suggested Post-Processing Steps

To reduce computation time, we suggest users evaluate STORKI model output from select grid cells that are representative of larger Everglades landscape regions. However, users can modify the model code to provide output for all model cells evaluated if desired. Here we provide some suggestions for aggregating model output for users interested in comparing estimated effects of alternate hydrologic scenarios on wood stork foraging conditions. Figure 11 illustrates these first three suggestions and Figure 12 illustrates the last option.

(1) We suggest users visually depict foraging suitability output for various hydrologic scenarios over the full time period of model simulation. We suggest averaging colony suitability scores within landscape regions (i.e. WCA 1, WCA 2, WCA 3A, WCA 3B, and ENP). Depending on the model application, users can select smaller landscape areas to aggregate results. The results for multiple hydrologic scenarios can then be depicted in a graph for each respective landscape region showing year and breeding season month in an increasing temporal sequence on the x-axis plotted against the foraging suitability index on the y-axis. Model output from various hydrologic scenarios can be plotted on the same graphic providing for an illustration of scenario performance over a range of varying climatic conditions. The tabular output from such a graphic is also recommended for presentation so that users can also compare relative percent change among hydrologic scenarios.

(2) We suggest users visually and quantitatively depict aggregated scores with cumulative plots of foraging suitability. Cumulative scores aid in rapidly differentiating between hydrologic alternatives. The plots may be aggregated in different ways temporally and spatially (e.g., weekly, monthly, by season, at colony location, CEPP region, landscape region, etc.) depending on the purpose and needs of the analysis. The cumulative score provides a procedure for obtaining an aggregated quantitative score for scenarios. The planning score for a season would be the cumulative score at the end of the season – or the planning score for a 40 year alternative would be the sum of the seasonal cumulative scores. The final scores may be standardized between 0 and 1 where 0 is referenced to a thoroughly degraded foraging site and 1 is referenced to an optimal foraging site.

(3) We suggest users visually depict the numeric spread of the foraging suitability output for various hydrologic scenarios. We suggest users generate boxplots of average breeding season wood stork foraging probability output for grid cells containing Everglades wood stork colonies (and their respective 23.4 km foraging radius) for the full time period of model simulation. (Users can also generate the boxplots of a limited representation of the model output, for example during individual years with varying climatic conditions.) Boxplots of colony scores aggregated by Everglades region (Water Conservation Area 1, Water Conservation Area 2, Water Conservation Area 3, and Everglades National Park) are suggested to help depict results. Depending on the model application, users can

select smaller landscape areas to aggregate results.

(4) We suggest users depict spatial and temporal output of foraging suitability from individual model grid cells using the EverVIEW data viewer (www.jem.gov/Modeling) or ESRI ArcMap. We suggest users depict the spatial output from all model cells because alternate hydrologic scenarios could result in improved foraging locations and colony locations that are not necessarily reflected by current colony locations. We suggest aggregating results by depicting average breeding season foraging suitability for the full period of model simulation. (Users can also generate spatial output from individual years with varying climatic conditions.)

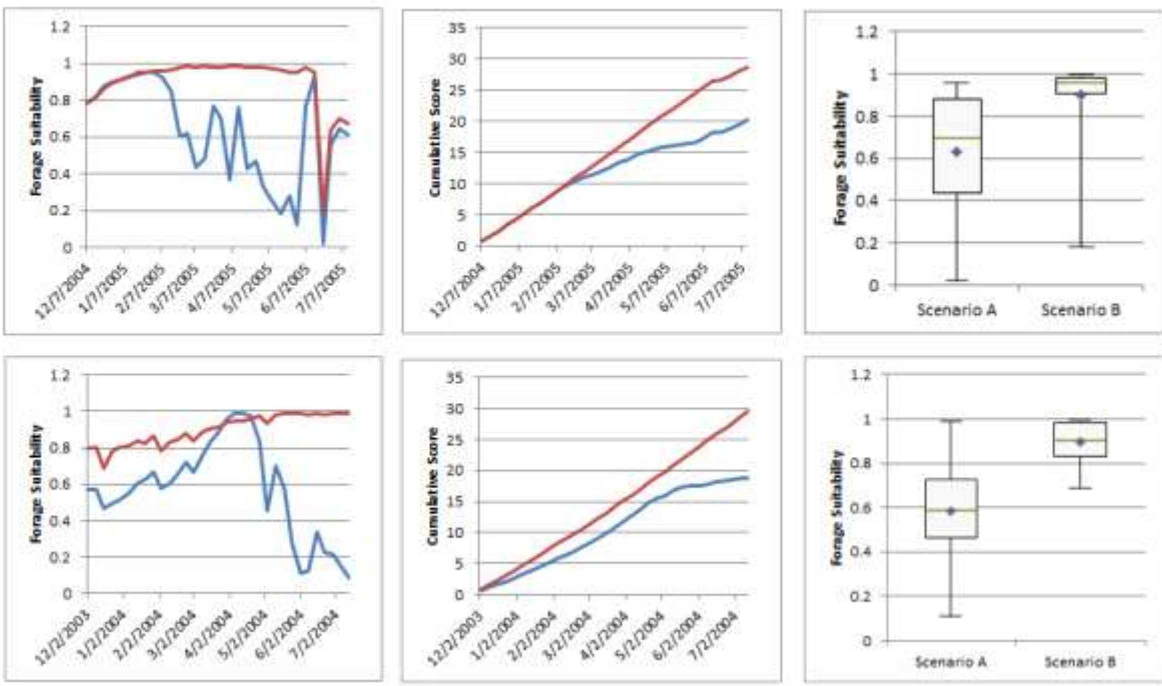

Figure 11. Examples of forage suitability over time are shown in the left-hand plots for two potential scenarios. The blue line is Scenario A and the red line is Scenario B. The middle plots shows the cumulative scores for those same scenarios. For the time period shown, Scenario A in the bottom plot has a cumulative score of 18.8 and Scenario B has a score of 29.7. The right-hand plots show box and whiskers plots of these same scenarios.

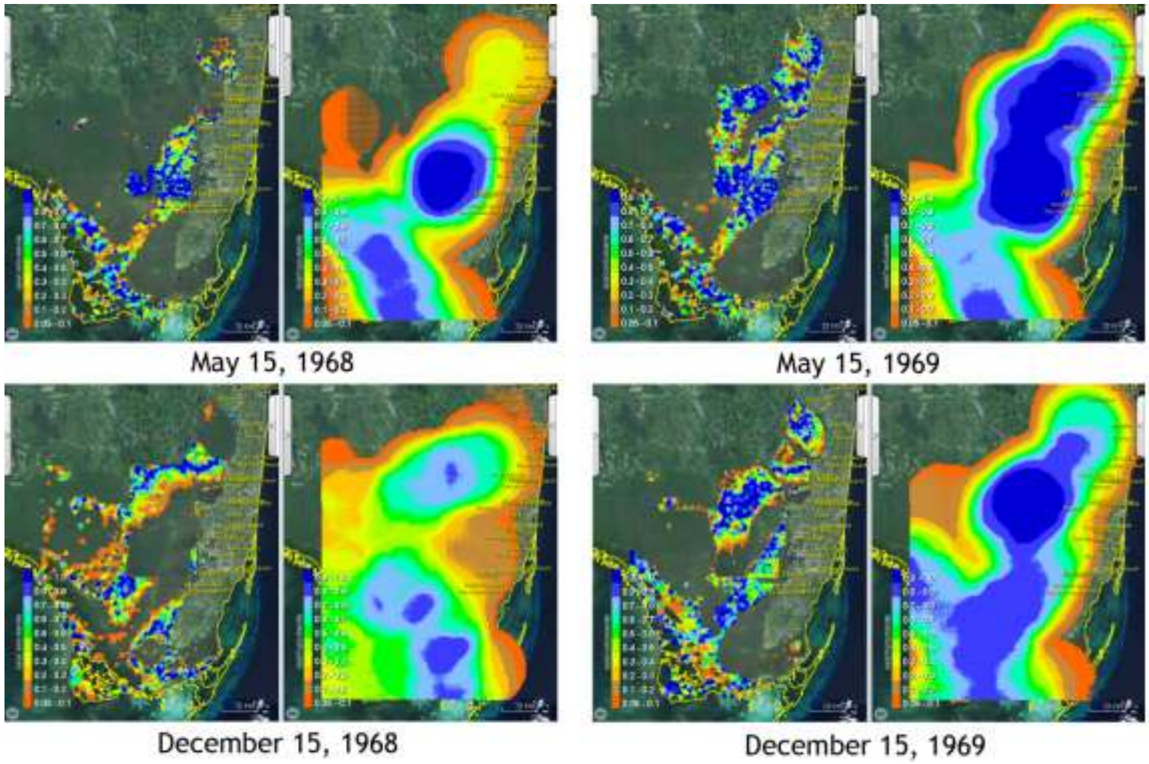

Figure 12. Examples of spatial results displayed for 2 dates one year apart. The left-hand panel for each date is the foraging suitability at each cell. The right-hand panel is the top foraging suitability within a 23.5 km radius around each cell. These wood stork foraging suitability results demonstrate the considerable shifts in landscape position of optimal foraging that are apparent in both spatial and temporal responses. These results are from a test of hydrologic output from the SFWMD RSM (AltA) and are for illustrative purposes only.

Future Model Development

Gawlik et al. (2011) provide evidence that vegetation type significantly affects wood stork foraging responses and that and the mangrove swamp-saltwater marsh ecotone provides preferential foraging habitats in the Florida Everglades. Therefore, modeling vegetation succession dynamics within the mangrove swamp-saltwater marsh ecotone is recommended. The Everglades Landscape Vegetation Succession Model (ELVeS v. 1.0) currently simulates vegetation succession within select communities within the freshwater marsh and coastal communities are being added. Therefore, further development and integration of the ELVeS and the STORKI are recommended in future STORKI model iterations. Additional wood stork foraging flight-following studies to further examine the preferential habitat selection in association with improved remote sensed mapping methodologies would also provide valuable data for future model iterations.

Integration of sea level rise and other climate change scenarios is also recommended in future model iterations, particularly in combination with expansion and improvement of hydrologic models along the coastal regions.

Model Availability

This model was developed at the South Florida Natural Resources Center. The application and its source coding is available for Government and public use at the South Florida Natural Resources Center Ecomodeling website simglades.org. Please refer to the User's Guide for instructions on how to install and use the STORKI application.

Model Presentation and Publications

Lo Galbo, A.M., Fennema, R., Pearlstine, L., Lynch, J., Supernaw, M., and D. Hallac. 2010. A synopsis of the effects of historical changes and the effects of CERP restoration projects to endangered Everglades avian populations. Poster presentation: Greater Everglades Ecosystem Restoration Conference. Naples, Florida.

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