Spatial analysis of potential nesting habitat for Florida sandhill cranes

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Abstract

The Florida sandhill crane *Antigone canadensis pratensis* is designated as threatened by the state of Florida, where there is an urgent need to map and quantify available habitat. First, we used habitat suitability index (HSI) modelling to map and assess potential nesting habitat for sandhill cranes in Florida. Second, we used spatial optimization approaches to calculate the maximum number of breeding pairs that can simultaneously occupy potential nests given that they both must be of some minimum quality and must be spaced some minimal distance apart. Mapping results reveal that nesting habitat is concentrated in the central portion of the state, with adequate brooding habitat appearing to be the most limiting factor affecting habitat suitability. Assuming nesting only occurs in habitat rated as high quality (HSI $\geq 0.7$) and spacing between adjacent nests is at least 1,000 m, we conservatively estimate that 5,540 nesting pairs of Florida sandhill cranes can potentially be supported. Additional nesting pairs may be supported in habitats of marginal (HSI $\geq 0.3$; 14,530) to moderate (HSI $\geq 0.5$; 8,723) quality. The suitability maps and breeding pair estimates can be used to identify important habitat areas to focus crane conservation efforts, determine potentially limiting habitat features across the landscape, and potentially guide future population monitoring efforts. For example, grassland/prairie restoration could be used to potential increase nesting pairs in the southern portion of the state where emergent wetlands are abundant but brooding habitat is lacking.

Key words: anti-covering location problem, GIS, high performance computing, spatial carrying capacity, wading birds.

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INTRODUCTION

The Florida sandhill crane *Antigone canadensis pratensis* is a subspecies of sandhill cranes which is found throughout central and southern Florida, Georgia’s Okefenokee Swamp, and in Mississippi (Bennett and Bennett 1992). The population in Florida, which is designated by the state as threatened, was estimated to have declined to about 4500 birds by the mid-2000s from much larger numbers in previous decades (Nesbitt and Hatchitt 2008). Current estimates for Florida are thought to be between 4000 and 5000 birds, although these numbers are based on an analysis of habitat availability by the Florida Fish and Wildlife Conservation Commission (2020). Given dramatic changes in land use-land cover in Florida over the last decade and a half (Hernández et al. 2012; Kautz et al. 2007), which pose threats to sandhill cranes, there is an urgent need to map and quantify remaining Florida sandhill crane habitat (Florida Fish and Wildlife Conservation Commission 2013).

Habitat suitability index (HSI) models offer one approach for mapping and assessing habitat conditions for wildlife species (Roloff and Kernohan 1999). These models generally assess suitability on a continuous scale from 0.0 (completely unsuitable) to 1.0 (optimal). Contemporary HSI models are implemented using GIS with spatial data layers representing habitat or other environmental features (e.g., Latif et al. 2018). Downs et al. (2008) developed a HSI model for greater sandhill cranes *Antigone canadensis tabida* in Ohio that identifies potential nesting sites (emergent marsh) located in close proximity to abundant wetlands, cropland, and pastures or grasslands. Because Florida sandhill cranes have similar habitat requirements to other subspecies of sandhill cranes (e.g. U.S. Fish and Wildlife Service 1991; Baker et al. 1995; Miller and Barzen 2016), we adapted the existing HSI model for greater
sandhill cranes based on the literature for Florida sandhill cranes and applied it to identify and assess the suitability of potential nesting sites across Florida.

Downs et al. (2008) also proposed an approach to calculate the maximum number of breeding pairs that can simultaneously occupy nests given that they both must be of some minimum quality and spaced some minimal distance apart, sometimes referred to as spatial or landscape carrying capacity (Lui and Wang 2010; Donovan et al. 2012; Glenn et al. 2017; Chapman and Byron 2018). A minimum HSI threshold is used to identify nesting habitat, while observations of nesting density are used to specify an appropriate minimum distance of separation. Once these values are specified, the maximum number of nests that can be occupied at once can be formulated as the anti-covering location problem (ACLP). The ACLP is a combinatorial optimization problem that can be solved using linear programming techniques (Moon and Chaudhry 1984). This process involves writing a set of linear equations as a text file and then using specialize software to solve them. We used the ACLP to quantify the maximum number of occupied nests at two spatial scales: each county and the state as a whole, leveraging high performance computing as necessary to obtain solutions for the larger problems. This formal habitat suitability assessment will allow managers and decision makers to identify important habitat areas for crane conservation, determine possible limiting habitat features across the landscape, identify locations to target population monitoring efforts, and update estimates of potential breeding population size.

METHODS

HSI model
Florida sandhill cranes nest in emergent palustrine wetlands and roost in shallow wetlands (Dwyer 1990; Dwyer and Tanner 1992; Layne 1981; Layne 1983; Walkinshaw 1982), often selecting sites free from human disturbance (Dwyer and Tanner 1992). They forage and loaf in shallow wetlands (Bennett 1992; Nesbitt and Williams 1990; Toland 1999), crop fields (Bennett 1992; Nesbitt and Hatchitt 2008; Toland 1999), pastures, prairies, and other grasslands (Nesbitt and Williams 1990). Open lands dominated by grass and other herbaceous vegetation are particularly important to cranes during the brood-rearing and pre-fledging stage, as they support abundant insects and other invertebrates for foraging (Stys 1997). Downs et al.’s (2008) HSI model identifies optimal nesting sites for sandhill cranes based on the availability of these habitat features in close proximity to one another. Habitat is assessed based on five suitability variables (SVs): potential nesting habitat, immediate nesting area, brooding area (includes hatching through pre-fledging), wetland composition, and upland composition. Values for these SVs are then combined into an equation to compute a final HSI value. Here, we used this existing model but add an additional variable, road proximity, to reflect human disturbance and documented road effects on cranes in Florida (Folk et al. 2001; Table 1).

In practice, SVs are calculated for all individual raster, or grid, cells in a map simultaneously using a GIS and overlaid to compute and map the overall HSI values (Figure 1). Each raster cell is considered as a potential nest site. Potential nesting habitat, SV1, evaluates if a raster cell in a map contains nesting habitat. The cell is assigned a value of 1.0 if it is classified as emergent wetland and 0.0 otherwise. Immediate nesting area, SV2, measures the availability of nesting habitat immediately surrounding the raster cell. It is measured as the percent of habitat within 120 m of the cell that is classified as emergent wetland. This SV reflects wetland size, where larger wetlands proportionally provide more nesting habitat than smaller ones, up to

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4.5 ha. For example, if a cell is surrounded by 75% wetland, SV2 is equal to 0.75. SV3, brooding area, is measured as the abundance of prairie, pasture, grassland, or other herbaceous open land found within 450 m of the potential nest site. If those types comprise at least 20% of the area, then SV3 is equal to 1.0. If the amount is lower, the cell receives a value proportionally lower, as the computed percentage is divided by 20%. For example, if those habitats comprise 10% of the area, SV3 is equal to 0.5. Wetland composition, SV4, is based on the abundance of wetlands of all types within 780 m of the potential nest site. This SV assigns larger values to areas with more abundant freshwater wetlands. All freshwater wetland types were included, because they can support foraging, roosting, and other activities and provide additional protective cover from disturbance further away from the nest. If the percentage of wetlands is >15%, then SV4 is equal to 1.0. If it is lower, the cell receives a value proportionally smaller. For example, if the percentage of wetlands is 6%, SV4 is equal to 0.4. Upland composition, SV5, is based on the abundance of grassland, prairie, pasture, cropland, or other herbaceous open land within 780 m of the potential nest site. Similar to SV4, if the percentage of suitable uplands is >15%, then SV5 is equal to 1.0. If it is lower, the cell receives a value proportionally smaller. For example, if the percentage of uplands is 7.5%, SV5 is equal to 0.5. Road proximity, SV6, is based on the distance between the potential nest site and nearest road. If the distance is >100 m, SV6 is equal to 1.0. Shorter distances receive proportionally smaller values. For example, if the distance is 90 m, then SV6 is equal to 0.9.

The six SVs are combined into an equation to compute overall HSI values. Multiplying SV1 by the remainder of the equation ensures that only cells containing nesting habitat receive HSI values greater than zero. Also, SV2 multiplied to ensure that large wetlands receive the largest values, while smaller wetlands reduce the overall HSI value proportionally to their size.
Next, the product of SV1 and SV2 is multiplied by a weighted average of SV3, SV4, and SV5, where SV3 is weighted by 2 to reflect the importance of adequate brooding habitat for successful reproduction. Finally, this intermediate value is multiplied by SV6, which has a similar effect of proportionally reducing the overall HSI values for sites near roads. The HSI equation is structured in such a way to ensure overall HSI values are constrained between 0 and 1. Any cell not classified as nesting habitat is calculated as 0.0, regardless of the other SVs. Optimal habitat (HSI = 1.0) is only identified when all individual SVs are also equal to 1.0. Values between 0 and 1 represent a range of marginal to moderate to high quality habitat. For example, using sample values from the previous paragraph describing the model, the overall HSI value for that cell would be: 

\[ 1 \times 0.75 \times \frac{(0.5 \times 2 + 0.4 + 0.5)}{4} \times 0.9 = 0.32. \]

In this case, habitat is marginal because of suboptimal amounts of wetlands, uplands, and herbaceous open lands.

We applied this updated model to Florida using 10-m resolution land cover data from the Florida Natural Areas Inventory (FNAI) published in 2018 to calculate SV1-SV5. We used road data from the US Census Bureau’s TIGER/Line database for 2018 to calculate SV6. We calculated the index using standard tools in ArcGIS v. 10.5 (ESRI, Inc.; Table 1).

**Estimation of maximum number of occupied nests**

Once nesting habitat for Florida sandhill cranes was identified, the number of breeding territories that can be supported was calculated given a specified spatial distance between neighbouring nests by using the ACLP. The ACLP determines the maximum number of nest sites that can be occupied such that no two sites are within a specified distance of one another. Although the ACLP has multiple formulations, the simplest formulation is described below.

\[ \text{Maximize} \]
(1) $K = \sum_{i \in I} x_i$

Subject to

(2) $x_i + x_j \leq 1, \forall_{i,j \in I}$ where $i \neq j$ and $d_{ij} \leq R$

(3) $x_i = \{0,1\}, \forall_i$

Where

$K$ = maximum number of occupied nest sites

$i$ = index of potential nest sites

$d_{ij}$ = distance between potential nest site $i$ and another site $j$

$R$ = minimum distance required between occupied nests

The objective function (1) maximizes the total number of potential nest sites selected to be occupied at one time. This simply represents a sum of all decision variables $x_i$, which identify whether a potential nest site is selected by the model (i.e. $x_i = 1$) or not (i.e. $x_i = 0$).

Constraints (2) prohibits locating any two nests within the restriction distance, $R$, of one another. These constraints work by ensuring if a nest site $x_i$ is selected by the model, then any nearby sites $x_j$ cannot be selected at the same time, as the the sum of their values must be less than or equal to 1. Constraints (3) impose binary integer restrictions on the decision variables $x_i$, forcing their values to be either 0 or 1. In practice, such problems are formulated as linear programs (typically a text files containing the complete sets of linear equations) and solved using commercial, open source solvers, or custom algorithms (see Tong and Murray 2012). In practice, they attempt to solve the objective function to optimality—or as close as possible.

Output records the value of the objective, values for all of the decision variables, and optimality gap (percentage the solution is guaranteed to be within the optimal solution).
We formulated the ACLP to estimate the maximum number of occupied nests in each county in Florida. Maximum numbers for the state were modelled separately, because summing the county values would overestimate totals due to boundary effects. For reference, a county map is included (Figure S1). As the ACLP is classified as an NP-complete combinatorial optimization problem, which means it can be very challenging to solve for large problems (Dimitrijević et al. 2013), we used an aggregation approach to reduce the problem size. Rather than solving the problem using 10-m raster cells as a potential nest sites, we reduced the problem by aggregating them to a grid of hexagons with a 100-m spacing between centroids (Downs et al. 2020). If a hexagon contained nesting habitat based on a minimum HSI value threshold, then its centroid was considered as a potential nest location. In practice, this means that the hexagon centroids represent centers of possible nesting territories, with those centers located no more than ~50 m from nesting habitat. This is a relatively negligible distance considering Florida sandhill crane home ranges average 447 ha (Nesbitt and Williams 1990). Maximum numbers of occupied nests were computed for each county, as well as the state overall, using four minimum HSI value thresholds: 0.3, 0.5, 0.7, and 1.0. These values represent a range of habitat quality from marginal to moderate to high quality to optimal, respectively. A restriction distance of 1000 m was applied for all scenarios, as that value approximates the average nesting density of 1.9 birds/km² for pairs in Florida (Bennett 1989). Using these values and inputs, the ACLP was formulated for each scenario in three steps: (1) identify potential nesting sites based on the specified minimum HSI threshold and compute the distance between them; (2) use a custom Python script to read the centroid identifiers and distances from a database and write the appropriate ACLP equations in lp format; and (3) solve the lp files using IBM CPLEX v. 12.9.0, a commercial optimization solver. Sample input and output files are available in supplementary
Data S1-S4. For all scenarios, the solver was initially run for a maximum of 5000 seconds on a Windows-based personal computer with 32GB of RAM. If the problem did not solve to optimality in that amount of time, then the problems were run on a Linux machine with an AMD Threadripper 16-core processor with 128GB RAM.

RESULTS

Mapping SV1 reveals that emergent marshes available for nesting Florida sandhill cranes are widespread across the state, although more dominant in the southern and central portions of the state (Figure 2a,b). The average value of 0.07 suggests that emergent marshes cover 7% of the state (Table 2). Herbaceous open lands for brooding are more abundant in central Florida, extending into the panhandle, and noticeably sparse in the south (Figure 2c). Other than the binary SV1 layer, this variable had the lowest layer average, suggesting it is the most limiting. Available upland habitats, including a variety of agricultural cover types, are abundant across the state, although sparse in the south and some parts of the panhandle (Figure 2d). Wetlands are abundant state-wide (Figure 2e). Road effects generally follow the distribution of cities in the state, with significant roadless areas found in rural areas (Figure 2f). When combined, overall HSI values reflect the spatial intersection of these habitat features. Although local variability is somewhat masked at the state-wide scale, optimal nesting habitat is concentrated in central Florida, with marginal quality habitat also abundant in the south (Figure 3). Nesting habitat is very sparse in the panhandle and other parts of northern Florida.

Optimal solutions for maximum numbers of occupied nests were found within 5000 s for all counties and the state using minimum HSI thresholds of 1.0 and 0.7. For a HSI threshold of 0.5, optimal solutions were found on the initial runs for all but Okeechobee County and the state. These were solved to optimality on subsequent runs on the higher performance computer. For
the 0.3 HSI threshold, optimal solutions were found on the initial runs for all but DeSoto, Glades, Hendry, Highlands, Okeechobee, Osceola, and Sarasota counties, but they also were solved to optimality on subsequent runs in less than one week of running time. However, the state-wide problem was terminated after one month of running time with an optimality gap of 0.78%.

Estimates of maximum occupied nests were largest for Polk, Osceola, Okeechobee, Hendry, and Highlands counties, all of which are located in the central part of the state (Table 3). For all counties, as the minimum HSI value is reduced, maximum nesting numbers increase substantially. For example, depending on the threshold, estimates for Pasco County ranged from 39 nests (HSI = 1) to 154 (HSI ≥ 0.7) to 246 (HSI ≥ 0.5) to 423 (HSI ≥ 0.3; Figure 4). State-wide estimates displayed a similar pattern ranging from 1794 nests (HSI =1) to 5540 (HSI ≥ 0.7) to 8723 (HSI ≥ 0.5) to 14530 (HSI ≥ 0.3). On average, county estimates were five times as large when comparing the 0.5 HSI threshold to 1.0, indicating the results are sensitive to the threshold specified. This is expected, since greater availability of habitat would be expected to accommodate larger numbers of nests. However, increases were not uniform between counties due to differences in both the quality and spatial distribution of nesting habitat.

**DISCUSSION**

Our HSI map displays the spatial distribution of Florida sandhill crane nesting habitat, identifying specific wetlands that may potentially support breeding pairs. Additionally, mapping individual SVs highlights habitats that may be limiting population growth and range expansion. Few cranes have been documented in the panhandle and northeast Florida, which can be explained largely by the lack of emergent marshes and limited brooding habitat. In the south, emergent marshes are abundant, but both brooding habitat and other uplands are sparsely distributed. However, central Florida supports all requisite habitat types, often in close proximity.
proximity to one another, supporting optimal habitat conditions for nesting in some locations. The most limiting factor appears to be herbaceous open lands for brooding, which reduces overall suitability in many local areas where emergent marshes, other wetlands, and cropland are abundant, even within central Florida.

Although the HSI map identifies potential nesting habitat, simply computing the area of habitat would not be a reliable indicator of potential population size, as it would not reflect the required spacing between neighboring territories. Conversely, estimates of maximum numbers of occupied nests obtained by solving the ACLP do reflect the spatial distribution of habitat and should be a reliable indicator of potential population size. However, as expected, estimates are sensitive to both the minimum HSI threshold and specified restriction distance. The distance has little effect at optimal HSI values but is substantial at lower thresholds. Despite this trend, the 1000-m spacing reflects the average observed in the state, so they are the most reasonable values to report. However, greater sandhill cranes have been observed nesting at much greater densities in Wisconsin (Barzen et al. 2016), so these estimates might be conservative. In terms of HSI threshold, a conservative approach is to use a minimum value of 0.7, which represents high quality. This ensures that potential nest sites are nearby a significant amounts of herbaceous open lands needed for brooding. Therefore, 5540 pairs represents a conservative estimate of the number of breeding pairs of Florida sandhill cranes that can be supported in Florida, with greater numbers possible if cranes will nest in marginal to moderate quality habitats or at greater densities than previously observed. In more optimistic scenarios, upward of 15,000 pairs could be supported, a much larger value than currently estimated by the Florida Fish and Wildlife Conservation Commission (2018).
A potential limitation is that GIS and optimization techniques are data and processing time intensive and require some level of training. Previous efforts to compute maximum numbers of occupied nests for greater sandhill cranes were completed only for relatively small, isolated management areas (Downs et al. 2008). However, our results demonstrate these problems are solvable on a state-wide scale with modest high performance computing resources. Only one of the state-wide scenarios did not solve to optimality, though the optimality gap was less than 1% which is a relatively small amount for this problem. For larger problems, alternative formulations of the ACLP can be used to improve solvability (Murray and Kim 2008). Future work might compare the availability of nesting habitat in Florida to other regions, or to repeat the analysis over different time periods to evaluate changes to nesting habitat availability.

Combined, the HSI map and nest occupancy estimates offer wildlife managers tools to identify where to find a species and predict potential population sizes. Given the Florida sandhill crane is currently state-listed as threatened, these outputs provide useful resources to guide a variety of research and management activities. For example, these maps might be used to guide population surveys, the results of which might be used to update breeding pair estimates if they are observed nesting at greater densities. Aerial surveys in high suitability nesting habitat or road surveys along upland habitats near nesting habitat could be conducted to locate breeding pairs (Hereford and Dedrickson 2018). Additionally, the HSI maps might also be used to identify crane habitats in need of protection or guide restoration efforts. For example, it may be possible to target grassland restoration efforts in areas where herbaceous open land is the only habitat missing. This activity that might be used to increase population sizes across the Florida landscape, especially in the south where wetlands are abundant.
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Any use of trade, product, website, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.
Supplemental Materials

Data S1. Python program used to generate linear programming (lp) files for the anti-covering location problem (ACLP). The ACLP can be formulated to calculate the maximum number of breeding bird pairs that can simultaneously occupy nests given that they both must be of some minimum quality and spaced some minimal distance apart. The program requires a csv file that records the distances between potential nest sites that are located less than that distance from one another. It outputs a text file in lp format that can be used with a commercial optimization solver. The user must specify the file path for both the input csv file and the output lp file in the program and the total number of potential sites for the problem. The program provided was used to calculate the spatial carrying capacity for Florida sandhill cranes in Alachua County, Florida.

Data S2. Sample csv file recording distances between potential nest sites. The csv file requires three columns: the identifier of the potential nesting site (“INPUT_FID”), the identifier for the nearby potential nesting site (“NEAR_FID”), and the distance between them (“DISTANCE”). The first column in the csv file records the record number but is not used by the program. The sample csv file provided was used as an input for the Python program in S1, representing potential nesting sites in Alachua County, Florida.

Data S3. A sample lp file generated from Python program S1 using csv file S2. This lp file records equations used to solve the anti-covering location problem, including the objectives (“Maximize”), constraints (“SUBJECT TO”), and binary decision variables (“BINARIES”). This lp file was used with csv file S2 to calculate the maximum number of nesting pairs for Alachua County, Florida, using IBM CPLEX.

Data S4. Shapefile representing locations of potential nest sites for sample problem from S1-S3. The GIS layer provides a spatial reference for mapping the locations of potential nest sites in the sample problem of calculating the maximum number of occupied Florida sandhill crane nests in Alachua County, Florida.

Figure S1. Reference map of counties in Florida.

Reference S1. Florida Fish and Wildlife Conservation Commission. 2013. A species action plan for the Florida sandhill crane. Tallahassee, Florida.

Reference S2. Latif QS, Saab VA, Haas JR, Dudley JG. 2018. FIRE-BIRD: A GIS-based toolset for applying habitat suitability models to inform land management planning. Gen. Tech. Rep. RMRS-GTR-391. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 74 p. 391.
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Table 1. Formulation of a Habitat Suitability Index (HSI) model that evaluates nesting habitat for Florida sandhill cranes *Antigone canadensis pratensis* based on six suitability variables (SVs). The HSI model was used to map potential nesting habitat for Florida sandhill cranes across the state of Florida using a geographic information system.

Table 2. Mean and standard deviation (SD) for suitability variables (SVs) and resulting habitat suitability index (HSI) layers used to map nest site suitability for Florida sandhill cranes *Antigone canadensis pratensis* (2018). The values are based on mapping potential nesting habitat for the entire state of Florida.

Table 3. Maximum numbers of occupied Florida sandhill crane *Antigone canadensis pratensis* nests for counties in Florida (2018) based on minimum habitat suitability index (HSI) values of 0.3, 0.5, 0.7, and 1.0 with a minimum separation distance of 1000 m. Maximum numbers of pairs were estimated using the anti-covering location problem, which calculates the maximum number of potential nest sites that can be simultaneously occupied given a minimum HSI value and a minimum separation distance.
Figures

Figure 1. Computation of a habitat suitability index model (HSI) for Florida sandhill cranes *Antigone canadensis pratensis* using six suitability variables (SVs) for a sample landscape: (a) SV1 potential nesting habitat, (b) SV2 immediate nesting area, (c) SV3 brooding area, (d) SV4 wetland composition, (e) SV5 upland composition, (f) SV6 road proximity, and (g) HSI overall suitability. Values for each grid cell in the map extend from 0.0 (unsuitable conditions) to 1.0 (optimal conditions). The overall HSI values measure suitability for nesting.

Figure 2. Map of suitability variables (SVs) for Florida sandhill cranes *Antigone canadensis pratensis* for Florida in 2018: (a) SV1 potential nesting habitat, (b) SV2 immediate nesting area, (c) SV3 brooding area, (d) SV4 wetland composition, (e) SV5 upland composition, and (f) SV6 road proximity. Values for each grid cell in the map extend from 0.0 (unsuitable conditions) to 1.0 (optimal conditions) for each SV.

Figure 3. Map of habitat suitability index (HSI) values for Florida sandhill cranes *Antigone canadensis pratensis* in Florida (2008). Values for each location extend from 0.0 (unsuitable) to 1.0 (optimal nesting habitat). The HSI map was used to identify potential nesting habitat across the state.

Figure 4. Optimal nesting distribution for Florida sandhill cranes *Antigone canadensis pratensis* in Pasco County, Florida (2008), for minimum habitat suitability index (HSI) thresholds of 1.0 (a) and 0.5 (b) with a restriction distance of 1000 m. The locations of selected nesting sites represent the maximum number that can be occupied simultaneously given those HSI and minimum distance thresholds, as determined by solving the anti-covering location problem.

Figure 5. Maximum number of breeding pairs of Florida sandhill cranes *Antigone canadensis pratensis* that can occupy nesting habitat in Pasco County, Florida (2018), across a range of minimum habitat suitability index (HSI) values and restriction distances. Maximum numbers of breeding pairs were calculated by solving the anti-covering location problem using minimum HSI and separation distance thresholds.
| Suitability Variable (SV)        | Description                                                                 | Equation                                                                 |
|---------------------------------|-----------------------------------------------------------------------------|--------------------------------------------------------------------------|
| Potential Nesting Habitat (SV1) | Suitability of a focal cell to support a nest                               | = 1 if focal cell is emergent wetland or wet prairie = 0, otherwise       |
| Immediate Nesting Area (SV2)    | Suitability of nesting habitat immediately surrounding cell (120 m x 120 m area) | = % emergent wetland or wet prairie in area surrounding focal cell        |
| Brooding Area (SV3)             | Suitability of brooding habitat (grassland, prairie, or pasture) within close proximity (area within 450 m radius of focal cell) | = 1 if % suitable brooding habitat within area is greater than 20% = % suitable brooding habitat divided by 20%, otherwise |
| Wetland Composition (SV4)       | Wetland (any type) availability in the surrounding landscape (area within 780 m radius of focal cell) | = 1 if % wetland within area is greater than 15% = % wetland divided by 15%, otherwise |
| Upland Composition (SV5)        | Suitable upland types (grassland, prairie, pasture, cropland, or other herbaceous openland) in the surrounding landscape (area within 780 m radius of focal cell) | = 1 if % suitable uplands types is greater than 15% = % suitable upland types divided by 15%, otherwise |
| Road Proximity (SV6)            | Distance to nearest road (in meters)                                        | = 1 if distance to nearest road is greater than 100 = distance to road divided by 100, otherwise |
| Habitat Suitability Index (HSI) | Overall suitability as derived from individual suitability variables        | = SV1 × SV2 × ((SV3×2) + SV4 + SV5)/4) × SV6                            |
Table 2.

| Variables | M  | SD  |
|-----------|----|-----|
| SV1       | 0.07 | 0.25 |
| SV2       | 0.19 | 0.27 |
| SV3       | 0.16 | 0.34 |
| SV4       | 0.51 | 0.45 |
| SV5       | 0.34 | 0.44 |
| SV6       | 0.85 | 0.30 |
| HSI       | 0.02 | 0.08 |
Table 3. Maximum numbers of occupied Florida sandhill crane nests for counties in Florida (2008) based on minimum habitat suitability index (HSI) values of 0.3, 0.5, 0.7, and 1.0 with a minimum separation distance of 1000m.

| County | HSI >= 0.3 | HSI >= 0.5 | HSI >= 0.7 | HSI = 1.0 | County | HSI >= 0.3 | HSI >= 0.5 | HSI >= 0.7 | HSI = 1.0 |
|--------|-----------|------------|------------|-----------|--------|-----------|------------|------------|-----------|
| Alachua| 160       | 84         | 44         | 12        | Lee    | 171       | 91         | 48         | 16        |
| Baker  | 6         | 2          | 0          | 0         | Leon   | 85        | 19         | 3          | 0         |
| Bay    | 3         | 0          | 0          | 0         | Levy   | 86        | 39         | 20         | 3         |
| Bradford| 11       | 3          | 1          | 0         | Liberty| 1         | 0          | 0          | 0         |
| Brevard| 241       | 105        | 58         | 25        | Madison| 168       | 8          | 38         | 11        |
| Broward| 50        | 9          | 4          | 0         | Manatee| 451       | 279        | 168        | 50        |
| Calhoun| 8         | 1          | 1          | 0         | Marion | 293       | 134        | 67         | 5         |
| Charlotte| 517     | 359        | 244        | 91        | Martin | 379       | 247        | 158        | 25        |
| Citrus | 155       | 66         | 31         | 11        | Miami-Dade| 88       | 30         | 4          | 1         |
| Clay   | 20        | 5          | 0          | 0         | Monroe | 32        | 10         | 2          | 1         |
| Collier| 376       | 191        | 119        | 41        | Nassau | 4         | 1          | 0          | 0         |
| Columbia| 23       | 6          | 3          | 2         | Okaloosa| 9         | 3          | 2          | 0         |
| DeSoto | 662       | 477        | 325        | 114       | Okeechobee| 1106     | 829        | 587        | 205       |
| Dixie  | 10        | 3          | 2          | 0         | Orange | 181       | 46         | 19         | 5         |
| Duval  | 10        | 2          | 0          | 0         | Osceola| 1213      | 815        | 539        | 209       |
| Escambia| 6         | 0          | 0          | 0         | Palm Beach| 262      | 39         | 5          | 1         |
| Flagler| 18        | 7          | 4          | 2         | Pasco | 423       | 246        | 154        | 39        |
| Franklin| 2         | 0          | 0          | 0         | Pinellas| 7         | 3          | 2          | 0         |
| Gadsden| 21        | 4          | 0          | 0         | Polk   | 1249      | 763        | 479        | 149       |
| Gilchrist| 43       | 14         | 7          | 3         | Putnam | 96        | 36         | 15         | 4         |
| Glades | 850       | 527        | 325        | 93        | St. Johns| 3        | 1          | 0          | 0         |
| Gulf   | 3         | 0          | 0          | 0         | St. Lucie| 239      | 144        | 82         | 19        |
| Hamilton| 35        | 14         | 4          | 0         | Santa Rosa| 12       | 1          | 0          | 0         |
| Hardee | 540       | 329        | 182        | 40        | Sarasota| 457       | 328        | 232        | 72        |
| Hendry | 1034      | 715        | 507        | 183       | Seminole| 75        | 29         | 13         | 4         |
| Hernando| 110      | 62         | 34         | 11        | Sumter | 372       | 252        | 155        | 35        |
| Highlands| 1007    | 719        | 518        | 211       | Suwannee| 33        | 10         | 3          | 1         |
| Hillsborough| 315   | 167        | 113        | 44        | Taylor | 35        | 9          | 5          | 1         |
| County        | Holmes | Indian River | Jackson | Jefferson | Lafayette | Lake  |
|---------------|--------|--------------|---------|-----------|-----------|-------|
| Union         | 67     | 187          | 98      | 72        | 11        | 668   |
| Volusia       | 8      | 44           | 29      | 22        | 4         | 408   |
| Wakulla       | 2      | 19           | 11      | 7         | 3         | 250   |
| Walton        | 5      | 144          | 0       | 3         | 0         | 63    |
| Washington    | 1      | 52           | 0       | 14        | 0         |       |
|               | 0      | 24           | 0       | 56        | 6         |       |
|               | 0      | 2            | 0       | 2         | 1         |       |
The graph shows the relationship between HSI (Horizontal to Vertical) and Breeding Pairs for different distances. The distances marked are 500 m, 750 m, 1000 m, 1250 m, and 1500 m. The trend line indicates a decrease in breeding pairs as HSI increases, with distances having a more significant impact at higher HSI values.