Optimal Strategies for Grassland Restoration to Increase Spatial Carrying Capacity of Florida Sandhill Cranes in Pasco County, Florida

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Optimal Strategies for Grassland Restoration to Increase Spatial Carrying Capacity of Florida Sandhill Cranes in Pasco County, Florida

by

Ibrahim Kaya

A thesis submitted in partial fulfilment of the requirements for the degree of Master of Science with a concentration in Environmental Science and Policy
School of Geosciences College of Arts and Sciences University of South Florida

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# TABLE OF CONTENTS

List of Tables ........................................................................................................................................... ii  
List of Figures ........................................................................................................................................ iii  
Abstract ................................................................................................................................................ iv  

## Chapter One: Introduction  
- Literature Review ......................................................................................................................... 1  
  - Life History ....................................................................................................................................... 2  
  - Grassland Restoration ..................................................................................................................... 2  
  - Conservation Status of the Florida Sandhill Crane ........................................................................ 6  
- Objectives ........................................................................................................................................... 10  

## Chapter Two: Study Area .................................................................................................................... 11  

## Chapter Three: Material and Methods .............................................................................................. 14  
- Assessment of Current Florida Sandhill Crane Habitats in Pasco County ...................................... 15  
- Identification of Potential Restoration Sites .................................................................................... 18  
- Strategic Selection of Sites .............................................................................................................. 22  

## Chapter Four: Results  
- Assessment of Current Florida Sandhill Crane Habitats in Pasco County ...................................... 26  
- Identification of Potential Restoration Sites .................................................................................... 29  
- Strategic Selection of Sites .............................................................................................................. 32  

## Chapter Five: Discussion  
- Implications ......................................................................................................................................... 36  
- Limitations and Future Study ........................................................................................................... 39  

References ........................................................................................................................................... 41
LIST OF TABLES

Table 1: Software and data used in this study .................................................................14

Table 2: Formulation of the HSI based on six habitat suitability variables .......................17

Table 3: Habitat assessment of Florida sandhill crane habitat in Pasco County, Florida, using a Habitat Suitability Index (HSI) model comprised of six Suitability Variables (SVs): SV1 Potential nesting site, SV2 Immediate nesting area, SV3 Brooding area, SV4 Wetland composition, SV5 Upland composition, and SV6 Road proximity .................................................................28

Table 4: Total areas covered by nesting locations .............................................................32
LIST OF FIGURES

Figure 1: An adult Florida sandhill crane .................................................. 3
Figure 2: A wet prairie .............................................................................. 7
Figure 3: A chick fed by its parent on grasses .......................................... 8
Figure 4: Map showing the study area ...................................................... 12
Figure 5: An illustration of creating buffer zones around potential nesting locations .......... 21
Figure 6: An illustration of intersecting suitable land use/land cover types with the buffers ........................................................................................................... 22
Figure 7: Maps for each suitability variable: SV1 Potential nesting site, SV2 Immediate nesting area, SV3 Brooding area, SV4 Wetland composition, SV5 Upland composition, and SV6 Road proximity .......................................................... 27
Figure 8: Map of overall habitat suitability index (HSI) ................................ 28
Figure 9: Map showing the wetlands around which brooding habitat is limited based on three threshold values ................................................................. 30
Figure 10: Potential nesting locations based on three threshold values .................. 31
Figure 11: Optimal sets of nesting locations ................................................ 33
Figure 12: Map showing the locations of the restoration sites ....................... 34
ABSTRACT

The Florida sandhill crane (Antigone canadensis pratensis) is a non-migratory bird species occurring throughout the Florida peninsula and the Okefenokee Swamp in southeastern Georgia. Human land-altering activities have led to a substantial decline in the amount and condition of suitable habitat, including grasslands, for the species in Florida, thereby decreasing the population size significantly. Grasslands located in close proximity to nesting locations are one of the habitat types on which the population viability of the species depends, as they provide foraging and brooding habitat which is crucial for successful reproduction. The purpose of this study is to propose the most effective strategies for grassland restoration to increase the spatial carrying capacity of the Florida sandhill crane living in Pasco County, Florida. An existing GIS-based Habitat Suitability Index (HSI) model for Florida sandhill cranes was applied for habitat assessment by using a geographic information system (GIS). To identify how much spatial carrying capacity can be increased through grassland restoration, an existing Anti-Covering Location Problem (ACLP) model was solved, using a custom Python script to generate equations in linear programming format and IBM CPLEX to solve the equations. It was found that the amount of suitable habitat is significant, depending on the suitability threshold value. Respectively, 4, 22, and 54 areas favorable to grassland restoration were detected based on three scenarios in which suitability thresholds at 0.5, 0.7, and 1.0 were applied, respectively. If strategic number of those sites are restored to grasslands, the increases in the spatial carrying capacity would be 2, 10, and 24 breeding pairs, respectively.
A considerable number of suitable habitats for Florida sandhill cranes have been destroyed, including grasslands (Nesbitt and Hatchitt, 2008). The majority of Florida’s grasslands have been mainly lost through conversion to agricultural land and other human land uses (Stephenson, 2011; Noss, 2013). For example, only 19 percent of historical dry prairies which occurred extensively in pre-settlement Florida (Stephenson, 2011) remained, according to Shriver and Vickery (1999). This loss of Florida’s ecologically valuable grasslands (Brown, 1985) played an active role in the decline in Florida sandhill crane population size (Nesbitt and Hatchitt, 2008). As of today, the population size is believed to be between 4000 and 5000 (FWC, n.d.), whereas it was 7142 in 1974, based on the estimation made by Nesbitt and Hatchitt (2008). Recent quantification of nesting habitat suggests Florida sandhill cranes might number more than 8,000 if moderately suitable habitats are occupied across the state (Downs et al., 2020).

Grasslands are critical, because along with wetlands used for nesting, they provide primary habitat for Florida sandhill cranes (Abrahamson and Hartnett, 1990). Grasslands are one of the foraging habitats preferred by adult and subadult Florida sandhill cranes; moreover, they are important for the survival of chicks because territorial adult pairs with young use grasslands intensively to feed their chicks after hatching (Nesbitt and Williams, 1990; Layne, 1981; Armbruster, 1987).
This overall situation gives urgency to restore Florida’s grasslands affecting the Florida sandhill crane population. The purpose of this study is to provide the most effective strategies for grassland restoration to increase the spatial carrying capacity of Florida sandhill cranes in Florida. Pasco County is used as the case study, but the methods could be applied to other regions of the state. Specifying the sites where grasslands need to be restored for Florida sandhill cranes could help wildlife managers and restorationists propose restoration sites. This study aims to prioritize restoring grassland near wetlands that are otherwise suitable for nesting while maintaining a separation distance between optimal nesting habitats to accommodate territorial behavior. If the identified restoration sites are restored to grassland, the population size of Florida sandhill cranes could increase due to the cranes’ strong reliance upon grasslands in Florida.

This thesis is organized as follows. The literature review gives detailed information about life history of the species of interest, from physical description to nesting, express the need for grasslands restoration, and indicates the species’ current conservation status. Research objectives are demonstrated at the end of the chapter. Chapter 2 and Chapter 3 describe the study area and methodology, respectively. Chapter 4 describes the results. Lastly, Chapter 5 is comprised of a discussion of the implications of the study, limitations, and future research.

Literature Review

Life History

The Florida sandhill crane (Antigone canadensis pratensis) is one of the 6 subspecies of sandhill crane breeding in North America. It is a non-migratory bird inhabiting peninsular Florida and Okefenokee National Wildlife Refuge in both Charlton and Ware counties located in
southeastern Georgia all the year round (Walkinshaw, 1973). The Florida sandhill crane is a
large wading bird having an average weight of 3.36 kg and length of 102 cm, with long neck,
long legs, and a characteristic of dropping tail feathers forming a bustle, as can be seen in Figure
1 (Maehr and Kale, 2005; Stys, 1997). Females and males of this perennially monogamous
species are alike in appearance, with black legs, faded red skin on lore and red crown, gray
plumage overall, and whitish chin, cheek and upper throat; but males are slightly larger than
females and immature ones have rusty gray bodies and no red crowns (Stys, 1997; Baughman,
2004; Rappole, 2006).

![Figure 1. An adult Florida sandhill crane.](image)

There are a large number of studies with regard to the ecology of the species, such as
habitat preference, foraging sites, home range, clutch size, and nesting biology, though very few
recent studies. To begin with, Nesbitt and Williams (1990) conducted a research to find out
habitat use of Florida sandhill cranes lived in Alachua, Levy, Marion and Putnam counties in
North Central Florida. The study indicates that 86 percent of the cranes were observed in pasture, emergent palustrine wetlands, pasture-emergent palustrine wetland transition, and pasture-forest transition, making them the most preferred habitats. Likewise, the percentage of the use of the mixed-grass herbaceous marsh covering 13 percent of the study area was 55 throughout the year, and it received greater usage in the fall and winter, 62 percent and 72 percent respectively, according to Bennett (1992) explaining which type of habitats are used by Florida sandhill cranes in different seasons in the Okefenokee Swamp.

In terms of the foraging habitats, the Florida sandhill crane forages in open uplands and marshes (FWC, 2003). Similarly, Bennett (1992) states that in addition to marshes playing a crucial role for the cranes’ diet especially in the summer and spring, the cranes in the Okefenokee Swamp spend a considerable amount of time in uplands to feed. Walkinshaw, Layne, and Bishop say uplands which are preferred by Florida sandhill cranes to forage in Central Florida are comprised of open pine forests, live oak hammocks, agricultural croplands, and improved pastures which have scattered cabbage palm, oak, or pine trees. (as cited in Stys, 1997).

In another study of Bennett (1989a), movements and home ranges of adult (> 3 years old) and subadult (1-3 years old) Florida sandhill cranes in the same area, the Okefenokee Swamp, were determined. The average annual home range size for adults was 93 ha while it was 402 ha for subadults. Among subadults, the mean home range size for juveniles (≤ 1 years old) was 590 ha, whereas it was 329 ha for 3-year-old subadults. Also, the mobility that was the linear distance between roosts and feeding places and home range size for both adults and subadults were greatest in the summer.
Nesbitt et al. (2001) indicated the clutch size was an average of 1.78, based on 210 nests observed in Alachua and Osceola counties. According to another study carried out on the Loxahatchee National Wildlife Refuge by Thompson (1970), 64 nests observed had 118 eggs, meaning that the mean clutch size was 1.84. He also explains nesting habitat requirements of the Florida sandhill crane. The nests were usually made in open sloughs of wet prairies that had shallow water during the nesting season and located between tree islands. The average water depth for 44 nest spots was 25 cm.

In addition, 365 pairs were observed in 10 different counties in Florida, with a greater focus on north and west of Lake Okeechobee, by Layne (1983). All nests were built in standing water mashes or densely vegetated ponds, with the exception of one nest built on dry ground. In another study conducted by Walkinshaw (1981) in Okeechobee, Osceola, and Polk counties, 81 of 137 nests observed were located in ponds that were less than 4.1 ha, and 56 nests were in larger wetlands. Furthermore, 92 of 119 nests (77.3 %) were successful. 176 of 224 eggs (78.5 %) hatched, and 174 chicks (77.7 %) fledged. In another study carried out on and near the Kissimmee Prairie (Walkinshaw, 1976), he indicated that the average nesting date was February 20, ranging from February 2 to April 12, with 30 days incubation. It is also stated that the water level in nesting sites, precipitation during the nesting season and the weather condition in January and February affected nest success significantly. In the case of nest failure arising from flooding (Nesbitt, 1988) or predation, such as by raccoons (Bennett and Bennett, 1990) and birds (Dusek et al.), the Florida sandhill crane can attempt to build a nest several times in a nesting season (Bent, 1926).
Grassland Restoration

Grasslands defined as terrestrial areas which are dominated by herbaceous and shrub vegetation and maintained by the disturbances, such as fire, herbivory, frost, and drought (White et al., 2000; Gibson, 2009), provide a myriad of ecosystem services (Hönigová et al., 2012). Besides food and freshwater supply, carbon storage, erosion control, recreation, and ecotourism (Zhao et al., 2020; Gibson, 2009), they promote biodiversity by supporting fauna (Carlier et al., 2009).

Despite the ecosystem services they provide, grasslands have experienced significant changes because of various factors, such as agriculture, fragmentation, desertification, urban sprawl, and domestic livestock worldwide (Gibson, 2009). For example, about 40% of the global grassland ecosystems were degraded by human activities and climatic factors over the period from 2000 to 2013, according to the study of Liu et al. (2019). As a result, the importance of grassland restoration has increased (Hamilton et al., 2020).

Florida’s grasslands, which can generally be classified as wet prairies (Figure 2) and dry prairies (Stephenson, 2011), are no exception to this rule. The grasslands that provide habitats for different types of mammals, butterflies, moths, insects, spiders, amphibians, reptiles, and birds (Brown, 1985), some of which are threatened like burrowing owl (Athene cunicularia) (Abrahamson and Hartnett, 1990), have been significantly lost to the conversion to agriculture and other human land uses in Florida (Noss, 2013). For example, about 81 percent of historical dry prairies that once occurred extensively in pre-settlement Florida, especially in the area extending from west cost of Lake Okeechobee to Hillsborough and Manatee counties, (Stephenson, 2011) were degraded, based on the estimation made by Shriver and Vickery (1999)
in 1995. Consequently, this loss has increased the need for restoration of Florida’s grasslands supporting biodiversity (Stephenson, 2011).

A myriad of grassland restoration projects are conducted for different purposes worldwide, and grassland bird populations are one of the objectives of grassland restoration efforts (Jaster and Jensen, 2014). It is because plant communities in grasslands can create environmental conditions that birds need for their life cycles (Brennan and Kuvlesky, 2005), and restoring grasslands can improve their populations. For instance, Silva and Fontana (2020) indicate that grassland restoration carried out between 2015 and 2019 in southern Brazil improved bird species richness and abundance. Likewise, Fletcher and Koford (2002) compared 10 restored grasslands to 10 natural tallgrass prairies located in northern Iowa between 1999 and 2000 and concluded that the species richness of breeding birds surveyed in restored grasslands and natural grasslands were similar.

**Figure 2.** A wet prairie.
If we look at the Florida sandhill crane, it is not unlike the Florida grasshopper sparrow (Ammodramus savannarum floridanus) which relies heavily on Florida dry prairies (Perkins, et al., 2008). Florida sandhill cranes are exclusively reliant on grasslands (Boughton et al., 2018; USFWS, 1999). Layne (1981) observed a pair with two chicks, and the family stayed in the flooded area near their nest in the next few days after hatching. In the following weeks, the parents constructed accessory nests which were used as resting and brooding sites for the chicks, not to mention confusing the predators, by using dry grasses, as the family increased the foraging distance gradually up to 500 m and foraged in drier pasture habitats. In the following months until the juveniles became independent of the parents, the family was sometimes observed at the distance of 800 m from the original nest, and the average distance observed from the nest site was 420 m. Similarly, Armbruster (1987) indicates that greater sandhill cranes (Antigone canadensis tabida) use uplands dominated by grasses, maximum 50 cm in length (Stys, 1997), intensively in search of food after the young hatch. In short, grasslands adjacent to permanent

![Figure 3](image)  
Figure 3. A chick fed by its parent on grasses.
emergent wetland habitats in Florida sandhill crane territories play a vital role for the survival of chicks since those areas provide grassy vegetation on which pairs forage and feed the young (Figure 3) (Nesbitt and Williams, 1990; Layne, 1981).

Conservation Status of the Florida Sandhill Crane

Land use and land cover in Florida have changed significantly since 1900 (Volk et al., 2017). For instance, about 50 percent of the wetlands have been drained for agriculture, urban and rural development (Dahl, 2005; Rains et al., 2013), in addition to the transformation of substantial majority of the grasslands into farmland and other human land uses in Florida (Stephenson, 2011; Noss, 2013), which in turn has led to the decline of the Florida sandhill crane population (Nesbitt and Hatchitt 2008).

Nesbitt and Hatchitt (2008) explain the habitats for the Florida sandhill crane, such as grasslands and freshwater marshes, have declined dramatically since 1974. It is indicated that the appropriate habitat was 31,180.9 km² in 2003 while it was 53,776.2 km² in 1974, meaning that 42 percent of suitable habitats for Florida sandhill cranes have been lost. Also, the Florida sandhill crane population was 4594 in 2003, whereas it was 7142 in 1974. As of today, the population size is estimated to be between 4000 and 5000 (FWC, n.d.).

Therefore, the Florida sandhill crane is listed as state-designated Threatened species by Florida’s Endangered and Threatened Species Rule (FWC, n.d.). According to the rule 68A-27, harassment, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing and collection of the Florida sandhill cranes are banned for the purpose of conservation and enhancing the population status, and they can only be taken with state or federal permission or authorization if there is a conservation or scientific purpose (FAC&FAR, n.d.). The species is
also under the protection of US Migratory Bird Treaty Act, and similar regulations, such as the prohibitions of hunting, taking, capturing, killing, possession, selling, purchasing, shipping, transportation, carriage, or export of the species, or any part, nest or egg are enforced by this act (USFWS, n.d.).

Objectives

This study aims to propose the most effective strategies for grassland restoration to increase the spatial carrying capacity of the Florida sandhill cranes living in Pasco County, Florida. Determination of the areas that need to be restored to grasslands for Florida sandhill cranes can help wildlife managers and restoration planners decide which areas should be prioritized for restoration. If proposed restoration sites were restored, the number of Florida sandhill cranes could increase, for restored grasslands play an important role for the survival of the chicks and as foraging habitats strongly preferred by Florida sandhill cranes in the county.

Objectives under the main goal include:

1. Assessing the current status of Florida sandhill crane habitats in Pasco County, Florida.

2. Identifying potential and priority areas for grassland restoration near existing potential Florida sandhill crane nesting habitats in Pasco County.

3. Calculating the maximum change in spatial carrying capacity for Florida sandhill cranes in Pasco County that can be achieved through grassland restoration.
CHAPTER TWO:

STUDY AREA

Pasco County is located on the west central coast of Florida and borders on the Gulf of Mexico (Figure 4). It has a total area of 768.89 mi$^2$, and the population of the county was estimated to be about 554,000 in 2019 (U.S. Census Bureau, n.d.), meaning that population density was 742 people per square mile. Wesley Chapel and Land O’ Lakes are the most populous cities in the county, according to the 2010 Census. In terms of the climate, the county falls within the subtropics and has a humid subtropical climate (Collins, 2017). It has an average of 54.17 inches of precipitation per year, based on the 1981-2010 climate normals (NOAA, n.d.). The summer season receives the greatest amount of precipitation, with an average of 23.52 inches while the average precipitation for the winter season is the lowest, with 9.08 inches. The average minimum and maximum temperatures in the summer and winter seasons are 72.5 °F and 92.1 °F, and 51.0 °F and 73.7 °F, respectively.

According to the “2011 National Land Cover Dataset” (USDA, 2016), almost three quarters (73%) of Pasco County are undeveloped. The percentages of hay/pasture and herbaceous land cover types are about 17% and 1.5%, respectively. About 14% of the area consist of forests, with evergreen forests comprises the overwhelming majority of them. Woody wetlands and emergent herbaceous wetlands cover 24% and 4.6% of the area, respectively. In addition, the proportions of the areas occupied by shrub/scrub and cultivated crops are
approximately 8.5% and 2%. The rest of the county (1%) is classified as *open water* and *barren land*.

**Figure 4.** Map showing the study area.
With respect to the flora of Pasco County, various woody and herbaceous plant species occur in a variety of ecosystems, such as swamp, marsh, forest, and pine flatwood. Principal woody species are red maple (*Acer rubrum*), sand pine (*Pinus clausa*), slash pine (*Pinus elliottii*), longleaf pine (*Pinus palustris*), red mangrove (*Rhizophora mangle*), saw palmetto (*Serenoa repens*), pond cypress (*Taxodium ascendens*), bald cypress (*Taxodium distichum*), Carolina willow (*Salix caroliniana*), and the oaks (*Quercus spp.*), such as live oak (*Quercus virginiana*) (Wunderlin, 2020). Also, some native herbaceous species growing in the grasslands are wiregrass (*Aristida stricta var. beyrichiana*), ticklegrass (*Agrostis hyemalis*), yellow indiangrass (*Sorghastrum nutans*), switchgrass (*Panicum virgatum*), broomsedge bluestem (*Andropogon virginicus*), and eastern gamagrass (*Tripsacum dactyloides*) (Brown 1985; Wunderlin, 2020; USDA, NRCS, 2020).
CHAPTER THREE:

MATERIAL AND METHODS

The methodology for this study is divided into three parts: (1) assessment of current Florida sandhill crane habitats in Pasco County, (2) identification of potential restoration sites, and (3) strategic selection of sites. Table 1 briefly shows which software and data were used to meet each objective.

Table 1. Software and data used in this study.

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Software</th>
<th>Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Assessment of Current Florida Sandhill Crane Habitats in Pasco County</td>
<td>*ArcGIS Pro 2.4</td>
<td>*HSI (Downs et al., 2020)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*USGS National Transportation Dataset (USGS, n.d.)</td>
</tr>
<tr>
<td>2. Identification of Potential Restoration Sites</td>
<td>*ArcGIS Pro 2.4</td>
<td>*HSI (Downs et al., 2020)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*USGS National Transportation Dataset (USGS, n.d.)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*Statewide Land Use/Land Cover Dataset (FDEP, n.d.)</td>
</tr>
<tr>
<td>3. Strategic Selection of Sites</td>
<td>*ArcGIS Pro 2.4</td>
<td>*Results from the previous section</td>
</tr>
<tr>
<td></td>
<td>*ArcMap 10.6.1</td>
<td>*ACLP formulation (Downs et al., 2020)</td>
</tr>
<tr>
<td></td>
<td>*Python 3.8</td>
<td>*Master Plan Units for Development (Pasco County, n.d.)</td>
</tr>
<tr>
<td></td>
<td>*IBM C-PLEX</td>
<td></td>
</tr>
</tbody>
</table>
Assessment of Current Florida Sandhill Crane Habitats in Pasco County

Habitat suitability index (HSI) models that were first introduced by the United States Fish and Wildlife Service in 1981 (USFWS, 1981) have become prevalent in evaluation of habitat quality (Brooks, 1997; Theuerkauf and Lipcius, 2016). HSI models are designed by considering habitat requirements of species and describe the suitability of a given area for a species of interest with index values that range from 1 being fully suitable habitat and 0 being fully unsuitable habitat (USFWS, 1981; Schamberger et al., 1982). In this study, an existing GIS-based HSI model developed by Downs et al. (2020) (Table 2) for Florida sandhill cranes was modified and used to evaluate the availability of the habitats in the study area for the species. This model evaluates nesting location suitability based on six habitat suitability variables (SVs) using a geographic information system (GIS). The geospatial layers used in GIS operations consist of land cover data with a 10-meter spatial resolution and road data in a vector format. Variables, criteria and the importance of each variable in the final equation were determined based on the nesting biology and other species-habitat relationships.

The first variable (SV1) potential nesting habitat assesses the availability of a focal cell to support a nest. If a raster cell is classified as emergent wetland, it is assigned the value of 1, and 0 otherwise. The second variable (SV2) immediate nesting area evaluates the suitability of nesting habitat in the circular neighborhood of 120 m. The higher the percentage of emergent wetland or wet prairie in that area surrounding the raster cell, the more the suitability score the raster cell has. The third variable (SV3) brooding area is based on the suitability of brooding habitat within the circular area that has the radius of 450 meter. The raster cells surrounded by the circles in which prairie, pasture, grassland, or other herbaceous open land cover at least 20 percent of the area are assigned a value of 1. If the percentage is lower than 20, the value is
divided by 20 percent to obtain a value proportional to the amount observed. The fourth variable (SV4) wetland composition measures the abundance of any type of freshwater wetland in the circular area with the radius of 780 m. The raster cell is assigned a value of 1 if the percentage of wetland land cover type in the specified neighboring area is more than 15 percent. Proportionally lower values are assigned if the percentage observed is smaller than 15 percent. The fifth variable (SV5) upland composition calculates the percentage of suitable upland types in the area within 780 m radius of the raster cell. If the percentage of grassland, prairie, pasture, cropland, or other herbaceous open land in the specified area around the raster cell is more than 15 percent, the raster cell receives a value of 1. If the percentage is lower than 15 percent, it is assigned proportionally less values. The last variable (SV6) road proximity measures the distance to nearest road. If the focal cell is located more than 100 m from the nearest road, it is assigned a value of 1. Proportionally lower values are assigned to smaller distances. In this study, this variable was modified. The same assignment method was used. However, a more up to date transportation data layer was used, and road types were weighted differently. First, USGS National Transportation Dataset (USGS, n.d.) showing the transportation network in the study area was obtained. Then, the data was divided into two classes, primary and secondary. Primary class included main roads, railroads, and airport runways, whereas secondary class included minor roads. The weight of the primary class was twice that of secondary class’ in the final raster representing SV6 road proximity because the transportation features in the primary class are busier, noisier, and thereby more disturbing to cranes.

Hence, six distinct raster layers showing index values for each variable were obtained. Lastly, the updated SV6 road proximity and other raster layers were integrated into the equation
at the end of the Table 2 as per Downs et al. (2020) to obtain the raster layer indicating the final habitat suitability index value.

**Table 2.** Formulation of the HSI based on six habitat suitability variables (Downs et al., 2020).

<table>
<thead>
<tr>
<th>Suitability Variable (SV)</th>
<th>Description</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potential nesting habitat (SV1)</td>
<td>Suitability of a focal cell to support a nest</td>
<td>= 1 if focal cell is emergent wetland or wet prairie = 0, otherwise</td>
</tr>
<tr>
<td>Immediate nesting area (SV2)</td>
<td>Suitability of nesting habitat immediately surrounding cell (120 m x 120 m area)</td>
<td>= % emergent wetland or wet prairie in area surrounding focal cell</td>
</tr>
<tr>
<td>Brooding area (SV3)</td>
<td>Suitability of brooding habitat (grassland, prairie, or pasture) within close proximity (area within 450 m radius of focal cell)</td>
<td>= 1 if % suitable brooding habitat within area is greater than 20% = % suitable brooding habitat divided by 20%, otherwise</td>
</tr>
<tr>
<td>Wetland composition (SV4)</td>
<td>Wetland (any type) availability in the surrounding landscape (area within 780 m radius of focal cell)</td>
<td>= 1 if % wetland within area is greater than 15% = % wetland divided by 15%, otherwise</td>
</tr>
<tr>
<td>Upland composition (SV5)</td>
<td>Suitable upland types (grassland, prairie, pasture, cropland, or other herbaceous openland) in the surrounding landscape (area within 780 m radius of focal cell)</td>
<td>= 1 if % suitable uplands types is greater than 15% = % suitable upland types divided by 15%, otherwise</td>
</tr>
<tr>
<td>Road proximity (SV6)</td>
<td>Distance to nearest road</td>
<td>For both primary and secondary roads; = 1 if distance to nearest road is greater than 100 m (328 ft) = distance to road divided by 100 m (328 ft), otherwise Then; = ((2 × primary roads) + secondary roads) / 3</td>
</tr>
<tr>
<td>Habitat Suitability Index (HSI)</td>
<td>Overall suitability as derived from individual suitability variables</td>
<td>= SV1 × SV2 × (((SV3 × 2) + SV4 + SV5) / 4) × SV6</td>
</tr>
</tbody>
</table>
The weights for the variables were not the same in the formula because the importance of each variable differed; brooding habitat is weighted double due to its importance for successful reproduction. That is, brooding habitats adjacent to nesting locations are heavily used for foraging and resting by crane families (Layne, 1981) and thus play an essential role for the survival of the chicks. This final raster measures overall suitability, with optimal locations being located in large wetlands that are in close proximity to an abundance of wetlands, grasslands, and other upland feeding areas that are distant to roads.

In this study, the HSI model was used to evaluate the Florida sandhill crane nesting habitat in Pasco County. The analysis was conducted using a GIS (ArcGIS Pro version 2.4 developed by Environmental Systems Research Institute). Also, selecting an appropriate map projection is important in a map making process to minimize distortion (Madej, 2001), so NAD 1983 StatePlane Florida West FIPS 0902 (US Feet) was used as the coordinate system for the maps throughout the study because the study area is located in the west zone in the state plane coordinate system for Florida. First, maps for each SV and the final HSI values were generated for the county. Next, the values were summarized according to ranges to explore which habitat factors might be the most limiting in the study area. It was expected that the results would show that large amounts of the county have low values for SV3 brooding area, supporting the idea that grassland restoration can improve suitability for cranes.

Identification of Potential Restoration Sites

The next step was to use the SV and HSI maps and Statewide Land Use/Land Cover Dataset created by water management districts in Florida (FDEP, n.d.) to identify potential grassland restoration sites. A model that contains a series of GIS operations were used to identify sites for potential grassland restoration. Site identification occurred in three steps. First, three
new rasters with the cell size of 10 x 10 feet were created using the Raster Calculator tool in three scenarios. The direct effects of suitability thresholds on the results of the study necessitated the construction of three scenarios. Threshold values were specified using the equations below:

\[
\begin{align*}
(1) \quad & \text{Con}(("SV1" = 1.0) \& ("SV2" = 1.0) \& ("SV3" \leq 0.5) \& ("SV4" \geq 0.5) \& ("SV5" \geq 0.5) \& ("SV6" \geq 0.5)), 1, 0) \\
(2) \quad & \text{Con}(("SV1" = 1.0) \& ("SV2" = 1.0) \& ("SV3" \leq 0.5) \& ("SV4" \geq 0.7) \& ("SV5" \geq 0.7) \& ("SV6" \geq 0.7)), 1, 0) \\
(3) \quad & \text{Con}(("SV1" = 1.0) \& ("SV2" = 1.0) \& ("SV3" \leq 0.5) \& ("SV4" = 1) \& ("SV5" = 1) \& ("SV6" = 1.0)), 1, 0)
\end{align*}
\]

The output rasters contained the pixels which were suitable for nesting according to all variables described previously, save third variable (SV3 Brooding Area). That is, the cells did not meet the criterion of having the sufficient number of suitable uplands, such as grassland, prairie, pasture, cropland within the distance of 450 m (1476 ft) from their centers. As you can see in the expressions, the lowest suitability threshold at 0.5 was applied to SV3 Brooding Area under all scenarios because determination of locations where brooding habitat condition was very poor was intended. Also, SV1 Potential nesting habitat and SV2 Immediate nesting area had to be assigned the value of 1 in all three scenarios due to the calculation methods as explained previously, so the locations determined based on the expressions ended up being wetlands. Thresholds for SV5 Upland composition and SV6 Road proximity were varied using values of 0.5, 0.7, and 1.0, representing a range of surrounding conditions that would allow for grassland restoration to increase overall suitability. These processes, thus, identified initial sets of candidate nesting locations.
The second step restricted the initial candidate nesting locations based on existing nesting habitat. Because cranes are territorial, in order to increase population size most efficiently, restoration sites should not be located in close proximity to optimal habitat where cranes are most likely to be currently nesting based on the HSI. For this reason, using a separation distance was necessary. Population densities of cranes differ dramatically according to habitat, for instance, population density of Florida sandhill cranes varied from 0.4 cranes/1 km² to 6.1 cranes/1 km² among different marshes which were in different sizes and had different vegetation structures and configurations in Okefenokee Swamp as summarized in Bennett (1989b). In this study, the average distance of 0.5 km (5.1 cranes/1 km²) between adjacent nests was used to define a baseline minimum distance of separation. Therefore, after potential nesting locations were converted into a point feature class by using the Raster to Point tool, the list of initial candidate nesting locations was reduced by removing those that were located within 0.5 km (1640 ft) of highly suitable nesting locations based on the HSI under each scenario. As a result, potential nesting locations were obtained, and the areas adjacent to those potential nesting locations are candidate for grassland restoration.

In the third step, those candidate restoration sites were reduced based on the land use/land cover types that would be conducive to grassland restoration. The land use/land cover types classified as low density, other open lands (rural), shrub and brushland, tree plantations, disturbed lands, and row crops were regarded as suitable to grassland restoration. First, a polygon was created for the county representing all of the suitable restoration sites based on the land use/land cover types. Then, a 450-meter (1476 ft) buffer was created around each point representing the potential nesting locations using the Buffer tool (Figure 5). The distance was
based on the fact that the areas dominated by grasses within that distance are crucial, especially for foraging and brooding (Layne, 1981; Downs et al., 2020), as explained previously.

**Figure 5.** An illustration of creating buffer zones around potential nesting locations.

Third, the two vector layers (suitable restoration sites based on land use/land cover types and the buffers around potential nesting locations) were intersected (Figure 6). Lastly, a few sites obtained from this overlay operation located in close proximity to the primary roads, so the sites within 100 m (328 ft) of primary roads were eliminated. Secondary roads were not considered because it was observed that secondary roads do not deter cranes from foraging. Hence, the output feature class obtained from this elimination showed potential restoration sites.
Figure 6. An illustration of intersecting suitable land use/land cover types with the buffers.

Strategic Selection of Sites

The term *carrying capacity* is used in different disciplines. In ecology, it is defined as the natural limit of a population established by the resources, such as food, water, and cover in a given environment (Sinclair et al., 2006). Carrying capacity is a useful indicator in investigation of species viability in an ecosystem (Ma et al., 2017; Chapman and Byron, 2018). Spatial carrying capacity, or landscape carrying capacity, defines the maximum number of individuals a site can support given spatial constrains that require breeding pairs or family units to be separated by a certain distance. In this study, spatial carrying capacity of Pasco County for
Florida sandhill cranes was estimated under three scenarios to determine how grassland restoration might potentially increase population size.

One might think that it can be estimated by finding out the number of cells designated as suitable areas for nesting. In reality, however, it is not possible that all suitable nesting habitats can be occupied by Florida sandhill crane pairs at a time. They are territorial and defend their territories (Nesbitt and Williams, 1990). For this reason, the Anti-Covering Location Problem (ACLP) can be used to solve for spatial carrying capacity.

The ACLP, which was first introduced by Moon and Chaudhry in 1984, maximizes the number of sites that can be located with a specified minimum separation distance or time standard of each other in a given environment (Murray and Church, 1997; Niblett, 2014). Usage of the ACLP to estimate carrying capacity for sandhill cranes was first attempted by Downs et al. (2008). It was for sandhill cranes in northern Ohio. Then, Downs et al. (2020) took a similar approach to estimate the carrying capacity of Florida sandhill cranes. In both studies, habitat suitability models were also utilized for calculations.

The methodology in Downs et al. (2020) was employed for estimation of the spatial carrying capacity in this study. First, the mathematical model representing the ACLP is given as follows:

Maximize

\[ K = \sum_{i \in \mathcal{I}} x_i \]  

Subject to

\[ x_i + x_j \leq 1, \forall_{i,j \in \mathcal{I}} \text{ where } i \neq j \text{ and } d_{ij} \leq R \]  

\[ x_i = \{0, 1\}, \forall_i \]
Where

\[ K = \text{maximum number of occupied nest sites} \]
\[ i = \text{index of potential nest sites} \]
\[ d_{ij} = \text{distance between potential nest site } i \text{ and another site } j \]
\[ R = \text{minimum distance required between occupied nests} \]

The objective (1) of the ACLP formulation involves maximizing the total number of potential nest sites that can simultaneously be occupied. Constraints (2) ensure that no two nest sites are located within the restriction distance, \( R \), of one another. If a nest site \( x_i \) is selected by the model, any neighboring sites \( x_j \) are unable to be selected as nest sites at the same time, as the sum of the values of \( x_i \) and \( x_j \) must be less than or equal to 1. Constraints (3) represents the binary integer restrictions for the nest selection variable \( x_i \). The decision variable \( x_i \) is forced to be either 0 or 1. Solving the problem results in: (1) the maximum number of breeding pairs that can be supported under those constraints and (2) the locations of the nest sites identified under that scenario.

The ACLP was used in this study to identify how much carrying capacity for Florida sandhill cranes can be increased through grassland restoration. The maximum increase in carrying capacity was determined by assuming grassland could potentially be restored for all potential nesting locations. This was accomplished by solving the ACLP for the potential nesting locations using a restriction distance of 0.5 km (1640 ft). The ACLP was formulated and solved as per Downs et al. (2020), using a custom Python script to generate the equations in linear programming format and IBM CPLEX to solve the equations. The outputs included the optimal sets of nesting locations in each scenario where carrying capacity was maximized; grassland restoration can be optimized in close proximity to these specific wetlands for nesting. Relating
these locations back to the buffers, potential restoration sites can be identified for each potential nest location.

Also, the potential restoration sites that are located in master plan units for development (MPUD), such as property development in Pasco County were excluded based on the GIS data acquired from the county’s website (Pasco County, n.d.). Final decision on which land parcels within the buffers would be selected for grassland restoration would be based on the factors included in the discussion, such as, land ownership, preexisting conditions of the sites, restoration costs, and other factors that were included in the discussion.
CHAPTER FOUR:

RESULTS

Assessment of Current Florida Sandhill Crane Habitats in Pasco County

Figure 7 maps each suitability variable for Pasco County. The continuous color scheme represents the values between 0, unsuitable, and 1, optimal. First inset map, SV1 Potential nesting site, illustrates only the areas assigned the value of 1, since the cells could be either fully unsuitable or fully suitable, according to the criterion explained previously. In other words, only herbaceous wetlands favorable to nesting are shown. In contrast, the suitability index values of the areas displayed in the rest of the SV maps vary between 0 and 1. In addition, the offshore boundary is included in the county boundary used in the maps. For this reason, the water body in the entire west part of the county is seen as totally unsuitable for all variables, except SV6 Road proximity. That area appears optimal, as no road exists therein. In inland areas, however, the distribution of the suitability index values based on each variable can be seen.

The overall habitat suitability index demonstrates the capability of Pasco County to support the species of interest (Figure 8). A cluster of suitable habitats are located in slightly northeast of the centroid of the county. Also, there are considerable number of scattered suitable habitats in the eastern areas. Overall, it is predicted that the study area contains 5,654 acres of suitable habitat based on the suitability threshold value at 0.5. The amount is 2,265 acres according to the threshold value of 0.7. If we consider only the cells that were assigned the value of 1 suitable habitat, the amount is 149 acres.
Figure 7. Maps for each suitability variable: SV1 Potential nesting site, SV2 Immediate nesting area, SV3 Brooding area, SV4 Wetland composition, SV5 Upland composition, and SV6 Road proximity.
Table 3. Habitat assessment of Florida sandhill crane habitat in Pasco County, Florida, using a Habitat Suitability Index (HSI) model comprised of six Suitability Variables (SVs): SV1 Potential nesting site, SV2 Immediate nesting area, SV3 Brooding area, SV4 Wetland composition, SV5 Upland composition, and SV6 Road proximity. Values in the table record the percent of cells in the county within that range of values.

<table>
<thead>
<tr>
<th>Value</th>
<th>SV1</th>
<th>SV2</th>
<th>SV3</th>
<th>SV4</th>
<th>SV5</th>
<th>SV6</th>
<th>HSI</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 – 0.1</td>
<td>95.5</td>
<td>88</td>
<td>59.5</td>
<td>24.2</td>
<td>36.4</td>
<td>0.1</td>
<td>96.3</td>
</tr>
<tr>
<td>0.1 – 0.2</td>
<td>0</td>
<td>4.4</td>
<td>2.2</td>
<td>4.2</td>
<td>5</td>
<td>0.2</td>
<td>1</td>
</tr>
<tr>
<td>0.2 – 0.3</td>
<td>0</td>
<td>2.4</td>
<td>2</td>
<td>3.2</td>
<td>3.1</td>
<td>0.2</td>
<td>0.7</td>
</tr>
<tr>
<td>0.3 – 0.4</td>
<td>0</td>
<td>1.5</td>
<td>1.7</td>
<td>2.7</td>
<td>2.6</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>0.4 – 0.5</td>
<td>0</td>
<td>1</td>
<td>1.6</td>
<td>2.5</td>
<td>2.5</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>0.5 – 0.6</td>
<td>0</td>
<td>0.8</td>
<td>1.5</td>
<td>2.3</td>
<td>2.1</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>0.6 – 0.7</td>
<td>0</td>
<td>0.6</td>
<td>1.4</td>
<td>2.4</td>
<td>2</td>
<td>5.5</td>
<td>0.3</td>
</tr>
<tr>
<td>0.7 – 0.8</td>
<td>0</td>
<td>0.4</td>
<td>1.3</td>
<td>2.3</td>
<td>1.8</td>
<td>12.3</td>
<td>0.2</td>
</tr>
<tr>
<td>0.8 – 0.9</td>
<td>0</td>
<td>0.3</td>
<td>1.3</td>
<td>2.3</td>
<td>1.7</td>
<td>8</td>
<td>0.1</td>
</tr>
<tr>
<td>0.9 – 1.0</td>
<td>4.5</td>
<td>0.5</td>
<td>27.5</td>
<td>53.9</td>
<td>42.5</td>
<td>72</td>
<td>0.1</td>
</tr>
</tbody>
</table>
The percentages of the cells in the study area within different ranges are shown in Table 3. For example, based on the suitability threshold at 0.5, the most limiting factor is SV2 immediate nesting area, with 2.6%. The percentage of the SV1 Potential nesting habitat is 4.5, making it the second most restrictive factor. SV6 Road proximity, SV4 Wetland composition, and SV5 Upland composition are the least restrictive, with 98.3%, 63.2%, and 50.1% respectively. With respect to the SV3 Brooding area, the percentage of the appropriate brooding habitat in the study area is 33. In comparison to other variables, it is the most limiting habitat factor other than the first two variables assessing the availability of nesting habitat based on wetlands and wet prairies. Lastly, the percentage of the final HSI is 1.1 based on the threshold value of 0.5, meaning that only 1.1% of the study area are appropriate for breeding Florida sandhill cranes. If suitability threshold values of 0.7 and 1.0 are applied, the percentages are much lower, with 0.4 and 0.03 respectively.

Identification of Potential Restoration Sites

The model created produced intended outcomes. First, Figure 9 shows initial candidate nesting locations under three scenarios. They cover areas of 516, 392 and 232 acres based on the suitability threshold values of 0.5, 0.7, and 1.0, respectively (Table 4). They are herbaceous wetlands and suitable according to all suitability variables, except third variable Brooding area. In other words, there is not a sufficient amount of brooding habitat within a radius of 450 m (1476 ft) of each cell. Also, because it was assumed that suitable nesting locations have occupancy by cranes, the specified initial candidate nesting locations located in 0.5 km (1640 ft) of suitable nesting locations were eliminated due to territorial behavior of cranes, causing that the areas decreased drastically to 60, 77, and 117 acres, respectively. These wetlands are, thus, potential nesting locations for the analysis (Figure 10).
Figure 9. Map showing the wetlands around which brooding habitat is limited based on three threshold values.
Figure 10. Potential nesting locations based on three threshold values.
### Table 4. Total areas covered by nesting locations.

<table>
<thead>
<tr>
<th>Suitability Threshold</th>
<th>Initial Candidate Nesting Locations</th>
<th>Potential Nesting Locations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cell (10 ft)</td>
<td>Area (acre)</td>
</tr>
<tr>
<td>0.5</td>
<td>224,680</td>
<td>516</td>
</tr>
<tr>
<td>0.7</td>
<td>170,614</td>
<td>392</td>
</tr>
<tr>
<td>1.0</td>
<td>100,871</td>
<td>232</td>
</tr>
</tbody>
</table>

In addition, after intersecting land use/land cover types conducive to restoration with 450-meter (1476 ft) buffer zones surrounding those potential nesting locations, 13, 36, and 84 potential restoration sites were obtained based on each threshold values of 0.5, 0.7, and 1.0, respectively. Further, those located in close proximity to the primary roads were eliminated because they create disturbance to cranes, lowering the numbers to 12, 34 and 79, respectively. Secondary roads were not considered a disturbance because it was observed that cranes sometimes forage in the areas adjacent to secondary roads. These sites falling into the specified distance of potential nesting locations have potential for grassland restoration.

### Strategic Selection of Sites

After detecting the potential nesting locations, ACLP was solved to find out how many of those locations can simultaneously be occupied by Florida sandhill crane pairs by using the restriction distance of 0.5 km (1640 ft). It was found that respectively, 5, 15, and 38 of them can be occupied at a time based on the suitability threshold values of 0.5, 0.7, and 1.0. In other words, they are optimal sets of nesting locations where carrying capacity is maximized (Figure 11).

The findings from solving the ACLP reduced the number of potential restoration sites indicated in the previous section. That is, the areas around the optimal sets of nesting locations
Figure 11. Optimal sets of nesting locations.
Figure 12. Map showing the locations of the restoration sites.
determined based on the ACLP solving can be the central focus for grassland restoration. Furthermore, not all of those optimal sets of nesting locations can be turned into suitable nesting locations through grasslands restoration because the potential restoration sites overlapping with master plan units for development in Pasco County were also excluded. Those units are where a development, such as housing will take place in the near future. Hence, the numbers of potential restoration sites ended up being, respectively, 4, 22, and 54. They cover areas of 38, 249, and 662 acres, respectively; and land use/land cover types in these sites include low density, other open lands (rural), shrub and brushland, and tree plantations.

Figure 12 shows the restoration sites. They are the sites where a grassland a restoration project can be conducted in order to potentially increase spatial carrying capacity for cranes. If these sites are restored to grasslands, the specified potential nesting locations could be suitable for the species of interest, thereby increasing the spatial carrying capacity. As a result, restoring those sites would increase spatial carrying capacities by 2, 10, and 24 breeding pairs under three scenarios, for there is not available restoration sites in close proximity to all optimal sets of nesting locations, as can be seen in Figures 11 and 12, once future developed sites are removed from the analysis.
CHAPTER FIVE:

DISCUSSION

Overall, the number of suitable areas for breeding Florida sandhill cranes in the area of study based the final habitat suitability index (HSI) is considerable. However, some of the variables comprising the final HSI are significantly more limiting than others. For example, SV2 immediate nesting area and SV1 potential nesting habitat are very limiting. These two habitat variables are based on the availability of herbaceous wetlands for nesting. However, if we look at the variables assessing the availability of uplands surrounding the determined available nesting locations, SV3 brooding area is the most restrictive factor. This suggests the idea that grassland restoration can improve the suitability for cranes, thereby increasing the spatial carrying capacity.

Since the suitability threshold values had direct influence upon the results, three scenarios in which different thresholds are used are constructed. In the phase of detection of initial candidate nesting locations, which are unsuitable wetlands for nesting only because of insufficient amount of brooding habitat, the results revealed that the lower suitability threshold values, the more wetlands. The number of initial candidate nesting locations based on the threshold value of 0.5 is twice as high as the number based on the threshold value of 1.0. In contrast, after the determined initial candidate nesting locations within the restriction distance from suitable nesting locations according to the final HSI are eliminated, the number of potential nesting locations under the third scenario was higher relative to the first and second scenarios. It
is because there are more suitable habitats if we use low suitability thresholds, and this situation leads to the elimination of more initial candidate nesting locations due to usage of the restriction distance.

Optimal sets of nesting locations that can be transferred into suitable nesting locations through grassland restoration and therefore occupied by maximum number of breeding pairs at any one time represent potential increases in spatial carrying capacity. Also, the numbers of restoration sites, especially under the third scenario, are significant even though only the potential restoration sites around those optimal sets of nesting locations were focused. The findings showed that usage of higher suitability values generated larger increases in the spatial carrying capacity. The increase in spatial carrying capacity is the biggest when suitability value of 1.0 is used, with 24, whereas the increase is not as big as expected in the first scenario.

The previous study (Downs et al., 2020) estimated the spatial carrying capacity of sandhill cranes in Pasco County. It was found that the current carrying capacities were 423, 246, 154, and 39 based on the suitability thresholds of 0.3, 0.5, 0.7, and 1.0 respectively. This study shows those estimated spatial carrying capacities can be increased by 0.8%, 6.5%, and 61.5% through grassland restoration based on the suitability thresholds of 0.5, 0.7, and 1.0 respectively. In addition, wetland loss in Florida is also regarded as one of the contributory factors to the population decrease of the cranes, as explained previously. The areas where wetland restoration is needed so as to increase the spatial carrying capacity can be detected in a similar manner as done for grasslands in this study, or grassland restoration activities can be incorporated into wetland mitigation projects conceived by Florida Department of Environmental Protection. Such applications could accordingly increase the current spatial carrying capacity of the cranes considerably more.
Implications

In this study, the increase in spatial carrying capacity of Florida sandhill cranes in Pasco County were determined under three scenarios. If the sites located in close proximity to the optimal sets of nesting locations are restored to grasslands, the nesting locations are expected to be occupied by breeding pairs. Especially, the increases in special carrying capacities under the second and third scenarios gain more significance if newly created suitable nesting habitats through grassland restoration were inhabited by the breeding pairs that would reproduce successfully each year, which would in turn promote the population size in the study area.

There may be major constraints, such as time, human resources, and economic resources on restoration projects. In this case, restorationists can be selective in proposing final restoration sites and reduce the number of restoration sites, especially if a limited funding is allocated to restoration projects. Another option can be changing restoration methods to lower costs (Brancalion et al., 2019), or the land use/land cover types may be a criterion for selecting final restoration sites. For example, restoring the areas of shrub and brushland to grasslands may require less efforts than do other land use/land cover types in defined sites. That is, natural fire is a natural disturbance that is necessary to maintain grasslands in Florida like most grassland systems across the world, and without a natural fire regime, grasslands tend to turn into shrublands or woodlands (Abrahamson, 1990; USFWS, 1999; Merola-Zwartjes, 2004). If they occurred as a result of a human alteration of the natural fire frequency, prescribed fires may be enough for restoration.

Moreover, designating land parcels located in conservation areas and other public lands as restoration sites and drafting a management plan would not be difficult. Conducting a restoration project on private land, however, poses challenges not encountered on public land;
for example, Brook states that landowners may have discomfort with governmental agency intervention in their property (Morrison, 2009). For this reason, a restoration project on private land requires an effective collaboration with landowners, and they need to be consulted in the project planning phase if an agreement on designation of their privately owned land as a restoration site is reached.

Furthermore, abiotic and biotic filters affecting occurrence or abundance of animal species can be modified to allow desired species in (Morrison, 2009). In this case, lack of grasslands around the nesting locations plays a role as an abiotic filter, but breeding crane pairs are expected to occupy the nesting locations if grassland restoration projects are successfully conducted. Morrison (2009) also suggests assessing predator or competitor assemblages and how they will react to restoration. So, manipulation of biotic filters, such as predation and competition can also be considered in project planning process to allow the cranes to occupy the nesting locations and persist.

**Limitations and Future Study**

In this study, which sites can be restored to grasslands to increase the spatial carrying capacity was determined. However, whether or not the species will occupy newly created suitable nesting locations is not clear even if favorable habitat conditions are reconstructed. It is because not all available nesting locations are occupied by species in nature.

Also, historical vegetative conditions of the restoration sites need to be identified. The sites that were once grassland should be selected. One of the ways to assess preexisting conditions of a site is to use literature, such as field notes. If we look at the map showing the distribution of prairies and savannah as recorded on the U.S. General Land Office surveys of
Florida in the 19th century (see Stephenson, 2011), the number of grasslands in Pasco County is quite significant. It can roughly be said that around 10 percent of the inland areas in the county were once grasslands, and most of the historical grasslands stretched in the middle part of the county where the majority of the restoration sites under the second and third scenarios locate.

Optimal sites for grassland restoration to increase the spatial carrying capacity were detected. It is also known that there is not an ongoing or planned development in those sites, not to mention land cover/land use types. However, the ownership of the sites certainly needs to be determined. It is important not only because landowners are one of the stakeholders as indicated above, but also this early determination will allow restoration planners to know if they can acquire access rights and learn about any restrictions that may limit or even prevent them from conducting a restoration project (Rieger et al., 2014). Moreover, the usage of distinct suitability threshold values generated markedly different results. Field trips can be taken to compare the nesting locations where the species occurs presently to the suitable nesting locations that determined based on the HSI model used, which may help decide which suitability threshold is the most proper.

Lastly, this study showed the combination of an HSI model with an optimization model can be effective. The HSI can be used to detect the areas where a habitat factor is limited while the optimization model can be applied to reflect the reality of species occurrence in nature and prioritize the determined areas, especially if there is a barrier, such as financial. This efficient method can also be employed not only for the Florida sandhill crane subpopulations in other counties within its geographic range but also for other species that are listed as threatened or endangered elsewhere.
REFERENCES


FDEP (Florida Department of Environmental Protection) (n.d.). Retrieved August 1, 2020, from https://geodata.dep.state.fl.us/datasets/2f0e5f9a180a412fbd77dc5628f28de3_3


Pasco County GIS (n.d.). Retrieved September 5, 2020, from https://www.pascocountyfl.net/342/GIS-Data-Shape-Files


