

U.S. Fish & Wildlife Service

Habitat suitability of historical Mississippi sandhill crane nest sites 1991-2022

Biological Technical Publication
BTP-101-2026



Photo credit:
Scott G. Hereford

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Henry W. Woolley¹

Scott G. Hereford²

1. U.S. Fish and Wildlife Service, National Wildlife Refuge System
2. U.S. Fish and Wildlife Service, National Wildlife Refuge System (retired)

Author contact information:**Henry W. Woolley**

U.S. Fish and Wildlife Service
Northeast Regional Office
300 Westgate Center Drive
Hadley, MA 01035
Phone: 413-253-8654
E-mail: henry_woolley@fws.gov

Scott G. Hereford

U.S. Fish and Wildlife Service (retired)
Mississippi Sandhill Crane National
Wildlife Refuge
7200 Crane Land
Gautier, MS 39533

Recommended Citation:

Woolley, Henry W. and Scott G. Hereford. 2026.
Habitat suitability of historical Mississippi sandhill
crane nest sites 1991-2022. U.S. Department of the
Interior, Fish and Wildlife Service, Biological
Technical Publication FWS/BTP-101-2026,
Shepherdstown, West Virginia.

DOI: 10.3996/btp46233

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About the Series

The purpose of the Biological Technical Publication series is to provide a streamlined and accessible platform for employees of the U.S. Fish and Wildlife Service and their collaborators to technical documents such as (but not limited to) preliminary reports, guides, assessments, management approaches, and project syntheses. The report series provides immediate access to science by the USFWS to the broader conservation community.

The Biological Technical Publication report series was initiated in 1999 and relaunched in 2025 with a focus on sharing USFWS authored reports. It is published by the USFWS Conservation Library at the National Conservation Training Center in Shepherdstown, West Virginia.

Previous report numbering systems (1999-2021) for the series referenced the USFWS region. The reports beginning in 2025 are numbered sequentially, starting with 101, with the year included for reference.

Reports undergo technical review only. The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Abstract

Certain areas of Mississippi Sandhill Crane National Wildlife Refuge have consistently produced more Mississippi sandhill crane nests and chicks than others, even as the crane pair nesting in those areas have changed. Understanding the drivers of this pattern is an important step toward achieving the goal of a self-sustaining wild Mississippi sandhill crane population. By adapting a Habitat Suitability Index (HSI) for Florida sandhill cranes to Mississippi sandhill cranes, we examined whether differential habitat suitability of nest sites explained the historical variation in nesting production across the refuge.

Between 1991 – 2022, mean HSI of geolocated nest sites ($n = 554$, $X = 0.52$) was significantly higher than that of an equal number of random points across the refuge

($X = 0.36$). This indicates that our HSI model corresponds to historical nest site choice. However, fledging rate as measured by number of chicks surviving to fledge divided by number of nests did not differ between high and low HSI nest sites, suggesting that factors outside of habitat suitability contribute to chick survival.

Background

Mississippi Sandhill Crane National Wildlife Refuge (MSCNWR, established 1975) consists of 7,810 ha of pine savanna and flatwoods habitat managed primarily to maintain high quality habitat for Mississippi sandhill cranes (*Antigone canadensis pulla* [Formally *Grus canadensis pulla*]) in Jackson County, MS (U.S. Fish and Wildlife Service 2007). The Mississippi sandhill crane (MSCR) population is a distinct nonmigratory subspecies (). The MSCR population fell to a low of 40 individuals during the 1960s (Valentine and Noble 1970), prompting the establishment of a captive breeding program. Beginning in 1965, the US Fish and Wildlife Service's Patuxent Wildlife Research Center raised Mississippi sandhill cranes in captivity; the captive population was transferred to facilities in Louisiana and Florida in the mid-1990s. Captive-reared MSCR began to be released on the refuge in 1981, which led to an increase in the refuge population from 50 MSCR in 1981 to 135 in 1993 (Gee and Hereford 1995). With annual supplementation from captive-reared juveniles, protection from predators, and intensive habitat management, the MSCR population increased to over 170 by the end of 2023, (Hereford and Dedrickson 2025). However, the goal of a self-sustaining wild MSCR population remains elusive. High rates of chick mortality perpetuate the need for annual releases of captive-reared juveniles to supplement the population.

Maintenance of wet pine savanna habitat on MSCNWR is achieved by vegetation management including prescribed burning and mechanical mulching, which combats woody encroachment into the savannas. The refuge is divided into management compartments, which are burned on a rotating schedule, with the goal of burning each compartment at least once every 2-3 years (USFWS 2007). One management compartment, G-06, has consistently produced more nests and chicks than any other area of the refuge (Table 1). Other studies (Woolley 2021) have explored habitat and climate drivers of MSCR population dynamics across the refuge, but have not revealed a mechanism for this observed differential fledging success. Understanding the drivers of this pattern would aid in managing the habitat to promote a self-sustaining wild MSCR population.

Table 1. Total geolocated nests and chicks fledged by management compartment, 1991 – 2022.

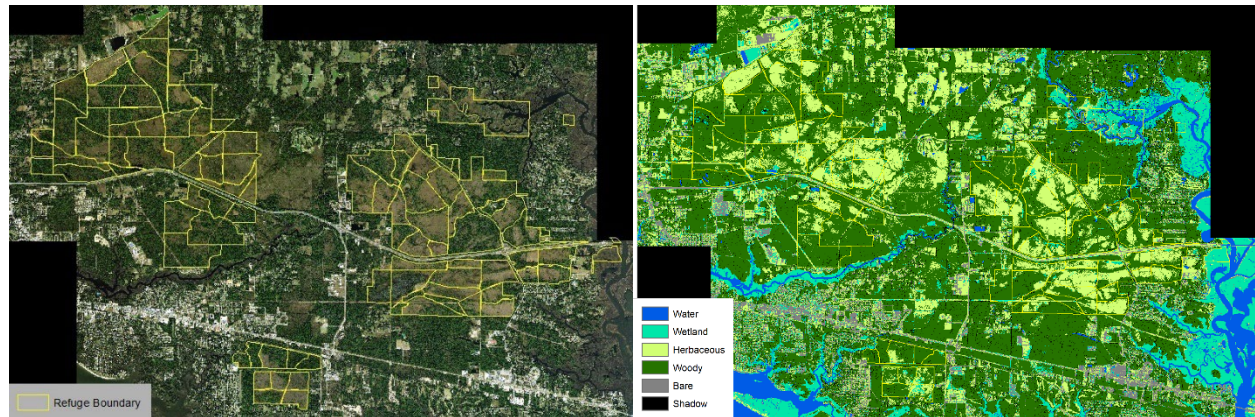
Compartment	Total nests	Total fledged	Fledged rate
G-06	97	23	0.24
G-12	55	12	0.22
O-06	49	11	0.22
G-15	48	8	0.17
G-14	43	7	0.16
O-03	37	5	0.14
G-11	36	3	0.08
G-02	35	4	0.11
O-05	32	1	0.03
G-08	27	0	0.00
G-03	26	2	0.08
F-03	20	2	0.10
F-02	20	0	0.00
O-16	18	0	0.00
O-02	14	3	0.21
O-10	14	3	0.21
G-16	13	0	0.00
G-19	11	2	0.18
G-05	10	2	0.20

Methods

Landcover classification

A Habitat Suitability Index (HSI) can be used to model the suitability of habitat for a species. Downs et al. (2020) created an HSI for Florida sandhill cranes (*Antigone canadensis pratensis*) that we have adapted for MSCR to explore whether habitat suitability is related to observed nesting patterns. Differences in landcover classification rasters and behavioral patterns of cranes between the Mississippi and Florida study systems necessitated adjustments of the Suitability Variables (SVs) used by Downs et al. (2020). Downs et al. (2020) used an existing landcover classification raster for the state of Florida to develop SVs which describe the suitability of habitat for crane use and are weighted and combined to form the HSI model. An existing landcover classification raster did not exist for MSCNWR so we performed supervised classification (following Price 2016) of National Agriculture Imagery Program (NAIP) satellite images of the refuge for the years 2012, 2014, 2016, 2018, 2020, and 2021. These were the years available during the study period. We classified each available year so that the average habitat conditions during the study period could be captured. We used Esri ArcGIS Desktop version 10.8.2 (ESRI 2021) for image classification and all other geoprocessing functions. Figure 1 shows a side-by-side comparison of NAIP imagery and our classification raster for 2018. See Appendix 1 for a detailed landcover classification workflow.

Figure 1. Side-by-side comparison of NAIP satellite imagery (left) and landcover classification (right) for MSCNWR in 2018.



Suitability variables

Our adaptations of the SVs and HSI equation used by Downs et al. (2020) are described in Table 2. SV values are set to range from 1.0 (highly suitable) to 0 (not suitable), so HSI values also fall within that range. Table 2 references focal cells, meaning a cell (or pixel) in a landcover classification raster. We used the Reclassify Raster geoprocessing tool to assign a value to each pixel in the classification raster for each NAIP image, according to the corresponding SV value. This resulted in a separate raster for each SV for each year satellite imagery was available. SV1 was defined as potential nesting habitat. At MSCNWR MSCR pairs have been known to nest in a variety of habitat types including water, wetland, herbaceous vegetation, and woody vegetation. We defined potential nesting habitat as any habitat that is not bare ground. To include SV1 in the HSI model, we reclassified each pixel in the landcover classification raster to have a value of 1 if not bare ground, and 0 if bare ground. SV2 quantified the percent of wetland or herbaceous vegetation in the immediate area (120 m x 120 m) surrounding each potential nest site (each pixel) in the classification raster.

Table 2. Suitability variables (SVs) and Habitat Suitability Index (HSI) model estimating the quality of nesting habitat for Mississippi sandhill cranes, adapted from the work of Downs et al. (2020).

Suitability variable (SV)	Description	Value
SV1 Potential nesting habitat	Ability of a focal cell to support a nest	= 1 if focal cell is not bare ground = 0 if focal cell is bare ground
SV2 Immediate nesting area	Suitability of habitat immediately surrounding cell (120 m x 120 m)	= % wetland or herbaceous vegetation
SV3 Brooding area	Availability of brooding habitat (herbaceous vegetation) within 450 m radius	= 1 if % brooding habitat > 20% = % brooding habitat ÷ 20%, otherwise
SV4 Wetland area	Wetland availability within 780 m radius	= 1 if % wetland > 15% = % wetland ÷ 15%, otherwise
SV5 Upland area	Herbaceous vegetation within 780 m radius	= 1 if % herbaceous vegetation > 15%, = % herbaceous vegetation ÷ 15%, otherwise
SV6 Road proximity	Distance to nearest road (m)	= 1 if distance is > 200 m = distance ÷ 200 m, otherwise
Habitat Suitability Index (HSI)	Weighting SVs and combining them to model overall habitat suitability	$= SV1 \times SV2 \times \frac{(SV3 \times 2) + SV4 + SV5}{4} \times SV6$

To generate the SV2 raster, we first reclassified the classification raster to assign each pixel that was wetland or herbaceous vegetation a value of 1, and all others a value of 0. Then we used Focal Statistics in the Neighborhood geoprocessing toolset to assign each pixel in the SV2 raster a value equal to the percent of wetland or herbaceous vegetation in the designated area around the pixel. The value of SV3 was conditional, based on the percentage of herbaceous vegetation within a 450 m radius of each focal cell. The cell was assigned a value of 1 if the percentage of herbaceous vegetation was greater than 20%, and a value equal to the percentage of herbaceous vegetation divided by 20%, otherwise. This effectively provided a threshold (20% herbaceous vegetation) above which habitat suitability did not increase. To achieve this, we first reclassified the classification raster to assign herbaceous vegetation a value of 1 and all other landcover types a value of 0. Then we used Focal Statistics in the Neighborhood geoprocessing toolset to assign each pixel a value equal to the percentage of herbaceous vegetation in the surrounding area. Then we used the Calculate Raster function with the appropriate conditional statement to generate the SV3 raster. We followed a similar procedure for SV4, which was based on wetland percentage within a 780 m radius of the focal cell and a threshold of 15%, and for SV5 which was based on herbaceous vegetation within a 780 m radius of the focal cell and a threshold of 15%. To generate the SV6 raster, we used the Euclidian Distance function in the Distance toolset to assign each pixel a value equal to the distance in meters from the nearest road. We used the TIGER/Line dataset for road location. We only included through roads and increased the distance to 200 m from the 100 m distance Downs et al. (2020) used. Then we used the Calculate Raster function using the SV6 conditional statement to generate the SV6 raster.

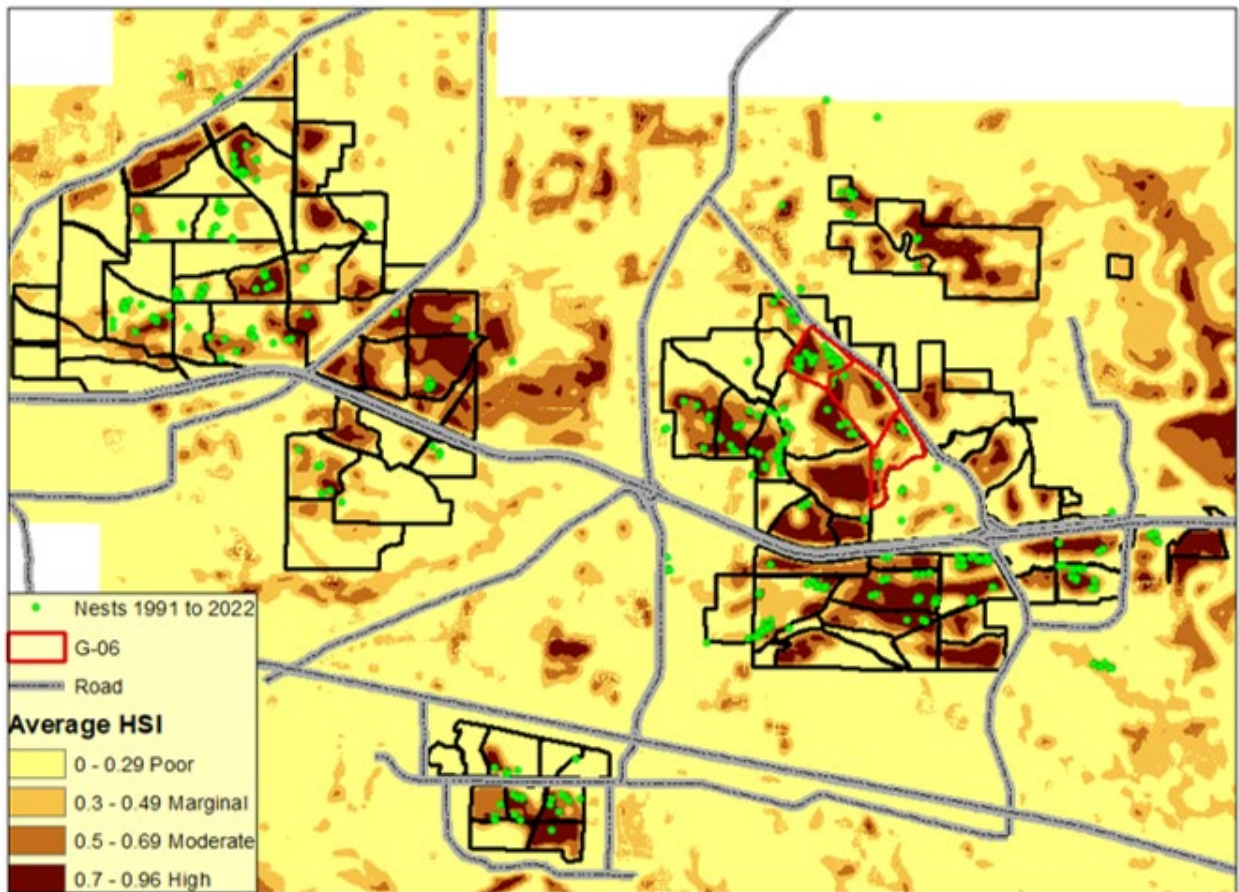
Habitat suitability index

Once we had SV rasters for each year, we used Map Algebra to multiply them together according to the HSI equation, which resulted in an HSI raster for each year. We then averaged the HSI rasters to create a combined HSI raster, which represented the mean HSI during the study period (Figure 2). We followed Downs et al. (2020) for defining HSI values from 0 – 0.29 as poor habitat, 0.3 – 0.49 as marginal habitat, 0.5 – 0.69 as moderate habitat, and 0.7 – 1.0 as high-quality habitat.

Correlation to nesting and fledging

To explore the relationship between nest sites and HSI, we imported the locations of geolocated nests from 1991 – 2022 ($n = 554$, Figure 2). We used binary regression to test whether HSI was correlated to fledging outcomes. We used chi-square tests to compare fledging rates (defined as the number of nests that produced chicks that survived to fledge divided by the total number of nests) between nests at poor ($HSI < 0.3$) and better than poor sites, between poor and marginal or better ($HSI \geq 0.5$) sites, between poor and high quality ($HSI \geq 0.70$) sites, and between bottom half ($HSI \leq 0.56$) and top half sites. We used a z-test to compare the mean HSI values of nest locations to an equal number of random points across the refuge. All statistical analyses were carried out in R version 4.3.1 (R Core Team 2021).

Figure 2. Combined HSI raster representing mean HSI generated from NAIP imagery for the years 2012, 2014, 2016, 2018, 2020, and 2021. Geolocated nest sites from 1991 to 2022 are shown in green, and management compartment G-06 is highlighted in red.



Results

The average HSI values at MSCNWR during the study period ranged from 0 to 0.96. There were 554 geolocated nests from 1991 – 2022, with 60 of those nests producing a total of 67 chicks that survived to fledge. HSI values at nest sites ranged from 0.03 to 0.87, and HSI values at nest sites that fledged chicks ranged from 0.09 to 0.81. Binary regression indicated that HSI was not correlated to whether a nest produced chicks that survived to fledge. Whether a nest produced chicks that survived to fledge will be abbreviated going forward as “did fledge”. Chi-square analyses indicated there were no differences in fledging rates between poor ($HSI < 0.3$) and better than poor quality nest sites, between poor and marginal or better quality ($HSI \geq 0.5$) nest sites, between poor and high quality ($HSI \geq 0.70$) nest sites, and between bottom half ($HSI \leq 0.56$) and top half quality nest sites. However, a z-test comparing the mean HSI value at nest sites to the mean HSI value at an equal number of random points across the refuge indicated that geolocated crane nest sites occurred at significantly higher-quality HSI locations. Results of statistical analyses are summarized in Table 3.

Table 3. Results of statistical analyses exploring relationships between HSI and geolocated nest sites at MSCNWR, 1991 – 2022. Bold font indicates a statistically significant relationship.

Statistical test	Variables (dependent; independent) or comparison if chi-squared/z-test	Results
Binary regression	Did fledge ; HSI	$\beta = 0.09, R^2 = 0.002, F(1, 552) = 2.13, p = 0.15$
Chi-square	Fledging rate; poor HSI (< 0.3); better than poor HSI (≥ 0.3)	$\chi^2(1, 554) = 2.98, p = 0.08$
Chi-square	Fledging rate; poor HSI (< 0.3); marginal or better HSI (≥ 0.5)	$\chi^2(1, 554) = 3.24, p = 0.07$
Chi-square	Fledging rate; poor HSI (< 0.3); high HSI (≥ 0.7)	$\chi^2(1, 554) = 2.03, p = 0.15$
Chi-square	Fledging rate; bottom half HSI (≤ 0.56); top half HSI	$\chi^2(1, 554) = 0.67, p = 0.41$
Z-test	HSI; nest sites; random	$t(554) = 12.24, \text{mean HSI (nest)} = 0.52, \text{mean HSI (random)} = 0.36, p < 2.2 \times 10^{-16}$

Discussion

HSI at geolocated nest sites was significantly higher than at an equal number of random points across the refuge. This suggests that our HSI model reflects actual habitat quality as perceived by Mississippi sandhill cranes. However, HSI was not correlated to fledging rates, which indicates that those are governed by other factors. HSI values in management unit G-06 appear similar to many other areas across the refuge, thus HSI mapping did not illustrate any notable difference between more- and less-productive areas of the refuge. Some management units were fuller of high-quality habitat than G-06, without producing as many fledglings. We did not conduct further analysis to determine in what other ways these management units differ from G-06. It is possible the sampling bias described below led to an under-representation of geolocated nests in management units other than G-06, which is generally open and easy to survey with lots of wetland edge habitat. However, it is unlikely that fledglings are missed during year-round monitoring. Individual pair behavior, proximity to ponds, working fields, and captive release sites may also play a role in increasing recruitment. Some pairs are more successful than others at provisioning and protecting chicks; only a relatively small percentage have fledged chicks in more than one year.

MSCR use ponds for protection from ground predators, roosting, drinking, and as nest sites. G-06 has at least four ponds. G-12 has three territories built around the edge of the Perigal Swamp and its ponded edges. Sandhill cranes are known to choose low grassy areas for foraging and seem to prefer the 18 “working fields” totaling 182 ha. G-06 has two working fields either within or adjacent to the unit. G-12 includes one. Additionally, captive-reared MSCR tend to nest not far from their release site. The first several years of releases occurred in G-05 (near G-06), building up the population in that area in the 1980s and 1990s and eventually producing nesting adults. G-12, O-06, and F-02 also include release sites, and

ground predator protection offered by the Ocean Springs Pen within O-06 likely contributed to the number of chicks fledged from this unit. For our purposes, developing an HSI which could be used to characterize good quality MSCR habitat was adequately useful to identify new suitable habitat to release MSCR and fulfill management objectives.

Sampling bias

Because of time and staff constraints, not every nest at MSCNWR is geolocated each year. Nests that are geolocated are typically those that are relatively easy to access, more visible, or are in locations where MSCR are known to nest year after year. This likely led to an overrepresentation of nests in ponds and at the edge of wetlands, and an underrepresentation of nests in open savanna or woody areas. Thus, geolocated nests are not representative of the total distribution of nests across the refuge. From 1998 – 2012, refuge staff had the ability to do nest surveys by helicopter, which likely led to a more representative sample of nest locations across the refuge during that period. With a jump in nesting pairs after 2017, reduced staff, and fewer adults with working VHF radios, a smaller portion of nests were geolocated.

Future work

Future areas of research that may provide insight into observed patterns of differential nesting and fledging across the refuge include further examination of habitat characteristics, as well as examination of the nesting cranes themselves. Generating average HSI values for each management unit would allow further examination of the relationship between HSI and nesting and fledging success. Introducing ponds as an additional SV to the HSI could be used to explore the effect that the presence of ponds has on nesting and fledging. Canopy height models generated via LiDAR data can be used to differentiate between vegetation with similar spectral reflectance characteristics which evades detection using satellite image classification alone. Machine learning techniques such as random forest could be used to build a competing HSI model by using the habitat characteristics surrounding known nesting locations to train the model. The competing HSI models could be compared by testing goodness-of-fit to see which model best captures observed patterns of nesting and fledging.

MSCR are long-lived and some pairs are likely more skilled at provisioning young and protecting them from predators than others. Tracking the success of each MSCR pair while controlling for HSI could reveal the size of a parent effect. Tracking parents could also reveal the propensity of cranes to nest in close proximity to the refuge area in which they were released.

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Appendix 1: Landcover classification workflow

ArcGIS Desktop 10.8.2

Following Mastering ArcGIS 7th Edition (Price 2016), especially Chapters 10 and 11, and Esri geoprocessing documentation.

1) We took MARIS NAIP IR Images for 2021, 2020, 2018, 2016, 2014, 2012.

https://maris.mississippi.edu/HTML/DATA/data_Aerial/NAIP/NAIP.html#gsc.tab=0

Refuge quadrants:

3008826_se_16

3008834_ne_16

3008834_nw_16

3008834_se_16

3008835_ne_16

3008835_nw_16

3008835_se_16

3008835_sw_16

3008836_nw_16

3008836_sw_16

Turn on Spatial Analyst

Customize > Extensions from main menu toolbar.

Check box to activate Spatial Analyst

List by drawing order in Table of Contents

Create geodatabase to work in

Catalog > Folder Connections > MSCNWR > R click > New > File Geodatabase

Name: [year].gdb (e.g. 2012.gdb)

Environment Settings

Geoprocessing > Environments from main menu bar

Expand Workspace

Set Current Workspace and Scratch Workspace to [year].gdb

Expand Processing Extent

Set Extent drop-down to *Default*

Combine using Mosaic to New Raster Tool:

Arc Toolbox > Data Management Tools > Raster > Raster Dataset > Mosaic to New Raster.

Input Rasters: All 10 tiles

Location: [year].gdb

Name: MosaicRast[year]

#don't put numbers at beginning or it won't work

#when storing in .gdb don't add file extension

Spatial reference: NAD_1983_UTM_Zone_16N

Cell size: 1

Number of bands: 4

#Make sure processing extent is set to default. Also make sure Cell Size matches raster resolution.

Geoprocessing

Expand Processing Extent

Set Extent drop-down to *Same as layer MosaicRaster*

Add Refuge Compartments Layer.

Set projection to NAD_1983_UTM_Zone_16N

Buffer then Clip to reduce classification area but include all nests, including 780 m buffer around refuge boundary for HSI.

Analysis Tools > Proximity > **Buffer**

Input Features: Minor Management Compartment
Output Feature Class: Refuge Layers\boundarybuffer.shp
Distance: Linear Unit 780 m
Dissolve Type: All

Data Management Tools > Raster > Raster Processing > **Clip**

Clip by boundarybuffer layer (can use this for all years because it doesn't change.)

Input Raster: MosaicRast[year]

Output Extent: boundarybuffer

[year].gdb\Clip_[year]

Geoprocessing

Processing Extent

Set Extent drop-down to *Same as layer Clip_[year]*

2) Classification:

Data Exploration/Preprocessing:

Band data and training samples must follow normal distribution.

Add each band to map. Check distribution for each individual band using Histogram in Spatial Analyst Toolbar.

Check distribution for the training samples using the Training Sample Manager Show Histograms.

Train classes. 4 bands so documentation recommends each class should be between 40 and 400 pixels. We need larger training samples because that helps distinguish between similar classes like water, wetland, woody, and shadow; and bare. In our experience ArcGIS Desktop may freeze if the training samples are too large.

6 classes:

1. Water

2. Potential nesting habitat

Wetland

Downs et al. (2020) use emergent wetland, but we were unable to differentiate between wetland types, so we just use any wetland.

3. Brooding area

Herbaceous vegetation

4. Woody vegetation

Necessary to differentiate between herbaceous and woody vegetation

5. Bare

6. Shadow

Necessary to differentiate between water, shadow, and road. Important to closely observe shadow classification to avoid overlap between other classes, esp. wetland, water, and shadow.

3) Evaluate samples to see if there is enough separation between the classes.

The information we were able to find online (ArcGIS documentation and YouTube training videos) makes this process seem entirely subjective.

We skipped this because it is subjective and causes ArcGIS to crash if using larger training samples which we found to be necessary.

4) Create the signature file.

We had difficulty saving signature file. Necessary to save to Desktop.

5) Run Maximum Likelihood Classification

Image Classification Toolbar > Classification > Maximum Likelihood Classification.

Input raster bands: Clip_[year]

Input Signature File: [year].sig

Output Classified Raster: [year]_max

This part is finicky. Saving to Documents file worked.

Once classification layer is added to map, change class colors to match training sample.

Properties > Symbolology > Import...

The first classification iteration will have some misclassification, especially water, wetland, and shadow, among other misclassifications. Keep adding to training samples and reclassifying until classification stops improving.

Proceed to postprocessing.

7) Postprocessing

Note: a lot of what postprocessing does is remove isolated or small groups of pixels and envelops them into the surrounding landcover type. The goal should be to clean up the classification raster without losing isolated landcover features such as shrubs.

a. Filtering: removes isolated pixels, aka “noise.”

Use Majority Filtering Tool

Spatial Analyst Tools > Generalization Toolset > Majority Filter

Input: classification layer (last filtered if iterating filtering)

Number Neighbors: 4

Majority_definition: Filter

The output raster will stabilize (no longer change) after a few runs of Majority Filter. We ran it three times.

b. Smoothing Class Boundaries: clumps and smooths ragged edges. Increases spatial coherency; adjacent regions may become connected.

Use Boundary Clean Tool

Spatial Analyst > Generalization > Boundary Clean

Input: Majority filter layer (last iteration)

Name: Boundary

Use default values.

c. Generalize Output: removing small isolated regions

i) Region Group Tool

Spatial Analyst > Generalization > Region Group

Input: Boundary

Output: RegionGroup

Use default values

Open Attribute Table to see Count (pixels) of every item (blob) on the raster.

#10 pixels was appropriate for our needs. Can use select by attribute Count <= 10 to visualize those areas.

ii) Set Null Tool

Spatial Analyst > Conditional > Set Null

Input: RegionGroup

Expression: Count <= 10

Input false raster: 1

Name: SetNull

iii) Nibble Tool

Spatial Analyst > Generalization > Nibble

Input: Boundary

Input mask: SetNull

Name: landcover[year]

Keep the other fields default

This is the end of the landcover classification workflow, which will generate a landcover classification raster that can be used to generate Suitability Variables for a Habitat Suitability Index model using Calculate Raster geoprocessing.