Habitat suitability modeling for the Mississippi Sandhill Crane, Grus canadensis pulla

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Habitat suitability modeling for the Mississippi Sandhill Crane, 
*Grus canadensis pulla*

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

by 

Linda Carol Salande 
B.S. University of New Orleans, Louisiana 2011 
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# TABLE OF CONTENTS

LIST OF FIGURES ................................................................................................................. iv  
LIST OF TABLES ......................................................................................................................... v  
ABSTRACT ................................................................................................................................. vi  
INTRODUCTION .......................................................................................................................... 1  
MATERIALS AND METHODS ................................................................................................. 8  
  Study area ............................................................................................................................... 8  
  Telemetry ............................................................................................................................... 9  
  Land Use/Cover Classification and Analysis ............................................................... 11  
  Land Use/Cover Change Detection and Analysis ......................................................... 14  
  Habitat Suitability ............................................................................................................. 15  
RESULTS .................................................................................................................................. 18  
  Telemetry ............................................................................................................................... 18  
  Land Use/Cover Classification and Accuracy ............................................................. 18  
  Area Status and Change in Land Use/ Land Cover ..................................................... 24  
  Analysis of Habitat Suitability for Mississippi Sandhill Cranes ......................... 26  
DISCUSSION ............................................................................................................................. 33  
  Land Use/Land Cover Map Products .......................................................................... 33  
  Land Use/Land Cover Change Over Time .................................................................. 33  
  Crane Use of Land Cover Classes ............................................................................. 34  
  Habitat Suitability Model Products .......................................................................... 36  
  Change in Habitat Suitability Over Time ................................................................... 37  
  Crane Use of Habitat Suitability Classes ................................................................... 38  
  Conservation Implications ............................................................................................. 40  
LITERATURE CITED ............................................................................................................... 43  
VITA .......................................................................................................................................... 46
LIST OF FIGURES

FIGURE 1. Location of the Mississippi Sandhill Crane National Wildlife Refuge in Jackson County, MS……………………………………………………………………………..8

FIGURE 2. Land use land cover classification map of the Mississippi Sandhill Crane National Wildlife Refuge for the growing season (June 13, 2011)………………………………………20

FIGURE 3. Land use land cover classification map of the Mississippi Sandhill Crane National Wildlife Refuge for the non-growing season (December 11, 2013)……………………………..21

FIGURE 4. Mississippi Sandhill Crane habitat suitability model for the growing season (June 13, 2011)……………………………………………………………………………..29

FIGURE 5. Mississippi Sandhill Crane habitat suitability model for the non-growing season (December 11, 2013)……………………………………………………………………………..30
LIST OF TABLES

TABLE 1. Description of land use/ land covers classes used for growing and non-growing season habitat classifications……………………………………………………………………19

TABLE 2. Contingency table illustrating the accuracy of correctly and incorrectly classified pixels from 2011 LULC classification…………………………………………………………………22

TABLE 3. Contingency table illustrating the accuracy of correctly and incorrectly classified pixels from 2013 LULC classification…………………………………………………………………23

TABLE 4. Area and number of crane occurrences for each LULC class within the Mississippi Sandhill Crane National Wildlife Refuge for two different reference years…………………………25

TABLE 5. Change in LULC area over years (2011-2013)…………………………………………………………26

TABLE 6. Typical features of grade criteria used for each habitat suitability model………………26

TABLE 7. Area and number of crane occurrences within each grade of the growing season habitat suitability model……………………………………………………………………32

TABLE 8. Area and number of crane occurrences within each grade of the non-growing season habitat suitability model………………………………………………………………32
ABSTRACT

In this study, I modeled the suitability of habitat on the Mississippi Sandhill Crane National Wildlife Refuge for the federally endangered Mississippi Sandhill Crane (*Grus Canadensis pulla*). Habitat type and suitability changed over time due to seasonality of vegetation and succession in the absence of burning. Cranes used highly suitable habitat more in the non-growing than in the growing season, and may have been more constrained by resource availability during winter months. Cranes used some less-suitable areas including cypress drains, which provide roosting sites, and supplemental food plots. The mismatch between predicted quality and crane use suggests that no single habitat provides all resources required for the population to persist. Prescribed burning to maintain grassland habitat is essential for maintaining high quality habitat for cranes. The relative availability of food on supplemental food plots and grasslands, as well as the behavior of cranes toward roads, require additional investigation.

**Key words:** Mississippi Sandhill Crane, *Grus Canadensis pulla*, Mississippi Sandhill Crane National Wildlife Refuge, habitat suitability
INTRODUCTION

Human activities are changing the natural world at alarming rates, causing the global extinction rate to rise by an estimated three or four orders of magnitude over background rates (Pimm et al., 2006; May and Tregonning, 1998; Venter et al., 2006). Based on Red List 2015 estimates, 22,784 out of 77,340 evaluated species will be extinct in the near future (IUCN, 2015). Several comprehensive studies of threats to endangered species have identified habitat loss as the most pervasive cause for endangerment (Czech and Krausmen, 1997; Wilcove et al., 1998; Pimm et al., 1995). Since habitat loss is the main factor for species decline, habitat preservation and restoration are likely to be essential conservation strategies for preventing or reversing species loss.

The crane family (Gruidae) is an ancient family of birds and is among the most threatened group of birds in the world (Jones et al., 2006). Fifteen species and fourteen recognized subspecies survive today and are grouped into one of two subfamilies, Balearicinae and Gruinæ, in the family Gruidae (Archibald and Lewis, 1996). The thirteen species of Gruinæ are further divided into 3 genera: Bugeranus, Anthropoides, and Grus. The species in the genus Grus includes four distinct groups of closely related species: The Sandhill Crane (Grus canadensis), the Siberian Crane (Grus leucogeranus) which both stand alone, The Sarus Crane species group (Grus antigone), and the Whooping Crane species group (Grus Americana) (Archibald and Lewis, 1996).

Of the fifteen existent species, eleven are considered globally threatened (IUCN, 2015). Although many factors threaten the survival of crane species, habitat loss and anthropogenic disturbances are thought to be the most important (Meine and Archibald, 1996). Many crane species depend on aquatic and semi-aquatic habitats for part of their life cycle, and crane
populations are particularly vulnerable to conversion and over-exploitation of wetlands (Meine and Archibald, 1996). These modes of habitat loss affect the distribution, movement, and breeding success of cranes. Conversion and degradation of wetlands is thought to be the most significant factor of habitat loss (Archibald and Lewis, 1996), because this destroys breeding grounds, migration stopover points, staging areas, wintering grounds, and roosting areas which are critical for the survival of crane species.

Cranes often serve as “umbrella” and “flagship” species in conserving wetlands and grasslands around the world that provide protection for a broad array of species and ecosystems (Schoff, 1991). Therefore, cranes present excellent opportunities to develop programs that combine varied conservation goals, activities, and techniques that can be applied to other species that require conservation. A primary example is the conservation program for the Wattled Crane (Bugeranus carunculatus) of South Africa. Their primary wetland habitats have been drastically reduced by the creation of dams. Efforts are currently underway to designate several wetland habitats as national parks (Beilfuss et al., 1996), which will also protect the flora and fauna in that region.

The Sandhill Crane (Grus canadensis) is distributed across a wide range in North America and Eastern Siberia with wintering grounds in Southern United States and Mexico (Meine and Archibald, 1996). Morphological features include a distinctive red crown, grayish brown plumage, four foot stature, and unique vocalizations. Six subspecies of Sandhill Cranes are currently recognized: The Lesser (G. c. Canadensis), Canadian (G.c. rowani), Greater (G. c. tabida), Mississippi (G. c. pulla), Florida (G.c. pratensis), and Cuban (G.c. nesiotes) Sandhill Cranes (Archibald and Lewis, 1996). Three subspecies, the Lesser, Greater, and Canadian Sandhill Cranes, are renowned for their long migrations between the high arctic of Siberia and
Canada and wintering grounds in Mexico and the southern United States. These three subspecies have stable population numbers and are not considered endangered. The remaining three subspecies, the Mississippi, Florida, and Cuban Sandhill Cranes, are non-migratory and exist as small remnant populations with restricted ranges in the Southern United States (Mississippi, Florida, Georgia) and Cuba (Meine and Archibald, 1996). Both Mississippi and Cuban Sandhill Cranes are classified as critically endangered with wild population numbers below three hundred (IUCN, 2015).

Historically, there were scattered populations of the nonmigratory Sandhill Cranes all along the Gulf Coast as far west as Louisiana and east into Florida (Gee and Hereford, 1995). By the 1960s, the only remaining population west of Florida was a small one in Jackson County, Mississippi. Today, the Mississippi Sandhill Crane (*Grus canadensis pulla*) is only found on or adjacent to the Mississippi Sandhill Crane National Wildlife Refuge. This refuge was established in 1975 in Jackson County, Mississippi after the crane was placed on the endangered species list in 1973. The Mississippi Sandhill Crane National Wildlife Refuge is within the Southeastern Coastal Plain Ecosystem along the Gulf Coast and consists of 8000 hectares.

In 1972, the small isolated population of Mississippi Sandhill Cranes was recognized as a separate subspecies with distinctive morphological, physiological, and genetic traits (Aldrich, 1972). These cranes are darker in color, mature earlier, and have lower levels of heterozygosity from other Sandhill cranes.
Currently the population consists of 126 individuals (U.S. Fish and Wildlife Service, 2015) and is supplemented by annual releases of captive bred birds originating from White Oak Conservation Center and Audubon Institute Species Survival Center. Despite supplementation, reproduction in the wild is still below replacement levels (Valentine and Logan, 1991; Ellis et al., 1992, U. S. Fish and Wildlife Service, 2007a).

Mississippi Sandhill Cranes are found in semi open, wet pine savanna habitats which are meadows interspersed with long leaf pines established on acidic waterlogged soil. These wet pine savannas habitats were once widespread throughout the central Gulf South including Southern Jackson County (U. S. Fish and Wildlife Service, 2007a). It is estimated that 95-97 percent of wet pine savanna habitat in the Gulf South has been altered by development and forest conversion (U.S. Fish and Wildlife Service, 2007a). Less than five percent of the original savanna habitat remains in the Gulf South and the refuge protects a portion of the remnant ecosystem. The decline of the Mississippi Sandhill Crane coincides with the disappearance of the dry and wet pine savannas in the Gulf South region. Due to habitat loss and degradation within the Southeastern Coastal Plain ecosystem, Mississippi Sandhill Cranes are only found on the refuge and adjacent private lands (U. S. Fish and Wildlife Service, 2007a).

Historically, the longleaf pine community was the predominant vegetative community on the Gulf Coast, but is now highly fragmented and degraded by logging, grazing, intensive site preparation, and fire suppression (U. S. Fish and Wildlife Service, 2007a). Fragmentation has created more edge habitat, allowing predators to move easily and likely increasing predation rates (Butler, 2009).
Fragmentation has also left islands of high-quality habitats surrounded by inhospitable lower quality habitats. The loss of connectivity between remaining high quality habitat obstructs wildlife movement and further reduces the value of the remaining habitat (U.S. Fish and Wildlife Service, 2007a).

Currently, the Mississippi Sandhill Crane National Wildlife refuge supports a mosaic of habitat types of varying suitability for cranes, including pine savannas, pine flatwoods, pine scrubs, hydric drains (swamps), estuarine (marsh), agricultural, and open water. The relative use of these habitats by cranes greatly affects the ability of the refuge to support a viable crane population, and it is critical to understand how crane habitat use corresponds to the availability of high- and low-quality habitats.

A straightforward approach to understanding crane habitat use is to utilize habitat suitability index (HSI) models (Roloff and Kernohan, 1999). These models are commonly used to assess habitat quality and to identify potentially suitable habitats for particular species (U.S. Fish and Wildlife Service, 1981). HSI models incorporate information such as structure and composition of preferred habitats into a mathematical model that indexes overall habitat quality on a scale of 0 (unsuitable) to 1 (optimal). These models also use different environmental factors such as, land cover, terrain morphology, and distribution of human activities to produce maps of potential suitability of geographic distribution of a species habitat in a region. Once HSI models are developed, the actual use patterns of a target species can be overlaid to determine the extent to which population density matches the apparent suitability of habitats. Cases of mismatch (high-quality habitat is underutilized or low quality habitat is overutilized) can identify previously unrecognized limiting factors, guide habitat management decisions, and even alter our understanding of habitat quality.
Remote sensing data have often been used for classifying and mapping habitat cover types in conjunction with geographic information systems (GIS) (Congalton et al., 1993). Geographic information system is an interface that can link remotely sensed data with spatial modeling to quantify and assess habitat suitability. A previous study (Na et al., 2015) utilized remote sensing and GIS to build a habitat suitability index model for the endangered red crowned crane (*Grus japonensis*) in the wetlands of the Zhalong National Nature Reserve in China. Remote sensing was used to identify and distinguish wetland habitat from other surrounding habitat types. GIS was then used to effectively identify and map potential high-quality wetland habitat for (*Grus japonensis*). The principles and methods used in this study were essential for the management and conservation of this rare species and could be applied to the conservation of Mississippi Sandhill Cranes.

Previous work by refuge biologists attempted to create a habitat suitability index model for the Mississippi Sandhill Crane. In 2007, the U. S. Fish and Wildlife Service (USFWS) performed a very general habitat classification of the refuge using remote sensing but several classes (woodland, shrub, and scrub) were combined, leaving out critical habitats for the creation of a HSI model. The gaps in the previous data make it desirable to develop a more comprehensive model using more discrete habitat categories.

The objectives of this study were: (1) use radio telemetry to collect locational data for Mississippi Sandhill Cranes; (2) use remote sensing to differentiate and classify habitats within the Mississippi Sandhill Crane National Wildlife Refuge; (3) use geographic information systems (GIS) to map and assess crane habitat suitability; and (4) determine whether patterns of crane use match expectations and predicted suitability grades. I expected that cranes should disproportionately use higher quality habitats on the refuge.
The Mississippi Sandhill Crane National Wildlife Refuge experiences marked seasonal change in vegetation cover, water features, and crane distributions. To track the dynamic seasonal changes in habitat suitability and crane use patterns across this relatively small landscape, I developed and validated separate habitat suitability models for growing and non-growing seasons. Habitat suitability for sandhill cranes is thought to be largely dependent upon the availability of upland savannas for foraging, water features for nesting and roosting, and roads, which expose cranes to human disturbance and dispersing predators (U.S. Fish and Wildlife Service 2007b). In this study I asked whether habitat suitability models based on these criteria successfully predicted the distribution of cranes on the Mississippi Sandhill Crane National Wildlife Refuge.
MATERIALS AND METHODS

Study Area

The study was conducted on the Mississippi Sandhill Crane National Wildlife Refuge (MSCNWR), located in Jackson County, Mississippi. The study area is located at 30° 28’ 55” N and 88° 47’ 33” W, west of the Pascagoula River. The refuge consists of 8600 hectares and is subdivided into the Gautier, Ocean Springs, and Fontainebleau units (Figure 1). Each unit lies within the limited nesting range of the endangered Mississippi Sandhill crane. The study landscape comprises a mosaic of land cover types, including wet pine savanna, pine lands (flatwoods and scrubs), hydric drains, estuarine, agricultural, open water, and developed land.

Figure 1. Location of the Mississippi Sandhill Crane National Wildlife Refuge in Jackson County, MS.
Telemetry

In this study radio telemetry was used as a tool to mark, locate, and monitor endangered Mississippi Sandhill Cranes. During the study, I tracked five different cranes to obtain locational radio fixes between September 2012 and August 2013. Crane 825 was a costume-reared female that was hatched in 2008 at the Audubon Institute. Crane 953 was a costume-reared female that was hatched in 1999 at the Audubon Institute. She was released on the Gautier unit using an acclimated method which requires confinement in a captivity pen for several weeks before release on the refuge. Crane 1111 was a captive costume reared male that was hatched in 2011 at the Audubon Institute. Crane 1115 was a captive parent reared male that was hatched in 2011 at White Oak. Cranes 825, 953, 1115, and 1111 were all initially released on the Gautier unit using an acclimated method. Crane W-25 was a wild reared male that was hatched in 2002 near the Gautier Unit.

Each crane was mounted with a VHF transmitter by MSCNWR staff with its own unique radio frequency. Cranes 825 and W25 were mounted with a model A1540 backpack VHF transmitter (Advanced Telemetry Systems, Isanti, MN). Crane 953 was mounted with a Biotracker model U481 backpack VHF transmitter (Lotek Wireless, Newmarket, Ontario). Cranes 1111 and 1115 were mounted with model BT-1 backpack VHF transmitters (Communications Specialists Inc., Orange, CA). The transmitter on 1111 stopped functioning due to bird death on June 13, 2013.
I obtained locational radio fixes for each crane twice a month during four different time periods, roosting (1 hour after sunset to 1 hour before sunrise), morning (6-10 AM), midday (10 AM – 2 PM, and afternoon (2-6 PM). Within these time periods, cranes utilize different habitat types for different behaviors. For example, cranes utilize shallow ponds or cypress swamps during roosting periods to avoid predators while open pine savannas are utilized for foraging during morning periods.

The number of location fixes was not equal for each crane for several reasons, including inclement weather, receiver malfunction, and the crane being out of receiver range. Refuge biologists provided supplementary location fixes for the five focal cranes and supplied six hundred and fifty location fixes for an additional seventeen cranes to increase the sample size. The larger sample size better reflects the actual population of cranes and enhances the understanding of actual habitat use patterns.

I determined the location for each crane during each time period from four radio bearings obtained using a Telonics model RA-23 antenna and Australis 26 k receiver (Titley Scientific Inc., Columbia, MO). Refuge roads were used to drive as close as possible (generally within 0.5 km) to the probable location of each crane before taking bearings, and I attempted to obtain bearings offset by as large an angle as possible. All bearings for a given locational fix were completed within 15 minutes of obtaining the original bearing. I established UTM coordinates of the receiver location for each radio fix using a Garmin Colorado 400t GPS. A handheld compass was used to establish and record azimuths for each radio fix.
A shape file of the Mississippi Sandhill Crane Refuge in ARC Map 10.1 (Esri., Redlands, CA) was used to triangulate radio fixes to obtain final location points. Final location points were compiled into a large Excel version 14.0 (Microsoft Corp., Seattle, WA) dataset used to create two separate shapefiles representing points from growing and non-growing seasons. The growing season shapefile contained location points from April through October, 2011 and 2012. The non-growing season shapefile contained location points from November through March, 2012 and 2013. These two shapefiles were overlaid onto corresponding land use/land cover classification maps to display crane habitat use patterns.

**Land Use/Cover Classification and Analysis**

ERDAS Imagine Software (version 2014) was used to classify different habitats and vegetation types in the Mississippi Sandhill Crane National Wildlife Refuge. Two satellite images were used to perform the classification and were obtained on March 20, 2014, from the U.S. Geological Survey (http://earthexplorer.usgs.gov). The images were obtained for dates corresponding with growing and non-growing seasons. High quality cloud-free Landsat imagery was not available for consecutive years during my study period. I selected two images based on the availability of high quality imagery closest to my study period.

The first image was a Landsat 5 image (scene ID LT50210392011164EDC00; 7 spectral bands) was acquired on June 13, 2011 and corresponded with growing season. The second image was a Landsat 8 image acquired on December 11, 2013 (scene ID LC80210392013345LGN00; 11 spectral bands) and corresponded with the non-growing season. Both images used the datum (WGS84), map projection (UTM), UTM zone (16), path (WRS 21), row (WRS 39), and grid cell size (30).
Initially, both images were layer stacked within ERDAS software to incorporate the proper bands of each image for classification. Bands 1,2,3,4,5,and 7 were used for the Landsat 5 image and bands 2,3,4,5,6,and 7 were used for the Landsat 8 image. Subsets were cut from each layer stacked image by overlaying a Mississippi Sandhill Crane National Wildlife Refuge (MSHCNWR) polygon shape file as an outline. A slightly larger area than the refuge outline was selected and a subset function was used to create two new resultant images. A principle component analysis was then performed on the subset images using the first four components. A K-means unsupervised method was then selected to complete the initial classification. Thirty seven classes were created using a 0.99 convergent threshold running for 25 iterations.

After the images were classified by ERDAS software, each image was separately displayed over a raster image of Jackson County, Mississippi in order to refine and recode classes. The classified image’s attribute table was used for refinement and recoding by changing the color scheme of each of the thirty-seven rows to correspond with a newly created United States National Vegetation Classification (USNVC) feature class.

I initially distinguished eight feature classes: water (canals, channels, ponds), marsh/wet meadow, cypress drain, paved road, grassland, developed vegetation (lawns and cultivated areas), forested, and building footprint. The water feature class represents canals, channels, and man-made ponds. The cypress drain feature class represents cypress swamps that are dominated by either bald cypress or pond cypress and may be inundated with shallow water as much as nine months out of the year. The marsh/wet meadow feature class also known as non-tidal marshes or wet meadows represent freshwater marshes that frequently occur along streams in poorly drained depressions and in the shallow water along the boundaries of lakes, ponds and rivers. The paved road feature class represents gravel roads, paved roads, highways, and Interstates. The grassland
feature class represents pine savannas and pine scrubland. The developed vegetation feature class represents pastures, mowed / maintained areas (lawns), farms, pastures, and cultivated areas. The forested feature class represents Southeastern North American warm temperate forests that include oak and pine species. The building footprint feature class represents anthropogenic structures such as buildings and trailers.

The anthropogenic features were easily identifiable and were classified first, followed by water, then vegetation. Initially, each row’s color of the attribute table was turned black, which turned all pixels in that feature class on the classified image to black. Once the black pixel features were identified, that row of the attribute table was labeled with a United States National Vegetation Classification (USNVC) code and then a color was selected for it. This was done for all thirty-seven rows for both images.

After the refinement and recoding process was complete, the MSHCNWR polygon shapefile was used as an outline to cut the final subsets of the classified images to include only refuge areas. The final land use land cover classified images were uploaded into ARC GIS (arc map 10.1) where 2 final map products were created for growing and non-growing seasons.

Separate accuracy assessments were performed growing and non-growing season land use land cover maps to determine accuracy of classification using ERDAS Imagine software (version 2014). A 6 inch, ortho-rectified, 3 band compressed Jackson County, Mississippi color mosaic was used as a reference image for the non-growing season accuracy assessment. The image was produced from high resolution digital orthophotographs produced from aerial photos collected over Jackson County, MS on March 4, 2012. The image is referenced to NAD 83, State Plane Coordinate System, East Mississippi, and was obtained on August 16, 2014 from MARIS (Mississippi Automated Resource Information Systems) http://www.maris.state.ms.us.
Randomly selected points were generated within the ERDAS software from the non-growing LULC classification map. To match the LULC classification map to reference imagery, classification class values were displayed in an accuracy assessment table and high resolution reference imagery were displayed in a second viewer. The randomly selected points generated from the LULC maps were loaded onto the reference image and each point was closely inspected to identify the land cover type. A corresponding class code was entered for each point in the reference column of the accuracy assessment table. Matching class code and reference number indicated pixels accurately classified. Finally, an accuracy report was generated within the software that included error matrix and kappa statistics.

For the growing season, accuracy assessment points were selected in a different manner because high quality reference imagery for Jackson County was unavailable during the growing season of 2011. Ten random points were manually selected from each class of the LULC map using UTM coordinates. The selected point localities were visited on foot using a Garmin GPS in June, 2014 to determine whether pixels were correctly classified on the LULC map. An excel spreadsheet with location number, LULC class, coordinates, and true LULC class was used to generate an accuracy report within ERDAS software.

*Land Use/Cover Change Detection and Analysis*

Area, change in area, and percent change of each individual land use land cover classification class were calculated in order to detect temporal differences between the two LULC classified images. Each LULC classified image was uploaded into ERDAS software (version 2014) in its own viewer and its associated raster attribute table was displayed. An area column was added to the attribute table and statistics tool was utilized to provide the final area of each class. An area summary table was created to record the summaries of area and percentages
of area for each LULC class for the different years (2011, 2013). Change in area and percent change for each LULC class was calculated by subtracting the area of the most recent year (2013) from the area of the older year (2011) to obtain final change in area. The number and percent of crane occurrences for each LULC class was calculated by spatially joining location point shapefiles to classifications.

Finally, chi square analyses were performed on crane occurrences for each LULC classification to test for randomness in distributions. Expected values were derived from the percent of area for each LULC class and observed values were derived from the percent of crane occurrences for each LULC class.

**Habitat Suitability**

In this study, Arc Map GIS 10.3 was utilized to analyze and assess Mississippi Sandhill Crane habitat suitability on the Mississippi Sandhill Crane National Wildlife Refuge. A multi-criteria analysis using a weighted overlay was used to determine potential habitats for the Mississippi Sandhill Crane. Because there were large changes in area of land cover types between growing and non-growing seasons, separate habitat suitability models were created for each season. In order to perform a habitat suitability analysis using a weighted overlay approach, three criteria that directly affect crane foraging and roosting were selected for the characterization of potential crane habitats on the refuge; land cover, slope, and distance from roads. Each criterion was represented as a spatial thematic data layer.

Land cover reflects foraging habitat and safety of shelter, slope reflects the ability of soil to retain water, and the distance from roads reflects disturbances to cranes. The land cover layers were derived from the remote sensing habitat classifications. The slope layer was created within GIS from a DEM file obtained from the U.S. Geological Survey database.
http://nationalmap.gov/elevation.html. The distance from roads layer was created from a Jackson County road shapefile. This layer includes refuge roads, surrounding highways, and Interstate 10.

A numerical weighting factor or percent influence was assigned to each criteria layer according to its relative importance compared to all other layers. Based on discussion with refuge staff and previous studies of crane requirements and habitat use, land cover appears to be the single most important determinant of habitat suitability (U.S. Fish and Wildlife Service 2007b), and I assigned land cover the highest weight at 0.60. Slope affects both the ability of sandhill cranes to forage and the availability of water features required for successful breeding and nighttime roosting (U.S. Fish and Wildlife Service 2007b). I assigned slope a weight of 0.30. Finally, roads expose cranes to human disturbance, risks from collisions, and provide travel routes for common mesopredators (Butler 2009). I assigned distance to roads a weight of 0.10. Criteria factors and weights remained the same for each habitat suitability analysis. The only difference was that the land cover layer used for each habitat suitability model was derived from that season’s habitat classification.

Each layer was reclassified to represent data within five classes. Each class was then ranked on a scale of 1-5, 5 being the best ranking while 1 was lowest. The rankings for the land cover layer include: grassland (5), marsh / wet meadow (4), water (3), cypress drains (3) developed vegetation (2), forested (1), buildings (1), roads (1). The slope layer was ranked on a gradient scale with the lowest slope receiving a 5 and the highest slope receiving a 1. Euclidian distance was calculated for the distance from roads layer in order to create a spatial distance raster that could be reclassified. Ranking for this layer include: 0 – 50 m (1), 50 – 100 m (2), 100 – 150 m (3), 150 – 200 m (4), 200 m and beyond (5).
After all criteria layers were weighted and ranked, they were overlaid to create resultant suitability layers for growing and non-growing seasons. The Mississippi Sandhill Crane habitat suitability layers were graded on a scale of 1-5: very high (5), high (4), medium (3), low (2), and very low (1). The areas or locations within the suitability layers with the highest grade value (5) were classified as highly suitable while the layers with the lowest grade value (1) was classified as least suitable. The area and total percentage of area for each suitability grade was calculated for each model within the GIS software.

Five hundred and sixty four crane locational points obtained from telemetry were used to validate model accuracy. Three hundred and forty six points were used for the growing season model while two hundred and nineteen points were used for the non-growing season model. A spatial join between the location points and habitat suitability layer was performed to obtain the number of crane location points in each grade of the overall suitability model. Percent occurrences were then calculated in each suitability grade to validate overall accuracy of the Mississippi Sandhill Crane habitat suitability model. Chi square analyses were performed on crane occurrences to test for randomness in distributions for each habitat suitability model. Expected values were derived from the percentage of area for each suitability grade whereas observed values were derived from the percentage of crane occurrences for each suitability grade.
RESULTS

Telemetry

In all, 1119 location fixes from twenty-two Mississippi Sandhill Cranes were compiled into a large excel dataset. A total of 469 location fixes were collected for the five study cranes. I collected 55 location fixes for crane 825 and MSCNWR personnel supplied 104 additional fixes. Sixty-three fixes were collected and 42 were provided for crane 953. Forty-six fixes were collected and 18 were provided for crane 1111. Twelve fixes were collected and none were provided for crane 1115. Very few location fixes were collected for crane 1115 because it was a replacement for crane 1111 that died late in the study. Twenty-one fixes were collected and 108 were provided for crane W-25. For the additional seventeen cranes (id numbers: 163, 434, 723, 731, 833, 834, 982, 984, 985, 991, 994, 1001, 1002, 1103, 1112, W09, W37), 650 location fixes were provided. From this dataset, two separate shapefiles were created to include refuge only crane location points from growing and non-growing seasons. The growing season dataset contained 345 location points from the months April through October during the years 2011 and 2012. The non-growing season dataset contained 219 location points from the months November through March during the years 2012 and 2013.

Land Use/Cover Classification and Accuracy

The eight distinct land cover classes delineated from the Mississippi Sandhill Crane National Wildlife refuge are illustrated in Figures 2-3. Each land cover class included its own distinguishing vegetation or feature type shown in Table 1. The developed vegetation land cover class represents modified, mowed/maintained areas including orchard and pastures. This class also includes agricultural features such as farms and plantations.
There were spectral similarities between developed and agricultural vegetation therefore these classes were combined. The building footprint land cover class represents anthropogenic structures including: buildings, pools, driveways, trailers, slabs, and other non-roadway paved surfaces.

**Table 1. Description of land use/land covers classes used for growing and non-growing season habitat classifications.**

<table>
<thead>
<tr>
<th>LULC Types</th>
<th>General Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>Natural streams, tributaries, rivers, natural and human-made ponds and lakes.</td>
</tr>
<tr>
<td>Marsh/Wet Meadow</td>
<td>Grass/shrub land appearing to be wet and muddy with standing water and may surround ponds.</td>
</tr>
<tr>
<td>Paved Road/Urban</td>
<td>Anthropogenic features including: highways, interstates, and local/private paved roadways/thoroughfares.</td>
</tr>
<tr>
<td>Grassland</td>
<td>Predominately grasses, brush, and a few small widely spaced trees including pine savannas.</td>
</tr>
<tr>
<td>Developed Vegetation</td>
<td>Modified, mowed, or maintained areas including pastures, food plots, farms, and plantations.</td>
</tr>
<tr>
<td>Forested</td>
<td>Warm temperate forests (oak, pine, mixed).</td>
</tr>
<tr>
<td>Cypress Drain</td>
<td>Any area that is primarily composed of cypress, which may be flooded or not.</td>
</tr>
<tr>
<td>Building footprint</td>
<td>Anthropogenic structures including: buildings, driveways, trailers, slabs, and other paved surfaces.</td>
</tr>
</tbody>
</table>
Figure 2. Land use land cover classification map of the Mississippi Sandhill Crane National Wildlife Refuge for the growing season (June 13, 2011).
Figure 3. Land use land cover classification map of the Mississippi Sandhill Crane National Wildlife Refuge for the non-growing season (December 11, 2013)
The contingency table showing the classification accuracy obtained in mapping habitat and distribution features from the 2011 Landsat 5 image is shown in Table 2. Overall, map accuracy was 85.2% with a Kappa statistic of 0.829. A total of 88 pixel locations were checked in order to determine the accuracy in each class. Producer’s accuracies of individual classes ranged from 68.8% (developed vegetation and forested) to 100% (grasslands, building footprint, and paved road). User’s accuracies of individual classes ranged from 50% (paved road) to 91.6% (grasslands, water, developed vegetation, marsh, forested, and cypress drain).

Two classes had the lowest producer’s accuracy levels: 68.8% (forested) and 68.8% (developed vegetation). Building footprint and paved road classes had the lowest user’s accuracy levels at 75% and 50%, respectively. These locations represent pixels that were classified as paved road rather than the correct developed vegetation and forested classes. A review of some of these errors suggests that they originated from misclassification of mixed pixels located on the edge of the paved road class boundary. On the other hand, grasslands, water, marsh/wet meadow, and cypress drain classes achieved producer’s and user’s accuracies above 90%. Confusion and misclassification in these classes were low.

**Table 2. Contingency table illustrating the accuracy of correctly and incorrectly classified pixels from 2011 LULC classification.**

<table>
<thead>
<tr>
<th>Classified Data</th>
<th>Grass Lands</th>
<th>Water</th>
<th>Developed Vegetation</th>
<th>Marsh</th>
<th>Forested</th>
<th>Building Footprint</th>
<th>Paved Road</th>
<th>Cypress Drain</th>
<th>Total</th>
<th>PA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasslands</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>91.6</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>91.6</td>
</tr>
<tr>
<td>Developed Vegetation</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>91.6</td>
</tr>
<tr>
<td>Marsh/Wet Meadow</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>91.6</td>
</tr>
<tr>
<td>Forested</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>12</td>
<td>91.6</td>
</tr>
<tr>
<td>Building Footprint</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>75</td>
</tr>
<tr>
<td>Paved Road</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>0</td>
<td>12</td>
<td>50</td>
</tr>
<tr>
<td>Cypress Drain</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>11</td>
<td>12</td>
<td>91.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>11</strong></td>
<td><strong>12</strong></td>
<td><strong>16</strong></td>
<td><strong>12</strong></td>
<td><strong>16</strong></td>
<td><strong>3</strong></td>
<td><strong>6</strong></td>
<td><strong>11</strong></td>
<td><strong>88</strong></td>
<td></td>
</tr>
<tr>
<td><strong>PA (%)</strong></td>
<td><strong>100</strong></td>
<td><strong>91.6</strong></td>
<td><strong>68.8</strong></td>
<td><strong>91.6</strong></td>
<td><strong>68.8</strong></td>
<td><strong>100</strong></td>
<td><strong>100</strong></td>
<td><strong>91.6</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Overall accuracy = 85.23; Kappa statistic = 0.829.
In the 2013 Landsat 8 image habitat classification (Table 3), an overall accuracy of 86.7% was obtained with a Kappa statistic of 0.845. A total of 113 pixel locations were checked in this accuracy assessment. Producer’s accuracies of classes ranged from 50% (grasslands) to 100% (developed vegetation, marsh/wet meadow, and building footprint). User’s accuracies of individual classes ranged from 80% (building footprint) to 90.9% (water, and paved road).

The two classes with the lowest producer’s accuracy levels were grasslands (50%), and cypress drain (70%). The grasslands class was most often confused with the developed vegetation class, probably due to the similar spectral characteristics between habitats. For example, both habitats are characterized by open areas with short vegetation and lack of trees.

The confusion between the cypress drain and forested classes can be attributed to the same source. Cypress drain habitats contain shallow waters which dry up during the winter months. During this time period cypress drain habitats have similar spectral characteristics to hardwood forests habitats, consequently causing confusion and misclassification. User’s accuracies for all individual classes were at least 80% and greater indicating low commission error.

**Table 3.** Contingency table illustrating the accuracy of correctly and incorrectly classified pixels from 2013 LULC classification.

*Reference Data (Aerial Photography Samples)*

<table>
<thead>
<tr>
<th>Classified Data</th>
<th>Grass Lands</th>
<th>Water</th>
<th>Developed Vegetation</th>
<th>Marsh</th>
<th>Forested</th>
<th>Building Footprint</th>
<th>Paved Road</th>
<th>Cypress Drain</th>
<th>Total</th>
<th>UA(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grasslands</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12</td>
<td>83.3</td>
</tr>
<tr>
<td>Water</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>11</td>
<td>90.9</td>
</tr>
<tr>
<td>Developed Vegetation</td>
<td>0</td>
<td>0</td>
<td>17</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>19</td>
<td>89.5</td>
</tr>
<tr>
<td>Marsh/Wet Meadow</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>11</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
<td>84.6</td>
</tr>
<tr>
<td>Forested</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>23</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>26</td>
<td>88.5</td>
</tr>
<tr>
<td>Building Footprint</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>1</td>
<td>0</td>
<td>10</td>
<td>80.0</td>
</tr>
<tr>
<td>Paved Road</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>10</td>
<td>0</td>
<td>11</td>
<td>90.9</td>
</tr>
<tr>
<td>Cypress Drain</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>9</td>
<td>11</td>
<td>81.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>15</td>
<td>11</td>
<td>17</td>
<td>11</td>
<td>28</td>
<td>8</td>
<td>11</td>
<td>12</td>
<td>113</td>
<td></td>
</tr>
</tbody>
</table>

PA (%) | 50 | 91.9 | 100 | 100 | 82.1 | 100 | 91.9 | 70 |

Overall accuracy = 86.72; Kappa statistic = 0.845.
**Area Status and Change in Land Use/Land Cover**

For the reference year 2011, grasslands were the dominant LULC class, making up 42.7% of the study landscape, followed by forests (39.2%), cypress drains (8.3%), developed vegetation (5.2%), marsh/wet meadow (2.4%), and water (1.2%), (Table 4). Buildings and paved roads shared a small portion of the entire landscape (0.7%) and (0.3%). Chi square results were significant in the growing season, which indicates crane distributions were not random in the refuge, (chi square=157, df=7, P < 0.001). Cranes occurred more often in some LULC classes than others. For example, cranes occurred more often in grasslands (56%) and less often in forests (25%) than expected. Cranes also occurred more often in developed vegetation (17%) than expected.

In 2013, the dominant LULC classes changed significantly, with forests (52.5%), dominating the landscape instead of grasslands (33.5%). In 2013, cypress drains decreased to 5.3% of the landscape, developed vegetation decreased to 3%, and marsh/wet meadow increased to 3.6%. Water (1.4%), buildings (0.5%), and paved roads (0.2%) occupied similar portions of the landscape in 2013 as they did in 2011. Chi square results were also significant in the non-growing season, which also indicates non-randomness in crane distributions, (chi square=175, df=7, P < 0.001). Similar to 2011, cranes occurred more often in grasslands (49%) and less often in forests (25%) than expected. Cranes also occurred more often in developed vegetation (15%) than expected.
Table 4. Area and number of crane occurrences for each LULC class within the Mississippi Sandhill Crane National Wildlife Refuge for two different reference years. 2011 represents growing season conditions, while 2013 represents non-growing season conditions.

<table>
<thead>
<tr>
<th>LULC Types</th>
<th>2011</th>
<th></th>
<th>2013</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Area</td>
<td></td>
<td>%</td>
<td># of Crane Points</td>
</tr>
<tr>
<td>Grasslands</td>
<td>3,428</td>
<td>42.7</td>
<td>195</td>
<td>56.5</td>
</tr>
<tr>
<td>Water</td>
<td>96</td>
<td>1.2</td>
<td>1</td>
<td>0.3</td>
</tr>
<tr>
<td>Developed Vegetation</td>
<td>420</td>
<td>5.2</td>
<td>59</td>
<td>17.1</td>
</tr>
<tr>
<td>Marsh/Wet Meadow</td>
<td>193</td>
<td>2.4</td>
<td>4</td>
<td>1.2</td>
</tr>
<tr>
<td>Forested</td>
<td>3,149</td>
<td>39.2</td>
<td>87</td>
<td>25.1</td>
</tr>
<tr>
<td>Building Footprint</td>
<td>53</td>
<td>0.7</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Paved Road</td>
<td>27</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cypress Drain</td>
<td>663</td>
<td>8.3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The refuge experienced 1,191 ha of LULC change 2011 to 2013, of which 1,172 ha was due to vegetative loss (Table 5). Grasslands (-21.6%), developed vegetation (-45.5%), cypress drain (-36.2%), buildings (-22.6%), and roads (-25.9%) all experienced negative change in land area between the two images, while forests (+33.8%), marsh/wet meadow (+54.4%), and water (+22.9%) experienced positive change in land area over the course of the study period. Although all classes experienced a large percentage change in area, changes in absolute area were relatively small for buildings, roads, marsh/wet meadow, and open water. In contrast, grasslands, cypress drains, developed vegetation all saw large decreases in absolute area, while forest saw a large increase in absolute area (Table 5).
Table 5. Change in LULC area over years (2011-2013).

<table>
<thead>
<tr>
<th>LULC Types</th>
<th>2011-2013</th>
<th>Area (ha)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grassland</td>
<td>-741</td>
<td>-21.6</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>22</td>
<td>22.9</td>
<td></td>
</tr>
<tr>
<td>Developed Vegetation</td>
<td>-191</td>
<td>-45.5</td>
<td></td>
</tr>
<tr>
<td>Marsh/Wet Meadow</td>
<td>105</td>
<td>54.4</td>
<td></td>
</tr>
<tr>
<td>Forested</td>
<td>1,064</td>
<td>33.8</td>
<td></td>
</tr>
<tr>
<td>Building Footprint</td>
<td>-12</td>
<td>-22.6</td>
<td></td>
</tr>
<tr>
<td>Paved Road</td>
<td>-7</td>
<td>-25.9</td>
<td></td>
</tr>
<tr>
<td>Cypress Drain</td>
<td>-240</td>
<td>-36.2</td>
<td></td>
</tr>
</tbody>
</table>

Analysis of Habitat Suitability for Mississippi Sandhill Cranes

Habitat suitability was calculated for Mississippi Sandhill Cranes according to the grades very high, high, medium, low, and very low for growing and non-growing seasons (Figures 4-5). The general description of criteria for each suitability grade is shown in (Table 6). For example, cranes utilize open habitat for foraging, shallow water for roosting, and are wary of disturbances. Therefore, the highest suitability grade (very high), represents grasslands located in areas with the lowest slope, and furthest from roads.

Table 6. Typical features of grade criteria used for each habitat suitability model.

<table>
<thead>
<tr>
<th>Suitability Grades</th>
<th>Typical Features of Grade Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>Includes forests, buildings, and roads within 0 to 50m from roadways, with a slope ranging from 3.83 to 10.85.</td>
</tr>
<tr>
<td>Low</td>
<td>Includes developed/agricultural land within 50 to 100m from roadways, with a slope ranging from 2.17 to 3.83.</td>
</tr>
<tr>
<td>Medium</td>
<td>Includes cypress drains within 100 to 150m from roadways, with a slope ranging from 1.10 to 2.17.</td>
</tr>
<tr>
<td>High</td>
<td>Includes marsh/wet meadow, and water bodies within 150 to 200m from roadways, with a slope ranging from 0.38 to 1.10.</td>
</tr>
<tr>
<td>Very High</td>
<td>Includes grasslands farther than 200m from roadways, with a slope ranging from 0.38 to 0.</td>
</tr>
</tbody>
</table>
The same criteria factors: (land cover, slope, and distance from roads) were used to characterize potential crane habitats on the refuge for both models. The only difference between models was the seasonal difference for the land cover criteria factor; therefore each suitability grade represents the same habitat type for both models. For example, the very high suitability grades of both models were found only in grasslands. The high suitability grade was distributed through marsh/wet meadows and large areas of grasslands. These two grades were always found adjacent to one another. The medium suitability grade was primarily distributed through cypress drains and smaller patches of forests bordering cypress drains. The low suitability grade was distributed through developed vegetation and large patches of forests that bordered grasslands and cypress drains. The very low suitability grade was distributed through large patches of forests, buildings, and paved roads amongst the refuge.

The area and total percent of area of each suitability grade varied considerably for the habitat suitability models in the two seasons (Table 7-8). For the growing season habitat suitability model (Table 7), the very high suitability habitat covered 953 ha, accounting for 12% of the total study area. Highly suitable habitat accounted for the largest area of the refuge, encompassing an area of 2,981 ha, or 37% of the total area. The medium suitability habitat covered 1,355 ha, accounting for 17% of total area. When combined, these three grades accounted for 66% of refuge area. Low suitability habitat covered 2,172 ha, or 27% of the study area. Very low suitability habitat accounted for the smallest area of the refuge, encompassing an area of 585 ha, or 7% of the total study area.
For the non-growing season habitat suitability model (Table 8), the very high suitability habitat covered an area of 1,105 ha, accounting for 14% of the total study area. Highly suitable habitat covered an area of 1,909 ha, accounting for 24% of the total area. The medium suitability habitat accounted for the smallest area of the refuge, encompassing an area of 484 ha, and accounting for 7% of total area. When combined, these three grades accounted for 45% of refuge area. Low suitability habitat accounted for the largest area of the refuge, encompassing an area of 2,696 ha, or 33% of the study area. Very low suitability habitat covered 1,736 ha, accounting for 22% of the total study area.

All grades were dispersed throughout the refuge in unequal proportions for both models. In the growing season model, the high and low suitability grades were more prevalent and dispersed unevenly across the landscape. The high suitability grade was more prevalent in the Gautier unit while the low suitability grade was more prevalent in the Ocean Springs unit. The very high, medium, and very low suitability grades were dispersed more equally throughout the entire refuge. In the non-growing season model, low and high suitability grades were more prevalent. Although these grades were common throughout the entire refuge, the low suitability grade was more prevalent in the Ocean Springs unit. The very high and high suitability grades were more prevalent in the Gautier unit while the medium suitability grade was dispersed throughout the entire refuge.
Figure 4. *Mississippi Sandhill Crane habitat suitability model for the growing season (June 13, 2011).*
Figure 5. Mississippi Sandhill Crane habitat suitability model for the non-growing season (December 11, 2013).

Three hundred and forty five crane location points within the Mississippi Sandhill Crane National Wildlife Refuge were used to validate the growing season habitat suitability model (Table 7), while two hundred and nineteen points were used for the non-growing season model (Table 8). It was expected that cranes would disproportionately utilize higher quality habitat, which offered roosting sites, protection from predators, and high food availability.
This use pattern was displayed in the non-growing season model (Table 8). In the growing season model, crane utilization generally matched the availability of habitat types on the refuge (Table 7).

For the growing season habitat suitability model, very high suitability grade contained 12% of crane location points which were predominately distributed within grasslands. The highest percentage of crane location points (43%), were found within the high suitability grade. Within this grade, points were also predominately distributed within grasslands. There were also a small number of points distributed within marsh/wet meadows. The Medium suitability grade contained 14% of crane location points, which were predominately distributed within cypress drains. There were also a small number of points distributed within developed vegetation. Low suitability grade contained 21% of crane location points which were distributed within forests that bordered grasslands and developed vegetation. Very low suitability grade contained the lowest percentage of crane location points (10%), which were distributed within forests that were in close proximity to paved roads and interstates (Table 7). Overall, the frequency with which cranes used habitat suitability classes during the growing season matched their representation on the landscape (Table 7). Chi square results indicated crane distributions were not random, but expectations for disproportionate use of higher quality habitats were not met, (chi square=13.8, df=4, P < 0.01). Cranes occurred more often in low suitability grade habitat (21%) than expected and less often in very high suitability grade habitat (12%) than expected.

For the non-growing season habitat suitability model, very high suitability grade contained 21% of crane location points. The highest percentage of crane location points (34%), were found within the high suitability grade. The medium suitability grade contained 9% of crane location points and the low suitability grade contained 29%. Very low suitability grade
contained the lowest percent of crane location points (7%), (Table 8). In contrast to the pattern in the growing season, cranes were located more frequently than expected in the very high and high habitat suitability grades, and less frequently than expected in the very low suitability grade (Table 8). Chi square results indicated that crane distributions were not random and in this case expectations for disproportionate use were met, (chi square=41.6, df=4, P < 0.001). Occupancy of very high suitability grade habitat increased from 12% in the growing season to 21% in the non-growing season.

Table 7. Area and number of crane occurrences within each grade of the growing season habitat suitability model.

<table>
<thead>
<tr>
<th>Suitability Grade</th>
<th>Area (ha)</th>
<th>%</th>
<th># of Crane Points</th>
<th>% of Crane Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>585</td>
<td>7</td>
<td>34</td>
<td>10</td>
</tr>
<tr>
<td>Low</td>
<td>2172</td>
<td>27</td>
<td>74</td>
<td>21</td>
</tr>
<tr>
<td>Medium</td>
<td>1355</td>
<td>17</td>
<td>48</td>
<td>14</td>
</tr>
<tr>
<td>High</td>
<td>2981</td>
<td>37</td>
<td>150</td>
<td>43</td>
</tr>
<tr>
<td>Very High</td>
<td>935</td>
<td>12</td>
<td>40</td>
<td>12</td>
</tr>
</tbody>
</table>

Table 8. Area and number of crane occurrences within each grade of the non-growing season habitat suitability model.

<table>
<thead>
<tr>
<th>Suitability Grade</th>
<th>Area (ha)</th>
<th>%</th>
<th># of Crane Points</th>
<th>% of Crane Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Low</td>
<td>1736</td>
<td>22</td>
<td>15</td>
<td>7</td>
</tr>
<tr>
<td>Low</td>
<td>2696</td>
<td>33</td>
<td>64</td>
<td>29</td>
</tr>
<tr>
<td>Medium</td>
<td>484</td>
<td>7</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>High</td>
<td>1909</td>
<td>24</td>
<td>74</td>
<td>34</td>
</tr>
<tr>
<td>Very High</td>
<td>1105</td>
<td>14</td>
<td>46</td>
<td>21</td>
</tr>
</tbody>
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DISCUSSION

**Land Use/Land Cover Map Products**

The 2011 and 2013 map products are reasonable and reliable based on individual map overall accuracy, class by class accuracy statistics, and Kappa results. Kappa statistics were > 0.80 for both map products indicating a high level of agreement between the classification maps and reference data. Overall, these results support high confidence that habitats were correctly classified and accurately represent actual habitats within the refuge.

**Land Use/Land Cover Change Over Time**

Grasslands, developed vegetation, cypress drains, buildings, and roads decreased in land area between 2011 and 2013, while forest, marsh, and open water increased in land area. Buildings, roads, marsh and open water experienced large percentage changes, but these represent only minor changes in area of 100 ha or less. The loss of building and road area is likely due to misclassification of spectral signatures, and because they occupy such a small area even a small decrease in classified area would result in a large percentage of change. Marsh/wet meadow and open water occupied low-lying areas that tend to accumulate water during the non-growing season, likely accounting for the increase in area.

Grassland and cypress drain LULC classes experienced the most significant reduction of area between the 2011 and 2013 images, and the loss of area in these classes account for nearly the entire increase in forested area. Seven hundred forty one ha of grasslands and 240 ha of cypress drains changed to forests during the study period. The increase in forest area and decrease in grassland area is likely due to seasonal changes in vegetation characteristics and succession to forest on grasslands. In the Gulf South, grass species die back during the winter months, changing the spectral characteristics of this habitat. This change in spectral
characteristics likely contributed to the loss in area for the grassland LULC class. The grassland habitats on the refuge are also maintained by prescribed burning, which prevents the encroachment of trees. Due to budget cuts in 2012 and 2013, federal funding for prescribed burning was reduced, allowing fast-growing shrubs and pines to quickly spread. Once woody vegetation emerges above the grass layer, the spectral signature of the habitat changes to that of forest, even though succession to forest is only in the early stages. The change of cypress drains to forests may be due primarily to temporal changes in spectral signature among seasons. Cypress drains are typically inundated with shallow waters, but during winter months these shallow waters recede, exposing bare soil. When cypress drain soils are exposed they become spectrally similar to forests, increasing the area classified as forest.

Developed vegetation also showed a large decrease in area between growing and non-growing season. In this study, developed vegetation included mowed fields and plantings of supplemental food crops, and these activities take place primarily during the growing season. During the non-growing season vegetation in these areas dies back and acquires spectral signatures that resemble grassland habitat. This was particularly noticeable in patches of developed vegetation in the eastern half of the Ocean Springs unit (Figures 2 and 3).

**Crane Use of Land Cover Classes**

I expected cranes to be found predominantly in high-quality habitat types, especially grasslands, which are preferred for foraging, and water features, which provide roosting and nesting habitat. The expectation was met for grassland habitat, which had more crane location points than expected from its representation in the environment. However, cranes were found in water features much less than expected from their representation on the refuge. Open water, marsh/wet meadow, and cypress drains combined accounted for 11.9% of total area in the
growing season of 2011 and 10.3% of total area in the non-growing season of 2013, but only 1.5% of crane locations in 2011 and 8.6% of crane locations in 2013 were found in these areas. In addition, 25% of crane location points were found in forest in both growing and non-growing season. Although this is less than the percent occurrence of forests on the refuge, it is surprising that cranes were found in forested areas even to this extent given their preference for open grassland.

The under-representation of cranes in water features and apparent occurrence of cranes in forest may be due in part to the close association of forest and wetlands. Low-lying wetland habitats such as cypress drains support significant tree growth, and the classification of these areas can be complicated by the physical proximity of water features and forest. In addition to natural bayous and ponds, the refuge has built numerous shallow ponds to provide nesting and roosting sites, and some of these have become overgrown with woody vegetation (U.S. Fish and Wildlife Service 2007b). Although not true forest, the spectral reflectance of broad-leaved shrubs is similar to that of deciduous trees, and these pixels are most likely to be classified as forest. It is likely that some instances of cranes roosting in water may have appeared to be located in forest due to the complex matrix of wetland and forest habitats.

The difficulty of accurately assigning crane locations to habitats is compounded due to the approximate nature of position fixes determined through telemetric triangulation. The Mississippi Sandhill Crane National Wildlife Refuge is a small-scale landscape with a complex matrix of small habitat patches. Even small errors in triangulation may shift apparent locations from one habitat to another. The GPS unit used in this study was accurate to 9 m, and this may have caused substantial uncertainty in crane locations triangulated from sites located with GPS.
In addition, the Landsat images used in this study have a 30 m resolution, which affects the accuracy of assignment for pixels located at habitat edge. Given these potential sources of error, it is likely that some fixes that appeared to be located in forest were actually in adjacent grasslands or water features.

Cranes were also found disproportionately in developed vegetation. The occurrence of cranes in developed vegetation is likely due to this habitat type including food plots, in which the refuge provides supplemental food. Chufa (*Cyperus esculentus*) is planted in these areas for its roots, which are rich in oil and highly nutritious (Arafat et al., 2009; Adejuyitan 2011). The easy availability of a high-quality food source is likely responsible for the occurrence of cranes in these areas, and may attract them away from adjacent savanna areas.

**Habitat Suitability Model Products**

I attempted to rank land cover classes according to their ability to support crane populations, but the linear ranking of land cover classes used in deriving habitat suitability models did not fully capture crane requirements for resources found in disjunctive locations. The clearest example is the contrast between grassland, which provides optimal foraging habitat and which were ranked as highly or very highly suitable, and wetland features such as cypress drains, which provide roosting but not foraging sites and were ranked as less suitable in part due to the slopes associated with them. The habitat suitability model failed to capture the extent to which cranes require both upland savannas and wetlands for successful breeding.
The large number of crane locations outside of high- and very high-suitability habitat is consistent with the idea that no single type of habitat meets all the requirements of the crane population. The requirement for multiple habitats is likely to constrain the growth of the crane population and its expansion off the refuge into surrounding areas.

**Change in Habitat Suitability Over Time**

Two of the three criteria used to derive habitat suitability indices, slope and distance to roads, were constant over time, so change in habitat suitability between growing and non-growing seasons was driven by change in habitat characteristics. The shift in spectral signatures from those indicating grassland and cypress drains to those typical of forest was the strongest contributor to the increase in low and very low suitability habitat grades and the decrease in high suitability habitat between the two images. While the seasonal shift from cypress drain to forest habitat is more apparent than real, the environmental changes associated with this shift are biologically important to cranes. Drying of cypress drains deprives cranes of safe roosting sites during winter months, and they might be expected to be more concentrated in remaining water features during the non-growing season. This is consistent with the observed increase in crane locations associated with water features from 1.5% in the growing season to 8.6% in the non-growing season.

The shift from grassland to forest spectral signatures reflects both seasonal dieback of herbaceous vegetation and the emergence of woody vegetation over the 30 months between growing season and non-growing season images. Seasonal dieback and dormancy of grassland vegetation is associated with lower availability of animal foods such as insects and small vertebrates, and cranes become more dependent on plant foods during winter months (Iverson et
al 1982). Reduced burning on the refuge between 2011 and 2013 allowed woody species to begin growing in grasslands, and even early successional change to shrubs has major consequences for cranes. Emergent woody vegetation is likely to inhibit crane movement, lower foraging efficiency on mobile prey, and offer more cover to potential predators. Succession in longleaf pine savannas from graminoid- to shrub-dominated habitat also results in major shifts in insect community composition, potentially reducing the availability of important insect prey such as grass-associated Orthoptera. The large shifts in apparent habitat suitability over time are thus both consistent with biological processes in the landscape and significant for crane habitat use.

**Crane Use of Habitat Suitability Classes**

During the growing season, cranes were distributed among habitat suitability classes approximately in proportion to their occurrence on the landscape. This was surprising, given that habitat type was weighted most heavily in habitat suitability, and cranes were disproportionately found in grasslands, the highest quality habitat type. However, grasslands of higher slope and close proximity to roads were assigned to lower habitat suitability classes, and these factors appear to have been more heavily weighted in the model than they were by cranes. Although the impact of slope on suitability of grasslands is difficult to evaluate, cranes appeared to be relatively indifferent to dirt roads within the refuge. Cranes were also often located close to paved highways such as Old Spanish Trail, which bisects the Fountainbleau unit, on sprayfields near Seaman Road bordering the Ocean Springs unit on the west, and near the Interstate Highway 10 corridor and the Gautier-Van Cleave road south of Interstate 10 on the Gautier Unit.
Many cypress drains were bordered by areas of relatively high slope, and generally fell into lower habitat suitability classes. However, cranes were found in close proximity to cypress drains north of Perigal Road and near East Glendale Road on the Ocean Springs unit, and in scattered locations on the rest of the refuge. It appears that the advantages of safe roosting may have outweighed the impact of slope on suitability. Developed vegetation was often close to roads and was classified as generally low suitability for cranes. However, this class included mowed fields and agricultural plantings of chufa, which were more heavily used than expected. The disproportionate use of this land use class likely contributed greatly to the unexpected distribution of cranes in less suitable habitat during the growing season.

In the non-growing season crane distributions conformed more closely to expectations; cranes were found disproportionately in areas of high- and very high-suitability habitat, and less than expected in areas of very low suitability habitat. High-suitability habitat such as grasslands may offer significantly greater food resources during the winter months than lower-suitability habitat, and the relative value of high-quality habitat may be greater during the non-growing season than the growing season. This interpretation is consistent with the clustering of crane locations in grassland areas of high to very high suitability in the eastern Ocean Springs unit, the central Gautier unit near Valentine Road, and the southeast corner of the Gautier unit, south of Interstate Highway 10 and east of the Gautier-Van Cleve Road. The impact of distance to roads again appeared to be minimal; both concentrations of cranes on the Gautier unit were relatively close to major paved roads.
Despite the increased concentration of cranes in high- and very high-suitability habitat during the non-growing season, almost a third of crane locations were in areas classified as low-suitability. While the resolution of Landsat images and triangulation error may have played a role in generating these locations, there also appears to have been persistent use of food plots and mowed fields even after vegetation dieback had occurred. This was particularly evident in the vicinity of the sprayfields near Seaman Road on the Ocean Springs unit and the southeastern corner of the Gautier unit. In areas of chufa cultivation, availability of tubers may have encouraged use of developed vegetation and potentially diverted cranes away from grasslands during the non-growing season.

**Conservation Implications**

Satellite imagery clearly captured the dynamic nature of the landscape on the Mississippi Sandhill Crane National Wildlife Refuge, revealing large shifts in habitat type and suitability among seasons as well as rapid successional change in the absence of extensive burning. Crane use patterns generally followed these changes, and management for grassland habitat including short fire return intervals appears to be essential to maintaining the refuge as high quality habitat for cranes. Even the brief period of reduced burning between June 2011 and December 2013 was enough to produce a noticeable reduction in pixels assigned to grassland and an increase in those assigned to forest as woody vegetation began to emerge through the graminoid canopy. These early successional changes are likely to have serious negative consequences for crane movement, foraging efficiency, energy balance, and vulnerability to predators, and an aggressive burning program appears to be necessary for the maintenance of high quality habitat for the crane population.
The observed distribution of crane locations in both growing and non-growing seasons suggests that habitat suitability strongly tracks land cover and appears to be much less affected by slope and distance to roads. The Gulf Coastal plain is a generally flat landscape with few areas of high slope, and those areas that do exist on the refuge appear to be relatively narrow belts bordering wetlands such as cypress drain that have significant value as roosting sites. Although cranes tend to avoid steep slopes the rarity of these areas on the refuge means that their impact on the crane population is likely to be relatively small.

The location of many cranes within 100 m of roads is of more concern, since this is a potentially significant source of mortality. Captive-bred cranes are generally trained to avoid people, but this may not be sufficient to generate avoidance of all human activities if people in a vehicle are not clearly visible. Cranes may become habituated to roads if no negative consequences are associated with approaching them, and this may explain why cranes were willing to approach dirt roads on the refuge, which receive little vehicular traffic. A lack of negative experiences with these roads could promote indifference to the risks of approaching larger, more dangerous paved highways. Alternatively, cranes may be quite sensitive to road disturbance, but may have a smaller critical distance than the distance classes used to generate the habitat suitability classes in this study. The relationship between roads and crane behavior merits further study.

Perhaps the most striking result of this study is frequency with which cranes were located in low-suitability habitat, i.e., food plots in developed vegetation, in both seasons. Supplemental feeding of wildlife has benefits in terms of nutritional status and enhanced reproduction (Boutin 1990) but can also promote disease transmission (Sorenson et al 2014) and habituation to humans (Conover 2002), and crane preference for these areas may have both benefits and costs.
The high rate of use of developed vegetation (3-5 times greater than expected from its frequency) relative to that of presumably very high quality grassland (1.3-1.5 times greater than expected from its frequency) suggests that grasslands do not always offer the greatest rewards for foraging effort. Some areas of grassland are more consistently occupied by cranes than others, especially the eastern section of the Ocean Springs unit and the southeast corner of the Gautier unit. While this may be simply a function of the specific cranes tracked in this study, it may also indicate significant heterogeneity in food availability in grassland habitat on the refuge. An assessment of food availability in grassland areas consistently frequented or avoided by cranes would clearly be of value.

The use of developed vegetation by cranes also suggests an indirect method for assessing the quality of adjacent habitats. The marginal value theorem predicts that animals should forage in a resource patch until the rate of energy gain falls below the average rate of energy gain for all patches in the environment (Charnov 1976). Food plots that offer a given rate of reward should be exploited until the energy gained from foraging in the plot falls below the level available in surrounding habitat, and this should provide a rough estimate of the expected rate of energy gain in grasslands. In practical terms, food plots could be established in target areas and cranes allowed to forage in them ad libitum. The food density remaining after cranes abandon the plot (giving up density; Morris et al 2009) would be approximately equal to the average food density available in the surrounding environment. This approach may not adequately capture the subtleties of diet balancing for nutrients such as protein and lipid, but does offer a possible method for determining the relative quality of habitat in terms of energy gain.
LITERATURE CITED


Linda Carol Salande obtained her Bachelor’s degree in biological sciences from the University of New Orleans in 2011. In 2012, she was accepted into the University of New Orleans graduate program with a scholarship where she pursued a Masters in biological science. During her time as a graduate student, she worked with Mississippi Sandhill Crane National Wildlife Refuge biologists to conserve the critically endangered Mississippi Sandhill Crane. Linda’s research interests include conservation of endangered species and biological impacts of invasive species.