Correlates of Whooping Crane Habitat Selection

And Trends in Use

in the Central Platte River, Nebraska

Prepared for:

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June 8, 2017

Executive Summary

The Platte River Recovery and Implementation Program (PRRIP) monitors migratory habitat for the endangered whooping crane (*Grus americana*) and directs the management of land and water resources to provide benefits to this species, and ultimately improve the survival of whooping cranes during migration. The objective of this paper is to determine progress towards PRRIP's goal of providing benefits to whooping cranes by 1) analyzing in-channel habitat selection by whooping cranes in the central Platte River, a primary stopover area, and 2) assessing trends in whooping crane use of the central Platte River over time. Study results in the form of habitat characteristics associated with the highest selection ratios by whooping cranes will also help to inform future management actions by PRRIP. To this end, PRRIP researchers monitored whooping crane group use in the central Platte River with daily systematic aerial surveys during spring and fall migrations. The survey protocol outlines standardized survey methods and survey effort to facilitate consistent data collection and enable unbiased analyses of habitat selection. In-channel habitat selection from fall 2001 to spring 2013 was analyzed within the resource selection function framework utilizing penalized regression splines. Model selection determined the best fitting model among a list of a priori models containing various combinations of descriptors of habitat derived from land cover vector shapefiles, aerial imagery, and the HEC-RAS hydraulic model. There were 55 observations of unique whooping crane groups, 33 in the spring and 22 in the fall, located with the systematic aerial surveys. Each choice set extended 10 miles upstream and downstream from the use point. Unobstructed channel width, nearest forest, and nearest obstruction were the factors with the most influence on in-channel habitat selection. The impact of these variables was evident by the higher relative selection ratios at larger unobstructed channel widths, longer distances to nearest forest, and longer distances to nearest obstruction (dense vegetation), though all relationships declined after reaching a maximum and whooping crane groups were observed across a wide range of values for each of these variables. Analyses of all 176 systematic in-channel observations, and all 253 systematic and opportunistic in-channel observations were presented in appendices to the report as a comparison to the systematically obtained data.

Diurnal habitat selection from fall 2001 to spring 2013 was analyzed within the same modelling framework as in-channel habitat selection but was limited to descriptors of habitat that could be calculated for both in-channel and off-channel locations. There were 478 diurnal observations of whooping crane groups, 347 in the spring and 131 in the fall, located with the systematic aerial surveys. Each choice set extended 3 miles in all directions from the use point. Land cover, nearest disturbance and proximity to roost location were the factors with the most influence on in-channel habitat selection. The highest relative selection ratios were seen at in-channel and corn cover categories, longer distances to nearest disturbance, and shorter distances to previous night roost location.

Trends in whooping crane use of the central Platte River through time were analyzed from spring 2001 to fall 2014. To account for the documented increase in the Aransas-Wood Buffalo population of migrating cranes that could have stopped in the central Platte River during migration, two use metrics were quantified as the proportion of the population using the central Platte River and the crane use days per bird in the population. Simple linear models of trend were estimated after testing for temporal correlation in the error terms. Trends in the proportion of the population using the central Platte River were significantly increasing for the spring migration season, indicating the number of cranes that used the study area in the spring was increasing

faster than the population size. Both the fall trends and the combined spring and fall trends in the proportion of the population using the central Platte River were not significantly different from zero, i.e. no trend. Trends in the crane use days per bird in the population for the spring, fall, and combined spring and fall were not significantly different from zero, i.e. no trend. The non-significant result equates to the conclusion that the number of crane use days documented in the study area was increasing in proportion to the population size.

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1. Introduction

The whooping crane is a distinctive species found only in North America and is currently recovering its population to higher levels. It is the tallest of North American birds, standing nearly five-feet tall with a wingspan of 7-8 feet (Urbanek and Lewis 2015). Adult individuals are covered in white plumage with black primary feathers on the wings and a red face and crown, while plumage of juveniles is tinged reddish cinnamon in color (Allen 1952).

The historic population of the whooping crane was variously estimated at 500 to 1,400 individuals in 1870, with an overall range that extended from the Artic coast to central Mexico (Allen 1952). By 1941 the migratory population declined to only 16 individuals (Canadian Wildlife Service and USFWS 2005) and the species was listed as endangered in 1967 (USFWS 1986). The bulk of the population of whooping cranes today belongs to the Aransas-Wood Buffalo population, estimated at roughly 300 whooping cranes (Urbanek and Lewis 2015). Individuals in the Aransas–Wood Buffalo population are long-distance migrants that breed in Northwestern Canada and the Northern Territories. They arrive on breeding grounds in late April and individuals will typically lay two eggs between late April and early May, incubating for about a month, after which young are raised. Autumn migration begins in mid-September and most birds arrive on the wintering grounds on the Texas Gulf Coast by early to mid-December where they will remain until migrating north again in the spring (Allen 1952).

Individuals of the Aransas-Wood Buffalo population of the whooping crane migrate diurnally twice a year over the course of several weeks along a narrow corridor (approximately 200 miles wide and 2,485 miles in length) within the Central Flyway in the U.S. and Canada enroute between breeding and wintering grounds (Pearse et al. 2015). This migration corridor includes stopping points for roosting and foraging where whooping cranes will remain for one to several days to build energy reserves to complete migration (Howe 1989, Kuyt 1992, Canadian Wildlife Service and USFWS2007). At stopover sites, whooping cranes roost standing in shallow water associated with palustrine, lacustrine, or riverine wetlands. Some stopover sites in the migration corridor are used consistently and receive relatively high annual use. One of these sites, the Big Bend reach of the Platte River in central Nebraska, is the only stretch of river designated as critical whooping crane habitat under the Endangered Species Act (Armbruster 1990; Biology Workgroup 1990). Characteristics of central Platte River roost habitat have been examined and described in detail (Johnson 1981; Lingle et al. 1984; Ziewitz 1987; Faanes 1988; Faanes and Bowman 1992; Faanes et al. 1992). In early examinations of roost sites in the central Platte River, researchers identified wide, unvegetated channels and open visibility with the absence of tall trees or dense shrubs near the roost as important habitat characteristics (Johnson and Temple 1980; 1981; Johnson 1981; Ziewitz 1987; Armbruster 1990; Faanes et al. 1992; Austin and Richert 2001; National Research Council 2004).

Characteristics of whooping crane roost habitat have been examined and described for the central Platte River in Nebraska (Johnson 1981; Lingle et al. 1984; Armbruster 1990; Faanes 1988; Faanes and Bowman 1992; Faanes et al. 1992). Several characteristics common to whooping crane riverine roost sites include shallow, wide, unvegetated channels and open visibility with the absence of tall trees or dense shrubs near the roost (Johnson and Temple 1980; USFWS 1981; Johnson 1981; Armbruster 1990; Faanes et al. 1992; Austin and Richert 2001; National Research Council 2004). To date, however, roost characteristics and criteria have been developed based on a limited amount of quantitative information and most criteria have been derived from circumstantial roost locations that may not be representative of a typical stopover site (Armbruster 1990).

Farmer et al. (2005) reported whooping cranes selected channels with wider unobstructed channel widths at both scales they evaluated (i.e., use was not random with respect to unobstructed channel width). Past research indicates whooping cranes tend to select roost habitat with increased wetted width and area of suitable depth (Farmer et al. 2005). Unit discharge is related to flow, wetted width, and area of suitable depth in that an increase in unit discharge (increase in flow or decrease in channel width) would generally equate to an increase in wetted width and a decrease in area of suitable depth. A strong relationship between unit discharge or discharge divided by total channel width and whooping crane use was found by Biology Workgroup (1990) and Farmer et al. (2005). Additional studies are addressed in the Discussion section below.

The objective of this paper is to determine progress towards providing benefits to whooping cranes by 1) analyzing in-channel habitat selection by whooping cranes in the central Platte River, a primary stopover area, and 2) assessing trends in whooping crane use of the central Platte River over time. Inferences from this study will be influenced by fewer biases than past research on migrational habitat use by whooping cranes as the analysis is based on data from unbiased sampling using aerial surveys in a well-defined study area. Study results in the form of habitat characteristics associated with the highest selection ratios by whooping cranes will also help to inform future management actions by PRRIP.

Establishment of PRRIP

The Platte River Recovery Implementation Program (Program or PRRIP) was established as a program to manage land and water resources for whooping cranes within the central Platte River. Its origin goes back to efforts to relicense Kingsley Dam on the North Platte River in western Nebraska (PRRIP 2015). This relicensing was addressed at a time when threatened and endangered species such as the whooping crane were known to use the Platte River and the USFWS had released its 1994 Biological Opinion on Platte River operations; these factors combined to provide the potential for conflict over the Platte's vital water. Rather than engage in years of courtroom battles over limited water supplies and river species, the governors of the three basin states (Colorado, Nebraska, and Wyoming) joined with the Secretary of Interior in July 1997 to sign the "Cooperative Agreement for Platte River Research and Other Efforts Relating to Endangered Species Habitat along the Central Platte River, Nebraska" for the creation of PRRIP, which commenced on January 1, 2007, with its overall goal being to utilize federal and state provided land, water, and scientific monitoring and research to secure defined benefits for the whooping crane and its habitat in the central Platte River (PRRIP 2015).

Habitat Selection

For this analysis, we investigated habitat selection by whooping crane groups during migration stopovers on the central Platte River from fall 2001 to spring 2013. We fit statistical models to determine if there were habitat characteristics associated with the locations selected for use by whooping crane groups. We compared models containing different combinations of habitat descriptors to determine which were the most likely to describe selection by whooping cranes. The top models are intended to provide guidance for managing the central Platte River.

Habitat characteristics of use sites in the study area have typically been quantified using different metrics for in-channel (locations within the active channel) versus off-channel (locations outside of the active channel) use. Biologically, this equates to the assumption that whooping crane groups select for different habitat characteristics during the selection of in-channel versus off-channel use locations. This difference results in the need for two different habitat models, with the quantification of riverine metrics through hydraulic models restricted to the in-channel use locations. Here we have analyzed the in-channel habitat use locations that were observed from early morning aerial monitoring alone, while combining in-channel and off-channel habitat use for an additional study of habitat use during the diurnal time period when cranes were monitored by ground crews.

For the in-channel habitat use analysis we focused on the description of habitat metrics to facilitate application in PRRIP management. We quantified the characteristics of in-channel habitat with three basic sources of information: land cover vector shapefiles, aerial imagery, and the HEC-RAS hydraulic model. Each habitat descriptor was calculated with desktop analyses, at the time of the analysis, using consistent methods. There were no habitat descriptors measured in the field in the analysis. Our goal was to develop habitat models that could inform management using metrics that PRRIP will be able to measure and monitor.

For the diurnal habitat use analysis, we focused on descriptors of habitat metrics that could be measured for both in-channel and off-channel use locations. We quantified the characteristics of habitat with two basic sources of information: land cover vector shapefiles, and aerial imagery. As with the in-channel analysis, each habitat descriptor was quantified with desktop analyses to facilitate the development of models useful to PRRIP managers.

Trends in Use

The use of stopover habitat in the central Platte River by whooping cranes during migration has been monitored for the spring and fall seasons by PRRIP since spring 2001, with the exception of spring 2003. It is hypothesized that the incidence of whooping crane stopovers in the AHR will increase through time as PRRIP implements targeted management of land and water resources, although natural variation that will be inherent in sampled data of small populations like the whooping crane may have obscured any increases in the short-term. To evaluate this hypothesis, we investigated trends in the use of the central Platte River by groups of whooping cranes during migration stopovers on the central Platte River from spring 2001 to fall 2014.

For this analysis, we define trend as the change in the mean level of whooping crane use through time (Chatfield 2003). Consistent data collection for whooping crane group use by PRRIP in the study area is ideal for monitoring long term trends in use. Using these data, we estimated linear statistical models to determine if the mean level of use was increasing, decreasing, or not changing in the study area. Whooping crane use of the PRRIP study area was quantified in two ways: the number of cranes and the number of crane use days. This trend evaluation also accounted for the simultaneous change that has occurred in population size of whooping cranes that potentially stop on the central Platte River.

2. In-channel Habitat Selection Methods

The study area for the PRRIP monitoring program encompasses 3.5 miles on either side of the central Platte River from the junction of US Highway 283 and Interstate 80 (near Lexington, Nebraska to Chapman, Nebraska (PRRIP 2011). Aerial surveys were flown daily, weather permitting, during both migration seasons, with the spring time period spanning from March 21 to April 29, and the fall time period spanning from October 9 to November 10. Flights followed the main river channel and took place in the morning intending to locate crane groups before they departed the river to begin foraging. Return flights were scheduled after the main river channel flight and systematically surveyed upland areas and smaller side channels. Flights were flown at an elevation of 1,000 feet above ground as to not disturb whooping cranes as the plane passed over. A full description of the data collection methods can be found in the Program's Whooping Crane monitoring protocol (PRRIP 2011). All data were collected while adhering to the FWS guidelines regarding minimization or elimination of crane disturbance.

Whooping Crane Group Observation Data

The basic sample unit for this analysis was the location of a crane group within the study area. The PRRIP monitoring program compiled observations of crane groups in the study area into a dataset; the observations include those that were identified with the systematic aerial surveys, follow-up ground monitoring efforts, and opportunistically identified locations from the public and other professional biologists (Table 1). Analyses presented here only pertain to the data collected through the systematic aerial PRRIP surveys and for the first location of a crane group in the area. For example, if a crane group was identified using the channel multiple times throughout the day, or multiple days in a row, then only the first detection was included here, if it was identified with the aerial survey. We considered the first observation of a crane group as "unique", or independent, and did not include subsequent in-channel observations to ensure independence of observations. This dataset, and associated analysis, based only on observations from the aerial survey was intended to be representative of the entire study area and not biased by multiple observations of the same crane group or observations obtained by convenience sampling.

While PRRIP designed systematic aerial sampling of whooping crane use locations to ensure analyses could be conducted with data that were unbiased with respect to sampling methods, the abundance of data collected during multi-day stopovers provide an opportunity to conduct more robust analyses and evaluate the impacts of additional data on conclusions. Therefore, we conducted a second analysis of the data with all the systematically identified locations, both unique and non-unique, which can be found in Appendix C. Multiple observations of the same crane group were included. We performed a third analysis of the data with all locations in the PRRIP dataset, which is presented in Appendix D. This analysis included systematic and opportunistic sightings and multiple observations of the same crane group. The impact of the inclusion of non-unique observations in a subsequent analysis was evaluated using the same methods as for the systematic unique assessment presented here.

The use of stopover habitat by whooping cranes during migration has been monitored by the PRRIP since spring 2001, with the exception of spring 2003. By the end of 2002, the Program adopted a consistent monitoring protocol for the aerial survey methodology. Minor operating procedures were changed as a result of evaluations conducted during the early years (e.g., flight height, flight direction). Coincidently, our analysis excluded observations of crane groups during 2001 and spring of 2002 due to the lack of landcover data in 2001 and early 2002, but had the effect of removing survey data that was obtained during the years with slightly different survey methods. Analyses presented here were based on model selection with whooping crane group observations from fall 2002 to spring 2013 when the protocol remained consistent and land cover descriptors of habitat were available, while predictions and inferences from the resulting models included all observations.

Table 1. Number of in-channel observations of whooping crane groups detected in the study area during PRRIP surveys and opportunistically from fall 2001 to spring 2013. Analyses presented in this report were conducted with the systematic unique data. We present analyses with all systematic in-channel observations in Appendix C, and analyses with all systematic and opportunistic in-channel observations in Appendix D.

Year	Systematic Unique	All Systematic (Unique and Non-unique)	All Systematic And Opportunistic
2001	1	4	7
2002	4	20	22
2003	1	1	1
2004	1	2	3
2005	4	6	6
2006	4	27	28
2007	7	31	37
2008	3	5	6
2009	7	23	23
2010	8	20	21
2011	8	16	23
2012	1	7	39
2013	6	14	38
Total	55	176	253

Whooping Crane In-channel Habitat Selection

We evaluated habitat selection by whooping crane groups in the central Platte within the Resource Selection Function (RSF) estimation framework. In this model, characteristics of points (i.e., locations) used by whooping cranes were contrasted to characteristics of points available for use to the whooping crane. The relative difference in the distribution, or density, of these characteristics defines habitat selection. For example, cranes may choose to roost in a river channel of a certain depth while there are many deeper and shallower channels that they could have selected to roost. Multiple modelling paradigms were available for this estimation due to recent statistical advances which have demonstrated that spatial point process models underlie both the use-available approach and the presence-only approach (Johnson et al. 2006, Aarts et al. 2012, McDonald 2013, Warton and Aarts 2013). We chose the use-available approach for this study because of the need to handle an important factor that affects whooping crane selection in the central Platte River: changing availability.

Analyzing wildlife selection with changing availability has been a part of the RSF literature for more than 20 years (Johnson 1980, Arthur et al. 1996, McCracken et al. 1998, Manly et al. 2002, McDonald et al. 2006). Whooping crane use of the Platte River represents a unique situation in that availability of resources changes both temporally and spatially. A special case of RSF estimation, the discrete choice framework of analysis, accounts for changing availability in model estimation. By incorporating changing availability, the variability associated with the dynamic nature of riverine habitat was accounted for in the habitat selection model.

In-channel habitat available for use by whooping cranes is chiefly a function of river hydrology, adjacent and in-channel vegetation, and human disturbance. Natural snowmelt and rainfall, hydroelectric operations, and irrigation activities chiefly influence in-channel streamflow in the central Platte River. During a multi-night stopover by a whooping crane group, there can be a dramatic range in the volume of in-stream flows. As the characteristics of available habitat change temporally during a crane group stopover, so too does the definition of available habitat in this analysis.

The spatial aspect of changing habitat conditions is primarily due to the variability in geomorphic channel type throughout the 80 mile habitat reach. As an aerially migrating whooping crane group approaches the river, the options for a stopover location are presumably limited by sight to a reduced section of the study reach. We assumed that the entire length of the central Platte was not available to the migrating group, but rather the group evaluated a subsection during the selection process. We also assumed that this subsection was near the chosen use point. We acknowledge there may be exceptions to this, but we believe they are rare. Therefore, our definition of available habitat for crane groups was centered on the actual location used and changes spatially for crane groups in the area.

We have chosen the discrete choice method of RSF estimation to incorporate changing availability at temporal and spatial scales. The discrete choice model accounts for changing habitat conditions in the study area, while modeling the underlying relationships between selection and predictor variables. We handled non-linear changes in the RSF due to changing availability with penalized regression splines to approximate the functional response (Aarts et al. 2013). With the exception of mixed linear models (Hebblewhite and Merril 2008, Duchesne et al. 2010, Matthiopoulos 2011), other methods of estimating RSF's using the inhomogenous point process have not incorporated this facet of habitat selection into the statistical underpinnings of the method. It may be possible that recent advances in space-time point process models proposed by Johnson et al. (2013) may be appropriate for this type of data (Trevor Hefley, pers. Comm.), but the method does not address the incorporation of changing availability at this time.

<u>Defining the Available Choice Set</u>

The choice set represents a sample of points from an area that the crane group could have selected for use. This distribution is analogous to the background sample in Maxent (Phillips et al. 2006, Phillips and Dudik 2008) and the quadrature points in point process models (Warton and Shepherd 2010). In the discrete choice framework, the choice set is unique for each choice, or used location, and is linked to the choice through the likelihood terms in the model. In effect, the model allows the comparison between characteristics of each used location and the characteristics of the choice set. This pairing in the model is accomplished through the use of a strata term in the Cox model within the generalized additive model (GAM) framework using the `gam` function in the mgcv package (Wood 2014, R Core Team 2013).

For the in-channel habitat use analysis, the choice set was centered on the use location and extended 10 miles upstream and downstream from that point. We assumed the cranes could reasonably evaluate this area based on an assessment of viewsheds from 3,000 feet above ground level by PRRIP personnel, which was a reported elevation for long distance flights by telemetry-marked whooping cranes in the 1980s (Kuyt 1992). The sensitivity of results to this assumption was tested using an available area of 5 miles upstream and downstream of the use locations and we found our results were insensitive to what was defined to be available. There were 20 locations in the choice set for each use location in the model. This description of the choice set had the effect of limiting inference of the in-channel habitat model to areas within 10 miles of selected use locations, but was implemented in order to facilitate the study of habitat selection at the spatial scale of interest. The determination to use 20 locations in the choice set was determined based on a Monte Carlo simulation by PRRIP personnel. The analysis evaluated the change in the percent mean error of the average of one hydraulic metric across adjacent profiles simulated across a range of sample sizes from 2 to 200. The simulation results showed little decrease in percent mean error of the statistic after a sample size of 20 was reached.

Descriptors of In-channel Habitat

We quantified the characteristics of in-channel habitat with three basic sources of information: land cover vector shapefiles, aerial imagery, and the HEC-RAS hydraulic model. We calculated each descriptor of habitat for possible inclusion as a predictor variable in the habitat models. We calculated the metrics for both the whooping crane use point and the available points in the choice set.

We obtained land cover information from the land cover product produced for the PRRIP by USFWS-Rainwater Basin Joint Venture. This GIS product is a compilation of agriculture crop information taken from the USDA National Agricultural Statistics Service 2012 Nebraska Cropland Data Layer (CDL, Boryan et al. 2011) with field boundaries from USDA Farm Service Agency Common Land Unit (CLU). We calculated the following metrics for the analysis:

- Proportion Corn (PC)- Proportion of landcover within 3-mile radius buffer classified as corn
- Proportion Forest (PF)- Proportion of landcover within 3-mile radius buffer classified as forest
- Proportion Grassland (PG)- Proportion of landcover within 3-mile radius buffer classified as grassland
- Proportion Wet Meadow (PWM)- Proportion of landcover within 3-mile radius buffer classified as wet meadow
- Unforested Width (UFW)- Width of river corridor unobstructed by riparian forest
- Nearest Forest (NF)- Distance to nearest riparian forest. Distance larger than 1320 feet (1/4/ mile) were capped at 1320 feet.

We used aerial photographs and remote sensing data from LiDAR to determine the following metrics of channel openness for the analysis:

- Unobstructed Channel Width (UOCW)- Width of channel unobstructed by dense vegetation
- Nearest Obstruction (NO)- Distance to nearest dense vegetation.

We ran the HEC-RAS hydraulic model to predict metrics describing channel characteristics for the analysis. The Program developed the HEC-RAS model primarily using longitudinal profile surveys updated with 2009 topography, and 2005 land use conditions. The Program calibrated the model based on gaged rating curves, March 2009 inferred water surface elevation from LiDAR data, and water surface elevation measured in 2009. We calculated the following metrics for the analysis:

- Total Channel Width (TCW)- Total width of channel from left bank to right bank
- Wetted Width (WW)- Top width of wetted channel

- Proportion Wetted (PW)- Proportion of total channel width that was wetted
- Mean Depth (MD)-Mean depth of the wetted portion of the channel
- Unit Discharge (UD)- Flow (cfs) per linear foot of channel width.
- Width Depth Ratio (WDR)- Ratio of channel width to depth (WW/MD).

Data Summaries

For each descriptor of in-channel habitat, or the predictor variable, we developed mirrored histograms to graphically display the data. These figures show the distribution of the values for each variable in order to contrast the distribution for the set actually chosen by whooping cranes to the available set. For each probability histogram, the area of the bars sums to one. Although these figures display the relationship between the predictor variables and the outcome (use by whooping cranes), they simplify the assessment by combining data across the many choice sets. Despite this caveat, they are presented in Appendix B to provide a graphical precursor to understanding the statistical models of habitat use. Mean, standard deviation and coefficient of variation for each variable are in Table B.1 of Appendix B.

Candidate Model List/Model Selection

The PRRIP staff and Program Technical Advisory Committee members developed a list of 184 candidate models, each containing a different combination of covariates (predictor variables). This set of models, with the inclusion of a null model containing no covariates, composed the complete set of *a priori* models evaluated (Appendix A, Table A.1). We determined which *a priori* model was most useful in predicting habitat use with the model selection process known as the Akaike Information Criterion statistic (AIC, Burnham and Anderson 2002). The model in the *a priori* list with the lowest AIC value was considered the most parsimonious and the most likely given the data. This model was used to infer conclusions about habitat use. We also calculated the AIC weight to assist in the interpretation of the AIC rankings. The AIC weights were calculated for each model as the proportion of the relative likelihood of the model to the sum of the relative likelihoods over the complete model set. The weights express the magnitude of the difference in relative likelihood of a model, standardized to sum to 1 across all models in the candidate model list.

Management Model List

For the next step, we selected a subset of 10 of the *a priori* candidate models for the candidate management model list (Appendix A, Table A.1). We retained models from the list of 184 candidate models in this list if they contained variables that potentially could be used in management of the river by the PRRIP. PRRIP staff determined the management potential of each variable, i.e., which variables were ones they could affect physically on the ground and in relation to where whooping cranes may roost. In general, landcover variables were not included in these models, with the exception of nearest forest. We included unobstructed channel width, total channel width, and unit discharge in these models.

Functional Response to Resource Selection

We used penalized regression spline methodology to evaluate a functional response in habitat use. Resource selection models evaluate functional responses, i.e., the change in selection as a function of spatial or temporal changes in resource availability, and spline smoothers allow for non-linear effects. Smooth spline functions enabled a wide array of functional forms to be incorporated into the RSF, with the implementation of model selection determining the precise shape of the functional response. The smooth term was represented in the habitat model with a set of basis functions and associated penalties (Hastie and Tibshirani 1990, Wood 2006). The penalty was larger when the smoothing function was very "wiggly" and requires more degrees of freedom. The degrees of freedom for each smooth term was optimized for each iteration when the likelihood was maximized.

Statistical Modeling of Habitat Use/Resource Selection

Resource selection functions were developed to evaluate characteristics of whooping crane habitat selection in the central Platte River. The basic premise of resource selection modeling is that resources (which may be food items, land cover types, or any quantifiable habitat characteristic) that are important to cranes will be "used" disproportionately to the availability of those resources in the environment (Manly et al. 2002). In this analysis, we contrasted the characteristics at the used locations to characteristics at randomly selected "available" locations in the study area.

To model habitat selection, a discrete choice model (Manly et al. 2002) of resource selection was fit to the data. This model enables us to model habitat selection when the habitat that was available for use changes both temporally and spatially. The model was an exponential model of the form:

$$w(X_{ij}) = \exp(s_1(X_{1ij}) + s_2(X_{2ij}) + \cdots + s_p(X_{pij}))$$

where X_1 to X_p are habitat metrics, j indexes the units in the choice set, and i indexes the unit selected, s_1 to s_p are the smooth functions of X_1 to X_p, respectively. The smooth terms are penalized regression splines, or smooth functions of the predictor variables describing the relationship between selection and the habitat metrics. The incorporation of penalized regression splines (i.e., smooth terms) into the linear predictor of the model is analogous to the parameterization of a GAM (Wood 2006).

The use-availability likelihood was maximized using R statistical software (R Core Team 2013), specifically the `gam` function of the mgcv package within R. The mgcv package determines 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 parameter was determined for each iteration using generalized cross validation (GCV). We determined the final model among the set of candidate models with AIC criterion.

We interpreted the relationship between covariates in the model and habitat selection through response functions (see next section) and the degrees of freedom for the smooth terms. The estimated degrees of freedom indicate the amount of smoothness, with a value of 1 equivalent to a straight line. In cases where the estimated degrees of freedom were 1, we removed the smoothing component for that covariate and fit a parametric straight line. We only present p-values indicating the significance of the smoothed terms if the null hypothesis was not rejected, because these tests are known to reject the null too often when using penalized likelihood models (Wood 2006).

Response Functions

After identifying the best fit models, we estimated the predicted relative selection ratios across the range of observed values of the covariates in the models. This analysis provided a graphical display of the modelled relationship between the predictor variables (habitat characteristics) and the response (use by whooping cranes), holding constant the effects of the other variables in the model. These plots are analogous to two-dimensional partial-regression plots. The 90% confidence intervals for the response functions are approximated using a Taylor expansion approach (Wood 2006). For models without landcover metrics, the entire dataset, including 2001 and spring of 2002 was used for prediction.

Graphical displays of response functions were combined with rug plots to show the underlying data in model fitting. Rug plots display a tick mark for each data point in the model, with used points displayed at the top (use equals 1) and the choice set displayed at the bottom of the figure (use equals 0). The displayed outcome resembles that of a shag carpet, or rug. Response functions were scaled to the maximum value of the upper limit of the 90% confidence interval (maximum equals 1) and only displayed out to the 75^{th} percentile of the use points in order to limit the influence of values from the extreme end of the distribution (i.e., the largest values for habitat characteristics) in the interpretation of the results.

Statistical Modeling of Aerial Survey Detection

Members of the aerial survey crews used whooping crane decoys to conduct trials to measure the detection efficiency of observers on a sample of the daily aerial flights. The detection trials were intended to evaluate the probability of detecting whooping cranes during aerial surveys. Detection trials were conducted using a life-size whooping crane decoy placed in the area where an aerial survey was to be conducted. All trials were conducted using single decoys randomly placed on accessible conservation lands during 2001-2010 and all accessible land (privately owned or otherwise) during 2011-2013. We acknowledge the limitation of using single plastic decoys in lieu of a real feathered bird, possibly within a flock.

The number of decoys detected during the aerial flights was assumed to follow a binomial distribution with parameters n (the number of decoy trials) and p (the detection probability) (Reed 1996). Logistic regression models were developed to determine the influence of several factors on the probability of detection. Each descriptor of in-channel habitat (see above) was evaluated for inclusion in the model. There were a total of 197 detection trials from fall 2002 to spring 2013 in the model.

After identifying the best fit in-channel models, we evaluated each covariate for influence on the probability of detection. The covariates in the in-channel models were fit one at a time into the linear predictor of the probability of detection model to determine the significance of the linear fit. We conducted this analysis to determine if there was evidence of biased detection probabilities for whooping cranes in the study area, and if there was a need to account for this effect in the habitat analyses.

3. Diurnal Habitat Selection Methods

Analyses presented here pertain to the data collected through the systematic aerial PRRIP surveys used to document nocturnal roost locations and described above in section “Whooping Crane In-channel Habitat Selection” and all subsequent diurnal locations of crane groups documented in the study area by ground monitoring crews. Diurnal habitat use includes in-channel observations and out-of-channel observations that occurred within the study area during the day. The study area and data collection methods were described above in the in-channel habitat selection methods. The basic sample unit for this analysis was the location of a crane group within the study area. The data for this model comes from the PRRIP continuous use monitoring.

Whooping Crane Group Observation Data

Diurnal observations of crane groups in the study area were identified with the systematic aerial surveys and follow-up ground monitoring. We only included 1 roost location per crane group per day. We considered diurnal observations of a crane group independent if they were separated in time by 2.5 hours or more. This analysis was restricted to observations of crane groups that were first identified by the aerial survey. The dataset was intended to be representative of the entire study area and not biased by observations obtained by convenience sampling. This analysis excluded observations of crane groups during 2001 and spring of 2002 due to the lack of landcover data for 2001 and early 2002.

The ground monitoring effort, also called continuous use monitoring, identified locations of whooping crane group use both within the channel and outside the channel. Observers recorded the location of a crane group in the study area, including land cover type, every 10 minutes. In some cases, all observations for a crane group were in one contiguous land cover type, in other cases the crane group moved among land cover types. The continuous use monitoring dataset of these 10 minute increments was subsampled with frequency to satisfy independence assumptions, resulting in a dataset with multiple observations per crane group that were weighted by the length of time the crane group spent in the land cover type.

Whooping Crane Diurnal Habitat Selection

We evaluated habitat selection by whooping crane groups in the central Platte within the RSF estimation framework described for the in-channel habitat selection above. We used the discrete choice method of RSF estimation including penalized regression splines to approximate functional response.

<u>Defining the Available Choice Set</u>

For the diurnal habitat use analysis, the choice set was centered on the use location and extended 3 miles in all directions from that point. The habitat within the choice set area was described at a set of 1,171 points systematically spaced at 250m intervals. We assumed the cranes could reasonably evaluate this area while moving among use locations within the study area. To improve computer processing speeds during model selection, each choice set was sampled randomly to obtain a sample size of 50 for each choice set.

<u>Descriptors of Diurnal Habitat</u>

We quantified the characteristics of in-channel habitat with two basic sources of information: land cover vector shapefiles, and LiDAR. We calculated each descriptor of habitat for possible inclusion as a predictor variable in the habitat models. We calculated the metrics for both the whooping crane use point and the available points in the choice set.

We calculated the following metrics for the analysis using the land cover product generated by the USFWS-Rainwater Basin Joint Venture described above:

- Land cover type (LC)- Categories of land cover were 1) Corn, 2) Alfalfa, 3) Soybeans, 4) Wheat, 5) Channel, 6) Developed, 7) Grassland, 8) Trees, 9) Palustrine wetlands, 10) Wet meadow

We used aerial photographs and remote sensing data from LiDAR to determine the following metrics for the analysis:

- Nearest obstruction (NO)- Distance to nearest obstruction defined as trees greater than 1.5m high.

- Nearest disturbance (ND)- Distance to nearest disturbance defined as a house, town, road or railroad.

We used the crane group use location to calculate the following:

- Proximity to the roost location (PRL)- Distance to the roost location used by the crane group the previous night.

Data Summaries

Mirrored histograms, as described in the in-channel section, and summary statistics were made for the 3 continuous descriptors of diurnal habitat for the model selection dataset, from fall 2002 to spring 2013 (Appendix E).

Candidate Model List/Model Selection

The PRRIP staff and Technical Advisory Committee members developed a list of 15 candidate models, each containing a different combination of covariates (predictor variables). This set of models, with the inclusion of a null model containing no covariates, composed the complete set of *a priori* models evaluated (Appendix A, Table A.2). We determined which *a priori* model was most useful in predicting habitat use with the model selection process known as the Akaike Information Criterion statistic (AIC, Burnham and Anderson 2002). The model in the *a priori* list with the lowest AIC value was considered the most parsimonious and likely given the data and then used to infer conclusions about habitat use. AIC weights were calculated to assist in the interpretation of AIC rankings.

Statistical Model

We evaluated the characteristics of diurnal whooping crane habitat selection using the same statistical model described in the in-channel methods section. The functional response in habitat use was quantified using penalized regression splines in the resource selection function. Degrees of freedom for the regression splines were limited to 5 to facilitate model convergence. Predicted relative selection ratios across the range of the observed values of the covariates was estimated to facilitate model interpretation, as described above.

4. Trend Methods

Whooping Crane Group Observation Data

The study area for the PRRIP monitoring program encompasses 3.5 miles on either side of the central Platte River from the junction of US Highway 283 and Interstate 80 near Lexington, Nebraska, to Chapman, Nebraska (PRRIP 2011). Aerial surveys were flown daily, weather permitting, during both migration seasons, with the spring time period spanning from March 21 to April 29, and the fall time period spanning from October 9 to November 10. Flights followed the main river channel and took place in the morning, intended to locate crane groups before they departed the river to begin foraging. Return flights were scheduled after the main river channel flight and systematically surveyed upland areas and smaller side channels. A full description of the data collection methods can be found in the Program's Whooping Crane monitoring protocol (PRRIP 2011).

We compiled the observations of crane groups in the PRRIP monitoring program in the study area that were identified by the Program's monitoring contractor as well as opportunistic sightings that were reported by the public during the monitoring seasons. Crane groups were observed from either the air or the ground. There were a total of 25 survey seasons from spring 2001 to fall 2014, with the single exception of spring 2003.

Aransas-Wood Buffalo Whooping Crane Population Estimates

Biologists at the Aransas National Wildlife Refuge have conducted a winter aerial survey of the whooping crane population since 1950 (Stehn and Taylor 2008). In 2011, the survey methods were revisited and a new protocol was implemented to address issues of imperfect detection and expansion of the survey area (Butler et al. 2014). Despite the change in methods beginning in fall 2011, the two surveys represent the best available information on the size of the migrating population.

The population estimate of the Aransas-Wood Buffalo population, made in the winter every year at the Aransas National Wildlife Refuge in Texas and reported to PRRIP by the U.S. Fish and Wildlife Service (USFWS), has increased from 174 cranes in 2001 to 314 cranes in 2014 (Stehn and Taylor 2008, USFWS 2015). There has been an estimated increase in the size of the population of 4% per year (USFWS 2015) from 1938 to 2014 (Figure 1).

For the central Platte River use trend analysis, the population estimate for 2001 to 2011 came from the aerial survey during the time the population wintered in the Aransas, Texas area. This estimate was assumed to be for the same population that migrated across the central Platte River study area during spring migration following the survey. The fall estimate of the population from 2001 to 2011 came from the spring estimate, with documented mortality removed and the number of juveniles counted at Wood Buffalo added. For this analysis, the population estimate from fall 2011 to fall 2014 came from the sum of the winter aerial survey estimate and the number assumed to spend the winter beyond the primary survey area (USFWS 2015). The estimate from each winter survey was assumed to be for the same population that migrated across the central Platte River study area in the following spring and fall migration seasons.

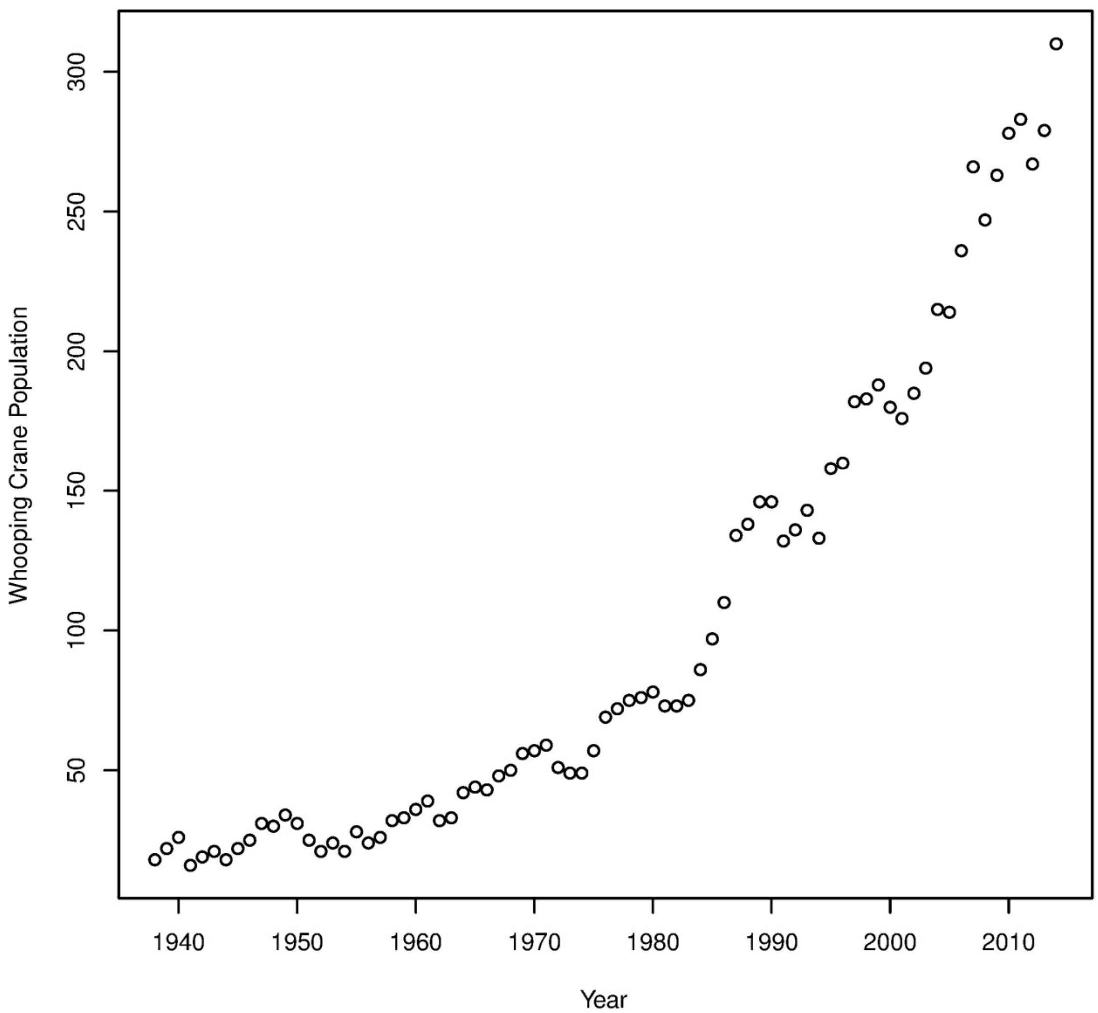


Figure 1. Trend in the estimated population size of the Aransas-Wood Buffalo whooping crane population from 1938 to 2014.

Statistical Methods

We analyzed two response metrics for the presence of trends across surveys: number of cranes and the number of crane use days. We divided each metric by the estimated size of the Aransas-Wood Buffalo population from the most recent survey, to account for the documented increase in the population of migrating cranes that could have stopped in the central Platte River. We quantified the proportion of the population using the central Platte River as the ratio of the number of cranes observed in the study area to the population size. We also quantified the crane use days per bird in the population as the ratio of the number of crane use days in the study area to the population size. We estimated trends in each metric separately for the spring and fall seasons and for both seasons combined. We used the data analysis package R to fit models (R Core Team 2013).

We developed the model structure for the trend estimation by evaluating the time series and auto-correlation functions for each response metric. We tested for correlation over time in the error terms. Based on these results, we were able to develop models assuming independent error terms (Kutner et al. 2005). Linear statistical models were fit for each metric with a continuous time covariate. We interpreted the p-value on the effect of time to determine if the trend was significantly different from zero at the alpha equal to 0.10 level of significance. We plotted the trend estimate with a 90% confidence interval.

We also estimated the Spearman rank correlation coefficient as a non-parametric estimate of the correlation between each use metric and time. This statistic evaluates the monotonic correlation and is more resistant to outliers than linear modelling. The test for a significant difference from zero was based on Spearman's rank correlation test using the exact distribution for sample sizes less than 22 (Savicky 2014). We interpreted the significance of the test statistic to identify the extent of corroboration with the significance of the linear trend estimate.

5. In-channel Habitat Selection Results

Whooping Crane Group Observations

We developed in-channel habitat selection models for the 33 spring, 22 fall, and the combined 55 spring and fall systematic and unique observations of whooping crane groups (Table 2, Figure 2). These observations span the time from fall 2001 to spring 2013. Actual sample sizes for the models were larger because of the inclusion of the data representing the choice set (Table 2).

Table 2. Sample size for in-channel models with 20 available locations in each choice set in addition to the location used by the whooping crane group. Observations of whooping cranes were obtained by systematic sampling through aerial surveys from fall 2001 to spring 2013.

Season	Number of Use Locations in Analysis	Total Number of Data Points in Analysis
Spring	33	693
Fall	22	462
Spring and Fall Combined	55	1155

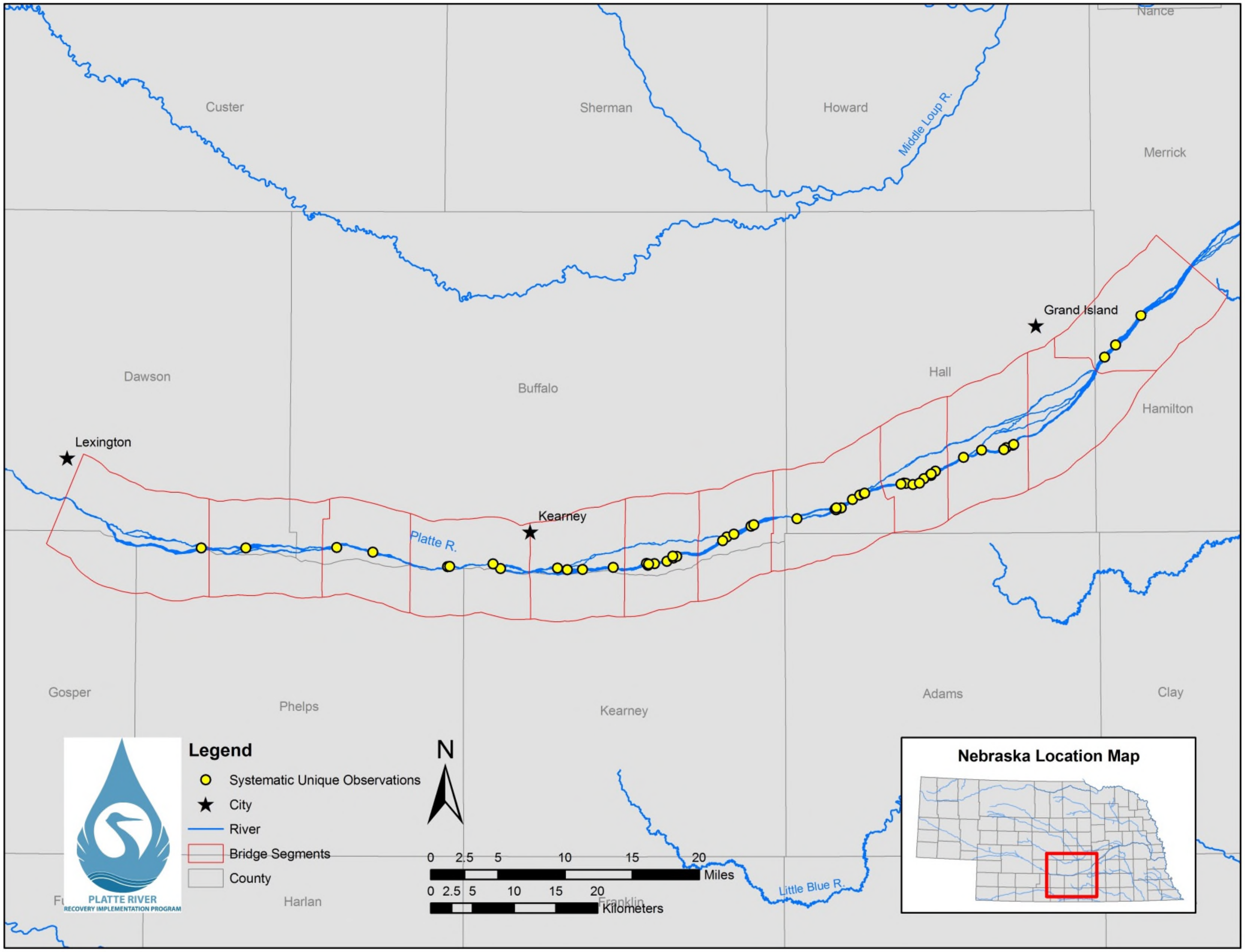


Figure 2. Spatial distribution of the in-channel systematic unique observations of whooping crane groups on the central Platte River from spring 2001 to spring 2013.

In-channel Habitat Selection for Spring and Fall Combined

Statistical modeling of habitat use indicated unobstructed channel width and nearest forest were the most important predictor variables for management purposes (Table 3). In addition, the top model exhibited a lower AIC value than an intercept only model. Additional variables in the top five models included total channel width, and unit discharge.

Table 3. Top management models for in-channel habitat use in the spring and fall, ranked by the AIC statistic. The AIC value for the null model was 847.57.

Rank	**AIC value**	**AIC Weight**	**Covariates**
1	826.83	0.45	UOCW + NF
2	828.45	0.20	UOCW + NF + TCW + UD
3	828.75	0.17	UOCW + NF + TCW
4	830.24	0.08	NF
5	831.93	0.04	NF + TCW + UD

* For definitions of covariates, see section in Methods titled, “Descriptors of In-channel Habitat”

The estimated smoothing spline functions for each of the variables in the top model were quadratic shapes depicting predicted selection ratios positively increasing with larger values of unobstructed channel width and nearest forest up to a point, after which declines were predicted. The model results for unobstructed channel width indicated the highest value predicted selection ratio to occur at 488 feet (Figure 3), though the relationship was not statistically significant ($p=0.0650$). Increased nearest forest was associated with a higher predicted relative selection ratios up to the highest selection ratio predicted to occur at 523 feet from the center of the channel (Figure 4). The estimated degrees of freedom for the smoothed terms were 3.47 and 3.69 for unobstructed channel width and nearest forest, respectively.

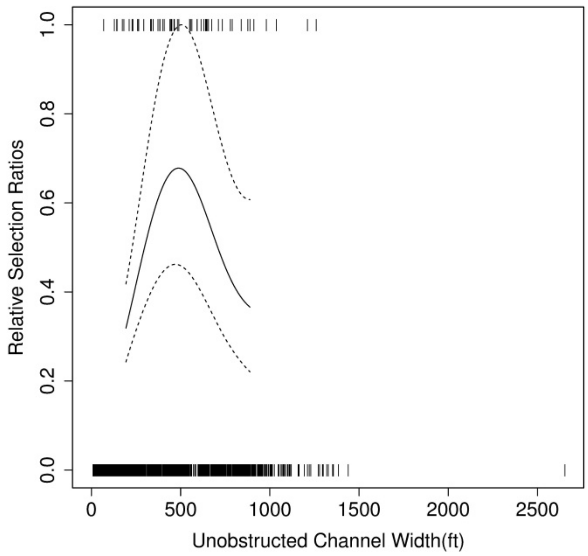


Figure 3. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of unobstructed channel widths in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The highest selection ratio value was predicted to occur at 488 feet at the mean value of nearest forest.

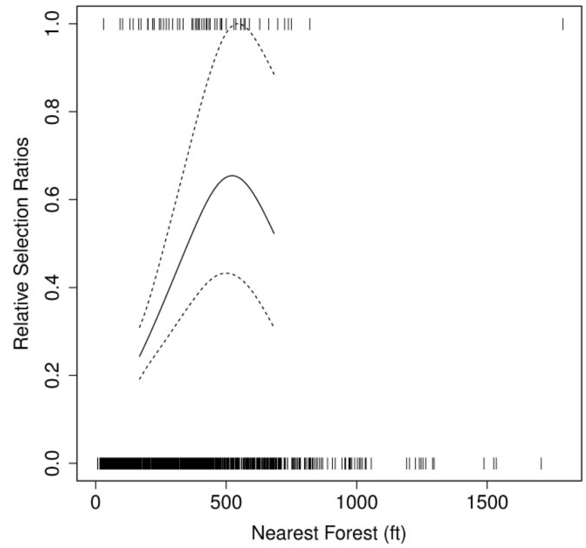


Figure 4. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest forest in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The highest selection ratio value was predicted to occur at 523 feet at the mean value of unobstructed channel width.

Model selection for in-channel habitat use for the spring and fall observations combined, across every candidate model in the *a priori* set, indicated nearest obstruction and nearest forest were the most important predictor variables (Table 4). Nearest obstruction was present in all of the top 5 models, and nearest forest was present in four of the top five models. These models do not appear at the top of the management model list because PRRIP staff does not consider nearest obstruction to be a variable that can be managed relative to where a whooping crane selects to roost (i.e., they could roost next to a vegetated bank in a wide unobstructed channel). The top model exhibited a lower AIC value than an intercept only model. The estimated smoothing spline functions for each of the variables in the top model were quadratic shapes depicting predicted selection ratios positively increasing with larger values of nearest obstruction and nearest forest up to a point, after which declines were predicted. The model results for nearest obstruction indicated the highest predicted selection ratio to occur at 144 feet (Figure 5). Increased distance to nearest forest was associated with a higher predicted relative selection ratios up to the highest selection ratio predicted to occur at 533 feet from the center of the channel (Figure 6), though the relationship was not statistically significant (p=0.0702). The estimated degrees of freedom for the smoothed terms were 3.43 and 3.40 for nearest obstruction and nearest forest respectively.

Table 4. Top models for in-channel habitat use in the spring and fall, ranked by the AIC statistic. The AIC value for the null model was 847.57.

Rank	AIC value	AIC Weight	Covariates
1	816.22	0.08	NO + NF
2	817.33	0.04	NO + NF + TCW + UD
3	817.45	0.04	NO + NF + TCW
4	817.69	0.04	NO + UOCW
5	817.71	0.04	NO + NF + PF

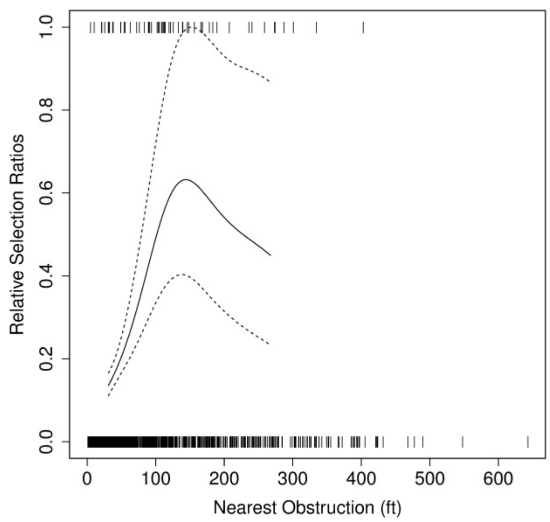


Figure 5. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of nearest obstruction in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The highest selection ratio value was predicted to occur at 144 feet at the mean value of nearest forest.

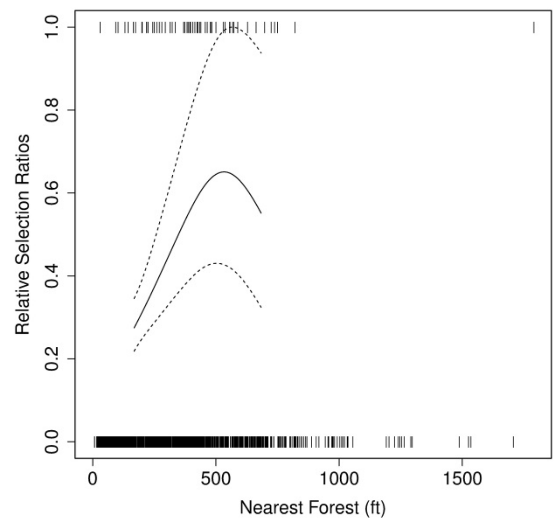


Figure 6. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of nearest forest in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The highest selection ratio value was predicted to occur at 533 feet at the mean value of nearest obstruction.

Spring In-channel Habitat Selection

Model selection for in-channel habitat use for the spring observations, across every candidate model in the *a priori* set, indicated nearest obstruction was the most important predictor variables (Table 5). Nearest obstruction was present in all five of the top five models. The top model exhibited a lower AIC value than an intercept only model. Additional variables in the top five models included total channel width, unit discharge, proportion forest, and nearest forest.

Table 5. Top models for in-channel habitat use in the spring, ranked by AIC statistic. The AIC value for the null model was 478.66.

Rank	AIC value	AIC Weight	Covariates
1	451.16	0.08	NO
2	451.61	0.06	NO + TWC + UD
3	452.14	0.05	NO + PF
4	452.28	0.04	NO + NF
5	452.60	0.04	NO + TCW + UFW + UD

The estimated smoothing spline function for nearest obstruction was quadratic shaped depicting predicted selection ratios positively increasing with larger values up to a point, after which declines were predicted. The model results for unobstructed channel width indicated the highest predicted selection ratio to occur at 136 feet (Figure 7). The estimated degrees of freedom for the smoothed term was 3.17.

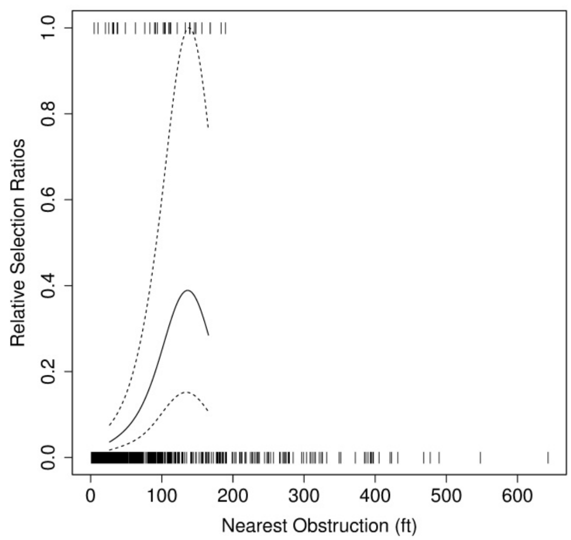


Figure 7. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest obstruction in the spring. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The highest selection ratio value was predicted to occur at 136 feet.

Fall In-channel Habitat Selection

Model selection for in-channel habitat use for the fall observations, across every candidate model in the *a priori* set, indicated nearest obstruction, total channel width, nearest forest, and unit discharge were the most important predictor variables for management purposes (Table 6). The top model exhibited a lower AIC value than an intercept only model. Additional variables in the top five models included unforested width, width to depth ratio, and proportion corn.

Table 6. Top models for in-channel habitat use in the fall, ranked by AIC statistic. The AIC value for the null model was 295.74.

Rank	AIC value	AIC Weight	Covariates
1	276.90	0.05	NO + TCW
2	276.97	0.05	NO + TCW + NF
3	277.01	0.05	NO + TCW + NF + UD
4	277.08	0.05	NO + TCW + UD
5	277.70	0.03	NO + TCW + PC

The estimated smoothing spline functions for nearest obstruction was positively increasing with larger values, indicating a positive relationship between predicted relative selection ratios and nearest obstruction. The model results indicate increased nearest obstruction was associated with a higher predicted relative selection ratios with the highest value predicted to occur at 299 feet (Figure 8). Increased total channel width was associated with variable relative selection ratios with lowest predicted values to occur at 1158 feet (Figure 9). The estimated degrees of freedom for the smoothed terms were 2.18 and 4.07 for nearest obstruction and total channel width respectively.

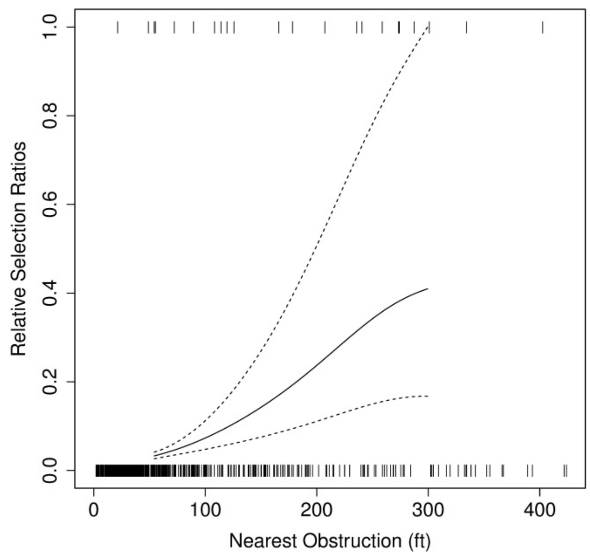


Figure 8. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of nearest obstruction in the fall. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The highest selection ratio value was predicted to occur at 299 feet at the mean value of total channel width.

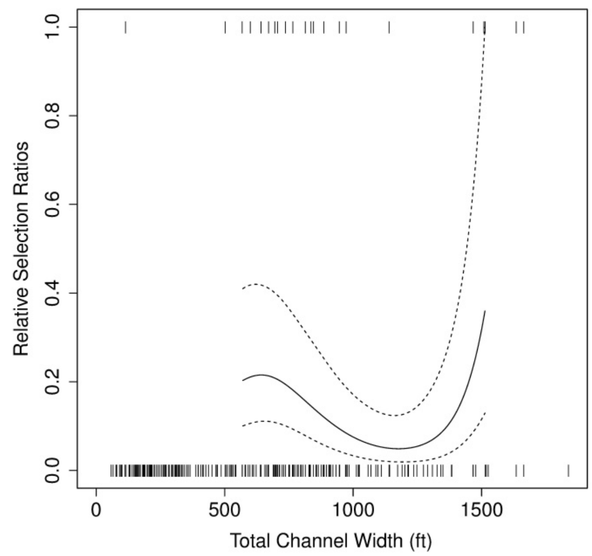


Figure 9. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to total channel widths in the fall. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The lowest selection ratio value was predicted to occur at 1158 feet at the mean value of nearest obstruction.

Aerial Survey Detection

The in-channel covariates were not found to be statistically significant predictors of detection probability. Each covariate had a non-significant linear effect. The p-value on the linear effect of unobstructed channel width was 0.2010, nearest forest was 0.1806, and nearest obstruction was 0.4148. Since covariates in the top habitat selection model were not statistically significant in the detection model, we can conclude that the imperfect detection of whooping cranes does not bias the linear predictor of the habitat selection model (Hefley et al. 2013).

6. Diurnal Habitat Selection Results

Whooping Crane Group Observations

We developed diurnal habitat selection models for the combined 478 spring and fall systematic continuous use observations of whooping crane groups. There were 347 observation in the spring and 131 observations in the fall. These observations span the time from fall 2002 to spring 2013. The actual sample size for the model was larger because of the inclusion of the data representing the choice set.

Diurnal Habitat Selection for Spring and Fall Combined

Statistical modeling of habitat use indicated the full model with all 4 covariates was most likely given the data. The full model contained the effects of nearest obstruction, nearest disturbance, proximity to roosting location and land cover (Table 7).

Table 7. Top models for diurnal habitat use for both seasons combined, ranked by AIC statistic. The AIC value for the null model was 10,610.97.

Rank	AIC value	AIC Weight	Covariates
1	8909.59	0.56	ND + NO + PRL + LC
2	8910.06	0.44	ND + PRL + LC
3	8978.51	0.00	PRL + LC
4	9218.41	0.00	NO + ND + PRL
5	9238.07	0.00	ND + PRL

The estimated smoothing spline function for nearest disturbance was increasing with larger values, indicating a positive relationship between predicted relative selection ratios and distance to nearest disturbance. The model results indicated increased distance to nearest disturbance was associated with a higher predicted relative selection ratios, with the highest value predicted to occur at 1,339 feet (Figure 10). The estimated parametric function for nearest obstruction was not statistically significant ($p=0.1727$). The estimated smoothing spline function for proximity to roost location was decreasing with larger values, indicating a negative relationship between predicted relative selection ratios and proximity to roost location. The model results indicate larger distances to the roost location were associated with a lower predicted relative selection ratios with the highest value predicted to occur at 0 feet (Figure 11). The estimated degrees of freedom for the smoothed terms were 3.65 and 3.95 for nearest disturbance and proximity to roost location respectively.

The model results for land cover were interpreted relative to the corn cover category. The relative selection ratio was significantly higher for the in-channel cover category relative to the corn cover category ($p=0.0048$; Figure 12). All remaining cover categories had lower relative selection ratio than corn cover. Relative to the corn cover category, the relative selection ratio was significantly lower for grassland cover ($p<0.0001$), soybean cover ($p<0.0001$) and wet meadow cover ($p<0.0001$). The cover of alfalfa was predicted to have a lower relative selection ratio than corn cover, though the result was not statistically significant ($p=0.7594$). The cover of wheat, cover of trees and developed areas also were predicted to have a lower relative selection ratio than corn cover, but we view this result with caution as the lack of data in these categories resulted in model estimates with extremely large standard errors.

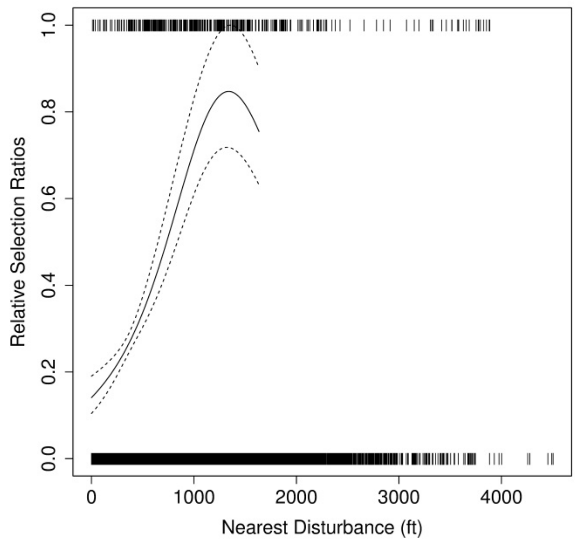


Figure 10. Predicted relative selection ratios for diurnal use by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of nearest disturbance in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0). The highest value for selection ratio value was predicted to occur at 1339 feet at the mean value of other variables in the model.

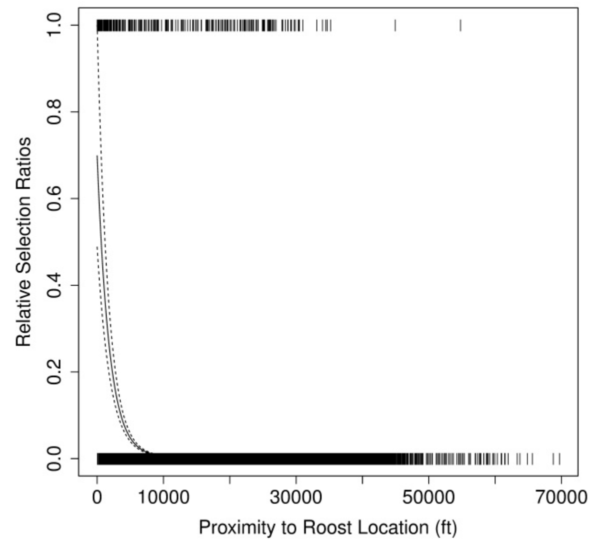


Figure 11. Predicted relative selection ratios for diurnal use by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of proximity to roost location in the spring and fall combined. Tick marks indicate actual data (use points at y=1, choice set points at y=0). The highest selection ratio value was predicted to occur at 0 feet at the mean value of other variables in the model.

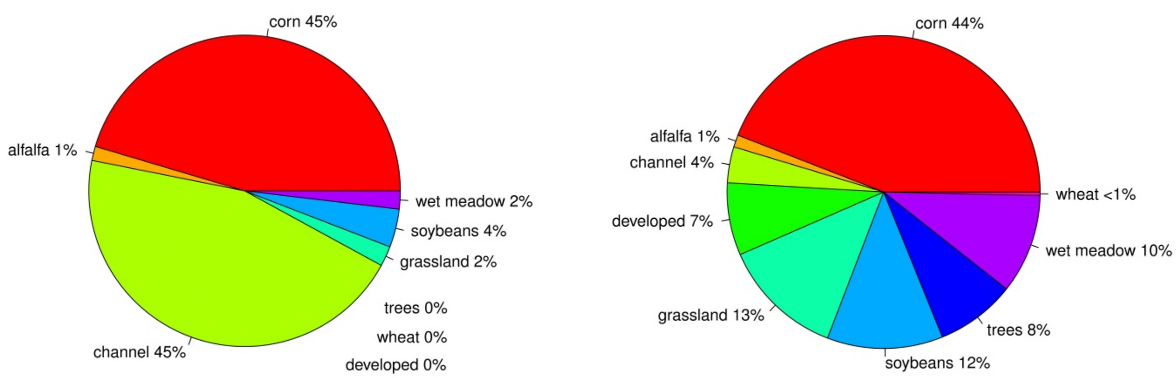


Figure 12. Relative abundance of land cover types for diurnal spring and fall locations of whooping crane use (left) and the choice set points (right).

7. Trend Results

Whooping Crane Group Observations

Observational data on whooping cranes was collected by surveyors with the PRRIP monitoring program and encompassed 13 spring migrations and 14 fall migrations for a total of 27 migration seasons (Table 8). The number of crane groups observed during a single survey season ranged from 1 to 13. The number of unique cranes ranged from 1 to 36 during a single survey season. Crane use days ranged from 1 to 121 per survey season.

Trends in Proportion of Population Using the central Platte River

<u>Spring</u>

Spring migration results showed an increase in the number of cranes using the central Platte River (Figure 13). Statistical modeling of the trend in the proportion of the whooping crane population using the central Platte River in the spring indicated a significant increase through time (Figure 14). The estimated trend was a positive 0.007 change per year (p=0.0168). The significance of the trend estimate indicated the number of unique individuals detected using the central Platte River in the spring had increased at a rate significantly faster than the size of the Aransas-Wood Buffalo population. Spearman's rank correlation statistic was 0.67 with a significant p-value of 0.0114, indicating a strong monotonic correlation between the metric and time. The autocorrelation function for these data indicated little serial correlation at a lag of 1 time period. The residuals of the model showed a slight increase in variance through time.

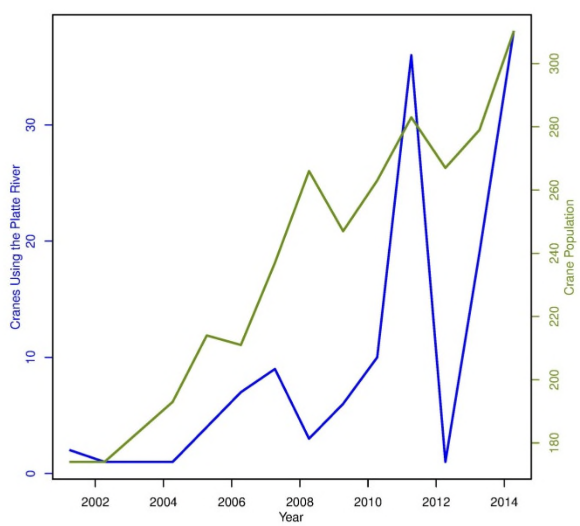


Figure 13. Cranes using the central Platte River during spring migration and population size from 2001 to 2014.

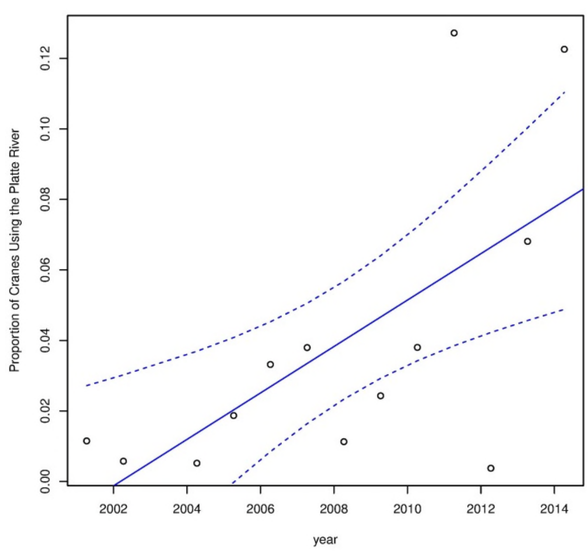


Figure 14. Proportion of population using the central Platte River, spring 2001-2014.

Table 8. Observational data from the Platte River Recovery Implementation Program (PRRIP) whooping crane migrational habitat use surveys in the central Platte River, Nebraska and USFWS Aransas-Wood Buffalo Population surveys, 2001-2014. There was no PRRIP survey conducted in Spring 2003.

	Spring						Fall					
Year	Population Size	# Crane Groups	# Unique Cranes	# Crane use days	Proportion of Population Using Platte	Number of crane use days to Population	Population Size	# Crane Groups	# Unique Cranes	# Crane use days	Proportion of Population Using Platte	Number of crane use days to Population
2001	174	2	2	8	0.01	0.05	174	1	1	2	0.01	0.01
2002	174	1	1	26	0.01	0.15	185	8	19	121	0.10	0.65
2003	184	-	-	-	-	-	194	1	1	2	0.01	0.01
2004	193	1	1	1	0.01	0.01	214	1	6	18	0.03	0.08
2005	214	3	4	13	0.02	0.06	216	1	2	4	0.01	0.02
2006	211	4	7	54	0.03	0.26	237	1	3	45	0.01	0.19
2007	237	5	9	71	0.04	0.30	266	2	10	23	0.04	0.09
2008	266	1	3	27	0.01	0.10	270	4	20	42	0.07	0.16
2009	247	4	6	42	0.02	0.17	264	4	12	44	0.05	0.17
2010	263	4	10	42	0.04	0.16	281	4	15	32	0.05	0.11
2011	283	1	36	104	0.13	0.37	267	2	6	12	0.02	0.04
2012	267	1	1	7	0.00	0.03	279	2	4	29	0.01	0.10
2013	279	10	19	48	0.07	0.17	310	2	3	8	0.01	0.03
2014	310	13	38	96	0.12	0.31	314	2	5	10	0.02	0.03

Fall

Fall migration results showed a variable number of cranes using the central Platte River (Figure 15). Statistical modeling of the trend in the proportion of the whooping crane population using the central Platte River in the fall indicated a decrease through time (Figure 16), though the trend was not significantly different from zero. The estimated trend was a negative 0.001 change per year (p=0.5940). Again, the Spearman's rank correlation statistic corroborated the results of non-significance with a correlation coefficient of 0.27 and a p-value of 0.3565 indicating the correlation coefficient was not significantly different from 0. The autocorrelation function for these data indicated little serial correlation past a lag of 1 time period. The residuals of the model showed little to no trend in pattern.

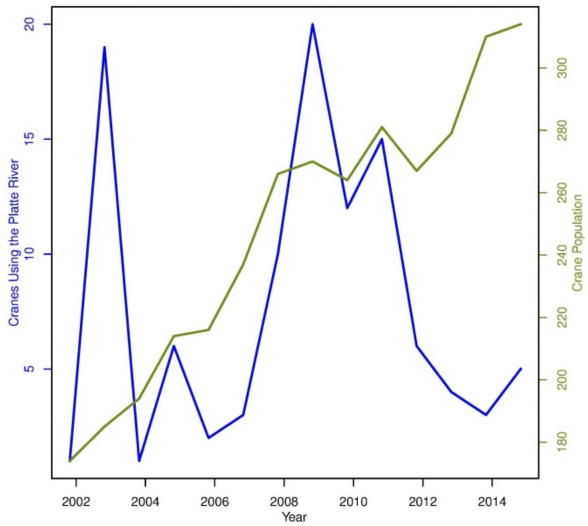


Figure 15. Cranes using the central Platte River during fall migration and population size from 2001 to 2014.

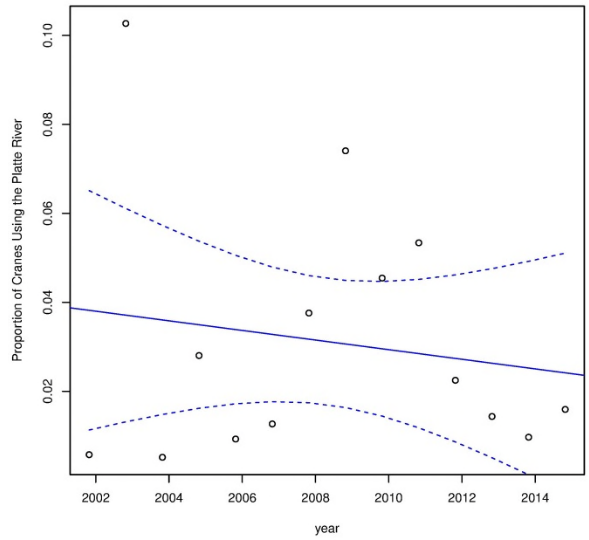


Figure 16. Proportion of population using the central Platte River, fall 2001-2014.

Combined Spring and Fall

Across both migration seasons, there was large variation in the number of cranes using the central Platte River (Figure 17). Statistical modeling of the trend in the proportion of the whooping crane population using the central Platte River indicated an increase through time (Figure 18), though the trend was not significantly different from zero. The estimated trend was a positive 0.002 change in the ratio per year (p=0.1390). The borderline significance of the trend estimate indicated the number of unique individuals detected using the central Platte River from 2001-2014 had increased at a rate that was faster than the size of the Aransas-Wood Buffalo population, though not significantly faster. Spearman's rank correlation statistic was 0.50 with a significance of 0.0076, indicating a strong monotonic correlation between the metric and time. The autocorrelation function for these data indicated little serial correlation past a lag of 1 time period. The residuals of the model showed no pattern.

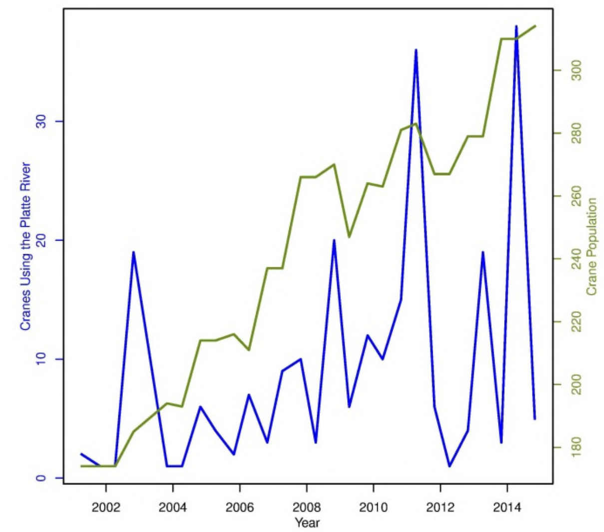


Figure 17. Cranes using the central Platte River during spring and fall migration and population size from 2001 to 2014.

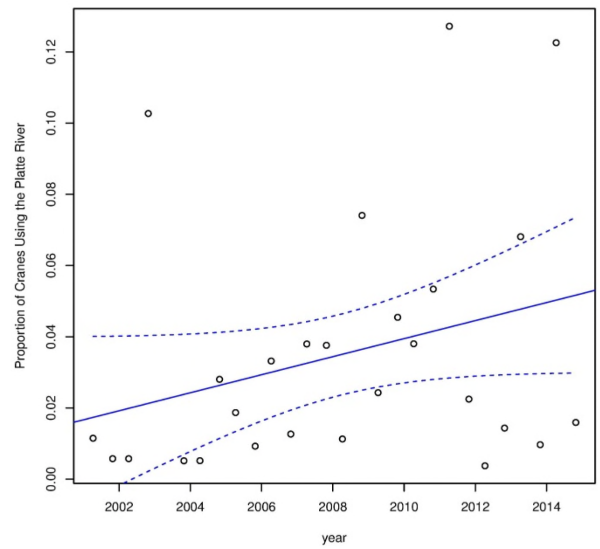
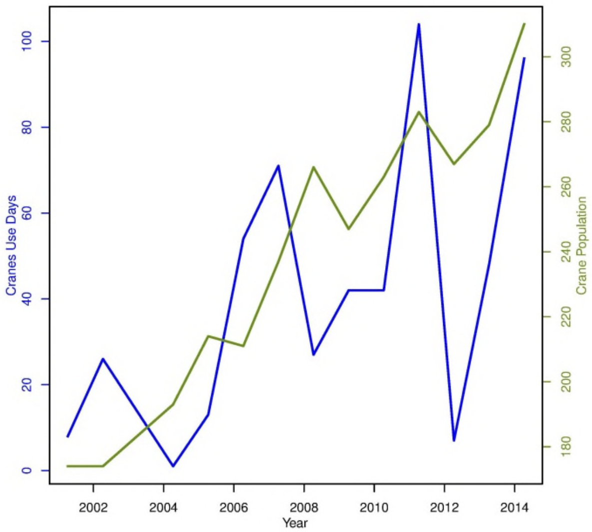


Figure 18. Proportion of population using the central Platte River, 2001-2014.

Trends in Crane Use Days per Bird in the Population

Spring

Spring migration results indicated an increase in the number of crane use days in the study area (Figure 19). Statistical modeling of the trend in crane use days per bird in the population in the spring indicated an increase through time (Figure 20), though the result was not significantly different from zero. The estimated trend was a positive 0.012 change in the ratio per year (p=0.1380). The borderline significance of the trend estimate indicated the number of crane use days on the central Platte River in the spring from 2001-2014 had increased at a rate that was faster than the increase in size of the Aransas-Wood Buffalo population, though not significantly faster. Spearman's rank correlation statistic was 0.56 with a significance of 0.0469, indicating a strong monotonic correlation between the metric and time. The autocorrelation function for these data indicated little serial correlation past a lag of 1 time period. The residuals of the model indicated good model fit with no discernable pattern.



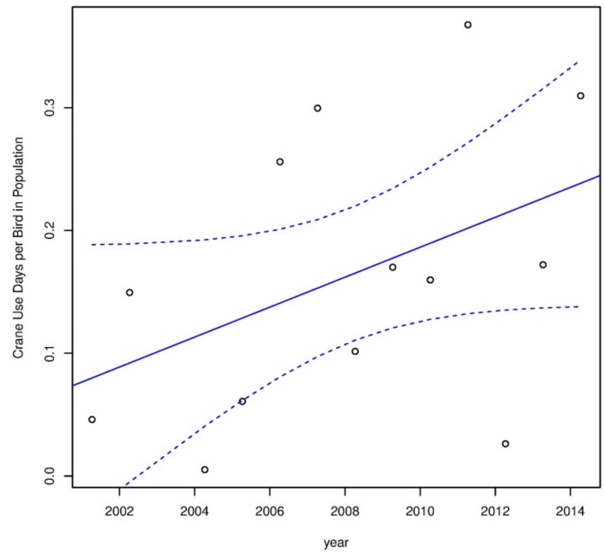


Figure 19. Cranes use days on the central Platte River during spring migration and population size from 2001 to 2014.

Figure 20. Crane use days on the central Platte River per bird in the population, spring 2001-2014.

Fall

Fall migration results showed a decrease in the number of crane use days in the study area (Figure 21). Statistical modeling of the trend in the crane use days per bird in the population in the fall indicated a decrease through time, though the trend was not significantly different from zero (Figure 22). The estimated trend was a negative 0.012 change in the ratio per year ($p=0.2760$). Again, the Spearman's rank correlation statistic corroborated the results of non-significance with a correlation coefficient of 0.09 and a p-value of 0.7591 indicating this coefficient was not significantly different from 0. The autocorrelation function for these data indicated little serial correlation past a lag of 1 time period. The residuals of the model showed little to no pattern.

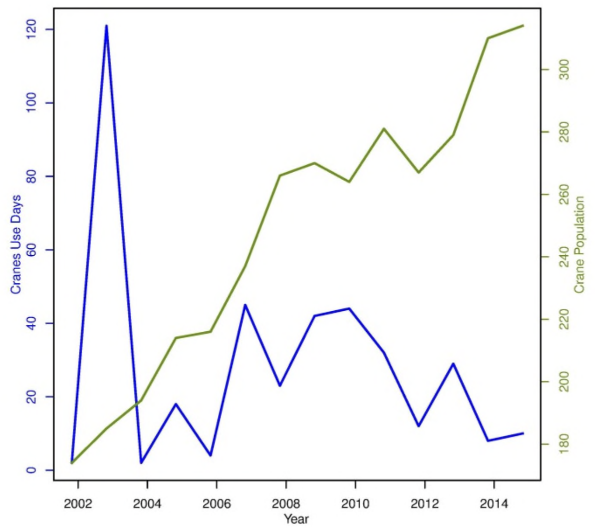


Figure 21. Cranes use days on the central Platte River during fall migration and population size from 2001 to 2014.

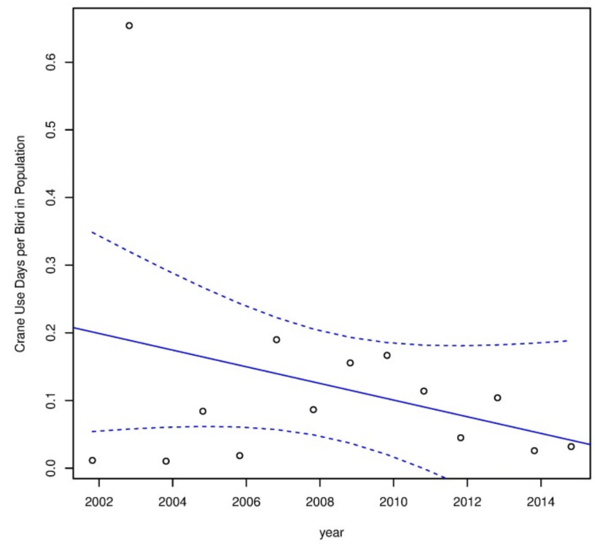


Figure 22. Crane use days on the central Platte River per bird in the population, fall 2001-2014.

Combined Spring and Fall

Across both migration seasons, there was large variation in the number of crane use days in the study area (Figure 23). Statistical modeling of the trend in crane use days per bird in the population indicated a decrease through time, though the trend was not significantly different from zero (Figure 24). The estimated trend was a negative 0.001 change per year (p=0.9090). Again, the Spearman's rank correlation statistic corroborated the results of non-significance with a correlation coefficient of 0.26 and a p-value of 0.1981 indicating this coefficient was not significantly different from 0. The autocorrelation function for these data indicated little serial correlation past a lag of 1 time period. The residuals of the model showed little to no pattern.

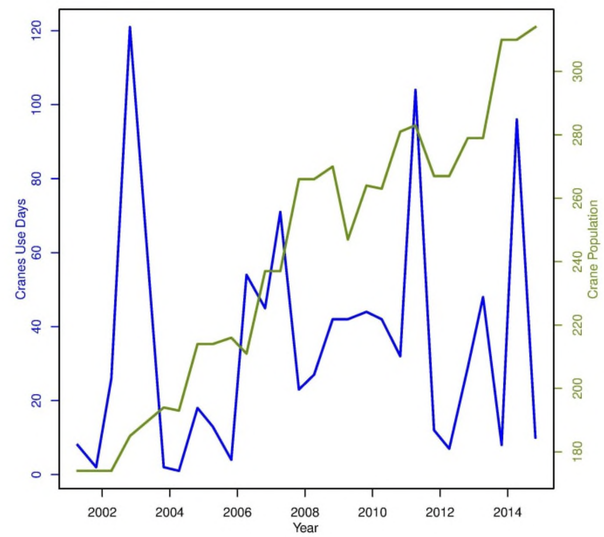


Figure 23. Cranes use days on the central Platte River during spring and fall migration and population size from 2001 to 2014.

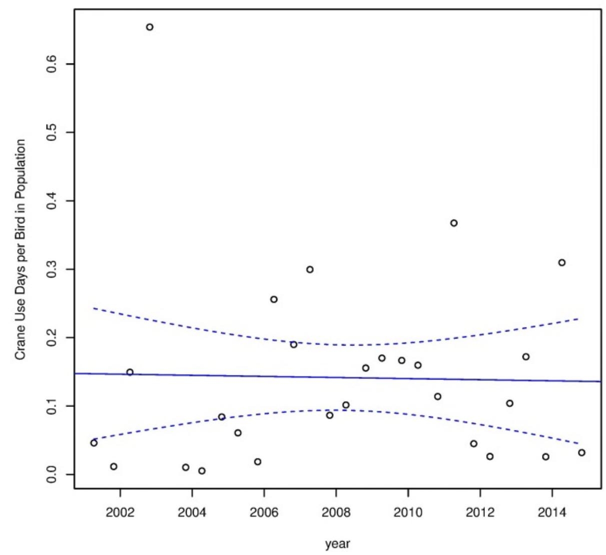


Figure 24. Crane use days on the central Platte River per bird in the population, 2001-2014.

8. Discussion

In-channel Habitat Selection

The combined spring and fall in-channel habitat models presented here relate a similar message about whooping crane habitat selection on the central Platte River. Unobstructed channel width, nearest forest, and nearest obstruction were the factors with the most influence on in-channel habitat selection. The overall top in-channel model suggested that whooping cranes were selecting in-channel habitat with large distance to nearest forest and obstruction up to a point after which the relative selection ratios declined. At the direction from PRRIP staff, the set of *a priori* management models did not contain nearest obstruction. The top management model differs from the top model for the combined spring and fall seasons. The management model suggested that whooping cranes were selecting in-channel habitat with large values of unobstructed channel width and large distances to nearest forest. Though the selection ratios for unobstructed channel width and nearest forest were maximized at 488 and 523 feet, respectively, it can be inferred based on the confidence intervals at these peaks, that widths between 275 and 745 feet for unobstructed channel width and distances between 305 and 686 feet for nearest forest would result in statistically similar selection ratios.

The spring in-channel model suggested that whooping cranes were selecting in-channel habitat with large distances to nearest obstruction, or dense vegetation. Whooping crane groups were observed across a wide range of values and it can be inferred based on the confidence intervals at the peak of 136 feet that nearest obstruction distances between 80 and 166 feet would result in statistically similar selection ratios. The fall in-channel model also suggested that whooping cranes were selecting in-channel habitat with large values of distances to nearest obstruction. Based on the confidence interval at the peak of 299 feet, nearest obstruction distances as small as 165 feet would result in statistically similar selection ratios.

In-channel and diurnal habitat selection analyses did not account for imperfect detection of whooping crane groups during the study. Although imperfect detection surely existed, it was assumed that the probability of detection was constant across each survey as a result of the consistency in survey methodology. Analyses presented here found the relationship between detection and variables in the top habitat models was not evident, and we conclude the results were unbiased with respect to detection (Hefley et al. 2013).

Diurnal Habitat Selection

The diurnal habitat model presented here indicates whooping cranes were selecting in-channel and corn cover categories that were close to the previous night roost location and did not have the possibility of disturbance in the form of houses, towns, roads, or railroads. The model results did not indicate whooping cranes show avoidance of vegetation greater than 1.5m during diurnal habitat use. Relative to the corn cover category, the relative selection was significantly lower for grassland, soybean, and wet meadow cover categories.

Trend

The study of rare or hard to detect wildlife populations consistently leads to high variance in observational use data. With 27 data points spanning 14 years from 2001 to 2014, the PRRIP dataset was highly variable, though some trends were apparent. For all trend analyses, it was assumed that the influence of imperfect detection of whooping crane groups in the survey data was consistent through the study period, as a result of the consistency in survey methodology.

The trend models presented here for the proportion of the Aransas-Wood Buffalo population using the Platte River showed a significant increase in spring migration use. The fall migration season showed a non-significant decrease in the metric through time, meaning there was no trend detected. The combined spring and fall migration season showed a non-significant increase with a p-value of 0.1390.

The trend models for the crane use days on the central Platte River during the spring migration per bird in the population also showed a non-significant increase with a p-value of 0.1380. This metric had a non-significant decline for fall and for both migration seasons combined. The positive estimate in the spring indicates the number of use days was increasing faster than the population size, while the non-significant results in fall and for the combined seasons indicated the number of crane use days in the study area was increasing in proportion to the population size.

It is unknown if the change in USFWS survey and estimation methods for determining the size of the winter whooping crane population had an impact on these results. There was not sufficient information to apply a correction factor to either the old or new population data to develop consistent estimates across the change in survey methods that occurred in 2011. It was noted that the consistent multiplicative increase in the population estimate throughout the time period did not appear to change abruptly at 2011. This consistency does lend credibility to the utility of these data across the change in methodology.

Comparison to Previous Literature

Faanes et al. (1992) describe the attributes of whooping crane roost sites on the Platte River, provided by Johnson and Temple (1980) and Johnson (1982; both articles were not available) as a channel width of at least 180 feet with most channels greater than 509 feet wide, horizontal visibility that included an “unobstructed view from bank to bank and several hundred meters upstream and downstream,” overhead visibility that included no tall trees or tall/dense shrubbery, feeding sites relatively close and typically within one mile, and usually more than 1,312 feet from human developments with tall trees or banks in between. It is not clear from the summary how these attributes were derived but they are very similar to our results for unobstructed channel width (selection ratios greatest at 488 feet and distance from human disturbance (selection ratios greatest at 1,339 feet from nearest disturbance).

Armbruster (1990) presented a synthesis of information on observations of habitats used by whooping cranes and sandhill cranes in North America but notes that these studies are based on assumptions due to small sample sizes and uncertainty regarding used versus available sites. Based on these studies the author concluded that 1) a distance of at least 66 feet between a site and any potential obstruction was required for consideration as habitat, 2) optimum water depth was equal or less than 12 inches, 3) the minimum size of a wetland usable for roosting was 0.04 ha (0.1 ac), and 4) sources of disturbance such as roads affected cranes out to at least 328 feet. Of the numerous studies described, the author reported unobstructed channel widths for two roost sites on the Platte River as 1,148 feet and 1,020 feet based on Lingle et al. 1984 and 1986, which is greater than the 488 feet described in our study.

Faanes et al. (1992) compared characteristics at 19 - 23 confirmed roost sites for whooping cranes (1983-1990) in the central Platte River to 1,381 unused sites using bank-to-bank transects. The authors reported the following results: 1) water depth was shallower than average at roost sites than at unused sites (8 inches versus 12 inches, respectively); 2) channel widths at roost sites ranged from 171 feet to 1,201 feet and 19 of the 23 roosts were in channels at least 492 feet wide; and 3) the average distance to shore was similar for both roost sites and unused sites (217 feet 66.2 and 215 feet, respectively). This study was an improvement on previous work because it used statistical methods to compare characteristics of unused and selected habitats. The outcome that most of the roosts were located in channels at least 492 feet wide is similar to the conclusion of this study (greatest selection ratios was for unobstructed channels that were 488 feet wide). Also, the water depth suggested by Faanes et al. was similar to that reported by Armbruster (1990).

Austin and Richert (2001) analyzed all known observational data on whooping cranes (1,352 sightings; 1943-1999) and all known site evaluation data (1,060 observations; 1977-1999) for areas used by whooping cranes in the Aransas-Wood Buffalo migration corridor. The authors acknowledged the limitations of their study such as observer biases, variation in the distribution and interest of biologists to confirm and collect further information on crane sightings, as well as varying landscape features that may hinder crane sightings. Although the authors did not summarize observations specifically for the central Platte River location used in our study, they did note that it was obvious from mapping observations that “whooping cranes were frequently observed in this area.” The authors found that whooping cranes using the Platte River tended to be single cranes or nonfamily groups. For riverine habitats such as the Platte River roosting cranes were more often recorded on unvegetated sites than vegetated sites and the width of river averaged 764 +/- 276 feet (SD) with a range of 249 feet to 1,499 feet. More than 70% of chosen riverine roosts were adjacent to woodland habitat.

For all observations, Austin and Richert (2001) found no relationship between roost site and use of the closest feeding sites, which varies from our study in which whooping cranes tended to use corn fields close to the previous night’s roost. Overall whooping cranes used cropfields often and more than 60% of all sites (and more than 80% of feeding sites) were on private land. The unobstructed visibility of about half of the roost sites and two-thirds of the feeding sites was less than 0.25 mile (1,320 feet), while over two-thirds of crane observations were recorded within 0.5 mile (2,640 feet) of human development. About 78% of spring records of whooping cranes in Nebraska were located on riverine sites including the Platte River while half of the fall records in Nebraska were located on riverine sites and 11% were from lacustrine wetlands.

9. Summary of Findings

We compared characteristics of habitat from 2001 to 2013 and trends in use from 2001 to 2014 within the central Platte River for whooping cranes using systematic surveys. Our findings show:

- Roosting whooping cranes chose a range of unobstructed channel widths; selection ratios were greatest for unobstructed channels that were 488 feet wide with widths between 275 and 745 feet resulting in statistically similar selection ratios.
- Roosting whooping cranes chose a range of distances to nearest forest; selection ratios were greatest for channels that were 523 feet from the nearest forest with distances between 305 and 686 feet resulting in statistically similar selection ratios.
- The inclusion of additional non-unique in-channel observations resulted in larger optimum distances and channel widths for the majority of linear and quadratic response functions, as reported in Appendices C and D, compared to the systematic unique results in this report.
- During the day whooping cranes used cornfields that were close to the previous night's roost with no possibility of disturbance; selection ratios were greatest at 1,339 feet from the nearest disturbance (i.e., house, town, road, or railroad) with distances between 1,009 and 1,635 feet resulting in statistically similar selection ratios.
- During the day whooping cranes were significantly more likely to choose riverine habitat over corn cover, but chose corn cover significantly more than grassland, soybean, and wet meadow cover.
- Trends in use over time within the central Platte River showed a significant increase in use in the spring, a non-significant decrease in use during the fall, and a non-significant increase in use for spring and fall combined.

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Appendix A. In-Channel *a priori* Models

List of Tables

Table A.1. In-channel *a priori* model list for whooping crane habitat use created by PRRIP. The interpretation assumes an *a priori* direction (positive or negative) in the relationship between whooping crane habitat use and the covariates but actual model fit, based on data, could have been in the opposite direction.* Indicates model was in the management candidate model list…1

Table A.2. Diurnal *a priori* model list for whooping crane habitat use created by PRRIP. The interpretation assumes an *a priori* direction (positive or negative) in the relationship between whooping crane habitat use and the covariates but actual model fit, based on data, could have been in the opposite direction……………………………………………………………………….9

Table A.1. In-channel *a priori* model list for whooping crane habitat use created by PRRIP. The interpretation assumes an *a priori* direction (positive or negative) in the relationship between whooping crane habitat use and the covariates but actual model fit, based on data, could have been in the opposite direction.* Indicates model was in the management candidate model list.

Model ID	Covariates	Interpretation
1	UFW	Channels w/o trees on bank line
2*	UOCW	Wide unobstructed views
3*	TCW	Wide channels
4	NO	Wide unobstructed views
5*	NF	Channels w/o trees on bank line
6	UOCW + UFW	Wide unobstructed views w/o trees on bank line
7*	TCW + UOCW	Wide channels with wide unobstructed views
8	TCW + WW	Wide channel widths with high wetted widths
9	TCW + PW	Wide channel widths with a high proportion of the channel that is wetted
10*	TCW + UD	Wide channel widths with moderate flow volume
11	TCW + MD	Wide channel widths with moderate to shallow depths across the channel
12	TCW + WDR	Wide channel widths with moderate width-depth ratio
13	NO + UFW	Wide unobstructed views w/o trees on bank line
14*	UOCW + NF	Wide unobstructed views w/o trees on bank line
15	NO + NF	Wide unobstructed views w/o trees on bank line
16	TCW + NO	Wide channels with wide unobstructed views
17	UFW + UOCW + TCW	Wide channels with wide unobstructed views w/o trees on bank line
18*	TCW + UOCW + UD	Wide channel widths with wide unobstructed views with moderate flow volume
19	TCW + UFW + UD	Wide channel widths w/o trees on bank line with moderate flow volume
20	TCW + UOCW + WDR	Wide channel widths with wide unobstructed views with moderate width-depth ratio
21	TCW + UFW + WDR	Wide channel widths w/o trees on bank line with moderate width-depth ratio
22	TCW + NF + WDR	Wide channel widths w/o trees on bank line with moderate width-depth ratio
23*	TCW + NF + UD	Wide channel widths w/o trees on bank line with moderate flow volume
24*	NF + UOCW + TCW	Wide channels with wide unobstructed views w/o trees on bank line
25	NF + NO + TCW	Wide channels with wide unobstructed views w/o trees on bank line
26	TCW + NO + UD	Wide channel widths with wide unobstructed views with moderate flow volume
27	TCW + NO + WDR	Wide channel widths with wide unobstructed views with moderate width-depth ratio

Model ID	Covariates	Interpretation
28	UFW + NO + TCW	Wide channels with wide unobstructed views w/o trees on bank line
29	TCW + UOCW + UFW + UD	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume
30	TCW + UOCW + UFW + WDR	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio
31	TCW + UOCW + NF + WDR	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio
32*	TCW + UOCW + NF + UD	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume
33	TCW + NO + NF + WDR	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio
34	TCW + NO + NF + UD	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume
35	TCW + NO + UFW + UD	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume
36	TCW + NO + UFW + WDR	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio
37	PC	Corn nearby
38	UFW + PC	Channels w/o trees on bank line and corn nearby
39	UOCW + PC	Channels with wide unobstructed views and corn nearby
40	TCW + PC	Wide channels and corn nearby
41	NO + PC	Channels with wide unobstructed views and corn nearby
42	NF + PC	Channels w/o trees on bank line and corn nearby
43	UOCW + UFW + PC	Wide unobstructed views w/o trees on bank line and corn nearby
44	TCW + UOCW + PC	Wide channels with wide unobstructed views and corn nearby
45	TCW + WW + PC	Wide channels with high wetted widths and corn nearby
46	TCW + PW + PC	Wide channels with a high proportion of the channel that is wetted and corn nearby
47	TCW + UD + PC	Wide channels with moderate flow volume and corn nearby
48	TCW + MD + PC	Wide channels with moderate to shallow depths across the channel and corn nearby
49	TCW + WDR + PC	Wide channels with moderate width-depth ratio and corn nearby
50	TCW + NO + PC	Wide channels with wide unobstructed views and corn nearby
51	UOCW + NF + PC	Wide unobstructed views w/o trees on bank line and corn nearby
52	NO + NF + PC	Wide unobstructed views w/o trees on bank line and corn nearby
53	NO + UFW + PC	Wide unobstructed views w/o trees on bank line and corn nearby
54	TCW + UOCW + UFW + PC	Wide channels with wide unobstructed views w/o trees on bank line and corn nearby
55	TCW + UOCW + UD + PC	Wide channels with wide unobstructed views with moderate flow volume and corn nearby

Model ID	Covariates	Interpretation
56	TCW + UFW + UD + PC	Wide channel widths w/o trees on bank line with moderate flow volume and corn nearby
57	TCW + UOCW + WDR + PC	Wide channels with wide unobstructed views with moderate width-depth ratio and corn nearby
58	TCW + UFW + WDR + PC	Wide channel widths w/o trees on bank line with moderate width-depth ratio and corn nearby
59	TCW + NO + NF + PC	Wide channels with wide unobstructed views w/o trees on bank line and corn nearby
60	TCW + NO + UFW + PC	Wide channels with wide unobstructed views w/o trees on bank line and corn nearby
61	TCW + NO + UD + PC	Wide channels with wide unobstructed views with moderate flow volume and corn nearby
62	TCW + NO + WDR + PC	Wide channels with wide unobstructed views with moderate width-depth ratio and corn nearby
63	TCW + NF + WDR + PC	Wide channel widths w/o trees on bank line with moderate width-depth ratio and corn nearby
64	TCW + UOCW + NF + PC	Wide channels with wide unobstructed views w/o trees on bank line and corn nearby
65	TCW + NF + UD + PC	Wide channel widths w/o trees on bank line with moderate flow volume and corn nearby
66	TCW + UOCW + UFW + UD + PC	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and corn nearby
67	TCW + UOCW + UFW + WDR + PC	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and corn nearby
68	TCW + NO + UFW + UD + PC	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and corn nearby
69	TCW + NO + UFW + WDR + PC	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and corn nearby
70	TCW + UOCW + NF + WDR + PC	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and corn nearby
71	TCW + UOCW + NF + UD + PC	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and corn nearby
72	TCW + NO + NF + UD + PC	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and corn nearby
73	TCW + NO + NF + WDR + PC	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and corn nearby
74	PWM	Wet meadow nearby
75	UFW + PWM	Channels w/o trees on bank line and wet meadow nearby
76	UOCW + PWM	Channels with wide unobstructed views and wet meadow nearby
77	TCW + PWM	Wide channels and wet meadow nearby
78	UOCW + UFW + PWM	Wide unobstructed views w/o trees on bank line and wet meadow nearby
79	TCW + UOCW + PWM	Wide channels with wide unobstructed views and wet meadow nearby
80	TCW + UOCW + UFW + PWM	Wide channels with wide unobstructed views w/o trees on bank line and wet meadow nearby
81	TCW + WW + PWM	Wide channels with high wetted widths and wet meadow nearby

Model ID	Covariates	Interpretation
82	TCW + PW + PWM	Wide channels with a high proportion of the channel that is wetted and wet meadow nearby
83	TCW + UD + PWM	Wide channels with moderate flow volume and wet meadow nearby
84	TCW + MD + PWM	Wide channels with moderate to shallow depths across the channel and wet meadow nearby
85	TCW + WDR + PWM	Wide channels with moderate width-depth ratio and wet meadow nearby
86	TCW + UOCW + UD + PWM	Wide channels with wide unobstructed views with moderate flow volume and wet meadow nearby
87	TCW + UFW + UD + PWM	Wide channel widths w/o trees on bank line with moderate flow volume and wet meadow nearby
88	TCW + UOCW + UFW + UD + PWM	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and wet meadow nearby
89	TCW + UOCW + WDR + PWM	Wide channels with wide unobstructed views with moderate width-depth ratio and wet meadow nearby
90	TCW + UFW + WDR + PWM	Wide channel widths w/o trees on bank line with moderate width-depth ratio and wet meadow nearby
91	TCW + UOCW + UFW + WDR + PWM	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and wet meadow nearby
92	NO + PWM	Channels with wide unobstructed views and wet meadow nearby
93	NO + UFW + PWM	Wide unobstructed views w/o trees on bank line and wet meadow nearby
94	TCW + NO + PWM	Wide channels with wide unobstructed views and wet meadow nearby
95	TCW + NO + UFW + PWM	Wide channels with wide unobstructed views w/o trees on bank line and wet meadow nearby
96	TCW + NO + UD + PWM	Wide channels with wide unobstructed views with moderate flow volume and wet meadow nearby
97	TCW + NO + UFW + UD + PWM	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and wet meadow nearby
98	TCW + NO + WDR + PWM	Wide channels with wide unobstructed views with moderate width-depth ratio and wet meadow nearby
99	TCW + NO + UFW + WDR + PWM	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and wet meadow nearby
100	TCW + NF + WDR + PWM	Wide channel widths w/o trees on bank line with moderate width-depth ratio and wet meadow nearby
101	TCW + UOCW + NF + WDR + PWM	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and wet meadow nearby
102	TCW + NF + UD + PWM	Wide channel widths w/o trees on bank line with moderate flow volume and wet meadow nearby
103	TCW + UOCW + NF + UD + PWM	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and wet meadow nearby
104	TCW + UOCW + NF + PWM	Wide channels with wide unobstructed views w/o trees on bank line and wet meadow nearby
105	UOCW + NF + PWM	Wide unobstructed views w/o trees on bank line and wet meadow nearby

Model ID	Covariates	Interpretation
106	NF + PWM	Channels w/o trees on bank line and wet meadow nearby
107	TCW + NO + NF + PWM	Wide channels with wide unobstructed views w/o trees on bank line and wet meadow nearby
108	TCW + NO + NF + UD + PWM	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and wet meadow nearby
109	TCW + NO + NF + WDR + PWM	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and wet meadow nearby
110	NO + NF + PWM	Wide unobstructed views w/o trees on bank line and wet meadow nearby
111	PF	Less forest nearby
112	UFW + PF	Channels w/o trees on bank line and less forest nearby
113	UOCW + PF	Channels with wide unobstructed views and less forest nearby
114	TCW + PF	Wide channels and less forest nearby
115	NF + PF	Channels w/o trees on bank line and less forest nearby
116	NO + PF	Channels with wide unobstructed views and less forest nearby
117	UOCW + UFW + PF	Wide unobstructed views w/o trees on bank line and less forest nearby
118	TCW + UOCW + PF	Wide channels with wide unobstructed views and less forest nearby
119	TCW + WW + PF	Wide channels with high wetted widths and less forest nearby
120	TCW + PW + PF	Wide channels with a high proportion of the channel that is wetted and less forest nearby
121	TCW + UD + PF	Wide channels with moderate flow volume and less forest nearby
122	TCW + MD + PF	Wide channels with moderate to shallow depths across the channel and less forest nearby
123	TCW + WDR + PF	Wide channels with moderate width-depth ratio and less forest nearby
124	NO + UFW + PF	Wide unobstructed views w/o trees on bank line and less forest nearby
125	TCW + NO + PF	Wide channels with wide unobstructed views and less forest nearby
126	UOCW + NF + PF	Wide unobstructed views w/o trees on bank line and less forest nearby
127	NO + NF + PF	Wide unobstructed views w/o trees on bank line and less forest nearby
128	TCW + UOCW + UFW + PF	Wide channels with wide unobstructed views w/o trees on bank line and less forest nearby
129	TCW + UOCW + UD + PF	Wide channels with wide unobstructed views with moderate flow volume and less forest nearby
130	TCW + UFW + UD + PF	Wide channel widths w/o trees on bank line with moderate flow volume and less forest nearby
131	TCW + UOCW + WDR + PF	Wide channels with wide unobstructed views with moderate width-depth ratio and less forest nearby
132	TCW + UFW + WDR + PF	Wide channel widths w/o trees on bank line with moderate width-depth ratio and less forest nearby
133	TCW + NO + UFW + PF	Wide channels with wide unobstructed views w/o trees on bank line and less forest nearby
134	TCW + NO + UD + PF	Wide channels with wide unobstructed views with moderate flow volume and less forest nearby

Model ID	Covariates	Interpretation
135	TCW + NO + WDR + PF	Wide channels with wide unobstructed views with moderate width-depth ratio and less forest nearby
136	TCW + NF + WDR + PF	Wide channel widths w/o trees on bank line with moderate width-depth ratio and less forest nearby
137	TCW + NF + UD + PF	Wide channel widths w/o trees on bank line with moderate flow volume and less forest nearby
138	TCW + UOCW + NF + PF	Wide channels with wide unobstructed views w/o trees on bank line and less forest nearby
139	TCW + NO + NF + PF	Wide channels with wide unobstructed views w/o trees on bank line and less forest nearby
140	TCW + UOCW + UFW + UD + PF	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and less forest nearby
141	TCW + UOCW + UFW + WDR + PF	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and less forest nearby
142	TCW + NO + UFW + UD + PF	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and less forest nearby
143	TCW + NO + UFW + WDR + PF	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and less forest nearby
144	TCW + UOCW + NF + WDR + PF	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and less forest nearby
145	TCW + UOCW + NF + UD + PF	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and less forest nearby
146	TCW + NO + NF + UD + PF	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and less forest nearby
147	TCW + NO + NF + WDR + PF	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and less forest nearby
148	PG	Grassland nearby
149	UFW + PG	Channels w/o trees on bank line and grassland nearby
150	UOCW + PG	Channels with wide unobstructed views and grassland nearby
151	TCW + PG	Wide channels and grassland nearby
152	NO + PG	Channels with wide unobstructed views and grassland nearby
153	NF + PG	Channels w/o trees on bank line and grassland nearby
154	UOCW + UFW + PG	Wide unobstructed views w/o trees on bank line and grassland nearby
155	TCW + UOCW + PG	Wide channels with wide unobstructed views and grassland nearby
156	TCW + WW + PG	Wide channels with high wetted widths and grassland nearby
157	TCW + PW + PG	Wide channels with a high proportion of the channel that is wetted and grassland nearby
158	TCW + UD + PG	Wide channels with moderate flow volume and grassland nearby
159	TCW + MD + PG	Wide channels with moderate to shallow depths across the channel and grassland nearby
160	TCW + WDR + PG	Wide channels with moderate width-depth ratio and grassland nearby

Model ID	Covariates	Interpretation
161	NO + UFW + PG	Wide unobstructed views w/o trees on bank line and grassland nearby
162	TCW + NO + PG	Wide channels with wide unobstructed views and grassland nearby
163	UOCW + NF + PG	Wide unobstructed views w/o trees on bank line and grassland nearby
164	NO + NF + PG	Wide unobstructed views w/o trees on bank line and grassland nearby
165	TCW + UOCW + UFW + PG	Wide channels with wide unobstructed views w/o trees on bank line and grassland nearby
166	TCW + UOCW + UD + PG	Wide channels with wide unobstructed views with moderate flow volume and grassland nearby
167	TCW + UFW + UD + PG	Wide channel widths w/o trees on bank line with moderate flow volume and grassland nearby
168	TCW + NO + NF + PG	Wide channels with wide unobstructed views w/o trees on bank line and grassland nearby
169	TCW + NO + UFW + PG	Wide channels with wide unobstructed views w/o trees on bank line and grassland nearby
170	TCW + NO + UD + PG	Wide channels with wide unobstructed views with moderate flow volume and grassland nearby
171	TCW + NO + WDR + PG	Wide channels with wide unobstructed views with moderate width-depth ratio and grassland nearby
172	TCW + NF + UD + PG	Wide channel widths w/o trees on bank line with moderate flow volume and grassland nearby
173	TCW + UOCW + NF + PG	Wide channels with wide unobstructed views w/o trees on bank line and grassland nearby
174	TCW + UOCW + WDR + PG	Wide channels with wide unobstructed views with moderate width-depth ratio and grassland nearby
175	TCW + UFW + WDR + PG	Wide channel widths w/o trees on bank line with moderate width-depth ratio and grassland nearby
176	TCW + NF + WDR + PG	Wide channel widths w/o trees on bank line with moderate width-depth ratio and grassland nearby
177	TCW + UOCW + UFW + UD + PG	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and grassland nearby
178	TCW + UOCW + UFW + WDR + PG	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and grassland nearby
179	TCW + NO + UFW + UD + PG	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and grassland nearby
180	TCW + NO + UFW + WDR + PG	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and grassland nearby
181	TCW + UOCW + NF + WDR + PG	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and grassland nearby
182	TCW + UOCW + NF + UD + PG	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and grassland nearby
183	TCW + NO + NF + UD + PG	Wide channels with wide unobstructed views w/o trees on bank line with moderate flow volume and grassland nearby
184	TCW + NO + NF + WDR + PG	Wide channel widths with wide unobstructed views w/o trees on bank line with moderate width-depth ratio and grassland nearby

Table A.2. Diurnal *a priori* model list for whooping crane habitat use created by PRRIP. The interpretation assumes an *a priori* direction (positive or negative) in the relationship between whooping crane habitat use and the covariates but actual model fit, based on data, could have been in the opposite direction.

Model ID	Covariates	Interpretation
1	LC	Land cover class
2	PRL	Near roost location
3	NO	Away from obstructions
4	ND	Away from disturbance features
5	NO + PRL	Away from obstructions and near roost location
6	ND + PRL	Away from disturbance features and near roost location
7	NO + ND	Away from obstructions and disturbances
8	LC + NO	Land cover class away from obstructions
9	LC + ND	Land cover class away from disturbance features
10	LC + PRL	Land cover class and near roost location
11	LC + NO + ND	Land cover class away from obstructions and disturbances
12	LC + NO + PRL	Land cover class away from obstructions and near roost location
13	LC + ND + PRL	Land cover class away from disturbance features and near roost location
14	NO + ND + PRL	Away from obstructions and disturbances and near roost location
15	LC + NO + ND + PRL	Land cover class away from obstructions and disturbances and near roost location

Appendix B. Mirrored Histograms and Summary Statistics for Systematic Unique In-Channel Whooping Crane Observations

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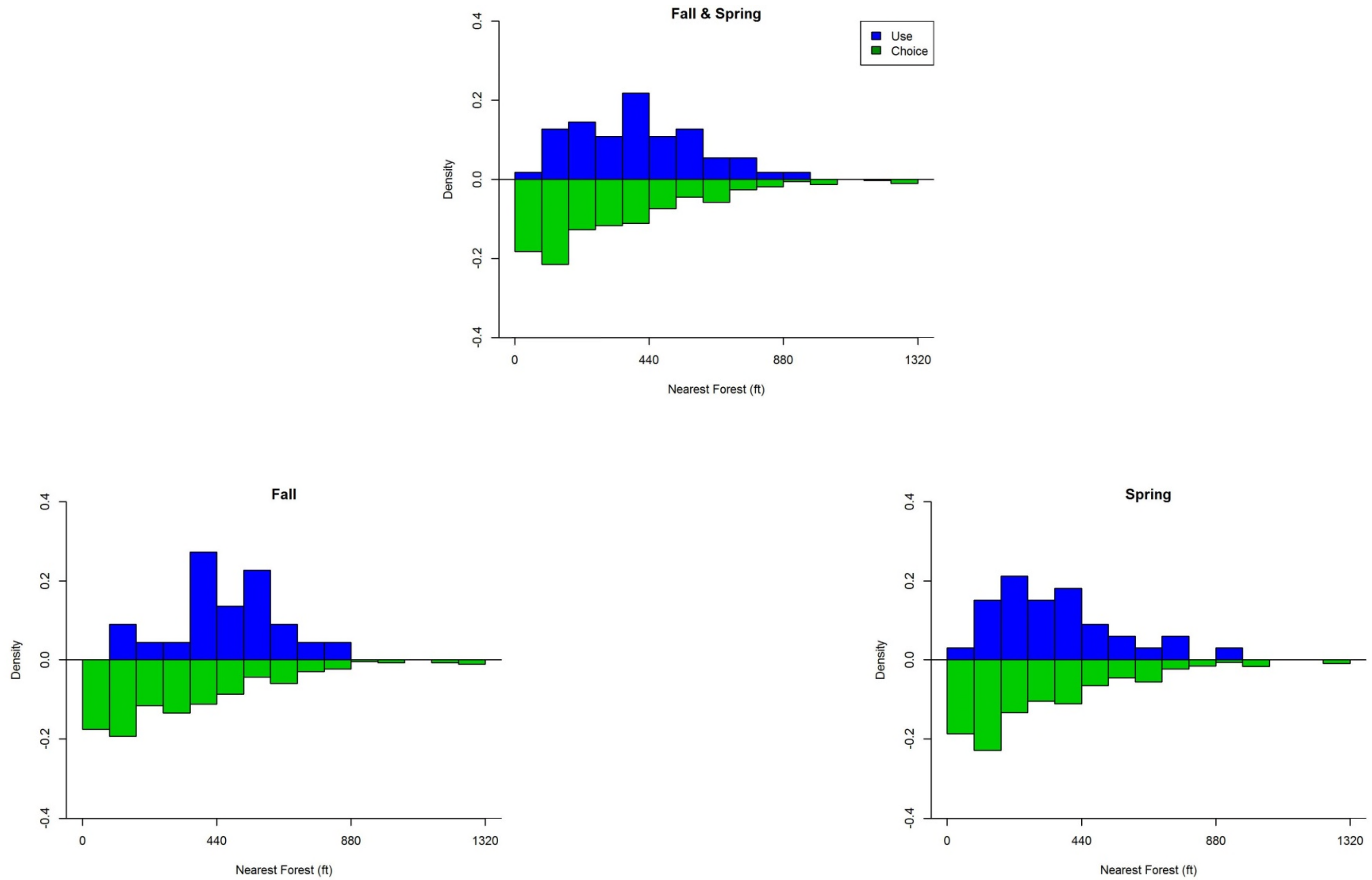
		Choice Sets			Used Locations		
Variable	**Season**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
UOCW	Fall	395.09	292.44	74.02	564.09	261.98	46.44
	Spring	378.22	330.88	87.48	471.10	320.36	68.00
	Spring and Fall	384.90	316.17	82.14	507.95	299.48	58.96
NO	Fall	86.00	89.54	104.12	172.99	103.86	60.04
	Spring	77.11	96.23	124.79	91.57	51.88	56.66
	Spring and Fall	80.63	93.69	116.20	123.83	85.85	69.32
UFW	Fall	2091.46	2504.55	119.75	1896.77	1029.13	54.26
	Spring	1993.26	2244.74	112.62	1860.68	1564.23	84.07
	Spring and Fall	2032.17	2350.45	115.66	1874.98	1366.15	72.86
NF	Fall	322.66	253.97	78.71	474.58	178.04	37.52
	Spring	299.94	248.08	82.71	347.58	195.78	56.33
	Spring and Fall	308.95	250.56	81.10	397.90	197.42	49.62
TCW	Fall	735.58	413.30	56.19	929.89	414.29	44.55
	Spring	631.41	388.64	61.55	664.56	322.35	48.51
	Spring and Fall	672.69	401.65	59.71	769.69	380.95	49.49
WW	Fall	358.95	226.11	62.99	478.60	217.51	45.45
	Spring	373.44	236.59	63.35	424.02	265.83	62.69
	Spring and Fall	367.70	232.49	63.23	445.65	247.09	55.44
PW	Fall	0.56	0.27	47.97	0.57	0.26	45.48
	Spring	0.64	0.23	36.07	0.64	0.26	39.58
	Spring and Fall	0.61	0.25	41.03	0.61	0.26	41.82
MD	Fall	1.02	0.55	54.45	0.97	0.61	62.77
	Spring	1.22	0.59	48.50	1.13	0.50	43.97
	Spring and Fall	1.14	0.58	51.33	1.07	0.54	51.01
UD	Fall	1.39	1.52	109.52	1.24	1.43	115.14
	Spring	2.16	2.56	118.56	1.79	1.41	78.77
	Spring and Fall	1.85	2.24	120.83	1.57	1.43	90.92
WDR	Fall	445.60	396.75	89.04	601.52	368.11	61.20
	Spring	381.22	317.72	83.34	444.70	349.73	78.64
	Spring and Fall	406.73	352.40	86.64	506.83	361.98	71.42
PC	Fall	42.00	6.43	15.31	40.79	6.37	15.61
	Spring	40.59	7.85	19.34	40.60	7.69	18.94
	Spring and Fall	41.15	7.35	17.86	40.67	7.13	17.53
PF	Fall	7.28	1.40	19.29	7.32	1.41	19.23
	Spring	6.99	2.87	41.05	6.69	2.72	40.70
	Spring and Fall	7.10	2.40	33.80	6.94	2.30	33.10
PWM	Fall	12.23	6.84	55.94	12.53	5.85	46.70
	Spring	11.18	5.92	52.94	11.49	6.62	57.64
	Spring and Fall	11.59	6.32	54.49	11.90	6.29	52.86

		Choice Sets			Used Locations		
Variable	**Season**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
PG	Fall	25.37	7.04	27.74	26.38	6.40	24.27
	Spring	24.13	6.92	28.68	23.99	7.40	30.85
	Spring and Fall	24.62	6.99	28.39	24.94	7.06	28.31



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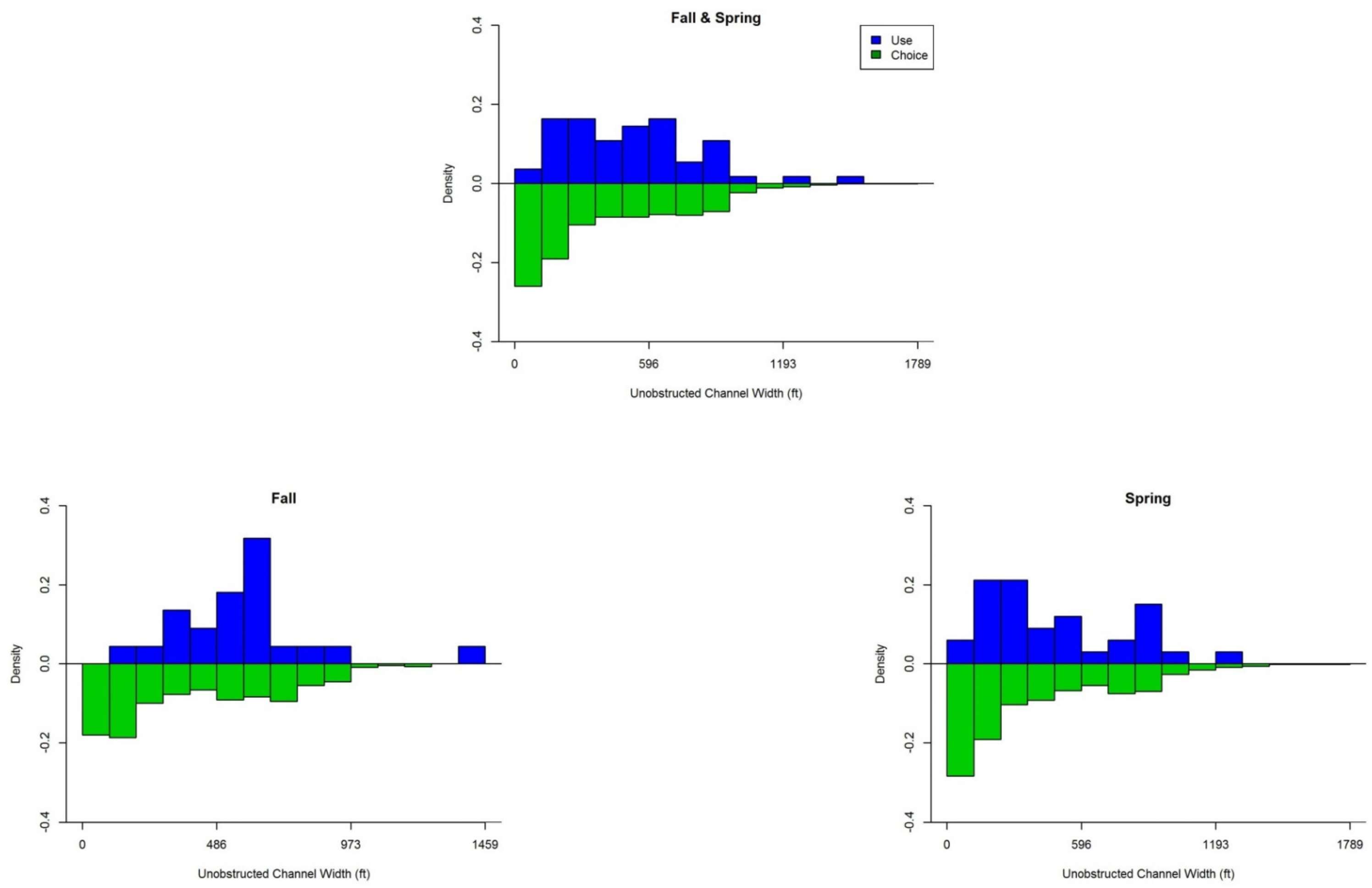

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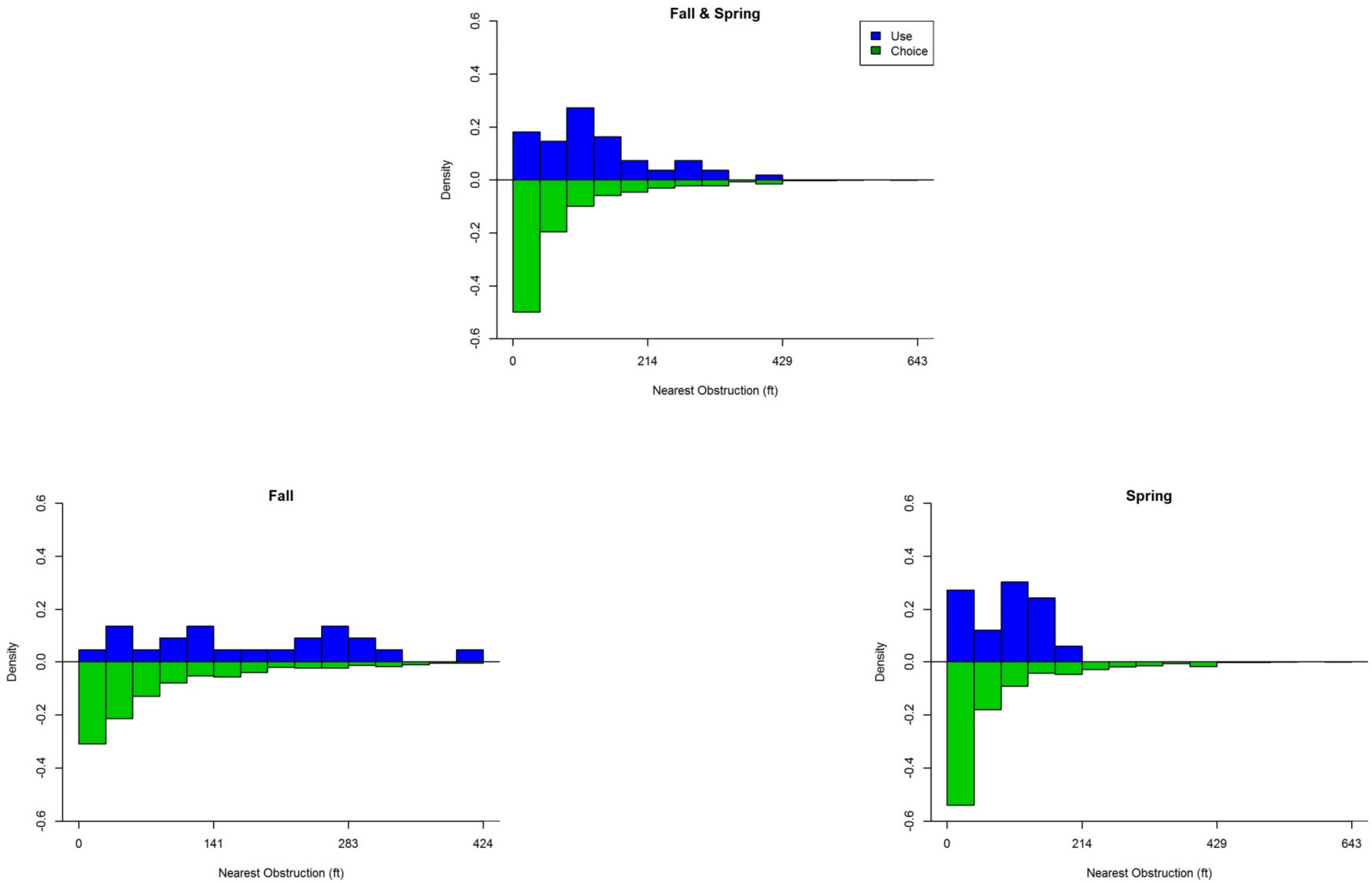

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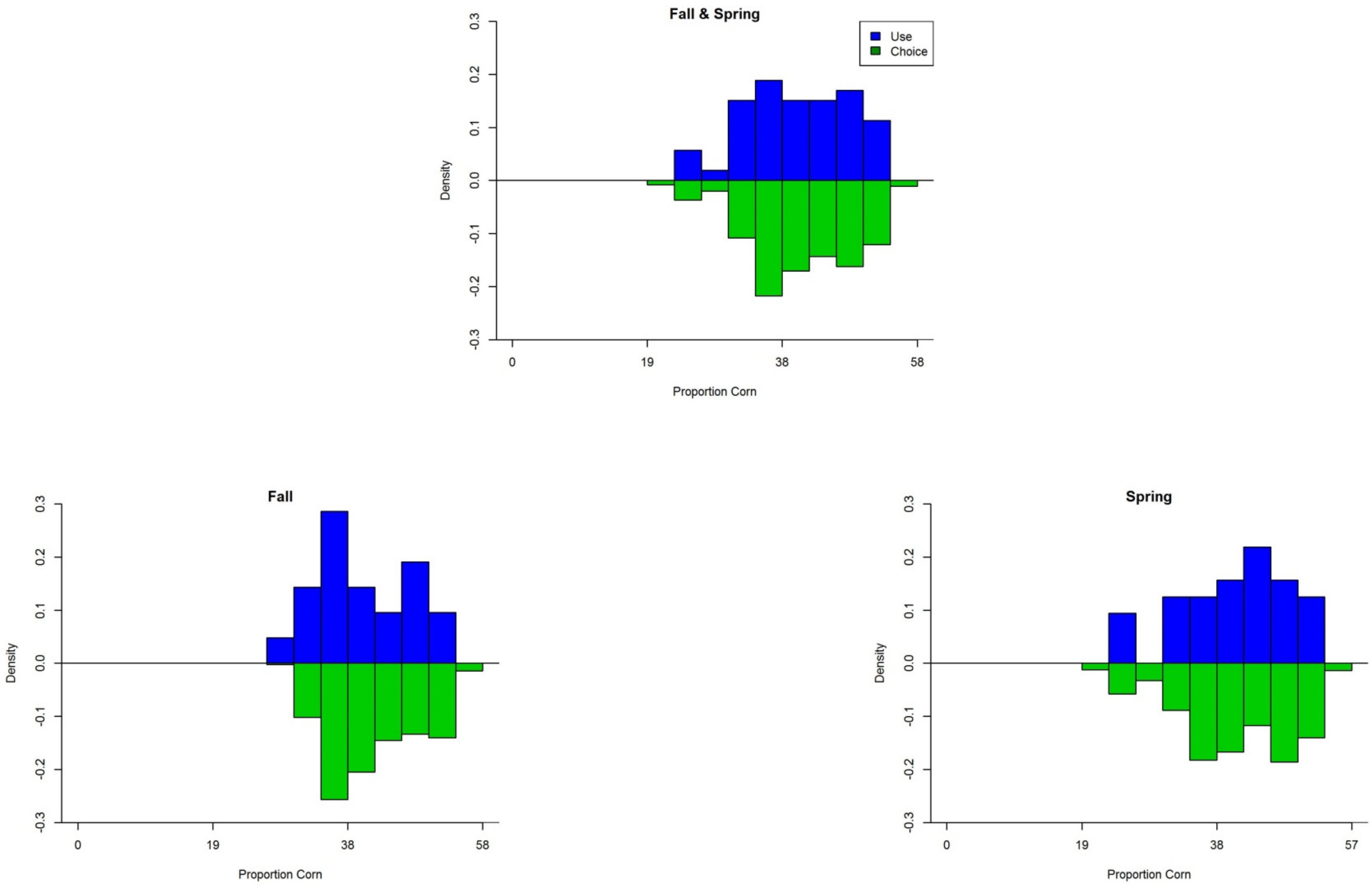

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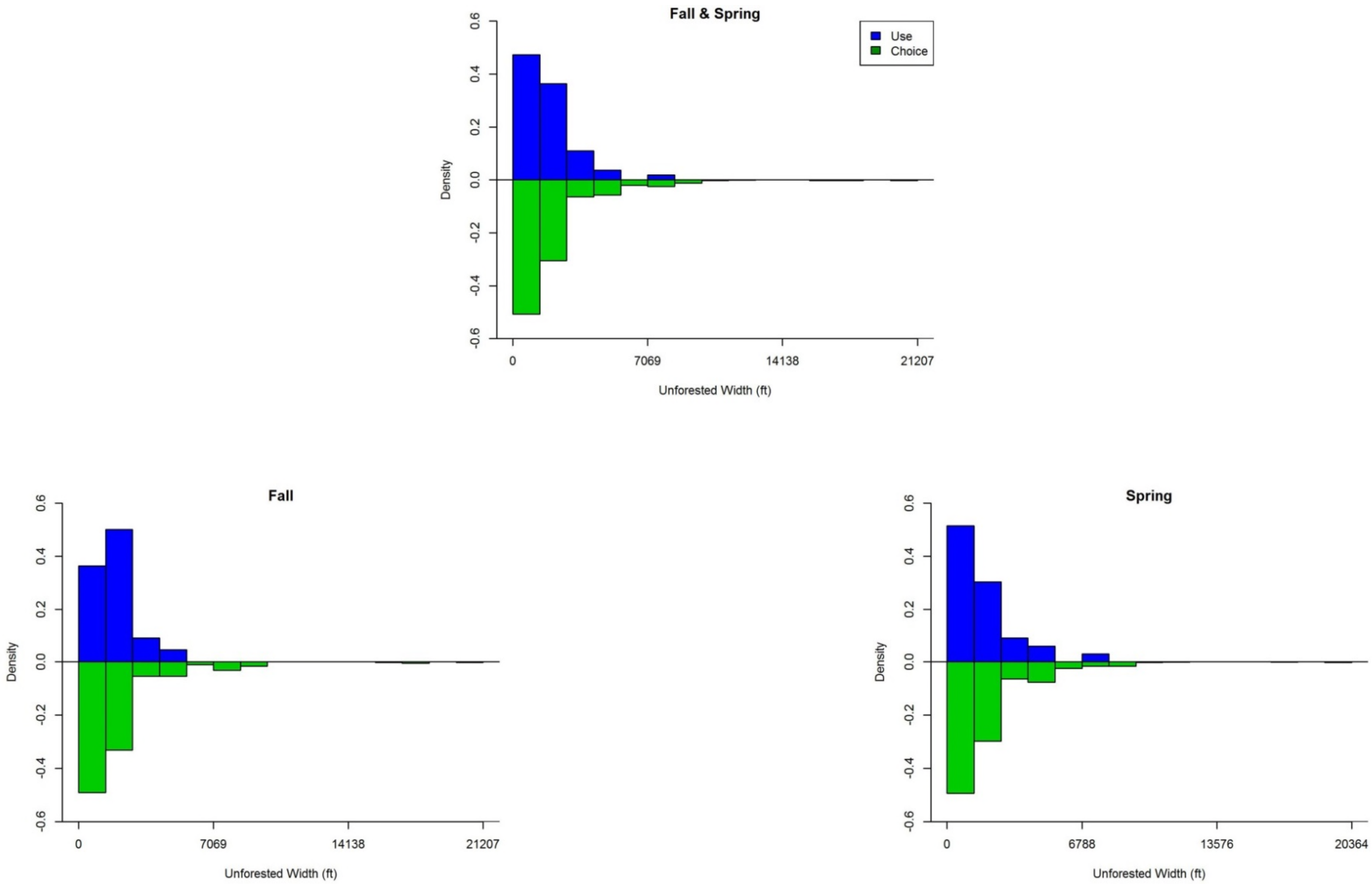

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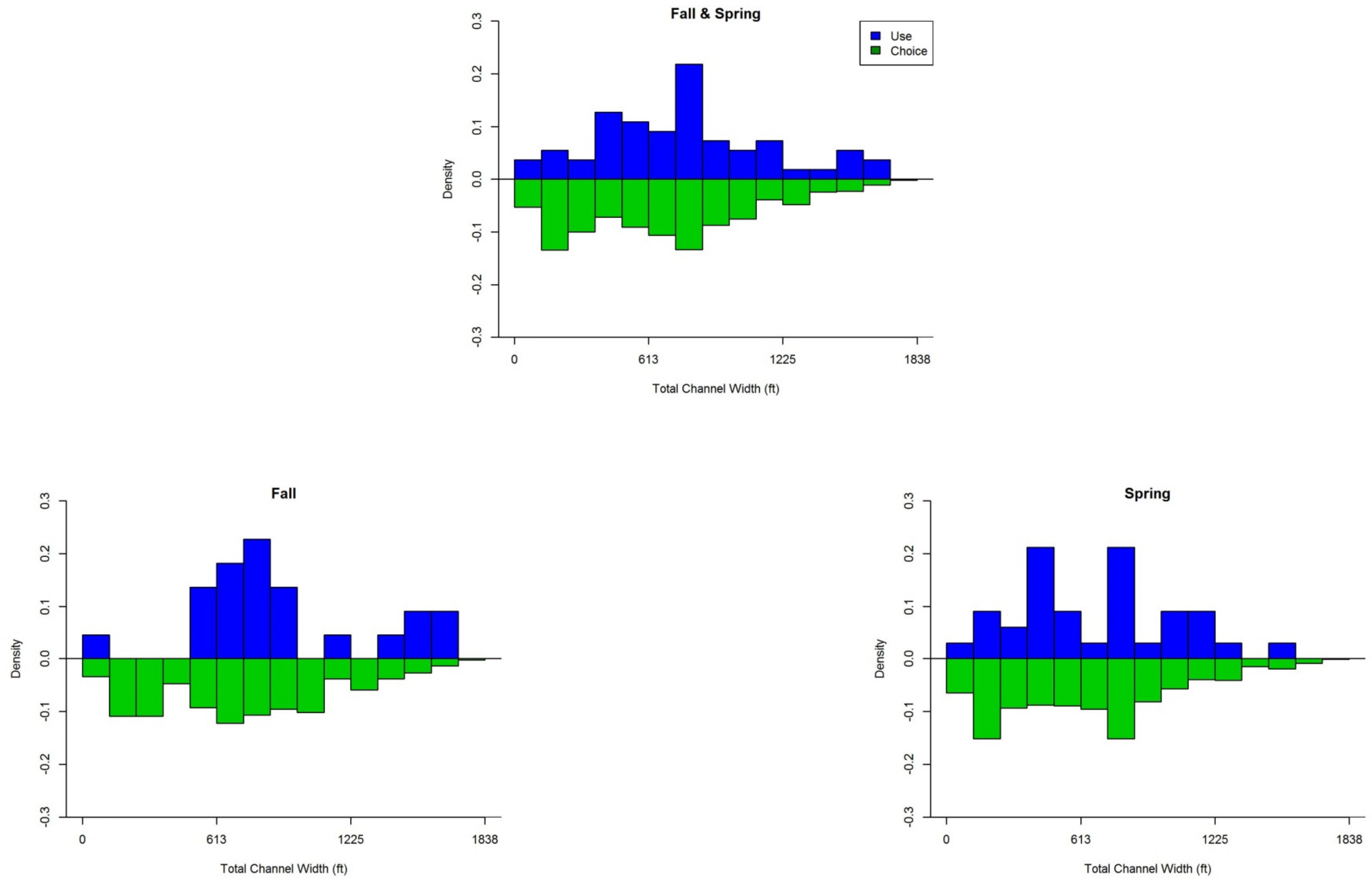

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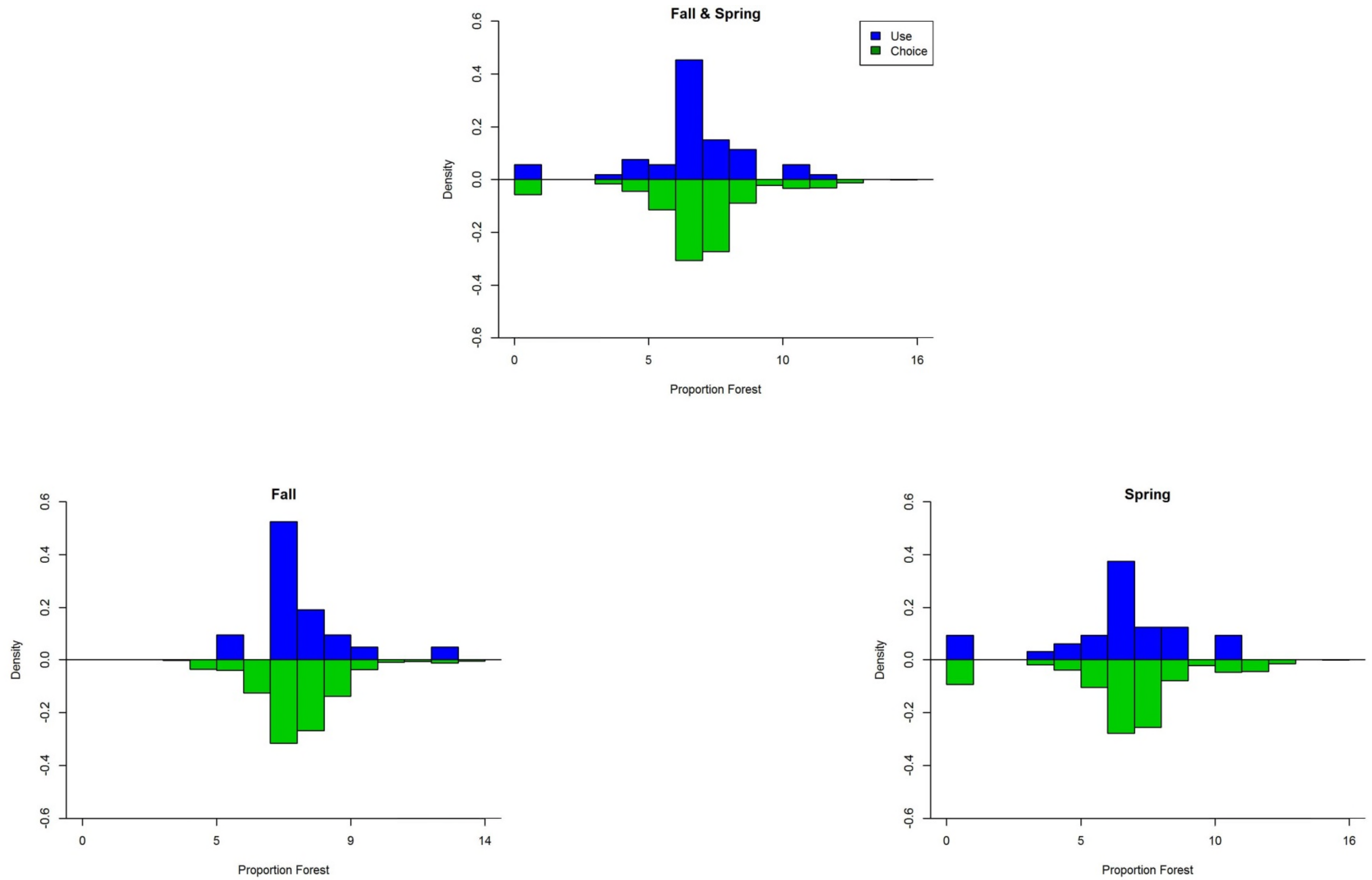

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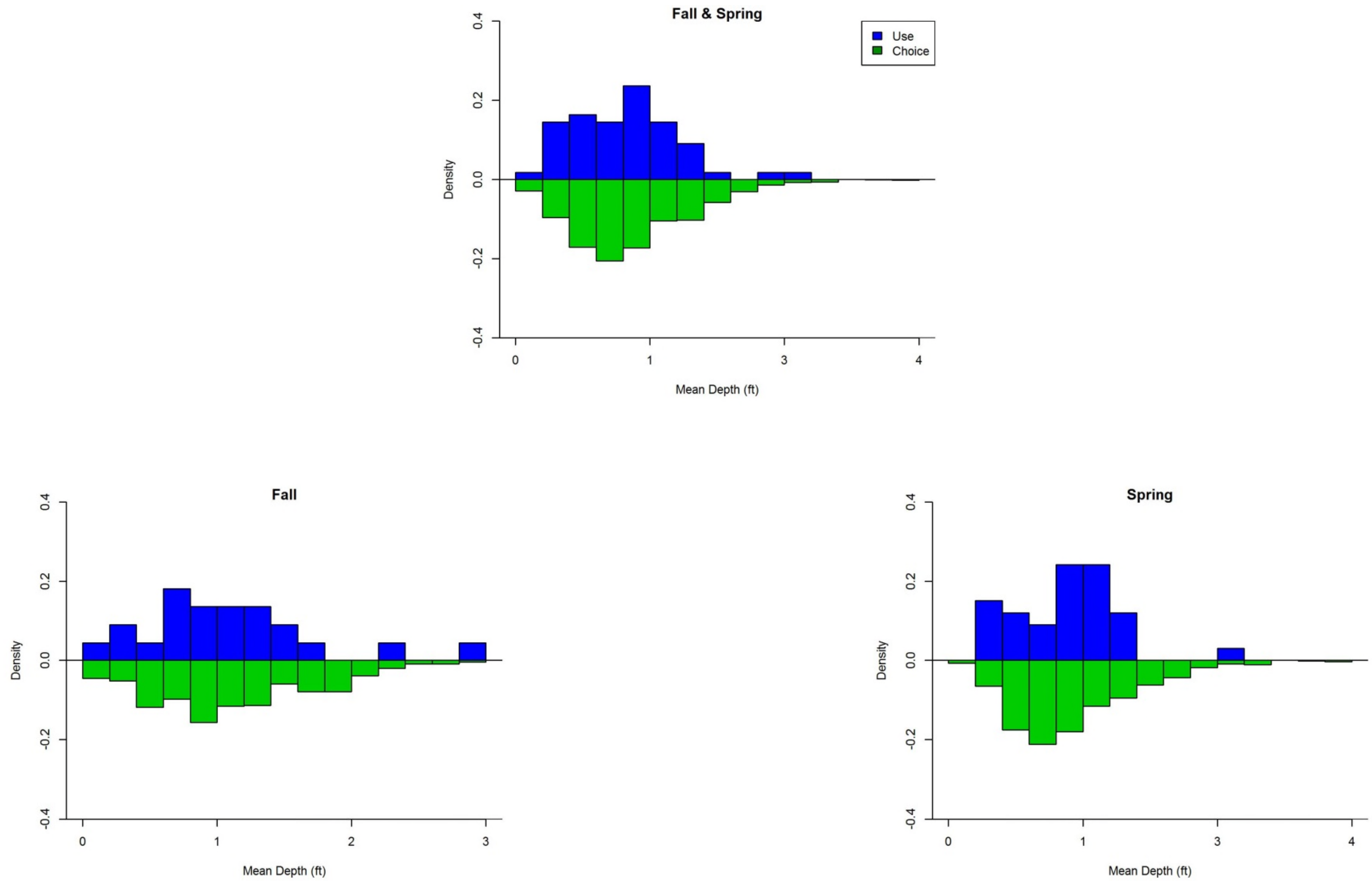

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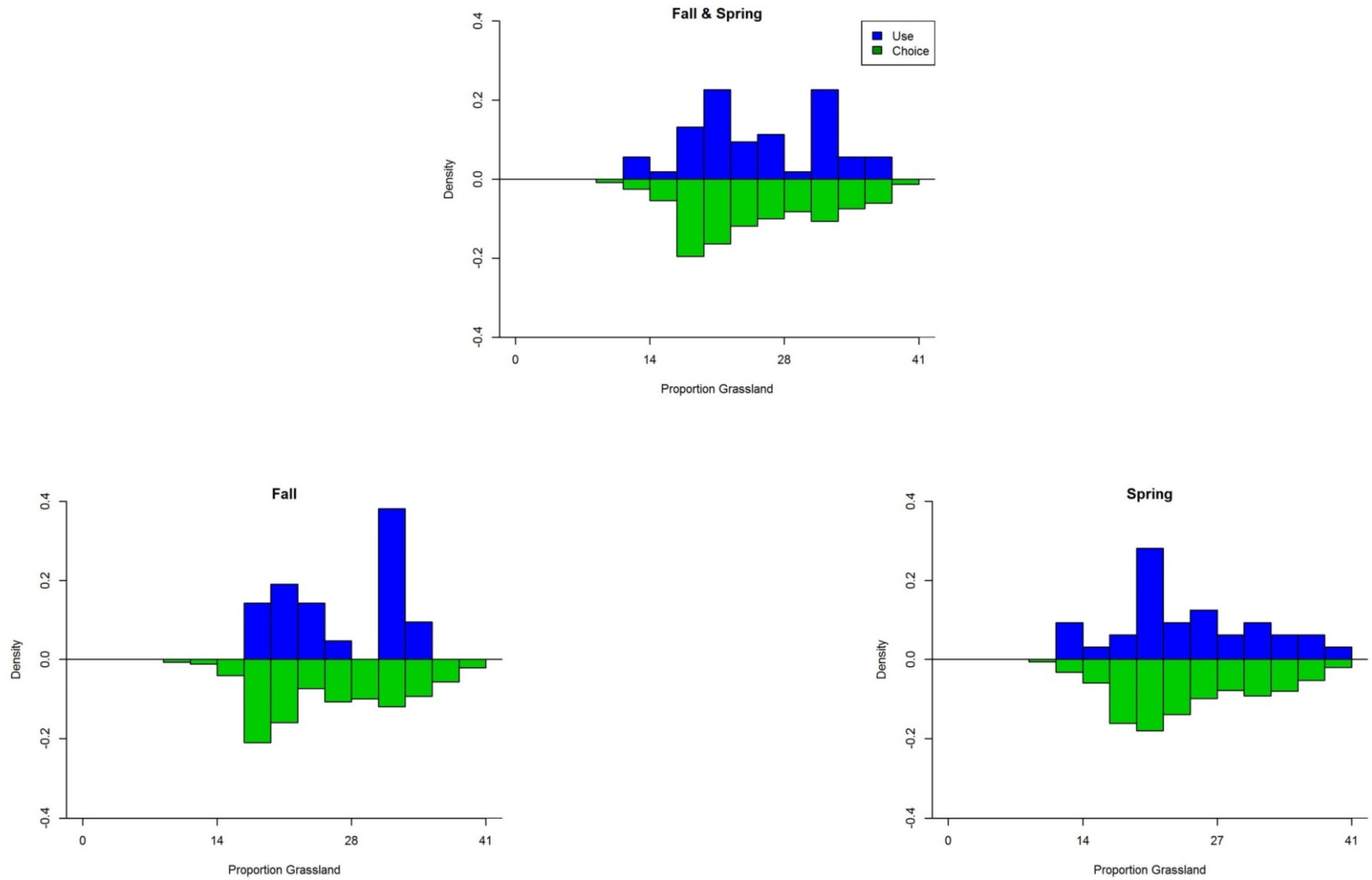

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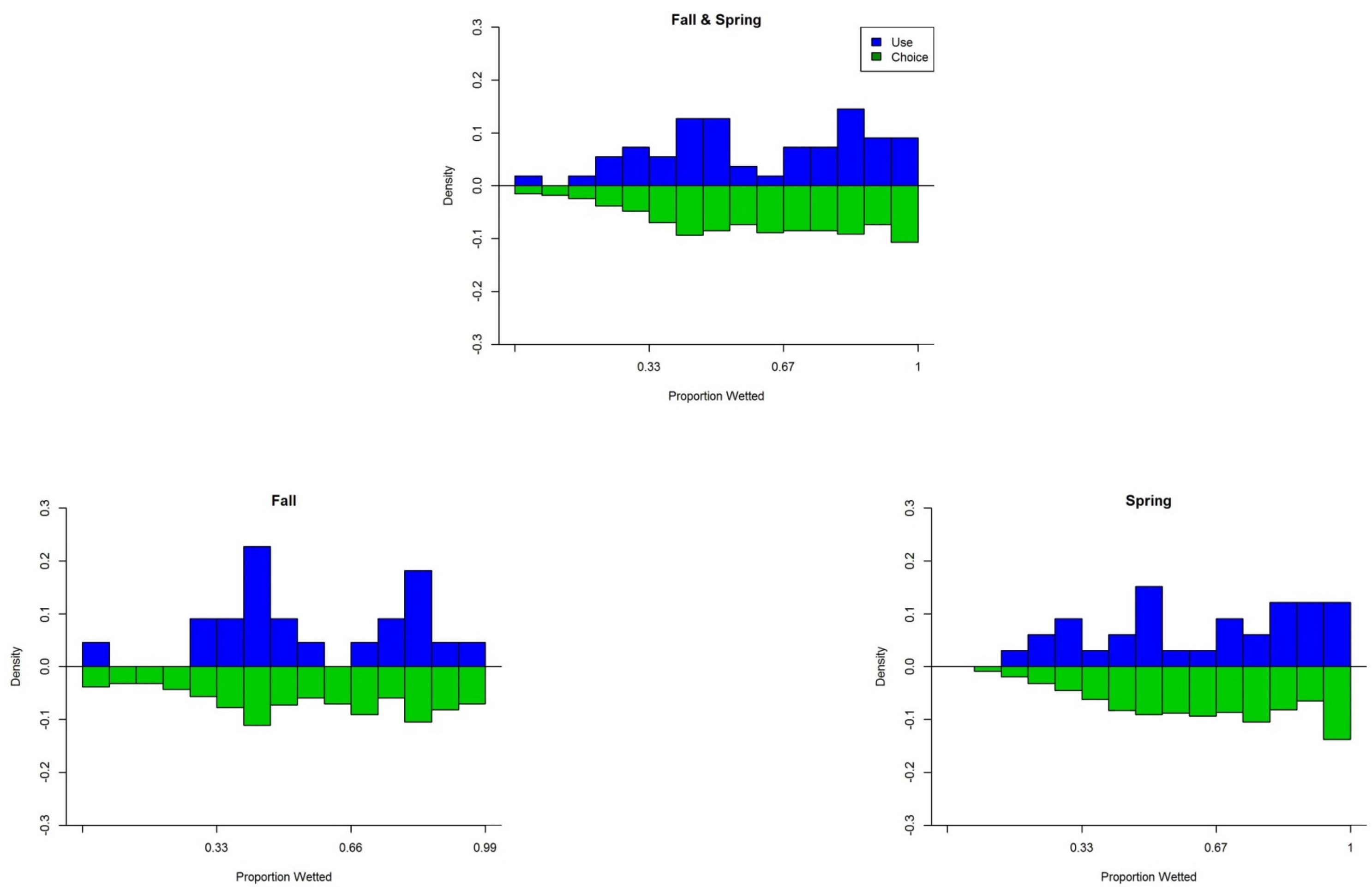

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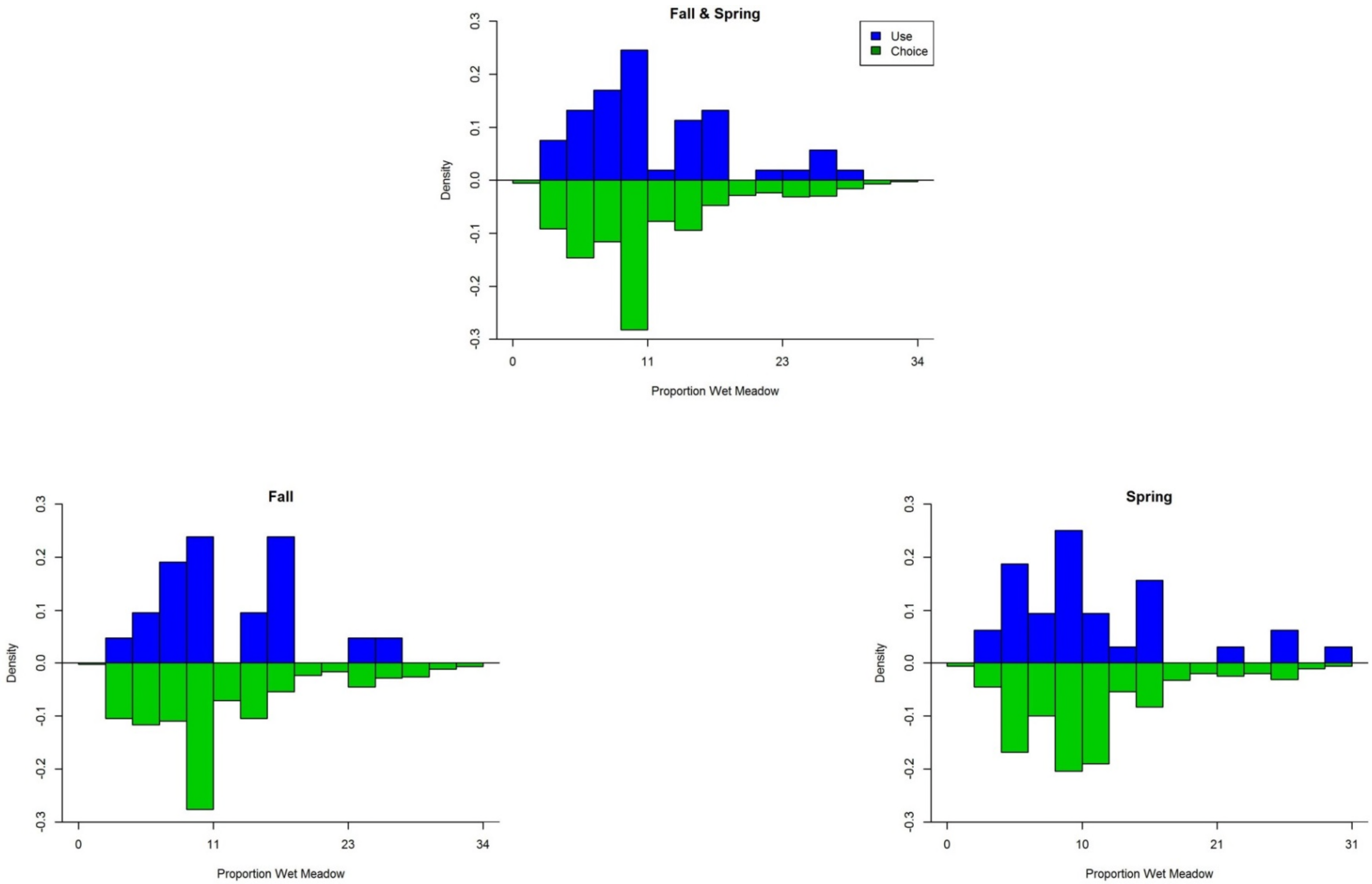

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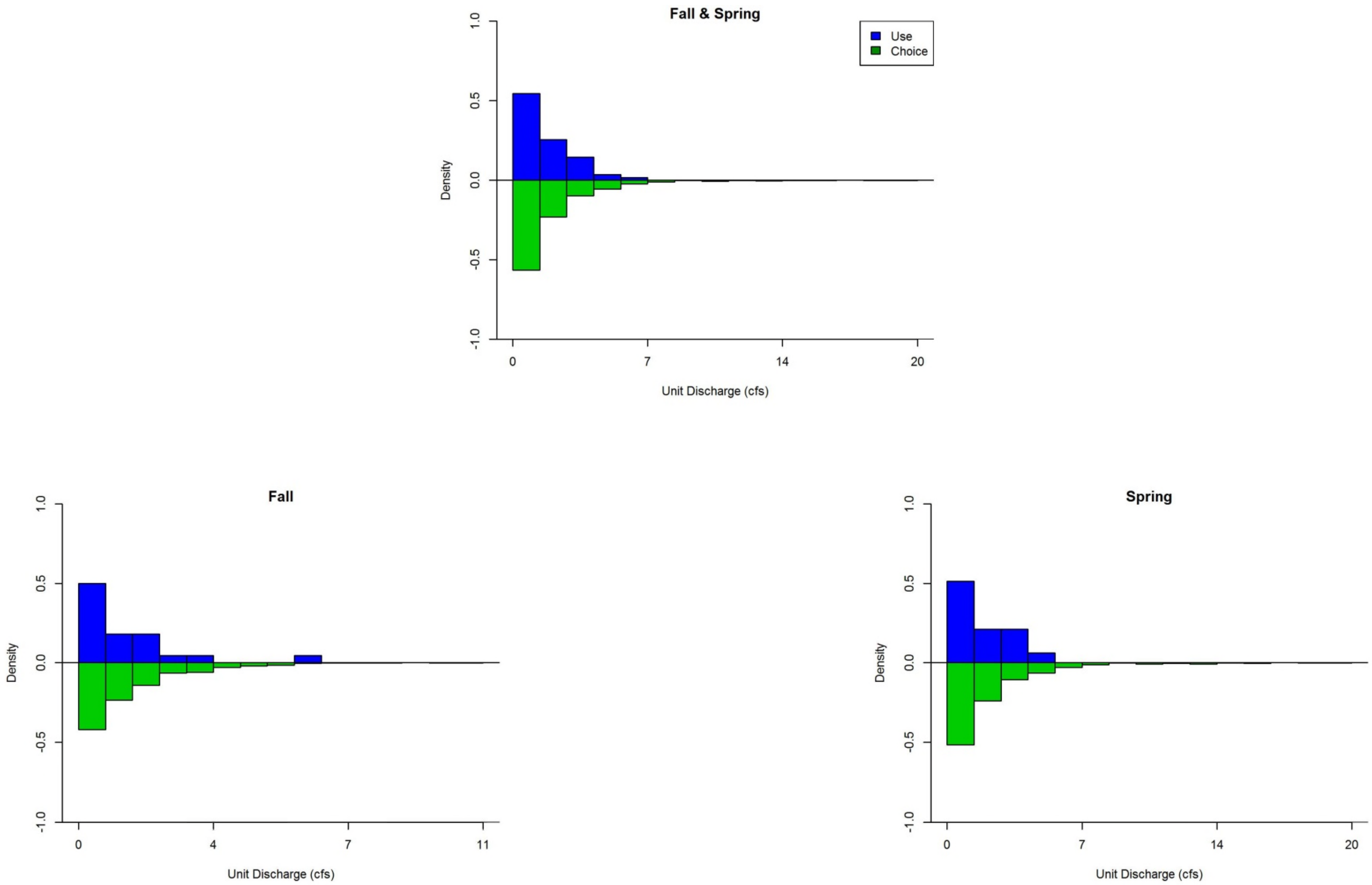

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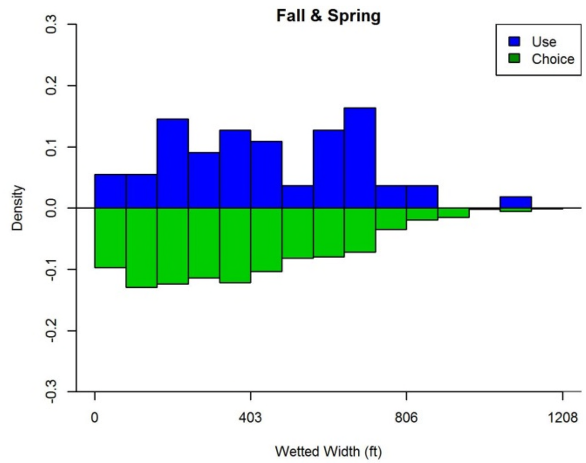

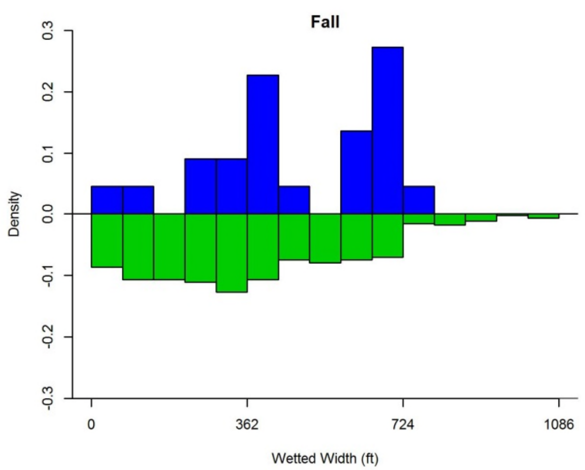

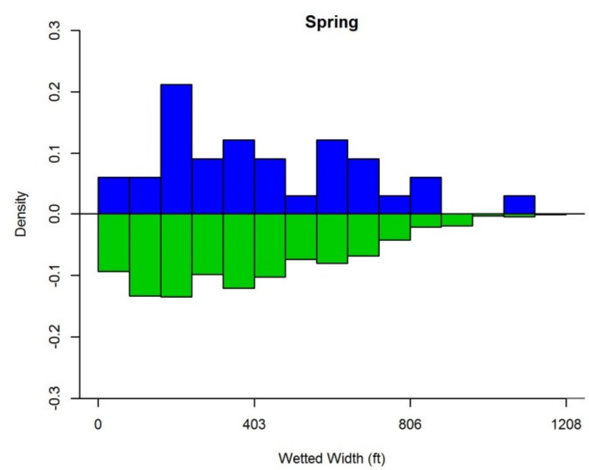

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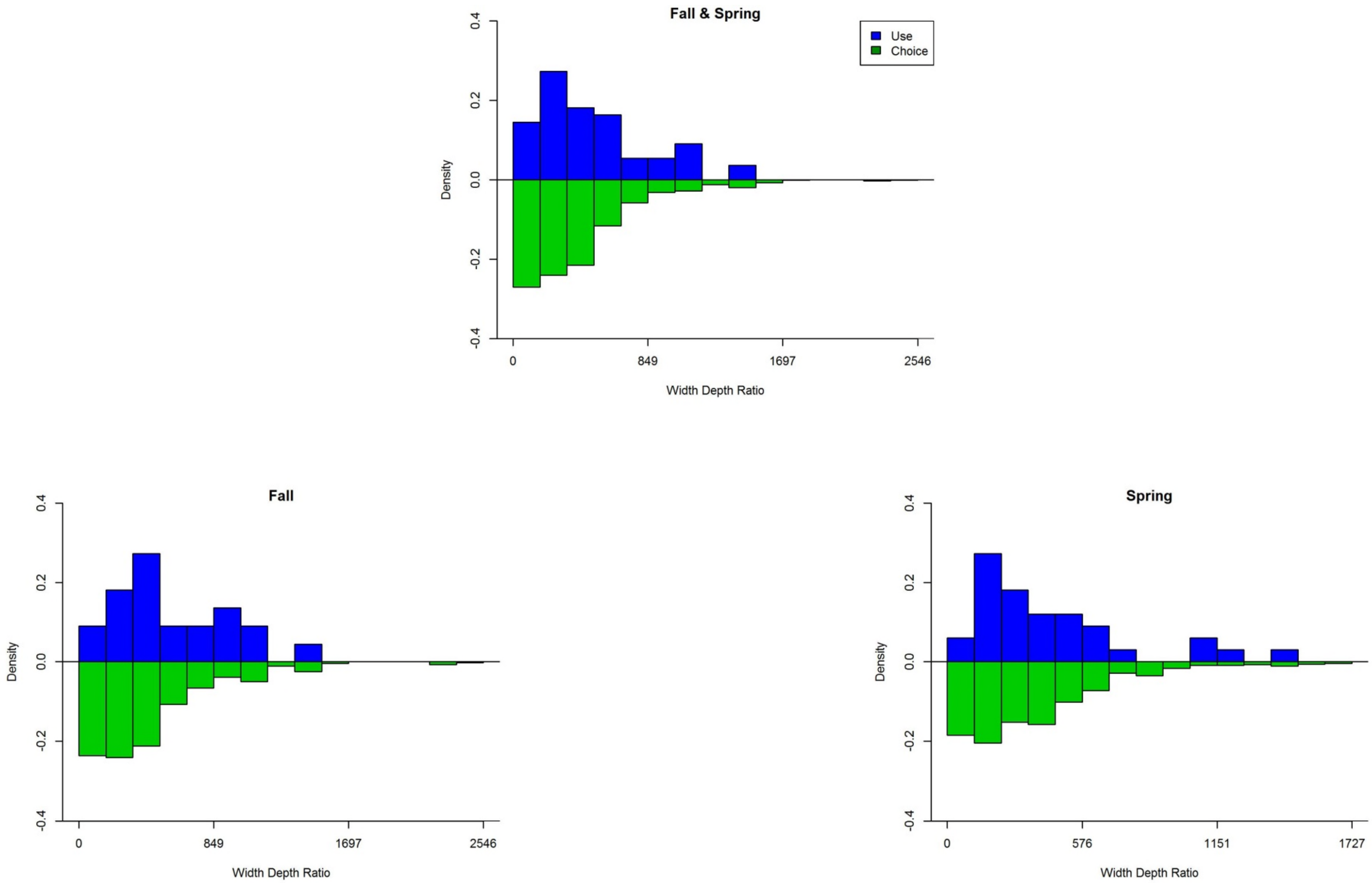

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1. Introduction

We reran the analysis presented in the main body of the report on a second set of data encompassing additional observations of group use by whooping cranes in the central Platte River. We conducted this analysis to incorporate every systematic observation of whooping crane groups in the central Platte River study area, in order to increase the sample size of the modelling efforts. All the observations included in this appendix were obtained through systematic sampling of the entire river corridor. The additional sightings come from multiple relocations of crane groups assumed to have been located previously in the study area, and are termed “non-unique” here. For example, a crane group identified during aerial surveys could also be observed on subsequent days during multi-day stopovers, thus providing one unique observation and one or more non-unique observations for one group of whooping cranes. In total there were an additional 96 non-unique observations detected during the spring migration and an additional 25 non-unique observations detected during the fall migration.

In general, exact identification of a migrating whooping crane group was not possible because individuals are not marked, nor do they have discernable phenotypical differences. For this reason, it was rarely known if an individual observed in the area was the same individual observed at a nearby area or even in the same area at another time. Biologists have typically used cues such as group size, group composition, timing, and location to make professional judgements regarding whooping crane groups that were seen on multiple days within a migration season. For example, biologists will generally agree that a crane group composed of two adults and one juvenile that has been observed on two consecutive days was the same group, if the sightings were within a reasonable spatial proximity.

In statistical analyses, there are important assumptions regarding the independence of the data (Breslow 1996). The treatment of non-independent data as independent data in an analysis is often called pseudo-replication (Hurlbert 1984). These assumptions directly relate to the ability of a random sample to provide unbiased inference towards a specified population. In order to have results that can be applied to the population, the data in the sample should be representative of the population of interest (Thompson 1992). When multiple observations of the same individuals are included when fitting a model, the response of interest, e.g. habitat use, can be biased by those individuals compared to other individuals that are observed only once, meaning that the habitat preferences of the individuals observed multiple times will be considered more heavily in the model than individuals observed once. In the case with migrating whooping cranes using the central Platte River, it is possible that the inclusion of non-unique sightings in an analysis is biased, as different durations of crane group stopovers can be related to the habitat encountered.

The PRRIP data collection for migrational habitat information on whooping cranes was conducted such that the professional judgements by the USFWS whooping crane coordinator regarding crane group identity were recorded, but were not inherently defined in the dataset. In other words, analyses can be conducted treating all crane groups as independent, or attributing multiple observations to repeated use of the same crane group.

The study of rare, or hard to detect, wildlife populations consistently leads to issues of pseudo-replication during the analysis. Researchers must balance the need for adequate sample size in the statistical analysis, with the perils of biasing the results with the inclusion of non-typical or non-random individuals. The results presented in the main body of the report, based only on unique or independent observations, contain less bias than results presented in this appendix. The impact of the inclusion of non-unique observations in this analysis was evaluated by fitting these data to the same models that were presented in the main body of the report.

2. Methods

For this analysis of habitat use we followed the same methods as written in the Methods section of the main body of the report. There were no changes in the definition of available habitat or the descriptors of habitat use. We did not repeat model selection but rather fit the best models identified during the analysis of the systematic unique data with all systematically collected data (i.e., unique and non-unique locations).

3. Results

Whooping Crane Group Observations

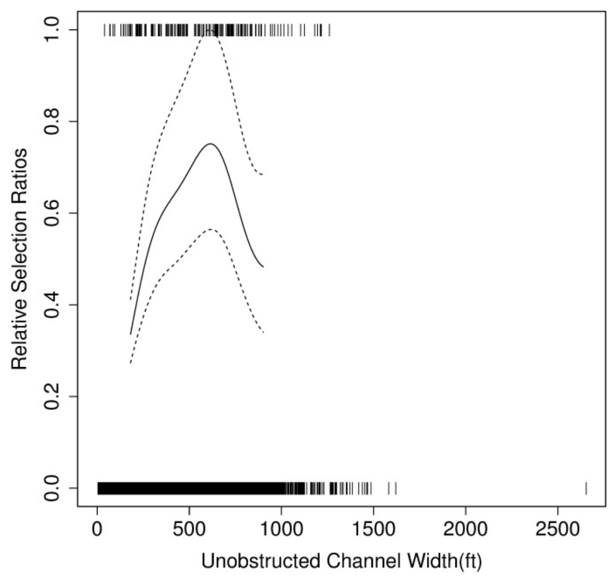
We developed in-channel habitat selection models for the 129 spring, 47 fall, and the combined 176 spring and fall systematic unique and non-unique whooping crane group observations (Table C.1). These observations span the time from fall 2001 to spring 2013. Actual sample sizes in the models were larger because of the inclusion of the data representing the choice set (Table C.1).

Table C.1. Sample size for in-channel models with 20 locations in each choice set. Observations include non-unique locations obtained by systematic sampling from fall 2001 to spring 2013.

Season	Number of Use Locations in Analysis	Total Number of Data Points in Analysis
Spring	129	2709
Fall	47	987
Spring and Fall Combined	176	3696

Habitat Selection for Spring and Fall Combined

As presented in the main body of the report, the top management model for spring and fall observations indicated unobstructed channel width and nearest forest were the most important predictor variables for management purposes. The estimated smoothing spline functions for each of these variables, when fit to all systematic data, were positively increasing with larger values of unobstructed channel width and nearest forest up to a point, after which declines were predicted. The model results indicated the highest selection ratio value was predicted to occur at 615 feet for unobstructed channel width (Figure C.1). Increased nearest forest was associated with a higher predicted selection ratios up to the highest selection ratio predicted to occur at 594 feet from the center of the channel (Figure C.2). The estimated degrees of freedom for the smoothed terms were 4.75 and 3.71 for unobstructed channel width and nearest forest respectively.



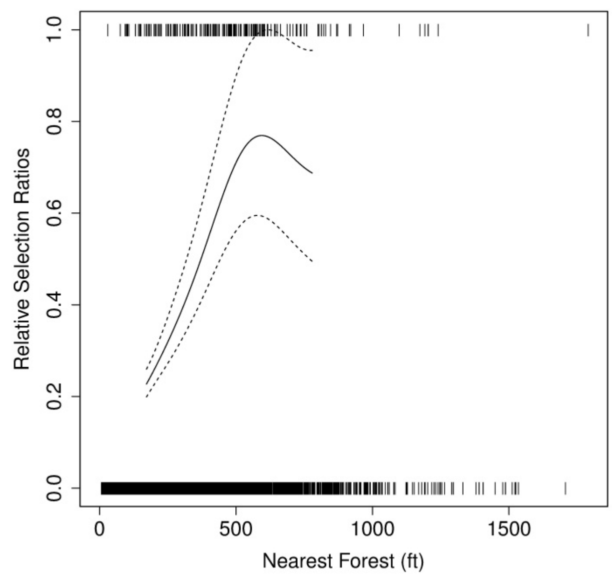


Figure C.1. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of unobstructed channel widths in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

Figure C.2. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest forest in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

As indicated in the main body of the report, the top model for in-channel habitat use for the spring and fall observations combined, across every candidate model in the *a priori* set, indicated nearest obstruction and nearest forest were the most important predictor variables. The estimated smoothing spline functions for each of these variables were positively increasing with larger values of nearest obstruction and nearest forest, indicating a positive relationship between predicted relative selection ratios and each variable. The model results indicate increased nearest obstruction was associated with a higher predicted relative selection ratio with the highest value predicted to occur at 261 feet (Figure C.3). Increased nearest forest was associated with a higher predicted relative selection ratio with the highest value predicted to occur at 697 feet (Figure C.4). The estimated degrees of freedom for the smoothed terms were 4.61 and 3.09 for nearest obstruction and nearest forest respectively.

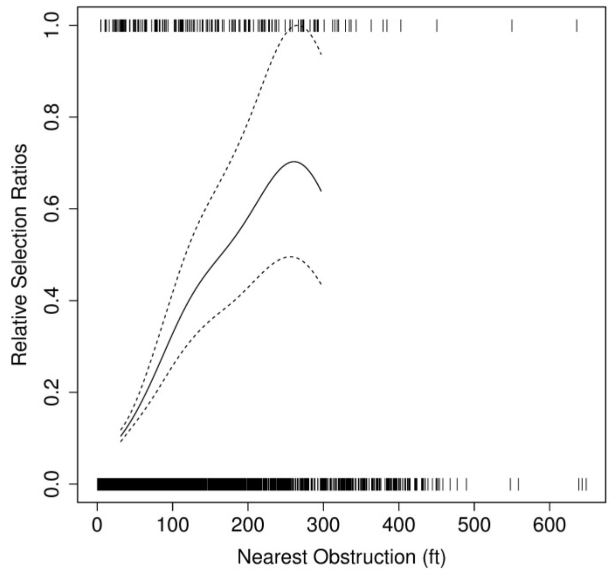


Figure C.3. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest obstruction in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

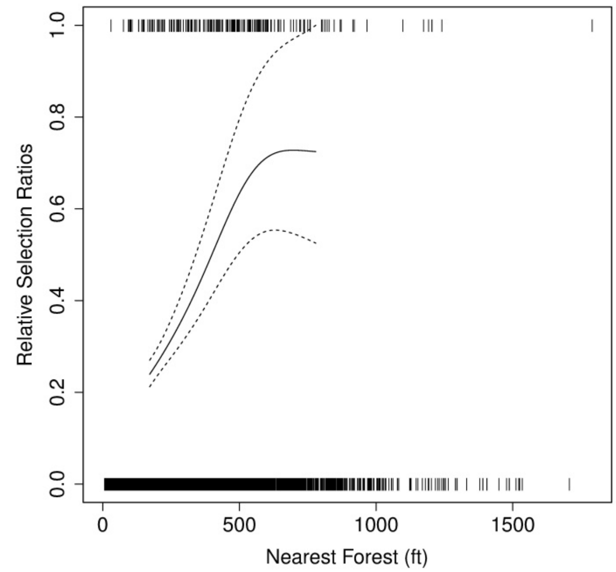


Figure C.4. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest forest in the spring and fall combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

Spring Habitat Selection

The estimated smoothing spline function for nearest obstruction was quadratic shaped depicting predicted selection ratios positively increasing with larger values up to a point, after which declines were predicted. The model results for unobstructed channel width indicated the highest selection ratio was predicted to occur at 266 feet (Figure C.5). The estimated degrees of freedom for the smoothed term was 4.47.

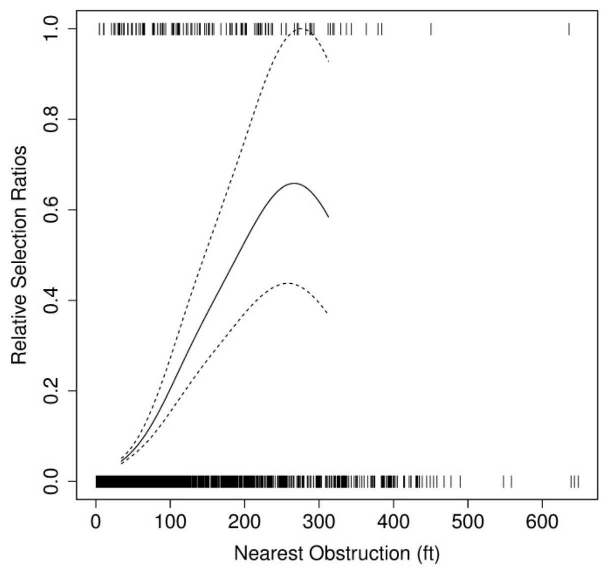


Figure C.5. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest obstruction in the spring. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

Fall Habitat Selection

The parametric function for nearest obstruction was positively increasing with larger values of nearest obstruction, indicating a positive relationship between predicted relative selection ratios and nearest obstruction. The model results indicate increased nearest obstruction was associated with a higher predicted relative selection ratios with the highest value predicted to occur at 289 feet (Figure C.6). Increased total channel width was associated with variable relative selection ratios with the highest value predicted to occur at 672 feet (Figure C.7), though the relationship was not statistically significant (p=0.1290). The estimated degrees of freedom for the model terms were 1 and 3.62 for nearest obstruction and total channel width respectively.

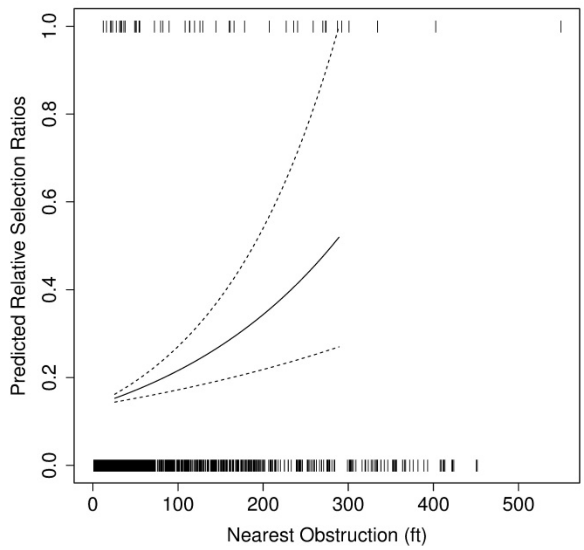


Figure C.6. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of nearest obstruction in the fall. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

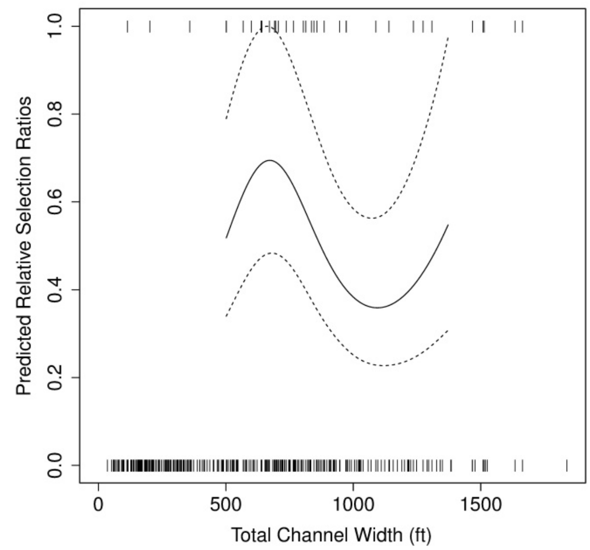


Figure C.7. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of total channel widths in the fall. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

Summary statistics for each variable for the used locations contrasted to the choice sets for fall 2002 to spring 2013 are in Table C.2 and graphical summaries are in Figure C.8 to Figure C.21.

4. Discussion

The in-channel habitat models presented here, with the inclusion of all unique and non-unique systematic locations, related a similar message about whooping crane habitat selection on the central Platte River compared to the results presented in the main body of the report. There were consistent modelled relationships between habitat descriptors and relative selection ratios for each season. The distances at which the curves were maximized, for the majority of linear and quadratic cases, were larger with the inclusion of the non-unique observations compared to the systematic unique results in the main body of the report.

The combined spring and fall models indicated whooping cranes selected for larger distances to nearest forest and obstruction and wider unobstructed channel widths up to a point after which the relative selection ratios declined. The selection ratios for unobstructed channel width and nearest forest in the top management model were maximized at 615 and 594 feet, respectively, it can be inferred based on the confidence intervals at these peaks that unobstructed channel widths between 315 and 799 feet and distances between 425 and 779 feet to the nearest forest would result in statistically similar selection ratios. For the top overall model, the selection ratios for nearest obstruction and nearest forest were maximized at 261 and 697 feet, respectively, based on the confidence intervals, that distances to nearest obstruction between 162 and 297 feet and distances between 432 and 779 feet to the nearest forest would result in statistically similar selection ratios.

The spring model suggested whooping cranes selected wide unobstructed views, with the maximum at 266 feet. Whooping crane groups were observed across a wide range of values and it can be inferred based on confidence intervals that nearest obstruction distances between 170 and 313 feet would result in statistically similar selection ratios.

The fall model suggested whooping cranes selected wide unobstructed views, with the maximum at 289 feet. Based on the confidence intervals at the peak, nearest obstruction distances as small as 148 feet would result in statistically similar selection ratios. Total channel width in the fall model suggested whooping cranes selected wide unobstructed views, with the maximum at 672 feet. Based on the confidence intervals at the peak, channel widths between 501 and 886 feet would result in statistically similar selection ratios.

Table C.2. Mean, standard deviation (SD), and coefficient of variation (CV) for each variable in the analysis, excluding fall 2001 and spring 2002 observations. Spring sample sizes were 115 for used locations and 2300 for the choice sets, fall sample sizes were 46 for used locations and 920 for the choice sets. Variable abbreviations are in the methods section of the main body of the report.

		Choice Sets			Used Locations		
Variable	**Season**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
UOCW	Fall	385.69	286.88	74.38	482.29	305.01	63.24
	Spring	365.11	326.56	89.44	552.65	295.64	53.50
	Spring and Fall	370.99	315.83	85.13	532.55	299.09	56.16
NO	Fall	87.06	93.48	107.37	138.67	116.95	84.34
	Spring	74.85	91.04	121.64	157.07	110.71	70.49
	Spring and Fall	78.34	91.90	117.31	151.81	112.47	74.09
UFW	Fall	1886.22	2073.91	109.95	2201.24	1442.50	65.53
	Spring	2045.23	2349.08	114.86	2977.81	2924.93	98.22
	Spring and Fall	1999.80	2274.68	113.75	2755.93	2608.58	94.65
NF	Fall	320.78	247.72	77.22	497.40	213.48	42.92
	Spring	298.17	244.92	82.14	447.73	264.53	59.08
	Spring and Fall	304.63	245.89	80.72	461.92	251.36	54.42
TCW	Fall	754.04	403.75	53.55	869.11	359.79	41.40
	Spring	644.34	402.61	62.48	765.92	344.29	44.95
	Spring and Fall	675.68	405.91	60.07	795.40	350.79	44.10
WW	Fall	339.78	212.87	62.65	447.52	229.15	51.20
	Spring	368.02	225.17	61.18	485.47	220.89	45.50
	Spring and Fall	359.95	222.06	61.69	474.63	223.22	47.03
PW	Fall	0.52	0.26	50.79	0.55	0.25	46.34
	Spring	0.63	0.22	35.48	0.67	0.23	34.44
	Spring and Fall	0.60	0.24	40.28	0.64	0.24	38.34
MD	Fall	0.95	0.58	60.42	0.93	0.58	62.40
	Spring	1.19	0.54	45.60	1.00	0.42	41.87
	Spring and Fall	1.12	0.56	50.13	0.98	0.47	47.92
UD	Fall	1.27	1.72	135.72	1.06	1.26	119.45
	Spring	1.85	2.00	108.06	1.53	1.19	77.55
	Spring and Fall	1.69	1.94	115.31	1.40	1.22	87.73
WDR	Fall	483.20	425.48	88.05	583.90	344.62	59.02
	Spring	387.48	326.02	84.14	581.56	365.71	62.88
	Spring and Fall	414.83	359.82	86.74	582.23	358.74	61.62
PC	Fall	42.39	6.34	14.95	42.10	6.82	16.21
	Spring	40.39	7.22	17.87	39.52	6.75	17.07
	Spring and Fall	40.96	7.03	17.17	40.26	6.85	17.01
PF	Fall	7.12	1.61	22.65	7.29	1.55	21.22
	Spring	7.22	2.33	32.27	6.61	2.25	34.03
	Spring and Fall	7.20	2.15	29.89	6.80	2.09	30.74
PWM	Fall	10.95	6.32	57.68	11.48	5.43	47.27
	Spring	12.59	6.34	50.35	14.27	7.41	51.89
	Spring and Fall	12.12	6.37	52.59	13.47	7.00	51.93

		Choice Sets			Used Locations		
Variable	**Season**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
PG	Fall	24.47	6.92	28.28	25.27	6.63	26.24
PG	Spring	25.79	7.15	27.73	27.13	7.20	26.53
	Spring and Fall	25.41	7.11	27.98	26.60	7.07	26.58

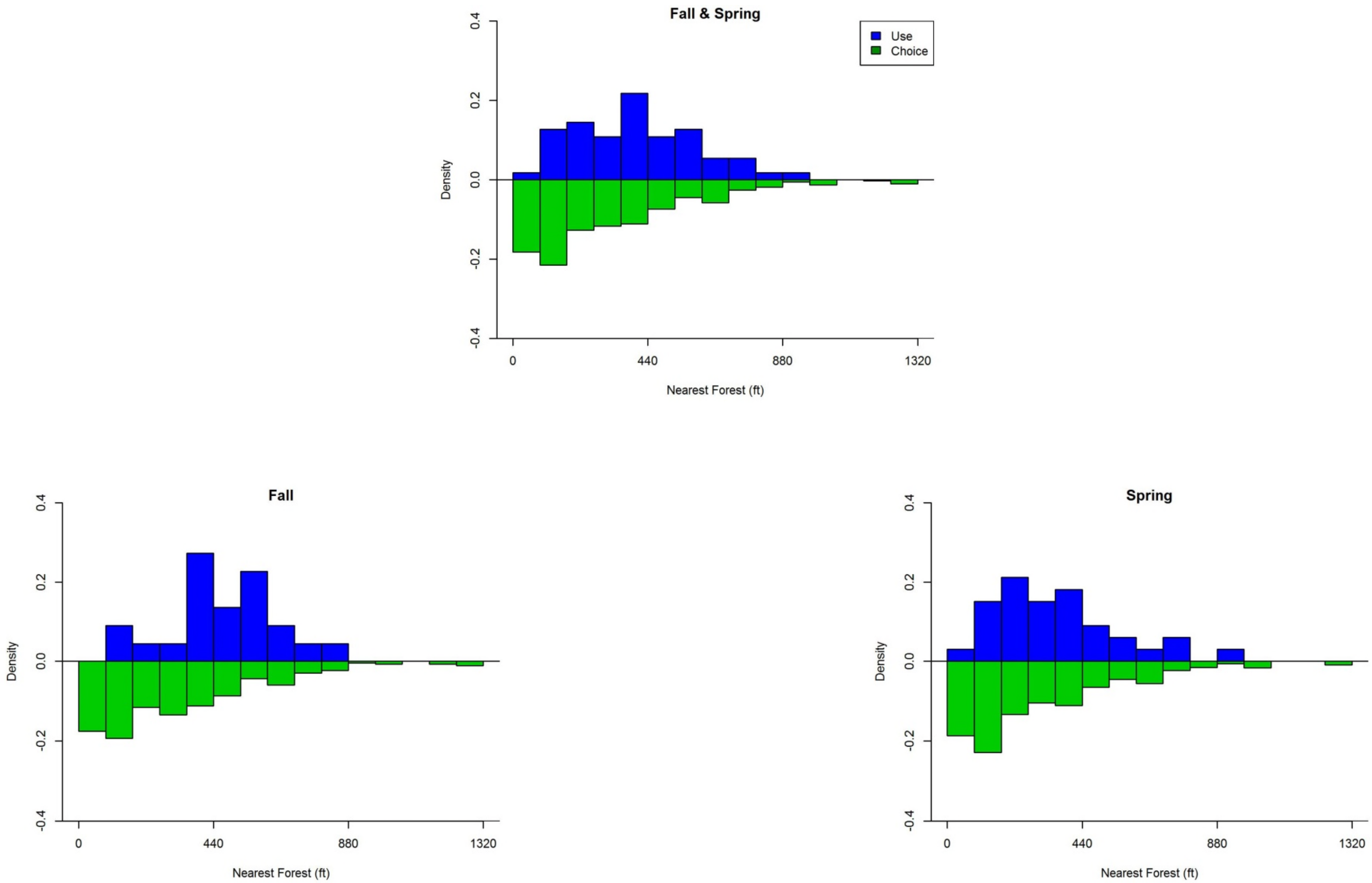
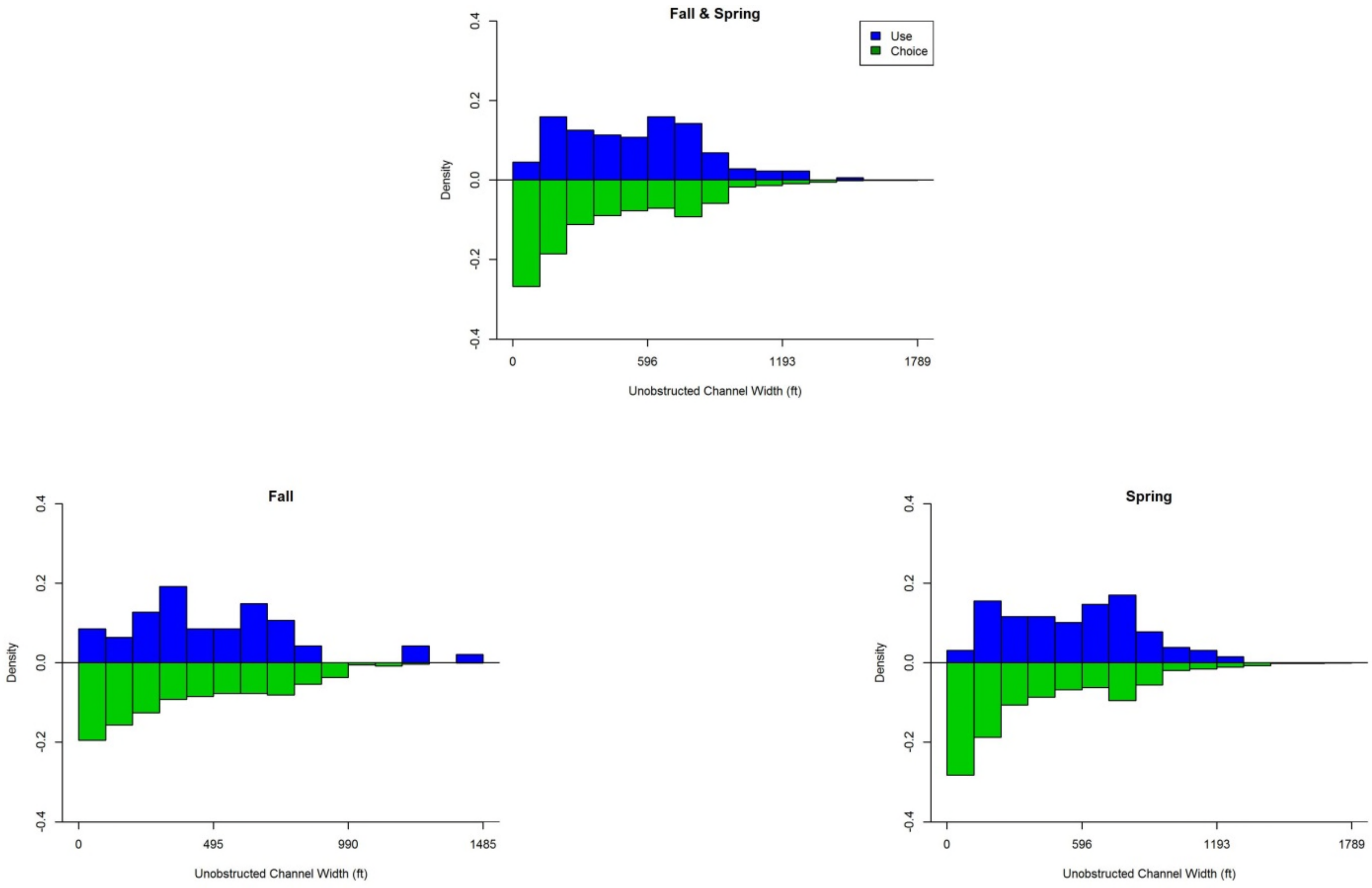


Figure C.8. Histograms of nearest riparian forest (feet [ft]) at all systematic locations of use by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).



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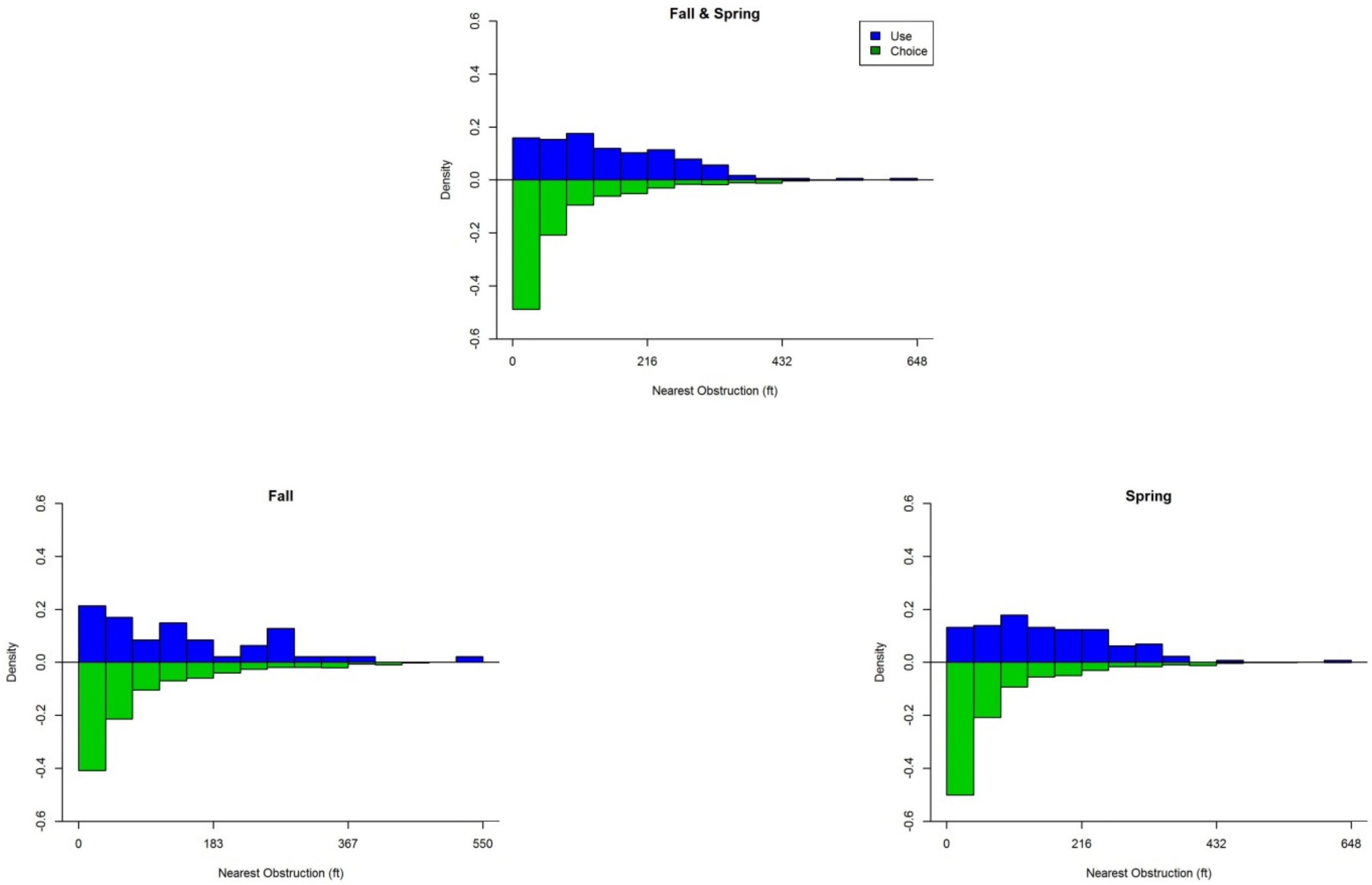

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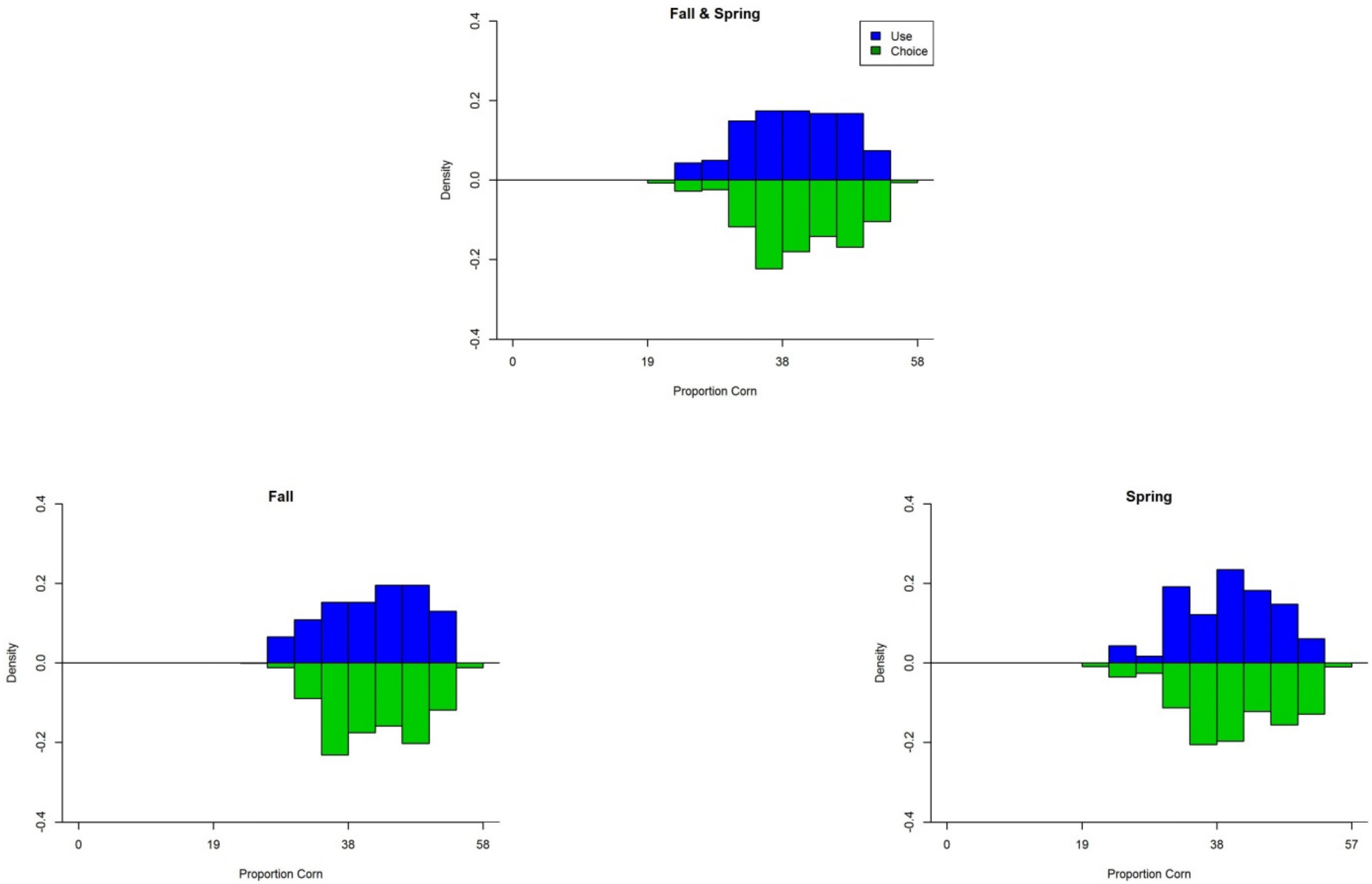

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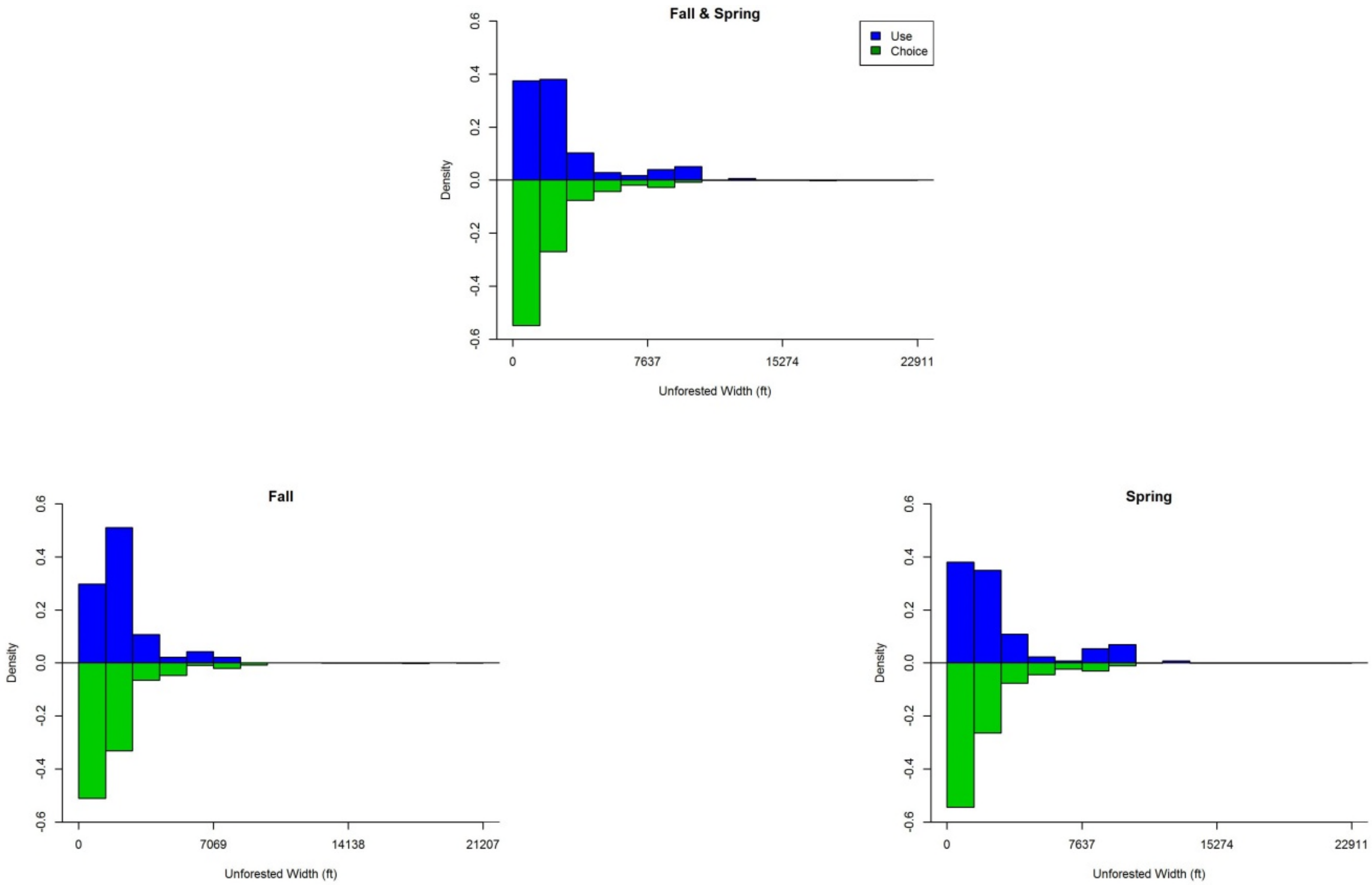
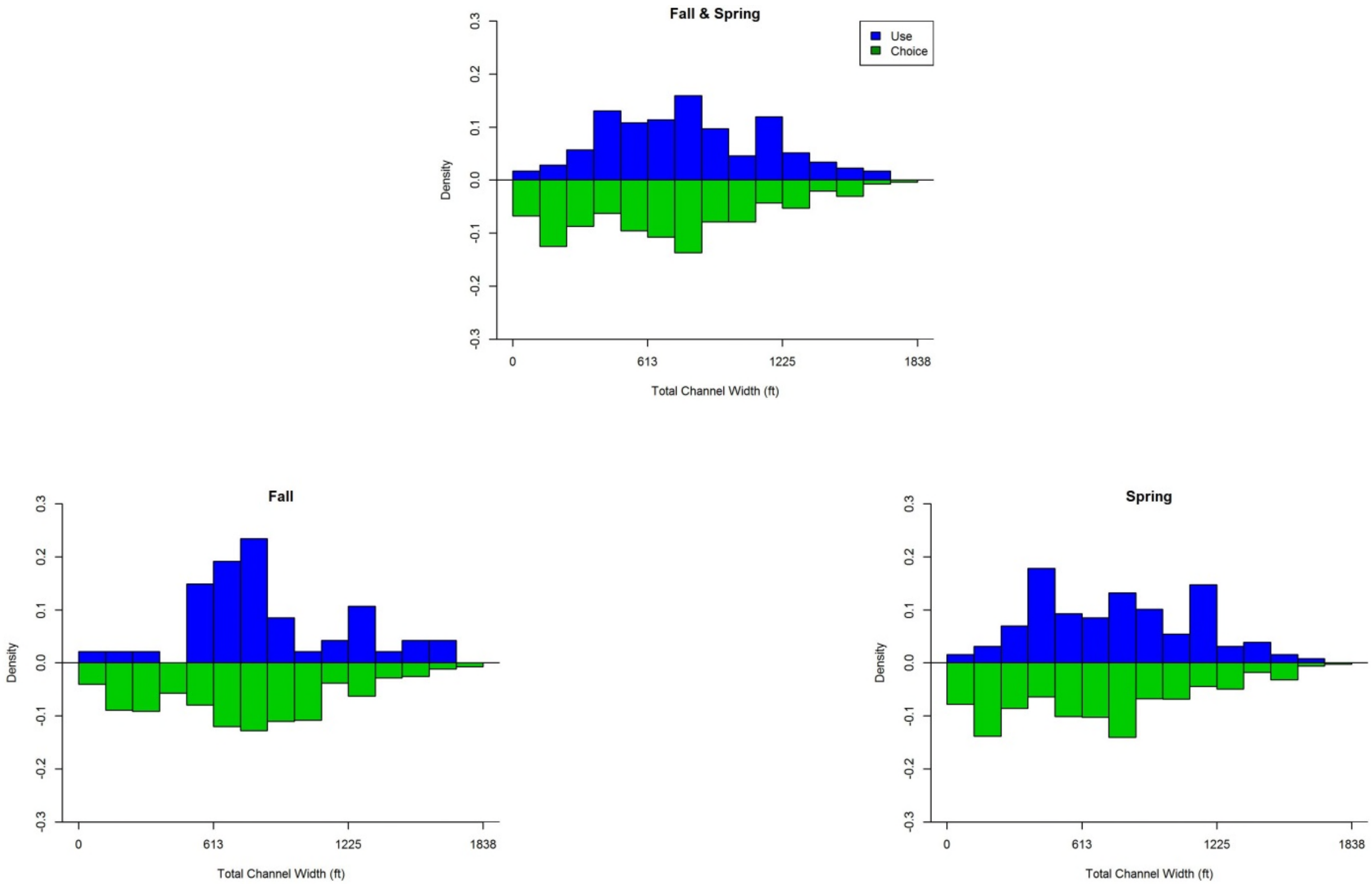


Figure C.12. Histograms of width of river corridor not obstructed by riparian forest (feet [ft]) at all systematic locations of use by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).



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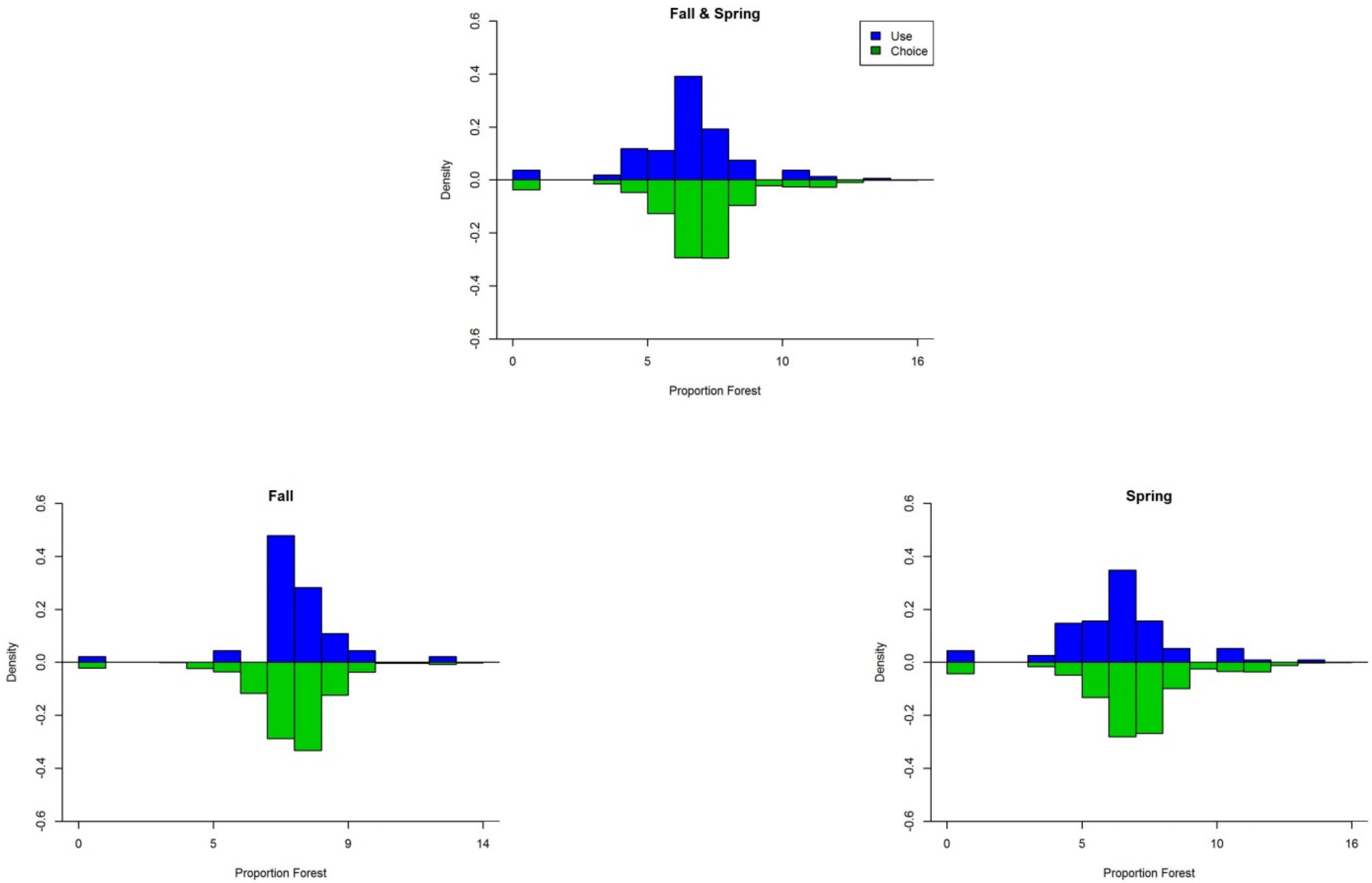

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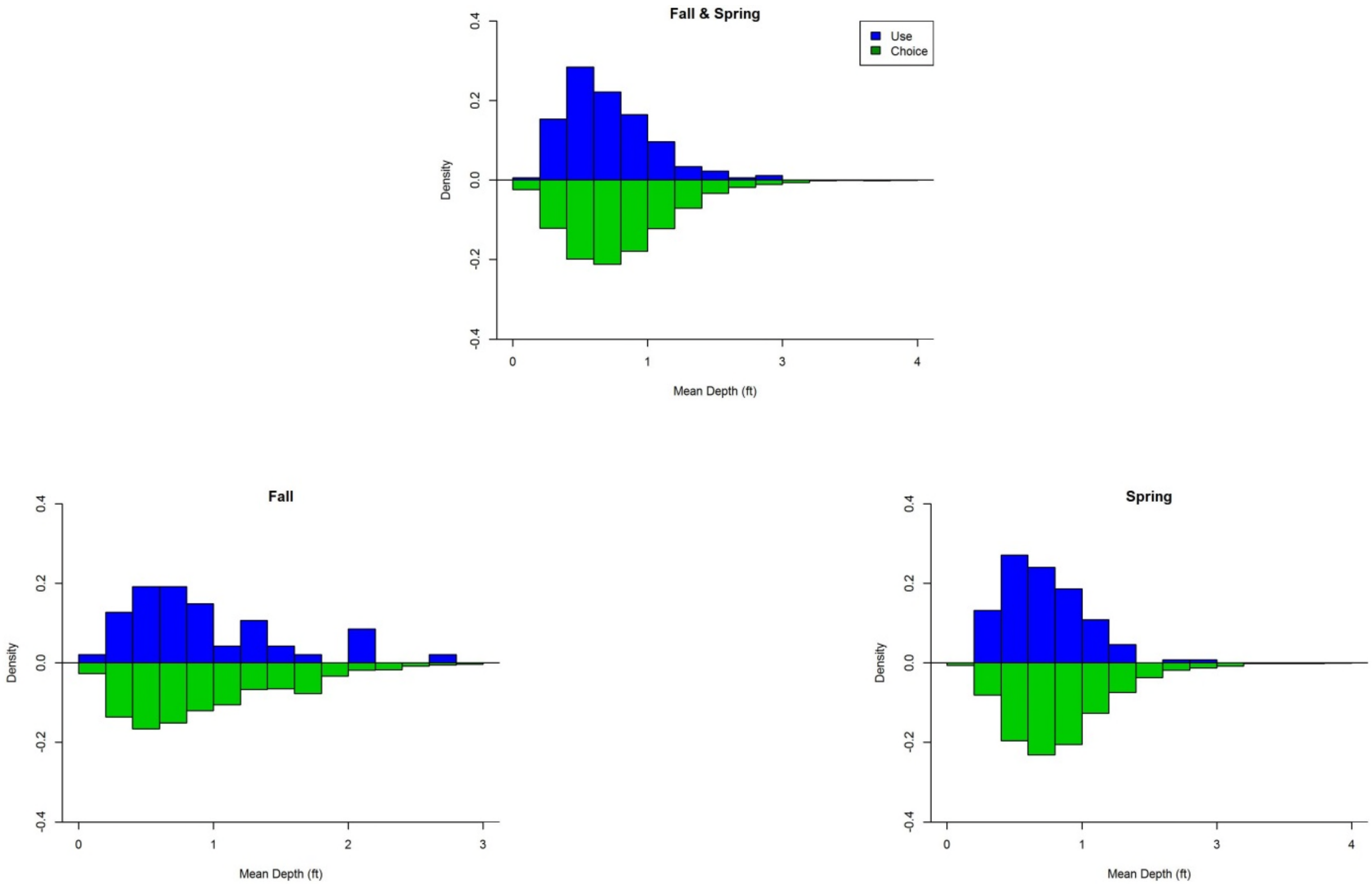

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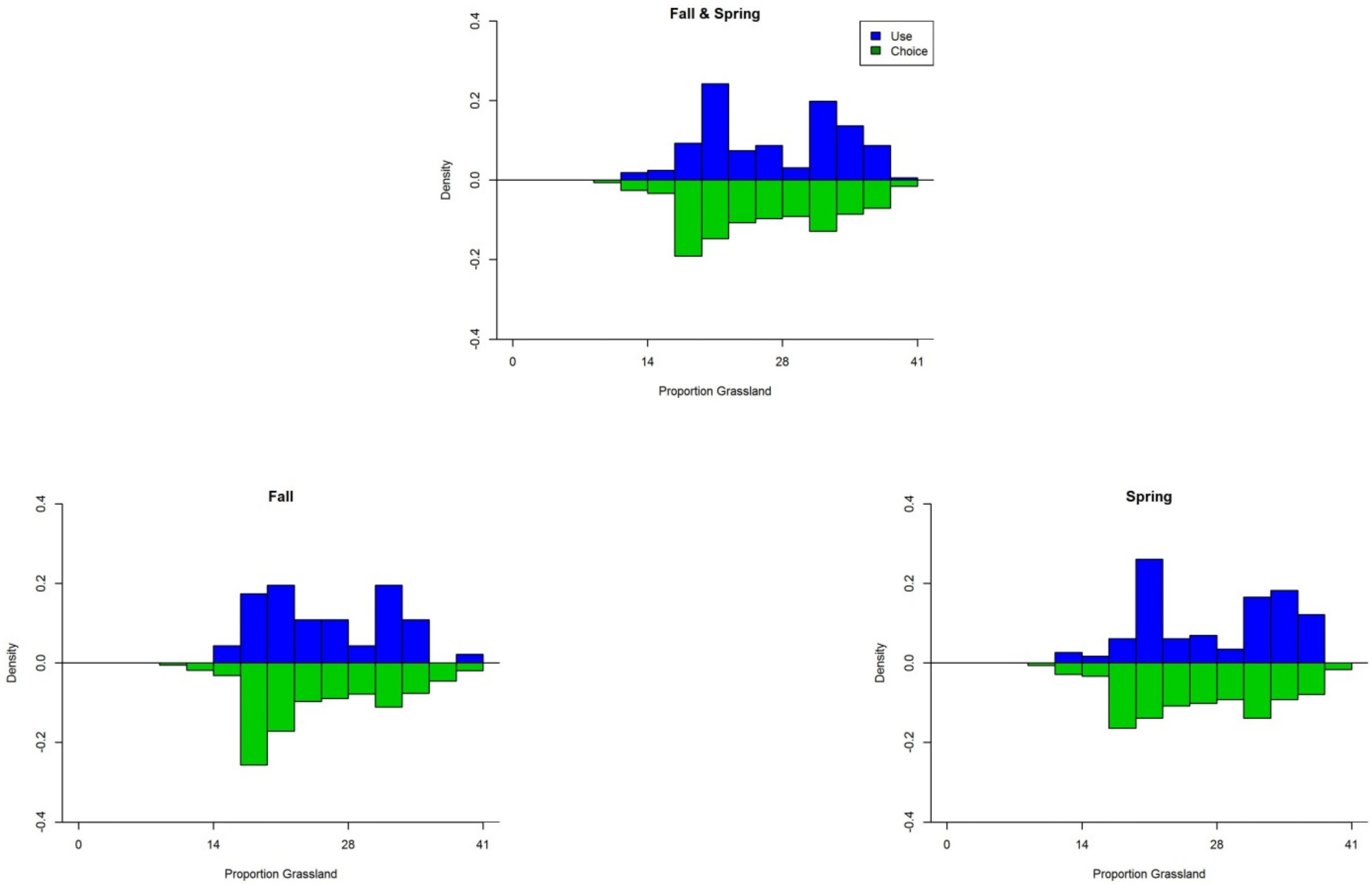

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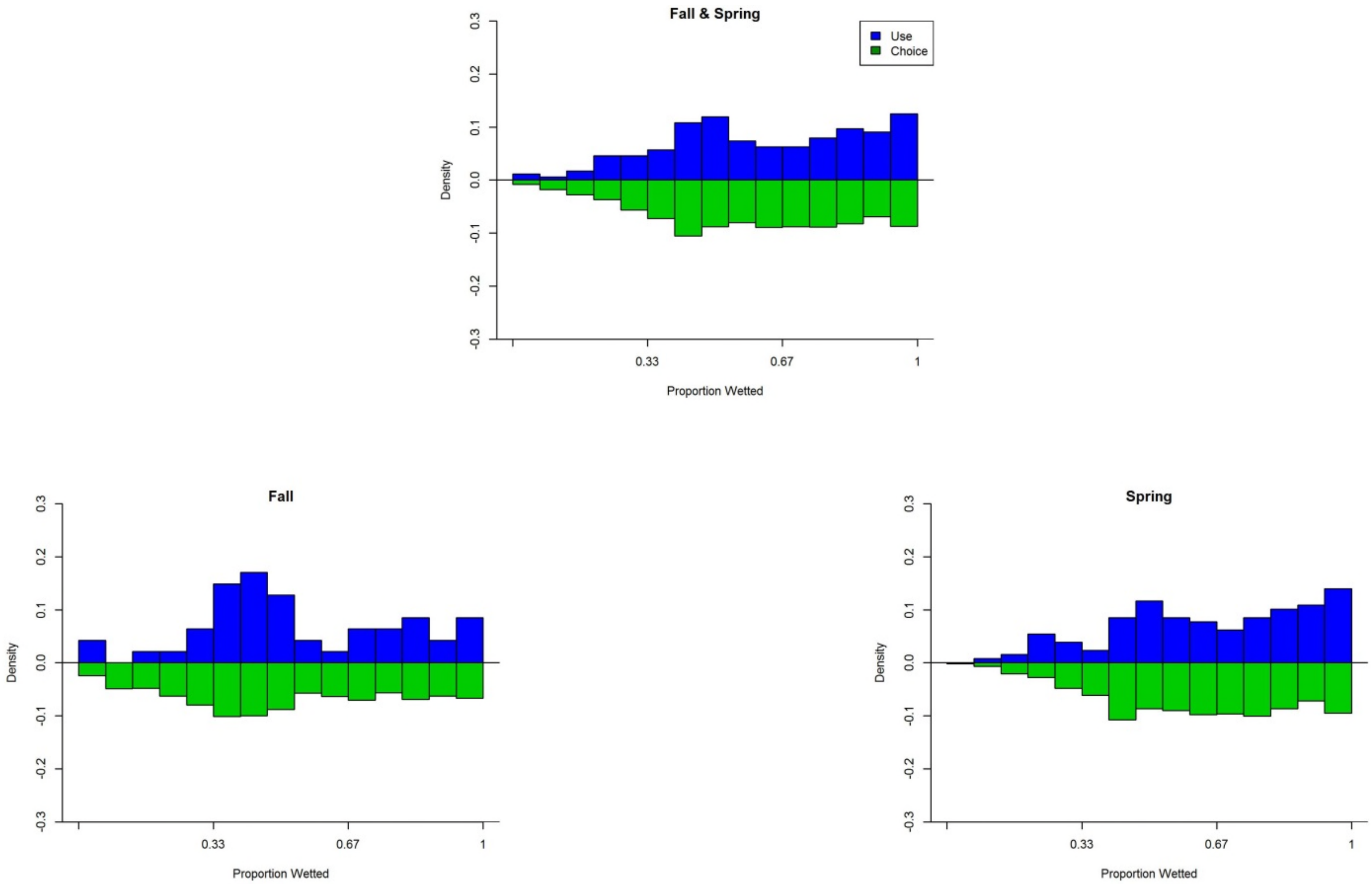

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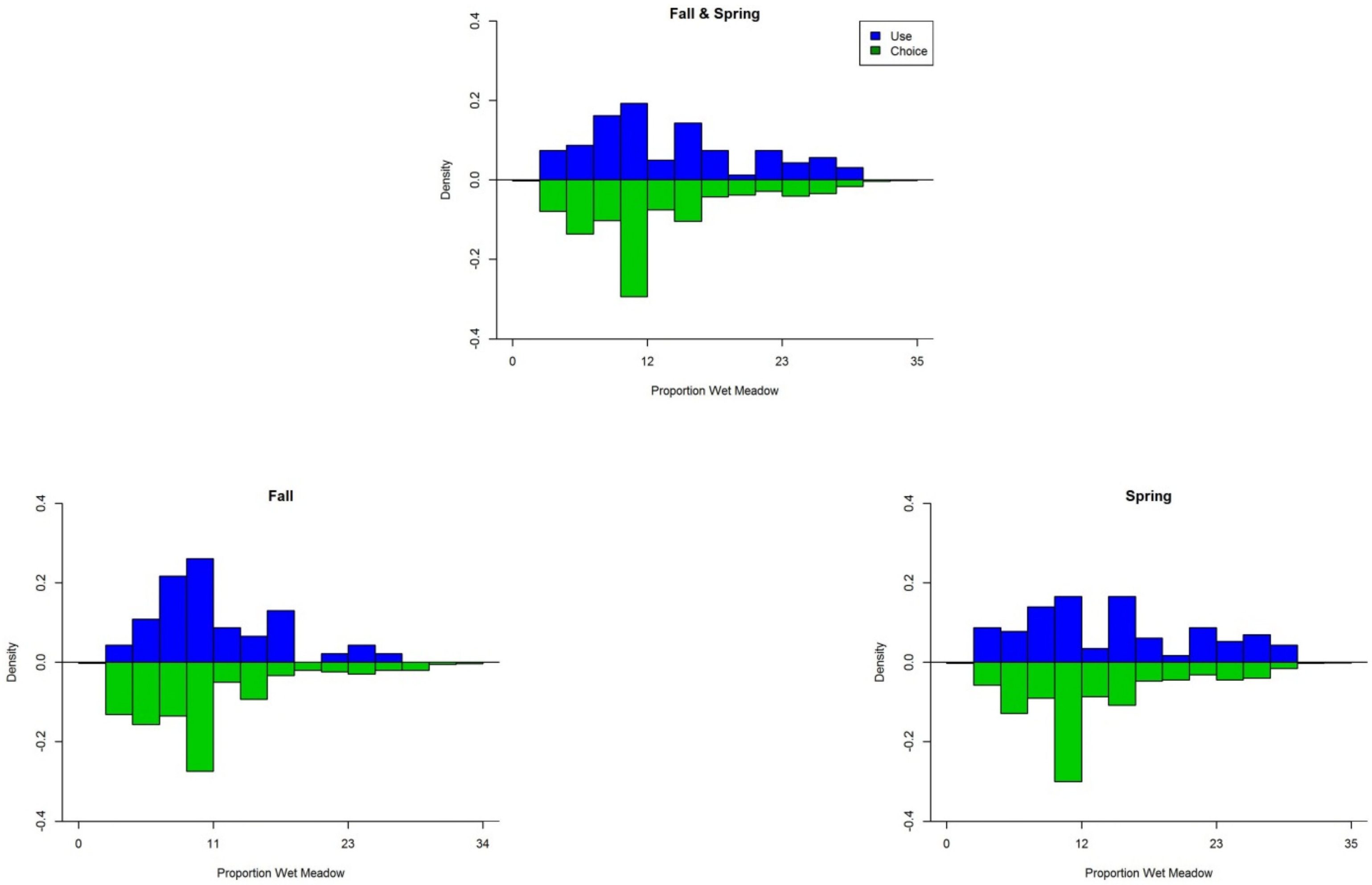

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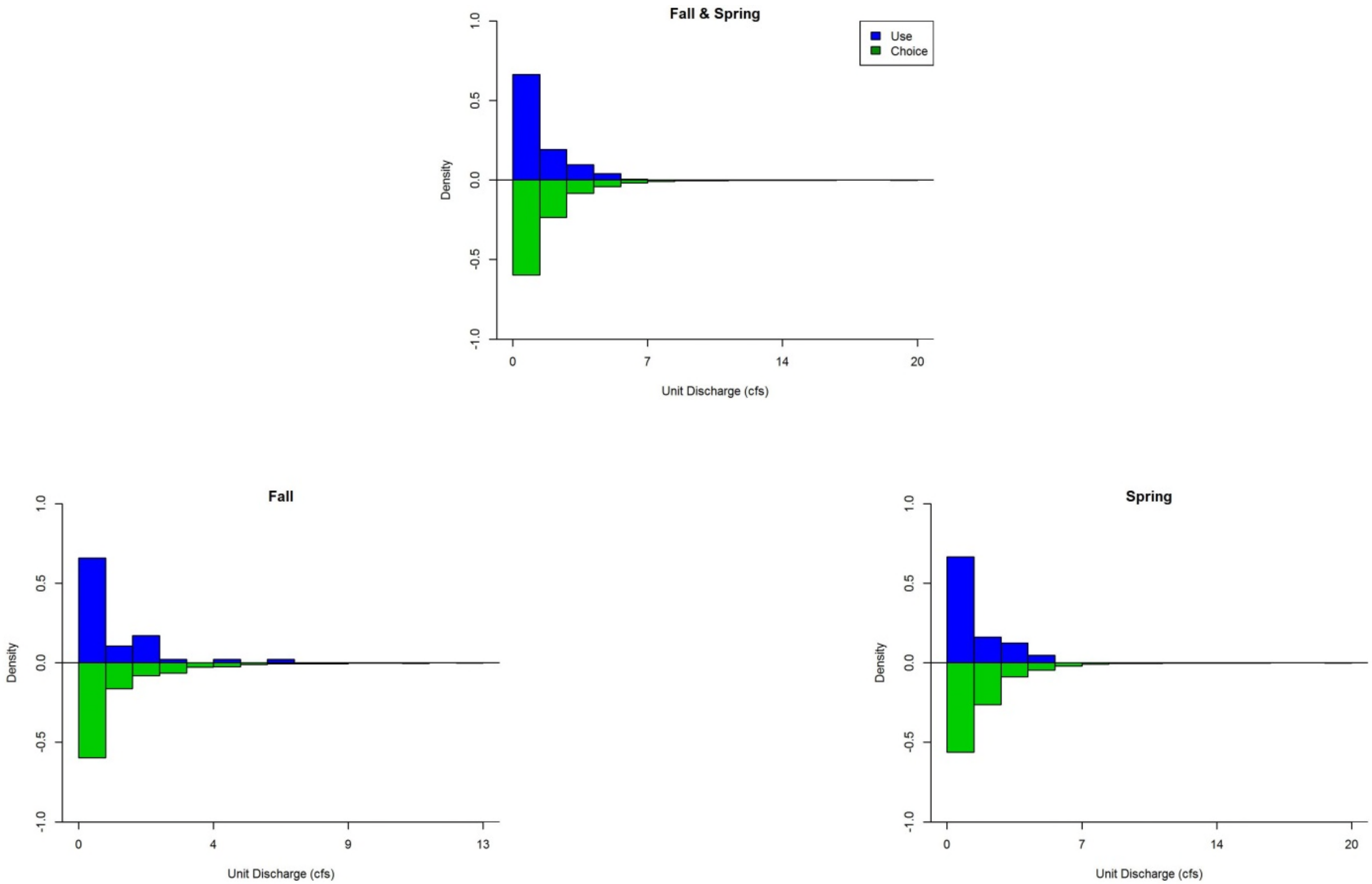

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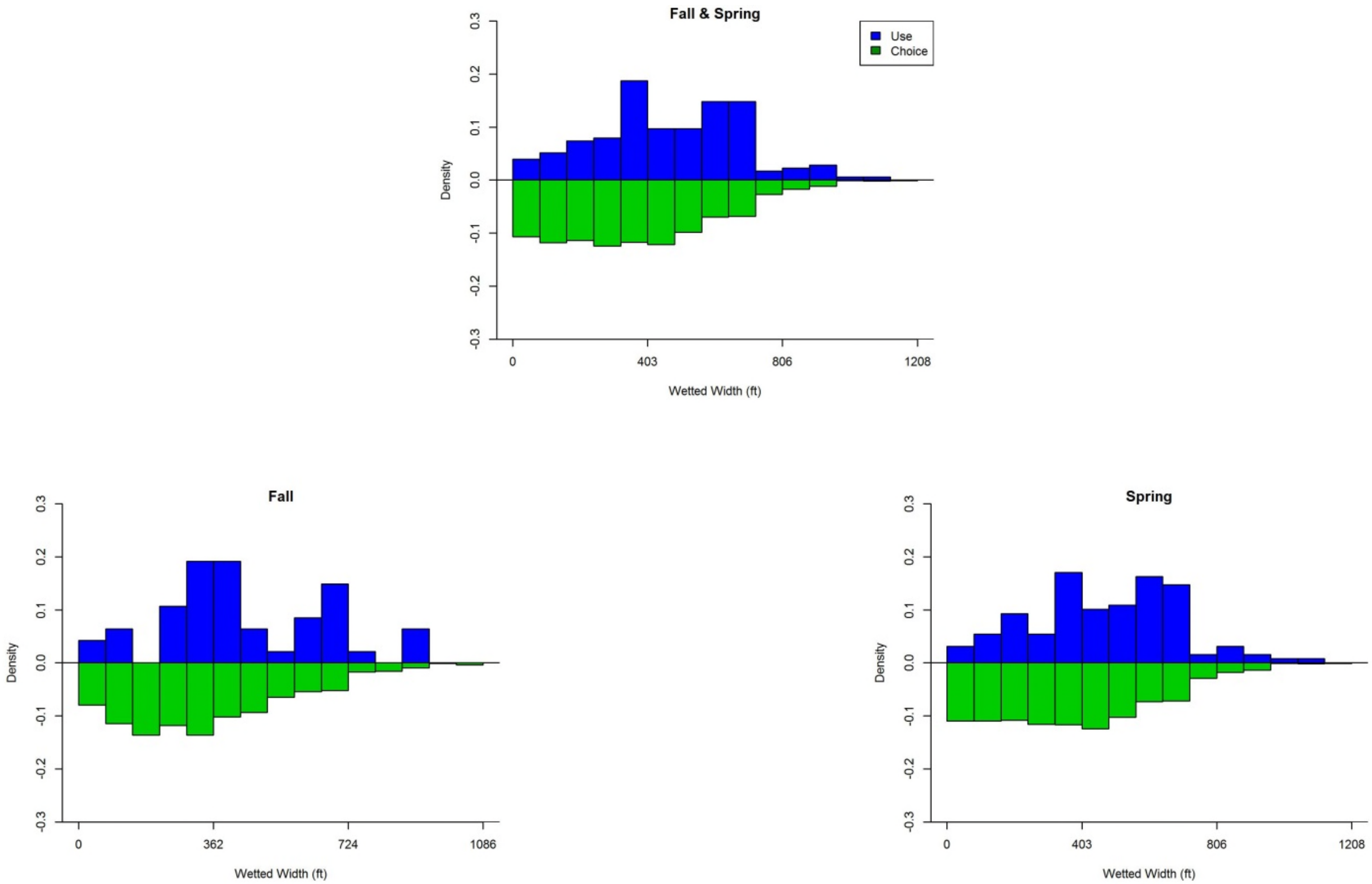

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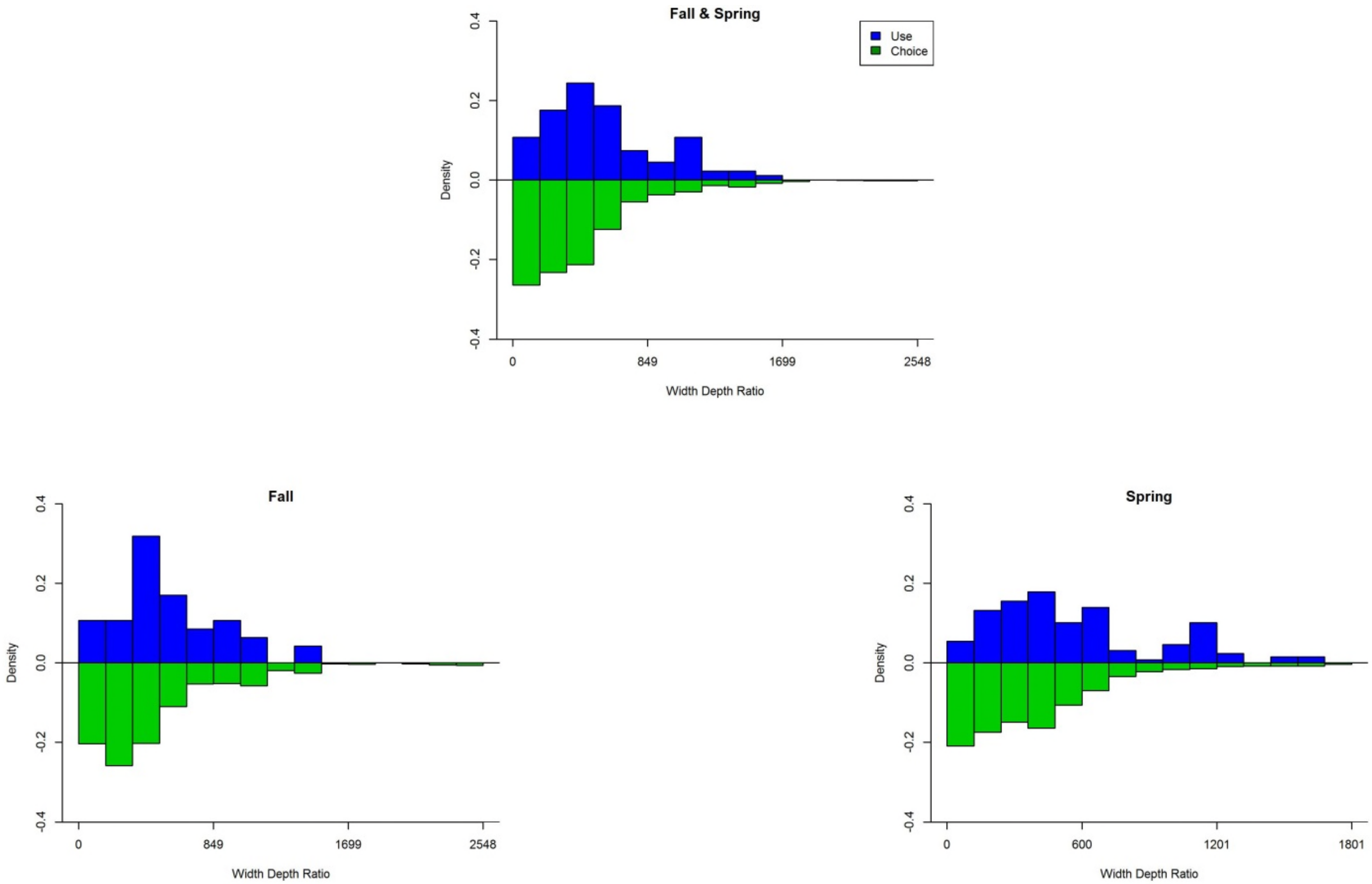

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Appendix D. Analysis of Systematic and Opportunistic In-Channel Whooping Crane Observations

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Table D.2. Mean, standard deviation (SD), and coefficient of variation (CV) for each variable in the analysis, excluding fall 2001 and spring 2002 observations. Spring sample sizes were 138 for used locations and 2760 for the choice sets, fall sample sizes were 56 for used locations and 1120 for the choice sets. Winter sample sizes were 42 for used locations and 840 for the choice sets. Variable abbreviations are in the methods section of the main body of the report. 8

1. Introduction

We reran the analysis presented in the main body of the report on a third set of data. This analysis was conducted to incorporate every observation of whooping crane groups in the central Platte River during the study period, in order to increase the sample size of the modelling efforts. We included all observations obtained through systematic sampling or opportunistic reports in the analysis for this appendix. This includes groups of whooping cranes spotted during the aerial surveys, observations by on-the-ground monitors during the surveys, and any other observation reported by the public or other entities along the central Platte River. The additional sightings are from both multiple sightings of crane groups assumed to have been located previously in the study area, and any observation reported to PRRIP or USWFS. There were an additional 25 observations in the spring migration, an additional 10 observations in the fall migration, and an additional 42 observations in the winter.

As mentioned in the introduction to Appendix C, the inclusion of multiple observations of crane groups in the sample can bias the response of interest, i.e. habitat selection. The results that have been presented in the main body of the report, based only on unique or independent observations, contain less sampling bias than results presented in this appendix. The impact of including non-unique and opportunistic observations in this analysis was evaluated by fitting these data to the same models that were presented in the main body of the report.

2. Methods

For this analysis of habitat use we followed the same methods as written in the Methods section of the main body of the report. There were no changes in the definition of available habitat or the descriptors of habitat use. We did not repeat model selection but fit the best models identified during the analysis of the systematic unique data.

3. Results

Whooping Crane Group Observations

We developed models of in-channel habitat selection for the 154 spring, 57 fall, and the combined 253 spring, fall, and winter observations of whooping crane groups (Table D.1). These observations span the time from fall 2001 to spring 2013. Actual sample sizes in the models were larger because of the inclusion of the data representing the choice set (Table D.1).

Table D.1. Sample size for in-channel models with 20 locations in each choice set. Observations include all locations obtained by systematic sampling or opportunistically from fall 2001 to spring 2013.

Season	Number of Use Locations in Analysis	Total Number of Data Points in Analysis
Spring	154	3243
Fall	57	1197
All Seasons Combined [A]	253	5313

[A]Includes 42 winter use locations each with a choice set of 20 locations.

Habitat Selection for Spring, Fall and Winter Combined

As presented in the main body of the report, the top model for spring and fall observations indicated unobstructed channel width and nearest forest were the most important predictor variables for management purposes. The estimated smoothing spline functions for unobstructed channel width when fit to all data, initially increased with larger widths, and then decreased before continuing to increase with larger widths. The model results indicated the highest selection ratio value was predicted to occur at 1,052 feet for unobstructed channel width (Figure D.1). The estimated smoothing spline function for nearest forest was positively increasing with larger values of nearest forest up to a point, after which declines were predicted. Increased nearest forest was associated with higher predicted selection ratios up to the highest selection ratio predicted to occur at 547 feet from the center of the channel (Figure D.2). The estimated degrees of freedom for the smoothed terms were 6.15 and 5.11 for unobstructed channel width and nearest forest respectively.

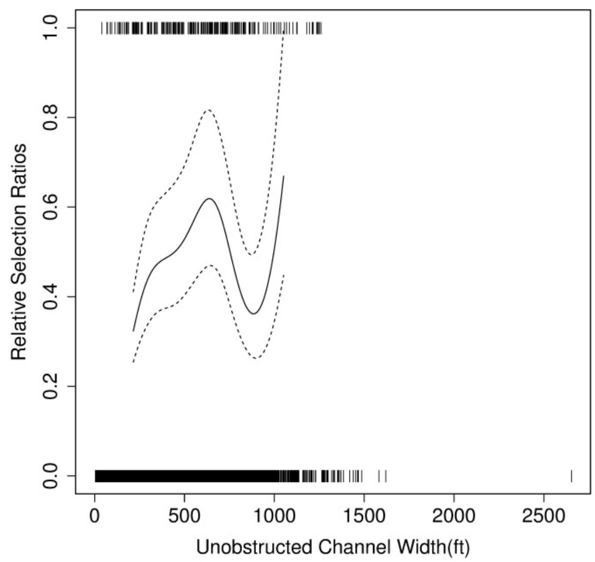


Figure D.1. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of unobstructed channel widths in the spring, fall, and winter combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

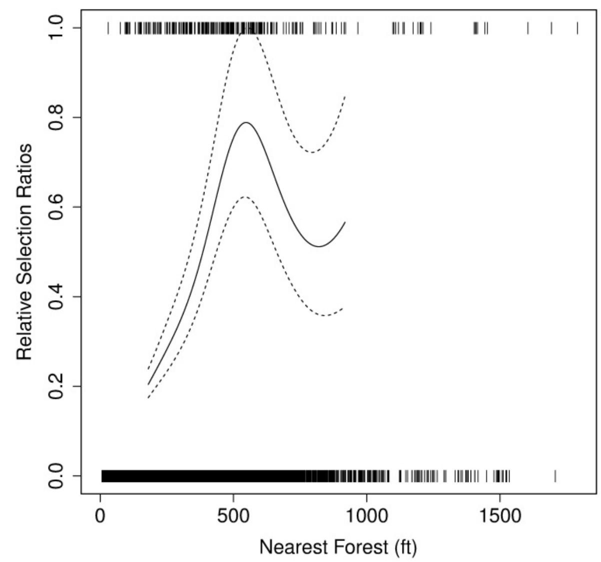


Figure D.2. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of nearest forest in the spring, fall, and winter combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

As indicated in the main body of the report, the top model for in-channel habitat use for the spring and fall observations combined, across every candidate model in the *a priori* set, indicated nearest obstruction and nearest forest were the most important predictor variables. The estimated smoothing spline functions for each of these variables were positively increasing with larger values of nearest obstruction and nearest forest, indicating a positive relationship between predicted relative in-channel selection ratios and each variable. The model results indicate increased nearest obstruction was associated with higher predicted relative selection ratios with the highest value predicted to occur at 260 feet (Figure D.3). Increased nearest forest was associated with higher predicted relative in-channel selection ratios with the highest value predicted to occur at 919 feet (Figure D.4). The estimated degrees of freedom for the smoothed terms were 5.42 and 3.94 for nearest obstruction and nearest forest respectively.

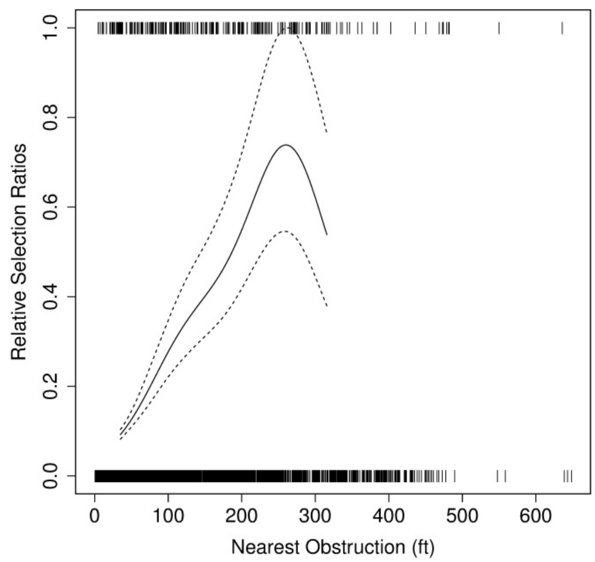


Figure D.3. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest obstruction in the spring, fall, and winter combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

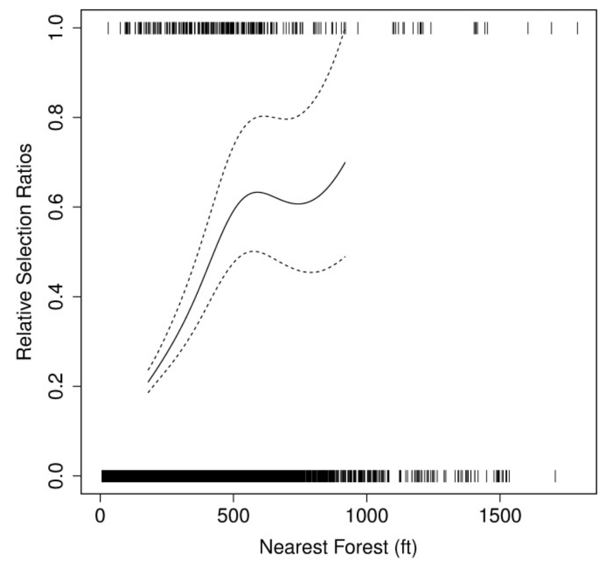


Figure D.4. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest forest in the spring, fall, and winter combined. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

Spring Habitat Selection

The estimated smoothing spline function for nearest obstruction was quadratic shaped depicting predicted selection ratios positively increasing with larger values up to a point, after which declines were predicted. The model results for nearest obstruction indicated the highest predicted selection ratio occured at 258 feet (Figure D.5). The estimated degrees of freedom for the smoothed term was 4.80.

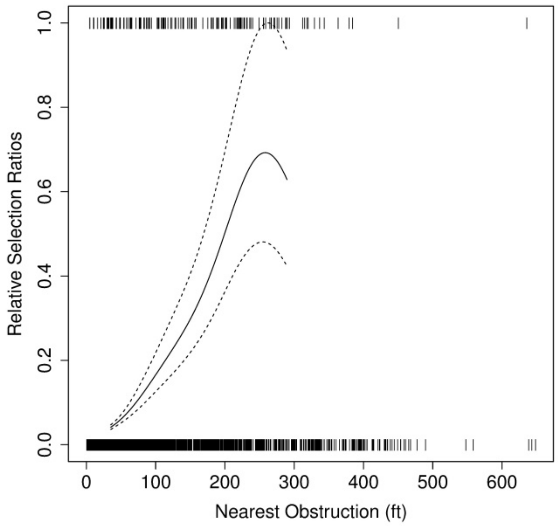


Figure D.5. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of distances to nearest obstruction in the spring. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

Fall Habitat Selection

The parametric function for nearest obstruction was positively increasing with larger values of nearest obstruction, indicating a positive relationship between predicted relative selection ratios and nearest obstruction. The model results indicate increased nearest obstruction was associated with a higher predicted relative selection ratios with the highest value predicted to occur at 279 feet (Figure D.6). Increased total channel width was associated with variable relative selection ratios with the highest predicted values to occur at 689 feet (Figure D.7). The estimated degrees of freedom for the model terms were 1 and 4.27 for nearest obstruction and total channel width respectively.

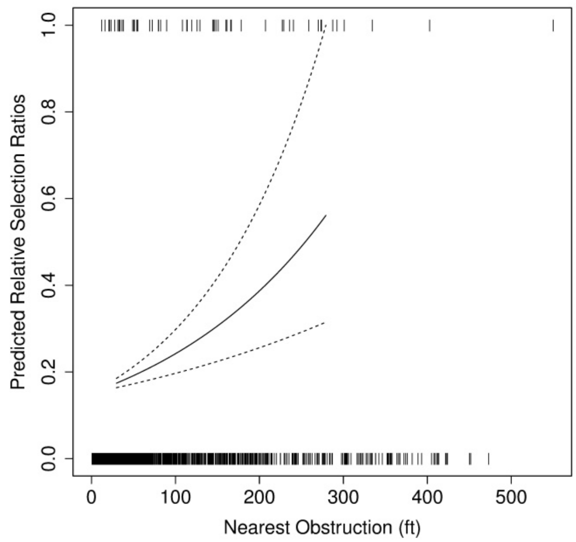


Figure D.6. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of nearest obstruction in the fall. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

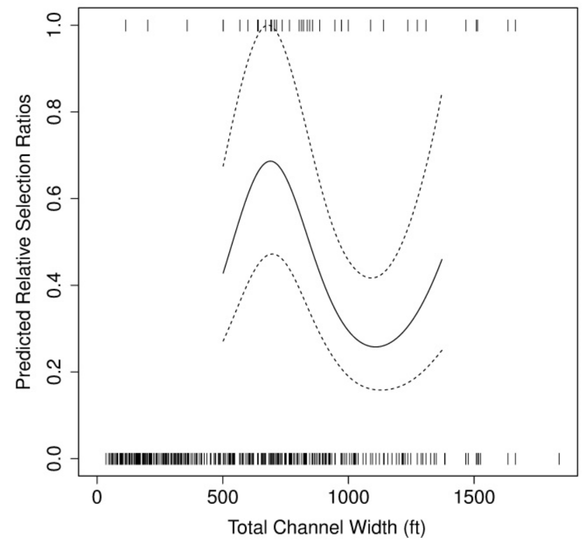


Figure D.7. Predicted relative in-channel selection ratios by groups of whooping cranes in the central Platte River, with 90% confidence intervals, across the range of total channel width in the fall. Tick marks indicate actual data (use points are above at y=1, choice set points are below at y=0).

Summary statistics for each variable for the used locations contrasted to the choice sets for fall 2002 to spring 2013 are in Table D.2 and graphical summaries are in Figure D.8 to Figure D.21.

4. Discussion

The in-channel habitat models presented here, with the inclusion of all systematic locations and opportunistic locations, relate a similar message about whooping crane habitat selection on the central Platte River as the analysis in the main report and the analysis with systematic locations presented in Appendix C. There were consistent modelled relationships between habitat descriptors and relative selection ratios for each season. The distances at which the response curves were maximized, for the majority of linear and quadratic cases, were larger with the inclusion of the non-unique and opportunistic observations compared to the systematic unique results in the main body of the report.

The combined spring and fall models indicated whooping cranes selected for larger distances to nearest forest and obstruction and wider unobstructed channel widths up to a point after which the relative selection ratios generally declined. The selection ratios for unobstructed channel width and nearest forest in the top management model were maximized at 1,052 and 547 feet, respectively, it can be inferred based on the confidence intervals at these peaks that unobstructed channel widths greater than 305 feet and distances between 436 and 682 feet to the nearest forest would result in statistically similar selection ratios. For the top overall model, the selection ratios for nearest obstruction and nearest forest were maximized at 260 and 919 feet, respectively, based on the confidence intervals, that distances to nearest obstruction between 199 and 314 feet and distances to the nearest forest greater than 420 feet would result in statistically similar selection ratios.

The spring model suggested whooping cranes selected wide unobstructed views, with the maximum at 258 feet. Whooping crane groups were observed across a wide range of values and it can be inferred based on confidence intervals that nearest obstruction distances between 195 and 290 feet would result in statistically similar selection ratios.

The fall model suggested whooping cranes selected wide unobstructed views, with the maximum at 279 feet. Based on the confidence intervals at the peak, nearest obstruction distances as small as 156 feet would result in statistically similar selection ratios. Total channel width in the fall model suggested whooping cranes selected wide unobstructed views, with the maximum at 689 feet. Based on the confidence intervals at the peak, channel widths between 524 and 860 feet would result in statistically similar selection ratios.

Table D.2. Mean, standard deviation (SD), and coefficient of variation (CV) for each variable in the analysis, excluding fall 2001 and spring 2002 observations. Spring sample sizes were 138 for used locations and 2760 for the choice sets, fall sample sizes were 56 for used locations and 1120 for the choice sets. Winter sample sizes were 42 for used locations and 840 for the choice sets. Variable abbreviations are in the methods section of the main body of the report.

		Choice Sets			Used Locations		
Variable	**Season**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
UOCW	Spring	369.00	323.86	87.77	593.36	309.98	52.24
	Fall	385.79	286.13	74.17	489.39	291.48	59.56
	Winter	379.86	280.12	73.74	743.43	360.14	48.44
	All Seasons	374.91	307.80	82.10	595.39	324.23	54.46
NO	Spring	75.24	89.76	119.29	159.60	108.01	67.68
	Fall	86.19	92.89	107.77	140.00	109.41	78.15
	Winter	81.41	84.06	103.26	245.61	136.21	55.46
	All Seasons	78.94	89.63	113.55	170.26	118.91	69.84
UFW	Spring	2045.92	2349.44	114.83	2940.87	2802.81	95.31
	Fall	1878.53	1994.15	106.15	2607.81	1775.44	68.08
	Winter	2377.97	2609.37	109.73	3731.98	2099.94	56.27
	All Seasons	2065.30	2325.22	112.59	3002.63	2494.25	83.07
NF	Spring	297.09	244.69	82.36	463.74	277.50	59.84
	Fall	314.26	246.96	78.58	495.04	198.02	40.00
	Winter	329.80	283.31	85.91	716.99	405.28	56.53
	All Seasons	306.98	252.78	82.34	516.24	302.75	58.64
TCW	Spring	641.05	401.14	62.58	786.11	348.77	44.37
	Fall	738.36	403.23	54.61	867.02	347.41	40.07
	Winter	624.77	416.95	66.74	965.44	352.93	36.56
	All Seasons	661.24	406.73	61.51	837.22	354.37	42.33
WW	Spring	374.41	227.96	60.88	511.85	236.45	46.19
	Fall	326.74	212.43	65.02	418.27	229.60	54.89
	Winter	372.48	247.48	66.44	640.01	283.95	44.37
	All Seasons	362.76	228.86	63.09	512.45	253.02	49.37
PW	Spring	0.64	0.22	34.59	0.69	0.22	32.56
	Fall	0.50	0.26	52.05	0.51	0.26	51.34
	Winter	0.65	0.22	33.86	0.70	0.23	33.47
	All Seasons	0.61	0.24	39.22	0.65	0.25	38.05
MD	Spring	1.23	0.56	45.68	1.01	0.43	42.08
	Fall	0.93	0.59	63.74	0.89	0.60	66.67
	Winter	1.27	0.58	46.07	1.01	0.58	57.68
	All Seasons	1.17	0.59	50.48	0.98	0.50	50.88
UD	Spring	2.02	2.11	104.75	1.66	1.50	90.37
	Fall	1.22	1.71	140.08	1.00	1.25	124.86
	Winter	2.30	2.87	124.55	1.66	2.35	140.97
	All Seasons	1.88	2.22	117.96	1.50	1.65	109.59
WDR	Spring	381.20	318.33	83.51	600.53	362.97	60.44
	Fall	481.75	426.13	88.45	565.73	325.00	57.45
	Winter	390.92	369.30	94.47	728.13	330.97	45.45
WDR	All Seasons	406.79	358.21	88.06	614.98	351.61	57.17

		Choice Sets			Used Locations		
Variable	**Season**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
PC	Spring	40.37	6.98	17.30	39.51	6.46	16.35
	Fall	42.24	6.36	15.06	42.30	7.24	17.11
	Winter	41.27	5.02	12.17	40.29	4.16	10.31
	All Seasons	40.97	6.57	16.04	40.31	6.40	15.87
PF	Spring	7.26	2.21	30.46	6.56	2.14	32.53
	Fall	7.07	1.81	25.55	7.17	1.80	25.04
	Winter	7.17	1.45	20.27	6.05	1.56	25.82
	All Seasons	7.20	2.00	27.83	6.62	1.99	30.12
PWM	Spring	13.12	6.56	49.98	15.27	7.75	50.74
	Fall	10.87	6.40	58.91	11.60	6.12	52.76
	Winter	16.22	7.16	44.13	21.68	7.92	36.51
	All Seasons	13.13	6.85	52.12	15.54	8.07	51.95
PG	Spring	25.99	7.14	27.48	27.65	7.23	26.16
	Fall	24.24	6.98	28.81	24.95	7.08	28.38
	Winter	27.27	6.52	23.92	31.08	6.56	21.10
	All Seasons	25.80	7.07	27.39	27.62	7.32	26.50

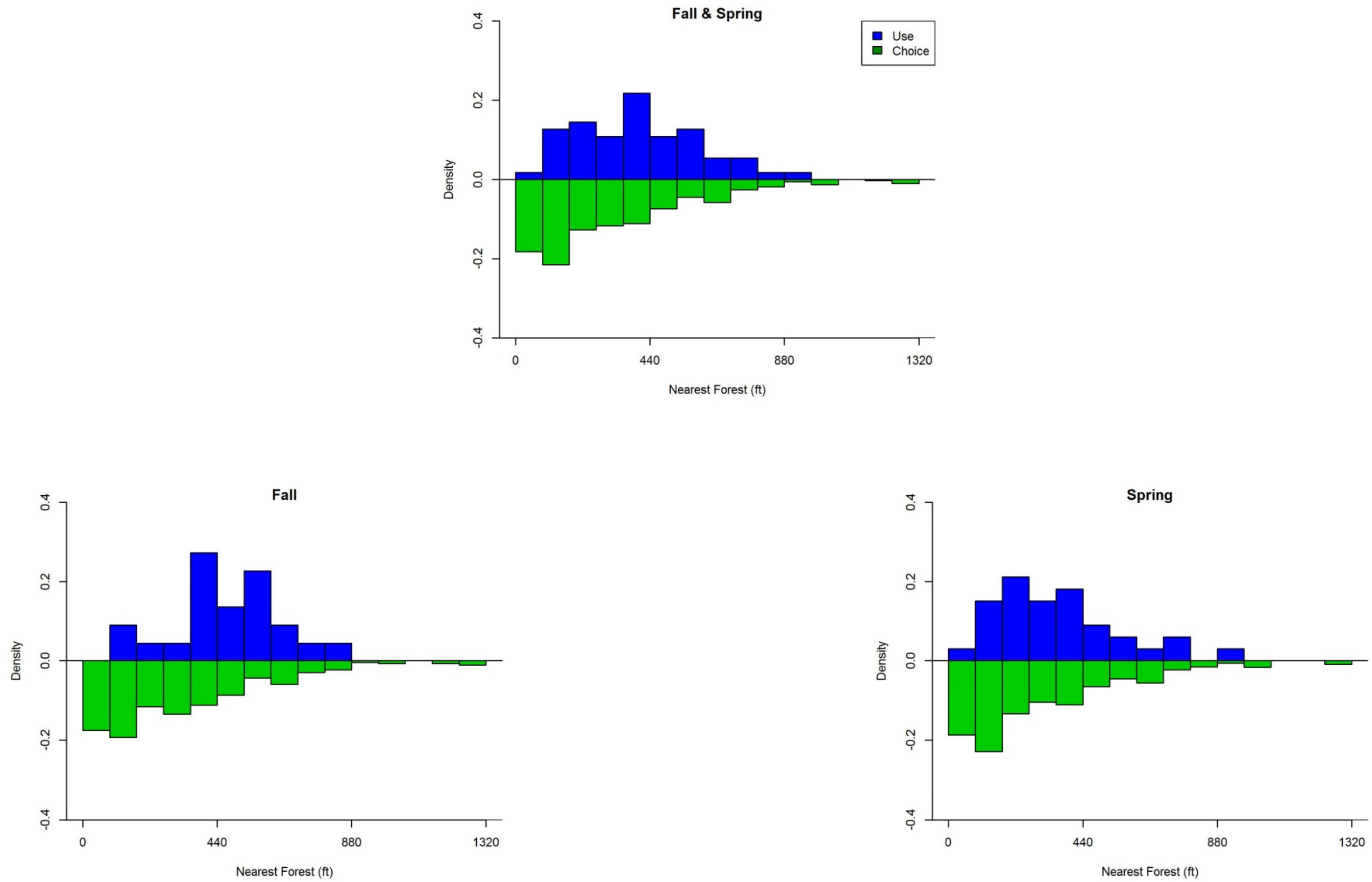
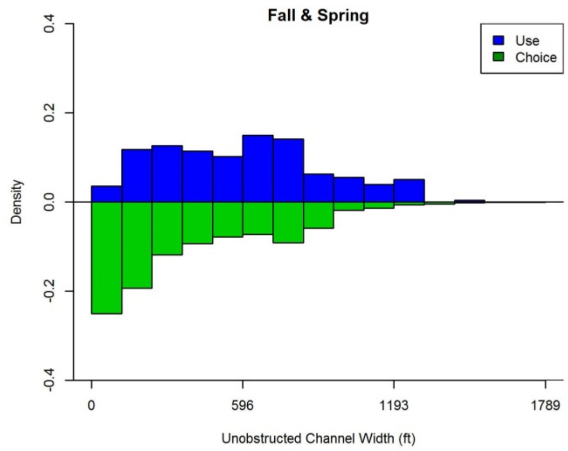
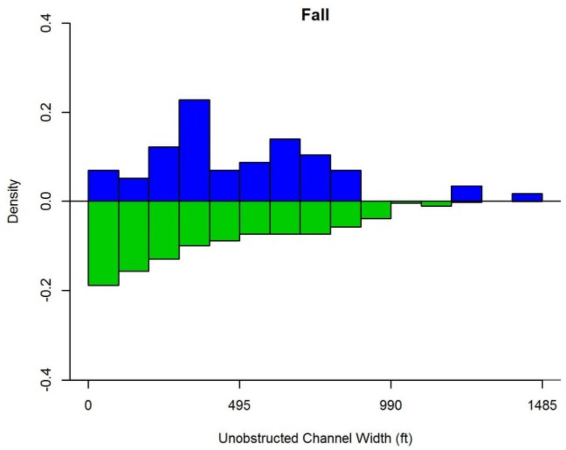


Figure D.8. Histograms of nearest riparian forest (feet [ft]) at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).





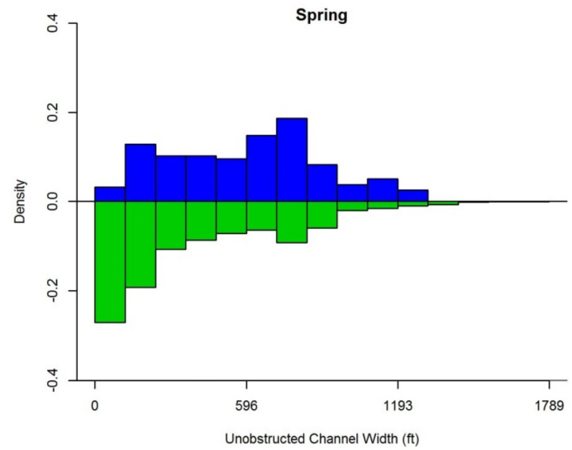


Figure D.9. Histograms of width (feet [ft]) of channel unobstructed by dense vegetation at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

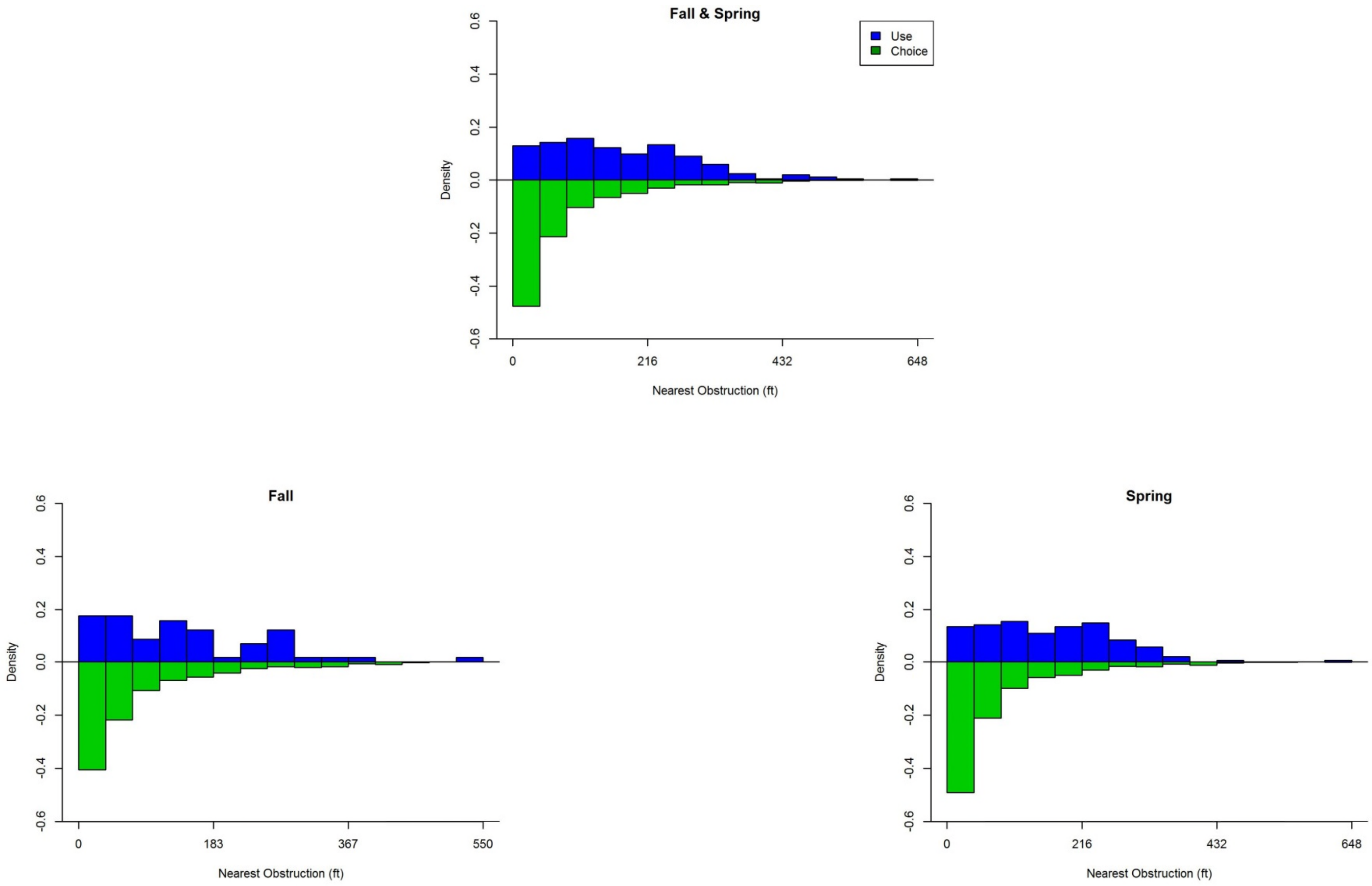


Figure D.10. Histograms of nearest obstruction (i.e., distance to nearest dense vegetation; feet [ft]) at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

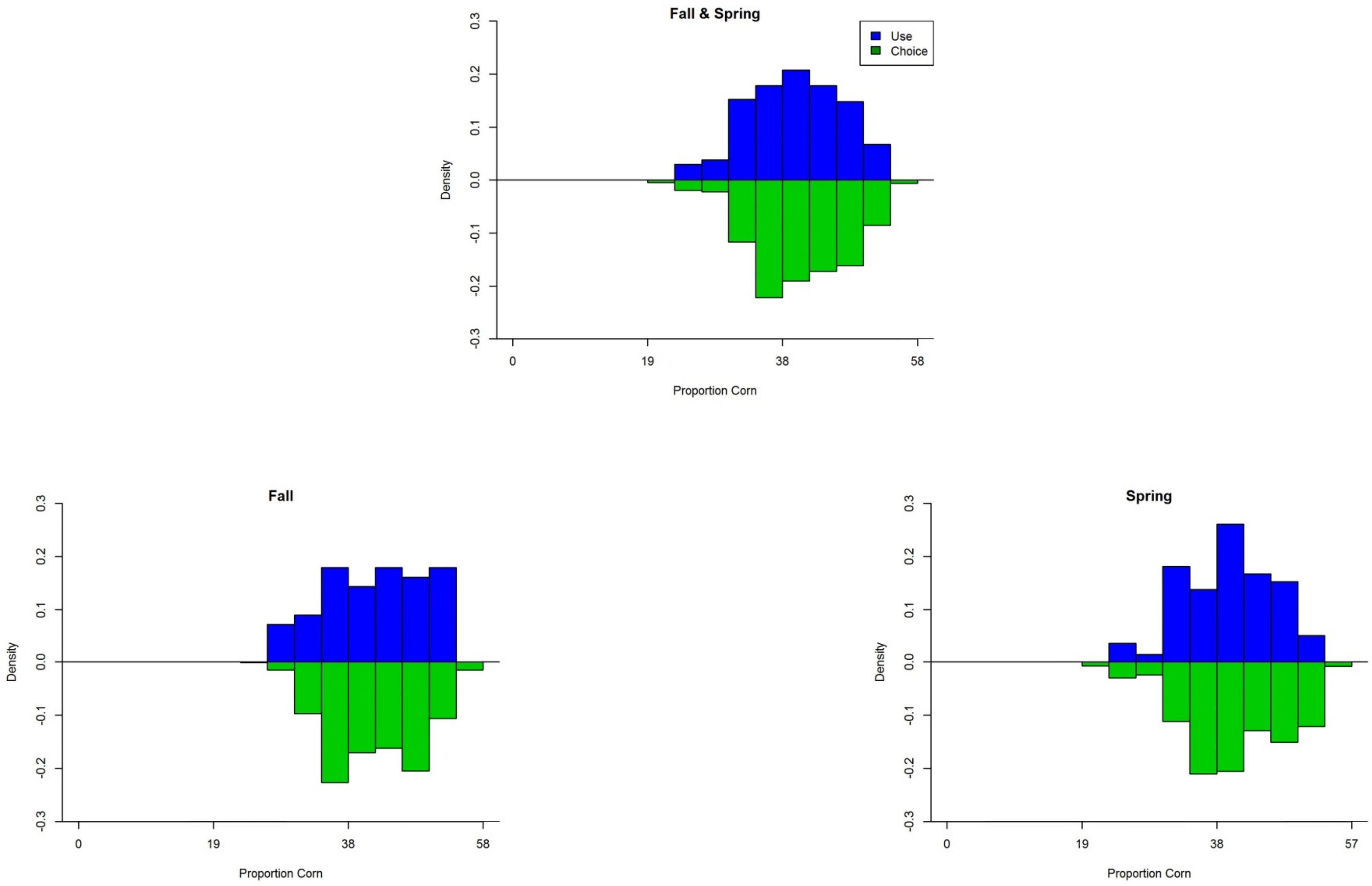


Figure D.11. Histograms of proportion of landcover within a 1-mile radius classified as corn at systematic and opportunistic locations used by a whooping crane group (“Use” in blue) and the choice set of locations (“Choice” in green). Spring and fall were combined (above) and shown separately (below).

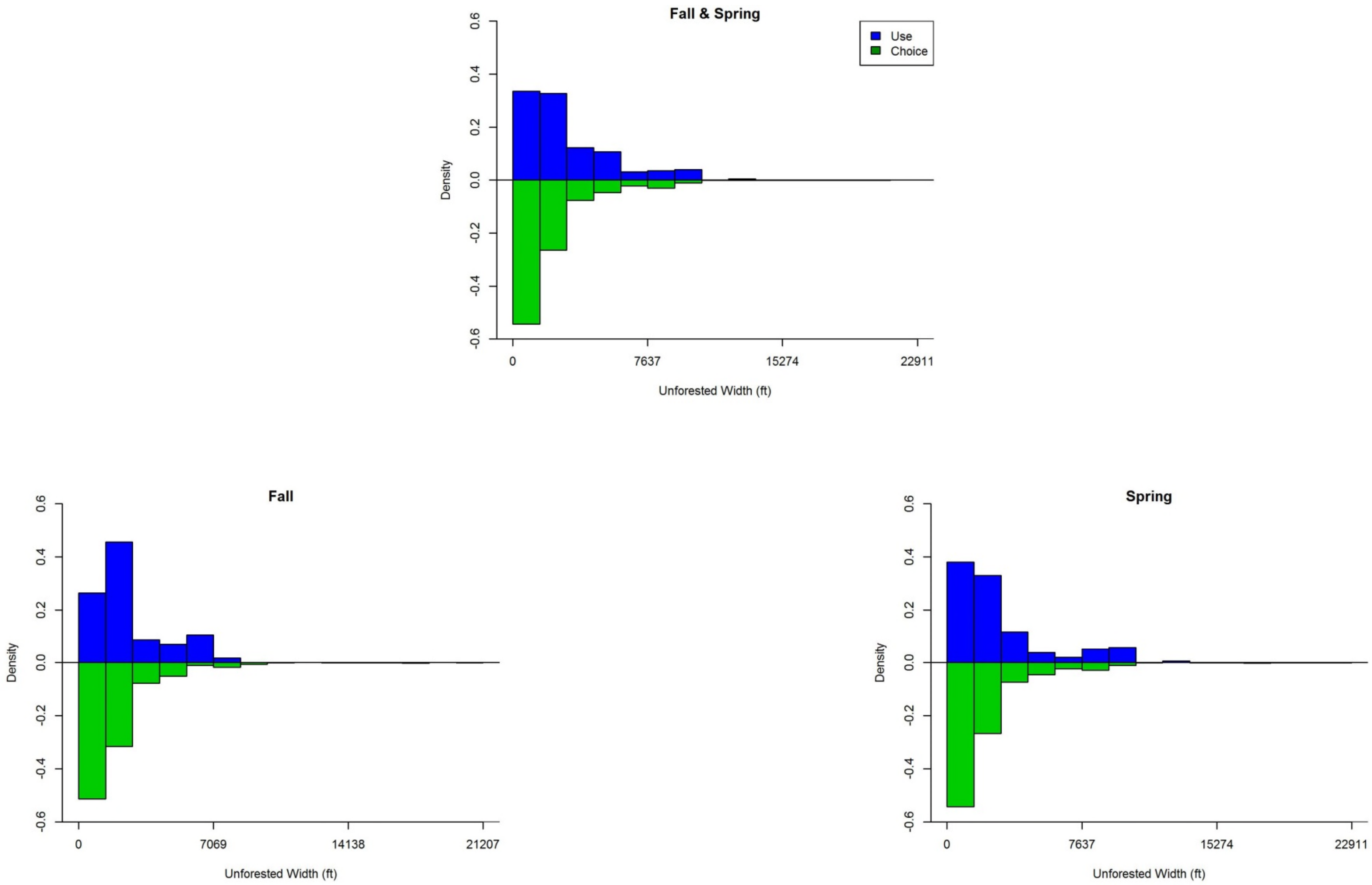


Figure D.12. Histograms of width of river corridor not obstructed by riparian forest (feet [ft]) at systematic and opportunistic locations used by a whooping crane group (“Use” in blue) and the choice set of locations (“Choice” in green). Spring and fall were combined (above) and shown separately (below).

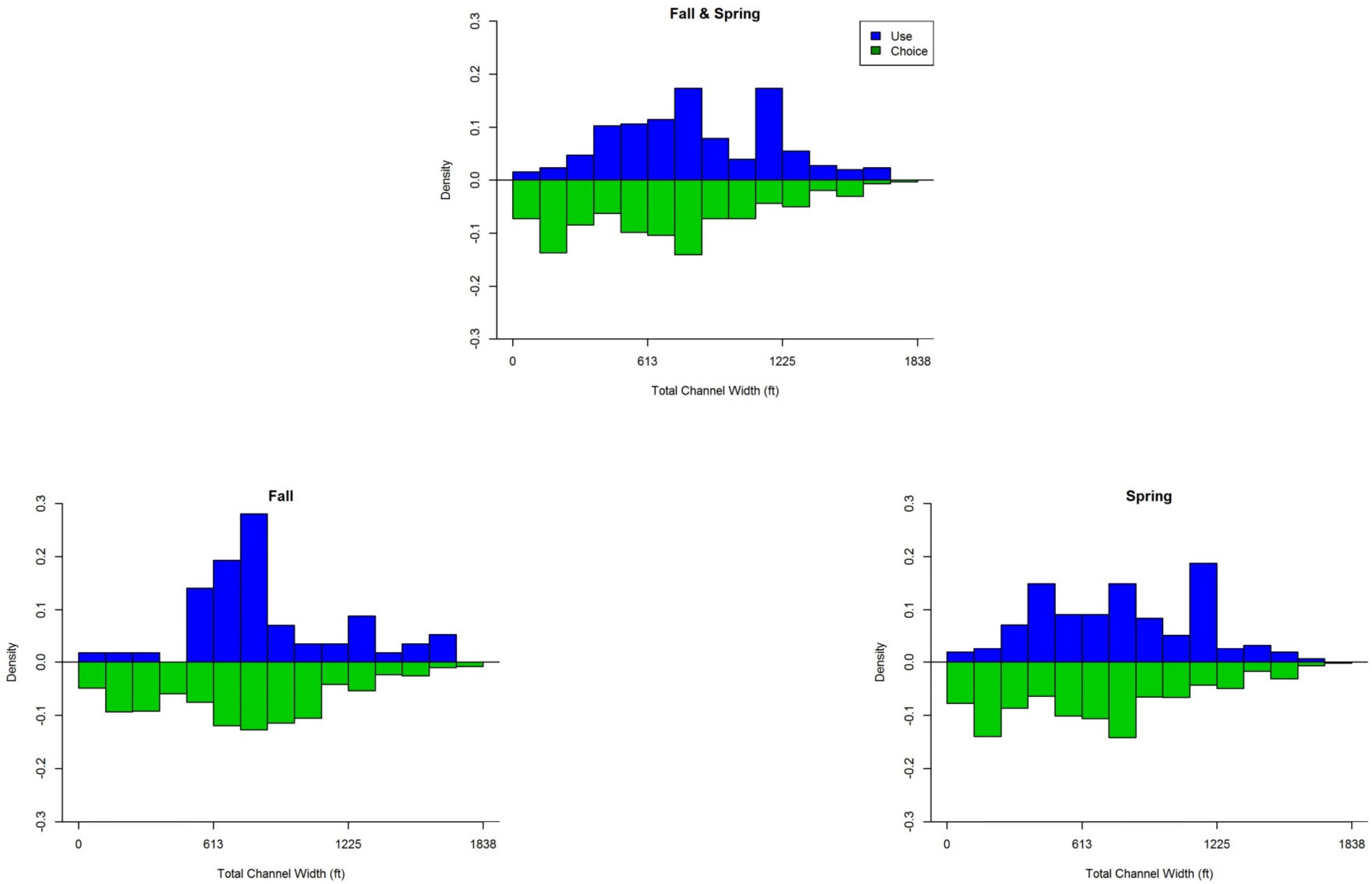


Figure D.13. Histograms of total channel width from left bank to right bank (feet [ft]) at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

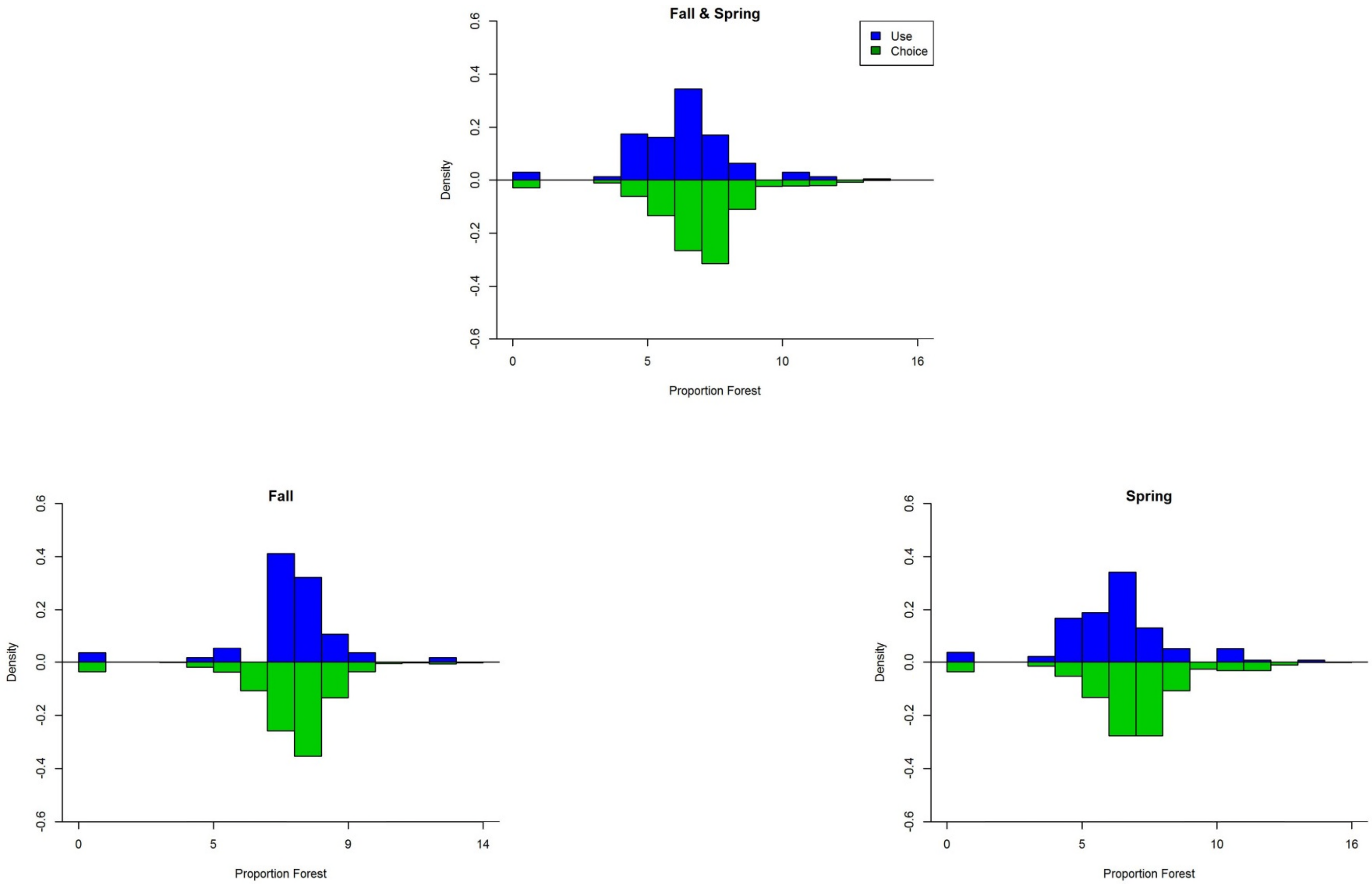


Figure D.14. Histograms of proportion of landcover within a 1-mile radius classified as forest at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

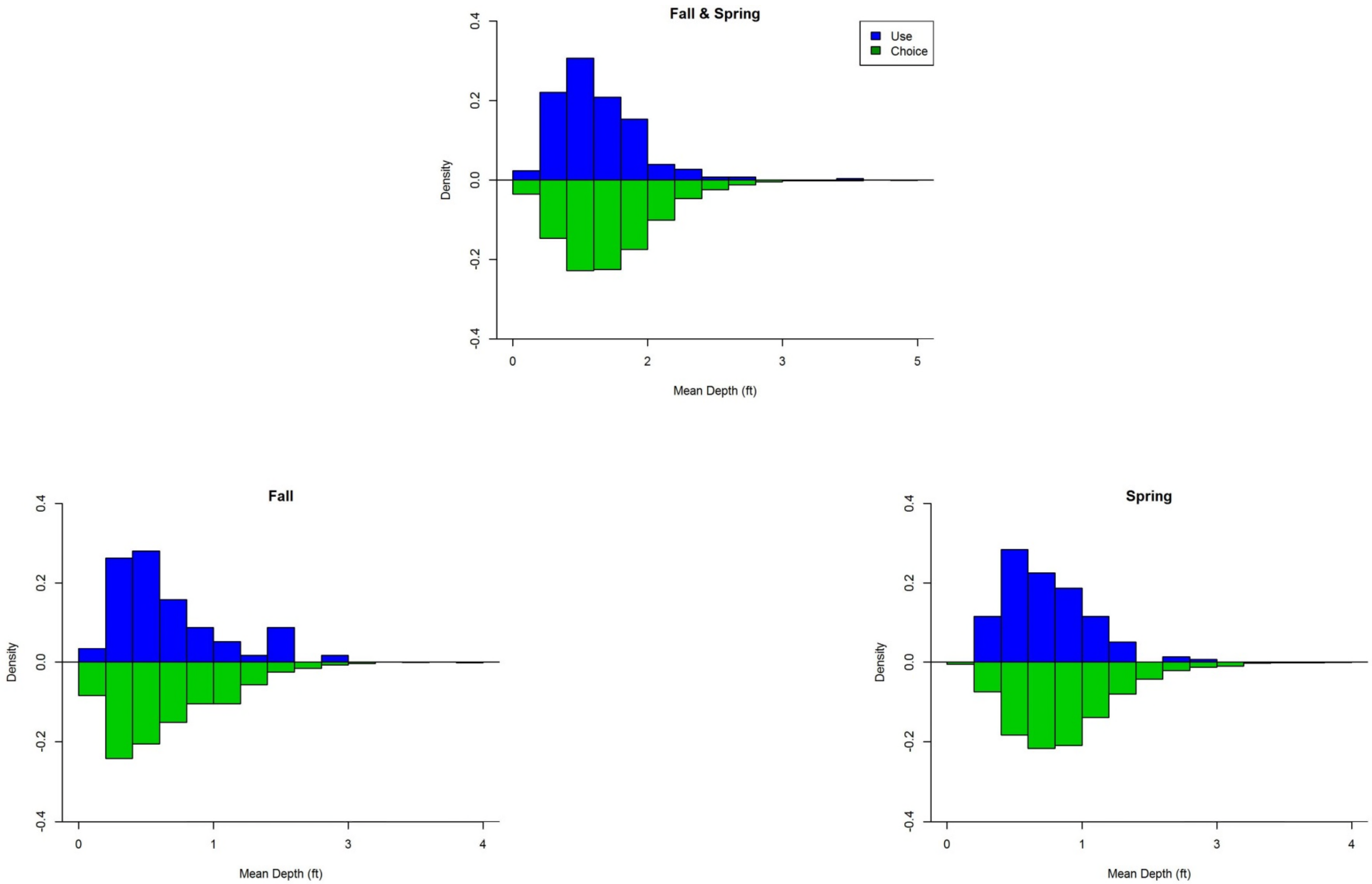
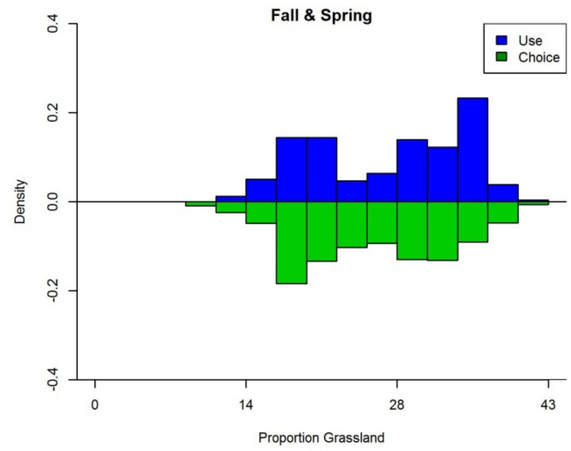
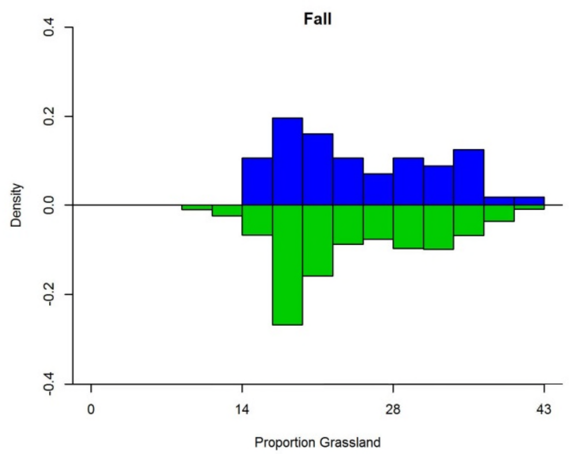


Figure D.15. Histograms of mean depth of the wetted channel (feet [ft]) at systematic and opportunistic locations used by a whooping crane group (“Use” in blue) and the choice set of locations (“Choice” in green). Spring and fall were combined (above) and shown separately (below).





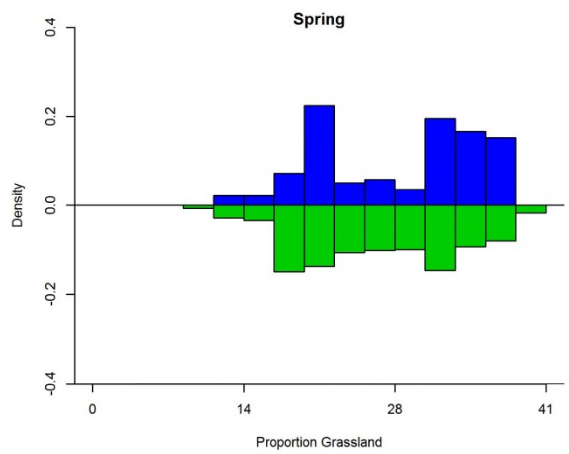


Figure D.16. Histograms of proportion of landcover within a 1-mile radius classified as grassland present at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

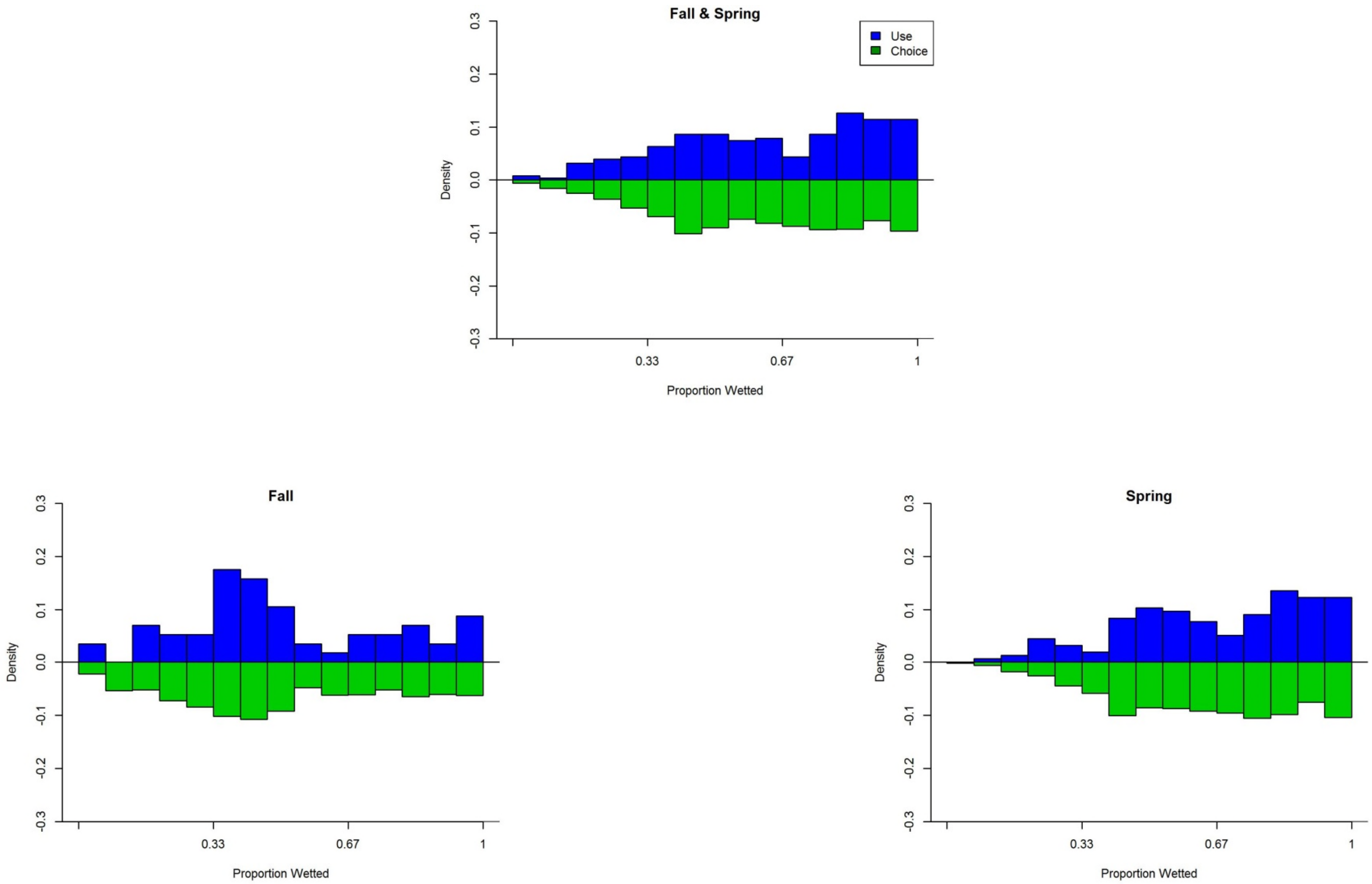


Figure D.17. Histograms of proportion of wetted area present at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

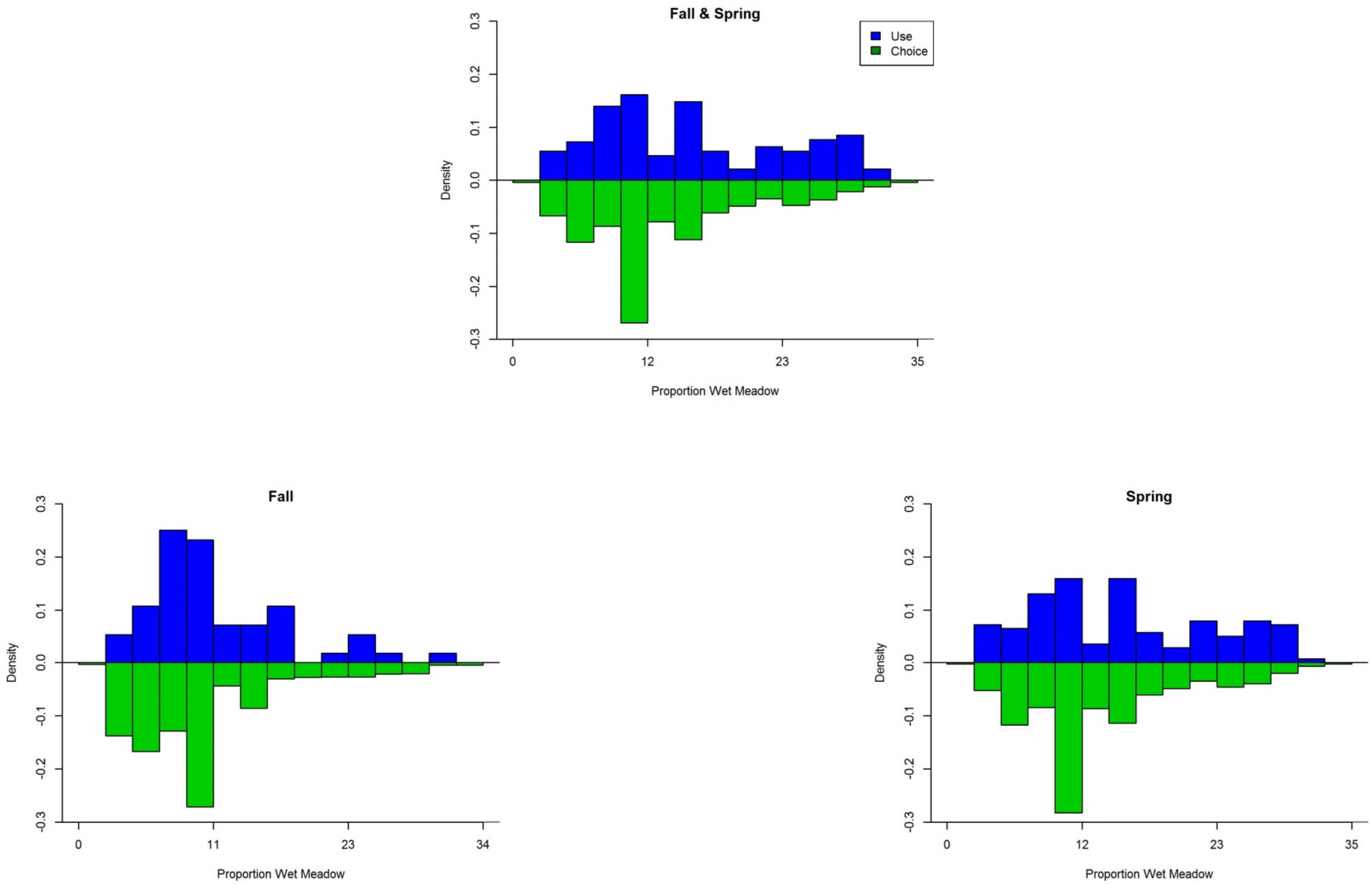


Figure D.18. Histograms of proportion of landcover within a 1-mile radius classified as wet meadow present at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

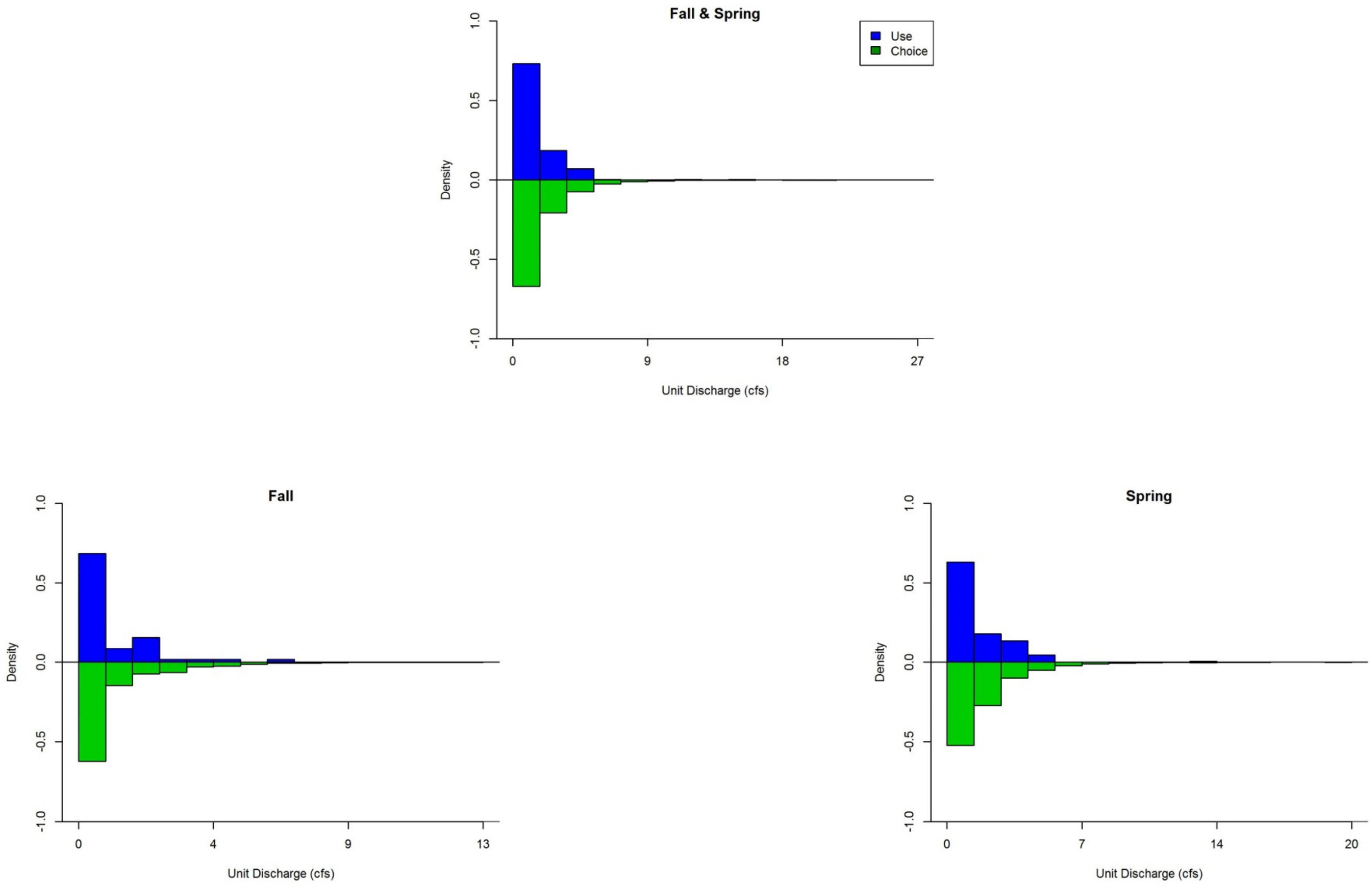


Figure D.19. Histograms of unit discharge (flow per linear foot of channel width; cubic feet per second [cfs]) at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

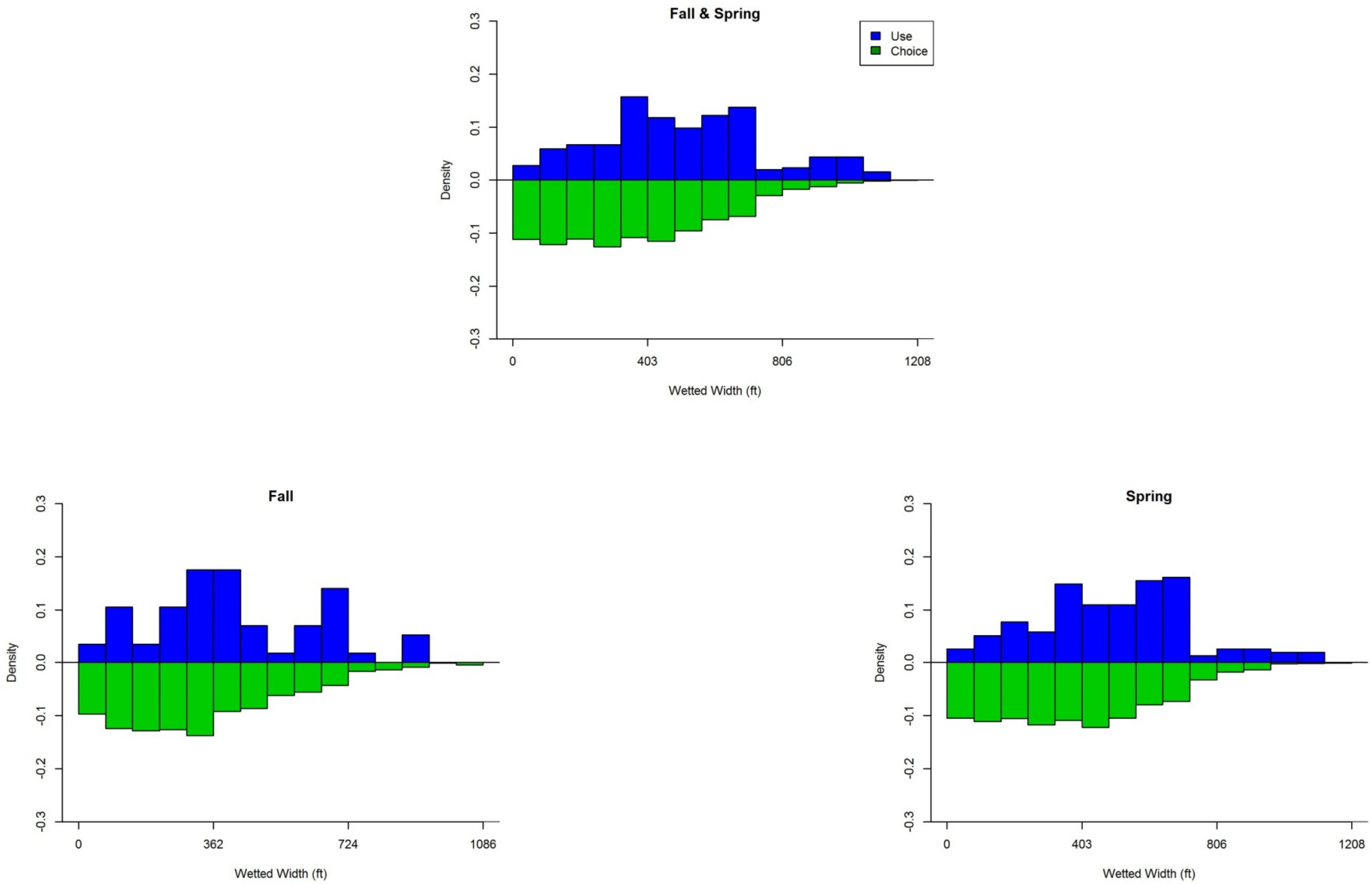


Figure D.20. Histograms of top width (feet [ft]) of wetted channel at systematic and opportunistic locations used by a whooping crane group ("Use" in blue) and the choice set of locations ("Choice" in green). Spring and fall were combined (above) and shown separately (below).

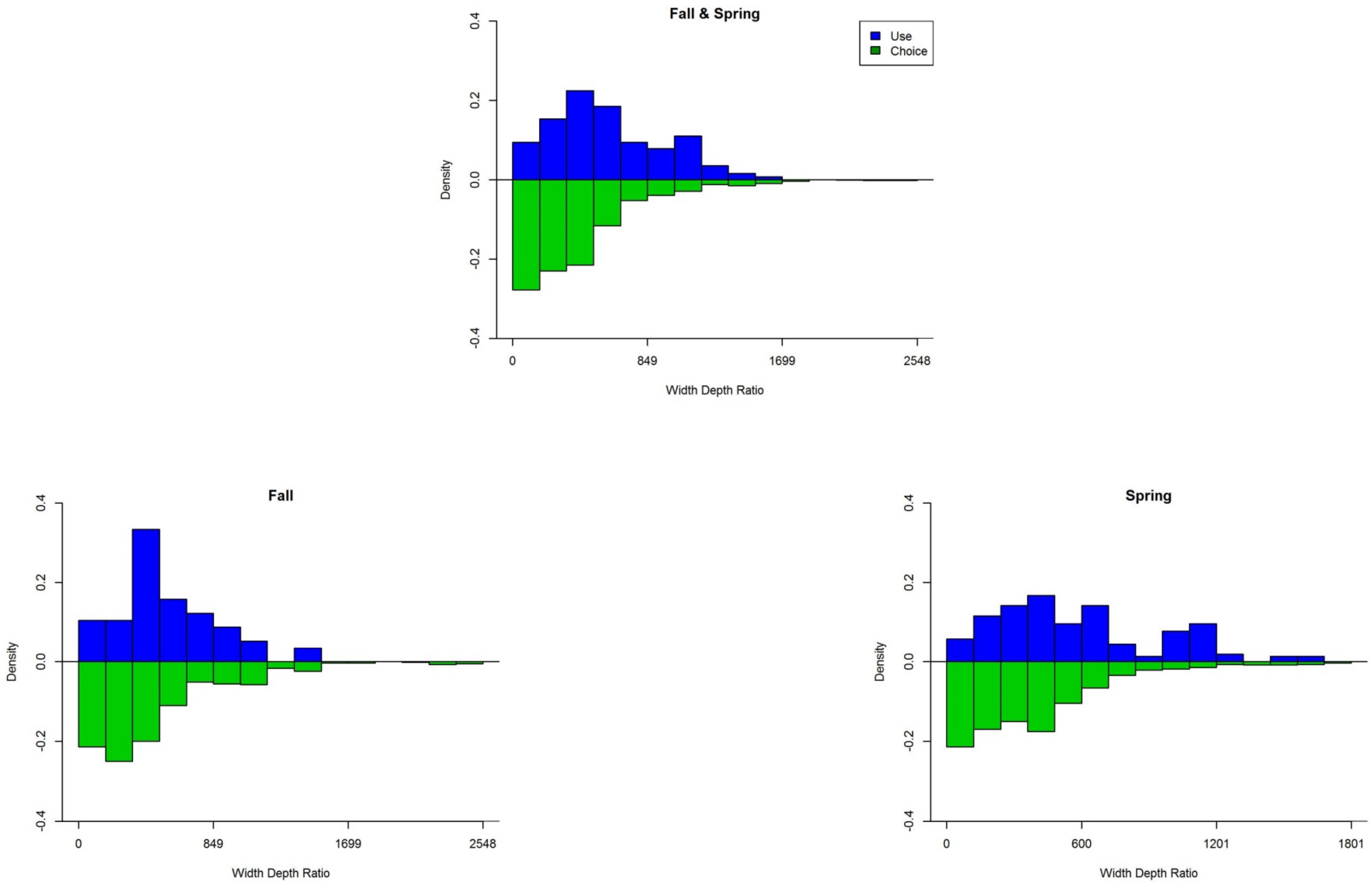


Figure D.21. Histograms of width-to-depth ratio (wetted depth / mean depth) at systematic and opportunistic locations used by a whooping crane group (“Use” in blue) and the choice set of locations (“Choice” in green). Spring and fall were combined (above) and shown separately (below).

Appendix E. Mirrored Histograms and Summary Statistics for Systematic Diurnal Whooping Crane Observations

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Table E.1. Mean, standard deviation (SD), and coefficient of variation (CV) for each variable in the analysis. Spring sample sizes were 347 for used locations and 17,350 for the choice sets, fall sample sizes were 131 for used locations and 6,550 for the choice sets. Variable abbreviations are in the methods section of the main body of the report.

		Choice Sets			Used Locations		
Variable	**Season**	**Mean**	**SD**	**CV**	**Mean**	**SD**	**CV**
PRL	Fall	11961.88	5659.54	47.31	4182.58	5777.99	138.14
	Spring	16547.67	9710.95	58.68	10758.30	11274.53	104.80
	Spring and Fall	15290.89	9023.21	59.01	8956.17	10484.48	117.06
NO	Fall	615.00	587.73	95.57	405.31	275.85	68.06
	Spring	1265.88	1717.82	135.70	1068.04	1272.68	119.16
	Spring and Fall	1087.50	1523.51	140.09	886.41	1132.78	127.79
ND	Fall	772.42	675.08	87.40	1461.70	813.17	55.63
	Spring	783.50	681.54	86.99	1240.99	817.85	65.90
	Spring and Fall	780.46	679.78	87.10	1301.48	821.65	63.13

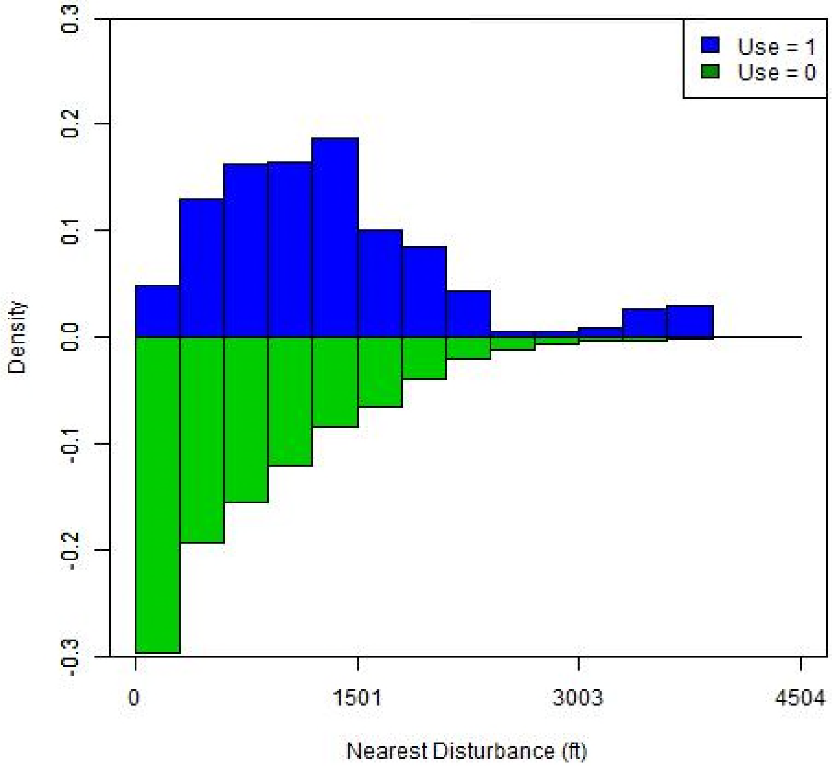

Figure E.1. Histogram of nearest disturbance (feet [ft]) for diurnal locations used by whooping crane groups in the spring and fall ("Use" in blue) and the choice set of locations ("Choice" in green).

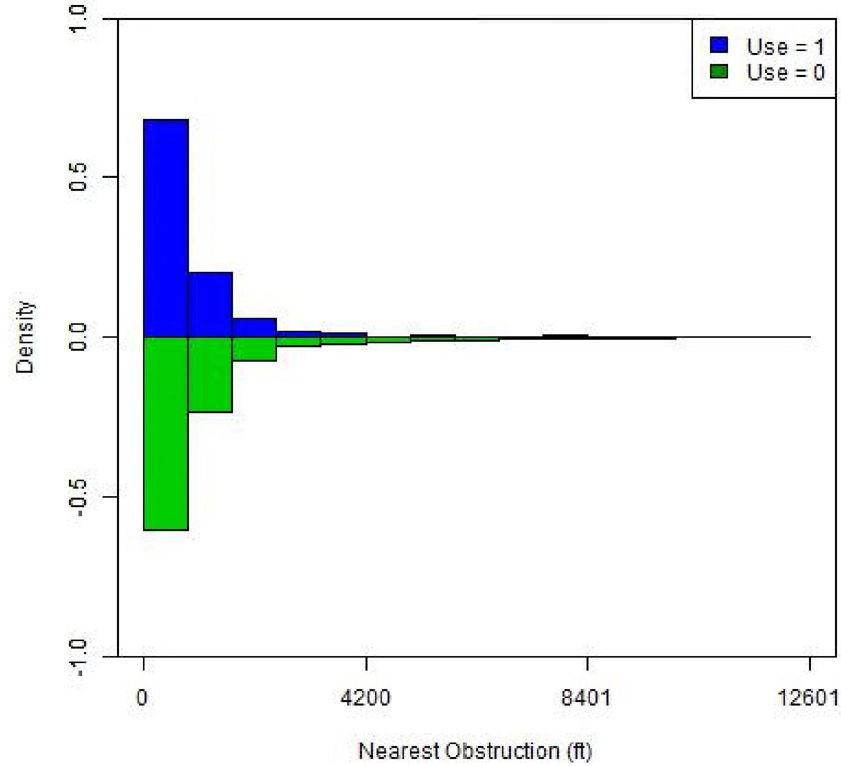

Figure E.2. Histogram of nearest obstruction (feet [ft]) for diurnal locations used by whooping crane groups in the spring and fall ("Use" in blue) and the choice set of locations ("Choice" in green).

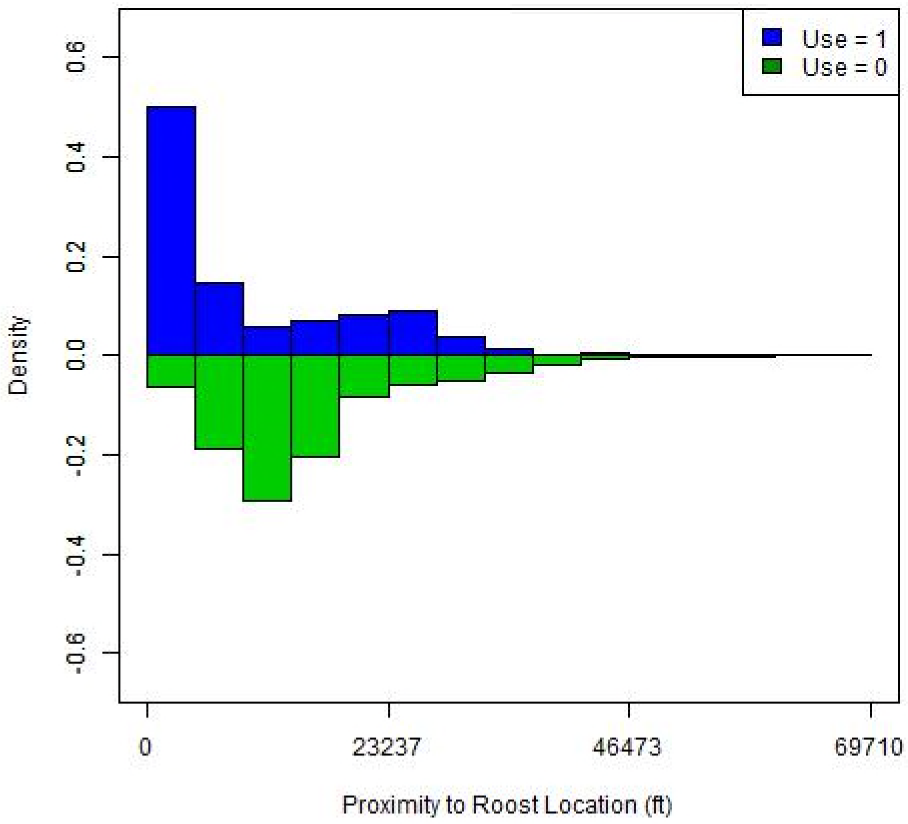

Figure E.3. Histogram of proximity to roost location (feet [ft]) for diurnal locations used by whooping crane groups in the spring and fall (“Use” in blue) and the choice set of locations (“Choice” in green).