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Sources of Nest Failure in Mississippi Sandhill Cranes, *Grus canadensis pulla*: Nest Survival  
Modeling and Predator Occupancy

A Thesis

Submitted to the Graduate Faculty of the  
University of New Orleans  
In partial fulfillment of the  
Requirements for the degree of

Master of Science  
in  
Biological Sciences  
Conservation Biology

By

Rose Marie Butler

B.S. University of North Carolina at Asheville, 2006

December 2009

## Dedication

I would like to dedicate this work to my uncle, Dr. Ralph Edward Newsome. Although he was a brilliant reconstructive plastic surgeon, he was always a bit of a naturalist at heart. I will carry his support and passion with me wherever I go.

## Acknowledgments

I thank my advisor, Dr. Jerome Howard for his support and guidance throughout this project. I thank all the staff at the Mississippi Sandhill Crane Wildlife Refuge for their help in various facets of my research. James Bates, and wildlife interns Lisa, Michelle, Ryan, and Liz were not only great help, but great company in the field. I am especially grateful for Scott Hereford, MSCNWR biologist, for allowing me to carry out this project at the refuge and for sharing his amazing wealth of knowledge on cranes, and all things natural. To committee member, Lauren Billodeaux, I am very grateful for all of your help in this project. Lauren was always there for me to brainstorm with and was essential in the development of many parts of this research. I would also like to thank committee member, Dr. Simon Lailvaux for his willingness to jump on board my committee late in my research and for his statistical guidance. I thank my lab mates Jessica Henkel and Jessa Madosky. A special thanks goes to Jessica Henkel for all of her help in the field and for her endless support throughout this process. I thank UNO and the U.S.F.W.S. for the financial support that made my research possible. A special thanks goes to Dr. Joe King who was instrumental in getting me funding through UNO. Finally, I would like to thank Bryan Wall and my family for their tremendous support of me in pursuing my passions.

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## Abstract

Low recruitment is the largest challenge facing the recovery of the critically endangered Mississippi Sandhill Crane (*Grus canadensis pulla*). Lack of information on sources of nest failure hinders effective management to increase recruitment. I examined sources of nest failure for 54 nests at the Mississippi Sandhill Crane National Wildlife Refuge, 2008-2009. Nest cameras identified predation as the primary source of failure, followed by flooding, abandonment, and egg inviability. Mean daily survival rate (DSR) was 0.72. The best approximating models included covariates for season date, temperature and nest age. DSR decreased with increasing season date, increasing nest age, and decreasing temperature. Hypotheses related to effects of renesting, human disturbance, precipitation, flooding, and winter rain were not supported. Because predation has been identified as a primary source of nest failure, I also monitored mammalian predators on the MSCNWR. Coyotes and raccoons were most common, with gray foxes, red foxes, domestic dogs, and bobcats also detected frequently.

Keywords: Mississippi Sandhill Crane, nest failure, daily survival rate, mammalian predator, camera

## Introduction

The Mississippi Sandhill Crane, *Grus canadensis pulla*, is a critically endangered subspecies, existing as a single population in Jackson County, MS. It is one of three nonmigratory subspecies, along with the Florida, *Grus canadensis pratensis* and Cuban, *Grus canadensis nesiotus* sandhill cranes. Although the Mississippi Sandhill Cranes (MSCs) have been monitored intensively since their listing as a critically endangered subspecies in 1973, little information is available on the history of the population. There are records of sandhill cranes nesting along the Gulf Coast, into the early 1900's (U.S. Fish and Wildlife 2007). A continuous population of sandhill cranes was known to exist from Georgia to Florida, with scattered populations across the coasts of Alabama, Mississippi, Louisiana, and Texas (U.S. Fish and Wildlife 2007). European settlement along with more recent increases in human populations in the Gulf Coast Region, have extirpated Sandhill cranes across most of their historic range (U.S. Fish and Wildlife 2007, USGS NPWRC 2006). Currently, populations of nesting sandhill cranes exist only in Southern Mississippi and the Florida Panhandle. The present population of MSCs may represent the western remnant of this once extensive nonmigratory sandhill crane population.

The first survey of MSCs was done by Leopold in 1929, at which time population numbers were already low due to habitat alteration (USGS NPWRC 2006). Since that time, the MSCs have been restricted to a small area in southeastern Mississippi, with a population not exceeding 100 individuals until the 1980's (U.S. Fish and Wildlife 2007). Aldrich identified MSCs as a unique subspecies in 1972 based on geographic isolation and differences in pigmentation



compared to other sandhill crane subspecies (Aldrich 1972). MSCs also mature earlier and begin egg production approximately one month later than neighboring Florida Sandhill Cranes (U.S. Fish and Wildlife 2007). New evidence suggests that the three non-migratory subspecies are the result of the long term effects of partial migration in Greater Sandhill Cranes, *Grus canadensis tabida* (Jones 2003). Each subspecies interacts with Greater Sandhills at different levels, and recent genetic work demonstrates that they are all closely related to Greater Sandhills, with only minor genetic differences between one another (Jones 2003). In any case, the MSCs represent a distinct population unit that is in need of protection.

Their endangered sub-species listing in 1973 and wildlife refuge designation in 1975 was prompted by early studies from Jake Valentine which suggested significant range reduction and population decline, compounded by the fact that a large highway was being constructed through the only remaining MSC habitat (Valentine and Noble 1970, Valentine 1982). By the time the refuge was established only 30-35 individuals remained (Valentine and Noble 1970, U.S. Fish and Wildlife Service 2007). Pine plantation spread, fire suppression, road construction, and residential encroachment diminished the unique pine savannah habitat in which the MSCs live (U.S. Fish and Wildlife 1991, 2007). Currently, less than five percent of the original habitat remains on the Gulf Coastal Plain, thereby restricting the MSCs to the areas protected by the refuge (U.S. Fish and Wildlife 2007).

Low recruitment in the wild has been cited as the largest challenge facing MSC recovery (U.S. Fish and Wildlife 2007). The population currently depends on captive propagation, with a current influx of about 10-15 juveniles released on the refuge per year to maintain a population

of approximately 100 birds. Captive releases began in 1981, and have been so extensive that 90% of the individuals within the wild population were either raised in captivity or are directly descendant to birds raised in captivity (S. Hereford, USFWS, per. com.). The primary objective of the Comprehensive Conservation Plan (CCP) for the MSCs is to create a self-sustaining population of 130-170 individuals, including 30-35 nesting pairs that fledge a total of 10-15 chicks per year for a minimum of ten years. Population viability modeling predicts that under current hatching and fledging rates, the MSCs have 100% risk of extinction in 100 years (U.S. Fish and Wildlife Service 1992).

According to the CCP, predation is the primary factor limiting MSC recruitment, with nest failure, egg loss during incubation, and chick loss before fledging all contributing to low recruitment (U.S. Fish and Wildlife 2007, 1992). Hatch success ranges between 21-64%, with zero to three chicks fledging each year (U.S. Fish and Wildlife Service 1992). Coyotes, red and gray foxes, bobcats, dogs and red tailed hawks have been identified as potential threats to cranes, with opossums and raccoons identified as egg predators. Attempts to reduce predation were first introduced in 1985 and have continued over the years with varying levels of intensity. Support for the efficacy of trapping is anecdotal, but in one year of high intensity trapping, annual crane deaths dropped from 6.3 to 2, suggesting that intensive trapping can be helpful. For predator regulation to be most successful, more information needs to be gathered on the relationship between predation and crane recruitment.

With zero to three chicks fledging in the wild each year, this sub-species will depend on supplements from captive breeding into the foreseeable future. My overarching goal is to

provide information that refuge biologists can use to improve MSC recruitment, with a focus on improving nest success. Analysis of mammalian predators on the refuge, coupled with nest monitoring should provide vital information on which predator species should be targeted. It should also give insight into other major factors contributing to nest success. My specific objectives were to: 1) determine important correlates of daily survival in nests, 2) determine factors that make predator visitation to a nest more likely, 3) identify common mammalian predators on the refuge.

## Chapter 1

### Introduction

#### Nest Success Estimators: Apparent Nest Success, the Mayfield Method, and Maximum

#### Likelihood Estimators

Recruitment is an important aspect of avian population dynamics and is often used as a measure of population fluctuation over time (Shaffer 2004, Rotalla et.al. 2004). Nest Survival, the probability of a nest hatching one or more eggs, has been identified as one of the most important components of recruitment (Walker et.al. 2005, U.S. Fish and Wildlife 2007). Despite its importance, a good method for estimating nest survival has not existed until relatively recently. Historically, ornithologists used apparent nest survival, which is simply the proportion of successful nests. Because all nests are not found on the day they are initiated, nest survival is overestimated by this method. Nests that are found earlier in the nesting stage have a lower probability of surviving to hatching than those found later in the nesting stage, because they have longer to survive before hatching. Also, nests that fail early on during the nesting stage are often missed and therefore underrepresented in the sample. Estimation of apparent nest survival would only be appropriate if all nests could be found at initiation or if failed nests could be detected with the same probability as successful nests. It is also important to consider that the extent of positive bias under this estimator will differ among samples, making them invalid for comparison. Using Monte Carlo simulations, Hensler and Nichols (1981) estimated that positive bias in apparent nest success ranged from 9 to 27 percent. The positive bias was

higher for species with low daily survival rates, but interestingly was not affected by sample size.

Although scientists were long aware of the problems associated with estimating apparent nest survival, no unbiased estimator was widely adapted until Mayfield developed an ad hoc estimator of daily survival rate (DSR) (Mayfield 1961, 1975). He argued that individual nests are not the appropriate sampling unit, but rather the number of days a nest is exposed. The Mayfield estimator is calculated as

$$\text{DSR} = (\text{number of exposure days} - \text{number of failed nests}) / \text{number of exposure days}$$

where failed nests are assigned a failure date half way between the day the nest was last checked alive and the day it was found failed.

For an estimate of nest success, Mayfield suggests raising DSR to a power equal to the typical number of days it takes a nest from initiation to hatching. The Mayfield estimator has been shown to outperform apparent nest success unless all nests are found at initiation (Hensler and Nichols 1981). A major limitation of the Mayfield estimator, however, is its assumption of constant DSR for all nests across space and time.

While coming up with an unbiased measure of constant DSR is important, it doesn't address many of the biologically important questions wildlife managers need answered. Some studies have used the Mayfield estimator to determine DSR and then used logistic regression to model apparent nest success in terms of nest specific variables. This method is obviously inappropriate, because findings will be based on the biased estimate of apparent nest success

(Shaffer 2004, Rotella et.al. 2004). Hypothesis testing using the Mayfield estimator has also been widely used, by dividing nests into groups according the variable in question, and comparing DSR estimates among groups. This division limits the number and complexity of variables that can be tested by creating smaller sample sizes with each group division, and lowering the power of analysis (Lloyd and Tweksbury 2007, Rotella et.al. 2004). For populations of endangered species, with already small sample sizes, this is not a viable option.

Recently developed methods improved upon Mayfield's method by developing a generalized linear modeling approach, based on binomial likelihood to estimate DSR (Dinsmore et.al. 2002, Stephens et.al. 2003, and Shaffer 2004). Intervals between nest visits are allowed to vary and known failure date is not required (Rotella et.al. 2004, Dinsmore et.al. 2002, Jehle 2004). While estimates of DSR have shown to be similar between the Mayfield estimator and these recently developed estimators, the Mayfield estimator is inferior for analyzing covariates as a function of nest survival (Lloyd and Tweksbury 2007). Under these new methods, DSR can be rigorously modeled as a function of nest-, group-, and time-specific covariates that can be either continuous or categorical (Rotella et.al. 2004, Lloyd and Tweksbury 2007, Grant et.al. 2005). This flexibility provides a framework for creating biologically realistic models that can evaluate the relative importance of specific variables of interest on nest survival.

#### Estimating DSR: Program MARK

Nest Survival models are saturated in that there is an estimate of DSR for every day of the nesting season. The nest survival module in Program MARK requires an encounter history be created for each nest containing a minimum of five pieces of information: (1) find date, (2)

last day nest checked alive, (3) last day nest checked, (4) fate of nest, (5) number of nests with the same encounter history (Dinsmore et.al. 2002). Continuous and categorical covariates can be added to the end of each encounter history. Each day a nest is known to survive contributes one degree of freedom since each day is a binomial trial in which fate is known. The interval in which nest failure occurs only contributes a single degree of freedom, since exact failure date is unknown.

The nest survival module in MARK operates under the following assumptions: 1) nests are aged correctly on the first visit, 2) nest fates are known with certainty, 3) nest checks do not influence nest fate, 4) nest fates are independent, 5) There is no un-modeled heterogeneity of daily survival rates (Dinsmore et.al. 2002). I also argue that this module operates under the assumption that nests found already hatched or already failed, do not contribute substantially to overall estimates of DSR.

MARK uses generalized linear models with a user-specific link function to characterize the relationship between DSR and the covariates of interest by generating maximum likelihood estimates. The logit-link function was used in all models. It is the most appropriate link function for the binomial distribution and has been used in nearly all nest survival studies (Rotella et.al. 2004, Bulluck and Buehler 2008, Moynahan et.al. 2005, Walker et.al. 2005, Dinsmore et.al. 2002, Stephens et.al. 2003, Shaffer 2004). The logit link function is

$$\text{Logit}(S_i) = \ln(S_i/1-S_i) = \beta_0 + \sum_j \beta_j x_{ji}$$

where  $\beta_0$  is the intercept term, the  $x_{ji}$  ( $j = 1,2,3,\dots,j$ ) are the values for  $j$  covariates on day  $i$ , and  $\beta_j$  is the effect or slope of the variable on daily survival rate (Rotella et.al. 2004, Dinsmore et.al.

2002). An estimate of daily survival rate can be obtained through back transformation of the logit link equation, where DSR on day  $i$  is modeled

$$\text{DSR} = \exp(\beta_0 + \sum_j \beta_j x_{ji}) / 1 + \exp(\beta_0 + \sum_j \beta_j x_{ji})$$

Program MARK generates a summary for each model. A coefficient from the logit equation ( $\beta_j$ ), along with its standard error and 95% confidence intervals is reported for each parameter, making examination of parameter effects straightforward. Biological importance of an individual parameter can be determined by examining 95% confidence intervals. If the estimate overlaps zero, the parameter is not likely important (Walker et. al. 2005). Real estimates of DSR rate are also reported for each model (Dinsmore et.al. 2002). Following an information theoretic approach, MARK also generates Akaike Information Criterion (AIC), or AIC for small sample size ( $AIC_c$ ) values for each model, for use in model selection (Burnham and Anderson 2002).

$$AIC_c = -2 \log L + 2K(n/n-K-1)$$

where  $\log L$  is the natural logarithm of the likelihood evaluated at the maximum likelihood estimates,  $K$  is the number of parameters, and  $n$  is the sample size. The second term corrects for small sample size.

### Nesting in Mississippi Sandhill Cranes

Mississippi Sandhill Cranes (MSCs) nest from late February through early July. Pairs have territories 90-500 acres in size, a portion of which is heavily defended during nesting and chick rearing. MSCs utilize mesic to wet savannah, along with wetland edges, drains, and ponds



for nesting, with a recognized shift from savannah to pond nests in the past several years as the refuge has added more ponds (U.S. Fish and Wildlife 2007). Previously, Valentine (1982) identified visual and noise disturbance from vehicular traffic as the two major disturbances to nesting cranes. Proximity to county highways and low traffic roads caused less disturbance than proximity to the larger Interstate 10 (Valentine 1982).

The number of nests in a season has ranged from two in 1980 to 33 in 2008 (U.S. Fish and Wildlife Service 1992). Females lay one to two eggs, with an average clutch size of 1.6 (U.S. Fish and Wildlife Service 1992). Eggs are incubated for approximately 31 days by both males and females (U.S. Fish and Wildlife Service 1992). Fertility rates range from 65-79%, with approximately 50% of fertile eggs hatching, and zero to three fledging annually (U.S. Fish and Wildlife Service 1992). In comparison to other North American Cranes, MSCs have the lowest hatch success and recruitment. For example, Whooping Cranes exhibit 76% hatch success, with greater than 55% of nests fledging a chick. Florida Sandhill Cranes have greater than 60% hatch success, with greater than 39% of nests fledging a chick. MSCs have 25% hatch success with only 4% of nests fledging a chick (U.S. Fish and Wildlife 1992, Drewien 1995).

My objectives were to: 1) Use nest cameras to identify sources of nest failure with certainty, 2) estimate nest survival and determine important contributing factors to daily survival rate, 3) identify variables that made a nest more likely to be visited by a predator, i.e. predation pressure, and 4) determine which factors make a nest more likely to be predated overall. Methodologically, it was also important to test the use of nest cameras as potential

tools to be used in the future nest monitoring projects for cranes. Study findings could be used to inform management actions for the MSCs to increase hatch success and overall recruitment.

## Methods

### Study Area

The MSCNWR is located in southeast Jackson County, Mississippi, east of the Pascagoula River and approximately 5km north of the Gulf of Mexico.

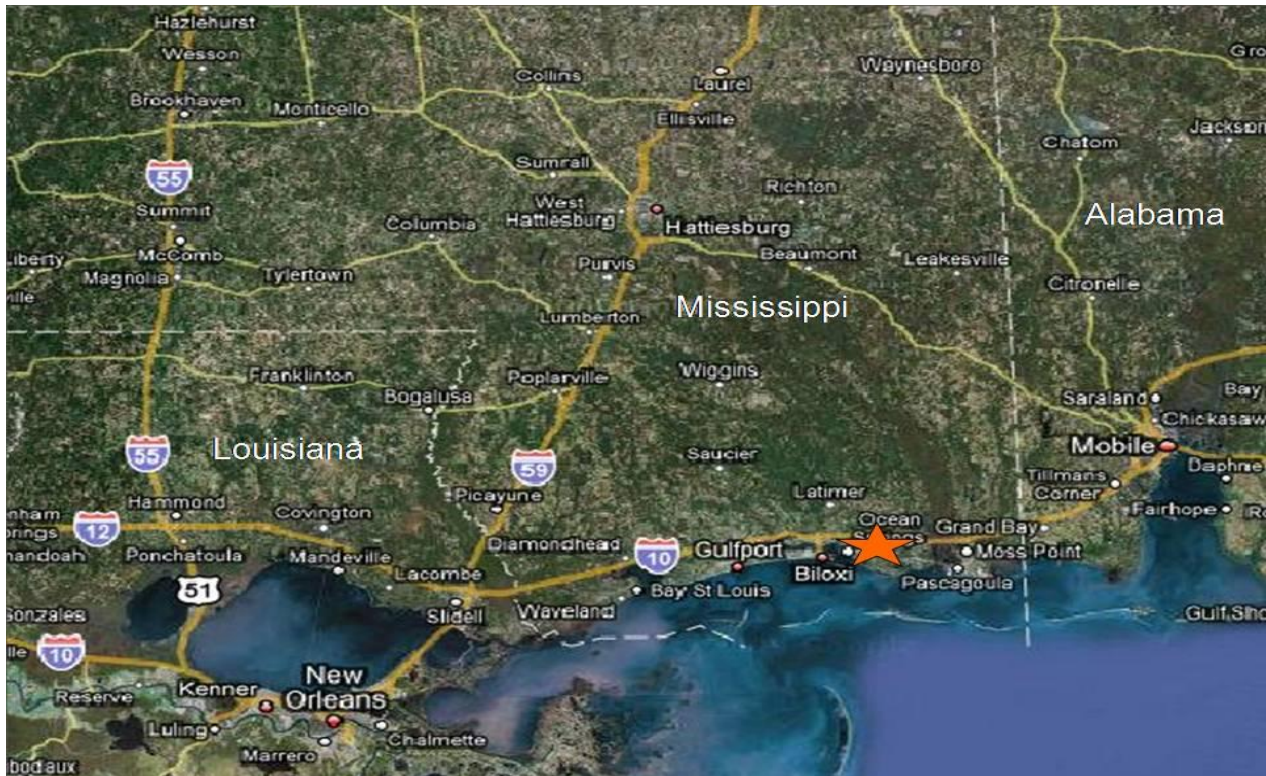


Figure 1. The Mississippi Sandhill Crane Wildlife Refuge is located in Jackson County, MS and covers approximately 19,000 acres.

The refuge is composed of three units: Gautier, Ocean Springs, and the considerably smaller Fontainebleau unit, covering over 19,000 acres. The refuge helps to preserve one of the only remaining large tracts of pine savannah. Pinelands (flatwoods and scrub), made up mostly of remnant pine plantations, dominate the refuge (11860 acres), followed by pine savannah (5216) and hydric drain (1354) habitats, with less than 1000 acres of each of

agriculture, estuarine and open water habitats (U.S. Fish and Wildlife 2007). A diverse herbaceous community makes up the understory of the pine savannahs, which are dominated by wiregrass, and scattered with longleaf pine, slash pine, and pond cypress (U.S. Fish and Wildlife 2007). Highway I-10 bisects the Gautier and Ocean Springs Units, Highway 90 borders the southern Fontainebleau Unit, and several roads in and around the refuge are becoming more populated and more highly trafficked (U.S. Fish and Wildlife 2007).

### Nest Monitoring: Field Methods

Nest searching was carried out from early March to late July in the 2008 and 2009 seasons. Searching was done in and around the MSCNWR, with specific focus on known territories. In many pairs, at least one bird carried a radio transmitter, which also helped determine when a nest was present and the general area in which it was located. Most nests were located through ground searches, with limited nest searching done via helicopter. When a nest was found, its coordinates were determined using a GPS (Garmin 76S) and cataloged in ArcMap 9.2 (ERSI 2006). After discovery, nests were checked approximately once a week. Eggs were floated on each visit to estimate nest age and determine fertility.

I monitored daily survival rate and nest fate using infrared, heat and motion sensory cameras. These kinds of cameras have been used in many nest monitoring studies recently, and have proven to be quite effective, with little to no obvious disturbance to the study animals (Richardson et.al. 2009). Reconyx Rapidfire RM45, 1.3 megapixel, black and white image, heat and motion sensory cameras (Reconyx Inc, Holmen WI) were deployed at 23/33 nests in 2008, and 20/30 nests in 2009. Cameras were attached to a tree nearby each nest, ranging from

approximately 2-30 m. Cameras were mounted with a clear field of view and oriented to avoid interference from direct sunlight to limit the number of extraneous pictures taken. To minimize disturbance, cameras were always installed during one of the refuge staff's weekly nest visits. Camera cards and batteries were changed out on a weekly basis whenever possible. For a few nests where no tree was present in close proximity, cameras were mounted on a steel fence post. Caution was taken to minimize disturbance to incubating adults by not changing the visual horizon close to the nest. Therefore, fence posts were only installed when they could be camouflaged in tall grass or brush. In cases where it was not possible to install a nest camera, or when nest cameras malfunctioned, daily survival rate estimates were based solely on data collected during nest checks.

#### Estimating DSR: Candidate Model Sets and *A priori* Hypotheses

Models require approximately ten samples per parameter to efficiently estimate DSR (Donovan and Hines 2007). Due to small sample size, I could not incorporate all covariates into one model set. Instead, I created five sets of models based on *a priori* hypotheses. Each set of candidate models included a suite of biologically related variables, as well as an intercept model, with constant daily survival rate, as a baseline for model performance (Table 1). Covariates were selected in consultation with MSCNWR biologists to ensure the most biologically relevant variables were evaluated. Weather covariates were measured at the weather station, MSC remote automated weather station located at the MSCNWR headquarters. Distance measures were estimated from GIS maps of the MSCNWR using ArcMap 9.2.

The first set of models was generated to examine the effects of habitat type and refuge unit on DSR. Habitat types included pond, savannah, marsh, and hydric drain. I expected pond nests to have higher DSR's, since they would likely have the fewest potential predators. Hydric drains and marshes should be navigable by some mesopredators such as raccoons, but would still be more protected than savannahs. The three refuge units, Gautier, Ocean Springs, and Fontainebleau, along with the nests located off refuge, have different habitat compositions, different levels of human disturbance, and likely different predator communities.

The second set of models examined temperature effects on DSR, including average temperature over nest life, maximum temperature during nest life, and the additive effects of the two. I hypothesized DSR would decrease with increasing temperatures. Incubating adults are more stressed in high temperatures, and evidence suggests that they may leave the nests more frequently (S. Hereford, USFWS, per.com.). When exposed to higher temperatures, eggs are more likely to become infertile than if left unattended under milder conditions. Average temperature during the nest period would be a good measure of stress on incubating birds, while spikes in temperature would be a measure of dangerous temperatures in which eggs would be likely to become infertile.

The third set of models was used to evaluate precipitation covariates, including average KBDI (drought index), cumulative precipitation, cumulative precipitation for the greatest rain event, and a dummy variable for flooding (any rain event over 10 cm). These weather covariates were measured for each nest from initiation to hatch or failure. I hypothesized that DSR would decrease with increasing drought and decreasing cumulative precipitation during

the incubation period, pending no flooding events. Similar to temperature, increased drought, measured by KBDI, is also thought to put stress on incubating birds, potentially causing nests to be exposed for longer periods of time (S. Hereford, USFWS, per.com.). In addition, high drought levels would signify less water protection for nests and potentially, concentrations of predators at water sources (L. Billodeaux, USFWS, per.com.).

Precipitation is thought to be an important contributing factor to nest success in MSCs (S. Hereford, USFWS, per.com.). High water levels surrounding nests in ponds, marshes, and drains should offer greater protection from mammalian predators. When individual rain events are 5 cm or less, adult birds can easily build their nests up with the rising water levels. However, when rain events exceed 10 cm, many nests are lost due to suffocation when sitting in water and abandonment by adults (S. Hereford, USFWS, per.com.).

The fourth set of candidate models was generated to examine disturbance factors and potential predator densities. I evaluated covariates that captured different types and levels of disturbance including distance from the nest to the nearest major road, refuge road, paved road outside the refuge, and distance to the refuge boundary. I hypothesized that DSR would decrease with decreasing distance to major roads, paved road outside of the refuge, refuge road and refuge boundary (Valentine 1982). Interstate and regional highways and their major arterials were categorized as major roads (Class 1 and 2 roads).

Traffic on major roads may cause increased disturbance to incubating adults, and may even result in nest abandonment. Distance to any paved road outside of the refuge was used as a measure of distance to human disturbance. The closer a nest is to suburban areas, the

more likely it is to be disturbed by human trespassing, human noises, and domestic pets.

Potential nest predators such as raccoons, coyotes, red foxes and gray foxes can thrive in urban fragments and habitat edges (Crooks 2002; Dijak and Thompson 2000; Sinclair et.al. 2005).

Nests in close proximity to refuge roads are subject to increased human disturbance via refuge vehicles and machinery which may cause incubating birds to flush from the nest, leaving eggs exposed to weather conditions and predators (Valentine 1982). Also, refuge roads can serve as predator highways (Karanth et.al. 2004, Dieni et.al. 1996).

Measurements to refuge boundary were also taken for those nests existing outside of refuge property, but were assigned a negative value. Nests existing off the refuge or on the refuge and in close proximity to the boundary, are likely subject to higher levels of human disturbance, domestic animal disturbance, and possibly the higher densities of mesopredators (Crooks 2002, Dijak and Thompson 2000; Sinclair et.al. 2005).

The fifth set of models was used to evaluate the effects of season date, nest age, and renesting, as well as the effects of winter rains prior to nesting season. I hypothesized that DSR would decrease with increasing season date and nest age, and for renests. I also expected DSR to be lower in seasons following dry winters. The winter rainy season fills many nesting areas, but as the season progresses these areas dry up, making nests later in the season more vulnerable to predation. Water depth at the nest is an important covariate of DSR for Greater Sandhill Cranes (McWethy and Austin 2009; Austin et.al. 2007). Predation intensity may also be higher later in the season, because predators such as coyotes and raccoons may have young to feed (Choate et.al. 1994, Lowery 1974, B. Leopold, Carnivore Ecology Research Project



Supervisor, per.com.). As temperature increases throughout the season, nesting birds may experience greater stress and exposed eggs are more likely to become infertile.

As nests age, they are exposed to disturbance and predation for longer periods of time. Also, there is some evidence of increased pair activity at the nest close to hatching, which may give more cues to predators. MSC renests have less energy invested in them, and are more likely than first nests to only contain a single egg (S. Hereford, USFWS, per.com.). Winter rains are important for filling up nesting areas, providing pond and marsh habitats that deter nest predators. Although season date was somewhat confounded with both renesting and nest age covariates, each of these variables were important to assess in their own right. I was unable to run interaction models due to issues with estimation for in small sample sizes.

Table 1. Descriptions of the five suites of models (I-IV) used to evaluate daily survival rate (DSR) for Mississippi Sandhill Crane nests in 2008 and 2009. Constant DSR models containing the intercept only are not included.

Model Suite	Variables
I.	Unit Habitat Type
II.	Average temperature over nest life Max temperature during nest life Additive effect of average and max temperatures
III.	Sum precipitation over nest life Maximum cumulative precipitation event over nest life Flood event over four inches during nest life Average KBDI over nest life Quadratic effect of sum precipitation Additive effect of sum precipitation and KBDI
IV.	Distance from major road Distance from any non-refuge road Distance from refuge road Distance from refuge boundary Additive effect of distance from major rd, any road, and refuge boundary
VI.	Day of Nesting Season Nest Age Additive effects of day of nesting season and nest age Renest Sum precipitation in the winter before nesting season

Table 1. Descriptions of the five suites of models (I-IV) used to evaluate daily survival rate (DSR) for Mississippi Sandhill Crane nests in 2008 and 2009. Constant DSR models containing the intercept only are not included.

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V.	Day of Nesting Season Nest Age Additive effects of day of nesting season and nest age Renest Sum precipitation in the winter before nesting season

I created a final model set including the most well supported models from the first four sets, along with an additional covariate for presence/absence of a nest camera. Although there is some concern of cameras disturbing incubating birds, a recent meta-analysis showed that the presence of cameras actually improved nest success in most studies (Richardson et.al. 2009). Because nest cameras should affect all nests in a similar way, the covariate was added only to the most parsimonious model, to see if it improved that model.

## Data Analysis: Estimating Daily Survival Rate and Model Selection Criteria

I modeled the relationship between daily survival rate and several variables of interest based on *a priori* hypotheses. DSR estimates were based on hatch success where a nest was considered successful if one or more eggs hatched. I used the nest survival module in Program MARK for all analyses, and evaluated model support using Akaike's information criterion for small sample sizes ( $AIC_c$ ) and  $AIC_c$  weights for model selection (Burnham and Anderson 2002). Burnham and Anderson (2002), suggest that models with  $\Delta AIC_c$  values between 0-2 have substantial support, models with  $\Delta AIC_c$  between 4-7 have considerably less support, and models with  $\Delta AIC_c > 10$  have essentially no support.

Nests found already hatched, already failed, or never found should generally not be included in these models since there are no intervals upon which to base DSR. The MSC population, however, is so small and nests are so heavily monitored, that it is possible to estimate timing of failures and successes for some nests that would not have otherwise been included. In rare circumstances where infertile eggs were replaced with fertile eggs of a similar age, that nest was counted as new nest in DSR analysis. This was done to meet DSR model assumptions by assigning the first nest as failed, and by maintaining the correct age of the egg taken from the second nest. I incorporated all nests for which there was reliable and appropriate information, including two nests that were found failed, for a total of 30 nests from 2008 and 24 nests from 2009.

I standardized season dates over the two years by using the earliest date of nest start date in either year as the first day of the nesting season, and the latest hatching or failure date

as the last day of the nesting season. This designation provided a 121 day nesting season, beginning on March 6<sup>th</sup> and ending on July 4<sup>th</sup> where daily nest survival was estimated for 120 daily intervals. Covariates of interest were added to each model set.

Because of the small sample size, it was not possible to include all variables of interest in one model. Individual models from the five model sets that received strong support were carried over into a global model set using the following criterion: 1) Models had to have a lower  $\Delta AIC_c$  value than the intercept model, 2) Models had to have a  $\Delta AIC_c$  value  $\leq 2$ . Burnham and Anderson (2002), suggested that models with  $\Delta AIC_c$  values less than 2 cannot easily be distinguished as the best approximating model. Using these criteria, six variables were carried over into the final model set. I used  $\Delta AIC_c$  values and  $AIC_c$  weights to choose the best approximating models within the final set (Burnham and Anderson 2002), and employed multi-model inference techniques described by Burnham and Anderson (2002) to account for model selection uncertainty. I calculated the relative importance of covariates in the best approximating models as:

$$\text{Importance value} = \sum w_i$$

where  $i$  is a candidate model containing the covariate of interest. Higher importance values, signify higher relative importance of the target covariate in comparison to all other covariates in the model set. In addition, I generated model-averaged estimates, model-invariant standard errors and 95% confidence intervals, to ensure unbiased estimates of variable coefficients ( $B_i$ ). Model averaging is suggested for most model sets unless the best approximating model carries a weight  $\geq 0.90$  (Burnham and Anderson 2002). Model averaged estimates were calculated as:

$$\widehat{B_i} = \sum w_i B_i$$

Unconditional SE estimates and resulting 95% CI were calculated for each variable. DSR was similarly model averaged. Goodness of fit tests were not performed. Because the nesting model is fully saturated, no satisfactory goodness of fit test exists (Rotella 2008).

### Analyzing Variables Related to Nest Predation

To better understand how predation affects hatch success, I determined which factors influence predation pressure and the overall likelihood a nest predation. I assessed predator visitation to nests for the 31 nests that had cameras in close enough proximity to reliably capture movement. Although the predators themselves were not seen in many occasions, I often recognized a predation attempt by the behavior of the incubating bird. Often the bird exhibited an alert behavior, followed by one or more of the following behaviors: crouch display, pre-attack behavior, and attack and mob behaviors (Ellis et.al. 1998). I defined predation pressure as: number of days a nest is visited by a predator/total number of days monitored by camera. I used analysis of variance in R (version 2.9.2 2009, The R Foundation for Statistical Computing) to analyze the effect of refuge unit, habitat type, temperature and disturbance variables on predation pressure. I log transformed continuous predictor variables with non-normal error distributions (Fry 1993). Cook's D statistic was used to detect outliers (Fry 1993).

### Predation Pressure: *A priori* Hypotheses

I hypothesized that refuge unit would have an effect on predation pressure, since each unit is a different size, and has different habitat structures, levels of fragmentation and human disturbance. I expected that nests located in Fontainebleau would experience higher predation

pressure. Because this unit is smaller, more fragmented, and experiences higher levels of human disturbance than the other two, it has the potential for a more dense mesopredator community than the other two units (Gehrt 2004).

I also hypothesized that habitat type would affect the level of predation pressure experienced at a nest. Savannah nests should suffer higher predation pressure than nests in ponds, marshes or hydric drains, because nests surrounded by water should provide protection from mammalian predators, and potentially increased warning of their approach.

I expected that a higher average temperature over the life of a nest would have a positive effect on predation pressure. When temperatures are high, birds can become stressed, causing them to leave the nest more often, thereby leaving eggs more exposed to predators and potentially detrimental temperatures. In addition, high temperatures may cause decreased energy levels in adults, which could lessen their ability to defend a nest.

I expected the level of human disturbance to affect predator visitation rates. I measured each nest's distance from major roads, any road, refuge roads, and refuge boundary. I hypothesized that nests experiencing the least human disturbance, i.e. the most interior nests, furthest from roads would have the lowest predation pressure. Mesopredator density is likely higher in more disturbed areas (Crooks 2002, Crooks and Soule 1999, Gehrt 2004). Nests closer to refuge roads should also experience higher predation pressure. Refuge roads serve as predator highways for many species, making predators more apt to come across nests closest to these routes (Karanth et.al. 2004, Dieni et.al. 1996).

To explore the affects of predation pressure on recruitment more directly, I asked if predated nests experienced higher levels of predator pressure than successful nests. A two sample t-test was run to test the effect.

I used the nest survival module in Program MARK to assess the effects of several covariates on DSR for predated or partially predated nests only. By isolating nests that were ultimately predated, I could determine which variables made predation more likely. For example, I could ask: Were more nests predated earlier or later during the nesting period? I used the same methodology for estimation of DSR and model selection as was used in analysis of all nests, based on a subset of the same *a priori* hypotheses. Precipitation and flooding variables were not included. These variables examine an alternative source of nest failure and may have confounded the analysis on effects of DSR when looking at predation. I had the same hypotheses for variable effects on DSR of nests that were ultimately predated as I did for the predation pressure analyses described above. Due to small sample size, variables of interest were again divided into model sets, analyzing one or a few biologically related parameters at a time (Table 2). Variables were carried over to the final model set based on the same criteria that were used for in the analysis of all nests. Because nest cameras should affect all nests similarly, a covariate to determine the effects of nest camera was added to the best approximating model to see if it improved that model.



Table 2. Descriptions of the seven suites of models (I-IV) used to evaluate daily survival rate (DSR) for predated Mississippi Sandhill Crane nests in 2008 and 2009. Constant DSR models containing the intercept only are not included.

Model Suite	Variables
I.	Unit
II.	Habitat Type
III.	Average temperature over nest life Max temperature during nest life
IV.	Distance from major road Distance from any non-refuge road
V.	Distance from refuge road Distance from refuge boundary
VI.	Day of Nesting Season Nest Age
VII.	Renest

## Results

### Nesting Parameters

A total of 63 MSC nests were found, 33 in 2008 and 30 in 2009. I was able to use 54 nests, for a total of 765 exposure days between March 6<sup>th</sup> and July 4<sup>th</sup> of 2008 and 2009 in the daily survival module in MARK (Figure 2). The remaining nests were not used in analysis because of lack of information needed to properly estimate DSR. Of the 33 nests in 2008, two were found already hatched, and three were never found but had strong evidence of existence due to pair behavior. These five nests were not included in analysis. Two nests failed and were subsequently replaced with fertile eggs, after which they were counted as a new nest. Therefore, a total of 30 nests from 2008 were included in DSR analysis. Of the 30 nests in 2009, four nests were found already failed, two were never found, and two had unknown fates. Two of the nests that were found failed had enough pair observations to be included; the remainder of nests were not used in analysis. Therefore, a total of 24, 2009 nests were included in DSR analysis. Cameras were placed on 43 of these 54 nests. Apparent survival (# of nests hatching one or more egg/ # of nests observed) was 0.38 (Table 3). Most of the failures in both years were attributed to predation (44%) (not including three known partial nest predations), followed by flooding (28%), and abandonment (15%). The remaining failures were due to egg infertility (13%) (Table 3).

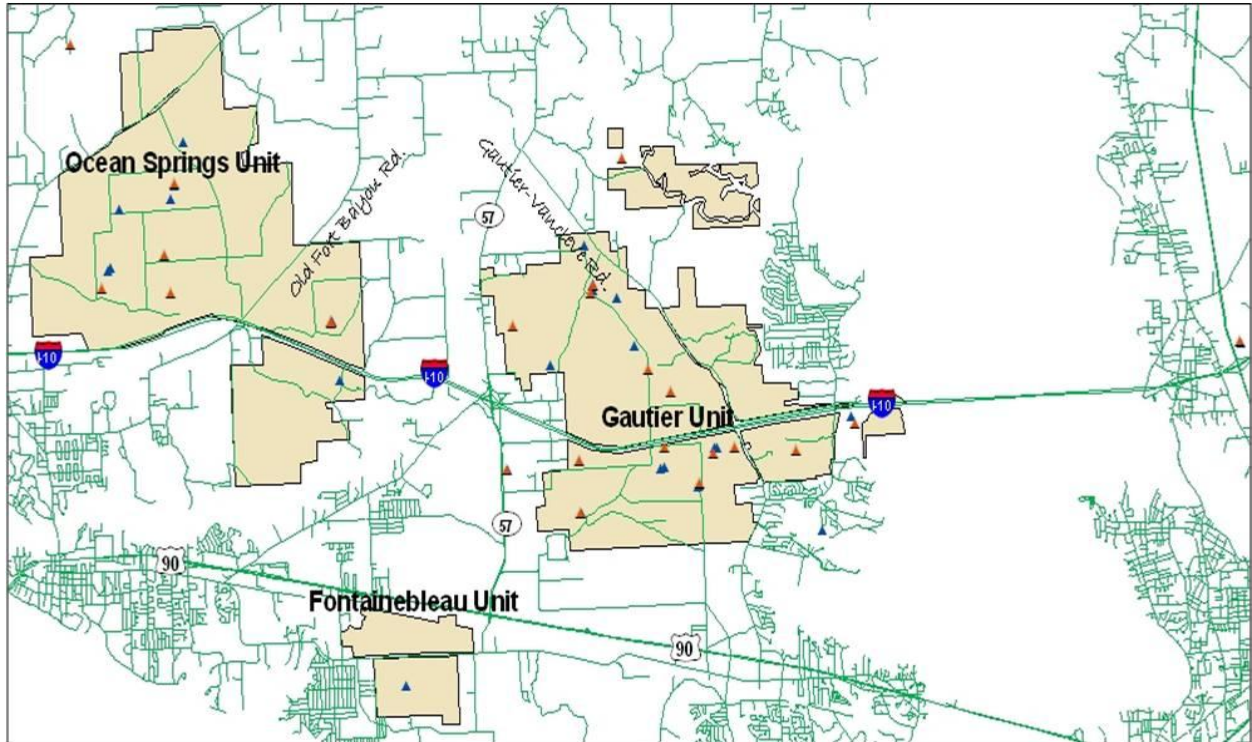


Figure 2. Map of nests used in DSR analysis. Thirty nests (blue triangles) were monitored for DSR in 2008, and 24 (orange triangles) in 2009.

Table 3. Total number, fate, and apparent causes of failure for Mississippi Sandhill Crane nests that were found in 2008 and 2009, and used in nest survival analyses.

Year	Total nests	Hatched	Failed	Apparent Cause of Failure			
				Predation	Flooded	Abandoned	Nonviable
2008	30	9	21	9	5	3	4
2009	24	6	18	8	6	3	1

Of the 54 nests included in analysis, 50 % were located in the Gautier unit, 30 % in Ocean Springs unit, 19 % off refuge property, and only a single nest in the considerably smaller Fontainebleau unit. Most pairs that nest off refuge property did not venture far, with an exception being a pair that nested nearly 8.2 km from the refuge boundary. Nesting habitat preference also differed among pairs, with approximately 59% of nests located in ponds (57% in

08 and 63% in 09), 20% in savannahs (27% in 08 and 13% in 09), 15% in hydric drains (13% in 08 and 16% in 09), and 6% in marshes (3% in 08 and 8% in 09). Overall, it appears that pairs in the 2009 season had a greater propensity to choose wetter nesting habitats, than those in the 2008 season, with 87% of nests located in wet areas in 2009 compared to 73 % of nests in 2008.

The 2009 nesting season was warmer than the 2008 season. In 2008, the average daily temperature was 20.7°C for 2008, with the lowest average daily temperature recorded at 5°C and the highest at 28.3°C. In comparison, the average daily temperature was 22.0°C in 2009 with the lowest average temperature for a day at 6.1°C and the highest at 31.1°C. Average temperatures experienced over the life of nest ranged from 13.9 °C for the first nest of the season and 26.3 °C for the last nest of the season in 2008, and 16.6 °C and 28.9 °C for the same measurements in 2009. The hottest daily maximum temperature recorded for a nest was 28.3 °C in 2008 and 29.4 °C in 2009.

Precipitation varied within each 121 day nesting seasons. Overall precipitation was higher in 2009 (71.8 cm) than 2008 (57.3 cm). Distribution of rain events also varied throughout the season. In 2008 there were several rain events throughout the season, but most were under 2.5 cm, with only two rain events reaching the 10 cm mark. In 2009, rain events were heavier overall, with many events over five cm, and one event in which more than 27.5 cm fell within a three day period. Differences in winter rains before each nesting season were even more dramatic than the differences in precipitation during nesting season. The 2008 rainy season was particularly wet, with 57.6 cm falling during the three month period, while only 34.1 cm fell during the 2009 rainy season.

Seven renests were recorded in 2008 and four in 2009. These numbers are slight underestimations, as there were a few renests at the end of each season that could not be included in DSR analysis.

Nests experienced varying levels of disturbance. The distance of a nest to the nearest refuge road averaged 0.232 km (SD = 0.195). The average minimum distance to roads outside the refuge was 0.708 km (SD = 0.554). Major roads included Highway 1-10, Highway-90, along with other Class 1 and 2 roads. Nests were an average of 1.35 km from the nearest major road, with minimum distances much further from major roads than from any road (SD = 1.057). Forty-four nests were located on refuge property an average of 0.723 km from a refuge border (SD = 0.427), and ten nests existing off refuge property at an average of 2.23 km from a refuge border (SD = 3.195).

#### Model Selection and DSR Estimates

The first five candidate model sets were evaluated to determine which factors had the strongest effects on DSR. In the first candidate model set, habitat type and unit models both had  $\Delta AIC_c > 2$  and performed worse than the constant DSR model, and were therefore not included in the final model set.

The additive effects of average and maximum temperatures ( $B = -0.297; 0.377$ ) performed best in the second model; both covariates were included in the final model set.

There was not much differentiation among models in the third set. Sum precipitation, average KBDI, greatest cumulative precipitation event, and flooding models each had  $\Delta AIC_c \leq 2.03$ . However, the model containing the covariate for sum precipitation ( $B = 0.024$ )

throughout the incubation period was the only one that performed better than the intercept model (Constant DSR), and was therefore the only model carried over into the final set.

The fourth model evaluated disturbance factors including nest distances to a major road, any non-refuge road, refuge road, and refuge boundary. The model containing only the covariate for distance to major roads ( $B = -0.289$ ), performed the best, with all other covariate models having  $\Delta AIC_c \geq 2.5$ .

In the fifth set, the model containing the covariates for season date and nest age were the best approximating models. The model with season date ( $B = -0.016$ ) alone performed best, followed by the model describing the additive effects of season date and nest age ( $B = -0.015$ ;  $-0.028$ ), and nest age alone ( $B = -0.032$ ). Each of these three models performed better than the intercept model; however, the nest age alone model had a  $\Delta AIC_c = 4.29$ . Because the additive model ( $\Delta AIC_c = 0.11$ ) performed equally well to the model where season date was considered alone, the nest age covariate was also carried over into the final model set.

In the final model set, each of the eleven models considered performed better than the intercept model with constant DSR. The best approximating model included the variables season date and maximum temperature (Table 4). Support for this model was strong, with an Akaike weight of 0.6162. The second and third ranked models also included the season date and maximum temperature covariates, with the addition of average temperature in the second ranked model, and both average temperature and nest age in the fourth ranked model. The second and third ranked models had  $\Delta AIC_c$  values of 1.68 and 3.43 respectively. Therefore, there is some support for both the second and third ranked models (Table 4). These top three models had combined Akaike weights of 0.9932, indicating that there is a 99% probability that,

of the models considered in the set, the best approximating model is one of those three. Although variables for sum precipitation and distance to major road performed well in prior model sets, there was little support for them in the final model set, so they were not considered further. The variable for season date and max temperature was in each of the top three models, thus producing importance values of 1.0 for each and indicating that these variables play a large role in explaining variation in DSR of MSC nests. Average temperature held an importance value of 0.38, followed by nest age with a value of 0.11 (Table 5).

To alleviate any model selection uncertainty, I calculated model averaged effect sizes and model invariant standard errors and 95% confidence intervals for each of the variables in the top three models, with the exception of nest age which could not be model averaged since it only appeared once (Table 5). Season date, max temperature, and average temperature each had model averaged effect sizes with confidence intervals not overlapping zero, thereby indicating biological importance (Table 5). The effect of season date is negative (-0.074), indicating that as the initiation date of a nest moves further into the nesting season, the likelihood of hatching decreases (Table 5). The effect of maximum temperature was positive (0.803), suggesting that the higher the maximum temperature during the life of a nest, the higher the DSR. Average temperature similarly had a positive slope, but with a somewhat smaller effect size (0.128). The effect size for nest age had confidence intervals that overlapped zero. While the variable had a slight positive effect size, a negative slope was reported in the other, lower ranking models in which nest age appeared. An estimate of DSR for each day of the nesting season was calculated using the model average function in Program MARK, for the top three models. (Figure 3). Overall, DSR declined slightly during the first half of the nesting

season, and then decreased at a greater rate from approximately day 50 through the remainder of the nesting season (Figure 3).

Table 4. Final set of Daily Survival Rate Models for Mississippi Sandhill Crane Nests 2008 and 2009. Models are ranked by differences in Akaike's Information Criterion for small sample size ( $\Delta AIC_c$ ) values.

Model	K <sup>a</sup>	$\Delta AIC_c$	w <sub>i</sub> <sup>b</sup>
Season Date + Max Temp <sup>d</sup>	3	0.00	0.6162
Season Date + Avg Temp <sup>c</sup> + Max Temp <sup>d</sup>	4	1.68	0.2658
Season Date + Nest Age + Avg Temp <sup>c</sup> + Max Temp <sup>d</sup>	5	3.43	0.1112
Season Date + Avg Temp <sup>c</sup>	3	10.41	0.0034
Season Date	2	12.84	0.0010
Season Date + Nest Age	3	12.94	0.0010
Season Date + Sum Precip <sup>d</sup>	3	13.52	0.0007
Avg Temp <sup>c</sup> + Max Temp <sup>d</sup>	3	15.52	0.0003
Major Rd <sup>f</sup>	2	16.56	0.0002
Sum Precip <sup>d</sup>	2	16.98	0.0002
Nest Age	2	17.13	0.0001
Constant DSR	1	17.63	0.0001

<sup>a</sup> Number of parameters.

<sup>b</sup> Model weight.

<sup>c</sup> Average temperature over nest life.

<sup>d</sup> Maximum temperature during nest life.

<sup>e</sup> Sum precipitation over nest life.

<sup>f</sup> Distance from Nest to a Major Road.



Table 5. Importance values and model averaged effect sizes for each variable appearing in the top three models from the final model set that describe DSR for Mississippi Sandhill Cranes in 2008-2009.

Variable	Importance value <sup>a</sup>	Effect Size <sup>b</sup>	SE <sup>b</sup>	Upper CI <sup>b</sup>	Lower CI <sup>b</sup>
Season Date	1.000	-0.074	0.018	-0.038	-0.109
Max Temp	1.000	0.803	0.234	1.261	0.345
Average Temp	0.380	0.128	0.028	0.184	0.073
Nest Age	0.112	0.017	0.031	0.077	-0.044

<sup>a</sup>Importance values were calculated as the sum of Akaike weights over the top three models in which the parameter of interest appeared.

<sup>b</sup>Effect sizes are model averaged and model invariant standard errors and 95% confidence intervals are given for each variable.

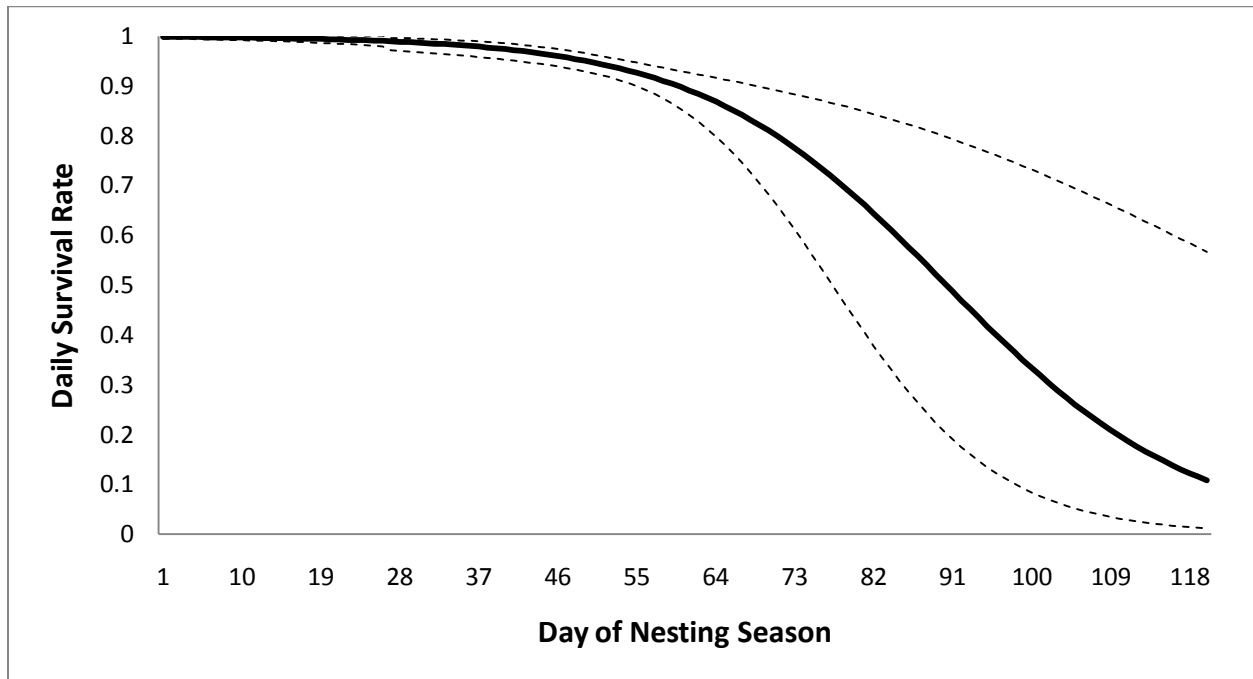


Figure 3. Model averaged DSR estimates and 95% confidence intervals for 54 Mississippi Sandhill Crane nests in 2008-2009. Estimates are based on the three best approximating models within the final set. Day 1 corresponds to 6 March and Day 120 corresponds to 4 July.

Interaction models could not be analyzed due to issues with small sample size. To explore potential relationship between season date and temperature, I divided the nesting

season into two halves, and evaluated the effect of temperature on DSR early in the nesting season and late in the nesting season. The effects of average temperature were similar for both halves of the season (early:  $B = 0.318$ ; late:  $B = 0.336$ ). The effect size of maximum temperature on DSR, however, differed between season halves (early:  $B = 1.146$ ; late:  $B = 0.715$ ).

### Nest Predation

Nest predation was the most common source of nest failure in the 2008 and 2009 nesting seasons (Table 3). Twenty of the 54 nests included in DSR analysis were predated across the 2008 and 2009 nesting seasons. Predation also occurred in at least two nests that could not be included in analysis. Complete nest predation occurred in 17 cases, with partial predation events, in which one egg survived, observed in three instances. Several predation attempts were also observed. The predator was usually deterred by the incubating bird from a distance or hidden by tall grasses, and so was not often caught on camera. Cameras did, however, capture unsuccessful predation attempts by raccoons, a barred owl, a crow, an alligator, and a snake.

Incubating birds showed the ability to defend their nests in most circumstances, even knocking a barred owl off of its perch and into the water in one case. However, all coyote attacks that were caught on nest cameras were successful. Raccoons were also successful in some cases, along with single recorded predation events for an alligator and an avian predator. In one event, chicks were predated by fire ants during pipping. This phenomenon may be even more common, but is difficult to determine unless explicitly witnessed during the event. On

another occasion, an entire family was killed at the nest by a domestic dog. This nest, however, was counted as successful, since the chick was several days old when the predation event occurred. Within a few days of this event, an incubating adult was thought to be killed by a dog in the same area, and the nest subsequently failed either directly due to the dog, or to raccoons scavenging eggs after the adult was killed.

Scavenging was recorded in several cases. Raccoons were the most commonly observed scavenger, and other scavengers included coyotes, river otters, rats, and slider turtles. Scavenging, although common, did not affect nesting success and was not included in any analysis of predation.

### Predation Pressure

Of the 31 nests assessed for predation pressure, one was located very far off the refuge property, giving it a large negative value for distance from refuge boundary. It was recognized as an outlier by R (version 2.9.2 2009, The R Foundation for Statistical Computing) because of a high standardized residual value and high leverage and was removed from the analysis. Forty-five percent of nests analyzed experienced some level of predation pressure ranging from 0.067 to 0.600. Of the covariates measured, only distance from nest to any off refuge road had a significant effect on predation pressure ( $p = 0.030$ ). Of the nests analyzed for predation pressure, 22 were successful, and 8 were predated, with successful nests experiencing a mean predation pressure of 0.067 (SD = 0.137) and predated nests having a mean level of 0.249 (SD = 0.147). The level of predation pressure did have a significant effect on whether or not a nest was ultimately predated ( $p = 0.004$ ).

## Model Selection and DSR for Predated Nests

Of the seven model sets analyzed, only one had covariates that performed better than the intercept model for constant DSR. Covariates for unit, habitat type, temperature, distance of nest to refuge roads, any road, major roads, refuge boundary, and reneest all performed worse than the constant DSR model in their respective model sets (Table 2). Therefore, the model set including only covariates for nest age and season date was selected as the final model set. The effects of season date and nest age together best explained DSR for nests that were ultimately predated, with an AICc weight of 0.95 (Table 6). Model averaging was not performed, because AICc weight was greater than 0.9 for a single model (Burnham and Anderson 2002). The effect of nesting camera was not relevant, as it did not improve the best approximating model ( $\Delta\text{AICc} > 2$ ). This covariate was therefore removed from the final model set. Both season date and nest age had a negative effect on DSR. Both appeared biologically important, as their 95% confidence intervals did not span zero. More nests were predated later in the season than earlier ( $B = -0.036$ ), meaning that DSR of nests that were ultimately predated were higher earlier in the season. Nest age had an even larger negative effect, meaning more nests were predated near the end of the nesting period than the beginning ( $B = -0.116$ ). Although, there is obviously some interaction between the two variables, as older nests will necessarily have older season dates. However, reneesting occurred throughout the season, and both variables contributed to the final model.

DSR estimates from the model including season date and nest age show a dramatic drop in DSR for predated nests about half way through the season (Figure 4). In 2008, the first

predation event was recorded on 29 March (day 24), followed by 6 April (day 32). These two predation events were carried out by atypical predators, as the first one was an alligator predation, and the second was predated by fire ants when the chicks were pipping. The remaining predation events occurred from late April through July. In 2009, one nest was found failed on March 24<sup>th</sup>, likely due to predation, but the next egg predation event was not recorded until May 3<sup>rd</sup> (day 59). Of the approximately 31 day incubation period, the earliest recorded predation event for any one nest was on day 12, and was a partial predation event by a raccoon. In total, only 4 nests were predated or partially predated on or before incubation day 20. Seventy-eight percent of the predation events occurred during the final third of the incubation period.

Table 6. Final set of daily survival rate models for predated (n = 17) and partially predated (n = 3) Mississippi Sandhill Crane Nests in 2008 and 2009. Models are ranked by differences in Akaike's Information Criterion for small sample size ( $\Delta AIC_c$ ) values.

Model	K <sup>a</sup>	$\Delta AIC_c$	w <sub>i</sub> <sup>b</sup>
Season Date + Nest Age	3	0.000	0.954
Nest Age	2	6.485	0.037
Season Date	2	9.940	0.007
Constant DSR	1	12.707	0.002

<sup>a</sup> Number of parameters.

<sup>b</sup> Model weight.

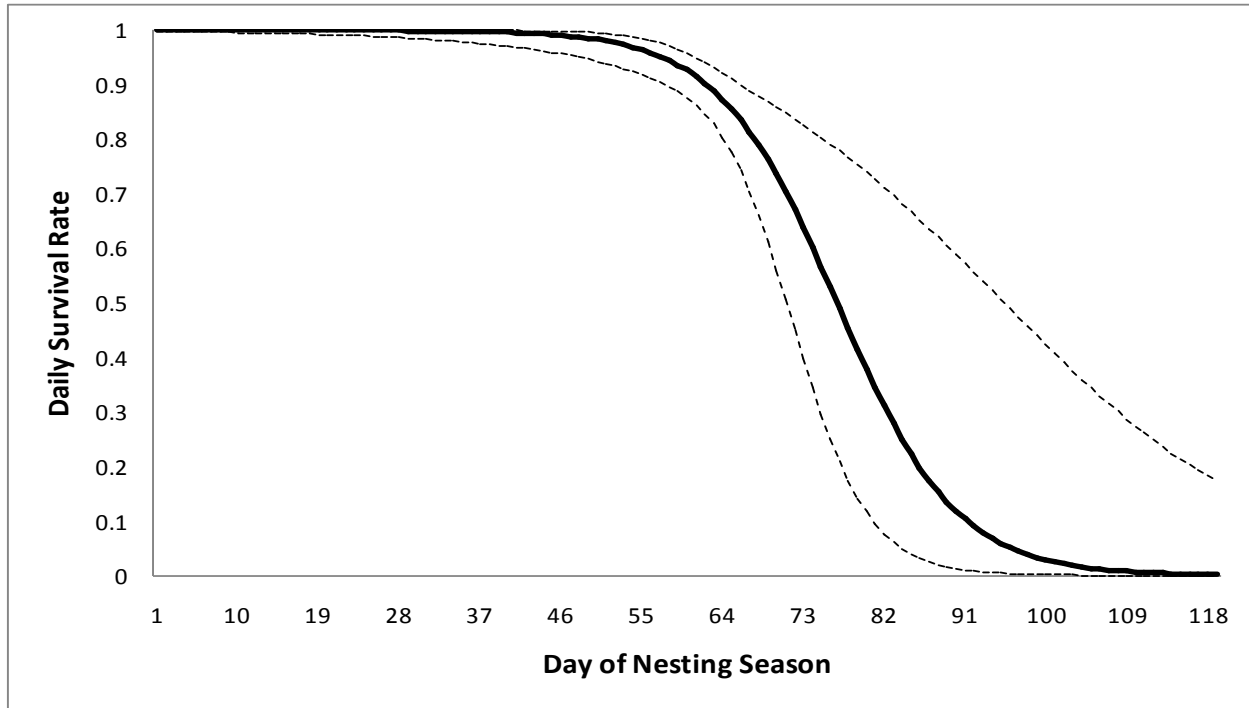


Figure 4. Daily Survival Rate Estimates and 95 % confidence intervals for Mississippi Sandhill Crane nests that were either predated or partially predated in 2008 and 2009. Estimates and Confidence intervals were generated using the logit-link function from the best approximating model:  $B_0 + B_1 \times \text{Season Date} + B_2 \times \text{Nest Age}$ . Day 1 corresponds to 6 March and Day 120 corresponds to 4 July.

## Discussion: Nest Survival and Nest Predation

### Nest Cameras

Use of heat and motion sensory cameras is becoming increasingly popular in wildlife studies. They are a practical, non-invasive tool for monitoring animal presence, abundance, and behavior and have been recently employed in many nest monitoring studies (Karanth et.al. 2004, Richardson et.al. 2009). Determination of nest fate through analysis of egg remains is still widely employed, despite widespread concerns with interpretation (Lariviere 1999, William and Wood 2002, Marini and Melo 1998). Cameras, on the other hand, should provide reason for failure unambiguously, and even allow examination of bird behavior.

There is concern, however, that cameras may adversely affect incubating birds by increasing predation or abandonment rates. A few studies have reported higher abandonment rates for nests with cameras, especially early in incubation (Anthony et.al. 2006, S. Hereford, USFWS, per.com.). A recent meta-analysis reviewed the effects of cameras on avian nest success for 21 species, and actually found increased survival rates for nests with cameras (Richardson et.al. 2009). Overall, presence of a camera, decreased predation rates, and increased nest survival probability by 16 to 35 percent (Richardson et.al. 2009). Richardson et.al. (2009) attributed this positive effect to neophobia that may prevent predators such as rodents, corvids, raptors, and canids from approaching a nest with a conspicuous camera. Sequin et.al. (2003), found that coyotes were wary of cameras and that level of wariness depended on social status. For example, alpha coyotes were never captured on camera within their homeranges.

To my knowledge, no studies have examined the effects of cameras on nest success in cranes. Video monitoring systems have been applied to several sandhill sub-species including the MSCs and Florida Sandhill Cranes, but heat and motion sensory cameras have never been applied on a large scale. Therefore, analysis of camera effects are important to understand if they are to be applied in future studies. For the two nesting seasons in which cameras were placed on MSC nests, they had a negative effect on DSR in the analysis of all nests, and a positive effect on DSR when analyzed for nests that were ultimately predated. However, 95% confidence intervals included zero, indicating little to no overall effect of cameras on DSR.

No nest abandonment was attributed to cameras in MSC nests. A few birds investigated cameras shortly following camera placement on their nest. In one extreme case, a bird spent greater than one hour examining a camera. While cameras may intrigue or disturb birds, abandonment or long term infliction were never observed.

If cameras were placed close enough to the nest (usually within 10m), with a clear view, they reliably recorded nest swaps, egg turning, hatching and bird behavior during predation and flooding events. They were also valuable in determining causes of abandonment, which allowed the refuge to examine effects of nest visitation and of prescribed burns in close proximity to nests. In addition, cameras identified previously unknown causes of nest failure. For example, prior to camera documentation, alligators had never been considered a potential MSC nest predator. Unlike video systems, these cameras are smaller and easier to set-up. Also, less time is required to examine the data collected.

Despite the benefits, I experienced several technical difficulties with both cameras and camera cards. One must choose quality cameras, quality camera cards with sufficient memory,



and long lasting batteries. Also, camera sensitivity must be set high enough to ensure small predators will be caught, but low enough such that camera card memory and batteries do not expire before the next check.

Nest cameras should be considered in future studies of nesting cranes, especially in endangered or threatened populations. For small populations, cameras can provide quality data when quantity is not possible. The level of monitoring and financial investment necessary may make nest cameras less optimal in studies of widespread or common crane populations. Conversely, endangered species are often heavily monitored already, such that camera placement and maintenance will not require significantly more effort. Also, the financial investment may be worthwhile since having precise data on causes of nest failure and daily activities is of the utmost importance. Lack of a decrease in survival rate due to camera placement also makes this an option for disturbance sensitive species.

#### Nest Survival: Potential Bias in DSR Estimates for Small Sample Sizes

Current methods of analyzing nest success using maximum likelihood of DSR are superior to previous methods such as of apparent nest success and Mayfield estimators. Despite improvements, bias could still be introduced, especially in small populations. The DSR module in MARK operates under the assumption that nests found already hatched or already failed do not contribute substantially to overall estimates of DSR. Any bias that is potentially introduced due to the exclusion of these nests is not considered in large scale studies, especially when it is rare to find nests already failed or already hatched. However, in heavily monitored populations with small sample sizes, this exclusion could make some difference in overall estimates.

I suggest identifying and removing as much bias as possible. In situations where pair behavior and nest fate data are sufficient, such that oviposit and hatch or failure dates estimates can be made; I suggest including those nests in the module. I recommend examining the seasonal distribution of those nests that cannot be included in DSR analyses. Nests that were found already failed or nests of unknown fate were distributed throughout the nesting season, with a peak in May, which aligns with the peak of nesting. Unless, several nests failed before we began nest searching, the effects of season date should represent a close approximation for the effect of season date on all nests.

If the effect of nest age on DSR is of interest, it is important to consider the age at which most nests are found. If most of the nests are found late in incubation then there is potential for a biased estimate for the effects of nest age, because those nests that failed early during the incubation period are not included in analysis. For the two seasons examined, we found nests across all stages of incubation with approximately one third of nests found within the first one third of the incubation period.

#### Nest Survival: DSR Covariates

Season date, maximum temperature, average temperature and nest age were the most important variables for explaining DSR for the models analyzed. The negative effect of season date could be explained by potential increases in predator densities or predator activity throughout the season (Grand et.al. 2006, Armstrong et.al. 2002, Best 1978, Roseberry and Klimstra 1970, Nolan 1963). In addition, many nesting areas dry out as the season progresses, making nests more vulnerable to predation (S. Hereford, USFWS, per.com.).

Although there is likely a strong interaction between season date and temperature variables, sample size prohibited me from examining it, making problems related to collinearity of concern. To address this, I examined the effect of temperature on DSR early and late in the season. Average and maximum temperatures had a positive effect in both halves of the season. Maximum temperature had a higher positive slope during the first half of the nesting season, and a lower positive slope during the second half of the season. It is likely that high temperatures promote incubation without stressing adults earlier in the season. The lower positive slope later in the season may be due to increased temperature related stress in adults as temperatures rise later in the season. Nests experiencing the highest maximum temperatures late in the season may also suffer from fertility related issues. Because there are few nests remaining late in the season, the detrimental effects of high temperatures on DSR were not observed.

Nest age had a small positive effect on DSR, but its 95% confidence intervals spanned zero, suggesting that the variable was not that biologically important. In addition, models including temperature and season date effects outperformed the model that also included the effect of nest age.

Winter rain, flooding events, disturbance factors, and habitat type were all expected to have important contributions to DSR for the MSCs (Valentine 1982, S. Hereford and L. Billodeaux, USFWS, per.com.). Despite this expectation, these covariates were not important contributors to DSR for MSCs. It is possible that the appropriate covariate was not chosen to determine DSR effects. For example, it may have been more appropriate to examine habitat structure around the nest, such as grass height, openness, and distance to habitat edge, than to

have a covariate for habitat type (Best 1978, Valentine 1982). In addition, water depth at the nest may have been a more important covariate than winter rain or flooding event covariates. For example, water depth was an important covariate for explaining DSR in Greater Sandhill Cranes (Austin et.al. 2007, McWethy and Austin 2009). In examining the effects of human disturbance, it may have been revealing to add a covariate for human population density within a certain radius of the nest, rather than only considering distances to residential roads or refuge boundaries. Sample size limited me from adding many more covariates. Also, examination of potential interactions among covariates and quadratic effects of covariates were not possible. In the future, these additional covariates and important interactions among them should be explored in larger datasets.

Rather than choosing an inappropriate variable to explain DSR, it is also possible that the sample size was too small to show the effects of certain covariates. If nests were analyzed across many years, different trends may appear. A final possibility is that some variables chosen are truly not important for explaining DSR for MSCs. For example, maybe proximity to off refuge roads and refuge edges was not as explanatory as expected, since two of the main egg predators, coyotes and raccoons, can thrive along edges and in the interior of the refuge. Also, nest predations by alligators in ponds, and by raccoons in marshy areas, revealed that nesting in a wet area may not lower chance of predation.

### Nest Predation

Important covariates of DSR should be explored in the context of documented causes of nest failure. Because predation was the cause of most nest failures, factors related to predator

behavior and life history should be driving most covariate effects. Nest predation is a key aspect of avian life that shapes both life history characteristics and behavior (Cote and Sutherland 1997). In a review of 74 bird species, O'Conner (1991) discovered that one in three nests was reported to have failed due to predation. Other reviews have reported numbers as high as 41.4% (Cote and Sutherland 1997). Birds also exhibit a great risk of extinction due to predation, with 31% of currently extinct species credited to introduced predators (Cote and Sutherland 1997).

Although predation is the principle cause nest failure in most bird species, it is rarely detrimental within a healthy ecosystem where predator-prey relationships are in equilibrium. This equilibrium begins to degrade under habitat loss or degradation, concentrating predators and prey in patches and generating a greater risk for predation (Goodrich and Buskirk 1995, Sovada et.al. 2005, Stolzenberg 2006). In a large patch, predators may only search certain areas efficiently, or at all, but there is evidence that in a small patch predators search for prey items across its entirety (Sovada et.al 2005). Additionally, many predator species, such as coyotes, red fox, raccoons, skunks, and opossums, thrive in disturbed habitats (Crooks 2002).

Covariates such as habitat type and proximity to roads and refuge boundary did not contribute to DSR for predated nests, suggesting that predators may be searching areas across their entirety and incidentally encountering crane nests. In addition, the only factor significantly affect predation pressure at the nest was distance to any road, which may suggest that nests closer to human disturbance and possibly closer to suburban areas, are more prone to predator visitation. Therefore, it makes sense that coyotes and raccoons were primary nest

predators, since they had high use rates across the refuge, and are tolerant of human disturbance. Also, both are opportunistic omnivores adept at handling many types of food resources (Choate et.al. 1994). The low numbers of MSC nests along with the large spatial distance between them would not provide an adequate food resource to a more specialized predator (Schmidt 1999).

DSR modeling reveals that nest age and season date have important negative effects on predation rates in MSCs. Several studies report decreases in nest survival as the season progresses due to increases in predators or predator activity (Baiser et.al. 2008, Grant et.al. 2005). To the contrary, many other studies report an increase in survival rate throughout the season due to factors such as increases in protective cover, and decreases in predator activity, predator numbers, or changes in predator diet (Grand et.al. 2006, Armstrong et.al. 2002, Best 1978, Roseberry and Klimstra 1970, Nolan 1963). Regardless of how time of season related to nest survival, predation played a role.

Consistent with these studies, I suggest the decline in DSR of MSC nests across the season is related to changes in predation rates. Seasonal changes may be partially attributed to the fact that the whelping-puprearing for coyotes starts at the beginning of June (Choate et.al. 1994, B. Leopold, Carnivore Ecology Research Project Supervisor, per.com.). Female coyotes have the greatest daily movement during this period, and have pups to feed, thereby subjecting late nests to potentially higher predation rates (B. Leopold, Carnivore Ecology Research Project Supervisor, per.com.). Similarly, raccoons exhibit the highest movement during parturition through young rearing. This period should start in May and increase throughout the nesting season, with the highest abundance and movement of raccoons later in the nesting season

(Choate et.al. 1994, B. Leopold, Carnivore Ecology Research Project Supervisor, per.com). Many nests were also lost to flooding even though the covariate for flooding did not contribute to the final model set. Flooding events were spread throughout the season in 2008, but in 2009 several nests were lost in a short period of time in late March, closer to the beginning of the season. Despite the effects of flooding, the overall effect of season date was still negative.

In comparison with seasons date, nest age had a more dramatic negative effect on DSR. Most predation events occurred near the end of the nesting cycle, just before hatching. Some recent studies on DSR have found no effect of nest age (Bulluck and Buehler 2008, Walker et.al 2005). Others report higher predation early in the incubation period, attributed to easily discoverable nests being knocked out early on, but also to species specific behaviors such as more frequent mate feeding earlier on in the season (Best 1978, Klett and Johnson 1982, Dinsmore et.al. 2002). Precocial bird species tend to have higher survival rates later in the incubation period, making the MSCs an exception to the rule (Klett and Johnson 1982, Dinsomre et.al. 2002).

Most nest failures for wild MSCs occur late in incubation (post 20 days) (U.S. Fish and Wildlife Service 1992). This drop-off, however, is not observed in the captive flock, so is likely not due to issues with fertility late in incubation, but to predation in the wild (U.S. Fish and Wildlife 1992). I found evidence that predators return to previously discovered nests. Therefore, nests predated late in incubation, may be attributed to predators ultimately predated a nest after several attempts. In addition, nest cameras revealed that, in some pairs, the non-incubating adult was in close proximity to the nest in the days before hatching. This increased activity may have drawn more attention from predators. For some nests, it is

possible that the eggs are no longer fertile, in which case the incubating adults may spend less effort defending them from an ensuing predator. Through the use of cameras, I was able to document the timing of failure and see that while birds were still incubating, some eggs were well past their hatch dates when predated. This trend of lower DSR late in incubation needs further research in the future so that managers can better understand why it occurring and what they can do to best protect nests during this vulnerable time period.

In addition to season date and nest age, maximum and average temperature were important covariates for explaining DSR. I expected high average and maximum temperatures to put stress on birds, making a nest more likely to fail. I also expected high maximum temperatures to cause fertility related failures due to overheating. For both covariates, I observed the opposite effect, where DSR increased with increasing temperatures. It is probable that warm temperatures early on in the season actually increase DSR for nests. By the time temperatures get into dangerous levels for incubating birds and their eggs, there are not many nests remaining, such that the effects of high temperatures are not seen. It is also possible that high temperatures do not negatively affect incubating birds and eggs as much as previously thought.



## Chapter 2. Assessment of Mammalian Predators: Occupancy Modeling

### Introduction

#### Assessing Mammalian Predators

Assessing mammalian predators on the Mississippi Sandhill Crane National Wildlife Refuge (MSCNWR) is an important step that needs to be taken before effective predator management can be carried out. Common methods for predator assessment include abundance and occupancy. While abundance estimations attempt to measure the number of animals of a given species at a site(s), occupancy estimations measure whether the species is present or absent. Measures of occupancy require presence/absence data to be collected from multiple sites, where the probability of occupancy is defined as the probability that a randomly selected site within a given area of interest is occupied by the targeted species (MacKenzie et.al. 2006). Because the probability is unknown, the observed proportion of sites occupied is used to estimate the underlying probability (MacKenzie et.al. 2006).

When measuring presence/absence data, failure to detect the presence of a species does not necessarily mean it is absent. Furthermore, different mammalian species will have different probabilities of being detected under any given census method (Karanth 2004, Silveira et.al. 2003, Sargeant et.al. 1998, Wilson and Cole 1996, Conner et.al. 1983). When detection probability is less than one, estimates of occupancy based solely on presence/absence can lead to severely biased results. In this situation, visiting sites multiple times allows detection probabilities to be incorporated into occupancy estimations. Programs MARK and PRESENCE

each have similar occupancy modules which take into account detection probabilities to create unbiased occupancy models (MacKenzie 2002, MacKenzie et.al. 2002, MacKenzie et.el. 2003, Royle and Nichols 2003, White and Burnham 1999). These modules use maximum likelihood methods to estimate detection probabilities, occupancy, and associated parameters and employ an information theoretic approach for model selection.

Unlike methods for measuring abundance, such as mark and recapture, presence/absence measures do not require unique identification or even direct observation of an animal, making them less invasive, less costly and less time consuming (Stanley and Royle 2005). In addition, presence/absence measures are more economical when censusing several animals at a time. Commonly used indirect measures of mammal presence include hair traps, scent stations, camera traps, animal counts and track counts. Scent stations and camera traps were used in this study because they have shown to be two of the most successful methods for detecting a wide range of species (Karanth 2004, Silvera et. al. 2003, Wilson and Cole 1996, Gompper et.al. 2006). Although it was not the goal of the study, I was also able to make some comparisons between the capabilities of the two methods to detect the general mammalian predator community.

### Refuge Predators

There are a wide array of mammalian predators that exist on the MSCNWR (Table 7). With the exception of the coyote, most mammalian predators on the MSCNWR are native. Coyotes *Canis latrans*, have exhibited remarkable range expansions in the past several decades, despite the fact that they are the target of most predator control programs (Mitchell et.al.

2004, Gompper 2002, Stolzenburg 2006, Whitaker and Hamilton 1998, Choate et.al. 1994). Their numbers have also been boosted due to sporadic introductions and removal of other large canids, as well as their generalist nature and high reproductive capacity (Choate et.al. 1994, Whitaker and Hamilton 1998). Coyotes are a dominant apex predator on the MSCNWR, and are a potential threat to all life stages in cranes. Red Foxes *Vulpes vulpes*, Gray Foxes *Urocyon cinereoargenteus* and Raccoons *Procyon lotor*, and opossums *Didelphis virginiana* are likely a threat to both eggs and chicks (Whitaker and Hamilton 1998, Lowery 1974). River otters *Lutra Canadensis* may also pose some threat to eggs and chicks (Whitaker and Hamilton 1998, Lowery 1974, personal observation). Bobcats *Lynx rufus* are often cited preying on juveniles, and are the most common predator of adults (L. Billodeaux, USFWS, per.com.). While there are recorded instances of bobcats predating bird nests, eggs are not cited as part of the bobcat diet (Whitaker and Hamilton 1998, Lowery 1974, L. Billodeaux, USFWS, per.com.). Nine-banded armadillos *Dasypus novemcinctus* are a potential threat to eggs (Whitaker and Hamilton 1998). Domestic dogs *Canis lupus familiaris* have also become a problem in the more recent past, as residential areas have expanded in the region. Dogs have been responsible for killing adults and juveniles, and maybe even chicks (S. Hereford, USFWS, per.com., personal observation). Abundances and activity levels, and therefore crane threat levels, will differ throughout the year for different predators. For example, coyotes and raccoons are highly active when they have young, which is typically in the summer months when cranes are still nesting (Choate et.al. 1994, Lowery 1974, B. Leopold, Carnivore Ecology Research Project Supervisor, per.com).

Tolerance to Habitat

Species	Home range Size (ha) <sup>a</sup>	Densities (per square km) <sup>a</sup>	Breeding-Gestation Period <sup>a</sup>	Frag/Human Disturbance <sup>b</sup>	Threat to Cranes <sup>c</sup>
Coyote, <i>Canis latrans</i>	760-6000	0.35-2.3	Feb - May	moderate-high	egg, chicks, juveniles, adults
Red Fox, <i>Vulpes vulpes</i>	60-600	0.2-5	Jan - March	high	eggs, chicks
Gray Fox, <i>Urocyon cinereogentus</i>	240-2000	1.2-2.1	Dec - May	moderate - high	eggs, chicks
Domestic Dog, <i>Canis lupus familiaris</i>	not applicable	not applicable	not applicable	high	chicks, adults, juveniles
Bobcat, <i>Lynx rufus</i>	300-6000	0.09-2.7	Feb - May	low	juveniles, adults
Raccoon, <i>Procyon lotor</i>	40-100	1.4 - 70	March - Aug	high	eggs, chicks
Possum, <i>Didelphis virginiana</i>	10-365	4.9-61.8	Dec - March	moderate-high	eggs
Armadillo, <i>Dasypus novemcinctus</i>	1 - 20	0.05 - 3	May - Aug <sup>d</sup>	moderate-high	eggs
River Otter, <i>Lutra canadensis</i>	700-1500	0.25-.33	Dec - May	low	eggs and chicks

<sup>a</sup> MSU (2009), Whitaker and Hamilton (1998), Choate et al. 1994, Lowery 1974, Gehrt (2004), IUCN/SSC Canid Specialist Group (2008)

<sup>b</sup> Crooks (2002).

<sup>c</sup> U.S. Fish and Wildlife (1992), Whitaker and Hamilton 1998, Lowery 1974

<sup>d</sup> Implantation in November, birth in March

## METHODS

### Monitoring: Field Methods

Scent stations and camera traps were used to identify common mammalian predators and to evaluate predator use of different areas of the refuge. I followed general guidelines for setting up transects, scent stations, and camera traps to detect mammalian predators (Conner et.al. 1983, Roughton and Sweeny 1982, Karanth et.al. 2004, Wilson and Cole 1996, Heske 1995). Census techniques were designed to give me the best chances of detecting mammalian predators with the limited resources available (Karanth et.al. 2004, MacKenzie et.al. 2006, Roughton and Sweeny 1982). Because species vary in detection probabilities, it was also important to have multiple sampling occasions for each transect to ensure a proper census of predators using an area (MacKenzie et.al. 2006). I set up scent stations and camera traps along 1 km transects throughout each of the three units of the MSCNWR (Figure 5). A transect consisted of 6 plots, each one meter in diameter, placed 200 meters apart. A general scent attractant was placed in the center of each plot. Reconyx RM 45 cameras were placed on trees opposite each scent stations to capture predator images. All transects were located on refuge roads or fire lines to increase probability of encountering mammalian predators and placed at a minimum distance of one km apart from one another to allow for some level of independence among transects. Transect locations were chosen based on recommendations from the refuge biologist using the following criteria: crane usage, distance between transects, and my ability to reliably get to the areas by refuge road. I ran transects during the months of December, January, February, and early March. This is the time period when many mammalian predators,

especially males, increase activity in order to find mates, thereby allowing me the opportunity to encounter the most predators (Edwards 1996, L. Billodeaux, USFWS, per.com.). Because many mammalian predators can move great distances over short periods of time, each sampling occasion was defined as a single day to maintain as much independence among occasions as possible.

In 2007-2008, only scent stations were used. I surveyed seven transects, three in the Gautier Unit, three in the Ocean Springs Unit, and one in the Fontainebleau Unit. I surveyed each transect for 2-4 consecutive days in each of four months, December, January, February and March, for a total of 10 sampling occasions. When possible, all transects were sampled on the same days. Each day, tracks within plots were identified and then cleared.

In the 2008-2009 season, I added a transect to each unit for a total of ten. Camera traps were used in addition to scent stations. The number of cameras limited the number of transects that could be run in a given sampling period. Two transects per week were randomly chosen and run for six full days. Each transect was run for two six day periods, for a total of 12 sampling occasions. Scent stations were only checked for one night during each sampling period.

I identified predator species in scent stations by tracks, using guides by Elbroch (2003) and Rezendes (1999). For cameras, I identified predator species via black and white image. A one week test was performed to determine how often camera cards and batteries should be exchanged, to ensure no data loss. Following the results of this test, I exchanged batteries and camera cards each week when cameras were placed on a new transect.

In both seasons, presence/absence data was recorded. Many transect studies employ relative abundance measures, by calculating the number of observations at a station over the total number of stations on a transect (Conner et.al. 1983, Sinclair 2005, Dijak 2000, Zoellick et.al 2004). Because individual predators can easily move across more than one plot in a transect, I counted each species as present or absent from an entire transect. A species was considered present on a transect if it was identified by either track or camera image in one or more of the six plots. Since data was collected using different methods, each year was considered separately in data analysis.

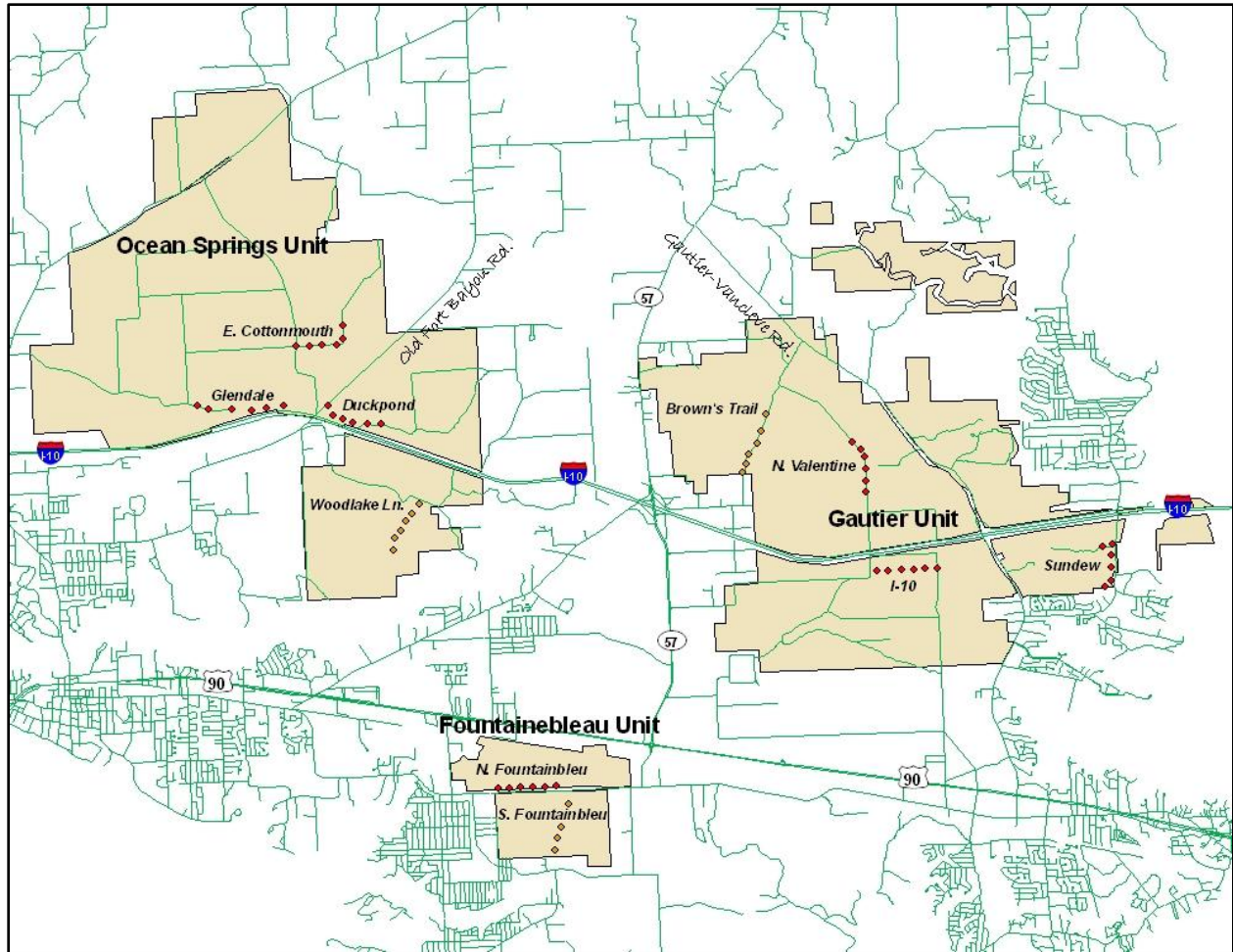


Figure 5. Map of Predator Occupancy Transects. Predator use was estimated on seven transects (red) in the winter of 2007-2008 using scent stations, and on 10 transects in the winter of 2008-2009 using both scent stations and camera traps (red and orange).

### Data Analysis

Data collected in the field was used to estimate occupancy ( $\Psi$ ) and detection probabilities ( $p$ ) of mammalian predators according to the method described by MacKenzie et.al. (2002). This method provides a likelihood-based framework for analyzing the proportion of areas occupied when detection probability is less than one, such that three outcomes are possible for any one site: 1) the site was occupied and the species was detected ( $\Psi \times p$ ), 2) the



site was occupied and the species was not detected ( $\Psi \times (1-p)$ ), 3) the site was unoccupied, therefore the species was not detected ( $1-\Psi$ ), where  $\Psi$  represent occupancy and  $p$  represents detection probability. The terms for each occasion at an individual site make up a detection history that is used to build the likelihood function for occupancy estimation. As recommended by MacKenzie et.al. 2002, I performed multiple sampling occasions for each site, allowing for proper estimation of detection probabilities. All analyses were carried out using the occupancy estimation module in Program MARK, which employs maximum likelihood to estimate both occupancy ( $\Psi$ ) and detection probability ( $p$ ) parameters (White and Burnham 1999).

Occupancy modeling in MARK is based on a few key assumptions: 1) there is no unmodeled heterogeneity among sites for occupancy and detection, 2) the occupancy state of a site does not change for the duration of surveying, 3) sites are independent from one another, so that there is no immigration or emigration during the sampling season, 4) and species are correctly identified. Some of the mammalian predator species identified on the refuge have large home range sizes and the ability to transverse across several study sites. With the goal of describing the predator community on the refuge, transects were necessarily placed on refuge property and often too close together to ensure independence among sites throughout the sampling period. Short sampling occasions were used to properly estimate detection probabilities. In addition, I placed transects a minimum of 1 km apart from one another, which is a greater minimum distance than many similar studies have used (Wilson et.al. 1996, Dijk and Thompson 2000, Sinclair et.al. 2004, Heske 1995). Even under these precautions, there was likely a lack of independence among many of the transects, especially for wide roaming predators such as coyotes and bobcats. Because of this known violation in assumptions, I am

following the suggestion of MacKenzie (2005) by replacing the term “occupancy” with “use”.

Predator use throughout the refuge is an important metric. If a predator “uses” an area, it has the potential to destroy nests, chicks, adults that reside in that area.

Estimates of predator use were based on models of constant detection probabilities and site use. This basic model provides a description of the proportion of sites used by each species, and is therefore in conjunction with the goal of identifying the most common predators throughout the refuge. I performed a goodness of fit test for each model to estimate overdispersion (MacKenzie and Bailey 2004, Cooch and White 2009). Overdispersion can occur due to: omission of important explanatory variables, failure to include important interactions, assuming a linear relationship when relationships are nonlinear, and including outliers. Overdispersion can also be indicative of lack of independence among animals or heterogeneity in the data that is not accounted for in the model (Cooch and White 2009, MacKenzie and Bailey 2004). Goodness of fit tests were carried out using bootstrap simulation in Program MARK. The variance inflation factor,  $\hat{c}$  was estimated for each model. Data fits the model perfectly when  $\hat{c}$  is equal to one. Low levels of overdispersion are indicated by  $\hat{c}$  values between one and two, while values greater than three indicate fairly high levels. As recommended by Cooch and White (2009), I tolerated  $\hat{c}$  values between one and two. To be conservative, I calculated  $\hat{c}$  using two methods: 1) observed  $\hat{c}$ /mean  $\hat{c}$  of bootstrap simulations, and 2) observed deviance/ mean deviance of bootstrap simulations, and used the larger  $\hat{c}$  (Cooch and White 2009).

Use estimates were only performed for species detected at greater than two sites. If a predator was detected at two sites or fewer, analyses in Program MARK were not possible because of lack of the appropriate number of degrees of freedom.

Because I collected predator use data with two different methods, scent stations and camera traps, I was able to make some comparisons in their abilities to detect mammalian predators. A direct comparison was made between the two methods for the occasions when data was collected for each during the same time period. The goal of this comparison was to show: a) the differences in the total number of predators detected by each method, and b) the differences in the predator species caught by each method. No formal statistical analyses were run due to the small sample size. I made additional comparisons of predator detection using scent stations only (2007-2008) or scent stations and cameras (2008-2009).

## Results

Nine mammalian predator species, in addition to human trespassers were detected in a total of 420 trap nights in the 2007-2008 and 720 in the 2008-2009 seasons. Predators detected included: coyotes, raccoons, bobcats, red foxes, gray foxes, opossums, armadillos, domestic dogs, and a river otter. During the two seasons, a wild hog, a black bear, and several domestic cats were also witnessed. Raccoons and Coyotes were the most frequently detected predators in both scent stations and camera traps across both sampling seasons.

### Predator Use: 2007-2008

Six mammalian predator species, in addition to human trespassers were detected in a total of 420 trap nights. Predators included: coyotes, raccoons, bobcats, red foxes, gray foxes, raccoons, bobcats, and opossums. A black bear and several domestic cats were also witnessed. Three predator species were detected at greater than two sites, allowing occupancy analysis. Occupancy was the highest for gray foxes, followed by coyotes and raccoons (Table 8). Because of the relatively high number of sampling occasions for each site, detection probabilities could be accurately estimated. Coyotes had the highest probability of detection, followed by raccoons and gray foxes (Table 8). Standard error and difference between upper and lower 95% confidence intervals was highest for gray foxes (Table 8). All occupancy models fit the data well, with no  $\hat{c}$  estimates greater than 2 for either calculation (Cooch and White 2009, MacKenzie and Bailey 2004).

Overall, I detected four predator species in the Gautier Unit, and three species in the Ocean Springs and Fountainbleu Units (Table 9). Coyotes, raccoons, and gray foxes were

detected in each unit. Bobcats and Opossums were each detected on a single occasion throughout the season. I detected the greatest number of species (5) on the Sundew transect, and the fewest on E. Cottonmouth (1) (Table 9).

Table 8. Use estimates for the most commonly detected mammalian predators on the Mississippi Sandhill Crane Wildlife Refuge in the winters of 2007-2008. Scent stations were used for detection on 10 occasions at 7 sites. Parameter estimates are based on a model of constant occupancy and detection probability,  $\Psi(.)p(.)$ .

Predator	$\Psi(.)$	(SE)	(Upper CI, Lower CI)	$p(.)$	(SE)	(Upper CI, Lower CI)
Coyote	0.857	(0.132)	(0.419, 0.980)	0.583	(0.064)	(0.456, 0.701)
Raccoon	0.437	(0.191)	(0.145, 0.780)	0.327	(0.089)	(0.180, 0.518)
Gray Fox	0.909	(0.460)	(.0002, 1.000)	0.094	(0.059)	(0.026, .288)

Table 9. Predator species detected using scent stations on 7 transects for each of 10 sampling occasions on the Mississippi Sandhill Crane Wildlife Refuge in December 2007-March 2008.

Unit	Site	Coyote/								
		Coyote	RedFox <sup>a</sup>	Gray Fox	Dog	Raccoon	Bobcat	Opossum	Armadillo	River Otter
Gautier	Sundew	X	X	X	0	X	X	0	0	0
	N. Valentine	X	X	0	0	X	0	0	0	0
	I-10	X	X	X	0	0	0	0	0	0
Ocean Springs	Glendale	X	X	0	0	0	0	0	0	0
	Duckpond	X	X	X	0	0	0	X	0	0
	E. Cottonmouth	X	0	0	0	0	0	0	0	0
Fontainbleu	N. Fountainbleu	X	X	X	0	X	0	0	0	0

<sup>a</sup>Red Fox prints could not be unambiguously differentiated from coyote prints. Coyotes are considered as a separate category because there were many circumstances under which a print was known to come from a coyote.

Predator Use: 2008-2009

Nine mammalian predator species, in addition to human trespassers were detected in a total of 720 trap nights in the 2008-2009 season. Predators detected included: coyotes, raccoons, bobcats, red foxes, gray foxes, opossums, armadillos, domestic dogs, and a river otter. A wild hog and several domestic cats were also witnessed, but were outside of survey transects. Five species were detected at greater than two sites, allowing occupancy analysis. Coyotes and raccoons were detected on all transects, giving them a 1.0 probability of use. For the remaining three species, domestic dogs had the highest use across the refuge, followed bobcats, and red fox (Table 10). Coyotes and raccoons also had the highest detection probabilities (Table 10). Red foxes and bobcats were detected less frequently, with domestic dogs having the lowest probability of detection (Table 10). All occupancy models fit the data well, with no  $\hat{c}$  estimates over 2 for either calculation (Cooch and White 2009, MacKenzie and Bailey 2004).

Table 10. Use estimates for the most commonly detected mammalian predators on the Mississippi Sandhill Crane Wildlife Refuge in the winter of 2008-2009. Camera traps and scent stations were used for detection on 12 occasions at 10 sites. Parameter estimates are based on a model of constant occupancy and detection probability,  $\Psi(.)p(.)$

Predator	$\Psi(.)$ (SE)	(Upper CI, Lower CI)	$p(.)$ (SE)	(Upper CI, Lower CI)
Coyote	1.000 (0.459 E-5)	(1.000, 1.000)	0.442 (0.045)	(0.356, 0.531)
Raccoon	1.000 (0.000)	(1.000, 1.000)	0.308 (0.042)	(0.232, 0.396)
Red Fox	0.319 (0.156)	(0.103, 0.657)	0.209 (0.074)	(0.099, 0.387)
Bobcat	0.599 (0.208)	(0.215, 0.891)	0.139 (0.052)	(0.064, 0.275)
Domestic Dog	0.616 (0.508)	(0.0234, 0.991)	0.054 (0.050)	(0.008, 0.279)

While coyotes and raccoons appear to be ubiquitous across the refuge, this was not the case for all predator species (Table 11). Red Fox were detected in Gautier Unit and

Fontainebleau Unit, but never in Ocean Springs. Gray fox, on the other hand, were detected only in Ocean Springs (Table 11). Bobcats were detected in approximately half of the sites in both of the Gautier and Ocean Springs Units, but never in the more suburban Fontainebleau Unit. Similarly, opossums and armadillos were detected in only the Gautier and Ocean Springs Units. Opossums and armadillos were detected fewer than four times throughout the season (Table 11). I recorded a single river otter observation at the N. Valentine site, which is bordered by a drain. Domestic Dogs were found in all three units, but under low detection probabilities (Tables 10 and 11). The fewest number of predator species detected on a transect was three. I recorded three species in the Duckpond transect in Ocean Springs and in each of the Fontainebleau transects. The greatest number of predator species detected on a transect was five. I detected five predator species in each of three transects in the Gautier Unit, Sundew, N. Valentine, and Brown's Trail, and on the Glendale transect in Ocean Springs (Table 11).

Human trespassers were detected frequently across the two seasons. While most observations of human trespassers were at sites near refuge edges, I did record a trespasser in the site furthest from the refuge boundary. In total, I observed 16 instances of trespassing, including either a single individual or a group of individuals. I observed trespasser activity through camera traps, scent stations, and even while walking transects. I recorded the following human activity on the refuge: driving trucks and recreational vehicles, exercising, and potentially hunting. Camera vandalism occurred in two different circumstances and theft of cameras on one occasion. Interestingly, I recorded the most human observations on the Sundew transect in the Gautier Unit, where I also recorded high predator diversity.

Table 11. Predator species detected using scent stations and camera traps on 10 transects for each of 12 sampling occasions on the Mississippi Sandhill Crane Wildlife Refuge in December 2008-March 2009.

Unit	Site	Coyote	Red Fox	Gray Fox	Dog	Raccoon	Bobcat	Opossum	Armadillo	River Otter
Gautier	Sundew	X	X	0	0	X	X	X	0	0
	N. Valentine	X	X	0	0	X	X	0	0	X
	I-10	X	0	0	X	X	0	0	X	0
	Brown's Trail	X	X	0	X	X	X	0	0	0
Ocean Springs	Glendale	X	0	X	0	X	X	X	0	0
	Duckpond	X	0	X	0	X	0	0	0	0
	E. Cottonmouth	X	0	0	X	X	X	0	0	0
	Woodlake Ln.	X	0	0	0	X	0	X	X	0
Fountainbleu	N. Fountainbleu	X	X	0	0	X	0	0	0	0
	S. Fountainbleu	X	0	0	X	X	0	0	0	0

My study design also allowed me to make some comparisons among scent station and camera trap methods. Both scent stations and camera traps detected coyotes, red fox, gray fox, raccoons, bobcat and opossums, armadillos, and domestic dogs, with river otters being the only species detected by camera traps alone. For the nights during the 2008-2009 season when both scent stations and camera traps were out simultaneously, there were noticeable differences in the number of predators caught by each method, with neither method standing out as superior for supplying the greatest number of detections (Table 12). The two methods also differed in ability to detect specific species (Table 13).

Table 12. Total number of mammalian predators detected in scent stations (SS) and camera traps (CT) on ten transects for each of two occasions on the Mississippi Sandhill Crane Wildlife Refuge in the winter of 2008-2009.

SS and CT	SS only	CT only	SS only	CT total
9	15	18	24	27



Table 13. Mammalian predator species detected in scent stations (SS) and camera traps (CT) on ten transects for each of two occasions on the Mississippi Sandhill Crane Wildlife Refuge in the winter of 2008-2009.

	Coyote	Red Fox	Gray Fox	Dog	Raccoon	Bobcat	Opossum	Armadillo
SS	12	0	2	1	7	0	0	1
CT	13	1	0	1	10	1	1	0

## Discussion: Refuge Predator Use

### Common Predators: Habits and Interactions

The MSCs face a wide variety of potential nest predators. While coyotes and raccoons were detected most frequently, red foxes, gray foxes, bobcats, and domestic dogs were also fairly common. It is not surprising that coyotes and raccoons were ubiquitous across the refuge. Both species are generalists and can thrive under circumstances in which many other predator species cannot (Crooks 2002; Choate et.al. 1994). Coyotes and raccoons are highly omnivorous, allowing them to easily adapt to environments with different food resources (Whitaker and Hamilton 1998, Choate 1994). In addition, both species tolerate human disturbance well, which is an asset in the fragmented MSCNWR ecosystem (Crooks 2002).

Unlike true islands, habitat patches are part of the landscape matrix, and a particular species utilization of that matrix depends on their perception. Coyotes only disappear from the smallest and most isolated of habitat fragments (Crooks 2002). Human disturbance should be detrimental to coyotes, since they have experienced the brunt of most recent predator control programs, and have had among the highest removal rates of any predator in the United States (Stolzenburg 2006, B. Leopold, Carnivore Ecology Research Project Supervisor, per.com.). To the contrary, coyotes have thrived under predator control and expanded their range tremendously (Whitaker and Hamilton 1998, Choate et.al. 1994, Stolzenburg 2006). This remarkable phenomenon is due, not only to their generalist diet and persistence in fragmented landscapes, but to their ability to rebound quickly after removal because of density-dependent changes in reproduction, mortality and dispersal. Knowlton (1972) discovered that coyotes can

even increase their litter sizes when subjected to population reduction. Due to their resilient nature, coyotes will likely continue to be a problem predator on the refuge into the foreseeable future.

Raccoons are probably the most common and widely distributed mammal in the Southeast (Choate et.al. 1994). They are usually ubiquitous across the landscape matrix, occurring at high densities along habitat edges and in areas with consistent food resources (Crooks 2002, Sinclair et.al. 2005, Dijak and Thompson 2000). Raccoons reap benefits from human impacted environments. They often have smaller homeranges and higher densities in suburban landscapes, due to increased availability of food and shelter (Gehrt 2004). Some studies have documented as much as a twenty-fold increase in raccoon density in urban versus surrounding rural environments (Gehrt 2004). Unlike coyotes, raccoons can also tolerate social feeding when enough resources exist (Gehrt 2004). Although I documented raccoons in all transects throughout the MSCNWR, it is possible that raccoon densities are higher along edges and in the more fragmented parts of the refuge, which would make cranes nesting in those areas more vulnerable to nest predation.

Gray foxes also had high probability of use across the refuge, probably owing to their omnivorous diets and abilities to tolerate human disturbed ecosystems fairly well (Crooks 2002, Harding et.al. 2001). Both were detected in three most human impacted transects, Sundew and North and South Fontainebleau. Gray foxes actually had the highest probability of use in the 2007-2008 season, suggesting that they are one of the most widespread species across the refuge. While this is likely true, gray foxes had low probability of detection, indicating that they

exist in low densities or they are not easily detected by the methods employed. In addition, use estimates may be inflated due to low detection probability (MacKenzie et.al. 2006).

Red foxes had high probability of use, but were never detected in the Ocean Springs Unit where a pack of coyotes is suspected to exist (L. Billodeaux per.com.). Unlike gray foxes, red foxes cannot climb trees, and are therefore more prone to coyote attack, often strictly avoiding areas where coyotes are prevalent (Sargeant et.al. 1984). I did, however, observe several occasions of coyotes and red foxes visiting the same transect in a night in the other two units. It is possible that one coyote is not enough to deter red foxes, whereas a pack of coyotes can exclude them from an area.

Bobcats also had high probability of use. Unlike coyotes, raccoons, and red and gray foxes, bobcats are sensitive to fragmentation and are almost always found in extensive undisturbed habitat patches (Crooks 2002). This was exemplified by the fact that bobcats were never found in the smallest unit of the refuge (Fontainebleau). Bobcats were, however, found in the Sundew transect which is along the edge of a unit, in an area where human disturbance is prominent. This transect bordered a field in which rabbits and domestic cats were commonly seen, which may have attracted the carnivorous bobcats. This edge was likely the extent of bobcat range in the larger Gautier Unit.

Although they were not detected often in scent stations or camera traps, domestic dogs had high probability of use across the refuge. Continuing suburban sprawl will likely make domestic dogs even more prominent. Opossums, armadillos, and river otters were not detected often. This study was not designed to survey river otters, so conclusions cannot be

made on their use throughout the refuge. Opossums and armadillos were either truly not that common on the refuge, or the survey methods were not the best for detecting these species.

Use estimates may be somewhat biased due to data loss and issues related to predator identification throughout this study. During the 2007-2008 season, there were two sampling occasions in which multiple scent stations were run over by four-wheelers on Sundew. Due to ambiguity in some red fox and coyote prints, in addition to scent stations substrate not recording clear enough prints in some cases, I had 18 unidentifiable predators which were not included in analysis. In 2008-2009, I had one camera vandalized on the Sundew transect, for which I lost three out of six days worth of data for that plot. I also had two cameras stolen on the E. Valentine transect, for which I obviously lost all six days worth of camera data for those two plots. Use of two detection methods reduced the number of unidentifiable predators in 2008-2009 to six. It is also important to consider that some predators were removed during the 2008-2009 season, potentially biasing estimates of predator use. During my sampling season, three raccoons, two possums, two dogs, and one coyote, gray fox, and bobcat were trapped. Trapping was usually done by a single individual, and precaution was taken not to trap near transects during the time I was sampling them.

Identifying the dominant predators across the refuge and understanding general distributions of these predators will help to answer questions, such as: What species should be considered top priority for predator control? What are the best ways to defend nests? In which habitats and refuge areas are nests likely to be most vulnerable?

Although all transects existed on the refuge, individual units and transects differ in surrounding habitat structure, levels of human disturbance and fragmentation, and hydrology.

The unique characteristics of each site help determine which predator species may use it. In the future it would be informative to sample more transects, so that these covariates could be included in the occupancy model in MARK. It would also be interesting to study predator activity levels throughout the nesting season. Studies like these could help target key areas for predator removal tactics and give insight into habitat management that could be done to reduce the predator population.

### Occupancy Modeling

Occupancy and abundance indices are commonly used for exploring animal population dynamics. Abundance measures necessarily require unique identification of individual animals, and often employ mark/recapture methods. Occupancy estimates, like those incorporated in Program MARK, are based on presence/absence, making them less invasive and less time consuming than abundance estimation. Occupancy measures are suggested for studies like this one, in which multiple species are targeted. Strict measures of occupancy, however, were not possible. Because I censused predator species with different homeranges and movement capabilities, I could only evaluate species “use” across the refuge. Estimation of predator use is important for determining which species are most widespread and which species are likely to utilize certain refuge areas.

Different predator species will have different probabilities of being detected in any given study. Recently developed statistical techniques account for imperfect detection, by estimating detection probabilities and incorporating them in occupancy estimation (White and Burnham 1999, MacKenzie 2002). Without this, my use estimates would have been biased, and

comparisons among species invalid. Domestic dogs, bobcats, and gray foxes were three species that had fairly low detection probabilities, but high use across the refuge. If I had not incorporated their detection probabilities, I would have assumed these species were uncommon, which could be potentially detrimental to informing management for the MSCs.

### Predator Monitoring Techniques

Census techniques can differ in their abilities to detect mammalian predators, depending on the species targeted. I suggest that there are considerable differences in detection rates and species detected between scent stations and camera traps. While I recorded a similar number of detections for each method, often one method would detect a predator when the other would not. Species specific differences in detection were also striking in some cases.

Past studies have indicated that scent stations provide a reliable index of bobcat abundance (Conner et.al. 1983, Linscombe et.al. 1983). In my observation, however, bobcats were attracted to scent stations in only one occasion. Camera traps proved far superior for detecting bobcats, and without their use, I would have assumed low probability of use across the refuge.

Camera traps were also best for recording domestic dogs, which, like bobcats, were only detected via scent station on one occasion.

There are mixed reviews for scent station performance in detecting raccoons (Gompper et.al. 2006, Conner et.al. 1983, Nottingham et.al. 1989). Gomperra et.al. (2006) reported

similar detection rates for raccoons using scent stations and camera traps. There were some instances in which I raccoons were caught on camera, but did not visit the scent stations, and other instances in which I recorded clear raccoon prints in scent stations, but the cameras were not triggered. Therefore, I suggest both camera traps and scent stations be used to ensure no loss of data.

I did not observe much variation between detection methods for coyotes. Some studies suggest that that coyotes are neophobic and reported that camera traps performed poorly in detection of coyotes (Gompper et.al. 2006, Sequin et.al. 2003). Some individuals were caught inspecting the scent stations in the first image taken, and running away in the second image, suggesting that they were deterred by the camera triggering. In these cases, I was still able accurately identify them. Although it is possible that I missed some individuals altogether, I maintain that camera traps are effective for detecting coyotes.

There was ambiguity amongst coyote and red fox tracks in some cases, especially when only a single or partial print existed, and when the substrate was not moist enough to record the fur on the footpad of the red fox. Therefore, I recommend using camera traps to best distinguish between the species.

Scent stations seem to outperform camera traps only for gray foxes. It is possible that the small size of gray foxes prevented them from being detected in camera traps. For example, Gompper et.al. (2006), found that small carnivores such as martens and weasels were more likely to be detected by track plates than camera traps.



Because the two techniques varied in detection performance for different species, and because a predator was often detected by one method and not the other when both were used simultaneously, I recommend using both techniques when monitoring the general predator community. Differences in probability of use for different species between the two seasons further supports implementing both survey methods. If cameras are in place, recording scent station data will not require much more expense or effort, and will greatly improve data quality. Having both methods is also a general safeguard in case of camera failure or inability to detect prints in scent stations. One potential problem with using two methods is that some species or individuals may be camera shy.

## Discussion: Nest Survival, Predator Use, and Implications for Management

The MSC CCP and MSC Recovery plan share the goal of creating a long term self-sustaining wild population (U.S. Fish and Wildlife 1991, 2007). Despite advances in captive rearing, release, and current research to maintain genetic diversity in captivity, a self-sustaining population cannot exist without improved recruitment in the wild. In addition, there may be financial incentives for improving wild recruitment, as captive reared chicks cost an estimated \$20,000 each (S. Hereford, USFWS, per.com.). Because nest success is a primary component of recruitment in MSCs, it is necessary to understand the underlying factors that drive it.

### Nest Monitoring

Heat and motion sensory cameras were useful for determining causes of nest failure, with no apparent adverse effects to the MSCs. Therefore, cameras should be considered for monitoring other crane populations. Predation was the primary cause of nest failure, followed by flooding, abandonment, and egg inviability. DSR was best explained by season date, nest age and temperature. The negative effects of season date could be explained by changes in predator density and activity as the season progresses (Choate et.al. 1994, Lowery 1974, B. Leopold, Carnivore Ecology Research Project Supervisor, per.com). Nest age had a strong negative effect on predated nests, where the majority of predation events occurred approximately a week from hatching. In addition, predation pressure had a negative effect on nest survival. Surprisingly, DSR increased with increasing temperatures. This is probably best explained by the potential positive effects of warm temperatures early in the season.

These results indicate that a high premium should be put on those nests laid early in the season. Future research should focus on solutions for preventing predation late in the season, and particularly late during the incubation period. It would be informative to incorporate different techniques for nest defense against predators and evaluate DSR under the treatments. It would also be informative to include additional covariates into analyses, such as habitat structure, water depth at the nest, parental experience, and genetic diversity to assess their relative importance in DSR and nest predation. It would also be interesting to incorporate some of the incubation behaviors recorded by camera such as egg turning, time take to return to nest after disturbance or nest visit and ability to defend nest. A formal comparison of DSR among non-migratory MSC, Florida Sandhill Cranes and Whooping Cranes could be performed to identify similar threats and identify common factors that drive DSR. Because MSCs have lower recruitment than the other two, a comparative study may give insight into improvements that could be made to increase DSR in the MSC population (Drewien et.al. 1995).

### Predator Use

I identified nine mammalian predator species that may be a potential threat to cranes. Of these, coyotes and raccoons were the most common and widespread across the MSCNWR. Because they are both generalists that can thrive in fragmented and human disturbed environments, they are likely to remain common across the refuge into the foreseeable future. There are also well suited as predators of MSC nests. As opportunistic omnivores, they can take advantage of MSC eggs, even though the eggs are not a common food source. Future studies

could add additional transects, and evaluate covariates of predator use such as habitat fragmentation.

### Predator Management: Consequences and Alternatives

Predator eradication is a common goal amongst wildlife managers (Goodrich and Buskirk 1995, Palm et.al. 1970). The complexity of predator population dynamics, makes removal efforts difficult and sometimes counterproductive (Kemp 1976, Mitchell et.al., 2004, Stolzenburg 2006). Mammalian predator communities are driven by the needs of particular species, in addition to competitive interactions and intraguild predation (Fedriani 2000, Henke and Bryant 1999, Goodrich and Buskirk 1995). Mesopredator release can occur when top predators are removed from a system because of habitat fragmentation, habitat disturbance or outright predator removal activities (Crooks and Soule 1999, Terborgh et.al. 2001). Many studies suggest that coyotes can depress red fox, gray fox, bobcat, raccoon, and opossum populations (Rogers and Caro 1998, Crooks and Soule 1999, Schmidt 2003, Henke and Bryant 1999, Sargeant et.al. 1984). Fedriani (2000) even reported coyotes predating bobcats and gray foxes. Extensive carnivore studies across the Southeast, however, suggest that coyotes do not exclude bobcats, gray foxes, or raccoons from a given area (B. Leopold, Carnivore Ecology Research Project Supervisor, per.com, Gehrt and Prange 2007). While I detected mesopredators using the same transects as coyotes, sometimes on the same nights, it is probable that many of these species would increase in range and numbers if coyotes were removed (Crooks and Soule 1999). A future study could focus explicitly on predator species interactions to determine if some predators avoid areas where coyotes dominate. This

information would be important for understanding the possible repercussions of coyote removal.

Predator removal for increased recruitment in avian populations has had mixed success (Pearse and Ratti 2004, Cote and Sutherland 1996, Drewien and Bouffard 1990, Littlefield and Cornely 1983, Armstrong 2002, Balser et.al. 1968). Some studies documented increases in nest predation when top predators were removed (Crooks and Soule 1999, Sargeant et.al. 1984, McDaniels 1987). Others showed lower nest predation rates, but usually for the short term and at a high financial cost (Pearse and Ratti 2004, Drewien and Bouffard 1990, Littlefield and Cornely 1983). For example, in two studies of sandhill cranes, intensive predator removal increased hatch success in the short term, but did not significantly increase fledge success (Littlefield and Cornely 1983, Drewien and Bouffard 1990).

Analysis of trapping data would help reveal the effectiveness of predator removal for different species. Trapping records are available and could be utilized for calculating population growth rates during different levels of trapping intensity, and for determining the level of control necessary to achieve short and long term population decline of target species (Harding et.al. 2001). Based on findings from population modeling in MSCs, a goal was set to “Conduct predator control sufficient to allow for 60 percent hatching success, 67 percent fledging success, and greater than 80 percent survival of after-hatch-year birds” (U.S. Fish and Wildlife 1992, 2007). Predator removal could be included as a covariate in DSR modeling to evaluate whether or not that goal is being achieved.

## Predator Management: Alternatives to Removal

Many argue against lethal removal of mammalian predators except in extreme cases, even for conservation of endangered species (Goodrich and Buskirk 1995, Schneider 2001, Stolzenburg 2006). High costs, inefficiency, potential for mesopredator release, and availability of viable alternatives are commonly cited reasons for not using lethal control (Goodrich and Buskirk 1995, Schneider 2001, Stolzenburg 2006). Therefore, removal should be considered along with other alternatives.

Understanding important covariates of DSR for MSCs, and knowing common predators on the MSCNWR will help identify possible solutions for decreasing nest predation. For MSCs, nest site selection appears to be important, since detection by a predator increases the chance of overall nest failure. Some nests, once detected were subsequently attacked numerous times, and were more likely to be predated. Identifying solutions that could be implemented directly at the nest should be considered. Future research could examine the effectiveness of nest concealment via habitat manipulation, or large nest enclosures. Enclosures may be especially effective at deterring coyotes, since they are primarily visual hunters and are neophobic (Gompper et.al. 2006, Sequin et.al. 2003). Taste aversion techniques could also be tested. For example, poisoned crane-like eggs, placed in crane-like nests, could be distributed heavily in nesting territories prior to the nesting season to see if it increases overall nest success throughout the season.

Behavioral conditioning may also be worthwhile. Heatley (2002) developed a promising anti-predator conditioning method for cranes in captivity. A similar method could also be

employed for juveniles in refuge release pens in the presence of adult birds, however, it would be important to ensure that the juveniles don't associate the pen with danger. Anti-predator conditioning may have an immediate positive effect for the survival of released juveniles, but it would take longer to determine its affect on nest success. Finding effective alternatives for predator removal should be a priority for management to help accomplish the goal of long term improvement in MSC recruitment.

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## VITA

Rose Butler was born into a loving family in Huntsville, AL. She received her B.S. in Biology (concentration in Ecology and Evolution), at the University of North Carolina at Asheville, where she also played Division I volleyball. She received departmental distinction in Biology as well as several awards for her academic achievements as an athlete. During the summers of her undergraduate career, Rose worked as a zookeeper for the Cape May County Park and Zoo, and as a beach nesting birds field technician for New Jersey Fish and Wildlife. In 2006, she was awarded a position as an R.E.U. (Research Experience for Undergraduates) student, for which she spent one summer doing research in conjunction with the Organization of Tropical Studies at La Selva Biological Station, Costa Rica. She published her work on forest understory regeneration in tree plantations in the peer reviewed journal, *Forest Ecology and Management*. In 2006 she was accepted as a Master's student into the Conservation Biology Department at University of New Orleans, under the advisement of Dr. Jerome Howard. In 2007, Rose moved to New Orleans with her boyfriend, Bryan Wall, and began pursuing her M.S. at UNO. Rose carried out her research on the USFWS Mississippi Sandhill Crane Wildlife Refuge, where she worked closely with refuge biologists Scott Hereford and Lauren Billodeaux. In 2007 she attended the Mississippi Sandhill Crane Recovery Meeting where she shared preliminary results of her predator occupancy work. Rose presented at the 11<sup>th</sup> annual International Crane Conference in Wisconsin Dells, Wisconsin, where she won the award for best student paper/presentation. In addition to research, Rose worked as a teaching assistant where she enjoyed teaching biodiversity labs to both majors and non-majors. While at UNO, Rose was also an advocate of Conservation Biology in New Orleans. She is an active member of

the New Orleans Chapter of Society for Conservation Biology, where she currently serves as the educational outreach coordinator. Through SCB, she has had the joy of participating in wetlands plantings, on campus recycling efforts, and educational outreach experiences at the high school and grade school levels. Rose also volunteers for Bayou Rebirth, an organization that serves to both rebuild wetlands and inform volunteers about the coastal Louisiana ecosystem, and has volunteered in educational outreach activities for the Crescent City Farmer's Market. She also serves as secretary for the Biology Graduate Student Association. Rose will finish her graduate work at the University of New Orleans with a 4.0 GPA, and a rich background in Biological Conservation. She hopes to continue working closely with her advisor and refuge biologists to collaborate on publications in the future.