PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Whooping Crane Riverine Roost Site Selection Update

PLATTE RIVER
RECOVERY IMPLEMENTATION PROGRAM

Prepared by staff of the Executive Director's Office for the Governance Committee of the Platte River Recovery Implementation Program

February 2024

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LIST OF ACRONYMS

AHR	Associated Habitat Reach
AL	Alfalfa
AMP	Adaptive Management Plan
AW	Agricultural Wetland
BQ	Big Question
CO	Corn
CWS	Canadian Wildlife Service
DE	Development
EBQ	Extension Big Question
EDO	Executive Director’s Office
ft	Feet
GAM	Generalized Additive Model
GR	Grassland
HEC-RAS	Hydrologic Engineering Center’s River Analysis System
ISAC	Independent Science Advisory Committee
LiDAR	Light Detection and Ranging
mi	Mile
MM	Meadow Marsh
NE	Nebraska
NF	Nearest Forest
NRCS	Natural Resource Conservation Service
NWI	National Wetland Inventory
OA	Other Agriculture
PRRIP	Platte River Recovery Implementation Program, or Program
SO	Soybeans
SW	Sand and Water
TAC	Technical Advisory Committee
TCW	Total Channel Width
UOCW	Unobstructed Channel Width
UFCW	Unforested Corridor Width
USDA	United States Department of Agriculture
USFWS	United States Fish and Wildlife Service
WC-3	Whooping Crane Hypothesis #3

EXECUTIVE SUMMARY

E.1 Why are we performing an updated analysis of riverine roost site selection for whooping cranes?

The Platte River Recovery Implementation Program (PRRIP or Program) is charged with providing suitable whooping crane roosting habitat along the Program's Associated Habitat Reach (AHR) to contribute to the survival of whooping cranes during migration. Early in the First Increment of the Program, an emphasis was placed on learning more about the characteristics surrounding whooping crane roost sites to better inform Program land and water management. The Program's Adaptive Management Plan set out plans for testing hypotheses that use was directly related to habitat suitability in the AHR (WC-3). Furthermore, First Increment Big Question #5 (PRRIP 2020) directed Program science to identify important habitat characteristics for riverine roosting by whooping cranes.

To accomplish this, the Program systematically documented whooping crane roost locations in the AHR from spring 2001 – spring 2017. In a habitat selection analysis, characteristics of roost locations were compared to characteristics of nearby in-channel locations that were available, but not selected by whooping cranes. Results of these analyses helped the Program to define suitable whooping crane roosting habitat and provided guidelines for land and water management (Howlin and Nasman 2017, PRRIP 2017b, Baasch et al. 2019a). Specifically, the Program has worked to create and maintain river channels with widths ≥650 ft that are unobstructed by tall, dense vegetation and cleared riparian forest along riverbanks and on in-channel islands to create unforested corridor widths of ≥1,100 ft.

Since spring 2017, The Program has continued to monitor whooping crane roost locations and suitable habitat availability in the AHR. During fall 2017 – spring 2022 monitoring, the Program observed nearly as many roost locations (207 roosts) as were observed during the previous 17 years (spring 2001 – spring 2017; 235 roosts). Additionally, since 2015 a broader availability of unobstructed channel widths has been maintained within the AHR. With the additional roost locations observed in recent years, and under different available roosting conditions, a check in on the factors important for roost site selection is warranted. The objectives of this updated analysis are to:

1) provide additional information for defining suitable roosting habitat within the AHR;

2) inform the Extension Science Plan Big Questions 1-3, which ask how water and sediment augmentation can maintain suitable roosting habitat for whooping cranes (PRRIP 2022a);

3) inform Program land and water management to provide benefits for whooping cranes.

E.2 What are the potential policy implications?

Results of the updated analysis will guide Program management actions by either:

1) reinforcing the importance of current criteria established as suitable roosting habitat for whooping cranes. IE, continue to manage land and water according to established criteria, or
2) identifying other factors to be included in the definition of suitable roosting habitat for whooping cranes. IE, potentially adjust Program land and water management to improve habitat suitability.

E.3 How did we conduct the updated analysis?

To perform the updated analysis for selection of riverine roost sites, we systematically documented whooping crane roost locations in the AHR from spring 2001 – spring 2022. Next, the Executive Director's Office (EDO) and Technical Advisory Committee (TAC) identified habitat characteristics for selection of riverine roosts. The characteristics included were both manageable by the Program (e.g., unobstructed channel width) and unmanageable but important to consider for whooping cranes (e.g., human development). We then measured each characteristic at roosts and locations that were available but not used. Finally, the resource selection framework from prior analyses was used to test the importance of characteristics to predict selection of roost sites.

E.4 What did we discover about riverine roost site selection through the updated analysis?

- Whooping cranes selected roosts along river channels that:
  - had wide unobstructed views that were somewhat wider than previous analyses;
  - were far from forests;
  - were in areas with less human development.

E.5 Do the results change the Program's criteria for highly suitable roosting habitat?

The Program's definition of highly suitable whooping crane roosting habitat has not changed as a result of the Program's five-year check-in on whooping crane roost site selection. Unobstructed channel width and distance to nearest forest continue to be the most important factors influencing riverine roost site selection for whooping cranes. The Program will continue to manage for 1,100 ft of unforested corridor width, as the results from this updated analysis reinforced previous findings of whooping crane selection of roosts with a minimum distance of 550 ft from nearest forest. Due to uncertainty surrounding whooping crane selection for unobstructed channel widths between 514 – 1,102 ft, the TAC has not made any formal recommendation to change the Program's current criteria for highly suitable roosting habitat from the current UOCW of ≥650 ft. However, the TAC agreed that the Program should identify and take advantage of opportunities in Program habitat complexes (e.g. Cottonwood Ranch, Jerry F. Kenny/Pawnee, and Fort Kearny) where wider unobstructed channel widths could be created and subsequently maintained by river flow (natural flows and/or Program water) without the use of extensive mechanical management (i.e., annual river channel disking).

The amount of development surrounding in-channel habitat was the only landscape-level factor found to influence riverine roost site selection. The amount of development surrounding on-channel habitat should also be considered when assessing habitat suitability for roosting.

1 - INTRODUCTION

The Platte River Recovery Implementation Program (PRRIP or Program) implements actions of the Whooping Crane (*Grus americana*) Recovery Plan (CWS and USFWS 2007) to reduce mortality during migration and protect migration stopover sites. More specifically, the Program manages water and land along the central Platte River in Nebraska to provide suitable whooping crane roosting habitat along the Program's Associated Habitat Reach (AHR). The Program's management objective for whooping cranes is to contribute to whooping crane survival during migration (PRRIP 2021a). To measure achievement of this objective, performance indicators were developed and include:

- increase area of suitable roosting and foraging habitat;
- increase crane use days; and
- increase proportion of whooping crane population use.

Early in the First Increment of the Program, an emphasis was placed on learning more about the characteristics surrounding whooping crane roost sites to better inform Program land and water management. The Program's Adaptive Management Plan (PRRIP 2021a) included multiple hypotheses related to whooping crane habitat suitability and use of the Associated Habitat Reach (AHR) including the following priority hypothesis:

- WC-3 Whooping crane use is related to habitat suitability. Riverine habitat suitability for whooping cranes is a function of channel characteristics such as water depth, channel width, and unobstructed-view widths.

This hypothesis was prioritized and became the basis of a First Increment Big Question (PRRIP 2020) to link science learning to decision-making. The First Increment Big Question pertaining to suitable habitat for whooping cranes states:

- Big Question #5 (BQ #5) – Do whooping cranes select suitable riverine roosting habitat in proportions equal to its availability?

To answer BQ #5, the Program compared conditions (explanatory habitat variables) at riverine roost locations to nearby locations that were available, but not selected, for roosting. Howlin and Nasman (2017) tested both proportional landcovers and point based variables, as well as a limited set of management-based variables that included:

- *Unobstructed channel width* – width of channel unobstructed by tall, dense vegetation;
- *Total channel width* – total width of channel from left bank to right bank, including vegetated islands;
- *Nearest forest* - distance to nearest riparian forest;
- *Unforested width* - width of channel unobstructed by riparian forest; and
- *Unit discharge* - total discharge divided by the wetted width of the active channel.

The analysis indicated that nearest forest and unobstructed channel width were the best predictors of roost site selection and proportional landcovers were not important to explain patterns of roosting.

Following this finding, the Program continued to systematically collect roost locations that were integrated into a refined analysis focusing on the previously identified management-based, in-channel variables (PRRIP 2017b, Baasch et al. 2019a). Both studies concluded nearest forest and unobstructed channel width were the most important variables to explain patterns of riverine roosting. Specifically, whooping cranes roosted disproportionately further from forest and in wider channels unobstructed by tall, dense vegetation than predicted by availability of those conditions. Using these results, the Program defined minimum criteria for suitable roosting habitat as river channels with *unobstructed channel widths* of ≥650 ft and an *unforested corridor width* of ≥1,100 ft (i.e., double the *nearest forest* suitable width of 550 ft).

The Program's Extension Science Plan specifies that roost site selection analyses be updated every five years (PRRIP 2022a) to reassess the minimum criteria for suitable roosting habitat. The Program now has five more years of information (fall 2017 – spring 2022) to add to the dataset used in Baasch et al. (2019a). This analysis will be used by stakeholders to:

1) provide additional information for defining suitable roosting habitat within the AHR;
2) inform Extension Science Plan Big Questions 1-3, which ask how water and sediment augmentation can maintain suitable roosting habitat for whooping cranes (PRRIP 2022a); and
3) inform Program land and water management to provide benefits for whooping cranes.

During the five additional years of data collection, in-channel conditions for roosting were stable throughout the AHR and were generally more suitable than most of the period of record (2001-2014). From 2015 – 2021, average UOCW remained near suitable (≥600 ft) throughout the reach in the main channel of the river (PRRIP 2022b). We also observed multiple migration seasons with more roosts than typically observed during a migration season, including 51 roosts in spring 2018 and 22 roosts in fall 2021. Large numbers of roosts concurrent with increased availability of wider channels could reveal a selection of wider channels than previously available. Alternatively, a reevaluation under altered habitat conditions could reveal a change in the factors important for selection of roosts.

In the current analysis, we include all previously examined in-channel management-based variables except unit discharge. Unit discharge, calculated as discharge divided by wetted width, was initially intended to address uncertainty around how whooping cranes respond to river flow; serving as a proxy for water depth, something thought to be important in roost site selection. Following input from the Program's Independent Scientific Advisory Committee (ISAC) and Technical Advisory Committee (TAC), unit discharge was excluded from our updated analysis because of a temporal mismatch between flow at the time of selection on the evening prior to observing roost locations and flow at the time of observing roost sites the next morning. In addition, wetted width was derived from a hydrodynamic model with inputs from 2009 to inform channel geomorphology. Together these mismatches in a highly dynamic sand bed river make results from this variable difficult to interpret.

We have also taken additional steps to broaden the explanatory variables considered in our analysis of roost site selection. In addition to in-channel management-based variables, we included off-channel landcover as hypothesized to influence riverine roosting patterns. We incorporated the landcover product from Baasch et al. (2022) that builds on the Brei and Bishop (2008) landcover classifications by defining finer-scale wetland features in the AHR. This product allowed us to generate landscape compositions that incorporated finer scale wetland features such as meadow marsh and agricultural wetland.

Science learning objectives

Our Program science learning objectives were to:

- Identify in- and off-channel habitat characteristics associated with whooping crane riverine roost selection in the AHR.
- Understand the influence of landscape composition on whooping crane riverine roost selection in the AHR.

Our results will provide information to help determine if the Program's definition of suitable roosting habitat needs to be updated and if there are changes to Program land and water management that might increase suitable roosting habitat to benefit whooping cranes during migration.

2 - METHODS

2.1 Study area

Our study area was the Program's AHR, encompassing a 90-mile reach of the central Platte River including a 3.5-mile buffer on either side of active river channels from US Highway 283/Interstate 80 junction near Lexington, Nebraska to Chapman, Nebraska (Figure 1). The AHR is characterized by river channels with associated wetlands, grassland, and forest in a landscape dominated by agriculture. The AHR is situated within the area of core use by whooping cranes migrating between Wood Buffalo National Park, Canada, and Aransas National Wildlife Refuge, Texas (Pearse et al. 2018). Observations of whooping cranes using the central Platte River prompted the AHR to become the only river segment in North America to be designated as critical habitat for migrating whooping cranes in 1979 (USFWS 1978). This critical habitat designation encouraged management efforts to widen river channels, rehabilitate wetlands, and remove woody vegetation in and near river channels to increase the availability of wide river channels and other habitats for whooping cranes.

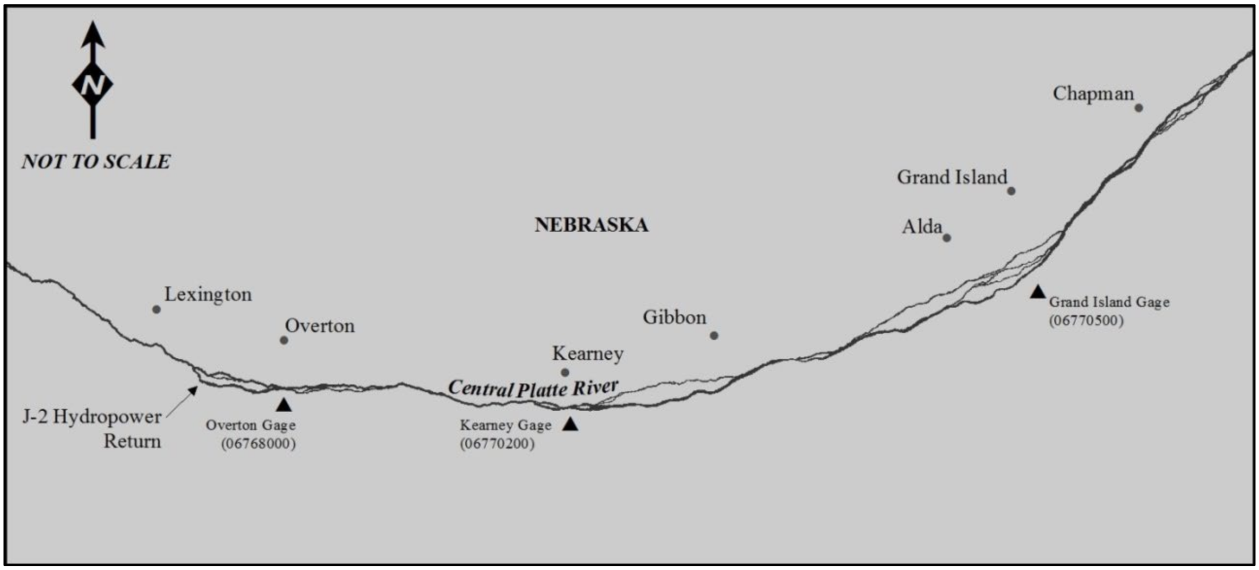


Figure 1. Map of the Program's Associated Habitat Reach and central Platte River from Lexington, NE to Chapman, NE along the central Platte River.

The central Platte River is a dynamic sandbed river system with a high degree of spatial and temporal variability in channel morphology and hydrology. Observations from the 19th and early 20th century described a wide and braided river with widths ranging from 1,500 to 4,000 ft until the 20th century. However, substantial narrowing occurred during the 20th century as water development intensified throughout the Platte River Basin (O'Brien and Currier 1987, Murphy et al. 2004). The primary driver of narrowing was reduction of flow due to water development, which encouraged woody (e.g. cottonwoods, willows) encroachment into the formerly active channel (Johnson 1994). The contemporary river consists of main and side channels with total widths ranging from approximately 400 ft to 1,500 ft (Fotherby 2009). Channel morphology, as distinguished by channel type, number of channels, and valley confinement, changes from the upstream to downstream ends of the AHR resulting in channel widths that are generally narrower upstream, widening as you move downstream (Fotherby 2009). Average unobstructed channel width, which is the linear distance unobstructed by tall, dense vegetation measured across the channel parallel to river flow, also varied over the course of our study period and influenced the amount of highly suitable in-channel habitat, as previously defined by the Program, available for roosting (PRRIP 2022b).

2.2 Roost and available location data

We identified whooping crane riverine roosts during spring and fall migrations per the Program's systematic whooping crane monitoring protocol (PRRIP 2017c) that relies on daily flights to locate crane groups while roosting on the channel prior to foraging in the adjacent landscape or leaving the area to continue migrating. We included the Program's systematic monitoring data from spring 2001 – spring 2017 published in Baasch et al. (2019a) and added roosts observed during systematic monitoring from fall 2017 – spring 2022. The Program's systematic monitoring protocol was first implemented in Spring 2001. The monitoring protocol consisted of aerial surveys along established transects observing the main channel of the river, which was the widest channel of all channels with flowing water, during the first two daylight hours. Two aerial surveys were flown east to west each day with the east flight covering Chapman, Nebraska to the Highway 10/Platte River bridge near Kearney, Nebraska and the west flight covering Highway 10/Platte River bridge to Lexington, Nebraska. When a crane group was observed, photographs were taken that included in-channel features and the surrounding landscape to identify a roost location. The number and age category (i.e. adult, subadult, or juvenile) of individuals in the group were also recorded.

Surveys of river channels remained similar from 2001 – 2022 except for the following changes in survey direction, monitoring period, and return flights.

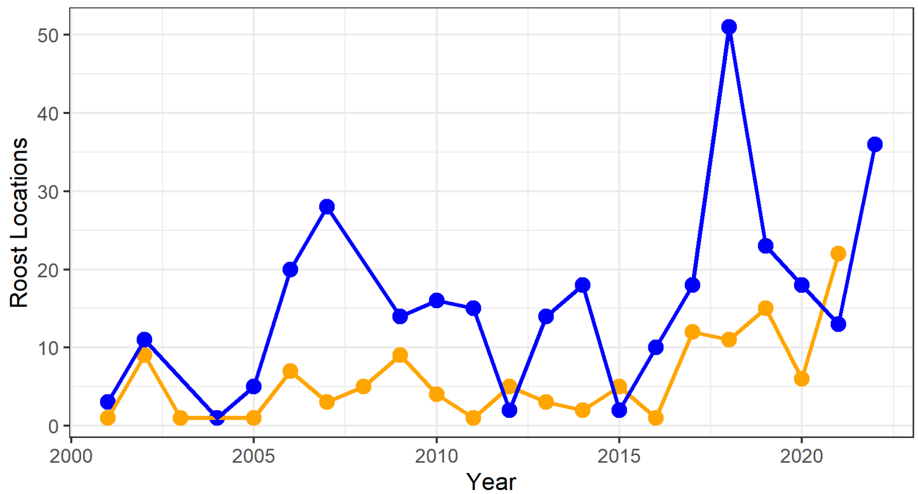
- In fall 2001, spring 2002, and fall 2002 surveys of river channels were flown in the eastward and westward direction on alternating days (Platte River Endangered Species Partnership 2001*a*, 2001*b*, 2001c, 2002, 2003).
- Prior to fall 2013, daily return flights followed one of seven transects assigned randomly each day. Starting in fall 2013, return flights followed one of two transects to observe wetland complexes on routes that alternated every other day (PRRIP 2017*a*).
- The spring monitoring period spanned from March 21st to April 29th in 2001-2013 but was extended to March 6th starting in 2014 to continue monitoring between the 5th and 95th percentile of initial observations of whooping cranes in Nebraska during spring migration (PRRIP 2017*a*).
- The fall monitoring period spanned from October 9th to November 10th in 2001-2016 but was extended to November 15th starting in 2017 to continue monitoring between the 5th and 95th percentile of initial observations of whooping cranes in Nebraska during fall migration (PRRIP 2017*a*).

The first observation of a crane group was considered the first, unique roost. Group demographics, roost location, and knowledge of other crane groups in the AHR on a given day were all used to identify each crane group. Along with the first unique roost, we observed subsequent daily roost locations to acquire the total roosts by each crane group during a stopover.

We made a distinction between the first and subsequent roost observations of each crane group for analysis purposes because subsequent roost were not independent observations. Ignoring this lack of roost independence can lead to results that do not represent population-level selection but instead represent a small subset of longer stopovers that are overly represented in our dataset (Lennon 1999).

Our systematic monitoring identified 163 crane groups yielding 163 first, unique roosts and a total of 442 roosts from spring 2001 – spring 2022 (Figure 2). No surveys were conducted in the spring of 2003, so surveys occurred over a total of 42 migration seasons. More roosts were observed in spring 2018 (n=51), spring 2022 (n = 36), and spring 2007 (n = 28) than any other seasons (Figure 2). The most roost locations during fall migration occurred in 2021 (n = 22). Of the 163 unique roosts, 85 were observed prior to fall 2017 and included in Baasch et al. (2019a). We observed 78 first unique roosts from fall 2017 – spring 2022. The number of unique roosts averaged 3 per migration season prior to fall 2017 and 8 per migration season from fall 2017 – spring 2022. The number of total roosts averaged 7 per migration season prior to fall 2017 and 21 per migration season from fall 2017 – spring 2022.

A



B

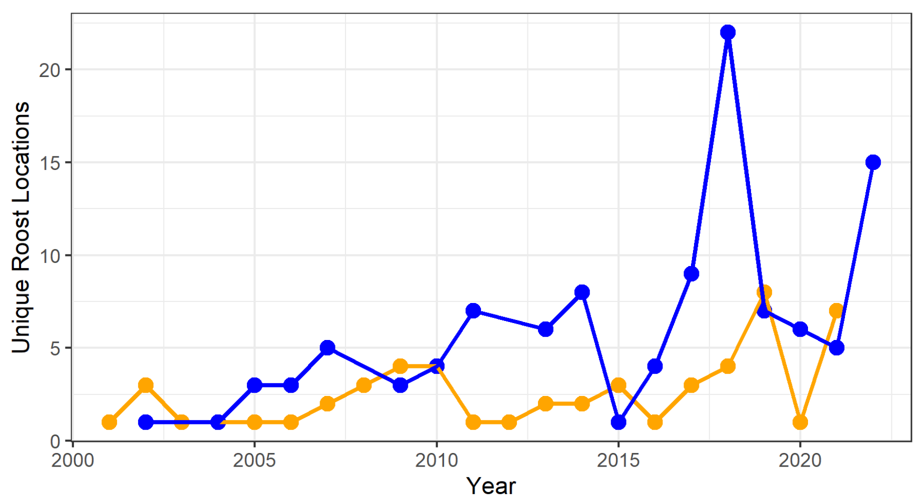


Figure 2A-B. Total number of whooping crane roosts (n=442) (A) and first, unique roosts (n=163) (B) identified by systematic aerial monitoring within the Associated Habitat Reach during the spring (blue) and fall (orange) migration seasons from 2001 to 2022.

For each roost, we generated a set of 20 available non-selected locations (8,840 available locations) for comparison of habitat characteristics to the roost location. Available locations were generated at random within the active channels of the Platte River (including side channels) within 10 miles upstream or downstream of each roost location. Availability was limited to 10 miles from a roost site because cranes were likely unable to perceive roosting conditions at distances >10 miles when flying at 3000 ft above ground elevation, which was a common flight height between stopovers observed in multiple telemetry efforts (Kuyt 1992, Pearse et al. 2020). Furthermore, a Program analysis using whooping cranes carrying cellular transmitters (n = 32) found cranes deviated ≤8 miles from migratory flight path to stopovers along the Platte and Loup River systems from 2018-2021 (Whooping Crane Tracking Partnership, unpublished data).

2.3 Landcover products

We developed annual landcover products representing both in-channel conditions and the landscape surrounding active river channels (Appendix 1) from which to measure our explanatory variables. We used the Brei and Bishop (2008) landcover, with modifications by Baasch et al. (2022), as the foundational layer of landcover information for our study. Since this layer was based on landcover from 2005, we modified both in-channel and some aspects of off-channel landcover annually to better represent the conditions available to whooping cranes to roost within a given year.

In-channel conditions from the 2005 land cover were replaced with object-based classifications and spatial extent of river channel disking when necessary to represent annual conditions. For years prior to 2015, object-based classification was performed in eCognition (Trimble Geospatial, 2016. Version 1.3.1, Colorado, U.S.) using annual aerial imagery to identify water and sand within river channels. From 2015-2021, classifications were performed with LiDAR coverage, and allowed us to classify water, sand, and vegetation <2 ft, 2-6 ft, 6-15 ft, and >15 ft in height within river channels. In addition to object-based classifications, we also included the spatial extent of river channel disking within our study as disking occasionally occurred after imagery was acquired each year. Areas where disking took place were assumed to be sand and water for the fall in which they occurred and the spring of the following year.

Off-channel modifications of the 2005 base layer included both tree clearing and alternation among specific crop types. The Program and other conservation organizations have conducted large-scale removal of trees for whooping and sandhill crane habitat since Brei and Bishop (2008) was created. Tree clearings were defined as the removal of gallery forests consisting of mainly cottonwoods (*Populus deltoides*) and were identified from the Program's land management geodatabase, as well as aerial imagery from 2005 to 2021. Off-channel annual landcover products mainly provided information on crop rotation outside of the floodplain. Tree clearings occurred within the floodplain where best available information was the static Baasch et al. (2022) layer. After updating this static layer by replacing areas of tree removal with upland grassland, we used aerial imagery to confirm the assumption of grassland structure moving forward through time, but no subsequent landcover products were available to provide a finer scale assessment. We also populated all upland agricultural areas, identified in Baasch et al. (2022), with annual crop type information from the National Agricultural Statistics Service's Crop Data Layer (CDL; Boryan et al. 2011; Table 1). Whooping cranes have been observed more frequently in corn fields compared to other crop types (Howlin and Nasman 2017), which may suggest increased corn near a roost location may be preferred. Alfalfa and soybeans may also be associated with whooping crane use during stopover activities (Caven et al. 2022). Since all the spatial data sources to develop these landscapes were created from annual fall conditions, each annual representation was used to derive explanatory variables in the fall of that year and the spring of the next year.

Table 1. Sources for landcover classifications used to quantify variables to explain roost selection of whooping cranes on the central Platte River from spring 2001- spring 2022. Similar landcover classes were grouped together to arrive at the more general landcover class represented by the explanatory variable. Landcover designations that correspond to one another across sources are contained within the same table row. See Appendix 1 for more information.

				Off-Channel Annual Adjustments	**In-Channel Annual Adjustments**
Abbreviation	**Explanatory variable**	**Brei and Bishop 2008**	**Baasch et al. 2022**	**Crop Data Layer**	**Object-Based Classification**
SW	Sand and Water	River Channel Unvegetated Sandbar			Sand Water
FO	Forest	Riparian Woodland Upland Woodland Rural Developed	Woodland	Forest	>15 ft vegetation height
MM (also a component of AG)	Meadow Marsh	Floodplain Marsh	Meadow-Marsh		
		Mesic Wet Meadow			
		Basin Wetland			
		Warmwater Slough			
GR (also a component of AG)	Grassland	Meadow Sand Ridge	Prairie	Grassland	
		Undisturbed Grassland	Wet Prairie		
		Upland Grassland			
		Xeric Wet Meadow			
AW	Agricultural Wetland	Agriculture + Palustrine Wetland	Agricultural Wetland		
DE	Developed	Roads Urban/Suburban		Developed	
CO	Agriculture + Corn (Corn)	Upland Agriculture	Agriculture	Corn	
AL	Agriculture + Alfalfa (Alfalfa)	Upland Agriculture	Agriculture	Alfalfa	
SO	Agriculture + Soybeans (Soybeans)	Upland Agriculture	Agriculture	Soybeans	
OA	Agriculture + Other (Other Ag)	Upland Agriculture	Agriculture	Other	
	Other	Phragmites	Invasive Dominated Wetland		
		Purple Loosestrife			
	Other	Canal/Drainage	Open Water		
		Irrigation Reuse Pit			
		Lagoon			
		Reservoir			
		Sand Pit			
		Stock Pond			
	Other	Bareground/Sparse Veg	Other		

2.4 Explanatory variables

We included explanatory variables hypothesized to explain patterns of roosting by whooping cranes. Channel openness is typically important for whooping crane riverine roost sites, especially in the AHR (Shenk and Armbruster 1986, Howlin and Nasman 2017, Baasch et al. 2019*a*) . We primarily used aerial and LiDAR imagery each fall along the entire AHR, along with a model built with the Hydrologic Engineering Center's River Analysis System (HEC-RAS; (Brunner 1996) to measure unobstructed channel width (UOCW) and total channel width (TCW). UOCW is the linear distance unobstructed by tall, dense vegetation measured at a roost or available point location in both directions across the channel perpendicular to river flow (Figure 3). From 2001 – 2016, UOCW was measured across river channels by hand delineation from aerial imagery taken during the fall season (Figure 3). Starting in fall 2017, we used object-based classification in eCognition to identify landcover from annual aerial imagery as water, sand, or vegetation (Table 1). The two methods were comparable in providing estimates of UOCW across years as demonstrated in comparisons from 2017-2020 (PRRIP 2022b). ECognition further classified vegetation in the active river channel into height classes of 0-2 ft, 2-6 ft, 6-15 ft, or >15 ft from annual topobathymetric LiDAR imagery (LiDAR). Water, sand, and the 0-2 ft vegetation height class were considered as unobstructed from a whooping crane's point of view. Areas with vegetation >2 ft in height were considered obstructed. In areas without full LiDAR coverage, we also considered river channel and unvegetated sandbars from the Brei and Bishop (2008) layer as unobstructed. To account for disking of the river channel to create bare unobstructed sandbars that occurred after the acquisition of aerial and LiDAR imagery in the fall, we layered the known extent of disking into annual landcover classifications and assumed areas disked within a year were sand for the fall migration of that year and spring migration of the next year. Remotely sensed landcover classifications allowed UOCW to be objectively measured across the channel without observer interpretation (PRRIP 2022b). To measure TCW, we developed a HEC-RAS model representing the floodplain of the central Platte River and used the topographical profile of river cross sections to calculate one-dimensional hydraulic outputs. Values for model roughness were derived from 2005 land use data from Brei and Bishop (2008). The model was calibrated using rating curves and LiDAR water surface elevations from March 2009, along with physically surveyed 2009 water surface elevations. We then identified the extent of active channel at each cross section from left to right bank from 2009 aerial imagery, across all active channels, to produce total channel width at the 5,000 cfs topographical profile (TCW). Thus, the TCW associated with each roost or available location was a one-time, 2009-based measurement of the total channel width at 5,000 cfs at the cross section nearest to the roost or available location.

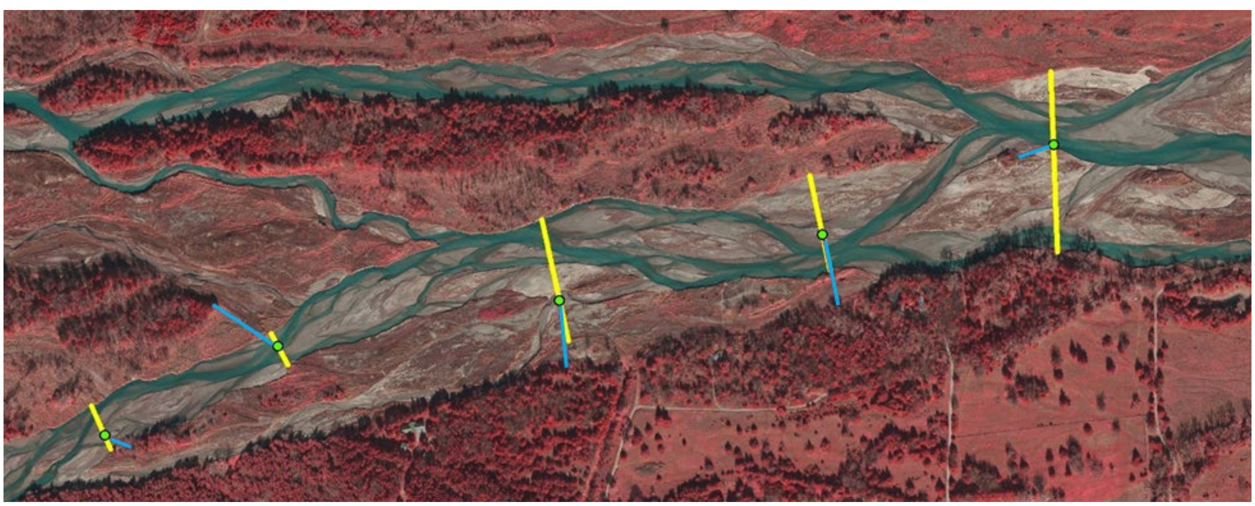


Figure 3. Example of how unobstructed channel width (UOCW; yellow lines) and nearest forest (NF; blue lines) were measured at whooping crane roost and available locations in the central Platte River from spring 2001 – spring 2022.

Whooping cranes generally avoid roosting near trees, thus forest is viewed as a having a negative impact on whooping crane roosting (Shenk and Armbruster 1986, Austin and Richert

2005, Pearse et al. 2017, Baasch et al. 2019*a*). To measure distance from roost and available point locations to nearest tree, group of trees, or forest in any direction (NF; Table 1), we relied on aerial and LiDAR imagery, supplemented with landcover classification and land management data. From 2001 – 2016, hand delineation was used to measure nearest forest from aerial imagery (Figure 3). We verified that hand-delineation and object-based classification methods produced comparable measurements of NF by measuring roost and available locations in fall 2017 and spring 2018 with both methods. With an average difference of 4% across methods, the Program's Technical Advisory Committee (TAC) deemed this was an acceptable amount of variability introduced by combining two methods for measuring NF over a long-term dataset, so object-based classification was used moving forward. Starting in 2017, we measured NF by combining the annual >15 ft vegetation class in the active channel with the riparian, upland woodland and rural development classes beyond the active channel from Brei and Bishop (2008), as well as forest identified in CDL data, to create an annual forest extent in the AHR (Figure 4). Rural development was included in the forest class because residential or commercial properties near the river were typically forested. Additionally, prior to measuring NF from 2017 – 2021, we updated each annual forest extent to reflect forest coverage changes not originally captured in Brei and Bishop (2008). We identified areas of tree removal, as well as the year removal occurred, and reclassified those areas as grasslands from that year until the end of our study. Measurements of NF were capped at 1,312 ft to limit the influence of extreme values on predicted relationships of nearest forest to roost site selection (Baasch et al. 2019a).

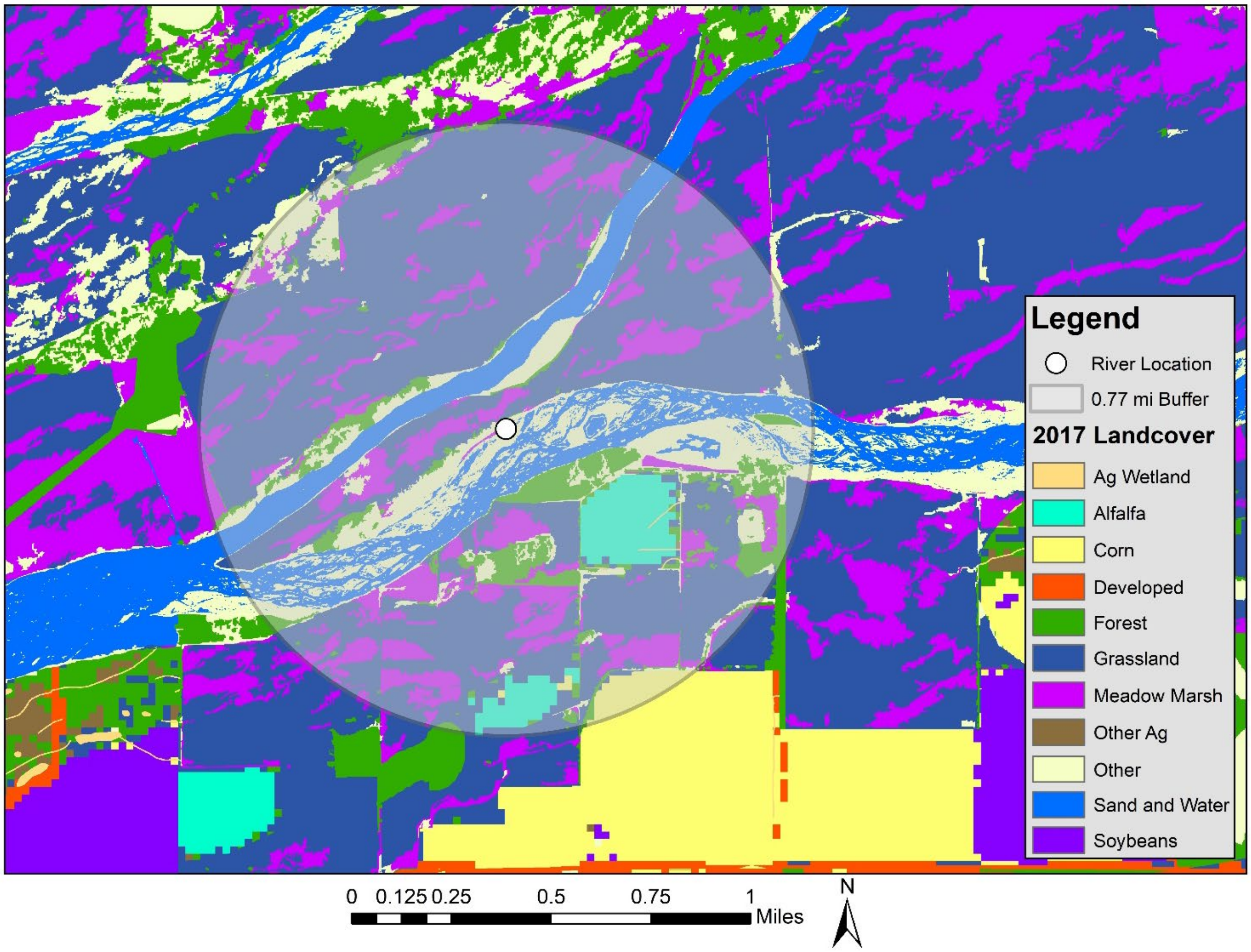


Figure 4. Example of the landscape used to quantify the proportion of each landcover class within 0.77 miles of each whooping crane roost and available location along the central Platte River from spring 2001 – spring 2022.

The surrounding landscape, providing foraging and resting opportunities, off-channel wetland features, or, alternatively, potential for disturbance was also hypothesized to influence whooping crane roosting patterns. We assessed the landscape composition within a 0.77 mi radius (buffer) around each roost and available location (Figure 4). We chose 0.77 mi because a Program analysis found 0.77 mi to be the radius of the average area used by whooping cranes carrying cellular telemetry units during stopovers along the central Platte and Loup Rivers (2018-2021; n = 50; Whooping Crane Tracking Partnership, unpublished data). Furthermore, recent publications have found similar landscape scales explain patterns of whooping crane use at stopovers (Pearse et al. 2017, Niemuth et al. 2018, Baasch et al. 2022).

As an in-channel aspect of landscape composition related to UOCW, a greater proportion of sand and water (SW) in the landscape was hypothesized to provide greater viewshed around a roost location (Shenk and Armbruster 1986, Pearse et al. 2017, Niemuth et al. 2018). We measured the proportion of SW within the 0.77 mi buffer around each roost and available location (Table 1; Figure 4). We used both the river channel and unvegetated sandbar classifications from Brei and Bishop (2008) and object-based classifications of sand and water. Prior to 2017, we used annual aerial imagery using object-based classification within eCognition that partitioned sand and water from vegetation. For the years when image quality was poor, we used a representative year of similar channel openness based on visual inspection of channel geomorphology from imagery. Specifically, we used 1998 imagery to classify SW for 2000-2002, Brei and Bishop (2008) classifications of river channel and unvegetated sandbar classifications for 2002-2006 SW, and 2010 imagery for 2007 – 2010. Starting in fall 2017, we identified SW from LiDAR-derived object-based classification. Like UOCW, we also accounted for disking that occurred after LiDAR was flown within a year and included disked areas in the quantification of quantify SW.

The composition of herbaceous wetlands and grasslands in the surrounding landscape were also hypothesized to be important predictors of whooping crane roost site selection. Whooping cranes have been observed selecting roost sites in or near herbaceous wetlands (meadow marsh), but selection of meadow marsh compared to other types of available grassland, both upland and lowland grasslands, has been less definitive (Niemuth et al. 2018, Baasch et al.

2019b). To test these hypotheses, we employed the Brei and Bishop (2008) landcover classification and the updated landcover classes from Baasch et al. (2022) to quantify the proportion of meadow marsh (MM), all grassland (AG), and agricultural wetland (AW) within the 0.77 mi buffer around roosts and available locations (Table 1; Figure 4). To create the meadow marsh class in Baasch et al. 2022, Brei and Bishop (2008) classifications were coupled with National Wetland Inventory Project (NWI; USFWS 2021) and flooding frequency information (USDA-NRCS 2019, 2020) to identify the most frequently flooded, herbaceous wetlands and sloughs along the central Platte River. Meadow marsh was combined with prairie and wet prairie classes (grasslands) from Baasch et al. (2022) to quantify all grassland (AG) representing the combination of wet and dry grasslands. Agricultural wetlands (AW) were palustrine wetlands, as indicated by the NWI, in agricultural fields of any crop type.

More development within the landscape and proximity to development have been negatively associated with use locations at stopovers during migration (Johns et al. 1997, Belaire et al. 2014, Pearse et al. 2021, Baasch et al. 2022). We also included development as an explanatory variable by measuring the proportion of development within 0.77 mi of each roost and available location. Development included roads and urban/suburban development from Brei and Bishop (2008), along with the development class identified from CDL data within upland agriculture areas (Table 1).

Agriculture fields consisting of corn were an abundant landcover type used by whooping cranes during diurnal activities in the AHR and the proximity to roost locations may be important (Howlin and Nasman 2017). We estimated the proportional area occupied by corn fields within the 0.77 mile buffer around roosts and available locations by using the CDL dataset within upland agriculture (Brei and Bishop 2008)/agriculture (Baasch et al. 2022) landcover types, which provided annual spatial information for agricultural products, including corn, in our study area from 2002-2021 (Han et al. 2012). No CDL data was available for 2000 and 2001, so we used CDL data from 2002 to approximate spatial coverage of corn from spring 2001 to spring 2002. We assumed spatial distribution of corn was similar 2000 – 2002 as 85% of the proportion of agriculture within our buffer for roosts and available locations was used for corn production across the study period. As such, it is unlikely major changes in corn distribution occurred between 2000 - 2002. Though proportional area covered by alfalfa, soybeans, or other agricultural products was quantified, specific hypotheses around the effect of these landcover types were not tested. All other landcovers types not previously mentioned were represented in an "other" category.

We developed a list of twenty-eight *a priori*, hypothesis-driven candidate models that included our point-based in-channel or area-based landscape scale variables, as well as combinations of both, to explain roost site selection. For the current effort, we expanded the suite of in-channel models considered by Baasch et al. (2019a) by incorporating models including broader, off-channel landscape scale variables, as well as current and potential future options for management (Table 2). Additionally, we added models to explore interactions between UOCW and off-channel metrics of DE, CO, and AG to test whether the amount of disturbance, proportion of corn as a potential food resource, or proportion agriculture as a short, vertical vegetation structure off the river channel influenced the width of unobstructed views necessary for roosting. We did not include any explanatory variable combinations if the Pearson's correlation coefficient exceeded $r = |0.6|$ (Figure 5). Prior to development of our suite of models, we chose among alternative metrics for representing the amount of agriculture, forest, and development on the landscape that were highly correlated by comparing their explanatory power to describe patterns of roost site selection for whooping cranes. Comparisons were made using the Akaike Information Criterion (AIC) scores of single variable models (Appendix 2). Only our unique roosts populated candidate models in the model selection process as subsequent roosts of the same crane group were not independent, thus violating model assumptions of error independence and underestimating uncertainty of variable effects on selection (Lennon 1999, Gelman and Hill 2006). Candidate models were evaluated using an Akaike Information Criterion (AIC) selection process to identify the most powerful model(s) to explain roost selection while using the fewest explanatory variables (Burnham and Anderson 2002). As such, we identified the top model(s) as the simplest, or most parsimonious model(s) with a ΔAIC ≤2.0.

Table 2. Suite of *a priori*, hypothesis driven models evaluated to explain roost selection of whooping cranes on the central Platte River from Spring 2001- Spring 2022.

Model[a]	Models	Interpretation
1	NULL	Habitat selection is random
2	Unobstructed Channel Width (UOCW)	Select channels with views unobstructed by dense vegetation or wooded islands.
3	Nearest Forest (NF)	Select channels with increased ‘openness’ which includes areas without trees located nearby in any direction.
4	Total Channel Width (TCW)	Select channels with increased distance from right to left bank including vegetated and wooded islands.
5	UOCW + NF	Select channels with views unobstructed by dense vegetation without trees nearby in any direction. Top model from Baasch et al. (2019a).
6	UOCW + TCW	Select wide, open channels from right to left bank without dense vegetation nearby.
7	UOCW + NF + TCW	Select wide, open channels from right to left bank without trees and dense vegetation nearby.
8	Sand and Water (SW)	Select for increased channel ‘openness’ within 0.77 mi

Model[a]	Models	Interpretation
9	All Grassland (AG)	Select for all grasslands (including meadow marsh) within 0.77 mi
10	Meadow Marsh (MM)	Select for lowland herbaceous wetlands within 0.77 mi
11	Agricultural Wetland (AW)	Select for lowland wetlands in agricultural fields within 0.77 mi
12	Development (DE)	Select against development within 0.77 mi
13	Corn (CO)	Select for upland corn within 0.77 mi
14	MM + AW	Select for any lowland herbaceous wetlands within 0.77 mi
15	AW+CO	Select for low lying, wet agriculture and upland cornfields within 0.77 mi
16	SW + MM	Select for channel openness and lowland, wet herbaceous vegetation within 0.77 mi
17	SW + MM + AW	Select for channel openness and all vegetated lowland wetlands within 0.77 mi
18	SW + AW + CO	Select for channel openness, lowland agriculture, and upland corn within 0.77 mi
19	UOCW + NF + AG	Select for channels with unobstructed views, greater distances to nearest forest, and grasslands as per current Program management model
20	UOCW + NF + AG + UOCW*AG	Current Program management model accounting for selection of wider unobstructed views as grasslands decrease within 0.77 mi
21	UOCW + NF + DE	Top model from Baasch et al. (2019a) accounting for development within 0.77 mi
22	UOCW + NF + DE + UOCW*DE	Top model from Baasch et al. (2019a) accounting for development within 0.77 mi and selection for wider unobstructed views as development increases within 0.77 mi
23	UOCW + NF + MM	Potential future management model #1, current Program management model plus meadow marsh
24	UOCW + NF + MM + AW	Potential future management model #2, current Program management model plus meadow marsh and agricultural wetland
25	UOCW + NF + MM + AW + CO	Stakeholder model, Program management model plus landcover variables hypothesized as important for roost site selection.
26	UOCW + NF + MM + AW + CO + UOCW*CO	Stakeholder model accounting for a selection of narrower unobstructed views as corn increases within 0.77 mi

Model[a]	Models	Interpretation
27	UOCW + NF + MM + AW + DE	Potential future management model accounting for the selection against increased development within 0.77 mi
28	UOCW + NF + MM + AW + DE + UOCW*DE	Potential future management model accounting for development within 0.77 mi and wider unobstructed views as development increases within 0.77 mi

[a]Models 2-7 include point-based, in-channel metrics from Baasch et al. (2019a). Models 8-18 identify the most important, literature supported, area-based metrics for whooping crane roost and diurnal resource selection. Models 19-28 combine on/off-channel metrics that reflect current Program management practices, variable combinations identified by Program stakeholders, and potential future management options.

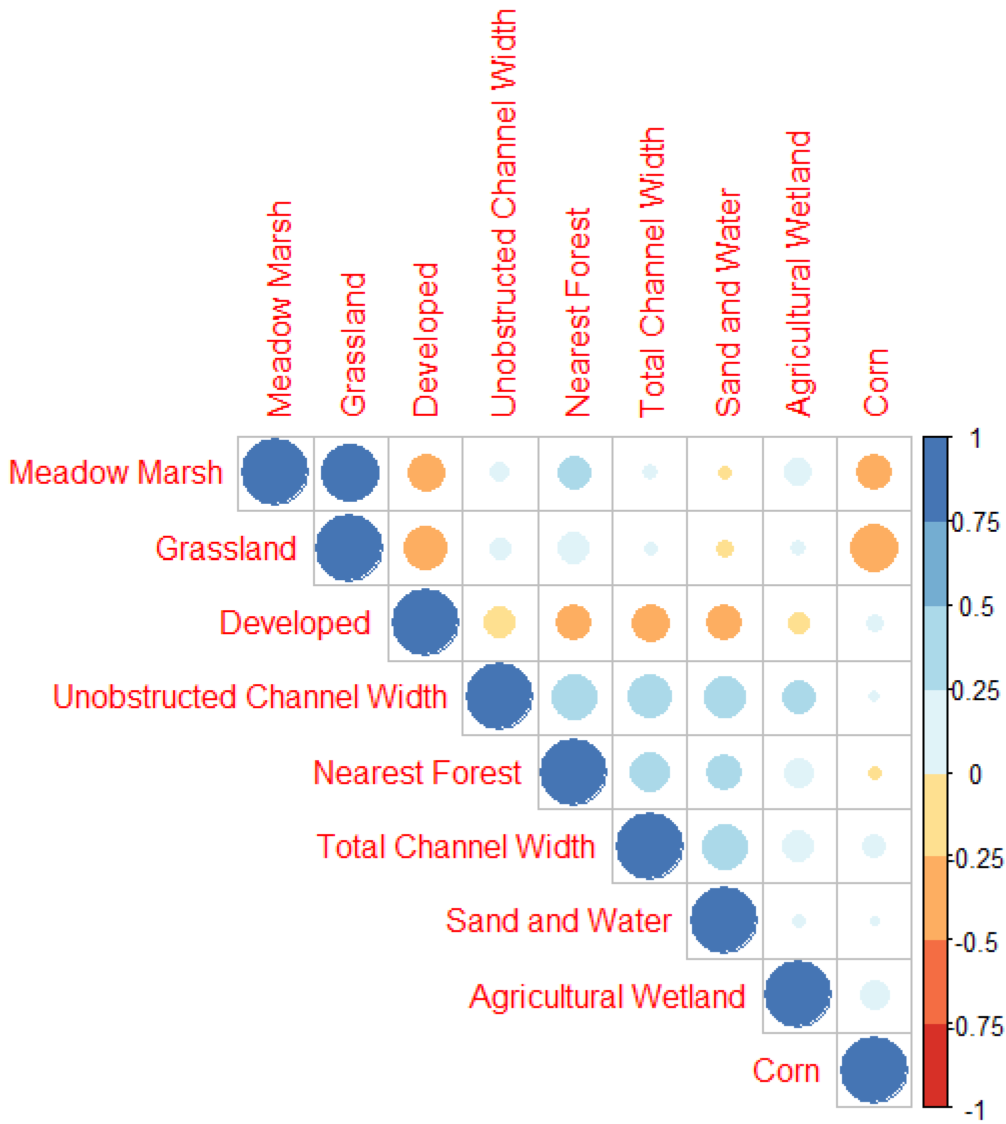


Figure 5. Correlation matrix of explanatory variables used to model resource selection of whooping cranes roosting along the central Platte River from spring 2001 – spring 2022. The degree and direction of correlation (correlation coefficient) between paired variables is indicated by the size and color of the symbol in the cell corresponding to the variables tested.

2.4 Roost site selection

In a sand bed river system with highly variable flow regime, channel morphology, and fluctuating land use practices, an analysis framework that pairs conditions at roost sites with conditions at nearby available sites at the time roost locations were observed allows for a fair comparison among selected and non-selected conditions. Our roost-available data collection allowed us to use resource selection functions (RSFs) with a discrete choice framework that accounted for changing availability of conditions during our study period (Johnson 1980, Arthur et al. 1996, McCracken et al. 1998, Manly et al. 2007). To account for possible non-linear relationships within RSFs, we used General Additive Models (GAMs) as an extension of the generalized linear model to estimate the relationship of selection and explanatory variables (Hastie and Tibshirani 1990). GAMs apply penalized regression splines, of smoothed terms, to allow for a variety of functional relationships, instead of relying on functional forms defined by investigators (Wood 2006). To limit overfitting and avoid results that may be ecologically irrelevant, we limited the potential degrees of freedom for smoothed terms to four. A smoothness value of 1 indicated a linear relationship and we removed the smoothing term for such variables and reran the candidate model. Our models evaluated a weighted relative selection ratio with a multinomial logit form expressed as:

$$w(X_{ij}) = \exp\left(s_1(X_{1ij}) + s_2(X_{2ij}) + \cdots + s_p(X_{pij})\right) \qquad \text{(eq. 1)}$$

Where X_1 to X_p were metrics, j indexes the units in the choice set, and i indexes the unit selected, s_1 to s_p were the smooth functions of X_1 to X_p, respectively. The discrete choice likelihood was maximized using R statistical software (R Core Team 2023) through RStudio (Posit Team 2023) with the gam function in R-package mgcv. We used a Cox Proportional Hazards Model with Restricted Maximum Likelihood within the gam function. The mgcv package determined the smoothness of the spline, and associated degrees of freedom, through iteratively re-weighted least squares fitting of the penalized likelihood (Wood 2006). The penalty for the smoothing parameters was determined at each iteration using generalized cross validation. Each candidate model was fitted with our GAM structure and then compared using our AIC model selection process.

Once model selection was complete, we examined the distributions and estimated relative selection ratios for each explanatory variable in the top model. We first compared the distribution of variables at roost and available locations with mirrored density plots, which are smoothed versions of histograms displaying the kernel density estimate of each variable at roost locations over the positive y-axis and available locations over the negative y-axis. We then used relative selection ratios, or relative probability of use, to estimate RSFs because availability was unique for each roost (Manly et al. 2007). To obtain relative selection ratios, we refit the top model with the first unique roosts and all subsequent roosts to estimate model parameters. We then predicted relative selection ratios and 90% confidence intervals between the fifth and ninety-fifth percentile of each explanatory variable to avoid extreme predictions at the end of variable distributions. All other variables were held at their mean values when predictions were calculated. We then scaled each relative selection ratio by setting the maximum value to one, thus generating scaled point estimates and 90% confidence intervals. When evaluating relationships of scaled selection ratios, we considered point estimates with overlapping 90% confidence intervals as statistically similar.

2.4 Variable importance and model validation

We used a leave-one-out approach to estimate the importance of each variable for model fit, similar to variable importance procedures in random forest models (Breiman 2001) .

Traditional effect sizes were not produced from smoothed functions, so we took each explanatory variable out of the top model and reassessed model fit. We additionally removed UOCW and NF together to understand model fit when the most important explanatory variables from Baasch et al. (2019a) were missing from the top model. Doing so produced a difference in deviance explained as variables were removed from the top model. Deviance explained is a measure of model performance which describes how close the fitted model is to a “perfect” model. A deviance explained of 100% would be a “perfect” model composed of variables that together completely explain the difference between roost sites and available locations. Variables more important for explaining roost site selection exhibited larger reductions in the deviance explained upon their removal from the model.

We employed two different datasets to assess how well our top model predicted observed roost locations in the AHR. The first dataset consisted of roosts observed from PRRIPs systematic aerial monitoring. The second dataset consisted of roost locations obtained from telemetered whooping cranes collected outside of PRRIP’s systematic monitoring protocol. These data included AHR roost locations from GPS-marked whooping cranes from 2010-2016 (n = 29; Pearse et al. 2020) and cellular-marked whooping cranes from 2018-2021 (n = 45 Whooping Crane Tracking Partnership, unpublished data). GPS terminals recorded locations every 4-6 hours, while cellular terminals recorded locations every 15 minutes. We categorized marked bird locations as ground points if the height above ground elevation was <33 ft and instantaneous speed was <22 mph, to account for device reading inaccuracies near ground level due to device specifications or GPS location error. Ground points were then grouped into distinct stopover events as defined in Pearse et al. (2015). To obtain roosts of marked birds within stopovers and to make those data comparable to observations from the systematic monitoring protocol, we identified and used the riverine location closest to 6:00 a.m. each day during a stopover event.

We minimized overlap between datasets that resulted from the collection of data simultaneously by two different methods and redundancy within the telemetry marked dataset using a buffer of 0.21 mi around each roost of a marked bird. A Program analysis found this buffer distance was the radius of the average area whooping cranes utilized within the active river channel during the first day of a stopover on the central Platte and Loup River systems from 2018-2021 (n = 50; Whooping Crane Tracking Partnership, unpublished data). Roosts recorded within <0.21 mi of one another on the same day may have been the same crane group recorded by both datasets. Moreover, multiple marked birds within <0.21 mi on the same day may have chosen roosts dependently as part of the same crane group. Given this rationale, we eliminated marked bird roosts if they occurred within 0.21 mi of a systematically observed crane group on the same day. If multiple marked birds roosted within 0.21 mi on the same day, only the roost of the adult bird with the most ground locations during the stopover was used. We also limited the number of roosts from any stopover event of marked birds to six to limit the influence of any individual stopover on model validation results. All stopover events of marked birds contained six or fewer roosts besides one stopover with twenty-three roost locations, from which we randomly chose six roosts.

To assess how well our top model predicted observed roost locations in the AHR, we ran an iterative cross fold validation where 2/3 of first unique roosts and subsequent roosts trained parameters in the top model and 1/3 tested the accuracy of predictions. This procedure was repeated 1,000 times with random samples of choice sets to populate the training and testing datasets. Second, we trained the top model on the total systematic monitoring dataset that included first unique and subsequent daily roosts and then tested the predictive ability of the model on telemetry data collected outside of PRRIP's systematic monitoring protocol.

To test model performance, each validation dataset compared RSF scores of roosts in the testing dataset to categories of RSF scores (Boyce et al. 2002). We accomplished this by using the top model to predict an RSF score for each training data point. We then identified 5th-100th percentiles of those scores in increments of 5%, to create twenty bins of percentiles and distributed each training data point into its appropriate bin based on an RSF score (Table 3).

Table 3. Model performance evaluation using telemetry data gathered outside of PRRIP's systematic monitoring protocol as the testing dataset. For evaluation of model performance with telemetry data, we compared the bolded columns with a simple linear regression.

Bin	Percentile	Sum of Relative Selection Scores	Training Data Roosts	Proportion of Expected Roosts	Number of Expected Roosts	Testing Data Roosts
1	0-5th	18.39	0	0.00	**0.00**	**0**
2	5th-10th	36.64	0	0.00	**0.00**	**0**
3	10th-15th	56.15	1	0.00	**0.17**	**0**
4	15th-20th	78.16	0	0.00	**0.00**	**0**
5	20th-25th	104.44	6	0.01	**1.00**	**0**
6	25th-30th	138.63	0	0.00	**0.00**	**1**
7	30th-35th	191.08	3	0.01	**0.50**	**2**
8	35th-40th	266.85	9	0.02	**1.51**	**0**
9	40th-45th	365.86	12	0.03	**2.01**	**1**
10	45th-50th	494.24	14	0.03	**2.34**	**1**
11	50th-55th	647.86	9	0.02	**1.51**	**2**
12	55th-60th	860.95	19	0.04	**3.18**	**2**
13	60th-65th	1131.42	22	0.05	**3.68**	**3**
14	65th-70th	1502.10	19	0.04	**3.18**	**11**
15	70th-75th	1922.35	39	0.09	**6.53**	**6**
16	75th-80th	2407.22	43	0.10	**7.20**	**6**
17	80th-85th	2890.84	55	0.12	**9.21**	**5**
18	85th-90th	3353.11	56	0.13	**9.38**	**4**
19	90th-95th	4070.47	53	0.12	**8.87**	**13**
20	95th-100th	5676.85	82	0.19	**13.73**	**17**
Total		26213.62	442	1	74	74

Once all points were distributed into their correct bins, we identified how many roost locations from the training data fell within each bin and divided the number in each bin by the total number of roost locations in the training data. This provided the proportion of roost locations expected to populate each percentile bin, which we then multiplied by the total number of roost locations in the testing dataset to obtain the expected number of roost locations. Our next step predicted RSF scores at roost locations in the testing dataset and distributed them into the appropriate bins. Doing so allowed us to compare the expected number of roosts to the observed number of roosts in each bin with a simple linear regression to assess the closeness of the slope to one (Howlin et al. 2003). For the cross validation, we averaged the slopes and confidence intervals from the total iterations of random sampling to grade model performance. A "good" predictive model had a 95% slope confidence interval incorporating one and excluding zero. An "adequate" predictive model had a 95% confidence interval of slope that did not incorporate one or zero and fit was "poor" if the 95% confidence interval of slope included zero.

3 - RESULTS

The top model (model 21 from Table 2) for predicting whooping crane roost locations included both in-channel variables and a single off-channel variable (Table 4). Models 27, 28, 22, and the selected top model 21 all had a ΔAIC ≤ 2.0, however, the explanatory power gained by additional variables in models 27, 28, and 22 was not enough to overcome the penalty of including additional information and model fit was very similar to model 21 (Arnold 2010). Additionally, selection relationships of UOCW, NF, and DE were similar in all the models with a ΔAIC ≤ 2.0 (see example in Appendix 5), rendering the larger models as non-competitive (Burnham and Anderson 2002).

Table 4. Top 5 models of roost selection by crane groups at stopover sites on the central Platte River from Spring 2001 – Spring 2022 as ranked by the Akaike Information Criterion (AIC) statistics. The AIC statistic of the null model was 2961. Variable descriptions are included in Table 1. The top model (bold) was model 21, as it was the most parsimonious (or simplest) model with a ΔAIC ≤ 2.0.

Model	Variables	df	AIC	ΔAIC	Weight
27	UOCW + NF + MM + AW + DE	174.32	2784.93	0.00	0.28
28	UOCW + NF + MM + AW + DE + UOCW*DE	174.32	2784.93	0.00	0.28
22	UOCW + NF + DE + UOCW*DE	169.76	2785.19	0.26	0.25
21	**UOCW + NF + DE**	**170.02**	**2785.73**	**0.80**	**0.19**
24	UOCW + NF + MM + AW	173.56	2796.67	11.74	0.00

In-channel variables included in the top model were UOCW and NF (model 21; Table 4). Whooping cranes typically roosted in areas with wider UOCW and farther from forest than availability would predict (Table 5, Figure 6). Selection of roost sites increased as UOCW increased up to 514 ft (Figure 7; Appendix 3 and 4). The relative selection ratio continued to increase and was maximized at 1,102 ft for UOCW, but due to wider confidence intervals that increased uncertainty around predicted selection of wider UOCW, the relative selection ratios for UOCW between 514 and 1,102 ft were statistically similar. Since the relative selection ratio for UOCW maximized near the 95th percentile (i.e., the upper end of predicted range on Figure 7), making it difficult to visualize where returns in terms of predicted increases in roost site selection might diminish, we also included a figure of the relative selection ratio for UOCW over the entire range of UOCWs observed at roost locations (Figure 8). For NF, the relative selection ratio was maximized at 559 ft, but the relative selection ratios were statistically similar when NF was >338 ft, which means there is uncertainty about the increase in selection beyond 338 ft (Figure 7). The degrees of freedom for in-channel smoothed terms were 3.43 for UOCW ($p = <0.001$) and 3.50 for NF ($p = <0.001$).

Table 5. Summary statistics of explanatory variables present in the top model (model 21) to explain riverine roost site selection of whooping cranes on the central Patte River in the Associated Habitat Reach from spring 2001 – spring 2022 from systematic aerial monitoring. Variables included the width of the river channel unobstructed by tall, dense vegetation (unobstructed channel width), distance to forest in any direction (nearest forest), and the proportion of human development (developed) within 0.77 miles of a roost or available location.

Location Type	Number of locations	Explanatory Variable	Mean	Median	Standard Deviation	Min	Max
Roost	442	UOCW	700	712	318	0	1566
		NF	450	425	227	30	1790
		DE	0.02	0.02	0.02	0	0.09
Available	8836	UOCW	393	296	318	0	1682
		NF	261	189	227	0	3089
		DE	0.04	0.03	0.02	0	0.25

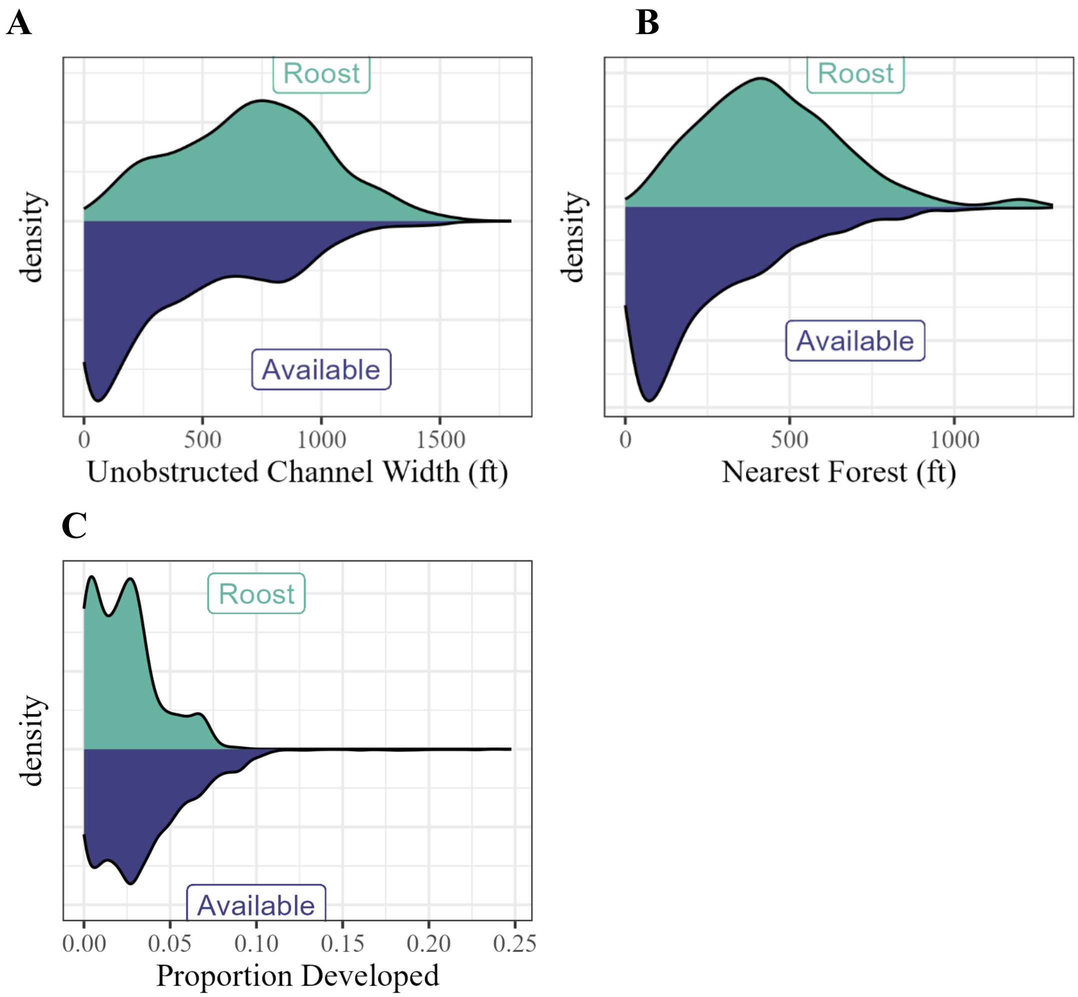


Figure 6A-C. Mirrored density plots of explanatory variables at whooping crane roosts (n = 442) and available locations (n = 8,840) on the central Platte River in the Associated Habitat Reach from spring 2001 – spring 2022 from systematic aerial monitoring. A mirrored density plot is a smoothed version of a histogram which displays the distribution of an explanatory variable at roost (positive y-axis, green) and available (negative y-axis, blue) locations. Dissimilarity in mirrored roost and available plots is indicative of selection either for or against a particular characteristic.

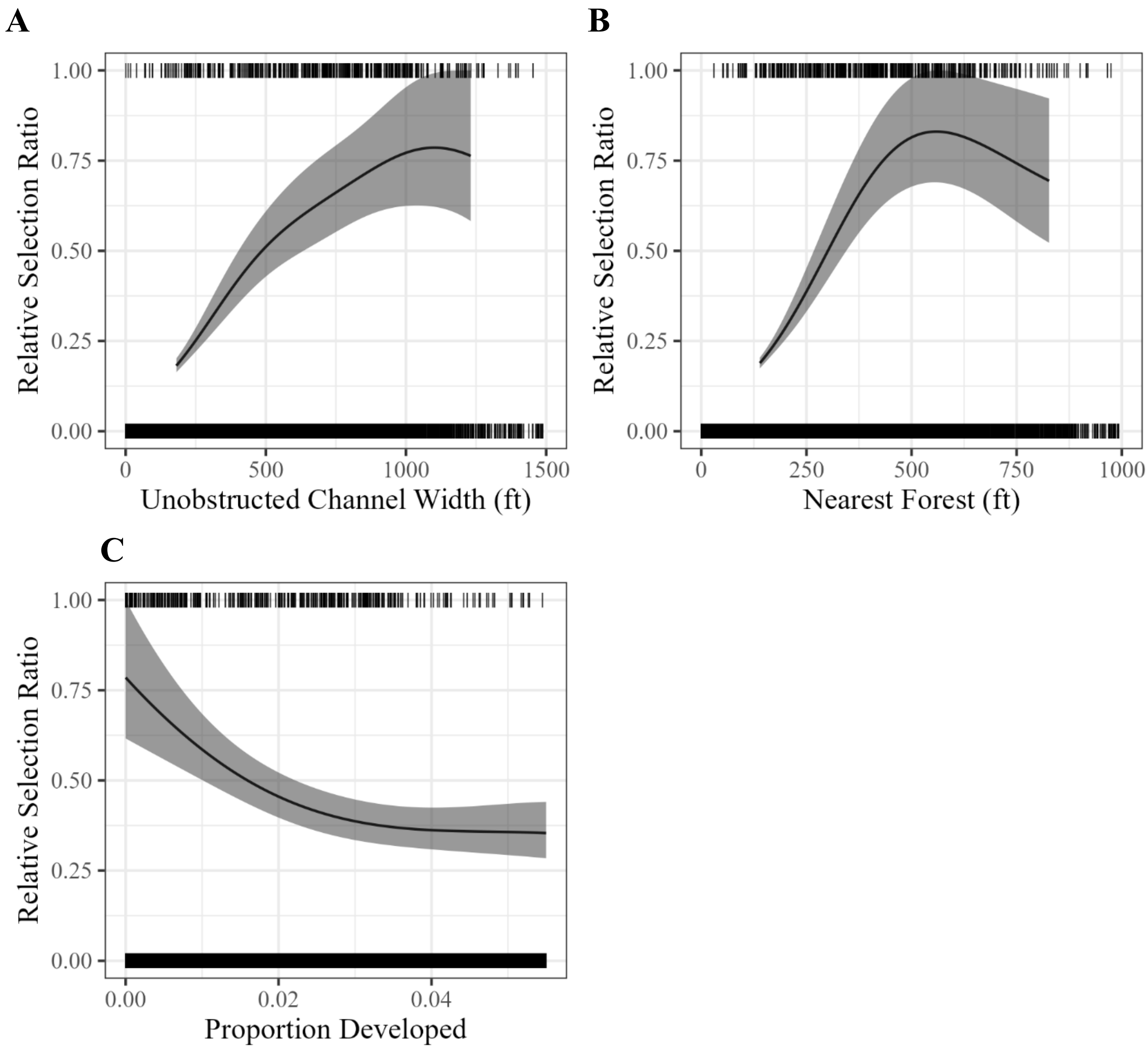


Figure 7A-C. Relative selection ratios of whooping crane roosts collected by systematic aerial monitoring from spring 2001 – spring 2022 on the central Platte River in the Associated Habitat Reach. The solid lines represent the average relationships between the 5^{th} and 95^{th} percentile of each variable at roost locations, while the shaded area represent the 90% confidence interval. Tick marks at y=1 show values of explanatory variables at roosts and ticks at y=0 show available location values.

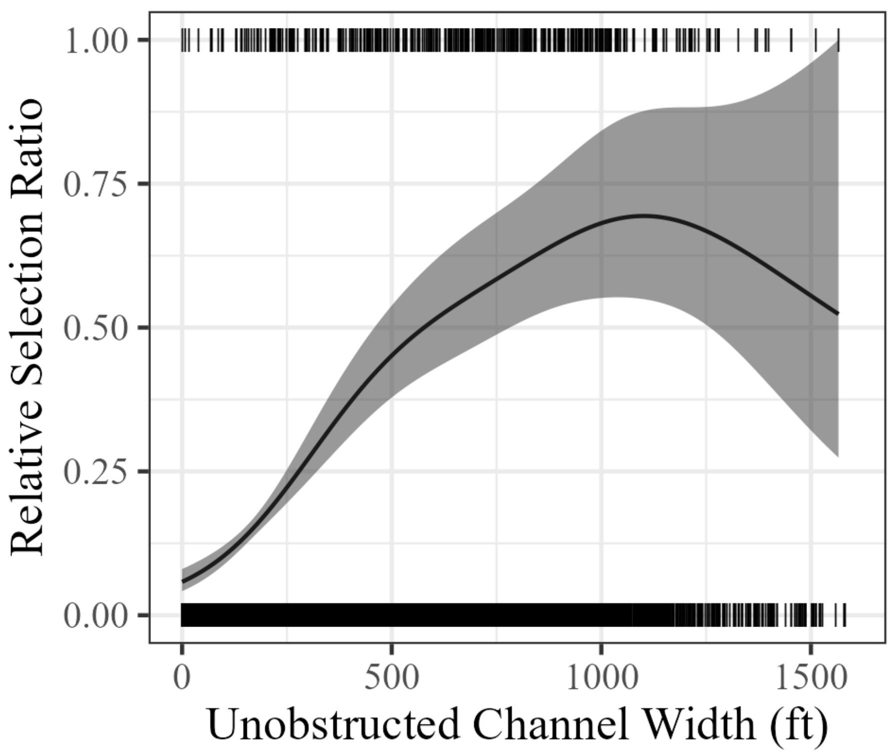


Figure 8. Relative selection ratio of unobstructed channel width, across the entire range of unobstructed channel widths observed at roost locations, for whooping crane roosting collected by systematic aerial monitoring from spring 2001 – spring 2022 on the central Platte River in the Associated Habitat Reach. The solid lines represent the average relationship while the shaded area represent the 90% confidence interval over the entire range of unobstructed channels widths observed at roost locations. Tick marks at y=1 show values of UOCW at roosts and ticks at y=0 show available location values.

DE was the only off-channel variable included in the top model and the only off-channel variable to contribute power to explain patterns of roost selection (Table 4). Whooping cranes typically roosted in areas with less development within 0.77 mi than availability would indicate (Figures 6 and 7). The DE relative selection ratio was maximized when the proportion of development within 0.77 mi of the roost was zero, but the relative selection ratios were statistically similar when the proportion of development was between zero and 0.014, which means there was uncertainty about the negative relationship within this range of development. The degrees of freedom for development was 2.7 for DE ($p = <0.001$).

UOCW and NF were the most important variables to explain roost site selection based on deviance explained (Table 6). The deviance explained decreased by 22% when UOCW and 21% when NF were removed from the top model individually. When UOCW and NF were removed together, the deviance explained decreased by 78% (Table 6). The deviance explained decreased by 5.5% when development was left out and model fit was reassessed.

Table 6. The deviance explained (DV) by the top roost selection model compared to DV of models with explanatory variables withheld to assess variable importance to model fit.

Withheld Explanatory Variables	DV	Decrease in DV	% Decrease in DV
None (Full Top Model = UOCW + NF + DE)	0.195	-	-
NF, UOCW	0.042	0.153	78%
UOCW	0.153	0.042	22%
NF	0.154	0.023	21%
DE	0.185	0.010	5%

Cross-validation using PRRIP’s systematic monitoring dataset and validation using telemetry marked birds both indicated good model fit of the top model. The average slope and confidence interval was 0.90 (95% CI = 0.72 – 1.07) for cross validation and 0.97 (95% CI = 0.63– 1.32) when using telemetry roost locations as the testing data.

Model 27 had the lowest AIC score, but it also included AW and MM as two additional variables to explain riverine roosting patterns with similar explanatory power as model 21. Because of Program interest in learning about the relationships and contributions made by AW and MM to explain whooping crane roost selection, we also calculated relative selection ratios and variable importance for model 27 (Appendices 5 and 6). Agricultural wetlands and meadow marsh each contributed only 1%, or 2% combined, of the total deviance explained by model 27.

4 – DISCUSSION

Our 22-year assessment of whooping crane riverine roost site selection within the Program's AHR on the central Platte River reinforced the importance of channel openness and avoidance of forest as established by Howlin and Nasman (2017) and Baasch et al. (2019a). We also assessed the contribution of the surrounding landscape to riverine roosting patterns and identified development as a factor influencing roost site selection. The proportion of other landcover types, such as grassland, meadow marsh, agricultural wetland, and corn surrounding roost locations had little influence on riverine roost site selection within the AHR. Interactions among variables were also unimportant for predicting roost site selection.

Although the relationship of roost selection to unobstructed channel width was similar in the current study to that found by Howlin and Nasman (2017) and Baasch et al. (2019a) across the lower to mid-range of widths, inclusion of five more years of data changed the form of the relationship previously established for roost site selection in response to wider UOCWs. In the two previous studies, selection increased as UOCW increased to a width of ~520 ft (Howlin and Nasman 2017) and ~650 ft (Baasch et al. 2019a) with no additional increase in selection as UOCW increased beyond those widths (Figure 9). After adding data from 2017-2022, we found the maximized selection ratio of UOCW was at 1,102 ft. The 90% confidence intervals overlapped for UOCWs between 514 – 1,102 ft, making the benefits to maintaining UOCW wider than 514 ft in terms of whooping crane roosting uncertain. Similar consideration of confidence intervals surrounding the relationships established by Howlin and Nasman (2017) and Baasch et al. (2019a) revealed statistically similar responses in terms of whooping crane roosting predicted for UOCWs between 287 – 520 ft and 361 – 650 ft, respectively. In comparison to earlier studies, our current results suggest that the range of UOCWs selected for by whooping cranes has shifted to wider UOCWs, but this range still encompasses the maximized selection widths from Howlin and Nasman (2017) and Baasch et al. (2019a), as well as the current Program criteria for highly suitable UOCW of ≥650 ft.

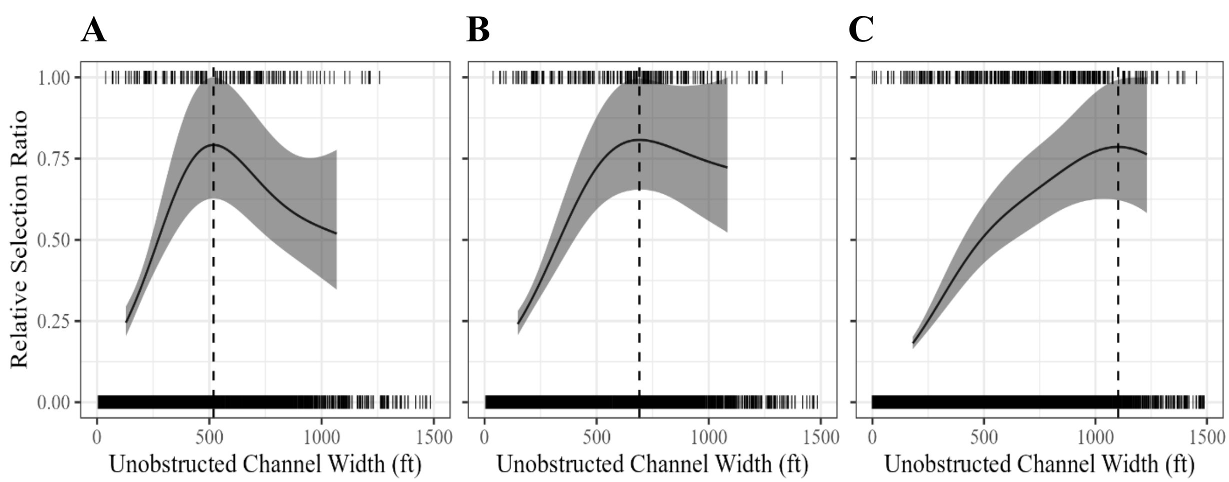


Figure 9. Predicted relative selection ratio of unobstructed channel width (UOCW) estimated from whooping crane roosts collected by systematic aerial monitoring from Howlin and Nasman (2017; A), Baasch et al. (2019a; B), and the current study from spring 2001 – spring 2022 on the central Platte River in the Associated Habitat Reach (C). The selection relationship for Howlin and Nasman (2017) presented here was predicted with a model using all systematic roost locations and constrained degrees of freedom (k=5) for each explanatory variable in the model, as was done in Baasch et al. (2019a) and the current analysis. The solid lines represent the average relationships between the 5^{th} and 95^{th} percentiles of UOCW at roost locations observed in each study, while the shaded area represent the 90% confidence interval over the entire range of unobstructed channels widths observed at roost locations. Tick marks at y=1 show values of UOCW at roosts and ticks at y=0 show available location values. Dashed vertical lines represent the maximized value for each selection ratio.

The shift in whooping crane selection for wider UOCW was likely due to the inclusion of roost locations with wider UOCWs in the latter years. The average UOCW for roost locations from fall 2017 to spring 2022 was 810 ft (n=207) compared to 602 ft (n=235) in Baasch et al. (2019a) with roost locations from spring 2001 – spring 2017. Though wide UOCWs were generally more available in the main channel across the AHR during the latter portion of our study, randomly chosen available locations were not limited to the main channel and included points in narrower side channels typically avoided by whooping cranes for roosting. Upon inclusion of roost locations from fall 2017 through spring 2022, the distribution of UOCWs at roost locations shifted toward wider widths. In comparison, the distribution of available UOCWs did not widen as much because of the inclusion of side channels as available, but rarely used for roosting. Thus, the disparity between UOCW at roost locations and available locations has grown.

Our results demonstrate a robust, long-term pattern of whooping crane avoidance of river channels with forested areas closer than 550 ft for roosting. Our results corroborate findings from past studies both outside and within the AHR. Austin and Richert's (2005) study of habitat use across the U.S. migratory corridor documented a lack of trees and shrubs near whooping crane roosts. Within the AHR, our current results found whooping cranes selected roosts >559 ft from nearest forest with no additional benefit in terms of increased roosting predicted for maintaining forest at distances further away from the river. These findings are very similar to results of Howlin and Nasman (2017) and Baasch et al. (2019a). In the AHR, the availability of roosting habitat farther than 800 ft from forest is minimal due to woody encroachment throughout the historical floodplain, including river islands and along banks of the active river channel (Johnson 1994). As such, few roosts have occurred further than 800 ft from forest. It is also worth noting that nearest forest is measured in any single direction from in-channel roost locations. Since the PRRIP (2017b) and Baasch et al. (2019a) work was completed, the Program has managed for two times the 550 ft recommended distance to nearest forest to manage for at least an 1,100 ft unforested corridor width to allow for the same distance from forest on both sides of roost locations. This management strategy may also contribute to our current result supporting selection for wider UOCW, maximized at 1,102 ft.

Though the amount of development on the landscape contributes much less to explaining roost site selection than in-channel metrics, we did find that whooping cranes may avoid even small areas of development when selecting roost sites in the AHR. Whooping cranes have a well-established aversion to development or disturbance at both local and landscape scales. Whooping cranes have demonstrated avoidance of areas with high road density and other forms of human infrastructure on the landscape throughout the migratory corridor (Johns et al. 1997, Belaire et al. 2014, Niemuth et al. 2018, Pearse et al. 2021). Within the AHR, Baasch et al. (2019b) and Howlin and Nasman (2017) found whooping cranes avoid areas near development for diurnal habitat selection and roost locations, respectively. Baasch et al. (2022) found development within 0.62 miles impacted patterns of off-channel diurnal use for whooping cranes in the AHR. The Program could use the relationship between development and roost site selection established in the current study to consider how nearby development may impact suitability when assessing land for habitat acquisition.

5 – PROGRAM MANAGEMENT IMPLICATIONS

The Program's definition of highly suitable whooping crane roosting habitat has not changed because of the Program's five-year check-in on learning about the factors that influence whooping crane roost site selection. Like previous analyses, UOCW and NF remain important for Program management of on-channel whooping crane roosting habitat. The Program will continue to manage on-channel habitat complexes to create or maintain unforested corridor widths of at least 1,100 ft (two times the 550 ft recommended distance to nearest forest) to allow for the same distance from forest on both sides of roost locations. Given the high degree of uncertainty surrounding the relationship between whooping crane roost site selection for unobstructed channel widths between 514 – 1,102 ft, the TAC has not made any formal recommendation to change the Program's current criteria for highly suitable roosting habitat of UOCW ≥650 ft. However, the TAC has created a working group that will review the current channel conditions for whooping cranes at Program habitat complexes to identify areas where river flow and channel morphology could support wider unobstructed channels widths. Specifically, Cottonwood Ranch, Jerry F. Kenny/Pawnee, and the Fort Kearny complexes have been identified as having UOCWs of less than 1,100 ft on average, currently averaging around 650 ft. The working group will determine if and where there is potential for additional widening that can be maintained by river flow (natural flows and/or Program water) without extensive mechanical management through river channel disking.

As the only off-channel element of the surrounding landscape to influence whooping crane roost site selection in the current analysis, the amount of development surrounding on-channel habitat should also be considered when assessing land for whooping crane habitat suitability. Though other landcover types were explored to evaluate their influence on whooping crane roost site selection, including meadow marsh and agricultural wetlands, they had little influence on selection of riverine roost sites. This result supports the Program's current management focus on creating and maintaining wide, unobstructed in-channel roosting habitat.

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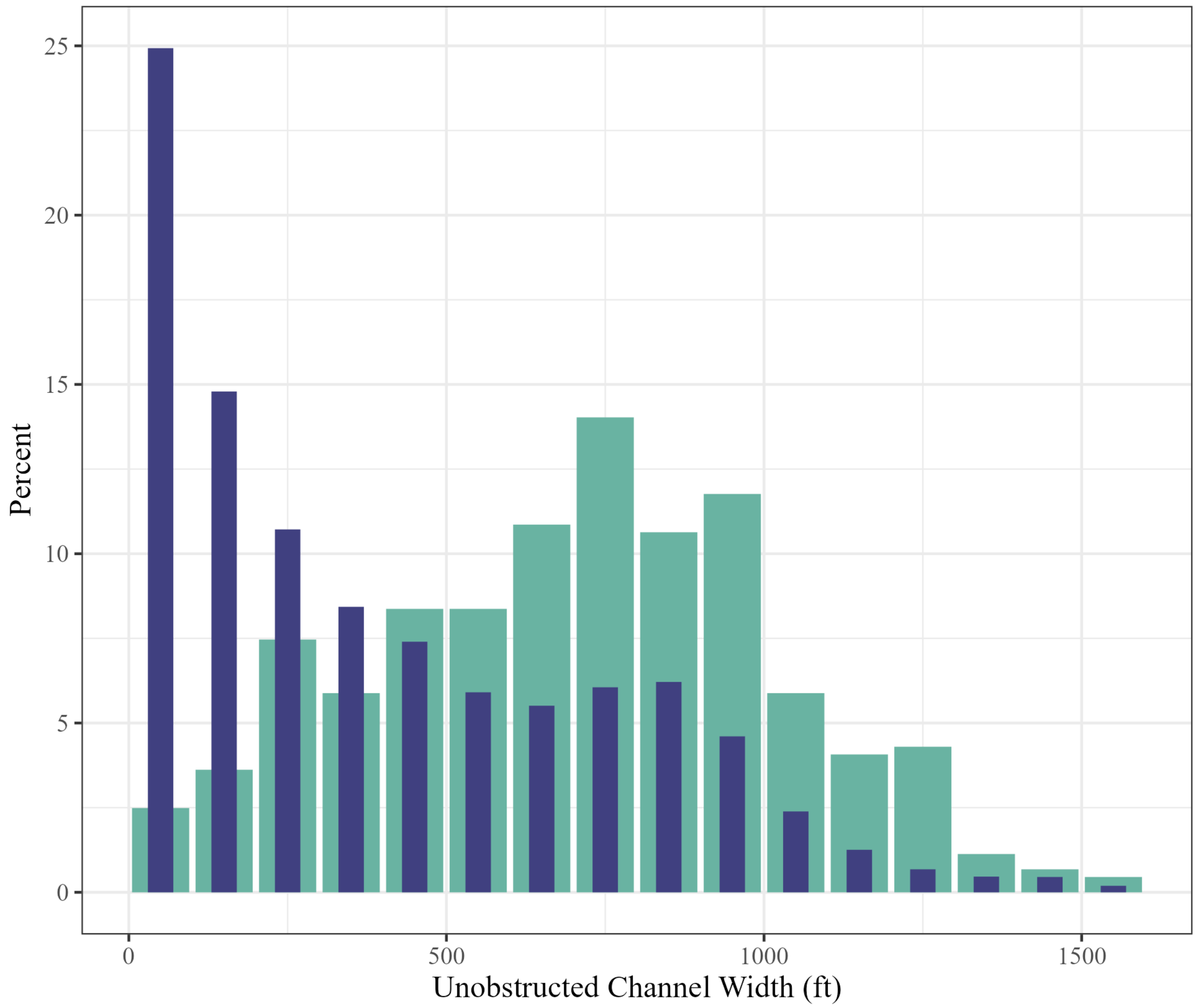
7 – APPENDICES

Appendix 1. Link to the annual landcover layers for 2010 and 2022 as examples and roost/available locations can be found here: (https://hwcorp.maps.arcgis.com/apps/instant/basic/index.html?appid=eb78754aa4c646609a9565320a2c8d5c). Due to file size, additional annual landcover layers can be made available upon request.

Appendix 2. Model selection table to compare primary explanatory variables to alternative variables. Prior to development of our suite of models, we compared related primary and alternative variables to identify which measure of agriculture, forest, and development had the best explanatory power to describe patterns of roost site selection for whooping cranes. Comparisons were made using the Akaike Information Criterion (AIC) scores of single variable models. For agriculture, we compared the proportion of corn (CO) within 0.77 miles to the proportion of alfalfa (AL), proportion of soybeans (SO), and proportion of all other agriculture (OA) within 0.77 miles of roosts and available point locations. For forest, we compared the nearest forest (NF) to unforested channel width (UFCW) at roosts and available locations and the proportion of forest (FO) within 0.77 miles. For development, we compared the proportion of development (DE) within 0.77 miles of roosts and available point locations to the minimum distance from transmission lines (TL; Homeland Infrastructure Foundation-Level Data – U.S. Electric Power Transmission Lines) for each location. We chose to proceed with CO for the final suite of models despite CO having a greater ΔAIC than AL and OA due to the *a-priori* hypothesis of corn's importance to whooping crane use patterns in the Associated Habitat Reach.

Category	Variable	df	AIC	ΔAIC	Weight
Forest	NF	165.64	2824.98	0.00	1.00
Forest	UFCW	165.36	2898.05	73.07	0.00
Development	DE	163.00	2912.78	87.80	0.00
Forest	FO	165.83	2922.13	97.15	0.00
Development	TL	163.00	2955.19	130.21	0.00
Agriculture	AL	164.87	2958.54	133.57	0.00
Agriculture	OA	163.00	2960.69	135.72	0.00
Agriculture	CO	163.00	2962.11	137.13	0.00
Agriculture	SO	163.00	2962.36	137.39	0.00

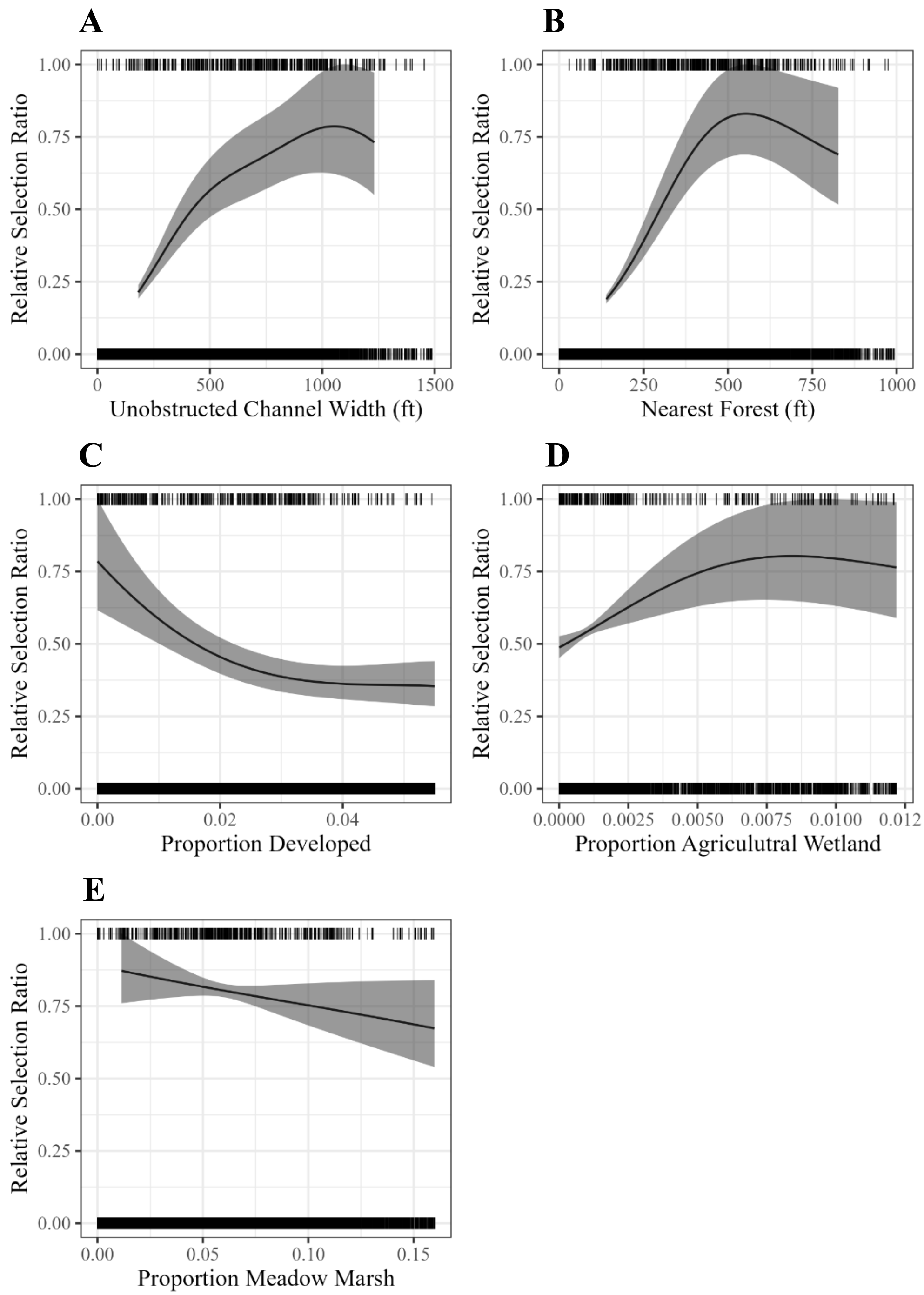
Appendix 3. Percent of unobstructed channel widths that occurred in each binned range (bin width = 100 ft) at roosts (green) collected by systematic aerial monitoring from spring 2001 – spring 2022 and their corresponding available (blue) locations. Roost percentages were calculated by dividing the count of the number of roosts with unobstructed channel widths in a bin by the total number of roosts (n = 442). The same procedure was used to calculate available percentages, with counts of available locations in each bin divided by the total number of available locations (n = 8836). Further comparisons of unobstructed channel widths between roost and available locations can be found in Appendix 4.



Appendix 4. Distribution of systematically collected roost locations from spring 2001 – spring 2022 and corresponding available locations across unobstructed channel widths (bin width = 100 ft). Roost percentages were calculated by dividing the count of the number of roosts with unobstructed channel widths in a bin by the total number of roosts (n = 442). The same procedure was used to calculate available percentages, with counts of available locations in each bin divided by the total number of available locations (n = 8836). The information in this table was used to create the visual comparison of percentages in Appendix 3.

	Unobstructed Channel Width Range (ft)																
	0-100	100-200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	1000-1100	1100-1200	1200-1300	1300-1400	1400-1500	1500-1600	Total
Roosts	11	16	33	26	37	37	48	62	47	52	26	18	19	5	3	2	442
Percent of Roosts	2.5	3.6	7.5	5.9	8.4	8.4	10.9	14.0	10.6	11.8	5.9	4.1	4.3	1.1	0.7	0.5	100
Total Percent of Roosts	2.5	6.1	13.6	19.5	27.8	36.2	47.1	61.1	71.7	83.5	89.4	93.4	97.7	98.9	99.5	100.0	
Available Locations	2203	1307	947	745	654	522	487	535	549	407	211	111	60	41	40	17	8836
Percent of Available Locations	24.9	14.8	10.7	8.4	7.4	5.9	5.5	6.1	6.2	4.6	2.4	1.3	0.7	0.5	0.5	0.2	100
Ratio (Roost%/Available%)	0.1	0.2	0.7	0.7	1.1	1.4	2.0	2.3	1.7	2.6	2.5	3.2	6.3	2.4	1.5	2.4	

Appendix 5A-E. Relative selection ratios, from model 27, of whooping crane roosts collected by systematic aerial monitoring from spring 2001 – spring 2022 on the central Platte River in the Associated Habitat Reach. The solid lines represent the average relationships between the 5th and 95th percentile of each variable while the shaded area represent the 90% confidence interval. Tick marks at y=1 show values of explanatory variables at roosts and ticks at y=0 show available location values.



Appendix 6. The deviance explained (DV) by roost selection model 27, not accounting for model complexity, compared to DV of models with explanatory variables withheld to assess variable importance to model fit.

Withheld Explanatory Variables	DV	Decrease in DV	% Decrease in DV
None (Model 27 = UOCW + NF + MM + AW + DE)	0.200	-	-
NF, UOCW	0.072	0.128	64%
UOCW	0.168	0.032	16%
NF	0.158	0.042	20%
DE	0.191	0.009	4%
AW, MM	0.195	0.005	2%
AW	0.197	0.003	1%
MM	0.198	0.002	1%