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Everglades and Dry Tortugas National Park
Homestead, FL 33030

Photograph by Elise Pearlstine
Photograph by Bill Perry
Purpose and Objectives

- Analyze long-term temporal and spatial wading bird abundance and alligator nesting trends in Everglades National Park

- Identify driving covariates linked with trends in wildlife abundance and nesting density

- Identify conservation, restoration and adaptive management recommendations for wading bird and alligator recovery
Systematic Reconnaissance Flight (SRF) Transects
Methods

• SRF transect data sorted into basins
• Spatially interpolated daily stage (ARC GIS interpolation)
• Monthly rainfall and temperature
• Daily water discharges
• Monthly Southern Oscillation Index (SOI) - NOAA
• Multicolinearity – Variance Inflation Factor and Kendall’s R
• Regression analysis
• Backwards/forward stepwise regression model selection using stepGAIC (R-statistical software)
General Additive Models (GAMs)

- Relaxes modeling linearity assumption and allows for a flexible data structure exploration.
- Nonparametric smoothing splines for predictors.
- GAMLSS - Rigby and Stasinopoulos (2005) enhanced existing GLM and GAM packages.
  - Highly skewed and/or kurtotic distributions and zero-inflated data (Stasinopoulos et al. 2008).
Wood Stork

Great Egret

White Ibis
Wading Bird Covariates

- Basin
- Sc. x coordinate
- Sc. y coordinate
- Sc. Discharges (Dec.-May)
- Rainfall (Jun.-Nov.; Dec.-May)
- Water Depth (Dec.-May)
- SOI (Dec.-May)
- Temperature (Jun.-May)
- Year
GAMLSS Wading Bird Models

**Wood Stork** ~1 + as factor(basin) + $f$(Temp., Jun.-May) + $f$(Year, df=8) + $f$(Rainfall, Jun.-Nov.) + $f$(Sc. y coordinate) + $f$(SOI) + $f$(Avg. Sc. Discharges, Dec.-May) + $f$(Sc. x coordinate) + offset(log(Transect Area))

* AIC: 8336

**White Ibis** ~1 + $f$(Avg. Sc. Discharges, Dec.-May) + as factor(basin) + $f$(Temp., Jun.-May) + $f$(Year, df=8) + $f$(Sc. y coordinate) + $f$(Rainfall, Dec.-May) + $f$(Water Depth, Dec.-May) + $f$(Sc. x coordinate) + offset(log(Transect Area))

* AIC: 13,246

**Great Egret** ~1 + $f$(Avg. Sc. Discharges, Dec.-May) + as factor(basin) + $f$(Year, df=8) + $f$(Rainfall, Jun.-Nov) + $f$(Sc. y coordinate) + $f$(SOI) + $f$(Water Depth, Dec.-May) + $f$(Sc. x coordinate) + offset(log(Transect Area))

* AIC: 11,268
Wood Stork Model Validation

Against Fitted Values

Against index

Quantile Residuals

Density Estimate

Normal Q-Q Plot

Theoretical Quantiles

Sample Quantiles

ACF

Partial ACF

Lag

Density

Sample Q

Lag
Covariate Response (Wood Stork)

- **Total Rainfall, in. (Jun.-Nov.)**
  - $f(x), df = 4$

- **Avg. Sc. Discharges, cfs (Dec.-May)**
  - $f(x), df = 2$

- **Temp°C (Jun.-May)**
  - $f(x), df = 13$

- **SOI**
  - $f(x), df = 2$
White Ibis Model Validation

Against Fitted Values

Quantile Residuals

Fitted Values

Against index

Residuals

Normal Q-Q Plot

Theoretical Quantiles

Sample Quantiles

Density Estimate

Quantile Residuals

Density

Lag

ACF

Partial ACF

Lag
Covariate Response (White Ibis)

1. Total Rainfall, in. (Dec.-May)
3. Water Depth, cm (Dec.-May)
4. Temp°C (Jun.-May)
Covariate Response (Great Egret)

-1.5 \leq f(x) \leq 1.5

-1.5 \leq \text{ES LPK LSS NESS PH RG SBC TS USS} \leq 1.5

-1.5 \leq \text{ Basin} \leq 1.5

1985 \leq \text{ Year} \leq 2010

0.0 \leq \text{ Year} \leq 0.4

-1.0 \leq \text{ Sc. x coordinate} \leq 1.0

-0.5 \leq \text{ Sc. y coordinate} \leq 2.5
Covariate Response (Great Egret)

- **Total Rainfall, in. (Jun.-Nov.)**
  - $f(x), df = 6$
  - $-0.1 \leq f(x) \leq 0.1$
  - $0 \leq \text{Total Rainfall} \leq 10$

- **Avg. Sc. Discharges, cfs (Dec.-May)**
  - $f(x), df = 3$
  - $-1.2 \leq f(x) \leq 0.0$
  - $0 \leq \text{Avg. Sc. Discharges} \leq 80$

- **Water Depth, cm (Dec.-May)**
  - $f(x), df = 7$
  - $-0.2 \leq f(x) \leq 1.0$
  - $-150 \leq \text{Water Depth} \leq 100$

- **SOI**
  - $f(x), df = 14$
  - $-1.0 \leq f(x) \leq 1.0$
  - $-0.4 \leq \text{SOI} \leq 0.4$
Alligator Nesting Densities

- Nest Density
- Average

Graph showing nesting densities over years from 1985 to 2010.
## Alligator Covariates

<table>
<thead>
<tr>
<th>Stage</th>
<th>Breeding Potential (female growth &amp; survival)</th>
<th>Courtship &amp; Mating</th>
<th>Egg Development</th>
<th>Nest Building</th>
<th>Egg Incubation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period</td>
<td>April 16- April 15</td>
<td>April 16- May 31</td>
<td>May 16- June 30</td>
<td>June 15- July 15</td>
<td>July 01- Sept. 15</td>
</tr>
</tbody>
</table>

- Average water depths
- Total rainfall during dry (Nov.-May) & wet (June-Oct.) season and annually
- Average discharge during dry & wet season and annually
- Average annual Southern Oscillation Index (SOI)
- Average annual temperature, Dec.–Apr. average temperature
- Transect centroid coordinates
- Basin
- Year
GAMLSS Alligator Model

- stepGAIC procedure - selects explanatory terms using GAIC

Start:  \text{AIC}= 3118, \text{family} = \text{ZINB}, \text{Distribution parameter:} \mu

\text{c.nest} \sim 1 + \text{offset}(\log(\text{area.sqkm})) + \text{as.factor}(\text{basin}) + f(\text{flow.wet.scaled}) + f(\text{x.scaled}) + f(\text{flow.dry.scaled}) + f(\text{cmwd}) + f(\text{nbwd}) + f(\text{y.scaled}) + f(\text{Ann.Temp}) + f(\text{year}) + f(\text{soi.noaa}) + f(\text{rf.wet}) + f(\text{rf.dry})

End:  \text{AIC}= 3098

\text{c.nest} \sim \text{as.factor}(\text{basin}) + f(\text{x.scaled}) + f(\text{flow.dry.scaled}) + f(\text{cmwd}) + f(\text{y.scaled}) + f(\text{Ann.Temp}) + f(\text{year}) + f(\text{rf.dry}) + \text{offset}(\log(\text{area.sqkm}))

\begin{table}[h]
\centering
\begin{tabular}{|l|l|l|}
\hline
\text{Df} & \text{AIC} \\
\hline
<none> & 3098.2 \\
- \text{f}(\text{rf.dry}) & -0.1 & 3099.6 \\
- \text{f}(\text{x.scaled}) & 1.2 & 3099.8 \\
+ \text{f}(\text{rf.wet}) & 0.8 & 3099.9 \\
+ \text{f}(\text{soi.noaa}) & -0.1 & 3100.4 \\
+ \text{f}(\text{flow.wet.scaled}) & -3.1 & 3115.3 \\
+ \text{f}(\text{nbwd}) & -4.0 & 3119.1 \\
- \text{f}(\text{flow.dry.scaled}) & 6.3 & 3119.5 \\
- \text{f}(\text{cmwd}) & -1.5 & 3119.6 \\
- \text{f}(\text{Ann.Temp}) & 5.6 & 3131.4 \\
- \text{as.factor}(\text{basin}) & -3.4 & 3192.1 \\
- \text{f}(\text{year}) & 10.0 & 3206.3 \\
- \text{f}(\text{y.scaled}) & 4.8 & 3240.5 \\
\hline
\end{tabular}
\end{table}
Alligator Model Validation

Against Fitted Values

Against index

Normal Q-Q Plot

Theoretical Quantiles

Sample Quantiles

Density Estimate

Quantile Residuals

Fitted Values

ACF

Partial ACF

Density

Quantile Residuals

Lag

Lag

-4 -2 0 2 4

0.0 0.1 0.2 0.3 0.4

-4 -2 0 2 4

-0.06 -0.02 0.02 0.06

5 10 15 20 25 30

0 5 10 15 20 25 30

-0.06 -0.02 0.02 0.06

-3 -2 -1 0 1 2 3

-3 -2 -1 0 1 2 3

0.0 0.1 0.2 0.3 0.4

5 10 15 20 25 30

Theoretical Quantiles

Sample Quantiles

Quantile Residuals

Fitted Values

Against

Density
Covariate Response (Alligator)

- Basin
- Year
- Sc. x coordinate
- Sc. y coordinate

ES LPK LSS NESS PH RG TS USS


- 187.0 188.0 189.0 190.0

- 46 47 48 49

- f(x), df = 2
- f(x), df = 7
- f(x), df = 10
Covariate Response (Alligator)

- Total Rainfall, in. (Nov.-May)
- Avg. Sc. Discharge, cfs (Nov.-May)
- Water Depth, cm (C&M: Apr.-May)
- Avg. Annual Temp., °C
Conclusions

- Aerial monitoring – effective method to monitor long-term wildlife trends
- GAM - a flexible modeling approach for modeling wildlife count data
- Anthropogenic and climatic covariates influence wading bird abundance and alligator nesting.
- Results provide viable information for water managers and restoration planners.
- Long-term monitoring programs important for detecting trends
References


Acknowledgements

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• Lori Oberhofer and Sonny Bass for supporting data collection.
• Leonard Pearlstine and Janice Lynch for providing general support to the project and analysis.
• Bill Perry and Elise Pearlstine for providing wildlife photographs.
Extra Slides
Nest Steps & Further Thought

• Consider interactions of covariates in the modeling analysis
• Assess wildlife trends in individual basins to better understand spatial effects
• Link change points with environmental covariate time series
• Improved covariate data collection – water depth, digital elevation model update, vegetation layer
Zero Inflated Models

- Ignoring zero inflation
  - Bias in estimated parameters and std. errors
  - May cause over-dispersion
- Solution-
  - Zero-inflated Poisson (ZIP), mixture model
  - Zero-inflated negative binomial (ZINB), mixture model
  - Zero-altered Poisson (ZAP), two-part model
  - Zero-altered negative binomial (ZANB), two-part model
- R- GAMLSS package (Rigby and Stasinopoulos 2005)
  - Includes ZIP, ZINB, ZAP, ZANB and many others
Regression Methods

- Simple linear model
- Generalized least square (GLS)
- Generalized linear models (GLM, GLMM)
- Generalized additive model (GAM, GAMM)
- Distributions:
  - Poisson, quasi-Poisson, negative-Binomial
- Software: R version 2.14.2 (2012-02-29)
- Packages: nmlr, lme4, mgcv, gamm4, gamlss
- Zero inflated data:
  - Alligator-71%, woodstork-20%, great egret-6%, white ibis-39%
GLM Alligator Model Validation

Residuals vs Fitted

Normal Q-Q

Predicted values

Scale-Location

Theoretical Quantiles

Residuals vs Leverage

Std. deviance resid.

Std. Pearson resid.

Cook's distance

Leverage